Chapter 1

Appearance of Life

> Then God said: Let us make man in our image, after our likeness; and let man have dominion over the fish of the sea, and over the birds of the air, and over the cattle, and over all the earth…. So God created man in his own image, in the image of God he created him…. And God blessed humans and God said to them: Be fruitful and multiply, and fill the earth and subdue it; and have dominion over the fish of the sea and over the birds of the air and over every living thing that moves upon the earth. — Genesis 1: 26–28

Life is the ability of organisms to self-replicate. Life began when prebiotic molecules were encapsulated long enough in a prebiotic cell for some molecules to self-assemble (synthesize) into larger molecules required for self-replication. Prebiotic cells and prebiotic molecules are inorganic chemical compounds that form in favorable environments, often in very large amounts. Prebiotic cells became living organisms when they acquired the ability to sustain self-replication. Could self-replication have happened because a great spirit (god) caused it to happen? Unlikely. Could self-replication have happened because of spontaneous chemical reactions? Probably.

The god explanation for the origin of self-replicating organisms is based on revelation. In the Judeo-Christian-Muslim religions the truths of revelation are validated by deductive reasoning. An omnipotent being revealed his purpose for creating life to humans and then directed the scope of life for human benefit.

All the complexities of the biosphere derive from god's purpose of making humans the governor of the biosphere. If a per-

son believes that life is the product of an omnipotent god, then a person can deduce all biological complexities from the power and purpose of this god. Immediately or ultimately geological and biological sciences are superfluous. If a person believes the Genesis myth is fact, all biological sciences not directly related to medicine or agriculture are marginal appendages to true belief.

If a person believes that the biosphere is a product of intelligent design because god created it for the benefit of humans, the principal purpose of scientific inquiry is to confirm the validity of the Genesis myth. This myth asserts that god created all life for the benefit of humankind. Humans are the final biotic creation in his design of the universe because he created humans in his image. Humankind is a reflection of god's omnipotence; therefore, humans must glorify him. Deductive reasoning from the Genesis myth gives purpose to human life in terms that are understandable by persons who are scientifically illiterate.

In its most bizarre form, large numbers of Christians reject the evolution of life from bacteria cells to chordate worms, to fish, to terrestrial vertebrates, to great apes, to humans. They favor a highly simplistic explanation. They believe that, in the recent past, god created humankind and all other organisms in the exact anatomical form they now exist. They are assured this is true by a literal interpretation of infallible scripture that assigns humankind dominion over all forms of life. They believe this even though the Genesis version of creation is one of many mythical accounts of creation composed by preliterate societies to explain how, why and where they came to occupy the geographic region where they live.

Religious faith is the only basis for claiming that god created self-replicating cells; or that god designed self-replicating cells to evolve into humankind; or that god created humans in the exact anatomical form they now exist. Religious faith allows clergymen to use deductive reasoning to validate the claim that

humankind is a special creation by god to govern the earth's biosphere. The primacy of deductive reasoning allows clergymen to deny the existence of evolution in order to elevate humankind into god's surrogate on earth. Deductive reasoning (based on revelation) allows scientific explanations to be ignored or denied.

The scientific explanation for the origin of self-replicating cells is based on inductive reasoning. Inductive reasoning requires experiments that can be confirmed by replication. These experiments are a foundation for additional experiments that increase the scope of the original experiment. Inductive reasoning is used to organize large amounts of data into coherent explanations that have a high degree of certainty.

Life came into existence because a series of chemical reactions within one (or more) prebiotic cells made it possible. Many of these chemical reactions can be duplicated by laboratory experiments. The inductive reasoning of science gives no purpose for the origin of self-replicating cells or their evolution into complex organisms. *How* life came into existence is the question asked by science because this question can be tested by experiments. *Why* life came into existence is not a question asked by scientists because there is no way to test this question.

PRECONDITIONS

What were the conditions that made life possible? This is an open question, but four physical conditions were essential for life to begin: (1) little or no oxygen in the atmosphere because oxygen would rapidly degrade prebiotic molecules to carbon dioxide and water; (2) warm oceans that had many favorable microenvironments where prebiotic cells and molecules could concentrate; (3) prebiotic cells that could concentrate favorable mixtures of prebiotic molecules; (4) a source of energy that could be cap-

tured by prebiotic molecules in order to assemble other prebiotic molecules into self-replicating chemicals. Sunlight, ultraviolet radiation, lightning and submarine volcanic vents (black smokers) were instantly available sources of energy.

Scientific researchers are trying to duplicate the origin of prebiotic cells and then map how encapsulated prebiotic molecules were synthesized into molecules that had the ability to self-replicate. Their research is guided by the hypothesis that sometime about four billion years ago there were favorable conditions somewhere in the oceans where simple prebiotic molecules were encapsulated by prebiotic cells, and that these cells endured long enough for encapsulated chemical compounds to synthesize into molecules that could self-replicate. In other words, the hypothesis that life had a spontaneous chemical origin allows the origin of life to be investigated by scientific experiments.

Natural concentrations of prebiotic molecules have been found in some contemporary marine microenvironments. These conditions were almost certainly present in favorable marine microenvironments when life first became possible. Sustainable replication cannot occur in random mixtures of dispersed molecules. Sustaining life requires that replication takes place in cells that concentrate essential molecules in order for them to synthesize into the larger molecules essential for life. Prebiotic cells are formed by membranes that have the ability to encapsulate the molecules necessary for self-replication. The cells must endure long enough for the molecular chemistry of replication to occur. How long is long? One second, a minute, five minutes, ten minutes, an hour, several days?

The working hypothesis of evolutionary biologists is that several chemically active prebiotic molecules could react to form new chemical compounds if they were confined in a cell. A prebiotic cell had to exist long enough for some encapsulated molecules to react with other encapsulated molecules to synthesize molecules

that could self-replicate. At the origin of life, prebiotic chemical reactions within prebiotic cells became biological when nonliving chemicals within a prebiotic cell synthesized themselves into chemical compounds that could sustain self-replication. The self-replicating cell became an organism. Life began.

Self-replication required an ability to capture energy and acquire nutrients in order to replicate. Sunlight was the most likely source of energy, meaning the first self-replicating cells were probably photosynthetic (organic compounds formed through the addition of light energy). These cells encapsulated prebiotic molecules that could catalyze sugars from water and carbon dioxide. The other possibility is prebiotic cells using the thick soup of mineral nutrients at geothermal vents to synthesize self-replicating molecules. As of now, however, no prebiotic cells have been found in this environment.

Sugars synthesized by the first cells were the nutrients that sustained replication. Self-replication may have happened several times immediately after the earth became habitable but only one pathway has survived. This is the pathway used by photosynthetic molecules and its variant, chemosynthesis (during which organic compounds are formed by energy derived from inorganic chemical compounds), used by molecules that inhabit geothermal vents. This pathway is the basis for all subsequent life from the most primitive archea to humans. After self-replication became a self-sustaining chemical reaction (called life), life had only one purpose: reproduction.

SELF-REPLICATING CELLS

Sustaining life required that the chemistry of replication take place in a cell. A physical mechanism that produces prebiotic cells has been discovered. The mechanism is a cycle of drying

and wetting of some naturally occurring prebiotic lipids. Lipid molecules self-assemble into prebiotic cells that have two layers. All cells of all organisms have walls composed of two layers. In several contemporary marine microenvironments prebiotic lipids concentrate in a broth.

One of the most favorable microenvironments is intertidal zones in desert climates where stranded liposome layers dry during low tide and rehydrate during high tide. Rehydrated lipid membranes self-assemble into two-layer membranes in the shape of spheres and cylinders (rods). These are liposome cells. Laboratory experiments have observed prebiotic liposome cells encapsulate many prebiotic molecules.

Liposome cells are stable as long as they remain in water. This means that there is time for molecular chemical reactions to occur within liposome cells. It is highly probable that encapsulation of chemically active prebiotic molecules contributed to the assembly/synthesis/polymerization of simple proteins in liposome cells.

Something similar has recently been discovered. Fullerenes (buckyballs) are a newly discovered crystalline form of carbon that is now known to be very common in the contemporary environment. Buckyballs are inorganic cells. They have hollow interiors that can encapsulate a large variety of molecules. Buckyballs have been discovered in sediments that are more than 250 million years old. And searching for them in older sediments will probably find them because they are very stable at atmospheric or near atmospheric conditions. This is evidence that prebiotic cells can exist in large numbers over extended periods of time.

Almost certainly, favorable marine microenvironments in the Archean era (4.0 to 2.2 billion years ago) contained a large variety of prebiotic organic molecules that were available for encapsulation in prebiotic cells. Experiments conducted by molecular chemists in an atmosphere without oxygen have produced large

quantities of prebiotic organic molecules by physical processes.

The gases used to create preorganic molecules in laboratories are water vapor, carbon dioxide, methane and nitrogen. They are confined in a large glass vessel and electricity (lightning) and ultraviolet radiation is passed through them. A large number of sugars, amino acids, short strands of RNA (ribonucleic acid) and other simple molecules have been synthesized. This is strong evidence that prebiotic organic molecules were synthesized in large quantities from these same gases that composed the earth's early atmosphere. These prebiotic molecules were concentrated in a prebiotic broth in favorable marine microenvironments. There they were encapsulated by prebiotic cells.

Almost certainly, from the inception of life until about 2.2 billion years ago, the earth's atmosphere and marine water had minimum amounts of oxygen. If there had been an oxygen-rich atmosphere, as exists today, prebiotic organic molecules would have been reduced to water and carbon dioxide almost as soon as they formed. Absence of oxygen in the atmosphere and marine water meant there was no ozone layer. Ultraviolet radiation reached the earth's surface and provided energy for synthesizing prebiotic molecules. Energy also came from lightning and visible light.

When did life originate? Almost certainly it occurred early in the Archean era, about four billion years ago. It began very soon after the earth became habitable, when warm water oceans covered most of its surface. Radiometric dating of meteorites and moon rocks indicates that the solar system—and earth—were formed about 4.6 billion years ago. The oldest rocks preserved in the earth's geologic record are about 3.8 billion years old, and the first evidence of life are microfossils of archea (primitive bacteria). They have been discovered in early Archean sediments that are about 3.5 billion years old. These sediments are found in Australia and South Africa.

A principal means of producing prebiotic molecules for encapsulation in prebiotic liposome cells was synthesis on templates of crystalline minerals. At least three possible templates exist in contemporary marine microenvironments (and also existed in the early Archean era). They are: (1) clay crystals with a high copper content held in suspension by winds, (2) surfaces of pyrite and other detrital crystals in sea floor sediments, (3) bubbly froth created by wind on water in bays that contained concentrations of prebiotic molecules.

Within liposome cells, prebiotic amino acids and other simple molecules were catalyzed and polymerized into the larger molecules necessary for life to begin. In the trillion, times a trillion, times a trillion, times a trillion, times a trillion, times a trillion that short-lived prebiotic cells formed every day in favorable marine microenvironments, there was a chance that one cell would capture the right mixture of prebiotic amino acids and other prebiotic molecules needed for prebiotic RNA to synthesize the correct mixture of molecules that could initiate and sustain self-replication.

Self-replication of cells occurred when several prebiotic molecules attached themselves to prebiotic RNA encapsulated in prebiotic cells. RNA formed a scaffold within the cell for synthesis to occur. Synthesis produced the pigment molecules that synthesized sugars using light as energy and the protein molecules needed to sustain cell replication.

Where did the concentrations of prebiotic molecules needed for synthesis of life come from? Almost certainly they came from prebiotic cells that disintegrated in storms, but which had existed long enough for some synthesis to take place within them. The prebiotic sugars, amino acids and other organic molecules from disintegrated cells were then available for encapsulation in existing or new prebiotic cells. In favorable marine microenvironments, there was no shortage of prebiotic molecules available for encapsulation in prebiotic cells.

The two places where life (archea) could have originated are: (1) warm water in tidal pools, (2) hot water around submarine volcanic vents. Energy and mineral nutrients were super abundant around submarine volcanic vents. If archea originated there, they acquired energy by breaking the chemical bond of hydrogen sulfide. This energy was used to break the bond of carbon dioxide and water in order to synthesize sugars. This is called chemolithic synthesis. Chemolithic metabolism is a highly efficient source of energy to sustain replication.

In the contemporary biosphere a high percentage of archea live in extreme anaerobic microenvironments. The most accessible of these environments is the peripheral water of volcanic springs that vent boiling water, but they also thrive around submarine volcanic vents (black smokers) found in midocean rift zones. Four billion years ago there was an incredibly large amount of submarine volcanism. Hydrothermal vents (black smokers) that are associated with this volcanism, vented huge volumes of hydrogen sulfide, iron sulfide and carbon dioxide gas into ocean water. Submarine volcanic vents had abundant energy and mineral nutrients. Although energy and mineral nutrients were ample, experiments have not yet discovered prebiotic cells.

Alternatively, if archea originated in warm tidal pools, they could sustain metabolism by using sunlight to break the chemical bonds of carbon dioxide and water to synthesize sugars. This is photosynthesis. Photosynthesis and chemolithic synthesis supplied cells with an internal source of food by converting solar energy and chemolithic energy into sugars that sustained metabolism. For more than 1.5 billion years, life concentrated and evolved in one or both of these niches.

Laboratory experiments have produced prebiotic RNA molecules. RNA molecules alone can synthesize some proteins that store sufficient sequencing information to form a replicating

pathway for the entire cell. These proteins are called enzymes. Enzymes control replication and metabolism by controlling the speed, sequence, function and location of all protein cells in all organisms. They are the biologic engines of cell replication.

Replication by RNA alone was inefficient because the RNA pathway makes many mistakes. (RNA has no repair mechanism but DNA does.) Nonetheless, laboratory experiments indicate RNA was sufficiently efficient to initiate and sustain cell replication. Some of the mistakes in replication were beneficial because after the first appearance of life, mutations in the RNA pathway began the evolution into the DNA pathway. This indicates that natural selection was contemporary with the appearance of life.

Efficiency and speed of replication were improved by the attachment of more proteins on longer strands of RNA within cells. This was first step in the synthesis of DNA that vastly increased the efficiency of replication. Efficiency of replication by DNA rapidly displaced cells that replicated by RNA alone. No organisms using RNA alone have been discovered in the contemporary biosphere. The great unanswered question of molecular and evolutionary biology is how RNA evolved into DNA. The earliest microfossils are archea. The morphology of these cells closely resembles the morphology of archea that live in deep marine mud and other extreme environments.

Chemolithic and photosynthetic metabolism frees two hydrogen molecules. In chemolithic metabolism the sulfur molecule from the metabolism of hydrogen sulfide is added to FeS (pyrrhotite), a mineral vented in huge quantities by black smokers. This reaction synthesizes pyrite (FeS2). Pyrite is the waste product of chemolithic metabolism. There are huge quantities of pyrite around volcanic vents from the Archean era to the present. The two oxygen molecules that are the waste product of photosynthesis reacted with soluble iron to form magnetite or soluble calcium to form limestone.

During the Archean era, chemolithic archea/bacteria deposited huge quantities of carbon and pyrite in deep-water black shale. The black was caused by immense quantities of dead microbes incorporated into sediments. Chemolithic microbes were hugely abundant in Archean oceans because there was an abundance of mineral nutrients and there were no animal predators.

From my experience as a geologist exploring for mineral deposits on the Canadian Shield, I know there are incredibly large amounts of carbon in volcanics and black sediments of Archean age (3 to 2.2 billion years ago). In most places the carbon is now graphite. There are many thousands of lenses of graphite and massive pyrite sandwiched between lava flows. Frequently the graphite lenses are fifty meters thick. In the Archean era, chemolithic microbes prodigiously multiplied wherever there was submarine volcanism. Originally, the graphite was a trillion, times a trillion, times a trillion, times a trillion, times a trillion, times a trillion chemolithic archea/bacteria cells that accumulated in depressions around hydrothermal vents associated with submarine lava flows

In most places, metamorphism has obliterated all evidence of the microbial origin of graphite, but the biogenic origin of graphite is not in doubt. These accumulations could not have occurred unless there were huge abundances of hydrogen sulfide and carbon dioxide gases venting from submarine volcanism and equally huge amounts of microbial life—as exists around many contemporary black smokers found along midocean rift zones.

In my opinion, the best location for the origin of life is in warm tidal pools or shallow marine bays where evaporation concentrated a broth of prebiotic molecules. This environment also produced an abundance of prebiotic liposome cells; additionally, solar and ultraviolet energy was always available as a source of energy. But the spontaneous origin of life was equally possible by chemosynthesis. Although photosynthetic and chemolithic

microbes appear to be genetically different, they share the same RNA–DNA pathway of cell replication except they use a different source of energy to sustain the metabolism that sustains reproduction.

Sometime around three billion years ago one specie of archea evolved into bacteria. Bacteria were more efficient synthesizers of sugars and other organic molecules used for the metabolism that sustains reproduction. All of the earliest preserved microfossils are in shallow-water sediments, and the best preserved are associated with kerogen.

Kerogen is a hydrocarbon derived from organisms. It contains a higher percentage of carbon-12 isotopes than atmospheric carbon dioxide because microorganisms preferentially use carbon-12 rather than the heavier isotope carbon-13. Kerogen is a sure indicator of biologic activity.

Soon after photosynthetic bacteria evolved, some species became colonial. They formed mats, oncolites and stromatolites in shallow water. Mats and stromatolites prevented storms from dispersing them to less hospitable environments. A colonial habit also facilitated the exchange of genes so that beneficial mutation became more frequent (measured in units of 100 million years).

Red-colored sediments are very rare in the Archean era because both the atmosphere and marine water had minimal amounts of oxygen. There was, however, abundant iron dissolved in marine water. About 2.2 billion years ago red sediments became common in stratigraphic sequences. The first appearance of abundant red-colored rocks measures the changed composition of the atmosphere. The oxygen that changed the composition of earth's atmosphere was the waste product of photosynthetic bacteria.

The red was caused by iron oxide that was concentrated in iron formations that were deposited in shallow water where oxygen was continually renewed by the photosynthetic bacteria.

Iron formations are unambiguous evidence that an oxygen-rich atmosphere came into existence because iron-rich sediments (banded iron formations) of this age are found on all continents. They are the source of 90 percent of the ores that are smelted into metallic iron. Some geologists characterize the precipitation of soluble iron from marine water as the rusting of the oceans. This marks the end of the Archean era.

Oxygen produced by photosynthetic bacteria transformed the earth's atmosphere from little or no oxygen to approximately the 20 percent that exists today. The oxygen came from bacteria that evolved the ability to live in an oxygen-rich atmosphere that they created. Many anaerobic microbes evolved into aerobic microbes or they became extinct. The oxygenation event may be related to the evolution of the RNA pathway of reproduction into the RNA–DNA pathway of reproduction.

Did photosynthetic and chemolithic microbes originate according to the above analysis? Did photosynthetic archea/bacteria evolve into chemolithic microbes or vice-versa? Little evidence is preserved in living microbes of how cell replication began and became self-sustaining or where it first occurred—but it did occur. We know this with certitude; otherwise, life would not be self-sustaining.

Investigating how life originated is expensive and time consuming because it must be done by highly trained persons at generously funded laboratories. Complex instruments must be built, techniques developed to use them, knowledge accumulated and the accumulated knowledge accurately interpreted. Investigations to discover how replication began are in their infancy because molecular biology, and its sister discipline evolutionary biology, did not become separate disciplines until the 1970s.

As of now, there is only limited understanding of how life originated; although, there is considerable understanding of how specific enzymes catalyze the proteins required to sustain life.

We do know, however, that during the first two billion years of life (from about four billion to about two billion years ago), there were many beneficial mutations within archea and bacteria cells that helped improve reproduction and expand the number of niches where life could reproduce.

MOLECULAR BIOLOGY

Molecular biology investigates the chemical reactions that take place in the cells of all organisms. Put in other terms, molecular biology seeks to understand the chemical origin of life and how reproduction is sustained. It focuses on the structure of enzymes and how enzymes are synthesized within cells. Enzymes are organic catalysts that can synthesize themselves and other proteins necessary for cell replication in the RNA–DNA pathway.

The origin of life probably began when a prebiotic cell encapsulated several short strands of prebiotic RNA. RNA is a single-strand polymer that can replicate itself and synthesize some protein molecules that contribute to replication. RNA is not a protein but protein molecules (enzymes) can attach to long strands of RNA, and long strands can store sufficient information for sequencing the molecular chemical reactions necessary for replication.

Laboratory experiments indicate that some common clay crystals can act as templates to synthesize short strands of prebiotic RNA. Inorganic templates are the probable origin of prebiotic RNA. This mode of synthesis could have produced very large numbers of RNA molecules. From the perspective of evolutionary biologists, life began with the ability of short strands of encapsulated RNA molecules to polymerize into longer strands of RNA that could sequence enough information for cells to replicate themselves.

Laboratory experiments confirm that the RNA molecule alone can: (1) encode genetic information, (2) encode sequences of molecular reactions, (3) catalyze molecular reactions that reproduce cells by division (mitosis), (4) catalyze simple proteins. There is rapidly accumulating evidence that pre-archea cells reproduced by the RNA pathway alone.

The first self-replicating cells were pre-archea. These cells retained their integrity long enough for RNA molecules to replicate along a pathway that was transferable to daughter cells by division. They also had the ability to synthesize or encapsulate food. Subsequently, sites on longer strands of RNA attached encapsulated prebiotic amino acids (or simple proteins) that improved: (1) replication, (2) metabolism, (3) strengthened cell membranes, (4) increased the ability to absorb molecules through cell membranes, (5) encoded increasing amounts of genetic information for sequencing the chemical reactions necessary that improved the precision of replication.

There is overwhelming circumstantial evidence that the RNA pathway was the prerequisite for pre-archea cells to evolve into archea cells and then evolve into bacteria cells that use the RNA–DNA pathway of replication. The RNA–DNA pathway of replication is found in all cells of all organisms today. The circumstantial evidence for this means of replication (and evolution) is that no other microorganisms have been discovered that could evolve this pathway of replication.

After the RNA–DNA pathway evolved, replication by the RNA pathway alone became extinct. If pre-archea cells still exist they have not yet been discovered. All organisms now living in the biosphere use the RNA–DNA pathway of reproduction. There are no known exceptions.

Replication, however, could not be sustained unless there was a metabolic source of energy. Chlorophyll produced the needed energy—after prebiotic chlorophyll molecules were en-

capsulated in a prebiotic cell or, alternatively, chlorophyll was catalyzed from amino acids encapsulated in pre-archea cells.

Chlorophyll is an enzyme that uses the sun's energy (light) to break the chemical bond of water and carbon dioxide in order to synthesize sugars. Life originated at the moment when photosynthesis by chlorophyll or related enzymes became a sustainable chemical reaction within a cell that used an RNA molecule to replicate itself. Current research in molecular chemistry indicates that molecular chemists will soon be able to define most of the chemical reactions necessary for reproduction by RNA alone.

There is little evidence of how the RNA pathway evolved into the RNA–DNA pathway, but it is possible to make an intelligent guess. All living bacteria continually exchange genes that are composed of RNA–DNA molecules. It is probable that the exchange of RNA fragments with attached protein molecules, plus the encapsulation of amino acid molecules, contributed to the evolution of the RNA–DNA pathway.

The great advantage of the RNA–DNA pathway is that replication became highly predictable compared to the molecular chemistry of the RNA pathway. In the RNA pathway lethal mutations (mistakes) were frequent, but the number of mutations increased the possibilities of beneficial mutations.

Beneficial mutations propelled the evolution of the RNA pathway into the RNA–DNA pathway. The chemical reactions in the RNA–DNA pathway are the result of an immense number of natural selections that made it possible for pre-archea cells to evolve into archea and archea to evolve into bacteria. Bacteria could occupy many more marine niches than archea.

Reproduction requires a code (map) that regulates replication and metabolism. In all contemporary organisms the replication code is stored in genes and chromosomes.

What are genes? What are chromosomes? Genes are short

strands of DNA that have attached enzymes that synthesize proteins, as well as encode the sequences of molecular synthesis necessary for reproduction. Like the RNA molecule, the DNA molecule is not composed of proteins. It is a nonprotein scaffold where genes and enzymes are attached in highly predictable sequences. Enzymes synthesize themselves, catalyze the synthesis of other proteins, encode the sequence of protein synthesis and emplace them in the organism. Chromosomes are long strands of genes that contain all of the genetic information required for the reproduction of an organism.

Like RNA, DNA is a long strand (polymer) of small molecules, but unlike RNA it forms a double helix. The double helix has two great advantages compared to RNA. It is the scaffolding for an infinite number of variations and it has a self-repair mechanism that insures almost all replications are exact copies.

The RNA–DNA pathway that evolved in archea probably occurred 3 billion years ago. This pathway has been hyperconserved because it is the core chemistry of reproduction. Its hyperconservation is strong circumstantial evidence that the molecular chemistry that evolved the RNA–DNA pathway happened only once because reproduction of all cells in all existing organisms use it, including humans. Put in another perspective, the genes and chromosomes that govern human reproduction are not unique. They are a variation in the package of genes and chromosomes that govern the reproduction of all organisms.

The DNA molecule has a curious scaffolding. In all humans there are many spaces on it that appear to have no function. They are blank. Blank spaces are about 97 percent of human DNA. It is highly probable that at some time during the one billion years (four to three billion years ago) that it took archea to evolve into bacteria these blank spaces were sites for genes that regulated replication and metabolism.

During this long evolution they were turned off whenever a

mutation increased the efficiency of replication and metabolism. More efficient enzymes were accommodated by adding them to new sites on the DNA scaffold. Older gene sites remained in place but were disabled by becoming noncoding sites. Alternatively, the noncoding (blank) sites perform sequencing or other functions that have not yet been discovered.

The sequencing of molecular chemistry by RNA–DNA is highly predictive but is not perfect. There are numerous mutations. Most mutations are repaired or are benign, but lethal mutations are terminated by natural selection or perhaps some survive as short lengths of DNA after the death of the microbe. This could be the origin of viruses.

VIRUSES

Viruses are short lengths of DNA. Some have only one helix of DNA. The simplest viruses have ten genes or less, compared to several thousand in the cells of the simplest archea and bacteria. Viruses are not alive because they lack the ability to self-replicate; or perhaps they are half-alive. They are composed of short lengths of DNA that use enzymes to pierce the membranes of healthy cells. After they enter a cell, other enzymes activate the cell's enzymes and appropriate newly synthesized proteins for their replication and metabolism. During replication viruses become alive. When replication is complete they crystallize into a giant molecule because they have no cell walls.

How did viruses become half living? Only a guess is possible. One possible explanation is that archea expelled unneeded genes instead of disabling them after a beneficial mutation increased the efficiency of metabolism. The surface of marine water contains incredible numbers of viruses. Marine microbiologists estimate that every milliliter of marine water contains 50 million

virus crystals. They estimate that marine viruses alone number ten times the amount of all living organisms. Virus numbers are sustained because about 20 percent of all marine microbes die each day from viral predation. However they originated, viruses are predators of microbes and, alternatively, parasites of metazoan organisms.

EUKARIA

Eukaria are single-cell organisms with chromosomes enclosed in one or more compartments within the cell. In contrast, chromosomes in archea and bacteria cells float within a cell that has no interior compartments. The principal compartment in eukaria cells is the nucleus. Other compartments are called organelles. Organelles are the modified cells of encapsulated bacteria within eukaria cells. Most eukaria cells have many organelles that contain many sets of chromosomes. The first eukaria cell with one nucleus and no organelles was the first complex organism.

Eukaria evolved about 1.5 billion years ago when one species of bacteria encapsulated another species with which it had an obligatory symbiotic relationship. The encapsulated bacteria retained its DNA and became a nucleus within the cell. Many species of eukaria made multiple encapsulations of bacteria. The encapsulated bacteria retained their cell integrity and their DNA. Almost certainly, the evolution of bacteria into eukaria happened many times because symbiotic relationships are extremely common in contemporary microbes.

The largest eukaria cells in the contemporary biosphere have as many as 1,600 organelles and are 100 to 1,000 times larger than bacteria. Multiple encapsulations and multiple organelles containing DNA give eukaria a large pool of genes that can be continually transferred within cells. This transfer speeded the

evolution of metazoan (multicell organisms) faster than the evolution of archea into bacteria during the first billion years of life (from four billion to three billion years ago).

How do mutations occur? Within eukaria cells there is a continuous transfer of genes between organelles and the DNA within the nucleus. Genes ensure that when cell divisions occur an exact copy of DNA is transferred to the new cell, however, the transfer of genes is never exact because genes are continually reshuffled on chromosomes. In humans, reshuffled genes are responsible for different colored hair, eyes, skin, height and other differences of greater significance, like brain capacity.

Gene shuffling also produces lethal mutations. For example, a lethal mutation in lions would be feet without claws and a beneficial mutation in marine iguanas in the Galapagos Islands is a flattened nose to aid grazing on algal mats growing on rocks in the tidal zone. If serial mutations increase the ability of an organism to gather food or reproduce, natural selection will eliminate less competitive members of a species and a new species will evolve.

Lethal and beneficial mutations of genes have identical origins. They are random occurrences that happen at random intervals and at random sites on DNA molecules. Natural selection is a biological sieve that rejects lethal mutations and preserves beneficial mutations, but it operates only after random mutations have occurred. In other words, mutations of genes and natural selection are unrelated processes. The speed and direction of evolution has no design, intelligent or otherwise. There is no divine plan. Evolution depends on random mutations that are beneficial.

Cell reproduction in eukaria is fundamentally different from bacteria. Bacteria reproduce by simple division (mitosis). Mutations are infrequent and beneficial mutations are therefore even less frequent. Eukaria cells reproduce by two divisions that

produce four cells (meiosis). In the first division, chromosomes within the parent cell divide into pairs, and in the process genetic material is exchanged. Then the two successor cells divide into four cells. The four successor cells have half of the chromosomes of the parent cell, but in the exchange of chromosomes each new cell receives slightly different sequences of genes on DNA. The cumulative effect of these small, but continuous, differences in DNA sequences is more mutations; and if a serial sequence of mutations is beneficial, a new specie evolves.

For the first 3.3 billion years of life on earth, life existed as single-cell organisms (pre-archea, archea, bacteria, eukaria). It took about one billion years for pre-archea and archea to evolve into bacteria. An additional 1.5 billion years (to about 1.5 billion years ago) for some bacteria to evolve into eukaria. There was no certainty that diversity of life would proceed beyond single cell organisms, but it did.

It took an additional 800 million years for eukaria to evolve into metazoan organisms. The first metazoan organisms appeared about 700 million years ago. From another perspective, the mutations that began after the origin of life (about four billion years ago), to when archea evolved into bacteria (about three billion years ago), and bacteria evolved into eukaria (about 1.5 billion years ago), are far more complex than the mutations that have taken place during the last 550 million years when Cambrian chordate worms evolved into fish, reptiles and humans.

METAZOA

Metazoans are multicell organisms. They evolved from colonies of eukaria cells. All metazoan organisms use only eukaria cells in their bodies. A reservoir of genes existed in eukaria cells because most of those cells had encapsulated one or more archea,

bacteria or other eukaria cells with which they had symbiotic relationships. The array of genes in the nuclei and organelles of eukaria cells was a reservoir of genetic possibilities for evolution into metazoa. It is highly probable that many species of colonial eukaria evolved into metazoan organisms.

Metazoan organisms evolved after DNA could sequence the activity of multitudes of enzymes that could synthesize other enzymes. These enzymes synthesized the specialized cells required for the evolution of eukaria into complex organisms. Thereafter, metazoa evolved into animals and plants. Metazoans that evolved into animals evolved the ability to control movement. Metazoans that evolved into plants encapsulated photosynthetic bacteria. Fungi were the third metazoan organism to evolve from undifferentiated metazoa. Like predatory animals, fungi metabolized an existing food supply that consisted of dead microbe cells that fell from the surface layer of photosynthesis to the ocean floor.

Metazoan life began when symbiotic eukaria cells failed to disperse after reproduction. They formed colonies that evolved interdependence. Interdependence was accomplished by an exchange of genes within eukaria cells. Interdependence then evolved into organisms that had an obligate colonial organization, meaning single cells from these colonial organisms could reproduce a whole organism. These metazoan organisms had to be simple because there were no cells that specialized in reproduction, metabolism or protection. In the contemporary biosphere, sponges retain the ability of one cell to reproduce the whole organism. The ability of one cell in these organisms to reproduce the whole organism is clearly a transitional stage to the evolution of organisms with greater complexity.

The time of the first appearance of metazoans is highly circumstantial. The most likely estimate is about 700 million years ago. The best evidence is the preservation of hydrocarbons in

pre-Cambrian sediments (especially in Australia) that contain compounds (terpenoids) specific to eukaria. Microscopic metazoans were the likely source of these hydrocarbons. The best candidates for the earliest metazoan organisms are several species of very simple algae (volvocines) that have survived into the contemporary biosphere. They have only four to thirty-two cells glued together by gelatinous substances. They are living fossils from the pre-Vendian era.

Late in the Vendian era (about 560 million years ago) some soft-bodied metazoan organisms evolved into highly visible megaorganisms—this is known as the ediacaran assemblage. These organisms lived in shallow water on shelf sediments. They were anchored to bottom sediments by holdfasts in order to prevent dispersal by tides and to retain access to light. Many of them had fronds as long as one meter and some had multifronds. Other organisms were oblong disks that were as large as one meter in the long dimension. Others may have been shallow cups up to 25 centimeters in diameter that were flattened by fossilization. Ediacaran fossils have a worldwide distribution but none of them survived into the Cambrian.

The ediacaran assemblage is enigmatic because of the large size of organisms when all other late-Vendian organisms are barely visible with low-powered microscopes, as well as the inability to classify the assemblage as plant or animal. They were probably filter-feeding animals or were animals like some coral species that have an obligate symbiotic relationships with: (1) photosynthetic bacteria, (2) photosynthetic eukaria, (3) photosynthetic metazoans. They would be a kind of marine lichen.

Geologists, paleontologists and biologists have documented six events in the evolution of metazoan organisms during the Vendian era (610–550 million years ago): (1) most organisms were microscopic except for the enigmatic super giant fossils of the ediacaran assemblage; (2) colonial eukaria evolved into

metazoan organisms after; (3) some colonial cells evolved specialized functions; (4) that became obligate for the organism's survival; (5) most Vendian metazoan organisms were microscopic and lived in niches where they evolved into animals, plants, fungi and other less familiar organisms; (6) fossils of these organisms are very scarce in late Vendian sediments, but there is very strong circumstantial evidence that the organisms existed. The evidence is the Cambrian explosion.

SEXUAL REPRODUCTION

Eukaria made sexual reproduction possible because all cells had two or more internal compartments that contained molecules of DNA. Eukaria cells continually exchanged genes between the nucleus and internal compartments (organelles). During meiosis, DNA is not exactly copied because DNA comes from two different cells that have variant genes. This is the basis for sexual reproduction (male–female). Sexual reproduction produces frequent mutations. All are random and most of them are lethal, but sexual reproduction has the possibility for increased numbers of beneficial mutations.

Mutations that produce specialized cells can increase the size of organisms, increase protection from predation, improve reproduction and improve metabolism. These mutations directly translate into the ability of metazoans to occupy and reproduce in vacant niches. During the first 150 million years of their existence (700–550 million years ago), metazoans were the largest marine organism. Even if they were composed of only four eukaria cells, they were giants when all other life in the oceans took the form of single-cell microbes.

After metazoans evolved there were few constraints on the shape of animals (body plans) that evolved to fill huge numbers

of vacant niches. Circumstantial evidence strongly indicates that the hugely diverse body plans that became visible in the Cambrian evolutionary explosion evolved late in the Vendian era (555–550 million years ago). Measured against the previous record of bacterial evolution by mitosis, the evolution of eukaria and metazoa by meiosis and sexual reproduction proliferated new body plans. Although, there are no undoubted animal fossils in the Vendian era, almost certainly the highly variable body plans that became visible in the Cambrian evolutionary explosion were propelled by mutations that occurred because of sexual reproduction during the Vendian era.

SUMMARY

All of the evidence presented in this chapter indicates that evolution by natural selection is a hypothesis with a very high degree of certainty. There is no reason to believe that natural selection operates any differently now than it operated during the Precambrian era. Everything that science has discovered about the ability of bacteria and metazoa to reproduce and mutate is in agreement with Charles Darwin's hypothesis that natural selection propels evolution.

There is no evidence in the fossil record that there has been a pattern of beneficial mutations that guides evolution for any other purpose than immediate advantages in reproduction. The fossil record is a record of failed body plans, noncompetitive metabolism, insufficient protection, but above all, a failed ability to competitively reproduce. The fossil record clearly indicates that there is no linear pathway to reproductive success.

We know with a high degree of certainty that the molecular chemistry of RNA–DNA used by archea and bacteria for reproduction is the same pathway used for the reproduction of all

cells in all metazoans, including humans. In the process of reproduction, life has evolved many forms, some of them bizarre, but there are some that have undergone minimal mutations for two billion years.

It took one billion years for pre-archea organisms to evolve into archea and archea to evolve into bacteria. It required an additional billion years for bacteria to evolve into eukaria. For the next 1.3 billion years (2 billion years to 700 million years ago) the molecular chemistry of eukaria cells continued to evolve. When metazoan organisms evolved about 700 million years ago, single-cell organisms had existed on earth for about 3.3 billion years. Metazoan organisms were late arrivals in the biosphere. In other words, 83 percent of the time that life has existed on earth it has been single-cell organisms.

More than 99.9 percent of all visible animal and plant species that have lived since the Cambrian era are extinct, but the survivors from the Cambrian eras have conserved a reservoir of genetic possibilities for replacing extinct species in subsequent geologic eras. The fossil record provides unambiguous evidence that extinctions are an integral part of the evolution of life and extinctions are ongoing events. The other side of the coin is that reproduction is the only purpose of life.

There is overwhelming scientific evidence that large, complex organisms like humans are evolutionary appendages to the world of microbes (archea, bacteria and eukaria). In the four billion years that life has existed, humans are one among many organisms that have temporarily occupied the top of the food chain. The post-Cambrian geologic record indicates that large animals, like humans, occupy the top of the food chain for a limited number of years and then become extinct.

This is contrasted to the Genesis myth that god created all organisms in the immediate past, in their exact contemporary forms, for the benefit of humankind. Or alternatively, god creat-

ed life in the distant past and designed evolution so that humans would inevitably reach the apex of the food chain. In both versions, the Genesis myth is presented as incontestable certainty because the creation of life is the work of an omnipotent god. In both interpretations of the origin of life, humans are the ultimate purpose of life on earth. There is zero scientific evidence for the Genesis account of the origin of life or for the purpose of human life on earth.

This interpretation, however, conforms to a strong human bias to believe that the contemporary status of humankind at the top of the food chain was designed by god. Humans could then glorify him for the gift of life and give thanks for enjoying supremacy over the earth's biosphere. This interpretation of the origin and purpose of life is wholly based on deductive reasoning that claims that the Genesis myth is a true explanation for the origin of life.