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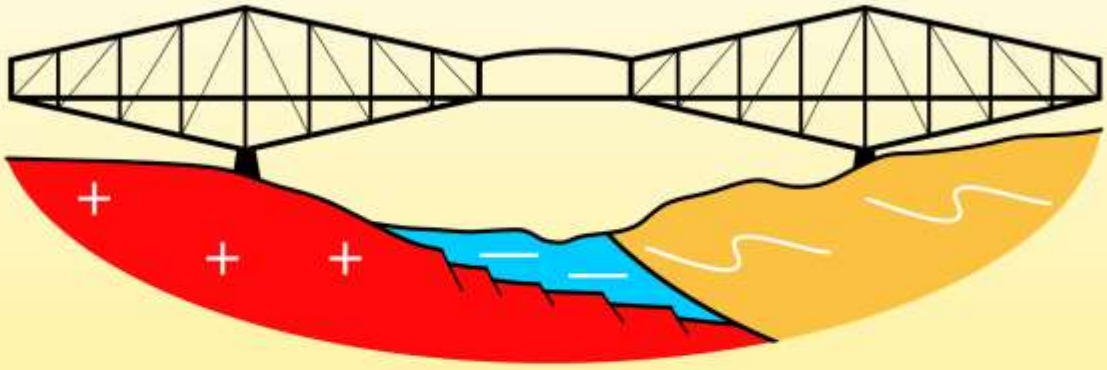
Où les géosciences convergent



Where geosciences converge

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MAI 12-15 MAY

RÉSUMÉS • ABSTRACTS **VOLUME 42**

GEOLOGICAL ASSOCIATION OF CANADA
ASSOCIATION GÉOLOGIQUE DU CANADA

MINERALOGICAL ASSOCIATION OF CANADA
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The Associations

The Geological Association of Canada (GAC®), Mineralogical Association of Canada (MAC) and the Canadian National Chapter of the International Association of Hydrogeologists (IAH-CNC) are Canadian geoscience organizations with national and international members. The Associations contribute to the promotion and development of geosciences in Canada through publications, awards, conferences, meetings and exhibitions. The Associations are pleased to publish this brief overview of the research conducted by their community, a knowledgeable and respected community whose contribution is vital to the economic prosperity and social well-being of the nation. The Associations are joining forces to promote life-long learning through this meeting *Where Geosciences Converge* and to recognize the excellence of their members and meting participants through a large realm of professional awards and prestigious medals as well as student grants.

Les Associations

L'Association géologique du Canada (AGC), l'Association minéralogique du Canada (AMC) et la section nationale canadienne de l'Association internationale des hydrogéologues (AIH-SNC) sont des organismes géoscientifiques canadiens qui comptent des membres au national et à l'international. Ces associaations contribuent à la promotion et au développement des géosciences au Canada par le biais de publications, prix, conférences, réunions et exhibits. Elles ont le plaisir de publier ce bref aperçu des recherches menées par leur communauté, une communauté bien informée et respectée dont la contribution est essentielle à la prospérité économique et au bien-être social du pays. Par le biais de cette réunion *Où les géosciences convergent*, les associations s'unissent pour promouvoir la formation continue de leurs membres et des participants au congrès et en reconnaître l'excellence grâce à un vaste éventail de prix, de médailles prestigieuses et de bourses aux étudiants.

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Welcome * Bienvenue

Welcome to Québec!

The Geological Association of Canada (GAC®), the Mineralogical Association of Canada (MAC) and the Canadian National Chapter of the International Association of Hydrogeologists (IAH/CNC) welcome you to the GAC®-MAC-IAH/CNC meeting, May 12th to 15th, 2019 in historic Québec City, a UNESCO World Heritage site.

Three Canadian Associations with national and international members have joined forces to promote life-long learning through this meeting *Where Geosciences Converge* and to recognize the excellence of its members and participants through a large realm of professional awards and prestigious medals as well as student grants. The program of this joint meeting provides a brief overview of the research conducted by the GAC®, MAC and IAH geoscience community whose contribution is vital to the economic prosperity and social well-being of the nation.

As participants, you have the opportunity to visit and discover the warmth and charm of Québec, and to explore its many attractive natural sites. More importantly, you have the superb opportunity to mingle among your peers and share knowledge.

The GAC®-MAC-IAH 2019 meeting could not happen without exhibitors and sponsors, which we thank for their financial contribution. A special acknowledgement goes to the four organizations involved in the local organizing committee: Institut national de la recherche scientifique (INRS), Natural Resources Canada and its Geological Survey of Canada, Université Laval and Québec Ministère de l'énergie et des ressources naturelles. Our sincere thanks also go to the GAC® and MAC employees and volunteers.

The local organizing committee also thanks all those who contributed to the initial offer of symposiums, special sessions, short courses and excursions, which allowed to propose a strong and diversified scientific program.

Finally, thanks to all attendees that make this meeting a success.

Bienvenue à Québec!

L'Association géologique du Canada (AGC), l'Association minéralogique du Canada (AMC) et la section nationale canadienne de l'Association internationale des hydrogéologues (AIH/SNC) vous souhaitent la bienvenue au congrès AGC-AMC-AIH/SNC 2019 qui se tient du 12 au 15 mai 2019 dans la ville historique de Québec, site du patrimoine mondial de l'UNESCO.

Trois associations canadiennes avec des membres nationaux et internationaux ont uni leurs efforts pour diffuser les connaissances et promouvoir la formation continue à travers ce congrès « *Où les géosciences convergent* ». Les associations veulent également reconnaître l'excellence de leurs membres et des participants par le biais d'un large éventail de prix professionnels et de médailles prestigieuses ainsi que de bourses d'études. Le programme du congrès conjoint fournit un bref survol de la recherche menée par la communauté de l'AGC, l'AMC et l'AIH dont la contribution est essentielle à la prospérité économique et au bien-être de la nation.

En tant que participants, vous avez l'opportunité de visiter et vivre le charme et l'hospitalité de la ville de Québec ainsi que d'explorer ses nombreux sites naturels. Plus important encore, vous avez l'opportunité unique d'échanger avec vos pairs et de partager vos connaissances.

Le congrès AGC-AMC-IAH 2019 ne pourrait avoir lieu sans les exposants et les commanditaires que nous remercions pour leur contribution financière. Un remerciement tout spécial aux quatre organismes impliquées dans le comité d'organisation local : l'Institut national de la recherche scientifique (INRS), Ressources naturelles Canada et sa Commission géologique du Canada, l'Université Laval, et le Ministère de l'Énergie et des Ressources naturelles du Québec. Un immense merci au personnel et bénévoles de l'AGC et de l'AMC et leurs bénévoles.

Le comité organisateur local remercie également tous ceux qui ont contribué à l'offre initiale de symposiums, sessions spéciales, cours intensifs et excursions, ce qui a permis de proposer un programme scientifique solide et diversifié.

Enfin, merci à tous les participants qui vont faire de ce congrès un succès.

THE ASSOCIATIONS * LES ASSOCIATIONS

GAC®
Geological Association of Canada

The Geological Association of Canada (GAC®) is the national multidisciplinary geoscience organization. Its academic, industrial and government members come from all areas of Earth Sciences. The association promotes and offers opportunities for discussion and dissemination of geological knowledge. It has several divisions. Its journal, *Geosciences Canada*, welcomes your technical papers of broad interest.

AGC
Association géologique du Canada

L'Association géologique du Canada (AGC) est l'organisation géoscientifique multidisciplinaire nationale. Ses membres des milieux académiques, industriels et gouvernementaux proviennent de tous les domaines des sciences de la Terre. L'association promeut et offre des occasions de discussion et de diffusion des géosciences. Elle comporte plusieurs divisions. Sa revue *Geosciences Canada* acceuille vos articles techniques d'intérêt général.

MAC
Mineralogical Association of Canada

The Mineralogical Association of Canada (MAC) is a non-profit scientific organization that promotes and advances the knowledge of mineralogy and the allied disciplines of crystallography, petrology, geochemistry and mineral deposits. Its journal is *The Canadian Mineralogist*.

AMC
Association minéralogique du Canada

L'Association minéralogique du Canada (AMC) est une organisation scientifique à but non lucratif qui promeut et fait progresser les connaissances en minéralogie et dans les disciplines connexes que sont la cristallographie, la pétrologie, la géochimie et les gîtes minéraux. Son journal est *The Canadian Mineralogist*.

IAH-CNC
International Association of Hydrogeology
Canadian national chapter

The International Association of Hydrogeologists - Canadian National Chapter (IAH-CNC) regroups hydrogeologists, scientists, engineers and others, who have an interest in groundwater resources. It offers members a variety of talks, seminars, networking opportunities, and conferences.

AIH-SNC
Association d'hydrogéologie du Canada
Section nationale d'hydrogéologie

L'Association internationale des hydrogéologues - Section nationale canadienne (AIH-SNC) regroupe des hydrogéologues, des scientifiques, des ingénieurs et autres personnes s'intéressant aux ressources en eaux souterraines. Elle offre aux membres une variété de conférences, séminaires, opportunités de réseautage et conférences.

The **GAC®, MAC and IAH-CNC and GAC® divisions** recognize excellence of their peers through medals and awards at the annual meeting and welcome their members to their annual luncheons and to their business meetings where awards and medals are presented.

L'AGC, l'AMC et l'IAH-SNC et les divisions de l'AGC reconnaissent l'excellence de leurs pairs par le biais de médailles et de prix et convient tous leurs membres à leurs diners annuels et leurs réunions d'affaires au cours desquels les prix et médailles seront décernés.

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The organizing committee would like to thank James Conliffe (GSNL/ GAC®), Karen Dawe (GAC®), Eleonor Penney (GAC®), Étienne Girard (GSC), Carl Guilmette (U. Laval), Marco Boutin, Richard Martel (INRS), and Normand Tassé (retired INRS) for their help during meeting preparation.

Le comité organisateur tient à remercier James Conliffe (CGTN/AGC), Karen Dawe (AGC), Eleonor Penney (AGC), Étienne Girard (CGC), Carl Guilmette (U. Laval), Marco Boutin, Richard Martel (INRS) et Normand Tassé (retraité INRS) pour leur aide lors de l'organisation du congrès.

WHERE GEOSCIENCES CONVERGE: THE THEMES

OÙ LES GÉOSCIENCES CONVERGENT : LES THÈMES

1 - Geosystems and hydro-geosystems

This theme explores how the biosphere meets the geosphere from the study of groundwater circulation and migration of nutrients and contaminants, groundwater/surface interactions, and climate change to the study of Laurentia, Pannotia, Pangea, ophiolites, accretionary orogens, melts and fluids migration, geo- and thermochronology, P-T-t-D paths, diffusion, volcanology, carbonate to clastic foreland, narrow shelf-slope environments, deltas and moraines, impact structures and seismic zones.

1 - Géosystèmes et hydrogéosystèmes

Ce thème explore comment la biosphère rencontre la géosphère, incluant l'étude de la circulation des eaux souterraines, la migration des nutriments et contaminants, l'interaction eau de surface/eau souterraine et les changements climatiques. Sont aussi examinés la croissance de la Laurentie, la Pannotie et la Pangée, les orogènes accrétionaires, les ophiolites, la migration des liquides et des fluides, la géo- et thermochronologie, les trajectoires P-T-t-D, la diffusion, la volcanologie, les environnements carbonatés à clastiques et ceux à faible pente, les deltas et moraines, les structures d'impact et zones sismiques.

Keynote speakers

Conférenciers et conférencières d'honneur

Brian Kendall

Isabelle Coutand

John Cottle

Kim Barlow

Lina Lin

Michael Higgins

Richard Palin

Robert Martin

Shoufa Lin

Stephen Piercey

Ursula McKnight

Wenjiao Xiao

2 - Resources, energy and environment

This theme explores gold, golden magmas, metasomatism, greenstone belts, ore systems including IOCG, U, magnetite-apatite and affiliated deposits, mine waste geochemistry, the early Earth, impact geology, cratonic mantle, Arctic sedimentary basins, fluid-rock interaction, magmatic ore deposits, indicator minerals, gems, submarine volcanism, marine minerals, geothermal resources, reservoir geomechanics, the integration of geophysics, petrophysics and geology, and how related industrial activities impact the environment.

2 - Ressources, énergie et environnement

Ce thème explore l'or et le magmatisme associé, le métasomatisme, les ceintures de roches vertes, les systèmes minéralisés à gîtes de magnétite-apatite, IOCG, U et affiliés, les gîtes magmatiques, la géochimie des déchets miniers, la Terre primitive, les cratères d'impact, le manteau cratonique, les bassins sédimentaires arctiques, les interactions fluide-roche, les minéraux indicateurs, l'ablation au laser appliquée aux gisements, les gemmes, le volcanisme sous-marin, la géothermie, la géomécanique des réservoirs, l'intégration de la géophysique, de la pétrophysique et de la géologie et comment les activités industrielles qui y sont liées peuvent affecter l'environnement.

Keynote speakers

Conférenciers et conférencières d'honneur

Anne McCafferty

Benoit Dubé

Bill Morris

Bryce R. Frost

Daniel Harlov

Jeff Hedenquist

Keiko Hattori

Kirsten Marcia

Mike Hamilton

Mike Lesher

Mostafa Naghizadeh

Patrick Ledru

Peter Fermor

Richard Smith

Richard Grieve

Roger Paulen

Sarah-Jane Barnes

Teckla Harms

Tobias Schlegel

Tobias Bauer

Trond Slagstad

3 - Data Science for geosciences

This theme addresses artificial intelligence (AI), algorithms, data-driven discoveries, and machine learning with a geoscience perspective.

3 - Science des données pour les géosciences

Ce thème aborde l'intelligence artificielle, les algorithmes, les découvertes basées sur les données et l'apprentissage automatique dans une perspective géoscientifique.

4 - Geosciences and society

This theme addresses our geoheritage, development of geoparks and approaches to teaching geosciences.

4 - Géosciences et société

Ce thème traite de notre patrimoine géologique, du développement de géoparcs et de nos méthodes d'enseignement des géosciences.

Keynote speakers

Godfrey Nowlan

Richard From

Conférenciers d'honneur

Patrick McEver

Symposiums and sessions in honor of:

Symposiums et sessions en l'honneur de :

Benoit Dubé

Bill Morris

Damian Nance

In memoriam

Tom Lane
(1947-2019)

Patrick Williams
(1957-2018)

PLENARY SESSIONS ∗ SÉANCES PLÉNIÈRES

The Geological Association of Canada, the Mineral Association of Canada, and the Canadian Chapter of the International Association of Hydrogeologists are honoured to have Dr. Barbara Sherwood Lollar, Mr. Darrell Beaulieu and Dr. Guy Desharnais as keynote speakers for the plenary sessions of their 2019 joint annual meeting in Quebec City.

L'Association géologique du Canada, l'Association minéralogique du Canada, et la section nationale canadienne de l'Association internationale des hydrogéologues sont honorées d'avoir Mme Barbara Sherwood Lollar, M. Darrell Beaulieu et M. Guy Desharnais comme conférenciers d'honneur pour les séances plénières de leur congrès annuel 2019 à Québec.

Barbara Sherwood Lollar
Professor, University of Toronto
Professeure, Université de Toronto

Subsurface habitability in the Earth's deep hydrosphere: Implications for planetary science and astrobiology

Science has long relied on fluid inclusions – microscopic time capsules of fluid and gas encased in host rocks and fracture minerals – to access preserved samples of ore-forming fluids, metamorphic fluids, and remnants of the ancient atmosphere and hydrosphere. Until recently, groundwaters were thought to reflect only much younger periods of water-rock interaction (WRI) and Earth history, due to dilution with large volumes of younger fluids recharging from surface hydrosphere. In the last 10-20 years, global investigations in the world's oldest rocks have revealed groundwaters flowing at rates > L/min from fractures at km depth in Precambrian cratons. With mean residence times ranging from Ma to Ga at some sites, and in the latter case, geochemical signatures of Archean provenance, not only do these groundwaters provide unprecedented samples for investigation of the Earth's ancient hydrosphere and atmosphere, they are opening up new lines of exploration of the history and biodiversity of extant life in the Earth's subsurface.

Rich in reduced dissolved gases such as CH_4 and H_2, these fracture waters have been shown to host extant microbial communities of chemolithoautotrophs dominated by H_2-utilizing sulfate reducers and, in some cases, methanogens. Recent estimates of global H_2 production via WRI including radiolysis and hydration of mafic/ultramafic rock (e.g. serpentinization) show that the Precambrian continents are a source of H_2 for life on par with estimates of H_2 production from WRI calculated for the Earth's marine lithosphere. To date this

L'habitabilité dans l'hydrosphère profonde de la Terre : implications pour la science planétaire et l'astrobiologie

La science s'est longtemps fiée aux inclusions fluides – capsules microscopiques de liquide et de gaz dans des roches et des minéraux – pour accéder à des échantillons préservés des fluides minéralisateurs et métamorphiques, et les restes des anciennes atmosphères et hydrosphères. Jusqu'à tout récemment, on croyait que les eaux souterraines n'enregistraient que des épisodes jeunes d'interaction eau-roche et de l'histoire de la Terre, à cause de la dilution due à la recharge de grands volumes de fluides plus récents de l'hydrosphère de surface. Dans les dernières 10 à 20 années, les recherches globales dans les roches les plus vieilles du monde ont montré des écoulements d'eaux souterraines à des taux > L/min dans des fractures à des kilomètres de profondeur dans des cratons précambriens. Avec une moyenne de temps de résidence variant de millions à milliards d'années dans certains sites, et dans ce dernier cas, avec des signatures géochimiques de provenance archéenne, non seulement ces eaux souterraines fournissent des échantillons sans précédent pour l'analyse des anciennes atmosphères et hydrosphères de la Terre, elles ouvrent des pistes de recherche sur l'histoire et la biodiversité de la vie existant en sous-surface de la Terre.

Riches en gaz dissous réduits comme le CH_4 et le H_2, ces eaux de fractures contiennent des communautés microbiennes actuelles de chimiolithoautotrophes dominées par des sulfato-réducteurs utilisant le H_2 et, dans certains cas, des méthanogènes. Les récents estimés de la production globale de H_2 par l'interaction eau-roche, incluant la radiolyse et l'hydratation des roches

extensive deep terrestrial habitable zone has been significantly under-investigated compared to the marine subsurface biosphere. Beyond Earth, these findings have relevance to understanding the role of chemical water-rock reactions in defining the potential habitability of the subsurface of Mars, as well as that of ocean worlds and icy bodies such as Europa and Enceladus. This talk will address some of the highlights of recent exploration of the energy-rich deep hydrogeosphere, and connections to deep subsurface life on Earth and to planetary exploration and astrobiology. An overview of the key recommendations of the recent National Academies Report – the 2018 Astrobiology Science Strategy for the Search for Life in the Universe will be provided as well.

mafiques/ultramafiques (e.g. la serpentinisation), montrent que les continents précambriens sont une source de H_2 pour la vie cohérente avec les estimés de la production de H_2 calculée de l'interaction eau-roche de la lithosphère marine de la Terre. Actuellement, cette zone habitable terrestre très profonde n'a été que peu explorée comparée à la biosphère marine de sous-surface. En dehors de la Terre, ces découvertes sont pertinentes pour comprendre le rôle des réactions chimiques eau-roche pour analyser le potentiel d'habitabilité à la surface de Mars, aussi bien que dans les mondes océaniques et les corps glacés comme Europa et Enceladus. Cette conférence présentera quelques points forts de la recherche récente sur l'hydrogéosphère profonde riche en énergie, et les liens avec la vie en sous-surface profonde sur la Terre, l'exploration planétaire et l'astrobiologie. Une revue des recommandations-clés du récent rapport des National Academies, 2018 Astrobiology Science Strategy for the Search for Life in the Universe, sera aussi présentée.

DR. BARBARA SHERWOOD LOLLAR, Companion of the Order of Canada and Fellow of the Royal Society of Canada, is a University Professor in Earth Sciences at the University of Toronto and a Canada Research Chair in Isotopes of the Earth and Environment and a Norman Keevil Chair. She has published extensively on stable isotope geochemistry and hydrogeology, the fate of carbon-bearing fluids and gases such as CO_2, CH_4 and H_2 in ancient fracture waters in the Earth's crust, and the role of deep subsurface microbial populations in carbon cycling. She has been a recipient of academic awards (including the NGWA Darcy Lecturer, Killam Research Fellowship of the Canada Council for the Arts, and NSERC Accelerator and Steacie Awards), the 2012 Eni Award for Protection of the Environment, 2012 Geological Society of America Geomicrobiology and Geobiology Prize, 2014 International Helmholtz Fellowship, 2015 Fellow of the American Geophysical Union, 2016 NSERC John Polanyi Award, 2016 Bancroft Award for the Royal Society of Canada and 2018 Logan Medal of the Geological Association of Canada.

Dr. Sherwood Lollar is currently Director of the Earth, Atmosphere and Ocean Sciences Division of the Royal Society of Canada; Member of the Advisory Council to the Governor-General for the Order of Canada, and Chair of the United States National Academy of Sciences 2018 Review for the Strategy for Astrobiology and the Search for Life in the Universe. She has served in numerous advisory roles for the Canadian Space Agency, NSERC and NASA including the National Academies (NAS) Committee on Astrobiology and Planetary Sciences, NAS Committee on the Origin and Evolution of Life, and is currently a member of the U.S. National Academy of Sciences Space Studies Board (2016-2020).

MME BARBARA SHERWOOD LOLLAR, Compagnon de l'Ordre du Canada et Membre (Fellow) de la Société royale du Canada, est professeure au département des sciences de la Terre de l'Université de Toronto et titulaire de la chaire du Canada Isotopes of the Earth and Environment et de la chaire Norman Keevil. Elle a beaucoup publié sur les isotopes stables en géochimie et en hydrogéologie, le devenir des fluides et des gaz tels le CO_2, le CH_4, et le H_2 dans les eaux anciennes dans les fractures de la croûte terrestre, et le rôle des populations microbiennes profondes dans le cycle du carbone. Elle a été récipiendaire de nombreux prix académiques (NGWA Darcy Lecturer, Bourse de recherche Killam du Conseil des arts du Canada ainsi que le supplément d'accélération à la découverte et le Prix Steacie du CRSNG). Elle a aussi reçu le prix Eni pour la Protection de l'environnement et le prix Géomicrobiologie et géobiologie de la Geological Society of America en 2012, le prix International Helmholtz Fellowship en 2014, le prix Fellow de l'American Geophysical Union en 2015, le prix John Polanyi du CRSNG en 2015, le prix Bancroft de la Société royale du Canada en 2016, et la médaille Logan de l'Association géologique du Canada en 2018.

Mme Sherwood Lollar est actuellement directrice de la division des sciences de la Terre, de l'atmosphère et de l'océan de la Société royale du Canada, membre du comité aviseur du Gouverneur général du Canada pour l'Ordre du Canada et présidente du United States National Academy of Sciences 2018 Review for the Strategy for Astrobiology and the Search for Life in the Universe. Elle a joué des rôles d'aviseure pour l'Agence spatiale canadienne, le CRSNG, et la NASA, incluant pour le comité du National Academies (NAS) Astrobiology and Planetary Sciences, et le comité NAS Origin and Evolution of Life. Elle est actuellement membre du U.S. National Academy of Sciences Space Studies Board (2016-2020).

Darrell Beaulieu
CEO, Denehdeh Investments Inc.
PDG, Denehdeh Investments Inc.

A Dene perspective on resource development in Canada for, by and among First Nations

In his plenary talk, Mr Darrell Beaulieu addresses how mineral exploration and environmental studies are means to walk, explore, take care of and benefit from the land. How being involved first hand in the mineral industry fosters empowerment, economic growth and prosperity for the Dene First Nations and Canadians in general.

Over the last decade, the Dene people have gone from developing a strong indigenous service industry, where they worked for mining projects owned by others, to being decision-makers, controlling their own mineral exploration company and exploring the land they have walked upon for centuries, from Great Slave Lake to Great Bear Lake. Mining drives the NWT economy and First Nations people, including many of today's leaders, have worked in the mining and exploration sectors. In the process, First Nations have become an important part of the mining industry and are well positioned to participate in resource development, ensuring a balanced approach between preserving the environment and developing Canada's natural resources.

First Nations share with geologists and prospectors a love for the land. This includes conducting mineral exploration and baseline environmental studies, extracting mineral resources, remediating mine tailings, making informed decisions on land use, and managing the lands. Encouraging First Nations youth to stay 'On the Land', where their ancestors travelled and lived, can mean promoting careers in geology and geosciences with broad applications – for exploration, mining and the environment.

Mr. DARRELL BEAULIEU epitomizes the new face of mining in Canada for his overall achievements in First Nations involvement in natural resources development. He is the founding Director, President and CEO of DEMCo Ltd., a mineral exploration company, and of iDene Ltd., a remediation and environmental solutions company owned by the Dene people. He is also President and CEO of Denendeh Investments Inc., the umbrella structure that invests in mineral exploration, energy, remediation, environment, communications, and infrastructure logistics on behalf of the Northwest Territories Dene First Nations.

Une perspective des Dénés sur le développement des ressources au Canada pour, par et au sein des Premières Nations

Dans cette conférence plénière, M. Darrell Beaulieu aborde comment l'exploration minérale et les études environnementales sont des moyens de marcher et explorer le territoire tout en prenant soin et en bénéficiant de la Terre. Il montre comment l'implication des Premières Nations dans l'industrie minière favorise l'émancipation, la croissance économique et la prospérité de la Première Nation des Dénés et des canadiens en général.

Dans la dernière décennie, le peuple Déné est passé du développement d'une forte industrie de service autochtone où ils ont travaillé pour les projets miniers des autres, au développement de leur propre compagnie d'exploration, prenant eux-mêmes les décisions quant à l'exploration des terres sur lesquelles ils avaient marché pendant des siècles, depuis le Grand lac des Esclaves au Grand lac de l'Ours. L'industrie minière stimule l'économie des Territoires du Nord-Ouest et les membres des Premières Nations, incluant plusieurs dirigeants d'aujourd'hui, ont travaillé dans le secteur de l'exploration et des mines. Ce faisant, les Premières Nations sont devenues partie prenante de l'industrie minière et sont bien positionnées pour participer et assurer une approche équilibrée entre la préservation de l'environnement et le développement des ressources naturelles.

Les Premières Nations partagent avec les géologues et les prospecteurs l'amour de la Terre. Cela signifie faire de l'exploration minérale et des études environnementales, extraire les ressources minérales, remettre en état les résidus miniers, prendre des décisions éclairées sur l'usage des terres, et les gérer. Amener les jeunes des Premières Nations « Sur la terre » où leurs ancêtres ont voyagé et vécu implique aussi promouvoir des carrières en géoscience avec des applications variées – de l'exploration, aux mines et à l'environnement.

M. DARRELL BEAULIEU incarne la nouvelle figure de l'industrie minière au Canada pour l'ensemble de ses réalisations, entre autres dans la participation des Premières Nations dans le développement des ressources naturelles. Il est le directeur-fondateur, président et PDG de DEMCo Ltd., une compagnie d'exploration minière, et de iDene Ltd, une compagnie d'assainissement et de solutions environnementales appartenant au peuple Déné. Il est aussi président et PDG de Denehdeh Investments Inc, une société d'investissement en exploration minérale, énergie, assainissement, environnement, communication, infrastructure et logistique au profit de la Première Nation des Dénés des Territoires du Nord-Ouest.

Mr. Beaulieu is an Akaitcho Dene from Yellowknife. He has been Chief of the Yellowknives Dene First Nation, and started early his efforts to foster empowerment, economic growth and prosperity of the Dene First Nations by founding the Deton'Cho Corporation that services the resource industry and Deton'Cho Diamonds that processed diamonds. He has served on the Mine Training Society, NWT Chamber of Mines Boards of Directors, several foundations, the National Orphaned and Abandoned Mines Initiative, etc. Mr. Beaulieu received the Skookum Jim Award from the Prospectors and Developers Association of Canada for his exceptional Aboriginal accomplishments in the mineral industry, and the MAX award for indigenous achievement.

M. Beaulieu est un Déné de l'Akaitcho de Yellowknife. Il a été chef de la Première Nation des Dénés Yellowknifes, et a débuté tôt ses efforts pour favoriser l'émancipation, la croissance économique et la prospérité de la Première Nation des Dénés en créant la Deton'Cho Corporation qui sert l'industrie des ressources et Deton'Cho Diamonds qui traite les diamants. Il a servi sur la Mine Training Society, la NWT Chamber of Mines Board, plusieurs fondations, et la National Orphaned and Abandonned Mines Initiative, etc. Monsieur Beaulieu a reçu le prix Skookum Jim du Prospectors and Developpers Association of Canada pour ses réalisations exceptionnelles au sein de l'industrie minière autochtone et le Prix MAX pour son accomplissement autochtone.

Guy Desharnais
Director of Mineral Resource Evaluation, Osisko Gold Royalties
Directeur - Évaluation des ressources minières, Redevances Aurifères Osisko

How BIG data is changing mining

Every industry is undergoing transformation to adapt to a massive influx of new data and innovative ways to extract knowledge from them. The mining industry is no exception. A new suite of small and inexpensive sensors are enabling collection of an extreme number of qualitative data. The magnitude of potential economic and social benefits will depend on the capability and wisdom of the humans behind the algorithms used to mine that data.

GUY DESHARNAIS, Ph.D., P.Geo, has worked in mineral exploration, resource estimation consulting and is currently working as the Director of Mineral Resource Evaluation with Osisko Gold Royalties. He led the team which won the Integra Gold Rush Challenge in 2016 (500k$) which applied a combination of geology, virtual reality, weight of evidence and machine learning techniques to identify the most prospective exploration targets. He was named CIM distinguished lecturer in 2017 where he shared his knowledge on Metallurgical Sample Selection, Application of Machine Learning to Exploration Targeting, and Mineral Resource Over-Estimation.

Comment les mégadonnées (big data) changent l'industrie minière

Toutes les industries subissent actuellement une transformation pour s'adapter à l'influx massif des nouvelles données et aux meilleures façons d'en extraire deconnaissances. L'industrie minière ne fait pas exception. Plusieurs nouveaux capteurs portables et peu coûteux sont maintenant capables de recueillir un nombre imposant de données de qualité. L'ordre de grandeur des bénéfices potentiels sociaux et économiques de ces mégadonnées dépendra de l'aptitude et de la sagesse des humains derrière les algorithmes utilisés pour exploiter ces données.

GUY DESHARNAIS (Ph.D., P.Géo) a d'abord travaillé en exploration minérale, puis comme consultant en estimation des ressources, et il est maintenant Directeur-Évaluation des ressources minières pour Redevances Aurifères Osisko. Il a dirigé l'équipe qui a gagné le concours Ruée vers l'or d'Integra en 2016 offrant une bourse d'une valeur de 500 000$. L'équipe a appliqué une combinaison de données géologiques et de techniques de ciblages traditionnels, ainsi que la réalité virtuelle et l'apprentissage automatique pour identifier les cibles d'exploration les plus prospectives. Il a été nommé conférencier de prestige de l'ICM en 2017 afin de partager ses connaissances sur la sélection des échantillons métallurgiques, l'application de l'apprentissage automatique au ciblage de l'exploration, et la surestimation des ressources minières.

GAC®-MAC-IAH AWARDS ∗ PRIX AGC-AMC-AIH

GAC® Awards

Prix de l'AGC

Cees van Staal
Geological Survey of Canada and University of Waterloo
Commission géologique du Canada et Université de Waterloo

Logan Medal

Médaille Logan

The highest award of the Geological Association of Canada is awarded to an individual for sustained distinguished achievement in Canadian Earth Sciences. This year, the medal is presented to Dr. Cees van Staal (Geological Survey of Canada).

"For achieving unprecedented resolution in orogenic analysis, through integrated structural, stratigraphic and metamorphic geology; mafic and felsic rock geochemistry; high-precision geochronology; seismic sounding; and comparison with active Circum-Pacific tectonics, as applied to the Canadian Appalachian orogen and its extensions."

Le prix le plus prestigieux de l'Association géologique du Canada est décerné à une personne pour son oeuvre remarquable en sciences de la Terre au Canada. Cette année, la médaille est décernée à M. Cees van Staal de la Commission géologique du Canada.

"Pour sa résolution sans précédent de l'analyse des orogènes grâce à l'intégration de la géologie structurale, de la stratigraphie et du métamorphique; de la géochimie des roches mafiques et felsiques; de la géochronologie de haute précision; des levés sismiques; et de la comparaison avec la tectonique circum-pacifique active, telle qu'elle a été appliquée à l'orogène canadien des Appalaches et à ses extensions."

Address:
A field geologists' view of the Taconic orogenic cycle in the Northern Appalachians: along strike complexities and variations in tectonic style

Allocution :
Point de vue des géologues de terrain sur le cycle orogénique taconique dans les Appalaches du Nord: complexité et différence de styles tectoniques

It is generally accepted that the Taconic Orogeny was caused by ophiolite obduction and arc-continent collision in the Canadian Appalachians. Detailed stratigraphic studies of the Laurentian margin in Canada by numerous workers has shown that the margin was tectonically loaded by an approaching, Laurentian realm oceanic terrane during the Early to Middle Ordovician. This relative simple tectonic history is in sharp contrast to the complex tectonic evolution recorded by the accreted suprasubduction zone terranes during the Taconic. Especially the tectonic style (hard collision) and evolution of the Notre Dame (Taconic) arc in Newfoundland is sharply contrasting with the soft collision recorded on the adjacent Laurentian margin in Quebec and Newfoundland. Juxtaposing different segments of the Taconic orogen by large strike-slip movements is one possible way to explain some of the observed complexities, but evidence for piercing points is circumstantial or absent. Many questions remain unanswered and are in need of more research.

Il est généralement accepté que l'orogenèse taconique a été causée par une obduction d'ophiolite et par une collision arc-continent dans les Appalaches au Canada. Des études stratigraphiques détaillées de la marge laurentienne au Canada, effectuées par de nombreux chercheurs, ont montré que la marge était chargée tectoniquement par une bande océanique en marge du craton laurentien qui approchait au cours de l'ordovicien précoce à moyen. Cette histoire tectonique relativement simple contraste fortement avec l'évolution tectonique complexe enregistrée par les terranes de la zone de suprasubduction accrétée pendant le taconique. Le style tectonique (collision « dure ») et l'évolution de l'arc Notre Dame (taconique) à Terre-Neuve contrastent fortement avec la légère collision enregistrée sur la marge laurentienne adjacente au Québec et à Terre-Neuve. La juxtaposition de différents segments de l'orogène taconique par de grands mouvements de glissade est un moyen possible d'expliquer certaines des complexités observées, mais les preuves sont circonstancielles ou absente. Beaucoup de questions restent sans réponse et nécessitent davantage de recherche.

Brian Kendall
University of Waterloo
Université de Waterloo

W.W. Hutchison Medal

This medal is awarded to a young individual for recent exceptional advances in Canadian Earth Sciences research. This year, the medal is presented to Dr. Brian Kendall (University of Waterloo).

"For the application of unconventional geochemical and isotopic techniques to address questions related to interactions between atmospheric, oceanic, and biological systems; geochronology; and the geochemical evolution of Earth from the Proterozoic to Cenozoic."

Médaille W.W. Hutchison

Cette médaille est décernée à une jeune personne pour une découverte exceptionnelle récente dans le domaine de la recherche en sciences de la Terre au Canada. Cette année, la médaille est décernée à M. Brian Kendall de l'Université de Waterloo.

"Pour l'application de techniques géochimiques et isotopiques non conventionnelles afin de répondre aux questions liées aux interactions entre les systèmes atmosphérique, océanique et biologique; la géochronologie; et l'évolution géochimique de la Terre du Protérozoïque au Cénozoïque."

Beth McLarty-Halfkenny
Carleton University
Université Carleton

E.R. Ward Neale Medal

The Neale Medal, named after the legendary E.R. Ward Neale, is awarded to an individual for sustained outstanding efforts in sharing Earth sciences with Canadians. This year, the medal is presented to Mrs. Beth McLarty-Halfkenny (Carleton University).

"For her continued outstanding efforts to communicate and explain geoscience topics through professional development workshops for teachers, educating students in elementary and secondary schools, and organizing and promoting outreach events for the public."

Médaille E.R. Ward Neale

La médaille Neale, nommée d'après le légendaire E.R. Ward Neale, est décernée à une personne pour ses efforts exceptionnels et soutenus dans la diffusion des sciences de la Terre auprès des canadiens. Cette année, la médaille est décernée à M^{me} Beth McLarty-Halfkenny de l'Université Carleton.

"Pour ses efforts remarquables en matière de communication et d'explication de sujets géoscientifiques par le biais d'ateliers de perfectionnement professionnel destinés aux enseignants, l'éducation des élèves des écoles primaires et secondaires, ainsi que pour l'organisation et la promotion d'activités de sensibilisation pour le grand public."

Carolyn (‘Lyn) Anglin
Imperial Metals Corporation

J. Willis Ambrose Medal

This medal is awarded to an individual for sustained dedicated service to the Canadian Earth Science community. This year, the medal is presented to Dr. Carolyn (‘Lyn) Anglin (Imperial Metals Corporation).

“For her outstanding contributions to the scientific management of public- and private-sector geoscientific research and development, and for her long-term volunteer contributions to Canadian geoscientific organizations, including the Geological Association of Canada.”

Médaille J. Willis Ambrose

Cette médaille est décernée à une personne pour son dévouement exceptionnel à la communauté canadienne des sciences de la Terre. Cette année, la médaille est décernée à M^{me} Carolyn (‘Lyn) Anglin de l’Imperial Metals Corporation.

“Pour ses contributions exceptionnelles à la gestion scientifique de la recherche et du développement géoscientifique dans les secteurs public et privé et pour ses contributions à long terme en tant que bénévole auprès d'organismes géoscientifiques canadiens, dont l’Association géologique du Canada.”

Katie Maloney
University of Toronto, Mississauga
Université de Toronto, Mississauga

Eric Mountjoy Exchange Award

The Eric Mountjoy Exchange Award is available to encourage the exchange of young geoscientists between Quebec and other parts of Canada. This year, the award is presented to Mrs. Katie Maloney (University of Toronto, Mississauga).

“Will be visiting McGill University to analyze redox-sensitive trace elements in shale samples from the Wernecke Mountains to better constrain paleo-ocean oxygenation conditions during deposition, which will inform the habitability of such environments for early eukaryotic life in the Tonian.”

Prix Échange Eric Mountjoy

Le prix Échange Eric Mountjoy vise à encourager l’échange de jeunes géoscientifiques entre le Québec et les autres régions du Canada. Cette année, le prix est décerné à M^{me} Katie Maloney de l’Université de Toronto, Mississauga.

"Elle visitera l'Université McGill pour analyser les éléments traces sensibles au redox dans des échantillons de schistes des montagnes de Wernecke afin de mieux contraindre les conditions d'oxygénation du paléo-océan lors du dépôt, ce qui éclairera sur l'habitabilité de tels environnements pour la vie eucaryote précoce du Tonien."

Andrew Steiner
University of British Columbia
Université de la Colombie-Britannique

Mary-Claire Ward Award

The Mary-Claire Ward Geoscience Award is presented annually to a graduate student at a Canadian university whose thesis incorporates geoscience mapping as a significant component. This year, the award is presented to Mr. Andrew Steiner (University of British Columbia).

"For his M.Sc. research, which aims to map auriferous fluid pathways, identify the salient geological controls on fluid flow, and assess the physiochemical evolution of ore fluids in the Carlin-type gold deposits of the Nadaleen trend, Yukon."

Prix Mary-Claire Ward

Le prix géoscientifique Mary-Claire Ward est présenté chaque année à un(e) étudiant(e) diplômé(e) d'une université canadienne dont le mémoire comporte une composante importante de cartographie de terrain. Cette année, le prix est remis à M. Andrew Steiner de l'Université de la Colombie-Britannique.

"Pour sa recherche au niveau de la maitrise qui vise à cartographier les voies des fluides aurifères, à identifier les principaux contrôles géologiques sur leur écoulement et à en évaluer l'évolution physicochimique au sein des gîtes aurifères de type Carlin de Nadaleen, au Yukon."

GAC® Mineral Deposit Division (MDD) Awards

Prix de la Division des gîtes minéraux de l'AGC

Jeremy Richards
Laurentian University
Université Laurentienne

Duncan R. Derry Medal

The Duncan R. Derry Medal is the highest award bestowed by the Mineral Deposits Division (MDD). It is awarded annually to an outstanding economic geologist who has made significant contributions to the science of economic geology in Canada. The 2019 recipient is Dr. Jeremy Richards from Laurentian University.

"For sustained outstanding contributions to our understanding of porphyry copper deposits"

Médaille Duncan R. Derry

La Médaille Duncan R. Derry est la plus haute distinction attribuée par la Division des gîtes minéraux de l'AGC. Ce prix est décerné chaque année au ou à la géologue qui a contribué (e) de façon la plus significative à la science de la géologie économique au Canada. Le récipiendaire pour 2019 est M. Jeremy Richards de l'Université Laurentienne.

"Pour ses contributions exceptionnelles et soutenues à notre compréhension des gisements porphyriques de cuivre"

Michelle DeWolfe

Mount Royal University
Université Mount Royal

William Harvey Gross Award

The William Harvey Gross Award is bestowed annually by the Mineral Deposits Division (MDD) to a geoscientist less than 40 years of age (as of December 31 of the nomination year) who has made a significant contribution to the field of economic geology in a Canadian context. The 2019 recipient is Dr. Michelle DeWolfe from Mount Royal University.

"In recognition of illuminating research on the volcanology and petrogenesis of ancient submarine volcanic successions, resulting new concepts in VMS formation, devotion to education and service to the geoscience community."

Prix William Harvey Gross

Le Prix William Harvey Gross est attribué chaque année par la Division des gîtes minéraux de l'AGC à un ou une géoscientifique de moins de 40 ans (au 31 décembre de l'année de nomination) qui a contribué (e) de façon significative au domaine de la géologie économique dans un contexte canadien. La récipiendaire pour 2019 est M[me] Michelle DeWolfe de l'Université Mount Royal.

"En reconnaissance de recherches éclairantes sur la volcanologie et la pétrogenèse d'anciennes successions volcaniques sous-marines, ayant résulté en de nouveaux concepts sur la formation des SMV, son dévouement à l'éducation et ses services à la communauté géoscientifiques."

GAC® Volcanology and Igneous Petrology Division Awards

Prix de la division de la volcanologie et de la pétrologie ignée de l'AGC

Donald Bruce Dingwell
Ludwig Maximilian University, Munich
Université Ludwig Maximilian. Munich

Career Achievement Award

The Volcanology and Igneous Petrology Division of the Geological Association of Canada annually presents a Career Achievement Award in recognition of career achievements in the field of volcanology and/or igneous petrology. Candidates are judged on their lifetime scientific contributions. The award will be presented to Dr. Donald Bruce Dingwell, Ludwig Maximilian University of Munich.

Prix de réalisation de carrière

La division de la volcanologie et de pétrologie ignée de l'Association géologique du Canada décerne chaque année un prix de carrière pour récompenser des réalisations professionnelles dans le domaine de la volcanologie et / ou de la pétrologie ignée. Les candidats sont jugés sur leurs contributions scientifiques à vie. Cette année, le prix sera remis à M. Donald Bruce Dingwell, de l'Université Ludwig Maximilian de Munich.

"Prof. Donald Dingwell's research focuses primarily on the physics and chemistry of geological materials. His >430 publications formed a basis for many developments in the modern field of experimental volcanology. This award reflects his intellectual abilities and his adaptability to explore widely contrasting questions in volcanology and igneous petrology."

"Les travaux du professeur Donald Dingwell portent principalement sur la physique et la chimie des matériaux géologiques. Ses plus de 430 publications ont servi de base à de nombreux développements dans le domaine moderne de la volcanologie expérimentale. Ce prix témoigne de ses capacités intellectuelles et de son adaptabilité à explorer des questions très différentes en volcanologie et en pétrologie ignée."

Melissa Anderson
Gold Medal
Médaille d'or

Gabriel Sombini Dos Santos
Silver Medal
Médaille d'argent

Rebecca Canam
Bronze Medal
Médaille de bronze

Léopold Gélinas Medals

The Volcanology and Igneous Petrology Division of the Geological Association of Canada annually presents three medals for the most outstanding theses, written by Canadian students or submitted to Canadian universities, which comprise material at least 50% related to volcanology and/or igneous petrology. A gold (plated) medal is awarded for the best PhD thesis, a silver medal for the best MSc thesis, and an antique copper medal for the best BSc thesis. Theses are evaluated on the basis or originality, validity of concepts, organization and presentation of data, understanding of volcanology and petrology, and depth of research.

The gold medal will be presented to Dr. Melissa Anderson for her thesis entitled *"Relationships between tectonics, volcanism, and hydrothermal venting in the New Hebrides and Mariana back-arc* basins, Western Pacific".

The silver medal will be presented to Gabriel Sombini Dos Santos for his thesis entitled *"Petrology, geochemistry, age and tectonic setting of the Margaree pluton, Aspy terrane, Cape Breton Island, Nova Scotia".*

The bronze medal will be presented to Rebecca Canam for her thesis entitled *"Age, petrology, and geochemistry of an appinitic lamprophyre, Hjalmar Lake, South Rae Craton, Northwest Territories"*

Médailles Léopold Gélinas

La division de volcanologie et de pétrologie ignée de l'Association géologique du Canada décerne chaque année trois médailles aux thèses les plus remarquables, rédigées par des étudiants canadiens ou soumises à des universités canadiennes, dont le sujet comporte au moins 50% de volcanologie et / ou de pétrologie ignée. Une médaille d'or est attribuée à la meilleure thèse de doctorat, une médaille d'argent à la meilleure thèse de maîtrise et une médaille de cuivre antique à la meilleure thèse de licence. Les thèses sont évaluées sur la base de l'originalité, la validité des concepts, l'organisation et la présentation des données, la compréhension de la volcanologie et de la pétrologie et la profondeur de la recherche.

La médaille d'or sera remise à Mme Melissa Anderson pour sa thèse intitulée *«Relations entre la tectonique, le volcanisme et la ventilation hydrothermale dans les bassins d'arrière-arc des Nouvelles-Hébrides et de Mariana, Pacifique occidental».*

La médaille d'argent sera remise à Gabriel Sombini Dos Santos pour sa thèse intitulée *«Pétrologie, géochimie, âge et cadre tectonique du pluton de Margaree, terrane d'Aspy, île du Cap-Breton, Nouvelle-Écosse».*

La médaille de bronze sera remise à Rebecca Canam pour sa thèse intitulée *«Âge, pétrologie et géochimie d'un lamprophyre appinitique, lac Hjalmar, craton de Rae Sud, Territoires du Nord-Ouest».*

Susan L.S. Stipp
Technical University of Denmark
Université technique du Danemark

Peacock Medal

The Peacock Medal is awarded to a scientist who has made outstanding contributions to the mineral sciences in Canada. There is no restriction regarding nationality or residency. This year, the award is presented to Dr. Susan L.S. Stipp, Professor at the Department of Physics, Technical University of Denmark.

"Born in Canada (Ontario) and after working for several years as an exploration geologist and hydrogeologist, she began a foray into what would become a long-term passion: understanding the science of mineral-surface chemistry. She has sought to employ novel techniques (XPS, AFM) to investigate atomic-scale processes occurring at the mineral surfaces and by better understanding these, to develop insights into how these impact on mineral transformations and the reactivity of minerals. Prof. Stipp has followed a remarkable career, building on her combined experiences, curiosity and scientific rigor that have culminated in her both creating and running the Centre for Interface Geochemistry in Lausanne, Switzerland and the NanoGeoScience Center in Copenhagen, Denmark. Throughout her illuminating and most-impressive career, she has not forgotten where she has come from and continues to lead and inspire the next generation."

Médaille Peacock

La médaille Peacock est décernée à une personne qui a contribué de manière exceptionnelle à la minéralogie au Canada. Il n'y a aucune restriction concernant la nationalité ou la résidence. Cette année, la médaille est décernée à M^me^ Susan L.S. Stipp, professeure au département de physique de l'Université technique du Danemark.

"Née au Canada (Ontario) et après avoir travaillé pendant plusieurs années comme géologue de terrain et hydrogéologue, elle a débuté sa croisade envers ce qui allait devenir une passion à long-terme : comprendre la science de la chimie de surface des minéraux. Elle s'est efforcée à utiliser des techniques novatrices (XPS, AFM) afin d'étudier les processus à l'échelle atomique rencontrés à la surface des minéraux et à mieux les comprendre, pour développer des connaissances sur comment ces processus impacte les transformations minérales et la réactivité de ces minéraux. Elle a mené une carrière remarquable, bâtie sur ces expériences combinées, sa curiosité, et sa rigueur scientifique, qui l'ont conduit à créer et gérer le fonctionnement du centre 'Centre for Interface Geochemisty' de Lausanne en Suisse ainsi que le centre 'NanoGeoScience Center' à Copenhague, au Danemark. A travers son impressionnante carrière, elle n'a pas oublié d'où elle venait et elle continue à diriger et inspirer la nouvelle génération."

Lecture abstract

What IS a Mineral Surface? And why do we care?

Inside, minerals are beautifully ordered. Even defects and inclusions of other elements are overpowered by the precision of the atomic structure, giving each mineral its unique properties. A surface, formed by cleavage or fracture, produces a huge defect where the atoms, to a depth of about three molecular layers, feel out of balance. Surfaces satisfy their dangling bonds immediately, even in vacuum, by reacting with whatever they find, the fluid (gas, liquid, all that flows) in contact. So when we consider a mineral surface, what IS its composition and structure? After nearly a lifetime, I am sure of a couple of things. A surface is NOT a termination of the bulk structure. Water, sometimes torn apart to H^+ and OH^-, delocalises surface charge. Surfaces are decorated with adsorbed species of all sorts, organic compounds, some of which simply cannot break free, once they get close, and sometimes nanominerals. Though we cannot see it with classical X-ray diffraction, this surface material is what the fluid sees and it

Résumé de l'allocution

Qu'est-ce qu'une surface minérale ? Et pourquoi s'en soucier ?

À l'intérieur, les minéraux sont magnifiquement ordonnés. Même les défauts et les inclusions d'autres éléments sont maîtrisés par la précision de la structure atomique, conférant à chaque minéral ses propriétés uniques. Une surface, formée par clivage ou fracture, produit un énorme défaut au niveau des atomes, qui se sentent déséquilibrés sur une profondeur d'environ trois couches moléculaires. Même s'il n'y a rien, les surfaces satisfont immédiatement leurs liaisons pendantes en réagissant avec ce qu'elles trouvent, le fluide (gaz, liquide, tout ce qui s'écoule) qui se trouve en contact. Ainsi, quand on considère une surface minérale, quelle est sa composition et sa structure? Après presque une vie, je suis certain de deux choses. Une surface n'est PAS une terminaison de la structure en vrac. La molécule d'eau, parfois séparée en H^+ et OH^-, délocalise la charge de surface. Les surfaces sont alors garnies avec toutes sortes d'espèces adsorbées, de composés organiques, parfois de nanominéraux dont certains, une fois proches, ne peuvent tout simplement pas

defines the mineral behaviour. For example, wettability (i.e. surface tension or surface free energy) controls our ability to produce oil or remove toxic solvents from soil, to optimise flotation in ore refining, delivery of pharmaceuticals in the body and production of insulation. Adsorbed organic compounds can make or break the production of particles for making paints, pigments, paper, cosmetics and a host of other products. And when you think of it, what happens at the mineral-fluid interface, at the nanometre scale, determines what happens at the gigametre scale, for formation of a gold deposit, behaviour of toxic organic compounds in hydrogeologic systems, melting or crystallisation deep in the Earth's crust, evolution of CO_2 from geothermal plants and in carbon capture and storage (CCS), the behaviour of particles in the atmosphere and in the cosmos. Mineral-fluid interactions are at the base of it all.

se libérer. Bien que nous ne puissions pas le voir avec la diffraction à rayons X classique, ce matériau de surface est ce que le fluide voit et qui définit le comportement du minéral. Par exemple, la mouillabilité (tension superficielle ou énergie libre de surface) contrôle notre capacité à produire de l'huile ou à éliminer les solvants toxiques du sol, à optimiser la flottation lors du raffinage du minerai, à permettre la diffusion de produits pharmaceutiques dans le corps et la production d'isolant. Les composés organiques adsorbés peuvent produire ou interrompre la production de particules pour la fabrication de peintures, de pigments, de papier, de cosmétiques et de nombreux autres produits. Lorsque l'on y pense, ce qui se passe à l'interface minéral-fluide, à l'échelle nanométrique, détermine ce qui se passe à l'échelle gigamètrique, pour la formation d'un gisement aurifère, le comportement de composés organiques toxiques dans les systèmes hydrogéologiques, la fusion ou la cristallisation dans les profondeurs de la croûte terrestre, l'évolution du CO_2 provenant de centrales géothermiques et dans le captage et le stockage du carbone (CSC), le comportement des particules dans l'atmosphère et dans le cosmos. Les interactions minéral-fluide sont à la base de tout cela.

Rémy Poulin
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Beth McClenaghan
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Hawley Medal

Médaille Hawley

The Hawley Medal is awarded to Drs. Rémy S. Poulin, Daniel J. Kontak, Andrew McDonald (Harquail School of Earth Sciences, Laurentian University), and Dr. Beth McClenaghan (Geological Survey of Canada) for the best paper published in The Canadian Mineralogist in 2018 and entitled "Assessing scheelite as an ore-deposit discriminator using its trace-element and REE chemistry."

La médaille Hawley est décernée à Rémy S. Poulin, Daniel J. Kontak, Andrew McDonald (École Harquail des sciences de la Terre, Université Laurentienne) et M^{me} Beth McClenaghan (Commission géologique du Canada) pour le meilleur article publié dans The Canadian Mineralogist en 2018 et intitulé "Assessing scheelite as an ore-deposit discriminator using its trace-element and REE chemistry. "

"The winning paper demonstrates that the crystal-chemical characteristics of a widely occurring mineral can be successfully used to discriminate between samples arising in different ore-deposit settings. By using a multi-pronged methodology (CL imaging, major, minor and trace-element chemistry, stable-isotopes, etc.), the authors have established several key, elegant features that make discrimination possible. Besides contributing to our knowledge of the processes behind the formation and evolution of scheelite in a broad range of geological

"L'article gagnant démontre que les caractéristiques cristallochimiques d'un minéral commun peuvent être utilisées avec succès pour distinguer entre des échantillons provenants de différents contextes métallogéniques. En utilisant une méthodologie à plusieurs volets (imagerie CL, chimie des éléments majeurs, mineurs et traces, isotopes stables, etc.), les auteurs ont établi plusieurs critères clés qui rendent la différenciation possible. En plus de contribuer à la connaissance des processus menant à la formation et l'évolution de la scheelite

environments, they have also created an extensive database of crystal-chemical data that will serve researchers far into the future. Their study illustrates key relationships between geology, mineralogy, crystal-chemistry and the impact these can have in understanding geological processes and in the exploration for ore deposits."

dans une vaste gamme d'environnements géologiques, ils ont aussi créé une vaste base de données cristallochimiques qui servira longtemps aux chercheurs. Leur étude illustre les relations-clés entre la géologie, la minéralogie, la cristallochimie, et l'impact que ces dernières peuvent avoir sur la compréhension des processus géologiques et l'exploration des gîtes minéraux."

Vincent van Hinsberg
McGill University
Université McGill

Young Scientist Award

This award is given to a young scientist who has made a significant international research contribution in a promising start to a scientific career. This year, the award is presented to Vincent van Hinsberg, Department of Earth and Planetary Sciences, McGill University.

"For using the chemistry of minerals to elucidate the conditions under which the minerals develop and by extension, to better understand the broader geological processes behind mineral and rock formation. He is also recognized for combining mineralogy and geochemistry, using quantitative modelling based on laboratory experiments and measurements in the field, to investigate how fluid chemistry is recorded in minerals, invoking novel approaches including lattice-strain theory and the controls it exerts on mineral and fluid compositions."

Address:
Minerals as probes of fluid composition: Exploring the physico-chemical controls on element uptake by minerals with applications to understanding ore formation, plate tectonics and the early evolution of life

The incorporation of trace elements into a mineral structure is highly systematic. It is controlled by the degree of mismatch in a trace element's radius and charge compared to the element it is replacing. As a result, the composition of a mineral directly reflects that of the fluid from which it formed. When element partition coefficients between mineral and fluid are known, fluid composition can be quantitatively reconstructed from the mineral record. Given the scarcity of fluid samples, especially for the deep Earth and its earliest history, the mineral record provides a powerful alternative approach to investigate the compositions of fluids and their impact on geological processes.

Prix jeune scientifique

Ce prix est décerné à un (e) jeune scientifique qui a contribué (e) de manière significative à une recherche internationale dont le début de carrière scientifique est prometteur. Cette année, le prix sera remis à Vincent van Hinsberg du département des Sciences de la Terre et des planètes de l'Université McGill.

"Pour l'utilisation de la chimie minérale en vue d'élucider les conditions de cristallisation des minéraux et, par extension, mieux comprendre les processus géologiques globaux derrière la formation des minéraux et des roches. Il est également reconnu pour combiner minéralogie, géochimie et modélisation quantitative basée sur des expériences de laboratoire et des mesures sur le terrain afin de caractériser comment les minéraux enregistrent la chimie des fluides et ce en appliquant de nouvelles approches dont la théorie de la déformation des réseaux et les contrôles qu'elle applique aux minéraux et aux fluides."

Allocution :
Les minéraux en tant que sondes de la composition des fluides: exploration des contrôles physico-chimiques de l'absorption des éléments par les minéraux et leurs impacts sur la compréhension de la genèse des gîtes, de la tectonique des plaques et de l'évolution précoce de la vie

L'incorporation d'éléments traces dans une structure minérale est fortement systématique. Elle est contrôlée par le degré de disparité dans le rayon et la charge d'un élément par rapport à celui qu'il remplace. De ce fait, la composition d'un minéral reflète directement celle du fluide à partir duquel il s'est formé. Lorsque les coefficients de partage des éléments entre le minéral et le fluide sont connus, la composition du fluide peut être reconstruite quantitativement à partir des assemblages minéralogiques. Compte tenu de la rareté des échantillons de fluides, en particulier à des profondeurs significatives, les assemblages minéralogiques constituent une approche alternative puissante pour étudier la

The crystal lattice systematics underlying element partitioning are formalised in Lattice-Strain Theory (LST), which provides a quantitative description of the strain resulting from radius and charge mismatch and the resulting impact on partition coefficients. LST has proven hugely successful in describing partitioning among minerals and melts at a wide range of pressure-temperature conditions, and we have shown that it can also be used to describe mineral-fluid element partitioning if element speciation in the fluid is accounted for. The key advantage of Lattice-Strain Theory is that it allows for partition coefficients to be estimated, modelled and extrapolated to elements and conditions for which no experimental data exist.

In this presentation, I will show how a fundamental understanding of crystal lattices allows for prediction of mineral-fluid partitioning behaviour, and use this insight to reconstruct the compositions of fluids in ore forming systems and subduction zones, and to characterize the black smoker flux into the Archaean oceans.

composition des fluides et leur impact sur les processus géologiques. Le partage des éléments issus du réseau cristallin est formalisé dans la théorie Lattice-Strain Theory (LST), qui fournit une description quantitative de la déformation résultant de la disparité des rayons et des charges et de l'impact qui en résulte sur les coefficients de partage. La théorie LST a très bien réussi à décrire la répartition entre minéraux et liquides magmatiques dans une large gamme de conditions de pression et de température et nous avons montré qu'elle pouvait également être utilisée pour décrire la répartition d'éléments minéral-fluide si la spéciation des éléments dans le fluide est prise en compte. Le principal avantage de la théorie des réseaux de tensions est qu'elle permet d'estimer, de modéliser et d'extrapoler les coefficients de partage à des éléments et à des conditions pour lesquels il n'existe aucune donnée expérimentale. Dans cette présentation, je montrerai comment une compréhension fondamentale des réseaux cristallins permet de prédire le comportement du cloisonnement minéral-fluide, et utiliserai cette information pour reconstruire la composition des fluides dans les systèmes de formation de minerai et les zones de subduction, et pour caractériser le flux dans les océans archéens.

Lee A. Groat
University of British Columbia
Université de la Colombie-Britannique

Berry Medal

The Berry Medal recognizes the long-term dedication of individuals to the association. This year, the award is presented to Dr. Lee A. Groat of the University of British Columbia.

"For being actively involved in MAC for more than 25 years, taking on many leadership roles including Foreign Secretary, Councillor, Membership Secretary, Vice-President and President-Elect. He currently serves as Editor of The Canadian Mineralogist, a role he accepted in 2012 and continues to hold today. He has also acted as a strong advocate of research within the MAC, organizing Short Courses and Special Sessions on a variety of themes ranging from petrology, to biological interactions with minerals, to gems."

Médaille Berry

La médaille Berry reconnaît le dévouement à long terme d'un membre de l'association. Cette année, la médaille est décernée à M. Lee A. Groat de l'Université de la Colombie-Britannique.

"Pour avoir été activement impliqué dans l'AMC pendant plus de 25 ans, assumant de nombreux rôles de leadership, dont ceux de secrétaire aux affaires étrangères, conseiller, secrétaire aux adhésions, vice-président et président élu. Il est présentement éditeur du journal 'The Canadian Mineralogist, un rôle qu'il a accepté en 2012, et qu'il assume encore à ce jour. Il s'est aussi fait l'ardent défenseur de la recherche au sein de l'AMC, organisant des cours intensifs et des sessions spéciales sur une variété de sujets, allant de la pétrologie, aux interactions biologiques avec les minéraux, jusqu'aux pierres précieuses."

IAH-CNC Award and Lecture

Prix de l'AIH-SCN et Allocution

J. Tóth Award

Prix J. Tóth

The Tóth Award is given for the Best Student Presentation in Hydrogeology. This award is named in honour of the founder of the Canadian National Chapter of the International Association of Hydrogeologists, Professor József Tóth. During his long and productive career in Canada, Dr. Tóth made many important contributions to Canadian hydrogeology and was an inspirational teacher. The award is presented each year when the IAH-CNC hosts or participates in a national conference and is intended to promote active participation in the IAH-CNC among hydrogeology students attending Canadian Universities and to recognize excellence in hydrogeology. The award provides an incentive for students and recent graduates to attend the national IAH-CNC conferences and present the results of their studies.

Le prix J. Tóth récompense la meilleure présentation étudiante en hydrogéologie. Ce prix a été créé en l'honneur du fondateur de la Section nationale canadienne de l'Association internationale des hydrogéologues (SNCAIH), le professeur Josef Tóth. Durant sa longue et fructueuse carrière au Canada, le professeur Tóth a non seulement contribué de façon considérable au domaine de l'hydrogéologie canadienne, mais il a été une source d'inspiration pour ses étudiants. Le prix récompense l'excellence en hydrogéologie et encourage la participation des étudiants au sein de l'AIH-SNC. Le prix vise à inciter les étudiants et les nouveaux diplômés des universités canadiennes à participer aux congrès de l'AIH-SNC et y présenter les résultats de leurs recherches.

IAH-CNC Lecturer

Conférencier AIH-SCN

Richard Jackson
Geofirma Engineering and University of Waterloo
Geofirma Engineering et Université de Waterloo

Natural resource development and the hydrogeologist: the case of shale gas in Canada
IAH-CNC Luncheon

Canadians can have different attitudes about natural resource development. In urban areas – Vancouver, Toronto, Montréal – it is often subject to questioning and even criticism. In western Canada and Québec and Ontario beyond the great cities, it is often accepted as a means of economic and social benefit. The hydrogeologist is often drawn into these debates – development of new aggregate quarries to supply nearby cities, the use of groundwater for bottled water and, especially, the development of shale gas over the past ten years. The shale gas debate in Quebec and the Maritimes exposed how little influence hydrogeologists have in clarifying what is physically likely and what is not. Was it appropriate that we as a community of informed geoscientists should have been so silent?

Le développement des ressources naturelles et l'hydrogéologue: le cas du gaz de schiste au Canada
Diner-causerie de l'AIH-SCN

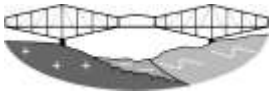
Les Canadiens peuvent avoir des opinions différentes à propos du développement des ressources naturelles. Dans les zones urbaines - Vancouver, Toronto, Montréal - il est souvent sujet à des interrogations et même à des critiques. Dans l'Ouest canadien, au Québec et en Ontario, au-delà des grandes villes, il est bien souvent accepté en tant que moyen de générer des retombées socio-économiques importantes. L'hydrogéologue est souvent impliqué dans ces débats - développement de nouvelles carrières de granulats pour approvisionner les villes à proximité, pompage d'eau souterraine pour la vente d'eau embouteillée et, en particulier, exploitation des gaz de schiste au cours des dix dernières années. Le débat sur les gaz de schiste au Québec et dans les Maritimes a révélé le peu d'influence des hydrogéologues pour clarifier ce qui est physiquement probable et ce qui ne l'est pas. Était-il approprié que notre communauté de géoscientifiques informés demeure si silencieuse?

Canadian Journal of Earth Sciences Award

The *Canadian Journal of Earth Sciences* Best Paper Award for 2018 is presented to Drs. Chris White, Sandra Barr, and Ulf Linnemann for their paper entitled ‘‘U-Pb (zircon) ages and provenance of the White Rock Formation of the Rockville Notch Group, Meguma terrane, Nova Scotia, Canada: evidence for the "Sardian gap" and West African origin’’.

Prix de la Revue canadienne des sciences de la Terre

Le prix pour le meilleur article de la *Revue canadienne des sciences de la Terre* pour l’année 2018 est décerné à M. Chris White, Mme Sandra Barr et M. Ulf Linnemann pour leur article portant sur l’âge U-Pb (zircon) et la provenance de la formation de White Rock du Groupe de Rockville Notch (terrane de Meguma, Nouvelle-Écosse, Canada) comme preuve de la présence du "fossé de sardien" et d’une origine de l'Afrique de l'Ouest.



1 - Geosystems and hydro-geosystems

1 - Géosystèmes et hydrogéosystèmes

SY-GH01

The growth of Laurentia: recent advances in reconstructing metamorphosed, deformed and deeply eroded continental margins

Conveners: van Rooyen, D., Corrigan, D., Indares, A.

Breaking the Grenville-Sveconorwegian link in the Rodinia supercontinent [Keynote]
Slagstad, T., Roberts, N.M.W., Kulakov, E., Kirkland, C.L.

Mesoproterozoic evolution of the SE Laurentian margin as recorded in the central Grenville Province.
Groulier, P.-A., Indares, A., Dunning, G., Moukhsil, A.

Lateral variations of the SE Laurentian margin and the architecture of the central Grenville Province
Indares, A., Groulier, P.-A.

Large-scale tectonic processes in the Grenville orogeny: insights from Cordillera and Himalaya-Tibet
Hyndman, R.

A convergent plate boundary along the southern margin of Laurentia from ~ 1.5-1.3 Ga
Aronoff, R., Vervoort, J., Jones, J.V.

Evaluating the late tectonothermal evolution of anorthosite massifs: evidence from the Flowers River Igneous Suite, Hopedale Block, Labrador
Ducharme, T., van Rooyen, D., McFarlane, C.R.M., Corrigan, D.

The Wyoming Province, a long-lived craton on the periphery of Laurentia [Keynote]
Frost, B.R., Frost, C.

Defining the Mesoproterozoic 1450-1360 Ma Picuris orogeny in the southwestern United States and exploring possible linkages with the 1510-1450 Ma Pinware orogeny, eastern Canada
Daniel, C., Aronoff, R., Doe, M.F.

Detrital zircon provenance and tectonostratigraphic evolution of the mid- to southern Labrador Trough
Corrigan, D., Rayner, N., van Rooyen, D.

Tectonic evolution of the New Quebec Orogen: new insights from field mapping and U-Pb geochronology in the Kuujjuaq area
van Rooyen, D., Corrigan, D., McNicoll, V., Rayner, N.

Paleoproterozoic metasupracrustal suites on the NW flank of the Wyoming Province: the stories they do and do not tell about an evolving continent [Keynote]
Harms, T., Baldwin, J.

Building the Athabasca Mylonite Triangle: new insight from microstructural analysis, petrology and crystallographic preferred orientations
Graziani, R., Larson, K., Soret, M.

Structural characterisation and geochronology of the Wager shear zone, northwestern Hudson Bay, Nunavut
Therriault, I., Larson, K., Steenkamp, H.

Petrogenesis of the late- to post-tectonic granitoids of Boothia Peninsula, NU: Lu-Hf and Sm-Nd isotope characterization of the granitoids and their source rocks
Osinchuk, A., Chacko, T., Heaman, L., Regis, D., Sanborn-Barrie, M.

Reconstructing supercraton Superia: complexities in Superior-Karelia connections due to orogenic crustal block rotations in Western Karelia
Davey, S., Bleeker, W., Kamo, S.L., Ernst, R., Vuollo, J., Cousens, B.

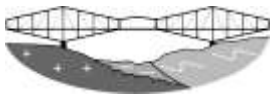
Metamorphism and tectonics of the Hunt River greenstone belt in Labrador, Canada
Zelt, C., van Rooyen, D., McFarlane, C.

New 1:250 000 scale bedrock geology maps of the South Rae craton in NWT (NTS 75A, B, G and H)
Martel, E., Pehrsson, S., Regis, D., Thiessen, E., Jamison, D., Percival, J., Davis, W.

U-Pb zircon chronology of basement gneisses and granitoids in the Nonacho Lake area, NT: Correlations to the Queen Maud block
Neil, B., Heaman, L., Chacko, T., Martel, E.

The U-Pb-Hf detrital zircon record of a Montauban-type quartzite: implications for the accretionary evolution of the Western Grenville Province
Papapavlou, K., Moukhsil, A., Poirier, A., Davies, J.

Heterogeneous preservation of Archean tectonism recorded by titanite within the Paleoproterozoic Snowbird Tectonic Zone
Thiessen, E., Gibson, H.D., Regis, D., Pehrsson, S.



SY-RE01

Gold: Recent advances, and 20 years of research through GSC's Targeted Geoscience Initiative Program under Dr. Benoît Dubé's leadership

Conveners: Mercier-Langevin, P., de Souza, S., Malo, M., Archer, P., Galley, A., Bécu, V.

Gold: recent advances, and 20 years of research through GSC's Targeted Geoscience Initiative Program under Dr. Benoît Dubé's leadership – An introduction
Mercier-Langevin, P., Archer, P., Malo, M., de Souza, S.

Gold deposits of the Archean Abitibi greenstone belt, Canada [Keynote]
Dubé, B., Mercier-Langevin, P.

In search of the gold fluid: results of fluid inclusion studies in Abitibi Greestone Belt deposits
Kontak, D., Tuba, G., Hastie, E., Pfister, J., Choquette, B., Zajacz, Z.

Crustal-scale faults, syn-orogenic clastic rocks, magmatism and orogenic gold deposits
Bleeker, W.

Auriferous intrusion-related sheeted veins in the Abitibi-Wawa subprovince
Lafrance, B., Smith, J., McDivitt, J., Kontak, D.

Revealing the histories of geological minerals in auriferous mineral deposits using laser ablation LA-ICP-MS imaging techniques
Jackson, S., Pilote, J.-L., Lawley, C., Petts, D., Yang, Z., Dubé, B., Mercier-Langevin, P.

On the nature and origin of Dubéesque gold in the Abitibi and beyond
Hastie, E., Kontak, D., Lafrance, B., Schindler, M.

Gold endowment in iron sulphide nodules: insights on the enrichment controlling factors from the carbonaceous metasedimentary rocks of the Timmins-Matheson gold corridor, Ontario, Canada
Pilote, J.-L., Jackson, S., Mercier-Langevin, P., Dubé, B., Lawley, C., Rhys, D., Petts, D., van Hees, E.

The structural control and geochemical footprint of the world-class Hardrock orogenic gold deposit, Geraldton, ON
Toth, Z., Lafrance, B., Dubé, B.

Geological setting and revised genetic and exploration models for the world-class BIF-hosted Musselwhite gold deposit, Superior Province, northwestern Ontario
Oswald, W., Castonguay, S., Dubé, B., McNicoll, V., McCormack, K., Malo, M., Mercier-Langevin, P.

Nature and origin of the hypozonal gold mineralization at the Éléonore mine, Eeyou Istchee, Baie James, Superior Province, Québec
Fontaine, A., Dubé, B., Malo, M., Ravenelle, J.-F., McNicoll, V., Jackson, S., Prud'homme, N., Turcotte, J.

The Troilus deposit: a new structural model and a new perspective
Brassard, B., Hylands, B.

Tracking hydrothermal fluid evolution of an Archean orogenic gold deposit through multiple sulphur isotope analysis linked to detailed structural paragenesis
Sugiono, D., LaFlamme, C., Thébaud, N., Fiorentini, M., Martin, L., Rogers, J.

Paleozoic gold in central Newfoundland: lithological setting, structural development, and lessons from structurally controlled gold systems of the Archean Abitibi greenstone belt
Honsberger, I., Bleeker, W., Sandeman, H., Evans, D.

Setting and characteristics of Au-Ag-Cu-Zn volcanic-hosted mineralization in the Tireo belt, Dominican Republic
Galley, A., Gonzales, N., Franklin, J., Moore, M., Boyd, T., Fisher, W.

Revisiting the relationships between Paleogene tectonics and gold mineralization in the Cordilleran Orogen
Ootes, L., Castonguay, S.

Gold-bearing arsenian pyrite in Carlin-type gold prospects of the Nadaleen trend, Yukon
Sack, P., Cline, J., Ren, M., Petts, D., Pinet, N.

U-Pb ages of hydrothermal calcite associated with Carlin-type gold mineralization, Nadeleen trend, north-central Yukon
Davis, W., Pinet, N., Petts, D.C., Jackson, S., Mercier-Langevin, P.

Controls on the Tiriganiaq gold deposit banded iron formation-hosted ore zones, Meliadine district, Nunavut
St Pierre, B., Mercier-Langevin, P., Malo, M., Blais, J.-C., Servelle, G., Simard, M., Hjorth, M.

Stratigraphic setting and geochemical footprint of the world-class Amaruq BIF-associated gold deposit, Churchill Province, Nunavut
Valette, M., de Souza, S., Mercier-Langevin, P., Côté-Mantha, O., Simard, M., McNicoll, V., Wodicka, N., Barbe, P.

Deciphering multi-stage ore-forming processes in metasedimentary-rock-hosted orogenic gold deposit settings using LA-ICP-MS sulphide analysis
Gourcerol, B., Kontak, D.J., Thurston, P.C., Petrus, J.

Lithological and structural controls on the nature and distribution of gold at the LaRonde Zone 5 project, Doyon-Bousquet-LaRonde mining camp, Abitibi, Québec
Boily-Auclair, E., Mercier-Langevin, P., Ross, P.-S., Pitre, D.

Geology of the Windfall Lake gold deposit, Québec, Canada
Choquette, B., Kontak, D., Padilla, R., Côté-Lavoie, E., Davis, D., Fayek, M.

Geometallurgical domains in a gold deposit: example from the Whale Tail deposit, Amaruq project, Nunavut
Guillevic, F., Mathieu, L., Simard, M., Chopard, A.

Au-As association at the Orenada Zone 4 deposit, Val-d'Or, Québec
Powell, C., Linnen, R.

Archean gold mineralization in the Wawa Gold Corridor, Wawa, Ontario
Wehrle, E., Montreuil, J.-F., Samson, I., Hoyle, J., Kontak, D.

Enrichment of secondary gold by lateritic weathering on Gentio do Ouro Golden District, State of Bahia, Brazil – a geochemical approach
Souza, F., Lemos, C., Souza, N., Sidro, J.

SY-RE02

Golden magmas: Precambrian magmatism features and relationship to gold and base metals mineralisation

Conveners: Mathieu, L., Jébrak, M.

Archean greenstone-hosted base metal and gold mineralization: igneous fertility indicators from analogous younger terranes [Keynote]
Hattori, K.

Archean Cu-Au porphyry systems: the Chibougamau pluton example
Mathieu, L.

The East-Sullivan intrusion and its associated Au, Ag, Cu, Mo mineralization, Val d'Or District, Abitibi, Quebec
Bigot, F., Berthelot, P., Jébrak, M.

U-Pb LA-ICP-MS apatite age and characterization of Archean auriferous quartz veins of the Ptarmigan and Tom Gold deposits, Yellowknife, Northwest Territories
Richardson, M., Lentz, D., McFarlane, C., Falck, H.

Use of geometry and topology for deciphering pluton-hosted gold-rich stockwork, Baie James area
Turlin, F., Jébrak, M., de Souza, S., Turcotte, J.

New U-Pb ages and compositional data from zircons to establish the timing and evolution of porphyritic intrusions and plutonic bodies in the Yellowknife greenstone belt, NWT
Speight, S., McFarlane, C., Hanley, J.

Impact of fluorine in post-collisional magmatic-hydrothermal systems: case studies from Neoarchean Douay (Au-REE-F) and Bachelor (Au-F) deposits
Azevedo, C., Jébrak, M., Pinti, D.L.

Stable isotopic composition of arc-related magmas and associated hydrothermal alteration [Keynote]
Hedenquist, J., Arribas, A.

Oxygen fugacity and volatile content of syntectonic magmas from the Abitibi greenstone belt
Madon, B., Mathieu, L.

Geology of the auriferous Archean Mistumis pluton, James Bay, Quebec
Blu, F., Jébrak, M., de Souza, S.

Temporal evolution of magmas associated with Au-Cu mineralization in the Hualgayoc mining district, Northern Peru
Viala, M., Hattori, K.

Comparison of the Eisler and Laonil Lake Intrusive Complexes: hosts to gold mineralization, Glennie domain, northern Saskatchewan
Witvoet, L., Partin, C.A., Ansdell, K., Carlson, A.

SY-RE03 (cancelled)

SY-RE04

Greenstone belt architecture and metal endowment of the Superior craton

Conveners: Thurston, P., Ayer, J., Gibson, H., Lafrance, B., Sherlock, R.

The role of geophysics in the Metal Earth project [Keynote]
Smith, R., Eshaghi, E., Cheraghi, S., Naghizadeh, M., Roota, E., Hil, G.

Potential field data modelling along Metal Earth's Chibougamau transect using geophysical and geological constraints
Maleki, A., Eshaghi, E., Smith, R., Altwegg, P., Snyder, D., Mathieu, L., Naghizadeh, M.

Seismic imaging of crystalline crust in Canada's Superior Archean province: progress with the Metal Earth project [Keynote]
Naghizadeh, M., Snyder, D., Cheraghi, S.

Age and metal endowment of the lithospheric mantle beneath the Abitibi greenstone belt
Czas, J., Pearson, D.G., Shirey, S.B., Waterton, P., Schulze, D.J.

Isotopic terrane mapping and intra-cratonic architecture of the Superior Craton
Mole, D., Marsh, J., Thurston, P., Ayer, J.

Meeting the Metal Earth challenge: a U-Pb geochronological perspective on metal endowments in the Abitibi greenstone belt and beyond. [Keynote]
Hamilton, M.

Magmatic chromium and nickel endowment in the Superior Province
Houlé, M.G., Lesher, C.M.

A new geological map of the Lau Basin: implications for mineral prospectivity in modern and ancient arc-backarc systems
Stewart, M., Hannington, M., Emberley, J., Petersen, S., Brandl, P., Baxter, A., Anderson, M., Mercier-Langevin, P.

Metal Earth in Chibougamau: Neoarchean magmatism and its importance for mineralizing processes
Mathieu, L., Bedeaux, P., Madon, B., Boucher, A., Kieffer, M., Huguet, J., Youssoufou, Y.A., Réal, Daigneault, Bédard, L.P., Gaboury, D.

Metal Earth in Chibougamau: stratigraphy, chemistry and age of the Obatogamau Formation
Boucher, A., Mathieu, L., Daigneault, R.

Mobilization of Ni-Cu-(PGE) mineralization at the Cubric showing in the Southern Manneville fault zone, southern Abitibi subprovince, Quebec
Shirriff, D., Lesher, C.M., Lafrance, B., Zhou, X.

On the geodynamic evolution of the Pontiac subprovince, Superior Province, Rouyn-Noranda, Quebec, Canada: constraints from a detrital zircon geochronology transect
Joergensen, T., Marsh, J.

Stratigraphic and structural setting of gold mineralization along the Malartic transect in Southern Abitibi and Pontiac subprovince within the Superior Province, Quebec, Canada
Zhou, X., Lafrance, B.

Structural and stratigraphic framework of the Larder Lake area, southern Abitibi subprovince: highlights from recent seismic and magnetotelluric surveys
Rubingh, K., Sherlock, R.L.

Structural architecture and gold mineralization of a metasedimentary basin along the Larder Lake-Cadillac deformation zone in the Abitibi greenstone belt, Quebec
Samson, B., Lafrance, B., Zhou, X.

The Abitibi-Opatica contact, Archean Superior Province (Quebec): is it a tectonic plate boundary suture?
Tremblay, A., Daoudene, Y., Ruffet, G., Leclerc, F.

Volcanic reconstruction of the ca. 2701 Ma Duprat-Montbray formation: implications for targeting new volcanogenic massive sulfide (VMS) deposits in the Lower Blake River Group, Rouyn-Noranda, Quebec
Sutton, J., Gibson, H., Joergensen, T.R.C.

Stratigraphic and geochemical constraints on the paleo-environmental and geodynamic setting of the Timiskaming-like Stormy Lake Group, western Wabigoon subprovince, Ontario, Canada
Frieman, B., Perrouty, S.

Structural-Stratigraphic analysis of the Powell Fault Zone: implications for metallogeny of the Powell Block, Rouyn-Noranda, Quebec
Schofield, M., Lafrance, B., Gibson, H., Poulsen, K.H.

Sedimentary basins of the Swayze area, Abitibi greenstone belt: provenance, timing and facies association
Haugaard, R., Gemmell, T., Marsch, J., Ayer, J., Thurston, P., Hamilton, M.

The potential for intrusion-related gold systems in the western Wabigoon subprovince based on lithogeochemical and mineralogical investigations of the Lost Lake area, Ontario
Downie, D., Frieman, B., Perrouty, S.

Metallogeny and chemostratigraphy of the Elmhirst-Rickaby assemblage: an Archean andesitic package
Strongman, K., Strongman, K., Gibson, H., Lafrance, B., Toth, Z.

Normal movements along the reactivated Barlow thrust fault during exhumation of the Abitibi-Opatica boundary, Canada
Bedeaux, P., Brochu, A., Mathieu, L., Daigneault, R.

Identification of partial melting relationships in the southern Kapuskasing Structural Zone, Ontario, Canada
Estrada, N., Tinkham, D.K., Joergensen, T.

Structural characterization of the Nemiscau subprovince, Superior Province, Canada: tectonic implications for the development of Archean sedimentary basins
Pedreira Pérez, R., Tremblay, A., Daoudene, Y., Bandyayera, D.

Metal Earth: pluridisciplinary research to improve our understanding of the genesis of Precambrian metals deposits
Quesnel, B., Scheffer, C., Beaudoin, G., Laflamme, C., Guilmette, C., Dupuis, J.C.

Geologic history of the Cobalt region, Ontario: controls on mineralized veins
White, S.E., Sherlock, R.L., Hamilton, M., Lewis, D., Santaguida, F.

Structural evolution of mineralized and barren deformation zones in the western Wabigoon subprovince, Ontario: new constraints from regional mapping and petrographic analyses
Zammit, K., Frieman, B., Perrouty, S.

SY-RE05

Ore systems within IOA, IOCG, skarn and polymetallic albitite hosted deposit: A symposium in memory of Dr. Patrick Williams

Conveners: Corriveau, L., Montreuil, J.-F., Beaulieu, D., Zhao, X.-F.

Using alteration facies as proxies to metal pathways for IOCG and affiliated deposits: a global perspective from Olympic Dam and its metallogenic province to Laurentian margin examples
Corriveau, L., Blein, O., Ehrig, K., Montreuil, J.-F., Potter, E., Acosta-Góngora, P., Reid, A., Fabris, A.

Apatite and magnetite as a fluid recorder during the genesis and evolution of IOA deposits [Keynote]
Harlov, D.

Pb isotopes in the El Laco magnetite-apatite deposit, Chile
Pietruszka, D., Hanchar, J., Tornos, F., Whitehouse, M.

Iron oxide-apatite deposits form from hydrosaline liquids exsolved from subvolcanic intrusions
Zhao, X-F., Zeng, L.-P., Hu, H., Hofstra, A.

Carbonatitic to limestone syntectic decarbonation reactions in silicate magmas: CO_2 oxidant enhancing IOA liquid immiscibility
Lentz, D., Steele-MacInnis, M., Charlier, B.

The role of evaporite units in the ore-forming processes of the iron-oxide apatite deposits
Duan, C., Li, Y., Hou, K.

3D geophysical insight into Mesoproterozoic IOA/IOCG mineral systems under cover, U.S. Midcontinent [Keynote]
McCafferty, A., Phillips, J., Hofstra, A., Day, W.

Structural controls on IOA, IOCG, VMS and orogenic Au deposits in the northern Fennoscandian Shield [Keynote]
Bauer, T., Andersson, J., Sarlus, Z.

A newly recognised IOCG like mineralization with enriched Ni, Cu, Co and REE in Gadarwara, M.P., India
Sunder Raju, P.V., Merkle, R.K.W.

Possible iron-sulphide copper gold mineralization in western Labrador, and the potential for IOCG exploration in the Labrador Trough
Conliffe, J.

The Highlands Gold occurrences, eastern Cape Breton Highlands, Nova Scotia: an unrecognized IOCG district?
Baldwin, G.

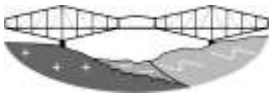
Geochemical characteristics of IOCG systems: examples from the Olympic Cu-Au Province, South Australia
Fabris, A., Reid, A.

Why are only certain IOCG deposits copper-rich? Insights from the Prominent Hill hematite breccia deposit, Gawler craton [Keynote]
Schlegel, T.U., Wagner, T., Wälle, M., Boyce, A., Heinrich, C.A.

Origin of iron oxides in IOCG deposits: implications from texture anatomy and mineral chemistry
Hu, X., Chen, H., Beaudoin, G.

Be-W-Sn rare metals, Pb-Zn polymetals and Au metallogenic system of the Cuonadong Dome in the Tethys Himalayan orogenic belt, Tibet, China
Li, G.

Mineralization age and formation mechanism of the Shilu hematite deposit, South China
Li, Y., Hou, K., Duan, C.



SPECIAL SESSIONS ∗ SESSIONS SPÉCIALES

1 - Geosystems and hydro-geosystems

1 - Géosystèmes et hydrogéosystèmes

SS-GH01 - SS-GH02 (cancelled)

SS-GH03

Canadian volcanology, Archean to recent, depth to surface, at home and abroad

Conveners: Ross, P.-S., Kolzenburg, S., Berlo, K.

Development of dacite magma from chemical and textural studies: example from the Kameni Islands volcanic centre (Thera, Greece)
Higgins, M., Debecq, A.,J., Nomikou, P.

A new approach to chemical heterogeneity in volcanic glass: LA-LIBS
Berlo, K., Paisley, R., Kolzenburg, S., Tuffen, H.

The nature and processes of Cordillera backarc volcanism: geochemistry and geophysical constraints
Hyndman, R.

Geochemical, mineralogical and textural characterization of cooling and diagenetic events related to two emplacement domains represented by the lower and upper members of the Middle Cretaceous alkaline volcanic rocks of the Crowsnest Formation, Southweste
Adair, R.

Assessing morphological characteristics of graphite breccias of the Albany deposit using semi-automated digital analysis
Conly, A., Greco, M.

Metallogeny of the Woman River iron formation: implications for timing of hanging wall and foot wall volcanic successions, Swayze Area of the Abitibi greenstone belt, Ontario
Mowbray, B., Gibson, H., Gemmell, T., Haurgaard, R.

Miocene eruptive activity of the Round Butte maar-diatreme volcano, Hopi Buttes volcanic field, Arizona
Latutrie, B., Ross, P.-S.

Diatremes and root zones in the Cerro Chivo Volcanic Field (CCVF), Chubut Province, Argentina
Ross, P.-S., White, J.D.L, Haller, M.J., Lefebvre, N.

Non-isothermal viscous compaction of volcaniclastic deposits: implications for volcanic outgassing
Kolzenburg, S., Ryan, A.G., Russell, K.

Non-newtonian behavior influences pyroclast shapes in lava fountains: experimental evidence
Comida, P.P., Ross, P.-S., Zimanowski, B., Büttner, R.

New 1:10 000 scale bedrock maps of the Sunset Lake Area, Slave Craton, Northwest Territories (parts of NTS 85I)
Knox, B., DeWolfe, M., Austin-Fafard, S.

A review of the geological characteristics of the Murray Brook volcanogenic massive sulphide deposit, New Brunswick
Toniazzo Braga, M., Lentz, D.R, McClenaghan, S.H.

SS-GH04

Challenges in measuring and modeling groundwater/surface water interactions

Conveners: Paniconi, C., Therrien, R., Paradis, D.

A field investigation of aquifer-stream connectivity related to groundwater abstraction
Allen, D., Hall, G., Whistler, A., Simpson, M., Lepitre, M.

A goal-oriented fully-coupled surface and subsurface hydrological model for basin-scale baseflow predictions
Delottier, H., Paradis, D., Therrien, R.

Deciphering surface and groundwater interactions in the eskers and moraines of the Barlow-Ojibway clay belt using GIS-Based and geochemical approaches
Rosa, E., Cloutier, V., Blanchette, D.

From the snowpack to deep groundwater: integrated hydrological modelling af a steep, geologically complex Alpine catchment
Thornton, J., Mariéthoz, G., Therrien, R., Brunner, P.

Site-wide conceptual hydrogeologic model with water budgets for a mine in northern British Columbia: implications for seepage monitoring and interception, and groundwater management
Worley, J., Mendoza, C., Crozier, T., Chong, A.

Aquifer vulnerability and capacity within the rural municipality of Springfield, Manitoba
Estrella-Legal, J.P., Bell, J., Neufeld, J.

Investigating the groundwater impact on the quantity and the quality of a surface drinking water source with an integrated hydrological model: the case of the Nelson River Watershed (Quebec)
Gatel, L., Tremblay, Y., Therrien, R.

SS-GH05

The construction and use of P-T-t-D paths in understanding orogenic systems

Conveners: Larson, K., Yakymchuk, C., Dyck, B.

Transient mesozoic thermal pulse recorded in Paleoproterozoic Jungsan Complex, Korea
Chu, X., Zou, Y.

Multidisciplinary investigation into the Cenozoic tectonic evolution of the Colorado Plateau
Palin, R.M., Hernandez Uribe, D.

Assessing the interplay between equilibrium and kinetics in regional metamorphism
Forshaw, J., Pattison, D.

Metamorphic diachronism and structures of the Connecticut Valley-Gaspé trough, Northern Appalachians
Perrot, M., Tremblay, A., Ruffet G., Labrousse, L., Gervais, F., Caroir F.

Deciphering prograde, peak and retrograde metamorphism in the ~ 2.1 Ga Mistinibi Complex, Canada
Godet, A., Guilmette, C., Labrousse, L., Davis, D., Smit, M., Vanier, M.-A., Lafrance, I., Charrette, B.

Using petrochronology to unravel the metamorphic and magmatic development of orogenic systems
Cottle, J.

The Kapuskasing Structure revisited: new insights into reworking of Neoarchean crust from garnet geochronology
Kendrick, J., Yakymchuk, C., Duguet, M., Vervoort, J.

Petrochronology of oxidized ultrahigh-temperature granulites from the Arequipa Massif of southern Peru
Yakymchuk, C., Cottle, J.

Timing and characterization of tectonometamorphism in the northwest Opinaca, Superior Province, Eeyou Istchee Baie-James region
Côté-Roberge, M., Guilmette, C., Goutier, J., Cleven, N., Harris, L., Davis, D., Smit, M.

A cryptic metamorphic discontinuity in the Paleoproterozoic New Quebec Orogen: overthrusting of the foreland basin revealed by integrated petrochronology
Godet, A., Guilmette, C., Labrousse, L., Smit, M., Davis, D., Raimondo, T., Vanier, M.-A., Charette, B., Lafrance, I.

Assessing the magma-loading model for prograde metamorphism in continental arcs: a case study from Harrison Lake, British Columbia.
Golovetskyy, M., Dyck, B.

P-T-T evolution of metapelite from the Boothia Uplift: quantifying the time and conditions of tectono-metamorphism in North-Central Rae Craton
Kinney, C., Sanborn-Barrie, M., Regis, D., Yakymchuk, C.

SS-GH06

Crustal melting, migration, and mineralization processes: Partial melting through fractionation to volatile saturation, from the micron to the continental scale

Conveners: Steele-MacInnis, M., Dyck, B., Azadbakht, K., Sawyer, E.

Microstructural record of melt-fluxed metamorphism in the Himalayan tourmaline leucogranites
Dyck, B.

Melt-budget for crustal melting reveals accumulation and fractionation in the mid crust
Sawyer, E.

Mineral reactions and element migration during selvedge formation in migmatites
Lin, L., Sawyer, E.

Nucleation delay in magmatic systems
Baker, D., Rusiecka, M.

Entrapment and post-entrapment processes in melt inclusions in granulites and migmatites
Steele-MacInnis, M., Bartoli, O., Esposito, R.

Trace element zoning in biotite from Devonian-related felsic intrusions of New Brunswick, Canada: implication for studying magma history
Azadbakht, Z., Lentz, D., McFarlane, C.

Petrogenesis of intrusive rocks in the vicinity of the Teahan and Lumsden base metal prospects, Caledonia Highlands, Southern New Brunswick: implications for mineralization
Gebru, A.

Melting in varicolored Grenvillian marble
Martin, R., Schumann, D., de Fourestier, J.

Carbonate liquids in the Buena Vista IOA system: implications for genetic models of IOA mineralization and evidence for crustal anatexis related to mafic magmatism
Bain, W., Steele-MacInnis, M., Mazdab, F., Marsh, E.

Metallogeny of the LREE-rich peraluminous pegmatitic granite dykes from the central Grenville Province (Québec)
Turlin, F., André-Mayer, A.-S., Vanderhaeghe, O., Moukhsil, A., Gervais, F., Solgadi, F.

Petrogenesis and rare element potential of late tectonic pegmatites, Hall Peninsula, Baffin Island, Nunavut
Bigio, A., Lentz, D., McFarlane, C.

Origin of mineralizing fluids at the Cantung and Mactung skarn-hosted tungsten deposits, Yukon-NWT
Elongo, V., Legros, H., Falck, H., Adlakha, E., Lecumberri-Sanchez, P.

Evolution of mineralizing fluids at the Cantung W-Cu skarn deposit, Northwest Territories, Canada
Legros, H., Elongo, V., Lecumberri-Sanchez, P., Falck, H., Adlakha, E.

Metallogeny, mineralogy and isotopic geochemistry of the Kipawa rare-earth deposit: genetic implications and comparison with other rare-earth deposits in peralkaline syenites
Matte, S., Stevenson, R., Constantin, M.

Characterization of apatite hosted silicate melt inclusions in magmatic rocks associated with the Cantung (W-Cu) skarn deposit, Northwest Territories
Wagner, A., Adlakha, E., Hanley, J., Falck, H., Lecumberri-Sanchez, P., Neyedley, K.

Geochronology indicates a long life span discrete pulses porphyry-epithermal Cu deposit - Tiegelongnan, Tibet, China
Yang, C., Beaudoin, G., Tang, J.

SS-GH07

Deep groundwater circulation and its potential influence on shallow water resources and ecosystems

Conveners: Rivard, C., Molson, J., Lefebvre, R.

Sulphur water and the legacy gas wells of southwestern Ontario
Jackson, R., Dusseault, M., Frape, S., Illman, W., Rudolph, D., Phan, T.

Assessing the usefulness of multiple isotope systems (C, O, Li, B, Sr) for CO_2 and brine leakage monitoring at a CO_2 flooding oil field in Texas, USA
Phan, T., Sharma, S., Gardiner, J., Thomas, R., Stuckman, M., Stewart, B., Capo, R., Lopano, C., Hakala, J.A.

Traceurs de l'évolution naturelle de l'eau souterraine dans une région périglaciaire du Bouclier canadien à partir de la détermination de pôles hydrogéochimiques régionaux
Walter, J., Chesanux, R., Gaboury, D., Cloutier, V.

Research contributions to advance understanding of risks to water security in northeast British Columbia: a shale gas context
Allen, D., Kirste, D., Holding, S., Dierauer, J., Morgan, S., Bystron, I., Simon, M., Rosales-Ramirez, T., McKoen, Z., Dandurand, R., Allen, A.

Assessing the potential for deep fluid upflow near gas fields with geochemical indicators
Rivard, C., Bordeleau, G., Lefebvre, R., Lavoie, D.

Impact of topographic resolution on simulated regional groundwater flow and residence time
Abhervé, R., Lefebvre, R., Laurencelle, M., Paradis, D., St-Hilaire, A., Bour, O.

Techniques for installation and monitoring of deep groundwater wells
Harrington, J., Provost, H., Holden, S., Crozier, T.

SS-GH08

Diffusion in geoscience: A multidisciplinary perspective

Conveners: Al, T., Parker, B., Wanner, P.

Solving the mysteries of molecular diffusion of noble gases for climate reconstruction using ab initio molecular dynamics
Pinto de Magalhães, H., Tyroller, L., Brennwald, M., Kipfer, R.

Isotope fractionation due to aqueous phase diffusion: what do diffusion models and experiments tell – A review
Wanner, P., Hunkeler, D.

What pore water chemistry in Champlain Sea muds reveals about hydrogeology, marine salinity, and sensitivity to landslides
Hinton, M., Alpay, S., Crow, H.

Évaluation d'un profil de conductivité thermique de la subsurface à partir d'un profil de température mesuré dans un échangeur de chaleur géothermique
Koubikana Pambou, C.H., Raymond, J., Velez Marquez, M.-I.

Measuring 2-D distributions of intra-particle diffusion coefficients in sulfide-rich mine waste rock
Miller, R., Al, T.

Indigenous groundwater geoscience: identifying information needs
de Jong, S., Russell, H.

SS-GH09

Emerging contaminants in soil and groundwater

Conveners: McGregor, R., Carey, G.

Geoenvironmental characteristics of the St. Lawrence columbium mine at Oka, Québec: mineralogy and geochemistry of waste rock, tailings, slag and drainage waters
Percival, J., Desbarats, A.J., Parsons, M.B., Venance, K.E., des Roches, S., Balkwill Tweedie, H., Bilot, I.

The in situ treatment of synthetic musk in groundwater using colloidal activated carbon
McGregor, R.

The insitu treatment of PFAS-impacted groundwater using colloidal activated carbon
Galbraith, B., McGregor, R.

Effect of phosphate and Fe-oxyhydroxide coating on nanoscale titanium dioxide ($nTiO_2$) transport in water-saturated sand columns
Rastghalam, Z.S., Cheng, T.

Is there still a chance to save the groundwater in Taleza aquifer?
Boumaiza, L., Chabour, N., Drias, T.

Groundwater at risk: a post-wildfire water security perspective
de Jong, S., Leybourne, M., Russell, H.

Emerging contaminants in leachate of old/historic closed landfills
Roy, J.W., Propp, V., de Silva, A., Smith, J.

SS-GH10

Geochemical and isotopic tracers in groundwater studies

Conveners: Bordeleau, G., Ahad, J., Utting, N., Pinti, D., Zuo, E.

Heavier noble gas analysis on Thermo Scientific Helix SFT
Zuo, E., Lapp, A., St-Jean, G., Clark, I.

Mantle 3He in groundwater of Southern Québec: a fossil record of the New England hotspot?
Pinti, D.L., Méjean, P., Kagoshima, T., Vinet-Roulleau, E., Takahata, N., Sano, Y., Larocque, M.

Using noble gases as a tracer of subsurface gas migration at a CO_2 injection research station
Utting, N., Utley, R., Gilfilian, S., Darrah, T., Lawton, D.

Characterizing Devonian brines of the Williston Basin with multiple isotope systems
Mowat, A., Francis, D., Ferguson, G., McIntosh, J.C., Eglington, B.M., Lindsay, M.B.J.

Compositional hydrochemical data analysis to explore geochemical processes controlling the inorganic groundwater quality in southern Quebec
Cloutier, V., Bondu, R., Rosa, E.

Delineating recharge areas and characterizing groundwater evolution in a regional-scale carbonate bedrock groundwater system with hydrochemistry and isotopic tracers
Priebe, E., Frape, S., Jackson, R., Rudolph, D.

Geochemical and isotopic study of the occurrence and fate of nitrate in Alberta groundwater, Canada
McClain, C., Wilson, L., Humez, P., Nightingale, M., Nasr, M., Mayer, B.

Multiple isotopes help unravel the origin of methane in shallow groundwater of two regions in eastern Canada
Bordeleau, G., Rivard, C., Lavoie, D., Malet, X.

SS-GH11

Groundwater and climate change

Conveners: Larocque, M., Allen, D.

Cold regions, groundwater and climate change: state of the science and future directions
Kurylyk B., McKenzie, J., Walvoord, M., Lamontagne-Hallé, P., Zipper, S.

Groundwater and climate change: a view from the west
Ferguson, G., McIntosh, J.C.

Integrated modelling in the Great Lakes Basin to assess watershed response under varied climate change scenarios
Persaud, E., Levison, J.

Simulation of future climate and land use changes to identify sustainable agricultural water management practices in a subwatershed using SWAT-MODFLOW
Saleem, S., Gagné, S., Larocque, M., Levison, J.

Water resources impacts by climate change in Prince Edward Island, Canada
Li, Q.

Groundwater importance and vulnerability to climate change in glacierized watersheds
Baraer, M.

PyHELP: an open source Python library to estimate spatially distributed groundwater recharge with the HELP infiltration model
Gosselin, J.-S., Raynaud, M., Huchet, F., Lefebvre, R.

Ressources en eau souterraine au Québec: l'état des connaissances
Roy, N., Stapinski, M., Ouellet, M., Bourque, E.

Gestion des eaux souterraines au Québec: défis et recherches en cours
Stapinsky, M., Roy, N., Ouellet, M.

SS-GH12

Groundwater nutrients and contaminants affecting surface waters

Conveners: Roy, J., Robinson, C.E.

A race against time: subsurface nutrient legacies provide new insight into improving water quality
Basu, N., van Meter, K.

Legacy phosphorus dynamics near the sediment-water interface of agricultural drainage ditches
Sawyer, A., Casillas-Ituarte, N., King, K., Covault, A., Danner, K.

Groundwater-surface water interactions and agricultural nutrient transport in a Great Lakes clay plain system
Mackie, C., Levison, J., Binns, A., Gardner, S., Persaud, E.

3D fully-integrated modeling of subsurface drainage flow in a Danish agricultural area
Ferreira Boico, V., Therrien, R.

Assessing links between groundwater gaining areas and nutrient status in agricultural streams during summer and winter base flow conditions
Boreux, M., Roy, J.W., Yates, A.G., Robinson, C.E.

Innovative approaches for characterizing groundwater contaminant plumes impacting aquatic ecosystems in peri-urban streams
McKnight, U.S., Sonne, A., Rønde, V.K., Cremeans, M., Devlin, J.F., Rasmussen, J., Traunspurger, W., Höss S., Bjerg, P.L.

Evidence of spatio-temporal variations in a shallow groundwater contaminant plume discharging in a small urban stream
Lemaire, G., Schulz, H., McKnight, U.S., Bjerg, P.L.

Groundwater contributions to trace elements in urban streams
Mowat, A., Lindsay, M.B.J., Roy, J.W., Eglington, B.M., Bickerton, G.S.

Evaluation of groundwater discharge to a large inland lake using 222-radon and regional scale groundwater models
Robinson, C.E., Wallace, H.

Impact of variable wave conditions on groundwater-derived nitrogen discharge to coastal waters
Robinson, C.E., Wu, M.

The threat to urban freshwater benthic ecosystems from groundwater laden with chloride (road salt)
Roy, J.W.

SS-GH13

Hydrogeology of cold regions

Conveners: Lemieux, J.-M., Cey, E.

Carbon-cycling and weathering in lake Untersee, Dronning Maud Land, East Antarctica
Marsh, N., Lacelle, D., Clark, I.D., Andersen, D.T.

Cryohydrogeology of rock glaciers in the central Andes (31-35° S)
Harrington, J., Edmunds, A., Wainstein, P., Arenson, L.

Infiltration, groundwater recharge and preferential flow dynamics in frozen ground
Cey, E., Mohammed, A., Pittman, F., Hayashi, M.

Development of a 3D cryohydrogeological model of a small watershed in a degrading permafrost environment in Nunavik, Québec
Fortier, R., Lemieux, J.-M., Molson, J., Therrien, R.

Groundwater dynamics within a watershed in the discontinuous permafrost zone near Umiujaq (Nunavik, Canada)
Lemieux, J.-M., Fortier, R., Murray, R., Dagenais, S., Cochand, M., Delottier, H., Therrien, R., Molson, J., Pryet, A., Parhizkar, M.

Numerical predictions of permafrost thaw under climate change near Umiujaq (Nunavik) Quebec: only twenty years to go?
Molson, J., Dagenais, S., Therrien, R., Fortier, R., Lemieux, J.-M.

Transport and deposition of fine sediments in an area of discontinuous and degrading permafrost
Khadhraoui, M., Molson, J., Bhiry, N.

Numerical modelling of convective and conductive heat transfer in a talik beneath the Kuuguluk River at Salluit in Nunavik (Canada)
Liu, W., Fortier, R., Molson, J., Lemieux, J.-M., Grenier, C.

SS-GH14

Marine geosciences

Conveners: Jamieson, J.W., Lajeunesse, P, Normandeau, A.

Lofting turbidity currents: exploring the effects of interstitial fluid density on turbidite architecture and morphology
Steel, E., Simms, A., Buttles, J., Mohrig, D.

Controls on the triggers and flushing of turbidity currents in submarine canyons of eastern Canada
Normandeau, A., Campbell, D.C.

Ice-stream flow switching by up-ice propagation of instabilities along glacial marginal troughs
Brouard, E., Lajeunesse, P.

Morphological signatures of deglaciation and postglacial sedimentary processes in a fjord-lake of the Eastern Canadian Shield: Grand Lake, Labrador
Trottier, A.-P., Lajeunesse, P., Gagnon-Poiré, A., Francus, P.

The new GSC marine geoscience for marine spatial planning program: directing sea-bed mapping at environmental protection
Enkin, R.J., Sonnichsen, G.V., Kostylev, V.E., Todd, B.J., Conway, K.W.

Autonomous Underwater Vehicles (AUV) for improved understanding of deep-water (~ 2000 m) geological hazards
Campbell, D.C., Fraser, P., Normandeau, A.

Discovery of giant submarine canyons on the Davie Ridge (western Indian Ocean) and their significance
Maselli, V.

SS-GH15

Melt, fluids and architecture of accretionary orogens

Conveners: Kellett, D., Barr, S., Layne, G., Archibald, D.

Paleozoic-Early Mesozoic multiple accretionary processes in the Altaids [Keynote]
Xiao, W., Windley, B., Han, C., Wan, B., Zhang, J., Ao, S., Zhang, Z., Song, D., Wang, H., Liu, K.

Early Cretaceous sinistral strike-slip faulting in NW Pacific: implications from the U-Pb dating of detrital zircon in Sikhote-Alin, Russian Far East
Liu, K., Zhang, J., Wilde, S., Xiao, W.

Paleozoic subduction of the northwestern Dunhuang orogenic belt, northwest China: metamorphism, geochronology and tectonic implication
Wang, H., Xiao, W.

Evolution of the southern Beishan Orogenic Collage, NW China: implications for the closure of the Paleo-Asian Ocean
Hong, T., van Staal, C., Lin, S.

Irregular continental margins, promontory collision and orogen-parallel strike-slip faulting in accretionary and collisional orogens: examples from the Canadian Appalachians and South China [Keynote]
Lin, S.

Analysis and interpretation of the precious metal mineralization in the Bald Hill antimony deposit, New Brunswick
Gray, A., Lentz, D., Thorne, K.

Mineralogical and geochemical analysis of the Devil Pike Brook gold deposit, south-central New Brunswick
Haidarian, H., Lentz, D., McFarlane, C., Thorne, K.

Kinematic development of the Eastern Highlands shear zone, Cape Breton Island, Nova Scotia
Piette-Lauziere, N., Larson, K., Kellett, D., Graziani, R.

Ore mineralogy, geochemistry, and genesis of the Hog Mountain orogenic gold deposit, southwestern Appalachians, USA
Kline, A., Brueckner, S.M., Bilenker, L.D., Poole, J., Whitney, M.

Controls of reactivated accretionary and protocraton margins on pluton emplacement and Ni-PGE-Cr, Au, IOCG, and polymetallic mineralization
Harris, L.,

Metallogeny of accretionary peri-continental orogens [Keynote]
Piercey, S., Eglington, B.M., Huston, D., Pehrsson, S.

Post-collisional Arrowsmith plutonism in the southern Rae craton: evidence for multiple sources of melt generation and possible juxtaposition of crustal levels
Cloutier, M., Bethune, K., Ashton, K.

New structural features of Central Labrador Trough and evolutionary model of an accretionary wedge under oblique shortening
Konstantinovskaya, E., Ivanov, G., Feybesse, J.-L., Lescuyer, J.-L.

Tracking slab sediment devolatilisation using the mass independent fractionation of sulfur signature of Proterozoic magmatic arcs
LaFlamme, C., Fiorentini, M.

Post-accretionary exhumation of the Meguma terrane relative to the Avalon terrane in the Canadian Appalachians
Archibald, D., Murphy, J.B., Reddy, S.M., Jourdan, F., Gillespie, J.A., Glorie, S.

Structural and tectonic setting of the Gubaoquan eclogite in the Beishan Orogenic Collage in NW China: a field-based study
de Vries, J., Lin, S., van Staal, C., Yakymchuk, C.

Linking metamorphism and orogenic gold in the Proterozoic Lynn Lake greenstone belt, northern Manitoba
O'Connor, R., Lawley, C., Schneider, D.

SS-GH16 - SS-GH17 (cancelled)

SS-GH18

Pannotia to Pangea: Paleozoic orogenic cycles in the circum-North Atlantic region: a celebration of the career of Damian Nance

Conveners: Murphy, J.B., Strachan, R., Quesada, C.

Damian Nance, the supercontinent cycle and much more
Murphy, J.B., Quesada, C., Strachan, R.

Cusp tectonics: Ediacaran mega-karst landscape and bidirectional mass slides constrain flexural properties of a weak plate at a cusp - the join of the Pan-African Kaoko and Damara orogens in NW Namibia
Hoffman, P.

Super Wilson Cycle: the birth and destruction of superoceans during supercontinent cycles
Li, Z.-X.

The assembly of Pannotia: a thermal legacy for Pangea?
Murphy, J.B., Nance, R.D.

Problems with Pannotia
Evans, D.

Laurentia during the mid-Ediacaran: paleomagnetism and 580 Ma age of the Saint-Honoré alkali intrusion and related dykes, Québec
McCausland, P., Higgins, M., Pisarevsky, S., LeCheminant, A., Jourdan, F., Hamilton, M., Murphy, J.B.

Ediacaran supercontinent: did it exist?
Pisarevsky, S.

Cambrian through Devonian sedimentary successions on the Laurentian margin in western Newfoundland: the effects of an irregular margin geometry on provenance
White, S.E., Waldron, J.W.F., Dunning, G., DuFrane, S.A.

Isotopic composition of hafnium and geological history of Avalonian and Ganderian Proterozoic basement from New England and Atlantic Canada
Pollock, J., Barr, S., van Rooyen, D., White, C.

Provenance of Early Paleozoic sandstones: implications for peri-Gondwanan terrane affinities in the Appalachian-Caledonide Orogen
Waldron, J., Schofield, D., Pearson, D.G., DuFrane, S.A., Sarkar, C., Luo, Y., Dokken, R.

Cambrian to Ordovician evolution of the Lower Paleozoic peri-Gondwanan continental margin in the UK segment of the Appalachian-Caledonian Orogen
Schofield, D., Leslie, G., Waldron, J., Wilby, P., Kendal, R.

Palaeozoic mineralisation associated with plate convergence in tropical to sub-tropical ocean basins
Eglington, B.M., Pehrsson, S., Huston, D., Piercey, S., Rogers, N.

Evidence for a Late Cambrian juvenile arc and a buried suture within the Laurentian Caledonides of Scotland: comparisons with hyper-extended Iapetan margins in the Appalachians and Norway
Strachan, R., Dunk, M., Cutts, K., Lasalle, S., Storey, C., Whitehouse, M., Fowler, M., Moreira, H., Dunlop, J., Moreira, I.

Timing of collision initiation and location of the orogenic suture in the Scandinavian Caledonides
Slagstad, T., Kirklan, C.L.

Caledonian strike-slip displacement in Svalbard, High Arctic: new age constraints from 40Ar/39Ar dating
Faehnrich, K., Majka, J., Schneider, D., Mazur, S., Ziemniak, G., Wala, V., Strauss, J.

The Iapetus suture zone in Ireland
McConnell, B., Riggs, N., Fritschle, T.

Age, petrogenesis, and tectonic setting of the Donegal batholiths
Archibald, D., Murphy, J.B., Dunlop, J., Strachan, R.A.

The evolution of geological interpretations vs. geological evolution in southern New Brunswick: Iapetus, Rheic, and more
Barr, S., White, C., Johnson, S., Park, A.

Speculations on the origin, drift and mode of accretion of the peri-Gondwanan terranes in the Appalachian mountain belt
van Staal, C., Barr, S., White, C.

Silurian U-Pb zircon intrusive ages for the Red River anorthosite (northern Cape Breton Island): implications for the Laurentia-Avalonia boundary in Atlantic Canada
Keppie, J.D., Shellnutt, G., Dostal, J., Keppie, D.F.

The Cadomian Arc and orogeny in SW Iberia revisited
Quesada, C.

Avalonia meets Cadomia: the Central European Variscides in the light of modern U-Pb zircon geochronology
Linnemann, U., Gärtner, A., Hofmann, M., Zieger, J.

Cambrian uplifted rift shoulders fringing West Gondwana: a comparison of the Avalon Peninsula (Newfoundland) and the Moroccan Coastal Meseta
Álvaro, J.J.

Time-space propagation of Cambrian-Ordovician rift-related magmatism in NW Gondwana: the evidence in Iberia
Sánchez-García, T., Quesada, C., Díez-Montes, A., Bellido, F.

A first estimation of the shortening related to vertical axis rotation: the case of the Ibero-Armorican Arc
Casas, J.M., Guimerá, J., Murphy, J.B.

Magmatic recycling along 50 My in the Variscan belt: orogenic melt reworking in NW Iberia
Gutiérrez-Alonso, G., López-Carmona, A., García-Acera, G., Martín-Garro, J., Fernández-Suárez, J., Gärtner, A., Hofmann, M.

The puzzle of the pre-Variscan basement rocks of the Western Mediterranean: the role of the Variscan and Alpine thrusts and large strike-slip faults on the reconstruction of the Early Paleozoic geometry
Casas, J.M., Álvaro, J.J.

Potential geodynamic link between Paleo-Asian and Tethyan tectonic domains
Xiao, W., Li, L., Windley, B., Song, D., Zhang, J., Ao, S.

Sedimentary records of Permian subduction processes in the Alxa, NW China: implications for the final closure of the Paleo-Asian Ocean
Song, D., Xiao, W.

Why did a concave Pangaea assemble and break apart across along-strike subduction zones?
Keppie, D.F.

Devonian ophiolites of the Variscan Belt and their controversial origin: from the decease of the Rheic Ocean to the birth of an intracontinental pull-apart basin
Sánchez Martínez, S., Arenas, R., Fernández-Suárez, J., Gerdes, A., Andonaegui, P., Albert, R., Díez Fernández, R.

Detrital zircon U-Pb geochronology and Hf isotope geochemistry from the Hecla Hoek Succession of northeastern Svalbard, Norway
Allen, T., Gibson, T., Wallace, V.C., Piepjohn, K., Bergmann, K., McClelland, B., Strauss, J.

SS-GH19

Precambrian sedimentology: Open session on recent advancements in paleogeographic and paleoenvironmental reconstructions in deep time

Conveners: Ielpi, A., Halverson, G., Lechte, M.

Towards an integrated multi-proxy approach to constrain Proterozoic Global Ocean redox conditions using redox-sensitive trace metal enrichments and isotope compositions [Keynote]
Kendall, B., Lu, X., Sheen, A.I., Yang, S., Dahl, T.W., Owens, J.D., Reinhard, C.T.

A Paleoproterozoic macro-tidal to shallow marine shelf, characterized by microbial, tide, and storm activity: the Gordon Lake Formation, Huronian Supergroup
Hill, C.M., Corcoran, P.L.

Feast then Famine: exiting the GOE and setting the stage for a billion years of environmental stability
Hodgskiss, M., Crockford, P., Peng, Y., Wing, B., Horner, T.

Carbon isotope fluctuations in shallow-water marine carbonates and the evolution of carbonate production over the past 2.0 Gyr
Hoffman, P., Lamothe, K.G.

Paleomagnetism of 1.96 Ga Rifle Formation in Kilohigok basin, NU, Canada: archive for early geomagnetic field reversal hyperactivity and true polar wander?
Gong, Z., Evans, D.

Quadrupolar Geodynamo: implications for Proterozoic supercontinents
Sears, J.

Paleoproterozoic and Mesoproterozoic strata of Northwest Laurentia record episodes of rifting, drifting, collision and obduction
Thorkelson, D., Furlanetto, F., Medig, K., Verbaas, J.

Paleoenvironmental analysis and geochronology of black shale units from the late Mesoproterozoic Fury and Hecla Group, arctic Canada
Greenman, J.W., Wong, W., Patzke, M., Gibson, T., Ielpi, A., Halverson, G.

Sedimentology of sandstone-dominated units in the Mesoproterozoic Fury and Hecla Group (Nunavut, Canada)
Patzke, M., Ielpi, A., Greenman, J.W., Halverson, G.

Macrofossils from the Tonian Dolores Creek Formation of the Wernecke Mountains, Yukon
Maloney, K., Halverson, G., Gibson, T., Lechte, M., Millikin, A., Murphy, J., Wallace, M., Schiffbauer, J., Laflamme, M.

Paleoproterozoic banded iron formation deposition controlled by Milankovitch forcing
Davies, J., Lantink, M., Hilgen, F., Mason, P., Schaltegger, U.

δ13C isotopic signatures of Late Paleoproterozoic and Mesoproterozoic stratigraphic sequences of Yukon, Canada, and their correlation to the global isotopic curve
Furlanetto, F., Medi, K.P.R., Thorkelson, D.J.

Tectono-stratigraphy and facies architecture of the Tonian Hematite Creek and Katherine groups, Wernecke Mountains, Yukon
Gibson, T., Halverson, G., Macdonald, F., Cumming, V., Kunzmann, M., Wörndle, S., Lechte, M., Maloney, K., Millikin, A., Murphy, J., Wallace, M.

Constraining the end-Lomagundi Excursion transition in the Labrador Trough
Hodgskiss, M., Lamothe, K.G., Halverson, G., Sperling, E.

Was the glacial erosion flux on Snowball Earth insensitive to active tectonics?
Hoffman, P.

Ironstones of the Katherine Group, Yukon: marine iron cycling in the early Neoproterozoic
Lechte, M., Halverson, G., Wallace, M., van Smeerdijk Hood, A., Gibson, T., Milikin, A., Maloney, K., Murphy, J.

Evolution and diversity of early eukaryotes: insights from the Proterozoic of Arctic Canada
Loron, C., Helverson, G.P., Rainbird, R.L., Skulski, T., Turner, E.C., Javaux, E.J.

Re-Os geochronology of carbonaceous shales provides new constraints on the depositional age of Mesoproterozoic strata in the Hornby Bay and Amundsen basins, northern Canada
Rainbird, R., Rooney, A.

Turbidite record of the Neoproterozoic active-continental margin in the western Cathaysia Block, South China
Wang, L., Zhang, K.

SS-GH20

Quantifying timing and rates of geologic processes

Conveners: Enkelmann, E.

Discordance and open-system behavior in baddeleyite revealed by combined SIMS δ18O and TIMS U-Pb analysis
Nilsson, M., Stern, R., Heaman, L.

Kinematics, deformation history and preliminary U-Pb geochronology of a crustal-scale shear zone, Boothia Peninsula, Nunavut
Drayson, D., Camacho, A., Sanborn-Barrie, M., Regis, D.

Seventy million years of suprasolidus conditions in the large, hot, long-duration Grenville Orogen
Turlin, F., Deruy, C., Eglinger, A., Vanderhaeghe, O., André-Mayer, A.-S., Poujol, M., Moukhsil, A., Solgadi, F.

U-Pb titanite geochronology to decypher metamorphic events
Dunning, G.

A compilation of Ar/Ar cooling ages for the Canadian Shield
Kellett, D., Regis, D., Skipton, D., Pehrsson, S., Camacho, A.

Extracting tectonic and erosional signals from detrital thermochronology in the Eastern Himalaya
Coutand, I., Whipp, D.M., Bookhagen, B., Grujic, D.

Characterizing the Phanerozoic history of the Canadian Shield using multi-kinetic apatite fission track analysis: examples from the Hudson Bay region
Pinet, N., McDannell, K., Issler, D., Currie, L.

Differential erosion of a Mesozoic rift flank: establishing the source of anomalous topography across Karrat, central West Greenland
Jess, S., Stephenson, R., Roberts, D., Brown, R.

Laser ablation U-Th-Sm/He dating of apatite
Matthews, W., Enkelmann, E., Pickering, J.

Detrital zircon U-Pb and fission track double dating: investigating sediment provenance and the thermal history of source rock regions
Enkelmann, E.

Detrital zircon double-dating of forearc Cook Inlet basin strata reveals the thermal history of sediment source regions
Enkelmann, E., Finzel, E.S., Sanchez Lohff, S.K.

New geo- and thermochronological insights into Jurassic accretion and syn-orogenic sedimentation in the Northern Canadian Cordillera
Kellett, D., Zagorevski, A.

Determination of radiation ages for zircon during U-Pb LA-ICP-MS measurements
Matthews, W., Koblinger, B., Angelo, T.

Thermal and exhumational history of the Labrador passive margin: insights from apatite and zircon (U-Th)/He thermochronology
Vogler, K., Vahrenkamp, S., Coutand, I., van Rooyen, D., Corrigan, D.

SS-GH21

Terrestrial analogues for comparative planetary geology and astrobiology

Conveners: Cloutis, E., Osinski, G.R.

Mineral resources and the biosphere: the challenge for far-future extraterrestrial explorationists
Kerr, A.

Simulated rover explorations of two Mars analogue sites: Gypsumville and East German Creek, Manitoba, Canada
Cloutis, E., Stromberg, J., Applin, D., Connell, S., Kubanek, K., Kuik, J., Lechowicz, A., Parkinson, A., Ramirez, M., Turenne, N., Cieszecki, J., Kum, R., Walker, R., Wiens, E.

Lava tube caves as exploration targets on Earth and Mars
Léveillé, R.

Bay of Island Ophiolite Complex, Newfoundland: an analogue for ultramafic bodies and serpentinization on other worlds
Morrill, P., Cook, M., Cumming, E., Ahmed, A., Brazelton, W.J., Schrenk, M., Ono, S., Rhim, J.H.

Acritarch-like eukaryotic microorganisms from the 1.9 billion-year old Gunflint Chert, Canada
Gonzales Flores, A.L., Claprood, M., Jin, J., Osinski, G.

Periglacial and glacial processes on Earth and Mars: a comparative study
Osinski, G., Andres, C., Bina, A., Godin, E., Hawkswell, J., Hibbard, S.

2 - Resources, energy and environment

2 - Ressources, énergie et environnement

SS-RE01

The cratonic mantle, its carbonate-rich melts, kimberlites and carbonatites

Conveners: Kopylova, M., Chakhmouradian, A.

Petrogenesis of dolomite and calcite carbonatites in orogenic belts
Wei, C.W., Xu, C., Chakhmouradian, A.R., Brenna, M., Kynicky, J., Song, W.L.

Lamprophyres, carbonatites and phoscorites of the Saguenay City alkali province, Quebec, Canada
Higgins, M., Bédard, L.P., dos Santos, E., Vander Auwera, J.

The Good Hope Carbonatite, Ontario: a potential Nb deposit with pyrochlore-apatite cumulates
Mitchell, R., Wahl, R., Cohen, A.

Assessing the distribution of REE mineralization in Fe-dolomite carbonatite drill cores from the Fen Complex, Telemark, southern Norway
Coint, N., Dahlgren, S.

Wekusko Lake dikes (central Manitoba): long-overdue kimberlites, oddball carbonatites, or "a missing link"?
Chakhmouradian, A., Reid, K.

Revisiting the complexity of kimberlites from northeastern Angola
Robles Cruz, S., Melgarejo, J.C., Gali, S.

Metamorphism and metasomatism of felsic xenoliths in kimberlite
Niyazova, S., Kopylova, M., de Stefano, A.

New insights into cratonic mantle metasomatism from HP-HT reaction experiments between saline fluids and mantle rocks
Bussweiler, Y., Grützner, T., Rohrbach, A., Klemme, S.

From regional to local metasomatism in the peridotitic mantle of the Chidliak kimberlite province (Southern Baffin Island)
Kopylova, M., Tso, E., Ma, F., Liu, J., Pearson, D.G.

Petrology of ijolites from the Prairie Lake carbonatite complex
Savard, J., Mitchell, R.

The importance of syenite enclaves in the evolution of the Saint-Honoré alkaline complex
Bédard, L.P., Desjardins, D., Matton, G.

Trace element partitioning between apatite and kimberlite-like melts: implications for volatile degassing and formation of different kimberlite facies
Chow, R., Fedortchouk, Y., Normandeau, P.

Determining the origin of megacrysts from the Muskox kimberlite pipe, Northwestern Canada
Cone, D., Kopylova, M., Swerjensky, D.

Behaviour of ore-forming elements in the subcontinental lithospheric mantle below the Slave craton
Veglio, C., Lawley, C., Kjarsgaard, B., Pearson, D.G.

SS-RE02 (cancelled)

SS-RE03

Impact cratering in the solar system

Conveners: Osinski, G.R., Tornabene, L.L.

The Canadian impact cratering record [Keynote]
Grieve, R.

Understanding the origin and evolution of impact melt from the Mistastin Lake impact structure
Hill, P., Osinski, G., Banerjee, N.

Scientific and sustainable developments related to the Rochechouart impact structure (France)
Lambert, P.

Hydrothermally altered impact crater lakes and the secondary clay minerals they left behind
Svensson, M., Osinski, G., Longstaffe, F.

A review of the North Range Offset Dikes at the Sudbury impact structure, Canada
Pilles, E., Pilles, E., Osinski, G., Grieve, R.

Breccias and anatexis in the footwall of the Sudbury impact structure
Genereux, C.-A., Tinkham, D.K., Lafrance, B.

Role of impact devolatilization in the genesis of Ni-Cu-PGE mineralization in the Sudbury Igneous Complex
Lesher, C.M.

Anomalously young detrital zircon ages, related to the Sudbury meteorite impact, within the lower Huronian Supergroup, Ontario, Canada
Menard, J., Davis, D., Yakymchuk, C., Lin, S.

Shock veins in paired lunar meteorites Northwest Africa 3163 And 4881.
Hopkins, R., Spray, J.

Impact Earth: revisiting the Earth impact cratering record
Osinski, G., Grieve, R., Hill, P., Newman, J., Patel, P., Tolometti, G.

SS-RE04 (cancelled)

SS-RE05

Fluid-rock interaction

Conveners: Lecumberri-Sanchez, P., Adlakha, E., Kontak, D., Ansdell, K.

From soil and wine to hydrothermal systems: insights from combined radiogenic and stable Sr isotopes [Keynote]
Stevenson, R., Guibourdenche, L., Widory, D.

Volumetric properties of fluid inclusions on the path to homogenization
Klyukin, Y., Steele-MacInnis, M., Lecumberri-Sanchez, P., Bodnar, R.J.

Controls in K/Na ratios of magmatic-hydrothermal fluids
Lecumberri-Sanchez, P., Luo, M., Steele-MacInnis, M., Runyon, S., Sublett, M., Pearson, J., Bodnar, R.J.

Characterization of apatite within the Mactung W (Cu,Au) skarn deposit, Northwest Territories: implication for the evolution of skarn fluids
Roy-Garand, A., Adlakha, E., Hanley, J., Falck, H., Lecumberri-Sanchez, P.

Muscovite as a monitor of primary versus secondary rare-metal enrichment in albite-topaz keratophyres from Ongon Khairkhan, Mongolia
Kontak, D., Dostal, J., Petrus, J.

Geology and U-Th-Pb dating of the Gakara REE deposit, Burundi
Boulvais, P., Ntiharirizwa, S., Branquet, Y., Poujol, M., Morelli, C., Ntungwanayo, J., Midende, G.

The mineralogy, paragenesis, and petrogenesis of the Co-Ni-As-Au occurrence in the Annapolis Valley, Nova Scotia
McNeil, N., Kennedy, N., Adlakha, E., Kerr, M., Baldwin, G., Wightman, J.

Trace element characteristics of pyrite from the upper Huronian Supergroup and their application to Sudbury offset dykes
Howe, T., Corcoran, P.L., Osinski, G.

Bedding-parallel, fibrous veins record hydrocarbon generation in laminated source rocks
Wang, M., Chen, Y.W.M, Liu, K., Song, G., Zhou, Z., Steele-MacInnis, M.

Impact of rock block's shape and orientation on the hydraulic erodibility process
Boumaiza, L., Saeidi, A., Quirion, M.

Microanalysis of Mg isotope abundances in carbonate minerals using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS): application to hydrocarbon reservoirs
Al-Aasm, N., Gagnon, J., Al-aasm, I.

Fluid inclusion systematics of the polymetallic (Co-Ni-As-Au) veins of Nictaux Falls Dam occurrence, Annapolis Valley, Nova Scotia
Kennedy, N., McNeil, N., Adlakha, E., Kerr, M., Hanley, N., Baldwin, G., Wightman, J.

SS-RE06

Indicator minerals and exploration methods

Conveners: Makvandi, S., Beaudoin, G.

Indicator mineral dispersal trains of northern Canada in a modern glacial and mineralogical context [Keynote]
Paulen, R.C.

SEM-Based automated mineralogy: a comparative between the particle segmentation and clustering approaches
Girard, R., Tremblay, J., Néron, A.

PLS-DA of chemical compositions of native gold from various Au-bearing deposits: implications for mineral exploration
Liu, H., Beaudoin, G., Makvandi, S., Bédard, E.

Variation of trace elements in magnetite from volcanogenic massive sulfide deposits of the Matagami mining camp, Canada: implications for mineral exploration
Genna, D., Dare, S., Habib, I., Lessard, P.

Chemical compositions of anatase and rutile associated with U mineralization at the Kiggavik-Andrew Lake area (Nunavut, Canada)
Makvandi, S., Huang, X., Beaudoin, G., Quirt, D., Fayek, M., Ledru, P.

Li-micas geochemistry as indicators of fluid circulation in magmatic-hydrothermal ore systems
Legros, H., Marignac, C., Mercadier, J., Richard, A., Cuney, M., Charles, N., Wang, R., Lespinasse, M.

Comparison of ammonium abundance and its short wave infrared absorption spectrum based on alteration halo of Mexican silver deposits
Sheppard, T., Hattori, K., Fonseca, A., Rios Romero, M.A.

Quantification of gold grain morphology using X-Ray 3D microscope and secondary electron microscope
Masson, F.-X., Beaudoin, G., Laurendeau, D.

Geochemistry and glacial dispersal patterns of kimberlite indicator minerals in the South Slave Province, NT
Campbell, D., Campbell, D., Zurevinski, S., Elliott, B.

Cathodoluminescent and compositional heterogeneity in fluorite and its relationship to Sn and W-Mo mineralization from Mount Pleasant, New Brunswick
Greene, J., Samson, I., Gagnon, J.

Hypogene and supergene alteration at the Farallón Negro intermediate-sulfidation epithermal Au-Ag deposit, NW Argentina
Herzog, M., Hagemann, S., Gilg, H.A., Fogliata, A., Montenegro, N.

Application of trace element geochemistry of Fe-(hydro)oxides and rutile to exploration for U mineralization: an example from Hook Lake and Contact deposits
Huang, X., Beaudoin, G., Makvandi, S., Ledru, P.

Isotopic and geochemical signatures of base metal indicator minerals from regional surficial samples in the southern Mackenzie region, Northwest Territories
King, R., Piercey, S., Paulen, R., Smith, R., Day, S., Petrus, J.

SS-RE07

Integrating geophysics, petrophysics and geology: a session to honour the career of Dr. Bill Morris

Conveners: Ugalde, H., Enkin, R.

A three-component mag-interpretation: case study using multiple magnetic data sources from the E&L Deposit, BC
King, J., King, A.

Incorporating geological and geophysical data to determine surface-based model geometry
Lelièvre, P., Galley, C., Farquharson, C.,

Assimilation stochastique 3D de données ERT et gravimétriques en utilisant la simulation séquentielle bayésienne
Tirdad, S., Bouchedda, A., Gloaguen, E., Dupuis, J.C.

Contribution of constrained gravity and magnetic inversion to geoscience integration: lessons from the Footprints project
Vallée, M.A., Morris, W.A., Perrouty, S., Lee, R.G., Wasyliuk, K., King, J., Ansdell, K., Mir, R., Shamsipour, P., Farquharson, C., Chouteau, M., Smith, R.S.

3D inversions of gravity and magnetotelluric data from the Howley Basin, Western Newfoundland: an assessment of basin depth and hydrocarbon potential
Kangazian, M., Farquharson, C.

Geophysical expression of a unglaciated porphyry copper-gold deposit: Casino deposit, Yukon
Witherly, K.

Lithology classification of historical borehole geophysical data using machine learning
Thomson, V.

From the British Caledonides to Sudbury: a review of Bill Morris career
Ugalde, H.

Use of diabase dikes for tectonic reconstruction: constraints on the deformation history of the Sudbury Igneous Complex [Keynote]
Morris, W.A.

Rock Physical Properties Part 3: 30 years of collaboration and promotion of the importance of rock physical properties with Bill
Hearst, R.

Optimization of geophysical methodologies to discover magmatic intrusive Ni-Cu-PGE ore bodies in a challenging geological setting
Malo-Lalande, C., Boisvert, M.

Remanent magnetization in geophysical data interpretation: how to recognize it, how to measure it, and how to model it
Ugalde, H., Morris, W.A.

Inferring post-Jurassic movement of the Oak Bay Fault in southwestern New Brunswick through marine magnetic mapping and modelling of the Ministers Island Dyke
Butler, K., Evangelatos, J., Adam, J., Morris, W.A.

Use of the WorldView-3 satellite for lithologic mapping and mineral mapping
Wickert, L.

Optical Borehole Televiewer image enhancement for mineralogical purposes
Ghoraishi, F., Dupuis, J.C., Gloaguen, E.

Data integration of corrected Time-Domain Electromagnetics (TDEM) & LIDAR-derived surfaces across a Devonian rift basin in New Brunswick, Canada
Furlan, A., Onderco, A., Ugalde, H., Milkereit, B.

Comparing magnetic susceptibilities derived from aeromagnetic data and outcrop scale measurements in the western Abitibi greenstone belt
McNeice, W., Eshaghi, E., Smith, R.

The elusive Phoenician/Persian harbour of ancient Akko: where geophysics, petrophysics and geology meet archaeology
López, G.I., Jol, H., Bauma, P., Giaime, M., abu Hamid, A., Quartermaine, J., Waldmann, N.D., Artzy, M.

Modelling prospectivity of under explored regions: deploying ore system concepts and AI to focus infrastructure development
Rogers, N., Azadbakht, Z., Smith, J.

Optimization of integrated geophysical and geological structural variability analysis for Archean greenstone belts: a case study in the western Wabigoon subprovince, Ontario
Montsion, R., Perrouty, S., Frieman, B.

Mineralogy and lithology from physical properties: analysis of the Canadian rock physical property database [Keynote]
Enkin, R.J., Hamilton, T.S., Morris, W.A.

Use of petrophysical anisotropies for gold exploration in the footprint of the Canadian Malartic deposit, Québec, Canada
Perrouty, S., Enkin, R.J., Morris, W.A.

SS-RE11

Submarine volcanism and marine minerals: Key resources for the future

Conveners: DeWolfe, M., Stewart, M.

Stratigraphy and volcanic setting of the host rocks of the Neoarchean Sunrise VMS deposit, Beaulieu volcanic belt, Slave craton
DeWolfe, M., Knox, B., Oberland, A.

Volcanic reconstruction of a VMS-hosting subsidence structure: the Chisel sequence, Snow Lake, Manitoba
Stewart, M., Gibson, H., Lafrance, B., DeWolfe, M.

A mineralized system exposed in the Swiss Alps: a Jurassic analogue to present-day hydrothermal systems, Platta nappe, Switzerland
Coltat, R., Boulvais, P., Branquet, Y., Pelleter, E.

Stratigraphy and lithogeochemistry of the Upper Jurassic volcano-sedimentary Iskut River Formation at Koopa, northwestern British Columbia, Canada: implications for exploration
Brueckner, S.M., Gibson, H., Wafforn, S., Anstey, C., McNaughton, K.

Subseafloor alteration of a modern seafloor massive sulphide deposit hosted in primary volcaniclastic rocks
Anderson, M., Hannington, M., McConachy, T., Jamieson, J.

Advances in the lithogeochemical study of drill core from the Heath Steele E Zone, Bathurst Mining Camp, New Brunswick
Jimenez-Gonzalez, J., Lentz, D.R, Walker, J.A., Day, J.D.

Structural evolution of the NE Lau back-arc basin: links to tectonic regime and mineralization
Norris-Julseth, C.

Preliminary sulphide ore characterization at the Murray Brook volcanogenic massive sulphide deposit, New Brunswick
Toniazzo Braga, M., Lentz, D.R, McClenaghan, S.H.

Utilization of field portable X-Ray Fluorescence (pXRF) at the Nash Creek Zn-Pb-Ag Deposit, New Brunswick: Analysis of reproducibility and application of pXRF geochemical data
Higbee, S., Lentz, D., Walker, J., Brown, D.

SS-RE12

Unifying international research forces to unlock geothermal resource

Conveners: Raymond, J., Blessent, D.

DEEP Earth Energy Production's Williston Basin Hot Sedimentary geothermal power project development [Keynote]
Marcia, K.

Characterisation of the basement-sedimentary transition zone in the Saint-Pierre-Bois quarry (Vosges, France)
Dezayes, C., Lerouge, C., Kushnir, A.

Geothermal potential assessment of the Charlevoix meteoritic crater
Velez Marquez, M.-I., Taborda Ortiz, M.A., Miranda, M., Moreno, D.A., Raymond, J., Blessent, D., López-Sanchez, J.

Evaluating geothermal potential in Yukon Territory: a collaborative effort to characterize geothermal gradient through temperature gradient drilling in the Canadian North
Fraser, T., Colpron, M., Relf, C., Witter, J., Grasby, S.

Geothermal potential and enhanced geothermal system (EGS) performance in the St. Lawrence Lowlands Basin, Quebec, Canada
Nowamooz, A., Therrien, R., Molson, J., Raymond, J., Malo, M.

Alberta's western Canada Sedimentary Basin's first electrical geothermal project proposal
Hickson, C.

Stratigraphy, reservoir properties and thermofacies: a Silurian case study in eastern Québec
Larmagnat, S., Lavoie, D., Francus, P., des Roches, M., Daigle, L-F., Raymond, J., Malo, M., Aubiès-Trouilh, A.

Addressing geoscience gaps for energy and heating projects in the Northwest Territories (NWT)
Fiess, K., Grasby, S.

Geothermal potential of Anticosti sedimentary basin, Québec
Gascuel, V., Bédard, K., Comeau, F-A., Raymond, J., Malo, M.

Evaluation of deep hydrothermal fluid circulation in the Asal rift, Republic of Djibouti
Hassan Aden, A., Raymond, J., Giroux, B., Sanjuan, B.

Geothermal energy in Canada
Hickson, C., Dusseault, M., Ferguson, G., Fraser, T., Grasby, S., Huang, K., Marcia, K., Noone, F., Poux, B., Raymond, J., Witter, J.

Geothermal potential of Ambilobe and Sambirano, North Madagascar
Rajaobelison, M.M., Raymond, J., Malo, M.

Analysis of thermal and hydraulic properties of rock samples from the Nevado del Ruiz geothermal area
Taborda Ortíz, M.A., Vélez Marquez, M.I., Moreno, D.A., Raymond, J., López, J., Blessent, D.

SS-RE13

Uranium ore systems research: Fluid pathways, metal traps and expressions of the systems

Conveners: Potter, E., Chi, G., Thomas, D.

An Archean source of sulfur for the Proterozoic Kiggavik uranium deposit, Nunavut, Canada
Fayek, M., Shabaga, B., Quirt, D., Ledru, P.

Geological factors controlling fluid flow related to uranium mineralization in the Athabasca Basin
Chi, G., Li, Z., Eldursi, K., Bethune, K., Rabiei, M., Wang, Y., Ledru, P., Quirt, D., Potter, E., Bosman, S., Card, C.

The structural and lithological evolution of the Patterson Lake corridor, southwestern Athabasca Basin, Saskatchewan
Johnstone, D., Bethune, K., Tschirhart, V.

The giant Arrow uranium deposit, Patterson Lake corridor, Athabasca Basin: overview of present knowledge
Hillacre, S., Ansdell, K., McEwan, B., Batty, M., Onstad, C., Johnson, J., Mohrbutter, R., Cross, S.

Are footprints critical elements for the exploration of unconformity-related uranium deposits? [Keynote]
Ledru, P.

First insights on permeability development associated with uranium-rich mineralization of the Spitfire orebody, in the Patterson Lake Corridor in Western Athabasca, Canada
Abdelrazek, M., Benedicto, A., Ledru, P., Gerbeaud, O.

Evolution of hydrothermal fluids in the Patterson Lake Corridor, southwestern Athabasca Basin: significance for uranium mineralization
Rabiei, M., Chi, G., Potter, E., Tschirhart, V., Feng, R., MacKay, C., Frostad, S., McElroy, R., Ashley, R., McEwan, B.

Western Laurentia extension ca. 2000-1200 Ma as reflected in basin development and changing fluid flow paths: implications for uranium geology
Ramaekers, P., Catuneanu, O.

Nature and context of deformation bands associated with post-depositional faulting of the basal Athabasca Basin and their insight into the genesis of unconformity-related uranium deposits: case study of the C1 fault zone in the eastern Athabasca Basin, no
Kitchen, A., Bethune, K., Delaney, G., Miller, E.

The occurrence and chemistry of Ti-oxide phases and their timing of crystallization along the P2 fault, Athabasca Basin, Saskatchewan, Canada
Adlakha, E., Hattori, K., Kerr, M., Boucher, B.

The evolution of metasomatic uranium ore systems in the Central Mineral Belt of Labrador
Duffett, C., Potter, E., Cousens, B.

Compaction and cementation of quartzose sandstone in the Proterozoic Athabasca Basin: petrographic study and numerical modeling
Wang, Y., Chi, G., Li, Z.

Contrastive study on the Mianhuakeng-Shulouqiu granite-hosted and Malou volcanic-hosted uranium deposits in Guangdong Province, South China, and their implication for the genetic link between the granite- and volcanic-hosted uranium mineralization
Zheng, Y., Lu, Q., Chi, G., Li, Z.

SS-RE14

Recent advances on ore forming processes related to magmatic Ni-Cu-PGE, Cr-PGE, and Fe-Ti-V deposits and their implications for mineral exploration: A special session in memory of Dr. Thomas Lane

Conveners: Houlé, M., Smith, J., Sappin, A.-A.

A comparison of platinum-group element dominated deposits [Keynote]
Barnes, S.-J.

How does pentlandite form? New constraints from the distribution of highly siderophile elements in pentlandite
Mansur, E., Barnes, S.-J., Duran, C.

Origin of low sulfide-high PGE mineralization in the W Horizon, Coldwell Complex, Canada: evidence for injection of PGE mineralization as syn-magmatic sill
Good, D., Cao, Y., Brzozowski, M., Shahabi Far, M., Linnen, R., Samson, I., McBride, J.

Sulfide textures and precious metal distribution within pegmatitic gabbros of the Crystal Lake intrusion, 1.1 Ga Midcontinent Rift, Ontario, Canada
Smith, J., Bleeker, W.

Anatomy of the Ni-Cu-(PGE) mineralized Expo-Raglan magmatic system in the Early Proterozoic Cape Smith belt, Québec, Canada
McKevitt, D., Lesher, C.M., Houlé, M.G.

Emplacement and localization of magmatic Ni-Cu-(PGE), Cr, and Fe-Ti-Vdeposits [Keynote]
Lesher, C.M.

The Grasset Ultramafic Complex: an emerging komatiite nickel district in the northern Abitibi greenstone belt, Quebec, Canada
Tucker, M., Wagner, D.

Emplacement history of the Archean Cr-bearing Black Thor intrusion of the Esker intrusive complex in the McFaulds Lake greenstone belt, Ontario, Superior Province
Houlé, M.G., Lesher, C.M., McNicoll, V., Carson, H.E.J., Spath, C.J., Metsaranta, T.R.

Multiphase ore emplacement in the Eagle's Nest Ni-Cu-(PGE) deposit, McFaulds Lake greenstone belt, Superior Province, northern Ontario, Canada
Zuccarelli, N., Lesher, C.M., Houlé, M.G.

The role of country rock assimilation on chromite crystallization in the Ring of Fire, James Bay lowlands, Ontario, Canada
Brenan, J.M., Keltie, E., Woods, K., Mungall, J., Weston, R.

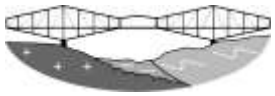
Constraining the formation of Fe-Ti-V-P deposits using trace elements in Fe-Ti oxides: insights from the chemostratigraphic variation of magnetite and ilmenite in the Upper Zone of the Bushveld Igneous Complex
Dare, S., Bethell, E., Barnes, S.-J.

Numerical petrography on ore samples from the vanadiferous magnetite deposit of the Lac Doré Complex (Québec, Canada) and its application
Arguin, J.-P., Tremblay, J., Néron, A., Girard, R.

Ni-Cu-PGE mineralization in a syn-collisional setting: geochronology of the Turnagain Alaskan-type intrusion, northern Cordillera, Canada
Nixon, G.T., Scheel, J.E., Scoates, J.S., Friedman, R.M., Wall, C.J., Gabites, J., Jackson-Brown, S.

Mobilization of platinum by high-temperature orthomagmatic brines
Sullivan, N.A., Zajacz, Z., Brenan, J.M.

Ni isotopic fractionation associated with Ni mineralization in the Zambales and Palawan ophiolite complexes, Philippines
Zhu, C., Schardt, C., Wang, S., Wasylenki, L., Withers, A., Bouvier, A.



SS-DS01

Artificial intelligence in natural resources, algorithm development and applications

Conveners: Gloaguen, E., Gagné, O., Mercier, P. H.J.

Automated identification of geodynamic features and associations in plate tectonic models
Nguyen, H.A.T.(L.), Englington, B.

Managing and synthesizing provincial groundwater data
Ishikawa, J.-A., Baye, A., Doyle, J., Lepitre, M., Sloma, A., Young, E.

Machine-learning for real time control of the chemical quality of tunnel-boring cuttings
Heude, A., Beraud, T.

Volumetric calculation of minute gold grain: insight from machine learning!
Néron, A., Madon, B., Girar, R.

Machine learning application for exploration targeting and mineral processing
Laporte, M.-A.

Machine learning methods in ore grade estimation for laterite nickel deposit
Wang, J., Zhou, Y., Li, X.

Chemistry of detrital gold grains as footprint discrimination tool in drift exploration
Girard, R.

Development of a plate margins database for use with plate reconstruction software
Hone, P., Eglington, B.M.

SS-DS02, SS-DS03 (cancelled)

SS-DS04

Machine Learning as an interpretation tool for geologists

Conveners: Blouin, M., Girard, R., Claprood, M., Caté, A., Perozzi, L.

Applying machine-learning to mineral exploration: feedback from a pioneer
Oswald, W., Sterckx, S., Cain, M., Sun, S.

The Bayesian logic in mining industry: HyperCube to predict mineral deposits
Dombrowski, C.

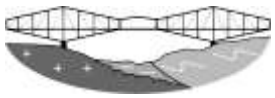
Supervised and unsupervised classification to explore geophysical data
Cedou, M., Gloaguen, E., Blouin, M.

Random Forests classification of ore deposit type based on pyrite trace element analyses
Gregory, D., Cracknell, M., Figueroa, M., McGoldrick, P., Large, R., Steadman, J., Fox, N., Baker, M., Belousov, I., Kuh, S., Lyons, T.

Convolutional neuron network image classifier optimized for detection of rare geological features: an example on gold grains in tills
Néron, A., Tramblay, J., Girard, R.

Optical reconnaissance of minerals: the contribution of machine learning
Maitre, J., Bédard, L.P., Bouchard, K.

Content-based Recommendation System algorithm applied to deposit data mining and ore-prospecting prognosis
Wang, K., Zhou, Y., Li, X., Wang, J.



SS-GS01

Geoheritage: From local to international

Conveners: Desrochers, A., Verpaelst, P., Malo, M.

Geoheritage: World Heritage Sites and UNESCO Global Geoparks [Keynote]
McKeever, P.

How to organize it? History and governance of the Joggins Fossil Cliffs UNESCO World Heritage Site
Kosters, E., Grey, M.

Toward the nomination of Anticosti Island to the UNESCO World Heritage Program
Desrochers, A.

Blue Beach (Nova Scotia) – early land vertebrates near the centre of developing Pangea: the case for protection and a museum
Keppie, J.D., Mansky, C., Wood, S.

Defining the Anthropocene at Crawford Lake as an integral part of the Niagara Escarpment Geoheritage
McCarthy, F., Head, M., Patterson, R.T., McAndrews, J., Krueger, A., Heyde, A., Turton, C., Alderson, A., Cocker, S., Tepavcevic, M.

Fossil treasures: Canada's rich geological heritage revealed in a new permanent gallery at the Royal Ontario Museum
Caron, J.-B.

The growth and development of UNESCO Global Geoparks in Canada [Keynote]
Nowlan, G.

Celebrating geological heritage in the Discovery Aspiring Global Geopark: a candidate for UNESCO Global Geoparks designation
McCallum, A.

Geoheritage in Quebec: promotion and protection
Verpaelst, P.

Reflections on the recognition of geoheritage in Canada
Calder, J.

North America's first Geopark: educating through engaging experiences
Bremner, G., Nowlan, G., Mille, R.

Classification, evaluation and prioritization of geosites for Geoparks in remote areas: a case study of the Tumbler Ridge UNESCO Global Geopark
Drever, C., Waters, S.

Geoparks in Canada
Verpaelst, P., Bremner, G., Waters, S., Camirand, R., Nowlan, G.

Charlevoix Aspiring Geopark - a region sculpted from the sky?
Verpaelst, P., Gastonguay, J.-M.

Integrating indigenous oral traditions and intangible heritages into understanding our landscape: tales from the Tumbler Ridge UNESCO Global Geopark
Waters, S., Drever, C.

SS-GS02 (cancelled)

SS-GS03

Innovative and effective approaches to teaching geosciences: Ideas and strategies

Conveners: Bank, C., Ryan, A.-M., Bank, C., Daxberger, H.

An integrated approach for 3D-visualization skills and spatial ability training in Geosciences
Daxberger, H., Moumblow, R.

3D-printed models: overcoming challenges of scale, dimensionality, and abstraction in introductory structural geology
Waldron, J., Snyder, M.

Une expérience de transfert circulaire des connaissances sur les eaux souterraines au profit de l'aménagement du territoire: ARIM-Eau
Walter, J., Lambert, M.

A student-centered approach to teaching science communication
van der Flier-Keller, E.

Beyond content: making geoscientific reasoning explicit in the undergraduate years
Ryan, A.M.

Assessing a sample module that infuses geoethics into a geoscience course for non-science students
Bank, C.-G., Ryan, A.M.

Making indigenous connections: interdisciplinary collaboration for a more holistic approach to science
From, R., Hart, M., Ziffle, V.

Comparing effectiveness of different learning tools to convey geologic concepts
Worthington, Q.

GENERAL SESSIONS ∗ SESSIONS GÉNÉRALES

GS-01

General hydrogeology

Conveners: Lefebvre, R., Rivard, C.

Hydrogeological monitoring of infiltration through waste rock using active fibre optic distributed temperature sensing
Wu, R., McKenzie, J., Martin, V., Broda, S., Bussiere, B., Aubertin, M.

Geoenvironmental characterization protocol for environmental risks assessment and waste rock management
Vermette, D., Demers, I., Benzaazoua, M.

Methane dynamics in fluid fine tailings in an oil sands end pit lake
Francis, D., Barbour, S.L., Lindsay, M.B.J.

Numerical evaluation of the effect of the excavated damaged zone on the solute exchanges between backfilled pits and the environment
Rousseau, M., Pabst, T.

An integrated methodology for hydrogeological assessment around man-made installations
Claprood, M., Gloaguen, E., Couegnas, C., Krimissa, M., Paradis, D.

Integrating geophysical, geological, and hydrogeological studies for regional groundwater mapping in Northeast British Columbia: the Peace Project
Morgan, S., Allen, D.M., Salas, C.J., Kirste, D., Levson, V.M., Best, M.

Better water management-related decisions: making data useable in the Greater Toronto Area
Holysh, S., Gerber, R., Marchildon, M., Doughty, M., Smith, B.

Long term water management in Alberta's Southern Athabasca Oil Sands region: using modelling tools to evaluate sustainability
Boutin, L.-C., Brewster, M.

Evaluation of the anisotropy of hydraulic conductivity by electrical resistivity tomography
Gernez, S., Gloaguen, E., Bouchedda, A., Paradis, D.

How using flow dimension sequences improves the reliability of pumping test interpretations?
Ferroud, A., Chesnaux, R., Rafini, S.

Hydrodynamic characterization of complex aquifers based on flow dimension analysis
Meite, D., Chesnaux, R., Rafini, S., Ferroud, A.

Hydrogeology of channel systems within Early to Middle Wisconsinan sediments, south-central Ontario
Gerber, R., Holysh, S.

Résultats préliminaires du projet d'acquisition de connaissances sur les eaux souterraines des territoires de Lanaudière, de la Mauricie-Est et de la Moyenne-Côte-Nord
Lambert, M., Walter, J., Ferroud, A., Chesnaux, R., Rouleau, A.

Assessment of groundwater quality using trend analysis
Mohammadi, K., Bayat-Varkeshi, M.

Investigation of a potential dewatering system adjacent to the Red River in Winnipeg, Manitoba
Estrella-Legal, J.P., Bell, J., Neufeld, J.

Numerical simulation of isotopic fractionation for an integrated treatment system involving persulfate oxidation and microbial sulfate reduction
Arai, U., Molson, J., Thomson, N.R.

Origins of the geochemical fingerprint of shallow groundwaters in the Bas St-Laurent region
Chaillou, G., Tommi-Morin, G., Cloutier, C.-A., Buffin-Bélanger, T.

Development of a municipal groundwater supply for the town of Niverville, Manitoba
Estrella-Legal, J.P., Bell, J., Neufeld, J.

Demanding geoethical roadmaps: GeoHazard researchers prepare for the 2020 Disaster Ethics Conference
de Jong, S.

Seasonal fluctuations of conductivity in unconsolidated glacial till
Huddart, S.

Modelling of heat transport from the Danube River into a shallow alluvial aquifer: a case study near Bratislava, Slovakia
Krcmar, D., Laurent, L.J, Molson, J., Hodasova, K., Kovacs, T.

Towards quantifying groundwater resources of southwestern Finland: the case of the Kurikka buried glacial aquifer system
Rashid, A., Ross, M., Putinen, N., Lefebvre, R., Lindsberg, E.

GS-02

Geophysics

Conveners: Gloaguen, E., Giroux, B.

A novel polarization filter based on a correlation matrix analysis
Nasr, M., Giroux, B., Dupuis, J.C.

Microseismic monitoring of mines in real time with Ensemble Kalman Filter
Dip, C., Giroux, B., Gloaguen, E.

Surficial vectors of exploration for high-grade deposits in the Pine Point Mining District, Pine Point, NT, Canada
McDougall, Z., Lentz, D., Adair, R.

Design of a 3D electrical resistivity imaging system for seepage monitoring at an embankment dam abutment
Boulay, D., Butler, K.

Mobile time domain electromagnetic system for hydrogeophysical characterization
Bouchedda, A., Gloaguen, E., Dupuis, J.C., Giroux, B.

Open measurement standards for better physical property measurements
Dupuis, J.C., Tirdad, S., Gloaguen, E., Intissar, R., Moukhsil, A., Smith, R.S.

An integrated approach in characterization of triple porosity Nisku Reefs Alberta: a quest from core and borehole images to 3D earth model
Zaluski, W., Andjelkovic, D., Lahmar Benslimani, H.A., Faskhoodi, M., Xu, C., Mukisa, H., Rivero, J.A., Sawchuk, W., Pearson, W.

1D inversion of magnetotelluric data from Ashute, Butajira geothermal prospect, South-East Ethiopia and its geothermal implications
Tadess, T.

Improving coherency of petrophysical and geochemical datasets using XRF data
Hebert, C., Dupuis, J.C., Milkereit, B.

GS-03

Glacial geology and geomorphology in Canada

Conveners: Paulen, R., Ross, M., Gauthier, M.S.

Ice-flow reconstruction of southwestern Hudson Bay, Manitoba, Canada
Gauthier, M., Hodder, T., Ross, M., Kelley, S.

Glacial erosional footprint of a migrating Laurentide Ice Sheet ice-divide in northeastern Quebec through 10Be and remote sensing analysis
Rice, J., Ross, M., Paulen, R., Kelley, S., Briner, J.

The sedimentary record of the early phase of deglaciation in a dammed valley system of the Appalachian Highlands, Eastern Quebec: Glacial Lake Madawaska
Morissette, A., Lajeunesse, P., Hetu, B.

Contrasting till dispersal patterns from kimberlites, southeast of Lac De Gras, Northwest Territories
Stirling, R., Kelley, S., Ross, M., Elliott, B., Normandeau, P.

Modelling the bedrock topography of Alberta using machine learning: combining subsurface point data with geologic and topographic predictors
Atkinson, L., Pawley, S.

A quantitative analysis of sorted patterned ground within the Haughton Impact Structure, Devon Island, with implications to Mars
Andres, C., Godin, E., Osinski, G., Zanetti, M., Kukko, A.

Ice-flow and deglacial history of the Laurentide Ice Sheet in the southwestern Great Slave Lake area
Hagedorn, G., Ross, M., Paulen, R., Smith, R., Neudorf, C., Gingerich, T., Lian, O.

Ice-flow history of the Laurentide Ice Sheet in the southwest Northwest Territories: a Shield to Cordillera transect
Paulen, R., Smith, R., Ross, M., Hagedorn, G., Rice, J.

GS-04

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Conveners: Constantin, M., Guilmette, C.

Apatite accommodating arsenic: a potential new oxybarometer
Maciag, B.J., Brenan, J.M.

Trials and tribulations of graphite geothermometry by Raman microspectroscopy
Conly, A., McDonald, A.

Cadwaladerite, $Al_5(H_2O)_3(OH)_{15}\cdot(H_2O,Cl)$ from Cerros Pintados, Chile, defined as a valid mineral species and the discreditation of lesukite
Peterson, R., Metcalf, M., Kampf, A., Contreira, R., Reid, J., Joy, B.

Carbonate platforms and controls on the genesis of sapphire, gem spinel, and lapis lazuli: insight from the Lake Harbour Group, Nunavut, Canada and implications for exploration
Belley, P., Groat, L.

Latest news on pink and red spinels in marble from Mogok (Myanmar) and Luc Yen (Vietnam)
Giuliani, G., Fallick, A.

Correlative petrography: foundations for virtual, accurate, sustainable and shareable petrographical data
Tremblay, J., Neron, A., Girard, R.

Caldera-filling and outflow tuffs of the ca. 25 Ma Underdown caldera, Shoshone Mountains, Nevada
Little, K., Cousens, B., Henry, C., Tennant, E., Klausen, K.

Contribution of the upper asthenosphere to <0.6 Ma rejuvenated Hawaiian magmas; evidence from the Southern Hawaiian Island Chain
Trenkler, M., Cousens, B.

Multiscale evidence of silicate-carbonate liquid immiscibility at the Crevier alkaline intrusion, Grenville Province, Québec
Groulier, P.-A., Turlin, F., André-Mayer, A.-S., Ohnenstetter, D., Crépon, A., Boulvais, P., Poujol, M., Rollion-Bard, C., Zeh, A., Moukhsil, A., Solgadi, F.

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Annesley, I., Sykes, J., Pandur, K.

The distribution and partitioning of silver in the Banana Zone sediment-hosted Cu-Ag deposit in the Ghanzi-Chobe Copper Belt portion of the Kalahari Copper Belt: constraints from LA-ICP-MS study
Bineli Betsi, T.O., Kelepile, T.

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Basalt lava flows of the Fury and Hecla Group and younger Franklin mafic magmatism, northwestern Baffin Island, Nunavut
Dufour, F., Stevenson, R., Halverson G., Steenkamp, H.

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Fassbender, M., Stewart, M., Hannington, M.

Volatiles (halogens, N) in volcanic front magmas, Miyake-Jima, Northern Izu-Bonin Island Arc, Japan
Huyer, G., Hattori, K.

Preliminary in situ U-Th-Pb electron microprobe geochronology of monazites from the Rae Province on Devon Island, Nunavut, Canada
Laughton, J., Osinski, G.

Petrographic and geochemical characterization of host rock lithologies to auriferous quartz veins, Fisher Property, Seabee Gold Operation, Saskatchewan
Onstad, C., Ansdell, K., Partin, C., Carlson, A.

Evaluation of portable XRF for characterizing basalts: a case study on ballistic blocks from Kilauea, Hawai'i
von Bassenheim, D.W., Nair, R., Lundblad, S., Swanson, D.

Ion exchange between hydrotalcite group minerals and petroleum-produced brine: applications to brine desalination and carbon mineralization
Zhu, B., Wilson, S.A, Zeyen, N., Raudseppm, M.J., Alessi, D.S.

GS 05 (cancelled)

GS-06

Sedimentology, stratigraphy and paleontology

Conveners: Larmagnat, S., Lavoie, D.

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Hesse, R., Fong C., Schumann, D.

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Ielpi, A., Lapôtre, M.

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Sears, J.

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Head, M.

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Foulon, T., Ross, M., Parent, M.

GS-07

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Conveners: Castonguay, S., Konstantinovskaya, E.

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Fermor, P.

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Structural similarities between the Ottawa River Gneiss Complex, western Grenville Province, and the Tertiary Shuswap Complex, southern Canadian Cordillera
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Salim Amaral, L.F., Kelly, C., Slater, E., Pentek, A., Sofonio, K., Wowkodaw, M., McNeil, S., Awad, O., Andersen, P, Knight, R.

Borehole drilling and testing in crystalline rocks: an approach to subsurface exploration for siting a deep geological repository
Sykes, M., Sánchez-Rico Castejón, M., DesRoches, A., Parmenter, A., Hirschorn, S., Blyth, A., Sykes, E., Vorauer, A.

Ductile shear zones as flat heterogeneous inclusions in the continental lithosphere: a numerical investigation based on the Eshelby Formalism
Lu, L., Jiang, D.

Influence of flow partitioning on quartz CPO fabric: a modeling investigation based on micromechanics
Bhandari, A., Jiang, D.

A level set method with direct reinitialization applied to the modelling of multiphase geological flows
Wu, Q., Lin, S.

The Liuyuan complex in the Beishan orogen, NW China: an ophiolite at the southern edge of the Central Asia Orogenic Belt

Sombini dos Santos, G., Bédard, J., Lin, S., van Staal, C.

Geology of the Baidunzi area in the Central Asian Orogenic Belt in NW China: results of 1:25 000 scale geological mapping

Hong, T., van Staal, C., Lin, S.

Paleomagnetism of ca. 750 Ma syenite dykes of the southern Congo Craton, northern Namibia: implications for the reconstruction of Rodinia and the nature of the pan-African Damara Orogen

Houlihan, S., Evans, D.

Long-term seismic behavior of western Anatolia, Turkey: 36Cl surface exposure dating of fault scarps

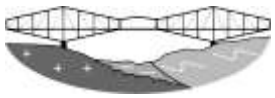
Mozafari Amiri, N., Tikhomirov, D., Sümer, O., Özkaymak, C., Uzel, B., Yesilyurt, S., Ivy-Ochs, S., Vockenhuber, C., Sözbilir, H., Akçar, N.

Development of L-tectonites in isolated rock volumes: a numerical investigation

Yang, R., Jiang, D., Lu, L.

Episodicity of stress state in an overriding plate: evidence from the Yalu River fault zone, East China

Zhang, S., Zhu, G.



ABSTRACTS * RÉSUMÉS

(by alphabetical order * par ordre alphabétique)

First insights on permeability development associated with uranium-rich mineralization of the Spitfire orebody, in the Patterson Lake Corridor in Western Athabasca, Canada

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The NE-trending Patterson Lake structural corridor located in the Western Athabasca Basin, hosts the most recent high-grade uranium discoveries of the last decade in the Athabasca basin (Triple R, Arrow, and Spitfire). A particular feature of these new deposits and prospects is that they are basement-hosted, sometimes deeply-rooted (up to 800 meters at Arrow) and located within and outside the present limits of the basin. This work brings new insights on the deformation mechanisms and permeability network to which mineralization is associated in the Spitfire prospect. Recent work on the Spitfire prospect have defined a composite orebody made of three main lenses hosted within the inherited ductile fabric of a major shear zone. This work focuses on a micro-scale petro-structural study of selected drill-core samples representative of each lense. Petrographic and micro-structural analyses were performed on thin-sections using optical microscopy, SEM and EMPA. Examination of mineralized samples indicates that mineralization is concentrated in graphitic shear zones or chloritized intrusive and silicified orthogneiss or massive grey quartz veins in the hanging wall. These zones are preferential places where brittle deformation develops. Micro-veining uses and extends up through weakened foliation planes within the gneiss. Dilatational micro-brecciation develops within the silicified gneiss. Strong dissolution features affecting quartz and pyrite were observed in association with mineralization. Dissolution textures extend from micro-veins into the host rocks, facilitating mineralization to occur out of fractures. Permeability networks expanded by connections between micro-veins, inter-grains porosity, and quartz dissolution and pyrite replacement. We emphasize the development of permeability networks by the combination of physico-chemical deformation mechanisms which overprint the inherited ductile fabric and structures. We suggest a unique main mineralizing event associated with strong dissolution and automorphic Fe-Mg chlorites hosting disseminated sulfides. Oxidizing ore remobilization occurred dominantly at the top of the prospect, below the unconformity.

Impact of topographic resolution on simulated regional groundwater flow and residence time

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Large regional numerical models are often used for the prediction of groundwater fluxes to surface water or to assess the impacts of changes in either climate, land use or groundwater exploitation. Such models typically use a large grid size and a low-resolution land surface topography. The objective of our study was to assess if such large models can provide accurate predictions of fluxes to rivers based on representative recharge and hydraulic properties. For this purpose, a simplified 95 km-long 2D cross-section hydrogeological model was developed using the topography of an area from the Appalachian Highlands to the St. Lawrence Lowlands in southwestern Quebec (Canada). Numerical simulations were completed with a fixed numerical grid but with four levels of topographic resolution using data points at intervals of 30, 90, 500 and 1000 m. The regional rock aquifer models all used the same depth-decreasing hydraulic conductivity (K) profile based on field conditions. Steady-state groundwater flow and age simulations were done by imposing heads corresponding to the topography in order to obtain flowpaths and surface fluxes (inflow and outflow). Simulated inflows were compared to recharge values independently estimated with the HELP infiltration model calibrated with total flow and baseflow in gauged watersheds. Results show that topographic resolution has a major impact on surface fluxes, both entering and exiting the aquifer. In order for smooth-topography models to represent fluxes to streams, it is necessary to use "equivalent" K values that are significantly higher than estimates based on thousands of specific capacity tests. For simulations using large regional groundwater flow models with smoothed topography, a choice has to be made between the proper representation of surface fluxes using unrealistic K values and the underestimation of surface fluxes using representative K profiles.

Geochemical, mineralogical and textural characterization of cooling and diagenetic events related to two emplacement domains represented by the lower and upper members of the Middle Cretaceous alkaline volcanic rocks of the Crowsnest Formation, Southwestern Alberta

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The Crowsnest Formation is divided into lower and upper members on the basis of emplacement by related, though different, subaerial pyroclastic mechanisms and bulk compositions. The lower member is crystal and clast-rich and was emplaced by fallouts, pyroclastic flows, and pyroclastic surges. The upper member is characterized by massive, crystal-poor, clast-rich pyroclastic breccia deposits. Porphyritic cognate and juvenile lithic clasts are abundant in both members. TAS classification of, and minerals present in, pristine cognate fragments indicate three compositions: 1) sanidine-melanite trachyte, 2) sanidine-melanite-analcime phonolite, and 3) analcime tephriphonolite. These compositions and crystal components are characteristic of deposits in the lower member, whereas a marked difference is observed in the upper member where the groundmass of the breccia is potassic and feldspar crystalline aggregate dominated. Whole rock data from the lower member suggests diagenetic depletion of alkali elements resulting in a modified bulk trachyte composition. The < 2 µm size fraction is composed entirely of mixed-layer illite (65 %) and smectite (35 %). Conversely, the upper member exhibits micro-crystalline texture in the groundmass dominated by K-feldspar. The < 2 µm size fraction is characterized by chlorite and K-feldspar. Macroscopically, reaction between cognate/juvenile lithic fragments and the groundmass in the upper member is common. Deposition of the lower member is interpreted to be at temperatures that preserved glass in the groundmass, whereas deposition of the upper member was at significantly elevated temperatures that induced recrystallization of the groundmass during cooling and resulted in a significant reduction of porosity. Subsequent reaction with seawater during submergence during transgression of the Western Interior Seaway produced an initial pure smectite phase in the groundmass of the lower member. Subsequent burial to maximum temperatures of ~ 200 ˚C produced the mixed-layer clay species, supporting a classical devitrification process followed by burial diagenesis. Mineral species in the upper member reflect the stability of the recrystallized groundmass.

The occurrence and chemistry of Ti-oxide phases and their timing of crystallization along the P2 fault, Athabasca Basin, Saskatchewan, Canada

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Titanium oxide minerals were examined in hydrothermally altered rocks along the P2 fault, the main structure hosting the McArthur River deposit. Two TiO_2 polymorphs occur with contrasting mineral assemblages: i) rutile with oxy-dravite, graphite, pyrite, zircon and quartz in basement metapelite, and ii) anatase with hematite (± dolomite, kaolin, illite and aluminum phosphate sulfate minerals) in basement rocks and overlying sandstone. Rutile contains variably high Nb_2O_5 (up to 3.86 wt %), Ta_2O_5 (up to 0.42 wt %), Cr_2O_3 (up to 0.48 wt %), Fe_2O_3 (up to 1.48 wt %), ZrO_2 (up to 0.49 wt %), WO_3 (up to 2.54 wt %), and V_2O_3 (up to 2.12 wt %), suggesting low water/rock ratios during crystallization. The coupled substitution mechanisms $M^{3+} + M^{5+} \rightarrow 2Ti^{4+}$ and $2M^{3+} + M^{6+} \rightarrow 3Ti^{4+}$ partially explain the incorporation of non-tetravalent cations in rutile. However, high abundances of trivalent cations relative to pentavalent and hexavalent cations, coupled with weak Raman shifts near 3100 cm^{-1}, indicate protonation of oxygen in the rutile crystal structure through the exchange $M^{3+} + OH^- \rightarrow Ti^{4+} + O^{2-}$. The Zr-in-rutile geothermometer yields temperatures between 740 and 890 °C, reflecting granulite facies regional metamorphic conditions of the 1.8 Ga Trans Hudson Orogeny. However, the U-Pb ages of rutile are younger, ranging from 1726 to 1771 Ma. The rutile ages represent either: i) slow cooling to 400-500 °C, or ii) a thermal event, possibly related to the ~ 1.75 Ga anorogenic Neultin Suite. With the exception of variably high Fe_2O_3 (up to 1.96 wt %), anatase contains low elemental impurities reflecting crystallization at low temperature. High Fe^{3+} is likely accommodated by substitution with OH^-. Anatase gives a relatively young age of 1569 ± 31 Ma in the basement far below the unconformity, indicating the onset of oxidizing basinal hydrothermal activity in the basement rocks along the P2 fault.

Microanalysis of Mg isotope abundances in carbonate minerals using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS): application to hydrocarbon reservoirs

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The chemical composition of dolomitized hydrocarbon reservoirs is controlled by the interaction between infiltrating dolomitizing fluid(s) and carbonate host rock(s). Diagenetic fluids can impart a unique chemical composition, which is manifested, in part, by characteristic $^{25}Mg/^{24}Mg$ and $^{26}Mg/^{24}Mg$ ratios. These unique Mg isotope "fingerprints" are potentially invaluable for characterizing the formational conditions and hydrocarbon potential of reservoirs. Characterization of the complexity of fluid/rock interactions, however, necessitates that the elemental and isotopic variability of these rocks be quantified on a micrometer scale. ICP-MS is routinely used to measure the elemental and isotopic composition of geologic samples, however, these analyses typically employ solution nebulization (SN) of samples prepared as aqueous solutions. This time-consuming approach potentially introduces deleterious matrix effects, and does not preserve the natural, fine-scale elemental/isotopic variability of the samples. Consequently, critical information on the history of fluid/rock interactions is lost. Elemental and Mg isotopic microanalysis of samples of dolomitized hydrocarbon reservoir rocks using LA-ICP-MS has the potential to characterize the compositional complexities of these materials. Measurement of the Mg isotopic composition of carbonate minerals by LA-ICP-MS, however, requires further validation to demonstrate the accuracy and precision of the method before routine application is possible. This study evaluates the potential for using LA-ICP-MS for the in situ microanalysis of the Mg isotopic composition of dolomitized rocks from hydrocarbon reservoirs. Prior to application to natural samples, validation of the method is demonstrated using standard reference materials by SN- and LA-ICP-MS methods. Subsequently, the elemental and Mg isotopic compositions of dolomitized rocks obtained from reservoirs in northern Iraq and western Canada are used to: 1) assess the microscale compositional variability of these materials, and 2) whether this variability is useful in determining the history of fluid/rock interaction and hydrocarbon potential of reservoir rocks.

A field investigation of aquifer-stream connectivity related to groundwater abstraction

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Abstraction of groundwater from a pumping well located beside a stream can change the direction and magnitude of the groundwater flux. A change in flux can potentially result in streamflow depletion and alter the thermal regime of the stream. The purpose of this field investigation was to quantify changes to the thermal and hydraulic regime of Union Creek in Langley BC under non-pumping and pumping conditions. The site was instrumented with one pumping well, two monitoring wells, six instream nested piezometer pairs, seepage meters, and four hydrometric stations. TidbiT® temperature loggers were installed along the stream reach to monitor water temperatures at the streambed; air temperature was also monitored at the site. Pumping tests were conducted to estimate the hydraulic properties of the aquifer, and to effect a change in the groundwater flux, the streambed temperature and streamflow. Three separate constant discharge pumping tests were conducted; two 2 h tests and one 48 h (higher pumping rate) test. During non-pumping conditions, hydraulic gradients between the piezometer pairs indicated predominantly downward flux, but complex reversals in the flux directions occurred. Seepage measurements showed an upward groundwater flux, but are considered uncertain. Streambed temperatures at upstream locations lagged behind those downstream by 0-45 seconds. During pumping, drawdown measured in the instream piezometers ranged from 1 to 5 cm depending on piezometer location. All of the deep instream piezometers showed more drawdown than their shallower counterparts. Streambed temperatures did not change, although the lag times between upstream and downstream temperatures decreased to 0-2 seconds. Unfortunately, stream stage was too low to be accurately measured, and thus could not be compared with the analytical models of streamflow depletion. Overall, the field investigation had numerous challenges and highlighted the difficulty of quantifying aquifer-stream connectivity in practice.

Research contributions to advance understanding of risks to water security in northeast British Columbia: a shale gas context

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Over the past several years, and ongoing to date, several groundwater-related investigations have been carried out in Northeast British Columbia (NEBC) to advance our understanding of risks to water security in context of rapid shale gas development. These studies span

water security vulnerability mapping; geochemical and isotopic characterization of groundwater and dissolved gases; assessing the impacts of surface water use and climate change on the water security of small headwater catchments; assessing the groundwater resource potential in buried valley aquifers; mapping the likelihood of spring occurrence and spring source areas; investigating the subsurface footprint of wastewater disposal; characterizing the mobility of wastewater leaks in the shallow subsurface; investigating the role of regional groundwater flow on slope stability; and currently, conducting methane migration monitoring and impact assessment. These various studies were largely carried out under the auspices of an international project "Human-Environmental Security in Asia-Pacific Ring of Fire: Water-Energy-Food Nexus" led by the Research Institute for Humanity and Nature in Japan, and involved various collaborators and partners from Geoscience BC, the BC Oil and Gas Commission, Encana Corporation, the Pacific Institute for Climate Solutions, and the University of British Columbia. This presentation will give an overview of salient results of each study.

Detrital zircon U-Pb geochronology and Hf isotope geochemistry from the Hecla Hoek Succession of northeastern Svalbard, Norway

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The Svalbard archipelago has been divided into three basement provinces that were juxtaposed during the Ordovician-Devonian Caledonian Orogeny. The Northeastern basement province includes the ~ 6 km thick Neoproterozoic-Ordovician Hecla Hoek Succession that consists of, in ascending stratigraphic order, the Veteranen, Akademikerbreen, Polarisbreen, and Oslobreen groups. Proposed stratigraphic ties between the Hecla Hoek Succession and age-equivalent strata of the Eleonore Bay Supergroup, East Greenland, provides an important paleogeographic constraint on pre-Caledonian tectonic reconstructions of the North Atlantic region; however, there is limited published data indicative of provenance to support these correlations. We conducted U-Pb laser ablation-inductively coupled mass spectrometry (LA-ICP-MS) and Lu-Hf isotopes on detrital zircon from sedimentary units throughout the Hecla Hoek Succession of Ny Friesland and Nordhaustlandet, Svalbard, to test the presumed Neoproterozoic-early Paleozoic paleogeographic linkages. Sandstone samples from the Hecla Hoek Succession yield two distinct zircon U-Pb age distributions: 1) bimodal distributions with peak age populations ranging from ca. 1920-1820 and 2830-2650 Ma, and 2) polymodal distributions with peak age populations ranging from ca. 1250-930, 1540-1380, 1680-1630, and 2830-2650 Ma. These age populations are consistent with derivation from the main basement domains of western Baltica and eastern Laurentia (in present coordinates), including a source region within the Grenville-Sveconorwegian orogen.

Cambrian uplifted rift shoulders fringing West Gondwana: a comparison of the Avalon Peninsula (Newfoundland) and the Moroccan Coastal Meseta

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A handful of peri-Gondwanan terranes lie scattered through the Palaeozoic orogens of the circum-North Atlantic. During Ediacaran and Early Palaeozoic times, they positioned along the northern margin of West Gondwana. After Ediacaran accretion of several of these arcs to Gondwana (Avalonian, Pan-African and Cadomian orogens), the new composite margin recorded post-collisional Cambrian rifting conditions that led, since Early Ordovician times, to the opening of the Rheic Ocean. The margins of the Cambrian rift are recognized as the Atlas/Ossa-Morena Rift in the western Mediterranean region and the Avalonian Rift in the future Avalonian Microcontinent. In offshore-to-basinal rifting branches, some Cambrian episodes of carbonate production occur in shoulders (or palaeohorsts) commonly associated with tilting pulses and hydrothermal activity, leading to the development of lenticular limestones surrounded and onlapped by monotonous shales and greywackes. Microbial and shelly carbonate production is punctuated by the influence of hydrothermal activity, volcanism and mass-wasting events, leading to the record of amalgamated erosive surfaces and angular discordances linked to geodynamic perturbations. A comparison of these short-term episodes of carbonate productivity embedded in monotonous successions of shales-greywackes is documented here from both sides of the Cambrian rift, based on exposures from the Avalon Peninsula (Newfoundland) and the Moroccan Coastal Meseta.

Subseafloor alteration of a modern seafloor massive sulphide deposit hosted in primary volcaniclastic rocks

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Seafloor massive sulphide (SMS) deposits have been studied for more than four decades; however, little is known about the third dimension of these hydrothermal systems owing to the fact that very few of them have ever been drilled. This study focuses on the subseafloor of the Tinakula SMS deposit, which is the first massive sulphide deposit described in the Solomon Islands on land or on the seafloor. This study provides the first description of a large active submarine hydrothermal system developed entirely within permeable mafic volcaniclastic rocks, representing a potentially important modern analog of a well-known class of ancient VMS deposits with broad, semi-conformable alteration zones. Geological mapping and core logging is integrated with a wide range of analytical techniques, including whole-rock geochemistry, detailed mineralogy, isotope analyses, fluid inclusion microthermometry, and ^{226}Ra/Ba dating, in order to establish the alteration and mineralization history. Alteration is distributed in broadly conformable zones, in order of increasing depth and temperature: (1) montmorillonite/nontronite; (2) nontronite + corrensite; (3) illite/smectite (I/S) + pyrite; (4) I/S + chamosite; and (5) chamosite + corrensite. δ^{18}O and δD values of clay minerals confirm increasing temperature with depth, from 124 °C to 256 °C, and seawater-dominated hydrothermal fluids at high water:rock ratios. We propose that the pervasive alteration of the volcaniclastic units close to the seafloor coincided with a progressive increase in subseafloor temperatures parallel to the seabed, reaching temperatures high enough to form anhydrite within two metres of the seafloor, sealing off the permeability. Over-pressuring and fracturing of the sulfate- and clay-cemented volcaniclastic rocks produced the pathways for higher-temperature fluids to reach the seafloor, leading to the formation of barite- and sulphide-rich chimneys and chimney mounds over an area of ~ 77 000 m^2. In ancient deposits, anhydrite is often not preserved, so this important process has been poorly documented.

A quantitative analysis of sorted patterned ground within the Haughton Impact Structure, Devon Island, with implications to Mars

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Permafrost underlies 24 % of the Earth's land area and is a major control for the generation of patterned ground and other terrain anomalies that can also be found on Mars. The study area in Devon Island, located in the Canadian High Arctic (75.1982° N, 81.8512° W), is in the continuous permafrost zone where periglacial features are widespread. Patterned ground, specifically sorted stone circles, are periglacial

features of interest that can provide insight into past climate, water availability, and geologic substrate on both the Earth and Mars. In this study, we test a quantitative remote sensing methodology coupled with understanding periglacial landform evolution to identify spatial variance and sorting of different stone circle morphologies in a remote sensing and Geographical Information System (GIS) interface. Spatial modelling of geomorphologic landforms and processes is currently one of the prevailing issues in geomorphology. Remote sensing provides an opportunity to collect spatially continuous and versatile information on environmental determinants of sorted patterned ground. Data was acquired in late July 2017 using a high resolution UAV (for image context), tripod LiDAR scans (new Polaris instrument supplied by Teledyne Optech), and a novel backpack-mounted Kinematic Mobile LiDAR scanner (KLS). After processing the (~ 1-5 cm/pixel) LiDAR data, we carried out a geomorphometric analysis using kernel estimation and cumulative sorting analysis. Quantitative analysis of the form and spatial distribution of sorted stone circles within the HRV identifies a number of distinctive patterns that may reflect spatial variability in processes and conditions responsible for their formation. There are several factors that control sorted stone circle morphology. For example, microtopography, water/ice availability, and the cyclic burial and exhumation of sediments/rocks is believed to play an important role in the sorting and spatial distribution of stone circles, which can then be used to determine periglacial surface kinematics.

The geological evolution of high-grade rare earth elements (REE-Th-U) mineralization at Alces Lake, Northern Saskatchewan

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The Alces Lake property, northern Saskatchewan, is an emerging world-class, high-grade rare earth elements ("REE") deposit of critical metal REEs required for the "green technology" industry. Surface channel samples and diamond drill hole results have identified total rare earth oxide ("TREO") concentrations exceeding 20 wt % TREO within multiple zones at/near surface, including up to 53 wt % TREO. During summer 2018, Appia Energy Corp. carried out a field exploration program for REEs, which consisted of: 1) overburden stripping of 7 REE surface-outcropping zones (Bell, Charles, Dante, Dylan, Ivan, Wilson, Wilson South-Central), 2) collection of 844 systematic channel samples, 3) collection of 6 heavy mineral black beach sand samples, and 4) completion of the first-ever diamond drill program on the Alces Lake property. The latter included 15 diamond drill holes within 3 zones (Charles, Ivan, and Wilson). At Alces Lake, the REEs are completely hosted within monazite (REE-Th-rich phosphate). The monazite is red in color, coarse-grained (0.5 to 3.0 mm in width), forming as isolated grains, banded, or as clustered masses exceeding 85 % monazite within the Ivan and Dylan zones. Previous studies of Alces Lake monazite have suggested a crystallization date of 1927.1 ± 1.2 Ma, which places mineralization within the Taltson-Thelon Orogeny. Petrographic studies reveal that the monazite crystals are euhedral to rounded, suggesting undisturbed crystalline growth for the former and a physically active "magmatic entrainment from source" for the latter. The Alces Lake REE mineralization is hosted within polyphase anatexites that contain massive braided biotite schist and quartzofeldspathic pegmatite augen, with equal distribution of monazite within schist and pegmatite. This mineralized anatectic system appears to clearly cross-cut previously solidified gneissic material, suggesting late orogenic development. The Alces Lake geological suite lies within a regional synformal anticline, with the eastern limb hosting the REE zones, suggesting folding controls on mineralization deposition.

Numerical simulation of isotopic fractionation for an integrated treatment system involving persulfate oxidation and microbial sulfate reduction

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An emerging strategy for the remediation of contaminated sites is the integration of different treatment technologies. One example of a synergistic sequential treatment system is to use persulfate, a strong chemical oxidant (ChemOx), to target the bulk of the contaminant mass in the high concentration zones and then allow the produced sulfate to enhance biodegradation of the remaining mass. The design and subsequent performance of this combined remedy depends on the development of an enhanced bio-remediation (EBR) zone from the initial ChemOx zone. To provide insight into the development of these two dynamic mass removal zones, the isotopic fractionation signatures of representative petroleum hydrocarbons were simulated using the BIONAPL/3D model, which includes groundwater flow and multi-component reactive transport. This model was used to simulate a pilot-scale experiment conducted at the Canadian Forces Base Borden where persulfate was injected into a controlled-release plume of dissolved BTX components (benzene, toluene and xylene). Isotopic signatures of $\delta^{13}C$ and $\delta^{2}H$ were used to identify redox reactions, and to provide insight into hydrocarbon degradation pathways including aerobic biodegradation, chemical oxidation by persulfate, and anaerobic biodegradation by microbial sulfate reduction. Isotopic fractionation of C and H was included by associating the fractionation factors with the maximum substrate utilization rates. Simulated isotopic signatures agree reasonably well with the observed isotope ratios, showing increasing shifts of $\delta^{13}C$ and $\delta^{2}H$ over time in the remaining dissolved BTX. Spatially distinct redox zones, which are also affected by advection and dispersion, were identifiable from the simulated isotope ratios. The simulation results show that mass loss was dominated by chemical oxidation followed by sulfate EBR. The modelling tool and approach will be useful for application at other sites to support the design of persulfate/EBR sequential treatment systems, and to investigate the role of engineering controls on system behavior.

Age, petrogenesis, and tectonic setting of the Donegal batholiths

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The Silurian to early Devonian Donegal batholith (Ireland) is a classic example of a composite batholith. Regional syntheses indicate the batholith intruded into Dalradian marine siliciclastic rocks intercalated with carbonate and volcanic rocks that were variably deformed and metamorphosed during the Grampian Orogeny (ca. 470 to 460 Ma). New in situ zircon LA-ICP-MS U-Pb isotopic data and LA-ICP-MC-MS hafnium isotopic data provide important petrogenetic information about the magma sources and active processes during the assembly of the Donegal batholith. The U-Pb (zircon) data indicate batholith emplacement occurred over ca. 30 Ma between ca. 430 Ma and 400 Ma. Hafnium (zircon) isotopic data show mixed mantle and more evolved crustal isotopic signatures that are consistent with field relationships indicating magma mixing and crustal assimilation processes. A compilation of published and new lithogeochemical data are consistent with a slab-failure geochemistry, which is consistent with regional syntheses invoking slab failure magmatism in the aftermath of the Scandian phase (collision of Baltica and Laurentia before ca. 430 Ma) of the Caledonian orogeny. Together, these new petrochronological data and our syntheses of lithogeochemical data indicate that emplacement of the batholith resulted from episodic magma pulses sourced from the mantle, subducted slab, and/or lower crust following Iapetus Ocean closure during the Silurian.

Post-accretionary exhumation of the Meguma terrane relative to the Avalon terrane in the Canadian Appalachians

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The accretion of the Avalon and Meguma terranes to the Laurentian margin was a major event in the development of the Appalachian orogen. The Minas Fault Zone delineates the boundary between these terranes. A strongly lineated and foliated granite intrusion (Kelly Brook pluton) exposed along the West River St. Mary's Fault intruded into Meguma Supergroup metasedimentary rocks. Well-developed C-S fabrics characterize the pluton with muscovite aligned in the S fabric, and a shallow (~ 10°) westerly plunging quartz stretching lineation. New U-Pb (zircon, LA-ICP-MS) geochronological data yield a crystallization age of 375.0 ± 4.6 Ma for the Kelly Brook pluton that is indistinguishable from other Late-Devonian intrusive rocks in the Meguma terrane. Petrographic data for muscovite indicate that it grew prior to deformation. A 100 % plateau $^{40}Ar/^{39}Ar$ age of 369.0 ± 1.2 Ma on a single muscovite grain constrains the time of cooling of the granite through approximately 450 to 420 °C. Apatite grains also demonstrate pre- to syn-deformational fabrics and yield a U-Pb (LA-ICP-MS) age of 361.2 ± 5.6 Ma indicating the granite was still above 350 °C at this time. Earliest Tournaisian fossils in the unconformably overlying Horton Group strata indicate that the granite was exposed by ca. 359 Ma. Exhumation rates of the Kelly Brook pluton and the Meguma terrane from approximately 9.5-13.3 km depth at ca. 375 Ma to surface exposure at ca. 359 Ma are 0.06 to 0.08 cm a^{-1}. Estimates for the Upper Devonian regional geothermal gradient in the northern Meguma terrane are high, between 39.5 °C km^{-1} and 67.8 °C km^{-1}, gradients that are common in extensional tectonic environments such as the Basin and Range province. An apatite fission-track age of 215 ± 14 Ma indicates Mesozoic reburial and reheating of the granite prior to opening of the Atlantic Ocean.

Numerical petrography on ore samples from the vanadiferous magnetite deposit of the Lac Doré Complex (Québec, Canada) and its application

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Automated quantification of minerals is a key modern approach for understanding the ore behavior in comminution and beneficiation plants, and ultimately, optimising resource extraction. The vanadiferous magnetite deposit of the Lac Doré Complex in Québec is an exemplary case study since magnetite is complexly interlocked with ilmenite exsolutions and gangue minerals that contaminate the concentrate, and may render it unsuitable for recovery of vanadium by roasting, smelting or other extraction methods. Seventy-eight ore samples collected from a section across the stratigraphy of the deposit have been scanned at high resolution using a scanning electron microscope coupled with silicon drift detector energy-dispersive X-ray spectrometry (SDD-EDS) system. Phase maps have been produced by chemical clustering using the individual EDS maps. Quantitative mineralogical data such as modal proportions, relative perimeters, relative spatial distribution, and mineral association indexes were extracted by digital petrography using the image analysis tools of the proprietary software ARTSection. Our method led to quantify the relationships between magnetite and gangue minerals including, in decreasing order of average proportion, ferro-chlorite, ilmenite, epidote-group minerals, ferro-pargasite, and many other mineral species such as sodic feldspars, potassic micas, sulfides, ferro-actinolite, almandine, corundum, hercynite, and apatite. According to our preliminary results, magnetite is preferentially in "contact association" with ilmenite (55.9 %), followed by ferro-chlorite (39.7 %), ferro-pargasite (2.4 %), corundum-hercynite (0.7 %), epidote-group minerals (0.6 %), sericite (0.3 %), and other mineral species (0.1 %). These results give the first appreciation of the probability that each of these minerals remains attached to magnetite following the comminution processes, and enable the prediction of attachment of deleterious calcium-bearing minerals across the deposit. Abundance and size of ilmenite inclusion in magnetite have also been characterized in order to optimize the grinding process and reduce abundance of non-deleterious minerals diluting the vanadium concentrate.

A convergent plate boundary along the southern margin of Laurentia from ~ 1.5-1.3 Ga

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We present a tectonic model for Laurentia in which ca. 1.5-1.3 Ga igneous rocks formed along and inboard of a long-lived convergent margin along the southern edge of the continent. A convergent margin model allows us to explain the formation and stabilization of the North American craton using standard tectonic mechanisms for crustal growth and modification. The tectonic model is supported by spatial and temporal analysis of zircon U-Pb crystallization ages from the literature, spanning the southwestern USA, the midcontinent, and eastern Canada. In aggregate, the zircon age data exhibit distinct patterns that are comparable to Phanerozoic convergent margin processes. This tectonic model links the Pinware orogeny of eastern Canada with the Picuris orogeny, which is newly identified in the southwest USA. The tectonic model is compatible with complimentary geologic datasets, such as the presence of regional high-temperature metamorphism along the proposed margin, the distribution of sedimentary basins along and inboard of the margin, and documented patterns of regional strain in Mesoproterozoic rocks. A subset of Mesoproterozoic igneous rocks is also well-known for exhibiting ferroan geochemistry. Our model does not directly address the petrogenetic development of these igneous rocks, and therefore does not provide a mechanism to explain this unique geochemical marker. Future work should focus on reconciling the ferroan geochemistry of a subset of these Mesoproterozoic igneous rocks with the tectonic constraints provided by this model.

Modelling the bedrock topography of Alberta using machine learning: combining subsurface point data with geologic and topographic predictors

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The Alberta Geological Survey has directed resources towards better representing the local variability of the bedrock topography of Alberta. Improving the bedrock topography is necessary as it represents an important unconformity upon which Neogene-Quaternary sediments were deposited. Knowledge of the position and thickness of these sediments is critical for resource management in groundwater, aggregates, energy, and other land-use applications. The bedrock topography is also an important digital product, as it is the top of the 3D Provincial Geological Framework model of Alberta, and it constrains 42 subcropping bedrock units in the current version of the geomodel. Previous bedrock topography surfaces were generated using subsurface data measured at discrete locations. These data were interpolated with methods such as ordinary kriging which, with no other input predictors, results in a simplified and smoothed bedrock topography. This is especially true in areas of high relief where bedrock is known to be near surface, but few data points exist to inform

the local features. In low-lying data poor areas, the modelled surface follows the trend of the data causing the bedrock topography to irregularly undulate above and below the present-day land surface topography, which results in erroneous sediment pinch-outs. In this work, Alberta's bedrock topography surface is generated using machine learning to combine numerous subsurface point datasets of varying quality and coverage with geologic (e.g. bedrock and surficial geology) and topographic predictors (e.g. physiographic regions and relative height in the landscape). Integration of multiple data sources in the predictive algorithm results in a bedrock topography surface that honours both the subsurface data and the geological interpretation across multiple settings and throughout a diverse range of surficial environments.

Trace element zoning in biotite from Devonian-related felsic intrusions of New Brunswick, Canada: implication for studying magma history

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Twenty-two grains of biotite of various sizes and compositions were mapped with the laser ablation -inductivity coupled plasma-mass spectrometer (LA-ICP-MS) at the University of New Brunswick to investigate the ability of biotite in: 1) retaining magmatic trace-element zoning patterns and 2) using the patterns to study the host magma evolution. The results indicate that grains larger than 500 x 500 µm with minimum mineral inclusions and alteration retained better zoning. Despite the homogenous major element composition of the grains, two-thirds of the examined samples show zoning for large ion lithophile element (LILE), including Ba, Rb, and Cs. More importantly, a lithian-siderophyllite from the Pleasant Ridge topaz Granite (PRG) shows Ti, Ta, Sn, and W zoning. Barium zoning is the most common zoning observed among the mapped biotites, and the deficiencies in both octahedral and intralayer sites suggest coupled substitutions, namely that of Ba-Al vs. K-Si responsible for Ba incorporation in the structure of examined grains. Cesium values show an increase from 200 to 1400 ppm from core to rim in the lithian-siderophyllite of the PRG. Tin and W follow the same pattern but show a diverse trend where their values decrease toward the rim of the grain (50 to 10 ppm and 100 to 10 ppm, respectively). Tantalum and Ti values show fewer variations, but drop abruptly close to the rim of the grain (100 to 20 ppm and 2000 to 500 ppm, respectively). These observations may indicate crystallization of mineral phases with high partition coefficient for these highly incompatible elements (except Ti) and (or) fractionation of a fluid phase at the late stage of magma crystallization. The zoning may also indicate the retention of zoning due to post-crystallization rapid cooling.

Impact of fluorine in post-collisional magmatic-hydrothermal systems: case studies from Neoarchean Douay (Au-REE-F) and Bachelor (Au-F) deposits

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Fluorite (CaF_2) is commonly associated with alkaline, Sn-bearing S-type granites and low-temperature hydrothermal systems. It is therefore rarely observed in Archean environments. However, fluorite is observed in association with post-collisional Neoarchean gold-bearing Sanukitoid. This study investigates apatite $Ca_5(PO_4)_3(F,Cl,OH)$, fluorite (CaF_2), and REE-F rich minerals chemistry of the Neoarchean golden magmatic-hydrothermal systems Douay (Au-REE-F), and Bachelor (Au-F) deposits of the Abitibi greenstone belt. Its objective is to unravel the impact of fluorine on REE fractionation, and economic gold mineralization processes in these systems. Because apatite crystallizes earlier in the magmatic systems, it is commonly used to fingerprint the petrological, geochemistry of magmatic rocks. It allows: 1) tracking incorporation of Mn, Ce, and Eu, which are sensitive to the oxidation state of the magma; 2) tracking the Cl and F content of the magma, which participate, as ligands, to metal transport within the hydrothermal system; 3) measuring SO_3 which relates to the S abundance of the magma and to its capacity to form ore minerals. Fluorine occurs as fluoroapatite and fluorite in the Bachelor deposit, and as fluoro-carbonates such as bastnaesite associated with fluorite in the Douay deposit. The abundance of fluorine in these plutons may reflect a fluorine-enriched source that developed at the end of the Late Archean orogeny, and that was previously enriched by subduction or crustal delamination processes during the Neoarchean.

Carbonate liquids in the Buena Vista IOA system: implications for genetic models of IOA mineralization and evidence for crustal anatexis related to mafic magmatism

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Genetic models for Kiruna-type iron-oxide apatite (IOA) deposits are controversial and span a spectrum between purely magmatic and hydrothermal endmembers. Core to this controversy are questions regarding the mechanism for iron transport and precipitation in these systems and the role of magmatic versus hydrothermal fluids. The Buena Vista IOA deposit (Pershing County, NV) was previously interpreted as an endmember hydrothermal IOA system related to the intrusion of gabbro into carbonate-bearing sedimentary rocks. Here we present detailed petrography of apatite and actinolite from Buena Vista which shows abundant assemblages of coexisting brines and carbonate melt inclusions. The ubiquitous occurrence of carbonate melt inclusions in this system is a strong indication that Buena Vista is not a purely hydrothermal system. Furthermore, petrography and LA-ICP-MS analysis showed that carbonate melt inclusions contain ~ 8-10 wt % Fe and are significantly enriched in Fe relative to coexisting brines. This data suggests a new model for the Buena Vista system in which Fe-transport is accomplished by coexisting carbonate and aqueous fluids. We interpret that the carbonate melt was generated by the partial melting of evaporite-bearing carbonate rocks as a result of intrusion of mafic magma into the country rock package. In this presentation we revisit some of the lines of evidence for carbonate anatexis during emplacement of mafic plutons and discuss potential implications for IOA genesis.

Nucleation delay in magmatic systems

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The time between attainment of supersaturation and the first appearance of crystals in cooling melts and glasses can vary from less than a second to many years. Differing nucleation delay times of minerals can alter the crystallization sequence of a melt depending upon the rate of cooling. A better understanding of nucleation delay will improve our understanding of the textures of igneous rocks and our modeling of their petrogenesis. Classical nucleation theory was developed in the early 20th century, and nucleation delay times of plagioclase, olivine and clinopyroxene in basaltic melts, and of feldspars and quartz in granitic melts were experimentally determined in the late 20th century. However, a quantitative model applicable to magmatic systems remains elusive. Fokin and his coworkers proposed to use the nucleation delay time equation worked out by Collins for silicate melts 50 years earlier. A modification of this equation can be solved using knowledge of the structure, thermodynamics, and transport kinetics of melts and crystals. Applying thermodynamic data from PhasePlot, activation energies for Si-Al effective binary diffusion, estimated interfacial energies, and the

ionic radius of either Al^{3+} or Si^{4+}, previously published experimental nucleation delay times of selected minerals in basaltic and granitic melts were modeled. The predicted nucleation delay of plagioclase, olivine and clinopyroxene in basaltic melts is within a few hours of that measured in experiments, although differences were longer at undercoolings within 20 °C of the saturation temperature, where the largest nucleation delay times occur. Calculated nucleation delay times for granitic melts are within a factor of ~ 5 of most experimental measurements. The agreements between model and experiments suggests that quantitative estimations of nucleation delay times are possible and can be used as an additional tool in the interpretation of magmatic evolution.

The Highlands Gold occurrences, eastern Cape Breton Highlands, Nova Scotia: an unrecognized IOCG district?

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First documented in the 1980's, high gold grades of up to 85 g/t from grab samples from bedrock trenches have been reported from the Highlands Gold prospect in the eastern Cape Breton Highlands, Nova Scotia. Repeated attempts at defining a deposit at this site proved unsuccessful, due in large part to the combination of poor exposure with deep weathering, and the lack of a deposit or exploration model. Consequently, little progress has been made in the development and understanding of this gold occurrence. Gold mineralization at the Highlands Gold prospect is typically associated with pyrite (trace-10 %) and specular hematite (trace-20 %), along with minor chalcopyrite, hosted in en echelon quartz veins dipping to the southeast, hosted in Neoproterozoic metaigneous and metasedimentary rocks. Major deformation occurred during the Silurian, with the docking of the Aspy and Bra d'Or terranes along the Eastern Highlands Shear Zone (EHSZ), 5 km to the west of the major gold occurrences: however the gold-bearing veins appear to be late, or possibly even post-kinematic. Many of the traditional gold pathfinder elements are present, including anomalous, but overall low, concentrations of As, and to a lesser extent Sb. However, elements such as Co and Bi are quite elevated (hundreds of ppm), and correlate strongly with gold concentrations, suggesting that these occurrences are neither a traditional orogenic gold system, nor are they an epithermal deposit. Regional observations provide evidence that this may be an IOCG, or similar system, however. Several post-tectonic, Devonian-aged plutons occur throughout the region, including the West Branch North River Pluton to the south, which appears to stitch the EHSZ. This pluton, as well as other Devonian intrusions in the area, are commonly associated with specular hematite veins, contained both within the plutons, and extending into the older country rocks. Epidote alteration is regionally extensive, reflecting a very large, and apparently post-tectonic hydrothermal system. Although inconclusive, fluid inclusion studies suggest that the gold-bearing veins formed at temperatures between 300 and 400 °C, which is broadly consistent with fluid temperatures for IOCG deposits. Although more detailed study on these occurrences, both locally and regionally, is warranted, the mineralogical and geochemical associations, the proximity of a crustal-scale structure, the local presence of post-tectonic, iron-bearing granitic intrusions, and the available fluid temperature estimates suggest that the Highland Gold prospect and occurrences are potentially part of a larger IOCG system occurring along the EHSZ. Such potential may extend to other portions of the terrane boundary between the Aspy and Bras d'Or terranes on Cape Breton Island.

Assessing a sample module that infuses geoethics into a geoscience course for non-science students

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Geoethics allows educators to combine societal issues with scientific concepts and enhance critical thinking skills. We propose a 5-step framework to help students think through an ethical decision where societal as well as scientific aspects are at the forefront of the issue. This framework parallels the scientific research process, in that it considers viewpoints from various stakeholders and evaluates alternative options before deciding on a course of action, taking the scientific into account. Based on this framework we developed a module for a first-year undergraduate course, using flooding of the Red River and its consequences as an example of a natural disaster which requires society to make choices. A set of rubrics helps us to evaluate students' work. We were unable to assess whether the module indeed changed students' ethical awareness because only 10 % of the students completed both a pre- and a post-module questionnaire. However, in addition to these questionnaires, to assess students' capacity for critical thinking about this geoethical issue following completion of the module, we analysed 353 student answers to an exam question which asked "Would you evacuate a small First Nations community and allow it to be flooded to divert floodwater away from a large metropolis?" Many students (61 %) wrote they would evacuate, and some (11 %) did not provide a conclusive decision. Most students mentioned three or more stakeholders (85 %) and mentioned one or more contributions by geoscientists (83 %). However, 41 % made no mention of alternative options; only 40 % outlined at least 2 assumptions, although 43 % did recognize and acknowledge that a solution to the problem is complex. We encourage colleagues to try the framework and module in their courses.

Groundwater importance and vulnerability to climate change in glacierized watersheds

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Groundwater in glacierized alpine watersheds has long been considered as a secondary source of water, almost negligible compared to the contribution of the cryosphere. With glaciers retreating as a consequence of climate change, quantifying the groundwater contribution in mountain environments has become a priority. We here explore recent advances in groundwater research in glacierized catchments in two different environments: the tropical Andes and the subarctic St-Elias Mountains. In tropical Andes, climatic conditions are not favorable to the formation of cryospheric elements other than glaciers. During the dry season, catchment outflow is mainly composed of glacier melt water and groundwater. Studying this binary system over the last 15 years using a multimethod approach (natural tracers, geophysics, hydrogeological monitoring and modelling) has shown that groundwater is a major hydrologic contributor in the mesoscale glacierized watersheds of the tropical Andes. Most of the studied aquifers were shown being recharged by precipitation while a limited number of those were recharged by melt water. In the St-Elias Mountains, the cryosphere is composed of different elements such as glaciers, seasonal snow cover, rock glaciers, permafrost and aufeis, making tracing groundwater origins more challenging. Using comparable methods as in the tropical Andes, it has been possible so far to associate groundwater to different cryospheric sources and to show a non-negligible contribution to proglacial field outflows. Quantifying the groundwater contribution to mesoscale watersheds in those complex environments remains difficult. The vulnerability of groundwater to climate changes in both environments is first associated with the cryospheric components of the recharge and, at least in the tropical Andes, to enhanced evapotranspiration.

A comparison of platinum-group element dominated deposits

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There are five intrusions containing zones of disseminate sulfides that are mined primarily for platinum-group elements (PGE): the Bushveld Complex (South Africa), the Stillwater Complex of Montana (USA), the Great Dyke (Zimbabwe), the Lac des Iles Complex of Ontario (Canada), and the Noril'sk I Intrusion (Russia). In all cases, the origin

of the mineralized zones is debated. There are two end member models. At one end lies an orthomagmatic model suggesting that the PGE were collected in the magma chamber from a silicate magma by a magmatic sulfide liquid during vigorous magma mixing. At the other end is a model suggesting that, the PGE and some S were collected by aqueous fluid from the underlying cumulates. Both models have weaknesses. On one hand, the extremely high ratios of silicate to sulfide magma (R-factors) required by the orthomagmatic model, ~ 50 000, seem unrealistic, but on the other hand, experimental work indicates that the PGE are not mobile in magmatic fluids. Despite the similarity in geological context of the mineralized zones of the Stillwater (J-M Reef) and the Bushveld and Great Dyke reefs the Pd/Ir and Pd/Pt ratios of the J-M Reef are much higher and more closely resemble the Noril'sk I or Roby Zone (Lac des Iles) mineralized zones. The Noril'sk I disseminated sulfides occur in a narrow sill (100 m) close to the surface. The sulfides cannot have segregated in situ, so neither of the standard models apply. The sulfides are thought to have been transported into the sill as droplets. This raises the possibility that the sulfides in the J-M reef (and possibly sulfides in other reefs) segregated elsewhere and were transported as droplets into the magma chamber by a silicate magma. During transport the droplets interacted with a large volume of magma and were partially dissolved thereby increasing the effective R-factor.

The evolution of geological interpretations vs. geological evolution in southern New Brunswick: Iapetus, Rheic, and more

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Southern New Brunswick has played a significant role in interpretations of the Appalachian orogen since the 1970s, when the Brookville gneiss was considered Archean basement and mafic dykes in what is now the Kingston terrane were attributed to Proterozoic rifting associated with the opening of the Iapetus Ocean. In those days the current nuances of Ganderia and Avalonia were unknown, and all southern New Brunswick was part of the "Avalon zone". Damian Nance played a fundamental role in the detailed studies of that area which laid the groundwork for our current understanding, including his remarkably accurate investigation of the complex structure and stratigraphy of the so-called Mispec Group, his recognition with R. Doig and others in 1990 that the Kingston belt is Silurian and not Precambrian, and his pioneering $^{40}Ar/^{39}Ar$ dating and resulting recognition of the structural complexity and variations in cooling ages among the numerous fault-bounded belts of rocks that comprise southern New Brunswick. In the subsequent 3 decades, it has taken a wealth of field mapping, petrological studies, and U-Pb geochronology to fill in the details of the diversity of these belts, which seem to include something of everything: at least two passive margins (one tropical and one not), two high-pressure metamorphic belts (Ediacaran and Silurian), at least 5 different volcanic arcs built on different types of continental crust, a similar number of arc-related plutonic belts and sedimentary basins, and an as yet-to-be-determined number of mylonite zones, all shuffled by Carboniferous strike-slip, transpression, and transtension and ultimately extended by Mesozoic rifting. The current interpretation recognizes fragments of both Avalonia and Ganderia, and tectonic models require the closing of several oceans and/or back-arc basins. Over the years, especially as age constraints have improved and tectonic events have become better understood, the picture has become clearer, albeit still exceptionally complicated.

A race against time: subsurface nutrient legacies provide new insight into improving water quality

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Water quality is under severe threat from increasing incidences of algal blooms and hypoxic zones in inland and coastal waters, climate change and wildfires threatening our drinking water supplies, emerging contaminants from rapid urbanization, and concentrated livestock operations. Despite widespread implementation of a range of conservation measures, the last few decades have seen a lack of improvement, and sometimes even a deterioration of the water quality in surface and groundwater bodies. Our work shows that such lack of response can be attributed partly to legacy stores of nutrients that can accumulate in the landscape over decades of intensive agriculture, which then contribute to time lags between conservation measures implemented on the landscape and water quality benefits realized in receiving water bodies. Through a combination of top-down analysis--using large datasets to identify patterns in landscape behavior--and mechanistic modeling, we attempt to capture the ways in which long-term legacies of land use and management impact current dynamics in water quality. We have developed a unique modelling framework called the ELEMeNT (Exploration of Long Term Nutrient Trajectories), which pairs a simulation of soil nutrient dynamics with a travel time-based approach, to reconstruct historic nutrient yields at the outlets of watersheds and to model future nutrient loading under a range of scenarios. The uniqueness of the model is that in addition to time lags it can also provide information on magnitudes of legacy accumulation in various landscape elements. Our modeling of future scenarios indicates that even if agricultural nutrient use were to become 100 % efficient, it would take on the order of decades to meet policy goals for improving water quality.

Structural controls on IOA, IOCG, VMS and orogenic Au deposits in the northern Fennoscandian Shield

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The northern Fennoscandian Shield is dominated by Archean and Palaeoproterozoic rocks, whereas the vast majority of ore deposits are hosted by 2.4-1.8 Ga rocks. The area hosts abundant deposits such as the Kiruna and Malmberget iron-oxide apatite (IOA) deposits, the Aitik Cu-Ag-Au (-Mo) deposit and the Suurikuusiko Au deposit (Kittilä mine). Bedrock was affected by multiple deformational events each related to specific phases of hydrothermal activity and ore formation. A phase with multiple rifting events between 2.4-2.1 Ga created a mafic volcanic belt and was very likely responsible for the creation of large fault systems. At 1.9-1.88 Ga, a subduction zone developed at the southern margin of the Archean continent causing opening of transpressional pull-apart structures, the formation of a volcanic arc (Skellefte district) in the south and an area with back arc extension to the north. Structures with 1.88 syn-extensional activity host the vast majority of VMS deposits in the Skellefte district as well as IOA deposits in northern Norrbotten. Subsequent arc accretion at 1.87 Ga resulted in basin inversion, structural reactivation, greenschist to amphibolite facies metamorphism and transposition of ore deposits. Around 1.80 Ga a comparable subduction system commenced from the west and resulted in another phase of extension followed by compression. Structural observations indicate a shallow crustal level for the 1.80-1.78 Ga deformation event ranging around brittle-ductile conditions with a gradient from somewhat more ductile towards more brittle from north to south. The syn-tectonic emplacement of large volume of granites under low P, high T, conditions resembles a regional contact metamorphism. This intrusive activity provided a heat source for large hydrothermal systems, preferentially utilizing shear zones and the formation of Cu-Au and Au deposits that are classified

as IOCG or orogenic Au deposits depending on the region and crustal level of formation.

The importance of syenite enclaves in the evolution of the Saint-Honoré alkaline complex

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The Saint-Honoré alkaline complex located near the Saguenay River (Grenville Province, Québec) has a syenite outer rim and concentric units of calcio-, magnesio- to ferro-carbonatite moving towards the centre. The Mg-carbonatite hosts a niobium deposit, and the Fe-carbonatite hosts a rare earth-rich zone at its centre. The Nb mineralization has a close spatial relationship to the syenite enclaves suggesting that the syenites may have played a critical role in concentrating the pyrochlore (Pcl). There are two forms of Nb mineralization: high- and low-grade. Low-grade mineralization is characterized by highly variable Pcl chemistry with higher U concentrations and a low abundance of fluoroapatite (Ap), whereas high-grade mineralization has a consistent Pcl chemistry (low-U), abundant Ap (with many acicular crystals) and more abundant phlogopite and magnetite. Some of the Pcl crystals have been altered to columbite by hydrothermal processes. It is interpreted that the metamict Pcl (rich in radioactive elements) was altered more readily than the Pcl having undamaged crystal structure. The high-grade mineralization is generally located near the syenite enclaves. Syenite enclaves (from a centimetre scale to several tens of metres in size) reacted with the carbonatite magma to produce a phlogopite rim. Ap is also abundant along the immediate contact between the enclaves and Mg-carbonatite. Large enclaves show hydro-fracturing by the carbonatite suggesting they were crystalline enough to be brittle. There are smaller textures (3-6 mm in diameter) that share many similarities with the syenite enclaves; however, these textures are rounded and could be interpreted as being related to liquid immiscibility. The interaction of carbonatite magma with syenite enclaves is interpreted to have started with abundant crystallization of acicular Ap which depleted the magma in F and lowered the magma's Nb-solubility. Pcl then crystallized in abundance in the vicinity of the syenite enclaves to create the economic Nb-rich zone.

Normal movements along the reactivated Barlow thrust fault during exhumation of the Abitibi-Opatica boundary, Canada

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The Chibougamau area, located in the northeast part of the Abitibi subprovince, was mapped during the 2018 summer as part of the Metal Earth project, which aims to providing a better understanding of differential metal endowment in Archean subprovinces located in Canada. The Barlow Fault, located in the northern part of the studied area, correlates with a strong seismic reflector and separates the younger Archean sedimentary rocks to the south from older volcanic rocks to the north. The fault is parallel to the contact between the Opatica and the Abitibi subprovinces that is located 3 km further north. This study aims at defining the cinematic evolution of the fault and its relationship to the tectono-metamorphic evolution of the Chibougamau area. Based on detailed mapping, the fault strikes east-west, its dips varies from 30° to 85° toward the south and is expressed by a 0.5 to 1 km wide deformation zone with strong developed foliation. Most shear sense indicators suggest reverse movement, but several indicating normal movement were also observed. Based on petrographic observations, the sedimentary rocks located south of the fault experienced middle to upper greenschist metamorphism that formed chlorite, acicular actinote and biotite orientated along foliation. On the north side of the fault, volcanic rock display metamorphic facies ranging from upper greenschist to middle amphibolite facies. In these rocks, prismatic actinote and hornblende grow in random direction and overprint the foliation. The Barlow Fault likely developed as a reverse structure during north-south shortening of the Abitibi subprovince. This led to the burial of supracrustal rocks, which experienced prograde greenschist metamorphism. Rocks buried at greater depth were affected by amphibolite facies metamorphism and the temperature pic post-dates cinematic movements. The Barlow Fault was then reactivated as a normal fault during the exhumation of boundary between Opatica and Abitibi subprovinces.

Carbonate platforms and controls on the genesis of sapphire, gem spinel, and lapis lazuli: insight from the Lake Harbour Group, Nunavut, Canada and implications for exploration

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Baffin Island's Lake Harbour Group (LHG), a Paleoproterozoic granulite facies metasedimentary sequence rich in carbonates, contains occurrences of the gemstones sapphire (corundum), spinel (including cobalt-blue spinel), and lapis lazuli (haüyne). Most occurrences of these gem minerals are uniquely metasedimentary (carbonates and calc-silicate rock), while a few spinel occurrences formed from metasomatic reactions between Si-Al-rich rock (syenogranite or gneiss) and marble. The metasedimentary corundum, spinel, and haüyne occurrences have similar protoliths: primarily dolomitic marls with a high Al/Si relative abundance (interpreted as sandy mud to clay siliciclastic fraction in the protolith). Kimmirut-type sapphire deposits can only be formed by a multi-step metamorphic process under three different and specific P-T conditions. Lapis lazuli formation required the presence of evaporites to provide Na and S for the blue mineral haüyne. In addition to high Al/Si calc-silicate rocks, spinel also occurs in impure dolomitic marbles with very low K/Al. Potential for Kimmirut-type sapphire deposits is expected to be restricted to marbles proximal to the thrust fault separating the LHG from the Narsajuaq Arc, where retrograde upper amphibolite facies mineralization is most pervasive. Spinel and Kimmirut-type sapphire deposits are expected to be found in dolomitic marble sequences rich in calc-silicate layers. The potential occurrence of lapis lazuli is more difficult to predict. Aerial hyperspectral and photographic surveys are well-suited to gemstone exploration in this remote region thanks to excellent rock exposure with minimal sedimentary or plant/lichen cover. Spectral mapping of dolomite-, diopside-, phlogopite-, and scapolite-rich domains in LHG metacarbonate sequences is expected to provide exploration targets. Ground based exploration efforts could be aided by the use of a portable unmanned aerial vehicle (UAV).

A new approach to chemical heterogeneity in volcanic glass: LA-LIBS

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The process of magma differentiation through fractional crystallisation and its impact on trace element concentrations was first established by Bowen in the early 1900s and re-affirmed by countless studies since. The chemical heterogeneity induced by the exsolution of magmatic gas has received comparatively little attention. This reflects the difficulty of analysing the main volatiles (e.g. H_2O and CO_2) at low concentrations in the residual glass and of identifying samples that preserve a geochemical record of degassing processes. Typically H_2O is analysed by FTIR, Raman or SIMS in conjunction with only a few other elements. However, recent studies that combine FTIR with LA-ICP-MS have shown that other elements (such as Li, Pb, Cu) display heterogeneities and diffusion profiles that provide key additional constraints on degassing. To advance the field an analytical technique is required that

can analyze all elements of interest simultaneously at their natural range of concentrations. Here, we present preliminary results from evaluating LA-LIBS (tandem Laser Induced Breakdown Spectroscopy and Laser Ablation Inductively Coupled Plasma Mass Spectrometry) for that role. This tandem instrument enables the simultaneous analysis of H, C, Cl and the major elements via LIBS and trace-elements via ICP-MS. Moreover, recent advances in data processing use the combined optical and mass spectra, thereby lowering detection limits and increasing precision. This presentation will address the challenges of LA-LIBS in calibration and data processing of complex multi-element geologic samples, and present the potential of the method with initial results from rhyolitic glasses of recent volcanic eruptions in Chile.

Influence of flow partitioning on quartz CPO fabric: a modeling investigation based on micromechanics

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Variation in quartz crystallographic preferred orientation (CPO) in mylonites remains poorly understood. Although it has been proposed that the variation may be due to flow field partitioning, there is no quantitative analysis on the effect of partitioned flow. The analysis requires a multiscale approach. Here, we couple our Multi-Order Power Law Approach (MOPLA) with the visco-plastic self-consistent (VPSC) model to quantitatively investigate the problem of quartz CPO formation. We regard quartz aggregates as rheologically distinct elements (RDEs) embedded in a heterogeneous macroscale medium. The latter is represented by a homogeneous equivalent medium (HEM) that has effective rheology obtained self-consistently from the constituent materials, in this case, quartz, feldspar and mica grains. This configuration is representative of the natural mylonites where quartz aggregates occur as heterogeneous inclusions in the quartz-feldspar-mica matrix. We use MOPLA to obtain the partitioned flow field in a RDE. This flow field is used in turn as the boundary condition for simulating quartz CPO development with the VPSC model. Our modeling reproduces commonly observed patterns of quartz CPO, particularly the puzzling peripheral c-axis maxima in mylonites that can be synthetic and antithetic to the shear sense. This occurrence of synthetic and antithetic c-axis peripheral maxima within a shear zone does not require a reversal of sense of vorticity. The CPO pattern depends on the viscosity and initial shape of the quartz RDE. Bulk finite strain of the deforming rocks is found to be an important parameter in determining CPO pattern as also reported in recent experimental deformation studies.

Petrogenesis and rare element potential of late tectonic pegmatites, Hall Peninsula, Baffin Island, Nunavut

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Numerous granitic pegmatites intrude the Paleoproterozoic country rock of the Hall Peninsula, southern Baffin Island, Nunavut. This project examines the source of the pegmatites' parent melts, their genesis and timing in relation to orogenic evolution, and their absolute ages of emplacement. Methods used include whole-rock geochemistry, LA-ICP-MS on micas and other minerals, and U-Pb geochronology. Any rare metal, rare-earth element (REE), or gem occurrences in the studied pegmatites will be highlighted, with an emphasis on economic potential for Sn, Li, Cs, and/or Ta. The pegmatites are generally undeformed, and display primary textural characteristics, indicating that emplacement occurred late in the region's tectonic history, but a detailed examination of their distribution and mineralogy is in progress to better understand their significance in the region. Part of this research includes the development of a remote predictive mapping (RPM) approach to identify pegmatites; several suspected pegmatite occurrences identified in RapidEye satellite data were ground-truthed during field work. Whole-rock geochemistry data analysis from 19 pegmatites shows a range of degrees of fractionation in the population, and either syncollisional or volcanic arc granitic sources. LA-ICP-MS analysis of micas found high concentrations of REEs at mica-K-feldspar boundaries. Initial geochronology of monazites and zircons from 7 samples gives a preliminary age of 1.75 to 1.80 Ga, marginally post-dating peak metamorphism of the Trans-Hudson Orogeny (1850-1830 Ma); the pegmatites are likely related to the last partial melting of the country rock. Economic rare-element mineralization potential in the southern Hall Peninsula region is low, with only one pegmatite qualifying as an 'occurrence'. However, published reports of pegmatite-hosted Ta and REE-mineral occurrences further north on Baffin Island suggest that this potential may still be present. With a better understanding of their origin and characteristics, the Hall pegmatites can be properly integrated into the geotectonic setting of southern Baffin Island.

The East-Sullivan intrusion and its associated Au, Ag, Cu, Mo mineralization, Val d'Or District, Abitibi, Quebec

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The gold-bearing district of Val d'Or (Lamaque, Sigma, Goldex) represents the archetype of "orogenic" gold mineralization, i.e. formed by circulating late-orogenic metamorphic fluids. However, near these well-known deposits and showing, several atypical gold mineralization has been discovered. These mineralizations are mainly observed at the southern edge of the East Sullivan pluton, immediately north of the Cadillac Break, southeast of the town of Val d'Or. The area has been extensively explored since the 1930s, which led to the discovery of Cu-Mo (Porphyre and Ducros Zone1) and Cu-Au-Ag (Ducros Zone2) showings on the southern edge of the East-Sullivan pluton. Chalcopyrite, molybdenite and pyrite mineralizations are hosted in porphyritic intrusive facies that are strongly altered (mainly epidotized and sericitized). In the East-Sullivan pluton area, the mafic volcanic rocks interbedded with sills and gabbroic dykes of the Heva Formation are folded and metamorphosed to greenschist facies conditions. The East Sullivan pluton is a large intrusion of calc-alkaline affinity, which includes monzonites and trachytes that have affinities with syn-Temiskaming sanukitoids. South of the contact between the intrusion and its volcanic hostrocks, a 200 meters thick contact metamorphism halo is observed that contains many mineralized hydraulic breccias. These breccias are cemented by epidote, carbonates, magnetite, pyrite, pyrrhotite and chalcopyrite, and are localy enriched in gold. They were observed at the Orenada Zone 5, Hogg and Jolin showin. The most intensely brecciated zones form sub-parallel corridors in contact with the intrusion and cut through local stratigraphy. This style of mineralization is similar to the Akasaba mine, located 10 km further east, and that has been interpreted as a skarn. The East Sullivan pluton sector is an exceptional example of periplutonic (porphyry and skarn), volcanogenic (East-Sullivan mine), as well as orogenic gold and copper mineralization in the Abitibi belt, which points to the protracted gold-copper metallogeny of the area.

The distribution and partitioning of silver in the Banana Zone sediment-hosted Cu-Ag deposit in the Ghanzi-Chobe Copper Belt portion of the Kalahari Copper Belt: constraints from LA-ICP-MS study

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This study uses in situ laser ablation inductively-coupled mass spectroscopy (LA-ICP-MS) to carry out spots analysis and trace elements mapping of sulphide minerals from the Banana Zone in the Botswana Ghanzi-Chobe Copper Belt portion of the Kalahari Copper Belt. Silver contents as high as 84.7 ppm, 890 ppm, 874 ppm, and 511 ppm were recorded in chalcopyrite, bornite, chalcocite and galena,

respectively. Siver is preferentially partitioned into the high Cu-rich phase. For example, in the chalcopyrite-bornite assemblage, almost all the Ag is partitioned into bornite (i.e. 96 % of Ag) over chalcopyrite. Likewise, in the bornite-chalcocite assemblage, chalcocite contains almost 60 % of the Ag. This is in agreement with the previously observed geochemical assay data that indicated a positive correlation between Cu and Ag. In addition, the concentration of Ag in galena correlates positively with that of Sb and is possible results of Ag-Sb inclusions and solid solution. The homogeneous distribution of Ag and Bi as observed in LA-ICP-MS elemental maps and small to medium standard deviations averaging 3 to 44 % of the mean suggest that these elements are most likely in solid solution in both the structures of bornite and chalcocite. It is also observed from LA-ICP-MS maps that there are at least two precipitation events of Ag as demonstrated by an Ag-rich veinlet that crosscut both the chalcocite and the bornite. Of note is the variation in Ag and Bi contents between chalcocite grains from the same sample and within a single chalcocite grain, with the latter demonstrating compositional zoning of at grain scale. These arguments may indicate a change in the composition of the mineralising fluid through time.

Crustal-scale faults, syn-orogenic clastic rocks, magmatism and orogenic gold deposits

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Numerous orogenic gold deposits and camps show a repeating template of a spatial association with large fault systems, folded and disrupted panels of syn-orogenic clastic rocks, and syn-orogenic magmatism. This tectono-magmatic template and associated ore system can be recognized through time, from the oldest gold camps in the world (e.g. Barberton), to numerous examples across the Archean (e.g. Abitibi, Yellowknife) and Proterozoic (e.g. Trans-Hudson), to the Phanerozoic (e.g. Appalachians, Cordillera), arguing for a fundamentally similar process chain that is, to a first order, independent of geological time. This tectono-magmatic template will be introduced and reviewed with a number of examples, particularly from the Abitibi greenstone belt. Parameter-by-parameter comparison of Archean systems with younger systems (e.g. central Newfoundland vs. Abitibi) can shed light on key processes involved. Invariably, the controlling fault systems have a complex history and different segments of the faults may preserve different and incomplete snapshots of the overall structural evolution. Together with the inherent complexity of vein systems, this explains the lack of consensus on kinematic history in many areas. Commonly, a final phase of movement on the fault systems involves strike-slip dominated transpression, which displaced parts of the overall system and which must be restored for a complete understanding. The asymmetric capture and preservation of deformed and metamorphosed panels of syn-orogenic conglomerates, often with gold-mineralization, on one side of the major faults (i.e. the footwall), indicates a key role for high-angle reverse faulting in all cases, prior to final degeneration to strike-slip. In many cases, the reverse faults or thick-skinned thrust appear to invert earlier extensional faults, and syn-orogenic extension and associated magmatism may be critical to overall gold endowment. By limiting long-term depth of erosion, syn-orogenic extension also plays a key role in preservation of the upper crustal 'gold window'. This 'gold window' is more strongly skewed towards the syn-orogenic surface than perhaps realized.

Geology of the auriferous Archean Mistumis pluton, James Bay, Quebec

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The James Bay area (Superior Province) comprises numerous gold showings that are hosted within Archean plutonic rocks and remain poorly understood in terms of classification and genesis. The Mistumis pluton is a large polyphased TTG intrusive suite located in the Lower Eastmain greenstone belt (La Grande subprovince) and hosts a variety of gold showings. The purpose of this study is to characterize the Mistumis pluton and to interpret the gold showings in accordance to the petrogenesis of the pluton and to the tectonic evolution of the La Grande subprovince. This pluton emplaced into 2723 ± 2.2 Ma bimodal volcanic rocks of the Anatacau-Pivert Formation, which were metamorphosed at upper greenschist to lower amphibolite facies conditions. It is composed mostly of 2716 ± 13 Ma biotite tonalite (U-Pb zircon; LA-ICP-MS this study) that is crosscuted by subordinate granodiorite and an intrusive breccia facies. The geochemical analyses for tonalite and granodiorite suggest a similar calc-alkaline affinity and derivation from a low-K basaltic source. Gold occurs as 1) anomalous concentrations in late magmatic breccia pipe; and 2) mineralized high-strain zones with disseminated sulfides and veins. Anomalous gold values in magmatic breccia pipes is associated with sericitic alteration and disseminated euhedral pyrite in a porphyritic to equigranular felsic matrix. The mineralized ductile-brittle high-strain zones (up to 1.15 g/t Au over 64 m) belong to the E-W trending D2 phase of regional deformation, to which most of the gold deposits in the area is related. Hydrothermal alteration correspond to sericitization and chloritization. The structural setting of the veins and alteration, as well as the geochemical footprint, suggest an orogenic gold metallogenic model for the gold mineralization within the Mistumis pluton. Anomalous gold concentrations in magmatic breccia pipe, on the other hand, indicate an early phase of magmatic-hydrothermal alteration that predates regional deformation.

A preserved oceanic core complex in the Cache Creek terrane, northern Cordillera, Canada

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The Carboniferous-Jurassic Cache Creek terrane of the Canadian Cordillera comprises oceanic mantle rocks, submarine lavas, chert, limestone and rare plutonic rocks. The Cache Creek is bounded by the Quesnel and Stikine arc terranes, which were accreted to North America and deformed by the Middle Jurassic. Large, thrust-bounded ophiolitic massifs expose well-preserved mantle/crust transitions in northern British Columbia (BC) and southern Yukon. In the Atlin area (BC), mantle harzburgite and minor dunite are in structural contact with a crustal sequence comprising slivers (~ 400 m) of gabbro, and a composite volcano-sedimentary sequence dominated by depleted arc tholeiites, calc-alkaline lavas and dykes, and rare alkali basalts. The SW-dipping mantle-crust contact is a ~ 100 m wide chrysotile/antigorite serpentinite shear zone that contains cm- to m-scale fragments of mantle and crustal rocks. These are interpreted to be thrust-related structures as asymmetric fragments and C-S structures show reverse motions. Small structural windows expose the mantle rocks beneath the crust on Union Mountain. Shears in these windows are shallowly SE-dipping and C-S structures show a normal motion. Such fabrics could represent syn-oceanic, extensional structures as they are affected by a SW-dipping spaced cleavage. An excellent example of an extensional shear contact occurs near Squanga Lake (Yukon), where a shallowly SE-dipping, serpentinite shear zone separates a dominantly lherzolitic mantle from brecciated crustal rocks, including ultramafic cumulates, massive gabbro, basalt, chert and limestone. Serpentinites preserve pseudomorphic textures such as mesh-lizardite and bastite. Rodingites at the mantle/crust interface display an actinolite-prehnite-epidote-chlorite mineral assemblage, suggesting greenschist facies conditions. The occurrence of syn-oceanic extensional low-angle shear-zones between mantle and crust, along with the scarcity of lower crustal rocks, the lack of lateral stratigraphic continuity, and the brecciated aspect of many Cache Creek supracrustal sequences, suggest common structural exhumation of the oceanic mantle prior to its continental accretion.

Lithological and structural controls on the nature and distribution of gold at the LaRonde Zone 5 project, Doyon-Bousquet-LaRonde mining camp, Abitibi, Québec

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The LaRonde Zone 5 (LZ5) project of the LaRonde mining complex contains reserves and combined resources of 15 Mt at 1.9 g/t Au for ~ 28 tonnes of gold, or 0.9 million ounces. It has been mined in part from the former Bousquet 1 mine that operated from 1978 to 1996. The LZ5 is located in the Doyon-Bousquet-LaRonde mining camp (DBL) within the Blake River Group in the southern Abitibi region. The LZ5 mineralization is hosted within a succession of volcanic and volcanoclastic units (tuff and lapilli tuff) that vary in composition from mafic to felsic, and which are presumably part of the lower member of the Bousquet Formation. The LZ5 consists of three separate mineralized corridors, namely zones 4.1, 4 and 5. The rocks from the Bousquet Formation are strongly deformed, i.e. moderately to intensely foliated, locally stretched and sheared into the main E-trending foliation that dips steeply to the south. The host succession is homoclinal, dipping to the south. The main ore horizon of the LZ5 project (zone 5) is hosted in dominantly mafic to intermediate massive rocks that are tentatively correlated with those of the Bousquet heterogeneous unit (unit 4.4). Ambiguous timing relationships between the sulphides, the associated gold, and the structural features has led to contrasting interpretations for the LZ5 mineralization (synvolcanic versus syntectonic). Also, the style of mineralization at LZ5 (pyrite ± chalcopyrite veins and veinlets, ± disseminated pyrite) and its setting (mafic-intermediate rocks of the lower member of the Bousquet Formation) largely differs from most of the synvolcanic ore zones elsewhere in the study area. Therefore, ongoing research at LZ5 aims to document the ore styles and setting, establish the relative timing of events, compare with the other deposits of the camp, and contribute to the metallogenic models for Archean gold deposits in the southern Superior Province.

Multiple isotopes help unravel the origin of methane in shallow groundwater of two regions in eastern Canada

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The tremendous increase in unconventional hydrocarbon exploitation in the mid-2000's has prompted the need for baseline studies that assess the presence and origin of methane in shallow aquifers used for water supply located above developed or explored shale or tight hydrocarbon reservoirs. To distinguish between microbial and thermogenic gas origins, traditional indicators such as the gas dryness ratio (concentration of methane / [ethane+propane]) and carbon isotopic values of methane ($\delta^{13}C_{CH4}$) have commonly been used, but have often led to ambiguous results. Here, we report on two studies carried out in Quebec and New Brunswick, where additional indicators were used to help unravel methane origin. These indicators include isotopic values of dissolved inorganic carbon ($\delta^{13}C_{DIC}$) and water ($\delta^{2}H_{H2O}$, $\delta^{18}O_{H2O}$), as well as hydrogen isotopic values of methane ($\delta^{2}H_{CH4}$). In total, 69 wells were sampled, many of them several times. Results showed that dissolved methane was present in the majority of wells. When concentrations allowed, traditional indicators of gas origin (dryness ratio, $\delta^{13}C_{CH4}$) were used to separate wells into three classes, namely wells with: 1) predominantly microbial gas (17 wells), 2) predominantly thermogenic gas (8 wells), and 3) gas of ambiguous origin (19 wells). For the latter, the additional indicators helped to assess the nature of processes which may affect the isotopic values of methane, such as late-stage methanogenesis and methane oxidation. This approach proved enlightening and allowed reducing the number of wells with unknown gas origin, attributing them to either late-stage (7 wells) or oxidized (5 wells) gas of microbial origin. The gas origin of the last 7 wells remains ambiguous given the lack of isotopic data. Noteworthy, late-stage microbial gas could generally be identified from a single sample, while the identification of methane oxidation required isotopic analyses on multiple samples per well, stressing the importance of obtaining temporal series.

Assessing links between groundwater gaining areas and nutrient status in agricultural streams during summer and winter base flow conditions

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Nutrient enrichment of surface waters by anthropogenic phosphorus degrades water quality in the Laurentian Great Lakes and their tributaries, causing the loss of economic, recreational and ecological benefits. Current mitigation efforts in agricultural landscapes focus mainly on reducing surface runoff pathways that deliver nutrients to adjacent streams. The importance of the groundwater pathway in delivering nutrients to streams in agricultural areas remains unclear. This study evaluated the contribution of groundwater inputs on stream nutrient budgets in agricultural landscapes. To achieve this, two adjacent headwater streams in the upper Thames River watershed, Ontario, were surveyed for groundwater tracers and stream chemistry. Streams were sampled every ~ 200 m during summer and winter baseflow conditions to quantify and map large-scale variability of groundwater discharge and nutrient stream chemistry. Two stream segments of ~ 1.5 km were also sampled at ~ 50 m intervals under different seasonal and weather conditions to evaluate the temporal dynamics of groundwater and nutrient inputs. Water samples were analysed for water stable isotopes ($\delta^{18}O$ and $\delta^{2}H$), 222-radon, ion chemistry, orthophosphate and total phosphorus. Stream flow and basic physico-chemical parameters were also measured. Preliminary results from summer baseflow conditions showed that groundwater discharge in streams is primarily located in higher permeability terrain. However, there was no clear association between groundwater and phosphorus inputs in streams at the larger scale. Monitoring of the two stream segments revealed that groundwater discharge to streams was fairly constant during baseflow conditions whereas it was significantly higher after storm events. Likewise, phosphorus concentrations displayed similar values during baseflow conditions and were higher after storm events. Results from the winter baseflow conditions will also be compared to the summer baseflow findings. This study provides new insights into the pathways by which phosphorus is delivered to streams in agricultural landscapes.

Mobile time domain electromagnetic system for hydrogeophysical characterization

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Ground electrical and electromagnetic methods have been successfully used in hydrogeophysical applications because of the strong relationship between electrical conductivity and hydrogeological parameters. However, more and more hydrogeological studies need detailed investigation of large areas which requires new efficient ground geophysical methods capable of creating 3-D high resolution conductivity model of the zones under study. In order to achieve this, we have adapted the Dynamic NanoTEM system from Zonge (USA) which is characterized by very fast turn-off transmitter to construct a mobile time domain electromagnetic (M-TDEM) system. The developed system consists of plastic made transmitter and receiver structures mounted on

robust wheels. The transmitter structure can be equipped using a 2.5 m × 6 m wire loop with 2 turns or 10 turns. The two transmitter magnetic moment coils (low: 2 turns and high moment: 10 turns) are used to measure the early and late time gates corresponding to shallow and deep information about the subsurface layers. The M-TDEM system is towed by an all-terrain vehicle. It has a 2.5 m x 2 m z-component receiver placed at 7 m offset from the transmitter. The operational speed of the system is 10-15 km/h. The inversion of the data is carried out with 1-D laterally constrained Bayesian approach based on non-stationary Matérn precision matrix which allows to form a pseudo 3D conductivity model. The system has been successfully used for assessing aquifer contamination in Ville-Mercier, Canada. We are also planning to carry out M-TDEM survey in the summer of 2019 for sea water intrusion mapping in Magdalena Island (Canada).

Metal Earth in Chibougamau: stratigraphy, chemistry and age of the Obatogamau Formation

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The Obatogamau Formation is a volcanic unit located in the Chibougamau area, NE corner of the Abitibi subprovince. It consists mainly of mafic lavas with up to 20 % feldspar macrocrysts. Based on this feature the formation has been recognized over a 100 of km in the E-W direction. In the studied area, the formation is sandwiched between the ~ 2.76-2.79 Ga Chrissie and des Vents Formations and the ~ 2.73 Ga Waconichi Formation. The Obatogamau Formation is usually viewed as a monotonous, ~ 4 km thick, pile of lava flows. The chemical and petrological heterogeneity of this formation, as well as the origin of the feldspar macrocrysts, is undocumented. Similar macrocrysts are contained by the mafic lavas of the Chrissie Formation and by two synvolcanic layered intrusions containing anorthosite units of the Chibougamau area, whose relationship with the Obatogamau Formation is undetermined. To address these issues, the chemistry and petrology of the Obatogamau Formation was investigated. The rocks range from basalt to andesitic basalt and have a tholeiitic affinity, with a high compositional homogeneity. Field mapping revealed several episodes of volcanic quiescence, marked by levels of claystones, tuffs, chert and rhyodacite flows. The felsic flows have a calc-alkaline affinity. As the age of the Obatogamau Formation is unknown, the rhyodacite flows have been sampled for dating. A detailed characterisation of the feldspar macrocrysts from the Obatogamau Formation, the Chrissie Formation, the Doré Lake and Opawica River complexes was undertaken in order to distinguish between the Obatogamau Formation and older volcanic units, and to discuss the relationship between the studied lava flows and exposed anorthosite-bearing intrusions.

Design of a 3D electrical resistivity imaging system for seepage monitoring at an embankment dam abutment

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Concrete structures at the Mactaquac hydroelectric generating station, located on the Saint John River near Fredericton, NB, are experiencing an aggregate-alkali reaction, causing them to expand. It has been hypothesized that differential expansion of the concrete abutment to the embankment dam could lead to elevated seepage along that interface. We have installed a 3D resistivity imaging system, installed on the back of the dam, which will be used to monitor for spatial variations in resistivity that may be caused by such seepage. The electrical resistivity of earth materials is sensitive to changes in water saturation, pore fluid temperature and total dissolved solids, all of which may change seasonally inside the dam in response to changes in headpond temperature and solute load. To start, we will identify zones inside the dam where resistivity variation with the changing seasons is anomalously high, suggestive of changes in temperature, water conductivity and/or moisture content arising from concentrated seepage. Observed seasonal changes in resistivity within different parts of the embankment will be compared to those expected based on prior modelling of seasonal variations in temperature accompanying bulk seepage. Working on a slope of the embankment presents novel challenges, as previous resistivity monitoring systems have more typically been installed along the crests of dams. Pole-dipole array measurements are being used to increase the depth of exploration available from relatively short lines. Installing electrodes through rip-rap cover, overcoming high electrical noise levels, achieving sensitivity within the core of the embankment, and accounting for the effects of conductive concrete are among the other hurdles. Repeated measurements of the annual cycle of resistivity within the dam will complement ongoing monitoring of temperature using Distributed Temperature Sensing (DTS) thereby strengthening seepage monitoring at the embankment's interface with the concrete Diversion Sluiceway.

Geology and U-Th-Pb dating of the Gakara REE deposit, Burundi

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The Gakara Rare Earth Elements (REE) deposit is one of the world's highest grade REE deposits, likely linked to a carbonatitic magmatic-hydrothermal activity. It is located near Lake Tanganyika in Burundi, along the western branch of the East African Rift. Field observations suggest that the mineralized veins formed in the upper crust. Indeed, veins texture does not bear any ductile shear component and corresponds to brittle opening, with REE-minerals crystalizing in the resulting open spaces. Also, fluids were localized along fractures zones and heterogeneities in the host rocks (including the steeply-dipping foliation, the walls of vertical aplitic veins). Where such heterogeneities were absent, over-pressure features are recorded by the ore bodies. The fact that we document hydrothermal fluids coming from below is consistent with the classical hypothesis of a hidden carbonatitic body at depth. The involvement of surface-derived fluids, notably during the alteration of bastnaesite into monazite, is ruled out by stable isotope data. The paragenetic sequence and the geochronological data show that the Gakara mineralization occurred in successive stages in a continuous hydrothermal history. The REE veins contain mainly bastnaesite, which can be replaced, in a second stage, by monazite. Because this replacement is not ubiquitous, the REE-bearing minerals in these veins vary from pure bastnaesite to nearly pure monazite. Quartz (several generations) and wall rock clasts constitute the other components found in the ore veins. The primary mineralization in bastnaesite was followed by an alteration stage into monazite. The U-Th-Pb ages obtained on bastnaesite (602 ± 7 Ma; in situ LA-ICP-MS method) and on monazite (589 ± 8 Ma) belong to the Pan-African cycle. The emplacement of the Gakara REE mineralization most likely took place during a pre-collisional event in the Pan-African belt, probably in an extensional context.

Is there still a chance to save the groundwater in Taleza aquifer?

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Located in the North-Eastern region of Algeria, the coastal aquifer of Taleza has potential to act as a signficant source of potable groundwater. It contains hundreds of private wells installed by the population for several purposes including drinking water. Recently, the groundwater has become salinized and reported to have a rotten egg odour assciated with it. The groundwater quality is most likely

controlled by two factors: 1) the aquifer's lithology and soil/rock interactions with groundwater, and 2) anthropogenic activities such as agricultural production, industrial growth, urbanization with increasing exploitation of water resources, and private sanitation systems. Currently the anthropogenic activities are considered to be the most serious sources of groundwater contamination. Unfortunately, most of Taleza's people don't have any idea about the anthropogenic groundwater contamination., An urgent, efficient and durable groundwater protection plan is required to limit, and potentially improve the effects of the anthropogenic sources on groundwater quality. Determining the origin of saline components in aquifer may provide more precision about the development of salinization process, and constitutes a useful tool to propose alternative solutions for ensuring the long-term protection of water resources. Accordingly, it is planned to perform a multi-tracer study, combining isotopic and hydro-geochemical analysis, to identify the origin and fate of groundwater salinization. Prior to the tracer study, a review of the potential anthropogenic sources of groundwater contamination related to the Talezaaquifer will be completed. This presentation will describe the review of these potential anthropogenic sources, which potentially have led to the degradation of groundwater quality.

Impact of rock block's shape and orientation on the hydraulic erodibility process

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The most commonly used method for assessing the hydraulic erodibility of rock is the Annandale's method. This method is based on a correlation between the force of flowing water and the capacity of rock resistance. This capacity is evaluated using the Kirsten's index which was initially developed to evaluate the excavatability of earth materials. This index is determined according to certain geomechanical factors, such as the compressive strength of intact rock, the rock block size, the discontinuities shear strength and the relative block structure. This last characteristic represents the required effort to erode the rock and, it can be quantified considering the rock block's shape and orientation relative to the direction of flow. To determine the relative rock structure in the field, the dip and dip direction of closer spaced joint set, as well as the ratio of joints spacing are required. It is found that the Kirsten's concept can be applied only when the direction of flow is perpendicular to the strike of closer spaced joint set. Our proposed communication focuses on the adjustments introduced to Kirsten's initial concept concerning the relative block structure parameter. Thus, two equations are proposed to evaluate the impact of rock block's shape and orientation when the direction of flow is not perpendicular to the strike of closer spaced joint set.

Long term water management in Alberta's Southern Athabasca Oil Sands region: using modelling tools to evaluate sustainability

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Production of oil (bitumen) from Canada's Southern Athabasca Oil Sands (SAOS) region is accomplished primarily through steam based in situ recovery methods. More than 90 % of injected water is recovered and recycled; nonetheless a significant volume of "make-up" water is required to sustain these operations. To reduce environmental impacts, make-up water is obtained from deep and often saline aquifers. While every individual project undergoes a strict environmental approval process, a regional view of aquifer sustainability is also needed to effectively manage resources for the future. Canada's Oil Sands Innovation Alliance (COSIA) was formed in 2012 to enable responsible and sustainable growth of Canada's oil sands while delivering accelerated improvement in environmental performance through collaborative action and innovation. Over the past 5-years, COSIA's Regional Groundwater Solutions (RGS) project has evaluated the potential cumulative effects resulting from groundwater usage associated with current and future in situ oil production in the SAOS region. Through industry and government collaboration, a sophisticated regional numerical flow model was developed using the best available geologic and hydrogeologic information. Recognizing that hydrogeologic parameter values applied in the numerical model are based on spatially limited data and a regional conceptualization, prediction uncertainty from model parameterization was explored using a null space Monte Carlo approach. A total of 300 realizations with independent parameter sets were developed to evaluate the likelihood of unacceptable cumulative drawdown and highlight areas of potential concern. A range of potential industry growth scenarios were developed to quantify operational uncertainties around future make-up water demand. This case study will provide an overview of RGS modelling results that are helping decision-makers to quantify uncertainty to responsibly manage water resources in the SAOS region and help to ensure their sustainability into the future. Challenges associated with defining predictive scenarios and spatial visualization of the uncertainty will also be discussed.

Evaluation of previously undocumented mafic-ultramafic intrusions on NW Baffin Island

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Mafic-ultramafic bodies that intrude Rae craton ortho- and para-gneiss occur as structurally transposed intrusions and discontinuous dykes and/or sills across northwestern Baffin Island and on the northern Melville Peninsula. Regionally, the rocks in this area are ascribed as the ca. 3.0-2.5 Ga felsic orthogneiss of the Committee Bay belt including the ca. 3.2-2.8 Ga Prince Albert and Roche Bay greenstone belts located on the Melville Peninsula. These greenstone belts are characterized by mafic and ultramafic (komatiite) volcanic rocks that were deformed during multiple orogenic episodes. Previously undescribed mafic-ultramafic intrusions on NW Baffin Island, observed during regional mapping in 2018, experienced at least three of the four orogenic events that the surrounding basement experienced. The axial surface of a large isoclinally folded mafic intrusion is parallel to the dominant foliation in the surrounding gneissic basement. Two of the larger intrusions range from gabbro to pyroxenite with local layers of hornblendite and leucogabbro. Features such as magmatic cumulate layers, rhythmic layering, and gradational layering are key features observed in the intrusion suites. This rhythmic layering (hornblende gabbro to leucogabbro) is in general parallel to the dominant foliation of the surrounding basement. Foliation within the intrusions defined by aligned biotite is also generally concordant to the dominant foliation in the surrounding basement. Late syenogranite pegmatites occur as dykes in both the surrounding basement and mafic-ultramafic intrusions, and are interpreted to have experienced the three latest deformation events recorded in the area. Future geochronological work will constrain the timing of this magmatic event and place constraints on the timing of deformation. Major, minor and trace geochemical data will also be acquired for economic potential.

The Troilus deposit: a new structural model and a new perspective

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The Troilus mine, which closed in 2012, began producing gold and copper in 1996 from three conventional open-pit operations (zone 87 and J zone). Over the life of the mine, two million ounces (~ 65 t Au) of gold and almost 70 000 tonnes of copper were produced. The 16 000hectare Troilus property is located 125 km North of the town of Chibougamau within the Frotet-Evans greenstone belt in Quebec, Canada. The Troilus deposit consists of strongly deformed disseminated to stockwork sulphide (pyrite, pyrrhotite and chalcopyrite) gold mineralization

accompanied by biotite-actinolite-albite-dominated, pseudobreccia-style hydrothermal alteration. The deposit is hosted within a sequence of dioritic intrusive rocks. The deposit has previously been interpreted both as a porphyry-style system and as an orogenic gold deposit, although recent work indicated that mineralization is early, pre-main stage deformation. In early 2018, Troilus Gold began re-evaluating former pits Z87, J4 and J5. Recent results and geological interpretation from the diamond drilling campaign and field work confirmed that the emplacement of gold mineralization was first lithologically controlled by the presence of dioritic breccia acting as a preferential host and felsic dykes acting as fluids barriers. The deposit was subsequently affected by the main deformation event (D1). In addition to shortening, tilting and stretching of the rock package, all mineralized zones have been affected by late, major folding, which had not ben previously recognized. These new evidences involve a complete re-evaluation of the metallic potential at local and regional scales. The conference integrates the previous geological interpretations of the Troilus property with new geological data collected recently to provide further constraints on the genesis of the deposit and on exploration models in the fertile Frotet-Evans belt and in similar contexts elsewhere.

North America's first Geopark: educating through engaging experiences

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Stonehammer, located in Southern New Brunswick, Canada has a complex geology exposed along rugged ocean and river shorelines, on sparsely vegetated landscapes and on roadways. The scenic landscape has resulted in a rich mosaic of parks scattered through the region that are highly dependent on geology for their beauty. The geopark encompasses 2500 square kilometers and incorporates more than 60 significant geological and fossil sites, including more than 15 publicly accessible sites. Connecting both visitors and our communities to the Earth through engaging and fun tourism products has been a priority for Stonehammer. Utilizing a paid membership model for tourism providers gains them access to the geological information, how to integrate the information into their experiences and how to deliver this academic information in a fun and engaging way. This model allows Stonehammer to partner with quality tourism operators and provides a means for geopark brand management and ensuring high quality standards are adhered to. Policies and procedures have been developed and implemented for any tourism program that is branded Stonehammer UNESCO Global Geopark including a mystery shop component for evaluation. Both financial and human resources have been invested in product providers such as; interpretive walks, kayaking, boat cruises, meals, snowshoeing and exhibits. Stonehammer is able to extend our reach as it relates to educating the general public through the tourism products. With Stonehammer's location on the world renowned Bay of Fundy cruise passengers also participate in the tourism experiences. A comprehensive marketing plan promotes the experiences within the geopark and provides incremental benefits to our members. Through quality experiences Stonehammer generates sustainable economic development and extends the reach of our educational platform.

The role of country rock assimilation on chromite crystallization in the Ring of Fire, James Bay lowlands, Ontario, Canada

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The Ring of Fire Intrusive Suite (RoFIS) in the James Bay lowlands (Ontario) is emplaced into the 2.7 Ga McFauld's Lake greenstone belt, and hosts the Black Thor, Big Daddy, Blackbird, and Black Label chromite deposits, together comprising ~ 192.7 million tonnes of measured and indicated chromite resources. Evidence suggests that magma contamination occurred during the emplacement of the RoF intrusion – a process that has been evoked in general for the formation of massive chromitite segregations. We have evaluated the role of contamination as a chromitite-forming mechanism in the RoF context by combining phase equilibrium experiments with trace element measurements on chromite, and modelling. Experiments involved equilibrating mixtures of synthetic komatiite and country rocks to the RoF intrusion (banded iron formation, Fe-rich metasediment, and granodiorite) at 0.1 MPa and the FMQ buffer to measure phase equilibrium, chromite solubility, and chromite composition. The most notable results of this work are: 1) The addition of all contaminants reduces the mass fraction of olivine at a given temperature, 2) the effect of contamination on the chromium content of the melt at chromite saturation (CCCS) depends on the resulting melt FeO content, with increasing melt FeO by addition of BIF or Fe-rich metasediment lowering the CCCS, 3) the addition of Fe-rich contaminants increases the cotectic proportion of chromite relative to olivine crystallized, and 4) the combined effects of 1 and 2 can result in chromite-only crystallization by, for example, the addition of ~ 15 wt % BIF to a primary melt with ~ 3000 ppm Cr. Results therefore suggest that contamination of Fe-rich material can result in an overall enhancement of the amount of chromite formed, and possibly lead to chromite-only precipitation. We are now searching for additional evidence of contamination and enhanced chromite precipitation through LA-ICP-MS analysis of individual chromite grains from various RoF chromitites.

Ice-stream flow switching by up-ice propagation of instabilities along glacial marginal troughs

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Ice stream networks constitute the arteries of ice sheets through which large volumes of glacial ice are rapidly delivered from the continent to the ocean. Modifications in ice stream networks have a major impact on ice sheet mass balance and global sea level. Reorganizations in the drainage network of ice streams have been reported in both modern and palaeo-ice sheets and usually result in ice streams switching their trajectory and/or shutting down. While some hypotheses for the reorganization of ice streams have been proposed, the mechanisms that control the switching of ice streams remain poorly understood and documented. Here, we interpret a flow switch in an ice stream system that occurred during the Pliocene-Pleistocene on the northeastern Baffin Island shelf (Arctic Canada) through glacial erosion of a marginal trough, i.e. deep parallel-to-coast bedrock moats located up-ice of cross-shelf troughs. Shelf geomorphology imaged by high-resolution swath bathymetry and seismostratigraphic data in the area points to the extension of ice streams from Scott and Hecla & Griper troughs towards the interior of the Laurentide Ice Sheet. Up-ice propagation of ice streams through a marginal trough is interpreted to have led to the piracy of the neighboring ice catchment that in turn induced an adjacent ice stream flow switch and shutdown. These results suggest that competition for ice discharge between ice streams, which implies piracy of ice-drainage basins via marginal troughs, was the driving mechanism behind ice flow-switching in the study area. In turn, the union of ice catchment by piracy increased the volume and discharge of Scott Ice Stream, allowing it to erode deeper and flow farther on the continental shelf. Similar trough systems observed on many other glaciated continental shelves may be the product of such a competition for ice discharge between catchments.

Stratigraphy and lithogeochemistry of the Upper Jurassic volcano-sedimentary Iskut River Formation at Koopa, northwestern British Columbia, Canada: implications for exploration

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The Koopa area is located ca. 15 km southeast of the Brucejack epithermal gold mine and 30 km southeast of the Au-rich Eskay creek VMS deposit. All occur within the Jurassic Hazelton Group of the Stikinia Terrane, northwestern British Columbia. This area, referred to as the Golden Triangle, hosts many former gold producers (e.g. Grandduc, Homestake Ridge, Schaft Creek). Koopa is underlain by a volcano-sedimentary package of the Middle to Late Jurassic Iskut River Formation, Upper Hazelton Group. Detailed mapping and core logging indicate a volcanic stratigraphy comprising predominately volcaniclastic lithofacies ranging from tuff to coarse, pillow fragment tuff breccia and is interpreted to represent re-sedimented submarine pyroclastic and autoclastic deposits. The block-rich pillow clast lithofacies is interpreted as debris derived from collapse of nearby submarine pillow edifices or fault scarps. The volcaniclastic lithofacies are intercalated with sandstone-siltstone beds that increase in abundance towards the top of the stratigraphic section that is capped by a fine silt- and sand-sized sedimentary succession with rare marine fossils. Porphyritic basalts and fine-grained aphyric sills occur at the contact between the volcaniclastic and marine sedimentary successions. The volcaniclastic lithofacies are basaltic and have a MORB-like REE pattern. Zircon U-Pb geochronology of 2 volcaniclastic samples have ages of 176.0 ± 1.7 and 179.0 ± 1.0 Ma. Mineralization at Koopa is characterized by thin, commonly vuggy or blocky quartz veins that cross-cut tuff to lapilli tuff. The veins contain arseno-antimonides, with several thousand ppm As and Sb. The veins are mantled by alteration envelopes of chlorite and clay minerals that range from ~ 2 cm to 30 cm in width. Stratigraphy and geochronology indicate that Koopa is younger than Brucejack and occurs in the same stratigraphic level as the Au-rich Eskay Creek deposit. The MORB affinity of volcaniclastic lithofacies indicate the formation within a (immature) rift system that was also responsible for the formation of Eskay Creek host lithologies and mineralization. Additionally, the syngenetic As-Sb mineralization at Koopa is of hydrothermal origin and could indicate precious metal mineralization in the area.

New insights into cratonic mantle metasomatism from HP-HT reaction experiments between saline fluids and mantle rocks

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Saline (Cl-rich) fluids potentially play an important role as metasomatic agents in the lithospheric mantle. Natural evidence for deep saline fluids exists as inclusions within diamonds and within groundmass minerals in kimberlites. Previous experimental studies have investigated melting relations in the chloride-carbonate-silicate system at upper mantle conditions, but a systematic experimental study of how saline fluids react with the lithospheric mantle is still lacking. Here, we present high-pressure, high-temperature (HP-HT) reaction experiments between a saline fluid and different mantle rocks (lherzolite, harzburgite, eclogite) at conditions corresponding to the lower cratonic lithosphere. Experiments were performed over a P-T range of 3-6 GPa and 1050-1300 °C using a multi-anvil apparatus. Preliminary results show that the interaction between saline fluid and mantle rocks is very reactive, compared to reactions with silico-carbonate melts. The reaction between saline fluid and lherzolite at 4 GPa and 1200 °C leads to extensive melting. The restite consists mainly of olivine and garnet, whereas pyroxenes are only observed as rare inclusions within garnet. In contrast, reactions between saline fluid and eclogite at 4 GPa and 1200 °C also lead to melting, but the melt is more enriched in Si. The restite consists exclusively of garnet. The experimental results demonstrate how saline fluids react with different components of the lithospheric mantle and support evolutionary models of high density fluids within diamonds.

Inferring post-Jurassic movement of the Oak Bay Fault in southwestern New Brunswick through marine magnetic mapping and modelling of the Ministers Island Dyke

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The Ministers Island Dyke in southwestern New Brunswick trends ENE-WSW from eastern Maine across the St. Croix River and St. Andrews peninsula, terminating beneath Passamaquoddy Bay. The dyke is a quartz tholeiitic basalt, approximately 180 Ma (early Jurassic) in age, and crosses the near-perpendicular Oak Bay Fault (OBF) beneath the St. Croix River. A 2001 aeromagnetic survey revealed a kink in the dyke's linear magnetic anomaly over the river, and prompted re-evaluation of an earlier conclusion that the OBF has been dormant since dyke emplacement. In particular, it has long been questioned whether elevated seismicity in the region is a result of recent movement along this fault. In 2005, higher resolution marine magnetic data were acquired in the St. Croix River in an effort to confirm whether faulting has displaced the dyke. This survey delineated the dyke to the east of the OBF, but the survey boat could not travel into the shallow waters of Brooks Cove, Maine, to trace the dyke's extension to the west. In 2016, we returned to conduct a shallow-water marine magnetic survey by kayak. The resulting total magnetic field and vertical derivative maps show that the dyke is clearly offset across the OBF. Dramatic weakening of the anomaly over a span of 100 m is suggestive of demagnetization within the fault zone. Curving of the dyke anomaly on either side of the fault, supported by forward modelling with constraints on magnetic susceptibility and remanence, is suggestive of strike-slip dextral offset of approximately 300 m since the early Jurassic. This is opposite to the net sinistral displacement evident along the OBF based on crosscutting relationships preserved in older Silurian formations to the north. The tectonic origin and timing of fault reversal is unknown, although one could speculate it was connected to the breakup of Pangea which began at about the same time as dyke emplacement.

Reflections on the recognition of geoheritage in Canada

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The concept of Geoheritage is now formally ensconced in international geoscience and conservation organizations such as the IUGS and IUCN, and has dedicated international journals. Its implementation and formal recognition across Canada, however, remains incomplete and approaches are inconsistent. A call for Canada-wide documentation of geoheritage sites arising from a special session of the GAC®-MAC annual meeting in Fredericton in 2014 has resulted in modest progress, most notably in Ontario. Five different models of geoheritage recognition are employed across Canada: i) geodiversity-based (Ontario); ii) legal protection of geosites by category (Québec); iii) non-legal, based on geoscientific or cultural significance (Nova Scotia); iv) regional recognition (e.g. Ottawa, Yellowknife); and v) identification and protection of paleontological sites only (New Brunswick, Newfoundland and Labrador). Although not mutually exclusive, the recognition of geoheritage in Canada primarily follows one of two approaches: i) protection-driven; or ii) public education-driven. The requirement of legal designation can be burdensome, and

has delayed completion of geoheritage recognition in some countries and in some jurisdictions within Canada. In an effort to avoid this pitfall, Nova Scotia elected for a non-legislated approach to geoheritage recognition. A Geoheritage Sites list, map and database for the Province was successfully established over the course of 4 years, and documented geosites have been used to identify a prospective global geopark (Cliffs of Fundy) which is now in the formal evaluation stage by UNESCO. Across Canada, UNESCO Global Geoparks are a growing manifestation of the potential of geoheritage recognition, but they cannot in themselves encompass the wealth of geoheritage across Canada. The Nova Scotia model was established on universal principles that are applicable in any jurisdiction, does not require onerous legal resources, and is recommended as an achievable first step for jurisdictions that have yet to formally document their geoheritage.

Autonomous Underwater Vehicles (AUV) for improved understanding of deep-water (~ 2000 m) geological hazards

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Multibeam echosounders have revolutionized our ability to map marine geohazards in Canada's offshore lands. When operated from a surface vessel (e.g. a ship), horizontal resolution decreases markedly with depth. As a result, conventional surface-acquired data from the continental slope of eastern Canada has a horizontal resolution that varies from 50 m to more than 100 m. This resolution is sufficient to map and study large-scale geological features but does not allow us to understand the fine-scale processes occurring on the deep seafloor. In 2018, a joint Natural Resources Canada / Nova Scotia Department of Energy and Mines expedition on the CCGS Hudson offshore Nova Scotia mapped parts of the deep seafloor at unprecedented resolution using an Autonomous Underwater Vehicle (AUV). These data, at a resolution of 0.5 m, were acquired at 2000-3000 m water depth and gave a new picture of the fine-scale features and sedimentary processes occurring at those depth, such as the occurrence of cold seeps, pockmarks associated with submarine landslides and gullies. These data demonstrate the utility of AUV mapping for collecting very high resolution swath bathymetry, sidescan sonar, and sub-bottom profiler data in deep water environments. The increased resolution allows imaging features that are not visible on surface collected data, which leads to an enhanced understanding of geological conditions at and below the seabed of Canada's offshore lands. The high resolution data comes at the cost of survey area coverage and is therefore not a replacement for regional mapping. However, it is a valuable tool for targeted, site specific research. This presentation will thus give an overview of the new geological hazards observed on the seafloor using AUV technology.

Geochemistry and glacial dispersal patterns of kimberlite indicator minerals in the South Slave Province, NT

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Drift prospecting has been utilized throughout the Slave Province in the Northwest Territories for decades, where glaciation and erosion within the past 10 000 years has produced the dispersion of minerals from their original host to till in their surrounding areas. This study is part of the greater Slave Province geophysical, surficial materials and permafrost study: a Northwest Territories Geological Survey (NTGS) led government-academic-industry research program. The purpose of this particular research is to assess kimberlite indicator minerals (KIMs) for any potential signature that may coincide with glacial dispersal trains through quantitative mineralogical and geochemical analysis. The NTGS has recently published data on Southern Slave Province surficial materials, which is useful as a comparative tool in the analysis of potential dispersal trains. Samples were collected from surficial sediment at various targets throughout the 75N and M NTS zones. Sample locations were chosen based on their down-ice position with respect to known kimberlites and gravity anomalies previously identified by the NTGS. Samples were preferentially collected from active and recently inactive frost boils. Overall, twenty-one 10 kg samples were collected and examined for KIMs. Several samples contain KIMs in moderate to high concentrations. Positive identifications of Cr-pyrope, chromite, Mg-ilmenite, and Cr-diopside have been confirmed in preliminary analysis. Of the identified KIMs garnet is the most abundant at 78 %, followed by chromite at 13 %, ilmenite at 8.9 %, and Cr-diopside at 0.5 %. Quantitative analyses are reported on confirmed KIMs: Cr-pyrope, Mg-ilmenite, Cr-diopside, chromite, and olivine for each sample site. The results of the analyses will be used to make further insights into till and kimberlite geochemistry of the Southern Slave Province.

Fossil treasures: Canada's rich geological heritage revealed in a new permanent gallery at the Royal Ontario Museum

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The rocks of Canada were formed over more than 4 billion years of Earth's existence, preserving fossils recording some of the major events in the history of life like nowhere else on Earth. This exceptional geological heritage will be showcased prominently in the future Willner Madge Dawn of Life Gallery at the Royal Ontario Museum. This 10 000 square foot permanent gallery will narrate the story of life from its origin through the end of the Triassic period and will complement two existing permanent galleries dedicated to the ages of dinosaurs and mammals. Highlights of this new gallery will include fossils from coast to coast. Some of the fossils featured prominently in this gallery will come from iconic geoheritage areas, including from four celebrated UNESCO World Heritage Sites, namely Mistaken Point (Ediacaran) in Newfoundland, the Burgess Shale (Cambrian) in British Columbia, Joggins Fossil Cliffs (Carboniferous) in Nova Scotia, and Miguasha (Devonian), in Quebec. A fifth site, Anticosti Island (Ordovician-Silurian), in Quebec, currently listed as a prospective World Heritage Site, will also be featured. In this talk I will present a brief overview of the current project and its goals.

A first estimation of the shortening related to vertical axis rotation: the case of the Ibero-Armorican Arc

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Different models have been proposed to synthesize the structural evolution and to explain the characteristic arcuate geometry of the western Variscan European Belt. The indentor model highlights the role of the Gondwana promontory during the Gondwana-Laurussia collision, and requires a curved geometry of the Gondwanan margin prior to collision. Other models emphasize the deformation associated with large-scale strike-slip shear zones as the main origin for the formation of the Ibero-Armorican arc. A third group of models propose that this arc constitute an orocline formed by secondary vertical axis buckling of an originally oriented N-S belt during Gondwana-Laurussia collision. Although the indentor and oroclinal models may appear to be mutually exclusive, some authors reconcile both models in a proposal involving a combination of some indentation and subsequent buckling. One of the most critical points to discern between the different proposals is the amount of required vertical axis rotation. The secondary orocline models propose counter-clockwise vertical axis rotations ranging from 60º or 70º to 90º for the southern arm of

the Ibero-Armorican arc and clockwise rotations of 25º for its northern arm. In contrast the amount of rotation required for some of the reconciling models is ca. 27.5º for both branches. Although they clearly differ, these vertical axis rotations require in both cases a significant amount of shortening and extension yet to be quantified and which should be recognized in the surrounding regions. In this contribution we propose an estimation of the amount of shortening related to the different vertical axis rotations proposed for the southern branch of the Ibero-Armorican arc. This is a first step to include these values in future reconstructions and doing so may contribute to testing the validity of the proposed models.

The puzzle of the pre-Variscan basement rocks of the Western Mediterranean: the role of the Variscan and Alpine thrusts and large strike-slip faults on the reconstruction of the Early Paleozoic geometry

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The eastern branch of the Armorican Arc in SW Europe constitutes a puzzle made up by several pre-Variscan basement rock fragments. In this puzzle the relics of two Early Paleozoic inner platforms were superposed due to Variscan and Alpine deformations: the Pyrenees and the Occitan Domain of the French Massif Central. Both areas display repeated proximal-to-distal S-N palaeogeographic trends, and their actual relationship point to important movements along large strike-slip faults during Variscan and Alpine phases. Southwesternward, the Moroccan and Iberian margins of Gondwana broadly preserve a framework of Cambrian rift branches linking the Atlas and Ossa-Morena rift axis. The axis is marginal to an inherited Panafrican-Cadomian back-arc basin that became a passive-margin basin since Furongian-Early Ordovician times. The relationships between the marginal Atlas/Ossa-Morena rift and these inner platforms, are controlled by SW-NE trending migrations of several Cambrian-Ordovician paleogeographic indicators as: (i) gradual trend (parallel the Gondwana margin) of detrital zircon provenance from the West African craton to the Saharan metacraton and the Arabian Nubian Shield, (ii) the proximal evaporitic and distal phosphoritic belts, (iii) the centres of carbonate production associated with framebuilding structures, (iv) the migration of Panafrican-Cadomian sutures and the subsequent opening of rifting axes, and (v) the migration of Toledanian-to-Sardic geodynamic phases during Furongian-to-Mid Ordovician times. All these data point to a new vision of the northwestern margin of Gondwana during Early Palaeozoic times, which were differently affected by the Variscan and Alpine phases of deformation.

Supervised and unsupervised classification to explore geophysical data

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With the arrival of new and powerful data integration algorithms like machine learning libraries, reinterpretation of airborne data has known a phenomenal growth for geological targeting. Indeed, unlike geological sampling, airborne geophysical data presents no repartition or interpretation bias and they are quantitative. For example, magnetic surveys allow delimitating most of the geological bodies, the visualization of their geometry at depth, and the interpretation of their nature relying on their physical characteristics. However, to complete the geological interpretation, the data must be processed. Each different processing scheme shows bodies of a particular nature. Thus, extracting a maximum amount of information from the data require several processing. This leads to layer multiplication, and make the interpretation more difficult for humans. Moreover, this difficulty is enhanced when multiple physical data are measured. Supervised and unsupervised classification methods are designed to sort and explore large data set. For the supervised methods, labels are assigned to a training dataset. During the training, the best characteristics defining each class are extracted. Then, they can be used on an untrained dataset. For unsupervised methods, undefined classes are separate based on the number of clusters in high-dimensional spaces. Those kinds of methods can be used to explore airborne geophysical datasets and extract their textural characteristics at different scales. We applied unsupervised classification to Cadillac-Larder Lake area. The results show that the methodology allows for automatic geology classification but also highlights some pitfalls in terms of depth of source of the anomalies. This textural clustering of geophysical datasets can then be correlated with the geology at different depth.

Infiltration, groundwater recharge and preferential flow dynamics in frozen ground

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Frozen ground and soil freeze-thaw processes control the partitioning of snowmelt water between runoff, infiltration, and deep percolation near ground surface, thereby strongly influencing the hydrology and hydrogeology of cold regions. Preferential flow along soil macropores has the potential to drastically alter water movement in frozen soil, but flow dynamics are complicated by coupled water and heat transfer processes. Furthermore, water movement is affected by meteorological and soil moisture conditions prior to and during a snowmelt event, resulting in highly variable subsurface water inputs in both space and time. We present the results of field and laboratory investigations of snowmelt infiltration and groundwater recharge through frozen ground in the Canadian prairies. Meteorological and subsurface measurements at three field sites in Alberta were combined with laboratory infiltration experiments on frozen undisturbed soil columns to examine hydraulic and thermal processes governing water movement. Laboratory data from macroporous and non-macroporous soil columns clearly showed the critical role of antecedent soil moisture on diffuse and preferential water movement into and through frozen soil. Corresponding field data revealed infiltration into frozen ground as the major sink of the snowmelt water balance at all sites (43-96 %), with distinct temporal trends observed with repeated melt events (i.e. mid-winter and spring). Relatively rapid infiltration and deep percolation occurred while the ground was frozen or partially frozen, indicating preferential flow and groundwater recharge through frozen soils under certain conditions. Overall, these studies highlight the importance of preferential flow in frozen soils and the processes that control infiltration and groundwater recharge in these seasonally frozen landscapes.

Origins of the geochemical fingerprint of shallow groundwaters in the Bas St-Laurent region

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Groundwater provides the primary source of water supply in the eastern part of the Bas Saint-Laurent region (BSL), a region shaped by the Appalachians, a strong Quaternary glacial heritage, and coastal dynamics from the St. Lawrence Estuary. Groundwater hydrogeochemistry of the BSL aquifer system was extensively studied over the last 5 years as part of a regional hydrogeological characterization project. Around 150 groundwater samples were collected in private and municipal wells distributed evenly over the study area. A hierarchical cluster analysis, based on the distribution of major and trace elements and stable isotope signatures of water, revealed the occurrence of four distinct geochemical groups: from less mineralized groundwater in the Appalachian recharge areas to more mineralized water in the coastal areas. We proposed that most of the groundwater mineralization was induced by the mixing with

evaporated or remnant seawater originated from past transgressions and cation exchange processes along the groundwater flow. However, it was not possible to discriminate the relative contribution of geological versus hydrogeological contexts on this evolution. Here, we use canonical analyses to discriminate control of environmental factors (including geology, stratigraphy, aquifer confinement conditions, piezometric level, physiographic settings, etc.) on the geochemical groundwater fingerprints. Using this approach, we hope to propose a model to divide the BSL territory with distinct geochemical groundwater quality, with a minimum of groundwater samples. This work is a contribution to the *Programme d'acquisition des connaissances sur les eaux souterraines* (PACES), a vast program studying groundwater in municipal regions in the province of Québec.

Wekusko Lake dikes (central Manitoba): long-overdue kimberlites, oddball carbonatites, or "a missing link"?

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Manitoba, with its 400 000 km^2 of exposed Precambrian basement, remains the most conspicuous "white spot" on the map of Canadian kimberlites. The apparent absence of these rocks from the regional geological record seems all the more paradoxical, given the existence of large Phanerozoic kimberlite fields just across the provincial border in eastern Saskatchewan, and abundant evidence of mantle-derived carbonate-rich magmatism (carbonatites and ultramafic lamprophyres) across central Manitoba. Interestingly, rocks of this type were first identified in the Province in 1983 at Wekusko Lake, where they crosscut supracrustal assemblages of the Paleoproterozoic Flin Flon belt, and were tentatively logged as kimberlites. This interpretation, based to a large extent on their high Cr + Ni contents and the presence of indicator minerals in their modal composition, was challenged in subsequent research. Similar rocks have been recognized recently in similar settings south of Wekusko Lake. These discoveries expanded not only the area of known post-Paleoproterozoic mantle magmatism, but also the petrographic and geochemical spectrum of its products. The primary carbonate phase in these rocks is dolomite that shows a variable degree of subsolidus isotopic re-equilibration under CO_2-rich conditions. Fluid-rock interaction was also responsible for the replacement of olivine, phlogopite and groundmass perovskite by secondary minerals and deposition of hydrothermal carbonates in fractures, although the relative timing of these processes with respect to dike emplacement is poorly understood at present. Notably, indicator minerals indistinguishable from those in bona fide kimberlites are common in all of the examined dikes. These recent discoveries may hold key to understanding the genetic relations between kimberlites and primitive carbonatites, and have practical implications for heavy-mineral-based diamond exploration.

Geological factors controlling fluid flow related to uranium mineralization in the Athabasca Basin

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The formation of unconformity-related U (URU) deposits in the Athabasca Basin, known for their high grades and large tonnages, requires the circulation of large amounts of fluids. According to Darcy's law, the amount of fluid flowing through a potential mineralization site depends on permeability of the rocks, hydraulic gradients driving fluid flow, and duration of the fluid flow system. Each of these parameters are related to a number of geological factors. Due to dominance of low-matrix sandstones (arenite), the sedimentary rocks immediately above the basement are of high permeability, favoring fluid flow within the basin. In contrast, the basement rocks are generally of low permeability, and fluid flow may be mainly channeled along fracture zones. Thus, reactivated basement faults crosscutting the unconformity are key factors connecting basinal and basement fluid reservoirs. The hydraulic gradients driving fluid flow are related to the types of driving forces, which include deviation of fluid pressure from hydrostatic pressure (overpressure or underpressure), topographic relief, and density variation. Overpressure and underpressure may be caused by rock deformation, and density variation may be related to geothermal gradient and/or salinity. Numerical modeling of sediment compaction suggests that the basin was at near-hydrostatic pressure throughout the sedimentation history, which favored brine infiltration from the upper part of the basin as well as fluid convection, facilitated by high geothermal gradients as constrained from elevated temperatures and shallow burial conditions. Numerical modeling also shows that reactivation of basement faults may drive fluid flow either from the basin into the basement (ingress flow) or from basement into the basin (egress flow). Deformation-driven fluid flow may be relatively short-lived, whereas fluid convection may have lasted for a longer time. The combination (alternation) of these two driving forces may be responsible for the formation of most of the URU deposits in the Athabasca Basin.

Geology of the Windfall Lake gold deposit, Québec, Canada

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Windfall Lake is an Archean greenstone-hosted gold deposit located in the Urban-Barry greenstone belt of the Abitibi subprovince in Québec, Canada. The deposit has a combined indicated and inferred resource of 2.88 Moz Au (12.9 Mt at 6.84 g/t Au). The gold mineralisation is hosted in mafic to felsic volcanic rocks of the 2718 Ma Macho Formation that are cross-cut by several generations of calc-alkaline quartz-feldspar porphyry (QFP) dykes. The QFP dykes are separated into two groups based on cross-cutting relationships and zircon U-Pb TIMS dating: 1) a pre-ore (2698 ± 3 Ma) type which hosts the gold mineralisation and associated hydrothermal alteration; and 2) a post-ore (2697.6 ± 0.4 Ma) type which truncates the former. The auriferous zones occur as thin, sub-vertical and elongate lensoids that plunge moderately towards the NE and are coincident with the contacts between some pre-ore QFP dikes and host volcanic rocks. Three styles of gold mineralization are present: 1) early crustiform-colloform carbonate ± quartz veins; 2) grey quartz veins and stockworks with subordinate ankerite-pyrite-tourmaline; and 3) pervasive to patchy sericite-ankerite ± silica, fuchsite alteration with disseminated pyrite-tourmaline. Sulphides consists predominantly of pyrite with traces of chalcopyrite, sphalerite, tennantite, arsenopyrite, pyrrhotite and galena with the related gold as free gold, inclusions in pyrite, and invisible gold in pyrite. The spatial and temporal association of the QFP intrusions and gold mineralisation at the Windfall Lake gold deposit provides a unique opportunity to assess the relationship between Archean felsic magmatism and gold mineralisation and the current intrusion-related model for the deposit. The latter will be done by using a variety of methods: 1) field relationships, 2) petrography and supporting SEM-EDS analysis and CL imaging, 3) fluid inclusion microthermometry and geochemistry, 4) in situ SIMS isotopic measurements (O, C, S), and 5) pyrite geochemistry (LA-ICP-MS).

Trace element partitioning between apatite and kimberlite-like melts: implications for volatile degassing and formation of different kimberlite facies

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Primary melt composition of kimberlites remains poorly constrained due to the contamination from mantle and crustal rocks, loss of volatiles during emplacement, significant alteration, and the lack of any quenched melts. Additionally, kimberlite bodies have multiple morphologies of which their emplacement mechanism remains elusive. Apatite is a common accessory mineral in kimberlite. Its structure incorporates many trace elements of which partitioning depends on the composition of the melt. Concentrations of trace elements in kimberlitic apatite can help to assess the content of carbonate and silicate components in kimberlite melt. Apatite is also often used as an indicator mineral of magma degassing in igneous systems. As such, it should be applied to kimberlitic systems to study the volatile behaviour during emplacement. However, the existing estimates for the trace elements partitioning in apatite provide controversial estimates for carbonatitic melts and estimates for silicate melts use compositions very different than the composition of kimberlites. This study experimentally determines partition coefficients of trace elements and kimberlite-like melts. The experiments were done in piston cylinder apparatus at 1250-1350 °C and 1-2 Gpa. Partition coefficients for Nb, Sr, Rb, Zr, Sm, Cs, Hf, La, Yb, and Eu were examined in synthetic compositions representing evolved kimberlite melts: three lamproitic compositions (17-23 wt % SiO_2 and 9-33 wt % CO_2) and a composition modelled after a magmatic kimberlite (14-29 wt % SiO_2 and 7-33 wt % CO_2). The effects of melt composition, temperature, pressure, water, and oxygen fugacity have been tested. The obtained partition coefficients were applied to natural kimberlitic apatites from Ekati Mine (Canada) and Orapa cluster (Botswana) to model kimberlite melt composition. Observed variation in the presence, textures, and composition of natural apatites relative to depth in kimberlite pipes of differing lithologies is compared to experimental run products to infer crystallization conditions of different kimberlite bodies.

Transient mesozoic thermal pulse recorded in Paleoproterozoic Jungsan Complex, Korea

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The Paleoproterozoic Jungsan Complex of the Korean Nagrim Massif is broadly correlated with the metasedimentary and metavolcanic sequences in the Jiao-Liao-Ji Belt of the North China Craton. Recent geochronological studies have revealed regional high-grade metamorphism at 1900-1850 Ma, and local Mesozoic 155-110 Ma overprint. In this study, we investigate an outcrop of Paleoproterozoic Staurolite-kyanite gneiss (1848 ± 3 Ma, zircon U-Pb) close to a Cretaceous porphyry intrusion. Rutile from the gneiss yields Mesozoic ages (100-110 Ma) that overlap the age of the porphyry intrusion (104-111 Ma). Contemporaneous granitoid intrusions are widespread in the northern Korean Peninsula in association with the subduction of the Pacific Plate. The sample consists of garnet + staurolite + kyanite + biotite + quartz + plagioclase + rutile/ilmenite. The garnet exhibits homogenized compositional domains that are crosscut by sharp chemical "dikes" of 40-60 µm widths. The dikes are featured by high Ca, and low Mg, Fe and P contents, so that that garnet appears brecciated in chemical maps. Nevertheless, the chemical dikes are not concordant with cracks or inclusions, and thus are likely produced by a fluid-induced dissolution-reprecipitation process. Phase equilibria simulation suggests that the homogeneous garnet domain corresponds to 7.5 kbar, 680 °C, and the chemical dikes 7-8 kbar, 580-620 °C. At this P-T condition, the sharp chemical profiles across the chemical dikes yield diffusion timescale shorter than 50 000 years, documenting an extremely short thermal excursion. We speculate that the local heat input by the Mesozoic porphyry intrusion caused reworking of the Paleoproterozoic gneiss and induced chemical dikes that crosscut preexisting garnet porphyroblasts. We also note that the converted depth of 7-8 kbar is significantly greater than common emplacement of subvolcanic porphyry. Rapid re-dehydration within the gneiss might build up transient fluid overpressure.

An integrated methodology for hydrogeological assessment around man-made installations

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We present a nested hydrogeological characterization methodology to optimize the use of existing data and better plan the acquisition of new data around man-made installations. The workflow is presented at a site where the construction of a nuclear power plant has disturbed the local hydrogeology setting. Man-made installations have to be considered when simulating the groundwater flow. The first step is to lever historical data coming from hydrogeological tests and civil engineering operations before and during the construction of the nuclear installations into a 3D GIS platform to build the frame of the hydrogeological model. This frame includes buildings, reactors and chimneys foundations, geotechnical enclosures left in place after the construction, and the different geological and geotechnical information. The model integrates historical geotechnical cone penetration tests and well information within and outside the site. Based on the review of this information, new geophysical data acquisition can be scheduled to refine the interfaces between geological units where needed. Statistical relationships are used to simulate the hydrogeological properties within the geological units of the 3D geological model. Groundwater flow and transport is run and calibrated using groundwater levels. This methodology has proven to be efficient to optimize the acquisition of new data while maximizing the level of information required for the model to be accurate for the environmental management of the site. This initial model serves has a training image to simulate multiple equiprobable scenarios of the site geology while preserving the well information and the location of the buildings as, obviously, deterministic. These geological scenarios are populated with anisotropic hydraulic conductivity fields using sequential Gaussian simulation. These heterogeneous hydraulic conductivity models are run with a flow and transport simulation algorithm to constitute an ensemble of realizations that will be used in an ensemble Kalman time series assimilation scheme.

Compositional hydrochemical data analysis to explore geochemical processes controlling the inorganic groundwater quality in southern Quebec

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Groundwater is a major source of freshwater in rural areas of the Province of Quebec, where people largely rely on private wells for their water supply. The quality of groundwater is of paramount importance for public health. According to the Regulation respecting the quality of drinking water (Government of Quebec), a private well must meet standards of drinking water quality. The Ministry of the Environment thus recommends private well owners to perform water analysis, including microbiological and physico-chemical parameters. On the other hand, as private wells are not subject to quality control by the Regulation, water quality is generally unknown by owners as observed in sampling campaigns. To increase knowledge on the resource, the Government of Quebec implemented a Groundwater Knowledge Acquisition Program (PACES program). From

2009 to 2015, 13 hydrogeological mapping projects were completed by seven universities in Quebec's municipal territory. In this program and three previous projects, 2577 groundwater samples were collected and analyzed for inorganic major, minor and trace elements according to a standard protocol. The results indicated that groundwater is affected by hazardous concentrations of F, Ba, Mn and As. In this study, exploratory data analysis and geochemical modeling techniques were used to gain insight into the processes controlling the mobilization of these contaminants. In particular, hierarchical clustering and correlation analysis were implemented taking into account the compositional nature of hydrochemical data. The results highlight the geochemical processes and conditions responsible for the stability of each contaminant in groundwater. The large amount of data allows identifying the link between the occurrence of contaminants and major hydrogeological features such as water types, groundwater flow patterns and recent geological history. This work could serve as a basis to derive natural background concentrations and to produce risk maps of undesirable elements in groundwater at the scale of Southern Quebec.

Post-collisional Arrowsmith plutonism in the southern Rae craton: evidence for multiple sources of melt generation and possible juxtaposition of crustal levels

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Following the 2.37-2.34 Ga metamorphic culmination associated with the Arrowsmith orogeny, orogenic collapse in the southern Rae craton is recorded through both depositional and igneous processes. The Murmac Bay group is found in the Beaverlodge and southeasternmost Zemlak domains of the southern Rae craton. The lower part of this package, comprising mainly quartzite, psammite and mafic volcanic rocks, with a maximum age of 2.33 Ga, represents the supracrustal expression of this collapse. Two coeval suites of 2.33-2.29 Ga granitoids from the Beaverlodge and Zemlak domains post-date Arrowsmith metamorphism. The Beaverlodge suite is predominately a K-feldspar megacrystic monzogranite with 2-20 % combined biotite and hornblende. Some of the Beaverlodge granites crosscut the lower Murmac Bay group, while others are cut by dykes correlative with the Murmac Bay group volcanic rocks, suggesting broadly synchronous emplacement. The Zemlak suite is located in the northern and western portions of the Zemlak domain and is more intermediate, comprising magnetic granite-granodiorite with 10-15 % hornblende and 5-10 % biotite. Sm-Nd and Lu-Hf isotopes for both suites have negative epsilon Nd(t) and epsilon Hf(t) values respectively with Nd model ages of 3.06-2.87 Ga indicating significant crustal input for the two suites. Both suites have post-collisional geochemical affinities, but the Zemlak suite has much higher Ba concentrations, lower Al_2O_3/TiO_2, and a more fractionated HREE profile indicative of an amphibole-bearing, biotite-free residue. These chemical differences suggest two distinct sources, and that the Zemlak suite was derived from lower crustal levels than the Beaverlodge suite. The two suites may have been juxtaposed by the north- to northeast-trending Island Bay fault, which marks the western limit of the Murmac Bay group.

Simulated rover explorations of two Mars analogue sites: Gypsumville and East German Creek, Manitoba, Canada

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An important contributor to Mars exploration is exploiting terrestrial analogue sites, which can be used for various purposes, such as: (1) developing expertise in rover operations and assessing operational procedures; (2) assessing performance and utility of scientific instruments on past, present, or future Mars rovers; and (3) testing instruments in environments with Mars-relevant characteristics. In summer 2018 we undertook rover-like investigations at the Gypsumville and East German Creek, MB, Canada Mars analogue sites. The sites consist of impact shock-affected granites and sedimentary rocks (Gypsumville), and fossil and active perennial hypersaline springs (East German Creek). A 3-day field campaign was undertaken at each site involving an off-site science team and an on-site team (for instrument deployment). The off-site team was tasked with initially identifying regions of interest (ROIs) within each landing site (LS) on the basis of panoramic color imagery, and then targets of interest (TOIs) within each ROI which were imaged at higher resolution and characterized in the field by reflectance and Raman spectroscopy. These data were all used to rank the TOIs for science value/sample return. Because of uplink/downlink issues we were only able to perform qualitative analysis of the spectral data. Lessons learned include: (1) We were unable to confidently search for, or identify small differences in absorption band positions, which could be indicative of important mineralogical variations. (2) Spectral analysis would have benefited from the availability of spectral libraries and easy-to-apply and rapid spectral analysis tools. (3) The use of imagery at the three different scales (LS, ROIs, TOIs) resulted in changes in sample prioritization with potential TOIs being both upgraded and downgraded. (4) Target selection and geological interpretation was hampered by the lack of scale bars in the imagery. In summary, field-based rover-relevant deployments provide invaluable operational experience, help to identify operational issues, and inform best practices.

Assessing the distribution of REE mineralization in Fe-dolomite carbonatite drill cores from the Fen Complex, Telemark, southern Norway

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The Fen Complex is a 2 km-wide subcircular intrusion composed mainly of sovite, Fe-dolomite carbonatite, damtjernite (lamprophyre) and minor alkaline rocks such as nepheline syenite and ijolite, emplaced at 580 Ma through Mesoproterozoic orthogneisses forming the Fennoscandian Shield. Previous bulk-rock isotopic study indicates that the carbonatite magma originated in the upper mantle [$(^{87}Sr/^{86}Sr)_i$ = 0.7029] and underwent contamination during its ascent throughout the crust. This study focuses on two deep cores (1000 m and 700 m), drilled to assess the distribution of REE mineralizations in the Fe-dolomite carbonatite. Hyperspectral data, allowing investigators to log cores objectively and quantify lithologies, were acquired using a SisuRock Gen 2 system composed of three cameras gathering data in the following wavelengths: RGB, Near-Visible Short-Wave Infrared (VN-SWIR) and Long-Wave Infrared (LWIR). In addition, every meter of the first core and 500 m of the second one were analyzed for bulk-rock geochemistry to characterize the distribution of elements. In this study, we compare the results obtained by the imaging technique with the bulk-rock data and present preliminary results of the textural variations observed in rare-earth mineralizations. Preliminary results indicate that neither of the deep bore holes reached the fenitized host-rock and that the Fe-dolomite carbonatite continues at depth. In both cores, the dominant carbonate is Fe-rich dolomite, although calcite and Fe-Mg carbonate have been observed locally. REE-minerals, composed mainly of bastnäsite, parisite/synchisite and monazite, display

variable textural relationships and often occur together in clusters associated with barite and minor Fe-oxides, sulfides (pyrite ± sphalerite) and locally thorite.

A mineralized system exposed in the Swiss Alps: a Jurassic analogue to present-day hydrothermal systems, Platta nappe, Switzerland

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Mid-oceanic ridges are places where fluid-rock-magmatism-deformation interactions lead to i) serpentinization of mantle rocks, ii) formation of oceanic mineralized systems (i.e. Lost City, Rainbow, TAG at the Mid-Atlantic Ridge (MAR)) and iii) seafloor carbonation. Oceanic hydrothermal systems have been investigated by mineralogical, geochemical and tectonic means. However, the observation of the seafloor is limited to two dimensions, precluding investigation of hydrothermal cells in three dimensions. Ocean-continent transitions show numerous similarities with Mid-Oceanic Ridges (mantle exhumation during detachment faulting, establishment of mafic magmatism, high geothermal gradient) and hence are good candidates to decipher oceanic hydrothermal processes. In this study, we present a metallogenic system in the Swiss Alps associated with the opening of the Liguria-Piedmont Ocean during the Jurassic. The system has been preserved from a strong Alpine orogenic overprint. It is visible in three dimensions and outcrops vertically for 200 m. The Fe-Cu-Zn ultramafic-hosted mineralization is visible at the footwall of a detachment fault juxtaposing basalts and serpentinites, the latter being crosscut by rodingitized mafic dykes. The hydrothermal alteration zone shows a typical funnel-like structure from the base to the top and hence is a good proxy to constrain the fluid pathway to the surface. From the petrographic study of mineralization, which follows a previous study on hydrothermal carbonation, several hydrothermal events can be distinguished: i) a syn-serpentinization event forming magnetite and pentlandite, ii) a main hydrothermal phase remobilizing the previous stock and associated with magnetite, chalcopyrite, pyrrhotite, pentlandite and later covellite, bornite and sphalerite, iii) a late Ca-rich metasomatism associated with ilvaite, andradite and diopside. Laterally, an actinolite-rich alteration affects the serpentinites. The mineralogical assemblage is similar to present-day hydrothermal systems such as Rainbow (MAR) and provides a better understanding of these systems.

Non-newtonian behavior influences pyroclast shapes in lava fountains: experimental evidence

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Hawaiian lava fountains are mildly explosive eruptions where low viscosity magma is fragmented in the conduit and ejected as juvenile fragments, along with gasses. Juvenile pyroclasts produced by lava fountains include spatter, scoria, Pele's spheres, Pele's tears, Pele's hairs, and reticulite. We are particularly interested in the smaller pyroclasts, i.e. the spheres, tears and hairs, which cool completely before landing. In the literature, the shapes of these pyroclasts are thought to be controlled by ejection velocity, magma surface tension, and magma viscosity. The composition of the magma has not typically been cited as an important parameter, except indirectly through its influence on viscosity. A series of laboratory scale "blowout" experiments were performed at the Physikalisch Vulkanologisches Labor in Würzburg (Germany). These experiments are partly similar to natural lava fountains. In each run, 200 g of volcanic rock was re-melted at 1200 °C for 1 hour using an induction furnace. The melt was fragmented and expelled from the steel crucible via the use of compressed argon injected from the base. Blowout experiments were performed on three melt compositions ranging from olivine-melilitite (ultramafic) to basaltic trachy-andesite (intermediate); these three compositions have approximately the same equilibrium viscosity for low shear rates at 1200 °C. The artificial pyroclasts were collected and hand-sieved in order to obtain grain-size distribution, then different size fractions were examined under the binocular microscope. Particles in the 0 Φ size fraction were assigned to different classes based on shapes and other visual features. Major differences in the particle shapes were observed between the three magmas, despite using the same experimental conditions, comparable magma surface tensions, and equilibrium viscosities. Therefore, instantaneous viscosity and non-Newtonian behavior probably play a role in controlling particle shapes in lava fountains and other styles of explosive eruptions.

Determining the origin of megacrysts from the Muskox kimberlite pipe, Northwestern Canada

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Megacrysts are mineral grains of garnet, clinopyroxene, orthopyroxene, ilmenite, olivine, phlogopite and zircon larger than 10 mm frequently observed in kimberlite occurrences across the world, with reported sizes commonly exceeding 10 cm. Despite their common occurrence and decades of research into their origin, megacryst petrogenesis is still a debated topic amongst petrologists. A strictly phenocrystal origin is doubted, with recent research suggesting a multi-stage model involving isobaric formation over a wide temperature range, followed by metasomatism of a protokimberlite fluid that replaces mantle minerals. Our project aims to contribute to ongoing research by modeling the metasomatism of the ambient peridotitic mantle affected by the fluid using major and trace element data obtained from megacrysts from the Jurassic Muskox kimberlite pipe of the Slave province of Canada. We report major element compositions of 24 megacryst samples of garnet, olivine, clinopyroxene and ilmenite and employ DEW (Deep Earth Water) modelling to establish the composition of the potential metasomatizing agent and mineral trends that result from the mantle metasomatism. This project has important implications for not only constraining the composition of the source fluids, but also understanding the reactions in the cratonic mantle leading to the kimberlite melt formation.

Possible iron-sulphide copper gold mineralization in western Labrador, and the potential for IOCG exploration in the Labrador Trough

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The Montgomery Lake Cu-Au prospect in the Paleoproterozoic Labrador Trough was first discovered in 1942, and trenching and diamond drilling have recognized low-grade Cu and Au mineralization in strongly hydrothermally altered and brecciated graphitic shales of the Menihek Formation. Grab samples have returned up to 5.48 % Cu and 425 ppb Au, and diamond drilling has intersected altered rocks grading 0.31 % Cu over 14.5 m. Two main generations of alteration have been recognized, early quartz-albite-pyrrhotite alteration followed by later carbonate-quartz-albite alteration associated with chalcopyrite-pyrrhotite mineralization. Breccia zones, with fragments of quartz-albite in a matrix of carbonate-quartz-albite-chalcopyrite-pyrrhotite are common, and are typically associated with the highest Cu grades. Previous studies at Montgomery Lake have assigned the mineralization to an orogenic gold or sediment-hosted Cu model. However, the Montgomery Lake prospect displays many features typical of iron-sulphide copper gold (ISCG) deposits (e.g. Eloise, Pahtohavare), a group of deposits with strong IOCG affinities. These

include: 1) Early Na-metasomatism, overprinted by a later mineralizing event; 2) Graphite-bearing host rocks which inhibit formation of magnetite-rich IOCG deposits; 3) Association of mineralization with matrix breccia; 4) Identification of hypersaline, halite-bearing fluid inclusions; and 5) Location of the prospect close to a major shear zone (Walsh Lake Fault). ISCG deposits are typically spatially and temporally associated with magnetite-group IOCG mineral deposits (e.g. Cloncurry and Norrbotten districts), and the identification of ISCG-style mineralization at Montgomery Lake may have wider implications for exploration in this part of the Labrador Trough.

Trials and tribulations of graphite geothermometry by Raman microspectroscopy

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The use of Raman microspectroscopy of graphite as a geothermometer to determine maximum temperature conditions reached during graphitization is well established. The advantages of Raman over XRD and HRTEM methods for quantitatively characterizing the degree of organization of the graphite structure are: i) spectra can be acquired in situ, thus providing a high spatial resolution; and, ii) short acquisition time allowing for numerous spectra to be obtained, thus enables assessment of heterogeneities. The graphite geothermometer uses the ratios of the G (1565-1580 cm^{-1}), D1 (~ 1350 cm^{-1}) and D2 (~ 1620 cm^{-1}) bands, which comprise the first-order region of the Raman spectrum. For well-ordered graphite there are no D1 and D2 bands. An increase in the intensity and widening of these bands reflects higher degrees of disorganization and equates to lower temperatures for graphitization. Graphite samples from several metasedimentary graphite deposits from Ontario (Grenville age) and one from fluid-derived igneous-hosted graphite (Albany deposit, Ontario), fluid-derived metamorphic vein deposits (Miller deposit, Quebec; Bogala, Sri Lanka; Aukam, Namibia) were analyzed by Raman microspectroscopy. For each deposit large intra-sample variations in Raman spectra, resulting in large estimated temperature variances, were observed. Most graphite samples yielded temperature estimates as low as 300 °C (where spectra had well developed D1 and D2 bands). However, all samples produced spectra (G-only band) that yielded the maximum temperature (641 °C) permitted by the geothemometer. The maximum temperature is not in agreement with other thermometric estimates for most deposits. Attempts to resolve these discrepancies involve acquisition of Raman spectra on orientated crystals (using a spindle stage), integration of XRD and HRTEM to identify the specific nature of structural defects, and investigation of second-order bands (2500-3100 cm^{-1}). There is no systematic variation of the first-order bands induced by crystal orientation or XRD-HRTEM-determined defects. Some potential useful differences in the second-order region are observed; however, the nature of these spectral bands is not fully understood.

Assessing morphological characteristics of graphite breccias of the Albany deposit using semi-automated digital analysis

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The Albany deposit is an igneous-hosted, brecciated graphite deposit located near Hearst, Ontario. The 24 Mt deposit consists of two vertical pipe structures that were emplaced near the southern margin of the Nagagami River Alkali Complex. The east and west breccia pipes are texturally distinct and contain different graphite grades (5.60 % and 2.85 %, respectively). The current genetic model for the deposit proposes that the pipes were emplaced violently within a hypabyssal environment by magmatic-hydrothermal activity and in response to large-scale depressurization. A quantitative assessment of the morphology of graphite-hosting breccia within the deposit is conducted by semi-automated digital image analysis. Results from this analysis are used to assess textural attributes of the east and west pipes, and to constrain the genesis of the Albany deposit. Key morphological attributes of the pipes include size and relative proportion of fragments to matrix, fragment shape, sorting and fragment orientation. Fragments within west pipe breccia samples exhibit a higher degree of roundness and isotropy than those from the east pipe. Impact erosional processes responsible for this roundness can be attributed to a higher number of fluid pulses and or higher energy brecciation during the formation of the west pipe. These attributes are characteristic of volume expansion brecciation and fluid assisted brecciation processes. The relatively angular nature of fragments within the east pipe suggest that it was more strongly influenced by fluid-assisted brecciation. Both pipes exhibited very poor sorting; consistent with very high degree of energy associated with volume expansion brecciation. Fragment orientation is inconsistent within east pipe and absent in west pipe. The inconsistent fragment orientation of the east pipe is likely caused by increased influence of fluid-assisted brecciation processes and possible structural controls. The data suggests that both pipes are volume expansion breccia, with characteristics of fluid assisted and corrosive wear breccia. These results support the existing model of emplacement for the Albany deposit.

Detrital zircon provenance and tectonostratigraphic evolution of the mid- to southern Labrador Trough

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The Labrador Trough comprises autochthonous and parautochthonous sedimentary and volcanic sequences that were deposited along the eastern margin of the Superior Craton between ca. 2.16 and 1.80 Ga. The classic interpretation of Trough stratigraphy includes three depositional "Cycles" separated by unconformities. Cycle 1 consists of rift to drift sedimentary and volcanic assemblages deposited between 2.17 and 2.0 Ga and includes voluminous continental flood basalt. Cycle 2 sequences include a wide variety of clastic and chemical sedimentary formations, comprising the economically important Sokoman iron formation, associated with a ca. 1.88 Ga mafic to felsic volcanic rocks. East of these assemblages lies the thrust-bounded Doublet Terrane (also Cycle 2) which includes a basaltic to picritic volcanic/volcaniclastic assemblage (Murdoch Fm.), a sulphide-rich sequence of mostly mudstone and siltstone (Thompson Fm.) and a thick sequence of pillowed basalt and associated deep-water sediments (Wilbob Fm.), intruded by voluminous, ca. 1.88 Ga gabbroic to ultramafic sills. Clastic sequences from the Thompson Formation contain a distinctive peak at ca. 1.88 Ga, suggesting deposition contemporaneous with mafic to ultramafic magmatism in a deep, reducing environment that could possibly represent a continental back-arc setting. Fe released in this environment may have provided the source for Superior-type BIF deposits in the oxidated Sokoman Formation in shallow marginal waters. All the above rock assemblages are thrust-bounded to the east by the Rachel-Laporte Group, which has been previously interpreted as high metamorphic grade equivalents of the Labrador Trough sedimentary and volcanic sequences. Our observations suggests that this is incorrect and that in this area it is instead predominantly formed of a distinctive, foreland basin sequence derived in part from uplift and erosion of the Core Zone. This sequence includes the Menihek Formation, which unconformably overlies and is infolded with, Cycle 1 and 2 lithological units.

Using alteration facies as proxies to metal pathways for IOCG and affiliated deposits: a global perspective from Olympic Dam and its metallogenic province to Laurentian margin examples

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Metasomatic ore systems with iron oxide and alkali-calcic alteration form a wide variety of ore deposits, such as iron oxide-apatite (IOA), iron oxide copper-gold (IOCG), skarn and albitite-hosted polymetallic deposits as well as their REE, Co, Bi, Mo, Re and U-rich variants. From the deep roots of the systems to surface, the alteration facies evolve from: 1) Na (albitites) and local skarns to 2) high-temperature Ca-Fe, 3) high-temperature K-Fe, 4) transitional K (brecciated felsites) and K-Ca-Mg (K-skarns), 5) low-temperature K-Fe and Ca-Fe-Mg and 6) epithermal alteration. This prograde path – with marked changes in bulk rock composition induced by fluid-rock reactions in each facies – and the varied permutations of alteration facies associated with tectonic telescoping, fluid mixing, periodic magma emplacement and cooling, record the various metal pathways that lead to deposits from sources to sinks. Diagnostic geochemical footprints arise in all our case studies (e.g. Central Mineral Belt and Great Bear magmatic zone, Canada, and the Olympic Cu-Au province including Olympic Dam, Australia) that encompass 1) high intensity alteration and their prograde features, 2) gradual alteration of protoliths at each facies, and 3) superimposition or tectonic telescoping of alteration facies. By reporting data on the IOCG discriminant diagram, it is possible to distinguish alteration zones with retrograde, tectonically telescoped and/or cyclical metasomatic paths from least-altered host-rocks, even where their composition fall within the least-altered field. Based on this work, we interpret the footprints of the Central Mineral Belt in the Makkovik province as an array of segmented and tectonically telescoped metasomatic paths that display, like the Bondy gneiss complex in the Grenville Province, the intrinsic characteristics of metasomatic systems that can generate IOCG, albitite-hosted U deposits and various orogenic remobilization events.

Timing and characterization of tectonometamorphism in the northwest Opinaca, Superior Province, Eeyou Istchee Baie-James region

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The Opinaca subprovince, in the Superior craton, is an important Neoarchean metamorphosed sedimentary basin. Various models have been proposed to explain the formation and evolution of the Opinaca, ranging from accretional prism to back-arc basin. In the north-western Opinaca subprovince, isograds traced from index minerals highlight a progression from greenschist facies in the north-west to upper amphibolites facies in the south-east. The chemistry of metamorphic minerals shows a global homogenisation of growth zonation. In the northernmost Opinaca subprovince, textural relations and phase equilibrium modelling indicate a clockwise P-T-t path with an isothermal decompression segment from 6 to 4 kbar at ~ 600 °C. In the southern part of the study region, the clockwise P-T-t path is characterized by stronger, suprasolidus isothermal decompression from 9 to 5 kbar at ~ 800 °C. We constrain deposition of the Opinaca greywacke from 2712 to 2690 Ma with the youngest detrital zircon population and crosscutting felsic intrusions. U-Pb monazite and zircon geochronology indicates two pulses of metamorphism, at ~ 2670 and ~ 2645 Ma. Lu-Hf dating of garnet supported by textural analysis and trace element mineral chemistry indicates that garnet growth is coeval with the younger population of monazite, ca. 2645 Ma. The first generation of monazite around 2670 Ma is thus interpreted as a low-pressure metamorphic event that did not involve garnet growth. These results point towards a polymetamorphic evolution for the Opinaca subprovince consistent with the tectonic inversion of a rift-like basin. Clastic sedimentation between 2712 to 2690 Ma in a magmatically active, rift-like basin was followed by regional low-P metamorphism at 2670 Ma. The onset of crustal shortening and thickening in the basin by 2645 Ma resulted in Barrovian-type metamorphism, and involved isothermal decompression that could have been accommodated by some degree of ductile extrusion.

Using petrochronology to unravel the metamorphic and magmatic development of orogenic systems

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Understanding the tectonic development of orogenic systems requires detailed knowledge of both the absolute timing, as well as the duration, of geologic events. Drawing on examples from different orogenic systems, this presentation will highlight recent advances and potential future directions in the field of petrochronology. Specifically, I will focus on four key developments: 1) the concomitant analysis of trace elements and/or other isotope systems of petrologic importance (e.g. REE abundances and Hf, Nd, Sr isotopes) along with U-Th/Pb dates in order to integrate ages with structural, pressure-temperature, phase relationships and geochemical data; 2) application of multiple geochronometers (e.g. garnet, monazite and zircon) and multiple isotope systems (e.g. U/Pb, Lu-Hf and Sm-Nd) to reveal the full history of an orogenic system; 3) development and application of novel geochronologic data acquisition methods (e.g. Single Shot Laser Ablation Split Stream, SS-LASS) to unlock previously unknown information recorded in sub-micrometer spatial domains in accessory minerals, and; 4) development of 'campaign-style' geochronology methods to elucidate the spatial and temporal scale of geologic processes at scales ranging from single crystals to entire mountain belts. Together these examples demonstrate the key role that geochronology plays in unraveling the first-order processes the control the evolution of orogenic systems through time.

Extracting tectonic and erosional signals from detrital thermochronology in the Eastern Himalaya

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In active orogens, interaction of tectonic and erosional processes is recorded in the exhumation history of rocks at the surface and in sediments carried by mountain rivers. Detrital thermochronology has become an important tool to quantify the erosion history of orogens yet it remains challenging to relate age distributions to various tectonic and erosional processes. Here we use a three-step approach to study modern fluvial sediments from the Bhutan Himalaya improving our understanding of detrital records in terms of spatiotemporal erosion rates. First, based on a preferred tectonic scenario extracted by inversion of in situ multi-thermochronological ages for the western Bhutan Himalaya, we predict apatite fission-track age (AFT) distributions in 10 catchments using the thermokinematic modeling package Pecube. Second, we compare AFT age distributions from modern sand bars collected at each catchment outlet to distributions

extracted from Monte Carlo sampling of the predicted catchment ages. We find that observed and predicted age distributions are statistically equivalent for only ca. 50 % of the catchments. Third, we recalculate predicted detrital age distributions by scaling the prevalence of ages in the catchment in proportion to: 1) topographic and climatic metrics (e.g. local relief, steepness index, specific stream power with discharge calculated from precipitation); 2) variable target mineral concentrations in bedrock geological units; 3) non-uniform sediment sourcing from moraine- or glacier-covered regions; and 4) landslide-driven erosion, to quantify their effects and relationships to the observed detrital AFT age distributions. Scaling age prevalence by specific stream power and increasing the flux of material from glacial formations improves the agreement between the observed and predicted ages in most catchments. Sediment production by bedrock landsliding can produce the observed ages in the remaining catchments. In summary, the results highlight the critical need to carefully evaluate the range of geomorphologic processes that can be detected in river detritus.

Diagenetic pore fluid evolution of the paleozoic successions, Huron Domain of Southern Ontario

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Laterally extensive carbonate formations occur throughout the Paleozoic sequences of the Huron Domain of southern Ontario, Canada. As part of a broad multi-year investigation to better quantify the diagenetic history and pore fluid evolution of the region, core samples from multiple deep boreholes within the Huron Domain were analyzed for petrographic, stable and Sr isotopic composition, fluid inclusion microthermometry and major, trace and REE to characterize diagenetic history, fluid composition and sedimentary provenance. Cambrian and Ordovician data suggest two possibly isolated diagenetic fluid systems: i) an earlier fluid system that is characterized by a pronounced negative shift in oxygen and carbon isotopic composition, a more radiogenic ratios, warm (84-156 °C for dolomite and 87-141 °C for calcite;) and saline signature (23.2 to 27.2 wt % NaCl eq for dolomite; and 23.6 wt % NaCl eq for calcite); and ii) a later Ordovician system, characterized by less negative shifts in oxygen and carbon isotopes, hypersaline (22.4 to 30.1 wt % NaCl eq for dolomite and 27.5 to 29.7 wt % NaCl eq for calcite;), comparable homogenization temperature (85-132 °C for dolomite and 66 to 153 °C for calcite) and a less radiogenic fluid system. In contrast, the isotopic data of the overlying Silurian and Devonian carbonates show overlaps between $\delta^{13}C$ and $\delta^{18}O$ values. However, $\delta^{18}O$ values show evidence of dolomite recrystallization. Negative shifts of $\delta^{18}O$ in early-formed dolomite can be due to alteration during burial. Ordovician, Silurian and Devonian Sr isotopic ratios of both age groups show seawater composition of their respective age as the primary source of diagenetic fluids with minor rock/water interactions. Hydrothermal fluid migration and its influence on later saddle dolomite, likely occurred during Paleozoic orogenesis. Evidence indicates that diagenesis is horizontally continuous across the Huron domain, displaying few signs of significant vertical connectivity beyond formation tops, except in areas with local heterogeneity (faults).

Age and metal endowment of the lithospheric mantle beneath the Abitibi greenstone belt

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Large scale precious metal enrichment in the Earth's crust must ultimately relate to the mantle because the crust is derived from the mantle. To fully evaluate the processes that govern the metal residence and transfer from the mantle into economic endowments in the crust, it is essential to obtain a better understanding of the location and source of metals in the ancient continental lithospheric mantle roots that underlie world-class metal deposits. We focus our study on the mantle root beneath the Abitibi greenstone belt (AGB), which hosts some of the world's largest precious and base metal deposits. A suite of mantle xenoliths from the Jurassic (157-152 Ma) Kirkland Lake kimberlites (KL; peridotites) and the Neoarchean (2744 ± 44 Ma) Wawa lamprophyres (websterites) have been analyzed to characterize the composition, age, and metal endowment of the lithospheric mantle underlying the AGB at two different times in Earth's history. Initial $^{187}Os/^{188}Os$ ranges from 0.1075 to 0.1276, with the websterites having overall lower isotopic ratios (0.1075-0.1149) than the peridotites (0.1105-0.1276). In the peridotites, Re depletion ages (TRD) span a broad range from 2.6 to 0.1 Ga with main modes at 2350 Ma and 1100 Ma. This indicates that the cratonic root underlying Kirkland Lake stabilized during the Neoarchean and underwent significant metasomatic disturbance in the Paleo- and Meso-proterozoic, with the ~ 1100 Ma age mode coinciding with the Midcontinent Rift event at the southern edge of the Superior Craton. Concentrations of precious and base metals within individual mantle minerals, such as olivine, obtained via LA-ICP-MS, are reported to examine potential precious metal gradients in the lithospheric mantle and the implications for the role of the mantle root as a starting point in the genesis of crustal metal ore deposits are discussed.

Defining the Mesoproterozoic 1450-1360 Ma Picuris orogeny in the southwestern United States and exploring possible linkages with the 1510-1450 Ma Pinware orogeny, eastern Canada

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Precambrian rocks of the southwestern United States preserve a relatively recently discovered and quite remarkable record of Mesoproterozoic, ca. 1500 Ma to 1450 Ma deposition, followed by ca. 1450 to 1350 Ma regional metamorphism, deformation, and plutonism. The Yankee Joe Group and the uppermost Mazatzal Group in central Arizona preserve detrital zircon with U/Pb isotopic ages as young as 1590 Ma to 1470 Ma. Metatuff layers at the base of the Yankee Joe Group yield U/Pb zircon crystallization ages between 1500 Ma and 1480 Ma. These rocks record greenschist facies regional metamorphism, and north- to northwest-directed contractional deformation classically attributed to the Mazatzal orogeny. The Yankee Joe Group is crosscut by the ca. 1450 Ma Ruin granite consistent with burial to depths of 10-12 km between 1470 Ma and 1450 Ma. The Trampas Group and the Marquenas Formation in the Picuris Mountains of north-central New Mexico yield detrital zircon ages as young as about 1475 Ma and 1450 Ma and metatuff zircon crystallization ages between ca. 1500 Ma and 1470 Ma. These rocks experienced amphibolite facies regional metamorphism, and deformation between about 1450 Ma and 1365 Ma at depths of 10-15 km. Upper amphibolite to near granulite facies supracrustal rocks from the northern Taos mountains yield metamorphic zircon with ages between about 1450 Ma and 1400 Ma, at depths of 18-25 km. The regional deformation and metamorphism of these Mesoproterozoic supracrustal rocks define the Picuris Orogeny in the southwestern US. We propose that the 1510 to 1450 Ma Pinware orogeny of eastern Canada and the ca. 1450 to 1360 Ma Picuris orogeny record a time transgressive orogenic event associated with a convergent plate margin along the southern margin of Laurentia (present day coordinates).

Constraining the formation of Fe-Ti-V-P deposits using trace elements in Fe-Ti oxides: insights from the chemostratigraphic variation of magnetite and ilmenite in the Upper Zone of the Bushveld Igneous Complex

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Magmatic Fe-Ti-V-P deposits commonly form in the evolved parts of mafic-ultramafic intrusions in layered intrusions and anorthosite massifs. However, their formation, in particular the physical processes required to accumulate massive oxide layers/lenses, is still debated. In situ trace element analysis of the oxide minerals themselves may help us place better constraints on the petrogenesis of Fe-Ti-V-P deposits and identify the dynamic processes in the intrusion that might play a role in their formation. Current models include double diffusive convection, magma mixing, reinjection of more primitive magma (or crystal mush), and slumping of crystal slurries. To achieve this, first we need to better understand which trace elements in Fe-Ti oxides track magmatic processes (i.e. differentiation of the magma) and which are modified by post-cumulus processes (i.e. effect of trapped liquid, re-equilibration with silicates and exsolution of Fe-Ti oxides). Using the 2 km-thick, magnetite-rich Upper Zone of the Bushveld Igneous Complex (South Africa) as an example of Fe-Ti-V-P mineralization in the world's largest layered intrusion, we present chemostratigraphic trends for a full suite of trace elements in magnetite and ilmenite, determined in situ by laser ablation ICP-MS. The chemostratigraphic trends, preserved in oxide-rich lithologies (~ 10 % oxides), show an overall decrease in compatible elements (V, Cr, Ni, Co) in Fe-Ti-oxides, which are punctuated by 2 reversal trends toward the top. These trends match those recorded by the An content of co-existing plagioclase (a robust proxy for differentiation). Incompatible elements, such as Mo and Mn, systematically increase in Fe-Ti oxides towards the top. These chemical reversals are best explained by the model of double diffusive convection of a stratified melt, rather than reinjections of more primitive magma. The chemostratigraphic trends, however, are less well preserved in oxide-poor lithologies due to significant chemical modification during post-cumulus processes.

Reconstructing supercraton Superia: complexities in Superior-Karelia connections due to orogenic crustal block rotations in Western Karelia

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Superior and Karelia-Kola cratons are two of several dispersed crustal fragments of a late Archean ancestral landmass, supercraton Superia. A first-order reconstruction of Superia is suggested by matches between the ages and geometries of several Paleoproterozoic giant mafic dyke swarms. While swarm matches between Karelia-Kola and Superior are well established, the detailed positioning of Karelia-Kola with respect to the southeastern Superior craton remains a matter of debate. First, Karelia involves several Archean crustal blocks separated by younger shear belts. Poorly constrained tectonic rotations between these crustal blocks complicate the generalization of Karelian dyke swarm trends for reconstruction. Second, dyke studies are complicated by metamorphic overprints related to the 1.8-1.9 Ga Svecofennian orogeny. Overprints have degraded paleomagnetic signatures and made local and regional dyke swarm patterns difficult to interpret from aeromagnetic maps. The geochronological record is similarly compromised. Minerals used for dating are commonly rimmed by metamorphic zircon and damaged crystal lattices can result in variable degrees of Pb loss. U-Pb data are often discordant and reported ages typically involve interpretation of upper intercepts. The Pudasjärvi block is a granitoid gneiss complex in Western Karelia. Host to the oldest rocks in Fennoscandia, the 3.5 Ga Siurua gneiss, the tectonic relationships between Pudasjärvi and adjacent crustal blocks Taivalkoski, Kuhmo, and Iisalmi are poorly constrained. Here, we present U-Pb ID-TIMS geochronological results for three dykes from the Pudasjärvi block and review the overall dyke swarm patterns of this crustal block. Our data include refinements to the previously dated ca. 2.4 Ga Uolevinlehto and ca. 2.1 Ga Sipojuntti dykes and a new locality, Myllykangas, part of the same swarm as the Sipojuntti dyke. Together, these dykes and their orientations are compared to dykes in other blocks within Western and Central Karelia and the possibility of relative rotation of the Pudasjärvi block is discussed.

Paleoproterozoic banded iron formation deposition controlled by Milankovitch forcing

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Banded iron formations (BIFs) were widely deposited in the Neoarchean to early Paleoproterozoic oceans between 2.8 and 2.4 Ga. Their formation has typically been linked to hydrothermal plume activity, continental growth and the rise of oxygen in the ocean and atmosphere. However, very little attention has been paid to climate variability and its potential role in the formation of BIFs. Climate oscillations on the thousands to millions of years scale known as Milankovitch forcing must have been operative at that time and may explain the rhythmic layering observed in BIFs. This hypothesis has never been fully tested, partially due to the unknown depositional rate of BIF. In this study, we carried out high-precision, high-accuracy TIMS U-Pb zircon dating of four ash intervals interbedded in the Paleoproterozoic Kuruman BIF, South Africa to precisely determine the depositional rate. We combined these results with cyclostratigraphic analysis of rhythmic alternations in the weathering profile from field exposures which are laterally consistent over 250 km. Based on our spectral analysis results and precise U-Pb ages, we hypothesize these patterns are related to orbital forcing.

U-Pb ages of hydrothermal calcite associated with Carlin-type gold mineralization, Nadeleen trend, north-central Yukon

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U-Pb dating of calcite veins from the Neoproterozoic-hosted Sunrise and Conrad prospects constrains the age of Carlin-type gold mineralization in the Nadaleen trend, north-central Yukon. The dated calcite veins occur within Au mineralized intervals that are commonly associated with realgar, and are interpreted to have formed during the late stages of Au mineralization. Data were acquired with an Agilent 7700 ICP-MS coupled to a Teledyne Analyte G2 Excimer laser ablation system (160-210 µm spot size) and calibrated using NIST614 and WC-1 calcite. The U-Pb data exhibit variable degrees of complexity. Three samples from the Conrad prospect have relatively simple systematics and define Tera-Wasserburg intercept ages between 75 and 72 Ma. A fourth sample has individual spot model ages between ca. 70 Ma and 20 Ma. Three samples from the Sunrise prospect exhibit variable U-Pb dates. One sample has an early generation of calcite veining associated with realgar dated at 73 Ma, and coarser calcite veins that have younger spot ages between 40 and

15 Ma. A sample of a complex calcite vein associated with realgar yielded individual spot ages from ca. 70 Ma to 45 Ma that are not clearly associated with specific calcite generations. Minor calcite veins in the sample are ca. 50-46 Ma and this younger veining may have disturbed the U-Pb systematics in earlier-formed calcite. A coarse calcite vein sample also yielded spot ages between 70 and 45 Ma with no clear spatial pattern. All samples preserve some evidence of calcite veining at 75-70 Ma but the significance of the younger apparent ages observed in two samples at ca. 50 Ma and possibly 36 Ma remains to be determined. To our knowledge, this is the first study to constrain the age of Carlin-type mineralization using U-Pb dating of calcite.

An integrated approach for 3D-visualization skills and spatial ability training in Geosciences

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Three-dimensional thinking and spatial skills are two of the most essential skills for a practicing geoscientist. These skills are important for efficient exploration targeting, as 3D geometry of ore deposits or mining/construction operations gives additional knowledge of the geometry of deformation zones in the target area, therefore reducing risk for exploration. However, it is the common assumption that students either possess these skills naturally, or are just not able to learn them. Hence, spatial ability training is often neglected in program curriculum. In this presentation we present a set of sample exercises that help to integrate spatial skill and 3D-visualization training in many courses throughout various Geoscience program curricula, extending from first- and second year courses such as Introduction to Geology, to upper year courses such as Structural Geology. After decades of research, it is known that handling 3-D objects, through the use of tactile sensors when exploring objects, results in a better understanding of spatial relationships, geometries of objects and basic concepts, compared to given 2-dimensional information, for example, figures of the same objects on a PowerPoint slide. To additionally intensify the experience and enhance the students 3D-visualization skills, we suggest combining the use of 3-dimensional teaching objects with exercises/projects during which the students have to actively create 3-dimensional objects or models, by either folding 3D-paper models of mineral crystals, or creating a 3D-printable block model of a geologic feature, from scratch. Hence the students gain not only software skills, but have to actively plan on what they want to create, how this can be achieved, and then manipulate shapes in 3D space. Students doing such a project were very engaged in their work and proud of their new skills. Preliminary student responses showed that students find this targeted integration of spatial skills training throughout the curriculum very beneficial.

Demanding geoethical roadmaps: GeoHazard researchers prepare for the 2020 Disaster Ethics Conference

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With the Sendai framework for Disaster Risk Reduction (DRR 2015-2030) four priorities for action, Indigenous Peoples, governments, industry, communities and organizations (e.g. the International Association for Promoting Geoethics) around the world are seeking to achieve large-scale systemic change. Important baselines for exploring intersections amoung hazards, disaster risk and geoethics are being developed, such as 2020 Disaster Ethics Conference (Copenhagen Center for Disaster Research). In Canada, the focus has been on building the 2019 Emergency Management (EM) Strategy for Canada. This initiative could support an evolving geoethic framework in geoscience providers. As cross-sector groups engage more deeply in this practice, all stakeholders will be seeking answers to the question: How do you do this work well? In preparation for the 2020 Disaster Ethics Conference, this presentation presents a preliminary four-step roadmap. The steps are as follows: One: identifying an important ethical question or issue associated with the geohazard project. Two: linking the issue with general scenarios to identify possible paths for implementation. The scenarios acknowledge four general types of ethical responses: a) immediate personal reaction, b) personal duty; c) community duty; and, d) addressing extreme injustice. Three: developing a practical system to guide best practices Four: reflecting on how geoscientists can support a larger effective catalyst for achieving Sendai Framework (2015-2030) targets. This preliminary roadmap will be presented in Copenhagen to gain feedback. The refined version could be used to ensure geoscience research initiatives integrate an ethical response as they meet the demand made for geoscience information in several Canadian DRR activities, programs and projects. This presentation is best suited to those who have an interest in geoethics for complex DRR challenges. They are suited to those who are eager to engage with geoethical roadmap as they provide empirical evidence for disaster relief efforts and hazard data information dissemination platforms.

Indigenous groundwater geoscience: identifying information needs

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Much of the Federal government research to date has focused on groundwater geoscience reports, water system policy and practice, and provided reviews of water security service delivery issues. The key question that remains unaddressed is why do municipal, provincial and federal groundwater geoscience partnerships face limitations in providing fit-for-purpose geoscience for effective potable water management for/by Indigenous People? This research project was designed to investigate the groundwater geoscience information needs of Indigenous People of Canada. Methods used included secondary data analysis, interviews with stakeholders (email, telephone and face to face), case study of groundwater geoscience delivery review, and review of academic articles and primary documents (task forces, workshop and symposium reports such as the 2018 Resources for Future Generations Conference presentation: *Geoethics at Queen's University: Reconciliation through Indigenous Geoscience Education*). Key topics investigated include: 1) Current levels of Indigenous people's participation in groundwater geoscience research 2) Culturally relevant geoscience learning tools and techniques 3) Principles, practices and outcomes of Indigenous Geoscience Education. Preliminary findings include: 1) Existing guidebooks, tools and techniques demonstrate that the principles, practices and protocols on how to indigenize science and technology education are readily available 2) Theoretical and methodological frameworks could build a bridge between Indigenous people and geoscience education. Importantly, the evidence-based insights from case studies highlight the emerging need for geoscientists to build cultural competency to support Indigenous people's geoscience research and practice. The subsequent analysis provides a step-by-step account of the project findings, revealing the work required to grow the Indigenous people's capacity to interpret and apply aquifer-groundwater: surface-water data to refine decisions that may protect source water from threats and provide improved management of groundwater systems.

Groundwater at risk: a post-wildfire water security perspective

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In 2018, northeast and northwest Ontario was effected by dozens of large forest fires; for example, the Kenora 71 wildfire (10 887 hectares) the Parry Sound 33 wild fire (11 362 hectares) and the Nipigon 30 wildfire (32 850.5 hectares). Following the 2018 Ontario fire season, questions have been raised about the impact of the 2018

wildfires upon the local First Nation's water security. Critically, questions about post-fire groundwater geochemistry were missing. Our research seeks to understand one question: how can the post-wildfire water quality research provide guidance for future groundwater research in Canada? Informed by research from i) post fire mobilization of contaminants into surface water resources; ii) short term impacts of fire events on aquifers in karst; and iii) community-based fire management. This project has several objectives including reviewing post-fire groundwater quality,providing gap analysis of Canadian research taking a strategic view of post-fire water quality research to support on-reserve First Nations' land use planning and public health and safety initiatives andreviewing community preparedness planning information products on how to manage post-fire water quality This poster presents preliminary results on how natural events such as wildfires modify the surface environment by combusting vegetation and changing soil properties which leads to potential contamination of potable groundwater. Most research on post-fire water quality research has focused on surface water to determine fire-prone forested water source areas. There is little research being done to understand groundwater aquifers' vulnerability to post-fire debris, sediment and chemical constituents including indicators that could be used in future assessments. This poster is intended to stimulate discussion on the preparation of suitable post-fire water management plans for First Nations in Canada in order to maintain drinking water quality in a cost-effective manner.

Structural and tectonic setting of the Gubaoquan eclogite in the Beishan Orogenic Collage in NW China: a field-based study

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The Ordovician Gubaoquan eclogite is situated in the southern part of the Neoproterozoic-Paleozoic Beishan Orogenic Collage of the Central Asian Orogenic Belt in NW China. The region is underlain by a highly deformed belt of metamorphic tectonites, comprising orthogneiss, mafic schist, quartzite and marble, which are locally cut by granitoid intrusions. The eclogite has been proposed to be of oceanic or continental affinity based on trace element analysis. However, field relationships were not previously documented, though this information is crucial for determining the parentage and tectonic significance of the eclogite. The Gubaoquan eclogite is situated within the southern part of the metamorphic tectonite belt. Metamorphic mineral assemblages suggest regional high-grade metamorphism, primarily including amphibolite and (local) eclogite-facies assemblages. Foliations trend E-W to NW-SE with ~ 60° dips in the north, shallower (~ 30°) in the south. Lineations are divided into two groups: (1) trending E-W with subhorizontal plunges; and (2) N-trending with approximately down-dip plunges. E-W-trending isoclinal, southerly overturned F1 folds are refolded by N-S-trending, upright open to tight chevron and kink F2 folds. Late south-directed brittle-ductile thrusts with down-dip lineations are common in the south, near the border with the Liuyuan Complex, but their age relationships with respect to F1 and F2 folding are unclear. F2 folds indicate orogen-parallel shortening, whereas F1 folds and thrusts indicate orogen-perpendicular shortening. These may be related to different collisional events. The results of this study are consistent with a continental origin for the Gubaoquan eclogite. The protolith of the eclogite was probably a boudinaged Neoproterozoic dyke within a Proterozoic to Early Paleozoic metamorphic tectonite belt. This belt may represent an isolated continental fragment that was subducted northwards under the Huaniushan arc, or a piece of the leading edge of the arc terrane basement that was dragged down into the subduction channel.

A goal-oriented fully-coupled surface and subsurface hydrological model for basin-scale baseflow predictions

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The sustainable management of water resources under a changing climate is one of the main challenges of the 21st century. Water management plans can use numerical modeling as predictive tools. Usually, surface or conceptual hydrologic models are employed to support both short and long term forecasting. These models can be applied at the basin scale encompassing several surface water watersheds at a relatively low computational cost, but their conceptualization of surface water and groundwater interactions is often greatly simplified. This can be problematic when the prediction of interest highly depends on these interactions (e.g. low flow periods). In order to improve the basin-scale (36 900 km^2) predictions of streamflow during low flow periods, we investigate the potential of a fully-integrated hydrological model (HydroGeoSphere) that couples a three-dimensional variably saturated subsurface flow solution to a two-dimensional surface water flow solution. If one primary objective is to increase the reliability of streamflow prediction, especially during dry seasons, one primary limitation is the high computational cost that complicates model calibration and uncertainty analysis. As a solution, we propose a goal-oriented model where groundwater recharge is externally computed with a soil-water balance model. The proposed model is a fully-integrated hydrological model where groundwater flow processes are of the primary concerned. Such an approach mitigates the overall computational cost rendering advanced uncertainty analysis achievable. Finally, the model will be tractable to be used for hydrologic simulations in a climate change context in a fully transient mode.

Toward the nomination of Anticosti Island to the UNESCO World Heritage Program

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Anticosti Island is a globally significant fossil and stratigraphic site at the entrance of the Gulf of St. Lawrence that was inscribed on the Canada Tentative List of World Heritage Sites in December 2017, potentially making it the first Ordovician and Silurian site anywhere in the world to achieve this status. Anticosti Island is globally recognized as an outstanding record of fossil life anywhere in the world through the upper Ordovician and lower Silurian time interval. This period represents a milestone event in the history of the Earth, the first global mass extinction of animal life. The Anticosti fossil assemblages show how global change in climate and sea level at the end of the Ordovician caused the extinction of nearly all ocean life on the planet. The World Heritage status can only be granted after a comprehensive comparative analysis is performed via a series of objectives and qualitative measures. Site integrity, legal protection and viable management strategy are equally important and nominations may be deferred if these conditions are not met. The nomination is led by the Municipality of Anticosti Island, populated by a single village of 220 inhabitants. The municipality is planning a three-year process to prepare the nomination. This relatively short timeframe is possible because of several elements: i) a quickly established steering committee with a strong scientific orientation, ii) committee members with a wide range of expertise in natural heritage, iii) full support of the local and regional communities as well as the Innu Nation, iv) quickly available funding for preparing the nomination, and v) extensive geological and paleontological information on the site. Suitable protection and management plans will, however, require that the various government agencies worked cooperatively and effectively in favour of the nomination.

Stratigraphy and volcanic setting of the host rocks of the Neoarchean Sunrise VMS deposit, Beaulieu volcanic belt, Slave craton

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The Sunrise VMS deposit is located within the Neoarchean Beaulieu volcanic belt of the Slave craton, ~ 110 km northeast of Yellowknife. The belt is comprised of mafic volcanic flows with lesser felsic volcanic rocks. The deposit (historic indicated resources of 1.52 Mt at 5.99 % Zn, 2.39 % Pb, 0.08 % Cu, 262 g/t Ag, and 0.67 g/t Au) is a banded polymetallic Zn-Pb-Cu-Ag-Au sulfide lens hosted by rhyolitic rocks, but the age, stratigraphy and volcanic setting of the deposit is not well understood. Detailed mapping of the Sunrise area shows a complex stratigraphy comprising numerous lithofacies. The footwall to the deposit consists, from oldest to youngest, of pillow basalt (~ 200 m), formerly glassy rhyolite lobes surrounded by hyaloclastite (~ 100 m), felsic volcaniclastic rocks ranging from tuff breccia to tuff with depositional units between 2 and 10 m totaling ~ 100 m, and a massive (~ 100 m), weakly quartz and plagioclase porphyritic rhyolite dome with brecciated margins. Stratigraphically above the porphyritic rhyolite is a strongly sericitized and silicified rhyolite tuff to lapillistone that hosts the deposit. The deposit is overlain by a hanging wall of pervasively carbonate altered pillow basalt. The rhyolite flows and a thick sequence of rhyolitic volcaniclastic rocks that comprise the footwall to the Sunrise deposit end abruptly ~ 2 km along strike to the south where the stratigraphy is dominantly intermediate to mafic pillow lavas with subordinate amounts of volcaniclastic rocks. This abrupt lateral transition in lithofacies is interpreted to represent a synvolcanic graben wall, that restricted deposition of felsic lithofacies to the north. This suggests that the deposit, and host volcaniclastic rocks, correspond with an area of faulting, fracturing and the accumulation of permeable debris on the margin of a rhyolite dome, with cross-stratal permeability provided by synvolcanic faulting, leading to favorable conditions for the formation of a VMS deposit.

Characterisation of the basement-sedimentary transition zone in the Saint-Pierre-Bois quarry (Vosges, France)

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The development of geothermal exploitation for heat and power generation requires detailed knowledge of the subsurface in order to mitigate associated geological risk and streamline exploitation techniques. In addition to temperature, the presence of a geothermal fluid and adequate reservoir permeability are required conditions for geothermal energy exploitation. In the Upper Rhine Graben (France/Germany), the basement-sediment transition zone is located at depths where the temperature is sufficiently high (between 120 and 200 °C) to be economically exploitable for industrial heat or electricity. Furthermore, several recent projects have targeted this zone because it acts as a permeable fluid reservoir. However, the complexity of this zone makes characterization of its heterogeneities a great challenge to the development of geothermal resources, a problem common to deep basins throughout Europe. On the western border of the Upper Rhine Graben, the basement-sediment transition zone outcrops and is accessible at the Saint-Pierre-Bois quarry (France). At this location, the granitic crystalline basement is overlain by arkoses. Fracture orientation measurements and rock sampling were conducted on all accessible quarry benches, providing rich datasets for both the granite and the arkose. The porosity of the granite matrix is ca. 2 %, and essentially related to the feldspar alteration. In the cataclastic fracture zones, the porosity is slightly higher (ca. 4.6 %) and these zones are partially cemented by 3.5 % of barite. Arkose porosity is ca.12 % and is a result of plagioclase and K-feldspar alteration. Fractures observed on the wall have two main sets: N20°E and E-W. The first set is related to graben opening during Tertiary, but it is not the major fracture set. The E-W fracture set is more abundant, with large fractures distributed regularly along the wall. This dominant fracture set is related to the local Permian basin, which was active at the end of the Hercynian orogenesis. This study shows that the fracture network could be largely influenced by local tectonic and the rock porosity is mainly secondary porosity in relation to the paleocirculation of fluids.

Microseismic monitoring of mines in real time with Ensemble Kalman Filter

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Microseismic monitoring is a widely used technique which over the last 20 years, has evolved from just a research topic to an essential tool for mining-security. Sudden and violent releases of energy stored in the rock mass are induced by mining activity, and are a persistent threat to mine safety. To effectively monitor the microseismic activity of a mine, two key elements are needed: a good seismic velocity model that can be used to determine the location of events, and an efficient way to incorporate each new event caused by mining activity to our model, in order improve our knowledge of the mine. This work outlines a general framework for efficiently update velocity models combining Sequential Gaussian Simulation and Ensemble Kalman Filter techniques, facilitating real time monitoring of mines. This technique allows to see where the velocity changes occur, thus highlighting zones where the rock mass is under stress and where potential hazard can be expected. This scheme aims to constitute a tool for taking decisions related to workers safety and production, among others.

The Bayesian logic in mining industry: HyperCube to predict mineral deposits

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Prediction of mineralization from heterogeneous geo-data remains a constant challenge and continual improvements in data acquisition processes significantly increases the amount of information accessible to exploration geologists. So nowadays, prediction requires the capability to extract relations among large and heterogeneous datasets. Recent progresses in data-mining led to the development of a non-Euclidean and non-stochastic algorithm: HyperCube. The HyperCube algorithm is based on Bayesian logic, which provides the likelihood of a target occurrence in future trial (or a phenomenon to predict) based on occurrences in prior trials (or on the associations of known phenomena). The variables of the dataset can be from a wide variety of data, such as lithology, alteration, chemical analyses, magnetic and electro-magnetic data, distance to structure or contact, etc. All these data have to be carefully integrated in the dataset, which is a key step in the process. The algorithm being a brute force binary classifier, it tests all possible combination of "n" variables and computes their rate of association with the targeted phenomenon (rules or configuration of variables). The association rules are filtered and concatenated using different key indicators based on Bayesian logic to build a predicting model. The outcome model is composed of a series of simple, comprehensive and often non-intuitive multi-variable rules, which can easily be scripted in conventional GIS or 3D CAD systems. Following multiple analysis on voluntarily altered datasets and real case studies, this algorithm proved to be particularly robust to interrogate incomplete or asymmetrical databases composed of a mixture of continuous as well as discrete variables. Since this methodology is systematic and unbiased and then highlights non-intuitive multi-variable associations, it can detect target where other approach cannot, and could also lead us to new fields of research.

The potential for intrusion-related gold systems in the western Wabigoon subprovince based on lithogeochemical and mineralogical investigations of the Lost Lake area, Ontario

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Intrusion-related gold systems represent a relatively under-investigated deposit type in the western Wabigoon subprovince despite an abundance of intrusive complexes with spatially associated gold occurrences. This work aims to document the relative timing, structural setting, and alteration pattern associated with large felsic intrusions to determine their potential as exploration targets. The Lost Lake area, located approximately 55 km SE of Dryden, Ontario is a poorly documented domain with great outcrop exposure, well-preserved igneous relationships, and several recently reported gold occurrences. Detailed mapping and sampling for structural, petrographic, and whole-rock lithogeochemical analysis were conducted in the area. Supracrustal exposures are dominated by metavolcanic rocks of the Boyer Lake and Kawashegamuk groups and intruded by a km-scale felsic stock and metre-scale, dike-like bodies that are inferred to be genetically related to the stock. Hydrothermal alteration assemblages are observed throughout the study area. Proximal wall-rock alteration assemblages, found within a few metres of intrusive contacts, are characterized by silicification, carbonatization, and disseminated sulphide minerals. Distal assemblages include chloritization, epidotization, and sericitization. Density- and volume-adjusted elemental mass gains/losses were calculated from whole-rock major and trace element analyses of quartz-felspar porphyry dikes and metavolcanic host rocks. Mass gains in Au-Bi-S-Ag-Mo-Sb-W-Te-As-Pb-Cu-C are associated with the ore mineralogy (sulphide minerals, gold-silver tellurides, carbonates), and mass losses in Ba-Rb-Cs-K are associated with phyllic alteration, extensive fracturing, and carbonatization. Field relationships and lithogeochemical analyses from the Lost Lake area shows similarities with intrusion-related gold systems of the Abitibi subprovince, such as the world-class Coté Gold deposit, suggesting that there is potential for a similar type of deposit in the western Wabigoon subprovince.

Kinematics, deformation history and preliminary U-Pb geochronology of a crustal-scale shear zone, Boothia Peninsula, Nunavut

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The Boothia Peninsula, Nunavut, is transected by a ~ 165 km long, SW-striking, steeply (70° NW) dipping corridor of highly strained rocks, the Sanagak Lake shear zone. Field mapping, micro-structural analysis and in situ geochronology are allowing the extent, kinematics, history, and timing of deformation to be quantified. Strain is heterogeneous and typically increases in intensity towards the center defining a high-strain corridor up to 15 km wide. Kinematic indicators such as folds, shear bands and δ- and □, -type porphyroclasts indicate major sinistral shear sense. Micro-textures observed throughout the shear zone indicate high-temperature deformation (~ 650-700 °C) that formed quartz ribbons and caused grain boundary migration and chessboard extinction within the ribbons. Subsequent lower temperature strain (~ 400-500 °C) resulted in localized recrystallization of quartz ribbons by sub-grain rotation and bulging. U-Pb data acquired by LA-ICP-MS in monazite, titanite and apatite provide broad constraints on the timing of deformation, metamorphism and cooling. Furthermore, U-Pb SHRIMP zircon ages from a mylonitic granite dyke and a cross-cutting late-tectonic dyke, constrain the bulk of sinistral shear strain between ca. 1895-1860 Ma. Monazite yield an average $^{207}Pb/^{206}Pb$ age of ca. 1867 Ma, interpreted as (re)crystallization related to the high-temperature deformation. Titanite yield Tera-Wasserburg age populations of ca. 1880, 1843 and 1806 Ma. This variability is attributed to Pb loss during thermal events, likely related to ca. 1841 Ma and 1824 Ma late- to post-tectonic plutons that are widespread southeast of the shear zone. Apatite yields a Tera-Wasserburg age of ca. 1682 Ma that, if associated with cooling below ~ 500 °C, could reflect a maximum age of the low temperature deformation event. Although preliminary, our data support operation of a crustal-scale sinistral shear zone at mid-crustal levels at ca. 1890-1860 Ma, which has implications for regional uplift, cooling and late plutonism in the northern Rae Craton.

Classification, evaluation and prioritization of geosites for Geoparks in remote areas: a case study of the Tumbler Ridge UNESCO Global Geopark

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According to UNESCO, Global Geoparks are "single, unified areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development". A key piece of this definition is the sites of international geological significance, which are more commonly known as geosites. A minimum of one geosite needs to be of international significance within the boundaries of a Geopark to achieve a UNESCO designation. Frequently, to complement the sites of international geological significance, sites of regional and local significance are selected as well. However, the inclusion of regional and particularly local geosites may lead to "geosite overpopulation", whereby too many sites are provided with the geosite moniker. As all UNESCO Global Geoparks in Canada are led by non-profit organizations with small operating budgets, maintaining these geosites to an appropriate standard for geoheritage purposes may become burdensome. In July of 2018, identifying a similar problem, a collaboration between the Spanish Ministry of Science, Innovation and Universities and the Geological and Mining Institute of Spain produced a framework to evaluate and inventory sites of geological interest. However, due to population and infrastructure constraints, as well as a relative paucity of geological data, it was noted that the same parameters used in their study would not work for the Tumbler Ridge UNESCO Global Geopark. In this study, we examine the parameters associated with the Spanish method for geosite identification, evaluation and selection, evaluate the parameters for the case of the Tumbler Ridge UNESCO Global Geopark and make recommendations for new evaluation criteria for Geoparks located in remote regions.

The role of evaporite units in the ore-forming processes of the iron-oxide apatite deposits

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Iron oxide-apatite (IOA) deposits are an important type of Fe deposit with classically elevated magnetite or hematite and apatite contents. The genesis of IOA deposits has remained controversial over the past several decades. The Ningwu ore district, in the Middle-Lower Yangtze River metallogenic belt of East China, is a major Fe ore district which contains more than 30 IOA deposits and has a total estimated reserve of 2.7 billion tonnes (Gt) Fe. The mineralization model of these deposits emphasizes mainly a magmatic-hydrothermal origin, but the role of the sulfate-bearing evaporite units in the district, which have a close spatial relationship with IOA deposits, have yet to be assessed. In these deposits, the S isotope values of sulfide are abnormally high, and the average values are higher than 5 ‰. Most of the S isotope values of gypsum are about 20 ‰, similar to the value of marine sulfate. This is suggesting that the evaporite unit has been involved into the ore-forming processes, consistent with previous fluid inclusion and mineral trace elements studies. Different iron ore types have different sulfur isotopic signatures, with a decreasing trend from

a magmatic, to a magmatic-hydrothermal and to a hydrothermal signature, mainly controlled by the sulfate reduced temperature and the proportion of original magmatic sulfur. We infer that evaporite units not just provide a large number of agents of mineralization for the sodium alteration, scapolitization and skarn alteration, but also improve the transportation of iron (e.g. Na-Fe-Cl complex). In addition, the evaporite unit is an important oxidation barrier at depth, which could oxidize ferrous iron into ferric iron in silicate magmas and hydrothermal fluids, preventing iron to enter the lattice of silicate minerals and forming magnetite or hematite. The study supports that the evaporite units are a critical factor in ore-genesis of the IOA deposits of the Ningwu ore district.

Gold deposits of the Archean Abitibi greenstone belt, Canada

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The Abitibi greenstone belt has been one of the World's major gold-producing regions for almost a century with more than 6050 tonnes Au (194 Moz) produced and an estimated total gold content of more than 9550 tonnes Au (~ 307 Moz). Recent and current production comes from an increasing diversity of styles of mineralization that result from a complex interplay, in both space and time, between tectonic, magmatic, and metamorphic events within an evolving accretionary setting. Among those, four styles largely dominate the bulk of the gold endowment, namely: 1) quartz-carbonate orogenic veins, 2) intrusion-associated disseminated-stockwork, veins and replacements, 3) synvolcanic gold-sulphide, and 4) sulphide-rich Cu-Au-Ag veins. Each style of mineralization is associated with a specific lithological and structural setting, and all have a distinct hydrothermal footprint. The complex geological evolution and the various levels of exposure and preservation across the belt often makes it difficult to recognize the original characteristics of some deposits. Significant gold mineralization is synvolcanic and/or synmagmatic and therefore formed during the volcanic construction of the belt. However, the bulk of the gold (~ 5950 tonnes – 190 Moz Au) is associated with the main phase of regional deformation and hosted in late orogenic quartz-carbonate vein-style mineralization that were formed over a relatively short period of time (ca. 2665-2640 Ma), predominantly along the Larder Lake-Cadillac and Destor-Porcupine faults zones. The unique endowment of the southern Abitibi gold belt (> 8300 tonnes Au) may be due to the presence of gold-enriched source region(s) or reservoirs in the upper mantle and/or at lower to mid-crustal depths. The unique clustering of large Au-rich volcanogenic massive sulphide deposits in the Blake River Group in the southern Abitibi greenstone belt represents the early manifestation of such an inferred fertile source region that was later tapped at various times during the evolution of the belt through deep penetrating, crustal-scale faults.

Evaluating the late tectonothermal evolution of anorthosite massifs: evidence from the Flowers River Igneous Suite, Hopedale Block, Labrador

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The ca. 1272 Ma Flowers River Igneous Suite of north-central Labrador is one of several highly-evolved, peralkaline plutonic systems emplaced in close spatial and temporal association with an anorthosite-mangerite-charnockite-granite (AMCG) suite. Similar resurgences of magmatism within AMCG-dominated terranes have been recognized worldwide, but the mechanism driving the renewed activity remains unknown. New geochronologic data for Flowers River granites and their comagmatic Nuiklavik volcanic rocks indicates that magmatism may have instead been sustained following emplacement of the Nain Plutonic Suite's Coastal Trend anorthosites (ca. 1343-1290 Ma). A model of perpetuated magmatism requires a source for the marked geochemical difference between the Nain and Flowers River suites. Back-arc extension initiated during early accretionary phases of the Grenville Orogeny is the only regional tectonic influence known to have coincided with emplacement of Nain and Flowers River magmas. A fixed tectonic regime having encompassed the duration of magmatism aligns poorly with the geochemical shift indicated by the peralkaline Flowers River suite. Therefore, the change must reflect a gradual evolution of the underlying means, or source, of melt generation in the back-arc setting. Flowers River granites show relative petrologic and geochemical homogeneity and are thus ill-suited to resolving subtle changes to the system through time. Fortunately, the well-preserved Nuiklavik volcanic pile presents a series of stratified snapshots throughout the system's development. It is accordingly possible to observe the timing and nature of critical tectonothermal shifts by highlighting geochemical trends within the volcanostratigraphy. A U-Pb zircon age range of 1289 ± 2 Ma and 1273 ± 3 Ma indicated for crystal-rich Nuiklavik tuffs promises an approximately complete record of these trends. The tectonic implications of the Flowers River Igneous Suite's magmatic evolution may yield insight into the waning period of activity following AMCG magmatism.

The evolution of metasomatic uranium ore systems in the Central Mineral Belt of Labrador

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Uranium mineralization at the Kitts, Gear, Inda and Nash deposits of the Central Mineral Belt (CMB) is concentrated in the upper portion of the Post Hill Group, along a structurally complex shear zone located within the Makkovik Province of Labrador. Mineralization is primarily developed within the metasedimentary formation argillite unit, interbedded at times with the Kitts pillow lava formation and seems to be structurally controlled along foliation and shear zones. Recent research in the CMB has highlighted regional- to deposit-scale sodic, calcic, potassic and iron alteration, as well as local hydrothermal breccia, all of which are characteristic of iron oxide and alkali-calcic alteration systems worldwide. Iron oxide and alkali-calcic altered systems can host a variety of economically significant deposits (e.g. iron oxide-copper-gold, iron oxide-apatite, albitite-hosted uranium, certain skarns and certain intrusion-related deposits) that are rich in base, precious, specialty and/or actinide metals. These seemingly distinct deposit types form in systematic metasomatic-hydrothermal assemblages that evolve from depth-to-surface across very high-temperature geothermal gradients within the upper crust. Samples from the Kitts deposit were mineralogically characterized using a scanning electron microscope and electron microprobe and were geochemically analyzed using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). Quantitative LA-ICP-MS element mapping on uraninite, in addition to uraninite trace element abundances, were used to distinguish uraninite of different generations and/or samples. The 2D element maps and REE geochemistry revealed that each sample exhibits unique geochemical characteristics. In chondrite-normalized plots, all three samples are depleted in LREE relative to HREE yet show both positive and negative Eu anomalies. Contrasting REE signatures imply at least two uranium mineralization events along the corridor, at different temperatures and physico-chemical conditions based on the REE chemistry of uraninite. Hydrothermal zircon, from the Kitts and Gear deposits, was analyzed by sensitive high-resolution ion microprobe (SHRIMP) and is interpreted to be associated with the uraninite mineralization.

Basalt lava flows of the Fury and Hecla Group and younger Franklin mafic magmatism, northwestern Baffin Island, Nunavut

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The Mesoproterozoic Bylot basins are a series of extensional basins spanning the Canadian Arctic (Fury and Hecla, Borden, and Hunting-Aston basins) and northwestern Greenland (Thule Basin). We present new field relations and petrography for basaltic lava formations within the Fury and Hecla Group and cross-cutting mafic intrusions on northwestern Baffin Island. New mapping conducted in the summer of 2018 revealed that the basalt formations of the Fury and Hecla Group include massive flows and pillowed basalt and are likely related to the Mesoproterozoic Mackenzie igneous event dated at ca. 1270 Ma, although available low-precision K/Ar ages are inadequate to confirm this correlation and their equivalence to basalts in the other Bylot basins. The sedimentary and volcanic formations of the Fury and Hecla Basin are cut by younger gabbro sills and northwest-southeast trending gabbro dykes. This northwest-southeast trend is the same as the trend observed for Neoproterozoic dykes of the Franklin dyke swarm on Baffin Island. Thus, the intrusive sills and dykes that cut the Fury and Hecla Basin are tentatively ascribed to the Franklin magmatic event dated between 723 and 718 Ma. Samples for geochemistry and isotope (Sm-Nd) analyses, and U-Pb geochronology were collected during the 2018 field season with the goal of improving our understanding of the petrogenesis and ages of all the mafic rocks in the area of the Fury and Hecla Basin. Determining the precise ages of these igneous formations is crucial for correlating magmatic events and stratigraphic successions across the Bylot basins.

U-Pb titanite geochronology to decypher metamorphic events

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Titanite occurs in a wide compositional range of igneous and metamorphic rocks and in many cases displays clear textural evidence of its origin. It has a wide range of temperatures (T) of formation from high T igneous (> 800 ºC) to low T metamorphic or hydrothermal environments (< 300 ºC). While U-Pb titanite ages are often plotted at a point on cooling paths on pressure-temperature-time plots (at ca. 600 ºC), it may have a complicated history because it can crystallize from well above to well below its 'blocking T'. Determining whether titanite is providing a U-Pb age of crystallization, or cooling after crystallization, requires a thorough knowledge of the field area, ages of other minerals, and sufficient coverage of the study area with titanite ages of different samples. Examples will be presented of complicated U-Pb titanite data arrays from a small well-mapped part of the early Archean ISUA terrane, volcanic rocks of the Proterozoic Aillik Group and granite from the Trans-Hudson. The common presence of core-overgrowth relationships between two generations of metamorphic titanite indicates that, in many cases, the ages represent time of crystallization and not cooling through a blocking T. New generations of titanite can crystallize without disturbing the U-Pb systematics of older generations in the same rock or immediate area. The downside of this complexity is that a titanite age cannot be assumed to record cooling through a specific T at a specific time. The upside is that multiple thermal/deformation overprints in an area can each trigger crystallization of titanite and be dated, events that may not be recorded by other minerals such as zircon or monazite.

Open measurement standards for better physical property measurements

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The advent of new geophysical inversion and modelling codes are promising to extract more value from pre-competitive datasets. The quality of this outcome, however, still depends on the quality of the initial model that can be built. In order to obtain geologically plausible models, the petrophysical signature of the different units must be understood and included into the initial model. In principle, the values in the initial model could simply be sourced from tables in textbooks, however, much to the chagrin of many undergraduate students, these values are non-unique. The values found within the tables represent the average of measurements that were made on an unknown number of samples from unknown origins. It is impossible to ascertain if the values from these tables represent the mean of a well behaved standard distribution or if it is the intersection between bimodal populations with different levels of alteration. In order to ground-truth the initial model, it is therefore best to undertake a characterization of the different rock units encountered. Fortunately, it is relatively simple to setup a basic petrophysical laboratory to measure density and magnetic susceptibility on cores and hand samples. The instruments required are affordable and operators can be trained rapidly to make the measurements. Well documented measurement protocols and traceable reference standards are still, however, in short supply. Calibration curves and reference pads used by equipment manufacturers for their calibration are often kept as trade-secrets. When calibration standards are available for purchase, they are often an expensive option that is a substantial percentage of the purchase price of the instrument. This means that many organisations will only have one for their fleet of instruments or worst, none at all. Instruments drift or malfunction during the field campaigns can go un-noticed and jeopardize the quality of the data acquired during an entire summer. In this presentation we will propose standardized measurement protocols and open source measurements standards that can be manufactured easily and cost effectively. The long-term objective is to establish traceable open source standards that will help ensure the integrity of the physical properties measured.

Microstructural record of melt-fluxed metamorphism in the Himalayan tourmaline leucogranites

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Leucogranites are ubiquitous amongst the upper levels of the Himalayan metamorphic slab; their formation is a topic of great interest to petrologists studying the ramifications of melt generation on crustal strength, and orogenic heat budgets. One enigmatic type of Himalayan leucogranite, the 'nebulitic tourmaline leucogranite' (Tur-leucogranite), presents an interesting petrological problem because it exhibits rhythmic, compositional layering that is continuous with the transposed bedding of its psammitic country rock. Tur-leucogranites are always closely associated with intrusive muscovite-biotite leucogranite sills and dykes of a demonstrably anatectic origin. A comparison of microstructures in the Tur-leucogranite, muscovite-biotite leucogranite, and psammitic country rock indicate the Tur-leucogranite formed by the pervasive infiltration of a volatile-rich melt/fluid. The in situ alteration and microstructural modification of the compositionally layered psammite resulted in the growth of the volatile-bearing minerals tourmaline and apatite. Propagation of the reaction front through the psammite may have been driven by the exothermic tourmaline-forming reaction and governed by the chemical permeability of the psammite and the availability of boron. The

distribution and orientation of product phases were ordered by interface-controlled processes, operating on the domain-scale, which ultimately resulted in the inheritance of the psammitic compositional fabric. The removal of biotite and the presence of melt along protolith grain boundaries encouraged grain boundary mobility, resulting in a bulk grain-size coarsening. Highly irregular grain boundaries preserve a record of the late-stage crystallization of interstitial melt along mineral grain boundaries. These findings suggest that the transient passage of melt through a rock leaves a microstructural record, which is preserved during exhumation. A consequence of this finding is that estimates based on the proportion of leucocratic rock, considerably overestimate the volume of melt in the Himalaya (by up to 60 %), because they do not account for the volume of sub-solidus psammite that was involved in forming the Tur-leucogranites.

Palaeozoic mineralisation associated with plate convergence in tropical to sub-tropical ocean basins

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The record of VMS mineralization is remarkable for the concentration of world-class deposits in limited geographic regions. The mineralization is mostly associated with the closure of major ocean basins, primarily in tropical to sub-tropical settings. Although porphyry deposits occur in similar regions in some cases, as might be expected for generally convergent margin settings, it is noticeable that VMS deposits, which typically form in locally extensional settings, are often more widely preserved. However, sedimentary copper mineralization in many areas may reflect the erosion of coeval porphyry mineralization. Much of the VMS mineralization, even though formed over more than 100 million years, appears to be concentrated in a limited sector of the Earth's surface. Might this reflect regionally restricted fertile sectors of the mantle? To what extent do these reflect changing geodynamics with either introversion or extroversion providing more favourable opportunities for the development of multiple arc and ribbon continents? Since practically all of the known VMS mineralization formed during the Palaeozoic is limited to tropical to sub-tropical regions, is this a necessity for economic mineralization? Improved palaeogeographic plate reconstructions with additional constraints provided by the location and timing of subduction-related igneous activity provide a framework within which to assess the formation of economic mineralization associated with broadly convergent plate margin settings in the Palaeozoic.

Origin of mineralizing fluids at the Cantung and Mactung skarn-hosted tungsten deposits, Yukon-NWT

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Cantung and Mactung are tungsten-bearing (scheelite) exoskarn orebodies located in the Selwyn basin, between Yukon and Northwest Territories, Canada. These deposits are hosted in a Late Proterozoic to early Paleozoic sequence consisting of alternations of carbonates and siliciclastics. Mineralization at Cantung and Mactung is spatially associated with Cretaceous-aged monzogranitic plutons of the Tungsten plutonic suite: the Mine Stock and Circular Stock plutons for Cantung, and the Cirque Lake Stock and the Rockslide Mountain Stock plutons for Mactung. In addition to these granitic plutons, lamprophyres also outcrop at Cantung. While it is broadly agreed that there is a relationship between tungsten mineralization and crustal derived magmas, a potential role of mantle sources has been recently proposed for Cantung based on apatite chemistry and melt inclusions. In order to determine whether there is an input of mantle components in the magma associated with mineralization, this study will examine the isotopic signature of the tungsten-bearing mineral, scheelite, as well as the isotopic signatures of local lithologies. As Scheelite is a Ca tungstate, it can incorporate significant amounts of Sr in its Ca site. In this study, the Sr isotopic signature for scheelite crystals hosted in argillites located below the skarn orebodies can be compared to those within the deposit. The Sr isotopes signatures in the argillite-hosted scheelite is expected to be representative of the least modified magmatic fluid. The results will be compared with the Sr isotopic signatures obtained from whole rock composition of the granitic plutons and, in the case of Cantung, lamprophyres. These results aim to determine the nature of the magmatic system and processes responsible for the production of tungsten-fertile fluids at the Cantung and Mactung deposits.

Detrital zircon U-Pb and fission track double dating: investigating sediment provenance and the thermal history of source rock regions

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Recent development on laser ablation (LA) techniques allow us to analyze time and cost efficient large numbers of grains. This advancement revolutionized the field of sedimentology that now uses extensively LA-ICP-MS to generate U-Pb age spectra for sedimentary rocks. These new datasets reveal sediment provenance and estimate the maximum deposition age. The LA technique also allows to combine U-Pb dating with other analytical measurements on the same grain. A powerful tool is the combination of U-Pb dating with thermochronology methods such as fission track (FT) dating. For each individual zircon grain this double dating technique provides the time of crystallization and the time of cooling below 290-210 ºC. The two cooling phases may have occurred at the same time as it is the case for extrusive and shallow intrusive rocks, however, more often the thermochronology cooling occurred long after grain crystalization. Thermochonlogy quantifies cooling in the upper crust, which is mostly associated with rock exhumation due to erosion and/or tectonic denudation. Because of it's physical and chemical durability, zircon is a perfect provenance tool with a memory that survives multiple cycles of erosion and deposition. This prolonged memory, however, limits the zircon's ability to identify a source region uniquely, such as in regions of sediment recycling. Unlike the U-Pb age, the zircon FT age can be erased and reset by crustal heating. Thus the detrital zircon FT data from sedimentary strata can be used as an additional provenance tool to identify source areas with distinct thermal histories. We present examples from southern Alaska where double dating of detrital zircons has identified sediment source regions that are characterized by varying thermal histories including sediment burial, heating due to passage of a asthenospheric slab window, and erosional exhumation.

Detrital zircon double-dating of forearc Cook Inlet basin strata reveals the thermal history of sediment source regions

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At convergent plate margins, the geologic processes and landscape evolution of the overriding plate are affected by variations in subduction mode and should be recorded in the forearc basin strata. We investigate the Cenozoic to modern sediment of the forearc Cook Inlet basin in south-central Alaska using a double-dating approach that combines fission-track dating and U-Pb dating on individual detrital zircon grains. In total we analyzed more than 1700 zircons. We integrate our new data with the existing knowledge of the regional geology and published geo-and thermochronology data that allows us to discriminate between magmatic cooled grain of extrusive and shallow intrusive rocks, exhumational cooled grains, and thermal reset

grains. We find that the erosion of both shallow and deep intrusive arc rocks dominate the detrital age signal, while syn-depositional extrusive grains are lacking. The erosion of rocks that have been thermally altered during the Eocene subduction of a spreading ridge dominates the FT age signal. This pattern is particularly prominent in the accretionary prism where ages in the most inboard (older) portion have not been thermally reset, but thermal resetting is prevalent in the outboard (younger) portion located proximal to the near-trench intrusions. Thermal alteration is also evident in the region of the arc that was affected by the passage of the asthenospheric slab window. The erosional signal of the more inboard arc and backarc region of the Alaska Range is characterized by exhumational FT ages of deep-seated rocks, which currently provide material into the forearc basin. This age signal results from flat-slab subduction of the Yakutat microplate, which transfers stress far inboard and produces significant mountain building and deformation. This exhumational age signal, however, is not recorded in the late Cenozoic strata, suggesting that the modern landscape developed since ca. 3 Ma.

The new GSC marine geoscience for marine spatial planning program: directing sea-bed mapping at environmental protection

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Canada's "blue" economy, based on interactions and uses of the oceans and coasts, is growing rapidly, but these areas are very sensitive to development. Seabed mapping is essential for planning marine activities and infrastructure, and sets the baseline for environmental impact assessments. It provides input for resource management and disaster mitigation. To support evidence-based decision-making in offshore environmental impact assessments and regulatory processes, the Geological Survey of Canada (GSC) established the Marine Geoscience for Marine Spatial Planning Program. Natural Resources Canada in collaboration with Fisheries and Oceans Canada is starting with four large marine regions: Newfoundland and Labrador Shelves, Bay of Fundy: Scotia Shelf, Pacific North Coast, and the Salish Sea. Through the compilation of legacy data with new collections, we will produce new sea-bed maps and interpretations at regional and focused scales. For each region, there will be a framework of multibeam sonar bathymetry and backscatter strength, sub-bottom profiles, geological interpretation, and benthic habitat maps. Case studies will be presented to illustrate how fundamental marine geoscience is applied to policy decisions. Sediment transport mechanisms, such as turbidity currents or migrating dunes, must be spatially defined to assess impacts for habitat, dredging, oil spills and pollutants, coastal and marine infrastructure. Successful fishery management, such as establishing Rockfish Conservation Areas, requires advanced biozonation definition based on seabed mapping and understanding seabed processes. Marine protected areas (MPAs) are more effective and supported when developed in conjunction with accurate seafloor mapping within a spatial planning context. Renewable energy infrastructure and regulation requires detailed seabed assessments and baseline data. Maps, data and analyses arising from this Marine Geoscience Program will be open and freely available for all stakeholders.

Mineralogy and lithology from physical properties: analysis of the Canadian rock physical property database

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Knowledge of rock physical properties provides the link that makes geological interpretation of geophysical surveys possible. It is advantageous to know the typical distributions of physical properties associated with different lithologies, and the effects of alteration and mineralization. To this end, we have been compiling the Canadian Rock Physical Property Database, which currently contains petrophysical measurements, with associated locations and lithologies, on 20 000 samples. The results are interpreted using Mike Dentith's conceptual framework for petrophysical data, which places the various rock physical properties on a ternary diagram with end members of "Bulk (Overall composition)", "Grain (Amount, Size, Shape)", and "Texture (Geometric relationships between grains)". Density is dominated by the bulk composition and porosity. Electric resistivity is dominated by porosity and permeability, which are textural properties governing water, ions and interactions with mineral surfaces. Magnetic susceptibility is dominated by the concentration of the ferromagnetic minerals, principally magnetite. Particular emphasis will be given to the "Henkel Plot", that is Log (Magnetic Susceptibility) versus Density. The characteristic bimodal distribution on this plot results from mineral assemblages and reactions for iron oxide creation and alteration. The Henkel plot provides insight regarding mineral content and geological processes. Most information on the Henkel plot can be modelled in terms of three end member mineral assemblages as: QFC: Quartz-Feldspar-Calcite (non-magnetic, low-density), FM: Ferro-Magnesian silicate minerals such as biotite (paramagnetic), and M: Magnetite (ferromagnetic), along with the porosity. The high magnetic susceptibility mode is dominated by rocks that were formed within the Quartz-Fayalite-Magnetite oxygen buffer and have survived subsequent metamorphism or alteration. Rocks within either lower or higher oxidation states lie in the low magnetic susceptibility mode. Improved understanding of petrophysical variations of common rock forming minerals, lithologies and their responses enhance geophysical interpretation and improves our understanding of background versus anomalous responses in maps and surveys.

Identification of partial melting relationships in the southern Kapuskasing Structural Zone, Ontario, Canada

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The Archean Kapuskasing Structural Zone (KSZ) is interpreted as an intracontinental portion of the lower crust uplifted and thrust eastward upon the Abitibi subprovince, Ontario, Canada. Metamorphic rocks exposed in the KSZ show a gradational change from amphibolite to granulite facies towards the east and offers an opportunity to investigate fluid behavior and partial melting processes in the middle to lower crust. Field-based observations indicate that mafic gneisses in the study area contain the widespread assemblage Amp (Hbl) + Pl + Qz ± Cpx (Di) ± Grt ± Ttn, where migmatitic mafic gneisses are characterized by a variation in modal mineralogy at outcrop scale. Variation ranging from Amp-Pl-rich to Pl-Cpx-Grt-rich layers are identify as melanosome, while Pl-Qz-rich layers are identify as leucosomes. The variety of migmatitic textures observed suggest that melt was not only generated in situ (i.e. leucosomes with margins of melanosome) but has also migrated (i.e. leucosome networks). Grt locally occurs within leucosomes but not in the mesosome, and in these cases indicate that Grt formed during partial melting (i.e. peritectic). Anhedral Pl ± Qz interstitial to granoblastic Amp occur with low dihedral angles, suggesting the Pl ± Qz may have crystallize from silicate melt. In addition, Cpx locally replaces Amp, indicating the possibility of a dehydration melting reaction, but metamorphic Cal observed in Grt porphyroblast rims and the nearby matrix suggests an environment of reduce a_{H2O}, also compatible with Cpx growing at temperatures below dehydration melting. Future work will concentrate on understanding and characterizing the PT conditions of metamorphism constraining the tectonothermal evolutions of portions of the KSZ through mineral chemistry, phase equilibria modeling and in situ geochronology.

Investigation of a potential dewatering system adjacent to the Red River in Winnipeg, Manitoba

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The City of Winnipeg sanitary waste system crosses local rivers at numerous locations, including at the Kildonan Settlers Bridge where it crosses the Red River in the northern part of the city. Originally at this location, a pipe was laid across the river bed, which resulted in movement and eventual damage to the pipe. To replace the crossing, the City proposed micro-tunneling as a method to install a pipe into the carbonate bedrock which underlies the river channel sediments. The carbonate bedrock forms an extensive aquifer system that extends throughout much of the province. In addition, the Red River has been shown to be interconnected with the Carbonate Aquifer, especially in the north part of Winnipeg. Consequently, excavation and tunnelling below the river would require a significant dewatering effort. To assess the site conditions, a total of four test wells were installed on opposing river banks. Pumping tests were conducted and groundwater sample were collected from both sites. It was determined that the potentiometric surface would need to be lowered by 24.0 m. The natural hydraulic gradient at the site was shown to be from the aquifer into the Red River. Drawdown generated by the proposed dewatering system would reverse the gradient and result in seepage from the river into the aquifer. This seepage was challenging to quantify due to the complex distribution of sediments in the river channel and a general lack of data, however, it was estimated that the required discharge rates may be increased by as much as 70 %. In addition, the drawdown cone would extend far off site and would likely impact other groundwater users. This study highlights the challenges to geotechnical projects that result from groundwater levels in the City of Winnipeg and the challenges and importance of characterizing groundwater-surface water interactions in dewatering projects.

Development of a municipal groundwater supply for the town of Niverville, Manitoba

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The Town of Niverville is located approximately 20 km south from the City of Winnipeg, east from the Red River in the Province of Manitoba. The town site is situated near a saline-freshwater boundary present in the two bedrock aquifers (Sandstone and Carbonate) which extend through the region. The carbonate bedrock has been extensively weathered and includes karstic features which have been infilled with sand. These conditions have imposed recurring challenges to water supplies in the area. Initial supplies in the town were developed from private wells, although a small municipal supply and treatment system was developed in 2002. Production from the system was gradually expanded, however, pumping at higher volumes resulted in sand infiltration. These issues prompted further research into a new well field that would have suitable quality and capacity to address Niverville's long term community growth. In a joint project between Niverville and the Manitoba Water Services Board, Friesen Drillers was retained to undertake background research for a new groundwater supply. An area several miles east from the town site was selected for testing. Several multi-level test wells were constructed to assess groundwater conditions in the carbonate and underlying sandstone aquifers, utilizing geochemical and isotope analysis. Public consultations and a detailed well inventory were carried out in the study area and selected domestic wells were instrumented with pressure transducers for monitoring purposes. A 72 h pumping test, with geochemical and isotopic groundwater sampling and analysis, was completed to assess the potential long-term impacts of the new well field. Upon final analysis, the new well field was shown to produce groundwater that was much improved in both quantity and quality from the original system. A pipeline was constructed from the well field to the treatment plant within the town. The project was granted water use and environmental act licenses.

Aquifer vulnerability and capacity within the rural municipality of Springfield, Manitoba

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The Rural Municipality (RM) of Springfield, Manitoba, located immediately east from the City of Winnipeg, is a rapidly developing municipality that is underlain by two major regional bedrock aquifers. In addition, a portion of the Birds Hill Glaciofluvial Complex, an important zone of groundwater recharge, lies within the northwest corner of the RM boundaries. Management of groundwater resources has been a priority for the RM, which has become a leader in Manitoba by including elements of groundwater management in its regional development plans. Friesen Drillers conducted a study of groundwater vulnerability and capability within the RM of Springfield to identify areas vulnerable to potential impacts from increasing residential, commercial and industrial development. The available hydrogeological data were reviewed, including maps, reports, hydrograph and groundwater use records. The major risk factors identified in the study included 1) depth to aquifer; 2) unconfined/confined aquifer conditions; 3) flowing groundwater conditions; and 4) saline/freshwater boundaries and other geochemical considerations. The vulnerabilities identified in the study were evaluated based on a modified DRASTIC approach, initially developed by the United States Environmental Protection Agency. The results were plotted using GIS software to generate a comprehensive suite of vulnerability maps. The resulting vulnerability classifications indicated areas for further study and areas where development might be regulated to reduce potential risk to groundwater. For example, residential developments in areas with unconfined conditions could be required to install holding tanks instead of septic fields. This study expands upon previous hazard mapping by providing an assessment of the various aspects of groundwater vulnerability. The final maps and report are intended to support decision makers who seek information for a variety of purposes, including construction regulation, land use designation, and water resource development and protection.

Problems with Pannotia

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Pannotia is the hypothesized supercontinent of latest Proterozoic age, but its existence is uncertain. As the Ediacaran paleomagnetic record is fraught with ambiguity, other global records can be consulted. Here I show that such additional records do not argue strongly for the existence of a Pannotia supercontinent. The hypothesis demands assembly via Pan-African collisions prior to widespread passive-margin development around Laurentia. Available timing suggests that if Pannotia existed, it must have been relatively fleeting at ca. 600 Ma. Late stages of Pan-African collisions, ranging into Early Cambrian time as documented in the Paraguay, Araguaia, Araçuai, Kaoko-Damara-Lufilian-Zambezi, Mozambique, and Pinjarra orogens, are too young to accommodate Pannotia. As a possible supercontinental proxy, the global zircon abundance record links nadirs to the tenures of Pangea, Rodinia, and Nuna; by contrast, 600 Ma marks a notable peak in global zircon records, which likely only manifests Gondwanaland assembly (not necessarily a Pannotia landmass). As a second proxy, global Hf-isotopic records are noisy and can only (at best) be interpreted in the context of recognizable interior versus exterior orogenic systems; yet the paleogeographic framework of alleged Pannotia assembly remains highly tentative. As a third proxy, global sea level does appear to show a lowstand (perhaps indicating supercontinental tenure) prior to the Cambrian transgression,

but the context of that lowstand is rendered ambiguous by the profound eustatic effects of Cryogenian glaciations. If ice ages are to be linked to supercontinental assembly, then the Cryogenian glaciations themselves could be viewed as supporting Pannotia; but the onset of those deposits are stratigraphically linked to Rodinia rifting rather than Pan-African collisions. Finally, if the Cambrian radiation of multicellular diversity is attributed to supercontinental breakup, then alleged Pannotia rifting is a poor match, as it left Gondwanaland intact and thus created only a modest increase in global passive margin length.

Geochemical characteristics of IOCG systems: examples from the Olympic Cu-Au Province, South Australia

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South Australia hosts one of the world's great iron oxide copper gold (IOCG) terranes. Termed the Olympic Cu-Au Province, this belt hosts numerous economic and sub-economic IOCG occurrences including the deposits of Olympic Dam, Prominent Hill, Carrapateena and Hillside. While studies have focused on alteration characteristics, few have provided comprehensive trace element characteristics. The Geological Survey of South Australia undertook a widespread sampling program utilising publically available drill core. These new geochemical data enable the definition of minor and rare earth element characteristics common to the range of known IOCG occurrences in the Olympic Cu-Au Province. In this presentation, we focus on geochemical characteristics of magnetite- and hematite- dominated ore systems. In magnetite-dominated ore systems, the elements Cu, Au, Mo, S, Sb, Se, Sn, Te, Th, Tl, U and LREE are significantly enriched (~ 2 times average bulk continental crust). With increasing Cu content, samples from magnetite-dominated IOCG systems become increasingly enriched in Au, Co, Re, S, Se, Te, U and LREE with minor or less consistent increases in Ag, Mo, Pb and In. Minor element values associated with hematite-dominated IOCG systems are significantly enriched compared to average continental crust for most elements. Compared to magnetite-dominated systems, hematite-rich systems have far greater enrichment in Bi, Cd, In, Mo, Mn, Pb, Sb, W and Zn. Interestingly, most of the elements depleted in magnetite-dominated systems are enriched in hematite-dominated systems, supporting the mobilisation of these elements into fluids and precipitation as conditions cool and become more oxidised. Elements associated with economic systems are similar to those in sub-economic systems, however the larger deposits show greater enrichment in Au, Ba, F, U and LREE's. In particular, an enrichment in LREE's is regarded as a significant characteristic of economic IOCG systems in the Olympic Cu-Au Province.

Caledonian strike-slip displacement in Svalbard, High Arctic: new age constraints from $^{40}Ar/^{39}Ar$ dating

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The timing of Svalbard's assembly in relation to the middle Paleozoic Caledonian collision between Baltica and Laurentia remains contentious. The Arctic archipelago consists of at least three pre-Devonian basement provinces bounded by N-S-trending sinistral strike-slip faults, but the displacement histories of these structures remain poorly constrained. Sparse $^{40}Ar/^{39}Ar$ and U-Pb ages from northern Svalbard link local strike-slip deformation to the peak, late Silurian to Early Devonian Scandian phase of the Caledonian collision, invoking orogen-scale escape tectonics. However, more recent data contradict this model, and pre- or post-Scandian assemblies have been postulated on the basis of stratigraphic, paleomagnetic and provenance studies. Here, we present microstructural and mineral chemistry data integrated with multiple single-grain fusion $^{40}Ar/^{39}Ar$ muscovite geochronology from the sinistral Vimsoden-Kosibapasset Shear Zone (VKSZ) within the Southwestern Basement Province of Svalbard and explore their relationship with adjacent structures. Our results indicate that strike-slip displacement along VKSZ occurred in the late Silurian to Early Devonian (424 ± 6 Ma), and the shear zone most likely propagated along the eastern boundary of SW Svalbard. The activity along VKSZ was therefore contemporaneous with the main phase of Scandian collision in Greenland and Scandinavia and the onset of syn-orogenic sedimentation in Silurian-Devonian fault-controlled basins in northern Svalbard. Thus, the new age constraints pose a question about possible links between escape tectonics in the Caledonian orogen and the onset of terrane transfer across the northern margin of Laurentia during the middle Paleozoic.

Host rocks of seafloor mineralization in the active Lau Basin and ancient analogs

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The Archean Abitibi greenstone belt is host to world-class Cu-Zn volcanogenic massive sulfide (VMS) deposits and continues to be a primary exploration target. However, discovery of the next generation of deposits at greater depths will rely on improved geological models. In Archean terranes, overprinting deformation and metamorphism complicate the correlation of host-rock geochemistry with mineral potential. In contrast, modern submarine volcanic systems, such as the Lau Basin of the western Pacific margin, provide the opportunity to observe active ore-forming environments, including host rock geochemical signatures and structural controls. We present a lithogeochemical investigation of the relationship between volcanic host-rock compositions and magmatic-hydrothermal mineralizing systems in the Lau Basin as comparison for the Abitibi greenstone belt. This study focuses on the geological evolution of arc rifting events and the initiation of back-arc spreading, with an emphasis on the surface expression of geological environments and the use of trace element and isotopic signatures to identify small- and large-scale mantle flow regimes. Major similarities and differences in the lithogeochemical signatures of modern and ancient host rocks are highlighted and reveal that geochemical shifts in the composition of volcanic rocks signal changes in mantle and crustal processes that may be favorable for ore formation. A complete compilation from published literature and cruise reports of data collected in the Lau Basin since 1970, complemented by a lithogeochemical database for the Abitibi greenstone belt, forms the basis of this study. This lithogeochemical study provides further insight into the development of the Lau Basin and evolution of the Abitibi greenstone belt, which are both of significant interest for industry and the academic community. Lithogeochemical signatures of mantle processes associated with ore-forming environments in the Lau Basin will help identify exploration vectors in Archean greenstone belts and target the next generation of ore deposits in Canada and globally.

An Archean source of sulfur for the Proterozoic Kiggavik uranium deposit, Nunavut, Canada

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The Thelon Basin is temporily- and spacially-related to the Athabasca Basin in Saskatchewan, Canada, which is host to the highest-grade unconformity-related uranium deposits in the world. Several uranium deposits occur within the Aberdeen sub-basin of the Thelon Basin, and

it has been suggested that these deposits may also be unconformity-related deposits. However, the genesis of the deposits is still debated and the age of the uranium mineralization event in the Thelon remains loosely constrained. Sulfide minerals contain important isotopic information regarding their environment and origin. Consequently, the sulfur (S) isotopic composition of sedimentary pyrite has been used extensively to constrain the diagenetic history of sedimentary rocks, as a proxy for microbial metabolisms and redox evolution of the Earth's oceans and atmosphere over geological time-scales. Here we use Secondary Ion Mass Spectrometry (SIMS) to measure three S isotopes in pyrite from the Proterozoic Kiggavik uranium deposit. The Kiggavik uranium deposit is comprised of three zones (the Main, Center, and East Zones) that formed from fluids at ~ 200 °C at ~ 1600 Ma. Non-hydrothermal pyrite and galena from all three zones have a wide range of $\delta^{34}S$ values from -41.2 to 37.4 ‰. The $\Delta^{33}S$ values (> 0 ‰) indicate recycling of mass independent fractionated (MIF)-S, which suggests that most pyrites associated with the Kiggavik deposit derived their S from the Neoarchean greywacke of the Woodburn Lake Group (Pipedream Assemblage) that hosts the deposit. The preservation of these anomalous $\Delta^{33}S$ values suggests that these pyrites formed from low temperature processes (e.g. bacterial sulfate reduction) rather than from hydrothermal processes. Low-temperature, high latitude fluids may have been involved in the formation of these pyrites because some of these sulfides are also associated with uranium minerals that are devoid of Pb and corroded calcite, a mineral that is soluble in cool fluids.

Groundwater and climate change: a view from the west

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Groundwater resources will be affected by climate change in a variety of ways. Recharge rates will be affected as precipitation patterns shift and evapotranspiration rates increase. Snow and frozen ground will be less prevalent. However, some of the more acute impacts will arise from increases in water demand and reduced surface water availability. Streamflow throughout much of western North America is driven by melting snowpack from high elevation, and climate change will affect the water availability in the Colorado, Saskatchewan and other watersheds. In particular, late summer flow will be reduced. Recent water shortages in the Colorado watershed are likely to result in increased groundwater use in Arizona to support irrigated agriculture. Similar issues are likely coming to other watersheds in western North America. Crop types and their water requirements in Western Canada are changing with rising temperatures and longer growing seasons. Increasing groundwater demand appears likely in the Canadian Prairies. Much of the groundwater currently used in this area is fossil with low modern recharge rates. In addition, extensive oil and gas development has reduced the amount of high-quality groundwater available in the region. The extent to which groundwater resources can mitigate shortfalls in surface water supplies is currently unclear.

Structural geology of the Chief Mountain area, Montana

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The structure and topography of the Rocky Mountain front straddling the International Boundary is dominated by the Lewis thrust sheet. Its outstanding topographic feature is Chief Mountain in northernmost Montana, about 10 km south of the border. Chief Mountain stands as an isolated mass of mid-Proterozoic carbonates of the Belt-Purcell Supergroup (approx. 1.45 Ga), rising 1400 m above the adjacent plains with near vertical faces rising 450 metres to the summit ridge. Despite its prominence and frequent illustration in geological textbooks, there is no definitive description of the geology of Chief Mountain and its surroundings. The existing descriptions and mapping are either incomplete, vague, or inconsistent and are often erroneous. However the spectacular exposure and distinct, colourful Proterozoic stratigraphy permit detailed structural and stratigraphic analysis. Chief Mountain is one of at least five klippen extending back along a ridge to the main mountain front at Gable Mountain. All are composed of mid-Proterozoic carbonates of the Waterton and Altyn Formations, thrust an estimated 90-100 km northeast over upper Cretaceous strata. These erosional remnants, and adjacent cliff faces along the main mountain front, display one of the most spectacular duplex structures in the Rockies, up to 250 m thick, involving scores of fault slices. This duplex is sandwiched between the Lewis thrust as the floor, and the broadly folded Yellow Mt. thrust as the roof. The contrast between the complexity within the duplex structure and the smoothness of the roof and floor thrusts leads us to questions about the mechanism and sequence of duplex development.

3D fully-integrated modeling of subsurface drainage flow in a Danish agricultural area

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In agricultural catchments, subsurface drainage systems consisting of tile drains are usually required in low-permeability soils such as clayey till to promote root development and increase crop yield. These systems modify groundwater flow patterns and the cycling of nutrients such as nitrates, potentially leading to shorter nitrate residence times. In Denmark, new regulation strategies based on spatially differentiated nitrogen (N) fertilizer application have been studied to reduce nitrate leaching from agriculture and achieve the water quality status established by the European Union. However, estimations of the amount of water and nitrate flowing through tile drains must be more precise to identify the fields where the N fertilizer application most contributes to the nitrate load to the surface water bodies. The purpose of this research is to evaluate different modeling settings to improve surface water and groundwater flow simulations in tile-drained catchments, which is the basis for nitrate transport models. The physically-based HydroGeoSphere numerical model has been used for 3D fully-integrated modeling in a small tile-drained area. Primary results showed better fit with observed and simulated outlet discharge and reduced simulation time by a factor of 4 when tile drains are represented as seepage nodes compared to the approach where drains are represented as 1D line elements. However, representing the drains with 1D elements led to a better representation of the water table depth, the water exchange flux between the surface and the porous medium, and the accumulation of water in the drains located in flat areas of the catchment. Although the soil in the study area contains macropores, including this feature in the model did not improve its performance. This study is expected to simplify and increase the accuracy of hydrological modeling in humid agricultural areas to support legislative demands that water-regulatory agencies might use for water management.

How using flow dimension sequences improves the reliability of pumping test interpretations?

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The discrepancy between the complexity of real flow behavior and the simplicity of analytical flow models makes the interpretation of transient well tests an ambiguous and imprecise task. Based on a restrictive assumption of radial flow, most of our models cannot properly represent the complexity of flow behaviors in real situations. Interpretation of constant-rate pumping well tests using Theis-like models can indeed lead to inaccurate assessments of the hydraulic properties of aquifers. New avenues for the analysis of data obtained from pumping well tests are opened by combining the drawdown log-derivative ds/dlog(t) plot with the flow dimension parameter n. The sequence of n reflects the geometric evolution of the cross-flow area

in the aquifer, thus expressing transitions and changes of the physical and hydraulic conditions. Considering the evolution of the observed flow dimensions with time during a pumping-test allows us to detect and interpret radial and non-radial flow regimes. First, this presentation presents how to use the diagnostic tools of ds/dlog(t) and calculate n to better characterize the complexity of aquifers. Then, we compare the drawdown log-derivative signatures of aquifers obtained with various geological configurations. Finally, we present a literature review of n-sequences and their associated conceptual models which were published in the hydrogeology and petroleum industry literature.

Addressing geoscience gaps for energy and heating projects in the Northwest Territories (NWT)

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The Northwest Territories Geological Survey (NTGS), in collaboration with the Government of Northwest Territories (GNWT) Department of Infrastructure: Energy Division, recently identified two geothermal research projects requiring additional information to better assess their development potential. These are (i) a local district heating project for the former Con Mine in Yellowknife, and (ii) a potential heating and/or energy demonstration project located near a community in southwestern NWT. In 2008, the City of Yellowknife commissioned a feasibility study to evaluate the potential for using heat recovered from deep (~ 30 °C) waters of the flooded Con Mine for a downtown district heating system. The project ultimately did not proceed to development mainly due to the considerable price tag for the proposed system. The NTGS and the Geological Survey of Canada will lead a review of Con Mine information obtained during this earlier study to identify key knowledge gaps and support additional geoscience and modelling studies. The goal of this work is to assess whether heat pumps can be successfully used to extract energy from the mine for direct heating of a conceptual industrial park located on or adjacent to the mine site. In addition, the project will investigate the potential for solar heating and subsurface storage of mine water during the summer for later use during the winter. The southwestern NWT is an area of elevated to high heat flow with a geothermal gradient of 35 °C or more per km. Although the region is considered to have high geothermal energy potential, more detailed geoscience and engineering studies remain to be done. For example, detailed reservoir characterization and geothermal gradient studies are currently lacking. This presentation will summarize previous work, knowledge gaps, and targeted research required to better evaluate the geothermal resource potential of these two projects.

Nature and origin of the hypozonal gold mineralization at the Éléonore mine, Eeyou Istchee, Baie James, Superior Province, Québec

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The Éléonore mine is a world-class gold deposit located in northern Québec. Mainly hosted by < 2675 Ma sedimentary rocks, the deposit is located 1.5 km south of the interpreted tectonometamorphic contact between the Opinaca (paragneiss to migmatite) and La Grande subprovinces (volcano-sedimentary belts and Mesoarchean basement). Ore zones at Éléonore have a diversity of styles of gold mineralization including: 1) stockwork of quartz-dravite veinlets with microcline and phlogopite alteration haloes; 2) laminated quartz-diopside veins; 3) hydrothermal breccia; 4) pegmatitic quartz-(feldspar) high-grade veins; and 5) pegmatite dykes. The multiple nature and origin of such styles of gold mineralization are discussed in the context of the tectonometamorphic and magmatic frameworks and their relationship with the large-scale auriferous hydrothermal system. Our field-based approach includes extensive detailed surface and underground mapping and core logging, which are integrated into a 3D geological model. In addition, lithogeochemistry (mass-balance calculation), stable isotope analysis (S, O and B) and LA-ICP-MS analysis of ore samples were performed to constrain the hydrothermal footprint and interpret ore-forming processes. LA-ICP-MS data support the ubiquitous presence of auriferous loellingite inclusions (with high Sb, Ni, Co, Te) within arsenopyrite overgrowths (with high Bi, Pb, Se). Our data are consistent with the presence of a hypozonal alteration assemblage (diopside, hedenbergite, phlogopite), post-ore deformation and local partial melting of the ore. Consequently, the bulk of gold mineralization at Éléonore has recorded prograde metamorphism and coeval deformation associated with migration of a migmatitic front near a major tectonic boundary. Post-ore retrograde metamorphism is also documented. The discovery of the auriferous Cheechoo reduced intrusion (ca. 2612 Ma) and pegmatite dykes (ca. 2620-2600 Ma) support the contribution of magmatic-hydrothermal fluids to the large-scale hydrothermal system present in the Éléonore mine area. In this context, gold mineralization shares analogies with hypozonal orogenic gold deposits as well as reduced intrusion-related gold systems within a "deep-earlier" tectono-metamorphic setting.

Assessing the interplay between equilibrium and kinetics in regional metamorphism

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For over a century, metamorphic petrologists have interpreted mineral assemblages as products of an equilibrium process, in which rocks only negligibly depart from their stable state as they are buried and heated. However, this does not consider that the constituent mechanisms of recrystallization-nucleation, dissolution/growth, and transport – each have energetic barriers that need to be overcome before recrystallisation can occur. For a reaction to proceed, these obstacles must be surmounted by building up sufficient energetic driving force, sometimes termed reaction affinity, that results from the overstepping in pressure or temperature of the equilibrium conditions of the reaction. Studies in contact metamorphic settings have confirmed predictions of overstepping on mineral recrystallisation. In this study, we analyse two prograde regional metamorphic sequences – a regional Buchan-type sequence in the Harpswell Neck area, SW Maine and a regional Barrovian sequence in the Whetstone Lake area, SE Ontario – in an effort to determine whether the aforementioned kinetic impediments to recrystallisation are as important in regional settings. Detailed petrographic, textural and chemical analysis has allowed determination of the sequence, spacing, and nature of metamorphic reactions in each setting. Pressure-temperature-time paths have been constructed using phase equilibrium modelling against which the natural observations are compared. The evolution of reaction affinity with overstepping, which varies markedly from reaction to reaction, is assessed against the predicted versus observed reactions. The results of this study carry broad implications for the assessment of pressure-temperature conditions, and especially pressure-temperature-time paths, of metamorphic rocks, which in turn underpin our understanding of tectonic processes.

Development of a 3D cryohydrogeological model of a small watershed in a degrading permafrost environment in Nunavik, Québec

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Numerical modelling of the impacts of climate warming on groundwater in degrading permafrost environments is a challenging

task which requires realistic 3D cryohydrogeological models. These conceptual models must be based on the Quaternary history and environment, and on knowledge of relevant periglacial processes. Geospatial information including digital elevation models and maps of Quaternary deposits, periglacial landforms and drainage networks can constrain these models. Although cross-sections and borehole logs can provide ground truthing for local stratigraphy, defining the subsurface structure based on surficial geology is a major shortcoming. The use of complementary geophysical methods such as ground penetrating radar and induced polarization can overcome this shortcoming by providing information on the bedrock topography, extent of ice-rich permafrost, and the spatial distribution of aquifer and aquitard materials. Near the Inuit community of Umiujaq in Nunavik (Québec), Canada, a small 2 km^2 watershed within the discontinuous permafrost zone was recently investigated to study the groundwater availability and dynamics. Geomorphologic, hydrologic, hydrogeologic, thermal and geophysical investigations were carried out in this watershed. The valley bottom is covered by a thick succession of Quaternary sediments overlying the bedrock. Ice-rich permafrost mounds are also found in silty marine sediments. Two aquifers were also identified: a shallow aquifer in sandy littoral and pre-littoral sediments and a deep aquifer in glaciofluvial sediments partially confined by the unit of marine silt and permafrost. All available data were analyzed, synthesized, and integrated into GoCAD to build a 3D cryohydrogeological model of the watershed. This model is the cornerstone of cryohydrogeological simulations to assess the impacts of climate warming on groundwater resources in this degrading permafrost environment. Among the very few positive impacts of climate warming in cold regions, permafrost degradation can increase the availability of groundwater as a potential source of drinking water for northern communities.

Reconstructing the holocene evolution of the Rivière du Gouffre Valley (Québec) from its sedimentary record.

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Several valleys along the St. Lawrence estuary record the complex interplay of local processes, such as flooding and channel migrations, with regional to global processes such as glacial isostatic adjustment and eustatic sea level changes. These are fluvial sedimentary successions that hold clues to the Holocene evolution of postglacial rivers. One goal of this study is to reconstruct the Holocene evolution of the Rivière du Gouffre, a 76 km-long meandering river located in the Charlevoix region (Québec), by documenting its sedimentary successions. The river occupies an ancient glacial valley formerly invaded by the Goldthwait Sea. Several landslides occurred in the valley, but intact fluvial successions are exposed along the river banks. LiDAR data, as well as available bedrock and surficial geology maps, are used in conjunction with sedimentary observations and measurements. Fourteen river bank exposures were analyzed using facies analysis methods. Results so far show a marine-deltaic-fluvial facies association with several vertical successions containing fluvial channel and floodplain deposits at variable elevations and stratigraphic positions. In some exposures, coarse channel lags or imbricated gravel deposits overlie marine sediments about one meter above modern river level. They are typically overlain by a fining-upward succession containing organic-rich beds. In other exposures, it is floodplain sediments and organic beds that occur just above river level. Interestingly, fluvial deposits overlying paleosols and organic-rich beds were observed 20 meters above river level. Altogether, these records attest to a complex evolution with several base level changes. Large fossil wood logs and other organic material have been sampled for identification and for radiocarbon dating. Results will constrain the stratigraphy of the fluvial sequence and help establish its relationship with relative sea level changes. Geophysical surveys are also planned to determine the extent and depth of these fluvial and deltaic successions away from the modern river.

Methane dynamics in fluid fine tailings in an oil sands end pit lake

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Lean oil sands and tailings deposits in the Athabasca Oil Sands Region (AOSR) of northern Alberta, Canada, can generate fugitive methane during natural in situ biodegradation of petroleum hydrocarbons. Here we examine methane dynamics within fluid fine tailings (FFT) deposited in Base Mine Lake (BML), which is the first full-scale demonstration end pit lake in the AOSR. Dissolved methane concentrations approach or reach the theoretical solubility limit within the FFT deposit. Methane exsolution (bubble formation) and ebullition (bubble rise) occurs in BML. However, the depth at which these physicochemical processes occur and their impact on chemical mass transport and FFT settlement is poorly understood. Previous studies show that pore water is expressed during FFT consolidation, driving upward chemical mass transport into the overlying water cover. These studies invoked periodic mixing (i.e. strong wave action/lake turnover) of the upper 0.5 to 1 m of FFT to simulate observed depth profiles for conservative tracers. In this study, we develop a modelling framework to explore relationships between methane dynamics and chemical transport across the FFT-water cover interface. First, we re-evaluate conservative transport utilizing a mixing depth defined by seasonal temperature cycles, which strongly influence methane solubility and therefore, exsolution and ebullition. Second, we develop a reactive transport model of methane production, exsolution, ebullition, and consumption processes. These models are being compared to physical and chemical data collected from ongoing sampling programs along with eddy covariance modelling of methane flux from the water cap. Our study will improve our understanding of methane dynamics, processes controlling chemical mass transport across the tailings water interface, and potential long-term methane emissions from an end pit lake.

Evaluating geothermal potential in Yukon Territory: a collaborative effort to characterize geothermal gradient through temperature gradient drilling in the Canadian North

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Adjacent the 'Pacific Ring of Fire', Yukon Territory is a prime candidate for geothermal energy. Major geological features such as the Tintina and Denali faults, abundant Cretaceous and Cenozoic plutonic rocks, extensive sedimentary rock cover, and numerous hot springs all suggest the possibility of elevated geothermal heat. However, no geothermal system-specific exploration has been undertaken. Our understanding of heat flow in the territory comes from limited borehole temperature readings from existing exploration wells across the territory, the majority distal to population centres. Bottom-hole temperature readings indicate elevated geothermal gradients of up to 40.4 °C/km, and possibly higher. As part of the Canadian Government's commitment to establishing clean energy in the North, the Yukon Geological Survey is collecting subsurface temperature data near communities in the southern part of the territory. The research is a collaborative effort among government geoscientists, universities, First Nation governments, and geothermal consultants. Major goals are to establish if ground temperatures warrant further geothermal exploration, and to educate the public about geothermal energy applications. This presentation will describe results of geothermal research that began in 2016 with support from the Canadian Northern Economic Development Agency. Phase 1 used existing geoscience data to determine depths to Curie Point temperature, and to identify

locations of Cretaceous-Cenozoic plutons, and its potential heat generation. Phase 2 involved drilling two 500 m temperature gradient wells: one in a crustal scale fault zone (Tintina fault), and a second near an inferred radiogenic heat source and hot spring near Whitehorse, the capital city, where surface water is 46.3 °C. Phase 3 is currently in the scoping phase with geophysical data acquisition planned to image a segment of the seismically-active Denali fault system in southwest Yukon, and further investigation of highly radiogenic plutons in south-central Yukon, in order to delineate future temperature gradient drill targets.

Stratigraphic and geochemical constraints on the paleoenvironmental and geodynamic setting of the Timiskaming-like Stormy Lake Group, western Wabigoon subprovince, Ontario, Canada

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Timiskaming-type volcano-sedimentary basins represent stratigraphic recorders of the paleoenvironmental and geodynamic setting during the terminal phases of greenstone belt evolution. This study investigates the stratigraphic and geochemical record of the Stormy Lake Group (SLG), a greenschist-metamorphosed Timiskaming-like succession that occurs ~ 50 km SE of Dryden, Ontario in the western Wabigoon subprovince. The SLG (2703-2696 Ma) is structurally juxtaposed with the metavolcanic Boyer Lake Group (~ 2720 Ma) to the north along the Mosher Bay-Washeibemaga deformation zone and unconformably overlies the metavolcanic Wapageisi Group (2730-2725 Ma) to the south. Field investigations focused on the southern boundary of the SLG where strain is low and primary stratigraphic relationships are well-preserved. Basal units of the SLG are dominated by locally derived, angular, coarse-clastic material. Overlying units are dominated by a 300 m thick conglomerate-sandstone succession that contains abundant cross-bed and pebble channel lag structures that are interpreted to reflect an alluvial-fluvial, subaerial depositional setting. These units are overlain by a 100 m thick succession of volcanic/volcaniclastic units, which include basaltic to andesitic lava flows and andesitic to rhyolitic lapilli to crystal and ash tuff. In order to assess the geodynamic significance of syn-sedimentary volcanism in the SLG, major and trace element whole-rock lithogeochemical analyses were obtained for representative samples of the volcanic series. Results show a typical fractional crystallization trend from andesite to rhyolite compositions. MORB-normalized REE patterns display high La/Yb and Gd/Yb ratios suggesting amphibole and/or garnet residue in the melt source. On Th/Yb versus Nb/Yb plots, the SLG volcanic rocks form a linear trend which parallels the MORB-OIB array that may reflect assimilation of continental crust. Thus, while the SLG formed in an alluvial-fluvial environment, similar to other Timiskaming-type basins, it also contains volcanism associated with an evolved arc and/or peri-continental setting that is not observed in comparable Archean basins.

Making indigenous connections: interdisciplinary collaboration for a more holistic approach to science

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Recent initiatives to enhance the Indigenous content of curricula at the University of Regina and universities across Canada raises questions concerning pedagogy. An attempt to "Indigenize" curricula and culture at an educational institution cannot simply be importing Indigenous knowledge into the existing "western" model. The existing pedagogical methods at canadian universities are largely inherited from a European style that evolved through their experiences, histories, spirituality, culture and values, all of which are quite different that those of Indigenous North American peoples. For example, existing divisions between Geology, Biology and Chemistry departments are well-defined and compartmentalize the content from one another due to these organizational divisions. Therefore, students do not typically receive a holistic view of these interrelated sciences, whereas a Traditional, Indigenous learning approach would treat these concepts as crucial part of a whole. This project, is a collaboration between Instructors seeking to provide students a more holistic approach to science courses through Laboratory exercises. The authors have just received funding through the "President's Teaching and Learning Scholars Program" at the University of Regina for a 2-year project whose goal is to establish connections between materials in Geology, Biology and Chemistry through the weaving of Indigenous knowledge and ways of knowing into the "western" science framework. The initial stage involves an investigative comparison between materials, identifying suitable areas for cross-disciplinary infusions. Next, we aim to build relationships in the community to work with Elders and Traditional Knowledge-Holders to bring traditional knowledge to our students. Traditional styles of teaching will also be investigated and experimentation in pedagogy will evolve guided by continued collaboration and student feedback through questionnaires. Project outcomes will be aimed at enhancing student engagement, providing a more realistic and meaningful view of the interconnectedness of subjects, and establishing relationships within the community that will benefit all involved.

The Wyoming province, a long-lived craton on the periphery of Laurentia

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The Wyoming craton is one of the three cratons, Wyoming, Slave, and Nain, with Hadean roots that lie on the margins of Laurentia. The Wyoming and Slave provinces show many similarities, most notably a widespread supracrustal sequence that formed around 2.86 Ga. It is possible that the two cratons rifted apart at 2.86 Ga and docked onto Laurentia as separate entities in the Paleoproterozoic. The Wyoming province is characterized by elevated $^{207}Pb/^{204}Pb$ indicative of cratons that have a Hadean origin. The earliest rocks contain 3.8 to 4.0 Ga detrital and xenocrystic zircon grains. The 3.82 Ga xenocrystic zircon grains from 3.4 Ga tonalitic gneisses in the Granite Mountains have Hf isotopic compositions requiring Hadean precursors. The transition from tonalitic to granodioritic plutonism is diachronous; it occurs around 3.3 Ga in the Granite Mountains and around 2.85 Ga in the Bighorn Mountains. Granitic plutonism since 2.85 Ga is dominantly magnesian and calc-alkalic, compositionally identical to Phanerozoic arc magmas. The Teton Range, on the western margin of the province, records the earliest Himalayan orogeny on Earth at 2.7 Ga, further evidence that much of the Wyoming Province was constructed by processes similar to those operating in the Phanerozoic. The latest structural and metamorphic event in the evolution of the craton was accretion of crustal fragments along structures that trend broadly NE-SW at 2.62 Ga. The latest major magmatic event was the intrusion of the peraluminous granites of the Mount Owen batholith in the Teton Range at 2.55 Ga. The Wyoming craton was accreted to Laurentia in the Paleoproterozoic, probably during the later stages of the Trans-Hudson orogeny.

Data integration of corrected Time-Domain Electromagnetics (TDEM) & LIDAR-derived surfaces across a Devonian rift basin in New Brunswick, Canada

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Northwest of Bathurst Mining Camp lies a region undergoing base metal (Zn, Ag, Pb) exploration. To better understand the subsurface

and the various signatures associated, a GIS database was created. One of the many advantages of a GIS is the ability to compile multiple datasets into one document, allowing for direct analysis between them. This data compilation includes Airborne TDEM, Vehicle Towed Electromagnetics, LIDAR DEM Imagery, and publicly available data such as surficial geology and radiometrics provided by the Government of Canada and New Brunswick. Ancillary information, such as geotechnical boreholes, can be used in tandem to improve analysis. Using the surficial analysis tools built into ArcGIS, edge features, hillshading & slope were calculated for the area. Unfortunately, the TDEM dataset had substantial complications due to unconventional pole-mounted powerline transmitters carrying large voltages into isolated areas. The noise response from these transformers overpower the geological background response resulting in contamination of derived products such as the energy envelope, tau decays and conductivity depth imaging (CDI) reducing the possibility of identifying targets of interest. The scarce use of these transformers limits previous work done to remove such noise. The development of a successful method could then be applied anywhere stationary transformer powerlines are encountered. For removal, we use a time-series approach to analyze the unique stationary noise pattern and characterize the amplitude and phase response of the noise to design a prediction deconvolution to remove the noise. The cleaned data from this project can then be used to create accurate decay constant and conductivity maps of the 39.6 km^2 area.

$\delta^{13}C$ isotopic signatures of Late Paleoproterozoic and Mesoproterozoic stratigraphic sequences of Yukon, Canada, and their correlation to the global isotopic curve

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The late Paleoproterozoic Wernecke Supergroup and the Mesoproterozoic Pinguicula Group are sedimentary successions exposed in the Wernecke and Ogilvie Mountains of Yukon, Canada. They preserve sedimentary structures and retain much of their original geochemical signature. Carbonate samples from the Gillespie Lake Group (upper Wernecke Supergroup) in the Wernecke Mountains and from the Pinguicula Group Pass Mountain and Rubble Creek formations were analysed for stable isotope geochemistry. The 1663-1600 Ma Wernecke Supergroup $\delta^{13}C$ evolution curve is relatively monotonous (0 ± 1 ‰) overall and is consistent with signatures from other Paleoproterozoic carbonate successions in northern Canada, eastern Australia, North and South China, and Siberia, and is in agreement with the 2.0 to 1.3 Ga global $\delta^{13}C$ signature. The Pinguicula Group has a maximum possible depositional age of ~ 1322 Ma, and a minimum near 1270 Ma; and therefore, its likely age is somewhat older than the 1270-1250 Ma age boundary that defines a global Mesoproterozoic isotopic shift to higher per mil values. The $\delta^{13}C$ isotopic signature of the Pass Mountain Formation (middle Pinguicula Group) displays a curve that averages -0.36 ‰ and increases to an average of +1.6 ‰ in the Rubble Creek Formation (upper Pinguicula Group). If this transition is equivalent to the globally recognized shift, then the $\delta^{13}C$ Mesoproterozoic isotopic transition may have started prior to 1270 Ma, and perhaps as early as 1320 Ma.

The insitu treatment of PFAS-impacted groundwater using colloidal activated carbon

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Poly and perfluoroalkyl substances (PFAS) have been identified by many regulatory agencies of being compounds of concern within the environment. In recent years regulatory authorities have established a number of health-based regulatory values and evaluation criteria with values for groundwater typically being less than 50 nanograms per liter (ng/L). Traditionally, impacted groundwater is extracted and treated on surface using media such as activated carbon and exchange resins. These treatment technologies are generally expensive and not efficient and can last for decades. The application of insitu remedial technologies is common for a wide variety of compounds of concern however the application of insitu technologies for PFAS is just emerging. This study involved the application of colloidal activated carbon at a site in Canada that the PFAS compounds perfluorooctanoate (PFOA) and perfluorooctane sulfonic acid (PFOS) were detected in the groundwater at concentrations of up to 3260 ng/L and 1450 ng/L, respectively. The shallow silty sand aquifer was anaerobic in nature with groundwater flow velocities of approximately 2.6 m/d. The colloidal activated carbon was applied using direct push technology resulting in the removal of the PFOA and PFOS to concentrations below 30 ng/L over an 36-month period. Analysis of other PFAS post injection also showed that all of the compounds analyzed were below their respective method detection limits with the exception of perfluoroundecanoic acid (PFUnA) which was detected at 20 ng/L after 18 months. Detailed examination of cores taken post injection indicated that the colloidal activated carbon was successfully distributed within the target zone of the impacted aquifer with the activated carbon being measured up to 5 metres away from the injection point. The results of the study suggested that colloidal activated carbon could be successfully applied to address low to moderate concentrations of PFAS within a shallow anaerobic aquifer.

Setting and characteristics of Au-Ag-Cu-Zn volcanic-hosted mineralization in the Tireo belt, Dominican Republic

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The Greater Antilles Cretaceous arc-related volcano-sedimentary successions on the island of Hispaniola are host to a number of Au-rich deposits that have been the subject of debate as to whether their origins are submarine (VMS) or subaerial epithermal. This includes Pueblo Veijo, the largest gold deposit in the Caribbean. The Los Palmas segment of the Tireo belt of the Cordillera Central of the Dominican Republic is host to the Au-Ag-Cu-Zn Romero deposit and a number of stratigraphically equivalent, evenly-spaced occurrences of similar character. The Tireo mineralization is hosted within a succession of mafic to intermediate effusive flows and proximal to reworked volcaniclastic units. This lower Cretaceous succession is characterized by LOTI island arc tholeiitic magmas erupted during submarine nascent arc development. The Tireo group evolved compositionally up-section through various stages of more calc-alkalic island arc development up to the Cretaceous-Eocene transition. Subsequent plate collision and ocean floor-arc accretion resulted in SW-verging fold-thrust stacking and low grade regional metamorphism. Geological relationships, deposit morphologies, alteration, and geochemical/isotopic characteristics strongly suggest that the lower Tireo group Au-Ag-Cu-Zn mineralization formed as shallow water, syngenetic sea floor deposits. Evidence of shallow water VMS formation includes a predominance of open space and chalcedonic silica-sulphide vein stockworks associated with replacement sulphide bodies, and a predominance of sericite-illite-pyrite alteration within a chlorite-smectite halo containing anhydrite-gypsum veins and nodules with a seawater sulphate signature. The tops of the mineral occurrences are overprinted by jasper veins and infillings. The Au associations vary from Cu-Au through Au-Zn, Au-Ba to Au-Pb-As suggesting varying Au activity as both chloride and bisulphide complexes.

Geothermal potential of Anticosti sedimentary basin, Québec

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Anticosti Island is located in the Gulf of St. Lawrence. A first estimate of its geothermal potential was done in an effort to develop renewable energy technologies in out-of-grid areas. Geothermal resource was quantified using a numerical heat transfer model based on a 3D geological model, simulating heat conduction. The Anticosti sedimentary basin consists of an upper Ordovician to lower Silurian carbonate platform which unconformably overlies a Precambrian basement. A 3D geological model of the basin, integrating data from 24 oil and gas exploration wells as well as public seismic lines, was built with eight distinct geological units, mainly composed of limestone, dolostone and shale. Thermal conductivity and internal heat generation rate of the geological units were derived from geological descriptions, with a theoretical value for each lithology. The near surface undisturbed ground temperature (first type boundary condition), was calculated from a global correlation using meteorological data. A constant heat flow of 15 mW/m^2 was assumed at Moho depth (40.5 km; second type boundary condition). Available bottom-hole temperature data were corrected for drilling disturbances and paleoclimatic effects. Heat generation rate of the basement was analytically calculated at the location of the 24 wells, interpolated in 2D and included in the model. Vertical side boundaries were considered adiabatic and heat convection was neglected. The 3D heat conduction model was solved in steady state with the finite element method using FEFLOW. Results show that the most promising temperature anomaly (in the southeastern part of the island) reaches 120 °C at 4 km depth. In Port-Menier, the only village on the island, this temperature is reached at about 5 km depth. Direct geothermal heating appears more feasible that power generation with 57 °C reached at 2.1 km depth. Ongoing lab measurement of rock thermal conductivity will allow improving the model's parameters and realism.

Investigating the groundwater impact on the quantity and the quality of a surface drinking water source with an integrated hydrological model: the case of the Nelson River Watershed (Quebec)

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The protection of drinking water resources is a challenging task, involving a deep understanding of both surface water and groundwater dynamics and how they interact. A large research project is currently in progress, with the objective of providing useful tools to decision makers regarding the assessment of groundwater role in the quantity and quality of the surface water sources of Quebec City. The present study focusses on the Nelson river watershed (70 km^2) which is part of the major drinking water source watershed of Quebec City. Contaminant transfers result from a combination of complex process interactions, and surface/subsurface exchanges are particularly difficult to evaluate at the watershed scale with field measurements. Spatialized physically based models are useful to describe interaction mechanisms, provided that their parameterization is ensured by a representative database. The objective is thus to investigate the links between groundwater and surface water with the 3D modelling tool HydroGeoSphere, assessing surface/subsurface coupled water flow and contaminant transfer. The Nelson watershed model is calibrated with surface discharges and water table level measurements. Multi-annual simulations based on daily meteorological data are performed and output variables such as distributed infiltration and recharge, preferential flow pathways, or contaminant migration times, are analysed to deepen the understanding of surface/subsurface interactions in this particular context. The seasonality of these processes is as well examined.

Ice-flow reconstruction of southwestern Hudson Bay, Manitoba, Canada

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We present a reconstruction of a 10-phase ice-flow history from southwestern Hudson Bay in northeastern Manitoba (Canada), a dynamic region situated between two major ice dispersal centres of the Laurentide Ice Sheet. The study area is comprised of a substrate that varies from hard bed (Precambrian Shield granitoids and greenstones) to soft bed (Paleozoic carbonate bedrock and pre-existing glacial sediment), which provides the opportunity to examine the glacial record across both terrains. We utilize a diverse dataset including 1900 outcrop-based ice-flow indicators, 12 streamlined-landform flowsets, esker and meltwater corridor orientations, 103 till fabrics, and 1344 till-clast lithology counts. The glaciated landscape we document is fragmented, and forms a subglacial bed mosaic of coherent erosional and depositional assemblages that record both shifting ice-flow dynamics through time and shifting subglacial conditions. Our reconstruction suggests that both a pre-Marine Isotope Stage 2 (MIS2) and MIS2 glaciations followed similar growth patterns, where ice advanced into study area from the east (probably in northern Quebec), followed by a switch in ice-flow direction indicating flow from the Keewatin ice centre to the northwest and north. This was followed by widespread SW-trending ice flow in both pre-MIS2 and MIS2 glaciations.

Petrogenesis of intrusive rocks in the vicinity of the Teahan and Lumsden base metal prospects, Caledonia Highlands, Southern New Brunswick: implications for mineralization

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Quartz-carbonate veins containing Cu-Zn-Ag-(Pb) mineralization occur at the Teahan and Lumsden prospects in the eastern Caledonia highlands in southern New Brunswick. These veins are hosted by highly deformed volcano-sedimentary sequences of the Neoproterozoic Broad River Group that have been intruded by several plutons ranging in age from ca. 625 to 615 Ma including the Pollett River Granodiorite and spatially associated mafic rocks, Blueberry Hill Granite, Kent Hills Granodiorite, Rat Tail Brook Granodiorite, Forty Five River Granodiorite, Goose Creek Tonalite, and granodiorite/diorite/gabbro near the Teahan prospect. They all exhibit a deformational fabric with the Blueberry Hill Granite being the most intensely deformed. Major- and trace-element geochemistry shows that the Blueberry Hill Granite is distinctly different from the other granitoids as it contains higher SiO_2, K_2O, Rb, Ba, and Th, Pb, Ce, and lower TiO_2, MgO, CaO, Fe_2O_3, P_2O_5, Sr and V. Despite inter-intrusion variation in petrochemistry, the granitoid intrusions are likely petrogenetically interrelated, whereas the mafic intrusives may not be related to the granitoids. Tectonic discrimination diagrams indicate that these granitoids were formed in a volcanic arc setting. The mafic intrusions in the area have a tholeiitic magmatic affinity, their chondrite-normalized REE patterns show a less evolved magmatic system relative to the calc-alkaline granitoids that have a steeper REE profile, and they are moderately enriched in light REE. The Pollett River and Blueberry Hill plutons contain accessory magnetite and pyrite whereas the Teahan area granodiorite-diorite-gabbro bodies contain accessory chalcopyrite and pyrite. Based on the Mo/Cu and Rb/Sr ratios, the Pollett River Granodiorite, Kent Hills Granodiorite, and the Teahan area granodiorite/diorite are favourable for possible associated porphyry Cu mineralization. However, the Teahan Cu-Zn-Ag-(Pb) mineralization is unrelated to these granitoids since the $\delta^{34}S$ values of sulfides range between 12.4 and 20 ‰, thus indicating a sedimentary source of the sulphur in the ore-forming fluids.

Stratigraphy of Mount Sharp, Gale Crater, Mars, as seen by the APXS

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Stratigraphy was one of the key drivers for the selection of Gale Crater as landing site for the Mars Rover Curiosity. The flanks of the 5 km high central mound (Mount Sharp) show evidence from orbit for a sequence of hematite, clay and sulfate minerals that could shed light on the earliest habitable environment on Mars and its transition over time to the arid conditions of today. The Canadian built alpha particle X-ray Spectrometer (APXS) continues to document the chemical composition of the bedrock, as well as float and soils. So far, the APXS has measured ~ 700 dime sized samples during the ascent from the landing site in the plains over an elevation of 380 m. At Yellowknife Bay, the lowest point close by the landing site, clays were detected by the science payload of the rover. This area shows clear evidence for a habitable environment when the sediment was deposited. At Pahrump Hills, the foothills of Mount Sharp, for the first time the Murray Formation was encountered. It stretches up to and actually includes the Vera Rubin Ridge (aka Hematite Ridge) with a very constant chemical composition, interpreted as a lake sediments. Small changes in chemistry with elevation, mainly in Fe, Mn and a few other elements likely represent changes in the water chemistry and pH conditions. The Murray Formation is clearly distinct from the eolian Stimson Formation, which is similar in composition to modern soil. Both bedrocks show localized alteration trends with elevated Si, Fe, Mn, P and Cl, in addition to the ubiquitous late stage $CaSO_4$ veins. Details of the chemical trends with elevation and alteration trends will be discussed. By the time of the conference, first results of the Clay Unit might be available, which is just a few 100 meters ahead.

Breccias and anatexis in the footwall of the Sudbury impact structure

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Breccias are abundant in the footwall basement rocks of the Sudbury Igneous Complex (SIC), and multiple processes may be involved in their formation. Breccias near the SIC contact either formed by shock brecciation during the 1.85 Ga Sudbury impact event, by partial melting during the cooling of the impact melt sheet (i.e. the SIC), or by a combination of both processes. The matrix of some breccias has an igneous texture, suggesting a melt component in their formation, but the origin of this melt remains uncertain. This study focuses on phase equilibria modelling and detailed mapping of well-exposed breccias in the immediate footwall of the SIC (< 200 m) in the southwest area of the Sudbury impact structure. The outcrop comprises thermally metamorphosed, brecciated basalt, dacite, and minor subfeldspathic arenite. Phase equilibria modeling and the presence of crystallized partial melts in the metabasalt support high-temperature metamorphic conditions during metamorphism of these rocks, despite the absence of orthopyroxene in the mineral assemblage. Discontinuous, sub-meter wide breccia dikes intrude the metabasalt, and are interconnected with partial melt patches and veinlets in the surrounding rocks. This textural relationship suggests that the breccia dikes may have formed by crystallization of partial melts extracted from the immediate or nearby host rocks. This study integrates mapping, phase equilibria modelling, petrography and geochemistry to determine the role of thermal metamorphism and anatexis in the formation of breccias in bimodal metavolcanic rocks immediately underlying the SIC. The results of the study will ultimately further our understanding of brecciation processes in ancient impact craters containing a melt sheet, and in contact metamorphosed host rocks surrounding large igneous bodies.

Variation of trace elements in magnetite from volcanogenic massive sulfide deposits of the Matagami mining camp, Canada: implications for mineral exploration

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Magnetite is a common accessory mineral in volcanogenic massive sulfide (VMS) deposits. Recent studies show its potential use as a mineral indicator for exploration, based on the trace element signature of magnetite from numerous VMS ore deposits worldwide. However, the origin and timing of magnetite in VMS deposits is not well understood and this could influence the signature of magnetite. This is the first detailed study to investigate the spatial distribution and the geochemical variation of magnetite at the deposit scale, using the Zn-rich mining camp of Matagami (Abitibi, Quebec) as an example. Matagami is an ideal case study because a) the abundance of magnetite varies from accessory amounts (3 %) to massive magnetite pods (80 %) and b) magnetite is present in all three ore types (Zn-, Cu- and Fe-rich). Importantly, the five deposits studied occur at the same stratigraphic level (felsic volcanics), thus eliminating the influence of host and leached rock composition on the chemistry of magnetite. Our approach combines 3D modelling of the magnetite, detailed petrography and in situ trace element chemistry, by laser ablation ICP-MS, of magnetite and co-existing sulfides. Although there is a wide variation in magnetite textures, from macro- to microscale, magnetite composition is relatively homogenous at the thin section scale. However, ore type has a strong control on the trace element composition of magnetite. Therefore, once a VMS signature is identified in detrital magnetite it should be possible to determine, using Ga, Ge, Ti and V in particular, if is it from an economic ore zone (Zn- or Cu-rich) or from a sterile zone (Fe-rich). The overall chemical signature of magnetite from Matagami is similar to that from the worldwide dataset, but VMS hosted in mafic volcanics appear to have higher mafic element contents (Ni, Co, Cr) in magnetite than those from felsic-hosted deposits.

Hydrogeology of channel systems within Early to Middle Wisconsinan sediments, south-central Ontario

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Aquifers utilized for private and municipal supply within south-central Ontario occur within Early to Middle Wisconsinan sediments, specifically the Thorncliffe and Scarborough Formations. These formations, including the Sunnybrook Drift, are often referred to as Lower sediments. These deep Lower sediments are replenished by vertical groundwater flow through overlying aquitards including the Newmarket Till and/or silt-clay rhythmites of the late Thorncliffe Formation. Subsequent channelization episodes (Middle and Late Wisconsinan) characterized by fining-upward sequences are interpreted to have locally breached the overlying aquitard sediments. The current conceptual model considers two generations of roughly north-south channels: older pre-Newmarket Till channels within Lower sediments (termed Thorncliffe channel; ~ 20 ka) and younger post-Newmarket Till Oak Ridges Moraine-related channels (termed ORM channel; ~ 14 ka) that incise both Newmarket Till and Lower sediments. The 'Yonge Street Aquifer' (YSA) has been utilized for water supply since the mid-1900s, and is interpreted to occur within a Thorncliffe channel. These channel deposits consist of fining upward transitions from coarse gravel, to sand, to rhythmically bedded silt and

clay interpreted to be deposited within a channel-esker-subaqueous fan complex. The Thorncliffe Formation contains a wide range of facies assemblages characterized by contrasting permeabilities. The deposits with highest permeability occur within up to 80 m thick gravel and sand sequences at the base of the Thorncliffe channel. The response of piezometric levels to hydraulic stress confirms longitudinal connection along the channel with muted lateral hydraulic response in sediments outside channels. The YSA is considered a semiconfined (leaky) strip aquifer with observed transmissivities between 1500 to 4500 m^2/d, in contrast to regional aquifer transmissivities that are less than 500 m^2/d. Thorncliffe channels are interpreted to be up to 20 km long and approximately 2 km wide. This talk will explore the locations and characteristics of interpreted Thorncliffe channels within the study area.

Evaluation of the anisotropy of hydraulic conductivity by electrical resistivity tomography

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To have a good understanding of groundwater flow and mass transport, it is essential to characterize accurately the ground permeability. Hydrogeophysics (the use of geophysical methods to estimate important parameters to hydrological investigations) is a relatively recent geoscientific field that has shown promising results for hydrogeological characterization. Among existing methods, Electrical Resistivity Tomography (ERT), which allows for large underground sections or volumes coverage, is commonly used. Various theoretical, empirical or statistical means already relate electrical resistivity values to permeability values. Consequently, electrical anisotropy should be a proxy for hydraulic anisotropy. However, existing hydrogeophysical inversion tools do not generally consider these anisotropies. This study presents an anisotropic electrical forward and inverse modelling tool for the characterization of anisotropic permeability. First, we briefly present the theoretical basis of the involved physical processes and their numerical implementation. Then, we put our tool into practice on a realistic synthetic model to show its ability to efficiently characterize the ground's electrical resistivity and its anisotropy. Finally, we present a real case study on which various electrical methods have been carried out, including the anisotropic ERT we developed. This study allows to compare the different results that they provide and the relations linking them, justifying an integrated hydrogeophysical approach. These results suggest that anisotropy should be considered in any characterization study when its presence is assumed or proved, in order to provide more accurate and realistic groundwater and mass transport models.

Optical Borehole Televiewer image enhancement for mineralogical purposes

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Several factors control the physical properties measured for a given rock-mass. Crystallographic texture, lithology, granulometry, the presence of associated gangue minerals with similar physical properties, alteration and structural events (e.g. fractures and veins); all manipulate the physical response. As known by all geologists, visual texture is one key characteristic in order to infer the lithology types of rock samples. Texture is the physical appearance of a rock or the spatial relationship amongst rock components. It can be quantified by crystal size distribution, grain size, shape, and mineral arrangement. Definition of textural patterns into various classes helps to determine their impacts on the rock's physical properties. In geological core logging, information related to lithology, mineralogy, and texture is currently qualitatively described by geologists, a time-consuming task that is human dependents. However, it is possible to produce a reproducible quantitative textural interpretation of rocks by using cameras. For example, in-hole imaging systems like Optical Borehole Televiewers (OTV) allow for continuous high-quality and high-resolution imaging of the wall of a drill-hole in 24 bits RGB true colors. Borehole conditions, however, can still affect the clarity of OTV images and their quantitative description. We developed an algorithm to remove the visual effect of substances that partially covered the OTV camera window. These enhanced images permit to improve the textural description. We applied our methodology to OTV data collected on the Kipawa project, a rare earths deposit enriched in heavy REEs. We were able to produce mineral maps by automatic pixel clustering based on color and calculated the percentage of minerals in the ore. Our prediction was compared with the visual description and shows a good agreement.

Tectono-stratigraphy and facies architecture of the Tonian Hematite Creek and Katherine groups, Wernecke Mountains, Yukon

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We present a new sequence stratigraphic and facies architectural model for the ca. 900-850 Ma Hematite Creek and Katherine groups (lower and middle Mackenzie Mountains Supergroup, respectively) in the Wernecke Mountains of east-central Yukon, Canada. This ~ 3 km-thick internally conformable succession provides a virtually continuous tectono-sedimentary record spanning the putative "stable" configuration of supercontinent Rodinia. In the southern Wernecke Mountains, ~ 600 m of previously undocumented mudstone facies with minor debrite and authigenic dolomite horizons underlie and grade upwards into "typical" Dolores Creek Formation sub-littoral black shale and stromatolitic bioherms. In conjunction with a Re-Os isochron age from the upper Dolores Creek Formation, this newly described deep-water succession indicates that a substantial basin-forming event affected the region prior to ca. 900 Ma. Southward prograding stromatolite reefs in the south and back-reef facies in the north characterize a south-facing shoreline through the Dolores Creek Formation. This bathymetric trend persisted throughout deposition of the overlying Black Canyon Creek Formation, which comprises cyclic peritidal carbonates with a higher proportion of subtidal facies in the south. The Black Canyon Creek Formation transitions into the Tarn Lake Formation where fine-grained quartz sand and siltstone facies predominate. The Tarn Lake Formation represents a storm-dominated coastline fed by an influx of siliciclastic sediment eroded from recently generated topography. The Tarn Lake Formation is transitional into the overlying Katherine Group, which is ~ 1500 m-thick in the Wernecke Mountains. Intervals of thick-bedded quartz arenite alternate with finer-grained heterolithic facies, which we interpret to represent the combined effects of relative sea-level change and lobe-switching within a wave-dominated delta. The sequence stratigraphic architecture of this succession defines Tonian basin formation in NW Laurentia and will improve regional lithostratigraphic correlations across northwestern Canada. Ultimately, these interpretations will enable construction of an integrated model for the early Neoproterozoic tectono-stratigraphic evolution of northern Laurentia.

Chemistry of detrital gold grains as footprint discrimination tool in drift exploration

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Gold grain counting is the prime grassroot exploration technique for gold in glaciated terrain. Conventional approach is quite artisanal and usually limited to concentrating the heavy minerals and counting the grains underneath a stereomicroscope and estimating their size and shape. Recent advances enabled the automation of the method, using a scanning electron microscope to detect and counts the grains. Alongside with detection procedure, an EDS-SDD semi-quantitative chemical analysis is acquired for each detected grain to proof them. Approximately 53 700 analyses were acquired on gold grains in last two years, from all over the eastern Canadian Shield, of which approximately 15 % are chemically distinctive. The procedure enables a detection limit in the order of 1 % weight for metallic contaminant, such as silver, copper, PGE, bismuth, mercury, nickel, lead, etc. Gold chemical signature is distinctive, both on a regional scale down to a very local scale. Various deposits typically have their own signature, such as the mercury enrichment in Hemlo camp, nickel in Timmins area or copper in Eleonore mine. Chemical signature typically refers to specific metallogenic environment, such as copper in magmatic systems such as porphyries, mercury in low temperature orogenic system, or PGE in deep-seated deposits. It is quite common that individual mineralized occurrences have distinctive chemical signatures that enhance their contrast with distal background signal, or even enable discrimination of multiple dispersion trains within a single survey. Subtitles can be discriminated in noisy surveys affected by elevated distal background, enabling detection of individual dispersion trains otherwise not detectable. A review of the methodology and various case studies will be presented.

SEM-Based automated mineralogy: a comparative between the particle segmentation and clustering approaches

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Detection of non-visually distinctive indicator minerals remains the main drawback of the heavy mineral approach in exploration. Two SEM-based automated approaches are currently under evaluation, either through particle segmentation or EDS clustering. The current tests were conducted on a Zeiss Sigma 300-VP FEG-STEM equipped with a single Oxford Instruments Ultim-Max 170 EDS-SDD detector. The first approach discriminates the particle based on their BSE brightness, and conducts a point EDS analysis on their centroid. Contrarily to a MLA, each EDS spectrum is fully deconvoluted into chemical analysis, from which atomic proportion are computed. Mineral classification use the shortest Euclidian distance to theoretical mineral in the stochiometry space. Approximately 20 000 mineral analyses can be performed per hour, with a detection limit in the order of 1 % on light elements. The drawback of the method is the very large dataset it generates, a quarter million analyses per day. The second approach is based on a swift EDS scan of the sample, acquiring a spectrum per pixel, similarly to a QEMSCAN. Pixels are then clustered based on their similarities, regardless of their spatial distribution. EDS counts from similar spectrums are added and deconvoluted into near quantitative chemical analyses which are classified into minerals with the aforementioned algorithm. Only abundance of mineral species and their chemical composition are reported. Particle can be segmented by post-processing with image analysis software. Clustering algorithms are sensitive enough to discriminate phases with compositional difference of less than 1 % if required, with a resolution limit of a few pixels out of 3-5 millions. It is currently estimated that this method can be 5X faster than visual sorting, aside of being capable to detect a single grain of non-visually discernible minerals out of a million particles. Result from a recent till survey using both methods will be presented.

Latest news on pink and red spinels in marble from Mogok (Myanmar) and Luc Yen (Vietnam)

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Following the first oxygen isotopic data base of red spinels worldwide in marble deposits and placers presented in a previous work, the present work focusses on: (1) new $^{18}O/^{16}O$ data on spinels from Mogok (n = 3), Luc Yen (n = 1) and Hunza valley (n = 1) obtained by laser-fluorination, and (2) the oxygen isotope systematics for co-existing pairs of gem-spinel and calcite in marble from Luc Yen investigated in order to characterize the O-isotope fractionation between calcite and spinel. The O-isotope compositions ($\delta^{18}O$ in ‰ relative to V-SMOW) of three spinels of Mogok originating from the Dattaw, Mansin, and Kadote-tat mines are respectively 24.2, 23.9, and 25.7 ‰. These $\delta^{18}O$ values are higher than those previously defined for spinels from the Mogok area (19 ‰ < $\delta^{18}O$ < 22.8, n = 4) but strengthen the high $\delta^{18}O$ values range of these spinels with a mean $\delta^{18}O$ value of 22.9 ± 1.9 ‰, n = 7). The $\delta^{18}O$ value at 13.2 ‰ for a Cong Troi spinel fits within the lowish ^{18}O range defined for these spinels. The first $\delta^{18}O$ value at 22.3 ‰ obtained for a pink spinel from the Hunza valley confirms the buffering of the metamorphic fluids by the oxygen isotope composition of the marble. The O-isotope fractionation between calcite and spinel ($\delta^{18}O$cc-sp) was determined by analysis of sample pairs from several deposits in the Luc Yen area in northern Vietnam. The $\delta^{18}O$cc-sp = 3.7 ± 0.1 ‰ for six samples from the An Phu and Cong Troi deposits is remarkably constant. The combination of these data with those obtained on calcite-spinel pairs of Paigutan (Nepal, n = 2), Ipanko (Tanzania, n = 1) and Mogok (Myanmar, n = 2) are also consistent, overall $\delta^{18}O$cc-sp of 3.6 ± 0.25 ‰ for all the spinel samples (n = 11) with an excellent straight line correlation: $\delta^{18}O$cc = 0.96 $\delta^{18}O$sp +4.4.

Deciphering prograde, peak and retrograde metamorphism in the ~ 2.1 Ga Mistinibi Complex, Canada

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Burial, heating and exhumation rates in orogens, and the resulting metamorphic gradients, are thought to have undergone secular changes from Archean to modern times, although global trends remain unclear. In this context, the 2.1 Ga granulite-facies Mistinibi-Raude Domain, located in the South Eastern Churchill Province, Canada, offers a rare exposure of Rhyacian high-grade supracrustal sequences (Mistinibi Complex). Petrochronological investigations of these rocks was integrated as P-T-t-X paths and provide first order burial and exhumation rates and metamorphic gradients for the transient Paleoproterozoic times. Even if geochronometers are commonly used, interpretation of their behaviour in anatectic conditions is still challenging, with a notable lack of control on the timing of prograde metamorphism. Here, we present results of coupled multi-phase geochronology: Lu-Hf on garnet and U-Pb on zircon and monazite, integrated with detailed petrography, trace element chemistry and phase equilibria modelling. Our results indicate a clockwise metamorphic path involving significant melt extraction from the metasedimentary protoliths, followed by isobaric cooling from ~ 815

°C to ~ 770 °C at ~ 0.8 GPa. The timing of prograde burial and cooling from supra- to sub-solidus conditions is constrained through garnet, monazite and zircon petrochronology at 2150-2120 Ma and ca. 2070-2080 Ma, respectively. These results highlight a long-lived residence at mid-crustal supra-solidus conditions (~ 70 Ma) for the Mistinibi supracrustal rocks, with preserved prograde, peak and retrograde suprasolidus monazite and zircon. We also argue for prograde crystallization of peritectic zircon. We calculate slow burial rates (0.25-0.30 km/Ma) along a high metamorphic gradient (900-1000 °C/GPa) in agreement with other Paleoproterozoic orogens. The Mistinibi Complex did not record any significant metamorphism after 2070 Ma, despite being now surrounded by terranes that have recorded high-grade metamorphism during the gigantic ~ 1900-1800 Ma Trans-Hudson orogeny. The Mistinibi Complex would therefore represent a remnant of a local early paleoproterozoic metamorphic infrastructure, later preserved as superstructure in the Trans-Hudson orogen.

A cryptic metamorphic discontinuity in the Paleoproterozoic New Quebec Orogen: overthrusting of the foreland basin revealed by integrated petrochronology

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The South-Eastern Churchill Province, accreted and deformed in a transpressional regime during the Paleoproterozoic Trans-Hudson Orogeny, is among the best exposed remnants of transitional tectonics between Archean and modern dynamics. Determining its thermal regime and the pace of vertical movements in its wedge are key to understanding Paleoproterozoic tectonics. The accretionary New Quebec Orogen (NQO, 1.82-1.77 Ga) is located on the western part of the province and resulted from the oblique collision between the Superior craton and the Core Zone (CZ), while the Torngat Orogen (TO), on the eastern edge of the province involved the CZ and the North Atlantic Craton. NQO incorporated the Rachel Laporte Zone (RLZ) which transitioned from a continental forearc basin to a collisional foreland basin. We present the results of an integrated study, using petrography, phase equilibria modelling and petrochronology, of supracrustal rocks in the RLZ and CZ and interpret results in light of known pressure-temperature-time constraints at the Churchill Province scale. The RLZ experienced a clockwise hairpin metamorphic evolution, with a peak at 650 °C/0.7 GPa. Our estimate of the metamorphic peak for restitic granulites from the pervasively migmatized CZ is 790 °C and 0.72 GPa before isothermal decompression. Petrochronology in the CZ yields an age of 1836 ± 5 Ma for prograde garnet growth and 1807 ± 4 Ma for crystallization of zircon from the anatectic melt followed by rapid cooling recorded by rutile at 1798 ± 16 Ma. The RLZ exhibits metamorphic zircon ages from 1834 to 1837 Ma, i.e. older than garnet growth at 1804.4 ± 7.5 Ma and monazite crystallization at 1796 ± 4 Ma. We therefore interpret the zircon with ca. 1835 Ma overgrowths as detrital in the RLZ basin, eroded from the western CZ, while eastern CZ was exhuming. Our results suggest a phased sequential burial of supracrustal sequences along a Barrovian gradient during the NQ orogeny, with progressive recycling of inner zones in the foreland basin and subsequent involvement of the latter in the orogenic wedge, with a characteristic time of ca. 30 Ma, substantially longer than in modern orogenies.

Assessing the magma-loading model for prograde metamorphism in continental arcs: a case study from Harrison Lake, British Columbia.

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The Coast Cascade Orogen (CCO) along the western margin of North America preserves a record of continental growth by both terrane accretion and arc magmatism in the Mesozoic and early Cenozoic. The near-contemporaneous timing of crustal thickening and pluton emplacement across the orogen have led others to suggest that the prograde increase in pressure recorded by metamorphic rocks was primarily a result of magma-loading rather than crustal thickening. In this model, high-grade metamorphism is driven by extensive granitic plutonism intruded above the metamorphic rocks that are now exposed at the surface. The aim of our study is to test the validity of the magma-loading model by constructing P-T-D paths from metasedimentary rocks along a transect in the Harrison Lake area of southern British Columbia and comparing these to the results of endmember thermal-mechanical models for crustal thickening and magma over-accretion. The geology in Harrison Lake provides an excellent opportunity to study the evolution of the Coast Cascade Orogen with well-exposed low to high-grade metamorphic rocks as well as plutons, folds, and shear zones. We collected material along a West-East transect that crossed three metasedimentary units that were juxtaposed during terrane accretion and terminated in the late Cretaceous Urquhart pluton. Pelitic samples record wide ranging metamorphic conditions from biotite (~ 470 °C) through to sillimanite-K-feldspar grade (~ 700 °C). Additional P-T-d evidence, gained from quartz microstructures, indicate deformation related to crustal thickening continued during and after the magma-loading. Our preliminary results suggests that while magma-loading contributes a significant, yet short-lived, thermal input to the surrounding metamorphic rocks, it is the crustal thickening during terrane accretion that primarily drives the prograde pressure increase in the orogen.

Paleomagnetism of 1.96 Ga Rifle Formation in Kilohigok basin, NU, Canada: archive for early geomagnetic field reversal hyperactivity and true polar wander?

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The Paleoproterozoic Rifle Formation consists of decameters-thick red siltstone and was previously dated at 1963 ± 6 Ma by an intercalated volcanic ash bed, showing high potential for a paleomagnetic study. Two parallel sections with stratigraphic thicknesses of ~ 25 m were sampled every ~ 1 m starting from the lowermost Rifle strata in well-exposed sections NE of Bathurst fault. Antipodal remanence directions identified by thermal demagnetization define 8-10 magnetozones in both sections. Given that the underlying Hackett Formation is 1969 ± 1 Ma, and the zircon age of Rifle Formation is from the uppermost layer, sedimentation rate is not extremely slow and cannot account for high reversal frequency. Spotty remagnetization is also considered unlikely because statistically, samples no systematic difference between two antipodal directions (magnetic susceptibility, unblocking temperatures of characteristic remanence, color of samples, etc.). Taken at face value, the data indicate possible geomagnetic field reversal hyperactivity in Paleoproterozoic time. Furthermore, paleomagnetic declinations of our data largely differ from a previous study from Rifle Formation, SW of Bathurst fault. The old Rifle pole, together with younger 1.9-1.8 Ga poles from Slave craton, delineate an arcuate polar path that has been proposed as evidence for true polar wander. The discrepancy between old data and ours can be satisfyingly explained by true polar wander if old samples and ours are from different stratigraphic levels of Rifle Formation, or if the formation is significantly time-transgressive. Close temporal association of geomagnetic field reversal hyperactivity and true polar wander has also

been noticed in younger periods (Ediacaran and Jurassic), perhaps shedding light on heat budget variations in Earth's deep interior. Future study will include a resampling of known Rifle Formation sections, and a complete, high-resolution sampling of thicker sections in Bear Creek Hills.

Acritarch-like eukaryotic microorganisms from the 1.9 billion-year old Gunflint Chert, Canada

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Fossil data for the presence of eukaryotic life in rocks older than 1.8 billion years ago have been a matter of debate due mainly to the lack of preserved membrane-bounded nuclei or organelles. Similarly, the previously interpreted eukaryotic microfossils in the 1.9 billion-year old Gunflint Chert have severe cellular/organic degradation but lack convincingly imaged eukaryotic cellular structures. In this study, we use extended-focal-depth imaging technique, in combination with scanning electron microscopy (SEM) to identify several types of microfossils resembling eukaryotic acritarchs. Comparison between the structures of these organisms and those of acritarchs was carried out based on four criteria: 1) large cyst-like cells (15-35 µm) with radially arranged strands, similar to some acritarchs and dinoflagellates, 2) regularly spaced long and hollow processes, stubby pustules, or robust podia on the cell surface, 3) reticulate cell-wall sculpturing such as perforations/pits and ridges, and 4) common preservation of internal bodies that may represent membrane-wrapped organelles. Measurements of cell diameters as well as population in the samples yielded two ranges of 6.1-11.0 µm and 23.6-26.0 µm for the size of the complex single-celled organisms. The specimens that fall within the second range possess characteristics with greater affinity to the acritarchs, suggesting possible relationship with these ancestral organisms as well as possible eukaryotic affinity. These micro- and ultra-structures provide strong morphological evidence for the presence of protists in the Gunflint Chert.

Origin of low sulfide-high PGE mineralization in the W Horizon, Coldwell Complex, Canada: evidence for injection of PGE mineralization as syn-magmatic sill

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The low sulfide-high PGE mineralization (LSHPM) in the Marathon Cu-Pd deposit, referred to as the W Horizon, is hosted by the 100 m thick tube-shaped Two Duck Lake (TDL) gabbro that cuts syn-genetic metabasalt at the eastern edge of the Coldwell Complex within the Midcontinent Rift system in Canada. The TDL gabbro is a relatively homogeneous rock composed of coarse-grained subhedral plagioclase and olivine with sub-ophitic clinopyroxene. In outcrop, modal layering is rare but gabbro-gabbro cross-cutting features without chill zones are common. LSHPM is characterized by high PGE (up to 106 ppm Pd + Pt over 2 m) and low Cu/Pd (3 to 1000). Intervals of LSHPM occur within a much thicker zone (up to 75 m) of Lower Zone mineralization that is characterized by mantle-like Cu/Pd (~ 1 000). The two zones are compositionally distinct with respect to Pd/S, Pd/Au, Pd/Te, and Pd/Se, and exhibit notably different platinum-group mineral (PGM) assemblages. In plan view, Cu-rich zones (~ 0.4 wt %) of Lower Zone material occur within troughs along the footwall contact, whereas high-PGE zones (~ 4 ppm Pd+Pt) show no spatial relationship to Cu-rich zones or the footwall contact. We have developed a comprehensive and multi-faceted approach to characterize each type of mineralization based on 117 high precision and 20 000 exploration assays, sulfur isotopes, major element (EMP) and trace element (LA-ICP-MS) examination of major silicate, sulfide and oxide minerals, characterization of over 10 000 PGM grains, and 3D modeling of the mineralization relative to the footwall topography. Mathematical modelling illustrates that the LSHPM and Lower Zone mineralization can be represented as end-member compositions of a flow-through PGE upgrading process in a magma conduit system, as described by previous workers. Taken together, these observations are best explained by injection of a PGE-rich sulfide-bearing crystal slurry into the partially solidified gabbro containing the Lower Zone mineralization.

PyHELP: an open source Python library to estimate spatially distributed groundwater recharge with the HELP infiltration model

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Multiple methods are available to evaluate groundwater recharge that encompass a wide range of complexity and expense. However, only a few methods can define spatially distributed recharge at spatial and temporal scales of interest for regional water resources management. A practical method for doing this is to divide the study area into grid cells for which groundwater recharge is calculated using water balance modelling. One of the hydrological models that has been used in many regional hydrogeological characterization studies to estimate recharge with this approach is the physically based and complete HELP infiltration model (Hydrologic Evaluation of Landfill Performance). Besides groundwater recharge, HELP also estimates evapotranspiration and runoff. However, HELP is a one dimensional model, so its application to several thousands of cells with varying soil and geological conditions requires major efforts to process the input and output data, and thiis workflow is very prone to errors. Therefore, to facilitate the application of HELP to estimate spatially distributed groundwater recharge at the regional scale, a Python library named PyHELP was developed. PyHELP includes tools to easily integrate weather data from grids or stations, land conditions defined by a series of GIS maps as well as soil and geological material properties into HELP input files. PyHELP also processes HELP simulation results and outputs them as maps and graphs, including comparisons of simulation results with total flow and baseflow from stream hydrographs to calibrate model input parameters. PyHELP thus supports users through the entire recharge estimation workflow, from input file assembly to model calibration and to the documentation of results. PyHELP is an open source project written in the Python language and is available freely at https://github.com/cgq-qgc/pyhelp. This communication aims to present the HELP recharge estimation workflow and the main features available in PyHELP.

Deciphering multi-stage ore-forming processes in metasedimentary-rock-hosted orogenic gold deposit settings using LA-ICP-MS sulphide analysis

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Orogenic gold deposits span a large spectrum in regards to setting and style of mineralization, nature of gold (e.g. invisible, coarse) and favourable host rock. In addition, deposit formation is often attributed to protracted multi-stage hydrothermal processes. That gold mineralization also depends on a variety of features, such as metal-source reservoirs, metal-transport processes and wall-rock

stratigraphy, which add to the challenge of investigating origin of paleo-mineralized settings. Recent work using quantitative laser ablation inductively coupled plasma-mass spectrometry (LA-ICP-MS) element distribution maps/profiles and their corresponding time slice datasets (TSD) provides new insight into identifying and assessing elemental paragenesis, multi-dimensional element coupling/decoupling processes, and corresponding mineralizing events. To further assess complexities of mineralization, application of geostatistical tools (e.g. multidimensional scaling, principal component analysis, linear discriminant analysis) and various multi-element binary plots (e.g. Ag versus Au, Ni versus Co) is advised. To illustrate the application of this methodology, the results of LA-ICP-MS mapping and data processing for Fe sulphides from several metasedimentary-rock-hosted Canadian gold systems are presented: three Precambrian Algoma-type BIF-hosted gold deposits (~ 4 Moz Au Meadowbank, ~ 2.8 Moz Au Meliadine district, ~ 6 Moz Au Musselwhite) and eight slate-belt style vein gold deposits from the Paleozoic Meguma terrane (Nova Scotia). The maps and derived elemental plots generated from the various settings demonstrate that: 1) the gold mineralization present is the product of multi-stage processes; 2) elemental associations vary as mineralization progresses, such as the early growth history of sulphides versus later coupled dissolution-precipitation reactions; and 3) different metal-source reservoirs and stratigraphy influence the fluid signature. These results contribute to better deciphering the complex processes involved in the protracted evolution of these and other orogenic-type gold systems (e.g. remobilization of invisible gold from early sulphide, precipitation of visible gold in later sites, increase in Au fineness).

Analysis and interpretation of the precious metal mineralization in the Bald Hill antimony deposit, New Brunswick

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The wrench fault-controlled, NW-trending Bald Hill antimony deposit is located in the late Cambrian - early Ordovician Annidale belt in south-central New Brunswick, which is situated proximal to the southeastern margin of the classical Gander-Dunnage Zone. The area contains two major NE-trending thrust faults (Albright Brook and Taylors Brook) as well as shear zones that are commonly associated with gold, antimony, and base-metal sulphide occurrences hosted within quartz-carbonate vein systems and associated alteration zones. The Bald Hill deposit is primarily associated with the Bald Hill rhyolite dome complex in the Late Cambrian Carpenter Brook Formation. This unit is characterized mainly by sedimentary rocks of a sandstone-siltstone facies and a siltstone-shale facies with intercalated felsic volcanic rocks of the peralkaline Bald Hill rhyolite dome complex that are aligned parallel to a northeast-trending regional fabric. The complex contains extrusive felsic ash tuff, pyroclastic breccia, rhyolite flows and intrusive microgranite. The Bald Hill antimony system is rich in stibnite and other sulphides, such as pyrite and arsenopyrite, with local gold. Drill core samples were selected from intervals that are enriched in gold based on 2008 drill hole assay data. These samples were then analyzed using an Olympus Vanta model pXRF spectrometer. New analytical data for the samples using the Aqua Regia digestion yielded values up to 2 g/t Au and up to 24.9 % Sb. The Spearman Rank correlation coefficients were calculated on elements determined from the geochemical analyses and the assay data (n = 14). There is a significant association between Au and As (rs = 0.90), Au and S (rs = 0.72), Au and Sb (rs = 0.68), and Au and Sn (rs = 0.50). Associations of elements were also examined by mapping polished thin sections using Micro X-ray Fluorescence Spectrometry-Energy Dispersive Spectroscopy, which aids in the petrographic analysis of polished thin sections using reflected light microscopy.

Building the Athabasca Mylonite Triangle: new insight from microstructural analysis, petrology and crystallographic preferred orientations

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The Athabasca Granulite terrane (AGT) of the Western Canadian Shield is one of the largest exposures of lower continental crust on Earth. It is situated between the Rae and Hearne cratons that together comprise the Churchill Province. The AGT records several tectono-metamorphic events between ca. 2.60 Ga and its final exhumation ca. 1.77 Ga across its three main lithotectonic domains: the Lower Deck, Upper Deck and Chipman domain. The Lower Deck/Upper Deck contact is marked by a kilometre-thick mylonite zone, herein referred to as the Intra Tantato Shear Zone (ITSZ). Early studies used sparse shear sense indicators to interpret that this shear zone accommodated normal-sense motion, whereas more recent studies have argued for thrust-sense movement across it, based on the disparity in metamorphism recorded in the Upper (15 kbar) and Lower (10 kbar) decks. Clarifying the kinematics of the ITSZ is, therefore, critical for developing our understanding about the deformation events within the Churchill Province during the assembly of Laurentia. Field observations and quartz crystallographic preferred orientation analyses indicate a complex deformational history within the mylonite zone characterized by early NE directed thrusting followed by local normal-sense reactivation and discontinuous overprinting in proximity to the 1.85 Ga Grease River Shear Zone and associated structures. Quartz c-axis opening angle thermometry and other geothermometers indicate deformation temperatures of ~ 700-750 °C during the main thrusting event followed by a later retrograde equilibration, triggered by fluid circulation during exhumation at lower temperatures. The retrograde equilibration is syn-kynematic with overprinting related to the Grease River strain. Given the available data, the tectonic evolution of the ISTZ is tentatively interpreted to reflect a large-scale deep-crustal transpressive system that evolved through time from broadly compressive to dominantly dextral strike-slip kinematics.

Cathodoluminescent and compositional heterogeneity in fluorite and its relationship to Sn and W-Mo mineralization from Mount Pleasant, New Brunswick

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The Mount Pleasant W-Mo-Sn deposit is located in southern New Brunswick and consists of two zones: the North Zone (NZ) and the Fire Tower Zone (FTZ). Whereas both zones share the same set of ore minerals (molybdenite, wolframite, and cassiterite), they occur in significantly different proportions in the two zones. The dominant ore metals are Sn in the North Zone and W and Mo in the Fire Tower Zone. Fluorite is an important gangue mineral as it is ubiquitous throughout the deposit and potentially provides a record of fluid evolution. The complexity of the deposit is apparent from the deposit scale to micrometer-scale variations in fluorite crystals such that fluorite may be key to understanding the composition of the ore-forming fluids and their relationship to the metal endowment of the deposit. Fluorite crystals from the FTZ generally exhibit homogenous to simply zoned cathodoluminescent (CL) character, whereas fluorite from the NZ is complexly zoned and exhibits several stages of dissolution and reprecipitation. Trace element chemistry of fluorite in different ore assemblages was determined using LA-ICP-MS and compared on the deposit, sample, and crystal scale. Element concentrations (e.g. Fe, Rb, Sr, Y, Sn, Cs, Pb, Bi, and U) from different CL zones vary little in many simply and complexly zoned crystals. Variations in chemistry are most apparent in crystals mantled by molybdenite and where later wolframite and REE-inclusion rich zones are present. The ore events were

fingerprinted using fluorite chemistry within a given ore assemblage. Concentrations of Mo and W, and to a lesser extent Cu, Zn, and As, in fluorite from the FTZ are roughly an order of magnitude higher than in fluorite from the NZ, reflecting precipitation from chemically distinct fluids with metal signatures that in part reflect the associated ore bodies.

Paleoenvironmental analysis and geochronology of black shale units from the late Mesoproterozoic Fury and Hecla Group, arctic Canada

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The late Mesoproterozoic Bylot basins, comprising the Borden, Hunting-Aston, Fury and Hecla, and Thule basins, have proven critical in establishing the timing of the rise of photosynthesis among eukaryotes and secular changes in marine geochemistry. Correlations between the individual basins have historically been founded on lithostratigraphic similarities; however, a lack of age constraints make these proposed correlations difficult to corroborate. Strata of the Bylot basins represent one of the most complete geological records of this critical interval spanning the emergence of crown-group eukaryotes and the onset of fundamental changes to global biogeochemical cycling; therefore, understanding the depositional history of this basinal system, distributed in northeastern Canada and northwestern Greenland, is fundamental for developing a comprehensive timeline of recent findings. The Fury and Hecla and Borden basins, approximately 300 km apart, contain equivalently thick successions but the latter includes a much greater thickness of carbonate rocks and black shale. Radiogenic isotope data from the Borden Basin suggest a dynamic basin system that experienced marine, non-marine and restricted marine conditions. The Fury and Hecla basin, on the other hand, is dominated by mature quartz arenites interpreted to be have been deposited in a shallow-marine environment. Two thin organic-rich silty shales occur in the Agu Bay and Autridge formations of the Fury and Hecla Group and represent deposition in mid- to outer ramp depositional settings. These strata offer the opportunity to test correlations between the basins via Re-Os geochronology and compare redox conditions and geochemistry between the two basins.

Random Forests classification of ore deposit type based on pyrite trace element analyses

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Most surface ore deposits have been depleted and more effort must be spent exploring deep in the Earths crust. This necessitates increased drilling costs and means that we must develop methods to obtain as much information from each drill hole as possible. In the past few decades this has become increasingly possible due to the development of several different geochemical techniques and industrialization of these techniques. However, the accumulation of an enormous amount of data leads to the question of what to do with it. One way is the implementation of data learning algorithms. Here we provide an example of how this can be done using Random Forests, a supervised classification algorithm, to differentiate between seven major ore deposit types based on the trace element content of pyrite. To develop this classifier we collected nearly 4000 pyrite LA-ICP-MS trace element analyses from new and published sources from 71 different ore deposits and unmineralized shales. These data were then separated into three groups for classifier training and evaluation. A training set used to build the classifier; a test data set used to refine the classifier; and a blind test data set that were entirely from ore deposits or sedimentary formations, and not included in the classifier to determine how well the classifier could predict the origin of a true unknown sample. The results of the Random Forests classification on the test data were promising with analyses from 98 % of sedimentary pyrite, 95 % of IOCG, 93 % of VHMS, 92 % of SEDEX, 88 % of porphyry, 82 % of mesothermal veins, and 80 % orogenic gold, deposits being correctly identified. The proportion of correctly identified analyses tested against a blind dataset was also high, with sedimentary pyrite being correctly identified 95 % of the time, VHMS 94 %, orogenic gold 83 %, and SEDEX 81 %.

The Canadian impact cratering record

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Currently, there are 31 recognized impact structures in Canada. They range from Recent to 1.85 Ga in age and from 10s of m to ~ 200 km in diameter. Two-thirds of them occur on the exposed Precambrian Shield, which serves geologically as a relatively stable surface for the acquisition and, more importantly, preservation of impact structures. Studies of Canadian impact structures have produced a number of firsts in the understanding of cratering processes. These include: the recognition of planar deformation features (PDFs) in quartz as a shock metamorphic effect; the use of PDFs to map the spatial attenuation of recorded shock pressure in the parautochthonous rocks of the floor of both simple and complex structures; observational evidence that the transient cavity in natural impacts is formed, in part, by the displacement of parautochthonous target rocks; and the recognition of impact melt rocks as total melts, with relatively homogeneous compositions, even in impacts into crystalline target rocks with diverse compositions. Samples from Canadian impact structures were also used in the first Ar-Ar dating and determination of impactor composition, through siderophile analyses by neutron activation, of terrestrial impact events. These samples continue to provide new insights, including the observation that PDFs occur in so-called "ballen" quartz and ballen are, thus, not the result of volumetric changes due to phase transitions from shock-produced quartz glasses. A number of Canadian impact structures provide progenetic (uranium), syngenetic (Cu-Ni-PGE) and epigenetic (hydrocarbons, hydro-power) natural resources. The systematic study of Canadian impact structures formed the basis for the creation of the first searchable database of the attributes of terrestrial impact structures, in general. This now serves as a core component of the interactive website "Impact Earth" (www.impactearth.com), which is created and hosted by the Centre for Planetary Science and Exploration at the University of Western Ontario.

Multiscale evidence of silicate-carbonate liquid immiscibility at the Crevier alkaline intrusion, Grenville Province, Québec

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The Crevier alkaline intrusion (CAI, QC) is located in the Proterozoic Grenville Province and is composed of a suite of undersaturated alkaline rocks from ijolite to nepheline syenite and carbonatites. We present (i)

field relationships; (ii) comagmatic carbonatite, carbonate-free nepheline syenite and carbonate-rich syenite; (iii) textures of interstitial carbonates in nepheline syenite, silicate rims around carbonates in carbonatite, primary carbonates at the edges of nepheline and feldspar or as inclusion in albite in the carbonate-rich syenite, an orbicular facies with spheres of carbonate-bearing nepheline syenite in a carbonatitic matrix; (iv) coupled to LA-ICP-MS U-Pb geochronology on zircon from nepheline syenite and apatite from carbonatite, that argue in favor of a coeval emplacement of the silicate rocks and the carbonatites, and of their parental linkage from liquid immiscibility. The (i) petrography, (ii) textures and (iii) trace elements contents of pyrochlore provide evidence for the coexistence of these two magmatic differentiation trends. In the early carbonate-rich syenite, pyrochlore defines a Nb-Ta differentiation trend, whereas they follow a more classical Nb-Ti trend in the younger nepheline syenite. The later crystallization of Nb-rich pyrochlore with more constant Nb/Ta ratio and a correlative classic Nb-Ti trend in the nepheline syenite suggests that the Nb and Ta fractionation has stopped in response to the end of the immiscibility between the two liquids. In addition, the (i) textures, (ii) trace elements, (iii) Ti-in-zircon thermometry, and (iv) oxygen isotope compositions of zircon grains from the CAI, allows to constrain the temperature range of ca. 1000-815 °C at which the immiscibility process occurred. Accordingly, the deposit to microscopic multiscale evidence provided by petrographic textures, whole rock and accessory mineral geochemical signatures, and isotopic compositions of the various lithologies demonstrate the petrogenesis of the CAI through a silicate-carbonate liquid immiscibility from a parental silicate liquid of ijolite composition.

Mesoproterozoic evolution of the SE Laurentian margin as recorded in the central Grenville Province.

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Remnants of ~ 1.7 to 1.25 Ga arc and back-arc systems developed along of the SE Laurentian margin constitute a large portion of the Grenville Province. Despite high-grade metamorphism and deformation during the Grenvillian orogeny (1.09 to 0.98 Ga) primary characteristics and original tectonic setting of pre-Grenvillian rock associations can be variably inferred. The Geon 15 to 13 Quebecia terrane represents a unique composite arc belt in the central Grenville Province that separates crustal segments to the east and west that were parts of continental arc systems at that time. In contrast to these segments, Quebecia preserved a record of rifting at ~ 1.5 Ga, and re-amalgamation of peri cratonic slivers at 1.4 to 1.35 Ga. In the southern part of Quebecia, the Escoumins supracrustal belt represents remnants of a 1.50 to 1.45 Ga peri-Laurentian oceanic arc built on rifted crustal slivers. This belt consists of marine sedimentary rocks overlain by an island arc/arc-rift and back-arc bimodal volcanic sequence with back-arc sediments on top. The supracrustal package tectonically overlies a ca. 1.5 Ga suite of tonalite, trondhjemite and granodiorite with geochemical signatures of a mature oceanic arc, crosscut by arc-rift related granite. Farther north, ~1.5 Ga extension-related metasedimentary sequences are indicative of earlier rifting of the Laurentian margin, and a major 1.4 to 1.3 Ga felsic plutonic belt is inferred to represent stitching plutons emplaced during the re-amalgamation of peri-cratonic island arcs to Laurentia. Quebecia terrane also contains the only 1.3 Ga anorthosite complexes in the Grenville, the latter implying mafic underplating at the base of the crust up to 100 Ma earlier. Differences between Quebecia and continental arcs elsewhere in the Grenville attest to lateral variations in subduction dynamics under Laurentia comparable to the modern-day Andean system.

Geometallurgical domains in a gold deposit: example from the Whale Tail deposit, Amaruq project, Nunavut

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The current mining paradigm forces mining companies to exploit more and more refractory ores with complex mineralogy. As a general rule, the distribution of gold in a deposit is defined by geologists (exploration phase) while metallurgists focus on physical and chemical characteristics of the rocks to optimize gold recovery (pre-feasibility phase). However, an early understanding of gold recovery parameters and of potential environmental impacts could provide a competitive advantage to a mining company. This can be achieved by early-stage geometallurgy investigations, which integrate several disciplines of the geosciences to relate mineral recovery and environmental impacts to the mineralogical constraints. Ore processing can be optimized by the use of geometallurgical domains, which are zones with homogeneous mineralogical assemblages associated with specific metallurgical and/or environmental characteristics. This master project aims at developing a methodto help create geometallurgical domains using data from the exploration phase of the project, using Agnico Eagle Mines' Whale Tail deposit in Nunavut as a case study. The Whale Tail deposit is in the Kivalliq region of Nunavut and belongs to the neo-Archean rocks of the Woodburn Lake group within the Rae Domain in the Churchill province. At Amaruq, mineralized zones are hosted in a volcano-sedimentary sequence made of mafic to ultramafic volcanics, greywackes, cherts and iron formations. Gold is predominantly associated with iron and arsenic sulphides. The ore mineral assemblages and contrasted host rocks are responsible for some metallurgical and environmental challenges. The main objectives of the project are to: 1) complete a petrographic and metallographic characterization of the Whale Tail deposit; and 2) to correlate exploration data with metallurgical and environmental data. The results demonstrate the potential of geometallurgy to improve the feasibility of a mining project and to limit its environmental impact.

Subduction initiation mode in fossil systems revealed by ophiolitic crust and sole petrochronology: the Semail example

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Subduction zones are unique to Earth and fundamental in its evolution, yet the processes responsible for subduction initiation (SI) remain enigmatic. SI either results from far-field forcing or spontaneous lithospheric gravitational collapse, but unequivocal geological proof of one or the other remains elusive. A fundamental observable that would discern between the two processes is the time lag between nucleation of the subduction plane and ensuing upper plate extension, which should be nil in the case of spontaneous SI. Suprasubduction zone ophiolites such as the archetypal Semail ophiolite of Oman and its associated metamorphic sole expose remnants of the upper and lower plate of an incipient subduction zone. The age of extension and crustal accretion in the Semail ophiolite has been estimated at 96.1-95.5 Ma by U-Pb zircon dating of ophiolitic crust. On the other hand, the timing of initial lower plate burial was estimated from $^{40}Ar/^{39}Ar$ hornblende dating from the metamorphic sole and U-Pb dating of zircons from melt segregations. The resulting 96.16-92.6 Ma metamorphic ages overlap extensional ages from the overlying ophiolite, suggesting spontaneous SI. However, both geochronological methods in the sole date post-peak conditions, offering minimum age constraints on initial lower plate burial. Here, we apply Lu-Hf dating of garnet to the upper

sole section under the Semail ophiolite. Our results reveal that rocks from the metamorphic sole were already subducted by 104 Ma, 8 Myr before formation of the Semail ophiolitic crust. This important time lag provides the first unequivocal evidence for a far-field forced SI in a setting considered archetypal for spontaneous SI, thereby also showing that geological records widely quoted as evidence for spontaneous SI, are inconclusive and evidence for spontaneous gravitational collapse has yet to be found. Our results also clearly demonstrate a causal link between upper plate extension and exhumation of metamorphic soles.

Magmatic recycling along 50 My in the Variscan belt: orogenic melt reworking in NW Iberia

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In the Western European Variscan Belt (WEVB), the major stages of convergent tectonics are recorded by granitoid suites generated in a time span of 50 million years (ca. 340-290 Ma). There is however some ongoing controversy regarding: i) whether there was a significant magmatic event in the early Carboniferous, and ii) whether the Variscan magmatic activity was continuous or it rather occurred through discrete short-lived pulses. The advent of new U-Pb age data on Variscan granitoids (and some volcanic rocks) from NW Iberia has provided a more focused picture of the magmatic history of the WEVB, providing ground for interpretations that link periods of intense magmatic activity with large-scale crust-mantle processes during the collision and the subsequent Ibero-Armorican-Arc (IAA) generation. Based on the observation of new data, three main pulses of magmatic activity seem to be well established: i) Post-orogenic granitoid suite (POS henceforth) (ca. 305-290 Ma), known classically as G3-G4 or late granites in the regional literature that intrude all the structural domains of the orogen, including the foreland fold and thrust belt, which makes the WEVB rather unique. The POS includes volumetrically minor intrusions of mafic and ultramafic rocks. The POS has been interpreted as generated by lithospheric delamination triggered by the oroclinal bending of the mountain belt. ii) Syn-extensional collapse granitoids (ca. 325-315 Ma): mostly crustal (S-type) peraluminous leucogranites generated by decompression melting following the extensional collapse of the mountain belt. iii) A third suite of Variscan granitoids, not considered on most models, has been found with ages around 340 Ma. In addition, a significant amount of ca. 340 Ma zircon xenocrysts has been found in the ca. 320 Ma syntectonic leucogranitoids and in the ca. 305 Ma (POS), and also as detrital zircons in Variscan syn-orogenic sediments.

Ice-flow and deglacial history of the Laurentide Ice Sheet in the southwestern Great Slave Lake area

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Limited field studies and sparse chronological constraints in the southwestern Great Slave Lake area creates uncertainties about the Laurentide Ice Sheet (LIS) flow history and deglacial chronology. Improved understanding of the western LIS ice-margin morphology and retreat history is required to refine larger ice-sheet interpretations and timing for northwest drainage of glacial Lake McConnell. Using new field observations and geochronology we establish ice-flow history and better constrain regional deglaciation. Paleo-ice flow indicators (n = 66) show an oldest southwestern flow (230°), an intermediate northwesterly flow (305°), and a youngest westerly flow (250°). Till samples bulk sediment and matrix properties (n = 160) allowed identification of two till units. A lower grey till sourced mainly from local Paleozoic sediments produced clast fabrics indicating a southwesterly flow direction, overlain by a brown till that contained an increased Canadian Shield content with lodged elongate boulders a-axes and boulder-top striation orientations indicating a west to northwest ice-flow direction. Ice-flow results show a clockwise shift in direction interpreted as evidence for ice-divide migration followed by topographically controlled deglacial westward flow influenced by the Mackenzie River valley. Minimum deglacial timing estimates were constrained through optical dating of fine-sand deposits in a well-developed strandline (n = 2) and seven aeolian dunes; ages range from 9.9 ± 0.6 to 10.8 ± 0.7 ka BP. These ages are from dunes located below glacial Lake McConnell maximum water level and may thus provide new local lake level age constraints. Ice retreat is informed by a newly-mapped segment of the Snake River moraine, which is an understudied feature in the region. New ice-flow history and ice-margin retreat interpretations will be integrated into the larger body of work on the western LIS providing more confident conclusions on ice-sheet evolution and meltwater drainage pathways, specifically in the southwestern Great Slave Lake area.

Mineralogical and geochemical analysis of the Devil Pike Brook gold deposit, south-central New Brunswick

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The Devil Pike Brook gold deposit, located in south-central New Brunswick, exhibits similar geological characteristics to other Appalachian orogenic-related gold deposits. This deposit occurs south of the northeast-trending Taylors Brook Fault that separates rocks of Cambrian-Ordovician Annidale Group to the north from the late Neoproterozoic to early Cambrian Belleisle Bay Group to the south. Previous studies indicate that gold occurs in fault-fill quartz-carbonate veins that developed in primary shear zones cutting metamorphosed mafic volcanic host rocks of the Grant Brook Formation. Based on mineralogical and geochemical (pXRF) studies, gold is associated with sulfide phases within the quartz-carbonate veins that are enriched in Au pathfinder elements (Cu, Zn, and Sb) and S. Pyrite, the main sulfide phase associated with the gold mineralization, has two recognizable generations: (1) euhedral to subhedral primary pyrite is typically hosted by euhedral quartz and contains inclusions of pyrrhotite and sphalerite along with minor inclusions of gold, tellurides, chalcopyrite, and galena; and (2) subhedral to anhedral secondary pyrite associated with carbonate veinlets, iron oxides, and deformed quartz that contains fewer inclusions. Evidence suggests the secondary pyrite formed during brittle deformation of primary pyrite, which caused remobilization of the inclusion minerals (such as gold, sphalerite, and minor galena) and their subsequent precipitation in open spaces and voids. The gold mineralisation is mostly associated with chalcopyrite, galena, and other sulfide phases. MicroXRF scanned images confirm the existence of native gold with secondary pyrite proximal to other newly formed sulfides, carbonate (calcite, ankerite, siderite) and iron oxide minerals within veinlets mantled by sericite-chlorite alteration assemblages. Titanite and rutile associated with gold, sericite, and chlorite in carbonate veins, have been identified by micro-XRF and mineralogical studies. Dating of these minerals using U-Pb LA-ICP-

MS will be instrumental in establishing the age of the mineralization with significant implications for exploration in the area.

Meeting the Metal Earth challenge: a U-Pb geochronological perspective on metal endowments in the Abitibi greenstone belt and beyond.

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Combined efforts of regional and detailed mapping, structural, geophysical, lithogeochemical and isotopic analytical studies carried out through partnerships between federal and provincial geological surveys, academic researchers, students and industry professionals, have established the Superior craton as one of the largest, yet best studied tracts of Archean crust on the planet. A cornerstone of our knowledge from these initiatives emerged from efforts on many fronts to understand the nature and timing of ore deposition in several major world-class gold and VMS camps in the Abitibi subprovince in Quebec and Ontario. Critical was the establishment of a calibrated, high-resolution U-Pb ID-TIMS temporal framework of mostly Neoarchean volcanism, plutonism and sedimentation: a template onto which additional details of deformation, metamorphism and mineralization could be given context. Presently, the Metal Earth applied research project provides both challenges and opportunities to test and refine our understanding of the distribution of metal endowment to well-studied and understudied regions of the Canadian shield. This presentation reviews the critical role high-precision U-Pb geochronology plays in our understanding of the evolution of Superior craton granite-greenstone terranes and their ore systems. Focus is placed primarily on new results from the Abitibi and Wabigoon subprovince transects, where patterns of magmatic crystallization ages and the timing of different styles of mineralization are investigated. Recent improvements to both precision and accuracy in U-Pb TIMS geochronology have benefitted from advances in novel methodologies (e.g. chemical abrasion). Producing more reliable and robust (concordant) ages stems not only from these annealing/partial dissolution pretreatments for zircon, but also from improved ionization efficiencies, progressively lower levels of background Pb, low-noise instrumentation with enhanced sensitivities, and from new, calibrated mixed, double Pb-U isotopic tracer spike solutions that facilitate internal mass fractionation corrections. I review these advances and discuss a number of under-utilized and underappreciated accessory mineral chronometers.

Apatite and magnetite as a fluid recorder during the genesis and evolution of IOA deposits

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Worldwide, iron oxide-apatite (IOA) deposits represent intra- to sub-volcanic ore bodies composed mostly of magnetite, hematite, and apatite ± minor REE-bearing minerals. Notable examples include Kiirunavaara, northern Sweden; Grängesberg, central Sweden; Pea Ridge, Arkansas, USA; the Bafq Region, central Iran; the Chilean Andean Cordillera, Chile; the Great Bear Magmatic Zone, northern Canada; and the Middle-Lower Yangtze River Metallogenic Belt (LYRMB), southeast China. Subvolcanic igneous intrusions and fluids play a critical role in the formation of IOA deposits. Fluids can also modify the texture and composition of IOA minerals during post-emplacement, fluid-rock interaction. These in turn can be used to decipher the origin of the ore body and later metasomatic overprints. Fluid inclusion studies of two IOA deposits (El Laco, Chile and LYRMB) indicate that extremely hot (~ 800 °C) hypersaline fluids (up to 90 wt % NaCl eq) were present during their genesis. As such high-temperature fluids cool down, they would modify the IOA ore minerals via auto-metasomatism and/or fluid exchange with deep-seated meteoric waters and surrounding country rock fluids. One result of this fluid-rock interaction immediately after the deposition of the IOA ore body could be the skarns generally associated with many IOA deposits. Apatite and magnetite in IOA deposits can host a variety of elements and thus provide a detailed geochemical record of the ore-forming process and evolution of fluids associated with these deposits. For apatite, these elements include Si, Na, Sr, Ba, Fe, REE, F, Cl, OH^-, CO_3^{2-}, and SO_4^{2-}, whereas magnetite hosts variable amounts of Ti, V, Cr, Mg, Co, Ni, and Mn. The amount of these elements in either mineral is a sensitive indicator of the fluid chemistry, temperature, pH, and fO_2 present during the formation and subsequent evolution of the IOA deposit. The geochemical information supplied by apatite and magnetite suggest/imply that IOA deposits crystallize from highly evolved, hypersaline fluids, which originate as fluid segregations derived from subvolcanic, igneous intrusions.

Paleoproterozoic metasupracrustal suites on the NW flank of the Wyoming Province: the stories they do and do not tell about an evolving continent

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Metasupracrustal sequences interlayered with quartzofeldspathic gneisses distinguish the Montana Metasedimentary terrane on the NW flank of the Wyoming Province (WP). Early thinking correlated marble-bearing suites and considered them younger than carbonate-absent sequences, promoting models of WP continental crust evolution toward thick lithosphere supporting a stable marine platform in the period ~ 3.5-2.5 Ga. Metasupracrustal suite depositional ages constrained by (1) detrital zircons; (2) times of metamorphism; and (3) cross-cutting meta-igneous rocks now indicate a more complex pattern of tectonic environments along the NW margin of the WP. Carbonate-bearing metasupracrustal suites in the Tobacco Root Mountains and Ruby Range include marble, amphibolite, orthoamphibolite, pelitic gneiss, quartzite, and iron formation. Detrital zircons constrain the protolith age to 2.45 Ga. Interlayered quartzofeldspathic gneiss with calc-alkaline geochemistry were previously interpreted as suggesting a continental fringing arc superimposed on Archean basement. An episode of metamorphism and anatexis followed at 2.45 Ga, demonstrated by metamorphic monazite and intrusive ages of cross-cutting mylonitic leucogneiss. We interpret this to be a time of collision along the NW WP. Cross-cutting mafic sills and dikes suggest continental rifting at 2.06 Ga. Diverse metasupracrustal suites whose protoliths must be 1.8 Ga occur in the Ruby, Tobacco Root, and Highland mountains. A carbonate-absent suite of amphibolite, orthoamphibolite, pelitic schist and quartzite in the Tobacco Root Mountains represents oceanic crust, while aluminous schist and interlayered amphibolite in the Highland Mountains are consistent with a back-arc basin setting. The Ruby Range suite includes prominent marble, amphibolite, orthoamphibolite, pelitic schist, quartzite and iron formation and may represent a second, post-rift carbonate platform facing that basin. These suites collapsed against the WP during the 1.78-1.72 Ga Big Sky orogeny as a consequence of subduction directed beneath the WP.

Cryohydrogeology of rock glaciers in the central Andes (31-35° S)

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The hydrogeological role of rock glaciers in mountain hydrology is attracting increased scientific interest given their distribution across the major mountain ranges of the world. However, the general lack of subsurface lithological, hydrological, and thermal data presents challenges to understanding hydrogeological processes in rock glaciers. To address this gap, we combine detailed stratigraphic and cryological observations with ground temperature and piezometric head data to develop conceptual cryohydrogeological models of sub-watersheds containing rock glaciers in the South American Central

Andes. Firstly, stratigraphy and ground ice content (or soil moisture) can be heterogeneous both within individual rock glaciers and relative to other rock glaciers within the same watershed, which leads to differences in hydrogeological behaviour. Preliminary results from thermo-hydrological monitoring suggest that (i) with variations in water content and thermal conditions, both spatially and with depth, the hydrogeological properties within the rock glaciers are strongly heterogenous; (ii) year-round groundwater flow may occur in supra-permafrost taliks and complex sub-permafrost aquifers in non-cryotic fractured rock and/or basal sediments; and (iii) the dynamics of ground temperature and sub-permafrost groundwater flow can provide insights into groundwater recharge mechanisms. Nonetheless, understanding unsaturated and saturated flow in the active layer and supra-permafrost talik remains particularly challenging due to the seasonal variability and interdependency between heat and moisture transfer, which is further complicated by the difficulties of instrumenting the active layer in coarse blocky sediments of rock glaciers. Overall, these insights contribute to identifying the role of groundwater processes in the hydrology of rock glaciers and other coarse, blocky mountainous landforms. This underlines the importance of developing a site-specific conceptual understanding of hydrogeological processes in individual rock glaciers, and considering rock glaciers as hydrogeologic landscape units within a holistic catchment hydrology framework.

Techniques for installation and monitoring of deep groundwater wells

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Increases in anthropogenic disturbance and deep underground development have resulted in a need, and often a regulatory requirement, to monitor the effects and changes on groundwater at depth. For example, underground mining, geothermal energy development, unconventional shale gas extraction, in situ oil sands bitumen extraction, carbon storage and sequestration, lithium brine extraction, and groundwater abstraction from deep aquifers may all have potential impacts on groundwater resources. Installing monitoring wells, collecting groundwater samples, and monitoring deep water tables becomes increasingly difficult as well depths increase. This includes challenges or potential limitations to the drill rig, of installation practices or materials, and to typically used well development equipment. Based on experience from field programs at several exploration and operating mine sites in Canada involving deep groundwater monitoring well installation, development, and sampling, we summarize techniques that may improve the efficiency and efficacy of deep groundwater monitoring. This includes: (i) the data that should be reviewed in selecting well screen intervals, (ii) modifications to traditional well installation procedures to account for greater borehole and water table depth, and (iii) the variety of development methods we have found in our experience to be suitable for deeper wells and water tables. Deep groundwater monitoring, though challenging, can be done effectively, yielding representative hydrogeologic data, when considerations for specific challenges are incorporated into each project stage from planning through drilling and installation to development and monitoring.

Controls of reactivated accretionary and protocraton margins on pluton emplacement and Ni-PGE-Cr, Au, IOCG, and polymetallic mineralization

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Reactivated deep structures formed during terrane assembly, commonly oblique to near-surface regional trends, exert fundamental controls on Au, IOCG, and polymetallic mineral occurrences and the emplacement of mafic-ultramafic intrusions hosting Ni-PGE-Cr mineralization. Examples will be presented to illustrate: - The role of proto-craton margins and early accretionary structures on Ni-PGE-Cr mineralization in the Kaapvaal Craton (South Africa) and the N Superior and SE Churchill provinces (Canada). - Controls of reactivated domain (accretionary?) margins, oblique to surface structures, on Au, IOCG, and polymetallic mineralization in the NE Superior Province. - Emplacement of the La Blache mafic-ultramafic complex (that hosts several Ni showings) along the contact between the isotopically and geophysically distinct Quebecia and Labradoria terranes in the Québec Grenville Province. - Emplacement of Devonian intrusions in the Southern Québec Appalachians along a recently recognised, regional accretionary contact in Grenville Province basement. Identification of deep, early-formed structures from enhanced aeromagnetic, gravity, and seismic tomographic data is therefore important in regional mineral exploration targeting.

Evaluation of deep hydrothermal fluid circulation in the Asal rift, Republic of Djibouti

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A good knowledge of deep fluid circulation in hydrothermal systems can help to exploit geothermal resources. For this purpose, the location, size, extension, nature and water recharge of the hydrothermal system must be determined. The objective of this research is to define these parameters for the Asal rift region in Djibouti. In this extensive tectonic environment, the Earth's crust is thin and the geothermal gradient was shown to be ~ 169 °C/km. The temperature measured in some exploration wells at 2100 m was 355 °C. However, the fluid salinity that rises to 120 g/l and the low permeability at depth constitute a major challenge for the exploitation of this resource. A 3D electrical conductivity model will be developed as a first step from the inversion of magnetotelluric (MT) data at 81 stations taking into account the topography. Subsequent correlation between the temperature profiles measured in deep geothermal wells and the electrical conductivity profiles of the nearest MT stations will be established using neural networks to define a 3D temperature model. Then, a numerical multiphase flow simulations with variable fluid density representative of the field conditions will be developed with 2D models considering variations of the thermal and hydraulic properties of the bedrock linked to the increase of temperature at depth. Two productive aquifer layers have been identified so far with the analysis of temperature profiles. The expected results will help to characterize areas of geothermal interest with a correlation of electrically conductive zones to thermal anomalies. The thermal structure of the system and its physical heat transfer mechanisms, the influence of salinity and the role of depth of magmatic intrusions on the circulation of hydrothermal fluids will be better understood.

On the nature and origin of Dubéesque gold in the Abitibi and beyond

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Resolving the possibility and nature of Au remobilization is critical to both understanding the origin of high-grade ore zones in Au deposits with coarse native "Dubéesque" gold, and also improving our understanding of Au deposit formation. In this study, samples from two ore systems, Jerome and Kenty, in the Archean Swayze greenstone belt (SGB) of northern Ontario, Canada, together with coarse Au from another 39 deposits from across Ontario and Québec

sampled at the Royal Ontario Museum (ROM), were chemically characterized (SEM-EDS, EMPA, TEM, LA-ICP-MS) in order to evaluate processes responsible for Au upgrading. The Au-bearing pyrite from the two studied deposits record textures suggestive of dissolution-reprecipitation reactions whereby Au and associated elements (e.g. Cu, Ag, Te, Pb, Sb) were liberated from the auriferous pyrite (100 to 5000 ppm Au). During remobilization, Au and Ag were decoupled which resulted in: 1) changing initial Au-Ag ratios of 1-5 in host pyrite to ~ 9 in the neomorphic visible Au (900 Au fineness); and 2) incorporation of Ag into co-genetic secondary mineral phases (e.g. chalcopyrite, tetrahedrite, galena). Evidence for an association of low-melting point chalcophile elements (LMCE; Hg, Te, Sb) with Au at the Jerome, Kenty, and many (~ 50 %) of the 39 historic deposits sampled, along with native Au filling structurally favourable sites in quartz in all samples, strongly suggests that a fluid is not necessary for the transport of Au. Instead, the evidence favours a model whereby Au is remobilized at temperatures starting at 336 °C by fluid-mediated LMCE-rich melts and/or transport of Au as nanoparticles. These conclusions can account for the presence of coarse-grained native Au filling fractures in quartz, the paragenetically late-stage origin for such coarse Au, and the inability of fluid-only remobilization models to account for such Au given the relatively low concentrations of Au reported in fluids.

Archean greenstone-hosted base metal and gold mineralization: igneous fertility indicators from analogous younger terranes

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Archean greenstone belts host a variety of hydrothermal ore occurrences, including VHMS base metal and orogenic lode gold deposits. Despite their age difference, the fundamental physical and chemical constraints on magmatic and hydrothermal processes are essentially identical to those in younger terranes. Thus, recent findings on igneous rocks associated with hydrothermal mineralization in post-Archean areas provide insight applicable to the geological setting and magmatism of Archean greenstone belt-hosted mineralization. Fertile magmas are those that can transfer metals from their mantle or lower crust sources to a mineralizing hydrothermal environment in the upper crust. The oxidation state of magmas is critical to metal transport as base metals are chalcophile and have a strong affinity for sulphide S. In reduced magmas, sulphide S scavenges metals from silicate melt and concentrate these metals in immiscible sulphide liquid: in such systems, metals may not be available for hydrothermal mineralization. Since the asthenosphere mantle is reduced, magmas derived from it are reduced (i.e. oxygen fugacity below the FMQ buffer). By contrast, oxidized magmas are the product of subduction processes. This is consistent with the subduction signatures of igneous rocks associated with VHMS deposits. By contrast, lode gold deposits in Archean terranes are gold-only mineralization, with abundant arsenopyrite and pyrrhotite that points to reduce conditions. The mineralizing environments are analogous to low-sulphidation epithermal gold deposits in post-Archean terranes. Although such low-sulphidation gold deposits can be hosted by volcanic arc terranes, mineralization is related to magmatism associated with lithospheric extension and rifting, which causes upwelling of asthenospheric mantle and injections of reduced magmas. Good examples include Miocene and later gold deposits related to rifting in northern Nevada and in Japan. Information related to magma oxidation state, metal mobility and geological settings of deposits in recent orogenic belts provides key constraints for regional exploration in Archean terranes.

Sedimentary basins of the Swayze area, Abitibi greenstone belt: provenance, timing and facies association

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The Abitibi greenstone belt (AGB) in the Superior Province is the most prolific gold producing greenstone terrane in the world with a yield of ~ 180 million ounces of gold to date, much of which is from deposits spatially associated with synorogenic-type sedimentary basins. The Swayze area, which comprises the westernmost extent of the AGB, has historically been considered less mineral-endowed despite similar geology and stratigraphy. Understanding the nature of sedimentary basins in the Swayze area relates directly to the geodynamic history of this region, as well as the potential for lode gold deposits. Laterally extensive sedimentary basins exist in the southern and northern Swayze area for which sedimentary facies, setting and depositional timing are as yet poorly constrained. The basin in the south is characterized by a conglomerate-sandstone facies association, locally underlain by erosional unconformities, whereas a conglomerate-sandstone-mudstone facies association is observed in the northern basin. Detrital zircon U-Pb studies of the sandstone in the southern basin yield a maximum depositional age of 2678 ± 5.5 Ma. A porphyry body within the northern basin yield a U-Pb TIMS zircon age of 2685.7 ± 0.8 Ma, constraining a minimum age of the north basin sediment. All sandstones range from lithic arenite to greywacke; however, modally, south Swayze sandstones have higher lithic fragment input (~ 15 %) from variable sources compared to the northern sandstones, which, in contrast, have a larger contribution of subrounded quartz grains. Subtle differences in Zr/Sc-Th/Sc systematics reveal a better sorting of the north basin sandstones, indicating effects of weak resedimentation. Therefore, the south Swayze sediments reflect proximal source terranes and were deposited in a continental alluvial setting likely associated with a synorogenic basin. These may be distinguished from northern Swayze sediments, which appear to represent distal parts of a river delta prograding into a marine environment.

Formal subdivision of the Quaternary System: a focus on the Holocene and Anthropocene

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The global boundary stratotype section and point (GSSP) for the Gelasian Stage has served as the base of the Quaternary System (2.58 Ma) since 2009. The Vrica GSSP (1.80 Ma) was repurposed in 2011 to define the Calabrian Stage, effectively completing the Lower Pleistocene Subseries. The candidate for the Middle Pleistocene Subseries (and Chibanian Stage) GSSP (~ 773 ka) is the Chiba section, Japan. The Upper Pleistocene Subseries, with a base traditionally marked by the onset of the last interglacial, is not yet defined by GSSP. The Holocene Series was formally defined in 2008 using an ice core for the GSSP. In 2018, the Holocene was subdivided into the Greenlandian, Northgrippian and Meghalayan stages/ages and their corresponding Lower/Early, Middle, Upper/Late subseries/subepochs. The Greenlandian GSSP (11 700 b2k [years before 2000 CE]) is defined in the NGRIP2 Greenland ice core, the Northgrippian GSSP (8236 b2k) in the NGRIP1 Greenland ice core, and the Meghalayan GSSP (4250 b2k) in a speleothem from Meghalaya, India. This subdivision introduces the rank of subseries/subepoch to the geological time scale, and incorporates by far the briefest of all stages. Defining GSSPs in ice cores and a speleothem are innovations. The Anthropocene is presently undefined, but the rationale for formalization is compelling. The term is already used extensively in the scientific literature and, like Holocene subdivisional terms, its functionality will be enhanced by formal definition. The Anthropocene is not strictly anthropogenic: it reflects a

tipping point in the Earth-system response to progressive human impacts, not the impacts themselves. The formal Anthropocene, as currently envisioned, would start at ~ 1950. It would hold the rank of series, terminating the Holocene but not interfering with its subdivision other than to terminate the Meghalayan Stage at a point when the Holocene is already evenly subdivided.

Rock Physical Properties Part 3: 30 years of collaboration and promotion of the importance of rock physical properties with Bill

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Starting back in a basement laboratory at the University of Western Ontario in 1983, the seeds of a long working relationship with Dr Morris began which would result in the collaboration and promotion of the importance of rock physical properties in the understanding and interpretation of geophysical data that extends to the present. Through this period the importance of understanding, collecting and applying rock physical properties to geophysical interpretation has consistently been promoted through collaborative projects and presentations from the original "Rock Magnetic Properties: Why Bother?" (SEG 1991) followed by "Rock Magnetic Properties: Why bother part deux" (SEG 1995) and numerous collaborative projects on the Sudbury Basin, kimberlites, massive base metal sulphides and the ultility of in situ borehole physical property measurements resulting in the summary of this presentation: a long overdue part 3. A summary of the salient points from the collaborative research will be provided in addition to the growing importance of rock physical properties for exploration under cover and near mine exploration.

Improving coherency of petrophysical and geochemical datasets using XRF data

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Large petrophysical and geochemical databases associated with archived drill core from the Bathurst Mining camp (New Brunswick, Canada) were used to investigate the performance of X-ray fluorescence (XRF) to help improved the coherency of the information across datasets. The recent introduction of portable XRF instruments means that these data are increasingly being acquired by the mining industry to assist with the preliminary analysis of the chemical composition of geological features. Until now, however, further use of XRF in the field for geophysical exploration has been a risky venture since external and internal factors can have significant impact on the quality of the results. In this study, we investigate the feasibility of using XRF data to obtain proxy density and semi-quantitative geochemical results of given rock samples and use these data to improve the coherency of the geochemical and petrophysical datasets. Potential limitations such as repeatability, time dependence, geometric factors, and environmental conditions are all assessed and their impact on the results quantified. The results of this work show that if continuous data acquisition is done on drill cores, XRF can provide accurate results for imaging wide-spread alteration zones and associated mineralization. The results also highlight that, while the lack of co-location of the original data was considered as a major hurdle for the direct statistical analysis of geochemical and petrophysical datasets, XRF can provide an interesting way to improve the coherency of the information within datasets that were originally sampled at different sampling intervals. We also demonstrate that the integration of large and heterogeneous datasets provides a unique opportunity to investigate and visualize multi-parameter correlations and behaviour for this bi-modal felsic/mafic geological setting.

Stable isotopic composition of arc-related magmas and associated hydrothermal alteration

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Fifty years of study of volcanoes and young porphyry systems provides the framework to interpret aqueous fluids associated with intrusion-centered deposits. 1970s studies of hydrothermal biotite from porphyry deposits concluded that magmatic water had a composition of -40 to -80 ‰ D/H, consistent with igneous biotite from the Boulder batholith quartz monzonite, with -60 to -110 ‰ D/H. However, the H_2O content in the quartz monzonite, 0.5-1 wt %, indicates most water degassed prior to crystallization. On exsolution, water is ~ 20 ‰ heavier in D/H than that in melt, resulting in progressively lighter residual D/H during crystallization of intrusions due to Rayleigh fractionation; this accounts for light D/H recorded by hydrothermal minerals formed late in some porphyry deposits. By contrast, 1980s studies of water-rich (4+ wt %) obsidian indicated that a closer-to-original value of felsic magmas is -40 ± 10 ‰ D/H. At the same time, high-temperature (~ 600-800 ˚C) fumaroles discharging from active andesitic volcanoes in the Circum Pacific were being studied by workers in Japan, Russia and New Zealand. The low-salinity water-rich vapors have consistent D/H values of -20 ± 10 ‰. These heavy D/H values are caused by aqueous phase-melt fractionation of +20 ‰ D/H, followed by vapor-hypersaline liquid fractionation at the solvus of +20 ‰ D/H (with vapor the dominant aqueous phase). Using these observations, alunite and biotite mineral separates (contemporaneous advanced argillic and potassic alteration, respectively) from a Philippine porphyry deposit were recognized by us to record separated vapor and hypersaline liquid (-20 and -40 ‰ D/H endmembers, respectively), with later, cooler liquid in equilibrium with white mica also near -40 ‰ D/H. These magmatic fluids were originally water in melt at about -40 ‰ D/H, typical of arc-related magmas. After exsolution, the crystallized intrusion preserves a composition lighter than -60 ‰ D/H, i.e. residual magmatic water.

Hypogene and supergene alteration at the Farallón Negro intermediate-sulfidation epithermal Au-Ag deposit, NW Argentina

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Epithermal vein mineralization is notoriously associated with the formation of poorly-documented hypogene argillic alteration haloes. The formation and chemical composition of clay-alteration remain poorly understood and poorly utilised in exploration for these high-grade Au-Ag deposits. Here we investigate the relationship between hypogene mineralization and associated argillic alteration in the Au-Ag-Mn-bearing veins at Farallón Negro, NW Argentina, to demonstrate the applicability of small-scale alteration minerals in future exploration for intermediate-sulfidation epithermal veins. Petrographic and sulfide-mineral chemistry investigations reveal that the veins, hosted in the Alto de la Blenda monzonite and the Morada Central andesitic-breccia, document a maximum of four hypogene vein-infill-phases comprised of a silica, ± sulfide-sulfosalt and Mn-carbonate sub-stage each. Gold-silver precipitates in phase-2 and is characterized by the assemblage tennantite-tetrahedrite-sphalerite-pyrite-galena±electrum. Fluid inclusions trapped in ore-associated anhydrite record the highest entrapment temperatures (373-385 °C) and highest salinity (3.8 NaCl eq wt %). Phase-2-carbonate displays lower $\delta^{18}O_{V\text{-}SMOW}$ values ($\delta^{18}O_{calcite}$ = 8.83-12.49 ‰) than all other phases. Structural analyses of wall rock alteration minerals show that chlorite-interstratified-R3-illite/smectite±illite are the most abundant hypogene clay-alteration minerals. Supergene clay-sized-alteration minerals, generally dioctahedral smectite±kaolinite, predominate along fractures. In the hydrothermal periods, around 7.16 ±

0.06 Ma, the high phase-2 temperature, low salinity and isotopic composition indicate cooling of ascending hydrothermal fluids derived from a contracted-magmatic-vapor-phase and minor mixing with descending meteoric fluids. Hypogene quartz-R3-illite/smectite-chlorite-calcite-pyrite alteration in the andesitic-breccia and quartz-illite-R3-illite/smectite-chlorite-calcite-pyrite alteration in the monzonite is related to the first two vein-infill-phases and gold-silver deposition (260-350 °C). Weathering since 2.70 ± 0.80 Ma generates sulfuric and carbonic acids through the oxidation of hypogene sulfides and Mn-carbonates. These acidic fluids descend along vein-related fracture-networks to at least 450 m depth below the present-day level, forming the supergene alteration assemblage of gypsum-dioctahedral smectite-Mn-/Fe-oxides/-hydroxides±kaolinite±R0-chlorite/smectite in both wall rocks (~ 50 °C). The occurrence of vein-proximal-illite in the monzonite could serve as an exploration tool in the Farallón Negro mine.

Origin of spherulitic and cone-in-cone concretions in Cambro-Ordovician black shales, St. Lawrence Estuary, Quebec, Canada

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Spherulitic concretions are very rare among carbonate concretions that generally consist of micritic carbonate. The occurrence of spherulitic concretions in Cambro-Ordovician black shales of unknown stratigraphic age on a mid-channel island in St. Lawrence Estuary in Quebec is a new example in addition to only three hitherto reported occurrences of spherulitic carbonate concretions. Their origin is still poorly understood. These concretions occur in close association with, and show various transitions to, cone-in-cone structure. The spherules measuring 0.5 to 12 mm in diameter consist of intergrown fine fibers of ferroan calcite and quartzine, pointing to the formation of the concretions below the sulfate reduction zone. A phenomenological theory of spherulitic crystallization relates the thickness δ of an impurity-rich layer in front of impurity-rejecting growing crystals to the impurity-diffusion coefficient D and the growth velocity G of the crystal by $\delta=D/G$. In spherulite-forming environments, extremely small values of δ (on the order of < 1 µm) in conjunction with cellulation lead to spherulitic fiber growth. The theory of spherulitic crystallization is here applied to sedimentary deposits for the first time. The intimate association of calcite and quartzine in the concretions requires a chemical change from alkaline to acidic conditions, which occurs below the carbonate-reduction zone due to the dissolution of sponge spicules or radiolarians. The transition from spherulite to the silica-free cone-in-cone structure occurs when the silica reservoir as impurity is exhausted in the crystallization process.

Machine-learning for real time control of the chemical quality of tunnel-boring cuttings

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ENVISOL has had the opportunity to conduct a project with a strong AI component. The main objective of the talk is to give a feedback on the key steps of the project: from the data acquisition, the measurements methodology and the first statistical analysis to the implementation of machine learning algorithms that give away the final output. Machine Learning fulfilled a need in gaining time, money and efficiency in the chemical characterisation of cuttings from boring machines. "Random-Forest" algorithms, trained on built datasets, make possible a real-time classification of those cuttings. This talk, which aims to be accessible to everyone, will go through the main steps while avoiding going into unnecessary details. Limitations and difficulties encountered will also be developed to give a global picture of the use of Machine Learning in that practical and specific application. Above the actual advantages brought to the project, the use of machine learning is an important step in unlocking geological information and a natural evolution for the environnmental industry - which faces increasing challenges.

Utilization of field portable X-Ray Fluorescence (pXRF) at the Nash Creek Zn-Pb-Ag deposit, New Brunswick: analysis of reproducibility and application of pXRF geochemical data

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Field Portable X-Ray Fluorescence (pXRF) is a well-established non-destructive analytical technique capable of rapidly collecting multi-element geochemical data. It is capable of assisting with: protolith identification, identification of alteration, sample selection, and assessment of geotectonic setting. Using an Innov-X X-5000 pXRF, thin section off cuts obtained from volcanic rocks hosting the Nash Creek (Zn-Pb-Ag) sulphide deposit have been analyzed to assess; the accuracy and reproducibility of geochemical data compared to geochemical data obtained from a certified laboratory, and the subsequent application of the data to trace element based discrimination diagrams. Of the elements analyzed, Ti, Y, Zr, Nb, Th, and Rb were assessed due to their common use in trace element based discrimination diagrams. The comparison showed that within the majority of the basaltic/andesitic rocks analyzed, Ti, Y, and Nb values were reproducible to within 10% relative difference and Zr to within 15%, whereas Th at low concentrations consistently returned an overestimated value leading to a ~25% difference. Rhyolite trace element data showed that Rb was frequently reproducible to within 5%, Y within 10%, Ti, & Zr to within 15%, and Nb & Th to within 20%. Despite the variations, plotting both the pXRF and certified laboratory geochemical data on appropriate trace element based discrimination diagrams including: Ti-Zr-Y, Rb-(Y+Nb), Nb-Y, and Zr/TiO_2:Nb/Y. Showed that the majority of basaltic/andesitic rocks plot within the calc-alkaline field on Ti-Zr-Y discrimination diagrams. Whereas the majority of rhyolites plot in the within-plate granite field on both the Rb-(Y+Nb) and Nb-Y discrimination diagrams. The Zr/TiO_2:Nb/Y diagram was able to consistently plot the rocks within the same field as the laboratory results, leading to the same rock classifications. Showing the results were relatively comparable between the pXRF and laboratory, and the trace element-based discrimination diagrams comparable to previously conducted studies.

Alberta's western Canada Sedimentary Basin's first electrical geothermal project proposal

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In Canada's western provinces, the Western Canada Sedimentary Basin (WCSB) is known to have warm to hot brines in large extractable volumes from permeable, hydrocarbon bearing units. In Alberta's north western region, the Municipal District of Greenview (MDGV) has been actively supporting preliminary resource investigations within its lands. These investigations have been to determine if there is an economically viable resource under the MDGV and in particular a new heavy-eco industrial park, planned for a large tract of land south of the city of Grande Prairie. The industrial park, referred to as the Tri-Municipal Industrial Park (TMIP), will utilize both electrical and thermal energy produced by the project. The research suggests that temperatures above 125 °C are attainable at depths from 3500 m and below. The target formations at these depths are under the Beaverhill Lake Group and are comprised of the Swan Hills, Granite Wash, Gilwood and the basement unconformity. Importantly, the targets are below the hydrocarbon and shale rich Duvernay Formation. Only two wells within the TMIP have been drilled to the basement and only a handful of wells are drilled below the Duvernay Formation. There is limited flow test data on the target

formations but extrapolating from similar target formations elsewhere, it is anticipated that flow rates in 7 inch pipe will exceed 30 l/s. Fluid chemistry modelling of existing analytical data suggests that there will be no major issues with mixing of formation waters and injection into the Leduc Formation is a possibility.

Geothermal energy in Canada

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Geothermal research in Canada has rich past with many prominent and important early researchers, explorers and developers who worked within Canada and abroad. To support this work, the Canadian Geothermal Association (CGA) was launched in 1973 at the inaugural meeting of the US-based Geothermal Resources Council (GRC) and formalized in 1974. In 2018, the Society was rebranded Geothermal Canada. Dedicated to supporting the geothermal community in Canada to assist with networking to promote the exchange of ideas and innovations in all aspects of the geothermal world, the Society supports workshops, conferences, and other forms of information exchange. Across Canada the geothermal landscape has changed considerably during the past five years. Vibrant research groups exist through universities across the country; 543 scientific publications on geothermal energy written by Canadian researchers are reported in Scopus from 2013 to 2018. The focus is on resource assessment, direct-use and adapting technology for remote communities located in an arctic to subarctic climate. Provincial governments in BC, Alberta, Saskatchewan and Quebec are supporting projects and the exchange of ideas. In Canada's north, including the Yukon, Nunavut, Nunavik and the Northwest Territories, there are initiatives to assess the geothermal potential, especially through engineered geothermal systems (EGS), and supporting research for development challenges in extreme environments. Canada's federal government, through Natural Resources Canada, awarded a 25.6 million dollars grant to the DEEP Corp. project in Saskatchewan, and its Geological Survey of Canada continues to support geothermal research. As the global landscape continues to evolve away from hydrocarbons for heating and electricity generation, Canada is well-placed to fill in the gap with thermal and electrical generation from sedimentary basins, deep faults and volcanic systems, as well as to be a leader in EGS. Canadian scientists and engineers are poised to make significant contributions both here in Canada and globally.

Development of dacite magma from chemical and textural studies: example from the Kameni Islands volcanic centre (Thera, Greece)

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The Kameni Islands volcanic centre has erupted dacite at least 13 times during the last 2000 years: the limited range in chemical composition (SiO_2 = 64-68 %) contrasts with the wide range in textures (plagioclase = 3-22 %). Lavas are commonly glassy with abundant macrocrysts of plagioclase, some of which occur in loose clusters with relatively fine-grained cores. Most plagioclase crystals have simple zoning and belong to the same population. Enclaves are present but do not appear to have contributed significantly to magmatic diversity. Starting with the 46 CE eruption SiO_2 initially rose until the explosive 726 eruption and then descended until the last eruption in 1950. Plagioclase abundances mirror this variation and are broadly correlated with decreasing SiO_2 and increasing Eu/Eu*. To better understand magma chamber processes, we determined the crystal size distributions (CSD) of plagioclase and correlated it with composition. CSDs are curved and have been modelled by adding two straight CSDs, 'large' and 'small', reflecting deep and shallow processes respectively. 'Large' CSDs show relatively little temporal variation in characteristic length, but their abundance increases with time. 'Small' CSDs become steeper with time suggesting progressively more rapid transport. Mass balance calculations show that compositional diversity can be accommodated by crystallisation of plagioclase macrocrysts from a series of dacite liquids that became less evolved with time. We propose that there were 3 eruptive phases. During phase 1 (46-726) evolved dacite magmas were stored deep in the volcano, where minor amounts of plagioclase crystallised and coarsened. Phase 2 (1570-1928) magma crystallised more plagioclase in a cooler environment from less evolved dacite magmas. In the final phase (1939-1950) the composition of the dacite was the same as in phase 2, but the amount of plagioclase crystallisation was greater. The magmas also spent the shortest time in transit to the surface.

Lamprophyres, carbonatites and phoscorites of the Saguenay City alkali province, Quebec, Canada

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The Saguenay City alkali province (~ 580 Ma) comprises the Saint-Honoré alkaline complex (carbonatite-syenite), lesser-known minor subsurface carbonatite intrusions and several sets of lamprophyre (sl) dykes. Flat-lying, north-dipping dykes (l-100 cm) that crop out close the Saguenay River/Fjord were formed by multiple intrusions of a very fluid magma. The dykes are continuously variable in composition from carbonatite to ultramafic lamprophyre. Olivine phenocrysts (l-3 mm) are pseudomorphed by serpentine but phlogopite phenocrysts (l-5 mm) are well preserved in a matrix of a fine-grained serpentine, chlorite and carbonate. A few dykes are phoscorites, with abundant phenocrysts of phlogopite, oxides, apatite and accessory baddeleyite. In all dykes, the matrix may have been originally fine-grained or even glassy, and subsequently altered by water dissolved in the original magma. Several dykes contain abundant xenoliths: mostly crustal and possibly one of mantle origin. Low-carbonate dykes have a narrow range in Sr isotopes (0.7030-0.7033) versus the wider range of high-carbonate dykes (0.7032-0.7046), but this distinction is not seen in εNd (3.4-4.9). Overall, it appears that each batch of magma was small and came from independent mantle sources. Recently, we found a new set of vertical, NW-directed lamprophyres around the Baie des Ha! Ha!, about 15 km south of the main swarm. They have phlogopite phenocrysts to 50 mm and olivine pseudomorphs. Their contrasting orientation suggests that they have a different age to the Saguenay River dykes, but they have yet to be dated. The overall pattern is of an extensive mantle source that delivered small volumes of volatile-rich ultramafic magmas over a long period. We consider that some of these magma batches accumulated and differentiated in a magma chamber beneath the Saint-Honoré alkaline complex, whereas others rose uninterrupted to high levels of the crust where they were emplaced as dykes.

A Paleoproterozoic macro-tidal to shallow marine shelf, characterized by microbial, tide, and storm activity: the Gordon Lake Formation, Huronian Supergroup

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The ca. 2.45 to 2.22 Ga Huronian Supergroup is exposed north of Lake Huron, Ontario, and is interpreted to be the product of a partial Wilson

cycle and represents the transition from continental rifting to the establishment of a passive margin. The Gordon Lake Formation is the second youngest formation in the succession and was deposited along the newly formed, southward-facing continental margin. Compared to stratigraphically lower formations, the Gordon Lake Formation has received little attention, and to date no facies analysis or regional study has been described in the compendium of Huronian Supergroup literature. Detailed investigation of the sedimentological and stratigraphic characteristics of the Gordon Lake Formation took place in four areas of Ontario: near Bruce Mines, north of Elliot Lake, in Baie Fine and Killarney Provincial Park, and in Lady Evelyn-Smoothwater Provincial Park. This assessment led to the recognition of seven distinct lithofacies: 1) very fine- to fine-grained sandstone, 2) fine- to medium-grained sandstone, 3) carbonate, 4) interlaminated to interbedded mudstone and fine-grained sandstone, 5) coarse-grained sandstone, 6) intraformational granular to pebbly sandstone and conglomerate, and 7) mudstone. The lithofacies are interpreted to represent deposition along an open coast, specifically a mainly siliciclastic, tide- and storm-influenced marginal marine to shallow-shelf environment that was colonized by microbial mats. Deposition of the Gordon lake Formation is interpreted to have initiated in response to a transgression, which is characterized by a fining- and generally thinning-upwards trend from the base towards the middle of the formation. This is followed up section by a coarsening- and thickening-upwards succession to the upper formational contact, which may have been a result of a regression or an increase in sediment supply. This study provides a greater understanding of sedimentary processes on essentially non-vegetated surfaces and contributes to the depositional history of the largely unresolved upper Huronian Supergroup.

Understanding the origin and evolution of impact melt from the Mistastin Lake impact structure

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The Mistastin Lake impact structure is a complex impact crater within the Mesoproterozoic Mistastin batholith. This well-preserved structure preserves a series of impact melt rocks and melt-bearing breccias. Compositional heterogeneities were observed on the macro- and micro-scale, particularly within the matrices of the impact melt rock. It has been suggested that the entrainment and subsequent melting of clasts into the impact melt was the main cause of the variation in composition. To better understand this issue, this study aims to understand better the evolution of the melt at Mistastin Lake by examining the impact glass that was produced. Impact glass clasts were found in a range of lithologies, including polymict breccias and clast-rich melt rock, from a variety of outcrops. Four petrographic subtypes of glass were identified based on clast content, prevalence of schlieren, colour, texture, and habit. Several alteration phases were observed replacing glass and infilling vesicles; however, textural observations and quantified compositional data has allowed for the identification of pristine impact glass. Though the various types of glasses show significant overlap in their major oxide composition, several subtle variations are observed between each group. To investigate this variation, a least-squares mixing model was implemented utilizing the composition of the glass and the known target rock chemistry to model the initial melt composition. Initial results suggest varying degrees in the amount of each target rock is the controlling element in the overall composition of the glass. Further petrographical, geochemical, and textual analysis will be conducted to compare the glass at Mistastin Lake with other terrestrial impact craters (e.g. Ries) and the Moon to understand better the cause of the observed variation.

The giant Arrow uranium deposit, Patterson Lake corridor, Athabasca Basin: overview of present knowledge

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Recent significant discoveries of uranium mineralization in the southwestern Athabasca Basin have been associated with a series of conductors along a NE-SW-trending structural zone, termed the Patterson Lake corridor. The Arrow deposit, which is along this trend and hosted exclusively in the Taltson Domain orthogneisses below the Athabasca Supergroup sandstones, has an Indicated Mineral Resource of 256.6 Mlbs U_3O_8 at an overall grade of 4.03 % U_3O_8, and is thus one of the largest undeveloped uranium deposits in the world. The Arrow system developed along sub-vertical, NE-SW-trending heterogeneous high-strain zones (A1/A2/A3/A4/A5 shears) along the limb of a regional-scale fold, which may have been the focus of pre-mineralization metasomatism of varying ages (e.g. silica flooding preserved as blue quartz; sericite; graphite; Fe-sulphides). The kinematics of the early ductile shears are masked by later brittle-ductile and brittle deformation, alteration, and mineralization, although the structural system closer to the time of mineralization is interpreted as a sinistral strike-slip-dominated fault system of Riedel-style geometry. The hydrothermal system associated with mineralization comprises white mica (illite and muscovite), chlorite, dravite, quartz-healed breccias and veins, and hematite, within a complex paragenetic framework. Elevated precious metal concentrations occur locally, are associated with base metal sulphides and carbonates, and are late in the hydrothermal system. Mineralization occurs as botryoidal, cubic, vein, and massive uraninite, and secondary phases, such as coffinite and uranophane. SIMS and chemical ages from uraninite suggest a minimum formation age of about 1425 Ma, although younger ages are common and indicate remobilization during later fluid events, including interaction with low $\delta^{18}O$ meteoric waters. The oldest ages were obtained from the margins of the system, supporting the focusing of later fluids through the core of the fault zone. This work builds the framework for Ar-Ar geochronology, and analysis of fluids to determine the origin of the Arrow deposit.

What pore water chemistry in Champlain Sea muds reveals about hydrogeology, marine salinity, and sensitivity to landslides

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Champlain Sea muds, also known locally as Leda Clays, form a regionally extensive aquitard in the St. Lawrence Lowlands and the Ottawa Valley. Investigations of pore water chemistry, borehole geophysics, and geotechnical sensitivity (ratio of undisturbed to remoulded compressive strength) within a thick sequence of Champlain Sea muds provide insights into groundwater flow across the aquitard, original salinity, and development of landslide susceptibility. Typically, the assumption is that diffusion alone controls solute transport through Champlain Sea muds. However, this study uses 1D groundwater modelling to demonstrate that both advection (Darcy flux of approx. 4 mm/a) and diffusion contribute to solute transport at a site located in thicker (~ 75 m) Champlain Sea mud deposits at Breckenridge, QC, northwest of Ottawa. Previous hydrogeological studies estimate Champlain Sea salinity to be approximately 33 % of contemporaneous ocean salinity. However, in this study, where the sequence of Champlain Sea muds is thicker, the peak measured ionic concentrations in pore water represent at least 60 % of relic seawater salinity. Geophysical logs

of bulk apparent conductivity corroborate this finding. Additionally, transport modelling constrains the Champlain Sea concentration of seawater constituent ions (e.g. [Cl^-]), and hence, the original salinity. Although the concentrations of seawater ions (Cl^-, Br^-, Na^+) allow estimation of the seawater fraction, when combined with isotopic signatures (e.g. ^{18}O), these multiple tracers form the basis to estimate relative proportions of seawater, meteoric fresh water, and fresh glacial melt water of the Champlain Sea episode. Champlain Sea salinity, along with the combined effects of advection, diffusion, and thickness of the muds, controls the current pore water chemistry, which in turn, influences sensitivity development of Leda Clays and susceptibility to landslides.

Feast then Famine: exiting the GOE and setting the stage for a billion years of environmental stability

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The history of oxygenation of the early Earth has been the focus of intense research efforts. While the timing of the initial rise of oxygen in the atmosphere has received a great deal of attention, its behavior immediately after this initial pulse is much more poorly understood. It has been proposed that atmospheric oxygen reached values near or perhaps even exceeding modern values during the Great Oxidation Event, in what has been termed the "oxygen overshoot", before declining to lower values. However, the magnitude, cadence, and underlying cause of this decline remain enigmatic. Here, we present triple oxygen ($\Delta^{17}O$), multiple sulfur, and barium isotope analyses of barites from the Orosirian (2.02-1.85 Ga) Belcher Group, subarctic Canada. All measured $\Delta^{17}O$ values are consistently mass-independently depleted, ranging from -0.78 ‰ to -0.55 ‰. Interpreting these anomalous values in the context of estimates for Orosirian atmospheric pCO_2 and pO_2 provides estimates of gross primary productivity at this time. Paired with pre-existing Paleoproterozoic $\Delta^{17}O$ values that preceded the deposition of the Belcher Group barites, we document a dramatic decrease in primary productivity by at least 4-fold but potentially over a 100-fold, that sets the stage for the subsequent billion years of Earth history.

Constraining the end-Lomagundi Excursion transition in the Labrador Trough

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The Labrador Trough, a thick, structurally complex sedimentary-volcanic succession in northern Quebec and Labrador, has relatively few age constraints, despite the efforts of numerous researchers and large-scale geological field campaigns. This knowledge gap leaves much unknown about the evolution of the basin and the full implications of its sedimentary record for understanding the mid-late Paleoproterozoic. Melezhik and co-workers discovered that carbonates of the lower Labrador Trough record a $\delta^{13}C$ transition from 15 ‰ to 0 ‰, occurring somewhere between the Uvé Formation and the stratigraphically higher Denault Formation. This pattern was interpreted as part of the Lomagundi-Jatuli Excursion (LJE), Earth's largest and longest-lived positive carbon isotope excursion. To better constrain the end-LJE transition, field studies were conducted on the Le Fer Formation and the directly overlying Denault Formation. The vast majority of the Le Fer Formation is composed of green-grey silty-slates, with thin beds of dolomicrite sparsely scattered throughout. Carbonate $\delta^{13}C$ values in the Le Fer Formation range from -4.4 to +6.9 ‰, with a modal value of 3.5 ‰. $\delta^{13}C$ and $\delta^{18}O$ correlate (R^2 = 0.60), suggesting that many of the samples have been strongly altered and that the heaviest $\delta^{13}C$ values are most likely to record coeval seawater. $\delta^{13}C$ values in the overlying Denault Formation broadly decrease up-section, from +4.3 to -0.5 ‰, and are uncorrelated to $\delta^{18}O$ (likely owing to the Denault Formation being almost entirely carbonate, whereas the Le Fer Formation is almost entirely siliciclastic). These results suggest that the Le Fer and Denault formations together record the end-LJE transition and were therefore deposited very near the age range of the end-LJE as reported from other successions: 2106-2057 Ma. This conclusion has important implications for understanding the geological evolution of the Labrador Trough and the Earth's transition out of the LJE.

Cusp tectonics: Ediacaran mega-karst landscape and bidirectional mass slides constrain flexural properties of a weak plate at a cusp - the join of the Pan-African Kaoko and Damara orogens in NW Namibia

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Adjacent arcs join at a cusp. Cenozoic examples of continental lithosphere subducting at cusps include the Shillong Plateau in the cusp joining the Eastern Himalayan and Indo-Burman ranges, and the Musandam Peninsula arch in the cusp joining the Zagros and Makran ranges. An analogous cusp occurs at the join of the Pan-African Kaoko and Damara orogens in NW Namibia, where stratigraphic relations on the subducting plate (Congo craton, Cc) place quantitative constraints on forebulge height and wavelength in a weak continental plate abortively subducting ~ 50 Myr after continental breakup. Cc was covered by the carbonate-dominated Otavi Group (OG) of syn-rift (0.76 to 0.64 Ga) through passive-margin (0.64 to 0.59 Ga) age, which is disconformably (paraconformably) overlain by collision-related foredeep clastics of the Mulden Group (MG). At the arch of the cusp, the OG/MG disconformity defines an Ediacaran mega-karst landscape in which is < 1.4 km-high OG table mountains stood as outliers on a reexumed Orosirian Cc basement plain. The basement surface is locally incised to a depth of 0.3 km where its paleo-depth shallowed by the same amount over a buried rift shoulder. Coincident with megakarst development, map-scale slide masses were coherently translated 20 km westward and southward toward the advancing Kaoko and Damara orogens, respectively. The contracted leading zones of the slide masses were submarine but the extended trailing zones were terrestrial and actively eroding during translation. Corrected for subsequent shortening, the slide masses are lodged ~ 75 km from the crest of the arch, thus 150 km is the best estimate of the flexural wavelength transverse to the arch axis. Axial uplift during karstification was < 1.4 km wrt sea level outside the forebulge area. Any gravitational pull on sea level by the arch itself was likely compensated by additional carbonate accumulation prior to uplift and karstification.

Carbon isotope fluctuations in shallow-water marine carbonates and the evolution of carbonate production over the past 2.0 Gyr

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C-isotope fluctuations recorded in epi-platform carbonates were muted between 2.0 and 1.4 Ga (stage 1), after which their amplitude increased until the late Ediacaran (stage 2), before declining again (stage 3). These changes coincided broadly with basic changes in the nature of carbonate production. During stage 1, production was mainly benthic seafloor cements and cemented microbialites. In stage 2, non-skeletal lime mud became important, whereas skeletal production dominated stage 3. This suggests that marine carbonate production shifted from the seafloor (stage 1) into the water column (stage 2) and then into intracellular fluids (stage 3). Early Ediacaran epi-platform carbonates in NW Namibia have baseline $\delta^{13}C$ values (independent of short-lived excursions) that are either depleted or enriched (and scattered) relative

to stage 1 and 3 norms. The same baseline shifts are observed in carbonate turbidites in peri-platform deep-sea fans, suggesting that epi-platform carbonate was advected to the abyss with its C-isotope composition intact. However, correlative carbonates on the foreslope of the platform, where diagenesis is expected to have been fluid-buffered due to seawater invasion in response to geothermal porewater convection, have $\delta^{13}C$ values consistently in the range of modern seawater DIC (1 ± 1.5 ‰ VPDB), except during the post-snowball negative C isotope excursion which is quantitatively reproduced in all areas. If foreslope diagenesis was buffered by seawater, the anomalous baseline values in the epi-platform and deep-sea carbonates do not reflect the $\delta^{13}C$ of open-ocean DIC. We speculate that the perturbed compositions of epi-platform carbonate are related to nucleation kinetics of pulsed carbonate production in the water column ("whitings"). In contrast, nucleation inhibition and associated kinetic isotope effects would be unimportant in benthic and biotically-regulated intracellular carbonate production. In this view, amplified stage 2 isotopic variability is related to the changing nature of carbonate production, rather than to environmental, biological or biogeochemical perturbations.

Was the glacial erosion flux on Snowball Earth insensitive to active tectonics?

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In the Kunene Region (NW Namibia), the crust was actively stretching during the Sturtian glaciation, but only passive-margin subsidence occurred during the Marinoan glaciation in the same area. The contrast in tectonic regime is manifest by polymictic Sturtian diamictites but oligomictic Marinoan ones, and by angular unconformities of Sturtian age but Marinoan paraconformities. However, the regional average sedimentation rates for the two glaciations were not significantly different. The sediment accumulation rate for 110 complete sections of the Sturtian Chuos Formation was 4.0 m Ma^{-1}, averaged over the 58 Ma glaciation (717-659 Ma). The accumulation rate for 157 complete sections of the Marinoan Ghaub Formation was 3.5 or 5.3 m Ma^{-1}, assuming glacial durations of 15 Ma (650-635 Ma) or 10 Ma (645-635 Ma), respectively. All else being equal, the Marinoan rate should have been ~ 10 % faster (4.4 m Ma^{-1}) than Sturtian, simply on account of its shorter averaging time. Unless the Kunene Region is grossly unrepresentative, the thickness data indicate that active Sturtian tectonics and rift-related topography did not raise the glacial sediment flux relative to the Marinoan, when tectonic topography was absent. Tectonic topography may have been a weak driver of glacial erosion on Snowball Earth because of the large potential energy imparted by a net sea level fall equal to, or greater than, ca. 0.5 km. If so, Marinoan glacial erosion should have been biased toward an early stage of glaciation. As glaciation proceeded and atmospheric CO_2 accumulated, relative sea-level would have risen due to tectonic subsidence and ice-sheet mass reduction. Because of glacial reworking, an early bias in glacial erosion might not be reflected by sediment accumulation dates.

Better water management-related decisions: making data useable in the Greater Toronto Area

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A recent article in the Globe and Mail noted that "When it comes to basic data about its citizens, "Canada simply doesn't have the answers." Although referring to information regarding many aspects of our human society (e.g. health care, population dynamics, etc.), the statement also certainly rings true for all types of data related to our natural environment. There has been insufficient resources allocated to, and limited leadership expended, when it comes to properly managing environmental data, including information on our precious water resources. Since 2001 the Oak Ridges Moraine Groundwater Program (ORMGP) has been effectively tackling the issue of collecting, housing and managing a considerable breadth of water-related data. Through data synthesis and analyses, and in providing web-based access to this information, the Program has been advocating for efficiencies and improvements in the many day to day decisions regularly made by various government agencies across southern Ontario. In considering an idealistic pathway of taking useful water-related data, preparing interpretive products based on these data, making both the data and interpretive products accessible and thus useable, and ultimately having this information then used in decision making, the ORMGP sets a clear path that can be emulated elsewhere.

Development of a plate margins database for use with plate reconstruction software

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Plate reconstruction models seek to represent past plate tectonic motions and geodynamic associations. Models utilize many different types of data including paleomagnetism, geochemistry, and geochronology to map shifts in location through time of polygons representing crustal geodynamic units. Since plate tectonics is a primary factor in the location and characteristics of mineral deposits, understanding previous plate interactions provides a powerful tool to aid in interpreting and locating regions prospective for mineral occurrences. Most current Paleozoic and Precambrian plate reconstruction models fail to provide explicit locations of major plate boundaries with which most mineral deposits are associated. Several reconstruction models for younger time intervals have also demonstrated the benefit of delineating plate boundaries as an additional constraint on the quality of the models. A database design has been developed to assist in the compilation of plate boundaries for relatively complex models which extend from present day back to the Archean. This model is being integrated with plate reconstruction software like Paleogis and GPlates and the plate boundaries will be combined in a continuously closing topology with GPlates. Initial development of the plate margin database has focussed on the assembly and breakup of Gondwana so as to test the methodology and efficiency of the database design. Future work will link the location of subduction zones and other plate margins to broad latitudinal climate zones associated with varying degrees of weathering and to mineralisation.

Evolution of the southern Beishan Orogenic Collage, NW China: implications for the closure of the Paleo-Asian Ocean

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The Central Asian Orogenic Belt (CAOB) evolved for ca. 800 Ma from late Mesoproterozoic to early Mesozoic. Its terminal collision and accretion generally commenced in the west and terminated in the east, creating the Tianshan suture and Solonker suture, respectively. The Beishan Orogenic Collage connects the two sutures and contains some of the youngest ophiolitic complexes, arc terranes and sedimentary basins in the CAOB. Hence, investigations of the Beishan orogenic collage can contribute to correlating the geology on both sides and establishing an integrated tectonic history of the Paleo-Asian Ocean's closure. Through detailed mapping (1:25 000 scale) in southern Beishan, three distinct tectono-stratigraphic packages were identified. The Baidunzi Complex comprises a mixture of sheared and transposed metasedimentary and syn-kinematic metaplutonic rocks, ranging from greenschist to amphibolite facies. The metasedimentary sequences

contain Carboniferous-Permian marble and meta-calcareous clastic rocks, possibly deposited on a passive margin. A massive sheet of bedded quartzite in this complex, with detrital zircon ages from ca. 2432 to 856 Ma, is considered as the most probable candidate for basement in this area. The Baidunzi Complex was thrust on a volcanic group that is mainly composed of dacitic-rhyolitic tuff, pyroclastic flows, subvolcanic granitic intrusions and associated volcanogenic sedimentary rocks. These yielded U-Pb zircon ages of ca. 286-282 Ma and ca. 297-292 Ma without zircon inheritance. Preliminary geochemical data indicate this group formed in a dominantly felsic, yet relatively juvenile arc. A Permian foreland basin, with typical fold-and-thrust style deformation, developed unconformably on the volcanic group. From bottom to top, it consists of black shale, an unconformably overlying flysch-like sedimentary unit, and a syn-orogenic conglomerate with clasts of rocks from all underlying sequences. The overall field relationships record a transition from a passive to an active margin (Baidunzi Complex), formation and accretion of a relatively juvenile arc and collision during the Carboniferous-Permian.

Geology of the Baidunzi area in the Central Asian Orogenic Belt in NW China: results of 1:25 000 scale geological mapping

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As a part of a joint mapping project involving the China Geological Survey, the University of Waterloo and the Geological Survey of Canada, the Baidunzi area in the Beishan orogen in NW China was mapped at the 1:25 000 scale. Located in between the South Tianshan suture and the Solonker suture, the map area is ideal for solving some key questions concerning the tectonic evolution of the Central Asian Orogenic Belt (CAOB), in particular, the timing and processes of the final closure of the Paleo-Asian Ocean. The rocks of the Baidunzi area were divided into four distinct tectonostratigraphic units: (1) the Neoproterozoic to Permian Baidunzi Complex, comprising a structural collage of interleaved metasedimentary rocks (including marble and quartzite) and meta-plutonic rocks, and representing a transition from a passive to active continental margin; (2) the Permian Ganquan Group, mainly consisting of tectonized Permian felsic to intermediate volcanic rocks, interpreted as a relatively juvenile volcanic arc; (3) the Permian to Triassic Shuangbaotang Group, composed of sedimentary rocks with fold-and-thrust style structures and interpreted as foreland basin deposits; and (4) the Liuyuan Complex, mainly consisting of Permian basalt, gabbro and chert, which may constitute part of an ophiolite sequence. The Shuangbaotang Group locally unconformably overlies all the other units. They have been assembled into a large, predominantly north-verging imbricate stack following three generations of deformation. These preliminary results indicate that the Paleo-Asian Ocean did not close until the Permian or early Triassic in this part of the CAOB.

Paleozoic gold in central Newfoundland: lithological setting, structural development, and lessons from structurally controlled gold systems of the Archean Abitibi greenstone belt

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The Paleozoic gold district of central Newfoundland is emerging as a potential future mining jurisdiction in Canada. Gold mineralization occurs along a ~ 400 km long structural corridor characterized by crustal-scale faults and footwall panels of syn-orogenic conglomerates, remarkably similar to world-class gold deposits of the Archean Abitibi greenstone belt. In central Newfoundland, recent exploration by Antler Gold Incorporation northeast along strike from the well-endowed Valentine Lake property exposed a system of shear-hosted quartz veins with gold intercepts up to 101.5 g/t over 0.5 m. Detailed lithological and structural study of Antler Gold's property demonstrates that the main quartz vein (~ 230 m long by ~ 2 m wide) cuts the conglomerate host within an oblique sinistral reverse shear zone that accommodated north-northeast-directed thrusting. An early set of stacked, moderately dipping extensional quartz veins, consistent with sinistral reverse shear, emanate outwards into the country rock from the main vein. Younger, more steeply dipping sets of extensional quartz veins cut the main vein and the earlier shallow dipping vein set, and are consistent with at least transient phases of (local) horizontal extension and dextral transpression. Chalcopyrite and secondary malachite occur locally in the early vein sets, but are more abundant overall within the later, steeper vein set. Vuggy quartz and altered and unaltered sulphides occur in conjugate sets of steeply dipping extension fractures that cut the main vein and the two vein sets. Our research indicates that gold mineralization on Antler Gold's property is structurally controlled by the northeastern extension of the well-endowed Valentine Lake thrust structure. Mineralization occurs in the structural footwall of the thrust zone identical to gold deposits of the Abitibi, suggesting similarities between Archean and Paleozoic tectonic drivers of gold mineralization. Regional structural correlations suggest that the central Newfoundland vein system formed progressively during the latest Silurian to earliest Devonian.

Shock veins in paired lunar meteorites Northwest Africa 3163 And 4881.

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There are many examples of shock effects in lunar materials, such as shock veins, melt pockets, diaplectic plagioclase glass (maskelynite), and associated high-pressure/high-temperature polymorphs. These shock effects are the result of extensive bombardment by hypervelocity projectiles since the solidification of the lunar surface. On Earth, shock veins have only been identified in the central uplift structures of the Manicouagan (Canada), and Vredefort (South Africa) impact structures. This study examines the shock veins and melt pockets within the paired lunar meteorites Northwest Africa (NWA) 3163 and 4881, in an attempt to better understand the mechanism of formation of these features. NWA 3163 and 4881 are granulitic breccias that, when observed in thin section, display textures ranging from granoblastic to poikiloblastic with larger grains of plagioclase enclosing smaller grains of pyroxene and olivine. Almost all of the plagioclase has been converted to maskelynite, which infers that the meteorite has been subjected to shock pressures of 28-34 GPa (shock stage S3). Multiple shock veins (~ 100 µm wide) and melt pockets (~ 400 µm wide) are present, possessing fluidal-glassy textures. Within the larger shock veins and melt pockets there are small (~ 1 x 3 µm) elongate plagioclase crystals that have grown within the glassy matrix, as observed using Field Emission Scanning Electron Microscopy (SEM). Raman spectroscopy yields a small peak at ~ 1000 shift/cm^{-1} that was registering within shock veins ~ 80 µm in width. This correlates with a crystal composition of clinopyroxene. We explore the formation of these phases, and constrain the thermal conditions of crystallization following shock vein and melt pocket generation.

Emplacement history of the Archean Cr-bearing Black Thor intrusion of the Esker intrusive complex in the McFaulds Lake greenstone belt, Ontario, Superior Province

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The Neoarchean Esker intrusive complex (EIC) is a relatively large elongate intrusive unit exposed over a strike length of about 15 km and a maximum width of about 3 km, which includes the Black Thor intrusion (BTI), the Double Eagle intrusion (DEI), and the Eagle's Nest dike (END). The EIC is of komatiitic affinity with thick lower ultramafic parts and thinner upper mafic parts. EIC hosts world-class Cr and significant Ni-Cu-PGE mineralization mainly occurring within the ultramafic components. It is one of the best examples of stratiform conduit-style Cr mineralization in the world. The BTI and the DEI represent flow-through ultramafic-dominated feeder sills where the lower ultramafic parts have been produced by repeated influxes of komatiitic magmas accompanied by crystallization of Ol ± Opx ± Chr-rich cumulates and fractionation of the residual liquid, resulting in a layered stratigraphy comprising interlayered (from base to top) dunites/harzburgites, harzburgites/websterites/chromitites, and websterites/gabbros. After initial emplacement but before complete crystallization, a cogenetic late websterite phase (LWP) reactivated the feeder conduit and transected the basal part of the BTI and the END. Zircon U-Pb TIMS data indicate that the BTI crystallized over a ~ 2 Ma interval between 2736 Ma (Mafic Zone) and 2734 Ma (Ultramafic Zone and LWP). The dates reveal that the intrusion was not simply constructed in a strictly sequential stratigraphic order from the base (oldest) to the top (youngest) but exhibits a more complex organization. The Black Thor and consequently the Double Eagle intrusions are interpreted to have initially intruded separately but to have coalesced over time with magma inflation within a dynamic komatiitic system to form the Cr and Ni-Cu-PGE-bearing EIC, one of the most important members of an increasingly important class of polymetallic magmatic ore systems.

Magmatic chromium and nickel endowment in the Superior Province

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The Archean Superior Province is well known for its exceptional metal endowment. Ultramafic and mafic intrusions/flows are ubiquitous throughout the Superior Province and are highly prospective to host magmatic Ni-Cu-PGE, Cr-PGE and Fe-Ti-V deposits, but their abundance and endowments vary widely within different terranes/domains of the Superior Province. The Wawa-Abitibi terrane is characterized by the presence of numerous but generally small Ni-Cu-PGE deposits with a few large Fe-Ti-V deposits, the Bird River-Uchi-Oxford Stull-La Grande-Eastmain (BUOGE) superdomain is characterized by several and moderate to very large chromite deposits with a few moderate-small Ni-Cu-PGE deposits and a few potentially large Fe-Ti-V deposits that remain prospects due to the lack of definition drilling, and the other terranes/domains contain no significant magmatic Cr mineralization. Many factors are responsible for the variable metal endowment, but several critical features appear to be important and may define particularly prospective metallotects for Ni-Cu-PGE, Cr-PGE, and Fe-Ti-V mineralization, including the presence of (1) large magmatic events that generated abundant primitive mantle-derived magmas over a short durations, (2) magma compositions that favoured the generation of Ni-Cu-PGE (high-Mg komatiitic), Cr (low-Mg komatiitic), and Cu-Ni-PGE and Fe-Ti-V (basaltic) mineralization, (3) deep discontinuities that focussed magma flow through the lower crust, (4) shallow structures and densities that favoured emplacement of channelized lava/magma conduits at higher levels, (5) high magma fluxes to promote incorporation of crustal rocks, (6) high-level crustal rocks containing sulfur (e.g. sulfide-facies iron formation) and oxide (e.g. oxide-facies iron formation) reservoirs for generating and upgrading sulfide xenomelts and oxide xenocrysts, and (7) favourable deformation and erosion to expose prospective units for exploration. Targeting base and precious metals is challenging, even in well-endowed but partially exposed greenstone belts, however, understanding and these fundamental controls will constrain the likelihood of discovering additional resources in other frontier areas within the Superior Province and throughout the Canadian Shield.

Paleomagnetism of ca. 750 Ma syenite dykes of the southern Congo Craton, northern Namibia: implications for the reconstruction of Rodinia and the nature of the pan-African Damara Orogen

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The location and the orientation of the Congo craton within the Rodinia supercontinent are debated, as is the nature of the Damara orogen which united the Congo and Kalahari cratons in Early Cambrian time. Were the Congo and Kalahari cratons connected within Rodinia? What was the maximum width of the Damara Ocean? Paleomagnetism of early Neoproterozoic rocks on either side of the Damara orogen can address these questions. This study focuses on paleomagnetic data from ca. 750 Ma dykes emanating from the Oas Syenite in the Welwitschia inlier of northern Namibia, representing the southernmost extent of the Congo craton during initial rifting stages of the Damaran Pan-African orogenic cycle. The dykes show variable degrees of alteration, but are generally of low metamorphic grade. They are fine-grained, variably phenocrystic, and generally strike E-W. While the dykes are sometimes observed to cross-cut each other, they appear to belong to a single swarm. Thirty-three individual dykes were sampled, plus two sites of baked-contact tests to constrain the ages of magnetization. At the time of abstract submission, results are not yet complete, but preliminary data include both steep and shallow characteristic magnetic remanence directions amid much scatter. The most prominent cluster of steep directions is intriguing, as they would imply high paleolatitudes in apparent contrast to the stratigraphic record of coeval shallow-water carbonates on the developing Otavi passive margin. Further work in this region will focus on additional baked-contact tests to determine whether any particular mode of the data is primary.

Trace element characteristics of pyrite from the upper Huronian Supergroup and their application to Sudbury offset dykes

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Strata of the Huronian Supergroup, located north of Lake Huron in Ontario, Canada, preserve three Paleoproterozoic successions of glacial advance and retreat that were deposited between ~ 2.45 and ~ 2.2 Ga. The youngest of these glacial successions, which post-dates the Great Oxidation Event, is represented by tillite and argillite of the Gowganda Formation and overlying sandstone of the Lorrain Formation. We report Co and Ni concentrations in pyrite sampled from the Gowganda and Lorrain formations, and cross-cutting Nipissing gabbro from the Sault Ste. Marie area east to the Sudbury region. Trace element maps show that Co is locally concentrated in pyrite, which allows for characterizing a hydrothermal, magmatic or metamorphic derivation for the pyrite. Spot measurements of sulfur isotopes (SIMS) demonstrate that some pyrite crystals formed from a single sulfide fluid ($\delta^{34}S$ range ~ 2 ‰), indicating a complex history for pyrite crystal formation. In either case, spot chemical analyses and $\delta^{34}S$ measurements demonstrate that although Co substitutes for Fe in pyrite, the distribution of Co does not correlate with $\delta^{34}S$. Applying the same methodology to pyrite sampled from the Foy and Parkin offset dykes associated with the Sudbury impact structure, we show that $\delta^{34}S$ ~ 2 ‰ for all pyrite crystals, consistent with a single sulfide fluid source, and that trace element zoning of Co and Ni is consistent with a hydrothermal origin for the pyrite. The results of this trace element study provide new insights into the behavior of Co and Ni within pyrite and introduce a new strategy for characterizing ore deposits.

Origin of iron oxides in IOCG deposits: implications from texture anatomy and mineral chemistry

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Magnetite is a common mineral in many ore deposits and their host rocks. It contains a wide range of trace elements that can be used to fingerprint deposit types and ore-forming processes. Our study based on detailed textural and compositional data on magnetite of the Mina Justa deposit in southern Peru constrains the formation of iron oxide in iron oxide Cu-Au (IOCG) deposits. Two types of magnetite, i.e. platy (TM1 Mag) and granular magnetite (TM2 Mag) have been identified based on the morphology at Mina Justa. Platy magnetite (previously termed "mushketovite") shows three different zones (central bright, dark and outer bright) in the SEM images. The central bright part (TM1-1) characterized by abundant porosity and inclusions was intensively replaced by the dark part of the inner rim (TM1-2). The outer rim (TM1-3) is also bright but lack porosity and inclusions. Granular magnetite (TM2) is generally anhedral and shows two different colors in the BSE images. The dark (TM2-1) and bright (TM2-2) domains in TM2 are intergrown with irregular boundaries. In general, the dark zones of magnetite are characterized by higher Si, Ca, Al and lower Fe contents than the bright zones. We present mineralogical evidence to support that the platy magnetite is mushketovite at Mina Justa. Additionally, the lattice parameters of the two types of magnetite are subequal and lower than pure magnetite, indicating that some cations whose ionic radii is smaller than Fe^{2+} or Fe^{3+} entered into the magnetite lattice by simple or coupled substitution mechanisms. Oxygen fugacity and temperature changes are the dominant mechanisms leading to the formation of the different types of magnetite. The primary hematite was transformed into magnetite (TM1-1) due to a decline in fO_2 and then replaced by TM1-2 magnetite with increased temperature. Meanwhile, granular TM2-1 magnetite directly precipitated from hydrothermal fluid. With the decrease of temperature, TM1-2 and TM2-1 magnetite are replaced by TM1-3 and TM2-2 magnetite, respectively. This study shows that it is very important to combine texture and mineral chemistry to investigate the origin and evolution history of iron oxides.

Application of trace element geochemistry of Fe-(hydro)oxides and rutile to exploration for U mineralization: an example from Hook Lake and Contact deposits

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Magnetite and hematite are common Fe oxides in a wide variety of igneous, metamorphic, and sedimentary rocks. Trace element composition of iron oxides has been widely used in mineral exploration and ore genesis studies. Unconformity-related uranium (U) mineralization in the Athabasca Basin (Saskatchewan) and Kiggavik camp (Nunavut) are strongly associated with clay alteration and associated hematization of basement and sandstone lithologies. Iron (hydro)oxides such as hematite and goethite are closely related to U mineralization. In addition to iron (hydro)oxides, rutile is also closely associated with U mineralization in some deposits. In this study samples from the Hook Lake (Athabasca Basin) and Contact (Kiggavik camp) deposits are used to identify the importance of geochemical characteristics of iron (hydro) oxides and rutile that can be used in U exploration. Partial least squares discriminant analysis (PLS-DA) of electronic probe microanalyzer (EPMA) data showed that U mineralization-related iron (hydro)oxides are characterized by higher Ca, P, Mg, Si, and S contents, whereas barren samples have higher Fe, Ni, Mn, Ti, V, and Cr contents. PLS-DA of rutile EPMA data showed that rutile associated with mineralization can be discriminated from rutile from barren rocks due to higher Ti, Al, W, and Zr contents whereas the barren samples are characterized by higher Si, Mg, V, and Cr contents. PLS-DA of laser ablation ICP-MS (LA-ICP-MS) data of iron (hydro)oxides displays mineralized samples have higher U, Pb, Sr, Zr, and rare earth element contents. PLS-DA of rutile LA-ICP-MS data outlines that higher contents of U, Th, W, Cu, Mo, Zr, Hf, K, and rare earth elements discriminated U mineralized samples.

Seasonal fluctuations of conductivity in unconsolidated glacial till

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Salinity concentrations in aquifers supplying drinking water are a growing concern for municipal water providers as well as consumers. In the regions of southern Ontario, where salt is applied to roads and public walkways and glacial geology complicates interpretation of hydrologic parameters, this concern can be exacerbated. Understanding the seasonal fluctuations of salinity can provide insight of the risk to aquifers of variable parameters. This study attempts to interpret the relationship between conductivity in groundwater at the University of Waterloo North Campus Research Site, and seasonal fluctuations in air temperature, precipitation and periods of freezing related to road salt application. Preliminary findings show a varied set of trends in groundwater conductivity inconsistent across depth for each of the four sampled continuous monitoring wells reflecting the complex nature of salinity fluctuations across only several meters of glacial till.

Volatiles (halogens, N) in volcanic front magmas, Miyake-Jima, Northern Izu-Bonin Island Arc, Japan

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Miyakejima is a volcanic island composed of tholeiitic basalts erupted through 5 distinct eruption stages between 10 000 BP and 2000 AD. Following the most recent eruption in 2000, the volcano released 15 Mt of SO_2 over 20 months, with emission rates of up to 40 000 tonnes of SO_2/d. A total of 15 samples representing individual eruption events within these stages were examined for volatiles to evaluate their behaviour in subduction zones. They range in Mg# (= $100*Mg/Mg+Fe^{2+}$) from 35 to 54, and contain phenocrysts of Ca-plagioclase, olivine, clinopyroxene and Fe-Ti oxides. Fluorine (36-168 ppm) increases with increasing Y, suggesting its behaviour as an incompatible, insoluble element during fractional crystallization, and ~ 36 ppm F in primitive magmas. Cl (42-1200 ppm) shows a weak positive correlation with Y. Its enrichment is attributed to a contribution of external Cl (such as seawater-derived brine) coupled with fractional crystallization. Both Br (0.7-9.8 ppm) and Iodine (0.07-0.13 ppm) show weak inverse correlations with Y, indicating that they likely underwent various degrees of degassing from magmas. Even taking degassing into consideration, average concentrations (3.4 ppm Br, 0.09 ppm I) are twice the average MORB values (1.65 ppm Br and 0.048 ppm I), suggesting that Br and I released from subducting slabs are incorporated in arc magmas. The content of N varies from 20-60 ppm, which is greater than unaltered and altered MORB (~ 20 ppm), suggesting the contribution of N from sediments into the parental magmas. Copper content varies from 20 to 160 ppm, with a median value of 105 ppm, enriched relative to MORB (~ 80 ppm). The samples contain rare red Ca-plagioclase megacrysts, the color of which is due to the presence of native copper in crystals and melt-inclusions. Presence of native copper in these plagioclase and Cu-Fe-S inclusions in olivine melt inclusions suggest Cu remained in the melt and was not lost by degassing.

The nature and processes of Cordillera backarc volcanism: geochemistry and geophysical constraints

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The North American Cordillera has wide-spread small-volume volcanism from Mexico to Alaska. Volcanism extends over 800 km wide, sharply limited at the craton. We conclude that most volcanism is generated in the asthenosphere although commonly modified in upward transit. The basalts are wet (1-3 % H_2O), indicating a wet asthenosphere source, in contrast to a dry lithosphere from xenoliths. Geochemical data indicate equilibration at ~ 70 km and 1350 ˚C, likely at the base of the lithosphere. Complementary geophysical data indicate that the Cordillera and other backarcs are uniformly hot, with lithosphere base at a similar depth and temperature. The Cordillera Lithosphere-Asthenosphere boundary (LAB) has a strong 5-10 % seismic velocity decrease downward with an underlying gradient. This response is explained by partial melt rising from greater depth ponded at the base of the lithosphere; a sharp top and diffuse base. There is no seismic LAB under cratons and other stable areas. The concentration of partial melt in the asthenosphere upper ~ 50 km is a few percent from seismic velocity data, especially Vp/Vs. A process model has a wet asthenosphere with low temperature solidus that allows partial melting, whereas the lithosphere is nominally "dry" so has a high solidus temperature and generally remains stable. However, the lithosphere may be weakened and thinned by fluids percolating upward, as inferred for the Colorado Plateau. The present thin backarc Cordillera lithosphere may be the residual of a former thick stable lithosphere that has been thinned upward by erosion through water driven off the downgoing subducting plate.

Large-scale tectonic processes in the Grenville orogeny: insights from Cordillera and Himalaya-Tibet

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I discuss the large-scale tectonic history of the Grenville orogen by analogy with the current North American Cordillera and the India-Asia collision zone. This orogen involved collision between cratonic North America, Laurentia, and another continent, probably Amazonia to the southeast. Most of the eastern portion has been removed or overprinted. Two regions provide insight into the processes leading to the terminal collision at 1.0-1.1 Ga, the North American Cordillera, and the Himalaya-Tibet. Like the Cordillera and pre-collision Tibet, the Grenville was a 500 km wide uniformly hot backarc (with complex terrane accretion) for over 100 Ma prior to terminal collision. Inferred common characteristics are: (1) Uniformly hot subduction backarcs with thin readily-deformed lithosphere; Moho about 850 °C. (2) Large scale crustal deformation, including nappe structures, that appear to sole near the Moho, resulting in high grade rocks at the surface. (3) Widespread sporadic backarc volcanism, (4) Very weak lower crust detachment that facilitates displacement of the crust relative to the mantle. In all cases, the upper crust has been thrust over the cold strong adjacent craton; in the Cordillera Rocky Mountain fold and thrust belt; and in the Himalaya-Tibet frontal thrusts where the Asia crust is being thrust over the cold strong India craton, and to the north over several strong terranes. Similarly, the Grenville has been thrust over the adjacent Superior craton in the northwest and likely over the Amazonia craton to the southeast, using the pre-existing lower crust detachment of the former hot backarc.

Plant life hinders river meandering in the Bonneville Basin of Utah

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The debate on the controls of vegetation on river planform has recently become a topical aspect of sedimentology. Plant life is classically believed to have held a crucial role in stabilizing channel banks through geological time, e.g. through rooting and production of cohesive floodplain clays. Vegetation is thought to aid in the suppression of bar braiding and the formation of channel meanders. Despite available evidence from the rock record and flumes where vegetation significantly influences channel planform, the relationships between plants and river sinuosity remain largely unexplored in modern natural systems. Using remote-sensing and field data, we provide a statistically solid analysis of the physical and biotic drivers on channel sinuosity in the Bonneville Basin (Utah). The Bonneville Basin is an inland sink and part of the larger Great Basin of western USA, and is flanked by a set of active distributive fluvial systems that display diverse vegetation density and channel planforms. Statistical analyses of geomorphic parameters such as channel width and bar surface-area indicate that fluvial morphogenesis is largely controlled by base level and catchment size. No correlation is demonstrated between vegetation density and other physical parameters, e.g. channel width and surface area or sinuosity index of meanders. We corroborate these results by showing how desert-adapted vegetation preferentially occupies channel thalwegs, and in doing so it promotes flow disturbance, channel branching, and bar braiding rather than stabilizing channel banks. Once the role of plant life is excluded, the development of fluvial meanders can be related to cohesion offered by mud retention in the inland sink, and to discharge modulation along distributary, low-gradient channels. We thus conclude that meandering rivers may arise from entirely physical, rather than biotic, forcing mechanisms, and discuss relevant implications to the study of the Early Paleozoic fluvial rock record.

Lateral variations of the SE Laurentian margin and the architecture of the central Grenville Province

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The hinterland of the Grenville Province displays lateral variations that are potentially linked to features inherited from the SE Laurentian margin on which the Grenville orogen was built. Here, we use as an example the portion of the hinterland between two orogen-scale belts of anorthosite and related rocks that range in age between 1.1 and ~ 1.0 Ga, in the central Grenville Province. In this part, also known as Quebecia terrane, the 1.5 to 1.35 Ga history of the Laurentian margin is inferred to involve rifting at 1.5 Ga, formation of 1.5 to 1.45 Ga (Pinwarian-age) peri-Laurentian oceanic arcs on rifted crustal slivers, and accretion of the later at 1.4 to 1.35 Ga with development of a felsic plutonic belt. This contrasts with evidence for Pinwarian-age continental arc systems active in the eastern and western parts of the province and is attributed to lateral variations in subduction dynamics under Laurentia at that time. It is proposed that this configuration and the lithospheric-scale scars that it entailed is responsible, to some extent, for several features unique in the central Grenville such as: (a) the development of the two anorthosite belts following the former boundaries of different segments of the ~ 1.5-1.4 Ga subduction system; (b) the location (broadly parallel to the former rift zone) and development of a major shear zone network including the St Fulgence deformation zone (SFDZ), that was active throughout the Grenvillian orogeny; (c) the presence of 1.1 Ga anorthosite and orthogneiss, and voluminous 1.06 Ga broadly granitic suites on the SSE side of (and parallel to) the SFDZ; and (d) the presence, south of the SFDZ, of the most extensive section of the low-P belt preserved in the Grenville Province.

Managing and synthesizing provincial groundwater data

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In 2016, the province of British Columbia initiated groundwater licensing under the newly implemented Water Sustainability Act. The implementation of licensing highlighted the need for better access to groundwater and aquifer data in order to support science-based decision making in sustainably managing the provinces groundwater resources. Although the province has collected a significant amount of groundwater data over the years, it is spread out between numerous government agencies and stored in multiple isolated databases making it difficult and time consuming to access and compile all the information about a particular aquifer. Creating tools that synthesize key groundwater information from various data sources to support and facilitate informed decision making during the adjudication of groundwater licenses has been a priority. The province has recently undertaken a number of groundwater data initiatives which include launching a new application (GWELLS) to store and display water well records along with the development of an aquifer dashboard to facilitate access to key groundwater information. In addition, aquifer factsheets are being developed for the nearly 1300 provincial aquifers using scripting and an automated approach to retrieve, clean-up, analyse and summarize groundwater information from multiple data sources. Some of the challenges that have been encountered so far have been related to data integrity, information privacy, and coming up with standardized analysis methods that are appropriate for the various scales and varying levels of available knowledge for all provincial aquifers.

Sulphur water and the legacy gas wells of southwestern Ontario

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The emission of methane and hydrogen sulphide gas from legacy gas wells in southwestern Ontario is an emerging public-health issue. In the incised valleys and lowlands to the north of Lake Erie, there are approximately 9 000 old oil and gas wells. These wells often date to before the 1960s and were abandoned to standards of the time, i.e. filled with rubble, pounded lead "seals" and trees, with the steel casings often removed. Sulphate reduction, almost certainly by methane, produces hydrogen sulphide in the groundwater of the shallow Devonian formations. Artesian discharge at high rates of flow (~ 10 L/min) from the Devonian carbonate aquifer from a single abandoned borehole to the incised creeks may emit H_2S gas at ~ 100 ppm. This groundwater discharge is known as "sulphur water". This concept was outlined in 2010 by T.R. Carter (Ontario Ministry of Natural Resources) and appears in Canada's Groundwater Resources. A dozen problem wells have been identified since 2015, sometimes with H_2S emissions sufficiently high to cause evacuation of nearby homes. Four processes exacerbate this H_2S hazard and will create more such legacy-well incidents: 1. The progressive development of buoyant methane gas slugs that migrate up the poorly abandoned boreholes into the Devonian carbonate aquifer promoting sulphate reduction followed by groundwater discharge to the incised valleys. 2. The progressive deterioration of cement used in many plugging and abandonment operations due to sulphate-induced expansion and cracking. 3. The progressive corrosion of steel casings in sulphate-rich groundwater. 4. The progressive sprawl of communities into areas with many abandoned boreholes. Although gas migration issues will be more common and likely more severe in poorly abandoned wells, there is no guarantee that more modern wells with cemented casings and interior cement plugs will be entirely immune over time.

Revealing the histories of geological minerals in auriferous mineral deposits using laser ablation LA-ICP-MS imaging techniques

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As minerals grow and react, they record, in their element distributions, the processes that formed and modified them. Laser ablation (LA)-ICP-MS imaging can characterize the spatial distribution of elements in minerals, including trace elements, which are particularly sensitive indicators of geological processes. This presentation will describe procedures developed at the Geological Survey of Canada (GSC) for generating and interrogating quantitative LA-ICP-MS concentration and isotope ratio maps of complex, multi-phase mineral assemblages, including gold ores. These procedures were developed largely in response to demand from the Gold Projects of the GSC's Targeted Geoscience Initiatives for methods that cost-effectively reveal the complex chemistry of minerals at the micro-scale, including fractures and fine-grained matrix minerals, which are commonly ignored in conventional spot analysis work. Quantitative LA-ICP-MS trace element and isotope maps are providing remarkable insights into geological processes. Machine learning tools are also being developed which can extract the maximum information from the large data sets generated during LA-ICP-MS imaging; for example, correlating specific element associations with different mineral phases or hydrothermal events, even across multiple samples. Examples will be shown of how LA-ICP-MS elemental and isotopic imaging can be used to provide evidence for: 1) multiple phases of precipitation, resorption, fracturing and hydrothermal overprinting in auriferous pyrite; 2) significant early (syn-sedimentary) Au enrichment in the Porcupine mining district, western Abitibi greenstone belt; 3) generation of Au-rich fluids during metamorphic recrystallization of sedimentary pyrite at the Musselwhite Au deposit, North Caribou greenstone belt, and in the Porcupine mining district. With new map interrogation capabilities and ongoing developments in hardware and software, which are delivering major advances in imaging speed and interrogation capability, we are moving towards a paradigm shift in the application of LA-ICP-MS analysis in ore deposit studies, where quantitative imaging becomes the prevalent mode of data acquisition.

Differential erosion of a Mesozoic rift flank: establishing the source of anomalous topography across Karrat, central West Greenland

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The landscape of the Karrat region, West Greenland, contrasts between high elevation low relief topography, steep-sided fjords, and deep

bathymetric troughs. The mechanisms controlling landscape formation are highly debated, with initial work suggesting it resulted from episodic tectonic uplift throughout the late Cenozoic. Alternative models implying that the landscape is the product of isostatic uplift in response to differential glacial erosion. Here the results of a comprehensive low-temperature thermochronological study (apatite fission-track and apatite (U-Th)/He) and landscape evolution model are presented that help establish the source of the modern elevated landscape and the region's complex geomorphology. Joint modelling of the apatite fission track and apatite (U-Th)/He data outlines two significant periods of cooling, in the Mesozoic and Cenozoic respectively. The first (150 Ma to 110 Ma: 0.9 °C/Ma) correlates to the onset of extension between West Greenland and eastern Canada, suggesting uplift of the region during active rifting, while the second period (50 Ma to 0 Ma: 1 °C/Ma) is coeval to the cessation of volcanism in the region and likely represents widespread erosion. These cooling periods likely suggest the basement escarpment remained at height while being covered by extrusive volcanism and was later uncovered by the exhumation of the volcanic pile. Moreover, the latter phase of exhumation is outlined in the results of landscape evolution modelling, implying it encompassed localised differential erosion, producing a pre-glacial landscape that later aided ice stream onset and the advance of the Uummannaq Ice Stream. Glacial exhumation of the region was likely characterised by spatially varied rates of erosion, shaping the modern geomorphology through preferential ice stream development and isostatic rebound. These results highlight the complex interaction between rift tectonics and surface processes across the Karrat region and adds to a wider understanding of the post-rift evolution of passive continental margins.

Advances in the lithogeochemical study of drill core from the Heath Steele E Zone, Bathurst Mining Camp, New Brunswick

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The development of lithogeochemical techniques in geology has allowed for classification of rocks and minerals based on their chemical compositions; furthermore, lithogeochemical techniques are useful for defining magmatic affinity, alteration assemblages, and tectonic processes linked with the regional and local geological evolution. In this work, such techniques were used to study drill core from the Middle Ordovician volcanic-sedimentary sequence within the Heath Steel E Zone deposit (Bathurst Mining Camp). The rocks intersected in this borehole are affected by a strong, penetrative poly-phase deformation, intense alteration, and faulting. These events have obscured most of the primary textures in these rocks, making classification of rock types as well as their magmatic affinity challenging and a detailed stratigraphic division based on primary textures alone impossible. Consequently, lithogeochemical techniques, specifically portable X-Ray fluorescence (pXRF) spectrometry, were applied to solve these problems. The elemental determinations from the volcanic and sedimentary host rocks were used to identify the primary characteristics associated with petrogenesis, or secondary alterations such as hydrothermal and metamorphism. Statistical analysis of this data allows for the elaboration of immobile element-based discrimination diagrams, which show that the original volcaniclastic and associated sedimentary rocks mostly fall within a very narrow compositional range of calc-alkalic to transitional A-type rhyodacite to rhyolite, and have been subsequently variably affected by hydrothermal alteration and metamorphism. Thus far, chemo-stratigraphic units have been defined in terms of points or ranges of values of elemental compositions (Al_2O_3, TiO_2, P_2O_5, Zr, Nb, Ta, Th, Y, and REE), or combinations of elements and ratios involving these elements (e.g. TiO_2/Al_2O_3, Ti/Zr, Zr/Nb, Nb/Th, Ti/Ta, etc.). This work will also aid in correlating other volcano-sedimentary units and will ultimately contribute to resolving the complex lithostratigraphic relationships that are a key component of mineral exploration in the Bathurst Mining Camp.

On the geodynamic evolution of the Pontiac subprovince, Superior Province, Rouyn-Noranda, Quebec, Canada: constraints from a detrital zircon geochronology transect

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The Neoarchean Pontiac subprovince is a metasedimentary rock dominated subprovince of the southeastern Superior Province, located immediately south of the Abitibi subprovince. Metagreywacke samples (n = 5) collected from the ~ 2682 Ma Pontiac assemblage along a ~ 20 km north-south transect have zircon populations that show a significant range in Mesoarchean zircon grains from ~ 5 % to ~ 45 % compared to previous studies indicating a narrow range around ~ 18 %. There is also a correlation between sample location and Mesoarchean zircon content, with an overall decrease in Mesoarchean zircon grains from north to south. The significance of this relationship is difficult to assess because the stratigraphy of the Pontiac subprovince cannot be reliably constructed along the transect due to the complex deformation history of subprovince. Nonetheless, the results suggest an internal variation in provenance for the Pontiac assemblage. Detrital zircon studies on successor basins in the Abitibi subprovince have shown the 2690-2685 Ma Porcupine assemblage to contain ~ 5 % Mesoarchean zircon and the 2679-2669 Ma Timiskaming assemblage to contain ~ 13 %. The absence of local Mesoarchean sources in the Abitibi (or Pontiac) subprovince has been used to argue for input from an adjacent hinterland. The higher proportion of Mesoarchean zircon in the Timiskaming assemblage relative to the Porcupine assemblage was then used as evidence for detritus from the hinterland to become more prevalent during the later stages of tectonic development. A similar logic applies to the data presented here for the Pontiac assemblage, which was not previously recognized. As such, transect style sampling across any Archean successor basin succession might unlock the full potential of detrital zircon geochronology.

The structural and lithological evolution of the Patterson Lake corridor, southwestern Athabasca Basin, Saskatchewan

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The Patterson Lake corridor (PLC) is located along the SW margin of the Athabasca Basin and is host to recently discovered unconformity-related uranium (U) deposits (i.e. Triple R, Arrow) and prospects (e.g. Spitfire, Harpoon). It extends NE for more than 50 km and is situated in highly-deformed Paleoproterozoic basement rocks of the southern Rae Province, which are proximal to, and underlie the Athabasca Basin. Previous deposit-scale studies (i.e. Arrow and Spitfire) have indicated the importance of structural and lithological controls in concentrating the U system. However, the structural framework, tectonic evolution, and setting of the PLC within the larger context of the Rae Province remains poorly understood. This study aims to determine the structural-tectonic evolution of the region and related controls on U mineralization through an in-depth lithostructural investigation of the rocks hosting these promising new deposits. Drill-core investigation has verified that strongly foliated granite, granodiorite, ultramafic and alkali intrusive basement rocks define a deep-seated subvertical NE-striking heterogenous high-strain zone cut by a complex network of anastomosing ductile shears and brittle faults. The structural architecture is thought to be the result of early type-3 transitional to type-2 fold interference that happened during the Taltson (1.94-1.93 Ga) and Snowbird (1.92-1.90 Ga) orogens. Subsequent right-lateral ductile and semi-brittle shearing events led to further shortening and lateral transposition along the ENE strike of the

corridor and formed an anastomosing network of structures that now host U mineralization. The development of the ca. 1.75 Ga Athabasca Basin is associated with a set of NE-striking transtensional shears and related N- and NNW-striking normal faults. Late-stage W- and NNW-striking conjugate faults and subhorizontal reverse faults reactivated NE-striking graphitic-chloritic shears, allowing U-bearing fluids to penetrate and precipitate along the main ductile structural grain of the PLC.

3D inversions of gravity and magnetotelluric data from the Howley Basin, Western Newfoundland: an assessment of basin depth and hydrocarbon potential

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The Howley Basin is an onshore basin in western Newfoundland, located north-east of the town of Deer Lake. It is often considered to be a sub-basin of the Deer Lake Basin, and is thought to have hydrocarbon potential. However, the geology of the Howley Basin is not clear, with no wells deeper than a few hundred meters having been drilled in the area. Over the last several years there have been a number of complementary, collaborative projects at Memorial University that have attempted to improve our knowledge of the Howley Basin, especially regarding the depth of the Basin and hence its hydrocarbon potential. New gravity data have been acquired to extend and fill-in previous sparse coverage of the basin. Also, a line of magnetotelluric (MT) data was collected across the Basin, as it is assumed that the sedimentary rocks of the Basin are more conductive than the igneous rocks of the basement. 3D inversions have been carried out on both the gravity data (complete coverage using new and existing data) and the MT data (the electrical structure appears to be mostly 2D in the Basin, but not entirely so, especially at the south-eastern edge of the Basin). The inversions use unstructured tetrahedral meshes to parameterize the Earth models so that topography can be faithfully incorporated and so that the discretization of the models can be fine in the central volumes of interest and coarsen towards the extremities without necessitating an inordinate number of cells. Results will be presented from the individual gravity and MT inversions, and from preliminary constrained inversions in which the MT models are used to constrain the gravity inversions. In the future, it is intended that the necessary software to jointly invert the gravity and MT data will be developed and applied to the Howley Basin data-sets.

A compilation of Ar/Ar cooling ages for the Canadian Shield

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In the 1960s, the Geological Survey of Canada (GSC) published a series of reports that first delineated the structural provinces and orogenies of the Canadian Shield, based on an extensive K-Ar thermochronology dataset. Today, we rely primarily on the U-Pb method for bedrock mapping and tectonic studies in the Shield, and the K-Ar method has been largely superseded by the Ar/Ar method. Ar/Ar cooling ages are essential data for igneous and metamorphic thermochronological studies, but the available Ar/Ar dataset for the Canadian Shield has never approached the regional coverage of earlier K-Ar work. Recent bedrock mapping in several regions of the northern Canadian Shield under the GSC's Geomapping for Energy and Minerals program has included the acquisition of new Ar/Ar cooling age datasets. These data, combined with other recent Ar/Ar studies, have greatly expanded the cooling history dataset for the Canadian Shield. Here we present a compilation of all available Ar/Ar cooling ages for hornblende, muscovite and biotite. These three minerals record the temperature-time (T-t) evolution of rocks through the mid-crust, as they have transitioned from dynamic tectonism to tectonic quiescence. Our resulting maps reveal the spatio-temporal pattern of that transition, and can be used in conjunction with both high-temperature (e.g. U/Pb) and low temperature (e.g. (U-Th)/He) chronometers to reconstruct the T-t evolution of the Canadian Shield. As case studies for the utility of this compilation, we examine two new Ar/Ar datasets: one covering the southern portion of the Rae craton, and the other covering the Cape Smith belt portion of the Trans-Hudson orogen. With new and emerging peak pressure-T-t data from the same areas, we identify the domainal cooling histories for this region of the Canadian Shield.

New geo- and thermochronological insights into Jurassic accretion and syn-orogenic sedimentation in the Northern Canadian Cordillera

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The Early to Middle Jurassic accretion to the Laurentian margin of the so-called Intermontane terranes (Slide Mountain, Yukon Tanana, Stikinia/Quesnellia and Cache Creek) was the first major accretionary event forming the northern Canadian Cordillera. The Late Triassic to Cretaceous sedimentary record of the northern Canadian Cordillera, including northern British Columbia and southern Yukon, captures several aspects of the collisional event, including changes in depositional environment and basin extent, shifts in sediment types and provenance, and syn- to post-depositional basin shortening and deformation. In particular, recent and new geochronological and thermochronological data from the syn-tectonic Laberge Group, deposited into the Whitehorse trough in Early to Middle Jurassic, provide new constraints on sediment provenance, depositional constraints, and timing and conditions of basin deformation. Detrital zircon U-Pb age populations and double dating (U-Pb and (U-Th)/He) track the construction and collapse of Stikinia's early Mesozoic volcanic edifice through Early to Middle Jurassic. Local occurrence of detrital muscovite records the exhumation and erosion of Early Jurassic metamorphic rocks. Rutile in clasts of eclogite record rapid exhumation from high pressure conditions during Early Jurassic. These dated metamorphic detritus coincide with regional cooling ages of the exposed mid-crust of Yukon Tanana terrane. Following deposition of the Laberge Group, the strata were shortened during Middle Jurassic-Early Cretaceous, with the western portion of the basin buried most deeply during shortening, evidenced by resetting of He in detrital zircon. These and emerging new thermochronological data contribute to a reconstruction of the tectonic setting of accretion of the Intermontane terranes.

Towards an integrated multi-proxy approach to constrain Proterozoic Global Ocean redox conditions using redox-sensitive trace metal enrichments and isotope compositions

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Efforts to reconstruct global oceanic redox landscapes and identify oxygenation events during the Proterozoic Eon must rely on marine sedimentary rocks (e.g. shales, carbonates) preserved in continental margin environments because open-ocean abyssal seafloor has been lost to subduction. An attractive approach to infer global ocean redox conditions is to use the geochemical signature of redox-sensitive trace metals (e.g. Mo, U, Re, Tl) that have modern ocean residence times at least an order of magnitude greater than typical ocean mixing times. Existing global mass-balance models for Mo and U can use the

authigenic metal enrichment or isotopic composition in euxinic black shales to semi-quantitatively infer the global extent of seafloor covered by oxic, anoxic, and euxinic waters. These models take advantage of distinctive metal burial rates and isotope fractionations in different oceanic redox settings and are becoming more sophisticated. However, their successful application requires a sound understanding of local conditions in the depositional environment, which in turn requires an integrated approach to disentangle the effect of local versus global influences on the authigenic enrichment and isotope composition of Mo and U in black shales. The need for an integrated approach is highlighted by the overall lack of correlation between Mo and U isotope compositions for Proterozoic and Phanerozoic euxinic black shales. Local depositional factors such as extent of local basin restriction, intensity of euxinia, and delivery of Fe-Mn oxides can cause the Mo-U isotope systematics of a euxinic black shale unit to deviate from the positive correlation expected if global oceanic redox state was the dominant control. When this happens, it is possible in some cases to infer the global seawater isotope composition of one of the metals through careful evaluation of elemental and isotopic data and thus infer the global redox landscape. Even in such cases, Mo and U isotopes tend to be more informative regarding the extent of oceanic euxinia and more ambiguous regarding the extent of oxic and anoxic-ferruginous environments. Mass-balance models for emerging global oceanic redox proxies, notably authigenic Re enrichments and Tl isotope compositions, show potential to help further quantify oceanic redox states by constraining the extent of total anoxia (euxinic plus ferruginous; Re) and well-oxygenated seafloor where Mn oxides are permanently buried (Tl). Robust constraints on global ocean redox conditions are best achieved by large multi-proxy datasets, like those recently generated for the Ediacaran Doushantuo Formation (China) and Mesoproterozoic Velkerri Formation (Australia).

The Kapuskasing Structure revisited: new insights into reworking of Neoarchean crust from garnet geochronology

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The generation and reworking of Archean continental crust are poorly understood processes that are the subject of ongoing debate. Most exposed Archean rocks represent the middle to upper crust, which includes the products of these processes, tonalite-trondhjemite-granodiorite (TTG) suites. Crustal material beneath TTG suites is rarely exposed and may contain a metamorphic record crucial for understanding the formation and growth of Archean crust. The Superior Province in Ontario hosts one such exposure in the Kapuskasing uplift--a tilted segment of Neoarchean crust that represents a near-complete crustal cross section. The deep crustal portion of this cross section, the Kapuskasing Structural Zone, underlies TTG material and comprises a belt of high-pressure granulites that show widespread evidence for partial melting. The Kapuskasing Structural Zone was previously the subject of extensive scientific investigation as part of the Lithoprobe project, and a wealth of data was generated. The area has received relatively little attention during the past decade, during which innovative new geochronological and thermobarometric techniques have been developed. Here, garnet Lu-Hf geochronology and phase equilibria modelling provide a complementary approach to U-Pb geochronology of zircon, as it allows ages to be directly linked to metamorphic reactions and P-T paths. In the present study, garnet associated with leucosome is interpreted to have formed during partial melting at ~ 800 °C and 10-11 kbar. Lu-Hf garnet geochronology of three samples indicates that granulite-facies metamorphism and partial melting were underway by 2685 ± 8 Ma, earlier than the main pulses of metamorphic zircon growth at ca. 2660 Ma and 2645 Ma, and persisted for approximately 70 Ma. This new geochronological data allows a temporal connection to be made between partial melting in the Kapuskasing Structural Zone and crystallisation of overlying TTG rocks, providing new insights into crustal growth in this region.

Fluid inclusion systematics of the polymetallic (Co-Ni-As-Au) veins of Nictaux Falls Dam occurrence, Annapolis Valley, Nova Scotia

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An unusual occurrence of Co-Ni-Fe (+Au,Ag,Bi) sulfarsenide mineralization occurs in the Nictaux Falls Spillway, Annapolis Valley, Nova Scotia. Mineralization is constrained to early, laminated, quartz-sulfarsenide veins, and sulfarsenide mineralized wallrock clasts in quartz breccia, which crosscut Late Silurian Kentville Formation. Sulfarsenide-barren quartz veins showing similar textures are also present in the spillway and in the nearby Cloud Lake Pluton of the South Mountain Batholith. Quartz-hosted fluid inclusions are similar in both vein types (mineralized vs. unmineralized) and are classified into two types. Type-1 two-phase aqueous inclusions contain $L_{H2O\text{-}NaCl} + V_{H2O}$, whereas type-2 three-phase aqueous inclusions contain $L_{H2O\text{-}NaCl} + V_{H2O} + S_{halite}$. Cathodoluminescence imaging of the quartz does not clarify the origin of fluid inclusion assemblages and, tentatively, they are identified as having indeterminate origin, occurring as clusters in the core and between growth zones. Raman spectroscopy of type-1 and type-2 vapour phases demonstrates low concentrations (~ 0.5 mol %) of non-aqueous volatile species (e.g. CH_4, CO_2, N_2). Type-1 inclusions homogenize by vapour bubble disappearance between 136-240 °C, but did not freeze upon cooling. This prevented determination of final ice melting temperatures and suggests high abundances of divalent cations (e.g. Ca, Mg). Type-2 inclusions homogenize via halite dissolution at temperatures between 163-227 °C (ranges for individual assemblages much smaller) indicating high confining pressure during entrapment (~ min. 0.25 to 2.65 kbar) and bulk salinity between 30.4 and 34.4 wt % NaCl eq. The preliminary results indicate deep entrapment, high salinities (with high divalent cations), and no boiling. The possible origins of this fluid includes dissolution of evaporates, evaporated seawater, or deep brines. Ongoing and future work involves i) modelling of the P-T conditions of entrapment; ii) decrepitate mound analysis to clarify the solute composition of the different fluid inclusion types, and iii) determination of the O isotope systematics of vein quartz to clarify potential source(s) of fluid.

Silurian U-Pb zircon intrusive ages for the Red River anorthosite (northern Cape Breton Island): implications for the Laurentia-Avalonia boundary in Atlantic Canada

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Current interpretations of Cape Breton Island suggest that it exposes a complete cross-section of the Appalachians from Laurentia across Iapetan vestiges to Avalonia. Crucial to this view is the presence of ca. 1 Ga plutons, including anorthosites, which have been regarded as a piece of Grenvillian basement, overlooking the fact that Avalonia is also underlain by a ca. 1 Ga basement. We analyzed zircons from the Red River anorthosite (Blair River Complex, northwestern Cape Breton Island) previously dated as ca. 1.1 Ga: they yielded 421 ± 3 Ma intrusive ages with older ages between 865 ± 18 Ma and 1044 ± 20 Ma inferred to be either xenocrysts derived from the country rock or inherited from the source. Implications of these data suggest that the accompanying low pressure granulite-amphibolite facies

metamorphism of the Blair River Complex is either the root of a 440-410 Ma, magmatic belt produced during slab break-off or relict ca. 1 Ga basement. The Blair River Complex occurs in a NNE-SSW, sinistral positive flower that progresses upwards from a Neoproterozoic rifted arc through a low grade upper Ordovician-Silurian overstep sequence to amphibolite facies fault slices, capped by the low-pressure, granulite facies rocks (Blair River Complex). The correlation of Neoproterozoic, rifted arc units across most of Cape Breton Island suggests it represents the deformed northwestern margin of Avalonia intruded by a Silurian-Lower Devonian magmatic belt. As the geological record in the Blair River Complex is similar to both Grenvillian and Avalonian basements, its provenance is equivocal, however Pb isotopic data suggest the Blair River Complex has Amazonian (Avalonian) affinities. Thus, Cape Breton Island, rather than representing a complete cross-section of the Appalachian orogen, is part of pristine deformed Avalonia with a positive flower structure exposing a cross-section of Avalonian crust.

Why did a concave Pangaea assemble and break apart across along-strike subduction zones?

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Here, I review how Pangaea formed and broke apart. I review how the subduction zones responsible for accommodating the assembly of Pangaea (Rheic, etc.) are along-strike from the subduction zones responsible for accommodating the breakup of Pangaea (Tethys, etc.). I note that this curious relationship was possible because Pangaea formed a concave polygon with a reflex interior angle between Laurasia and Gondwana at the western limits of Paleo-Tethys/Tethys. I argue that prevailing ideas of supercontinent formation and breakup do not readily explain Pangaea's geometry and breakup because such ideas have not contemplated the case of concave supercontinents generally. I do so here and note that when supercontinents form with a concave geometry, a subduction zone must have already formed within the region ultimately bounded by the reflex interior angle. That Pangaea breakup was accommodated by this pre-existing (Paleo-Tethys/Tethys) subduction system is used as justification to advance the idea that these geometric factors may dominate over other formation and breakup controls when supercontinents are concave. No major changes to mantle flow may be implied or required in the formation and breakup of concave supercontinents.

Blue Beach (Nova Scotia) – early land vertebrates near the centre of developing Pangea: the case for protection and a museum

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It is proposed that Blue Beach (Nova Scotia) be established as a geological heritage site for the following reasons: HERITAGE: What are the key values preserved at Blue Beach? (1) It preserves a critical stage (362-345 million years ago) in evolution from fish to tetrapods as they emerged from water to land during the amalgamation of the supercontinent, Pangea. (2) Terrestrial vertebrate and arthropod fossils from this stage are rare, dubbed Romer's Gap, possibly a result of several factors, such as the terminal Devonian Hangenburg extinction event, paucity of non-marine lowest Carboniferous basins, and a lack of exploration. QUESTIONS: The Blue Beach site allows paleontologists, students and the general public to engage in critical questions, such as: (a) What caused the fish-tetrapod transition? This has been attributed to the "Drying Pond", changes in oxygen availability, marine transgressions, and Hox genes? (b) What is the relative timing of the development of limbs, digits, and lungs, colonization of the land, and climate change? (c) What caused the tetrapods to colonize the land? Food, vegetation, and distance from seas have all been suggested? Blue Beach lies near the centre of Pangea, remote from the sea that surrounded Pangea. ATTRACTION: What attracts people to Blue Beach? (i) Paleontologists doing research from many parts of the world, such as Canada, USA, UK, Germany, come in the hope of finding "missing links". (ii) A museum (benefactors sought) would allow archiving rare collections and contribute to the education of students (university and school) and tourists and allow their participation in research - anyone can find new fossils. (iii) Blue Beach would add to the growing geoheritage sites listed in Atlantic Canada by the International Union for Conservation of Nature (IUCN) and UNESCO: e.g. Miguasha National Park, Saint John, Joggins and Mistaken Point, and historical sites such as the nearby Grand Pre National Historic Park.

Mineral resources and the biosphere: the challenge for far-future extraterrestrial explorationists

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Our ideas about colonizing other planets envisage the use of mineral resources, and our ability to detect and extract such minerals is tacitly assumed. At the same time, we are increasingly aware that long-term Earth System evolution, including aspects of internal processes, was profoundly influenced by the biosphere. In this context, the idea that Earthly mineral deposit types, or mineral deposits of any type, might exist in the great beyond needs to be carefully contemplated. Clearly, many resources, such as fossil fuels, were once actually part of Earth's biosphere. Other critical types, including iron-ore, most base-metals and much uranium are products of biologically-dependent processes. They require bacterial precipitation of minerals, or redox reactions in our oxygenated surface environment, itself created by photosynthesis. Indirect biosphere links reach further than we might initially think. The metals in Ni-Cu sulfide deposits come from the mantle, but the sulfide liquid that forms an ore body needs external sulfur, usually from sedimentary sulfides formed via bacterial sulfate reduction. Porphyry-type Cu-Mo deposits might at first thought seem biosphere-independent, but they ultimately depend on the hydrosphere, as do all hydrothermal deposits. Earth's hydrosphere is no lucky accident, as it is maintained by regulation of atmospheric CO_2, in which the biosphere plays a critical role. Some would argue that global plate tectonics could not operate without the hydrosphere, or without life itself. Global plate tectonics is a vital framework for metallogenesis, as its associated magmatic concentrate rarer chemical elements such as U, Th and REE. It has an equally important pragmatic role, because it constantly rearranges Earth's outer lithosphere, in conjunction with isostasy and biologically-dependent erosion. Thus, a wide range of fossil geological environments are available for exploration near the planetary surface. The contemplation of other processes that might generate mineral deposits beyond Earth, such as impact events, is speculative compared to the hypothesis that familiar, accessible, mineral resources only form on a living, tectonically-active planets. As discouraging as it is, this conclusion seems logically unavoidable. Far-future explorationists may indeed discover mineral deposits that are "not as we know them", but they will need very different concepts from those that we rely upon today.

Transport and deposition of fine sediments in an area of discontinuous and degrading permafrost

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In the context of climate change, thawing of permafrost can have a significant impact on water flow and water quality, as well as on fine sediment transport in porous media and surface water. Studying the effects of changes in the permafrost thermal state is therefore essential to understand and solve potential environmental problems, particularly in northern areas, where natural risks are amplified. To date, research on fine sediment loads during permafrost degradation has been very limited, thus this project focuses on the interactions between groundwater flow, heat transfer and sediment transport processes which can affect water quality, soil stability and loading of surface water from groundwater discharge. To investigate these issues, sediment samples were collected

from an area of discontinuous permafrost in the Tasiapik Valley located near Umiujaq, Nunavik, Québec. Sample analyses were carried out in the laboratory using a non-destructive imaging technique (X-ray CT scanning) to predict the spatio-temporal evolution of the hydraulic properties and soil deformation controlling mass transport associated with permafrost thaw. A conceptual cryo-hydrogeological model of groundwater flow, heat transfer, permafrost thaw and suspended particle transport is developed for the Umiujaq site, based on field and laboratory data. A simulation strategy is then proposed based on the HEATFLOW finite element model, with preliminary conceptual simulations highlighting the roles of hydraulic conditions and physical soil characteristics on sediment transport and deposition mechanisms in porous media. Research on this subject is important since sediment transport has a direct link to our understanding of the scientific issues associated with the thawing of permafrost due climate change.

A three-component mag-interpretation: case study using multiple magnetic data sources from the E&L Deposit, BC

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The E&L mineral system is a Lower Jurassic magmatic Ni-Cu-PGM prospect, in northwestern BC. It is located in the central Stikine terrrane. The E&L Intrusion comprises a series of taxitic olivine melagabbros within the Nickel Mountain Gabbro Complex. The magmatic sulfide mineralization is hosted within the E&L Intrusion and adjacent metasedimentary rocks. Access and exposure are limited by an icefield and steep topography. Geologic interpretation is from outcrop, drillcore data, and geophysics. Mineralization occurs as disseminated and massive sulfides adjacent to the northern contact of the E&L Intrusion, and as massive sulfide sheets cross-cutting the sedimentary rocks. The deposit was periodically explored from the 1950 to the 2011 with mapping, sampling, drilling, the construction of an adit, and geophysical surveys. In 2017, 14 drill holes were completed with geochemistry, RQD and density measurements. A subset of these holes also has downhole BHEM survey and magnetic susceptibility data. A new airborne magnetic survey (VTEM) was flown in 2017. Three independent sources of magnetic data (magnetic susceptibility on core, airborne and downhole magnetic field) make this an ideal site to run constrained inversions to map geology and target mineralization. The UTEM downhole survey provided an additional magnetic survey, from the three-component fluxgate probe used to orient the EM tool. The combination of lower resolution, but areally extensive airborne magnetic data with detailed local borehole 3 component magnetic field data, and modeling constrained by mag susceptibly values provides the basis to create a detailed model of the magnetic response of the gabbro intrusion that hosts the mineralization. This new model helps to constrain the possible depth extent of the E&L intrusion. The results from the exploration program at E&L deposit will be used to show how multiple integrated geophysical surveys constrained by geological data can be used to build a model of the intrusion.

Isotopic and geochemical signatures of base metal indicator minerals from regional surficial samples in the southern Mackenzie region, Northwest Territories

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Heavy indicator minerals recovered from stream sediment and till samples are commonly used for exploration in glaciated terrain. The geochemical and isotopic composition of recovered heavy minerals can be used to determine provenance, deposit type, and guide exploration programs to prospective areas. As part of the Geological Survey of Canada's Geo-mapping for Energy and Minerals (GEM) program till samples and stream sediments were collected across an area of 35 000 km^2 in the southern Northwest Territories. The Pine Point Mississippi Valley-type (MVT) district is present within the study area and is the largest known mineral occurrence in the region. Despite the potential to host additional mineral resources, very little exploration has been undertaken outside of Pine Point. Till samples collected during previous studies in the region recovered elevated counts of base metal indicator minerals, including sphalerite, galena, chalcopyrite, and arsenopyrite. Sulphur and lead isotope determinations by secondary ion mass spectrometry and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) indicates galena grains were sourced from MVT occurrences distinct from Pine Point and likely sourced from within 5 km of peak galena abundance samples sites. LA-ICP-MS and electron probe micro analysis of sphalerite grains suggest they originated from MVT mineralization, but distinct from Pine Point. Sulphur isotopes from chalcopyrite grains show potential for manto and/or sediment-hosted Cu sources. Arsenopyrite grains are less abundant than other grains and were likely sourced from orogenic Au systems 380 km northeast of the study area in the Canadian Shield.

P-T-T evolution of metapelite from the Boothia Uplift: quantifying the time and conditions of tectonometamorphism in North-Central Rae Craton

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The Boothia "Uplift" exposes high-grade Precambrian ortho- and paragneisses, long attributed to the northern Rae craton reworked during the 2.0-1.9 Ga Thelon Orogen. The Rae craton is recognized as extensively reworked and variably affected by multiple orogenic events: the Rae (2.6 Ga), MacQuoid (2.56-2.50 Ga), Arrowsmith (2.5-2.35 Ga), Thelon (2.0-1.9 Ga), Trans-Hudson (1.9-1.8 Ga) and Caledonian (420-370 Ma) events. As part of Natural Resources Canada Geomapping for Energy and Minerals (GEM) initiative to provide modern geoscience context for frontier regions, this study aims to quantify the conditions and time of tectono-metamorphism recorded by two metapelitic rocks collected from northern Boothia and southern Somerset Island. Both samples contain similar peak metamorphic assemblages of garnet-sillimanite-K-feldspar-ilmenite-biotite. In addition, the northern Boothia sample contains corundum inclusions in sillimanite, and garnet cores preserving a rutile-K-feldspar-quartz-biotite-sillimanite assemblage. The Somerset pelite is compositionally layered containing quartz, rutile, graphite, and perthitic K-feldspar. In the Boothia sample, high-Ti and -F matrix biotite as well as low-Ti biotite in garnet core allow multiple P-T points to be constrained. Monazite, in both samples, occur as inclusions within garnet and as a matrix phase, providing the opportunity to evaluate the P-T-t evolution using textural relationships and mineral thermobarometry. Preliminary phase equilibrium modelling suggests that peak metamorphism occurred at ~ 750 °C at ~ 8.2 kbar for the Boothia rutile-bearing sample and 850 to 900 °C at ~ 6 kbar for the other sample. These values agree with previous geothermobarometric estimates of 700 to 850 °C at 6 to 8 kbar (up to 960 °C and 8.7 kbar) that were indirectly attributed to 2.0-1.9 Thelon orogenesis. Sensitive high-resolution ion microprobe (SHRIMP) monazite geochronology will provide texturally associated age constraints of prograde and retrograde metamorphism to directly establish the timing of regional metamorphism, re-assess the time and extent of Rae reworking, and refine tectonic models for this region.

Nature and context of deformation bands associated with post-depositional faulting of the basal Athabasca Basin and their insight into the genesis of unconformity-related uranium deposits: case study of the C1 fault zone in the eastern Athabasca Basin, northern Saskatchewan

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In northern Saskatchewan, world-class uranium deposits are associated with the unconformity between the Proterozoic Athabasca Basin and underlying basement rocks. In particular, many of the uranium deposits exhibit a strong spatial association with post-Athabasca faults formed by reactivation of older basement-rooted structures. The focus of this study is deformation bands in the basal Manitou Falls Group. Deformation bands are products of localized strain, resembling micro-faults; they develop in highly porous sediments and are associated with fault damage zones. Deformation band formation can result in a change in porosity due to grain rotation and granular flow which gives them the potential to act as fluid baffles or conduits. In this study, deformation bands were investigated in sandstones of the basal Manitou Falls Group in five drill-hole fences transecting the C1 fault, a mineralized NNE-trending structure extending from the Gryphon deposit to 5 km west of the McArthur River deposit. Our results indicate that compaction, shear, and cataclastic bands are present throughout the core and that the proportion of cataclastic bands increases with depth. Collectively, all bands define three major trends: one subhorizontal (286°/11°), and two which appear to share a conjugate relationship, (074°/57°) and (324°/65°). The derived paleostress field is incompatible with the orientation of the (020°/50°) C1 fault, which records significant reverse/thrust displacement. The fault zone may therefore have been reactivated after Athabasca Group sandstone deposition under a new stress regime (inferred from the orientation of the deformation bands). Alteration products related to mineralization were also observed; drusy quartz veins exhibit the same conjugate relationship as the general population of deformation bands, whereas dravite veins preferentially occur along the northeast trend. Further work aims to improve the understanding of deformation band genesis in relation to post-depositional fault reactivation, and the role these structures have in fluid movement associated with uranium mineralization.

Ore mineralogy, geochemistry, and genesis of the Hog Mountain orogenic gold deposit, southwestern Appalachians, USA

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Hog Mountain is an orogenic Au deposit within the eastern Blue Ridge region of the southernmost Appalachians with a grade of up to 2.5 oz/t Au. It is hosted within a phaneritic quartz-plagioclase tonalite that intruded into phyllites of the Wedowee Group at 384 ± 32 Ma. The deposit formed epigenetically and is related to brittle-ductile metamorphism at greenschist-amphibolite facies conditions that occurred during D2 to D3 deformation at 315 ± 18 Ma. The formation of the orogenic Hog Mountain Au deposit and nearby coeval Au mineralization in metasediments of the Goldville district are related to allochthonous thrusting of the eastern Blue Ridge onto the Laurentian continental margin during the Alleghanian orogeny. Gold mineralisation at Hog Mountain occurs within blocky quartz-sulfide veins with a thickness of few mm to 1 m that are steep-dipping and show alteration haloes of a few mm to several cm of dominantly chlorite-sericite assemblage. No crack-seal or ribbon-texture are observed. Mono-mineralic quartz veins also occur but show no mineralization. The sulfide assemblage in the mineralized veins consists of, in decreasing abundance: pyrrhotite; pyrite-chalcopyrite; arsenopyrite; sphalerite, and; galena. Gold is observed as free grains within quartz and with Fe-sulfides. Arsenopyrite also occurs as cm-thick veinlets within tonalite that have neither Au nor alteration envelopes. Electron microprobe analyses of pyrrhotite, pyrite, arsenopyrite, sphalerite and chalcopyrite all show a stoichiometric homogenous composition. Mineralogical and geochemical observations indicate that Hog Mountain was formed by one continuous hydrothermal fluid event instead of several stages. Low salinity and reduced fluid conditions were responsible for metal transport, and Au transport was dominated by a thio-complex, although colloidal Au transport cannot be excluded. Metal and especially Au deposition were controlled by wall rock-fluid interaction that resulted in changes of redox state and sulfur fugacity of the hydrothermal fluid.

Volumetric properties of fluid inclusions on the path to homogenization

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One of the basic properties measured using fluid inclusions (FI) is the homogenization temperature (Th), which represents the minimum temperature of FI trapping. Pressure-temperature (PT) paths of FI are well understood at temperatures above Th, but less attention has been given to the path from room temperature to Th. Although this latter path is less crucial to reconstructing formation conditions, nevertheless it provides insights into how we interpret observations made during microthermometry Here, we investigate how volumetric properties vary from ambient temperature up to Th for FI in the system H_2O-NaCl. We use thermodynamic analysis based on the constraints imposed by the inclusions being closed and isochoric systems. We calculate the evolving compositions, mass fractions, molar volumes and volume fractions of phases within the inclusion (liquid, vapor ± halite) as temperature and pressure evolve during progressive heating. We have modeled FI over a wide range of compositions and densities, spanning homogenization to the vapor to the liquid or by critical phenomena, and with or without halite. We show that, depending on the exact bulk composition and bulk density, inclusions can exhibit complex behavior wherein, for example, the volume fraction of vapor (i.e. the size of the bubble) may initially decrease with increasing temperature, before plateauing and eventually increasing to fill the inclusion. We relate these predictions to observations made during microthermometry. These predictions help serve as a guide for new practitioners to understand the process of microthermometry, as well as for experienced inclusionists to help interpret their observations.

New 1:10 000 scale bedrock maps of the Sunset Lake Area, Slave Craton, Northwest Territories (parts of NTS 85I)

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In 2018 the Northwest Territories Geological Survey (NTGS) conducted the third year of a multi-year bedrock mapping initiative along the Neoarchean Beaulieu River Volcanic Belt (BRVB) at Sunset Lake in the southern Slave craton. The study area is approximately 110 km east-northeast of Yellowknife and contains the "Sunrise" volcanogenic massive sulphide (VMS) deposit with a historic indicated resources of 1.52 Mt at 5.99 % Zn, 2.39 % Pb, 0.08 % Cu, 262 g/t Ag, and 0.67 g/t Au. The NTGS has produced new 1:10 000 scale bedrock maps of parts of NTS 85I, a significant improvement from previous 1:50 000 scale maps. This work has focused on volcanic rocks of the BRVB by documenting lithofacies changes, alteration types, alteration intensity,

and structures while investigating the relationship of these rocks to the underlying Central Slave Basement Complex and, where preserved, the Central Slave Cover Group. The NTGS mapping initiative also provides context to ongoing 1:2 000 scale mapping, lithogeochemical, isotopic and geochronological studies by collaborators at Mount Royal University and the University of Saskatchewan. This multi-scale approach to bedrock mapping, complemented by radiogenic and stable isotopic studies, is resolving complexity, including abrupt lateral changes in stratigraphy, indicating synvolcanic structures, and changes in volcanic environment. This recent targeted mapping and analytical studies are increasing our understanding of the regional and local setting of the "Sunrise" VMS deposit, the economic potential in the BRVB, and the geological characteristics associated with this Neoarchean VMS mineralization. Overall, the new NTGS maps and analytical work is placing the BRVB and its economic potential into context within the Slave craton to assist in present and future VMS exploration.

Non-isothermal viscous compaction of volcaniclastic deposits: implications for volcanic outgassing

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We use geometry-dependent conductive cooling models, in concert with the most up-to-date welding and permeability models, to assess the potential for "freezing in" permeability within (1) conduit-filling pyroclastic deposits and (2) tuffisite veins. We find that the geometry of each deposit dictates its thermal evolution and, with that, its transient outgassing capacity. Rapid cooling of the sheet-like tuffisite veins preserves high porosities and permeabilities. In contrast, cylindrical conduit-filling deposits cool slowly and permeability is annihilated over a period of minutes to hours. This highlights that conduit-filling deposits lose their outgassing capacity through welding, while tuffisite veins (previously thought to rapidly seal) can form long-lived outgassing features. We use the model results to calculate the time dependent gas flow budget of both degassing lithologies. Based on the reconstructed outgassing pattern we outline the potential to use the gas flow balance between the central conduit and distal fumaroles fed by tuffisite veins as a simple tool to monitor gas overpressure within a volcanic edifice.

The potential fault instability induced by pore pressure changes under the strike-slip regime: case study of 3D coupled reservoir geomechanical modeling in the St. Lawrence Lowlands, Quebec

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How high-angle normal faults would be reactivated under the strike-slip tectonic regime if pore pressure increases during injection operations? What parameters would control shear slip localization? To answer these questions, 3D coupled reservoir geomechanical modeling (Petrel-Visage-Eclipse) is carried out in the St. Lawrence Lowland region. We evaluate the potential for shear failure along the pre-existing sub-surface Yamaska high-angle normal fault under the present-day strike-slip tectonic regime. This study represents a follow-up of the previous step of 2D geomechanical modeling aimed to assess the potential of safe CO_2 injection into a sandstone reservoir (the Covey Hill Formation) within Early Paleozoic sedimentary basin in the Becancour area located at 110 km southwest of Quebec City. The Yamaska Fault in the area is oriented NE-SW with a strike varying from subparallel to ~ 35° to the orientation of maximum horizontal stress SHmax (NE63°) and dips to the SE at ~ 60° with ~ 800 m vertical throw. Multiple runs in the 3D model simulate several steps of increasing pore pressures due to CO_2 injection in the Covey Hill sandstone reservoir within the footwall at ~ 1.2 km of depth. The pore pressures increase by 4, 6, 8 and 15 MPa, respectively, at the four time-steps simulated. Our modeling results show that plastic shear deformations along the Yamaska Fault are initiated at the step of pore pressure increase by 8 MPa and a larger area slipped during the next injection stage. The non-linear geometry of the fault results in localization of plastic shear strain on the prominent fault segments optimally oriented, while other segments remain inactive. The shear slip occurs mostly at the depth level of the injection interval propagating upward to the top of the Utica shale in highly stressed fault segments. Our study helps to quantify the risk of fault reactivation induced by injection operations.

New structural features of Central Labrador Trough and evolutionary model of an accretionary wedge under oblique shortening

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The Central Labrador Trough, part of the New Quebec Orogen, is traditionally considered as a west-verging fold-and-thrust belt originated as a result of oblique collision and dextral transpression between the Archean Superior craton and the Archean block of the Southeastern Churchill Province during the Trans-Hudson orogeny (1.82-1.77 Ga). The structures associated with dextral transpression are well established in the northern segment of the orogen but not in the central part. We present new field structural observations along the ca. 70 km long W-E Minowean-Romanet transect that include not only elements of thrust tectonics but also newly documented examples of strike-slip shear zones and late brittle, semi-brittle and ductile extensional structures that occurred both in the frontal and rear parts of the accretionary wedge. The newly described low-angle mineral lineation, axes of cylindrical folds and dextral mylonitic shear zones in the footwall of the Romanet fault are oriented subparallel to the orogen and reflect the early phase of oblique convergence. The mineral lineation and striations on planes of normal faults in the hanging wall of the Romanet fault are oriented orthogonal to the orogen and correspond to a later phase of exhumation driven by the combined effects of erosion and underplating. To explain the increase in the degree of exhumation along the orogen in the study area from NW to SE, we propose a model of strain partitioning and differential exhumation that resulted from longitudinal variations in shortening and erosion under an oblique convergence setting. Our structural observations support that normal faults of the late extension phase very likely contributed to fluid circulation and mineralisation redistribution and should be considered in mineral prospecting analyses of the area.

Muscovite as a monitor of primary versus secondary rare-metal enrichment in albite-topaz keratophyres from Ongon Khairkhan, Mongolia

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Identifying a least altered precursor is a critical, but often challenging aspect of documenting mass change accompanying fluid:rock (F:R) interaction. An alternative to conventional mass balance is to use a mineral proxy which records both primary and secondary chemistry and thus tracts elemental transfer, hence gains and losses. This approach is applied to the Cretaceous albite-topaz keratophyres from Ongon Khairkhan, Mongolia, or ongonites. Originally described as pristine rare-metal (RM)-rich rocks, our recent work shows them to record pervasive but texturally cryptic F:R interaction as evidenced by abundant coupled dissolution reprecipitation (CDR) features in minerals such as the feldspars (e.g. pitted albite (Ab100) and K-feldspar (Or100)) and Li-F-

rich muscovite (LFM). SEM-EDS and EMPA analyses reveal euhedral, magmatic LFM with 2 wt % Fe and 8 wt % F is pseudomorphed via CDR to secondary LFM with 6 wt % Fe and 4 wt % F. Significantly fluorite and RM phases decorate cleavage traces in the secondary LFM. By using LA-ICP-MS traverses across the LFM types processed as time slice domains, 1750 analyses were generated to track the chemical signal of magmatic and hydrothermal LFM. The data indicate elemental changes from the magmatic to hydrothermal LFM as follows: decrease of Li (3000 to 5000 ppm), Rb (8000 to 5000 ppm), Cs (900 to 100 ppm), Be (150 to 20 ppm), and increase in Na (1000 to 4000 ppm), Ga (30 to 300 ppm), Zn (1000 to 5000 ppm), Sn (100 to 1000 ppm), Nb (< 10 to 200 ppm), Ta (< 10 to 60 ppm) and W (20 to 50 ppm). These trends record therefore substantial loss of LILE during formation of the new LFM phase whereas Na, Ga and RM were substantially gained. The latter enrichment of metals relates to hydrothermal processes and is not a primary magmatic signature as originally thought. This micro-scale method permits, therefore, sensitive discrimination between primary and secondary processes in altered rocks and identify the origin of different stages of the RM mineralization.

In search of the gold fluid: results of fluid inclusion studies in Abitibi Greestone Belt deposits

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A comprehensive fluid inclusion (FI) study of gold mineralized quartz-vein material from settings across the Abitibi greenstone belt (AGB) provides insight into the nature and chemistry of the preserved fluids, all critical to the understanding of the origin of the gold. Petrography reveals FI are mostly of secondary origin, although primary types rarely occur, and inundate quartz unless highly strained (i.e. FI-free), as expected in high fluid-flux systems. The FI are characteristically CO_2-rich (± CH_4), with H_2O type-FI also present, as expected in unmixed systems. Deposits dominated by H_2O FI are however less common, with the epizonal Grey Fox deposit being such an exception. Late-stage, saline, Ca-rich FI are common as well in the deposits studied. The ubiquity of decrepitate textures is noted, which likely reflects cycling of fluid-pressure during vein formation. Where quartz is luminescent, cathodoluminescence (CL) images reveal primary zoning, but contrasting zonations more commonly represent multiple stages of cross-cutting quartz and planes of secondary FI. Microthermometry, using well preserved FI, reveals that fluids are: 1) CO_2 rich with rare CH_4 based on Tm_{CO2}; and 2) salinities, excluding late high-salinity Ca-rich types, are variable within and among deposits (< 0.5 to 3100). This indicates that Na dominates, with lesser Na-K and Na-Ca types, and that S is common in addition to F (e.g. Coté Gold; Gap144). Limited LA-ICP-MS data (6 deposits) indicate a variable fluid chemistry (B, Li, Rb, Cs, Sr, As, Ag, Zn Cu, Pb, Sb, W), but uniformity for deposits. Interestingly, low $\delta^{13}C$ values of -10 to -31 ‰ for FI extracts (n = 50; 17 deposits) contrast markedly with published vein carbonate data (~ -5 ‰) for the AGB. The latter plausibly suggests the C in the FI is sourced from C-rich sedimentary rocks and, given the mostly secondary nature of the FI in the vein quartz, this highlights a likely source for some of the gold in these deposits.

From regional to local metasomatism in the peridotitic mantle of the Chidliak kimberlite province (Southern Baffin Island)

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We studied the petrography, mineralogy, thermobarometry and whole rock chemistry of 120 peridotite and pyroxenite xenoliths collected from the 156 - 138 Ma Chidliak kimberlites CH-1, -6, -7 and -44. The xenoliths have higher CaO contents relative to Al_2O_3, and high Al for a given Mg/Si ratio compared to other cratonic peridotites. We assign the complex Ca-Al systematics of the Chidliak peridotites to repeated episodes of Ca-rich, Si-poor metasomatism, which introduced clinopyroxene and garnet, and later replaced orthopyroxene and clinopyroxene with secondary clinopyroxene and monticellite. This carbonatitic metasomatism, manifest in formation of wehrlites, acted upon the entire sampled mantle depth on a regional scale, including the proximal blocks of the North Atlantic Craton and the Chidliak mantle, where clinopyroxene and garnet modes are uniformly and heterogeneously high in the ~ 110 km deep mantle segment. Another, more recent type of mantle metasomatism, is expressed as elevated Ti in clinopyroxene and elevated Na and Ti in garnet, typical of sheared peridotites from CH-1, -7, and -44, but absent from CH-6 xenolith suite. The Ti-Na imprint is most intense in xenoliths derived from depths equivalent to 5.5 to 6.5 GPa, where it is associated with higher strain, the presence of sheared peridotites and higher temperatures varying isobarically by up to 200 °C. The horizontal scale of the thermal-metasomatic imprint is more ambiguous and could be as regional as 10's of kilometers or as local as < 1 km. The latter is constrained by the varied abundance of Ti-enriched garnets within a single kimberlite. The time-scale of this metasomatism relates to a conductive length-scale and could be as short as 100's ka, shortly predating the kimberlite formation. The Ti-Na, megacryst-like metasomatism may have resulted from a highly localized influx of hot hydrous proto-kimberlite fluids that weakened the mantle and triggered the formation of sheared peridotites.

How to organize it? History and governance of the Joggins Fossil Cliffs UNESCO World Heritage Site

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The Joggins Fossil Cliffs UNESCO World Heritage Site, enlisted in 2008, exposes a nearly complete 300 million years old (Pennsylvanian) ecosystem. The cliffs' fame dates back to the days of Abraham Gesner, Charles Lyell, Charles Darwin and William Dawson who published extensively about this extraordinary window in time. The site is managed by the Joggins Fossil Institute (JFI), an independent charity, housed in an award-winning building and interpretive centre on top of the cliffs. How does one manage such a site and govern such an institute? Two Nova Scotia laws provide the foundation for the protection of fossils and cliffs: - the Special Places and Protection Act (SPPA) protects all fossils in Nova Scotia. Export or commercial trade of fossils is prohibited. Scientific collecting is allowed only to those who have an annually renewable Nova Scotia Heritage Research Permit, issued through the Nova Scotia Museum; and - the Nova Scotia Beaches Act states that all coastline below the high tide line is public property. Joggins is located on the hypertidal Bay of Fundy. The average tide range is 16 m and the high tide reaches halfway up the Cliffs. JFI's organizational and governance structure reflects the evolving interaction between the different stakeholders: the local community, science representatives and Provincial and Municipal government (both of which have contributed to the annual operating budget), all of whom shared the dream of obtaining World Heritage status for these cliffs, a process that took more than ten years. JFI is governed by a Board of Directors with representatives from all stakeholders. After an initial 6-year phase with an Executive Director and associated hierarchical structure, it now has a completely flat management structure. This governance system has proven to be effective and flexible to adjust to changing situations.

Évaluation d'un profil de conductivité thermique de la subsurface à partir d'un profil de température mesuré dans un échangeur de chaleur géothermique

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Les mesures distribuées de température, couramment obtenues au moyen d'une fibre optique insérée dans un forage, permettent d'identifier l'impact de l'hétérogénéité du roc et de l'Écoulement souterrain lors de l'Évaluation de la conductivité thermique avec un test de réponse thermique (TRT). Cette approche est toutefois complexe, nécessité une expertise pointue et conduit à des coûts prohibitifs pour des projets de conception d'échangeurs de chaleur géothermique (ECG). L'objectif de cette étude est de développer une méthode d'Évaluation alternative d'un profil de la conductivité thermique de la subsurface basée sur un simple profil de température mesuré à l'èquilibre sans perturbation thermique associé au TRT. L'approche développée consiste à reproduire, par la modélisation numérique inverse, le profil de température mesuré dans l'ECG. Le processus est réalisé par itération au moyen d'un solver d'optimisation minimisant la somme des résidus au carré entre la température mesurée versus simulée. La modélisation numérique 1D considérant un modèle multicouche est réalisée avec le logiciel COMSOL Multiphysics. Un profil de température à l'quilibre mesuré avec une sonde submersible dans un ECG aménagé aux laboratoires de l'Institut national de la recherche scientifique (Québec) a été utilisé comme exemple. Un profil de conductivité thermique avec une moyenne de 2,04 W/(m K) a été inféré. Ces résultats sont similaires à ceux provenant de TRT conventionnels et distribués réalisés sur le même ECG (1,75 à 2,19 W/(m K) et montrent les avantages de la nouvelle méthode lors de la conception des ECG.

Modelling of heat transport from the Danube River into a shallow alluvial aquifer: a case study near Bratislava, Slovakia

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Infiltration of river water into hydraulically-connected aquifers can have a significant influence on the aquifer temperature. Analogous to downwards propagation of a ground surface temperature signal, in simple cases of lateral river water infiltration as the only source of water in an aquifer, the groundwater temperature amplitude should dampen and the phase shift should increase with greater distance from the river. In cases where these aquifers are being pumped, the temperature signals in the aquifer can reveal relative contributions from the river compared to groundwater from upgradient recharge zones. Knowing the origin of the pumped water can help optimize the pumping system and control water quality. In this study, thermal signatures are used to determine groundwater origin at a site near Bratislava, Slovakia, where water from the Danube River is infiltrating into an adjacent aquifer containing groundwater pumping wells. The Danube River acts as a harmonic temperature boundary condition for heat transport into the pumped aquifer. Dampening of the amplitude and phase shift of the sinusoidal temperature signal into the aquifer are directly proportional to hydraulic and transport parameters of the aquifer. Because of the shallow depth of an aquifer, it is also necessary to account for heat coming from the ground surface and exchange of heat with the underlying bedrock. Monitoring wells along groundwater flowlines at the Bratislava site have shown decreasing mean groundwater temperatures with distance from the river which suggests additional possible sources of water in the aquifer than the river alone. Using heat as a tracer in a numerical model to calibrate the thermal signal, we determine relative contributions of river water and natural groundwater which is reaching the wells. The numerical codes Modflow / MT3DMS and Heatflow/Smoker are applied and compared to simulate the 3D hydrogeological system.

Cold regions, groundwater and climate change: state of the science and future directions

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Climate change is transforming Arctic and Subarctic hydrologic systems and water resources. Much of our knowledge is based on data collected at or near the land surface from localized field studies or through remote sensing observations. While these studies yield information about shifts in surface water and ground ice distribution, river discharge, and soil moisture, the underpinnings of many of these water-related changes are linked to changing hydrogeologic conditions. Permafrost thaw is opening new perennial and seasonal subsurface pathways for groundwater flow such as lateral taliks, thereby altering fluxes and distribution of water, energy, and solutes. We briefly review these processes and recent modeling efforts and identify different ways that these changes may impact Northern society, including the potential for increased contaminant transport, modification to water resources, and enhanced rates of infrastructure (e.g. buildings and roads) damage. Further, as permafrost thaws it allows groundwater to transport carbon and nutrients from terrestrial to aquatic environments via progressively deeper subsurface flowpaths. Groundwater has the potential to catalyze environmental change in the Arctic and is a critical driver of how the Arctic will respond to climate change, both physically and socially. Our presentation will highlight future field- and model-based research opportunities for Northern hydrogeology.

Tracking slab sediment devolatilisation using the mass independent fractionation of sulfur signature of Proterozoic magmatic arcs

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Early initiation of a supercontinent cycle amalgamates cratons through a series of subduction zones, above which juvenile crust forms in magmatic arcs in accretionary orogens. It is commonly assumed that the radiogenic isotope composition of the mantle-extracted juvenile crust should be identical to that of the depleted mantle at the time when crust was formed. However, the radiogenic isotope signature of the depleted mantle is commonly absent in these rocks. To unravel this paradox, it has recently been hypothesized that the subduction-driven incorporation of sediments derived from the erosion of continental crust to the mantle may significantly alter its depleted isotopic signature. To test this hypothesis, we investigate the flux of Archean surficial sedimentary rocks, a reservoir that preserves a unique and indelible sulfur isotope signature, through the lithosphere. As sulfur can form a volatile compound, it is mobile in and sensitive to fluids, thus tracking a pathway that is traceable even to the deepest parts of the lithosphere. The sulfur cycle across the lithosphere and the role of this volatile element in the metasomatism of the mantle at ancient cratonic boundaries are poorly constrained. We address these knowledge gaps by tracking the journey of sulfur in the assembly the formation of the Paleoproterozoic Capricorn Orogen, Western Australia, using mass independent isotope fractionation (MIF-S) as an indelible tracer. MIF-S is a signature that was imparted to Archean supracrustal sulfur reservoirs before the Great Oxidation Event. The spatial representation of multiple sulfur isotope data indicates that the

Dalgaringa granitoid arc preserves $\delta^{33}S$ values up to +0.8 ‰ in areas adjacent to the Archean Yilgarn Craton. These results indicate that suturing of cratons began with devolatilisation of slab-derived sediments deep in the lithosphere. Further, it lends insight into the transfer mechanism of sulfur, the primary complexing ligand in metal transport and precipitation, from metal-endowed Archean cratons to newly formed crust in accretionary (and then collisional) orogens.

Auriferous intrusion-related sheeted veins in the Abitibi-Wawa subprovince

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Auriferous intrusion-related sheeted veins are sets of parallel quartz-sulphide veins spatially associated with intrusions and largely coeval with their emplacement. For intrusions emplaced in large corridors of deformation, associated sheeted veins may undergo post-emplacement shearing and deformation and may be mistaken for orogenic vein systems. In the Archean Abitibi-Wawa subprovince, sheeted quartz-sulphide veins at the Renabie gold deposit in the Michipicoten greenstone belt and Côté Gold deposit in the Swayze greenstone belt were interpreted as orogenic gold-vein systems because of their association with shear zones and proximity to large crustal structures, such as the Ridout deformation zone in the southern Swayze greenstone belt. The sheeted veins are folded and boudinaged within shear zones which cross large plutons and batholiths, namely, the ca. 2740 Ma Chester intrusive complex (Côté) and the ca. 2720 Ma biotite tonalite of the Missinaibi Lake batholith (Renabie). These intrusions were emplaced prior to the development of regional fabrics and folds within the greenstone belts. Structural studies suggest that the veins predate the formation of the shear zones, their reactivation, and the development of regional fabrics. The sheeted veins formed from mineralizing fluids released during the crystallization of intrusions belonging to the same large intrusive complexes as the host intrusions. During regional deformation, the sheeted veins and their weak phyllic-style alteration halo acted as planar anisotropies that localized the formation of the shear zones and the channelling of later pulses of orogenic hydrothermal fluids (Renabie). This resulted in the formation of shear zones similar in appearance to those hosting orogenic gold veins. We compare the geometry and the development of structures in shear zones hosting orogenic and intrusion-related sheeted veins and suggest structural tools that can used to interpret their origin.

Résultats préliminaires du projet d'acquisition de connaissances sur les eaux souterraines des territoires de Lanaudière, de la Mauricie-Est et de la Moyenne-Côte-Nord

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Après avoir caractérisé les connaissances hydrogéologiques des territoires municipalisés du Saguenay-Lac-Saint-Jean et de Charlevoix et de la Haute-Côte-Nord, l'équipe de recherche sur les eaux souterraines de l'Université du Québec à Chicoutimi (UQAC) est depuis avril 2018 en charge de la caractérisation régionale des aquifères et des eaux souterraines des territoires municipalisés des régions de Lanaudière, de l'Est de la Mauricie et de la Moyenne-Côte-Nord. La phase I a porté sur l'inventaire, la collecte, l'évaluation, la numérisation et l'archivage des données hydrogéologiques existantes au sein de sources variées. Les données stratigraphiques de près de 35 466 forages ont été jusqu'à maintenant numérisées. Parmi ces derniers, 453 forages ont été extraits des rapports spécialisés en hydrogéologie et ont permis l'archivage de 122 résultats d'analyses chimiques, plus de 59 estimations de propriétés hydrauliques, d'environ 109 résultats de tamisage de dépôts granulaires et de plusieurs autres données pertinentes, telles des coupes stratigraphiques, des cartes piézométriques, des levés géophysiques, des estimations d'aire d'alimentation, des résultats d'essais au piézocône, par exemples. Ces statistiques sont préliminaires puisque seulement 20 % des rapports spécialisés récupérés au cours de l'année 2018 ont été pour le moment numérisés. En complément des livrables prévus par le PACES, certains travaux spécifiques sont réalisés dans le cadre de la formation d'étudiants de 2e et de 3e cycles afin d'améliorer les connaissances et la compréhension des eaux souterraines à l'échelle régionale. Les écoulements en milieux de roc fracturé, la moraine de Saint-Narcisse ainsi que l'hydrogéologie côtière sont des thèmes privilégiés pour ces projets. La présentation dresse le portrait hydrogéologique des territoires à l'étude, expose quelques statistiques sur les données intégrées dans la base de données et présente les projets de recherche ainsi que les travaux de terrain à venir.

Scientific and sustainable developments related to the Rochechouart impact structure (France)

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Owing to its size, accessibility and erosional level, the 24 km wide, Late Triassic, Rochechouart impact structure (western edge of the Massif Central, France) occupies a critical position within the population of rare terrestrial analogs to the large impacts craters observed on planetary surfaces. The crater infilling and the para-autochthonous target underneath are widely exposed over a 12 km wide centrosymmetric zone at the center of the structure. This allows a direct and detailed "3D" access to researchers investigating fundamental mechanisms both in impact-related geology (origin and evolution of planets) and biology (habitability of planets, emergence and evolution of life). Supported by the local territories and the scientific community in France and abroad, the Center for International Research and Restitution on Impact and on Rochechouart was established in 2016 with twofold objectives and activities. The first is scientific: installing Rochechouart as "International Natural Laboratory" for studying impact processes and collateral effects on planetary surfaces. A major step towards that aim is achieved with completion of the first drilling campaign at Rochechouart, the recovered 544 m of cores being made available to the community. The second objective, "Restitution", is dedicated to the public sensu lato, aiming at communicating/educating on impact and on Rochechouart, promoting impact geo-tourism at Rochechouart and other terrestrial impact structures, including in Canada and Quebec. With 7 members out of 60+, including 3 retired legendary peers of the discipline, the Canadian scientific community is well represented in the CIRIR. Its program, first results and the related opportunities for research and outreach will be developed at the conference.

Machine learning application for exploration targeting and mineral processing

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Exploration expenditure has increased significantly for the past decade with a substantial decrease in discoveries. This reality triggers the development of new tools that use 21st century technologies in order to help geoscientists to leverage historical data sets and generate new layers of information. Machine Learning and Artificial Intelligence generate massive investment for industrial applications and geoscience related disciplines have only recently started to use the prediction power for the exploration targeting and mineral processing. Various types of algorithms, including decision trees and stump boosting enhanced with domain adaptation, were adapted and used on different projects all over the world with significant results. Phylogenetic algorithms were also integrated into

an algorithmic toolbox to answer questions related to geological uncertainties, rock classification and mineral processing reconciliation. Those innovations were possible due to the gigantic step realized in the computer industry, hardware, and software, over the last decade that aided the application of the rapidly evolving science of artificial intelligence and its application to the mining industry. The exploration framework developed by SGS Geological Services was built to be completely updatable; this effectively transforms "missed" drill targets into more accurate predictions for the next crop of high prospectivity targets.

Stratigraphy, reservoir properties and thermofacies: a Silurian case study in eastern Québec

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In eastern Québec, the Sayabec Formation is a Silurian carbonate unit with natural macro porous intervals occurring both at the outcrop scale and in the subsurface, and interpreted as hydrothermal dolomite units (HTD). The Sayabec Formation represents a potential reservoir analog to Albion-Scipio oil field (Ordovician, Michigan basin, USA) and has instigated a local oil and gas operator to drill about 6000 m of stratigraphic wells in the Témiscouata area. This provided an ideal dataset to test how conventional methods for oil and gas exploration can be revisited to assess geothermal properties of reservoir units. A new methodology using medical CT-scanner was used to generate accurate 3D quantitative representations of the distribution and connection of micro- and meso-scale porosity of drilled cores. Ongoing work demonstrates that those quantitative CT-scan data are equivalent to conventional petrophysical data, while providing a submetric continuous record of porosity, bridging the gap between plurimetric e-logs and discrete core sub-sampling for gas porosimetry. The concept of thermofacies, namely how geothermal parameters are linked to sedimentary facies, was also applied to our case study. Up to eight distinctive lithologies were analysed by both infrared thermal conductivity scanner and probe permeametry providing critical fine scale understanding of thermophysical properties of the Silurian sedimentary succession. The definition of thermofacies is crucial to identify heat transfer mechanisms prevailing in geological units with the assessment of porosity/permeability and thermal conductivity/diffusivity for geothermal energy production. In the Témiscouata area, two specific thermofacies in the Sayabec formation, HTD breccia and bioclastic limestone, could be considered for heat production in the subsurface: they both present high thermal conductivity but low to very low permeability. As such, they are part of a petrothermal system controlled by conductive heat transfer and would require permeability improvement (e.g. hydraulic fracturing) for an economic use.

Miocene eruptive activity of the Round Butte maar-diatreme volcano, Hopi Buttes volcanic field, Arizona

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The Miocene Hopi Buttes volcanic field (HBVF) in the Navajo Nation (Arizona, USA) provides excellent exposures of maar-diatreme volcanoes at different erosion depths, from the maar ejecta ring and crater infill to the deep diatreme. Round Butte diatreme crops out ~ 190 m below the pre-eruptive surface, in the southeastern part of the volcanic field. It consists of a small but complex phreatomagmatic diatreme 170-190 m in diameter, of which the central 130-150 m is well-exposed in a massif featuring 20-30 m high sub-vertical cliffs. A 50 cm-thick basanite dike is also exposed outside the diatreme. Field mapping allowed us to define three main groups of pyroclastic rocks in the diatreme: undisturbed beds, disturbed beds and non-bedded rocks. Pyroclastic rocks range in grain size from coarse tuff to tuff breccia and in componentry from juvenile-rich to lithic-rich, with a dominance of heterolithic lapilli tuffs. Two minor facies groups were also documented: pyroclastic to sedimentary megablocks, and debris avalanche deposits. Rocks from the undisturbed bedded pyroclastic group are present above an unconformity found all around the massif, whereas the disturbed bedded and the non-bedded pyroclastic groups are always found below it. This unconformity was previously understood as the contact between the upper and the lower diatreme. The undisturbed beds above the unconformity indeed compose the upper diatreme, but the assemblage of non-bedded rocks (invasive columns) and disturbed beds (residual columns) below it are not typical of the lower diatreme. Instead, they represent a transition zone between the upper and lower diatreme. Such a transition zone also occurs in other diatremes, it is important genetically, and we propose to add it to the general model of maar-diatreme volcanoes.

Preliminary in situ U-Th-Pb electron microprobe geochronology of monazites from the Rae Province on Devon Island, Nunavut, Canada

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The remote and understudied Precambrian crystalline basement on Devon Island, Nunavut, is part of the Rae province's northern margin. Previous work on the Precambrian geology of Devon Island and neighbouring Ellesmere Island is largely limited to early reconnaissance work by the Geological Survey of Canada during the late 1970s and early 1980s. The tectonic framework of the Devon-Ellesmere region and how it correlates to the Arrowsmith (2.5-2.35 Ga), Thelon/Inglefield (2.0-1.9 Ga) and earlier, Archean orogenies on mainland Rae and Greenland, has been mostly speculative thus far due to a lack of geochronological, structural and geophysical data available. Samples collected on the northern and southern coasts of Devon Island from 1999, 2000, 2010, 2016, 2017 and 2018 field seasons are investigated by in situ electron microprobe chemical dating of monazites. Using a JEOL JXA-8530F field-emission electron microprobe, wavelength-dispersive spectroscopy (WDS) elemental maps were produced for U, Th, Pb and Y. Using the observed monazite zonation patterns as a reference, individual points were selected for WDS analysis for the same elements and a suite of REEs. Monazite ages were calculated from the U, Th and Pb concentrations for each WDS point analyzed, followed by a weighted mean age for each growth domain. Monazites from Devon Island display at least two and up to five generations of growth. On southern Devon, samples collected from Dundas Harbour and Burnett Inlet yield Archean and Paleoproterozoic ages of ca. 2.8-1.9 Ga. Monazites from alkali feldspar meta-granite near Dundas Harbour yield a possible intrusive age of ca. 2.7 Ga. On northern Devon, samples collected between Sverdrup Inlet and Eastern Glacier yield only Paleoproterozoic ages of ca. 2.2-1.9 Ga. Further work using isotopic dating on both monazites and zircons from Devon, southern Ellesmere and Coburg islands will be conducted to better constrain and validate the chemical dating results.

Burial-thermal history of the Hudson Bay Basin: multiple scenarios from multiple research approaches

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The burial-thermal history is a critical element for evaluating petroleum systems. Thermal parameters obtained through Rock-Eval and organic petrography have been the preferred approaches to understand the burial of basins. Mineral-based methods have also been developed and increasingly applied. The Paleozoic Hudson Bay Basin is a large intracratonic basin, which after an exploration phase in the 1970-1980 period, was abandoned because source rocks were deemed immature. The Geological Survey of Canada is re-evaluating the petroleum systems of this basin with a particular attention to its burial-thermal history. The burial-thermal research focusses on the Upper Ordovician interval at the base of the succession that reaches a maximum preserved thickness of 2500 m in the center of the basin. Organic matter-rich source rocks and porous potential reservoir units occur over a short stratigraphic interval. These are exposed at the northern reach of the basin where satellite and airborne radar images have identified potential seawater oil slicks and hydrographic surveys have mapped seafloor pockmarks. The Upper Ordovician Type I-IIs shales are rich in TOC (up to 35 %), with high HI value (average 630 mg HC/g TOC). New organic-matter based thermal indicators from Rock-Eval 6 and reflectance petrography indicate that the Upper Ordovician shales are immature (T_{max} below 435 °C and average $Ro_{vit\text{-}eq}$ of 0.44 %). Inverse modeling of apatite fission tracks data from basal Upper Ordovician sandstone suggests that the succession reach the early oil window with time-temperature acceptable paths between 65 to 85 °C. Fluid inclusions data in carbonate cements from Upper Ordovician reefs has identified an early hydrothermal event (Th of 120 °C) and late burial oil window conditions (Th of 93 °C). Preliminary clumped isotope data from these cements indicate lower temperature compared to fluid inclusions but similar fluid composition. Assuming proper analytical techniques, organic- and mineral-based thermal analyses may yield different results.

Ironstones of the Katherine Group, Yukon: marine iron cycling in the early Neoproterozoic

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The discovery of well-preserved, oncoidal ironstones hosted by shallow marine sediments of the ~ 850 Ma Katherine Group, Wernecke Mountains (YT) presents an opportunity to study marine iron cycling during a critical time in Earth's evolutionary history. Iron-rich chemical sediments (iron formations) are an important tracer of the evolution of the Earth's ocean chemistry and oxidation state, and the near-absence of iron formations in sediments younger than ~ 1800 Ma is traditionally interpreted to represent the demise of the ferruginous conditions that typified the early oceans. However, recent studies of Neoproterozoic strata increasingly reveal novel iron-rich sediments. In addition to the widespread Cryogenian (720-635 Ma) iron formations associated with 'Snowball Earth' glacial events, isolated examples of shallow-water facies iron formations (ironstones) are reported from the Tonian Period (1000-720 Ma). These rare Tonian ironstones challenge our understanding of marine chemical evolution yet remain critically understudied. The Katherine Group ironstones are hosted by a thick succession of quartz arenites and siltstones and are composed near-exclusively of hematite (in places exceeding 75 wt % Fe_2O_3) with minor detrital quartz and clays. The ironstones feature hematitic oncoids, ooids, stromatolitic textures and mudcracks. These ironstones are interpreted to have been deposited in a shallow-marine peritidal environment under ferruginous conditions with slow clastic sedimentation rates, possibly influenced by iron-oxidising bacteria. The ironstone-bearing unit of the Katherine Group is broadly correlative with the ironstone-bearing Aok Formation of the Shaler Supergroup (NWT), which may suggest that ironstone deposition was a regional phenomenon during the middle Tonian. This time period also experienced significant eukaryotic diversification. The coincidence of shifts in iron cycling with significant leaps in ecosystem complexity implies a link between changes in ocean chemistry and eukaryotic diversification during this time.

Controls in K/Na ratios of magmatic-hydrothermal fluids

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The K:Na ratio of hydrothermal fluids is one of the factors controlling the distribution of alteration mineral assemblages in porphyry systems. Therefore, determining how the K:Na ratio varies within magmatic-hydrothermal systems constitutes a next step towards optimizing hydrodynamic modelling of magmatic-hydrothermal systems and understanding the physicochemical parameters that regulate these deposits. In hydrothermal settings where fluids are buffered by two feldspars (typical of intermediate to felsic igneous rocks), the alkali-exchange reactions between fluid, K feldspar and plagioclase buffer the K:Na ratio of the fluid. However, in the shallow and distal regions of the magmatic hydrothermal system where two feldspars may not be present, the K:Na ratio is not constrained by this buffer. Back in 1979, Cloke and Kesler proposed that in halite-saturated magmatic-hydrothermal systems, the K:Na ratio in the fluid can be controlled by the precipitation of a halite-sylvite solid solution over a range of temperatures. Precipitation of a halite-sylvite solid solution has the additional effect of increasing the pressure-temperature stability field of the assemblage liquid-vapor-halite. As a consequence, liquid-vapor-halite immiscibility can occur over a pressure range of ~ 100 bar at 450 °C and over a temperature range of ~ 400 °C at 200 bar in shallow porphyry systems. In this study we present experimental and analytical results on the ratios of Na:K expected and observed in magmatic-hydrothermal fluids associated with porphyry-copper deposits.

Are footprints critical elements for the exploration of unconformity-related uranium deposits?

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Exploration for unconformity related uranium deposits mainly focuses on identification of lithological, geochemical and mineralogical footprints with an empirical approach that more footprints equals greater chances of finding a deposit. The information collected defines pathfinders that are a priori vectors towards mineralization. Thus, drilling programs target conductive horizons near the unconformity, alteration haloes and geochemical pathfinders. Less focus is put on physical properties and characterization of permeability of structures and lithologies at different scales. Experience from historical discoveries, exploration of fertile trends (i.e. along conductors) and recent discoveries in non-

conventional targets, provides opportunities to reassess some of the pre-conceived ideas and empirical models. From an industry perspective, this re-evaluation is challenging as there are technical bottlenecks and methodological frontiers to face, plus scientific questions that may need significant R&D. On the other hand, it can provide a baseline to reassess strategies and to identify/prioritize the most appropriate technologies at different stages and scales of exploration, from the early regional assessment to resource estimates. Several critical elements in exploration for unconformity-related uranium deposits may not be directly linked to traditional "footprints". Changes in paradigms may be necessary to include not only information collected from wells but also the architecture of main structures at regional scales and their ability during successive reactivations to enhance permeability of the systems through organized and focused fluid-flux. While footprints provide rather static observations that mainly illustrate the variety of ore deposit models, scientific and drilling targets should also focus on the characterization of the mineral systems, aiming to understanding the dynamics of paleo-hydrothermal systems and conditions for preservation of the deposits using modern geological analogs. In this perspective, the distribution of physical properties and characterization of the permeability of the systems are critical to constrain geophysical modeling and decrease the uncertainty of 3D geological models.

Li-micas geochemistry as indicators of fluid circulation in magmatic-hydrothermal ore systems

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Micas are known to be good recorders of magmatic processes in granites and pegmatites whereas applications to hydrothermal systems are still poorly documented. In vein-type W-Sn deposits, which are typically associated with fluid circulation around granitic plutons, micas are ubiquitous and crystallize as several successive generations from pre- to syn- and post-mineralizing stages. This work aims to give an insight into the potential of Li-micas as tracers of hydrothermal processes when integrated with detailed paragenesis. The present study shows that variation of compositions in Li-micas can be used as recorders of both magmatic and hydrothermal influences in the same system, and allows to identify multiple magmas and fluid interactions throughout the history of a rare metal deposit. The Maoping Sn-W deposit in the southern Jiangxi metallogenic Province (South China) offers the opportunity (i) to characterize magmatic and hydrothermal Li-micas of various compositions and timing in the paragenetic sequence defined in the veins, (ii) to relate them to the composition and interactions of the hydrothermal fluids responsible for the deposition of wolframite and cassiterite and (iii) to use for the first time the evolution of hydrothermal Li-mica composition through paragenetic stages to characterize fluids involved, in term of timing and interactions but also characterize the nature of the magmatic fluids involved in the system. In the particular case of the Maoping deposit, five types of Li-micas can be distinguished: (i) magmatic Li-micas associated with the late crystallization of a peraluminous melt, (ii) hydrothermal Fe-Li micas in barren veins, (iii) hydrothermal Fe-Li micas associated with the tungsten event, (iv) oscillatory zoned hydrothermal Fe-Li micas associated with a second melt from a different origin, and, (v) hydrothermal Li-muscovite in the late stages.

Evolution of mineralizing fluids at the Cantung W-Cu skarn deposit, Northwest Territories, Canada

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The Cantung deposit, located in the Canadian Cordillera (southwest corner of the Northwest Territories), is a world-class W-Cu skarn deposit. Since 1962, ~ 7.68 Mt of ore has been extracted at a grade of ~ 1.4 % WO_3. The Cantung deposit is hosted in the carbonate units of the Cambrian Sekwi Formation which are part of the Selwyn basin. This formation is genetically and spatially associated with monzogranite intrusions from the Tungsten plutonic suite (94-98 Ma). At Cantung, the main pluton is a sub-alkaline biotite monzogranite called the Mine Stock pluton. Tungsten in Cantung is hosted in scheelite ($CaWO_3$), which is mostly disseminated in the skarn facies or concentrated in quartz veins from the two ore bodies: the Open pit and the E-Zone. The main mineralization is located in the E-Zone ore body of the Cantung deposit which is hosted in Lower Cambrian to Devonian metasediments. The E-zone is locally in contact with the Mine Stock pluton. In this study, we aim to determine the nature and evolution of fluids involved in the formation of the Cantung deposit. Samples from the Mine Stock pluton below the E-zone deposit as well as from the orebody itself have been collected. Fluid inclusions have been petrographically characterized and range in paragenesis from the early magmatic fluid, to the ore-forming fluid, and finally the late post-mineralizing fluid. The least modified magmatic fluid samples are expected to be those from barren quartz in greisens of the Mine Stock below the ore body level. This fluid is preserved as two-phase aqueous fluid inclusions hosted in quartz. Scheelite, the main ore mineral preserved, has fluid inclusions with comparable phase relationships to those trapped in associated quartz veins crosscutting the skarn. Several types of fluid inclusion assemblages are preserved in scheelite and quartz: vapor-rich one-phase inclusions, halite-bearing three-phase aqueous brines, three-phase aqueous-carbonic inclusions and two-phase aqueous inclusions. These fluid inclusion types are consistent with those previously described. Finally, late fluids are characterized in late skarn phases as calcite-hosted two-phase aqueous fluid inclusions. Characterization of these fluids will take place through microthermometry, Raman spectroscopy, and LA-ICP-MS on the multiple generations of fluid inclusions.

Incorporating geological and geophysical data to determine surface-based model geometry

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Geologists' interpretations about the Earth typically involve distinct rock units with contacts between them. In contrast, traditional minimum-structure geophysical inversions are performed on meshes of space-filling cells and recover smooth models that are inconsistent with geologists' interpretations of the Earth. We are researching inversion methods that can better honour such interpretations. There are several approaches through which mesh-based geophysical inversion can help recover models with some of the desired characteristics: iterative strategies, alternative regularization functionals, discrete-valued inversions, clustering, and level set methods. However, a more effective strategy is to develop a fundamentally different inversion approach that parameterizes the Earth in terms of the geometry of the contact surfaces between rock units. In our surface geometry inversion method, the model comprises wireframe surfaces representing contacts between rock units. The inversion seeks the positions of the vertices in the surfaces. While surface geometry inversion is numerically challenging, it has some major advantages. First, geophysical and geological models can use exactly the same model representation, with no need to interpret between different

representations; this streamlines the incorporation of geological information into the inversions and helps frame the interpretation of the inversion results in terms of geology. Second, joint inversion of multiple types of geophysical data is greatly simplified because no coupling measure is required. Third, because the optimization is performed using stochastic sampling, uncertainty can be assessed and helpful information for decision makers can be calculated, such as tonnage estimates for mineral exploration. We are currently applying our 3D surface geometry inversion method to model seafloor massive sulphide (SMS) deposits using magnetic data. The susceptibility contrast between the massive sulphide lens and the surrounding rock allows our surface geometry inversions to model the lens volume and further increase our understanding of the resource value of these deposits.

Evidence of spatio-temporal variations in a shallow groundwater contaminant plume discharging in a small urban stream

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The potential pollution and impairment of stream water quality by xenobiotic organic compounds is one of the threats currently targeted by the enforcement of the European Water Framework Directive in Denmark. These compounds may seep into streams from multiple pathways with very different dynamics, which are not fully understood. In this study, we investigated the spatio-temporal variations of chlorinated compounds discharging from two contaminant sources located in the near vicinity of a confluence of two streams in Denmark. The investigated reach and near-stream surroundings are representative of urban settings, exhibiting high channel alteration and urban features such as drains and sewer outlets. The investigation was carried out by monthly water sampling of groundwater, an in-stream control plane and the hyporheic zone, combined with monitoring of piezometric heads and stream flow, over one year. Our study revealed substantial spatial variations locally and temporally affecting pathway contributions and overall contaminant mass discharging to the streams. Variable contributions of the groundwater seepage and drains were identified in the channelized part of the stream. Furthermore, variations in the hyporheic flows between the two streams were found to enhance contaminant transport from a second source located closest to the confluence resulting in significant temporal variations of the overall mass of contaminant discharged. Thus, an in-stream control plane approach was found to be an effective method for integrating multiple and variable discharge contributions quantitatively, although information on specific sources is lost. This study highlights the complexity and variability of contaminant fluxes occurring at the interface between groundwater and urban streams, and calls for the consideration of these variations when designing remedial actions for contaminated sites with the potential to impact streams.

Groundwater dynamics within a watershed in the discontinuous permafrost zone near Umiujaq (Nunavik, Canada)

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Groundwater distribution and flow dynamics were studied in a small watershed located in the discontinuous permafrost zone at Umiujaq in Nunavik (Québec), Canada, to assess the seasonal variations and perform a quantitative analysis of the water cycle in a subarctic watershed. Due to the complexity of the subsurface geology within the watershed, an integrated investigation was instrumental to provide a detailed understanding of the hydrogeological context as a basis for the water balance. Based on this water balance, for the two studied hydrological years in 2015 and 2016, the average values are 828 mm for precipitation, 337 mm for evapotranspiration, 46 mm for snow sublimation, 263 mm for runoff, 183 mm for groundwater exchange (losses with other aquifers outside the watershed), and 0 mm for change in water storage. Even if there is significant uncertainty and spatial variability in these values, this water balance is shown to be plausible. It was also found that permafrost limits surface and groundwater interaction. It is expected that permafrost degradation will likely increase stream baseflow, especially in winter.

Carbonatitic to limestone syntectic decarbonation reactions in silicate magmas: CO_2 oxidant enhancing IOA liquid immiscibility

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The formation of Iron Oxide-Apatite (IOA) systems has long been enigmatic. The compositions of both magnetite and apatite and the other component elements suggest derivation from high temperature (T) magmatic systems, with genetic models including iron oxide magmas or igneous magnetite and apatite flotation. Ideas related to the role of H_2O and associated oxidative mechanisms have resurfaced from models of the late 1960s. As such, salt melts forming in open, differentially degassing systems could represent an end-member to the formation of IOA deposits. Another end-member involves autometasomatic decarbonation reactions involving ferroan carbonatites with co-genetic melts or host rocks generating CO_2 capable of oxidizing carbonatites to enhance magnetite-apatite saturation. The syntectic decarbonation end-member presented here examines the reactions of carbonate melts of mantle origin or from syntectic reactions with limestone, with cogenetic silicate magmas. Although carbonate and silicate melts can coexist at magmatic pressure (P) and T, their compositions must be peralkalic. However, as P decreases, immiscibility or reactivity between these melts is such that CO_2 is exsolved (decarbonation) to the point that at near surface conditions, decarbonation is complete. The addition of CO_2 to silicate melt will drive the conversion of FeO to Fe_2O_3 in order to make carbon monoxide (CO), thus shifting the redox equilibria. For most silicate magmas, the amount of dissolved carbonate and CO_2 is quite limited, and differential CO_2 degassing results. These carbonate: silicate melt reactions then may result in oxidation of the silicate magma, to enhance immiscibility of IOA (liquation) and elemental partitioning associated with liquid-liquid immiscibility. This could be an oxidative mechanism for Fe-Ti tholeiites (ferrobasalts) and diorites to reach a two-liquid field and form IOA melts via liquation. Carbonates would typically be consumed in these reactions, although CO_2 is an important degassing product that would substantially increase ΔV of the reaction, which has implications during high-level emplacement.

Role of impact devolatilization in the genesis of Ni-Cu-PGE mineralization in the Sudbury Igneous Complex

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Most magmatic Ni-Cu-PGE deposits form from mantle-derived mafic-ultramafic magmas, are hosted by lava/magma conduits, and occur primarily in rift-related tectonic settings. However, the Ni-Cu-PGE mineralization in the 1850 Ma Sudbury Igneous Complex, the largest known accumulation of magmatic Ni-Cu-PGE mineralization on Earth, formed from a crustal impact melt and is hosted by norites and quartz diorites. Despite 135+ years of research, the genesis and mechanism of localization of the Ni-Cu-PGE mineralization in the SIC is not well

understood. Most models involve exsolution of immiscible sulfides during cooling of the impact melt, gravitational settling to the basal contact, and sweeping into topographic embayments by convection currents followed by, in some localities, injection into radial and concentric "offset" dikes. Variations in S-Pt-Os-Pb isotopic compositions of the ores around the SIC have been explained by later interaction with underlying rocks, but this cannot explain the insignificant variations in the Hf isotopic compositions of associated silicate rocks or the mismatch between observed ore tenors and metal depletion trends in overlying norites. The wide variations in Pb isotopic variations have been attributed to Pb loss during impact followed by incorporation of Pb from underlying rocks, but S is as volatile as Pb, so it should have been also devolatilized. This leads to an alternative model for ore genesis involving 1) syn-impact devolatilization of significant amounts of Hg-Tl-Cd-S-Se-Sn-Te-Zn-Pb-Bi and likely also Sb-Ag-Cu-Au-As from the impact melt, 2) mechanical and convective homogenization of all chalcophile (S-Pt-Os-Pb) and lithophile (Sr-Nd-Hf) isotopic systems during formation of the impact melt sheet, and 3) subsequent local thermomechanical erosion and assimilation of barren Fe sulfides (Huronian basalts/sediments), Fe-Cu-Ni-(PGE) sulfides (Nipissing and/or East Bull Lake Intrusive Suites), or Fe-Ni-Cu-(PGE) sulfides (Shakespeare-type Nipissing intrusives), forming sulfide xenomelts that reacted with overlying impact melt to produce the observed Fe-Ni-Cu-(PGE) ores and S-Pt-Os-Pb isotopic variations.

Emplacement and localization of magmatic Ni-Cu-(PGE), Cr, and Fe-Ti-Vdeposits

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The preferential localization of magmatic Ni-Cu-(PGE), Cr, and Fe-Ti-V deposits within horizontal components of dike-sill-lava complexes indicates that they were fluid dynamic traps. Oxides are almost always interpreted to have formed locally, but sulfides are often interpreted to have been transported upwards from deeper levels. Although fine, dilute suspensions of dense sulfide melt and oxide can be transported in ascending magmas, there are several problems with upward-transport models: 1) geological and/or S isotopic data are consistent with local S sources in almost all major deposits, 2) most xenoliths (if present) appear to be derived locally (from the same stratigraphic levels) rather than from significantly deeper sources, 3) lateral sheet flow/sill facies of major deposits contain few if any sulfides, 4) sulfide or oxide enrichments rarely (if ever) occur in the volcanic components of magmatic systems – even where they overlie abundant mineralization in underlying feeder dikes/sills/chonoliths – except where there is evidence for a local source, and 6) some overlying lavas are mildly to strongly depleted in PGE>>>Cu>Ni>Co, indicating that unerupted sulfides sequestered chalcophile elements at depth. Two potential solutions to explain this paradox are: 1) natural systems contained surfactants that lowered sulfide-silicate interfacial tensions, permitting sulfide melts to coalesce and settle more efficiently than predicted from theoretical/experimental studies of artificial/analog systems, and/or 2) sulfides and oxides existed not as uniformly dispersed droplets or crystals, as normally assumed, but as fluid-dynamically coherent pseudoslugs or pseudolayers that could not be transported upwards. Regardless of the ultimate explanation, it appears that most high-grade Ni-Cu-(PGE), Cr, and Fe-Ti-V deposits formed at the same stratigraphic levels as they are found. Sulfides that do not appear to have formed locally were likely transported horizontally or formed at higher levels and settled backwards into the same fluid dynamic traps that have been proposed to have trapped sulfides transported upward from putative “staging chambers”.

Lava tube caves as exploration targets on Earth and Mars

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The surface of Mars is currently a harsh environment, unlikely to enable life or even preserve traces of past life. Therefore, the Mars exploration community is turning increasingly to the subsurface in order to address questions of habitability and life detection. Lava tube caves represent natural subsurface environments that offer natural protection from surface conditions, including radiation, extreme temperatures, winds and dust. As such, they represent key exploration targets in the search for traces of life on Mars. Lava tubes are natural subsurface conduits that typically form as basaltic lava flows cool. As such, they are common on Earth (e.g. Hawaii, Iceland, etc.) and putatively also common on Mars. Because their mode of formation on Earth and Mars are essentially identical, terrestrial lava tubes represent high-fidelity analogues on Martian lava tubes. As such, we have been investigating lava tubes caves on Earth to better prepare for future missions that will seek to access and explore Martian lava tubes. Specifically, we are investigating the microbial ecology of lava tube caves, including cold-adapted organisms in perennially cold caves. We are also studying the formation and preservation of microbial biosignatures associated with secondary minerals that form through water-rock interaction in the lava tube environment. We have also tested field portable, stand-off analytical instruments (Raman spectroscopy, laser-induced breakdown spectroscopy and near-infrared reflectance spectroscopy) that may someday be developed for use on Mars. Our research has shown that there are diverse and abundant microbial communities adapted to different lava tubes, including the presence of cold-adapted organisms in the ice-containing caves. We have also found that organic biosignatures are variably preserved in different secondary mineral deposits and that these biosignatures can be detected in situ when present in sufficiently high concentrations. This work will help to prepare for an eventual mission to a Mars lava tube.

Water resources impacts by climate change in Prince Edward Island, Canada

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Physically-based hydrologic models HEC-HMS and MODFLOW were utilized to assess the impacts of climate change on surface water and groundwater resources at the watershed scale over the next 40 years on Prince Edward Island (PEI). Three watersheds located in the east, west, and center of PEI were simulated to quantify the hydrologic impacts of projected climate change scenarios, and to estimate changes in the water resources in each area. Long term stream flow and groundwater monitoring data were analyzed to validate the models and provide the trends of water resource changes in the last 40+ years. Climate data from the CGCM3.1 (T47) global climate model (GCM), developed by the Canadian Centre for Climate Modelling and Analysis, was selected for hydrologic model inputs. Three emissions scenarios, RCP8.5, RCP 4.5 and RCP2.6, which represent a range of high, medium, and low projected greenhouse gas emissions, respectively, were used. The daily climate data were downscaled using both the Bias Corrected Spatial Disaggregation (BCSD) statistical downscaling technique and the Bias Correction/Constructed Analogues with Quantile (BCCAQ) downscaling method, and the results were compared. The range of hydrological responses for the 2050s time period (2040-2070) were compared with the historical 1970s (1961-1990) period. Both the historical monitoring data and the results from the numerical models consistently conclude: (1) a slight increase in the long-term trend of streamflow and groundwater level on an annual basis; (2) streamflow has a much stronger response to climate change in terms of is seasonal variation. The snowpack and snowmelt are most significantly impacted by climate change. The earlier snowmelt results in increases in streamflow from December to March, and significant decreases in April and May; and (3) Groundwater level increases moderately in late fall to early spring but decrease slightly in May and June.

Super Wilson Cycle: the birth and destruction of superoceans during supercontinent cycles

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The Wilson Cycle refers to the opening and closure of oceans between continental blocks. Recent work suggests that in Earth history, superoceans may have been created and then destructed every two supercontinent cycles, here termed the Super Wilson Cycle. The Earth history since ca. 2 Ga has been dominated by the formation and break-up of three supercontinents: Nuna (ca. 1600-1300 Ma), Rodinia (ca. 900-700 Ma), and Pangaea (ca. 320-170 Ma). Each supercontinent cycle lasts ca. 500-700 Myr. However, there are records indicating that supercontinents do not all assemble the same way: some through introversion (the closure of the internal oceans formed during the break-up of the previous supercontinent) whereas others through extroversion (the closure of the external superocean surrounding the previous supercontinent). The two processes may have occurred in an alternating fashion over the past 2 Ga, therefore deemed the superocean only getting consumed every second supercontinent cycle. In the process, the subduction girdle surrounding the superocean also gets destroyed and recreated every second supercontinent cycle, leading to a complete reorganization of the mantle structure (e.g. new antipodal LLSVPs surrounded by the regenerated subduction girdle). Such a first-order supercycle explains the so-called Proterozoic "boring billion" and other billion-year-wavelength observations.

Be-W-Sn rare metals, Pb-Zn polymetals and Au metallogenic system of the Cuonadong Dome in the Tethys Himalayan orogenic belt, Tibet, China

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The Cuonadong Dome, a recently discovered dome in Tethys Himalaya, is located at the eastern part of the Himalayan orogenic belt. Three stages of granitic intrusion in the Cuonadong dome have been identified: 1) ca. 32-26 Ma deformed granites in the middle unit of the dome; 2) ca. 21-18 Ma weakly deformed two mica granites in the core, and 3) ca. 16-14 Ma white mica granites also in the core. Their petrological and geochemical data suggest that both ca. 21-18 Ma and ca. 16-14 Ma granites are characterized by high fractionation, but the white mica granites are more fractionated, which is typical of rare metal granites. From the center to the periphery of the Cuonadong dome, three major deposit types have been recognized: 1) the high temperature Xianglin and Rina Be-W-Sn deposits within the skarns and/or marbles of the Cuonadong dome; 2) the medium temperature Zhaxikang, Keyue and Jisong Pb-Zn deposits within the cover sequence of the dome; 3) the low temperature Mazhala, Jienagepu and Mingsai Au deposits in the periphery of the dome. Sphalerite from the Zhaxikang Pb-Zn deposit yielded a 20.48 Ma Re-Os age. Altered sericites from Jienagepu and Mingsai Au deposits, and Jisong Pb-Zn deposit yielded 17.6 Ma, 19.2 Ma and 16.6 Ma $^{40}Ar/^{39}Ar$ ages, respectively. Cassiterite from the Xianglin Be-W-Sn deposits yielded a 14.4 Ma U-Pb age. These ages are interpreted as the formation ages of the different deposit types, which are nearly consistent with the ca. 16-14 Ma highly fractionated granites in the Cuonadong dome. We proposed, therefore, a new comprehensive model for the metallogenic system of the Cuonadong Dome, which mainly consists of the high temperature Be-W-Sn rare metals deposits, medium temperature Pb-Zn deposits, and low temperature Au deposits from the center to the periphery of the dome, respectively.

Mineralization age and formation mechanism of the Shilu hematite deposit, South China

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The Shilu hematite deposit is located in the Changjiang County, Hainan Province of South China. It is a large high-grade hematite deposit (460 Mt @ 51 % for FeO), hosted by dolostones of the Neoproterozoic Shilu Group. There are three layers of iron ores that collectively form an upper Fe-ore body and a lower Co-Cu ore body. The genesis of this deposit remains controversial as it has experienced multiple deformation, metasomatism and skarnization events. To constrain the mineralization age and ore genetic model, Re-Os dating and isotope analysis have been performed. The Re-Os isochron age of the Co-pyrite and hematite, from Beiyi mining area, is 676 ± 6.6 Ma, which may imply the initial depositional age of low grade Fe-Co-Cu ores. The Re-Os model age of the massive cobalt-bearing pyrite in the South mining area is 224 ± 2.6 Ma, which is consistent with the age of the regional Indosinian magmatic event, considered as the mineralization age. The low $\delta^{30}Si$ values (-0.5 ~ -0.6 ‰) and the high $\delta^{18}O$ values (15.5 ~ 18.3 ‰) of the quartz in the iron jasper are similar to those observed in BIFs. The $\delta^{56}Fe$ values of the hematite range from 0.12 ~ 1.36 ‰, with a decreasing trend from the base to the top of the sequence. They indicate that the copper-rich sulfide ores formed firstly during a submarine exhalation event. With the oxygen fugacity increasing, the degree of oxidation of the Fe^{2+}-bearing hydrothermal fluid progressively increases, forming barite-bearing, high silica low grade iron ores. During the Indosinian magmatic events, these iron ores have been strongly metamorphosed and reworked. Through fluid-rock interaction, silica was leached from low grade ores, forming diopside and tremolite; while hematite has been preserved under the alkaline oxidation conditions, leading to the formation of high grade hematite ores.

Mineral reactions and element migration during selvedge formation in migmatites

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Partially melted rocks are called migmatites and the combined effects of melt segregation and deformation produce very heterogeneous rocks. Chemical exchanges will occur between the compositionally different parts within a migmatite, and are aided by the presence of hydrous melt. We studied biotite selvedges that developed between mafic schollen and surrounding semipelitic diatexite to investigate the chemical exchanges that occur as anatectic terrains cool. The study area at Lac Kénogami is in the central Grenville Province of Quebec. Typical mineral assemblages of the mafic schollen, biotite selvedges and diatexite are: Pl + Opx + Ilm, Bt + Pl + Opx + Qz + Ilm ± Grt, and Pl + Bt + Qz ± Grt ± Crd, respectively. Orthopyroxene in the selvedges is more euhedral and 5-10 times larger compared to orthopyroxene in the adjacent mafic schollen. Poikiloblastic garnet on the selvedge-diatexite contact have abundant (up to 20 %) inclusions of biotite, plagioclase, quartz and ilmenite, and because ilmenite is ubiquitous in the mafic schollen, but absent from diatexite, these garnets are considered to have grown with the biotite selvedge. The general biotite selvedge-forming reaction deduced from the microstructure and mineral chemistry is: $Opx_1 + Pl_1 + Melt \pm Ilm_1 = Bt + Pl_2 + Qz + Grt/Opx_2/Ap \pm Ilm_2$. Mass balance calculations using whole rock composition of the mafic schollen, selvedge and diatexite suggest Na_2O, K_2O and SiO_2 are from the diatexite but CaO, MgO, FeO, MnO, Ni, V, and Co are from the mafic schollen. Composition profiles across the selvedges and adjacent rocks obtained from micro-XRF and LA-Q-ICP-MS analysis are consistent with the mass balance calculations and suggest Na_2O, K_2O and SiO_2 diffused towards mafic schollen whereas Al_2O_3, FeO, MgO and CaO

diffused towards diatexite. Chemical exchanges occurred over distances of at least 6 cm.

Irregular continental margins, promontory collision and orogen-parallel strike-slip faulting in accretionary and collisional orogens: examples from the Canadian Appalachians and South China

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Continental margins, especially passive margins, are generally irregular in shape and exhibit promontories and reentrants. Where this is the case, collision between two continents is expected to start at a promontory or between two promontories. This leads to some unique geological processes at the site of promontory collision, including potentially deep subduction and burial of the continental crust of the promontory on the lower plate. Orogen-parallel strike-slip faults with significant displacements are also common in many orogens. The possibility of large-scale orogen-parallel movement, in addition to convergent motions, implies that presently neighboring terranes could have been far apart during subduction and collision. However, most tectonic models for orogens are focused on orthogonal divergent and convergent motions, without incorporating potentially significant transcurrent movement. Promontory collision and orogen-parallel strike-slip faulting played significant roles in the tectonic evolution of both the Canadian Appalachians and South China, two accretionary orogens. In the Canadian Appalachians, it has been proposed that a collision between the St-Lawrence and Cabot promontories occurred in the Silurian, resulting in a narrower Central Mobile Belt, stronger deformation and higher grade metamorphism in Cape Breton Island and southwestern Newfoundland, and that the Corner Brook Lake block in SW Newfoundland is a suspect terrane that moved along strike for over 400 km along the Laurentian margin. In South China, East Cathaysia is proposed to be a terrane that originated from the Indosinian orogen to the south and moved to the east of West Cathaysia through large-scale strike-slip faulting in the Mesozoic. It is further proposed that West Cathaysia was (part of) a promontory on the Yangtze-West Cathaysia continent and the Early Paleozoic Wuyi-Yunkai orogeny, characterized by high-temperature and high-pressure (up to ~ 1.0 GPa) metamorphism and extensive S-type magmatism, is a result of collision of the promontory with another terrane, most likely Australia.

Avalonia meets Cadomia: the Central European Variscides in the light of modern U-Pb zircon geochronology

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The Variscan orogen and its Avalonian-Cadomian precursors form the heart of the supercontinent Pangea. The Variscan orogen resulted from the continent-continent collision of the landmasses of Laurussia and Gondwana and its peripheral orogens. During the last decades, numerous high quality data sets have been produced. Especially new robust geochronological data paved the way for new interpretations concerning the formation of the orogen. The dispersal of Rodinia was followed by a plate tectonic re-organisation, which resulted in the formation of the Gondwana supercontinent. Subsequent Late Ediacaran plate interactions at the margins of the supercontinent were responsible for the origin of the composite microcontinents of Cadomia and Avalonia. Both microplates show differences concerning the zircon populations which were inherited from their primary cratonic hinterlands. Inheritance characteristics are provided by U-Pb ages and Hf-isotopes of detrital and magmatic zircon. Cadomia shows a clear reworking of a West African crust. In contrast, (at least East) Avalonia shows strong recycling of a crust, which is dominated by Mesoproterozoic tectonomagmatic events. Distinct detrital zircon populations relate East Avalonia to a peri-Baltic origin. These differences of Avalonian and Cadomian zircon populations have been used for plate tectonic reconstructions in Palaeozoic mobile belts such as the Variscan orogen in Central Europe, in which Cadomian and Avalonian rocks form the basement. Zircon provinces (U-Pb, Hf) of (micro-) continents like Avalonia, Cadomia, south Baltica, West Africa, and Amazonia allow a detailed reconstruction of Variscan orogenic processes preserved in Central Europe. Plate tectonic processes were much more complex than shown in previous models.

Caldera-filling and outflow tuffs of the ca. 25 Ma Underdown caldera, Shoshone Mountains, Nevada

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The ca. 25 Ma Underdown caldera was formed as a result of the mid-Cenozoic ignimbrite flareup, a sweep of magmatic activity from the northeast to southwest of Nevada, USA, triggered by subduction related activity. Located in the Shoshone Mountains of north-central Nevada, the Underdown caldera includes the Underdown tuff (24.95 ± 0.05 Ma), the Bonita Canyon formation (24.98 ± 0.02 Ma), and an unnamed tuff unit (24.72 ± 0.05 Ma). Other units of interest include the tuff of Clipper Gap (24.95 ± 0.07 Ma), an outflow tuff which extends east towards the Utah border, and other tuff units similar in age (ca. 25 Ma) which are exposed outside of the caldera. Ca. 18 Ma lava flows were emplaced along the bounding faults of the Shoshone Mountains, outside the caldera. We present new geochemical data for the intracaldera and outflow tuffs of the Underdown caldera to determine the relationships between these units. Major element geochemistry shows that intracaldera tuffs and outflow tuffs are trachyte to rhyolite (64-83 wt % SiO_2). Normalized incompatible element patterns show LREE-enrichment and negative anomalies in Sr, Eu, and Ti which indicates the fractionation of plagioclase feldspar and Fe-Ti oxide minerals in the Oligocene tuffs. New Pb, Sr, and Nd radiogenic isotopic data will help to identify a potential magma source for these units. For ignimbrites age corrected to ca. 25.0 Ma, $^{87}Sr/^{86}Sr$ = 0.7051-0.7091, εNd = -2.51 to -0.06, $^{206}Pb/^{204}Pb$ = 19.067-19.194, $^{207}Pb/^{204}Pb$ = 15.641-15.660, and $^{208}Pb/^{204}Pb$ = 38.766-38.884. Other (ca. 25 Ma) tuff units and potential outflow tuffs show isotopic similarities to tuffs of the Underdown caldera, indicating that all have similar sources. The ignimbrites plot just below and to the right of the bulk silicate earth on an $^{87}Sr/^{86}Sr$ vs. εNd plot which along with negative εNd values suggests a melt derived from an enriched mantle or upper crustal source.

Early Cretaceous sinistral strike-slip faulting in NW Pacific: implications from the U-Pb dating of detrital zircon in Sikhote-Alin, Russian Far East

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Sikhote-Alin orogenic belt in Russian Far East is a key area of the NW Pacific accretionary orogenic belt. Numerous NNE-trending belts are late Jurassic to early Cretaceous in age and separated by strike-slip and thrust faults, of which the most important is the Central Sikhote-Alin Fault, as long as 1200 km with sinistral displacement ~ 200 km. Detrital zircons of turbidites (J3-K2) on both sides of the fault were analyzed by U-Pb dating. The results show that the west accretionary belt mainly has Phanerozoic ages, indicating that the western Sikhote-Alin accepted the sediments from the adjacent NE China, the eastern part of the Central Asian Orogenic Belt. The eastern Sikhote-Alin belts contain many more

Precambrian zircons with peak ages at 1.8 and 2.5 Ga, similar to the dominant ages of Korean Peninsula. However, the present location of the eastern Sikhote-Alin belts is too far away from their provenance area, making it impossible for the Korean Peninsula or any other parts of the North China Craton to feed these belts. Thus, it is proposed that the eastern Sikhote-Alin belts were originally deposited along the eastern margin of the Korean Peninsula. Large-scale sinistral strike-slip faults, represented by the Central Sikhote-Alin Fault, cut through and dismembered these accretionary complexes or basins, and then transported them northwards to the Sikhote-Alin area. Strike-slip faulting played a significant role in the NW Pacific accretionary orogen during the early Cretaceous.

PLS-DA of chemical compositions of native gold from various Au-bearing deposits: implications for mineral exploration

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Geochemical composition of native gold is useful to provide a chemical signature for various gold-bearing deposit types. This study uses analyses of 607 gold grains collected from a total of 48 gold-bearing deposits of different types including orogenic, epithermal, volcanogenic massive sulfide (VMS), and reduced intrusion-related gold (RIRG) deposits. Electron probe micro-analyzer (EPMA) was employed to determine the in situ concentrations of certain major and minor elements. Among the elements examined, only the data for Ag, Fe, Co, Cu, Hg, S that contained equal or less than 40 % censored values were investigated by partial least squares discriminant analysis (PLS-DA) to yield discriminant models to differentiate among various types of gold-bearing deposits. Gold grains from RIRG and orogenic gold deposits on average have similarly limited fineness ranges, whereas gold grains from epithermal deposits have large variations of fineness. PLS-DA results indicate that gold from epithermal deposits can be separated from those from other groups mainly because of higher Ag and lower Cu and Fe. In contrast, gold from VMS deposits shows relative enrichment in Cu and Hg, whereas it is depleted in Fe, Co, and S. Gold from RIRG and orogenic deposits plot in vicinity of each other in PLS-DA score scatter plot indicating similar chemical characteristics such as high Fe, Co, and low Ag, Hg. The Hg enrichment and low Fe contents in gold from VMS and epithermal deposits are consistent with the composition of fluids associated with volcanic systems. The similar chemical characterization of gold both in orogenic and RIRG deposits probably indicates gold was remobilized due to fluid-and-deformation assisted recrystallization. In overall, this study suggests that chemical compositions of native gold can be used as indicators to identify different origins of gold particles.

Numerical modelling of convective and conductive heat transfer in a talik beneath the Kuuguluk River at Salluit in Nunavik (Canada)

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The Inuit community of Salluit in Nunavik (Canada) is located in the continuous permafrost zone where finding a sustainable supply of drinking water is challenging. A well drilled in a fractured rock aquifer in a talik beneath the Kuuguluk River is used as a source of water in this community. The heat transport by running water in the riverbed and groundwater flow in the talik is enough to keep above 0 °C a bulb of unfrozen ground beneath the riverbed which is called a talik. To assess the impacts of permafrost degradation due to climate warming on the talik and groundwater availability in the aquifer, a cryohydrogeophysical investigation, including electrical resistivity tomography for delineating the spatial extent of the talik, monitoring of thermo-hydraulic conditions of the riverbed, floodplain and plateau, and numerical modelling of conductive heat transfer, were carried out. Following this investigation, a conceptual cryogeological model of the talik as a cross-section perpendicular to the Kuuguluk River was developed to support a 2D numerical model of conductive heat transfer. Dirichlet boundary conditions were applied at the surface and Neumann boundary conditions on the sides (zero-heat flux boundaries) and bottom (geothermal heat flux boundary) of the 2D model. The complex heat transfer at the ground surface was simulated using empirical relationships between the surface and air temperatures found from the monitoring of air temperature and thermal conditions of the riverbed, floodplain and plateau. The variability of the mean annual air temperature (MAAT) from 1920 to 2015 was also taken into account. A training period of 70 years from 1850 to 1920 with a constant MAAT of -8.5 °C was first simulated to reach a steady-state thermal regime. The climate variability was then simulated according to climate data available in Nunavik. Based on the simulation results, the current thermal conditions along the Kuuguluk River and conductive heat transfer alone in the ground can explain the presence of the talik beneath the riverbed. Under the current climatic conditions, the simulated talik is 60 m wide and as thick as 8 m during the coldest month of the year while the maximum depth of the freezing front beneath the riverbed is 2 m. The extent of the simulated talik is also consistent with the one derived from the electrical resistivity model obtained from the inversion of the electrical resistivity tomography. However, for a more realistic simulation and a better understanding of the complex physical processes taking place in the talik, a 3D numerical model fully coupled conductive and convective heat transfer has been developed which takes into account the ground heterogeneity and groundwater flow in the talik. Scenarios of climate change in the coming decades will be also simulated to assess the impacts of climate warming on the talik and groundwater availability in the aquifer, and assess the vulnerability of the source of drinking water of the Inuit community of Salluit to permafrost degradation. And, finally, a better understanding of the formation of icing in the floodplain of the Kuuguluk River in winter will be achieved with the simulation results.

The elusive Phoenician/Persian harbour of ancient Akko: where geophysics, petrophysics and geology meet archaeology

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The reconstruction of the evolution of ancient coastal settlements can be quite challenging if a multi-disciplinary approach is not taken, even more so when the location of ancient landlocked anchorages/harbours are at stake. Numerous excavation campaigns were pursued throughout the 80's and 90's atop the ancient city of Tel Akko. Efforts to locate its elusive pre-Hellenistic anchorages/harbours were in vain thus far. This ancient tell, one of the oldest cities of the Ancient Mediterranean World with at least 4000 years of continuous habitation, was an important maritime trading point as indicated by the wealth of imported artefacts and its strategic location at an intersection of maritime and terrestrial Levantine routes. Situated in the vicinity of where the Na'aman River flows into Haifa Bay (the only large embayment along this Israeli coastline), Tel Akko's surrounding landscape has undergone significant changes from its early days of protected natural anchorage-prone estuarine/lagoon niches to a wide fertile agricultural coastal plain. The spatio-temporal 3D morphological changes along this coastal northern end of the Nile

Littoral Cell have been substantial and rapid to this once harbour city which presently sits ~ 1.5 km from the Mediterranean coast. Comprehensive multi-disciplinary investigations involving a multitude of geological and archaeological methods have been pursued since 2013 by our team to reconstruct the palaeo-environment around Tel Akko. So far, 25 sediment cores have been retrieved following extensive geophysical surveys (ERT and GPR). Cores underwent traditional petrophysical analyses besides application of novel stratigraphic tools such as luminescence profiles. Detailed sedimentological, mineralogical, bio-stratigraphic, and geochemical characterizations have also been pursued. Chronologies have been established by ceramic identification, ^{14}C and OSL-dating. Detailed geo-referencing and 3D modeling have been strategic for palaeo-topographic controls. At least two areas have been found where a 1st Millennium Phoenician/Persian harbour could potentially sit, however no remains have yet been found.

Evolution and diversity of early eukaryotes: insights from the Proterozoic of Arctic Canada

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During the Mesoproterozoic Era (1600-1000 Ma), early innovations within Eukarya (e.g. sexual reproduction, predation, multicellularity) led to the appearance of the main lineages of this new domain. These innovations, which continued and were enhanced in the Neoproterozoic (1000 to 542 Ma), defined and shaped life in the Phanerozoic. Two successions exposed in northwestern Canada are providing significant insights to the early evolution of eukaryotes. The ca. 1500-1300 Ma Dismal Lakes Group and the ca. 1070-720 Ma Shaler Supergroup record significant diversity of organic-walled microfossils, spanning 700 million years of Earth history. The lower Shaler Supergroup assemblages are rich in ornamented, acanthomorphic (process-bearing vesicles) and multicellular eukaryotes, and preserve the oldest evidence reported so far for eukaryovory. The Dismal Lakes Group, especially the Fort Confidence Formation, shows diverse eukaryotic forms reported for the first time from this succession. With additional data from geology, sedimentology and chemistry, these assemblages answer fundamental questions on the influence of ecological interactions and biological innovations on their diversity (predation) and on geographical distribution of taxa compared with broadly coeval rocks in China, India, the U.S and Africa. Furthermore, these assemblages from arctic Canada modify previous diversity estimates and patterns of eukaryote diversification during the Proterozoic and their analyzes may help resolve the possible biological affinities of some of these eukaryotes. In summary, the exceptional preservation of these assemblages allows a refined picture of eukaryotic life in the Proterozoic that helps complete the narrative of early eukaryote evolution.

Ductile shear zones as flat heterogeneous inclusions in the continental lithosphere: a numerical investigation based on the Eshelby Formalism

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The deformation of Earth's lithosphere is characterized by the development of localized high strain zones. Investigating the kinematics and mechanics of high strain zones is vital to construct the tectonic history of orogenic belts from multiscale structures and to understand the rheology of continental lithosphere. Previous studies have mainly focused on the kinematic and the geometry of homogeneous tabular zones. Here, we apply a fully mechanical approach toward shear zone deformation. We regard a ductile shear zone as a flat oblate heterogeneous inclusion in the lithosphere and consider the shear zone deformation and mechanical interaction with the lithosphere using the Eshelby inclusion formalism extended for general power-law viscous material. In a general obliquely convergent setting, the (partitioned) flow inside the oblate shear zone determines the fabric development in the shear zone and the perturbed flow field outside the shear zone inclusion will govern the fabric evolution in the immediate country rocks. Fabrics observed in natural shear zones are compared with model predictions. Our modeling shows that localization of boundary-parallel motion (simple shearing) into the shear zone is a mechanical consequence of partitioning whereas the components orthogonal to the zone are unpartitioned. We discuss the finite strain geometries of our models in the context of natural observations. Based on our model, within the shear zone, the foliation is parallel to the shear zone boundary, and lineations are from nearly strike-parallel (shearing component is large) to down-dip (compression component is large). In the vicinity of the shear zone, the foliations are at small angles of the shear zone boundary. However, the lineations are probably not observed in country rocks, because the finite strain is small and is dominated by flattening deformation.

Apatite accommodating arsenic: a potential new oxybarometer

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Apatite is a ubiquitous early-formed mineral in felsic magmas that selectively accommodates the As^{5+} species relative to the As^{3+} species. Since the relative proportion of the arsenic species is dependent on the oxygen fugacity, the potential exists to develop an arsenic-in-apatite oxybarometer relevant to felsic igneous systems. Our previous work has determined arsenic speciation as a function of oxygen fugacity in a basaltic composition quenched from 1200 °C at 0.1 MPa. Analysis of these samples by x-ray absorption near edge structures (XANES) shows that As^{5+} contributes up to 1 % of the arsenic species at FMQ +3.1. Based on these results a preliminary model for the arsenic-in-apatite oxybarometer has been formulated and tested against the variation in the arsenic apatite-whole rock partitioning exhibited in granites from the Lachlan fold belt (Australia). The model requires unrealistically large apatite-melt partition coefficients for As^{5+}, suggesting that the speciation measured in the basaltic composition underestimates the abundance of As^{5+} in cooler, more felsic melts. To improve the model, experiments are underway to measure both the magnitude of apatite-melt partitioning and the arsenic speciation as a function of oxygen fugacity in a hydrous felsic system. Experiments are performed in a piston-cylinder apparatus at 900 °C and 0.75 GPa. We employ a synthetic iron-free rhyolite composition, similar to Lake County obsidian (used in previous apatite solubility experiments) doped with 1000 ppm arsenic, 3.5 wt % apatite and 4 wt % water (added as kaolin). Using silver rod as a capsule material, three experimental charges are run simultaneously around a central metal-metal oxide oxygen fugacity buffer. These buffers ($MoMoO_2$, NiNiO, $ReReO_2$, and $RuRuO_2$) span the oxygen fugacity range of terrestrial magmatic systems.

Groundwater-surface water interactions and agricultural nutrient transport in a Great Lakes clay plain system

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Non-point source agricultural contamination (phosphorus and nitrogen) is a serious concern for surface and groundwater quality within the Great Lakes Basin. The dynamics and transport of nutrients through the groundwater-surface water interface is not presently well-

understood. This research aims to investigate the spatial and temporal evolution of phosphorus and nitrate in the groundwater, hyporheic zone, stream water, and tile drainage water in an agriculturally-dominated clay plain system within the Great Lakes Basin. Field-based data collection is being conducted in the Upper Parkhill Watershed in southwestern Ontario. Parkhill Creek, the main surface water feature in the watershed, is a tributary to Lake Huron, and thus this study will serve to examine the fate and pathways of agriculturally-derived nutrients discharging to a Great Lakes tributary. Continuous and discrete data and samples of the various water sources are being collected for the analysis of fundamental nutrient species (total, total dissolved, soluble reactive, and particulate phosphorus, and nitrate-N), in addition to field parameters (electrical conductivity, pH, temperature, oxidation-reduction potential, and dissolved oxygen). From June to December 2018, concentrations of total phosphorus (TP) ranged from 0.007 to 0.324 mg/L in surface water, and < 0.003 to 0.150 mg/L in groundwater. Concentrations of TP ranged from 0.027 to 0.066 mg/L in tile drainage water and from 0.136 to 0.203 mg/L in the hyporheic zone. Concentrations of total phosphorus were frequently found to exceed provincial guidelines in all sources of water investigated in this study. The results of this study will help to fill the knowledge gaps that exist concerning nutrient transport through surface water, hyporheic, and groundwater interfaces, and the hydrogeological processes influencing this transport in clay dominated subsurface settings.

Oxygen fugacity and volatile content of syntectonic magmas from the Abitibi greenstone belt

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The Neoarchean Abitibi subprovince is one of the most gold-endowed greenstone belts of the world. Depending on their ages, magmas are referred to as syntectonic or synvolcanic types. Several studies demonstrate a spatial, structural and/or genetic relationship between syntectonic magmas and intrusion-related gold mineralisation. The genesis of these deposits remains controversial. Defining a metallogenic model for these deposits requires an understanding of the role that syntectonic magmas play in the transport, concentration and deposition of gold. Documentation of these magmas is also important for the exploration of gold deposits. Oxygen fugacity (fO_2) and volatile content are important factors for the generations of gold mineralisation. Metals are transported by magmas and fluids in particular redox conditions and in the presence of specific ligands (S, Cl). High fO_2 and dissolved sulphur favour the transport of gold in magmas and fluids. Quantitative data on the fO_2 and volatile content of Neoarchean magmas are scarce. The aim of this study is to evaluate these parameters for six intrusions of the Abitibi subprovince using the chemistry of zircon, apatite and amphibole. The selected intrusions are alkaline or calco-alkaline as well as mineralised or barren. Apatite and zircon are resistant minerals enriched in elements with variable valence such as Ce, Eu and Mn that will be used to evaluate fO_2 conditions. Amphibole and apatite will be used to evaluate the volatile content (Cl, S, Fl) of the studied magmas. The result of this work will be used to evaluate the mineralising potential of the syntectonic intrusions of the Abitibi greenstone belt.

Optical reconnaissance of minerals: the contribution of machine learning

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The Canadian shield being mostly covered with glacial overburden, access to outcrops can be limited. Therefore, dispersion of detrital minerals in glacial sediment is a prime exploration method. Indicator minerals counting still rely upon optical microscope or SEM scanning. Visual sorting of millions of mineral particles is time consuming, costly and error prone even for fully trained personnel if the minerals are not distinctive enough. Most of the current techniques are sequential. SEM scanning is expensive and technology intensive while access to equipment is limited. To circumvent these issues, image analysis approach is currently being tested, using machine learning (artificial intelligence) for mineral particle identification. RGB images are acquired with a conventional microscope and transformed into various colour space such as hue, saturation and value (HSV) and lightness, green-red and blue-yellow colour components (CIELAB colour space). Then, images are process to 1) adjust threshold to discriminate grains from background, 2) improve brightness, 3) generate a mask to facilitate segmentation, 4) enhance saturation to better discriminate faint colors and 5) and equalizing RGB histograms to improve contrast. Then, a simple linear iterative clustering segmentation is used to generate superpixels that groups pixels of similar characteristics. The superpixel approach is an efficient alternative to traditional segmentation methods and efficiently isolates individual mineral grain. The features (colour, luminance, luster and surface texture, etc) of the superpixels are then related to subjacent minerals and used for the learning process. Classification and Regression Trees, k-Nearest Neighbour and Random Forest algorithms have been tested, the last one yielding the best results with an accuracy of about 90 %.

Chemical compositions of anatase and rutile associated with U mineralization at the Kiggavik-Andrew Lake area (Nunavut, Canada)

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Mineralogical and geochemical characteristics of 202 titanium dioxide (TiO_2) grains from 51 samples collected from mineralization and alteration zones from the Kiggavik Main and Center Zones (MZ & CZ), End and Andrew Lake deposits, and the Kiggavik North and East (KN & KE) areas were investigated using optical microscopy, laser Raman spectroscopy (LRS), and electron microprobe analysis (EPMA). Due to small grain sizes (< 100 µm) and/or inclusion-free surfaces, only forty-four of the grains could also be analyzed by LA-ICP-MS (laser ablation inductively coupled plasma mass spectrometry) for their trace elements concentrations. The LRS results indicated that 90 % of the TiO_2 grains from various host rock compositions are anatase, whereas 6 % are rutile and 1 % are brookite. A few grains also showed anatase-rutile mixed Raman spectra that may indicate the transformation between the polymorphs. Based on petrography, anatase is characterized with one or more of the following textures: 1) euhedral, elongated crystals; 2) pseudomorphs after coarse-grained ilmenite; 3) containing U-bearing micro-inclusions; and 4) disseminated anhedral grains partly replaced by uraninite and/or the alteration assemblage illite ± hematite ± quartz ± calcite. Petrography suggests that the crystallization of TiO_2 postdated the first stage of U mineralization, but predated the second and/or third stage of the mineralization in the Kiggavik-Andrew Lake area. Rutile occurs as 1) ilmenite replacement, or 2) disseminated anhedral grains containing U inclusions and/or replaced by U-bearing minerals. Partial least squares discriminant analysis (PLS-DA) of geochemical data illustrates that in spite of textural differences, anatase grains in samples from the Lone Gull granite (LGg) hosting the Kiggavik MZ deposit can be distinguished from that from the other groups based on higher Nb, Ta, Sn and Mn, and lower Cr contents. Higher V also separates rutile grains of different textures from the LGg from TiO_2 from the other groups. PLS-DA shows that TiO_2 grains from this study are also distinguished from rutile and anatase from various metallic deposit

types (e.g. Au ± Cu ± U, Au-Mo, Cu-Mo, Cu-Zn, Sn-Cu, W-Sn and Ni-Cu-Pd) due to higher Si, Ta, Nb and Fe contents.

Potential field data modelling along Metal Earth's Chibougamau transect using geophysical and geological constraints

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The Metal Earth (ME) project aims to understand the underlying geological mechanisms differentiating well endowed and less endowed mineralized zones in Precambrian greenstone belts of the Canadian Shield. ME acquires and collates various geological observations and geophysical data along 13 selected transects within the Superior Craton. The ME objective is to create valid 2D and 3D models of subsurface features, so as to identify components that contribute to mineralization processes. Thus far, the project has acquired gravity readings along 10 transects. The Bouguer reduced data were combined with the existing gravity data provided by the Geological Survey of Canada throughout the areas of interest. In this paper, data along the Chibougamau transect (~ 128 line kilometers oriented SW-NE) located in the northeastern part of the Abitibi sub-province is considered. The Chibougamau area is one of the well-endowed transects where the geology consists of volcanic and sedimentary rocks, with tonalitic gneissic cores. Gravity and compiled high-resolution magnetic data along this transect were modelled using an initial petrophysical model constrained by geological observations made at the surface, seismic sections at depth and measured petrophysical properties. Potential field data modelling requires adjusting the shape, densities and magnetic susceptibilities of features at depth and can resolve the geometry of some features which are transparent in seismic sections. For example, the model provides an improvement in estimating the size, shape, and depth of plutonic bodies such as the Barlow and Chibougamau plutons across the Lac Doré Complex. The new modified model is consistent with the known structural geology (the synclinorium and anticlinorium of volcanic and sedimentary rocks). The model also helps us to improve the seismic interpretation and identify dykes and faults. The improved understanding of these subsurface features will potentially help to identify components contributing to mineralising processes in the Chibougamau area.

Optimization of geophysical methodologies to discover magmatic intrusive Ni-Cu-PGE ore bodies in a challenging geological setting

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The Nunavik Nickel Property (NNP) sits in the Cape Smith Belt, very well known for its numerous Ni-Cu-PGE deposits. Ore bodies in this area are associated with mafic/ultramafic dyke-like intrusions related to the Expo Intrusive Suite. These magmatic flows cross-cut a vast formation of sediments and volcanics where they assimilated extra sulfur and have them precipitated as Ni-Cu-PGE rich lenses at their base. Outcrops and magnetic maps highly suggest that these mafic/ultramafic intrusions have been very turbulent, leaving the exploration team with quite a puzzle to resolve. Geophysics has proven to be a powerful tool for geological mapping and direct ore detection on the Nunavik Nickel Property. While magnetic surveys are very handy to outline the peridotite dikes throughout the property, the challenge increases in sectors where the fertile intrusions contain less magnetite. In addition, even if they are good electromagnetic (EM) conductors, Ni-Cu-PGE deposits can be missed easily, not only because they tend to be of limited size and variable geometry but also because they hide next to regional scale graphitic-rich sediments filled with veinlets of massive pyrrhotite. High resolution heliborne magnetic surveys, optimised time-domain EM configurations, systematic measurements of magnetic susceptibility and EM conductivity over drilled core and 3D mag inversion significantly contribute to discovering massive sulfides at Nunavik Nickel. However, there is no magic bullet at NNP as geophysical signatures of Ni-Cu-PGE lenses vary significantly. This project is a good example of how integration of geology and geophysics can lead to exploration success.

Macrofossils from the Tonian Dolores Creek Formation of the Wernecke Mountains, Yukon

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The Tonian (1000 to 720 Ma) represents a critical transition in Earth history between the Mesoproterozoic (1600 to 1000 Ma) and the low-latitude glaciations of the Cryogenian (720 to 635 Ma). However, the early Tonian period is notoriously poorly understood and well-preserved exposures are rare in the stratigraphic record. The Proterozoic inliers of Yukon present an opportunity to more accurately characterize the environmental conditions of the early Tonian and extract information on biospheric evolution at this time. Previously undocumented Tonian macrofossils were discovered in the ca. 900 Ma Dolores Creek Formation of the Wernecke Mountains during fieldwork in July 2018. The Dolores Creek Formation is the oldest formation of the basal Hematite Creek Group, which forms the base of the Mackenzie Mountain Supergroup in eastern Yukon. The Dolores Creek Formation in this studied location consists of dark grey to black siltstone with minor orange-weathering stromatolitic intervals. Ninety samples were recovered from seven macrofossil-bearing horizons in an ~ 1 km-thick section of the Dolores Creek Formation near the headwaters of Hematite Creek. The macrofossils have a filamentous structure and comprise repeated segments. There are clear taphonomic differences in the sampled specimens ranging from exceptionally preserved specimens with three-dimensional preservation to poorly preserved specimens that do not display clear segmentation. Analytical microscopy techniques will be used to the investigate structure and taphonomy of the macrofossils discovered in the Dolores Creek Formation to provide insight into their origin and phylogeny. Molecular clock analyses estimate that several key eukaryotic lineages evolved and began to diversify during the Tonian. These well-preserved macrofossils present a unique opportunity to add valuable paleontological data and gain insight into this crucial time period in Earth's biospheric evolution.

How does pentlandite form? New constraints from the distribution of highly siderophile elements in pentlandite

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The distribution of the highly siderophile elements is used in a wide variety of geological studies, from planet formation and evolution to the formation of ore deposits. Under mantle and crustal conditions, these elements behave as highly chalcophile elements, and pentlandite (Pn) is an important host for most of these elements. Therefore, understanding how Pn forms is important for understanding the processes that control these elements. The classic model for the formation of Pn is that below 650ºC, monosulfide solid solution (MSS) and intermediate solid solution (ISS), are no longer stable and exsolve into pyrrhotite (Po), Pn and chalcopyrite (Ccp).

However, Pn has been shown to be the main host of Pd in many ore deposits, and given that Pd is incompatible with both MSS and ISS this observation is inconsistent with the exsolution model. Furthermore, experimental work has shown that Pn can form by peritectic reaction between MSS and fractionated sulfide liquid. To date this type of Pn has not been reported in natural samples. In our study of chalcophile element concentrations in Pn from iconic magmatic Ni-Cu-PGE deposits (Noril'sk and Bushveld Complexes) we observed three textures of Pn: contact-Pn in between Po and Ccp, granular Pn included within Ccp or Po, and flame-Pn included within Po. The contact-Pn shows zonation in Mo, Rh, Ru, Re, Os, and Ir with these elements being enriched towards the Po contact and depleted towards the Ccp contact. In some cases, Pd displays a zonation antithetical to these elements. We propose that the contact-Pn formed via peritectic reaction and inherited Mo, Ru, Rh, Re, Os, and Ir from the MSS, whereas Pd was contributed from the fractionated sulfide liquid. We predict that this type of Pn should be present wherever MSS and fractionated sulfide liquid remained in contact.

DEEP Earth Energy Production's Williston Basin Hot Sedimentary geothermal power project development

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The DEEP ("DEEP") Earth Energy Production geothermal power project is located in Southeastern Saskatchewan, Canada, and a few miles north of the United States border. Analysis of thousands of public oil and gas well records in the area revealed the presence of a vast Hot Sedimentary Aquifer (HSA) at 3500 m depth in the Williston Basin. This aquifer has extensive laterally continuity for some hundreds of kilometres, is 150 m thick and has a measured temperature in the range of 120-130 °C. The Williston Basin HSA alone may support several hundred megawatts (MW) of power generating capacity, due to the extent of this vast resource. A full Bankable Feasibility Study is scheduled to be completed later in 2019. In December 2018, DEEP successfully drilled the first geothermal test well. The vertical well, reached its target total depth of 3530 m, the deepest well ever drilled in Saskatchewan's history. Preliminary data, acquired to assess the geothermal reservoir, indicates bottom-hole temperatures exceeding 125 °C, in addition to positive reservoir pressure and permeability that exceeds the minimum threshold for project feasibility. The next steps for the project include the drilling and coring of a 1300 m Mannville injection well in March, 2019. During production testing operations, brine from the source well will be injected and disposed into the injection well, enabling the first production/injection doublet. Further geothermal parameters will be acquired during this process, which includes a longer term (30 days) injection, production flow and build up test. Final feasibility engineering reporting to refine the assumptions made on the reservoir and effectively optimize the design parameters are expected by October 2019, with full-scale construction commencing in 2020 and final commissioning scheduled for completion by the end of 2021.

Carbon-cycling and weathering in lake Untersee, Dronning Maud Land, East Antarctica

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Lake Untersee is one of the largest (8.7 km^2) and deepest (~ 160 m) freshwater lakes in East Antarctica. The proglacial lake is perennially ice-covered and dammed by the Anuchin Glacier. Water mass balance shows that input is mainly from englacial meltwater and output occurs by sublimation of the ice cover. With the exception of an anoxic basin at the southwestern end, the lake is well-mixed by thermal convection, alkaline (pH ~ 10), and supersaturated with dissolved oxygen (~ 150 %). Volumetric planktonic primary productivity is close to the lowest on record, and the lake bottom supports an exclusively benthic microbial ecosystem. The study investigated the geochemical and carbon evolution in Lake Untersee through major and trace element chemistry and isotopes of the major carbon pools. Results for DIC, DOC and their $\delta^{13}C$ values show stable values through the oxic water column (DIC = 0.3 to 0.4 ppm, DOC = < 0.3 ppm, $\delta^{13}C_{DIC}$ = 7 to 10 ‰, $\delta^{13}C_{DOC}$ = 27 ‰). Organic carbon in the sediments (1 to 5 wt % in the top 20 cm) are derived from the microbial mats covering much of the lake bed. Lake-water and sediment stable-isotope and radiocarbon results, coupled with calculated CO_2 input from englacial melt, are used to constrain a carbon-mass-balance to determine the controls on pH and carbon in the water column. Geochemical modelling with PHREEQC and carbon mass balance calculations will further constrain the relative rates of plagioclase weathering, carbon fixation and respiration by heterotrophs) driving the high pH and low DIC in Lake Untersee.

New 1:250 000 scale bedrock geology maps of the South Rae craton in NWT (NTS 75A, B, G and H)

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The Rae craton and adjoining Hearne craton are part of the western Churchill Province of the Canadian Shield. The present-day lithospheric architecture of the Rae craton is the result of the cumulative effects of crustal growth and tectonic processes, which persisted from the Paleoarchean to the Paleoproterozoic resulting in the assembly of one of Earth's most ancient supercontinents Nuna. The nature of the Rae craton's Archean history is poorly understood, which hampers substantial understanding of its Proterozoic reworking. The least studied southern portion is termed the "South Rae craton" where a recent 400 km long transect, from the Hearne craton to the Taltson magmatic zone, was undertaken in order to update and modernize the geological framework. Presented herein are four new 1:250 000 scale bedrock geology maps (NTS 75A, B, G and H), which incorporate observations from three years of bedrock mapping. The geological interpretation is complimented with new U-Pb, Ar-Ar, and Lu-Hf geochronology and thermobarometric determinations on metaplutonic and metasedimentary rocks. New fundamental subdivisions (domains) of the South Rae craton are described, each with their own Archean basement units, and patterns of deformation and metamorphism associated with Paleoproterozoic polyorogenesis. These domains (Snowbird, Firedrake, Zemlak, McCann, Penylan, Boomerang and Porter) have been juxtaposed into their current architecture during multiple Paleoproterozoic orogenies (Arrowsmith, Snowbird, and Trans-Hudson) along newly mapped major crustal-scale structures. Amongst the newly delineated structures are the McArthur Lake shear zone, the Miller Lake shear zone and the Howard Lake shear zone on the western side of the study area, accommodating exhumation of the higher-grade McCann and Penylan domains against the upper crust of Porter domain; the Black Bay fault zone in Saskatchewan, now extended for 400 km into the NWT; and the Wholdaia Lake shear zone, which juxtaposes the Firedrake with the Snowbird domain to the east.

Melting in varicolored Grenvillian marble

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Silicate rocks melt as they attain the amphibolite facies of metamorphism, but what about carbonate rocks? Cross-cutting bodies of marble are traditionally attributed to the plastic behavior of calcite; in a stress field, calcite easily "flows" by slippage along its cleavage planes.

For this reason, few have bothered to search for evidence of melting. The evidence comes from the microtexture of polymineralic inclusions in calcite and in other neoformed minerals. We describe these micrometric inclusions as "jigsawed", in the sense that the constituent minerals are arranged in an interlocking way. Entire samples containing globules of multicomponent melts embedded in calcite and in neoformed crystals were imaged using the Zeiss large-area SEM imaging software Atlas 5. Overview image mosaics with the BSE and CL signals were acquired at resolutions of 150 to 200 nm/pixel. Samples of variously colored marble samples from Autoroute 5 near Wakefield (Quebec) contain numerous sets of micrometric to nanometric inclusions. Euhedral baryte and subhedral anhydrite crystallites ~ 200 nm to 540 µm across occur as single inclusions throughout. Polymineralic inclusions range from 50 µm to 700 µm in size and contain enstatite, diopside, orthoclase, albite, titanite, and phlogopite, whereas others contain pyrrhotite + chalcopyrite + magnetite + galena. The enstatite and diopside globules in the calcite samples contain a zoning pattern only visible in the CL signal. The green apatite contains sulfate and silicate. We have also investigated orange calcite from the Yates prospect, Otter Lake area (Quebec). Large crystals of fluorapatite are full of jigsawed micrometric to nanometric inclusions considered to have crystallized from globules of melt incorporated from the boundary layer. These inclusions contain Cal + Fl + Anh + Adr + Thr + Aln, mainly. In general, the evidence points to multiple melts formed by anatexis at the Rigolet stage of the Grenville event.

Discovery of giant submarine canyons on the Davie Ridge (western Indian Ocean) and their significance

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The effects of the East African Rift Systems (EARS) in shaping the African continent have puzzled geoscientists for the last few decades. In recent years, the existence of an offshore branch of the EARS in the western Indian Ocean has been introduced to explain the formation of the Kerimbas Graben and of the Davie Ridge. However, a clear picture showing the consequences of a vigorous tectonic activity for deep-water depositional settings, and its timing, is still missing. Using a combination of recently acquired data, this contribution presents the discovery of three giant deep-water canyons incising the Davie Ridge towards the Indian Ocean and which are currently disconnected from the active slope channels offshore the Rovuma delta. Regional correlation of dated seismic horizons, integrated with sediment samples and high resolution bathymetric data, prove that the tectonic activity driving the uplift of the Davie Ridge, and the abandonment of the canyons, is extremely recent, probably started in the Plio-Quaternary, and is still ongoing. The discovery of supra-elevated canyons on the deep-water Davie Ridge highlights that the tectonics of the offshore branch of the EARS has had a profound control on the evolution of the margin and on the transport of sediment and organic matter towards the Indian Ocean. Our findings contribute in placing the Kerimbas Graben and the Davie Ridge offshore Tanzania in the regional geodynamic context of the western Indian Ocean, show the effect of the offshore branch of the EARS on sediment distribution pathways, and underline the need of considering the offshore tectonic activity in future tsunami hazards assessments in East Africa.

Quantification of gold grain morphology using X-Ray 3D microscope and secondary electron microscope

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The shape of gold grains is commonly used to estimate the distance of transport from the source in various sedimentary deposits. However, the qualitative nature of gold grains shape classifications in fluvial, glacial and eolian environments is limited and depends on the observer. For this reason, the quantification of morphological parameters is required to estimate more precisely the distance of travel of a grain. The present work compares two quantitative methods to reconstruct the 3D model of a gold grain. The X-ray microscope (Carl Zeiss Xradia 520 Versa) yields density contrast images of the grain along tridimensional axes in order to reconstruct a high resolution (0.35 to 0.7 µm pixel size) 3D model of the particle. After processing, a mesh of the gold grain shape is produced to quantify axial lengths, area and volume, as well as parameters to calculate flatness indices, shape factors, sphericity and roundness of the particle. The scanning electron microscope (SEM) can also be used to reconstruct the shape of a gold grain. Photogrammetry is used to produce a 3D mesh of the grain from SEM images. The high resolution (1.2 nm) provides an accurate surface texture that is useful to calibrate the model in order to estimate the axial lengths, area and volume of the particle. However, SEM reconstruction is partial, because the grain face fixed on the stage is not observed. The results for the same gold grain analyzed by microtomography and SEM are consistent, with less than 10 % differences on the calculated morphological parameters. Microtomography remains more precise for particles higher than 70 µm but the photogrammetry based method enable grains smaller than 70 µm to be quantified.

Archean Cu-Au porphyry systems: the Chibougamau pluton example

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The Chibougamau pluton is a Neoarchean (~ 2715-2718 Ma) multiphase intrusion genetically related to Cu-Au porphyry-style deposits. In Archean greenstone belts, porphyry-style mineralisation is marginal and poorly documented. Such deposits are however important in the Chibougamau area, where the main historical mining camp (Central Camp) is interpreted as a magmato-hydrothermal system. The mineralization has characteristics observed in porphyry systems, e.g. intermineral porphyritic dykes and hydrothermal breccia. The "Chibougamau style" of mineralisation is structurally controlled; it consists in NW-SE-striking sub-vertical sulphide-filled fractures, quartz veins and late iron carbonate-magnetite-sulphide veins. The main ore minerals are chalcopyrite, pyrrhotite, pyrite, and ±sphalerite-galena-molybdenite. Remobilisation of these deposits formed chalcopyrite veinlets and isolated gold nuggets. According to field and petrological descriptions, the Cu-Au porphyry-style deposits associated with the Chibougamau pluton may have formed in two main stages: 1) syn-magmatic stage, with possibly overprinting events (porphyry stage); and 2) syn-metamorphism remobilization. These processes are tested using pyrite chemistry. Quantitative laser ablation inductively coupled plasma-mass spectrometry (LA-ICP-MS) analyses are performed and used as "time-slice data sets", following the recent recommendations of Goucerol and coworkers. This powerful technic reveals the nature of the mineralizing magmatic fluid and documents the effect of remobilization within individual pyrite grains. Standard statistical methods (i.e. principal component analyses, PCA) are also used to assess element associations, which provides further insights into the nature of hydrothermal fluids.

Metal Earth in Chibougamau: Neoarchean magmatism and its importance for mineralizing processes

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The Chibougamau area, NE corner of the Abitibi subprovince, is characterized by an abundance of Cu-dominated magmato-hydrothermal

mineralizing systems. Several of these systems are investigated as part of the Metal Earth project (Laurentian University), which aims at unrevealing the key differences between well metal-endowed and less endowed greenstone belts. This contribution provides an overview of the projects conducted at UQAC with the support of Metal Earth. One of these projects, which focuses on the Chibougamau pluton and its related Cu-Au mineralization, is then be presented in more details. The Chibougamau pluton is a Neoarchean (~ 2715-2718 Ma) multiphase intrusion (diorite and tonalite) genetically related to Cu-Au porphyry-style deposits. In Archean greenstone belts, porphyry-style mineralisation is marginal and poorly documented. Such deposits are however important in the Chibougamau area, where the main historical mining camp (Central Camp) is interpreted as a magmato-hydrothermal system. The comprehension of such systems requires a documentation of the chemistry of the related magmas. This contribution focuses on the petrogenesis of the Chibougamau pluton and on its capacity to contribute Cu and Au to mineralising systems. Using field descriptions, whole rock analyses and petrographic observations, the mode of production, emplacement mechanism and chemical evolution of the Chibougamau pluton is addressed. The Chibougamau pluton is a TTD (tonalite-trondhjemite-diorite) suite containing more K than most plutons of similar ages. The magma was generated at ~ 20 kbar from an heterogeneous source, i.e. hydrated basalt and mantle metasomatized by TTG melt. These are rare and possibly prospective characteristics for Archean intrusions. In addition, prolonged differentiation of the diorite phase may have favoured the concentration of metals and fluids in the evolved magma. These magmatic constrains are to be tested against a renewed comprehension of the Cu-dominated mineralising systems of the Chibougamau area.

Metallogeny, mineralogy and isotopic geochemistry of the Kipawa rare-earth deposit: genetic implications and comparison with other rare-earth deposits in peralkaline syenites

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We propose to study the Kipawa peralkaline complex, a rare-earth deposit principally composed of eudialyte, mosandrite and britholite. The Kipawa complex is situated in the Parautochton zone of the Grenville Province in the Tesmiscamingue region of Quebec, 55 km south of contact with Superior Province. The complex consists of peralkaline syenites, amphibolites, gneisses that are intercalated with calc-silicate rocks and marble, and overlain by a peralkaline gneissic granite. The Kipawa complex differs geochemically and petrologically from other well-known peralkaline complexes such as the Illimausaq, Lovozero, Thor Lake or Strange Lake complexes. Classic peralkaline complexes are large, circular igneous complexes, with or without volcanism and have an isotopic signature reflecting mantle origin with different degrees of assimilation and crustal contamination (for example Illimausaq is reported with εNd values of 0.4 and -5.7). The Kipawa Complex is a thin, folded stack of sheet imbricates between Kikwissi Suite rocks, McKillop Lake sequence and Red Pine Chute gneiss, suggesting a regional tectonic control. Isotopic analyses carried out by other teamsindicate a strong crustal signature (εNd = -8.7). Several hypotheses are possible: crustal contamination, hydrothermal activity, fluids alteration during formation, metamorphism or dominant crustal origin. Our objective is to characterize the geochemical and isotopic composition of the Kipawa complex in order to improve our understanding of the age and formation of the complex. Analyses of both whole rocks, eudialytes and zircons will be made to obtain isotopic signatures and determine formation ages and/or post-formation processes.

Laser ablation U-Th-Sm/He dating of apatite

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Laser ablation U-Th-Sm/He (LAHe) dating is an emerging technique in thermochronology and has been proven to reliably date single grains of monazite, zircon and titanite. The method eliminates some of the analytical problems associated with conventional whole-grain dating, including uncertainties related to alpha-ejection correction and eliminating dissolution safety hazards. We present a new measurement method for apatite LAHe dating that provides accurate, and reproducible dates for Durango and Fish Canyon Tuff age standards. This new apatite dating method improves analytical efficiency, widens the applicability to less pristine crystals, and preserves the grains for further analyses. These benefits make the method particularly interesting for detrital material. The LAHe method reduces grain-selection bias introduced in whole-grain methods due to the necessity in these methods to measure grains without inclusions, fractures or other surface defects and undesirable grain shapes. Surface frosting, which limits visual inspection of the grains for defects, is no longer an issue. As such LAHe methods could result in more complete characterization of detrital apatite populations in modern sand and sedimentary rocks. Besides the bias introduced due to the preferential grain selection for whole-grain methods, unknown erosive removal of the alpha-ejection affected portion of the grain is a large concern. Because the LAHe method dates the center of the grain, the alpha-ejection correction is not necessary and a large portion of the uncertainty of the date is eliminated. Improved analytical efficiency will allow for larger datasets to be acquired time- and cost-effectively allowing for more robust interpretation of detrital populations. The utility of the method is demonstrated using a modern river sand from a catchment in western Washington state, USA. Our new LAHe data reveal biases in the whole-grain detrital dataset due to grain-selection and low number of measurements, and reproduces known basement ages within the catchment.

Determination of radiation ages for zircon during U-Pb LA-ICP-MS measurements

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Double dating (U-Pb geochronology and thermochronology) of detrital zircon provides insights into either the cooling history of the source areas or post-depositional processes if burial is sufficient to partially or completely reset the thermochronological system. Currently, application of zircon double dating is limited by the significant cost and time involved in applying most zircon thermochronometers (e.g. ZFT, ZHe). The accumulation of radiation damage in zircon has been proposed as an inexpensive thermochronometer (radiation age), recording the time since the zircon passed through its annealing temperature. Initial radiation dating utilized Raman spectroscopy to determine zircon crystallinity and produced promising results. We present a method where radiation ages are determined using variations in ablation rate measured during standard laser ablation ICP-MS U-Pb analysis. First, measurements of reference material ablation rate (µm/pulse) in a measurement session are plotted against calculated effective alpha dosage, the amount of damage within the zircon crystal lattice to define a calibration curve. Then, the effective alpha dosage of an unknown is estimated using its measured ablation rate and the calibration curve. Finally, the radiation age is calculated using the estimated effective alpha dosage and measured U and Th concentration. Insights into the thermal history of individual detrital zircon grains is limited by the accuracy of the ablation rate measurements (~ 3 %) and the small variation in ablation rate between crystalline and metamict zircons (~ 17 %). For detrital zircons the method is useful for population-based inferences of timing

of source area cooling or post-depositional processes. Two datasets are presented to demonstrate the utility of the method.

3D geophysical insight into Mesoproterozoic IOA/IOCG mineral systems under cover, U.S. Midcontinent

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The southeast Missouri iron oxide-apatite (IOA ± REE) and iron oxide-copper-gold (IOCG) metallogenic province in the southern Midcontinent region of the United States is hosted in Mesoproterozoic igneous rocks that are largely concealed beneath Paleozoic cover. 3D inversion models of magnetic and gravity data reveal widespread prospectivity for IOA ± rare earth element (IOA ± REE) and IOCG ± cobalt mineralization. The models cover a multi-state area and image hydrothermally altered and mineralized rocks in volcanic units near the Precambrian surface as well as underlying intrusive complexes. The models extend to the mantle/crust interface. At shallow crustal levels, our models show that IOA ± REE deposits and IOCG deposits occur within or near the edges of large Early Mesoproterozoic (ca 1.4 Ga) silicic calderas and (ca 1.3 Ga) granitic plutons. Previous isotopic and geochemical studies conclude that the iron-oxide deposits and their volcanic host rocks originated from mantle-derived and crustal melts that erupted during regional extension. Extension was associated with thermal event(s) that produced the widespread ca 1.45 Ga Eastern Granite Rhyolite Province and the 1.35 Ga Southern Granite Rhyolite Province. We postulate that early in the evolution of the EGRP, several trans-crustal magmatic plumbing systems developed. The southeast Missouri metallogenic province is underlain by one such magmatic system that is expressed within the 3D susceptibility model as a northwest-trending ~ 50 km-wide by 200 km-long elongate track of high magnetization at deep crust levels. The high magnetization corridor splays upward through the crust to the Precambrian surface. Our findings confirm that the iron deposits, with no distinct connection at the surface, are connected to one large magmatic system at depth. Other similar susceptibility tracks that are present along the top of the mantle may mark additional feeder zones that allowed magma to ascend to the main eruptive centers that produced the Granite Rhyolite Provinces.

Celebrating geological heritage in the Discovery Aspiring Global Geopark: a candidate for UNESCO Global Geoparks designation

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Discovery Aspiring Geopark is located on the Bonavista Peninsula of Newfoundland Labrador, Canada. The region of the aspiring Geopark includes approximately 280 km of stunning rugged coastline and covers an area of 1150 km^2. The Bonavista Peninsula's diverse geology has played a key role in influencing the very fabric of daily life. It reveals a unique opportunity to connect how this areas' geological past shapes the landscape, where people live, what they eat, and economic activity. Discovery promotes itself as "Half a Billion Years in the Making", connecting stories of people and their coastal backdrop. The coastal geology offers a unique opportunity to observe, study, and celebrate one of the most significant transitions in Earth's history: the Ediacaran Period, and its associated rise of animal life. With rocks over half a billion years old, the aspiring Geopark is host to some of the most spectacular and exceptionally preserved Ediacaran fossils anywhere in the world. As a site of continuing scientific research, new discoveries are still being made, including the recent find of *Haootia quadriformis*, the first fossilized evidence of muscular tissue, and possibly the oldest animal fossil. The Bonavista Peninsula is a key tourism destination, showcasing a rich cultural heritage, local folklore and traditions, and an enchanting colorful history. The hiking trails within the aspiring Geopark give visitors remarkable vistas of a host of coastal formations, including caves, arches, and sea stacks. Through these stunning landscapes, active geomorphological processes can be viewed at the interface between land and sea. The aspiring Geopark initiative aims to raise awareness about the region's geological heritage so everyone can experience and enjoy the geology. It also seeks to engage local communities and its residents in the planning and management of the Geopark, to promote geoconservation and to contribute to local economies through sustainable geotourism.

Defining the Anthropocene at Crawford Lake as an integral part of the Niagara Escarpment Geoheritage

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Many studies have been conducted on Crawford Lake since the pollen of Zea mays and other cultivars from the middle of the last millennium were identified in the early 1970s. Varved sediments in the deep dolostone basin of this small lake near the edge of the Niagara Escarpment in Milton, Ontario provide annual/seasonal resolution through the last millennium, dating Iroquoian agricultural settlement between 1268 and 1486 CE and EuroCanadian land clearing beginning ~ 1822 CE. Exceptionally diverse assemblages of organic-walled microfossils including rotifer loricae and cellulosic dinoflagellate thecae characterize this Holocene Lagerstätte, which contains the oldest viable cysts of dinoflagellates germinated from varves dating to the early 1820s. In addition to subannual resolution, other attractive features of the Crawford Lake succession include its accessibility and protection by Conservation Halton since the first archeological investigation discovered artifacts and evidence of longhouses. The reconstructed Iroquoian village is a popular attraction, and the unique lacustrine environment and the micropaleontological research that led to the discovery of the site at the Conservation Authority's Interpretive Centre feature in display materials along the boardwalk around the lake. The geoheritage aspect of the site remains undervalued, however. The varved record of Crawford Lake is being investigated as a potential GSSP candidate for the Anthropocene Series, as required to formalize the term Anthropocene as a potential new unit of geologic time, with a proposed base at AD ~ 1950 (the "bomb spike"). It is anticipated that this initiative, keenly debated among the geoscience and broader community, will draw attention to geoheritage and its value in the broader societal context, particularly in clearly distinguishing between diachronous anthropogenic impact and the proposed boundary between the Holocene and Anthropocene Series.

Laurentia during the mid-Ediacaran: paleomagnetism and 580 Ma age of the Saint-Honoré alkali intrusion and related dykes, Québec

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We sampled the mid-Ediacaran Saint-Honoré alkali intrusion and related dykes in the Saguenay City region of Québec for paleomagnetic and U-Pb, $^{40}Ar/^{39}Ar$ geochonologic study. $^{40}Ar/^{39}Ar$ geochronology of phlogopite separates from carbonatite of the central intrusion return plateau ages with a weighted mean of 578.3 ± 3.5 Ma. Baddeleyite

from a phoscorite dyke provides a concordant age of 580.25 ± 0.87 Ma for the crystallization of the dykes associated with the St-Honoré intrusive complex. Paleomagnetic results from the intrusion itself and related carbonatite and lamprophyre dykes exhibit some streaking between higher to moderate inclination directions, even at the site level, after screening to remove a steep, present-day viscous remanence. The predominant St-Honoré mean direction (13 sites), which is primary (baked contact test on the host Lac St-Jean anorthosite), is D = 119, I = 72.3°; α_{95} = 9.5°, retained at higher coercivity and to high unblocking temperatures by titanomagnetite. Assuming a geocentric axial dipole, this result places the St. Honoré locality at 57° S at ~ 580 Ma, implying that Laurentia straddled mid-paleolatitudes at that time. Notably, the paleopole location at 27.2° N, 320.7 E (dp = 15°, dm = 17°) is consistent with similar mid-Ediacaran age paleopoles which place Laurentia at mid- to high paleolatitudes. The Saint-Honoré result implies that Laurentia had moved from low latitude in the early Ediacaran to higher southern paleolatitudes by 580-570 Ma, and then back to low paleolatitudes by as early as 564 Ma. Viewed as apparent polar wander (APW), this motion traces an 'Ediacaran loop' that can also be seen in similar-aged paleomagnetic results from at least two other paleocontinents. The similar APW loops suggest a role for true polar wander in Ediacaran geodynamics, and perhaps help to define a longitudinally-constrained global Ediacaran paleogeography.

Geochemical and isotopic study of the occurrence and fate of nitrate in Alberta groundwater, Canada

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This study documents the occurrence of nitrate contamination in groundwater across Alberta, Canada, and investigates sources and fate using isotopic tracers and determination of redox states. To map nitrate in Alberta groundwater we use a regional public health database collected by Alberta Health Services of domestic well water quality from 2001-2015 consisting of 60 016 samples from depths up to 150 m. Nitrate concentrations were detectable (~ 0.9 mg NO_3/L) in 32 % of samples, with a median concentration of 4 mg NO_3/L. Of these samples with detectable nitrate concentrations, 10 % exceeded 45 mg NO_3/L (the Canadian maximum acceptable concentration for nitrate in drinking water). Nitrate concentrations are highest (up to 1330 mg NO_3/L) in shallow groundwater (< 50 m) in agriculturally intensive areas along major transportation corridors and decrease with depth. Nitrate was mainly observed in oxic to sub-oxic groundwater whereas 73 % of all groundwater samples displayed sulphate-reducing or methanic redox conditions and negligible nitrate. This observation supports the hypothesis that reducing conditions may limit the extent of nitrate contamination in Alberta groundwater. To investigate nitrate sources and fate further, 25 groundwater samples from Alberta's Groundwater Observation Well Network were analyzed for the isotopic composition of water, and nitrogen and oxygen isotope ratios of nitrate. Deviations from the local meteoric water line (lower slope) result from evaporation during recharge and possibly mixing of infiltrating recharge waters with formation waters. Nitrate isotope ratios range from -10 to +22 ‰ $\delta^{15}N$ and from -15 to +25 ‰ $\delta^{18}O$, consistent with both anthropogenic (e.g. septic, manure, fertilizer) and natural contamination sources (e.g. soil N, weathering and nitrification of ammonium bearing clays in glacial till), as well as denitrification occurring in aquifers. As 90 % of Alberta's rural population relies on private groundwater wells, research on sources of nitrate contamination and relevance to human health continue.

The Iapetus suture zone in Ireland

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Evidence preserved in Ireland for the later stages of Iapetus ocean closure suggests a tectonic model that has important differences from the closure history along strike in Newfoundland. The Upper Ordovician Wenlock sedimentary tracts of the Southern Uplands-Down-Longford Terrane (SUDL) accretionary prism in eastern Ireland derived their sediment from Ordovician arcs and Dalradian rocks on the local Laurentian margin. Outboard, the Grangegeeth terrane is a Laurentian continental fragment with an Ordovician volcanic arc formed above a second subduction zone. During late Ordovician time, it formed the southern margin of the Rathkenny basin of Moffat Shale facies mudstone interbedded with volcaniclastic horizons. Together these were overstepped in the Wenlock by Laurentian-derived greywackes and became the southernmost tract of the SUDL accretionary prism, as subduction brought them into the Laurentian-margin trench. On the southern side of Iapetus, Floian arc volcanism in the Bellewstown terrane ended after deposition of a succession that includes a Celtic fauna. Renewed late Middle to Upper Ordovician arc volcanism on the Ganderian margin includes ca. 464 Ma extensional rhyolites. Structural relationships of two granitoids at Graiguenamanagh constrain a deformation event within Ganderia to ca. 460 Ma. The rapid switch from extension to compression records failed rifting of Ganderia followed by renewed compression during continuing subduction under a north-facing arc. In the Newfoundland sector of Iapetus, a Ganderian volcanic arc migrated across the ocean in mid-Ordovician times to accrete to Laurentia, leaving a Ganderian passive margin. In Ireland, the late-accreted arc on the Laurentian margin formed on a Laurentian microcontinent. Supra-subduction extension of Ganderia did not form an ocean basin and Ganderia had an active margin throughout late Ordovician times. The Laurentian-Gondwanan boundary lies between the Grangegeeth and Bellewstown terranes. Iapetus was narrow by Katian times, but subduction-related magmatism continued into the Wenlock on both margins.

Surficial vectors of exploration for high-grade deposits in the Pine Point Mining District, Pine Point, NT, Canada

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The Pine Point Mining District is a Mississippi Valley Type (MVT) Lead-Zinc mining district along the southern shore of the Great Slave Lake. From 1965 until 1986 Cominco Ltd. produced over 64 million tonnes grading 3.1 % Pb and 7.0 % Zn. Mineral exploration in the camp was largely inefficient using geographic grids of drilling and Induced Polarization geophysical surveys. Despite the lack of geological information at depth, the nature of the deposit and geological setting are expressed in surficial features and legacy infrastructure. The pervasive dissolution of the carbonate dominated reef facies developed significant void space and karst networks. These voids transported large volumes of hot dolomitizing brines and later metal-rich brines. The progressive growth of voids and weakening of the carbonate sequence, created complex collapse features and associated low temperature carbonate deformation. The vertical orientation of the collapse features promotes subsidence of overlying stratigraphy and preferential modern karst development. These structures have also been known to host higher than average grade and tonnage. Although the controlling structures of collapse karst have yet to be identified; sinkholes, stratigraphic sagging, and other structural features resulting from the karst are identifiable. The association of these structures with potentially high-grade deposits at depth allows surficial and shallow exploration to be used as a vector for targeting deeper deposits. With high resolution LIDAR and UAV

photogrammetry subsurface bedrock features can be defined beneath till cover. Furthermore, existing open pits can be mapped with UAV photogrammetry to measure various bedrock structures and help further define exploration targets. By using low cost surficial data, exploration regions can be refined and limit the extent of more expensive surveys. The Pine Point mining district and other MVT districts in the world may benefit greatly from these exploration technologies.

The in situ treatment of synthetic musk in groundwater using colloidal activated carbon

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Synthetic musk fragrances (SMFs) have been shown to be micropollutants in various aquatic and groundwater systems, often occurring at microgram per liter concentrations. Studies have shown that SMFs typically occur as either nitro musks or polycyclic musks. The SMFs are typically released to the environment in low continuous streams such as wastewater or land application of wastewater or sludge associated with the treatment of waste water. A pilot-scale test was conducted to determine if the use of colloidal activated carbon (CAC) could be effective in reducing dissolved concentrations of nitro and polycyclic synthetic musk compounds including musk xylene, musk ketone, galaxolide and tonalide in groundwater. The test was carried out down gradient of a septic system in Central Canada where a series of nitrification and denitrification reactions are occurring in an unconfined aquifer. The plume contained galaxolide and tonalide concentrations up to 687 and 187 nanograms per liter (ng/L), respectively, while the concentrations of musk ketone and musk xylene were below the method detection limit (20 ng/L). The results of the pilot test indicated that the colloidal activated carbon was effectively delivered to the target injection zone resulting in an increase in total organic carbon concentrations greater than 2 orders of magnitude compared to the background concentrations. Analyses of the groundwater indicated that the concentrations of galaxolide and tonalide were lowered to below their respective method detection limits within six months of application. Subsequent monitoring of the groundwater over a one-year period failed to detect either compound within the groundwater suggesting that the colloidal activated carbon was effective in attenuating the galaxolide and tonalide within the plume as well as any galaxolide and tonalide being released to the groundwater by the septic system.

Geoheritage: World Heritage Sites and UNESCO Global Geoparks

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In November 2015, the 38th session of the General Conference of UNESCO, by acclamation, adopted the new designation of UNESCO Global Geoparks. This marked the first time since the ratification of the Convention concerning the protection of the World Natural and Cultural Heritage in 1972 (which allowed for the creation of World Heritage Sites) that UNESCO has created a new site designation of this kind and the first time it has adopted a series of pre-existing sites (the Global Geoparks that pre-existed as part of the Global Geoparks Network). Geoheritage sites of international value can now be given global recognition under either, or both, of these two designations. While World Heritage sites focus on the fulfilment of one of 10 criteria that demonstrates outstanding universal value, UNESCO Global Geoparks have the concept of community empowerment and sustainable development at their core through appreciation of geological heritage of international value and its link to other aspects of natural, cultural and intangible heritage. Using examples, this presentation will present success stories concerning the protection, conservation and promotion of geoheritage from both labels and explain the concept and differences behind them.

Anatomy of the Ni-Cu-(PGE) mineralized Expo-Raglan magmatic system in the Early Proterozoic Cape Smith belt, Québec, Canada

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The central part of the 2.0-1.9 Ga Cape Smith Belt (Ungava Peninsula, Québec) is characterized by excellent exposure and low-grade metamorphism, providing an ideal setting to study the architecture and evolution of a mineralized magmatic plumbing system. The volcano-sedimentary stratigraphy in this area comprises (from bottom to top): siliciclastic and carbonate rocks (lower Povungnituk group); massive-pillowed tholeiitic basalts (middle Povungnituk Group); siltstones-shales (upper Povungnituk Group); thick ultramafic lava channels and locally invasive, channelized ultramafic to mafic sheet flows (Raglan formation); and massive-pillowed komatiitic to tholeiitic basalts (Chukotat Group). Olivine pyroxenite ± pyroxenite blade-shaped dikes in the middle-upper Povungnituk Group host Cu-Ni-(PGE) mineralization along their sides and keels (e.g. Expo-Méquillon deposits). Olivine pyroxenite ± gabbro sills in the upper Povungnituk Group host PGE-(Cu)-(Ni) mineralization (e.g. Delta showing). Peridotite lava channels and the olivine pyroxenite channelized parts of sheet flows at the base of the Chukotat Group host Ni-Cu-(PGE) mineralization at or near their lower contacts (e.g. Raglan deposits). U-Pb zircon geochronology has constrained the Expo-Méquillon and Raglan parts of the system to about 1882 Ma. However, field and geochemical data indicate that the Expo parts of the system were derived from less magnesian magmas than the Raglan parts; the most magnesian olivine pyroxenites and melagabbroic margins of the Expo units (up to 35 wt % and 16 wt % MgO, respectively) are less magnesian than the peridotites and pyroxenitic margins of Raglan units (up to 43 wt % and 20 wt % MgO, respectively). Raglan ores also have higher Ni/Cu (average ~ 5) than Expo ore (average ~ 1). These observations suggest that bladed dikes in the Expo parts of the system are not feeders to lava channels and channelized sheet flows in the Raglan parts of the system.

Innovative approaches for characterizing groundwater contaminant plumes impacting aquatic ecosystems in peri-urban streams

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The large number of micropollutants (e.g. pharmaceuticals, chlorinated solvents) and their transformation products makes it challenging to quantify their occurrence and ecological risk. Conventionally, chemical impacts to ecosystems and source types are assessed individually, and groundwater contamination is often neglected. This may lead to critical underestimations of the combined impact caused by interactions occurring between stressors not typically evaluated together, e.g. organic groundwater pollutants and metals, and prevent the linkage of chemical and ecological impacts in peri-urban catchments. Contaminated sites represent a major environmental problem for Denmark, potentially polluting soil, groundwater and surface water. Determination of flow paths and groundwater fluxes are essential for evaluating the transport and fate of contaminant plumes discharging to streams. Here, the application of novel approaches is presented for evaluating the governing parameters, including an appreciation of the scale of variability, in order to resolve ecological status under conditions of multiple stresses and to develop the scientific basis for assessing the risk potential of contaminated sites to impact streams. The overall aims of the field

investigations were to (i) test the applicability of different methods for mapping groundwater contamination impacting streams, (ii) perform a risk assessment using the contaminant mass discharge approach, and (iii) assess the stream's chemical and ecological status. We identified sources and levels of chemical stressors along a 16 km groundwater-fed stream corridor (Grindsted, Denmark). Potential pollution sources included two contaminated sites, aquaculture, wastewater/industrial discharges, and diffuse sources from agriculture/urban areas. The results indicate a substantial impact on Grindsted stream from multiple sources of many origins. Impaired ecological conditions, represented by a lower abundance of meiobenthic individuals, could be linked to zones where the groundwater plume discharges to the stream. This study highlights the importance of stream-aquifer interfaces for ecosystem functioning, and that multiple stressor systems need to be tackled from a multidisciplinary perspective.

Comparing magnetic susceptibilities derived from aeromagnetic data and outcrop scale measurements in the western Abitibi greenstone belt

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Magnetic susceptibility is a physical rock property commonly collected by field mappers in industry and government geological surveys. This data is important for understanding the magnetic properties of lithologies and mineralization, and can be applied to forward modelling of aeromagnetic data to remove a degree of freedom from the process. When using these outcrop-scale measurements to model aeromagnetic data a simple relationship between outcrop measurements and the rock properties that generate the measured aeromagnetic data is assumed, but it remains unclear whether a useful relationship exists. One way to test this is to produce an apparent magnetic susceptibility from the magnetic data to compare with the measured magnetic susceptibilities. Apparent magnetic susceptibility can be produced from total magnetic intensity by 1) applying a reduction to the magnetic pole, 2) a downward continuation to the terrain surface, and 3) a conversion to apparent magnetic susceptibility. A downward continuation is performed in order to remove regional and deep source effects. The apparent susceptibility values are then plotted against the mean of the values measured from outcrops located in the same grid cell. A bimodal distribution in susceptibility can be identified, with those in the mode below 10^{-3} SI showing no correlation. Values in the mode above 10^{-3} SI show a weak correlation with estimates frequently differing by an order of magnitude. This means that using the field-measured values to model aeromagnetic data could yield incorrect geological models. There are several possible explanations for these discrepancies: different measurement scales, near-surface weather affecting handheld readings, the effects of deeper-than-surface rocks on the aeromagnetic data, simplifications during calculation of apparent magnetic susceptibility, ignoring remanent magnetization effects, and the various filters' abilities to remove noise. When modelling the aeromagnetic data the outcrop-scale magnetic susceptibility values can be a useful guide, but caution should be exercised.

The mineralogy, paragenesis, and petrogenesis of the Co-Ni-As-Au occurrence in the Annapolis Valley, Nova Scotia

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The mineralogy of understudied polymetallic (Co-Ni-As-Au) veins in the Nictaux Falls Spillway are investigated in order to describe their petrogenesis. Mineralization is constrained to fault-hosted quartz veins in the Silurian-aged greenschist facies metasediments of the Kentville Formation, proximal to its contact with the Devonian-aged South Mountain Batholith (SMB). There are two styles of mineralization: i) laminated sulfarsenide-quartz veins, and ii) quartz breccia veins containing sulfarsenide-mineralized wallrock clasts. Sulfarsenides are spatially associated with wallrock material (chlorite, biotite, rutile, REE-phases) and exhibit unidirectional zoning regardless of mineralization style: early euhedral arsenopyrite cores (50 to 100 µm) are overgrown by a succession of arsenopyrite to cobaltite to gersdorffite. Textural evidence suggests arsenopyrite cores are inherited from the wallrock. Unidirectional zoning indicates settling of dense sulfarsenides in the fluid during mineralization. The compositional zoning may reflect removal of Fe and Co from the mineralizing fluid through progressive sulfarsenide mineralization, or decreasing pH. Late native Au (20 wt % Ag) occurs interstitial to gersdorffite rims of the sulfarsenide accumulations. Sulfur isotope analysis of the sulfarsenides and wallrock sulfides will be conducted in order to constrain the source of S. Bulk rock geochemistry of the metasediments and nearby outcropping gabbro and diabase show high Co and Ni (20-24 and 31-34 ppm Co and 55-71 and 21-107 ppm Ni, respectively), indicating these rocks as a potential source of metals. In the metasediments, the Co and Ni is hosted in chlorite and sulfides; however, in the mafic rocks the metals are associated with secondary actinolite and sulfides. Fluid derived from the dehydration of metasediments after emplacement of the intrusives are suspected to have enriched the mafic rocks in metals, suggesting the metasediments as the ultimate source of metals. Zircon geochronology of the mafic rocks will be used to understand their timing with respect to the SMB and mineralization.

Hydrodynamic characterization of complex aquifers based on flow dimension analysis

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The flow dimension n is a valuable tool, integrated in the hydrodynamic characterization of aquifers, allowing the determination of flow regimes that occur in the influenced zone of a pumping well. This parameter has been established with the Generalized Radial Flow (GRF) model proposed by Barker (1988), which generalizes the conventional and restricted model of Theis (1995). In the case of real and complex aquifers, the use of the logarithmic derivative of the drawdown as a function of the logarithm of time makes it possible to observe the flow dimension sequences to establish more accurate and realistic hydraulic models. This approach was systematically applied to a series of pumping test data compiled from consulting reports in different regions of Quebec, Canada. These pumping test data have been interpreted with the SIREN interface, which provides the advantage of performing dual simultaneous fit on both drawdown semi-log and drawdown log-derivative bilog plots. Thus, a correlative statistical study between geological contexts (both granular and hard-rock types) and the measured flow dimensions responses concluded to a predominance of the dimension n = 2 in most geological formations except in carbonates, where the fractional dimension n = 1.2 prevails. Furthermore, fractional flow dimensions n = 1.5 and n = 2.5 are of remarkable occurrence in contexts of fractured volcanic formations and of hydraulic connections between different aquifers, respectively. Finally, normalization of drawdown data to flow dimension values make it possible to integrate the information from piezometers in order to investigate the spatial homogeneity of the hydrodynamic response.

Anomalously young detrital zircon ages, related to the Sudbury meteorite impact, within the lower Huronian Supergroup, Ontario, Canada

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Detrital zircon U-Pb geochronology is a crucial tool in understanding the evolution of sedimentary basins and sediment provenance. The Huronian Supergroup is a Paleoproterozoic continental rift basin sourcing sediment from the Archean Superior Province in Ontario. The Ramsay Lake Formation of the Huronian Supergroup, sampled ~ 10 km west of Sudbury Igneous Complex, was previously proposed to contain an anomalously young population of detrital zircons. Individual grains from this population were redated by analyzing 1-11 additional spots. These zircons did not contain any visible inclusions at the macroscopic or microscopic level nor showed evidence for differential growth events in cathodoluminescence images. Previously reported young ages could not be reproduced and age ranges from single zircon grains scattered well outside analytical uncertainties. This anomalously young population was compared with ages from the main population of the same sample. When compared, grains from the main population have lower MSWD values and their ages remain reproducible within analytical uncertainty. The zircon age distribution from the Ramsay Lake Formation sample was then compared to distribution from a sample of the Mississagi Formation collected ~ 90 km west of the Sudbury Igneous Complex. The error range and MSWD values for the reanalyzed individual grains of the Mississagi Formation were much lower and resembled values obtained from an isotopically homogeneous secondary standard. Therefore, the ages of the anomalously young population do not represent crystallization ages and this effect is isolated to samples near the Sudbury Igneous Complex. These results imply that deformation related to the Sudbury impact has preferentially affected the grains of the young population, which may have suffered more Pb mobility, leading to apparently young ages. Overall, the effect of the Sudbury impact may have disrupted U/Pb systems much farther than previously estimated.

Gold: recent advances, and 20 years of research through GSC's Targeted Geoscience Initiative Program under Dr. Benoît Dubé's leadership – An introduction

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The last few decades have been very fertile in terms of advances made in the understanding of gold systems. This was largely fuelled by a new wave of government and/or industry-led, large-scale, collaborative and multidisciplinary research initiatives such as the Targeted Geoscience Initiative (TGI) Program that was launched in 2000. TGI is a Government of Canada (Geological Survey of Canada) led, multi-disciplinary and collaborative (governments, industry, and academia) geoscience research program dominantly directed towards improving the effectiveness of exploration by resolving foundational geoscience problems to constrain the critical ore-forming processes that lead to a deposit formation and preservation. The program is currently in its fifth iteration and has evolved through time from site specific (e.g. TGI-1 and 3) to thematic research (e.g. TGI-4 and 5). The flagship TGI-3 Abitibi, TGI-4 Lode Gold, and current TGI-5 Gold projects were all directly influenced by the scientific leadership of Dr. Benoît Dubé, whom has been instrumental in getting tens of geoscientists from federal, provincial, and territorial agencies, academia, and industry working on key knowledge gaps about the geology of gold and base metal deposits. Through his work in TGI and other research initiatives in Canada and abroad, Dr. Dubé has been responsible for the development of improved geologic and exploration models for greenstone-hosted quartz-carbonate vein systems, gold-rich volcanogenic massive sulphide deposits, and epithermal deposits, as recognized through numerous prestigious awards. Despite his managerial responsibilities, Dr. Dubé contributed tens of peer-reviewed papers and government reports, including the 2015 TGI-4 Lode Gold Project synthesis that has been recognized by the Society of Economic Geologists as "one of the most significant volume on the geology of gold published during the past decade". Dr. Dubé has mentored and trained numerous students who became, or will become, the next generation of mineral explorationists and researchers, leaving a long-lasting impact in the Canadian geoscientific community.

Measuring 2-D distributions of intra-particle diffusion coefficients in sulfide-rich mine waste rock

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Sulfide mineral oxidation in mine waste materials is one of the principal contributors to poor quality drainage. The oxidation process is generally limited by the diffusion of O_2 into the pore space of waste piles and rock fragments. In this project, we measure the diffusive properties of sulfide-mineral-bearing rock fragments, a subject that has not been investigated quantitatively. Knowledge of sulfidic waste rock diffusion properties is important to mine-waste management efforts because it will aid in the development of numerical models that aim to predict the rate at which poor quality mine drainage is generated. We are developing a non-destructive method that couples' laboratory measurements and modelling techniques to estimate the effective diffusion coefficients for O_2 in common waste rock lithologies. X-ray imaging is used to acquire time-series images of iodide tracer diffusion through the oxidized rim and into the unaltered core of the rock fragments. The distribution of diffusion coefficients is determined by fitting two-dimensional numerical simulations to the spatial distribution of iodide tracer in the oxidized and unaltered domains. The diffusion coefficients for solutes such as O_2 and SO_4 are calculated using the known relationship between free-water diffusion coefficients for iodide and the solutes of interest. Coupled with inter-particle diffusion coefficient estimates, these data will serve as input in shrinking-core reactive-transport models to predict oxidation rates and duration of hazardous leachate drainage from mine waste materials.

The Good Hope Carbonatite, Ontario: a potential Nb deposit with pyrochlore-apatite cumulates

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The Good Hope carbonatite is located adjacent to the Prairie Lake ijolite-malignite-calcite carbonatite complex in northwestern Ontario. The carbonatite is a breccia consisting of diverse calcite and dolomite carbonatites, with lesser REE-rich ferrocarbonatites, containing xenoliths of amphibole syenite, potassium feldspar+phlogopite and pyrochlore-apatite cumulates. The occurrence outcrops over an area of 500 m x 500 m and has been proven by diamond drilling to extend to a minimum depth of 650 m. Pyrochlore-apatite cumulates occur as elongated and/or irregular clasts up to 5 cm in maximum dimension. In these, pyrochlore has crystallized before apatite and occurs as euhedral crystals (0.1-1 cm; up to 5 cm) and can comprise up to ca. 25 vol % of a clast. Prismatic apatite is commonly flow-aligned and in some instances forms isoclinal folds. The apatite does not exhibit optical- or BSE-compositional zonation. However, cathodoluminescence imagery shows blue-green cores with thin (< 500 µm) blue margins. The cores are enriched in light REE (833-941 ppm La; 1790-2200 ppm Ce; 8.2-13.6 Yb ppm; $(La/Yb)_{CN}$ 62-42. The pyrochlores are Na-Ca-F-pyrochlore of relatively-uniform composition with fully-occupied A-sites, and minor SrO (l-1.5 wt %)

and low Ta_2O_5 (< 0.5 wt %). Some pyrochlores have irregular cores of resorbed Sr-bearing (6-11 wt % SrO) pyrochlore with overgrowths of Na-Ca-F-pyrochlore. Others contain inclusions of fersmite and/or columbite-(Fe). Pyrochlore also occurs as discrete crystals in calcite and dolomite hosts and represents disaggregated clasts. In accord with experimental data on the liquidus phase relationships of apatite and pyrochlore in haplocarbonatite melts the formation of apatite-pyrochlore cumulates in the initial stages of crystallization of such melts is to be expected. These cumulates were subsequently disrupted, disaggregated, and transported by pulses of later batches of carbonatite of diverse composition.

Assessment of groundwater quality using trend analysis

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Monitoring is one of the oldest and still standing methods to evaluate and predict the changes in groundwater quality. The purpose of this study is to evaluate the groundwater quality parameters trends in four selected aquifers. For this purpose, information of 15 groundwater quality parameters of four aquifers for the period of 2003 to 2014 were used. For each monitoring well, two time series were selected, one for wet period and one for dry period. SPSS software was used to analyze the data using nonparametric Mann-Kendall test. The Mann-Kendal test is commonly used to detect monotonic trends in series of environmental and hydrological data. As for the case study, four aquifers with primary use in agriculture were selected for this trend analysis. The aquifers are located in north, central and west of Iran with different climate conditions. The results showed that in both periods, the trends of most of quality parameters were downward, however, the wet period had faster downward slope. Moreover, the upward trend, although low, was observed in wet series. In both periods, the pH and Na % was increasing and SAR and SO_4 only in dry period showed upward trend. This downward trend shows that the quality of groundwater is improving with time and it can be attributed to using more surface water and less groundwater in agricultural sector. In addition, more agricultural lands are changed to residential areas and it reduces the infiltration of fertilizers and other elements to the groundwater.

Isotopic terrane mapping and intra-cratonic architecture of the Superior Craton

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Lithospheric and crustal architecture, the framework of major tectonic blocks, terranes and their boundaries, represent a fundamental first-order control on major geological systems, including ore deposits and the location of world-class mineral camps. Existing work has demonstrated the ability of radiogenic isotope systems (i.e. Sm-Nd, Lu-Hf) to constrain time-resolved intra-cratonic lithospheric architecture: regional Sm-Nd isotopic data was used to map the crustal architecture of the Yilgarn Craton, and, later, the association between that lithospheric architecture and BIF-hosted iron, orogenic gold, and komatiite-hosted Ni-Cu-PGE systems. Those results demonstrated the underlying control of lithospheric architecture and the potential for isotopic mapping as a greenfields area selection tool. Further work, using Lu-Hf isotopes, demonstrated that the technique could account for rocks, events and mineral systems of different ages, showing how Ni-Cu-PGE mineralized komatiite systems of the Yilgarn Craton migrated with the changing lithospheric boundary (craton margin) from 2.9 to 2.7 Ga. Beyond mineral systems science, the data collected in these studies allow a time-space assessment of craton construction and evolution, which provide vital information on the tectonic environment/s active on the Archean Earth. In the Superior Craton, the isotopic mapping technique has been applied to the Wabigoon region, but information from other regions is currently sparse, or has not be collated to produce a spatial product. A primary goal of the new Metal Earth project at Laurentian University is to apply this technique to the entire Superior Craton, producing a craton-wide Lu-Hf isotopic map that will be used to: (1) Understand the development and evolution of the craton; (2) evaluate the spatial variability of magmatism and mineral endowment; and (3) be available as an area selection tool for large-scale exploration activities.

Numerical predictions of permafrost thaw under climate change near Umiujaq (Nunavik) Quebec: only twenty years to go?

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Numerical simulations have been completed at an instrumented field site near the village of Umiujaq, Nunavik, Quebec, to investigate the behavior of coupled groundwater flow and permafrost thaw in the context of a warming climate. The numerical model, HEATFLOW/3D, includes groundwater flow and heat transport, with temperature-dependent properties including water density and viscosity, relative permeability, thermal conductivity and unfrozen water content. Analytical solutions and numerical benchmarks from the Interfrost consortium (wiki.lsce.ipsl.fr/interfrost) were used for model validation. The field site near Umiujaq is located in a small two square kilometre catchment containing degrading permafrost. A two-dimensional vertical-plane cryo-hydrogeological numerical model was developed for the site based on a 3D geological model which includes up to 30 m of Quaternary sediments composed of sands, gravels and marine silts, as well as fractured bedrock. Field-based groundwater recharge and observed air temperatures were applied as components of the ground surface boundary condition, while model calibration was based on detailed observed temperature profiles and ground heat fluxes. The simulations suggest that both supra- and sub-permafrost groundwater flow is contributing to permafrost thaw, driven by increasing mean annual air temperatures. Nevertheless, cooled sub-permafrost groundwater flow maintains cold temperatures in the downgradient discharge zone. A parameter sensitivity analysis showed that variations in the hydraulic and thermal conductivity of the uppermost soil layers and the shape of the unfrozen water saturation function had the most significant effects on permafrost degradation. Model calibration and predictive simulations based on IPCC climate warming projections suggest the active zone thickness is increasing by 12 cm/a while the base of the permafrost is thawing at a rate of about 80 cm/a, with complete permafrost thaw expected by around the year 2040.

Optimization of integrated geophysical and geological structural variability analysis for Archean greenstone belts: a case study in the western Wabigoon subprovince, Ontario

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In the early stages of mineral exploration, ground selection tools are applied to narrow search regions to prospective areas. Selecting an appropriate method that is both effective and efficient in identifying geologic features that are significant in a given deposit model is key to the success of an exploration program. For gold exploration, understanding regional structures is critical as they play a fundamental role in controlling the location, size, and quality of deposits since they act as both conduits and traps for mineralizing fluids. Therefore, structural variability or complexity could be used

for prospectivity mapping of favourable fluid pathways. In two Archean greenstone belts of the Superior Province, near Dryden and Kirkland Lake, Ontario respectively, aeromagnetic data, legacy GIS compilations, and field observations were integrated to build structural prospectivity maps for orogenic gold, intrusion-related and volcanogenic massive sulfide mineral systems. Spatial variability of lithologies, strike and dip of bedding, and the trend of automatically detected linear magnetic anomalies were calculated, gridded, and visually assessed. Grids were constructed using a range of cell sizes (50-500 m) and neighbourhoods of 100-3000 m to investigate optimal resolution and sensitivity to detect prospective targets and characterize geological domains. The resulting maps highlight areas of structural complexity which can be used for map interpretation and defining structural domains that may indicate favourable targets for base and/or precious metal exploration. Preliminary application of this method suggests that it may be an effective tool for green and brownfields exploration in structurally complex terrains of any age, worldwide. The integration of lithologic and structural variability with geophysical and structural measurements investigated in this study provide the geoscientific community with an effective tool to confidently narrow search areas in geographically extensive regions, better characterize geological domains, and effectively focus further exploration efforts.

Integrating geophysical, geological, and hydrogeological studies for regional groundwater mapping in Northeast British Columbia: the Peace Project

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Knowledge of groundwater resources and the distribution of aquifers in the Peace Region of Northeast British Columbia is critical for water management, especially given ongoing natural gas development in the area. The Peace Project was initiated in 2015 by Geoscience BC, along with a number of different partners across government, industry, and academia, to improve the understanding of groundwater resources in the northern Peace Region. The main purpose of the project was providing a regional overview of the Quaternary sediments and shallow bedrock geology, and locating potential aquifers, particularly within paleovalleys in the study area. Several approaches, ranging from local to regional scale investigations of the geology and/or hydrogeology, were applied, including an airborne electromagnetic (AEM) survey, drilling programs, and geological and numerical flow modelling. The results and interpretations of these studies were used to provide new insights into the Quaternary geology and an improved understanding of the distribution of aquifers within the Peace Project study area. The Quaternary sediments of the Peace Region are interpreted to be lithologically heterogeneous and of variable thickness. The results of this study suggest that porous and permeable sand and gravel deposits exist within the paleovalleys, but they are discontinuous and may not play a significant role in regional groundwater flow. Extensive sand and gravel deposits within the paleovalleys appear to exist at a local scale and may offer a viable groundwater source for low demand users. From a regional perspective, however, bedrock aquifers may provide more consistent aquifer systems. Additional investigations and extension studies are recommended to further improve geological and hydrogeological knowledge in the Peace Region. Results and data collected from the Peace Project are freely available as part of Geoscience BC's directive, and provide critical baseline information for future groundwater research.

The sedimentary record of the early phase of deglaciation in a dammed valley system of the Appalachian Highlands, Eastern Quebec: Glacial Lake Madawaska

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The thick and extensive rhythmites deposits of the former Glacial Lake Madawaska (GLM) provide sedimentary archives for understanding its evolution in relationship with topography and configuration of the retreated margin of Appalachian Ice (AI). Previous studies reported that this glacial lake occupied the Temiscouta-Madawaska Valley for at least 1200 years during late glacial times. However, the total duration and configuration of each phase of GLM remain unknown. Archives of glaciolacustrine sediments are used to reconstruct the evolution of GLM from the analysis of: 1) sedimentary facies of exposed rhythmite deposits, both from conventional cross-section stratigraphic descriptions and CT-Scan data from u-channels sampled in outcrops; 2) radiocarbon dates on organic matter collected in cross-sections; and 3) acoustic subbottom profiles collected in modern lakes located within the maximal extension of GLM. These results indicate that GLM persisted in the valley for ~ 5 000 years, as evidenced by radiocarbon dating spanning from 12 729 (ULA-6310) to 7 535 (ULA-6308) cal. BP. During its early phase, glaciolacustrine sedimentation was highly influenced by iceberg calving, as indicated by iceberg dump structures and ice-rafted debris. Silto-sandy rhythmites ranging from 8 mm to 5 cm were deposited during this initial phase. From the early phase of GLM to its maximum extent, the dynamics of the AI margin and the Appalachian Highlands topography both conditioned the processes of lacustrine sediment infilling. At the maximum extent of GLM, AI retreated to highlands, therefore gradually reducing the glacial influence on varve deposition. The silto-clay varve deposits have a constant thickness, as observed on the acoustic subbottom profiles by a unit of closely-space of high amplitude reflections. Sedimentary facies of GLM indicate that the early lacustrine phase was marked by iceberg calving and high sedimentation rates. The ice-contact and the calving processes contributed to the rapid deglaciation of the valley.

Bay of Island Ophiolite Complex, Newfoundland: an analogue for ultramafic bodies and serpentinization on other worlds

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The Bay of Island Ophiolite Complex (BIOC), on the west coast of Newfoundland, is a Canadian site of present-day continental serpentinization where habitability and detection of life on ultramafic bodies with serpentinized fluids are studied. Serpentinization may be occurring (or has occurred) in the subsurface of Mars, beneath the ice of Enceladus, and anywhere else where liquid water is in contact with ultramafic rock. Serpentinization produces hydrogen, and the reducing conditions necessary for abiogenic hydrocarbon synthesis, while also producing conditions amenable for chemolithotrophic life. BIOC is an analogue site that is ideal for testing methods of life detection in an extreme environment characteristic of serpentinization. Multiple ultra-basic reducing springs, representative of present-day serpentinization, have been identified and characterized for their geochemistry and microbiology. A near sub-surface microbial observatory has been established to study life in serpentinized groundwaters, the chemical species that are produced or consumed by this life, and the biosignatures (both molecular and isotopic) this life leaves behind.

Most interestingly, we have discovered that carbon monoxide can be used as a microbial carbon source, while methane is neither produced nor consumed microbially.

Use of diabase dikes for tectonic reconstruction: constraints on the deformation history of the Sudbury Igneous Complex

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Diabase dike swarms intruded at a specific instant in time have a preferred trend and generally retain a record of the Earth's magnetic field direction effective at the time of emplacement. They represent time and geometry marker horizons in the geologic record. Geometric, paleomagnetic, and petrologic studies along with magnetic anomaly models on dikes can provide insight into the impact of tectonic activity that has occurred since emplacement of the dikes. Maps of the North Range of the Sudbury Intrusive Complex (SIC) contain geometric evidence for two phases of late Archean dike emplacement. Comparison of this geometrical data with paleomagnetic data from the SIC reveals the North Range has been subject to regional scale tilting and block faulting. Re-assessed petrologic studies of Matachewan dike samples can be interpreted in terms of differential uplift between blocks. Magnetic profile models across the Foy Offset record fault block rotations. Comparison of remanence directions from South Range Offsets preclude any systematic folding in the immediate proximity of the Igneous Complex. Intrusion of the Sudbury Olivine diabase dikes preceded the final Grenvillian Orogenic event. Paleomagnetic studies limit thermal effects of the Grenville to a narrow zone near the Grenville Front. Dike orientation changes are also limited to a narrow zone near the Grenville Front. Positive contact tests indicate kilometer scale uplift of the South Range relative to the North Range. A sudden change in dike width suggests the Murray Fault might be the locus of much of this offset. Changes in dike offset along a fault provide evidence for scissor-like faulting of the interior portion of the Sudbury Basin.

Characterizing Devonian brines of the Williston Basin with multiple isotope systems

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Freshwater influx into the Western Canada Sedimentary Basin synchronous to regional flow reversal has produced complex geochemical signatures along the northeast flank of the basin. Infiltration to aquifers has generated distinct endmember sources and evidence of fluid mixing. The Elk Point Basin is a series of Devonian aged rocks situated in the Western Canada Sedimentary Basin which construct the open aquifer system between Montana, U.S.A, and Manitoba, Canada. The entirety of the Elk Point Basin ranges between the Canadian Yukon and Northwest Territories, through Alberta and southern Saskatchewan, into southwest Manitoba, and south into the states of North Dakota, Montana, and South Dakota. It is further divided into the Alberta Subbasin and Saskatchewan Subbasin, where the latter is concurrently known as the Williston Basin. In this study, we used solute and isotopic ($\delta^{18}O$, $\delta^{2}H$, $^{87}Sr/^{86}Sr$, $\delta^{37}Cl$, $\delta^{81}Br$) signatures of Devonian formation fluids to examine the potential sources and evolutionary history of fluids within the Williston Basin. We focus on the Devonian Prairie Evaporite formation and overlying strata including the Dawson Bay, Souris River, Duperow, and Birdbear formations. Two endmembers are interpreted from the geochemical signatures: (1) evaporative seawater and (2) a freshwater, meteoric component. The former endmember is derived from remnant evaporated seawater brine, while the latter is a result of Pleistocene glacial meltwater intruding into Devonian aquifers along the north-east margin of the basin. We report solute and isotope relationships to characterize these endmembers. Additionally, a 1D numerical transport model of vertical depth profiles for conservative tracers ($\delta^{18}O$, Cl/Br) is presented to propose and constrain an age of the first arrival of glacial meltwater to our study area and improve our understanding of large-scale fluid transport in the basin.

Groundwater contributions to trace elements in urban streams

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Urbanization can cause severe degradation of surface water and groundwater quality. The associated impacts, collectively defined as urban stream syndrome, include elevated concentrations of nutrients and contaminants, reduced biotic richness, and vulnerability of the ecological environment. Previous research on groundwater discharging to urban streams in Nova Scotia (n = 3), Ontario (n = 5), and Alberta (n = 1) found evidence of groundwater affected by point-source contamination from solvent plumes, petroleum compounds, and wastewater effluent, plus a large contribution of urban runoff (including road salt). Contaminant screening of groundwater collected from the shallow sediments of these urban streams identified several trace elements including Cd, Zn, Al, Cu, Cr, U, and As, at concentrations above regulatory guidelines in some locations. In this study, we combine thermodynamic modelling and statistical analyses to examine geochemical controls on these trace element concentrations. Modelling results indicate that sorption-desorption, precipitation-dissolution, and reduction-oxidation reactions within the shallow groundwater are likely important controls on trace element concentrations. Statistical analyses revealed that the data clusters by surficial geology (i.e. location) and that distinct groups of trace elements were apparent: (i) Al, As, Cr, Pb, Zn; (ii) Cu, Ni; and (iii) Mn, Mo, U. Based on our results, we speculate that urbanization may have both direct and indirect impacts on groundwater chemistry by driving changes in geochemical conditions that enhance trace element mobility.

Metallogeny of the Woman River iron formation: implications for timing of hanging wall and foot wall volcanic successions, Swayze Area of the Abitibi greenstone belt, Ontario

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The Swayze Area (SA) represents the southwestern extent of the Abitibi greenstone belt and comprises the same volcanic episodes. The lithostratigraphic units through the central section of the SA consist of the Woman River iron formation (WRif) and associated fine-grained clastic metasedimentary rocks that conformably overlie older (ca. 2735 +6/-4 Ma) felsic to intermediate metavolcanic rocks of the Deloro episode age (within error). Intermediate to mafic metavolcanic flows conformably overly the WRif and clastic sedimentary rocks, the absolute age of which is currently under investigation. The WRif attains a maximum thickness of 50 m and is overlain by clastic metasedimentary rocks intercalated with mafic volcanic flows. The WRif is crosscut by mafic dykes, which dilate clastic metasedimentary rocks as sills. Similar iron formation at the same stratigraphic position in the eastern Abitibi separates volcanic rocks of the Deloro episode from those of the lower Kidd-Munro episode, defining an approximate 5 Ma hiatus in volcanism. Mineralization in the WRif occurs as 1 - 5 m thick semi-massive to massive pyrite-pyrrhotite lenses that have a strike extent of several hundred meters, that locally transition to sphalerite- and galena-rich lenses and into discrete zones of stockwork chalcopyrite-galena- sphalerite mineralization that crosscuts the WRif and footwall metavolcanic rocks. Alteration associated with the stockwork mineralization, manifest by a chlorite-garnet mineral

association, transects the footwall felsic metavolcanicx rocks and extends into the overlying intermediate to mafic metavolcanic succession. The footwall rhyolitic succession has a pervasive, weak sericite alteration. Historically mineralization along the WRif has been interpreted to be syngenetic with the WRif, however, the presence of alteration within the WRif and overlying units suggests that base metal mineralisation did not form during the volcanic hiatus represented by the WRif, but is synvolcanic with hanging wall volcanism.

Long-term seismic behavior of western Anatolia, Turkey: ^{36}Cl surface exposure dating of fault scarps

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Reconstruction of paleoearthquakes is an essential step in order to widen our understanding of the future seismic behavior of specific faults and of the regional tectonic framework. Fault scarp dating using cosmogenic ^{36}Cl is a powerful technique to explore the rupture history in carbonate bedrock fault scarps. Deformation pattern of intensively active region of Western Anatolia since early Miocene is dominated by normal faults, locally affecting carbonates, which makes it an ideal site to explore past earthquake behaviors. However, the assessment of long-term seismic activity of faults is difficult due to lack of a complete earthquake database within and prior to the existing seismic archives. In order to model a long-term seismic history of western Anatolia, we dated several fault scarps within Büyük Menderes Graben, Gediz Graben, and Gökova Graben by analyzing 453 samples. We used a Matlab® code to simulate number of earthquakes, their age and amount of displacement. In total, 19 major seismic events have been recovered, which typically occurred as clustered earthquakes during the past 16 ka. The correlation of timing of paleoearthquakes at ca. 2.0, 4.0, 6.0 and 8.0 ka lead us to assert that western Anatolia experienced at least four periods of high seismic activity during Holocene. The regional recurrence interval of approximately 2000 years is concordant with the return period of earthquakes of several faults in the extensional tectonic setting of Aegean region. The vertical slip rates of the faults are generally accelerating through Holocene to recent time, which indicate western Anatolia is currently experiencing its most intensive period of seismic activity.

Damian Nance, the supercontinent cycle and much more

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Over the past three decades, it has become clear that Pangea was just the most recent of several supercontinents that have amalgamated and dispersed since at least 2.0 Ga. It was fully recognized at the time that the so-called "supercontinent cycle" had a profound effect on Earth Systems, possibly one of the most significant insights since the advent of plate tectonics. In the early 1980's, Damian Nance, along with colleagues Tom Worsley and Judith Moody, were the instigators of this phase of modern thinking and since that time so many international projects and research careers have been spawned by those insights. Although many elegant papers had proposed orogenic episodicity before the acceptance of the plate tectonic paradigm, Damian and colleagues were the first to link such episodicity to a supercontinent cycle. In addition, Damian has made seminal contributions to the understanding of orogenic processes in general, and through his detailed fieldwork, to our foundational knowledge of the geology of the Avalonian belt in Maritime Canada, Paleozoic and Proterozoic complexes in Mexico, recent (Quaternary) tectonics in Greece and even more recent Beam Engine tectonics in Cornwall and the rest of the world. His body of work has had first-order implications for the interpretation of ancient orogens and the processes responsible for them. Most important of all, we have all benefited from the positive impact Damian has had on all our careers and the generosity and collegial approach to research. His influence has extended far beyond his immediate research community as a result of his co-leadership of IGCP projects and his inclusive approach to sharing and developing new avenues in science. He has inspired generations of students and his peers and his legacy is immense.

The assembly of Pannotia: a thermal legacy for Pangea?

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Controversy about the status of Pannotia (Laurentia + Baltica + Gondwana) as an Ediacaran supercontinent centers on paleomagnetic data (which is permissive not conclusive) and geochronology (which implies breakup commenced before full assembly). But proof of past supercontinent assembly is not limited to these two criteria and can be found in evidence for many other phenomena that accompany the process. Irrespective of whether Pannotia qualifies as a supercontinent, a key unanswered question is whether the legacy of its amalgamation influenced global mantle convection patterns because such patterns are generally ignored in models claiming the transition from Rodinia to Pangea represents a single supercontinent cycle. We contend that the proxy signals of assembly and breakup in the Ediacaran are unmistakable and indicate profound changes in mantle circulation. These changes correlate with a wealth of geologic data for Pan-African collisional orogenesis, reflecting the amalgamation of the Gondwana, and for tetconothermal activity along the Gondwanan portion of Pannotia's periphery. Collisional orogenesis necessitates subduction of oceanic lithosphere between the converging continental blocks. By analogy with the amalgamation of Pangea, the subducted oceanic lithosphere should have congregated to form a "slab graveyard" along the core-mantle boundary that would have generated a superplume beneath the Gondwanan component of Pannotia, the effects of which can be seen along its margins. We suggest that such dramatic changes in mantle convection patterns can indeed be recognized, they provide insights into the processes responsible for the opening of the Iapetus and Rheic oceans, and a potential explanation for some of the enigmatic tectonothermal events that characterize the Late Neoproterozoic-Early Paleozoic tectonic evolution of the margin of Gondwana.

Seismic imaging of crystalline crust in Canada's Superior Archean province: progress with the Metal Earth project

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The Metal Earth project acquired ~ 1000 km of deep seismic reflection profiles from August to November of 2017. These surveys cover Archean Canada from Rainy River near the Manitoba-Ontario border in the Wabigoon geological subprovince to Chibougamau in eastern Quebec in the Abitibi geological subprovince. Vibroseis acquisition with both sources and receivers rated down to 5 Hz frequencies generated records with 2 Hz signal while sweeping up to 150-200 Hz leading to enhanced reflections from the deepest to the shallowest crust. Metal Earth regional-scale transects using over 5000 active sensors target mineralizing fluid pathways throughout the crust, whereas higher spatial-resolution reflection surveys target structures at mine camp scales. Because Metal Earth was proposed to map and compare entire Archean ore and geologically similar non-ore systems, regional sections cover the entire crust to the Moho in the Abitibi and Wabigoon greenstone belts. The processing workflow of Metal Earth's

crustal-scale seismic data was focused on robust static solutions, detailed velocity analysis, minimal trace smoothing, and high-resolution imaging. Where the new sections overlap with previous Lithoprobe surveys, a clear improvement in reflector detection and definition is observed. Improvements are here attributed to the increased bandwidth of the signal, better estimates of seismic wave speeds used in processing, and especially more accurate migrations of the data. The processing of high-resolution reflection surveys are underway utilizing accurate first break picks, dip move-out correction, and 3D processing of crooked lines.

A novel polarization filter based on a correlation matrix analysis

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Polarization filter is a widely used technique for raw seismic data denoising. Applications range from seismology and applied microseismic to vertical seismic profiling and subsurface imaging. The filter is mainly used for ground roll suppression in seismic reflection data and enhancing S and P waves detection. Previous implementations of the polarization filter involve covariance matrix analysis or the SVD decomposition of 3 components seismogram matrix. The Rectilignity, a description of the linear polarization level, is expressed as function of covariance matrix eigenvalues or data matrix singular values. High rectilinearly polarized body waves are amplified when non-rectilinearly polarized waves and unpolarized noise are attenuated. In this work, we present a new time domain polarization filter based on correlation matrix analysis. We aim at extending the notion of correlation coefficient in 3D space. The designed filter avoids the covariance matrix diagonalization or the SVD decomposition of seismic data as done in previous works. The implementation of this filter is easier and facilitates the choice of rectilignity threshold: we demonstrated that the problem of linear polarization in 3D is equivalent to three classic 2D correlation problems. A good linear polarization is detected when a high linear correlation between the three seismogram components is observed. The parameters of the new filter are the moving time window length, the filter order, and the rectilignity threshold. Realized tests using synthetic seismograms show that optimal results are reached with a filter order of 2 to 4, a threshold of 0.6 to 0.75, and window length between one or two times the signal wavelet. Furthermore, the filter can enhance signal to noise ratio 2 to 10 times depending of the initial noise level and could save up to 25 % of computational cost. The proposed filter was successful used then to denoise real microseismic data.

U-Pb zircon chronology of basement gneisses and granitoids in the Nonacho Lake area, NT: Correlations to the Queen Maud block

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Directly east of the Taltson magmatic zone in the southwest Rae craton, the ca. 1.91-1.83 Ga Nonacho Group unconformably overlies various gneisses and deformed granitoids. Detrital zircon geochronology of the Nonacho Group has revealed a spread of Paleoarchean to Paleoproterozoic dates that could reflect a protracted history in the local basement. Despite this, the basement remains largely unmapped and unstudied. The age and lithological character of this basement bear on its relationship to the major domains of the western Rae craton (e.g. Queen Maud block, Taltson basement complex) and on the evolution of the craton margin. Research is focused north-northeast of the main Nonacho basin where basement rocks predominantly comprise amphibolite-facies mafic gneiss, intermediate gneiss with components of granodiorite and diorite, variably deformed granitoids, and locally abundant mafic-ultramafic inclusions. Preliminary U-Pb zircon geochronology indicates that the majority of gneisses and granitoids are younger than typical Neoarchean Rae crust. Zircons from mafic components record dates between 2.54-2.35 Ga. Some 2.54-2.45 Ga grains are morphologically and texturally consistent with an igneous origin, whereas a population of homogeneous unzoned grains likely documents ~ 2.38 Ga metamorphism. A granodiorite is interpreted to have crystalized between 2.55-2.48 Ga. Locally preserved biotite-muscovite quartzofeldspathic gneiss is interpreted to be metasedimentary in origin. This unit contains a population of low Th/U (< 0.1) zircon rims that may be the product of ~ 2.48 Ga metamorphism. Approximately 20 km east of the rocks described above, a ca. 2.60 Ga feldspar porphyritic granite occurs that is more typical of Rae crust. These preliminary age data indicate the presence of rocks previously described from the Rae craton, Queen Maud block and Arrowsmith orogeny. A significant finding is that the 2.55-2.45 Ga history may contain elements of mafic to felsic magmatism and metamorphism that potentially correlate to contemporaneous events in the Queen Maud block.

Volumetric calculation of minute gold grain: insight from machine learning!

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Morphologic attributes of gold grains extracted from glacial sediments provide a wealth of information about source rocks and transportation processes, since their erosion. The shape of the grains is a print of surrounding minerals in source rocks, which has been modified by collision with other particles in the course of their transport in the secondary environment. The severity of the modification is dictated by transport distance since liberation, as well as by the grain size and shape. For example, gold has larger crystallization strength than quartz resulting in a well-developed crystalline habit in such setting. Inversely, when gold is hosted in sulphides, it tends to be bulbous and rounded. To fully interpret the morphological attribute of a grain, a 3D model is required and grains can be counted by the hundreds in a single sample. Since morphology is related both to crystallization environment and transportation, shapes are extremely diverse and no clear relation exists between the volume of the grain and its 2D image. A fast and inexpensive 3D measure of the gold grain morphology can be obtained using an extended depth of field method. Multi-focused images are acquired with a stepping motorized microscope and processed with ImageJ, an image analysis software, to generate the topology model of the grain. 3D morphologies of more than 500 grains were acquired, on grains ranging from 20 to 100 µm, from a wide variety of sources. A classic convolutional neural network was then trained to identify the morphological pattern from 2D SEM high resolution images and predict their volume or Corey factor. Volume prediction is used to estimate the percentage in weight of gold in the granular material, either for mineral exploration or mineral processing.

Convolutional neuron network image classifier optimized for detection of rare geological features: an example on gold grains in tills

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Image classifying is a scope of intense research in deep learning. It can be used in a variety of geological applications such as mineral/rock identification, textural discrimination, structural pattern recognition, morphological quantification and interpretation of geophysical features: so anything that requires pattern recognition. From a mineral exploration standpoint, features of interest, such mineralisation,

indicator mineral or specific alteration, are rare occurrences that need to be detected among heterogeneous natural materials. Problems arise when trying to generate an image classifier from such material: due to small and noisy dataset, a huge false positive on true positive ratio, an inadequate recall factor and labelling ambiguities. Those issues are addressed and solutions are proposed using a specific case study: the characterization of gold grain in tills. Gold grain counting and characterization in tills is the prime exploration method in glaciated terrain. From a 10 kg till sample, heavy minerals are concentrated are counted under a binocular to extract gold grains, which are then visually classified in regard of morphological attribute. The process is tedious and error prone, and improving its robustness requires automation. In the case presented, gold grain counting is performed using an optical scan with a motorized microscope. Images are then processed by a CNN based algorithm (ARTPhot) that recognizes gold particles. Sample and particle coordinates are then transferred in a scanning electron microscope to test the validity of the identification. Then, morphological classification of the grain is conducted with an image classifier based on Google' inception V3 model on backscatter electron image of the gold grain (ARTMorph).

Automated identification of geodynamic features and associations in plate tectonic models

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Plate tectonic reconstructions provide a framework within which one may better understand the association of geodynamic processes with mappable features and the symptoms of the processes. For instance, location of economic mineralisation is related not only to specific geodynamic processes but also to previous episodes of fertilisation of crust or mantle. Geological processes, plate boundaries and their locations through time also influence the interaction of atmosphere and hydrosphere, partially control the migration of species across continents and regional patterns of erosion and deposition. Accurate plate tectonic boundaries, for any reconstruction model, provide one mechanism for researchers to validate and improve plate models, but also constrain the location of important geological processes. Currently, only a few reconstruction models implement continually closing plate boundary topologies. No detailed reconstruction models with this capability exist prior to the Mesozoic, in part because of the complexity of motion of multiple geodynamic unit (GDU) polygons representing preserved older crustal blocks. Manual identification of geodynamic boundaries is very time consuming. We report on methods being developed to automate the process of identifying and delineating zones of divergence (rifts and midocean ridges) and convergence (subduction zones) using a variety of open source software code and machine learning techniques. A number of approaches have been tested and compared to optimise time and memory for current desktop computer systems. This approach also opens up opportunities to integrate additional layers of geo-information so as to derive additional insights and constraints for the reconstruction models being developed.

Discordance and open-system behavior in baddeleyite revealed by combined SIMS $\delta^{18}O$ and TIMS U-Pb analysis

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Baddeleyite (ZrO_2) is predominantly found as an accessory mineral in mafic rocks. Similar to zircon ($ZrSiO_4$), baddeleyite incorporates U while rejecting Pb during crystallization, making it a useful geochronometer for silica-undersaturated rocks where zircon is often absent. Although compared to zircon, baddeleyite typically yields more concordant U-Pb ages, as indicated by U-Pb analyses of co-existing zircon and baddeleyite, there are examples of discordant baddeleyite. The mechanisms of Pb-loss in baddeleyite are not yet well-understood. Recent years has seen an increased use of baddeleyite U-Pb geochronology, however, many promising aspects of baddeleyite geochemistry are just beginning to be studied. Oxygen isotopic compositions of baddeleyite have a high potential to shed light on magma petrogensis as well as post-crystallisation open-system behavior to understand the mechanics of Pb-loss and resulting discordance in baddeleyite. In this study, multiple fragments of Cenozoic baddeleyite isolated from the undeformed and unmetamorphosed Ymir syenite were analysed for oxygen isotopic compositions by SIMS, after which selected grains were extracted from the mount for individual, single grain U-Pb analyses by ID-TIMS. SIMS analyses reveal heterogeneous $\delta^{18}O_{V\text{-}SMOW}$ values, ranging from +2.5 to -5.1 ‰, clearly having interacted with meteoric water. An open-system behavior is also reflected in the U-Pb systematics, with grains being atypically discordant for baddeleyite. This is also corroborated by a high U content of the baddeleyite, which facilitates open-system behavior by a higher degree of alpha recoil damage.

Ni-Cu-PGE mineralization in a syn-collisional setting: geochronology of the Turnagain Alaskan-type intrusion, northern Cordillera, Canada

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The magmatic evolution and Ni-Cu-PGE mineralization of the Early Jurassic Turnagain Alaskan-type intrusion is inextricably linked to accretionary events at the North American continental margin. We have calibrated the multi-stage evolution of the Turnagain ultramafic-mafic intrusion using high-precision air and chemical abrasion ID-TIMS U-Pb and $^{40}Ar/^{39}Ar$ geochronology. Three of four intrusive phases (Stages 1-4, oldest to youngest) were successfully dated. Cooling ages obtained on Stage 2 dunite-wehrlite include statistically identical $^{40}Ar/^{39}Ar$ plateau dates of 187.4 ± 1.5 (2σ) Ma on hornblende and 188.6 ± 1.2 Ma on phlogopite; and a concordant $^{206}Pb/^{238}U$ date of 190.3 ± 4.6 Ma on titanite. Stage 3 diorite has a $^{206}Pb/^{238}U$ zircon crystallization age of 188.11 ± 0.13 Ma; and Stage 4 wehrlite and leucodiorite yield $^{206}Pb/^{238}U$ zircon crystallization ages of 185.68 ± 0.19 Ma and 185.30 ± 0.12 Ma, respectively. The ca. 189 Ma phlogopite date represents a minimum crystallization age for Stages 1-2, indicating that assembly of the Turnagain intrusion spanned at least ~ 4 million years (ca. 189-185 Ma). Regional progressive contractional deformation in the Early Jurassic, constrained by the geochronological results (> 189 to < 185 Ma), initially generated northeast-vergent folds in the country rocks and deformed Stage 1 wehrlite-clinopyroxenite prior to emplacement of Stages 2-4; and subsequently thrust the intrusion and its host rocks onto the miogeocline. Mississippian meta-volcanic/sedimentary host rocks of the Turnagain intrusion are correlated with Upper Paleozoic arc and basinal assemblages of Yukon-Tanana and Quesnellia terranes. The Early Jurassic deformation records the initial accretion of allochthonous arc terranes in the northern Cordillera in accordance with current geodynamic models.

Metamorphism and metasomatism of felsic xenoliths in kimberlite

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Kimberlites often entrain crustal felsic xenoliths, which show alteration and metamorphism as a result of interaction with the host kimberlite. We studied granite and gneiss xenoliths in the Renard 65

kimberlite pipe (Northern Québec, Canada). The study comprised a detailed petrographic examination of 45 thin sections, a scanning electron microscopy and an X-ray powder diffractometry of a sample sub-set. Two major units of the Renard 65 pipe (Unit A and Unit B/D) distinguished by abundance of crustal xenoliths along with the degree of their alteration, were investigated. Unit A is a volcaniclastic kimberlite with 40-90 % xenoliths, whereas Unit B/D is a hypabyssal kimberlite with textures transitional to pyroclastic, containing 15-40 % more intensely altered xenoliths. Both units carry xenoliths of coarse-grained leucogranite (K-feldspar, plagioclase, quartz, biotite with accessory garnet, apatite, and zircon) and medium-grained gneiss (plagioclase, quartz, biotite, orthopyroxene with accessory garnet, apatite and zircon). The Unit A xenoliths are partially replaced by chlorite, sericite, epidote, serpentine, richterite, actinolite and clinochlore vermiculite. In Unit B/D four distinct metamorphic and metasomatic mineral assemblages almost completely replace xenoliths. The assemblages include aegirine, pectolite, garnet, wollastonite, xonotlite, prehnite, calcite, K-feldspar and richterite in various proportions. Secondary K-feldspar and calcite may indicate the granite protolith, whereas wollastonite may be the signature of the gneiss protolith. The presence of secondary garnet and wollastonite, the hallmark skarn minerals, suggests the analogy between the classical skarn geological processes at the contact between felsic rocks and the host hot carbonate-rich melts. The observed mineralogy of the Renard 65 felsic xenoliths will be compared with the theoretically predicted mineralogy modelled using Theriak-Domino or Perplex software for the known bulk hybrid kimberlite compositions. The comparison will enable constraints on temperatures, volatile contents and thermal history of the kimberlite melt during emplacement.

Controls on the triggers and flushing of turbidity currents in submarine canyons of eastern Canada

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Turbidity currents and landslides in canyon settings are known to present major risk to coastal and submarine infrastructure; for example these processes have been implicated in tsunami generation and destruction of fiber-optic submarine cables. Understanding the triggers, the recurrence and the timing of these events is important to mitigate their impact. Depending on the morphological setting of submarine canyons, different external controls will govern the recurrence of turbidity currents. On passive continental margins, lowstands are believed to be the main driver for delivery of sediment to canyon heads and eventual export to the deep basin. Lowstands allow a direct connection from sediment supply to the continental slope. However, on glaciated passive margins, the influence of glaciers is also known to be important in supplying sediment to deep water. Here, we assess the recurrence of turbidity currents in a shelf-incising canyon off eastern Canada (The Gully) in order to examine the effects of external forcings such as glacier retreat and sea level on the sedimentary record. These results allow us to infer the triggers of turbidity currents over time and propose a conceptual model for the activity of turbidity currents during glacial retreat. We show that turbidity currents in The Gully submarine canyon were mostly active between LGM and 17 ka cal BP, when the ice sheet was directly delivering sediment to submarine canyon heads, likely through hyperpycnal flows. As glaciers retreated, the dominant sediment supply switched to glaciofluvial and then longshore drift, which gradually reduced the recurrence and flushing of turbidity currents. As sea-level inundated the shallow banks on the continental shelf, turbidity currents ceased almost completely until ca. 6 ka BP. In the late Holocene, landslide recurrence increased to 1/1 000 yrs, with at least 4 new landslide events recorded in deep water. This study thus clearly shows how glacial sediment supply and sea level controlled the type of sediment supply to the continental slope, which in turn controlled the triggers of turbidity currents over time and their flushing to the deep basin.

Structural evolution of the NE Lau back-arc basin: links to tectonic regime and mineralization

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A series of cruises have identified an unusual amount of hydrothermal and volcanic activity in the NE Lau back-arc basin. Hydrothermal systems operate and mineralize the seafloor in multiple settings, including along spreading centres, and surrounding submarine calderas and volcanoes. This project aims to further understand the structural evolution, and tectonic regime in the basin as this is an important control on where mineralized hydrothermal systems will develop. Identifying the generations of structures acting as hydrothermal conduits is crucial, as it is known that tectonism and volcanism behave episodically in extensional environments. There has been no detailed investigation of structures in the area, so the next step will be to identify and digitize structures, including faults and lineaments and also various types of volcanic features. Parameters of digitized structures, cross-cutting relationships, magnetic lineations, magnetic anomalies, gravity data, and earthquake centroid moment tensors (CMTs) will be used to constrain the structural evolution of the basin. Known mechanisms based on mid-ocean ridge and back-arc models will be tested in an attempt to explain why there is increased volcanism and hydrothermal activity in certain areas of the basin. It may also be necessary to identify new mechanisms, which are likely unique to the Lau basin, as the area is very tectonically complex as a result of microplate interactions, changing subduction regimes and tearing of the under-riding Pacific Plate. These interactions lead to the fastest back-arc spreading rates on the planet and produce a dynamic environment with abundant heat sources capable of driving hydrothermal systems, generating ore deposits and nurturing chemosynthetic/biologic communities. This project will add a structural dataset which researchers can use to further understand why seafloor massive sulfides form where they do in the modern environment. This work also has implications for exploration techniques used to locate volcanogenic massive-sulfide deposits in ancient terrains.

Geothermal potential and enhanced geothermal system (EGS) performance in the St. Lawrence Lowlands Basin, Quebec, Canada

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An enhanced geothermal system (EGS) consists of injecting relatively cool water into deep fractured sedimentary or basement rocks, and withdrawal of heated water from extraction wells. Formations with sufficiently high temperatures at depths which are technologically accessible and still economically profitable can be viable sources for geothermal energy production. Under these conditions, obtaining reliable measurements of deep subsurface temperatures and defining an optimal geothermal extraction strategy remain important challenges for EGS development. A 3D conceptual geothermal model has been developed based on a detailed geological model of the St. Lawrence Lowlands Basin, and on the distribution of hydrothermal properties and radiogenic heat production obtained from laboratory experiments and well logs. Numerical simulations of the basin thermal regime under natural conditions were conducted using the HydroGeoSphere model, assuming non-isothermal single-phase flow while the hydrothermal properties of the formations were predicted using the PEST parameter estimation package. The calibrated model was used to predict the depths where temperatures are expected to be higher than 120 °C. The

efficiency of favorable areas for future EGS development was then evaluated by conducting non-isothermal single-phase flow simulations in realistic fracture networks with variable orientation, size, and transmissivity. The results showed that in the St. Lawrence Lowlands Basin, temperatures higher than 120 °C can generally be found at depths greater than 4.5 km. The sandstones of the Potsdam group showed a higher potential for EGS development than the Precambrian granitic bedrock of the Grenville group. Simulated trends of thermal energy dissipation in the fractured reservoirs showed significant effects of water injection & production rates as well as fracture spacing on the practical lifetime of the reservoir. The results from these simulations can be used in the future to help define strategies for developing geothermal reservoirs in areas of greatest geothermal potential.

The growth and development of UNESCO Global Geoparks in Canada

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UNESCO Global Geoparks are defined geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development. Geoparks operate under existing local legislation and provide an alternative economy based on educational tourism. Three UNESCO Global Geoparks have been designated in Canada: Stonehammer UNESCO Global Geopark (2010) in southern New Brunswick, Tumbler Ridge UNESCO Global Geopark (2014) in northern British Columbia and Percé UNESCO Global Geopark in Gaspésie, Québec (2018). In addition, there are nine aspiring geoparks currently under development in Canada. They are at varying stages of readiness, but two of them submitted applications to UNESCO in 2018, one in Nova Scotia and one in Newfoundland. The Canadian National Committee for Geoparks (CNCG) oversees the development of aspiring geoparks and evaluates them prior to submission to UNESCO. When UNESCO adopted Global Geoparks in 2015, the Canadian Commission for UNESCO (CCUNESCO) included CNCG as one of its committees. As the number of designated and aspiring geoparks continues to grow in Canada, the CNCG has decided to establish a not-for-profit entity to manage geoparks from 2019 onward. A workshop was held in Ottawa in June 2018 for aspiring geoparks in Canada and the United States. An on-line toolkit was developed for the workshop for aspiring and designated Canadian geoparks at www.canadiangeoparks.org. It provides accessibility to key information, enabling sharing of best practices and helping to build overall capacity. Reconciliation with indigenous people is a priority in Canada. There is a strong emphasis on the inclusion of indigenous people in geoparks and one of the long-term goals is to have a geopark run by indigenous people. Canada is a large country with such a wide range of geoheritage that at least thirty geoparks is reasonable goal for the country.

Linking metamorphism and orogenic gold in the Proterozoic Lynn Lake greenstone belt, northern Manitoba

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Proterozoic greenstone belts represent complex assemblages of lithotectonic units whose ancient histories frequently comprise multiple overprinting deformational and metamorphic events. The timing of gold deposition within this complex geologic history often remains uncertain, which limits our current understanding of orogenic gold-style mineralisation. The Lynn Lake greenstone belt (LLGB) located in northern Manitoba represents a complex assemblage of Paleoproterozoic supracrustal rocks deposited in a variety of tectonic settings during the 1.9-1.8 Ga Trans-Hudson Orogeny (THO). An important metallogenic belt containing several historically productive Ni (orthomagmatic), Cu-Zn (volcanogenic massive sulphide) and Au (orogenic) deposits, the LLGB continues to be a major target for mineral exploration. This study employs in situ dating of metamorphic and/or hydrothermal xenotime, monazite and apatite in concert with biotite-garnet thermometry to quantify the thermal and temporal evolution of the LLGB. Preliminary biotite-garnet thermometry data obtained in meta-sedimentary and -volcanic rock samples indicate a systematic increase in temperature from the east to west across the LLGB (535-560, 680-610, 685-690 °C at MacLellan Mine, Dunphy Lake and Fox Mine, respectively), consistent with an increase in grade of the metamorphic mineral assemblages following the same trend. New monazite and xenotime SHRIMP U-Pb ages measured at the MacLellan deposit yield multiple, temporally distinct metamorphic and/or hydrothermal ages at 1.83, 1.81-1.76 and 1.75 Ga. The youngest xenotime age is interpreted as the lower limit for the timing of gold and west-trending, regional shear zones (e.g. Johnson and MacLellan Shears) that provide fluid pathways and structural traps for auriferous fluids. Forthcoming biotite-garnet thermometry and LA-ICP-MS U-Pb geochronology of metamorphic apatite are aimed at resolving the timing and conditions of metamorphism throughout the LLGB with the goal of further elucidating the link between tectonic events in the THO and the timing of gold deposition.

Petrographic and geochemical characterization of host rock lithologies to auriferous quartz veins, Fisher Property, Seabee Gold Operation, Saskatchewan

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The Seabee Gold Operation in northern Saskatchewan comprises the active Santoy mine and the recently decommissioned Seabee mine. These Paleoproterozoic orogenic gold deposits are hosted by shear zones in the Pine Lake greenstone belt of the Glennie Domain, which has a complex geologic history related to accretionary episodes during the development of the Reindeer Zone of the larger Trans-Hudson Orogen. Similar structural trends and rock types hosting the Santoy and Seabee deposits are interpreted to continue to the Fisher property, located to the southeast of the Santoy mine, and is thus the focus of active exploration. This study investigates the petrographic and geochemical characteristics of 38 representative drillcore samples selected from 8 drillholes of metamorphosed felsic to mafic volcanic units and various plutonic suites. Variably strong chlorite, epidote, K-feldspar, diopside, carbonate and albite alteration has been observed in volcanic and intrusive units across the property. Crosscutting auriferous quartz veins, up to 1.5 m thick, hosting minor pyrite, chalcopyrite and pyrrhotite have been identified in outcrop and drillcore. Petrographic analysis will distinguish the relict primary igneous minerals and textures from metamorphic overprinting and alteration mineral assemblages. The major and trace element compositions of the rocks, with a particular focus on conserved elements, will be used for classification and to provide constraints on petrogenesis and tectonic setting at the time of formation. The mineralization potential of the Fisher property will be assessed based on similarities to the Seabee and Santoy deposits. Geological mapping of the Fisher property will commence during the summer of 2019 to determine stratigraphic and structural relationships between rock units, and associated quartz veining.

Revisiting the relationships between Paleogene tectonics and gold mineralization in the Cordilleran Orogen

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The Paleogene was a time of change in the North American Cordilleran Orogen, during which late Cretaceous compression and arc construction transitioned to Eocene dextral strike-slip deformation. The tectonic switch appears related to a counter-clockwise rotation of the Pacific plate relative to the North America plate around ca. 57 Ma. This changed the intersection from relatively orthogonal to moderately oblique, consequently transitioning the Cordillera into transcurrent deformation. Features that are associated with this switch include: 1)

crustal-scale dextral strike-slip faults; 2) a magmatic flux in the Coast Plutonic Complex; 3) voluminous intermediate volcanism in the Intermontane; 3) development of metamorphic core complexes; and 5) orogenic and epithermal gold mineralization. West of the Coast Plutonic Complex, orogenic gold mineralization occurs within the Juneau gold camp, Alaska, where it is hosted in Paleozoic and Mesozoic metamorphic rocks and related to dextral transpressional deformation. East of the Coast Plutonic Complex, within the Intermontane of British Columbia and Yukon, low-sulphidation epithermal gold mineralization is associated with the development of intermediate volcanic complexes. These volcanic complexes may mark dilatational jogs or pre-existing plate boundaries along crustal-scale dextral strike-slip faults. In time and space, the volcanic activity progressed southward (from southern Yukon through British Columbia and into northern Washington) and epithermal gold mineralization occurs within several dispersed volcanic complexes. In northern BC and southern Yukon, the volcanic complexes formed in a relatively narrow belt, whereas in southern BC and northwest US they are widely distributed coincide with metamorphic core complexes farther to the east. The coincidence of all of the Paleogene features of the Cordilleran Orogen indicates that diverse gold-forming processes can be related to the same large-scale tectonic process, but the location of resultant mineralized zones/deposits is dictated by local processes.

Petrogenesis of the late- to post-tectonic granitoids of Boothia Peninsula, NU: Lu-Hf and Sm-Nd isotope characterization of the granitoids and their source rocks

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Across southern Boothia Peninsula, NU, polydeformed metasedimentary sequences are cut by 1.84-1.82 Ga weakly foliated to massive granitoid plutons that can be subdivided into a biotite-orthopyroxene monzogranite (charnockite) suite and a hornblende-biotite quartz syenite to syenogranite suite. These Boothia granitoids (BG) share A- to I-type granitoid major-element compositions and have relatively low LREE/HREE fractionation. The BG are geochemically similar to the 1.85-1.80 Ga Hudson granites, and broadly coeval with the ultrapotassic Dubawnt minette suite and tholeiitic Sparrow dykes that are widespread in parts of the Rae and Hearne cratons. However, the BG represent less evolved, higher-temperature magmas (opx-bearing, minimal xenocrystic zircon) than most Hudson granites. To further understand the petrogenesis of the BG and assess the tectonic setting in which they formed, we are investigating their whole-rock Sm-Nd and zircon Lu-Hf isotope systematics. The strongly negative εNd 1.83 Ga (-7.0 to -8.0) and εHf 1.83 Ga values (-8.5 to -11.0) obtained for the BG indicate that they are dominantly derived from older crustal source rocks. The syenogranite suite has slightly less negative initial εNd and εHf values and younger Nd depleted mantle model ages (εHf 1.83 Ga = -8.5 ± 0.2, εNd 1.83 Ga = -7.0 to -7.1, TDM = ~ 2.5-2.6 Ga) than the charnockite suite (εHf 1.83 Ga = -9.3 ± 0.2 to -11.0 ± 0.2, εNd 1.83 Ga = -7.3 to -8.0, TDM = ~ 2.8 Ga). This suggests either that the syenogranite and charnockite suites were derived from two distinct crustal source rocks with Neoarchean and Mesoarchean mantle extraction ages, respectively, or that the syenogranite suite, although dominantly derived from a Mesoarchean crustal source, also incorporated a small mantle contribution. The εNd 1.83 Ga values of the BG overlap the upper end range for the Hudson granites (εNd 1.83 Ga = -7.0 to -13.5). This observation, combined with the higher-temperature nature of the BG magmas, suggests a greater contribution of mantle heat, and possibly material, to magma genesis.

Periglacial and glacial processes on Earth and Mars: a comparative study

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Past and ongoing missions to Mars have yielded important results about the distribution and origin of water ice. Radar data suggests that large amounts of ice are present at depths of several 10's metres in the northern mid-latitude plains. A range of landforms have also been documented in the martian mid-latitudes that have been interpreted as being produced by glacial and periglacial activity in the past few ten's to ~ 300 million years. Landforms interpreted as thermal contraction polygons and thermokarst depressions are particularly abundant, but question remain as to the relative role or sublimation versus thaw any whether any ice remains in the near-surface at the present day. Indeed, there exists a fundamental gap in our knowledge about the distribution and amount of ice present at depths of ~ 1 m to ~ 10-20 m on Mars. The Icy Mars Analogue Program (IMAP) aims to use field-based studies in the Canadian Arctic to conduct comparative planetary geology studies and to train students about surface processes in cold, arid regions. We focus here on the questions: 1) How do periglacial processes lead to the production of regular and irregular polygons on flat terrain as well as hillslopes? and 2) How do periglacial processes on hillslopes give rise to the production of gullies and fluvial channels? In this work, the results of fieldwork conducted on Axel Heiberg and Devon Islands is presented. Our results show that polygon morphologic variations in the High Arctic are linked mostly to substrate, stage of evolution and topographic factors. Insights into the factors that influence specific polygon morphology has implications for previous methods of predicting polygon morphology using factors such as homogeneity, and for variations of polygonal terrain in the mid-latitudes of Mars.

Impact Earth: revisiting the Earth impact cratering record

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Impact cratering is one of the most important and ubiquitous geological processes in the Solar System. Impact craters are commonplace on the majority of the rocky planets, asteroids, and many of the rocky and icy moons of the inner and outer solar system. Over the past couple of decades, it has also become apparent that impact events have profoundly affected the origin and evolution of Earth. The impact cratering record on Earth, while incomplete due to erosion, volcanism, and plate tectonics, provides the unique opportunity to conduct geological fieldwork and laboratory analysis of samples from known locations. Through the new Impact Earth initiative we are conducting a comprehensive review of the impact cratering record on Earth. The website (www.impactearth.com) features a new searchable database of all confirmed impact craters on Earth and many of their most important attributes (e.g. age, size, target rocks, etc.). We currently list 195 confirmed structures. In this contribution, we provide a historical overview and motivation for this Impact Earth initiative, present new insights gleaned from the current database, and report on ongoing studies. It is important to note that the Impact Earth database traces its origins back to 1955 when the systematic search for impact structures was initiated by Dr. Carlyle S. Beals, the Dominion Astronomer of Canada. Following the first published worldwide listing of impact structures on Earth by Dence in 1972, which listed 50 structures, a searchable digital database was created and maintained at

the Earth Physics Branch and later at the Geological Survey of Canada in Ottawa. The new Impact Earth database is an outgrowth of these earlier efforts but is a full relational-database, with enhanced available attributes and search capabilities.

Applying machine-learning to mineral exploration: feedback from a pioneer

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The use of artificial intelligence (AI) and machine-learning (ML) in mineral exploration is a popular trend these days. However, it is far more complex than some advertise, and one must be wary of AI solutions presented as "ready-for-use". Through examples taken from experience of applying ML to mineral exploration, this presentation provides an overview of the complexity and challenges faced when using greatly diverse data sets to generate prospectivity maps. Major sources of data all have multiple sub-fields and techniques of data collection that come with their own specific constraints and issues to address. Those sources include: geology (e.g. lithology, structures, alteration), geophysics (magnetism, gravity, electrical, radiometric), geochemistry (e.g. rock, soil, till), and satellite imagery (e.g. multispectral data). The critical steps that are data assessment and cleaning thus require the appropriate domain expertise, which is also highly valued for engineering features that will guide the ML process. ML itself is a hugely diverse field, in which non-experts are prone to making mistakes that can bear heavy consequences. There are thousands of versions of supervised, unsupervised or reinforced learning algorithms that can be solutions for project specificities, provided that problems to be tackled are well-defined. In addition, ML comes with requirements on input data format, data and variables dimensionality, training set definition, and more that need to be addressed. Generating prospectivity maps is very sought-after; however, ML has countless potential uses in previous steps of the process. All things accounted for, our experience shows that multi-disciplinary teams of experts (i.e. geologists, geophysicists, geochemists, data scientists) are critical to correctly apply ML to mineral exploration and unlock the most added-value from big data. Finally, the very diverse fields of expertise involved provide enormous opportunity for new research.

Geological setting and revised genetic and exploration models for the world-class BIF-hosted Musselwhite gold deposit, Superior Province, northwestern Ontario

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The Musselwhite mine in northwestern Ontario has produced close to 5 Moz of gold and still holds 1.85 Moz of proven and probable reserves. This world-class deposit is hosted by poly-deformed, metamorphosed, Algoma-type banded iron formations (BIF) in the Mesoarchean North Caribou greenstone belt (NCG) of the Superior Province. The NCG is mainly composed of tholeiitic basalts and komattites dated between 3.05 and 2.91 Ga, overlain by syn-orogenic greywackes (< 2.85 Ga). Large TTG-type batholiths dated between 2.85 and 2.73 Ga surround the NCG. Three major phases of deformation have affected rocks of the NCG, and peak amphibolite facies metamorphism is dated at around 2660 Ma. New geological, structural, petrographic, geochemical and geochronological data on the Musselwhite gold deposit helped better understand the genesis of the deposit and led to revised geological and exploration models for the NCG. Narrow subvertical ore zones are hosted in garnet-grunerite BIF in D2 high-strain zones associated with tight to isoclinal folds. Epigenetic, hypozonal gold mineralization formed under garnet zone metamorphic conditions through pyrrhotite-replacement and silicification of the BIF by fluids stemming from metamorphic devolatilization of underlying rocks. This was accompanied by asymmetrical development of potassic (biotite) alteration and proximal calcic (hornblende) alteration of grunerite in the BIF. Gold correlates with Ag, Cu, Se and Te. Gold mineralization at Musselwhite is synchronous with D2 deformation and M2 metamorphism and is constrained between 2720 and 2660 Ma. The Musselwhite deposit shows features common with others such as Lupin (Canada), Homestake (USA), and Nevoria (Asutralia), notably the lithological control of silicate BIF on gold. Marker horizons (e.g. silicate facies BIF), tight fold hinge zones, and strong D2 deformation gradient are key exploration vectors in the NCG, the northwestern Superior Province, and other Precambrian terranes.

Multidisciplinary investigation into the Cenozoic tectonic evolution of the Colorado Plateau

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The causes of Cenozoic uplift of the Colorado Plateau, southwestern USA, are strongly debated, though most hypotheses acknowledge the importance of northwest-directed subduction of the Farallon oceanic plate beneath North America since ca. 100 Ma. Considerable insight into the effects of subducted slab-continental lithosphere interaction has been gained by multidisciplinary studies of crustal and mantle xenoliths that occur within diatremes emplaced at ca. 30-20 Ma in the Navajo Volcanic Field, Four Corners region. Here, we demonstrate how close integration of cutting-edge techniques, such as X-ray computed tomography, automated mineralogy, and petrological modeling, can provide new insight into the geological mechanisms that operated before, during, and after rapid uplift of the plateau during the Oligocene. In one case study, phase diagram-based thermobarometry performed on lawsonite-bearing mafic eclogite xenoliths provide evidence for low-angle subduction and shear-removal of the subcontinental lithospheric mantle beneath the proto-plateau, which subsequently allowed for asthenospheric upwelling and isostatic rebound of the remaining mass. In a second case study, garnet xenocrysts containing exsolution lamellae of hydrous and anhydrous silicate minerals provide insight into the petrological constitution of the asthenospheric mantle beneath the plateau from which they were exhumed.

The U-Pb-Hf detrital zircon record of a Montauban-type quartzite: implications for the accretionary evolution of the Western Grenville Province

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The collisional Grenville orogeny (1.09 to 0.98 Ga) concluded ca. 800 million years of accretionary growth of the Laurentia craton masking the original relations between pre-collisional lithotectonic elements in the Grenville Province. Despite the high-grade metamorphic conditions attained during the continental collision, Nd isotopes still retain a memory of juvenile and reworked granitoid production in the Pre-Grenvillian basement terranes associated with the Penokean (1.9 to 1.8 Ga), Labradorian (1.7 to 1.6 Ga), and Pinwarian (1.5 to 1.4 Ga) events. However, detrital zircon studies of pre-Grenvillian metasedimentary sequences that attempted to trace these basement sources remain sparse. Thus, in this contribution, we aim to constrain the nature and affinity of pre-Grenvillian crustal sources in Western

Grenville Province (La Tuque, Lac Saint-Jean, QC) using the U-Pb and Lu-Hf isotope microanalysis of detrital zircon grains from a quartzitic horizon of a Montauban-type supracrustal sequence. Four age populations were recognised in Kernel Density Estimation (KDE) diagrams with $^{207}Pb/^{206}Pb$ age peaks at ca. 1.47 Ga, 1.61 Ga, 1.86 Ga, and 2.7 Ga. The youngest detrital zircon grain yielded a concordant U-Pb age of 1388 ± 14 Ma (2σ), that represents the maximum depositional age of the Montauban-type quartzite, and is at least 50 Ma younger relative to the previous U-Pb age constraints of ca. 1.45 Ga from a lapilli tuff of the Montauban group. Preliminary Hf isotope data from the dated zircon grains show that the major age population at ca. 1.47 Ga has a juvenile signature with the older populations yielding a mixture of juvenile and recycled components. Overall, the concerted microanalysis of the detrital zircon grains from the Montauban-type quartzite can provide new insights on the pre-collisional origin of zircon proto-sources in the Western Grenville Province enhancing our understanding on the accretionary history of the Laurentia craton.

Sedimentology of sandstone-dominated units in the Mesoproterozoic Fury and Hecla Group (Nunavut, Canada)

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The Fury and Hecla Group is exposed on northwestern Baffin Island and northern Melville Peninsula in northern Nunavut and represents a Mesoproterozoic sedimentary basin that is poorly constrained, stratigraphically and chronologically. The Fury and Hecla Group is postulated to be part of the Bylot basins, which are composed of several isolated sedimentary basins considered to have formed during the assembly of the supercontinent Rodinia. The Fury and Hecla Group unconformably overlies Archean-Paleoproterozoic crystalline rocks associated with the Rae province, and is mostly composed of sedimentary rocks with minor volcanic rocks. There are five formations that makeup the stratigraphy: (1) Nyeboe Formation, (2) Sikosak Bay Formation, (3) Agu Bay Formation, (4) Whyte Inlet Formation, and (5) Autridge Formation. This presentation focuses on facies analysis and interpretations of the sandstone-dominated Nyeboe, Sikosak Bay, and Whyte Inlet formations based on new field data collected during the summer of 2018. The Nyeboe Formation is 500 m thick and contains a diverse assemblage of lithofacies including alluvial-fluvial, nearshore-marine clastic and clastic-carbonate. Most of the stratigraphy is interpreted to deposit along the shoreface, consistent with previous studies; however, eolian deposits are recognized for the first time. The Sikosak Bay Formation is 150 m thick and entirely composed of clastic shoreface deposits. The Whyte Inlet Formation is up to 3 km thick and contains shoreface facies and minor proximal-fluvial facies. Putative stratigraphic correlations can be made between the Fury and Hecla Group with other sandstone-dominated units in the Bylot basins. In conclusion, this study imparts new insights on the depositional setting of the Fury and Hecla Group and the larger Bylot basins. Furthermore, it contributes towards a new comprehensive sedimentological characterization of a volumetrically important and yet far neglected Mesoproterozoic sedimentary succession in the eastern Canadian Arctic.

Indicator mineral dispersal trains of northern Canada in a modern glacial and mineralogical context

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Glacial erosion, transport, and deposition has formed trains or fans of metal-rich debris down-ice from mineral deposits that are much larger exploration targets than their bedrock sources. Dispersal patterns may be the result of one or more phases of ice flow and vary in length from a few tens of meters to >100 km. Recognizing the complexity of continental ice sheets and ice-sheet dynamics is essential to understand the variation in glacial dispersal patterns and successfully searching for mineralized sources. Boulder tracing and till geochemistry have been widely used as exploration tools in glaciated terrain for more than 60 years. In the past 25 years, indicator mineral methods applied to till have become complementary key exploration tools. Geochemical and isotopic studies of recovered heavy minerals can then be used to provide information on sources of the grains, deposit types and potentially a vector towards mineralization. Indicator mineral chemistry has evolved considerably since the garnet classifications for diamondiferous kimberlite exploration and is now applied to a variety of mineral deposit types. The identification of glacial dispersal landforms and sedimentary deposits formed by fast-flowing glaciers was important to the earliest recognition of palaeo-ice streams of the Laurentide Ice Sheet in the 1970 and 1980s. In recent years, our understanding and reconstructions of the Laurentide Ice Sheet has undergone a new palaeo-ice stream paradigm, whereby we recognize that ice streams have impacted a large portion of the glacial landscape. The long (10s of km) dispersal trains of till with distinct chemical and/or mineralogical compositions, coupled with obvious erosive/depositional corridors of streamlined landforms, provide a means of identifying and reinterpreting unsourced dispersal trains impacted by hard-bedded ice streams in northern Canada.

Ice-flow history of the Laurentide Ice Sheet in the southwest Northwest Territories: a Shield to Cordillera transect

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Fieldwork conducted since 2010 by the Geological Survey of Canada under the GEM programs has revealed a more complex glacial history of the southern Great Slave Lake region of the Northwest Territories than was previously reported. New reconstructions of the Laurentide Ice Sheet paleo-ice flow history have been established from field observations of erosional and/or depositional ice-flow indicators (e.g. striae, bedrock grooves, till clast fabrics, and streamlined landforms), new geochronological constraints, and interpretations of glacial stratigraphy. Three distinct ice-flow phases are consistently observed in areas proximal to the western margin of the Canadian Shield between the Slave River near Fort Smith and Hay River further west. These phases are: 1) an oldest southwest flow; 2) a long-term sustained ice flow to the northwest; and, 3) a youngest west-southwest flow during Late Wisconsin deglaciation, which includes extensions of the Great Slave Lake and Hay River ice streams further east than previous mapped. At Hay River approaching the eastern limit of soft Cretaceous bedrock of the Western Canada Sedimentary Basin, the ice flow pattern no longer shows the aforementioned consistent chronology. From Hay River to the Liard River, near the zone where the Laurentide and Cordilleran ice sheet coalesced, a thinning ice profile, topographic highlands such as the Cameron Hills and Horn Plateau, and the deep basin that Great Slave Lake currently occupies, played a significant role on the dynamics of the Laurentide Ice Sheet during early ice advance, retreat during Marine Isotope Stage 3, Late Wisconsin advance and deglaciation. Other factors, such as increased sediment supply and clay content from Cretaceous shale bedrock were also significant in influencing ice-sheet behaviour. The role of elevated porewater pressures over subglacial clay-rich sediments controlled the extent and dynamics of several discordant ice streams in upland and lowland regions within the study area.

Structural characterization of the Nemiscau subprovince, Superior Province, Canada: tectonic implications for the development of Archean sedimentary basins

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The Archean metasedimentary Nemiscau subprovince is located in the central part of the Superior Province in Quebec (Canada), bounded by the volcano-plutonic subprovinces of La Grande and Opatica, to the north and to the south, respectively. In the study area, the innermost part of the Nemiscau consists in heterogeneously deformed and partially migmatized metasedimentary rocks and felsic orthogneisses. In contrast, mafic-to-ultramafic volcanic and intrusive rocks predominate along its northern and southern boundaries, forming the lac des Montagnes and Colomb-Chaboullié belts. The structural features of Archean terrains mainly consist of dome-and-basin fold geometry and large but localized shear zones. Subvertical E-W to NE-SW-trending strike-slip to oblique shear zones separate the Nemiscau subprovince from adjacent volcano-plutonic domains along both its northern and southern margins. Three deformational events have been recognized; (1) the earliest is related to NE-SW trending structures that are superposed by (2) E-W trending fabrics, and (3) a youngest set of locally-developed N-S-trending crenulation cleavages. All these structures are marked by steeply-dipping fabrics. The innermost part of the subprovince shows a well-developed dome-and-basin geometry and characterized by granulites facies metamorphic domains delimited by dextral E-W-trending shear zones. In the study area, regional metamorphism seems to decrease from granulite to amphibolite, from the inner to the outermost parts of the Nemisceau subprovince in the study area. The paleotectonic setting of the Nemiscau subprovince has been recently interpreted as a back-arc basin or an accretionary prism, implying that the Archean tectonics process responsible for its formation was similar to modern plate tectonics. Alternatively, the structural and metamorphic characteristics of the Nemiscau subprovince might also be attributed to gravitationally-driven tectonic processes, such as sagduction and diapirism.

Geoenvironmental characteristics of the St. Lawrence columbium mine at Oka, Québec: mineralogy and geochemistry of waste rock, tailings, slag and drainage waters

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The abandoned St. Lawrence Columbium Mine in Oka, QC, operated between 1961 and 1976, using open pit and underground mining, an on-site mill, and a ferroniobium converter. Although the mine produced over three million tonnes (Mt) of Nb ore, its long-term legacy is the nearly four Mt of waste material (rocks, tailings, slag) remaining on site. Waste rock and tailings are composed primarily of calcite with variable amounts of gypsum, apatite, mica, chlorite, amphibole, garnet, pyroxene, zeolite group minerals, rare earth elements (REE)-bearing phosphates and carbonates. The ore mineral is pyrochlore containing uranium (U) and thorium (Th). In waste rock dumps, the abundant sövite exhibits variable degrees of weathering. Mobilization of U, Th, REEs, and other metals, however, is limited as the waste contains relatively insoluble minerals. The tailings contain variable amounts of Niobium (Nb) (in unrecovered niocalite), and minor U and Th (in unrecovered perovskite), and seepage from the tailings shows low U but elevated fluorine (F) concentrations at circumneutral pH. Ferroniobium slag derived from the aluminothermic conversion of pyrochlore concentrates contains high-temperature oxide minerals interspersed in an aluminous glass matrix, and significant concentrations of U and Th. A field-scale on-site slag leaching experiment indicates elevated concentrations of Al, F and U in pH 9 waters. Results from seasonal water sampling in two flooded open pits at the mine demonstrate that waters are circumneutral to alkaline (pH 7.1-8.1; avg. 7.5) with high total dissolved solids. The concentrations of U, Th, F, Nb, REEs, and radionuclides (Pb-210, Ra-226, Ra-228) in pit waters are very low, except in anoxic waters below 30 m in one pit. The geoenvironmental signature from this abandoned mine includes radioactivity in the slag, elevated F in tailings seepage, and high metal levels in low-oxygen groundwater. Knowledge gained from this study has direct application to environmental assessments of future developments of carbonatite-hosted Nb- and REE deposits.

Metamorphic diachronism and structures of the Connecticut Valley-Gaspé trough, Northern Appalachians

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The Connecticut Valley-Gaspé (CVG) trough represents a major, orogen-scale Silurian-Devonian basin of the Northern Appalachians. From Gaspé Peninsula to southern New England, the CVG trough has experienced a contrasting metamorphic and structural evolution during the Acadian orogeny. From NE to SW, along its strike, the CVG trough is characterized by increasing strain and polyphased structures, variation in the intensity of regional metamorphism, i.e. from very low-grade to upper amphibolite facies, and in the abundance of crosscutting ~ 390 to 370 Ma granitic intrusions. In southern Quebec and northern Vermont, a series of NW-SE transects across the CVG trough have been studied to better understand these along-strike variations. Detailed structural analyses, combined with isochemical phase diagram sections (IPDS), Raman spectrometry and muscovite $^{40}Ar/^{39}Ar$ dating have been performed. The progressive and incremental deformation involves north-south-trending diachronism in the timing of regional metamorphism and plutonism. Regional plutonism is recorded around 378-366 Ma whereas regional deformation evolves from a D1 crustal thickening event that peaked at ca. 390 Ma in Vermont and 370 Ma in southern Quebec, followed by two compressional exhumation events, D2 and D3, evolving from south to north respectively from ~ 380 to 355 Ma and 355 to 335 Ma. D1 to D3 deformation events form part of a continuum with an along-strike propagation rate of ~ 50 km/Ma During D1, a differential of burial depth of more than 15 km between southern Québec and Vermont can be attributed to the occurrence of a major crustal indenter, the Bronson Hill Arc massif, in the New England segment of the Acadian collision zone. Alleghanian metamorphic ages (~ 300 Ma) are also found in easternmost part of Vermont, in the footwall of the Monroe Fault.

Use of petrophysical anisotropies for gold exploration in the footprint of the Canadian Malartic deposit, Québec, Canada

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The presence of petrophysical anisotropies in metamorphosed and poly-deformed rocks of Precambrian to Phanerozoic orogenic belts has been known for many years but is yet to be used in geophysical interpretation and modeling. Collecting extensive petrophysical data is becoming a common practice in modern mineral exploration. However, geological structures are rarely considered during data acquisition, even though they control the formation and geometry of

most ore deposits. A recent petrophysical and geophysical study demonstrated that the anisotropy of resistivity (derived from induced polarization) can be used to map structurally complex zones, which are prospective for gold mineralization in the footprint of the Canadian Malartic deposit. A similar approach has been used to integrate magnetic susceptibility measurements of 240 oriented samples of metasedimentary rock with geological structures and hydrothermal alteration mineralogy. The main structural fabric in the Canadian Malartic district consists of a NW-SE-trending penetrative foliation, marked by biotite and white mica and contemporaneous of a gold mineralization assemblage of quartz-microcline-albite-carbonates-pyrite-rutile. A syn- to post-mineralization metamorphic event resulted in pyrite being progressively replaced by pyrrhotite. The anisotropy of magnetic susceptibility indicates a strong magnetic fabric, oriented NW-SE and subparallel to the main structural fabric. Two methods (thermal demagnetization and isothermal remanence acquisition) were used to determine the magnetic mineralogy of this system, which is dominated by zones of pyrrhotite or magnetite. This work demonstrates that analyzing the anisotropy of magnetic susceptibility is complementary to petrographic and structural observations to determine the structural control and characterize the pyrrhotite distribution in the footprint of the Canadian Malartic deposit. Such advanced magnetic investigation could be used for regional-scale structural studies and mineral exploration elsewhere. Ultimately, petrophysical anisotropies should also be implemented in geophysical inversion codes to enhance 3D modeling of deformed environments.

Integrated modelling in the Great Lakes Basin to assess watershed response under varied climate change scenarios

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Integrated hydrological modelling represents a valuable tool for assessing watershed response to climate change in a manner that gives appropriate consideration to the interconnections between surface and subsurface domains. A 3D finite element model has been constructed using HydroGeoSphere for the Upper Parkhill Watershed in southwestern Ontario with the primary purpose of examining watershed response to changing climate conditions. Winter hydrological processes, which are particularly important in the Great Lakes Basin, have been incorporated. The constructed numerical model is supported in part by continuous data collected from an Ontario Ministry of the Environment, Conservation and Parks Integrated Water and Climate Monitoring Station on Parkhill Creek. This watershed features predominantly agricultural land use and surficial geology dominated by low permeability glacial tills. In an effort to account for the uncertainty associated with future climate scenarios, watershed behaviour has been examined in response to varied external climate stimulus. Anomalous historic climate conditions are examined as a potential analogue for future climate and historic conditions are further used to generate a synthetic climate scenario. The simulated watershed response generated from the application of these scenarios is compared to the application of projected climate data derived from general circulation models. Results from this study may be used to provide insight on meteorological forcing practices for hydrological climate change studies as well as identify potential future watershed response related to groundwater levels, surface flows, and groundwater-surface water interactions. Moreover, study results may be used to support improved water management practices and provide recommendations for data use from long term monitoring networks.

Cadwaladerite, $Al_5(H_2O)_3(OH)_{15}\cdot(H_2O,Cl)$ from Cerros Pintados, Chile, defined as a valid mineral species and the discreditation of lesukite

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Cadwaladerite, described in 1941 as $Al(OH)_2Cl\cdot 4H_2O$ and lesukite $Al_2(OH)_5Cl\cdot 2H_2O$ described in 1997 are very closely related but are found in very different environments. Lesukite has been described from volcanic fumaroles and burning coal seams. Cadwaladerite was found at the edge of a salar in Chile. Both materials have cubic symmetry with a = 19.788 to 19.859Å. The crystal structure common to both consists of a rigid three-dimensional framework of edge and corner-sharing $Al\text{-}(O,OH,H_2O)_6$ octahedra that form large inter-connected cavities where loosely held chlorine and water molecules are located. The fact that chlorine is loosely held within the structure is demonstrated by a dramatic reduction in chlorine content after washing the material in distilled water. Cadwaladerite is recognized as a valid mineral species and lesukite is discredited because the only difference between the two materials is the loosely held intra-framework chlorine and H_2O. By analogy to zeolite nomenclature, these materials should not be designated as unique mineral species. Cadwaladerite, $Al_5(H_2O)_3(OH)_{15}\cdot(H_2O,Cl)$, takes precedence over lesukite based on the date of description and is recognized by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association (2019-xx). Material similar to cadwaladerite is found as a corrosion product on some types of nuclear fuel elements and is also closely related to the molecular species used in antiperspirant and water filtration.

Rare earth elements and radiogenic strontium isotopes in carbonate minerals reveal diagenetic influence in shales and limestones in the Appalachian Basin

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Application of sequential extraction methods to target geochemical signatures in specific mineral fractions may provide greater insight into the complex processes that occurred during diagenesis and catagenesis. Using this approach, this study provides a detailed account for rare earth elements and yttrium (REY), $^{87}Sr/^{86}Sr$, and $\partial^{13}C$ in the carbonate fraction of the Marcellus Shale and adjacent formations in the Appalachian Basin. Shale and limestone samples collected from two cores recovered from Monongalia County, West Virginia, USA were analyzed. The results demonstrated that the REY patterns, $^{87}Sr/^{86}Sr$, and $\partial^{13}C$ of carbonate concretions in calcareous shales and carbonate cements in black shales were very distinct. The REY were more concentrated in the carbonate concretions than in the carbonate cements. The carbonate concretions displayed REY patterns that are similar to modern seawater, while MREE-enrichment was observed in the carbonate cements. Similarly, the $^{87}Sr/^{86}Sr$ values in the carbonate concretions were close to those measured for unaltered Middle Devonian carbonates, while the $^{87}Sr/^{86}Sr$ in the carbonate cements were more radiogenic (higher in $^{87}Sr/^{86}Sr$). This observation suggests that the carbonate cement signature could be a result of radiogenic ^{87}Sr expelled from clays during illite-smectite transition. Overall, this study demonstrated two distinct processes involved with controlling the carbonate geochemistry within Appalachian Basin shales and limestones: one fraction displaying minimal diagenetic alteration relative to depositional conditions (carbonate concretions in calcareous shales and limestone carbonate in limestones), and another fraction displaying the evidence for extensive

chemical alteration during illite-smectite transition and catagenesis (carbonate cements in black shales).

Assessing the usefulness of multiple isotope systems (C, O, Li, B, Sr) for CO_2 and brine leakage monitoring at a CO_2 flooding oil field in Texas, USA

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Potential leakage of CO_2 and brine from the subsurface into shallow groundwater is a critical issue associated with CO_2 injection at both enhanced oil recovery (EOR) and carbon storage sites. This study evaluates the usefulness of different isotope systems ($\delta^{18}O$ of water, $\delta^{13}C$ of dissolved inorganic carbon (DIC), $\delta^{7}Li$, $\delta^{11}B$, $^{87}Sr/^{86}Sr$) as tracers of CO_2 and brine leakage at a CO_2-EOR site located within the Permian basin (Seminole, Texas, USA). Water samples were collected from an actively producing CO_2 flooded formation (San Andres Fm), an overlying intermediate depth aquifer (Santa Rosa Fm), and the shallow fresh groundwater aquifer (Ogallala) over a four-year period. We found that isotope signatures of Li, B, and Sr in the intermediate aquifer are distinct from those in the oil-producing formation, thus demonstrating potential utility as early indicators of upward migration of brine from the underlying oil formation. Importantly, the distinction in $^{87}Sr/^{86}Sr$ values among three formations suggests that $^{87}Sr/^{86}Sr$ is a powerful tracer of hydrologic connectivity between these formations in the study area. A large increase in $\delta^{13}C$ of DIC (~ 20 ‰) in San Andres brine occurred soon after CO_2 flooding, primarily from a combination of the injected CO_2 and formation carbonate dissolution. During the sampling period, the absence of any change in $\delta^{18}O$ of H_2O or $\delta^{13}C$ of DIC values in the overlying Ogallala aquifer after CO_2 injection indicates that injected CO_2 has not impacted this aquifer. Likewise, no change in $^{87}Sr/^{86}Sr$ (within 0.1 ‰) in shallow groundwater suggests that groundwater is not influenced by formation brines. Overall, the implementation of multiple isotope tracer methods provides strong evidence that the water chemistry of shallow groundwater has not been influenced by CO_2-EOR operations. Among studied isotope systems, $^{87}Sr/^{86}Sr$ is likely the most sensitive tracer of brine leakage in this carbonate reservoir study site.

Metallogeny of accretionary peri-continental orogens

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Ancient accretionary orogens are important sites for a significant proportion of base and precious metal mineralization. Throughout these orogens a systematic spatial and temporal evolution of mineral deposit types reflects the complex interplay between tectonics, magmatism, metamorphism, and ocean and atmospheric evolution. The extensional accretionary phase of the orogen development involves rifting of arcs and the formation of intra-arc rifts and associated back-arc basins that contain various styles of volcanogenic massive sulphide (VMS) deposits. In peri-continental realms of some Proterozoic to Phanerozoic orogens, far field effects of back-arc rifting have led to the formation of extension-related clastic- (± carbonate) sediment-hosted Zn-Pb mineralization within the distal continental margins behind the extending arcs and back-arcs (e.g. Canadian Cordillera). The closure of back-arc basins and subsequent accretion of earlier formed arcs and back-arc assemblages during basin inversion, and intra-arc thrusting, resulted in formation of orogenic gold deposits in imbricated/accreted assemblages (e.g. Superior Province, Appalachians, Trans-Hudson), sometimes contemporaneous with formation of foreland fold and thrust belts. Migration of these belts into inverted carbonate platforms in continental hinterlands drove carbonate-hosted Zn-Pb mineralization in some Phanerozoic orogens (e.g. Appalachians; North Australia Craton). The establishment of oxidized thickened crust and/or oxidized subduction-related resulted the formation of porphyry Cu-(Mo-Au), skarn, iron oxide Cu-Au (IOCG), and epithermal Au-Ag mineralization in some post-Archean, but predominantly Phanerozoic orogens (e.g. Canadian Cordillera, Andean margin). Magmatism associated with the collisional to post-collisional phase of orogen development resulted in granite-related skarn, Sn-W, and rare-metal deposits in S-type granites (e.g. Canadian Cordillera, Appalachians, Trans-Hudson Orogen); post-collisional phases of magmatic activity have, in some cases, led to the formation of porphyry Cu-Au and epithermal Au-Ag mineralization. The above provide generalities regarding the metallogeny of accretionary orogens, specific examples from Archean to Phanerozoic and modern convergent margins will be provided.

Pb isotopes in the El Laco magnetite-apatite deposit, Chile

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El Laco is the youngest and most pristine example of so-called Kiruna-type magnetite-apatite (MtAp) deposits and is located in a Pliocene-Pleistocene volcanic arc in northern Chile. Previous studies of the El Laco deposit reported the presence of abundant melt inclusions in phenocrysts in plagioclase and clinopyroxene in the host andesite. In order to better understand how MtAp deposits form, and specifically, the relationship between the melt inclusions, iron mineralization, and the host andesite, Pb isotopes were measured by using secondary ion mass spectrometry in melt inclusions and their host phenocrysts. Whole-rock Pb isotopes were also measured by isotope dilution thermal ionization mass spectrometry on the least altered host andesites from El Laco (including the samples with the melt inclusions), magnetite ores, and samples from underlying sedimentary rocks of the Cretaceous-Paleogene Salta Group in order to evaluate the contribution of crustal contamination in the system. The melt inclusions and phenocrysts plotted on Pb evolution diagrams are scattered between the mantle field and radiogenic upper crust. This spread in the in situ Pb isotope data reveals heterogeneity in the magma chamber, likely caused by crustal contamination. The whole rock Pb data reveal that the magnetite ore samples and the andesite plot between average orogenic and upper crust reference lines whereas the Salta sedimentary rocks contain upper crust Pb signatures. The magnetite ore samples contain significantly lower $^{206}Pb/^{204}Pb$ ratios (e.g. 18.22-18.47 ± 0.001 [2σ]) in comparison with the andesite (e.g. 18.80-18.96 ± 0.001 [2σ]). This suggests that they do not share similar sources, or that the ore underwent later radiogenic lead loss. The andesite whole rock Pb data plot in a relatively limited field in the center of the melt inclusion and phenocryst data which suggests that the whole rocks are an average of the Pb isotope system preserved in these samples.

Kinematic development of the Eastern Highlands shear zone, Cape Breton Island, Nova Scotia

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The Eastern Highlands shear zone (EHSZ) is one of several crustal-scale structures that formed and reactivated during the episodic

evolution of the Canadian Appalachians accretionary orogen. Reconstructing the reactivation history of structures like the EHSZ is critical for determining the temporal and spatial controls on pathways for fluids and magmas in the orogen. The EHSZ is interpreted to record deformation related to the closure of an intra-Ganderian back-arc basin (D1) and a later reactivation (D2) of unknown tectonic origin. Previous work identified D1 C-S-C' fabrics indicating southeast-side-up kinematics mostly overprinted by D2 C-S-C' fabrics indicating oblique, southeast-side-down, dextral motion. To document the reactivation of the EHSZ, we characterized the D2 fabrics with quartz c-axis orientation analysis and kinematic vorticity axes determined from quartz lattice preferred orientation data. While most specimens yield quartz c-axis fabrics forming a cross girdle on the plane perpendicular to the foliation and parallel to the mineral lineation, some exhibit a cross-girdle oriented in the reference frame perpendicular to the mineral lineation and parallel to the foliation. The latter specimens also present vorticity axes sub-parallel to the steep D2 mineral lineation. This indicates that a portion of the shear zone may have accommodated vertical extrusion with strike slip transpression. The timing of deformation (D1 and D2) is bracketed with U-Pb zircon geochronology of variably deformed specimens. A rhyolite specimen that contains D1 fabrics and a late-D1 quartz-diorite dyke specimen yielded U-Pb zircon ages of 424 ± 4 Ma and 390 ± 8 Ma (2σ error), respectively. U-Pb in zircon from a granite dyke specimen with D2 fabrics provides a maximum age for D2 of 372 ± 4 Ma. These results indicate that the EHSZ likely formed during the Acadian orogeny [ca. 422 - 405 Ma] and was reactivated in a heterogenous transpressive environment during the Neoacadian orogeny [ca. 385 - 337 Ma].

A review of the North Range Offset Dikes at the Sudbury impact structure, Canada

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The Offset Dikes are impact melt-bearing dikes that formed as a part of the ~ 1850 Ma Sudbury impact structure. They consist of so-called inclusion- and sulfide-rich quartz diorite (IQD) in the centre of the dike, an inclusion- and sulfide-poor quartz diorite (QD) along the margins of the dike, and a recrystallized breccia ("metabreccia") that occurs as pods within IQD. The most common emplacement mechanism proposed is that QD melt was emplaced first, followed by a sulfide-rich IQD melt, although more recent studies suggest that the two phases were emplaced at the same time and separated due to flow differentiation. The timing relative to the impact cratering process is also uncertain, with some authors suggesting rapid emplacement shortly after the impact and others advocating for emplacement thousands or tens of thousands of years after impact. To address this and other pertinent questions related to the formation of the Offset Dikes and metabreccia: we synthesize observations from the least-altered of the dikes, those located in the North Range of the Sudbury structure (Hess, Trill, Ministic, Cascaden, Pele, Foy, Parkin, and Whistle dikes). We synthesize the results of over five years of field work on the North Range Offset Dikes, as well as chemical analysis, microprobe analysis, and petrographic observations. Results show that: 1) Many field relationships are inconsistent with a multiple emplacement model; 2) Variation in composition of the dikes is observed that cannot be attributed to assimilation or contamination from host rock material, suggesting that the dikes were emplaced at different times from the differentiating impact melt sheet; 3) Metabreccia has the same appearance at each Offset Dike where it is observed, and observations are consistent with the hypothesis that metabreccia represents footwall breccia that was ripped up and incorporated during the emplacement of the Offset Dikes and subsequently thermally metamorphosed.

Gold endowment in iron sulphide nodules: insights on the enrichment controlling factors from the carbonaceous metasedimentary rocks of the Timmins-Matheson gold corridor, Ontario, Canada

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Among the different metallogenic models for orogenic gold deposits, some consider metamorphic devolatilization of crustal and/or supracrustal rocks as a potential source for gold-rich fluids. These models are often sustained by the presence of interpreted diagenetic iron sulphides (e.g. pyrite) with anomalous gold contents (100's ppb or more) in host and/or nearby sedimentary sequences, which likely contribute to the variable metal endowment of these potential source rocks. In recent years, significant gold contents (< 10 ppm Au) have been observed in the cores of some pyrite nodules hosted in Archean carbonaceous metasedimentary rocks from the Timmins-Matheson gold corridor, which raises important questions as to the timing and the processes responsible for this enrichment. We examine textures and compositions of diagenetic and epigenetic iron sulphides from a variety of assemblages (e.g. Kidd-Munro, Tisdale, and Porcupine), with the objective of establishing their paragenesis and identifying possible factors controlling gold uptake and its subsequent remobilization. This research combines field-based observations, whole-rock geochemistry, in situ elemental analyses and 2-D mapping by laser ablation ICP-MS, and uses machine learning tools to identify disparate sulphide generations based on their geochemical assemblages. Iron sulphide nodules are of particular interests, for two main reasons: 1) their widespread occurrence in the Timmins-Matheson area, and 2) they record the ambient physico-chemical conditions during growth. Despite polyphase deformation and mid- to upper greenschist metamorphism, many nodules preserve textures interpreted as primary (e.g. bedding). The highest gold contents typically occur in pyritic nodule cores, which average 0.64 ppm Au (n = 187). Thin graphitic interflow units within the Tisdale assemblage contain the highest gold values. Pyrrhotite nodules also occur in the region and are generally gold-poor, except at the Hoyle Pond and Bell Creek deposits where interflow-hosted pyrrhotite nodules can contain up to 0.35 ppm Au. Ongoing work investigates whether any gold residing in sediment-hosted iron sulphides have contributed to the endowment of the orogenic gold deposits via metamorphic desulphidation.

Characterizing the Phanerozoic history of the Canadian Shield using multi-kinetic apatite fission track analysis: examples from the Hudson Bay region

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The quantification of geological processes that shape the earth surface during the Phanerozoic remains challenging in continental interiors (such as the Precambrian Canadian Shield) mainly because of sparse geologic records. Apatite fission-track (AFT) thermochronology has traditionally been the preferred method for characterizing low-temperature histories, however slow cooling amplifies the kinetic and compositional controls on thermochronometric ages and the resulting dispersed dates are often difficult to use or interpret. The convention in the majority of AFT studies is to collect 20 ages and 100 lengths per sample but this is sometimes inadequate for well-constrained thermal

history modelling. In addition, it has been known for decades that apatite chemical composition influences FT annealing yet chemical data are lacking for most published AFT studies. To overcome these issues, new AFT data were generated in order to put new insights on the four-dimensional exhumation patterns at the scale of the Canadian landmass. Our improved AFT workflow consists of: 1) collecting 30-40 LA-ICP-MS AFT single-grain age measurements and 120-150 length measurements; 2) obtain electron microprobe data (i.e. F, Cl, Fe, Na, Mg, etc.) on the same age/length grains; and 3) use age component mixture and grain chemistry to identify statistically viable kinetic populations. The interpreted multi-kinetic AFT age populations are inversely modelled simultaneously using published annealing kinetics to derive high quality thermal histories. We present examples from the Hudson Bay region comparing previously published AFT data using conventional methods, and new data from samples using our multi-kinetic approach, to illustrate the benefits of collecting more age/length data and full elemental chemistry for use in thermal history modelling and comparison with existing thermal maturity data.

Mantle ^{3}He in groundwater of Southern Québec: a fossil record of the New England hotspot?

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Monteregian Hills are an alignment of Cretaceous magmatic intrusions emplaced in the St. Lawrence Lowlands, Quebec, Canada. Their origin is controversial and numerous isotopic and geochemical studies failed to decipher between a hotspot trail or sub-continental magmatism related to the North Atlantic opening. Here we shown that modern to Holocene groundwater from the regional aquifer contain a fourth of the helium of mantle origin (23 % of the total) with a $^{3}He/^{4}He$ up to 3.32 ± 0.08 Ra (where Ra = 1.384 x 10^{-6} is the atmospheric ratio). It is suggested that a fossil Monteregian Hills magmatic signal diluted by local radiogenic helium and preserved in the Monteregian Hills intrusions is leached locally by flowing groundwater. Helium isotopic measurements in Monteregian Hills bulk rocks and clinopyroxenes show R/Ra values up to 4.96, confirming the presence of fossil mantle helium in the surrounding rocks. A "magma aging" model suggests that the initial $^{3}He/^{4}He$ ratio in these Cretaceous intrusions was at minimum 30 ± 5Ra, favouring the hypothesis that Monteregian Hills are the product of the passage of the North American plate over the New England hotspot.

Solving the mysteries of molecular diffusion of noble gases for climate reconstruction using ab initio molecular dynamics

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(Atmospheric) noble gases (NG) are routinely used to reconstruct past climate conditions and to analyse water transport and phase partitioning. In fact, the concentrations of NG isotopes can be employed to discriminate different physical transport mechanisms by comparison to the unfractionated atmospheric isotope composition. Molecular diffusive transport is one of the controls of such exchange mechanisms and is parametrized to convert NG concentrations into environmental conditions. Thus, the possible isotopic fractionations of Ne and Ar are often used to discard certain conversion schemes. To retrieve information on age and on past climate conditions lumped parameter models (LPM) are applied. Some of these LPMs account for molecular diffusion, which was thought to cause a fractionation of NGs and their isotopes according to the square root ratio of their masses. However, recent experimental investigations focusing on isotopic fractionation within a single element challenged this broadly accepted assumption. Remarkably, the experiments showed only Ar to undergo isotopic fraction. Consequently climate reconstruction from dissolved NG concentrations remained in a limbo as there was no decisive criteria to choose the adequate LPM. To close that conceptual limit we applied ab-initio molecular dynamics (AIMD) to elucidate the molecular mechanisms ruling noble gas diffusion. We show that due to weak intermolecular interactions NGs are on a molecular scale subject to different 'diffusive regimes' forcing He and Ar to isotopically fractionate, but much less so for Ne, Kr and Xe. These results of diverging dynamical properties allow using the possible fractionation of Ar isotopes to choose the 'correct' LPM and put climate reconstruction based on dissolved NGs back on solid conceptual grounds.

Ediacaran supercontinent: did it exist?

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The supercontinental cycle hypothesis has stimulated numerous paleogeographic reconstructions of ancient supercontinents. There is no general agreement about the definition of "supercontinent", but most workers agree that it should not necessarily include 100 % of existing continental lithosphere. Most commonly three or four supercontinents are suggested for the last 2000 Ma. Hypothetical Ediacaran Pannotia is supposed to exist after the assemblage of Gondwana (at 550 Ma or later), but before the opening of Iapetus Ocean, Tornquist Sea and Paleo-Asian Ocean, which led to a separation of Laurentia, Baltica and Siberia from Amazonia and West Africa. The time of separation Baltica and Siberia from Laurentia is likely to be older than 550 Ma, but the opening of western Iapetus, i.e. the separation of Laurentia from Amazonia, until recently has been considered by some workers to occur in Cambrian. This suggestion, based on the Cambrian age of the rift-drift transition in Newfoundland, leaves a possibility of the short (not more than 30 Ma) existence of Pannotia (Gondwana+Laurentia). However, recent publications on this matter suggest this rift-drift transition was due to the opening a narrow ocean (Humber seaway) by separation of small terrane(s) (e.g. Dashwood, Precordillera, and/or Chilenia) long after the opening of the western Iapetus at 600-590 Ma. Unfortunately most Ediacaran paleomagnetic poles (especially Laurentian ones) are controversial, which might be caused by certain specifics in the work of geodynamo rather than with weird tectonic movements.

Isotopic composition of hafnium and geological history of Avalonian and Ganderian Proterozoic basement from New England and Atlantic Canada

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Avalonia and Ganderia are crustal blocks exposed along the eastern flank of the Appalachian orogen that record a Gondwanan geologic and tectonic history prior to their accretion to eastern North America. The nature of the basement to these terranes is characterized indirectly from zircon crystals obtained from arc-related magmatic rocks and from clastic sedimentary sequences and analyzed in situ for their Hf-isotope composition. Data from 450 analyses in two dozen samples from Ganderia are characterized by mainly positive initial $^{176}Hf/^{177}Hf$ ratios with εHf values between -1 and +11, with calculated crust formation Hf-TDM model ages that range from 0.79 Ga to 1.20 Ga. The large proportion of initial $^{176}Hf/^{177}Hf$ ratios that are more radiogenic than CHUR preclude magma genesis involving large-scale anatexis of an evolved crustal source and coupled with whole-rock Nd isotope data, suggest formation by partial melting of juvenile mantle with long-term LREE depletion in a series of Neoproterozoic and Palaeozoic continental

arcs. The majority of magmatic and detrital zircons from 30 samples from Avalonia are dominated by initial $^{176}Hf/^{177}Hf$ values that are more radiogenic than CHUR with calculated crust Hf-TDM model ages between 0.85-1.35 Ga. A minority of zircons have older Hf-TDM model ages ca. 1.39 to 3.09 Ga with εHf values of -30 to -1 and indicate involvement of older lithosphere in their petrogenesis. Whole-rock Sm-Nd isotopic compositions from Avalonian felsic volcanic rocks are characterized by positive initial εNd values with Mesoproterozoic TDM model ages. We interpret the pattern of TDM model ages and Lu-Hf & Sm-Nd isotopic heterogeneity to result from a ca. 1.0-1.2 Ga igneous tectonomagmatic event that formed basement to Neoproterozoic magmatic arcs in Avalonia. The presence of evolved isotopic signatures, however, indicates that LREE-enriched Palaeoproterozoic crust is present locally beneath parts of Avalonia.

Au-As association at the Orenada Zone 4 deposit, Val-d'Or, Québec

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The Orenada Zone 4 deposit, owned by Alexandria Minerals Corporation, is situated approximately 8 km southeast of Val-d'Or, Québec in the southeastern Abitibi greenstone belt. Orenada is an Achaean orogenic gold deposit that occurs directly within the Larder Lake-Cadillac deformation zone. Gold is hosted by a volcanoclastic unit that overlies Piché Group ultramafics and is interlayered with and below the Cadillac Group metasediments. It is unlike most other deposits in the Abitibi because of its structural position, host lithology and association with arsenopyrite. To understand the controls of mineralization, a petrographic and geochemical study was undertaken. Petrographic observations have documented two types of tuff within the volcaniclastic unit. The first is characterized by medium-grained, sub-round, quartz phenocrysts, within a muscovite-sercite-quartz±chlorite±carbonate groundmass. The second is characterized by medium-grained, subhedral feldspar phenocrysts within a quartz-carbonate-sericite±chlorite groundmass. Both types are distributed throughout the deposit and share the same widespread tourmaline-sericite-chlorite-carbonate alteration. Lithogeochemical and petrographic observations show a correlation between arsenopyrite and gold mineralization. Tuff samples with greater than 0.1 ppm Au show elevated As values of greater than 1000 ppm. Both medium-grained euhedral arsenopyrite and, coarse-grained, anhedral to corroded arsenopyrite are associated with gold mineralization. Electron probe microanalysis identified three main styles of gold mineralization: Gold along thin fractures with quartz-muscovite-carbonate in arsenopyrite, fine-grained (1-10 µm) sub-rounded gold inclusions within arsenopyrite cores, and as free gold mineralized adjacent to anhedral arsenopyrite associated with the altered wallrock. All three styles of gold mineralization are present in anhedral arsenopyrite whereas, only micrometer-sized gold inclusions are observed with the euhedral grains. The strong association of Au and the anhedral arsenopyrite can be used as a useful exploration tool, as petrography can be applied to drill core logging where more-favourable arsenopyrites can be identified.

Delineating recharge areas and characterizing groundwater evolution in a regional-scale carbonate bedrock groundwater system with hydrochemistry and isotopic tracers

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The Early Silurian carbonate bedrock formations of the Michigan basin, southern Ontario, contain significant quantities of high-quality groundwater resources and provide the sole drinking water source to many large municipalities and private residences. These regional-scale groundwater systems are investigated in an 8 000 km^2 study area using several isotopic and geochemical indicators of recent recharge in groundwater. Spatial trends of higher tritium corroborate with aerobic redox chemistry in the carbonate groundwater systems underlying areas of thin or permeable sediment cover. Groundwater chemical evolution beyond recharge areas is assessed with general chemistry, redox characteristics and an investigation of water-rock interaction. A comparison of strontium isotope ratios ($^{87}Sr/^{86}Sr$) in bedrock and groundwater shows that long residence times may be required for the isotopic signature of the rock to imprint on the groundwater. Sulphur isotopic composition of sulphate ($\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$) in groundwater shows isotopic evidence of pyrite oxidation in recharge areas, and a Silurian sulphur isotopic signature in areas of thick and low permeability sediments, downgradient of identified recharge areas. For this investigation, isotopic and hydrochemical tools have provided essential lines of empirical evidence, supporting the development of a conceptual model of recharge and groundwater evolution in this complex geological setting.

The Cadomian Arc and orogeny in SW Iberia revisited

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The Ossa Morena Zone (OMZ) of SW Iberia records a complex pre-Variscan geodynamic evolution including the following major events: i) subduction/arc growth (~ 630-550 Ma); ii) back-arc opening and spreading (~ 600-570 Ma); iii) back-arc closure, polyphase deformation (Cadomian orogeny) and growth of a secondary arc at the N margin of OMZ (~ 565-535 Ma); and iv) subduction halt and rapid transition to rifting (~ 535-530 Ma). Neoproterozoic subduction/arc development at/near the outer margin of N Gondwana characterizes most Peri-Gondwanan terranes. In the SW Iberia segment no basement exposures occur but an Andean-type context is suggested by Ediacaran mature sandstones and carbonates (Serie Negra succession). Detrital and inherited igneous zircon data link this part of Cadomian Arc to the West African craton. Opening of a back-arc basin is indicated by tholeiitic mafic/ultramafic sequences interpreted as ophiolites, e.g. Calzadilla de los Barros (gabbro protolith dated at ca. 600 Ma). Back-arc basin opening and spreading was probably related to slab-rollback, whereas its inversion may have been connected to either subduction rate increase, a decrease of the subduction angle or both. Inversion was probably accommodated by antithetic subduction of the basin oceanic lithosphere and secondary arc growth (Malcocinado volcanics and associated plutons). Significant sinistral strike-slip components are suggested by juxtaposition of the OMZ to units derived from more easterly N-African areas (Saharan metacraton/Arabian-Nubian shield), currently outcropping north of the OMZ. Formation of a wide foreland basin onto those units, incorporating detritus sourced in the OMZ, and location of the secondary arc rocks close to the northern OMZ boundary support the antithetic polarity of subduction that led to closure of the back-arc basin. Finally, a process of oblique ridge-trench collision is envisaged as responsible for a rapid shift from subduction to rifting (Baja California style), which culminated in opening the Rheic Ocean ca. 495 Ma ago.

Metal Earth: pluridisciplinary research to improve our understanding of the genesis of Precambrian metals deposits

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Metal Earth is an ambitious research program designed to improve the understanding of metal enrichment during the Precambrian era. Our team, based at Université Laval, is involved in various Metal Earth projects (thirteen pluridisciplinary studies distributed across the Superior Craton) to characterize the nature and evolution of hydrothermal fluids in ore deposit genesis. The aims of this project are to better constrain the thermo-chemical features of the mineralizing fluids and also contribute to the understanding of the geodynamic processes associated to these various

fluids circulation systems that control ore localisation. Our first projects deal with the stable isotope composition of veins and metasomatised rocks, attesting for past fluid circulation along structural discontinuities. By combining various stable isotope systems ($\delta^{18}O$, δD, $\delta^{13}C$, $\delta^{34}S$, $\delta^{33}S$) the origin of the fluids, their temperatures, the intensity of fluid-rock interactions and the fluids fluxes can be determined. A scoping study has been carried along five transects studied by the Metal Earth teams (Malartic, Rouyn-Noranda, Larder Lake, Geraldton-Onoman, Stormy-Dryden) in order to decipher, at the large to local scale, the compositional variability of hydrothermal fluids. This campaign focused on sampling of veins of various mineralogy (mainly quartz, carbonate, tourmaline), localized in different geological units, within and outside of the main deformation zones and in mineralized and less mineralized areas.

Evolution of hydrothermal fluids in the Patterson Lake Corridor, southwestern Athabasca Basin: significance for uranium mineralization

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Unconformity-Related Uranium (URU) deposits in the Athabasca Basin formed from basinal brines under diagenetic-hydrothermal conditions along the intersections between the basal unconformity and basement-rooted faults. Fluid inclusion analyses from uranium deposits in the eastern Athabasca Basin suggests that two types of brines (NaCl-dominated and $CaCl_2$-dominated) were involved during mineralization, with salinities ranging from 25 to 35 wt % NaCl equivalent and the total homogenization temperatures (Th) from 120 to 200 °C. The purpose of this study is to evaluate whether or not the recently discovered uranium deposits in the Patterson Lake Corridor in the western Athabasca Basin, which are hosted in basement rocks up to 900 m below the unconformity, formed from similar basinal brines under comparable temperature conditions. Fluid inclusion analyses indicate that primary fluid inclusions from quartz veins that formed before mineralization have salinities ranging from 0.2 to 4.5 wt % NaCl, while those from syn-mineralization druzy quartz veins yield salinities ranging from 24 to 26 wt %, with NaCl –and $CaCl_2$ – dominated varieties. Total homogenization temperatures of fluid inclusions do not show any systematic variations among different generations of quartz, ranging from 80 to 250 °C. Elemental mapping by synchrotron X-ray fluorescence on fluid inclusions in syn-mineralization quartz veins suggests that the mineralizing fluid was enriched in uranium, similar to results reported from the eastern part of the basin. The coexistence of liquid-dominated, vapor-dominated and vapor-only fluid inclusions in fluid inclusion assemblages suggests fluid boiling occurred during mineralization, a process recently proposed for the eastern uranium deposits. Our fluid inclusion data suggest that the Patterson Lake Corridor uranium deposits formed under conditions comparable to the deposits in the eastern part of the Athabasca Basin and as such belong to the URU deposit class.

Re-Os geochronology of carbonaceous shales provides new constraints on the depositional age of Mesoproterozoic strata in the Hornby Bay and Amundsen basins, northern Canada

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Mesoproterozoic sedimentary and mafic volcanic rocks of the Hornby Bay and Amundsen basins are well exposed in the Coppermine area of Canada's northern mainland. The Hornby Bay Basin comprises, in ascending order, the Hornby Bay, Dismal Lakes and Coppermine River groups. The maximum depositional age of the uppermost Hornby Bay Group is approximately 1600 Ma based on U-Pb detrital zircon geochronology. The unconformably overlying Dismal Lakes Group is undated but it is conformably overlain by ca. 1270 Ma flood basalts of the Coppermine River Group. Unconformably overlying strata of the Rae Group (Shaler Supergroup), deposited in the Amundsen Basin, have a maximum depositional age of 1150 Ma, also based on detrital zircon geochronology. Most of these strata lack horizons suitable for direct dating via U-Pb (zircon) geochronology, but they do include carbonaceous mudstone that can yield relatively precise ages using Re-Os geochronology. Two such mudstone-bearing units are the Fort Confidence Formation at the base of the Dismal Lake Group and the Escape Rapids Formation at the base of the Rae Group. Thinly parallel-laminated, carbonaceous mudstone horizons are interbedded with lenticular-bedded sandstones within shallow sub-tidal marine strata of the Escape Rapids Formation. These strata were sampled in drill core from a section approximately 30 m above a low-angle unconformity with the underlying Coppermine River Group. Here we present new Re-Os sedimentary rock geochronology data from the Escape Rapids Formation that provide a robust lower depositional age for the Shaler Supergroup with a highly unradiogenic initial $^{187}Os/^{188}Os$ value. This new age constrains deposition of the ~ 4 km-thick succession over a period of approximately 350 Ma. Further, this new age suggests that the Shaler Supergroup correlates directly with the Bylot Supergroup, exposed in the Borden Basin on northern Baffin Island, and that the Amundsen and Borden basins were perhaps connected.

Geothermal potential of Ambilobe and Sambirano, North Madagascar

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Madagascar intends to reduce his dependence on fossil energy and to mitigate carbon emissions through his energy transition policy by developing alternative and renewable energy from solar, wind, hydro and geothermal energy. The North region was investigated for geothermal resource potential, where hot springs with temperature ~ 48 °C are found at surface. Geothermal prospects are mainly located into two areas of the North region: Ambilobe and Sambirano. Quartenary volcanic rocks, Permo-Trias sediments dominated by shale and sandstone, which overlie a faulted and fractured Proterozoic metamorphic basement dominantly composed by gneiss constitute the main geological units of those areas. Ambilobe prospect is spatially associated with a normal fault zone making the contact at surface between the Proterozoic basement and the Permo-Trias sediments, whereas Sambirano prospect is located in a larger graben structure. Reservoir temperature ~ 180 °C is anticipated from hydrochemical geothermometry that has been combined with hydrological, geological including tectonic and structural setting, defined from fieldwork and literature, to classify the geothermal system characteristics of each prospective target area. A first conceptual model was built to better understand factors controlling heat source, permeability and fluid migration. Ongoing laboratory measurements of thermophysical properties of collected rock samples will allow applying the thermofacies concept for characterizing the geothermal potential of the North region. The geothermal systems in the North region are classified as volcanic liquid-dominated moderate temperature associated with extensional domains defining the geothermal play. These findings indicate potential for production of geothermal electricity in the North. Ambilobe and Sambirano potential areas share similarities with other regions in the world that have successfully harnessed moderate-enthalpy geothermal energy.

Western Laurentia extension ca. 2000-1200 Ma as reflected in basin development and changing fluid flow paths: implications for uranium geology

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Laurentian Proterozoic basins host U deposits developed in continent-margin rifts, collisional Trans-Hudson Orogen (THO) basins, and cratonic rifts related to NUNA breakup. Athabasca 'unconformity-type' ore formed near the base of three stacked, overlapping basins (Jackfish, Cree and Mirror): the Athabasca Basin in older literature. The oldest basin (Jackfish) is structurally and sedimentologically, but not diagenetically, similar to the Hudsonian intermontane Martin Group basins, and may be regarded as its latest. The Cree Basin (1720-1660 Ma) formed a simple NW-trending trough as the THO was modified by orogenesis to the south. The oldest U ages in the Athabasca basins correspond to that of the upper evaporitic and tuffaceous unit of the Cree Basin, the Wolverine Point Fm. Most reported uraninite U-Pb ages coincide with the formation (1550-1500 Ma) and ongoing development (1500-900 Ma) of the complex Mirror Basin. Basin fill of over 2300 m of clastics, evaporites and dolomites (not including 3700 m or more of eroded strata indicated by stratigraphic, structural, and maturation data) is preserved in deep NE-trending troughs, consistent with renewed extension accompanying continental breakup to the NW. Mirror Basin subsidence controls the shape of the underlying basement troughs. These guided Wolverine Point, Douglas, and Carswell U-extracting and emplacing brines to basement U traps along basin formation faults, often near trough ends. The sabkhas in these basins trapped dissolved U derived from lateritic weathering until deep burial remobilization. Basin sequences from this time show comparable histories through much of NW Laurentia. Basin circulation was controlled by progressing permeability changes resulting from ongoing diagenesis as the basins deepened and unroofed. No single model can describe the changing circulation patterns that affected the U deposits. The continental nature of the rifting and U emplacement deep under transient basins suggests that unconformity-type U deposits may be more widely distributed than currently realized.

Towards quantifying groundwater resources of southwestern Finland: the case of the Kurikka buried glacial aquifer system

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Groundwater provides about 60 percent of drinking water in Finland. In southwestern Finland, drinking water for the town of Kurikka (pop. ~ 21 700) comes from glaciofluvial aquifers confined underneath thick glaciomarine aquitards along structurally-controlled bedrock valleys. The nearby town of Vaasa (pop. ~ 70 000) currently uses river water; however, it is considering exploitation of the same aquifer as Kurikka. The sustainable management of this groundwater resource requires answers to several questions about 1- recharge mechanisms, 2- aquifer hydraulic connectivity and, 3- overall groundwater dynamics. The goal of this research is to develop a quantitative understanding of the 170 square kilometer buried valley. Detailed data on the characteristics of the water and aquifers/aquitards structures and their properties are being analyzed. Currently, available datasets include topography and surficial geology maps, as well as a large variety of subsurface information from 6 pumping wells, numerous observation wells, 110 boreholes to bedrock, physical and chemical properties, water levels, and geophysical properties. These subsurface data have already been integrated in a 3D geological model. Average depth of pumping wells is 60 meters (max. = 90 m) and the screened intervals are within the lowermost aquifer (~ 10 m thick), which is part of a stratified ~ 40 m-thick ice marginal sequence that overlies crystalline bedrock. The buried glaciofluvial aquifer/aquitard sequence is overlain by different till (aquitard) units, which are in turn overlain by a deglacial sequence including fine glaciomarine sediments of low permeability. Based on the integrated 3D geomodel, a finite element subsurface flow simulation is also planned to provide a quantitative understanding of the groundwater flow dynamics and to support the sustainable management of groundwater.

Effect of phosphate and Fe-oxyhydroxide coating on nanoscale Titanium Dioxide ($nTiO_2$) transport in water-saturated sand columns

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The widespread production of nanoscale titanium dioxide particles (nTiO2) has resulted in increasing $nTiO_2$ release into subsurface environments where they are exposed to complex physicochemical conditions. To elucidate the influence of dissolved components and mineralogically heterogeneous transport media on $nTiO_2$ transport, we carried out column experiments to study $nTiO_2$ transport in the presence of dissolved phosphate and iron (Fe) oxyhydroxide coating on quartz sand. The column experiments were conducted under low ionic strength (1 mM NaCl) conditions at pH 5 and 9. DLVO theory was applied to determine the particle-particle and particle-collector interaction energies. Results showed that at pH 5 the attraction forces between $nTiO_2$ and quartz sand caused a delay in $nTiO_2$ elution. At ~ 4.5 PV the favorable deposition sites became saturated and the effluent concentration quickly increased and leveled off at $C/C_0 = 0.86$. A similar breakthrough curve was observed using Fe oxyhydroxide-coated sand under the same conditions, although Fe oxyhydroxide coating decreased the delay in the $nTiO_2$ breakthrough to ~ 1 PV owing to the repulsive forces between $nTiO_2$ and the Fe oxyhydroxide coating. The presence of phosphate at pH 5 inhibited $nTiO_2$ transport to nearly zero as a result of straining of the large $nTiO_2$ aggregates. At pH 9, the mobility of $nTiO_2$ was high in quartz sand column due to the repulsive forces between negatively charged $nTiO_2$ and quartz surface. A notable $nTiO_2$ retention in the absence of phosphate was observed using the Fe oxyhydroxide-coated sand, attributable to pH change, which resulted in attractive forces between the Fe oxyhydroxide coating and $nTiO_2$. Results from this study emphasized the importance of pH in determining how dissolved components and medium heterogeneity affect $nTiO_2$ transport and showed that $nTiO_2$ transport is controlled by the overall effect of different mechanisms including aggregation, attachment, blocking, and straining.

Glacial erosional footprint of a migrating Laurentide Ice Sheet ice-divide in northeastern Quebec through ^{10}Be and remote sensing analysis

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Complex ice-flow records are documented for major ice-divide regions of the Laurentide Ice Sheet, including areas where previous empirical work and numerical models predicted a low probability of warm-based subglacial conditions and concomitant low-erosion during the last glaciation. This suggests there are important unanswered questions regarding the long-term glacial dynamics and subglacial thermal regime surrounding these ice-divide regions. In this study, we analyze the subglacial erosional record across an ice-divide region (~ 7000 km^2) associated with migration of the Quebec-Labrador Ice Dome in central-northeastern Quebec using spatial analysis and field-based methods to gain insights into subglacial erosional patterns and erosional vigour. Subglacial erosional proxies (e.g. glacially streamlined landform abundance and elongation, and lake density) were mapped and spatially quantified to create an erosional index. In addition, cosmogenic ^{10}Be abundances were measured in bedrock and till samples to estimate the degree of inheritance across the study area.

From our analysis, six distinct zones of relative subglacial erosion were identified, with a large low-erosion region in the central-upland transitioning to higher-erosional zones near the northern corners of the study area. We interpret these results as indicative of polythermal conditions that shifted spatially under the influence of a migrating ice divide, which itself occurred in response to differential drawdown and changes in the Ungava Ice Stream dynamics and configuration. The net effect of these shifting conditions is a fragmented landscape comprised of distinctive pieces resulting from differential erosion relating to the local ice flow history. This work also brings new evidence of subglacial erosion within just a few kilometres from the inferred coeval position of the ice divide. Our results thus provide evidence for warm-based subglacial conditions underneath a saddle of the Quebec-Labrador Dome for at least part of the last glaciation that has yet to be captured by ice-sheet numerical models.

U-Pb LA-ICP-MS apatite age and characterization of Archean auriferous quartz veins of the Ptarmigan and Tom Gold deposits, Yellowknife, Northwest Territories

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The Ptarmigan and Tom mesothermal gold deposits are located in the Archean Yellowknife greenstone belt, Northwest Territories. Both gold deposits are comprised of a series of echelon vein-type gold deposits hosted within upper greenschist to lower amphibolite grade ca. 2630 Ma graywacke-mudstone turbidite sequence of the Burwash Formation. These gold deposits occur within the contact aureole the S-type Prosperous granite (2592 Ma), proximal to the numerous Prosperous-related pegmatite dykes. These relationships present a unique opportunity to evaluate the role (if any) that magmatic fluids may have played in the formation of these mesothermal gold deposits. The steeply dipping auriferous quartz veins were emplaced during dextral shearing. Three generations of structures were identified; (D1) a bedding-parallel, weakly spaced cleavage interpreted as S1, (D2) a dominant foliation with variable intensity that ranges from spaced cleavage in greywacke to a schistosity within slate horizons, and (D3) a crenulation cleavage. In addition to the structural generations, a sequence in style of quartz veins was observed. Structural interpretation displays progressive deformation as follows; (A) bedding parallel veins, ptygmatically folded and overprinted by porphyroblasts and refolded by outcrop-scale asymmetric folding. (B) stratabound echelon veins folded by asymmetric F2 folds. (C) Ptarmigan style veins, sub-parallel to cleavage that locally cross-cut bedding, locally boudinaged, asymmetrically folded and crosscut by straight shear veins. (C*) flat veins (extensional veins) that occur on both sides of the Ptarmigan and Tom veins, locally. (D) cleavage parallel, straight shear veins. Hydrothermal apatite hosted within the Ptarmigan vein was dated via LA-ICP-MS method and yielded a preliminary U-Pb age of ca. 2575 Ma. This result is consistent with the previously proposed timing for S-type pluton-related lode-gold within graywacke-mudstone turbidites ca. 2600 Ma. MicroXRF mapping of apatite grains via LA-ICP-MS and analysis of vein-hosted galena is integrated to refine common Pb.

Assessing the potential for deep fluid upflow near gas fields with geochemical indicators

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Conventional hydrogeological and geological data do not provide an adequate understanding of deep groundwater flow dynamics. Within the framework of two projects on potential impacts of unconventional reservoir development on aquifers, hydrogeochemical data have made key contributions to the development of representative conceptual groundwater flow models. In the St-Édouard project (St. Lawrence Lowlands, QC), initial geological and hydrogeological data had provided indications against the presence of a fluid migration pathway along regional fault zones. However, the occurrence of low Cl/Br ratios compared to sea water suggesting the presence of brines was detected in several shallow observation wells located near or downstream of a normal fault. ^{36}Cl values confirmed a contribution of old, deeper water, indicating that this normal fault acts as a discharge zone for deep regional groundwater flow. Permeability in this fault is likely higher and allows flow only in the upper 200 to 500 m, as methane in these wells showed a very different isotopic signature than that of the deep Utica Shale. In a project carried out in an active natural gas field in southern New Brunswick, most shallow monitoring wells showed $CaHCO_3$ water type, thus young water, while piezometric data and a regional groundwater flow model suggested a shallow groundwater flow zone, in the order of 100 m. However, two of these wells had distinct water types (CaCl and $CaSO_4$) that can only be associated to an underlying salt structure. The tectonized evaporite layer has a very variable topography, but the salt dome crest in the study area is located at a minimum depth of 250 to 300 m, confirming again that regional groundwater flow can be locally deeper than originally thought. Monitoring data provided evidence that large-scale upward migration is very unlikely.

Evaluation of groundwater discharge to a large inland lake using 222-radon and regional scale groundwater models

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Groundwater discharge is often neglected as a pathway for delivering pollutants to lakes. To understand the impact of groundwater inputs on lake water quality, the volume of groundwater discharge, the spatial distribution of this discharge, and the history of the discharging groundwater must be quantified. This study combines offshore boat 222-radon surveys with regional scale numerical groundwater modeling to evaluate groundwater discharge into Lake Simoce, a large inland lake in Ontario, Canada. The 222-radon survey data was first used to identify groundwater discharge hotspot areas along the shoreline and quantify groundwater discharge rates. The 222-radon results, which compared well with the regional scale numerical groundwater-surface water model results, were then used to provide insights into hydrogeological factors controlling groundwater discharge to large lakes in glaciated environments. Key factors included the shoreline proximity to moraine recharge areas, absence of streams along the shoreline, and presence of tunnel channel aquifers. Once validated using the 222-radon data, the regional-scale numerical models were applied to evaluate the history of the discharging groundwater so as to better identify the potential impact of the groundwater inputs on lake water quality trends. The study presents a robust approach for evaluating groundwater discharge to large inland lakes, as required to focus efforts aimed at managing non-point pollution sources.

Impact of variable wave conditions on groundwater-derived nitrogen discharge to coastal waters

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Groundwater discharge can be an important contributor of nutrients to coastal waters in some areas. While recent studies have illustrated that variable forcing (tides, seasonal recharge) can considerably affect the behaviour of nitrogen in coastal aquifers and its subsequent discharge to coastal waters, the impact of waves, in particularly variable wave conditions, is poorly understood. A numerical reactive transport model was developed in MODFLOW-NWT combined with PHT3D to explore the impact of variable wave conditions on nitrogen transformation in a nearshore aquifer and associated fluxes to coastal waters. A reaction

network considering organic matter mineralization, denitrification and nitrification was implemented. Results indicate that consideration of variable wave conditions compared to no waves or constant wave conditions considerably alters the flux of nutrients to coastal waters primarily due to higher wave-induced mixing in the nearshore aquifer between the discharging land-derived groundwater and recirculating coastal water. The findings suggest that variable wave conditions need to be considered in deriving estimates of nutrient fluxes from groundwater to coastal waters and in interpreting field data.

Revisiting the complexity of kimberlites from northeastern Angola

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The tectonic setting of northeastern Angola was influenced by the opening of the South Atlantic Ocean, which reactivated deep NE-SW-trending faults during the early Cretaceous. The new interpretation of a kimberlitic pulse during the middle of the Aptian and the Albian, which provides precise data on the age of a significant diamond-bearing kimberlite pulse in Angola, will be an important guide in future diamond exploration. These findings contribute to a better understanding of the petrogenetic evolution of the kimberlites in northeastern Angola and have important implications for diamond exploration. Six kimberlite pipes within the Lucapa structure in northeastern Angola have been investigated using major and trace element geochemistry of mantle xenoliths, macro- and megacrysts. Geothermobarometric calculations were carried out using xenoliths and well-calibrated single crystals of clinopyroxene. Geochronological and isotopic studies were also performed where there were samples available of sufficient quality. Results indicate that the underlying mantle experienced variable conditions of equilibration among the six sites. Subsequent metasomatic enrichment events also support a hypothesis of different sources for these kimberlites. The U/Th values suggest at least two different sources of zircon crystals from the Catoca suite. These different populations may reflect different sources of kimberlitic magma, with some of the grains produced in U- and Th-enriched metasomatized mantle units, an idea consistent with the two populations of zircon identified on the basis of their trace element compositions. This research shows the absence of fresh Mg-rich ilmenite in the Catoca kimberlite (one of the largest bodies of kimberlite in the world), as well as the occurrence of Fe^{3+}-rich ilmenite, do not exclude the presence of diamond in the kimberlite. This is a new insight into the concept of ilmenite and diamond exploration and leads to the conclusion that compositional attributes must be evaluated in light of textural attributes.

Modelling prospectivity of under explored regions: deploying ore system concepts and AI to focus infrastructure development

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A fundamental challenge of conducting mineral exploration in frontier regions, whether looking under cover or across northern Canada, is knowing where to look to begin with. Direct detection of mineral resources is cost prohibitive outside of the immediate vicinity of an actual minable deposit. Thus, the goal of frontier exploration is to identify the most prospective areas within which to undertake detailed studies and, hopefully, define an exploitable resource. The ore system concept attempts to consider all the aspects involved in the genetic, depositional and post-depositional processes related to the formation of an ore resource, which in turn provides a series of indicators for where a desired resource is liable to occur. To be economically viable though, a deposit needs to be readily extractable, which frequently corresponds to infrastructure access. Mineral prospectivity mapping represents the application of rule-based assessments as a mechanism to delineate target areas that will most likely contain mineral deposits. Existing predictive prospectivity methods are best applied to the broad regional scale, as effectiveness is diminished towards the deposit scale. Furthermore, current quantitative prospectivity mapping approaches have operational limitations in frontier domains, as they tend to break-down where data is sparse and heterogeneously distributed. Hence they are not suitable as a means to define where to build infrastructure corridors through frontier regions. A system for frontier exploration requires adaptability, scalability, attribution independence and accommodation of heterogeneity. A potential solution could employ machine learning to develop spatial meshes of first-order mineralization indicator vectors from all available datasets, integrated in multidimensional space by Bayesian statistics.

Deciphering surface and groundwater interactions in the eskers and moraines of the Barlow-Ojibway clay belt using GIS-Based and geochemical approaches

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In western Quebec, aquifers associated with glaciofluvial formations (eskers and moraines) are recognized for their high productivity and water quality. Several municipalities and private well owners depend on these aquifers for water supply. In addition, groundwater exfiltration zones are commonly found at the margin of eskers and moraines and kettle lakes are abundant on these formations. Such areas are conductive to the development of groundwater dependent ecosystems (GDEs). However, given the complexity of the local groundwater flow systems developed in glaciofluvial formations, evaluating the spatial distribution and extent of groundwater exfiltration zones remains challenging. In addition, knowledge of hydrological connectivity between kettle lakes and aquifers remains limited. This prevents the development of effective land use strategies aimed at protecting the GDEs. Fitting into the pre-established context, this study aims at developing approaches for evaluating groundwater/surface water interactions in the hydrological systems of eskers and moraines. The focus is set on peatlands and kettle lakes of the Abitibi-Témiscamingue region, in western Quebec, Canada. A regional-scale geological model based on geographic information systems (GIS) is used for evaluating the position of the water table within eskers and moraines. This model is compared with the spatial distribution of peatlands for identifying areas where peatlands are spatially associated with groundwater exfiltration zones. In addition, the geochemical data (major ions, trace elements and stable isotopes of water) gathered from more than 30 small lakes sampled during the summer of 2018 are discussed for evaluating the hydrological connectivity between kettle lakes and aquifers. In the long term, the results of the study will provide tools to better locate GDEs, with a view to ensuring their protection.

Diatremes and root zones in the Cerro Chivo Volcanic Field (CCVF), Chubut Province, Argentina

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Maars are the second-most common type of volcano on continents and islands. Their explosive eruptions pose hazards to people and infrastructure. Kimberlitic maars can carry diamonds, including in Canadian mines. The underground portion of a maar is called a diatreme, and the transition from diatreme to underlying feeder dike is the root zone. Very few root zones have been documented on outcrop worldwide. Yet this is where at least some of the phreatomagmatic fragmentation happens. Preliminary exploration of the Tertiary Cerro Chivo Volcanic Field (CCVF), Chubut Province, Argentina, has revealed the presence of several beautifully exposed root zones, adjacent to both diatremes and unfragmented basaltic dikes. The estimated erosion level is at least 0.5 km below the original ground surface. We provide an overview of two root zones. Cerro Raiz is an elongate structure exposed over about 100

m by 20 m. It lines up with La Hoyada diatreme further west. A common rock type at Cerro Raiz is well-mixed blocks of muddy to silty sedimentary country rock in a matrix of gravelly sand with sparse juvenile fragments. Locally, large domains of country rocks start to disaggregate, with irregular margins and are locally injected by other sediments. These rocks are cut by coherent basalt dikes and pods with marginal peperites. Cerro 117 is a 900 m-long structure which comprises mostly dikes about 1.5 m-thick. Some segments widen to up to 60 m thick and contain rocks partly similar to those at Cerro Raiz. In addition, Cerro 117 includes moderately to vertically dipping, dm-thick beds of tuff, lapilli tuff and tuff breccia which are similar in appearance to the main infill of La Hoyada diatreme. This confirms that Cerro 117 is a true diatreme root zone.

Numerical evaluation of the effect of the excavated damaged zone on the solute exchanges between backfilled pits and the environment

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In-pit disposal of mine wastes is a promising alternative management approach to reduce the size of waste rock piles and tailings impoundments on the surface. However, the presence of dissolved oxygen and ferric iron in underground water could contribute to generate acid mine drainage (AMD). Moreover, the presence of an initial contamination in the waste pore water should be controlled to avoid dispersion in the environment. Several approaches were proposed to limit solute exchanges between groundwater and reactive mine wastes in pits. For example, the pervious surround technique consist in the creation of preferential flow paths along the pit wall by selective disposal of permeable coarse-grained materials to divert underground water from reactive wastes. The approach was proven efficient to limit the contaminant fluxes from the pit to the environment in the long-term. The present study focused on the role of the excavated damaged zone (EDZ) created by blasting of host rock and constituted of fractures sub-parallel to the pit walls. Its role as a natural pervious surround was investigated. The effect of the damaged zone on the solute exchanges between the environment and the mine wastes was assessed using 3D numerical model. The fractured rock mass was simulated using a dual porosity representation and a parametric study was carried out to assess the impact of the properties of the EDZ and the pit shape on the reduction of solute exchanges. Numerical approach and main results will be discussed in this presentation, and recommendations for modelling the EDZ will be proposed.

Ressources en eau souterraine au Québec: l'état des connaissances

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La connaissance des eaux souterraines d'un territoire est une condition nécessaire pour en assurer la gestion optimale. Au Québec, la réalisation d'études régionales de caractérisation hydrogéologique a débuté dans les années 1970 et s'est poursuivie dans les années 1990 et 2000, en collaboration avec la Commission géologique du Canada et le milieu universitaire. En 2008, dans le but de caractériser les eaux souterraines de l'ensemble du territoire municipalisé du Québec méridional, le gouvernement du Québec a lancé une première phase de projets d'acquisition de connaissances sur les eaux souterraines (les PACES). À ce jour, treize projets ont été réalisés et une quatrième phase comportant six projets s'achèvera en 2022, ce qui permettra de couvrir la quasi-totalité des zones habitées du Québec. En parallèle, le gouvernement du Québec a financé la réalisation d'ateliers de transfert de connaissances auprès des acteurs de l'eau, le déploiement d'un réseau de suivi des eaux souterraines et la réalisation de plusieurs projets de recherches thématiques. Ces projets visaient notamment à mieux comprendre les interactions entre les eaux souterraines et les eaux de surface et à mieux prévoir les effets des changements climatiques. En plus de permettre le développement d'une expertise technique enviable en hydrogéologie au Québec, ces projets ont favorisé le contact et la collaboration des nombreux intervenants concernés par la gestion des eaux souterraines au Québec. Cette présentation résume les travaux d'acquisition de connaissances hydrogéologiques qui ont été effectués jusqu'à maintenant au Québec, les types de données disponibles et les stratégies de diffusion. Elle fait aussi état des projets de recherche en cours de réalisation. Enfin, elle présente les efforts d'intégration de l'information produite avec les autres préoccupations hydrologiques (eaux de surface, écosystèmes) dans une perspective de gestion intégrée des ressources en eau.

Emerging contaminants in leachate of old/historic closed landfills

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Many types of emerging contaminants have been found in leachate of operating municipal landfills. However, there have been few studies into leachate of old/historic closed landfills, and these have covered only a select few emerging compounds. There are many thousands of closed landfills across Canada, with many of them operational prior to current stringent environmental regulations (including leachate collection systems and engineered liners). These have the potential to leach any emerging contaminants present to groundwater and thus contaminate nearby wells and surrounding surface waters. Information on the types and concentration ranges of emerging contaminants in leachate of these old landfills would help evaluate this threat and advise on improved water quality monitoring requirements for closed landfill sites. In this study, we collected ~ 50 samples of leachate or leachate-impacted groundwater from 18 closed landfill sites across southern Ontario, with operating ages between the 1920s and 1990s. These were analyzed for standard leachate constituents (i.e. metals, nutrients, salts, petroleum hydrocarbons, chlorinated ethenes and benzenes), as well as emerging contaminants (including poly- and per-fluorinated alkylated substance (PFAS), organophosphate flame retardants, artificial sweeteners, bisphenol-A and related phenolic compounds, and several pharmaceutical and personal care products). The results of this suite of emerging contaminants will be presented and discussed in relation to the presence of other contaminants and landfill age, and the concentration ranges found from other emerging contaminant sources.

The threat to urban freshwater benthic ecosystems from groundwater laden with chloride (road salt)

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Chloride is also one of the most ubiquitous contaminants of groundwater in urban areas, with sources including road de-icing salts, industrial discharges, water softeners, domestic waste, landfill leachate, road dust suppressants, and fertilizers. While road salt impacts on urban waters have largely focused on melt water runoff, the discharge of chloride-contaminated groundwater also poses a considerable risk to freshwater ecosystems, and potentially through all seasons of the year. Endobenthic organisms (buried or burrowing in the benthic zone) may be especially at risk because they may experience less diluted concentrations than organisms on the sediment surface or in the overlying water. However, available information on endobenthic exposure to urban groundwater affected by road salt or other chloride sources is limited. Here we collate and analyze 22 chloride data sets from 15 different urban sites across Canada,

encompassing ~ 1300 samples of shallow discharging groundwater. Nearly all of the samples were collected in summer-autumn during base flow periods, but many exhibited an influence of road salt. Across the majority of these sites, average chloride concentrations were above those typically observed in urban wells (northern U.S.), reflecting contamination from surface of the shallow groundwater. The maximum chloride concentration per site ranged from 110 to 4600 mg/L and was higher for most sites than the maximum concentrations (typically measured during the melt period) for urban streams (northern U.S.). More than half of the sites had an average chloride concentration that surpassed chronic (long-term) freshwater guidelines for the protection of aquatic life (Canada and U.S.). These findings suggest that elevated chloride, largely from road salt, in shallow groundwater should be considered as a long-term threat to the endobenthic organisms of urban surface waters in Canada and other cold-region countries.

Characterization of apatite within the Mactung W (Cu,Au) skarn deposit, Northwest Territories: implication for the evolution of skarn fluids

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Skarn-hosted fluorapatite from the Mactung deposit has been characterized in order to understand the chemical evolution of mineralizing fluids. Early, zoned, type-i apatite is texturally associated with detrital phosphate nodules in skarned limestone. The apatite contains variable ∑REE+Y (1314 ± 821 ppm, 1σ, n = 78), negative sloping chondrite normalized REE+Y patterns with variable LREE/HREE (La_N/Yb_N = 27 ± 30), low LREE/MREE (La_N/Sm_N = 3 ± 1), and weak negative Eu anomalies (Eu_N/Eu_N^* = 0.6 ± 0.2; $Eu^* = ½Sm_N*Gd_N$). The data suggest that the breakdown of phosphate nodules influenced type-i apatite composition. Type-i apatite have high Sr (212 ± 308 ppm), Si (1225 ± 409), As (11 ± 9), Th (39 ± 35) and U (56 ± 67) with low Mn (178 ± 106) and Fe (566 ± 235). Type-ii apatite show no zoning. Individual grains in a single sample may show contrasting compositions, reflecting a continuum between two end-member REE+Y patterns. High REE+Y (e.g. 17 096 ppm) patterns are relatively flat (e.g. La_N/Sm_N= 1.25; Sm_N/Yb_N = 1.5) with negative Eu anomalies (e.g. 0.1). Relatively low ∑REE+Y (e.g. 161 ppm) patterns show negatively sloped LREE/MREE (e.g. La_N/Sm_N = 7.0) with flat to positively sloping MREE/LREE (e.g. Sm_N/Yb_N = 0.4) and positive Eu anomalies (e.g. 14.3), reflecting depletion in MREE. Scheelite did not fractionate MREE based on textural and trace element data. The REE+Y variation may reflect fractionation of MREE by apatite, or two fluids of contrasting compositions. Late type-iii apatite is associated with cross-cutting quartz-scheelite veins. Apatite contains high ∑REE+Y (7752 ± 496 ppm, 1σ, n = 3) and exhibits bowl-shaped REE+Y patterns corresponding to low MREE/LREE (Sm_N/La_N = 0.1) and MREE/HREE (Sm_N/Yb_N = 0.3) and no Eu anomaly. The results indicate apatite records the progression of the deposit from contact metamorphism to the onset and evolution of mineralizing fluids.

Structural and stratigraphic framework of the Larder Lake area, southern Abitibi subprovince: highlights from recent seismic and magnetotelluric surveys

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The Larder Lake research area located within the southern Abitibi subprovince of the Superior Province, involves targeted research along a 45 km transect, which extends across 2 crustal scale lithospheric structures, the Cadillac Larder Lake Deformation zone and the Lincoln Nipissing shear zone. These structures exhibit shared similarities in stratigraphy, structure and alteration, but vary significantly in relative metal endowment. The Cadillac Larder Lake Deformation zone and the Lincoln Nipissing shear zone, are both associated with mafic and ultramafic volcanic rocks of the Larder Lake Group (2710-2704 Ma) which are unconformably overlain by clastic sedimentary rocks of the Timiskaming (2679-2669 Ma) or Hearst assemblage (ca. 2700 Ma). This suggests an early stratigraphic relationship later overprinted by deformation and alteration. Numerous gold deposits are associated with the Cadillac-Larder Lake Deformation zone including the Kerr Addison mine which produced ~ 11 Moz of gold, where typically gold mineralization is associated with fuchsitic altered ultramafic rocks, and to a lesser extent with alkalic intrusions. Whereas gold mineralization along the Lincoln Nippising shear zone is associated primarily with Timiskaming aged weakly mineralized alkaline intrusions (2670 ± 0.7 Ma) which intrude the shear zone and to a lesser extent with fuchsitic altered ultramafic rocks. Characterization of these crustal-scale faults is imperative to address metal endowment in the Abitibi greenstone belt and combined with recent geophysical surveys indicate that the Cadillac Larder Lake Deformation zone can be resolved to ~ 30 km depths using seismic and has an associated conductivity anomaly from magnetotelluric surveys. However, the signature of the shear zone has a poor resolution on seismic surveys and has no associated conductivity anomaly, despite sharing similar characteristics with the Cadillac Larder Lake Deformation Zone. Therefore corresponding with the lack of metal endowment associated with the shear zone.

Beyond content: making geoscientific reasoning explicit in the undergraduate years

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Geoscience as a discipline has a core body of knowledge that most would likely agree upon, and on which we can build a content-rich curriculum. Geoscientists, however, also have unique perspectives and skills to contribute to issues of sustainability, the science-society connection, and other wide-reaching, multidisciplinary fields. G. Mora argued in 2013 that, as a historic and interpretive science immersed in broad temporal and spatial scales, and with the proficiencies and skills developed to tackle complex issues, geoscientists have much to offer to the wide-reaching and complex field of socio-environmental systems. Mora further argued that geoscientists have an agility in interpreting phenomena laden with uncertainty, in part by virtue of our interactions with the incomplete and vast geologic record. Yet, we remain absent in many of the conversations around these issues. If this is to change, we need to generate opportunities for our students, as future geoscientists, to recognize these potential contributions, so they can create situations where geoscientific perspectives and ways of thinking, in addition to geoscientific content and skills, add new depth and understanding to the issues of sustainability, and socio-environmental concerns more broadly. Because the teaching of undergraduates has traditionally focussed on the development of content knowledge and skills, while more tacitly assuming that students "pick up" the geologic thought processes that develop specifically-geoscientific reasoning skills, we risk ongoing failure in contributing to discussions on socio-environmental issues. This presentation addresses approaches that allow for making explicit these geoscientific reasoning skills, beginning in the first year of an undergraduate program. We provide examples of approaches to weaving ways of geoscientific thought into the core knowledge and skills, and building on this throughout the undergraduate program, without compromising content or skill development.

Gold-bearing arsenian pyrite in Carlin-type gold prospects of the Nadaleen trend, Yukon

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Gold in Carlin-type prospects of the Nadaleen trend, Yukon is within arsenian pyrite that precipitated as very small (< 2 µm) single-stage crystals and thin rims on pre-ore pyrite. Preliminary LA-ICP-MS results show that between 10 and 80 % of the gold is contained within the single-stage arsenian pyrite and the balance is contained in the rims on pre-ore pyrite. Gold-bearing arsenian pyrite progressed from 'blocky' single-stage crystals and rims to 'fuzzy' single-stage crystals and rims. Electron microprobe data show that early, 'blocky' gold-bearing pyrite has low 'Carlin-type' trace element content (i.e. 3 wt % As, 0.2 wt % Tl, 0.09 wt % Sb and 0.03 wt % Hg). Both types of gold-bearing arsenian pyrite are very small and contain similar amounts of Au. 'Blocky' gold-bearing arsenian pyrite has relatively low As and may have precipitated from fluids saturated in Au with gold partly deposited as nanoparticles. 'Fuzzy' gold-bearing arsenian pyrite has higher As content and likely precipitated from an unsaturated fluid with Au incorporated in solid solution. Electron microprobe data also indicate that within both types of gold-bearing arsenian pyrite, As substitutes for S which is consistent with hydrothermal fluids that were reduced throughout both early and late stages of mineralization. Arsenic (± Au) content of gold-bearing arsenian pyrite suggests that the late, 'fuzzy' arsenian pyrite precipitated at lower temperature than the early 'blocky' gold-bearing pyrite. The data presented here are consistent with gold-bearing arsenian pyrite precipitating from a reduced hydrothermal fluid that cooled over time, conditions that are similar to those described for hydrothermal fluids that formed Carlin-type gold deposits in Nevada.

Simulation of future climate and land use changes to identify sustainable agricultural water management practices in a subwatershed using SWAT-MODFLOW

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Agricultural water management is a global concern, especially when considering the changing climate. Ill-adapted agricultural practices and improper water use can lead to water availability and water quality issues. Climate change can also have a significant impact on the groundwater discharge due to the large fluctuations in groundwater elevation. The temporal and spatial variations of groundwater availability and contribution to river low flows, especially in water-stressed areas, need to be investigated. A small unconfined, water-stressed agricultural subwatershed was selected in southwestern Ontario to study the impact of future climate and land use practice changes on the water balance through an integrated surface and groundwater modelling approach. A fully-coupled SWAT-MODFLOW model was developed for the Lower Whitemans Creek subcatchment. The model was calibrated based on surface water flows (1960-2017) and groundwater elevation (2007-2017) data. Three contrasting climate change scenarios (1950-2100) and four different land use scenarios (business as usual, increased pasture acreage, higher water use, and best management scenario) were tested to evaluate the potential impacts of future climate change and land use practices on the water budget. The preliminary results indicate that the current agricultural practices are not significantly impacting the overall water budget. The results also indicate that climate change plays a more important role in subwatershed budget and can also govern the changes in agricultural practices. Changes in land use practices have less impact on the water budget since water use demands for different crops are not subjected to large variations. However, the combined effects of future climate change and land use changes can impact the water availability and thus may force farmers to increase irrigation rates or completely change the cropping patterns. The findings from this modelling study will help farmers to identify the best practices and provide an outlook of the future water budget in water-stressed areas for governing agencies.

Application of 3D photogrammetry to improve the geologic understanding of ore deposits: case study on the Fenelon Gold Project, Abitibi, Quebec

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Understanding the structural geology of ore bodies is imperative for successful mining and resource expansion especially in the case of complex, high grade, underground gold deposits. In active underground mines, geological modeling is often challenged by the lack of surface rock exposures and production-related time constraints on careful geologic mapping. A new technique known as 3D Photogrammetry has been implemented at Wallbridge Mining's Fenelon Gold project, located in northwestern Abitibi, Quebec, which improves the collection of data during underground mapping. The deposit is located along the Sunday Lake Deformation Zone and the gold mineralization is hosted within steeply dipping shear zones that cross-cut a package of metasedimentary-metavolcanic rocks intruded by a mafic-ultramafic sill complex. Bonanza grade mineralization is found associated with silicified portions of the shear zones forming ore shoots that plunge orthogonal or parallel to the stretching lineation. 3D Photogrammetry was incorporated into the geological mapping and grade control routine during ore drift development and consists of taking photographs at the face with an ordinary DSLR camera and post-processing using a software to produce 3D photorealistic meshes of the drift rounds. These meshes are then georeferenced and imported into a 3D modelling software to be used for daily updating of the geological model. This method represents a powerful, yet cost and time efficient new tool in underground mine geology and has several advantages over standard geologic mapping: 1) the digital mesh can be analyzed in more detail without increasing the time at the face; 2) structural measurements can be taken directly from the meshes; and 3) an unbiased record of the face is kept, which can be re-interpreted as the understanding of the geology is improved with time. Combined with traditional 2D mapping methods and geochemistry, 3D Photogrammetry is an extremely valuable tool for geologic modeling of complex ore deposits.

The Liuyuan complex in the Beishan orogen, NW China: an ophiolite at the southern edge of the Central Asia Orogenic Belt

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The Early Permian Liuyuan complex, located at the southern edge of the Beishan orogen, along the southern tip of the Central Asia Orogenic Belt, is mainly composed of pillow basalts, with subordinate gabbro, trondhjemite, and associated turbidites, carbonates and cherts.

Although the area has been investigated by several workers in recent years, with competing hypotheses if the Liuyuan complex comprise a continental rift or an oceanic setting. However, the internal structure and stratigraphic make-up of the units that comprise the complex are poorly known and controversial. The importance of the Liuyuan complex for understanding the Beishan orogen and hence, the terminal stages of the Central Asia Orogenic Belt justifies a more detailed structural and petrological analysis. Investigation of the gabbro at the base of the Liuyuan complex led to subdivision into comagmatic melanogabbro, leucogabbro, and diorite, probably linked by fractionation of plagioclase, clinopyroxene and olivine. These gabbros are intruded by trondhjemite and diabase, locally forming metre-scale mingling textures. The top section of the Liuyuan complex is composed of spectacular exposures of sheeted dykes and pillow basalts, preserving lava tubes, suggesting the complex is an ophiolite. The ophiolite is bounded in both the north and the south by a steeply north-dipping faults, the kinematics and tectonic evolution of which, at present, are not well understood. The existing geochemical signatures, the abundance of amphibole and presence of diorite suggest the ophiolite formed in a supra-subduction environment. Given that the ophiolite is imbricated together with Permian sediments, the Liuyuan complex is interpreted to have been incorporated in accretionary wedge during closure of the last vestige of the Paleo-Asian ocean. Future work will focus on the petrological and structural aspects of the Liuyuan complex, to refine the models for the late evolution of the Beishan orogen.

Structural architecture and gold mineralization of a metasedimentary basin along the Larder Lake-Cadillac deformation zone in the Abitibi greenstone belt, Quebec

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The Larder Lake-Cadillac deformation zone is a major structure between the Abitibi greenstone belt and the Pontiac subprovince in the Archean Superior Province. Near Malartic, Quebec, it forms the southern boundary of a metasedimentary basin comprised of turbiditic sandstone and minor iron formation of the Cadillac Group (< 2686 Ma) and polymictic conglomerate and sandstone of the Timiskaming Group (ca. 2677 to 2672 Ma). Multiple deformation events have affected the basin. Early shortening resulted in west-northwest trending isoclinal folds plunging moderately to the east-southeast. An axial planar cleavage, expressed as a continuous slaty cleavage in mudstone, a spaced disjunctive cleavage in sandstone, and by flattened clasts in conglomerate, is oriented anticlockwise to north-younging beds and clockwise to south-younging beds. A mineral stretching lineation, defined by biotite porphyroblasts in sandstone and elongate conglomerate clasts, plunges parallel to the regional fold axes. The folds, cleavage, and lineation are cut by gold-bearing quartz veins. These veins are tightly S-folded and oriented at a low angle anticlockwise to bedding on both limbs of regional folds. Their geometry and orientation suggests that they were emplaced during sinistral shearing after regional folding. A surrounding 5-10 cm alteration halo is comprised of white mica, arsenopyrite, carbonate, tourmaline and biotite. Mass balance calculations of the alteration show mass gains in S, C and K_2O and losses in Na_2O and CaO. Late dextral shearing produced synthetic shear bands, drag folds and boudinaged structures, all of which displace the gold-bearing quartz veins. At the nearby world-class Canadian Malartic gold deposit, mineralization is controlled by structures that formed during sinistral folding of the Pontiac metasedimentary rocks. As gold mineralization in the basin is also associated with sinistral structures, its emplacement could be structurally coeval with the mineralization at the Canadian Malartic deposit.

Devonian ophiolites of the Variscan Belt and their controversial origin: from the decease of the Rheic Ocean to the birth of an intracontinental pull-apart basin

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The suture zone depicted by the Variscan Belt includes several ophiolites of which the most frequent have yielded ages at ca. 395-400 Ma. Three of these ophiolites have been described at the Allochthonous Complexes from NW Spain: Careón, Purrido and Moeche ophiolites. They are mainly constituted by mafic rock types (greenschists, amphibolites, varied metagabbros and diabase dikes) and ultramafics, with no clear evidence of presence of metavolcanics and scarce sediments. Only the Careón ophiolite shows an identifiable original sequence where the relationships between the different rock types can be observed and it does not correspond to a classical Penrose-type structural architecture, reason why it was initially interpreted as supra-subduction type ophiolite. Considered as representative of the closure stages of the Rheic Ocean their origin and interpretation has changed with the studies of the geochemical features of their mafic lithologies. Their whole rock geochemistry varies from island-arc tholeiitic to N-MORB types supporting the initial hypothesis of a supra-subduction origin that was linked to the development of new oceanic crust at an intra-ocenic subduction zone responsible of the closure of the Rheic Ocean. Further studies of zircon geochemistry in the different units revealed the presence of a Mesoproterozoic zircon population and εHf signatures which pointed to participation of older crustal components in the origin of this Devonian oceanic crust. These data led to the proposal of a new interpretation suggesting that this oceanic basin originated in a pull-apart setting developed after a first collision between Godwana and Laurussia supercontinents. In order to achieve a most precise model it is time to display the whole set of geochemical data together and establishing in future work a comparison with equivalent Devonian ophiolites located along Europe in Cornwall, Armorican Massif and Bohemian Massif (Lizard, Drain and Sleza ophiolites respectively).

Time-space propagation of Cambrian-Ordovician rift-related magmatism in NW Gondwana: the evidence in Iberia

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The Ossa Morena Zone (OMZ) of SW Iberia records a rapid shift from subduction-related magmatism, ending ca. 535 Ma, to rift-related magmatism starting ca. 530 Ma. This shift is attributed to an oblique ridge-trench collision process, analogue to Cenozoic-recent evolution of the Pacific margin of North America. Ideally, ridge subduction might trigger formation of a slab window propagating at the trailing edge of the migrating triple point along the acute angle, and transformation of the trench into a transtensional transform margin in the obtuse angle. The magmatic expression of this process would consist in a sudden halt of subduction-related magmatism in the obtuse angle area and a progressive shift from subduction- to rift-related in the acute angle following the migration of the triple point. In NW Gondwana, recent dating has documented the along-margin propagation of the magmatic shift: latest Ediacaran (Moroccan Anti-Atlas), Terreneuvian (OMZ), Furongian (NW Iberia upper allochthon), Late Cambrian-Early Ordovician (Bohemian Massif). The evolution of the upper plate at the rear of the migrating triple point would be

controlled by impingement of the trailing slab window from below and the new prevailing transtensional regime, both providing conditions for rifting to develop, eventually leading to drifting away a terrane (part of Avalonia?) and opening behind a part of the Rheic Ocean. In Iberia the rift axis was located in OMZ, where two main magmatic pulses (Early-ca. 530-520 Ma and Main-ca. 515-500 Ma) are documented prior to breakup. A third post-breakup igneous event (Late-ca. 495-470 Ma) is more widely represented away from the OMZ (e.g. Ollo de Sapo and correlatives) where it precedes the rift-to-drift transition, reason why it is considered a late residual expression of the rifting process. This event suggests i) persistence of the deep thermal anomaly, and ii) cross-margin propagation towards more internal parts of Gondwana.

Petrology of ijolites from the Prairie Lake carbonatite complex

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This study investigates the major and trace element composition of minerals of the ijolite series rocks occurring at the Prairie Lake Carbonatite Complex, northern Ontario, together with comparative data with ijolites from the Fen complex, Norway. Trace element data (Sr, Zr, REE) were collected by LA-ICP-MS for clinopyroxene, garnet, and apatite, and in conjunction with the major element data are used to develop a petrogenetic model for Prairie Lake. The ijolites and calcite ijolites (hollaites) of Prairie Lake Carbonatite Complex have been formed by magma mixing, crystal settling, solid-state deformation, and deuteric alteration. The complex represents at least three stages of intrusion by melts of differing composition. The initial stage is predominantly biotite pyroxenite and associated coarse carbonatite veins. The second stage is primarily members of the ijolite series together with solid state deformation creating meta-ijolites, with differentiation forming malignites (potassic nepheline syenites). The third major stage is the intrusion of the CII carbonatites derived from different batches of magmas. These rocks contain xenoliths of ijolite suite rocks and phoscorites. Pyroxene compositions show an evolutionary trend from diopside in biotite pyroxenites to Fe enriched diopside-augite in ijolites, to aegirine in malignites. These data are used to show that a continuously filled fractionating magma chamber was not present at Prairie lake and that the complex formed as result of small intrusions of nephelinite into pre-existing ijolites. A similar style of petrogenesis is suggested for the Fen complex.

Melt-budget for crustal melting reveals accumulation and fractionation in the mid crust

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This study examines what happened to anatectic melt on its ascent and estimates what fraction of melt at the orogen-scale might have reached the upper crust. The anatectic rocks are, 1) residual metatexite, 2) diatexite and 3) leucogranite. The composition of a few diatexites lie on the metatexite (wall rock) - anatectic melt tie line and are simple mixtures of these. Most diatexites and leucogranites lie in the composition space crystallised solid:fractionated melt (both from the anatectic melt):metatexite. Mass balance modelling indicate a typical diatexite starts as a mixture 36 % metatexite + 64 % anatectic melt then when ~ 25 % crystallized, 73 % of the remaining melt was segregated from it. The diatexites are ~ 44 % "melt product" mostly cumulate plagioclase. Making the diatexites therefore expelled ~ 55 % of the initial amount of melt; this fractionated melt crystallised elsewhere. Mass balance modelling indicates the Ashuanipi leucogranites formed when anatectic melt attained between 12 and 46 % crystallization and ~ 45 % of the remaining melt was removed. Considering the area fraction of each rock type, the present Ashuanipi surface once contained 3.44 times as much melt as made there; it is a crustal level where anatectic melt accumulated, became contaminated and fractionated. Where did that fractionated melt go? The nearby Opinaca subprovince is a slightly shallower (P ~ 6 kbar, T ~ 810 °C) greywacke-dominated granulite terrain with < 5 % melting, but 63 % leucogranite. Most Opinaca leucogranites have highly fractionated compositions like the melts expelled from the Ashuanipi. Assuming the Opinaca represents the 2 km thick crustal layer above the Ashuanipi, and a geotherm of 30 °C km^{-1}, the volume of melt trapped between the solidus and the Ashuanipi surface is ~ 393,959 km^3, or 62 % of the total melt produced. Considerably less than 38 % of the anatectic melt produced in this collisional orogen reached the upper crust.

Legacy phosphorus dynamics near the sediment-water interface of agricultural drainage ditches

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Agricultural best management practices have reduced the total phosphorus (P) being delivered to Lake Erie, while the proportion of soluble reactive P (SRP) has steadily increased, contributing to harmful algal blooms. A possible continuous source of SRP to Lake Erie is sediment in the agricultural drainage ditches, which contains sorbed P that can be retained or released due to changes in shallow redox zonation. Here we performed a sequential P extraction on ten cores from two agricultural drainage ditches in the Lake Erie watershed to estimate the potential pool of legacy P in agricultural ditches and the fractions that are dissolved in pore water or associated with redox sensitive minerals. Loosely bound, highly mobile P contributes to < 1 % of the total SRP, while P associated with redox-sensitive Fe and Mn minerals constitutes ~ 15 % of the total SRP. Late summer measurements presented higher P concentrations on average than late spring measurements. The increase in summer may be due to reducing conditions created by stagnant, suboxic water, which can mobilize P. One site had chronically higher P concentrations, despite the implementation of best management practices such as grass buffers. The site also had low dissolved oxygen concentrations and high organic matter content in both seasons, suggesting that variations in hydrology, dissolved oxygen demand, and other factors could influence hot spots of P retention and release throughout the watershed.

Why are only certain IOCG deposits copper-rich? Insights from the Prominent Hill hematite breccia deposit, Gawler craton

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Iron oxide-copper-gold (IOCG) deposits are attractive targets for mineral exploration because they rank among the largest and richest copper, uranium and gold deposits. There is yet no consensus on the defining characteristics of IOCG deposits, nor on a genetic model which would explain why only certain deposits are rich in copper and iron. The Prominent Hill deposit features a high-grade Cu (189.7 Mt @ 1.32 % Cu, 0.5 g/t Au) and Au (78.8 Mt @ 0.06 % Cu, 1.4 g/t Au) resource hosted by hematite breccias as disclosed in a press release by Oz Minerals in 2009. The ores formed by replacement of sedimentary rocks and lavas separated by an unconformity. Intense alteration resulted in an aluminosilicate-poor rock body replaced by hematite and quartz forming the Cu-poor but Au-mineralized core of the deposit. Zones with phengite and carbonate extend outward, with alteration boundaries and Cu-grade contours overprinting lithological contacts. Economic mineralization was formed by a two-stage process in which all sulfur is derived from a magmatic source. Early pyrite formed in the host rocks as pyrite-rich

halos extending beyond the limits of regional magnetite alteration. Economic sulfide mineralization occurred via initially surface-venting magmatic fluids becoming completely oxidized by reaction with atmospheric oxygen. This main ore fluid migrated trough oxidized aquifers, for example along the unconformity, from the volcanically active land surface towards the zone of extreme leaching inside the hematite-quartz alteration rock body at Prominent Hill. Our fluid inclusion study permits the discrimination of four fluid end-members including a highly acidic, low-salinity fluid that derived from volcanic degassing likely into volcanic lake water. This fluid, charged with copper, uranium and sulfate, infiltrated the host rocks at Prominent Hill and interacted with a Fe-rich magmatic brine, local basement brines contributing some copper, and the pyrite-bearing host rocks. Surface-oxidized sulfur and copper of magmatic origin have been the oxidants in a process involving ferrous iron from the brines as reductant, resulting in redox-balanced reactions producing the low-sulfidation ore assemblage.

Cambrian to Ordovician evolution of the Lower Paleozoic peri-Gondwanan continental margin in the UK segment of the Appalachian-Caledonian Orogen

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The Appalachian-Caledonian Orogen preserves a complex record of piecemeal terrane transfer and accretion during the Lower Paleozoic collision between West Gondwana and Laurentia accompanying destruction of intervening Iapetus oceanic tracts. These terranes can be described simplistically as including arc fragments of Laurentian and Gondwanan affinity (the Notre Dame and Exploits terranes respectively), oceanic fragments incorporated into the Gondwanan continental margin (West Avalonia s.s.), and remnants of the Gondwanan continental slope apron and adjacent platform (both Ganderia and Megumia). In the UK segment of the orogen, a new tectono-stratigraphic synthesis for the island of Anglesey, and adjacent NW Wales, reveals a comprehensive record of the Appalachian Wilson Cycle recorded on this part of the peri-Gondwanan margin. We identify elements of Late Neoproterozoic accretion forming the pre-Appalachian basement; Cambrian extension, deposition and continental margin growth; Early Ordovician accretion and renewed extension; and finally, terminal collision and continental foreland basin development. A recently published synthesis of Neoproterozoic basement isotopic characteristic and provenance affinities of overlying Cambrian strata combined with a new tectono-stratigraphic synthesis of the island is used to propose that collision was strongly oblique. The result of this is interpreted to have given rise to lateral duplexing of the trailing edge of an Amazonia-proximal segment of the Gondwanan continental margin (Ganderia) against the leading edge of the West African segment (Megumia) during Early Ordovician (Monian-Penobscot) accretion.

Structural-Stratigraphic analysis of the Powell Fault Zone: implications for metallogeny of the Powell Block, Rouyn-Noranda, Quebec

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The Powell Block (PB), which hosts the Quemont Zn-Cu-Au volcanogenic massive sulfide (VMS) deposit, separates the Horne Au-Cu VMS deposit to the south from the Cu-Zn VMS deposits in the Amulet area to the north. The PB comprises a dominantly steep ENE-facing bimodal metavolcanic sequence, including distinctive volcaniclastic units as time-stratigraphic markers. Stratigraphic units are truncated by numerous NE- to E-striking faults and dislocated into several discrete fault blocks. The most extensive dislocative feature is the Powell fault (PF), an east-west striking 2-4 m wide zone of intense phyllonitic foliation with a 2.5 km strike length. It marks a discrete high strain zone along the northern boundary of the Powell syncline, an open fold with an E-W axial trace and an ESE plunge of 70°: an associated axial plane cleavage intensifies towards the PF. On vertical surfaces parallel to a sub-vertical stretching lineation within the PF, shear bands and asymmetrical strain shadows around carbonate vein clasts indicate north-over-south, reverse movement. The lack of intense crenulation of the main shear foliation and only minor younger, dextral shear sense indicators suggests that major dextral reactivation of the PF did not occur after the main stage of ductile deformation. This is in contradiction to the apparent 700 m dextral offset of a marker tuff unit found on both sides of the PF. Lithostratigraphic analysis of adjacent fault blocks shows a thickening of volcanic units and a local rhyolite dome south of the PF, indicating that this offset may result from synvolcanic, movement along the PF. The spatial association of the PF and subsidiary structures marked by dikes with intrusion-related breccias, with zones of locally spotted synvolcanic alteration and related Cu-Zn vein mineralization suggests that they acted as conduits for synvolcanic hydrothermal fluids in a VMS setting. The later syn-orogenic displacement may relate in timing to gold-quartz veins in the PB.

Structural similarities between the Ottawa River Gneiss Complex, western Grenville Province, and the Tertiary Shuswap Complex, southern Canadian Cordillera

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The 450 x 100 km Shuswap Complex, comprising the lower plate of a Tertiary metamorphic core complex (MCC) in the Canadian Cordillera, is detached via a pair of outward-dipping extensional shear zones from its low-grade metamorphic cover (upper plate). Similarly, the ~ 200 x 450 km Ottawa River Gneiss Complex (ORGC) in the western Grenville Province of eastern Ontario and western Quebec constitutes the lower plate of a 1050-1020 Ma MCC. At its southern flank, the detachment between the ORGC and the overlying upper plate, a portion of the Ottawan Orogenic Lid, involved extensional reactivation of a SE-dipping, 1090-1060 Ma reverse-sense shear zone, known as the Composite Arc Belt boundary zone (CABbz). However, the detachment at its northern margin is cryptic due to pervasive reworking at ca. 1000 Ma during formation of the Grenville Front Tectonic Zone. Both the Shuswap Complex and ORGC are composed of the reworked remnants of high metamorphic grade thrust-sheet stacks. Structural map patterns of both the Shuswap Complex and ORGC are dominated by late, gentle to open, upright to steeply-inclined, axially-lineated buckle folds, termed corrugations in the literature for the North American Cordillera and cross-folds or transverse folds in the western Grenville Province. The absolute age of the extensional detachment and associated cross-folding is well established for the Shuswap Complex, but has only recently been estimated for the ORGC, where it apparently postdated early-Ottawan ductile thrusting and crustal thickening in the CABbz by ca. 40-50 million years. This is consistent with relative dating of the L~S fabric in hinge zones of cross-folds, where stretched retrograde polycrystalline plagioclase-rich pseudomorphs after garnet porphyroblasts constrain the path of late bulk deformation and demonstrate that km-scale cross-folding occurred during exhumation of the ORGC. The sum of available evidence suggests that both MCCs formed in tectonic regimes of ductile transtension.

Labrador Sea's drowned delta, Canada's pre-Pleistocene Bell River basin, and the origin of Arizona's Grand Canyon

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Prior to destruction by continental glaciation, the Paleogene/Neogene Bell River drained an Amazon-scale basin that embraced most of Canada. The river emptied into the Labrador Sea through Hudson Strait, and fed the largest delta on the eastern seaboard between Florida and Baffin Island. Live headwaters of the Bell River basin are preserved in the Mackenzie Mountains and in the Rocky Mountains of Canada and Montana. Southern headwaters may have reached Arizona's pre-Pliocene Grand Canyon. Recent studies at Caltech suggest that Grand Canyon eroded to mid canyon depths between 28 and 18 Ma. The deeper half was cut beginning at about 5 Ma when the river was diverted to the newly-opening Gulf of California. In Montana, surviving Bell River tributaries include the headwaters of the Missouri River. Thick, fluvially deposited late Eocene through early Miocene ash beds fill remnants of paleo-tributaries in Montana. The ash may have been transported northward down a major Paleogene rift system that propagated southward from Montana along the edge of the Nevadaplano, reaching the latitude of Grand Canyon by 28 Ma. By 26 Ma, a second rift system (Rio Grande rift) propagated northward in New Mexico. Its uplifted west rim formed the east margin of the upper Colorado River drainage basin. The Colorado flowed westward through a knick point, entered the neighboring Nevadaplano rift, and began to dissect the upper levels of Grand Canyon. Erosion reached base level in the rift by 20 Ma, marking a hiatus in canyon deepening. By 5 Ma, a third rift system propagated from the newly opening Gulf of California and captured the Colorado near Lake Mead, initiating incision of the deep Inner Gorge through the broad Miocene floor of Grand Canyon. Basin-Range faulting, the Yellowstone hotspot, and continental glaciation destroyed the Bell River basin.

Quadrupolar Geodynamo: implications for Proterozoic supercontinents

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Models for the accretion and breakup of Proterozoic supercontinents commonly assume a geocentric axial dipole (GAD). Such GAD-based models are, however, often at variance with tectonic evolution. Geology-based models of Proterozoic supercontinents, however, are often incompatible with GAD. Here I propose a quadrupolar model for the Proterozoic geodynamo to permit certain geology-based supercontinent configurations, such as one proposed earlier. That model joins the eastern margin of the Siberian craton with the western margin of Laurentia, yielding precise geologic matches between ~ 20 Archean to Cambrian tectonic provinces. Provinces include orogenic belts, dike swarms, and epicratonic basins. The reconstruction also predicts a geologically viable rift/drift path for Siberia on a transform fault system along the Laurussian margin to its terminal Paleozoic collision with Baltica. The model is GAD-consistent from Ordovician through Permian time, but, instead, fits quadrupolar geometry for Proterozoic time. Correlative Proterozoic site-mean paleomagnetic data from the Siberian and Laurentian cratons fit the normal, tesseral quadrupolar base developed by Knapp in 1980. This second-degree spherical harmonic expansion ($l = 0$, $m = 2$) defines the most general non-zonal configuration of the quadrupole. The quadrupole model suggests magnetic field rotations, rather than rapid tectonic plate rotations for Proterozoic time, and is thus more consistent with geologic evidence. The Proterozoic geomagnetic field may have resembled the ambient field of Neptune, where, in the absence of large solid core, a quadrupolar field appears to be generated within a thin shell atop a stably-stratified liquid core. Those conditions may also describe Proterozoic Earth, before growth of the solid core. The solid state and conductivity of Earth's inner core and its tangent cylinder evidently anchor and stabilize GAD.

Comparison of ammonium abundance and its short wave infrared absorption spectrum based on alteration halo of Mexican silver deposits

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Epithermal silver mineralization is commonly accompanied by ammonium bearing alteration halos. Since ammonium produces absorption in shortwave infrared (SWIR), a portable SWIR spectrometer is widely used in exploration, but the detection limit of spectrometers is unknown. Furthermore, minerals hosting ammonium are not well understood. Samples were collected from the El Zapote prospect of the Tizapa mining district in the Sierra Madre Occidental of Mexico. The Ag mineralization forms quartz veins in Tertiary rhyolitic intrusions near the contacts with Mesozoic metasedimentary rocks of phyllite and limestone. Rhyolite samples are pervasively altered to form quartz, illite, muscovite and kaolinite. Samples with high ammonium abundance (~ 1000 ppm) are found near Ag veins (1000 ppm, produces the features of ammonium absorption in SWIR spectra, but the relationship between ammonium content and absorption is not apparent for samples with less than 500 ppm. Samples with no absorption of ammonium in SWIR spectrum yielded ammonium from 330 ppm to 1020 ppm, whereas samples with 540 ppm and 830 ppm ammonium show the specific absorption in the SWIR spectra. N isotopic composition values are similar among the samples, ranging from +1.1 to +9.2 ‰, plot within the range of sediments. The data suggest ammonium is derived from sediments, but the metamorphosed direct country rocks are an unlikely source.

Mobilization of Ni-Cu-(PGE) mineralization at the Cubric showing in the Southern Manneville fault zone, southern Abitibi subprovince, Quebec

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The Cubric Ni-Cu-(PGE) showing occurs in the Southern Manneville fault zone in the Abitibi greenstone belt of the Superior Province, ~ 24 km north of Malartic, Quebec. New geological mapping, core logging, petrographic-geochemical analyses, and high-resolution aeromagnetics provide new insights into the modification of Ni-Cu-(PGE) mineralization in the Abitibi Belt. Host rocks include ultramafic to felsic metavolcanic rocks of the 2714 ± 1 Ma La Motte-Vassan formation of the Malartic Group, a 2680 ± 1.5 Ma hornblende gabbro, and an oxide-facies iron formation. This age on the hornblende gabbro constrains both the maximum ages of D2 and D3 deformation as well as the maximum age of sulfide mobilization at the Cubric showing. D2 is manifested as a generally east-west striking primary S2 foliation related to the Southern Manneville fault and associated isoclinal folds, whereas D3 is manifested as a superimposed non-penetrative northeast-striking S3 cleavage. Ni-Cu-(PGE) mineralization occurs as semi-massive brecciated sulfides within the margins of the hornblende gabbro, as transposed sulfide bands parallel to foliation and durchbewegung texture within the iron formation, and as disseminated sulfides within ultramafic rocks. Sulfides are recrystallized and include pyrite-pyrrhotite-violarite-chalcopyrite-millerite-magnetite-pentlandite ± sphalerite ± galena. The mineralization has average grades of 2.5 % Ni and 0.2 % Cu at surface. The high Ni/Cu ratio suggests derivation from komatiites of the La Motte-Vassan Formation, which also host the nearby Marbridge deposit, and mobilization into the iron formation and hornblende gabbro, rather than derivation from the gabbro. Based on the lack of fractionation of Cu-rich and Cu-poor sulfides the sulfides appear to have been mobilized as monosulfide solid solution at amphibolite-facies metamorphic temperatures, but two end-member hypotheses – which are not mutually exclusive – are being considered for the mechanism of

mobilization: 1) wholesale tectonic mobilization during deformation, and 2) mobilization by a metamorphic-hydrothermal fluid.

Timing of collision initiation and location of the orogenic suture in the Scandinavian Caledonides

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The Scandinavian Caledonides formed during Baltica-Laurentia continent-continent collision in the late Silurian. We propose that initial contact along continental-margin promontories led to a drop in convergence rate, resulting in increased slab roll-back along parts of the margin still undergoing oceanic subduction. Slab roll-back caused extension of the overlying lithosphere with orogen-wide emplacement of mafic layered intrusions, ophiolite formation and bimodal magmatism at 438-434 Ma, in what immediately thereafter became the upper plate (Laurentia) in the Scandian collision. Initial collision at promontories may be challenging to identify due the metamorphic effects of full-fledged collision shortly thereafter. However, rapid deposition of sediments from eroding orogenic highs just prior to or during the 438-434 Ma period may represent a tell-tale sign of early collision. An example of such early Silurian deposits may be present on Magerøya, in the northernmost Scandianavian Caledonides, where the sediments appear penecontemporaneous with mafic intrusive units likely formed in a back-arc setting. This model provides a tight constraint on the timing of collision initiation, and provides a framework by which some tectonic units comprising the Scandinavian Caledonides can be assigned a Baltican or more exotic heritage, where other methods, such as detrital zircon (DZ) chronology cannot, as proved by DZ statistical similarity right across the entire North Atlantic region. Tracking the suture through the intrusive model highlights that many units conventionally ascribed a Baltican heritage are in fact much more far travelled.

Breaking the Grenville-Sveconorwegian link in the Rodinia supercontinent

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The Grenville and Sveconorwegian orogens have traditionally been interpreted as along-strike correlatives, resulting from ca. 1.1 Ga collision between Laurentia and Fennoscandia on one side and Amazonia on the other, forming the core of the Rodinia supercontinent. This configuration has been the stalwart of otherwise diverse reconstructions of Rodinia. Available geological data suggest that the southeast Laurentian and southwest Fennoscandian margins shared a similar active-margin evolution from pre-1.8 to 1.25 Ga and separated shortly thereafter. In the Grenville Province, this evolution appears to have ended with accretion of indigenous and exotic arc and back-arc assemblages, followed by continent-continent collision between 1.1 and 1.0 Ga, with northwestward translation of nappes in middle/lower ductile crust. In contrast, the tectonic evolution of the central and eastern Sveconorwegian Province is characterised by spatially and temporally discrete metamorphic events between 1.15 and 0.98 Ga, with near-continuous granitic magmatism to the west suggesting an active-margin setting until 0.92 Ga, with no evidence of a terminal continent-continent collision. Precambrian palaeomagnetic data are generally scarce and fraught with uncertainty, but appear to suggest significant latitudinal, and, by default, unknown longitudinal, separation of Laurentia and Fennoscandia at 1.1 Ga. By 0.95 Ga, Fennoscandia had drifted north to latitudes similar to those of Laurentia, but at an unknown distance east or west. The available geological and palaeomagnetic data therefore suggest that Laurentia and Fennoscandia were not contiguous during Grenville-Sveconorwegian orogenesis, which has major implications for Rodinia reconstructions. The ensuing Neoproterozoic evolution (Valhalla orogeny), preserved in Caledonian allochthonous units around the North Atlantic, may be key to constrain the relationship, if any, between the two continents following separation at 1.25 Ga until Caledonian collision at 0.44 Ga.

Sulfide textures and precious metal distribution within pegmatitic gabbros of the Crystal Lake intrusion, 1.1 Ga Midcontinent Rift, Ontario, Canada

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Ni-Cu-PGE sulfide mineralization within the Crystal Lake intrusion occurs in association with vari-textured gabbros and irregular Cr-spinel-bearing horizons. The association of sulfides and metal enrichment with pegmatitic units is not unique to the Crystal Lake intrusion, also being recognized within the Midcontinent Rift (MCR)'s Coldwell Complex and other major deposits (e.g. Merensky Reef, Norilsk, Voisey's Bay). To determine the controls, including the effects of volatiles, on the composition and distribution of base and precious metals throughout the Crystal Lake intrusion a detailed platinum group mineral (PGM) study is being undertaken and combined with LA-ICP-MS mapping of sulfides. Within the Crystal Lake intrusion, sulfide mineralization is largely disseminated, with massive sulfides developed locally. The ores are characterized by the magmatic assemblage pyrrhotite, pentlandite, chalcopyrite, cubanite, and accessory maucherite. In places, a low temperature assemblage of pyrite, chalcopyrite, and magnetite replaces primary sulfides to varying degrees. Palladium occurs in solid solution within pentlandite and as Pd-Bi-Sb-Te-bearing minerals. The PGMs are located within primary sulfide phases, secondary silicates, and thin chalcopyrite veinlets. Platinum resides as discrete As-bearing minerals. A close spatial relationship is observed between maucherite and the PGMs. Sulfides are variable in texture with globule (capped and uncapped), blebby, and interstitial sulfides identified. The silicate-capped sulfide globules are recognized in other Ni-Cu deposits (e.g. Norilsk) and are interpreted as the remnants of a former magmatic vapour phase that an immiscible sulfide melt attached to. Within the Crystal Lake intrusion, the morphology of the vapour phase is variable. Convex silicate caps, identical to those modelled experimentally, are present along with very irregular silicate attachments. Experimental studies have shown that sulfide/vapour compounds are capable of floating under certain conditions. The implications of these capped globules for sulfide transportation and deposition within the Crystal Lake intrusion is yet to be constrained.

The role of geophysics in the Metal Earth project

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The Metal Earth project (managed by Laurentian University) is studying the geology and geophysics along traverses in the Superior subprovince of the Canadian Precambrian shield to understand the processes controlling the distribution of mineral endowment. The work involves surficial lithological, geochemical, structural, alteration and mineralization mapping, plus geochronological studies. In this presentation, we introduce the complimentary geophysical techniques (reflection and passive seismic, magnetotelluric (MT), gravity, and regional magnetics) that the Metal Earth project is using to investigate the crustal and upper mantle structure. Existing magnetic data is being compiled to assist in the geological mapping and to determine structure above the Curie isotherm, below which rocks are not magnetic. The

modelling of the gravity and magnetic data will be assisted by physical properties measurements from both outcrop and field samples. On the Swayze transect, the MT resistivity model reveals narrow upper crustal sub-vertical zones of low resistivity interpreted to represent fluid pathways to the surface from a lower crustal quasi-horizontal zone of low resistivity. Interestingly, MT resistivity models from the Dryden area display a different character, with a quasi-horizontal zone of low resistivity being less clear. Preliminary results from the reflection seismic data show greater resolution and more features than the historic Lithoprobe data. A passive seismic survey is also being undertaken to determine the suitability of applying a traditionally much larger scale tool to more local exploration scale studies when reflection seismic is not practical. The geophysical data will be integrated with the geological data and interpreted to provide a model consistent with all data sets. The ultimate objective is that future exploration campaigns for metal-rich zones in greenfield areas can be designed more effectively.

Sedimentary records of Permian subduction processes in the Alxa, NW China: implications for the final closure of the Paleo-Asian Ocean

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The Alxa Tectonic Belt (ATB) in NW China lies between the Tianshan-Beishan orogenic belt to the west and the Solonker suture to the east along the southern Central Asian Orogenic Belt (CAOB). The geodynamic process of the ATB during the late Carboniferous-Permian is highly controversial with proposed models including Permian mantle plume, post-orogneic continental rifting, and subduction of the Paleo-Asian Ocean (PAO). This study provides field and zircon U-Pb-Hf isotopic data for the late Paleozoic sedimentary rocks from the ATB to reevaluate the late Paleozoic geodynamic process of the ATB. Field observations revealed a syn-tectonic unconformity between the middle and upper Permian sedimentary sequence. Detrital zircon U-Pb analyses show a major peak at ~ 273 Ma and a subordinate peak at ~ 440 Ma for the middle Permian sample. The upper Permian samples show consistently unimodal age spectra with single peaks at ~ 261 and ~ 263 Ma, respectively. The Permian zircons yield predominately positive $\varepsilon Hf(t)$ values, indicating major juvenile magmatic processes mixed with limited recycled Precambrian basement. The diagnostic zircon U-Pb-Hf isotopic characteristics and ubiquitous intermediate-felsic volcanic detritus in these rocks indicate rapid sediments accumulation sourced from a proximal magmatic terrane in a supra-subduction zone environment. The Paleozoic zircon U-Pb age peaks from this study are comparable to those for the Permian arc-related sediments along the Solonker Suture, thus linking the Alxa active margin with the northern margin of the North China Craton during middle-late Permian. The sedimentary rocks thus provide key constraints for the final subduction processes of the PAO, documented within the ATB, before the terminal amalgamation of the southern CAOB. This new data, combined with published data, imply that a large active continental margin existed in the Beishan, Alxa and the northern margin of the North China Craton, due to the south-dipping subduction of the Paleo-Asian Ocean (PAO) in the late Paleozoic.

Enrichment of secondary gold by lateritic weathering on Gentio do Ouro Golden District, State of Bahia, Brazil – a geochemical approach

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The Gentio do Ouro Golden District is located on the western edge of the Chapada Diamantina, the central region of the State of Bahia, Brazil. The principal ore-related geological characteristics of the study are include the presence of Proterozoic gabbroic sills in the lower portion of the Espinhaço Supergroup. The mafic sills were subsequently affected by hydrothermal (metasomatic) alteration that is associated with the emplacement of a first phase of gold mineralization along the contacts between the sills and the wall rocks. Quaternary surface weathering led to the development of thick zones of supergene alteration predominantly developed along topographic highs and which include saprolite, Latosol, duricrust, and pisolite.

Prolotlithe composition was established geochemically and more particularly through the systematic use of the Fe_2O_3 (T)/MgO ratio that is considered to be representative of the initial composition of the rocks. The formation of supergene-altered layers through weathering under lateritic conditions evolved from the parental rocks towards saprolite-duricrust-pisolite-Latosol predominantly in response to partial dessilicification and coprecipitation of trace elements with iron oxides/hydroxides. The dissolution of primary gold occurred in the presence of chemical complexes such as sulphates and sulphites were produced by the oxidation of hydrothermal auriferous sulphides in the presence of carbonates. Mobilized gold was transported under oxidizing conditions as colloidal gold and subsequently precipitated in an array of ferraneous fractures, or filling micro-cavities. The lateritic weathering processes responsible for the mobilization of gold and its secondary precipitation are responsible for its local enrichment, an increase of purity (all other associated trace metals being separated from gold), and, ultimately, in the development of nuggets in lateritic materials

New U-Pb ages and compositional data from zircons to establish the timing and evolution of porphyritic intrusions and plutonic bodies in the Yellowknife greenstone belt, NWT

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The Yellowknife greenstone belt (YGB) is located in the Archean Slave Province, in Northwest Territories, Canada. It is an area of active exploration and research promoted by the historic high-grade gold mines that produced 14.2 Moz gold (Giant and Con mines). The belt consists of a sequence of mafic and felsic metavolcanic rocks that become younger toward the southeast and that are variably intruded by three generations of intermediate to felsic dikes. The YGB is also intruded by several plutons, including the Duckfish Granite (2608 Ma), Defeat Suite (2630 Ma) and the Ryan Lake pluton (2675 Ma). To better understand the magmatic history, heavy mineral separates were obtained from these plutons and associated dikes, and U-Pb geochronology and trace element analysis were performed on zircons. The dikes include porphyritic quartz-feldspar and feldspar-quartz, as well as granitic aplites. Three populations of zircons with distinctive morphologies and colouring were identified in the mineral separates. The most abundant grains are translucent, colourless, and euhedral elongated zircons. The second and most diversified population are violet-brown, translucent to cloudy, sub-euhedral to euhedral crystals with a common faceted 'soccer-ball' shape. The least abundant population are pale yellow, translucent and euhedral crystals. Inclusions have been identified in all three populations and typically have a spherical-ovoid shape and black or red-brown colour. Overgrowths are rare and occur mostly around colourless and violet-brown crystals. The three zircons populations are present in feldspar-quartz porphyry dikes, and the yellow and colourless zircons are found only in granodiorite. U-Pb geochronology will be performed using LA-ICP-MS to determine the crystallization age for the zircon populations from each pluton and dike. In addition, in situ trace element chemistry will be gathered to determine crystallisation temperature and magmatic source, and to establish and relationship to ore-forming system(s).

Controls on the Tiriganiaq gold deposit banded iron formation-hosted ore zones, Meliadine district, Nunavut

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The Meliadine gold district in the Archean (~ 2.66 Ga) Rankin Inlet greenstone belt in Nunavut comprises numerous gold deposits and prospects that are spatially associated with the crustal-scale Pyke Fault and its splays. Many of these gold deposits, including Tiriganiaq, are partially to dominantly hosted within banded iron formation (BIF) units. The Tiriganiaq deposit is hosted in the structural hanging wall of the Lower Fault, a West-trending splay of the Pyke Fault located further to the South. The hanging wall hosts the ore-bearing, dm- to m-wide laminated quartz-ankerite shear veins referred to as the 1000 lode. There are sections along the 1000 lode vein with abundant shallowly north-dipping ore-bearing deformed extensional quartz-ankerite vein arrays. A large part of the ore is hosted within the Upper Oxide Formation, a package of iron-rich sedimentary rocks and BIF units. The southernmost ore zone (1100 lode) is a geometrically planar mineralized corridor associated with the transposed long limb of the folded BIF. The 1150 and 1250 "lode series" are more complex as they are located in the folded portion of the BIF succession controlled by Lower Fault-parallel, narrow North-dipping reverse shear zones that overprint the slightly steeper, North-dipping S2 foliation that is axial planar to tight F2 folds. Shallowly South-dipping extensional veins associated with the shear zones and related fault-fill veins are preferentially developed in tightly folded dm- to m- thick BIF layers around the moderately North-dipping reverse shear zones. Preliminary interpretations are in agreement with a protracted Paleoproterozoic compressional deformation (D2) that started with F2-folding of the host succession, followed by preferential strain partitioning along fold hinges, relatively less competent units, and lithological contacts by development of syn- to late-D2 reverse shear zones. These reverse shear zones controlled the development of shear-hosted ore-bearing veins and associated ore-bearing extensional veins, that have been progressively deformed.

Gestion des eaux souterraines au Québec: défis et recherches en cours

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Au Québec, tous les prélèvements d'eau souterraine ou d'eau de surface de 75 m^3/jour et plus ou qui alimentent plus de 20 personnes à des fins de consommation humaine doivent être autorisés par le Ministre responsable du ministère de l'Environnement et de la Lutte contre les changements climatiques (MELCC), sauf exceptions. Ce dernier agit au nom de l'état, à titre de gardien de la ressource eau, laquelle est définie dans la Loi affirmant le caractère collectif des ressources en eau et favorisant une meilleure gouvernance de l'eau et des milieux associés comme faisant partie du patrimoine commun de la nation québécoise. La Loi impose au Ministre d'exercer son pouvoir d'autorisation des prélèvements d'eau de manière à satisfaire en priorité les besoins de la population et à viser à concilier les besoins des écosystèmes aquatiques, puis des activités à caractère économique, en considérant notamment le développement du territoire et les effets des changements climatiques. Dans ce contexte, la gestion des ressources en eau du Québec par le Ministre sur le long terme et en regard des impacts appréhendés des changements climatiques nécessite la connaissance de l'état des ressources et de leur exploitation, ainsi que de leur évolution dans le temps et l'espace, ce qui représente tout un défi. Au cours des dernières années, plusieurs pays ont développé des indicateurs pour faciliter l'analyse de l'état des ressources et identifier les problématiques potentielles. Cette présentation discutera des indicateurs que le MELCC examine présentement en vue d'assurer la gestion durable, équitable et efficace des ressources en eau souterraine du Québec. Le développement de ces indicateurs doit notamment se faire en prenant en compte l'effet des changements climatiques (climat futur) et les pressions et contraintes qui ont été identifiées dans le cadre des études hydrogéologiques régionales réalisées au cours des dernières années.

Lofting turbidity currents: exploring the effects of interstitial fluid density on turbidite architecture and morphology

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River-derived hyperpycnal currents and turbidity currents initiated in relatively shallow water that travel into deeper and colder water commonly contain interstitial fluid less dense than the surrounding ambient water. These currents are initially ground-hugging due to their high suspended sediment concentrations. However, as sediment settles from suspension, bulk current density decreases and the current may become buoyant and detach from the basin floor. This process of lofting affects both the internal architecture of turbidites and their overall morphology. Here, we present results from field studies of Holocene fans on the continental shelf of Southern California and Jurassic hyperpycnites in the Neuquén Basin of Argentina, in combination with three-dimensional flume experiments, to demonstrate the ways in which lofted-current turbidites differ from classic turbidite models. The use of an unconfined experimental basin allows for the first detailed analysis of the lofting process and its effects on length-to-width ratios of turbidite lobes. Experimental results show that lofting currents are width-limited and generate narrower, more elongate deposits than ground-hugging currents. Cores collected from Holocene shelf fans in the Santa Barbara Channel provide grain-size trends, radiocarbon dates, and overall stratigraphic architecture of lofted-current deposits. The currents deposited slightly graded, structureless fine- to medium-grained sand beds. These beds became well-sorted through the stripping of fine-grained material in suspension at the point of lift-off. Similar to our experimental results, the lobes created by lofted flows are narrower than other non-lofted deposits. We compare our experimental results and Quaternary deposits with outer-shelf hyperpycnites of the Jurassic Lajas Formation of the Neuquén Basin in Western Argentina. Their well-sorted nature and narrow geometry suggest that these beds may be another example of deposition from lofting currents.

Entrapment and post-entrapment processes in melt inclusions in granulites and migmatites

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Melt inclusions are samples of silicate liquid trapped within host minerals during their growth or subsequent fracture healing, and commonly represent the best available tools to reconstruct the compositions, volatile contents, and other properties of melts. In recent years, much attention has been paid to post-entrapment processes occurring in melt inclusions in volcanic rocks, and how these affect properties such as volatile systematics which are commonly used to infer magma ascent and fluid exsolution. Meanwhile, melt inclusions trapped in peritectic garnets in anatectic settings ("nanogranites" or

"nanogranitoids") have provided a wealth of new insights into compositions and volatile contents of early-formed crustal melts. However, until now these two lines of research have been essentially separate, and little attention has been paid to whether or how the post-entrapment processes recognized in volcanic-hosted melt inclusions similarly affect inclusions in granulites and migmatites. Here, we explore the similarities and differences in mechanisms of trapping and post-entrapment modifications of peritectic melts to compare and contrast with melt inclusions in volcanic settings. We use a variety of numerical modeling techniques and simplified chemical systems, and interpret these results in light of observations on natural inclusions. Our results provide a conceptual framework in which to understand and interpret the properties of melt inclusions formed during anatexis, and thus help provide insight into the process of crustal melting.

From soil and wine to hydrothermal systems: insights from combined radiogenic and stable Sr isotopes

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The radiogenic Sr isotope ratio ($^{87}Sr/^{86}Sr$) is a proven proxy for magmatic sources and weathering. For example, the decay of ^{87}Rb with time leads to changes in the $^{87}Sr/^{86}Sr$ ratios and the evolution of crustal and mantle reservoirs that can be used to interpret the crust/mantle origin of igneous rocks. Differential weathering of Rb-rich or Sr-rich minerals leads to soils with distinct radiogenic Sr isotope ratios. Advances in mass spectrometry have made it possible to measure the stable $^{88}Sr/^{86}Sr$ isotope ratio with precision. Although, the majority of silicate rocks yield a constant (terrestrial) stable Sr isotope composition, significant fractionation of the stable $^{88}Sr/^{86}Sr$ ratio is observed in river waters due to the precipitation/dissolution of carbonate and silicate minerals. We present new research from a combined radiogenic/stable Sr isotope study of Quebec vineyards that demonstrates significant geological and biological fractionation of stable Sr isotopes within soils and between soils and plants. The stable Sr isotope fractionation within the soils is interpreted to reflect the evolution of the soil and the formation of secondary (carbonate/silicate pedogenic) minerals. The fractionation within the soil appears to be linked to stable Sr isotope fractionation in the plants/grapes and could serve as a proxy for soil fertility. The control of carbonate/silicate precipitation or dissolution on the stable Sr isotope ratio suggests that these processes can also provoke stable Sr isotope fractionation within hydrothermal fluids. This is tested through analyses of calcite from intrusion-related hydrothermal gold systems and calcite from magmatic/hydrothermal carbonatite systems.

Volcanic reconstruction of a VMS-hosting subsidence structure: the Chisel sequence, Snow Lake, Manitoba

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The Snow Lake arc assemblage of the Paleoproterozoic Trans-Hudson Orogen records a complete arc cycle, from primitive arc formation, to arc rifting, to seafloor spreading. Volcanogenic massive sulfide (VMS) deposit formation is associated with a protracted arc-rifting event, which is recorded by the Chisel sequence. Two distinct VMS deposit types formed during arc rifting: 1) the Cu-rich Anderson deposits, which are associated with felsic domes at the base of the Chisel sequence; and 2) the Zn-rich Chisel deposits, which are associated with a localized volcanic subsidence structure. Two of the Chisel deposits (Photo Lake and Lalor deposits) are anomalously enriched in Cu and Au relative to the other deposits. Voluminous primary and resedimented volcaniclastic rocks and rapid lateral facies changes indicate that intra-arc extension and rifting commenced at the transition between the Anderson and Chisel sequences and continued throughout the development of the Chisel sequence. The Chisel sequence represents a localized volcanic subsidence structure built on the primitive Anderson sequence. The Anderson and Chisel VMS deposits are distinct in terms of their stratigraphic positions, volcanic architecture and setting, and metal contents, consistent with their formation at different times during the evolution of a rifted arc. The Anderson VMS deposits formed during early widespread arc rifting, whereas the Chisel VMS deposits formed during localized extension above a magma chamber in the extended arc. The Photo Lake and Lalor deposits are interpreted to have formed along major bounding structures of the Lalor-Chisel subsidence structure. These structures acted as conduits for the upward ascent of magmatic hydrothermal fluids and were important for maintaining high fluid temperatures to shallow levels in the subseafloor, contributing to the Cu and Au enrichment of the two deposits.

A new geological map of the Lau Basin: implications for mineral prospectivity in modern and ancient arc-backarc systems

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Crustal-scale melt and fluid pathways at microplate boundaries are fundamental for productive mineralizing magmatic-hydrothermal systems; however, the processes associated with microplate formation and the timing of mineralization are poorly understood. Understanding the relationship between crustal-scale structures and crustal growth is critical for unravelling the metallogenic history and resource potential of a volcanic terrane, but in ancient VMS districts this relationship is obscured by overprinting deformation and metamorphism. As a result, most studies of VMS districts are at a scale that targets discrete volcanic centers or basins and are not informed by a larger-scale geodynamic framework. Modern seafloor systems present the opportunity to study the greater link between deep structure, crustal growth, and magmatic-hydrothermal activity beyond individual volcanic centers, but geological mapping of the seafloor is rarely done at the appropriate scale. The Lau Basin of the southwest Pacific is the location of some of the fastest-growing crust in the oceans and is associated with prolific hydrothermal activity. Although this region has been the target of 50 research cruises since 1970, there has been no attempt to create a comprehensive regional geological map of the seafloor. We have produced the first 1:1 million geological map of the Lau Basin that establishes the key lithostratigraphic assemblages and architecture related to crustal growth and mineral endowment at a regional scale. We integrate offshore geophysical data to identify geological provinces, sub-provinces, assemblages and formations in the Lau Basin in the same way that remote predictive mapping techniques have been applied to regional studies on land. The geophysical data are combined with the results of geological sampling programs to produce the first lithostratigraphic map of the Lau Basin. This map represents the first time the resource potential of an arc-backarc system can be quantitatively interpreted using area-age and volume calculations and lineament analysis.

Contrasting till dispersal patterns from kimberlites, southeast of Lac De Gras, Northwest Territories

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Complex ice flow history, variable bedrock topography, landform types, and drift thickness may lead to complex glacial sediment dispersal patterns that are difficult to interpret, with implications for subglacial sediment provenance and related ice sheet research, as well as for mineral (drift) exploration. This study investigates the controls of bedrock topography, drift thickness, and landforms on 3D dispersal patterns in two study areas located southeast of Lac de Gras, Northwest Territories. The two areas are situated only about 25 km apart and have a similar ice flow history (clockwise shift from SW to NW). However, study area #1 hosts kimberlites within low topographic relief, while area #2 hosts kimberlites on a small granitic hill. The distribution and type of sediment-landform assemblages, as well as drift thickness, also differ between the two areas. Sediment characteristics, matrix geochemistry, and kimberlite indicator minerals (KIM) from surficial samples (n = 51) were analyzed and compared with a sample subset (n = 2000, from 250 boreholes) from a large RC drilling dataset donated by industry. Digital elevation models and a surficial geology map were also used. Results show contrasting patterns between the two areas, despite a similar ice flow record. Area #1 has a well-developed, yet fragmented 3D dispersal train consistent with the clockwise ice flow shift record. Area #2's dispersal patterns are less clearly-defined and appear unrelated or only weakly related to the known local source within the granitic hill. We find relationships between: 1) the strength of dispersal patterns and the bedrock topography in the kimberlitic source area; and, 2) the dispersal style and 3D shape within sediment-landform landsystems. These relationships have implications for drift prospecting survey design, as well as the interpretation of dispersal train patterns.

Evidence for a Late Cambrian juvenile arc and a buried suture within the Laurentian Caledonides of Scotland: comparisons with hyper-extended Iapetan margins in the Appalachians and Norway

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U-Pb zircon dating establishes a Late Cambrian (Drumian) protolith age of 503 ± 2 Ma for a trondhjemitic gneiss of the calc-alkaline Strathy Complex, northern Scottish Caledonides. Positive ƐHf and ƐNd values from trondhjemitic gneisses and co-magmatic amphibolites respectively, and an absence of any inheritance in zircon populations, support published geochemistry that indicates a juvenile origin in a distal setting from the Laurentian margin. In order to account for its present location within a stack of Laurentian-derived thrust sheets, we interpret the complex as allochthonous and located along a buried suture. We propose that a microcontinental ribbon was detached from Laurentia during late Neoproterozoic to Cambrian rifting; the intervening oceanic tract closed by subduction during the late Cambrian and formed a juvenile arc, the protolith of the Strathy Complex. The microcontinental ribbon was re-attached to Laurentia during the Grampian orogeny which transported the Strathy Complex as a detached horse within a nappe stack. Peak metamorphic conditions for the Strathy Complex arc (650-700 ºC, 6-7.5 kbar) are intermediate in pressure between those published previously for Grampian mineral assemblages in structurally overlying low-P migmatites (670-750 ºC, 4 kbar) which we deduce to have been derived from an adjacent back-arc basin, and structurally underlying upper amphibolite rocks (650-700 ºC, 11-12 kbar) that we interpret to represent the partially subducted Laurentian margin. This scenario compares with the northern Appalachians and Norway where microcontinental terranes were detached from passive margins of the Iapetus Ocean during Cambrian rifting and re-amalgamated during Ordovician and Silurian orogenesis.

Metallogeny and chemostratigraphy of the Elmhirst-Rickaby assemblage: an Archean andesitic package

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Calc-alkaline andesitic rocks are ubiquitous in modern collisional settings and play a key role in their associated hydrothermal ore deposits. The lack of extensive andesitic packages and distinct bimodality of Archean volcanic successions points to their formation mainly in extensional environments where melts rise quickly to the surface without undergoing significant fractionation or mixing. Accordingly, most of the syn-volcanic mineralisation present in the Archean is associated with volcanogenic massive sulphide (VMS) processes that form in extensional settings. The ca. 2740 Ma Elmhirst-Rickaby (ER) assemblage represents the southernmost margin of the Onaman-Tashota (OT) greenstone belt, a portion of the Wabigoon Sub-Province within the Superior, and comprises one of the largest andesitic volcanic packages currently recognised in the Archean. The OT belt is one of the least-endowed Archean greenstone belts, and contains no past or currently producing VMS deposits; however, numerous atypical mineralisation styles have been recognised throughout the belt. Here we show that the andesitic portion of the ER formed either in a compressional setting , or through over-thickened crust, and that the unique metallogeny of this assemblage can be attributed to this geodynamic setting. The ER comprises a pillowed mafic sequence overlain by a thick andesitic package with minor felsic flows. This sequence appears to represent a progressive evolution from mafic to felsic compositions, suggesting significant source residence time in the crust. Mineralisation occurs in two main styles: 1) base-metal sulphide stringers associated with sericitic alteration, and 2) quartz-base-metal sulfide-magnetite veins associated with amphibole-chlorite alteration. Both of these occurrence styles are associated with syn-volcanic intrusions and have a distinct trace element association of Te-Cs-Cd-W-Sn-Hg-Se. The mineralisation styles, associated alteration, and host rock petrology of these occurrences are atypical in the context of VMS systems. This unique metallogeny and chemostratigraphy points to a geodynamic environment that would allow for significant magma storage.

Tracking hydrothermal fluid evolution of an Archean orogenic gold deposit through multiple sulphur isotope analysis linked to detailed structural paragenesis

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Our ability to detect mass independent fractionation of sulphur (MIF-S) with reliable precision in high spatial resolution on $\delta^{33}S$ when compared to the $\delta^{34}S$ ratio in micro-scale has opened a new dimension in tracking changes of hydrothermal fluid conditions and

sulphur reservoirs. In orogenic gold systems, auriferous hydrothermal fluids contain sulphur that complexes with gold during transportation in solution which is often, precipitated with sulphide minerals. The origin of the sulphur in orogenic gold hydrothermal fluids remains inconclusive. Further, the mechanism for gold precipitation is still yet to be fully understood and may linked to fluid mixing, fluid-rock interaction and/or rapid changes in the thermochemistry of the fluid. It is common for orogenic gold systems to yield a spread in $\delta^{34}S$ values; however, the single dimension $\delta^{34}S$ analyses have limitation in the ability to distinguish between changes in P-T-X conditions versus a change in sulphur reservoirs. Here, we present a multiple sulphur isotope dataset collected in situ which secondary ion mass spectrometry (SIMS) analyses targeted sulphides (pyrite and chalcopyrite) within five temporally-distinct vein sets that form the structurally-controlled Kanowna Belle orogenic gold deposit of the Kalgoorlie terrane, Western Australia. These vein sets cut across a variety of lithologies including porphyries, lamprophyres, sedimentary and volcanoclastic rocks. Results yield a consistent MIF-S anomaly ($\Delta^{33}S$ = +0.05 ‰ to +0.39 ‰) implying that the source of sulphur was consistent through the temporal evolution of the hydrothermal fluids and had limited sulphur reservoir influence from the adjacent host rocks. However, the $\delta^{34}S$ values vary significantly (-10.46 ‰ to +12.47 ‰) between different vein sets and mineral zonings. Therefore, our multiple sulphur isotope study concludes that the source of sulphur in Archean orogenic gold deposit fluids amalgamated deep, far away from the deposition site, and later precipitated gold through changes of pressure and oxygen fugacity changes.

Mobilization of platinum by high-temperature orthomagmatic brines

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Platinum-group element (PGE) ore deposits associated with ultramafic-mafic lithologies often show evidence of localized alteration resulting from migrating orthomagmatic fluids. The role of such fluids in the PGE ore-forming process has been uncertain, due in part, to the lack of precise experimental data for PGE solubility at the relevant P-T conditions. Previous studies to measure Pt solubility using the synthetic fluid inclusion (SFI) method reported 2-3 log unit variability in concentrations, attributed to fluid entrapment prior to metal-fluid-melt equilibrium. We have revisited this experimental system using a modified version of the SFI method, which enables the entrapment of an equilibrated, single-phase, NaCl+HCl-bearing fluid via in situ fracturing of a quartz cylinder at run conditions. All experiments in this study used Pt capsules and were conducted at 900 ºC and 200 MPa in an externally-heated rapid quench molybdenum-hafnium-carbide (MHC) cold-seal pressure vessel assembly. Oxygen fugacity (fO_2) was imposed using solid oxide buffers or by admixing a calculated amount of H_2 into the Ar pressure medium. Quartz-hosted SFIs that represent the metal content at run conditions were analyzed using LA-ICP-MS to quantify the Pt solubility in each experiment. A time-series was conducted for 14, 24, and 34 hour durations at identical run conditions. Platinum measurements from the time-series reproduced values within 1σ analytical error, indicating that Pt metal-fluid equilibrium has been reached within 14 hours. Preliminary results show that at ~ NNO+1 with a fixed NaCl/HCl ratio of 9:1, Pt solubility significantly increases from 8.8 ± 1.7 ppm to 73.5 ± 11.7 ppm as the total Cl concentration (mΣCl) doubles from 16 m to 32 m, respectively. This is contrary to previous work that predicts ~ 2 orders of magnitude decrease in solubility over a comparable salinity interval. Additional experiments investigating Pt solubility with variations in: i) total Cl concentration; ii) fO_2; and iii) NaCl/(NaCl+HCl) are currently underway.

A newly recognised IOCG like mineralization with enriched Ni, Cu, Co and REE in Gadarwara, M.P., India

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Airborne geophysical surveys by CSIR-NGRI identified an elongate, 1.8 km wide, 20 km long and 0.3 km deep magnetic anomaly of about 600 nT above background, south of Gadarwara, India, in a region covered by thick alluvium. Mineral exploration drilling indicates that the oval-shaped magnetic anomaly is caused by underlying magnetite-bearing banded iron formation belonging to the Mahakosal Formation of Archean to Early Proterozoic age. The anomaly is hosted in a tectonic rift zone (Narmada-Son Lineament), cuts easterly across the entire Indian subcontinent and separates the Dharwar Craton (south) from the Bundelkhan Craton (north). A drilling program (carried by a private company) penetrated alluvium up to 312 m thick to intersect rocks to depths of 612 m, thus providing core samples for research. Broadly the samples contain banded hematite jaspelite (BHJ) and banded magnetite (BM) iron formation with pervasive carbonate alterations. The samples were studied for carbon and oxygen isotope ratios, to understand the alteration chemistry, SEM, EPMA, LA-ICP-MS and U/Pb zircon isotopic dating. Laser spectroscopic analyses of C and O isotopes reveal that shale is a ^{13}C-enriched isotopic reservoir compared to carbonate in weathered iron bearing rocks. Three vertical diamond drill holes were drilled along a 1.4 km long N-S transect across the center of the geophysical anomaly. DDH-1, near the northern edge of the anomaly, went through 309 m of alluvium before intersecting bedrock and then cored 303 m of bedrock for a total depth of 612 m. Copper mineralization with appreciable amounts of cobalt, zinc, molybdenum, silver, rare earth elements, uranium and other elements was intersected. The Ni and Cr in these rocks vary from 4.63 ppm to 44.30 ppm and 11.80 to 108.10 ppm, respectively. The BIFS are highly oxidised with intense brecciation with hydrothermal overprinting. The EPMA analyses reflect abundant low Ti-Fe oxides, magnetite, hematite with grunerite and Fe-bearing actinolite. There is also Na-K intense metasomatism and Gadarwara is present in a rift type of tectonic environment.

Volcanic reconstruction of the ca. 2701 Ma Duprat-Montbray formation: implications for targeting new volcanogenic massive sulfide (VMS) deposits in the Lower Blake River Group, Rouyn-Noranda, Quebec

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The ca. 2701 Ma Duprat-Montbray formation (DMF), host to the Fabie and Magusi VMS deposits, is part of the Lower Blake River Group of the prolific Noranda VMS District. It is intruded by the 2700.6 ± 1.0 Ma synvolcanic Fabie tonalitic intrusion, which is the same age as the Flavrian-Powell intrusions. New geological mapping, geochronology, and geochemical research has resulted in a re-interpretation of the DMF with the following conclusions: (1) The DMF volcanic strata comprise basaltic andesite and andesitic flows that conformably overlie, separate and underlie a 2701.0 to 2701.5 Ma lower and upper rhyolite flow complexes. The upper rhyolite is host to the Fabie and Magusi VMS deposits and constrains the age of VMS formation. (2) Andesitic volcaniclastic lithofacies originate from primary subaqueous pyroclastic fragmentation based on the occurrence of ballistically emplaced volcanic bombs and tuffs generated by explosive hydrovolcanic fragmentation. (3) The Fabie intrusion is a composite, hypabyssal tonalitic intrusion that hosts equigranular diorite and porphyritic quartz-diorite xenoliths representing older intrusive phases. (4) The orientation and facing of the DMF strata define an open, steeply inclined anticline that wraps around the more competent Fabie intrusion and defines a previously unrecognized western

continuation of the DMF strata. (5) Hydrothermal alteration is manifested by discordant alteration mineral associations (e.g. chlorite-sericite) typical of high temperature VMS up-flow zones. The most prominent discordant VMS up-flow zone occurs at the eastern end of the Fabie Pluton where it trends north and crosscuts strata in the footwall to the Fabie and Magusi VMS deposits. A second, unrecognized and unexplored, discordant up-flow zone, located south of the Fabie Pluton, trends east-west, and cross cuts the lower rhyolite and foot wall andesitic units suggesting VMS potential for the newly discovered western extension of the DMF strata.

Hydrothermally altered impact crater lakes and the secondary clay minerals they left behind

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The formation of complex impact craters is commonly linked with generation of hydrothermal systems and post-impact lake environments. Hydrothermal venting into overlying lake environments could provide ideal habitats for life, which is of particular interest to the upcoming Mars 2020 sample return mission to Jezero Crater, an impact crater that hosts rover-accessible deltaic deposits. Many intra-crater-lakes on Earth or Mars could have been hydrothermally modified but deposits recording this interaction could have been eroded or could be otherwise inaccessible. The ~ 14.8 Ma Ries impact structure, Germany, provides a unique opportunity to study hydrothermally modified lacustrine deposits in detail as they are accessible though the Nördlingen 1973 and Wörnitzostheim 1965 scientific drill cores. Clay minerals formed during post-impact alteration of the Ries' lake deposits record temperature, fluid and source material changes involved in the alteration process. Wavelength dispersive spectroscopy (WDS) analyses and back-scattered electron (BSE) imagery shows that the ~ 100 µm sized non-clay mineral constituents are potassic feldspars and muscovite micas at shallower depths and a mixture of potassic and sodic feldspars at greater depths. This change in relatively coarse material is accompanied by a change in the mineralogy and grainsize of the clay minerals. The fine grained (< 1 µm) illitic clays are more common at shallow depths, whereas coarser (~ 1 µm) smectitic clays are more common at greater depths. Powder x-ray diffraction (pXRD) of the < 2 µm size fraction support the WDS and BSE results and additionally suggest that interstratified illite-smectite could comprise a less abundant mineral constituent throughout the drill core. pXRD of the < 0.2 µm size fraction indicates entirely dioctahedral clay minerals, consistent with illitic clays and kaolinite. These results suggest changing sediment and fluid sources with depth and demonstrates the analytical complexity required for detailed characterization of clay minerals for the upcoming Mars 2020 mission.

Borehole drilling and testing in crystalline rocks: an approach to subsurface exploration for siting a deep geological repository

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The Nuclear Waste Management Organization (NWMO) was established by Canada's nuclear energy generators (Ontario Power Generation, New Brunswick Power and Hydro Quebec) in 2002 as a requirement of the Federal Nuclear Fuel Waste Act. The NWMO's mission is to develop and implement collaboratively with Canadians, a management approach for the long-term care of Canada's used nuclear fuel that is socially acceptable, technically sound, environmentally responsible, and economically feasible. In 2005, after a multi-year dialogue with the public, the NWMO published the Adaptive Phased Management plan for managing Canada's used nuclear fuel which was accepted by the Government of Canada in 2007. The site selection process began in 2010 and 22 communities expressed interest in "Learning More" about the plan. The technical evaluation process occurs in three major phases: Initial Screenings, Preliminary Assessments and Detailed Site Characterization. These phases are part of a narrowing down process to ultimately select one site for Canada's used nuclear fuel. As of January 2019, there are 5 communities remaining in the process, including three in crystalline rock environments across northern Ontario and two in sedimentary rock environments in southern Ontario. The initial field work for Preliminary Assessments has been completed for all crystalline rock communities remaining in the site selection process. The work included the acquisition and interpretation of high-resolution airborne geophysics and geological mapping. Borehole drilling and testing is the current focus of work and includes a multidisciplinary drilling and testing program to understanding the subsurface in these five communities. Deep boreholes (1000 m) are planned to provide data to improve an understanding of the geology, geomechanics, hydrogeology, and geochemistry of potential sites. Presented are the methods used to collect this data such as: borehole deviation, core logging, hydraulic testing, geophysical well logging, groundwater sampling, and laboratory studies of core samples.

Analysis of thermal and hydraulic properties of rock samples from the Nevado del Ruiz geothermal area

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To determinate the technical viability of geothermal projects, it is necessary to conduct volcanological, geochemical, hydrogeological, and geophysics studies to propose a conceptual model of the geothermal system. Then, properties of the geological formations must be quantified or estimated to understand deep groundwater flow dynamics with numerical simulations, systematizing field information and quantifying variables of interest, such as temperature, heat flow, hydraulic heads, and groundwater velocities that affect the resource. The study area is located around the Nevado del Ruiz Volcano (NRV), in Villamaría Village, in the Caldas Colombian department. NRV is an active andesitic stratovolcano characterized by a hydrothermal system. The volcanism in the study area is caused by the subduction of the Nazca Plate below the South American continent. During a field campaign, rock samples from the main geological units outcropping to the west of NRV were collected. The thermal conductivity and diffusivity as well as the permeability and porosity of the rock samples will be evaluated in the laboratory. Permeability was also measured in the field. The quantification of these properties will help to build more accurate numerical models of groundwater flow and heat transfer. In previous modeling studies, permeability and specific heat capacity values were mostly taken from the literature and thermal conductivity measured with a needle probe only. The results obtained in this project will contribute to improve the understanding of the geothermal system in order to reduce the risks associated with the location of exploratory geothermal wells. Since this work will provide new rock samples analyses, a larger area will be covered with data, offering a better understanding of the study area and more representative temperature simulations.

1D inversion of magnetotelluric data from Ashute, Butajira geothermal prospect, South-East Ethiopia and its geothermal implications

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Geophysical surveying is one of the Earth science disciplines which is used for exploration of geothermal energy. Magnetotelluric (MT) survey was conducted in Ashute Geothermal prospect area acquiring 28 soundings. The major objectives of the study were to define the assumed up flow zone of the geothermal fluid. North-South of the major hydrothermal manifestations in the Ashute field and to make the suggest cross-section maps and 1D inversion model, to study the subsurface resistivity structure of the geothermal system at the Ashute, Butajira field, its relation to the geothermal field marked Aligned volcanic cones and the group of thermal spring in the axial part of Debre zait Selti graven suggest the main NE-SW Debre zait _ Selti fault system and transverse NW-SE older rift structure beyond to control Magmatism (heat source), water recharge and permeability of the system. Two possible heat source are suppose these are are straight associated with this young basaltic eruptions and intrusion less than 0.13 Ma and silicic centers centers identify position of in the southern part of the area. The flat low land of Butajira and Ashute plane is covered by this pyroclastic and sediment deposit. Both this pyroclastic and sediments are deposited at the same geologic time and stratigraphically they are set together one on another in undefined pattern. The trend of high and low resistivity anomaly and the discontinuities (NE-SW alignment) structure and transverse NW-SE faults and opening fissures, that indicated the possibility of the connection of the Ashute, Butajira geothermal systems. In Addition to this MT soundings towards NE-SW Ashute geothermal field and BTJ-068 in the Ashute field and reinterpretation of result using TEM data were recommended for a better definition of the anomalies and achieve the stated objectives.

Structural characterisation and geochronology of the Wager shear zone, northwestern Hudson Bay, Nunavut

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The Proterozoic Wager shear zone (WSZ) is a major zone of high strain located on the northwestern coast of Hudson Bay, Nunavut. New geological mapping was conducted during the summer of 2017 to characterise the timing, duration and kinematics of the deformation recorded by the WSZ and to interpret this new information in the regional tectonic context. At the outcrop scale, the shear zone is marked by a steep, east-west striking mylonitic foliation and a sub-horizontal mineral-stretching lineation and displays abundant dextral shear-sense indicators. Quartz crystallographic preferred orientations from mylonitic specimens indicate significant constrictional strain and that deformation mechanisms including variable amounts of dislocation creep and other processes such as grain boundary sliding operated. Paleopiezometry investigations of feldspar suggest that deformation occurred in the dislocation creep regime for that phase, near the transition into the diffusion creep field. The timing of deformation within the shear zone is informed by zircon geochronology of a suite of granitoid specimens variably affected by the WSZ. The results range in age between 1895 and 1826 Ma and indicate that the WSZ was actively deforming, at least locally, ca. 1835-1826 Ma, coeval with peak Hudsonian-age plutonism in the region. Further geochronology data are provided by titanite petrochronology results from mylonitic specimens in which cores, as well as recrystallised domains within the crystals, yield dates of ca. 1745 Ma, coeval with the Kivalliq event, known to have had far-reaching thermal effects throughout most of the western Churchill Province. The new structural and temporal data from the WSZ are similar to published information from nearby east-west striking structures such as the Amer mylonite zone.

Heterogeneous preservation of Archean tectonism recorded by titanite within the Paleoproterozoic Snowbird Tectonic Zone

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The Snowbird Tectonic Zone (STZ) is a 2800 km long crustal-scale structure that separates the Rae and Hearne cratons within the core of the Canadian Shield west of Hudson Bay. Despite its length and tectonic significance, few detailed P-T-t-D studies have been focused directly on the structure itself. New bedrock mapping of the STZ in southeast NWT has delineated multiple units including tonalite, granitoid, amphibolite and metavolcanic rocks. All units are penetratively sheared and transposed into southwest-striking, northwest-dipping mylonites that variably preserve thrust-sense kinematics and correlate well with similar units within the STZ 250 km to the southwest where deformation is dated at 1.9-1.8 Ga. Within the western portion of the study area relict high-pressure mineral assemblages are preserved in granitoids and amphibolites, whereas metavolcanic units to the east contain pillow-textures and greenschist-facies minerals, suggesting the eastern boundary of the Rae craton occurs along this paleo-pressure break. Mylonitic samples along this poorly-studied segment of the STZ were targeted for U-Pb dating to ascertain deformation ages. The two samples highlighted herein are separated by 50 km. U-Pb titanite dates of 1.83 Ga in dip-lineated anorthosite were acquired for the 3-Esker location and 2.6 Ga within the Kasba Lake granitoids to the south. The 2.6 Ga titanite are part of the foliation-defining assemblage and are considered syn-kinematic with respect to the foliation since they lack pre-kinematic porphyroblasic textures. Despite the penetrative overprinting of Paleoproterozoic shearing and recrystallization along the STZ, it is remarkable that only Archean titanite dates are preserved at Kasba Lake. Further work is underway to characterize Proterozoic vs. Archean deformation and to evaluate the P-T-t history of the high-pressure relict assemblages. Outstanding issues include evaluating the nature and extent of the Archean deformation and elucidating why Archean titanite at Kasba Lake escaped isotopic resetting during penetrative Paleoproterozoic teconometamorphism.

Paleoproterozoic and Mesoproterozoic strata of Northwest Laurentia record episodes of rifting, drifting, collision and obduction

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Much of the Proterozoic geological history of Yukon is recorded in sedimentary successions that span a billion years. Here, we describe the six oldest successions and their significance. The oldest sedimentary strata are thin sandstone interbeds within the Slab volcanics, a set of subaerially deposited mafic lavas. The sandstone records local erosion of the lava field concurrent with magmatism at ca. 1.7 Ga. The succession was built on Bonnetia, an oceanic terrane that was subsequently thrust over northwestern Laurentia. The next oldest succession ranges up to 9 km thick and was deposited on attenuated Laurentian crust during rifting between Laurentia and an adjacent landmass, probably Australia, from ca. 1.7-1.66 Ga. This unnamed and unexposed succession, identified by seismic and magnetic studies, may grade upward into the next succession, the Wernecke Supergroup, which was deposited on Laurentia as a 14 km-thick clastic-carbonate succession from ca. 1.66-1.62 Ga. The siliciclastic component was derived from the Laurentian craton and

deposited on a passive margin, which was deformed and metamorphosed during Racklan orogeny, obduction of Bonnetia, and collision with Australia, at ca. 1.60 Ga. These events were followed by deposition of sand and mud in a basin which overlapped Laurentia and the Gawler region of Australia from ca. 1.60-1.56 Ga. At ca. 1.5 Ga, the PR1 succession formed on Laurentia. The strata record deposition of silt and mud turbidites, and sediment gravity flows with carbonate olistoliths. The siliciclastic sediment was derived from the Mt Isa inlier of Australia. The last succession prior to the Neoproterozoic was the ca. 1.3 Ga clastic-carbonate Pinguicula Group. It was deposited in a southward-deepening basin with a Laurentian provenance. Collectively, these successions reveal that northwest Laurentia was involved in rifting, passive margin formation, collision, suturing to Australia, and a second event of continental separation, all from ca. 1.7-1.3 Ga.

From the snowpack to deep groundwater: integrated hydrological modelling af a steep, geologically complex Alpine catchment

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Climate change is threatening the established function of the European Alps as "water towers". The complex bedrock arrangements that are characteristic of such regions can strongly influence the broader hydrological cycle. Despite this, most predictions of climate change impacts continue to rely on conceptual hydrological models that employ highly simplified representations of groundwater flow (and indeed other processes). More physically-based, fully-distributed, integrated surface-subsurface models hold considerable potential in mountainous settings. For instance, they can directly incorporate 3D geological data where it exists, and are arguably unique in their ability to reproduce the dynamic, even ephemeral nature of headwater streams solely as a function of the meteorological forcing and domain properties. However, their application in steep, snow dominated, and geologically complex areas is impeded by a severe lack of the necessary 3D geological data, and by the fairly rudimentary approaches that are often taken with respect to modelling snow processes. Here, we present an energy balance simulation of snowpack dynamics that is subsequently combined with an integrated surface-subsurface flow model for a 37 km^2 catchment in the Swiss Alps. Wind and gravitational redistribution of snow are expected to be hydrologically significant, and are thus accounted for explicitly. Hourly, 25 m-resolution grids of i) snowmelt plus liquid precipitation, and ii) potential evapotranspiration form the input to the surface-subsurface simulator, whose structure is defined largely on the basis of a new bedrock 3D geological model and recent geophysical surveys. Uncertain subsurface hydraulic parameters are calibrated with regard to streamflow and groundwater level observations. The resultant model enables the spatio-temporal quantification of the water balance. Going forward, it will be applied firstly as a benchmark to assess the impact of various simplifying assumptions that are routinely made in integrated modelling, and secondly to predict the combined effects of anticipated changes in climate, vegetation, and permafrost on several hydrological variables.

Assimilation stochastique 3D de données ERT et gravimétriques en utilisant la simulation séquentielle bayésienne

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L'objectif de cette étude est de présenter un algorithme d'assimilation stochastique 3D de données gravimétriques et de tomographie de résistivité électrique de surface en prenant en compte explicitement le modèle conceptuel géologique ainsi que les relations spatiales entre les propriétés physiques des roches. L'approche est basée sur une méthode d'inversion stochastique dans laquelle le modèle géologique conceptuel de la zone d'étude est utilisé comme image d'apprentissage pour générer plusieurs scénarios géologiques équiprobables en utilisant une simulation multipoints. Un ensemble de modèles stochastiques de densité volumique est ensuite calculé à l'aide de simulations séquentielles gaussiennes conditionnelles à l'intérieur de chaque unité géologique afin d'explorer la distribution spatiale probable de la densité dans toutes les unités géologiques en utilisant des données de densité volumique mesurée en forage comme contraintes. Les différentes réalisations stochastiques de densité sont combinées de manière itérative et linéaire par déformation graduelle afin d'obtenir une correspondance satisfaisante avec l'ensemble des données observées. La fonction objective de la déformation graduelle est d'optimiser l'ajustement entre les anomalies de Bouguer mesurées et calculées. Le modèle de densité volumique optimisé et les données de conductivité de forage sont ensuite utilisés dans l'algorithme séquentiel bayésien pour calculer des modèles de conductivité électrique 3D qui respectent les données mesurées. Le modèle de conductivité passe par une autre étape d'optimisation de la déformation graduelle dans laquelle l'objectif est de minimiser la différence entre les potentiels électriques mesurés et calculés. Cette méthodologie est appliquée aux données du gisement de sulfures massifs volcanogènes de Lalor (SMV), situé près de Snow Lake, au Manitoba, au Canada. Le modèle pétrophysique construit avec notre méthode respecte le modèle géologique et il prend en compte la variabilité spatiale ainsi que l'incertitude inhérente à chaque méthode.

A review of the geological characteristics of the Murray Brook volcanogenic massive sulphide deposit, New Brunswick

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The Middle Ordovician Murray Brook volcanogenic massive sulphide deposit located in northeastern New Brunswick is one of the largest massive sulphide deposits in the Bathurst Mining Camp and contains 5.28 Mt of measured and indicated resources with average grades of 5.24 % Zn, 1.80 % Pb, 0.46 % Cu, 68.9 g/t Ag, and 0.65 g/t Au. The deposit occurs within the California Lake Group and is hosted within altered sedimentary rocks of the Charlotte Brook Member, in the lower part of the Mount Brittain Formation. It sits in the hinge of an F1/F2 synform and consists of a large, low- to moderate-grade massive sulphide body within which higher grade lenses occur in two structural zones: an eastern Cu-rich zone and a western Zn-Pb-rich zone, which may be tectonically dismembered parts of a single sulphide body. Both zones are stratigraphically and structurally stacked in a complexly deformed and metamorphosed succession of intensely hydrothermally altered rocks. The Cu-rich zone is considered to represent the exhalative sulphide zone that has undergone extensive replacement by hydrothermal recrystallisation during zone refining, which likely occurred during deposit formation on or near the seafloor, where the sulphides are separated based on their relative solubilities. It is characterised by approximately 20 % chalcopyrite on average with coarse, anhedral pyrite and arsenopyrite porphyroblasts. The chalcopyrite becomes finer toward the more distal zones (Zn-Pb). The Cu zone overlies the stockwork feeder system (situated on a syn-volcanic fault) and is overlain by the banded Zn-Pb zone, which is characterised by relatively high concentrations of sphalerite, galena, and locally tetrahedrite. In both zones, the sulphide distribution is highly variable and can be assigned to three different facies: pyrite-, Cu-, and Zn-rich zones. The zonation in the deposit makes it interesting in terms of metamorphic and alteration studies.

Preliminary sulphide ore characterization at the Murray Brook volcanogenic massive sulphide deposit, New Brunswick

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The Murray Brook volcanogenic massive sulphide deposit is located approximately 60 km west of Bathurst, New Brunswick. The deposit occurs within the California Lake Group and is hosted within altered sedimentary rocks of the Charlotte Brook member, in the lower part of the Mount Brittain Formation. The immediate footwall and host of the sulphide mineralization is dominantly shale with minor altered felsic volcanic rocks, whereas the immediate hanging wall consists dominantly of felsic volcanic rocks with minor related sedimentary rocks overlain by alkali basalts. Massive sulphide mineralization forms two lenses: an eastern copper-rich lens and a western zinc-lead-rich lens, and both lenses are stratigraphically and structurally stacked in a complexly deformed and metamorphosed succession of intensely hydrothermally altered rocks. Sixty-six core samples from different depths within both lenses were selected for detailed reflected light petrography and portable X-Ray fluorescence (pXRF) analysis to better establish the mineralogical and elemental associations of the different ore types. Based on preliminary observations, the samples generally show very fine-grained sulphides, semi-massive sulphide, and stringer-type sulfides. There is variability in the abundances, textures, and grain-sizes of sulphide minerals between drill-holes, and reasons for this are thought to be primary metal deposition, subsequent sedimentary processes, and metal re-distribution during dynamic deformation. The basal Cu-rich zone overlies the stockwork feeder zone and is overlain by Zn-Pb zone. Ductile chalcopyrite infills fractured pyrite and arsenopyrite grains and becomes finer toward the more distal zones. The Zn-Pb zone is characterized by relatively high concentrations of sphalerite, galena, and locally tetrahedrite. Regional metamorphism has resulted in the overall bedding/banding texture of this zone, where pyrite grains in a sphalerite matrix and the gangue form a relatively solitary banded phase. There are textural signs, in some samples, of disruption and re-sedimentation of massive and semi-massive sulphides and remobilization of chalcopyrite is also indicated.

The structural control and geochemical footprint of the world-class Hardrock orogenic gold deposit, Geraldton, ON

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The Hardrock orogenic gold deposit (6.4 Moz) is hosted by the polydeformed Beardmore-Geraldton greenstone belt that straddles the boundary between the granite-greenstone eastern Wabigoon and the metasedimentary Quetico subprovinces. The collaboration between the TGI-4 program of Natural Resources Canada and Premier and later Greenstone Gold Mines provided an excellent opportunity to improve the understanding of the gold mineralization in the Geraldton camp utilizing modern research techniques and the access to fresh drill core and new mechanically stripped outcrops. The deposit is hosted by 2700-2694 Ma turbiditic sandstone, banded iron formation and 2694 Ma feldspar-quartz porphyry that were deformed during an early thrust imbrication (D1), followed by D2 sinistral and D3 dextral transpression in the Bankfield-Tombill deformation zone. Gold is associated with strongly folded, early-D1 and E-to NE-striking, linear syn-D2 quartz-carbonate veins surrounded by sericite-carbonate-sulphide ± albite-rutile alteration halos as well as with NE- to E-striking, syn-D2 tourmaline ± quartz veins with tourmaline-carbonate-sulphide alteration selvages. Gold fills fractures and inclusions in sulphides and is bound to the lattice of inclusion-rich pyrite with elevated Au, Ag, As, Bi, Co, Ni, Pb, Sb and Te concentrations. The described alteration assemblages and sulphide chemistry are consistent with the results of the whole rock geochemistry indicating enrichment in K_2O, CO_2, CaO, S, Ag, As, Te, Sb, Se and Bi in turbiditic sandstone during gold mineralization. The deposit is surrounded by an up to 250 m wide carbonate-sericite alteration envelope with elevated S, Te, As, W and Bi concentrations. Therefore, gold mineralization was emplaced by reactivated hydrothermal pulses without major change in the fluid chemistry during multiple deformation events. Understanding the structural control and geochemical footprint of the Hardrock deposit provides important mineral exploration tools that will hopefully benefit future exploration and facilitate the discovery of additional gold resources.

Correlative petrography: foundations for virtual, accurate, sustainable and shareable petrographical data

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Petrography is an art. Information on textures and alterations gathered by the study of thin sections is highly valuable although quite inexpensive. Doing petrography is time consuming even for highly trained geologist and is user-dependant. Estimation of mineral proportions and size distribution, even for contrasting minerals, is typically tricked by our eyes. A fun survey was recently conducted in the course of a talk, where attendees were requested to estimate sulfide abundance of a thin section. Most people indicated about 15-20 %, while real abundance was 4.3 %. A numerical approach is most needed! Using a motorized light microscope (Zeiss Axio Zoom V16), a complete thin section can be scanned in a matter of minutes to obtain cross-referenced high resolution optical mosaics, both in transmitted and polarized light. Then, the same polished thin section is transferred to a SEM and scanned to produce complete BSE and EDS maps that are crossed-reference with the optical image. The EDS maps are processed by a clustering algorithm (DBSCAN) embedded in Aztec (OI) to generate a map of mineral phases that is cross-referenced with the optical images. Modal abundance, morphological features and chemical analysis of each species are computed. Even trace exotic mineral can be detected, based on a few pixels only. These maps are then used to assist the petrographer to interpret the section, based on accurate mineral identification and quantification. All images (optical, BSE and EDS) are spatially referenced and merged into a .czi file (proprietary of Zeiss) that can be visualized with various freewares. Files and images are shared with colleagues or clients through internet, without the need of shipping the thin sections. Coordinates can be extracted from the image and used to relocate minerals for further SEM, EMP or LA-ICP-MS analysis.

The Abitibi-Opatica contact, Archean Superior Province (Quebec): is it a tectonic plate boundary suture?

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Orogenic sutures mark the consumption of oceanic plate lithosphere by subduction. In Phanerozoic collisional orogens, they are underlined by major faults between terranes of contrasting geological evolution. For the Archean, the nature of tectonism remains debated, the main problem concerning similarities/differences with present-day plate tectonics. Archean cratons consist of greenstone belts juxtaposed to deeper crustal rocks dominated by TTG's. The greenstone belts show steep folds and shear zones whereas plutonic belts display dome structures. These rocks usually preserve MT/HT-LP/MP metamorphism that varies from greenschist- to granulite-facies, from upper to lower crustal domains. We present a structural and metamorphic study of the Abitibi greenstone belt (AGB) and Opatica Plutonic Belt (OPB) of the Archean Superior Province in Quebec. The AGB-OPB contact is currently interpreted as

an archetype example of Archean subduction, based on a LITHOPROBE seismic profile showing a North-dipping lithospheric-scale reflector interpreted as the vestige of subduction of an AGB plate. However, our mapping indicates that the AGB overlies the OPB. Moreover, that contact does not show evidences of significant shear deformation, as expected if it is a major upper plate-lower plate boundary. Furthermore, it does not show any metamorphic break but a progressive increase of metamorphism toward the OPB, from greenschist- to amphibolite-facies. Thus, we think that the OPB exposes the deepest part of a composite AGB-OPB crustal sequence. $^{40}Ar/^{39}Ar$ ages suggest that from ~ 2685 Ma to ~ 2632 Ma, the deepest level of the AGB and underlying OPB reached amphibolite-facies conditions, and that cooling was accompanied by strain localisation along strike-slip shear zones, when lateral flow of the lower crust became predominant over vertical tectonics after ~ 2600 Ma. Comparison with adjacent areas suggests that regional metamorphism has been coeval over a large region, which is consistent with pervasive deformation and slow cooling as expected in Archean vertical tectonic models.

Contribution of the upper asthenosphere to <0.6 Ma rejuvenated Hawaiian magmas; evidence from the Southern Hawaiian Island Chain

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The Lahaina Volcanics of West Maui represent the southernmost extent of nearly coeval rejuvenated volcanism (~ 0.3 to 0.6 Ma) along ~ 450 km of the Hawaiian Island Chain (West Maui to Ka'ula). K-Ar dating indicates two pulses of rejuvenated volcanism at 0.6 Ma and 0.4 Ma, producing four discrete eruptions. We present major and trace element geochemistry and high-precision Pb-Sr-Nd-Hf isotope data on samples from each Lahaina vent to characterize the source of rejuvenated melting at ca. 0.6 Ma, closest to the current plume location. All four Lahaina eruptions produced basanite with Pu'u Laina, the largest and least differentiated eruption, bordering on picrite. HREE concentrations (Yb_N ~ 10) indicate residual garnet in the source. Trace element concentrations vary over a wide range and are lowest in Pu'u Laina lavas (Th ~ 2 ppm). Isotopically the Lahaina Volcanics form two groups: (1) the Pu'u Laina eruption with high εNd and low $^{87}Sr/^{86}Sr$ similar to East Moloka'i, the North Arch field, and the most isotopically depleted rejuvenated lavas of Kaua'i; (2) the remaining three vents with lower εNd and higher $^{87}Sr/^{86}Sr$ typical of O'ahu, Ni'ihau, and Ka'ula rejuvenated lavas. Pyroxenite xenoliths and lavas from Ka'ula and O'ahu indicate a depleted rejuvenated component (DRC) intrinsic to the Hawaiian plume, characterized by low $^{208}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ and very high εHf (~ +16 to +17) relative to εNd (~ +9 to +10). Pu'u Laina lavas have low $^{208}Pb/^{204}Pb$, but at a relatively high $^{206}Pb/^{204}Pb$ ratio closer to ~ 90 Ma Pacific MORB. This is also the case for rejuvenated lavas of East Moloka'i, Kaua'i, and North Arch. Additionally, Pu'u Laina lavas have lower εHf (+14 to +15) at a given εNd (+8 to +9). The geochemical signature of West Maui and East Moloka'i rejuvenated stages suggest the upper asthenosphere, not the DRC, contributes to rejuvenated volcanism on the southernmost Hawaiian Islands.

Morphological signatures of deglaciation and postglacial sedimentary processes in a fjord-lake of the Eastern Canadian Shield: Grand Lake, Labrador

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High resolution multibeam bathymetric data and acoustic subbottom profiles were recently collected in Grand Lake (Labrador) in order to reconstruct the history of sedimentation since deglaciation in this 54 km-long and 3 km-wide fjord-lake that is one of the deepest in eastern North America. These results provide a morpho-stratigraphical framework that brings new insights on the style and pattern of the retreat of the Laurentide Ice Sheet in the region. The newly acquired dataset reveals that Grand Lake is mainly characterized by a deep (245 m) and flat bottom consisting of a sequence of deglacial to postglacial sediments containing series of mass movement deposits. However, the lake-bottom geomorphology and sediment-fill is complex with 1) numerous morainic sills near the shallow outlet; 2) steep sidewalls incised by dense dendritic networks of proglacial gullies; 3) a large-scale mass-movement scar and its associated deposit formed by an earthquake that occurred during deglacial times; and 4) a large prograding delta showing series of sediment waves on its frontal slope and prodelta, suggesting the occurrence of sediment density-flows in modern times. The series of closely-spaced morainic sills observed at the shallow lake outlet form a morainic complex that was most likely deposited synchronously with the Cockburn morainic complex formation on Baffin Island, around 8.2 cal ka BP, suggesting that the LIS retreat pattern in Grand Lake was both climatically and topographically controlled. The observation of numerous glacial lineations that follow the axis of the fjord allows reporting an undocumented ice stream in the valley of Grand Lake.

The Grasset Ultramafic Complex: an emerging komatiite nickel district in the northern Abitibi greenstone belt, Quebec, Canada

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Komatiite-related sulfide deposits represent an important source of nickel on a global basis as well as copper, cobalt, and platinum group elements (PGE). While komatiites are found in many Archean greenstone belts, economic nickel sulfide deposits are restricted to only a few regions globally. Prominent Archean deposits cluster in the Eastern Gold Fields Superterrane: Forrestania, Lake Johnston, and Ravensthorpe greenstone belts of the Yilgarn Craton of Western Australia. The Abitibi greenstone belt in Canada is the world's largest greenstone belt and contains numerous deposits/prospects of this type, but none that rival those of the Yilgarn. In 2014, Balmoral Resources discovered the Grasset nickel deposit in the northern Abitibi greenstone belt. The deposit is located at the southern end of a 10 km+ long sequence of komatiitic flows and sub-volcanic intrusions (the Grasset Ultramafic Complex) within a dominantly bimodal rhyolitic-komatiite host assemblage. The deposit is comprised of disseminated to net-textured sulfide (pyrrhotite-pentlandite-chalcopyrite) mineralization hosted within a moderately serpentine and/or talc-carbonate altered olivine mesocumulate sill. Favourable lithologies for ore mineralization appear to be those with moderate-high MgO contents (~ 35 wt % MgO), a common feature of many komatiite-hosted nickel deposits. A 2016 initial indicated resource estimate for the Grasset deposit outline a high-grade core of 3.46 million tonnes grading 1.54 % Ni. This makes the Grasset nickel deposit one of the largest komatiite-hosted nickel deposits discovered in the Abitibi to date. Further, renewed exploration in the fall of 2018 led to the discovery of a new, basal contact style nickel prospect ~ 7 km northwest of the Grasset deposit. These two recent discoveries, and other nickel sulfide occurrences outlined within the Grasset Ultramafic Complex, make the case for a potential emerging nickel district in Canada's Abitibi region.

Metallogeny of the LREE-rich peraluminous pegmatitic granite dykes from the central Grenville Province (Québec)

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Rare Earth Elements (REE) are first-order geological tracers. However, their mineral system remains poorly defined. The Grenville

Province (i) is a REE-rich province in which pegmatitic granite dykes ('PGD') are particularly abundant, and (ii) exposes its orogenic root, allowing insights into deep crustal processes. The PGDs may have been formed from (i) the partial melting of the orogenic root composed of reworked Archean and/or Proterozoic pre-existing continental crust, or from (ii) extreme differentiation of mantle melts produced during post-orogenic extension. A multidisciplinary investigation (field geology, petrogeochemistry, geochronology, isotopic analyses) allows us to characterize the PGDs and to discuss their petrogenesis in the frame of the Grenvillian tectono-metamorphic evolution. The PGDs intruded at ca. 1005-1000 Ma (U-Pb on monazite and zircon) (i) metaplutons (LREE in allanite) or (ii) metasedimentary sequences (LREE in monazite) from the mid-pressure allochthonous crustal segment. The intrusion of the PGDs is coeval with the initiation as early as ca. 1005 Ma of the protracted (~ 20 Ma) partial melting of underlying parautochthonous paragneisses. The peraluminous character of the PGDs, the pristine character of their magmatic zircon, and the (i) trace element content, (ii) supra-mantle $\delta^{18}O_{V\text{-}SMOW}$ signature and (iii) strongly sub-chondritic eHf(t) of zircon grains suggest the derivation of the PGDs by partial melting of parautochthonous Paleoproterozoic-Archean metapelites. The K/Rb ratios and Rb contents of K-feldspar and biotite from a leucosome of these migmatitic metapelites and a monazite-bearing PGD attest their genetic link. Petrogeochemical investigations show that the protracted partial melting of these metapelites up to the total consumption of zircon, monazite and apatite allowed the incompatible behavior of REE, their mobilization into the melts that subsequently formed the LREE-rich PGDs, and the sequestration of HREE into peritectic garnet. Accordingly, REE-rich PGDs derive from the reworking of the metasedimentary cover of the southeastern Laurentian margin during the Grenvillian orogeny.

Seventy million years of suprasolidus conditions in the large, hot, long-duration Grenville Orogen

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The duration of suprasolidus conditions in the mid to lower crust of large, hot, long-duration orogens exemplified by the Himalaya-Tibet belt is poorly-defined. In this study, we apply petrochronology to the Grenvillian Belt, which is a Proterozoic equivalent of the Himalaya-Tibet Orogen exposing its orogenic root composed of highly deformed high-grade metamorphic rocks. This study focuses on migmatitic paragneisses from the mid- to low-pressure segment of the Allochthonous Belt of the central Grenville Province to constrain the duration of suprasolidus metamorphic conditions. The petrochronology of monazite and apatite was performed on a leucosome of paragneiss formed by in situ partial melting. Suprasolidus metamorphism is recorded by: (i) prograde monazite shielded in peritectic garnet between ca. 1080 Ma and 1070-1050 Ma that corresponds to a maximum temperature of 850 °C; and by (ii) retrograde monazite from the matrix down to ca. 1020 Ma. A ca. 1005-1000 Ma PGD shows a lobate contact with its metasedimentary host with no evidence for contact metamorphism, implying a limited or negligible thermal exchange. This contact is interpreted as an intrusive contact within a sub-molten crust. Magmatic apatite from the matrix of the same leucosome yield cooling ages below ca. 550-450 °C of ca. 960 Ma. These data document cooling of the middle crust at a rate of 2 to 6 °C/Ma for the Allochthonous Belt of the central Grenville hinterland therefore characterized by protracted suprasolidus conditions during more than 70 Ma. This relatively slow cooling history supports the definition of the Grenville Orogen as a large, hot, long-duration orogeny.

Use of geometry and topology for deciphering pluton-hosted gold-rich stockwork, Baie James area

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Archean TTG intrusions of the Baie James area (Quebec) locally host gold deposits with complex structural control and vein paragenesis with an amphibolite facies overprint. The Neoarchean Cheechoo tonalite/granodiorite (ca. 2612 Ma) was emplaced in the volcanic-plutonic La Grande subprovince. It was variably altered and cut by successive vein generations. Quantification of the geometric and topologic parameters of the veins on drill cores from the Cheechoo intrusion were compared to the gold grade. It reveals that the high-grade values (~ 0.30 g/t) are controlled by the density and connectivity of the first two vein generations that are (1) quartz-only veinlets and (2) quartz-feldspar-diopside veins that contain sulfides and visible gold. They correspond to randomly distributed early fracturing events. They show asymmetric open to ptygmatitic folds and partial to complete transposition into the foliation, indicating intense ductile deformation. The late (3) pegmatitic veins and pegmatites locally control high-grade zones marked by gold-rich sulfide aggregates, but they are only auriferous where they cut the previously mineralized intrusion and do not control the bulk of the mineralization. These features suggest that they only had a remobilizing effect on the gold mineralization. They crosscut and are parallel to the foliation developped in the tonalite/granodiorite, and are folded with no evidence of solid-state deformation, therefore suggesting their syn- to late-deformation emplacement. These features point to the injection of pegmatites in the late stages of the hydrothermal system, possibly during the peak of metamorphim, after hydraulic fracturing of the pluton and deposition of the bulk of the gold. The latest (4) chlorite veins crosscut all the structures and veins described previously and are interpreted as retrograde veins. This study offers new perspectives on deciphering the mineralizing processes in complex natural fracturing systems with several injections stages, such as porphyry Cu-, Mo- and Au or IOCG.

From the British Caledonides to Sudbury: a review of Bill Morris career

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Bill Morris obtained his bachelor's degree in Earth Sciences from the University of Leeds. He then moved to Open University and became its second student to obtain a PhD, in 1974. He then emigrated to Canada, where he was a Postdoc at the University of Western Ontario with C.M. Carmichael (1973-1975) and the Earth Physics Branch of the Department of Energy, Mines and Resources, where he worked with E. Irving and J.L. Roy (1975-1977). Until then he was still mostly focused on paleomagnetic and rock fabric work. After the EPB, Bill started his own consulting firm, Morris Magnetics Inc., where he travelled Canada and other areas including northern Africa and the Maldives from 1977-1990. In 1990 he started his career at McMaster University, where he supervised close to 20 graduate students and a number of undergrads, and his main record was that most of them succeeded in securing an industry job in geosciences. The days at McMaster marked Bill's broadening of his career into geophysics, remote sensing, 3D modelling and data integration. Bill retired from McMaster in 2015 after an amazing career where he co-authored over 150 papers on subjects ranging from paleomagnetism, remote sensing, potential field interpretation, and recently borehole magnetic surveys.

For the past five years Bill was co-Director of the data integration theme for the NSERC-CMIC Mineral Exploration Footprints mineral exploration project. Since 2018 he is an Adjunct Professor at Brock University, where he is extending his previous work on 3D modelling and data integration and he keeps on going.

Remanent magnetization in geophysical data interpretation: how to recognize it, how to measure it, and how to model it

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Remanent magnetization is commonly encountered in many exploration settings. However, despite the advance in computer power for inverse and forward modelling of geophysical data, and the similar improvement in geophysical technology, the application of remanence in magnetic data modelling and interpretation is still very poorly understood. This contribution gives some tools on how to recognize the presence of remanent magnetization in the observed magnetic data, as well as how to measure it, and add it to the modelling and inversion of the data. The best way to measure remanent magnetization involves the collection of oriented samples and then follow with paleomagnetic studies to derive the individual remanent components associated to the cooling of the rock and any other subsequent metamorphic overprints. However, this is time consuming and limits the application to only a few samples per area. Magnetic data is widely available over vast areas and it has the advantage of regular sampling. The recognition of rotated dipoles on a total field and pole-reduced magnetic maps allows to identify zones of prominent remanent magnetization. Subsequent modelling of the magnetic data with varying remanence directions can yield a set of possible remanence directions that fit the data. However, one critical constraint is that after removing any tectonic deformation effects, these remanent directions must fit the apparent polar wander path for the age and location of the rocks being modelled. Another possibility is the use of Frequency Domain Electromagnetic (FDEM) data. The calculation of conductivity-depth-images from these data includes the generation of an EM-derived apparent susceptibility distribution. This can be utilized to map areas where remanence is dominant. Subsequently, modelling routines like the ones explained above can follow to estimate the direction of the remanence vector.

Using noble gases as a tracer of subsurface gas migration at a CO_2 injection research station

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In recent years interest has increased in the potential subsurface migration of gases during activities such as down-hole CO_2 sequestration or unconventional fossil fuel recovery. If gas migrates along faulty boreholes, for example, greenhouse gases may be released to the atmosphere and there is the potential for methane to migrate into drinking water aquifers. Noble gases are conservative tracers that do not participate in chemical or biochemical reactions. Concentrations of noble gases in water are determined by their solubility at recharge, the production of some isotopes in the subsurface, and modification by processes such as exsolution. Previous research has demonstrated the utility of these gases to identify mechanisms of fugitive gas migration in drinking water wells overlying the Marcellus and Barnetts shales. While noble gases can be useful tracers, the collection of samples can be challenging, and analysis is time consuming and costly. This research tests noble gas methods as a tracer of gas migration in aquifer and along boreholes at the CMC Research Institutes' Field Research Station near Brooks, Alberta. Along with testing more standard noble gas sampling methods, we are modifying existing sampling methods to be able to collect samples from narrow piezometers, as well as testing of a miniRUEDI field mass spectrometer for gas analysis. Current research and results will be presented including comparisons between field measurements and lab measurements.

Stratigraphic setting and geochemical footprint of the world-class Amaruq BIF-associated gold deposit, Churchill Province, Nunavut

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Precambrian gold deposits associated with Algoma-type banded iron formations (BIF) are complex systems in which lithological and structural traps are the principal controls on the location and geometry of the gold-rich ore. One such deposit is the 5.1 Moz Amaruq gold deposit, which is part of the polydeformed and metamorphosed Neoarchean (ca. 2.73 to 2.63 Ga) Woodburn Lake greenstone belt, within the Rae craton of the Churchill Province. The host rocks consist of a moderately to steeply-dipping, 250 m-thick stratigraphic sequence comprising upper greenschist facies BIF interlayered with greywacke, chert, graphitic argillite and mafic-ultramafic volcanic rocks, which have been affected by Archean and Paleoproterozoic orogens. The Amaruq gold deposit comprises the Whale Tail and IVR zones, which are characterized by several styles of mineralization and associated metamorphosed calcic and potassic hydrothermal alteration halos. The IVR and Whale Tail zones are located in the hinge zone, and along the limb of a deposit-scale fold, respectively. The mineralized zones all contain pyrrhotite and calcite and are characterized by: 1) stratabound (Fe-Mg)-hornblende, biotite, garnet ± arsenopyrite-gersdorffite replacement-style zones in chert-poor BIF associated with ultramafic rocks; 2) actinolite, stilpnomelane, chlorite, arsenopyrite ± lollingite-bearing zones of "silica-flooding" in chert-rich BIF interlayered within mafic volcanic rocks and greywacke, both predominately in the Whale Tail zone; and 3) fault-fill laminated quartz ± carbonate veins with Ca-amphibole or sericite in high-strain zones close to sheared and/or folded contacts between volcanic and sedimentary rocks mainly comprised in the IVR zone. Gold was in part exsolved from loellingite during retrograde metamorphism at lower greenschist facies. Rheological contrasts between BIF, sedimentary, and mafic-ultramafic rocks contributed to strain partitioning, which channelled ore-forming fluid flow in structurally and chemically favourable lithologies such as BIF.

Contribution of constrained gravity and magnetic inversion to geoscience integration: lessons from the Footprints project

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Geophysical inversions are techniques used to create geophysical models from geophysical data. Constrained geophysical methods integrate geological information in the inversion process to produce more meaningful results. This study analyses the validity of this assertion using real data sets. In the context of the NSERC-CMIC Mineral Exploration Footprints project, constrained geophysical inversions were

applied to three mining sites: a gold site (Canadian Malartic), a copper site (Highland Valley) and a uranium site (Millennium-McArthur). The same methodology was applied at the three sites: after unconstrained inversions of the magnetic data for each site, plus gravity data for the copper site, constrained inversions were developed based on physical property measurement and analysis, which provided the relationship between the geology and the geophysics, and on geological boundaries developed from surface and borehole geological control. In some cases, the geological model was improved using iterative geophysical forward modeling. At the gold and copper sites, the geology is mainly interpreted from a grid of airborne magnetic data, using sparse outcrops as constraints; therefore, the geological model is consistent with the geophysical inversion. The gold site contains units with high magnetic susceptibility that mask the subtler magnetic signature of the deposit. At the copper site, the contrast in physical properties (density and magnetic susceptibility) for the different units was subtle, and the variations in the geophysical signature were mainly explained by intraformational differences. At the uranium site, the main magnetic susceptibility units are buried below a thick (ca. 500 m) sedimentary cover and are complexly folded and extend to significant depths, and thus the magnetic signal is weaker than units at the two other sites. Consequently, the geophysical interpretation was more challenging. However, the final interpretation is reasonably consistent with the geology within the limitations of the methodology followed.

A student-centered approach to teaching science communication

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Communication is an integral part of the scientific process. Communicating, not only with peers but also with public audiences, is especially important in times of disinformation, fake news and societal relevance of science. As the need for scientists to communicate with a variety of audiences grows, so does the need for relevant science communication instruction. A new introductory science communication course in the Faculty of Science at Simon Fraser University, BC uses a student-centered approach to interest and empower emerging scientists in communicating their science to the public. Science communication practitioners from various science disciplines and sectors (including academia, science museums, science writing organizations, and the media), engage students in interactive activities, group work and discussion to develop understanding of audience, key messages, storytelling, visuals, and diverse communication formats. Students develop their presentation, writing and other communication skills through formal and informal opportunities to share their own science topics of interest, receiving peer feedback and developing awareness of best practices by being exposed to, and critiquing, science communication podcasts, videos, blogs and twitter feeds. Reflective learning through directed reflection questions following each module, as well as a final group science communication project are key components of the course. Student surveys, instructor feedback, as well as student reflection responses over two course offerings suggest, for example, that interactive lectures, group activities and journal responses contribute to student satisfaction and engagement with course content. Currently students take SCI 301 as an elective, however I am happy to report that the Department of Earth Sciences at Simon Fraser University is initiating the process of making this science communication course mandatory for students in their Major program.

Tectonic evolution of the New Quebec Orogen: new insights from field mapping and U-Pb geochronology in the Kuujjuaq area

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The ca. 1.83-1.79 Ga New Quebec Orogen is widely interpreted as resulting from collision of an exotic continental block (Core Zone) with the eastern Superior Craton margin and its supracrustal cover (Labrador Trough and related sequences). However, recent mapping supported by precise TIMS and SHRIMP U-Pb geochronology suggest a much longer and complex accretionary and collisional history involving continental arc magmatism starting as early as 1.87 Ga (Kuujjuaq Batholith), culminating with the emplacement of the voluminous De Pas Batholith between ca. 1.84-1.81 Ga. The younger, De Pas age-range of that arc magmatic event stitches the Core Zone with the reactivated edge of the Superior Craton (Kuujjuaq Domain), suggesting that both blocks were accreted by ca. 1.84 Ga. The earlier period of continental arc magmatism (ca. 1.87 Ga Kuujjuaq Batholith) was penecontemporaneous with voluminous mafic to ultramafic magmatism and shallow- to deep-water sediment deposition in a highly reducing, sulphide-rich environment in the lower Rachel-Laporte Zone, possibly in a continental back-arc basin that formed west of the active continental arc. The upper Rachel-Laporte Zone consists of basin-fill greywacke-flysch deposits and syn-orogenic molasse containing detrital zircons as young as ca. 1.83 Ga, but with large age-peaks at ca. 1.88 Ga as well as 2.4-2.3 Ga sources distinctive of the Core Zone. Furthermore, the eastern third portion of the Rachel-Laporte Zone hosts ca. 2.70 Ga metaplutonic rocks and orthogeiss, suggesting that this tectonic slice belongs to the Core Zone, and not the Labrador Trough. The present collisional architecture observed in the Kuujjuaq area reflects the strong transpressional nature of the collisional phase of the orogen and possible promontory/re-entrant pre-collisional architecture of the rifted Superior Craton margin.

Speculations on the origin, drift and mode of accretion of the peri-Gondwanan terranes in the Appalachian mountain belt

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The provenance drift and tectonic evolution of the peri-Gondwanan terranes: Ganderia, Avalonia, Meguma and Carolina, in the Appalachians and Caledonides is a contentious issue with many unknowns remaining. Ganderia, by a process of elimination, probably has an Amazonian provenance during the Late Neoproterozoic to Early Paleozoic, drifting away from it near the end of the Middle Cambrian due to backarc rifting and opening of the Rheic Ocean. It accreted obliquely and piecemeal to Laurentia starting in the Early Ordovician and finishing in the Silurian, with the leading edge in an upper plate and trailing edge in a lower plate setting. Avalonia has a markedly different provenance and tectonic evolution. It together with Carolina probably formed an assemblage of arc-backarc terranes situated in the Mirovoi Ocean during the Cyrogenian/Ediacaran but moved into the progressively widening gap opening between Baltica and Amazonia and obliquely collided with Ganderia and other parts of West Gondwana during the Late Ediacaran to Early Cambrian. In the process, parts of Ganderia may have been transferred to Avalonia, whereas Carolina seems to have been captured by Ganderia. In addition, Avalonia's westward drift introduced old Mirovoi oceanic lithosphere into the newly forming Iapetus Ocean. The provenance of Meguma may be North Africa and/or Armorica and its stratigraphy, magmatism, and tectonic evolution suggest it was isolated from Avalonia during most of the Early Paleozoic. Avalonia and Meguma occupied the lower plate during their accretion to Laurentia.

Behaviour of ore-forming elements in the subcontinental lithospheric mantle below the Slave craton

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The fertility of the subcontinental lithospheric mantle as source for metal-rich magmas remains poorly understood. We report new major

(EPMA), minor and trace element (LA-ICP-MS) results for olivine mantle xenocrysts sourced from the Jurassic age Jericho, Muskox and Voyageur kimberlites, western Nunavut in the Slave Craton, approximately 30 km north of the Lupin gold mine. Target elements include a suite of ore-forming elements that are unconventional for mantle petrology studies, but may represent important geochemical tracers for metal metasomatism. Using single-grain aluminum-in-olivine thermometry, formation temperatures for the olivine grains were calculated and projected on to a mantle geotherm to estimate PT conditions. The suite of xenocrysts corresponds to mantle sampling between 100-190 km depth. Their range in Mg# indicates that all 3 kimberlites sampled variably depleted mantle peridotite. The patterns of trace element enrichments found are consistent with those documented previously for mantle olivine xenocryst samples from the lithosphere below the Superior Craton in Kirkland Lake, Ontario. In both studies, some ore-forming elements were found to partition into mantle silicates more at the higher temperatures and pressure prevalent at the base of the lithospheric mantle, notably copper, with concentrations varying from ~ 1 ppm in shallow samples up to 11 ppm at the maximum depth sampled. Because the concentration of metals in melt-depleted lithospheric peridotite is expected to be low (< 20 ppm Cu), mantle silicates likely become a significant host for some ore elements at depth. Highly incompatible high field strength elements yield decreasing concentrations with depth, possibly the result of mantle metasomatic processes. Fluid metasomatized mantle peridotite domains are also inferred from olivine xenocrysts that yield unexpected trace element concentrations (ppb to ppm) for other highly incompatible ore-elements (e.g. As, Mo). We expect that some of these fluid-mobile and highly incompatible ore-elements represent trapped fluid and/or melt inclusions.

Geothermal potential assessment of the Charlevoix meteoritic crater

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The improvement of exploration methods to evaluate the groundwater flow potential of fractured rock in geothermal reservoirs is needed to unlock such resources, especially for the development of deep systems in basement rocks. The Charlevoix region in Québec is an area affected by a meteorite impact known as the Astroblème de Charlevoix. The impact of the meteorite created intense fracturing that can be favorable for groundwater flow. The presence of insulating rocks, such as the Saint-Urbain anorthosite, can be an appropriate setting where a stronger geothermal gradient makes it possible to find higher temperatures at depth. These two factors are necessary conditions for the exploitation of deep geothermal resources. During a field campaign, 26 rock samples from the main geological units outcropping in the Charlevoix region were collected. Surface characterisation of fracture networks was performed at 15 outcrops spread over the study area. The fracture characterisation indicated a high proportion of interconnected branches and node connections. The thermal conductivity and diffusivity as well as the permeability and porosity of the rock sample will be evaluated in the laboratory. The quantification of these properties and the fracture characterisation will be used as a basis for developing small scale numerical models of groundwater flow and heat transfer. These models will then be upscaled providing a tool to simulate the production of hot fluids for direct geothermal heat use in the study area. The results obtained will contribute to improve the understanding of the geothermal system in order to reduce the risks during the drilling of exploration wells. The methodology developed during this project will be used to improve exploration methods for deep geothermal resources at the pre-feasibility stage.

Geoenvironmental characterization protocol for environmental risks assessment and waste rock management

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The mining industry generates a large volume of waste rock that is generally stored in surface disposal areas (waste rock piles). These rocks often include different types of lithologies, each characterized by specific mineralogical and chemical compositions. Although their economic potential is limited, these lithologies may contain a certain proportion of deleterious elements representing potential risks towards the environment. Interaction between water, oxygen and non-economic sulphide minerals in waste rock piles can lead to the acidification of water and the dissolution of metals. When the proportion of neutralizing minerals is sufficient to neutralize the acidity, it remains a possibility to produce a neutral mine drainage, but which still contain heavy metals at concentrations that may exceed the regulation criteria. A comprehensive characterization of mine waste rock upstream becomes essential to assess their contamination potential and predict their adverse effects on groundwater and surface water. A four-stage protocol based on geoenvironmental characterization was developed to assess the environmental risks and optimize waste rock management. The first stage is to compile data from exploration work, including metallogenic, petrographic, mineralogical and geochemical data available in diamond drill logs and corporate exploration reports. The second stage is conducted once mineral resources estimation becomes available, and consists in a detailed assessment of various environmental parameters that have to meet the government agencies requirements. The third stage is implemented during the pre-feasibility study phase. The proposed work includes kinetic tests and quantitative mineralogy. The fourth stage involves gathering all the data acquired in the previous stages, then including them in small-scale geoenvironmental cells. These cells will be used to generate queries and created geoenvironnemental domains based on the environmental risks inherent to lithologies defined for the investigated orebody. These domains are then integrated into the 3D model and the mining plan to improve the waste rock management planification.

Geoheritage in Quebec: promotion and protection

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The imprint of geological heritage has been a constant in the history of Quebec. It was first recognized in the names of localities and particular geographical features, many of them in indigenous languages. Then, the museums undertook to preserve certain exceptional elements of Quebec's geological heritage, especially minerals and fossils: the Musée René Bureau (U. Laval), the Musée minéralogique et minier de Thetford, the Musée Minéralogique de l'Abitibi-Témiscamingue, the Redpath Museum (McGill University) to name a few. More recently, geological gardens started to appear. National Parks, although not created for this purpose, have increasingly valued geological heritage through the years. Outside national parks, geological heritage is composed sites of special geological interest called "geosites". They often first appeared on geological highway maps or in geological field trip guidebooks. Those geosites often occur in regional clusters and can be linked to themes or a geological timeline. Thus, during the 1990s and 2000s, the concept of geoparks, which became a UNESCO program in 2015, was created to promote geological heritage by showcasing their geosites in a global approach that includes sustainable development and geotourism. Québec now has the Percé UNESCO Global Geopark since April 2018, the first in Québec and the third in Canada. There are currently two geopark projects (known as aspiring geoparks) in Quebec, Charlevoix and Saguenay Fjord, and a geopark project that straddles Ontario and Quebec, the Timiskaming

Rift. A review of other regions of Quebec with the potential to become geoparks is presented, based on their historical, educational, scientific or spectacular value. All represent a new resource that can be developed for future generations. We will also briefly discuss efforts in the province to protect this heritage where it is threatened.

Charlevoix Aspiring Geopark - a region sculpted from the sky?

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Charlevoix is known for its landscapes, its climate and its cultural heritage. But few people know that Charlevoix has unique geological characteristics, mainly because of the tectonic and catastrophic events that have shaped it. The Charlevoix region is located at the convergence of three major geological provinces in North America: Precambrian rocks of the Canadian Shield north of the St. Lawrence, Paleozoic rocks of the St. Lawrence Shelf just south of the Shield and along the north shore of the St. Lawrence and the Appalachian rocks, traces of which are found in Île-aux-Coudres. All these rocks have witnessed a meteorite impact that has shaped the geology of the area. Discovered in 1966, the study of the Charlevoix Astrobleme allowed the identification of structures and rocks typical of meteorite impact. Its central peak and ring depressions are among the most visible and accessible structures in the world. The purpose of the Charlevoix Geopark project is to highlight the geological and astronomical heritage of Charlevoix, by showing the main elements that bear witness to its history, from the birth of the Laurentians to the current geological phenomena that constitute natural hazards such as erosion, shorelines, landslides and earthquakes. In addition to the geological heritage, the geopark project will integrate the rich prehistoric, historical and cultural heritage of Charlevoix. This is why the project will call on the partnership of the Charlevoix Biosphere Reserve, the Charlevoix Astronomical Observatory, and the Charlevoix business community.

Geoparks in Canada

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A Geopark is a geographical area comprising geological heritage sites that are part of an integrated concept of protection, education and sustainable socio-economic development. The Global Geoparks Network (GGN), created in 1999, became a UNESCO programme in November 2015. They highlight the geological heritage for present and future generations. A geopark is usually developed from the ground up, i.e. through local initiatives. It aims to protect and explain the geological and mining heritage. Geotourism and socio-economic development are encouraged. A geopark becomes a tool for regional development. It is not limited to the development of geology; it explores, develops and celebrates the links between that geological heritage and all other aspects of the area's natural, cultural and intangible heritages (UNESCO Global Geoparks web site). The Global Geoparks Network currently has 140 UNESCO Global Geoparks in 38 countries, including three in Canada: the Stonehammer GG in New Brunswick, created in 2009, the Tumbler Ridge GG in British Columbia, created in 2014 and the Géoparc mondial de Percé in 2018. Nine projects are underway in Canada: Saanitch Inlet (BC), Big Impact (Sudbury, ON), Temiskaming Rift Valley (ON and QC), Ohnia:kara (Niagara, ON), Charlevoix Astrobleme (QC), Saguenay Fjord (QC), Cliffs of Fundy (N.S.), Cabox (NF&L), and Discovery (Bonavista, NF&L).

Temporal evolution of magmas associated with Au-Cu mineralization in the Hualgayoc mining district, Northern Peru

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The Hualgayoc mining camp in northern Peru hosts the Cerro Corona Au-Cu porphyry, Tantahuatay high-sulfidation Au, and AntaKori skarn deposits, as well as other Au and Cu prospects. New U-Pb dating on zircon indicates that all igneous rocks formed during three pulses of Miocene magmatism: 14-15 Ma, ~ 13-12 Ma and ~ 9 Ma. The oldest event produced several intrusions in the eastern part of the district, including the Cerro Corona intrusive complex. These intrusions are diorite to granodiorite with phenocrysts of Hbl±Bt and Mag. Bulk rocks have high Sr/Y (40-90), moderately low Y (8-16 ppm) and $[La]_N/[Yb]_N$ (9-18), and low $[Dy]_N/[Yb]_N$ (1.4-1.1), suggesting that the magmas originated from the partial melting of the lower crust (with residual amphibole). The water-rich magmas prevented plagioclase crystallization, which induced high Sr values. Zircon grains from the suite of intrusions show consistent $[Yb]_N/[Dy]_N$ of ~ 9, suggesting no amphibole fractionation during zircon crystallization. Ce/Ce* ($=[Ce]_N/[[Nd]_N]2/[Sm]_N$) in zircon increases with decreasing magma temperature, as calculated with the Ti-in-zircon thermometer. To compensate for temperature effects, Ce/Ce* values were normalized to 690 °C. The normalized Ce/Ce* of the oldest suite of rocks ranges between 108 and 132, reflecting moderately oxidized parental magmas. The second magmatic event, 13-12 Ma, occurs in the western part of the camp and produced Qz-Pl porphyry intrusions and andesitic to rhyolitic volcanic rocks thathost the Tantahuatay and AntaKori deposits. Values of $[Yb]_N/[Dy]_N$ in zircon increased from ~ 5 to ~ 12 during magma evolution, suggesting amphibole ± garnet in the source and subsequent amphibole ± titanite fractionation. Zircon grains have high normalized Ce/Ce* (118-200), reflecting highly oxidized parental magmas. The results indicate that the oxidation state of magmas increased as the source changed from garnet-free to garnet-bearing over a span of ~ 3 Ma. The high oxidation state of all the magmas is consistent with the alteration and mineralization styles in the area.

Thermal and exhumational history of the Labrador passive margin: insights from apatite and zircon (U-Th)/He thermochronology

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Passive margins form an integrated source-to-sink system in which sediments from continental erosion transit to offshore basins and are preserved in depocenters constituting oil and gas storage. This study focuses on the Labrador margin, formed after the rifting and breakup between eastern Labrador and southwest Greenland followed by seafloor spreading of the Labrador Sea. Past studies determined that stretching and breakup occurred between 130-78 Ma and seafloor spreading began sometime between 90-33 Ma. Therefore, first order questions remain, including: 1) the time and duration of the rifting episode; 2) the onset of seafloor spreading in the Labrador Sea; and 3) the post-break-up thermal and erosional history of the Labrador margin. Apatite and zircon (U-Th)/He thermochronology, denoted AHe and ZHe, with closure temperatures of 70 and 170 °C respectively, has the ability to reconstruct the thermal and exhumational histories of the upper 8-10 km of the continental crust. These methods have been successfully applied to a number of passive margins worldwide, yet no data from the Labrador margin is available to the public. This study applies AHe and ZHe to 47 bedrock samples distributed along four transects perpendicular to the coast. Transects extend between 30-130 km inland from the coast at the latitudes of Saglek, Nain, Hopedale, and Makkovik (Labrador). Results pending,

our dataset will provide rates on processes that may include: 1) the long-term exhumation of the Labrador crustal block; 2) the spatial propagation of intracontinental rifting; and 3) the post-rift denudation of the Labrador passive margin. The Labrador margin is marked by the presence of up to 11-km-thick offshore basins sustained by pulses of continental erosion that only low-temperature thermochronology can identify and quantify.

Evaluation of portable XRF for characterizing basalts: a case study on ballistic blocks from Kilauea, Hawai'i

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Portable X-ray Fluorescence (pXRF) instruments are increasingly used in mineral exploration and provenance studies in geology and archaeology. Together with lab-based XRF (ED-XRF) instruments they provide a non-destructive method for characterizing major, minor and trace element composition of bulk rock. The advantage of pXRF over lab-based XRF instruments (ED-XRF) includes viability of data collection in the field, reduced measurement times, ability to conduct analysis on larger samples that do not fit into lab instruments, and increased quantity of measurements. But, questions still remain concerning the reliability of portable instrumentation in characterizing the chemical composition of rocks. In this study, we compare the robustness and practical applications of characterizing basaltic rocks using pXRF and ED-XRF. Factors that constrain the reliability of both portable and in lab XRF analysis methods include detection limits and calibration-based programming of instruments. While pXRF is potentially less sensitive for certain elements, this may not have a significant impact on the results obtained with an appropriately designed study and associated calibration procedures. Here we present results from analysis of basaltic samples from near the Keanakako'i crater, Hawai'i Volcanoes National Park, and show that they provide reliable information for the characterization of these basalts using selected elements. A direct application of this technique is in the characterization of ballistic block samples and in determining the provenance of stone tools used by ancient Polynesian Societies. Handheld analysis was conducted using an Olympus Delta InnovX system, using the factory-supplied settings to prevent calibration biases. While major element compositions show some variations (particularly for lighter elements), trace element variability show promising results for differentiating samples, including elements such as Zr, Nb, Y, and Sr, which are commonly used in tectonic discrimination diagrams.

Characterization of apatite hosted silicate melt inclusions in magmatic rocks associated with the Cantung (W-Cu) skarn deposit, Northwest Territories

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The Cantung (W-Cu-Au) skarn deposit, Northwest Territories, Canada, is one of the most significant high-grade W deposits in the world. The deposit is located in the eastern Selwyn Basin and is associated with the Tungsten-Tombstone magmatic belt of the northern Canadian Cordillera. Cantung is spatially associated with two sub-alkaline biotite monzogranite plutons (Mine Stock and Circular Stock) along with late aplite, pegmatite, and lamprophyre dykes. It has been suggested that mineralizing fluids were derived from the intrusions, or from a related magmatic-hydrothermal system at depth; however, very little work has been done to characterize related magmas, as sources of fluids, that produced Cantung. Felsic and mafic silicate melt inclusions (SMI) hosted in magmatic apatite of the Mine Stock intrusion suggest that at least some apatite are xenocrysts and sourced from mafic magma. This project will characterize apatite-hosted SMI in the Mine Stock as well as lamprophyric rocks using i) petrographic microscopy to identify phases within SMI and describe their texture, ii) scanning electron microscopy for imaging and major element composition, and iii) laser ablation inductively coupled plasma mass spectrometry to quantify trace elements abundances, including metal tenor. The overall aims of the work will be (i) to evaluate the suspected link between mafic and felsic magmas in the formation of the Cantung deposit, and (ii) to elucidate the composition and metal tenor of melts involved in the formation of W skarns.

Provenance of Early Paleozoic sandstones: implications for peri-Gondwanan terrane affinities in the Appalachian-Caledonide Orogen

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The Appalachians of Atlantic Canada, and the Caledonides of Britain and Ireland, include terranes attributed to both Laurentian and Gondwanan sources, separated along the Silurian Solway line in Britain, and the Ordovician Red Indian Line in Canada. Gondwanan elements to the south and east have been variably assigned to the domains Ganderia, East and West Avalonia, and Megumia, based on their Cambrian sedimentary histories, their provenance, and their isotopic characteristics. A sample of Red Callavia Sandstone from uppermost Cambrian Stage 3 of the Midland Platform, attributed to East Avalonia, yields a U-Pb age spectrum dominated by Neoproterozoic and Paleoproterozoic sources, resembling those in the Welsh Basin, the Meguma Terrane of Nova Scotia, and NW Africa. Initial ƐHf values suggest that the Neoproterozoic zircon component was derived mainly from crustal sources < 2 Ga, and imply that the more evolved Paleoproterozoic grains were transported into the basin from an older source terrane, probably the Eburnean Orogen of W. Africa. A sample from Cambrian Stage 4 in the Bray Group of the Leinster-Lakesman terrane shows, in contrast, a distribution of both U-Pb ages and ƐHf values closely similar to those of the Gander Terrane in Newfoundland and other terranes attributed to Ganderia, interpreted to be derived from the margin of Amazonia. East Avalonia is clearly distinct from Ganderia, but shows evidence for older crustal components not present in West Avalonia of Newfoundland. Comparison of these results with previous work suggests that Ganderia, Avalonia, and Megumia came from distinct locations on or close to the margin of Gondwana in the early Paleozoic, and that East and West Avalonia may have had different Neoproterozoic histories. Parts of Ganderia were in contact with Avalonia in the Ordovician whereas others arrived at the Laurentian margin well before Avalonia.

3D-printed models: overcoming challenges of scale, dimensionality, and abstraction in introductory structural geology

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Much of basic structural geology involves projecting data from maps of the Earth's largely two-dimensional (2D) surface into the opaque, three-dimensional (3D) subsurface, where structural relationships are typically invisible, or are sampled in very limited form by boreholes or geophysical data. Understanding 3D relationships in this opaque volume involves major challenges for the student. An important part of Earth science education provides students with the skills needed to

visualize these relationships. Typically, this involves introducing students to the tools that are used by professionals to visualize these relationships: structure contours, stereographic projections, and computer simulations. All these techniques present students with challenges of scale, dimensionality, and abstraction. Challenges of scale involve the representation of macroscopic structures on printed pages at reduced scale; different horizontal and vertical scales (vertical exaggeration) may further complicate this process. Challenges of dimensionality involve mentally or mathematically projecting the real, but invisible 3D subsurface world into 2D representations such as cross-sections and stereographic projections that can be easily communicated to other geoscientists, whether on paper or the 2D computer screen. Challenges of abstraction involve representing physical features, such as rock formations or a dipping surfaces, with an idealized representation such as a map pattern, a set of structure contours, or a pole on a stereographic projection. Students may fail to perceive these abstractions correctly in 3D. For example, structure contours may be visualized on the topographic surface instead of beneath it; stereographic projections may be visualized on the wrong hemisphere. 3D-printing offers the potential to ease these challenges by presenting models tailored to match the 2D maps typically introduced in lab exercises. However, the match needs to be close; it is recommended that 3D-printed models be at the same scale as printed maps, and be coloured so as to match either real-world satellite imagery or the corresponding printed geological maps, in order to avoid introducing additional challenges of scale and abstraction.

Traceurs de l'évolution naturelle de l'eau souterraine dans une région périglaciaire du Bouclier canadien à partir de la détermination de pôles hydrogéochimiques régionaux

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Les modèles d'évolution des faciès chimiques de l'eau souterraine en fonction de la profondeur et de la distance parcourue entre les zones de recharge et de résurgence (cellules d'écoulement locales ou régionales), permettent d'expliquer qualitativement la variabilité spatiale hydrogéochimique. Au Saguenay-Lac-Saint-Jean (SLSJ), cette variabilité est observée pour des résultats d'analyses chimiques de 321 échantillons d'eaux souterraines collectés dans le cadre du Programme d'acquisition de connaissances sur les eaux souterraines de la région Saguenay-Lac-St-Jean (PACES-SLSJ) et pour lesquels environ 40 paramètres physico-chimiques ont été mesurés. Á partir de ces données, des pôles régionaux de l'évolution naturelle de l'eau souterraine sont obtenus selon un traitement qui combine les techniques statistiques standards et l'analyse statistique multivariée. L'analyse statistique multivariée est appliquée en deux temps. La base de données est d'abord considérée dans son ensemble, ensuite, l'analyse est appliquée à un sous-ensemble de données, lesquelles sont sélectionnées à partir de leurs caractéristiques géochimiques. Cette méthode nous conduit à définir 2 pôles hydrogéochimiques régionaux distincts du point de vue de leur composition chimique: 1) un pôle compositionnel régional de l'évolution de l'eau souterraine profonde en milieu rocheux fracturé, et 2) un pôle compositionnel régional de l'évolution de l'eau souterraine en milieu granulaire poreux confiné par l'argile marine. Les différents stades d'évolution de l'eau souterraine sont comparés à l'aide d'une méthode normative multiéléments et les différences observées sont exprimées en indices de maturité. Ces indices de maturité, combinés aux résultats du traitement d'analyse multivariée et à la comparaison de la composition chimique des pôles avec celle d'eaux de référence, nous permettent de proposer des paramètres de traceurs géochimiques caractéristiques de l'évolution naturelle de l'eau souterraine vers l'un ou l'autre de ces pôles. Le tout est présenté sous la forme d'un modèle conceptuel intégrant les traceurs identifiés et les cellules d'écoulement de l'eau souterraine de la région d'étude.

Une expérience de transfert circulaire des connaissances sur les eaux souterraines au profit de l'aménagement du territoire: ARIM-Eau

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Les connaissances sur les eaux souterraines du Québec ont augmenté de façon considérable au cours de 10 dernières années, grâce surtout au programme d'acquisition de connaissances sur les eaux souterraines (PACES) du Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatique (MDDELCC). Dans la foulée du PACES, une série d'ateliers de transfert de connaissances ont été tenus par le Réseau québécois sur les eaux souterraines (RQES) avec les intervenants des régions couvertes par les projets PACES. Ces ateliers ont permis de maintenir temporairement l'intérêt des intervenants régionaux sur cette ressource essentielle. En décembre 2017, un comité régional constitué des 6 MRC de la région et de la communauté des premières Nations de Mashteuiatsh (comité ARIM-Eau: Accompagnement, Recherche, Implantation et Mise à jour) a été mis sur pied. En collaboration avec l'université du Québec à Chicoutimi (UQAC), le comité a pour mission de mettre à jour les données acquises dans le cadre du programme d'acquisition des connaissances sur les eaux souterraines (PACES) réalisé au SLSJ entre 2009 et 2013, de permettre une implantation harmonieuse des données hydrogéologiques au sein de leurs organisations respectives, de stimuler la mise sur pied de projets de recherches originaux et orientés vers des problématiques régionales et finalement, de mettre en œuvre des projets portant sur des problèmes spécifiques rencontrés de manière ad hoc sur le territoire. Le projet novateur ARIM-Eau permet de maintenir la dynamique créée par le projet PACES, incluant les liens entre les partenaires/acteurs municipaux et les scientifiques à l'université. La présentation présente comment cette structure a été mise en place, comment elle est maintenue actuellement et expose ses principaux mandats et objectifs.

Machine learning methods in ore grade estimation for laterite nickel deposit

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Grade estimation is a time and money consuming but essential job for mineral deposit development and value assessment. Thus to promote the accuracy and efficiency of ore grade estimation with limited capital and time investment has long been a focus for geologists. The introduction of a myriad of data-driven methods, especially machine learning technology, provided new ideas and tools for ore grade prediction. Among various machine learning algorithms, the support vector machine (SVM), random forest (RF) and neural network (NN) algorithms proved to have excellent performance in fitting non-linear problems, hence are suitable for discovering geological distribution patterns of elemental content, which is usually complex and displays non-linear behaviour. In this research, three machine learning models have been built and tested based on the survey and geochemical data from 1130 boreholes of a lateritic nickel deposit located in KBK region, Papua New Guinea. The elevation and slope at the location of drill holes' collars, combined with the content of ore-related elements in the earth within one meter underground were used as input data, and the average nickel grade used as target data. Then SVM, RF and deep neural network (DNN) models are trained and tested respectively based on the described dataset. Results show that the predicted values cannot precisely match the actual grade (with R^2 scores between 0.3 and 0.5). However, the predicted grade by all the three models, especially DNN model, are highly consistent with

the actual grade in spatial variation trend. This suggests that machine learning can be used as an auxiliary method to preliminarily assess the grade of a deposit and provide guidance for further exploration projects. Besides, since all the input data can be easily collected without deep excavation or drilling work, this method will be very efficient and economical for exploration practice.

Paleozoic subduction of the northwestern Dunhuang orogenic belt, northwest China: metamorphism, geochronology and tectonic implication

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The Dunhuang orogenic belt (DOB) lies to the east of the Tarim craton, to the south of the Beishan orogen and to the north of the Altyn Tagh fault, and is mainly a low- to high-grade metamorphic complex. It has long been considered as an ancient stable terrane with meta-recrystallized basement formed in the Early Precambrian. However, our recent studies, including the first discovery of Devonian eclogite, show that this area was in fact a Paleozoic orogenic belt, likely as a southernmost part of the Central Asian orogenic belt (CAOB), and the metamorphic event occurred during the Silurian to Devonian. The DOB was dismembered by Cenozoic faults into discrete tectonic blocks formed at different metamorphic grades. Here, we report the new finding of high pressure (HP) mafic granulite in the Dahongshan block, northwestern DOB. HP granulites and (garnet-bearing) amphibolites commonly occur as lenses or boudinages enclosed within metapelite, exhibiting typical block-in-matrix fabrics of tectonic mélange. Three stages of metamorphic mineral assemblages were identified in these metabasites. Clockwise metamorphic pressure-temperature (P-T) paths were obtained through geothermobarometry and thermodynamic modeling, passing from 660-670 °C / 7.4-9.7 kbar through 820-840 °C / 14.3-15.5 kbar to 690-700 °C / 5.2-5.7 kbar for the HP mafic granulite. The derived metamorphic P-T paths show similar tight clockwise loops including nearly isothermal decompression processes, typical of orogenic metamorphism. The metamorphic peak of the mafic granulite approaches the high P-T facies series, indicative of a subduction zone setting. Secondary-ion mass spectrometry (SIMS) U-Pb dating of metamorphic zircons indicates the HP metamorphism occurred at ca. 470-460 Ma and the exhumation (retrogression) at ca. 414 Ma. These data certify that the DOB shares a similar metamorphic history to the Beishan orogen. Our study further suggests that the DOB underwent subduction and subsequent exhumation processes caused by closure of the southern branch of the Paleo-Asian Ocean during the Ordovician to Devonian.

Bedding-parallel, fibrous veins record hydrocarbon generation in laminated source rocks

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Bedding-parallel, fibrous calcite veins (commonly referred to as "beefs") are widely developed within Eocene, lacustrine, laminated organic-rich source rocks in the Dongying Depression, Bohai Bay Basin, East China. The veins mainly occur in horizontal, organic-rich laminae composed of banded lamalginites in mature source rocks, particularly in layers with relatively high total organic carbon and relatively low carbonate content (compared to adjacent vein-absent sections). We demonstrate that the veins are products of diagenesis accompanying burial, and that their formation was coeval with hydrocarbon generation and migration from the initial fracture opening and subsequent dilation. Consequently, primary aqueous and hydrocarbon inclusions in the fibrous calcites record the early stages of fluid release during maturation of these source rocks. Primary two-phase (oil+gas) hydrocarbon inclusions with or without coeval aqueous inclusions are the most common inclusion assemblages in the calcite fibres. Less commonly, primary assemblages consist of inclusions with only liquid hydrocarbon (i.e. monophase, high-density petroleum inclusions). In addition, many bitumen-bearing oil inclusions were observed in the fibrous calcite veins. Consequently, we surmise that immiscibility and heterogeneous trapping of liquid petroleum, bitumen and aqueous solution during the fibrous calcite growth are the best explanation for the above features. By modelling the isochores of oil inclusions and aqueous inclusions, in light of the burial history for the basin, we infer that the bedding-parallel veins were formed during the Oligocene Dongying sedimentary stage. Moreover, almost all primary fluid inclusion assemblages indicate variable degrees of fluid overpressure during vein dilation, ranging from pressures only modestly in excess of hydrostatic, to pressures approaching and perhaps exceeding lithostatic.

Content-based Recommendation System algorithm applied to deposit data mining and ore-prospecting prognosis

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Discovery of new deposits is costly and challenging, a large amount of geological data (especially for the unstructured data) have been accumulated in the past three decades. The conventional methods, like WOE (weights of evidence) and nonlinear theory, seem to be limited. Pangxidong mining district is selected as our study area for its prospecting mineralization potential, which is located in the southern section of the Qin-Hang metallogenic belt. The Qin-Hang metallogenic belt is a giant suture separating Yangzi block from Cathaysian block in South China. This area has experienced repeated structural movements and the fault structure is well developed, and the NE-striking fault is the main ore-controlling structure. The Content-based Recommendation System algorithm is applied to analyze deposit data and predict ore-prospecting in Pangxidong area. Based on the known ore deposit data, we establish utility matrix (data source). The utility matrix includes regional location information and various factors that relate to mineralization (geochemistry, lithology, tectonics, etc.). It is used for data mining to calculate the similarity between the known Ag-Au deposits and other regions, and the prediction is made according to the results of similarity calculation. Wendi area is located in the northwest of Pangxidong area, which has three known Au-Ag deposits. For the prospecting of silver-gold deposits in Wendi area, the areas with high similarity are mainly distributed around the known ore deposits and on both sides of the NE-striking faults. It also extends along the NE direction as a whole, which is consistent with the fault direction. The results shows that the algorithm can better mine the information related to mineralization and quickly capture the potential metallogenic area which similar to a certain type of ore deposit (point).

Turbidite record of the Neoproterozoic active-continental margin in the western Cathaysia Block, South China

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South China consists of the Yangtze and Cathaysia blocks and is the largest block of Rodinia in southeastern Asia. It has been widely accepted that the Jiangshan- Shaoxing- Chenzhou suture zone is the boundary between these two blocks, whereas the time and evolution of the amalgamation remain highly debatable. We carried out geochemical and geochronological studies for the turbidic metasedimentary successions from the Shenshan Formation at the

northwestern margin of the Cathaysia Block. The turbidite sequence is composed of siliciclastic sedimentary rocks mixed with tuffaceous materials, and has geochemical compositions between felsic to intermediate arc igneous rocks. The overwhelming populations of euhedral detrital zircons consist of a major age peak at ca. 800-700 Ma, indicating that the detrital grains were derived mostly from locally distributed syn-sedimentary arc igneous rocks. Furthermore, a predominance of zircons with ages close to the time of deposition and the whole rock trace element compositions of the turbidite sequence imply a convergent plate margin setting for the Shenshan Formation. Most Neoproterozoic detrital zircons showing negative εHf(t) and other features of the Hf isotopic compositions of the older zircons favour a Cathaysia origin or other crustal sources, instead of the similar domains of the Jiangnan orogeny. These lines of evidence suggest that the Cathaysia Block represents part of a subduction-accretion system and that it does not collide with the Yangtze Block in the middle Neoproterozoic. The two blocks were closely connected and located along either the margin of Rodinia or on a plate isolated from Rodinia. We suggest that the early Paleozoic strike-slip movement along suture shear zones may have played a significant role in their amalgamation.

Compaction and cementation of quartzose sandstone in the Proterozoic Athabasca Basin: petrographic study and numerical modeling

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The Proterozoic Athabasca Basin in northern Saskatchewan is a uraniferous basin associated with many world-class U deposits. It is important to know the burial and thermal conditions of the basin in order to understand the U mineralization environment. The basin stratigraphy is divided into 9 formations (from bottom to top): Fair Point, Read, Manitou Falls, Lazenby Lake, Wolverine Point, Locker Lake, Otherside, Douglas and Carswell. This study aims to examine the compaction and cementation characteristics of the sandstone in the basin through statistical petrographic work on samples from four drill cores in the central part of the basin, and to carry out numerical modeling of dissolution and precipitation of silica in order to explain the observed dissolution-cementation patterns. The results indicate that the compaction of quartz wacke tends to be affected by the abundance of matrix, whereas that of quartz arenite is intimately related to the depth as indicated by packing parameters including compaction index (CI), tight packing index (TPI) and intergranular volume (IGV), which were established with point counting data. Most of the samples studied were sandstones from the Read to Lazenby Lake formations below the mud-rich Wolverine Formation. The sandstones from the top of the Lazenby Lake Formation are characterized by high degrees of quartz cementation (up to 23 %), and the degree of compaction increases sharply downward to the Read Formation. Such a compaction and cementation pattern may be related to a two-stage diagenetic evolution history: 1) coupled silica dissolution (at the bottom) and cementation (at the top) related to a fluid convection system before significant compaction of the sandstones, and 2) subsequent compaction of the sandstones that had not been cemented. Numerical modeling of reactive mass transport using TOUGHREACT yielded a silica dissolution-cementation pattern similar to petrographic observations.

Isotope fractionation due to aqueous phase diffusion: what do diffusion models and experiments tell – A review

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The interpretation of spatio-temporal stable isotope trends in saturated geochemical systems requires an understanding of all relevant processes that fractionate isotopes. Surprisingly, one of these relevant processes, aqueous phase diffusion, has received only recently attention and there is no general consensus on the magnitude of aqueous phase diffusion-induced isotope fractionation. To contribute to a better agreement regarding the magnitude of isotope fractionation due to aqueous phase diffusion, we reviewed how five common diffusion models (Fick, Maxwell-Stefan, Einstein, Langevin, Mode-Coupling Theory Analysis (MCTA) of diffusion) predict isotope fractionation due to aqueous phase diffusion and compared them with experimental results. The reviewed diffusion models are not consistent with respect to the mass dependency of the aqueous phase diffusion coefficient (D). The predictions range from an inverse to a positive correlation between D and the mass of the dissolved species. Experimental studies exhibited consistently a weak inverse mass dependency of D for the vast majority of dissolved species and a larger inverse relationship between D and the mass for dissolved low weight noble gases. The observed weak inverse mass dependency of D for dissolved species other than low weight noble gases by the experimental studies is consistent with the MCTA of diffusion. The MCTA suggests that the weak inverse mass dependency of D originates from interplays between strongly mass dependent short-term and mass independent long-term solute-solvent interactions. The larger inverse mass dependency of D for low weight noble gases could be attributed to quantum tunnelling related isotope effects significantly increasing the aqueous phase diffusion-induced isotope fractionation. Our review shows, that except for low weight noble gases, a weak inverse mass dependency of D is likely the most adequate assumption for aqueous phase diffusion-induced isotope fractionation in saturated geochemical systems.

Integrating indigenous oral traditions and intangible heritages into understanding our landscape: tales from the Tumbler Ridge UNESCO Global Geopark

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The Tumbler Ridge UNESCO Global Geopark is home to the traditional lands of numerous Indigenous Peoples, such as those in the Treaty 8 Tribal Association, including the Doig River First Nation, the Fort Nelson First Nation, the Halfway River First Nation, the Prophet River First Nation, the Saulteau First Nation, the West Moberly First Nations, and the McLeod Lake Indian Band as well as Kelly Lake Cree First Nations. These first peoples have been observers in this land over the past 10 000 years or more and have witnessed monumental changes in the landscape and climate. Many of the stories told by these first peoples, as passed down to them from their ancestors, give us a valuable window through time, from which it is possible to better understand the land on which we reside. The role of this study was to evaluate some of the oral traditions and intangible heritages supplied by several of the Indigenous groups in the Tumbler Ridge area and relate them back to valuable lessons that we can learn regarding geology, particularly as it relates to climate change. Additionally, we want to increase our current understanding of traditional Indigenous names for geographic and geological features and determine how the first peoples interacted with these sites through archaeological investigation. The Tumbler Ridge UNESCO Global Geopark will, with permission from the appropriate groups, use the results of this study to improve our educational material regarding the land on which the Geopark is situated.

Archean gold mineralization in the Wawa Gold Corridor, Wawa, Ontario

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The Wawa Gold Corridor (WGC) is hosted by intermediate igneous rocks of the ca. 2750 Ma Jubilee Stock in the Michipicoten greenstone

belt. It comprises auriferous shear zones formed during a protracted deformation event with quartz + carbonate ± tourmaline veins and disseminated arsenopyrite and pyrite; the principal shear zones are the Jubilee (JSZ) and Minto Shear Zone (MSZ). Fieldwork and drill core observations indicate that the MSZ formed during late JSZ deformation. Observations made by optical microscopy and scanning-electron microscope backscatter-electron imaging, coupled with mineral-chemical analysis by laser-ablation inductively-coupled-plasma mass-spectrometry, indicate: 1) gold on the margins of, and as inclusions in, Au-bearing (10s - 1000s ppm), syn-kinematic arsenopyrite; 2) native gold associated with chalcopyrite and Bi minerals in post-kinematic carbonate stringers that cross-cut quartz veins and sheared muscovite-carbonate-quartz rocks, and which alter Au-bearing (0.3 - 3 ppm) pyrite; and 3) curvilinear boundaries between gold and bismuth and bismuthinite. Observations (1) and (2) suggest that at least two gold mineralizing events affected the WGC; the first was restricted to the JSZ and the second overprinted multiple shear zones. Observations (2) and (3) suggest that some Au was probably transported in a Bi-rich melt during the second gold mineralizing event and that this gold may have been scavenged from earlier, Au-bearing pyrite. It is also possible that some new Au was introduced by the post-kinematic Cu- and Bi-bearing carbonic fluid. This work highlights the importance of a petrographic and micro-analytical approach to understanding complex mineralization histories in shear-zone-hosted gold systems.

Petrogenesis of dolomite and calcite carbonatites in orogenic belts

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Subduction zones are an important way for crustal materials to enter deep parts of the Earth. Therefore, carbonatites in orogenic belt are of great significance in revealing deep carbon cycling pathways. To date, mantle-derived carbonatites have been identified in many orogenic belts, and their origin is considered to be related to subducted sediments. However, almost all orogenic carbonatites are composed of calcite, and their C isotopic compositions show typical mantle values, lacking any evidence of sedimentary origin. Here, we report decoupling of C and Sr isotopes between intimately associated dolomite and forsterite-calcite carbonatites from Caotan in the Qinling orogen, central China. The dolomite carbonatite is mainly composed of dolomite (plus minor apatite and magnetite), which has elevated $\delta^{13}C_{PDB}$ values (-3.1 to -3.6 ‰) and low $^{87}Sr/^{86}Sr$ ratios (0.7026-0.7042). The forsterite-calcite carbonatite consists of calcite (60-65 vol. %), forsterite and its replacement products (30-35 vol. %), and magnetite. The calcite shows mantle-like $\delta^{13}C_{PDB}$ (-6.2 to -7.2 ‰) but high initial $^{87}Sr/^{86}Sr$ values (0.7053-0.7076). Neodymium and Pb isotopic compositions are comparable in the two carbonatite types. The forsterite-calcite carbonatite is interpreted to have formed by metasomatic interaction of primary dolomitic melts with eclogite in thickened lower crust during collision of the North and South China cratons. The reaction resulted in decarbonation and depletion of the carbonatitic magma in ^{13}C. Because of its initially low REE and Pb contents, the Nd-Pb isotopic signature of the primary dolomitic melt was preserved in the forsterite-calcite carbonatite. We propose that some orogenic calcite carbonatites may not be primary mantle-derived rocks and their mantle-like $\delta^{13}C_{PDB}$ values may be misleading.

Cambrian through Devonian sedimentary successions on the Laurentian margin in western Newfoundland: the effects of an irregular margin geometry on provenance

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Neoproterozoic to Cambrian break-up of Rodinia opened the Iapetus Ocean, forming an irregular Laurentian margin defined by NE-striking rift zones offset by NW-striking transfer faults. Detrital zircon populations from W Newfoundland indicate two distinct provenance domains in rift-to-drift rocks. A proximal western succession, dominated by Mesoproterozoic detritus, indicates derivation from local basement and the Grenville Province to the west. A distal eastern succession displays similarities with the Laurentian margin in Greenland and Scotland, with prominent 1.85 Ga peaks and many Archean grains. These contrasts may have resulted from a major NW-striking transfer fault, blocking sediment transport, between the Newfoundland Promontory and Québec Embayment. Ordovician through Devonian closure of the Iapetus resulted in multiple orogenic episodes and development of foreland basins above the rift-drift succession. Ages of detrital zircon within the foreland succession are consistent with Laurentian sources; however, details of the distributions indicate provenance changes associated with shifting loads and sources within the orogen. Previous results from the M. Ordovician Goose Tickle Group show ages similar to the Humber Arm Allochthon, including a prominent peak at 1.85 Ga. Younger foreland successions (U. Ordovician: Devonian) are dominated by ages between 0.95 and 1.3 Ga, with prominent peaks at 1.0 and 1.1 Ga, typical of the Grenville Orogen, indicating a major provenance shift. Continental margin units in Québec/New England show similar signatures, suggesting derivation of the U. Ordovician Long Point Group from the SW. Within the mid-Paleozoic Clam Bank - Red Island Road succession, the absence of Gondwanan ages is consistent with underthrusting of Gondwanan microcontinents during Salinian and Acadian orogenesis. An abundance of 1.0 Ga grains in the E. Devonian Red Island Road Formation is consistent with sources in Grenville massifs in W. Newfoundland or Cape Breton Island, uplifted during Acadian inversion.

Geologic history of the Cobalt region, Ontario: controls on mineralized veins

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During the early 20th Century, the Cobalt region in northern Ontario was one of the most prolific silver mining areas in the world. More than 500 Moz of Ag was produced from precious metal-bearing polymetallic veins; Ni, Bi and Co are also major constituents. With growing demand for Co, exploration has been revitalized. Our understanding of the regional geology is largely based on mapping from the 1950's. Sedimentary rocks of the Paleoproterozoic Huronian Supergroup unconformably overlie Archean granite-greenstone basement. All units are intruded by the 2.2 Ga Nipissing diabase. The mineralized veins, hosted in all rock types, have similar mineralogy, morphological characteristics, and proximity to the diabase and unconformity. However, there is limited understanding of structural/stratigraphic controls on their formation. Previous genetic models emphasize the significance of the unconformity, highlighting similarities with unconformity-associated polymetallic vein deposits of the Athabasca basin. Using new mapping, U/Pb geochronology, and geophysical interpretation, we define a stratigraphy for the Archean volcanic succession dominated by mafic flow with lesser felsic

volcanic rocks and minor interflow sedimentary units. Volcanic units are folded into isoclinal folds with primary layering transposed subparallel to a secondary, steeply-dipping foliation. Where schistose, this foliation may be crenulated into Z-shaped asymmetric folds. Younger Timiskaming sediments occur adjacent to near-vertical NW-striking faults. Although relatively flat-lying, map patterns indicate Proterozoic strata are broadly folded. In well-stratified and cleaved Archean units, veins follow foliations. Controls on vein formation are less clear in regions where units are massive. Veins in Proterozoic sediments form at a high angle to bedding, possibly controlled by basement structures, and occur in close proximity to major NW-striking faults. Proximity of veins to major faults might indicate these structures were important fluid pathways and/or veins filled fault-related fracture systems. Continued work in the region has important implications for future exploration efforts.

Use of the WorldView-3 satellite for lithologic mapping and mineral mapping

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This presentation provides a review of the author's experience using the WorldView-3 satellite as a tool for mineral exploration and geological (lithological) mapping since the launch of the satellite on August 13, 2014. Remote sensing data from surface, airborne and spaceborne sensors have been utilized for decades for compositional mapping; in mineral exploration the objective has been largely focused on use of imagery (data) to assist with geological mapping, or the surface targeting of hydrothermal minerals that may be associated with ore deposits at depth. The WorldView-3 satellite is the first multispectral spaceborne sensor with bands in the short wave infrared that provides this capability at high spatial resolution. WorldView-3 provides panchromatic data at 31 cm spatial resolution, visible to near infrared (VNIR) at 1.2 m, and short wave infrared (SWIR) at a native resolution of 3.7 m. This presentation will review features of the WorldView-3 satellite from a mineral exploration perspective, providing results from an early assessment of its data quality, and highlighting processing results on the use of the data for a variety of different deposit types and commodities.

Geophysical expression of a unglaciated porphyry copper-gold deposit: Casino deposit, Yukon

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A possibly counter-intuitive aspect of parts of the Yukon is that glaciers failed to form in a size sufficient to scour the upper part of the earth's surface. Where this did happen, the weathering layer present, often with a thickness of 25-150 m, was scrapped off the surface, leaving relatively fresh rock in an un-oxidized state. This phenomena occurred at the Casino porphyry copper-gold deposit in the central Yukon and results in a unusual response from geophysical surveys carried out over the deposit that are commonly used to explore for porphyry deposits: induced polarization/resistivity and magneto-tellurics (MT). The initial assessment of the geophysical surveys lacked an appreciation for this unusual setting and therefore failed to be able to contribute to the further understanding of this exceptional mineral system. When factored in to the processing and interpretation, the presence of the weathered zone, defined by the presence of an oxide and supergene layer, was much more apparent and allowed the geophysical results to map the porphyry system with far greater detail than previously possible.

Comparison of the Eisler and Laonil Lake intrusive complexes: hosts to gold mineralization, Glennie domain, northern Saskatchewan

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The Seabee Gold Operation, located in northern Saskatchewan, ~ 125 km northeast of La Ronge, has been in continuous operation since 1991. The host rocks for the gold mineralization are volcanic and plutonic rocks of the Pine Lake greenstone belt, which represent a volcanic island arc terrane that was accreted onto proto-North America during the Trans-Hudson orogen about 1.8 billion years ago. An older volcanic package ("A") is separated from a younger volcanic package ("B") by a regional unconformity. The Laonil Lake Intrusive Complex, which hosts the Seabee gold deposit, is thought to be part of Assemblage A, based on an imprecise age determination. This study aims to better understand the age and tectonic setting of the Laonil Lake Intrusive Complex and its relationship to the nearby Eisler Intrusive Complex which might represent the same igneous event, and therefore be of interest as an exploration target. Methods to test their correlation include whole rock geochemistry, petrography, and U-Pb geochronology. Preliminary petrography and geochemistry study of the samples indicate quartz gabbro (Hbl 70 %, Pl 20 %, Qtz 10 %, opaques ~ 1 %) and tonalite (Hbl 30 %, Pl 30 %, Qtz 25 %, Bt 10 %, opaques 5 %) rock types from the Laonil Lake Intrusive Complex and tonalite (Hbl 35 %, Pl 30 %, Qtz 20 %, Bt 10 %, opaques 5 %) and pegmatitic quartz gabbro (Hbl 50 %, Pl 40 %, Qtz 10 %, opaques ~ 1 %) rock types from the Eisler Intrusive Complex. The geochemical signatures of all samples suggest derivation in an arc setting. The samples exhibit a slight LREE enrichment ($(La/Yb)_N$ = 2.8-8.7) and the εNd values (+3.7 to +4.7) suggest a depleted mantle source for the magmas. The results of this research may provide constraints on the correlation between the Pine Lake greenstone belt and other volcanic belts in the Trans-Hudson orogeny.

Site-wide conceptual hydrogeologic model with water budgets for a mine in northern British Columbia: implications for seepage monitoring and interception, and groundwater management

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The Red Chris Project is an open-pit copper-gold mine located in the Canadian Cordillera of northwestern British Columbia. A site-wide conceptual hydrogeologic model, which includes preliminary water budgets, was developed to provide a framework for analytical and numerical models that replicate field conditions and simulate possible future scenarios. The surficial geology and associated hydrogeology in the area are complex; consequently, understanding the interrelationships between topography, climate, geologic history and hydrogeologic features is critical for advancing alternative conceptual hydrogeologic scenarios. Available field data include: local to regional climate data; local to regional geologic mapping; terrain analyses from air photos and satellite images; borehole lithology with associated monitoring well or vibrating wire piezometer installations; water level and water quality data; water level responses and hydraulic evaluations from slug tests, pumping tests, and operational pumping; and, observed changes in landforms, drainage and surficial deposits due to development at the mine site. Hydrogeologic conditions range from topography-driven regional systems at upper elevations, through fully-saturated intermediate systems and perched local systems in valleys. The development of water budgets relied upon spatially variable estimates of actual evapotranspiration with recharge; discharge functions were derived from regional climate, geology, topography and vegetation. Runoff was constrained by estimates from a limited number of gauged watersheds within the study area. The conceptual hydrogeologic model

is being used to support the evaluation of ongoing groundwater flow and water quality modelling studies, and to guide the iterative evaluation of seepage monitoring and interception in the tailings impoundment area. Furthermore, the work is crucial for evaluating the capacity of a deep valley aquifer to supply the volumes of water required for the project, and for developing an understanding of the possible mechanisms of seepage losses to groundwater from the tailings impoundment.

Comparing effectiveness of different learning tools to convey geologic concepts

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Can you describe the Paleozoic Bedrock Geology of Ontario ? This is seemingly a simple question until you delve into geospatial thinking in three dimensions of using real and modeled data that is used to find valuable resources such as oil, gas and water. We have just started the exploration of using new methods to enhance training of geoscientists and geological engineers in a second-year Stratigraphy course at the University of Waterloo. To extend beyond training with traditional resources, three laboratory exercises were redesigned to incorporate 2D paper maps, a 3D physical model with painted wooden cores that represent real data, and a newly accessed 3D digital model of the Paleozoic bedrock geology of Ontario. Each of these learning tools were accompanied with questions that target three essential yet challenging skills for a student to learn: geospatial skills, complications of data limitations, and understanding applications related to resources. We believe maps, tangible models, and the digital model, created in cooperation by the Geological Survey of Canada, Ontario Geological Survey, and Oil, Salt and Gas Resources Library, all serve important roles in adding value to students in training, assisting them to become proficient professionals and knowledgeable citizens.

Hydrogeological monitoring of infiltration through waste rock using active fibre optic distributed temperature sensing

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The typical design of a waste rock pile may influence the movement of fluids within the structure, potentially leading to oxidation of reactive mine wastes and promote the production of acidic or contaminated leachate. New designs that would incorporate inclined (e.g. 5 %) layers made of fine grained, non-reactive waste rock are being studied. The surface layer would induce a capillary barrier with the waste pile core and divert moisture towards the toe of the pile. The objective of the study is to evaluate the feasibility of active fibre optic distributed temperature sensing system (FO-DTS) to measure soil moisture in a waste rock pile and to evaluate the effectiveness of the capillary barrier. An active FO-DTS was installed in an experimental waste rock pile to infer moisture levels within and below a capillary barrier cover. The pile is 60 m long, 32 m wide, and covered with 0.25 m of non-reactive rock and 0.60 m of sand. Volumetric moisture content was measured every 30 minutes in the cover and waste rock over a period of 5 days following a large-scale infiltration test where 17 m^3 of water is applied to the pile. The active FO-DTS protocol monitors moisture levels while maintaining an accuracy margin of ± 0.06 in the cover and ± 0.03 in the waste rock. The active FO-DTS system detects water reaching the bottom of the cover 10 hours after the start of infiltration. The cover appears to create an effective capillary barrier and to divert water downslope to the toe of the pile. No appreciable amount of water was detected in the reactive waste rock core. The results of the research demonstrate that active FO-DTS allows for unprecedented moisture data to be measured geospatially in a waste-rock setting, allowing for improved validation of geotechnical design.

A level set method with direct reinitialization applied to the modelling of multiphase geological flows

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Modelling geological flows typically involves simulating the interaction between materials with different rheological properties, and therefore an algorithm is needed to track or capture the material interface. An interface-fitted grid can provide accurate description by sampling the interface with computational grid points. However, in the case of large deformation the grid suffers from large distortion and requires regridding that can be computationally expensive. Modelling approaches using marker particles employ a Lagrangian formulation on particles and therefore the interface movement is naturally incorporated into the update of particle position. However, this method suffers from the drawback of being memory intensive. The level set method is developed upon the idea of representing the material interface as the zero level set of a scalar function and is widely used in computational fluid dynamics community for the simulation of multiphase fluid flow. Under the framework of a finite element flow solver, we adopt the level set method by assigning each Gauss integration point of the flow solver a signed distance to the material interface. This level set field is updated by velocity computed from the flow solver by solving an advection equation with high order weighted essential non-oscillation (WENO) scheme. When the level set field deviates from a signed distance field, instead of solving for the Hamilton-Jacobi (HJ) reinitialization, we reconstruct the interface directly by the linear interpolation of the nodal level set values, which has the advantage of avoiding potentially lengthy iterations and ameliorating the non-physical interface movement and mass loss caused by HJ reinitialization. We test our formulation on a few benchmark cases and show that our approach gives results comparable to that obtained from level set method using HJ reinitialization and from traditional marker particle approaches.

Paleozoic-Early Mesozoic multiple accretionary processes in the Altaids

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The Altaids or Central Asian Orogenic Belt lies between the Baltica (East European) Craton to the northwest, the Siberia Craton to the north, and the Tarim and North China cratons to the south. The formation and development of the Altaids with large amounts of juvenile material is controversial, but played an important role for the making of continent in Central Asia. The Altaids record the accretion and convergence of three collages in which two major oroclines (Tuva-Mongol and Kazakhstan) were finally formed. The Tuva-Mongol collage was a long, NS-oriented composite ribbon attached to the Siberian Craton that rotated to its current orientation during formation of the Tuva-Mongol Orocline, resembling the head-shaking and tail-swaying of a huge tadpole in its paleogeography. The components of the Kazakhstan collage system were welded together into a long single composite arc that was bent to form the Kazakhstan Orocline, with its paleogeographic scenario similar to the curling of a giant butterfly. The cratons of the Tarim-North China collage system were united and sutured by the Beishan Orogeny, which terminated with formation of

the Solonker suture in northern China. All components of the three collage systems were generated in the Neoproterozoic and developed in the Paleozoic. Final amalgamation of all these collages may have occurred during the end-Permian to mid-Triassic. The Altaids evolved by multiple convergence and accretion of many orogenic components during multiple phases of amalgamation, followed by two phases of orocline formation. The cores of the two oroclines were characterized by trapped oceanic basins and intra-oceanic arcs which remained the major sites of long-lived and tremendous juvenile addition. During these long-lived, complicated geodynamic processes with multiple subduction systems in the Palo-Asian Ocean in the Paleozoic-Mesozoic, several world-class metallogenic belts were formed.

Potential geodynamic link between Paleo-Asian and Tethyan tectonic domains

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Almost all the major continents and microcontinents underwent northward drift during Phanerozoic, during which the Gondwana gradually brokeup, resulting in the southward enlargement of the Asian continent. The build-up of Asian continent was controlled by two different and sequential ocean systems, they are the Paleo-Asian ocean and Tethyan oceans, respectively, being responsible for the construction of Asian continent. The initial subduction of oceanic plates in the Paleo-Asian ocean can be dated back to ca. 1.0 Ga, which was much older than the earliest Tethys ocean, even the contentious Proto-Tethys ocean, but it overlapped with the Paleo-Tethys ocean during its late stage of tectonic evolution. In contrary to the Tethyan oceans that were short-lived and internal oceans, the Paleo-Asian ocean was long-lived and involved tremendous juvenile addition to continental crust, forming one of the largest accretionary orogens in the world. As the early building blocks of the Asian continent that first underwent northward drift during early Paleozoic, tectonic evolution and driving force for the northward drift of the Siberia, Tarim-North China blocks were controlled by the subduction of oceanic plates in the Paleo-Asian ocean domain considering the driving force for the drift of continents are closely associated with slabs, rifting of Tarim-North China blocks from the Gondwana represent the initial breakup of Gondwana and birth of Paleo-Tethys ocean, indicating maybe there was some geodynamic link between them that needs to be pursued in the future. Interestingly, there is also similarity in the forms of drift of continents between them, for instance, the northward drift of the Tarim block during late Paleozoic and India block during Cretaceous, that is the development of passive continental margin on the northern margins of both blocks, indicating the pull force of subducting South Tianshan and Neo-Tethys oceanic plates toward north provided the driving force, unlike the cases happened in the eastern Pacific, the westward drift of American continents and opening of the Atlantic ocean resulted in the development of Cordilleran accretionary orogens, and in the western Pacific, where no continental blocks of the same size as the Tarim-North China blocks underwent and are undergoing eastward drift. This similarity and above-mentioned coeval existence of them hint that there maybe was some geodynamic link between the Paleo-Asian ocean and Tethyan oceans tectonic domains, the sequential development of them resulted in the formation of modern Asian continent.

Petrochronology of oxidized ultrahigh-temperature granulites from the Arequipa Massif of southern Peru

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Sapphirine-quartz granulites from the Cocachacra region of the Arequipa Massif in southern Peru record early Neoproterozoic ultrahigh-temperature metamorphism. Phase equilibrium modelling and zircon petrochronology are used to quantify timing and pressure-temperature conditions of metamorphism. Modelling of three magnetite-bearing sapphirine-quartz samples indicates peak temperatures of ~ 950 °C at ~ 0.7 GPa and a clockwise P-T evolution. Elevated concentrations of Al in orthopyroxene are also consistent with ultrahigh temperature conditions. Neoblastic zircon records ages of ca. 1.0-0.9 Ga that are interpreted to record protracted ultrahigh temperature metamorphism. Concentrations of heavy rare earth elements in zircon do not show systematic trends with U-Pb age but do correlate with variable whole-rock compositions. Very large Ce anomalies (~ 100) in zircon from two samples probably relate to strongly oxidizing conditions during neoblastic zircon crystallization. Low concentrations of Ti in zircon (1300 °C/GPa) are consistent with minor crustal thickening, but in a region with a thin lithosphere.

Development of L-tectonites in isolated rock volumes: a numerical investigation

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Rocks with a well-developed lineation but a weak or no foliation (L-tectonites) commonly occur as isolated volumes dispersed in other tectonites. We use a multi-scale numerical modeling approach to investigate the conditions for the development of such L-tectonites. The approach combines the strength of kinematic and mechanical analyses in large-strain three-dimensional lithospheric deformations. Our modeling shows that, in progressive simple shearing deformation zones and general non-coaxial progressive deformation zones, L-tectonites develop only in rheological heterogeneities that are moderately stronger than the bulk material as a whole. Stronger elements never accumulate enough internal strain for fabrics to develop. Inclusions weaker than the bulk material will develop flattening strains. L-tectonites are most likely developed in macroscale simple shearing, simple-shearing dominated plane-strain general shearing, or simple-shearing-dominated Sanderson and Marchini transpression. The lineations of the L-tectonites are always nearly parallel to the lineations in the bulk material. Where the lineations are nearly 90° degree from the vorticity axis, the macroscale flow is close to a plane-strain general shearing. Where the lineations are oblique to the vorticity axis and more variable, a simple-shearing- dominated triclinic thinning zone with mainly uniaxial boundary stretching is likely. Obliquely divergent boundary conditions are accommodated by folding and fracturing structures in the upper lithosphere and development strain-localized simple-shearing-dominated detachment shear zones in the ductile lithosphere. The concept of a homogeneous transtensional zone with vertical vorticity axis is unrealistic and unsupported by fabric evidence. L-tectonites can occur in the detachment zones due to flow partitioning or in the wall rocks, especially in the footwall.

Geochronology indicates a long life span discrete pulses porphyry-epithermal Cu deposit - Tiegelongnan, Tibet, China

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The Tiegelongnan porphyry-epithermal Cu deposit is a recently discovery in the Duolong porphyry Cu-Au deposits district, within the Bangong-Nujiang belt in Tibet, China. It contains measured and indicated resources of around 2 000 Mt @ 0.53 % Cu, which is characterized by high sulfidation epithermal Cu mineralization telescoping on porphyry Cu mineralization. Intrusions zircon U-Pb (LA-ICP-MS) and high-precision (CA-ID-TIMS) dating and ^{40}Ar-^{39}Ar ages of hypogene biotite, sericite and alunite reveal an extremely long life span associated with several discrete magmatic and hydrothermal

events. Pre-mineral porphyry is dated at 123 Ma, which is followed syn-mineral multiple porphyries intruding at 121 Ma, 119.9 ± 0.1, 119.9 ± 0.24 and 119.1 ± 0.2 Ma. Younger porphyries are dated at 116.5 ± 0.7 Ma and 115.9 ± 0.4 Ma. All those are covered post-mineral volcanic andesite at around 111 Ma. ^{40}Ar-^{39}Ar age of biotite and muscovite are dated at around 121 Ma, which represents porphyry hydrothermal events. After that, several epithermal hydrothermal pulses associated with high sulfidation state copper mineralization are recorded by hypogene alunite ^{40}Ar-^{39}Ar ages at 117.9 ± 1.6 Ma, 116.3 ± 0.8 Ma, 112.5 ± 0.8 Ma, 111.7 ± 1.0 Ma and 100.6 ± 2.0 Ma. It is consistent with long discrete active igneous events within the Bangonghu-Nujiang ore belt, as results of prolonged plate subduction and tectonic collision events within Bangonghu-Nujiang Suture zone between 130 and 100 Ma. This protracted magmatic-hydrothermal history with several epithermal Cu mineralization events superimposing on porphyry Cu-Mo mineralization may be the reason why the Tiegelongnan is the largest deposit with the highest Cu grade in this Duolong district. We conclude that the longer lifespan made possible more pulses of hydrothermal fluids thus bring more metals to precipitate at specific ore locations.

An integrated approach in characterization of triple porosity Nisku Reefs Alberta: a quest from core and borehole images to 3D earth model

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Enhanced Oil Recovery (EOR) is an economic way of producing the remaining oil out of previously produced Devonian Pinnacle Reefs in the Nisku Formation within the Bigoray area of Alberta. To maximize the recovery factor of the remaining oil, it was necessary to first characterize the geological structure, reservoir properties and the natural fracture network of the two reefs of interest. This model was then used for reservoir simulation history matching and production forecasting. With the enhanced resolution of a newly reprocessed 3D seismic volume, more accurate seismic interpretation was completed to better delineate the internal and external structure of the reefs. The outputs of petrophysical analysis was porosity, permeability, water saturation and rock type logs as the primary input for the geologic property modeling. Borehole image interpretation, core mapping and core photo analysis were used to quantify fracture intensity, orientation and dip, together with vug intensity and estimation of vugular porosity. A discrete fracture network (DFN) model was developed with these well data and with Seismic Ant Tracking attributes. In these Devonian Pinnacle Reefs, and in other reservoirs, before investing in an EOR scheme, it is critical for the operator to understand the geologic structure and the petrophysical characteristics of the reefs in as much detail as possible. This paper demonstrates how log and seismic data that is up to 40 years old can be converted to modern data types and be used to characterize a reservoir in a way not possible before.

Structural evolution of mineralized and barren deformation zones in the western Wabigoon subprovince, Ontario: new constraints from regional mapping and petrographic analyses

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Crustal-scale deformation zones are commonly associated with orogenic gold occurrences in the Superior Province. Thus, it is important to understand geologic controls associated with the formation of mineralized and barren structures. This study investigates the temporal and kinematic evolution of three major structures in the Dryden area of the western Wabigoon subprovince: the gold-bearing Manitou-Dinorwic (MDdz) and the barren Wabigoon (Wdz) and Mosher-Bay Washeibemaga (MBWdz) deformation zones. We present preliminary results from regional- to outcrop-scale mapping and petrographic observations of representative samples from these zones. Three major deformation events are documented. D1 and D2 are well preserved along the Wdz and MBWdz. D1 is expressed as F1 isoclinal folds and an E-trending S1 axial planar foliation defined by biotite; it is interpreted as N-S shortening. D2 is characterized by F2 asymmetric z-folds of S1/S0, a weakly developed crenulation cleavage, a moderately W-dipping lineation, σ-clasts and C-S fabric indicative of dextral shear; it is interpreted as a transition to dextral transpression. D3 is observed along the Wdz, MBWdz, and MDdz. At the Wdz and MBWdz, it is expressed as small-scale faults that display sinistral offsets and a crenulation of earlier fabrics. Along the MDdz, it is characterized by intense development of a NE-trending S3 foliation defined by chlorite and σ-clasts indicative of sinistral shear; this NE-trending fabric crosscuts the E-trending S1/S2 fabrics; it is interpreted to represent late sinistral transpression. Therefore, formation of the MDdz postdates deformation associated with the Wdz and MBWdz. Since most gold occurrences and prospects are associated with localized D3 strain along the MDdz, we suggest that the primary gold mineralization event is late relative to regional terrane accretion (D1-D2), which may be a factor in explaining the low gold endowment of the western Wabigoon subprovince.

Metamorphism and tectonics of the Hunt River greenstone belt in Labrador, Canada

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The Hunt River belt (HRB) in the Hopedale block of the North Atlantic craton in Labrador, Canada, is a well-preserved Archean greenstone belt metamorphosed to upper greenschist to lower amphibolite facies. The belt comprises heterogeneous mafic metavolcanic rocks with interlayered felsic metavolcanic rocks, ultramafic schists and metasedimentary schists. The HRB is interpreted to rest on the 3100-3300 Ma tonalitic to trondhjemitic Maggo gneiss. U-Pb dating of zircons from a HRB meta-rhyolite and a tonalitic gneiss structurally associated with the HRB place deposition of the volcanic sequences in the belt at 3105 ± 3 Ma. The as yet relatively unconstrained Hopedalian and Fiordian metamorphic and deformational events that affected the Hopedale block between 3300-3100 Ma and 2900-2700 Ma may be recorded by the HRB in the form of microstructures and overprinting metamorphic mineral assemblages. The present study aims to construct a detailed lithostratigraphic section of the belt and the immediate underlying Archean basement rocks with a specific focus on clarifying the relationships between mineral growth, deformation and metamorphic conditions in order to understand the evolution of the HRB. Thermobarometric modeling using TWQ software of electron microprobe data will be done to estimate the conditions of metamorphism. The timing of deformation will be determined by LA-ICP-MS U-Pb dating on U-bearing minerals like monazite and titanite that define microstructures in oriented samples and pairing them with large-scale structures in the HRB. Preliminary dating of titanites within northeast trending foliations associated with Fiordian metamorphic structures in garnet-amphibolites show ages of 2725 ± 14 and 2835 ± 14 Ma.

Episodicity of stress state in an overriding plate: evidence from the Yalu River fault zone, East China

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The ca. 700-km-long Yalu River fault zone (YRFZ) in East China, adjacent to the Pacific Ocean, underwent a polyphase evolution during

the Cretaceous when it controlled the development of rift basins interrupted by several shortening events. The East China continent was part of the overriding plate with respect to the subducting paleo-Pacific plate during the Cretaceous. The YRFZ is ideal for studying the episodicity of stress state in the overriding plate. To constrain the polyphase evolution of the YRFZ, structural observations, fault-slip data measurements and LA-ICP-MS zircon U-Pb dating of Cretaceous volcanic rocks and sandstones were undertaken in this study. The initial faulting (D1) in the earliest Cretaceous was sinistral. The fault zone was then dominated by normal faulting (D2) that produced rift basins during the rest of the Early Cretaceous. Sinistral faulting (D3) developed again in the earliest Late Cretaceous, followed by dextral normal faulting (D4) and rift basin development during the rest of the Late Cretaceous, and finally reverse dextral faulting (D5) at the end of the Cretaceous. The fault-slip data show that there was a corresponding evolution of the stress field from N-S compression during D1, NW-SE extension during D2, N-S compression during D3, N-S extension during D4, and finally E-W compression during D5. The geochronological data show that the D1 and D3 episodes of compression each lasted ~ 3 Ma, D2 extension lasted ~ 31 Ma, and D4 extension ~ 27 Ma. These data indicate an episodicity in the stress state with longer periods of extension and shorter periods of compression. A slab-driven model with relatively long periods of low-velocity subduction alternating with shorter periods of high-velocity subduction could account for the episodicity of stress state in the overriding plate from D1 to D5.

Iron oxide-apatite deposits form from hydrosaline liquids exsolved from subvolcanic intrusions

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Iron oxide-apatite (IOA or Kiruna-type) deposits typically consist of a magnetite-apatite-actinolite assemblage that is superimposed on extensive Na-(Ca) alteration. The origin of these deposits has been ascribed to the separation of iron-oxide melts, magnetite emulsions, or aqueous fluids from silicate magmas. Here, we propose a novel model based on new findings from a cluster of IOA deposits in the early Cretaceous Ningwu andesitic volcanic field in eastern China. In these deposits, coarse-grained vein, massive replacement, and fine-grained disseminated magnetite occurs with apatite and actinolite in the albitized, and often brecciated, apices of diorite porphyry intrusions, overlying andesites, and adjacent marine sedimentary rocks. Magnetite mineralization is closely associated with alteration zonation of 1-2 km in diameter. The inner alteration zone is characterized by extensive albitization, which gradually transitions to an intermediate zone dominated by diopside/actinolite, epidote, magnetite, and apatite. The outer zone has chlorite, carbonate, and possibly abundant pyrite. Precipitation of magnetite was slightly later than albitization and was likely coeval with apatite and actinolite. Unmetasomatized magnetite with ilmenite lamellae has elemental compositions similar to magnetite phenocrysts in andesite. But the metasomatized magnetite shows coupled dissolution and reprecipitation textures, and has distinctively lower Ti and V. Diopside and garnet, paragenetically earlier than or coeval with magnetite, contain fluid inclusions with extremely high salinities up to ~ 90 wt % NaCl eq and homogenization temperatures of 745-846 °C. Phase relations suggest that hydrosaline liquid was trapped at low pressures. Together, the evidence suggests that these deposits formed from hydrosaline liquid and vapor exsolved from subvolcanic diorite porphyry intrusions at magmatic temperatures (~ 800 ℃). Fluid expansion and evolution of such unusual hydrosaline system is responsible for the extensive Na-Fe alteration and brecciation, which is a hallmark of IOA deposits.

Contrastive study on the Mianhuakeng-Shulouqiu granite-hosted and Malou volcanic-hosted uranium deposits in Guangdong Province, South China, and their implication for the genetic link between the granite- and volcanic-hosted uranium mineralization

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South China is prospective for hard-rock type uranium deposits, and therefore large amounts of data about their genesis are well documented. The genetic linkage between these uranium deposits (granite-, volcanic- and C-Si-shale-hosted) is still open to debate. To solve this problem, we carried out a series of comparative studies on the Mianhuakeng-Shulouqiu (M-S) granite-hosted and Malou volcanic-hosted uranium deposits in the North Guangdong Province. In this region, the red-bed mountain of Danxia, giant Fankou MVT-type Pb-Zn and numerous magmatic-hydrothermal W-Sn deposits occur. Based on field investigations, the M-S granite-hosted uranium orebodies are directly controlled by the NNW-trending faults, while the Malou volcanic-hosted uranium orebodies are hosted in the E-W-trending Malou Fault. The two types of uranium deposits develop similar ore minerals including uraninite, coffinite and pitchblende. Similar alteration minerals related to uranium mineralization are identified, including hematite, muscovite, chlorite, sulfides, carbonate, quartz, fluorite, kaolinite and montmorillonite. A general mineral sequence is obtained: host rocks-hematite-uraninite-coffinite-pitchblende-sulfide. High-precision LA-ICP-MS U-Pb dating was used to constrain the time of formation of the host rocks and mineralization. The zircon grains of Zhuguangnan pluton hosting the M-S U deposit yielded an age of ca. 160 Ma, whilst the associated uranium-bearing minerals have a wide age range from 90 to ~ 1 Ma. The Malou volcanic rocks revealed a two-staged volcanic eruption of 160 and 96 Ma, but mineralization ranges from 110 to ~ 1 Ma. Combined with the previous studies, we conclude that the uranium mineralization in M-S and Malou deposits is epigenetic and long-lived. There is a possible genetic link between the granite- and volcanic-hosted uranium mineralization and the regional red bed basins may play an important role is the formation of uranium mineralization in South China.

Stratigraphic and structural setting of gold mineralization along the Malartic transect in Southern Abitibi and Pontiac subprovince within the Superior Province, Quebec, Canada

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The Superior Province consists of generally east-striking fault-bounded Archean volcanic and sedimentary assemblages. Numerous world-class lode gold deposits occur near these volcanic-sedimentary boundaries, such as the Larder Lake-Cadillac break, Porcupine-Destor-Manneville fault zone. New targeted geological mapping along the Malartic transect across the southern Abitibi and Pontiac subprovinces reveals that a few sedimentary assemblages (i.e. < ca. 2687 Ma Cadillac and Chicobi group) unconformably overlie volcanic assemblages (i.e. ca. 2706 Ma Piche group and Desboues formation), based on basal conglomerate that youngs away from and comprises clasts of underlying volcanic rocks. These supracrustal rocks underwent multiple deformation episodes. They typically show a strong penetrative west-to-northwest-striking subvertical cleavage, which is axial planar to regional, upright, isoclinal to tight folds. A stretching lineation lies on this main cleavage and typically plunges steeply near the contact between metavolcanic terranes and sedimentary basins. The main cleavage is folded by late Z or M folds and overprinted by late crenulation and kink band cleavages. Auriferous veins include subvertical shear veins boudinaged along the

main cleavage and extension veins at an angle anticlockwise to the main cleavage. These veins were mostly emplaced pre- or syn-, and post-regional folding. They were then displaced by late dextral shear bands and brittle faults or folded by late drag Z-folds. Gold mineralization was likely introduced via major terrane boundaries and deposited in various host structures during late orogenic development of Archean greenstone belts.

Ion exchange between hydrotalcite group minerals and petroleum-produced brine: applications to brine desalination and carbon mineralization

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Maintaining net zero carbon emissions to limit global warming is becoming an increasingly important global goal. Carbon sequestration through the production of carbonate-bearing hydrotalcites can store excess atmospheric CO_2 in the structures of these minerals. Hydrotalcites have a high anion exchange capacity that can also be used to desalinate wastewater through uptake of anions; moreover, they can be synthesized in the laboratory through the reaction of atmospheric CO_2 with metal cations in aqueous solution. Petroleum-produced wastewater is of environmental concern owing to its high concentration of anions, heavy metal cations and organic carbon, which can be a source solution for hydrotalcite synthesis. The purpose of this research is to desalinate petroleum-produced water by applying carbonate-bearing hydrotalcites, as well as, modifying existing hydrotalcite synthesis methods to trap atmospheric CO_2. We conducted an anion exchange experiment between stichtite $[Mg_6Cr_2CO_3(OH)_{16}\cdot 4H_2O]$ and petroleum brine to investigate desalination of the brine through the production of woodallite $[Mg_6Cr_2(OH)_{16}Cl_2\cdot 4H_2O]$ at room temperature. Phase identification with X-ray diffraction indicated that chloride from produced water exchanged with interlayer carbonate species, producing woodallite as a crystallographic trap for chloride within 24 hours of reaction. Reactions between pyroaurite $[Mg_6Fe_2(CO_3)(OH)_{16}\cdot 4H_2O)]$ and chloride-rich solutions (i.e. 0.1 M HCl, 0.01 M HCl, 0.1 M NaCl and 1 M NaCl) were also used to investigate the effect of pH and salinity on the extent of brine desalination. The concentration of chloride decreased in solutions containing either 0.01 M HCl, 0.1 M NaCl or 1 M NaCl, demonstrating desalination by pyroaurite. Petroleum-produced brine will be used in further experiments to investigate its desalination and carbonation using carbonate-bearing hydrotalcites.

Ni isotopic fractionation associated with Ni mineralization in the Zambales and Palawan ophiolite complexes, Philippines

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Do nickel isotope ratios reflect weathering and leaching processes in laterite profiles in a systematic way that can be used to understand these processes ? The Zambales Ophiolite Complex (ZOC) and Palawan Ophiolite Complex (POC) are host to several Ni laterite deposits in the west-central Philippines. ZOC is a combination of island arc and back arc settings, while the POC is the result of subduction along the Asian continental margin. Nickel is primarily hosted in olivine and olivine-derived serpentine and leached into the groundwater during weathering processes. When weathering products (e.g. Fe-Mn oxides, goethite) form, Ni is incorporated into the newly-formed minerals. Here, we report Ni isotopic compositions for 23 river/groundwater, bedrock, laterite, saprolite, soil, and goethite-mineralization samples. X-ray diffraction analyses at the University of Minnesota Duluth (Duluth, USA) indicate that least-altered bedrock is made up primarily of olivine, pyroxene, and serpentine while the weathered samples contain mostly goethite. Bulk chemical compositions analyzed by Quadrupole ICP-MS at Western University (UWO - London, Canada) indicate that the Ni content decreases in sequence from saprolite to laterite, soil, bedrock, and river/groundwater. Nickel was purified from sample matrices at UWO and isotopic compositions analyzed using a Nu Plasma II Multicollector ICP-MS at Indiana University (Indiana, USA). Results show up to 1.3 ‰ variations in δ^{60}Ni (2σ) from 0.95 ± 0.11 ‰ for water (n = 1), 0.22 ± 0.57 ‰ (n = 4) for mineralized samples, -0.03 ± 0.99 ‰ (n = 6) for bedrock, -0.17 ± 0.01 ‰ for a limonite soil (n = 1), -0.19 ± 0.75 ‰ for saprolites (n = 6), and -0.22 ± 0.34 ‰ for laterites (n = 7). Results indicate that heavy Ni isotopes are preferentially leached into groundwater and incorporated into mineralization (e.g. garnierite and goethite), leaving saprolites and soils with lighter isotopic signatures. Ni isotopes can thus be used to trace weathering and mineralization processes of ultramafic rocks in tropical areas and to determine fractionation factors.

Multiphase ore emplacement in the Eagle's Nest Ni-Cu-(PGE) deposit, McFaulds Lake greenstone belt, Superior Province, northern Ontario, Canada

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The Eagle's Nest Ni-Cu-(PGE) deposit occurs within the Eagle's Nest Dike of the 2.73 Ga Esker Intrusive Complex (EIC) in the "Ring of Fire" region of the Superior Province. The dike is ~ 200 m wide x ≤ 50 m thick x ~ 1600 m deep and composed of komatiitic harzburgite ± lherzolite. Massive, semi-massive, net-textured (including rare net and more common patchy-, leopard-, pinto-, inclusion-, and disrupted-net), and disseminated sulfide mineralization occurs along the northern contact with granodiorite country rocks, consistent with localization along the lower edge of a subhorizontal blade-shaped dike that was rotated (along with the rest of the EIC) into its current subvertical orientation. Inclusion-net textures contain the most chalcopyrite; leopard-net textures contain the most pentlandite. Between surface and 300 m, massive sulfides occur in several 30-50 m deep embayments along the footwall and grade upward and laterally into more continuous and more abundant net-textured sulfide. Between 500 and 900 m net-textured sulfides contain localized zones of "disrupted-net texture" characterized by 3-60 cm thick zones of cross-cutting barren pyroxenite. Sulfide textures, cross-cutting relationships, and inclusions indicate a dynamic emplacement history involving: 1) emplacement of komatiitic magma and thermomechanical erosion of wall rocks to form embayments, 2) flow-through crystallization of olivine and accumulation of sparse anteliths/antecrysts from upstream in the system; 3) incorporation of sulfide xenomelts from isotopically-similar sulfide facies iron formations in the granodiorite, 4) transport, upgrading, and deposition of sulfide melt in the current location, 5) percolation of sulfide melt through the olivine network, forming leopard net-textured sulfides underlain by massive sulfides, and expulsion of silicate melt, leaving sulfide, Ol-sulfide, Ol-(sulfide), and Ol-(Pyx)-(sulfide) cumulates; 6) emplacement of late pyroxenite into partially-consolidated net-textured sulfide, forming disrupted net texture, and mobilization of earlier sulfide, forming massive sulfide schlieren and pods; 8) fractional crystallization of sulfide melt; and 9) greenschist-facies metamorphism and tectonic rotation.

Heavier noble gas analysis on Thermo Scientific Helix SFT

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Noble gas isotopes are increasingly applied in tracing and dating groundwater. Helix SFT is a magnetic sector static vacuum gas-source mass spectrometer produced by Thermo Scientific for the high-precision analysis of helium by the simultaneous collection of ^{3}He and ^{4}He, but is capable of measuring heavier noble gas isotopes up to Xe. An automatic processing line for noble gas analysis has been developed and tested, which is equipped with a multi-phase sample inlet, chemical getters and various cryogenic traps, allowing trapping and separation of all noble gases. The performance of the processing line and Helix SFT on heavier noble gas measurements (Ne, Ar, Kr and Xe) has been explored with a new method that resolves the issue of remnant magnetism of the pole pieces in the magnetic sector. From air standard samples, the sensitivities of this analyzing system for Ne, Ar, Kr, Xe are 8.96×10^{-5} A/Torr, 7.51×10^{-4} A/Torr, 1.03×10^{-5} A/Torr and 8.46×10^{-4} A/Torr, respectively. The precision of the isotopic ratios in air standard samples are /1.5 ‰ for ^{22}Ne/^{20}Ne, N1.3 ‰ for ^{86}Kr/^{84}Kr, K1.2 ‰ for ^{82}Kr/^{84}Kr, K4.5 ‰ for ^{132}Xe/^{129}Xe and X4.8 ‰ for ^{131}Xe/^{130}Xe. A common technical issue has been the lengthy time required to demagnetize pole pieces for ^{3}He/^{4}He analysis after measuring heavier noble gases, which we resolve with an inversed He isotope tuning protocol.

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