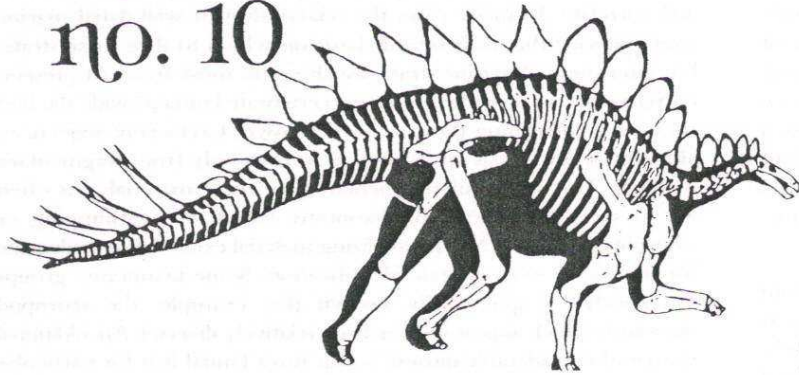


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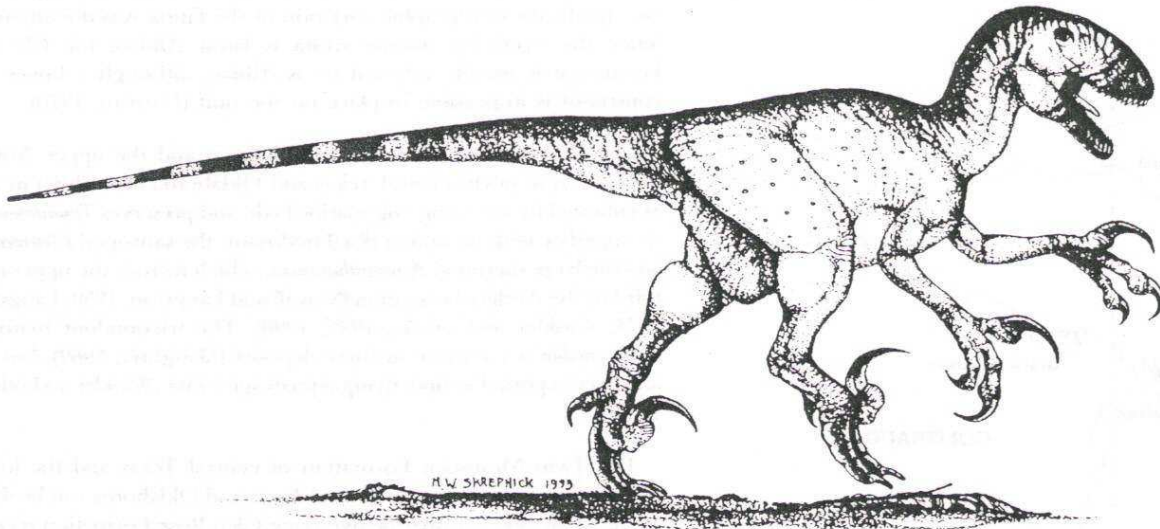
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A LARGE DROMAEOSAUR (THEROPODA) FROM THE LOWER CRETACEOUS OF EASTERN UTAH

JAMES IAN KIRKLAND
Dinamation International Society
P.O. Box 307
Fruita, Colorado 81521

ROBERT GASTON
395 34½ Road
Palisade, Colorado 81526

DONALD BURGE
College of Eastern Utah
Prehistoric Museum
200 East 100 North
Price, Utah 84501



ABSTRACT

A new genus and species of dromaeosaur, *Utahraptor ostrommaysi*, is described from the basal Cedar Mountain Formation (Barremian, Lower Cretaceous) of eastern Utah. The taxon is based on an associated disarticulated skeleton from one site and disarticulated material of one or more individuals from a second site. *Utahraptor* differs from *Deinonychus* in having a larger size, extremely blade-like manual claws, and distinctive lachrymal that is subrectangular in dorsal view.

INTRODUCTION

Compared to the faunas of the Late Jurassic and Late Cretaceous of North America, Early Cretaceous dinosaur faunas are very poorly known. These faunas from the Early Cretaceous present important data regarding the transition from the well known Late Jurassic faunas, dominated by sauropod-stegosaur components, to the better known Cretaceous hadrosaur-ceratopsian dominated faunas. The transition seems to have been carried out by way of a nodosaur-iguanodont dominated earliest Cretaceous fauna. The giant dromaeosaur described herein was a significant predator in this earliest Cretaceous nodosaur-iguanodont fauna.

The first collections made of the giant dromaeosaur are from Brigham Young University's Dalton Well Quarry, which was discovered in the late 1960s by Lin Ottinger of Moab, Utah. Currently, only a few specimens have been prepared of the hundreds collected during the summer of 1975 by Jim Jensen and his field crew. Although generally well preserved, the dinosaur bones from Dalton Well have been transported and are a mixture of a great many different individuals. Much of the material from the site represents a variety of new taxa.

The second collection of giant dromaeosaur remains from this region was generated during excavation of a nodosaur at the Gaston Quarry (discovered by Robert Gaston) north of Arches National Park (Fig. 1) by a joint project of the Dinamation International Society (DIS) and the College of Eastern Utah Prehistoric Museum (CEU) in Price, Utah (repository for all materials). At present, more than 300 bones have been mapped in the quarry, reflecting 20 days field work during the summers of 1991 and 1992. The nodosaur is the most complete primitive "spiny" nodosaur known and is the first to preserve the skull, which may profoundly change our view of these armored dinosaurs and their relationships. The co-occurring giant dromaeosaur provides us with more information about predators at the beginning of the Cretaceous and about the possible relationships of birds and dromaeosaurs. It is the oldest as well as the largest known dromaeosaur.

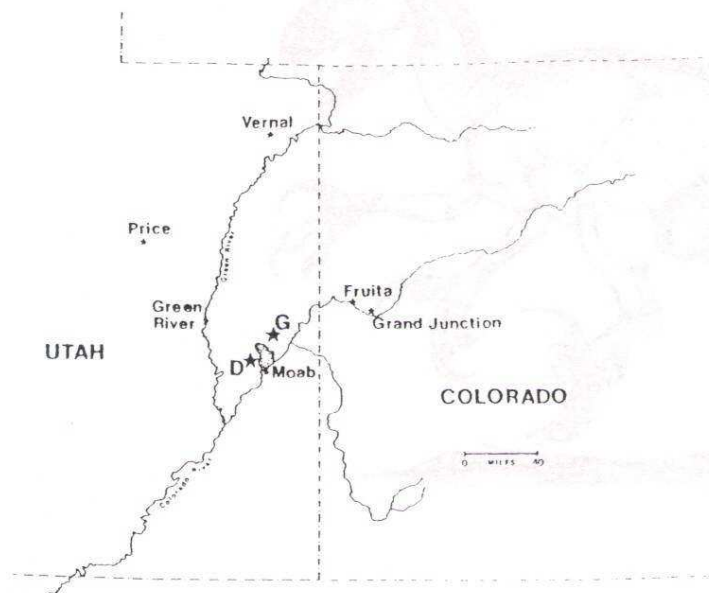


Figure 1. Locality map showing approximate position of Gaston Quarry (G) and the Dalton Well Quarry (D). Location of Arches National Park shown by stippled pattern.

CORRELATION

At present terrestrial Lower Cretaceous strata are difficult to date and correlate. In many cases the relationships of well dated marine strata provide the most reliable basis on which to date these strata, but intertongued marine strata are absent in most areas. At present, correlations based on the preserved vertebrate fauna provide the best means for correlating these terrestrial Lower Cretaceous sequences, although most faunas are at present known only from fragmentary material. The degree of fragmentation of these materials has often led to serious problems in taxonomy based on over lumping or oversplitting of taxa. Much tantalizing material exists that is inadequate for specific or even generic identification. Some taxonomic groups are poorly or sporadically known (for example, the sauropod dinosaurs, which appear to have been relatively diverse). An additional source of considerable dispute is that most faunal lists for particular formations do not attempt to differentiate successive biostratigraphic levels even when a formation is understood to represent a significant amount of time. The most recent faunal comparison of Early Cretaceous faunas was made by Ostrom (1970); this work, plus a few recent papers and unpublished discoveries, is the basis for much of the following discussion. In general this summary is arranged from younger to older strata.

Cloverly Formation and related Aptian to Albian faunas of North America. Until now, the Cloverly Formation of Wyoming and Montana has produced the best known Early Cretaceous dinosaur fauna from North America. It is characterized by the nodosaur *Sauropelta edwardsi*, the dromaeosaur theropod *Deinonychus antirrhopus*, the possible oviraptorid theropod *Microventor celer*, a large unidentified theropod, an ornithomimid theropod, the hypsilophodontid *Zephyrosaurus*, the ornithopod *Tenontosaurus tilletti*, and a large slender toothed sauropod (Ostrom, 1970; Sues, 1980). In addition, the large triconodont mammal *Gobiconodon* has been well documented from the Cloverly (Jenkins and Schaff, 1988). No significant stratigraphic variation of the fauna was documented. Since the overlying marine strata is latest Albian, the Cloverly Formation is usually referred to as Albian, although a lower age constraint is impossible to place on the unit (Ostrom, 1970).

The Pauluxy Formation in central Texas and the upper Antlers Formation in north-central Texas and Oklahoma are Albian in age, as indicated by intertonguing marine beds, and preserves *Tenontosaurus?* sp. together with an undescribed nodosaur, the sauropod *Pleurocoelus* and the large theropod *Acrocanthosaurus*, which is from the upper one-third of the Antlers Formation (Stovall and Langston, 1950; Langston, 1974; Winkler and others, 1989, 1990). The triconodont mammal *Astrocomodon* is common in these deposits (Slaughter, 1969), but has also been reported in underlying Aptian age strata (Winkler and others, 1980).

The Twin Mountain Formation of central Texas and the lower Antlers Formation in north-central Texas and Oklahoma can be dated as Aptian in age, because the overlying Glen Rose Formation records the base of the Albian. Although dromaeosaur, large theropod, and sauropod material have been recovered from the Twin Mountain-Lower Antlers bed, only the remains of numerous hypsilophodontids can be compared to the taxa known elsewhere at this time (Winkler and others, 1989, 1990). These dinosaurs represent a new genus close to *Hypsilophodon foxi* from the oldest Wealden strata of southern England.

The Arundel Formation of Maryland preserves a fauna of Aptian to Albian age, but the fauna is difficult to compare directly with other Early Cretaceous faunas due to the fragmentary nature of the known fossil material. The Arundel sample includes fragmentary nodosaur, ornithomimid theropod, one small theropod, and one or two large theropods (Gilmore, 1921; Ostrom, 1970). The type material of the sauropod *Pleurocoelus* is from the Arundel Formation (Marsh, 1888).

The Wealden Series of southern England and related Neocomian faunas from North America. The diverse faunas from the Wealden have typically been discussed as though they represent a single contemporaneous fauna, when in fact the Wealden spans most of the Neocomian (Norman, 1983). This over-lumping of strata has led to a tendency to synonymize taxa, for example the iguanodonts (Ostrom, 1970) and the nodosaurs (Coombs, 1978). Many taxonomic groups are in need of revision, such as the theropods and the sauropods. Revision of the Ornithischia has resulted in defining the temporal limits of the iguanodonts (Norman, 1988) and nodosaurs (Blows, 1987). The Wealden Series in the Weald District on the southern mainland of England has been divided into two formations: 1) the Hastings Sands, extending from late Berriasian to the end of the Valanginian; and 2) the Weald Clay, extending from the Hauterivian through the Barremian (Norman, 1988). The Wealden Marls on the Isle of Wight range from the Barremian to basal Aptian (Blows, 1987; Norman, 1988).

Norman (1988) has recognized *Iguanodon daousoni* and *Iguanodon fittoni* from the lower part and *Iguanodon anglicus* from the upper part of the Hastings Sands. All nodosaur material referable to the *Hylaeosaurus* is from the Hastings Sands as well (Blows, 1987). The Weald Clay preserves the only remains of the lightly built iguanodont, *Iguanodon atherfieldensis* (= *I. mantelli*), whereas the Wealden Marls on the Isle of Wight preserve both *Iguanodon atherfieldensis* and *Iguanodon bernissartensis* (Norman, 1988). In addition, the Wealden Marls have preserved the remains of the nodosaur *Polacanthus foxi*, the small ornithopod *Hypsilophodon foxi*, the sauropod *Ornithopsis hulki*, and several poorly known theropods (Blows, 1983).

Among the previously known North American Early Cretaceous dinosaur faunas, only the rather meager fauna from the Lakota Formation of the Black Hills region compares well with the Wealden faunas. The Lakota sample includes the nodosaur *Polacanthus marshi* (= *Hoplitosaurus marshi*) and the ornithopods *Iguanodon lakotaensis*, *Hypsilophodon wielandi*, and *Campiosaurus depressus* (Galton and Jensen, 1975, 1979; Blows, 1987; Weishampel and Bjork, 1989; Pereda-Suberbiola, 1991). The Lakota Formation has been dated independently of vertebrate fossils as Barremian (Sohn, 1979).

Correlation of faunas from the Cedar Mountain Formation. Typically the Cedar Mountain Formation has been correlated with the Cloverly Formation and its Albian age supported by palynomorphs (Tschudy and others, 1984) and the occurrence of *Tenontosaurus* (Weishampel and Weishampel, 1983). These reports are all from the west side of the San Rafael Swell of central Utah. Recent stratigraphic studies by Molenaar and Cobban (1991) have speculated on an age range from lowest Cenomanian at the top to as old as Neocomian at the base. New discoveries of the triconodont mammals *Gobiconodon* and *Astroconodon* from near the top of the Cedar Mountain Formation in the western San Rafael Swell area confirm an age determination of Albian (Cifelli, personal communication).

In recent years collections from near the base of the Cedar Mountain Formation near Arches National Park have revealed the presence of a distinctly older dinosaur fauna (Figs. 1,2). Collections in the Earth

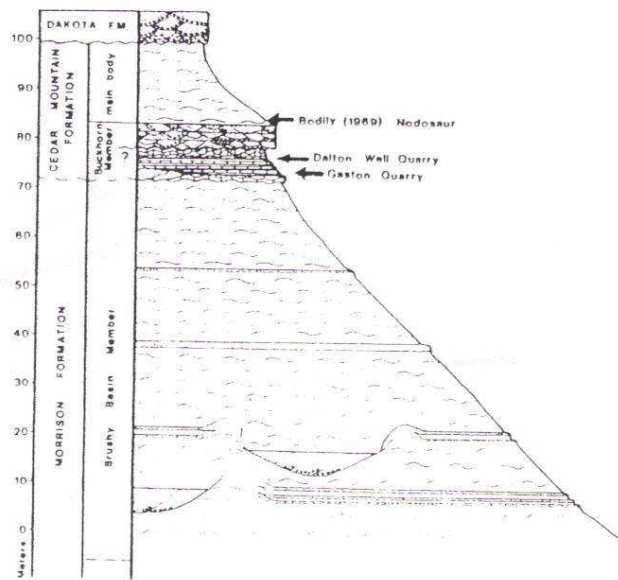


Figure 2. Stratigraphic section at the Gaston Quarry showing the stratigraphic positions of other Lower Cretaceous dinosaur sites in the Arches National Park region referred to in text.

Science Museum of Brigham Young University (BYU) from the west side of Arches at the Dalton Well Quarry contain a primitive nodosaur (cf. *Polacanthus*), a large theropod, a very large dromaeosaur, perhaps a small species of dromaeosaur, a sauropod with spatulate teeth like *Camarasaurus*, and the type specimen (maxillary fragment) of *Iguanodon ottingeri* together with hundreds of unprepared specimens (Galton and Jensen, 1979; personal observation). The present investigators have begun excavating a site (Gaston Quarry) north of Arches that preserves the remains of the nodosaur, cf. *Polacanthus*, a very large dromaeosaur, an iguanodont tooth, a hypsilophodont tooth, and part of the foot of a problematic dinosaur. The Gaston Quarry is at the same stratigraphic level as the Dalton Well Quarry approximately 40 kilometers to the southeast. Additional sites were discovered while testing this correlation.

These basal Cedar Mountain Formation faunas compare best with the Barremian, Wealden Marl faunas on the Isle of Wight in southern England, and the Lakota Formation fauna of the Black Hills region of South Dakota. This represents the last time during the Cretaceous that dinosaurs could migrate between eastern Utah and southern England through Greenland without getting their feet wet because of rising sea-level and continued continental fragmentation. The differences at a species level between Utah and Europe are easily explained as a result of the partial barrier imparted by the Appalachian-Hercynides mountain belt and the proto-North Atlantic, or by slight differences in time. Environmental and ecological differences may also be a factor.

The sites near Arches National Park occur below a regionally persistent conglomeratic sandstone unit, which could on casual observation be interpreted as the contact between the underlying Morrison Formation and the Cedar Mountain Formation (Fig. 2). However, just below the Gaston Quarry there is a prominent carbonate unit that Young (1960) used to define the base of the Cedar Mountain Formation in this area. The senior author interprets this carbonate unit as representing a possible calcrete, and found the unit

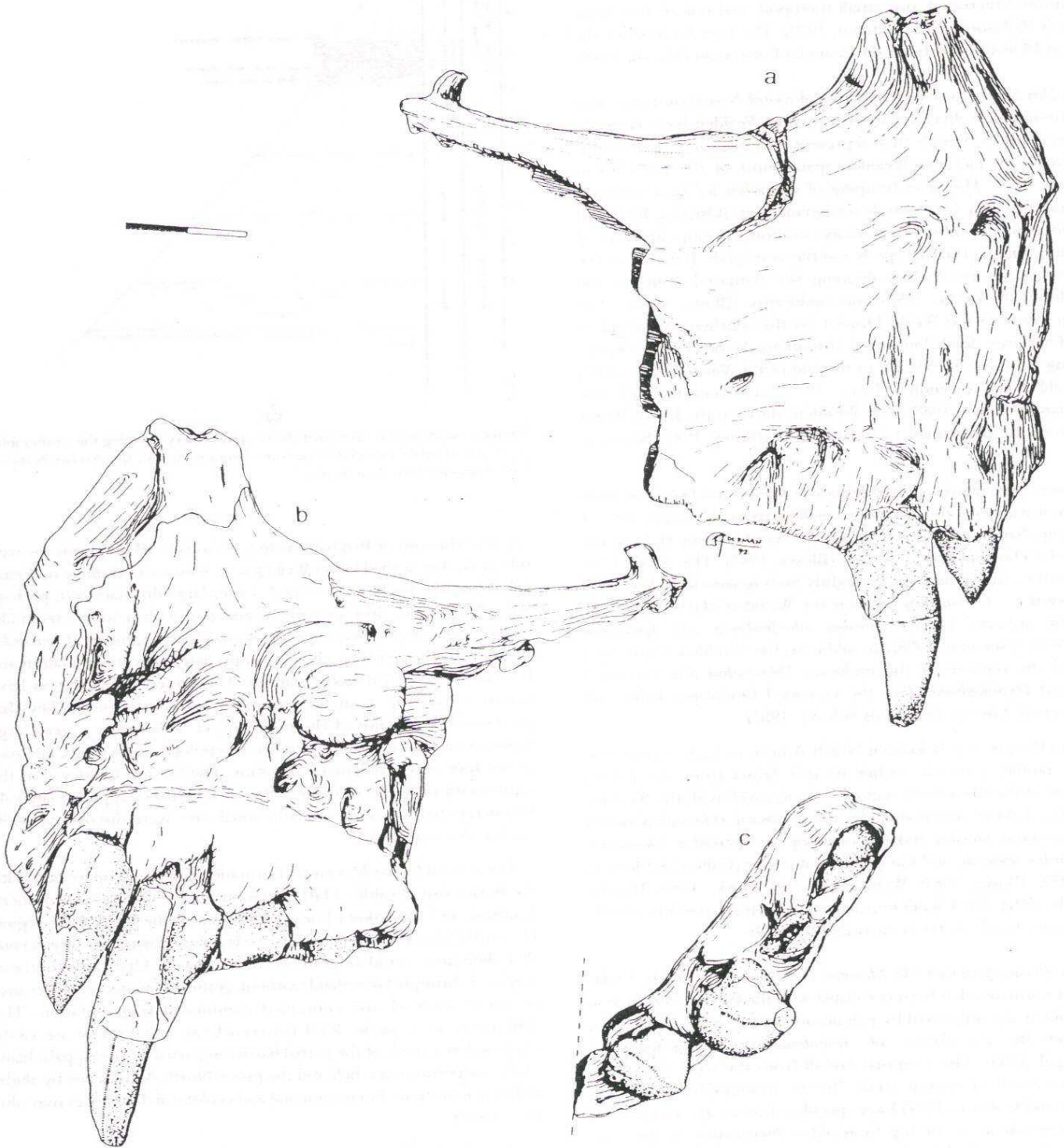


Figure 3. Right premaxilla of *Utahraptor* (CEU 184v.400): a) external view; b) internal view; c) ventral view of tooth row. Scale bar equals two centimeters. **Figure 3 continued on following page.** Outlines of external and internal views locate the features discussed in the text. Abbreviations: eaf — external anterior fossa, fsnp — foramin below subnarial process, iaf — internal anterior foraminae, idp — interdental plates, lef — lower external foraminae, ms — medial symphysis, mxc — maxillary contact, mxo — area of maxillary overlap, mxp — maxillary process, nc — narial contact, snf — subnasal foramina, snp — subnarial process, sunp — superior nasal process.

to be discontinuous. Young (1960) refers the overlying sandstone to his middle sandstone unit, whereas the senior author recognizes that locally there may be from 0 to 3 sandstones at the base of the Cedar Mountain Formation. The tentative hypothesis is that the basal Cedar Mountain Formation in the Arches area represents a distal fossiliferous fluvial facies that correlates to the basal Buckhorn Conglomerate Member of the Cedar Mountain Formation. All the sites reported from the west side of the San Rafael Swell thus far occur in the overlying main body of the Cedar Mountain Formation. A similar relationship is suspected for the Lakota Formation, with the Lakota representing a distal fluvial facies correlating with the Pryor Conglomerate at the base of the Cloverly Formation to the west. Thus a Barremian, "Lakota" fauna occurs in the Buckhorn Conglomerate Member and the overlying main body of the Cedar Mountain Formation preserves a Late Aptian-middle Aptian "Cloverly" fauna (Kirkland, 1992; Elder and Kirkland, in press).

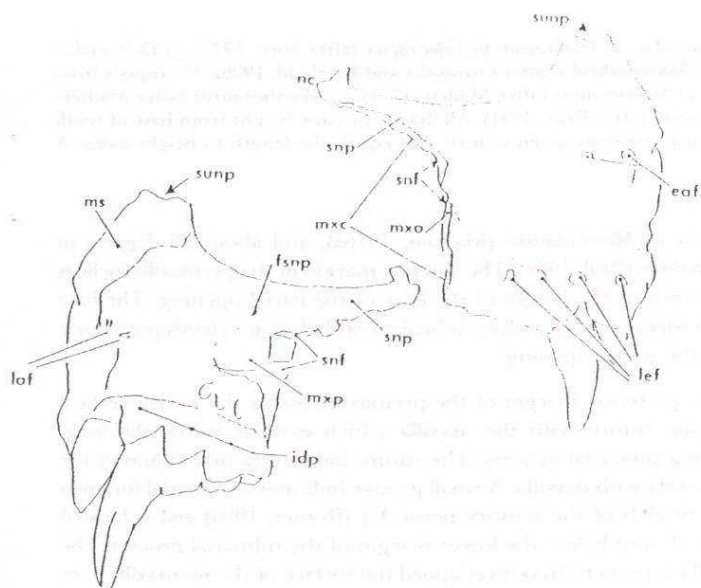
An intermediate fauna may also be present at the base of the main body of the Cedar Mountain. In the Arches region, this fauna may be represented by the Bodily (1969) nodosaur from the east side of Arches. This specimen represents a tail from a nodosaur closely related to the nodosaurs from the Gaston and Dalton Well Quarries, but is a much larger species. A more extensive site at this level is the Long Walk Quarry on the northeast side of the San Rafael Swell, which preserves the remains of sauropods identified as *Pleurocoelus* and the teeth of large theropods (DeCourten, 1991).

Thus, there appear to be at least two and perhaps three dinosaur faunas represented in the Cedar Mountain Formation. Extensive exploration and excavation will be needed in the future to glean the record of what may be the extensive terrestrial vertebrate record of the Early Cretaceous recognized in North America.

SYSTEMATICS

REPOSITORIES

BYU, Brigham Young University Earth Science Museum, Provo, Utah; CEU, College of Eastern Utah Prehistoric Museum, Price, Utah; MCZ, Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts; YPM, Yale Peabody Museum, New Haven, Connecticut.



Class DINOSAURIA Owen 1842

Order THEROPODA Marsh 1881

Family DROMAEOSAURIDAE Matthew and Brown 1922

Subfamily DROMAEOSAURINAE Matthew and Brown 1922

Genus *Utahraptor* gen. nov.

Etymology. Name refers to the occurrence of this formidable predatory dinosaur in Utah, "Utah's predator."

Diagnosis. Claws on hand more specialized as cutting blades than in other dromaeosaurs. Lacrymal has distinctly parallel mesial and outer sides, giving it an elongate subrectangular appearance in top view. Premaxilla has base of nasal opening parallel to premaxillary tooth row.

Utahraptor ostrommaysi sp. nov.

Type. Holotype, CEU 184v.86, right second pedal ungual and potentially other bones of the hypodigm from type locality (CEU 91-1) including first manus ungual (CEU 184v.294), tibia (CEU 184v.260), lacrymal (CEU 184v.83), and premaxilla (CEU 184v.400).

Hypodigm. All specimens from the type locality (Gaston Quarry) and referred specimens from the Dalton Well Quarry (BYU 7510) including first (BYU 13068) and possibly second (BYU 9438) manus unguals, mid-caudal vertebra (BYU 9429) and two distal caudal vertebrae (BYU 9435 and BYU 9436) from one or more moderately large individual(s).

Distribution. All known specimens from the basal Cedar Mountain Formation in the area around Arches National Park in eastern Utah (Fig. 1). Presently known from two localities: the type locality at the Gaston Quarry, CEU 91-1 and Dalton Well, BYU 7510. Both localities are situated under a prominent sandstone ledge (Fig. 2), which in eastern Utah has been referred to as the middle sandstone of the Cedar Mountain Formation (Young, 1960) or could represent a distal facies of the Buckhorn Conglomerate (Stokes, 1944, 1952) of the western San Rafael Swell of central Utah (Kirkland, 1992). Based on the occurrence of *Iguanodon* (Galton and Jensen, 1975, 1979) and *Blacanthus*, the strata are interpreted to represent the Barremian (Kirkland, 1992).

Diagnosis. This species is distinguished by its very large size (at least 100% larger than *Deinonychus*). Otherwise as for genus.

Etymology. Named in honor of Dr. John Ostrom of Yale University for his ground breaking research on *Deinonychus* and its relationship to birds; and in honor of Chris Mays, president of Dinamation International Corporation, who in founding the Dinamation International Society set the stage for the research presented herein.

DESCRIPTION

Premaxilla. A nearly complete right premaxilla (CEU 184v.400) is preserved in the collection made from the Gaston Quarry (Fig. 3). The tooth row is 75 mm long; comparisons with *Deinonychus* (Ostrom, 1969) suggest that the *Utahraptor* premaxilla is 250% larger. The superior nasal process has been broken away. Otherwise the premaxilla is well preserved, although moderately crushed and distorted side to side. The most apparent effect of crushing is that the subnasal process has been bent inward to nearly the midline and the base of the superior nasal process has been twisted outward. The width of the bone from the medial to the lateral margin of the posterior end of the tooth row is 51 mm, indicating the premaxilla portion of the skull is about 102 mm wide. The main body of the bone is nearly square. The length to height index (L/H x 100) of the premaxillary body is 101 for *Utahraptor*, as compared to an estimated 90 in *Deinonychus* (Ostrom, 1969), 164 in *Velociraptor* (Osborn, 1924; Sues, 1977), and 86 in

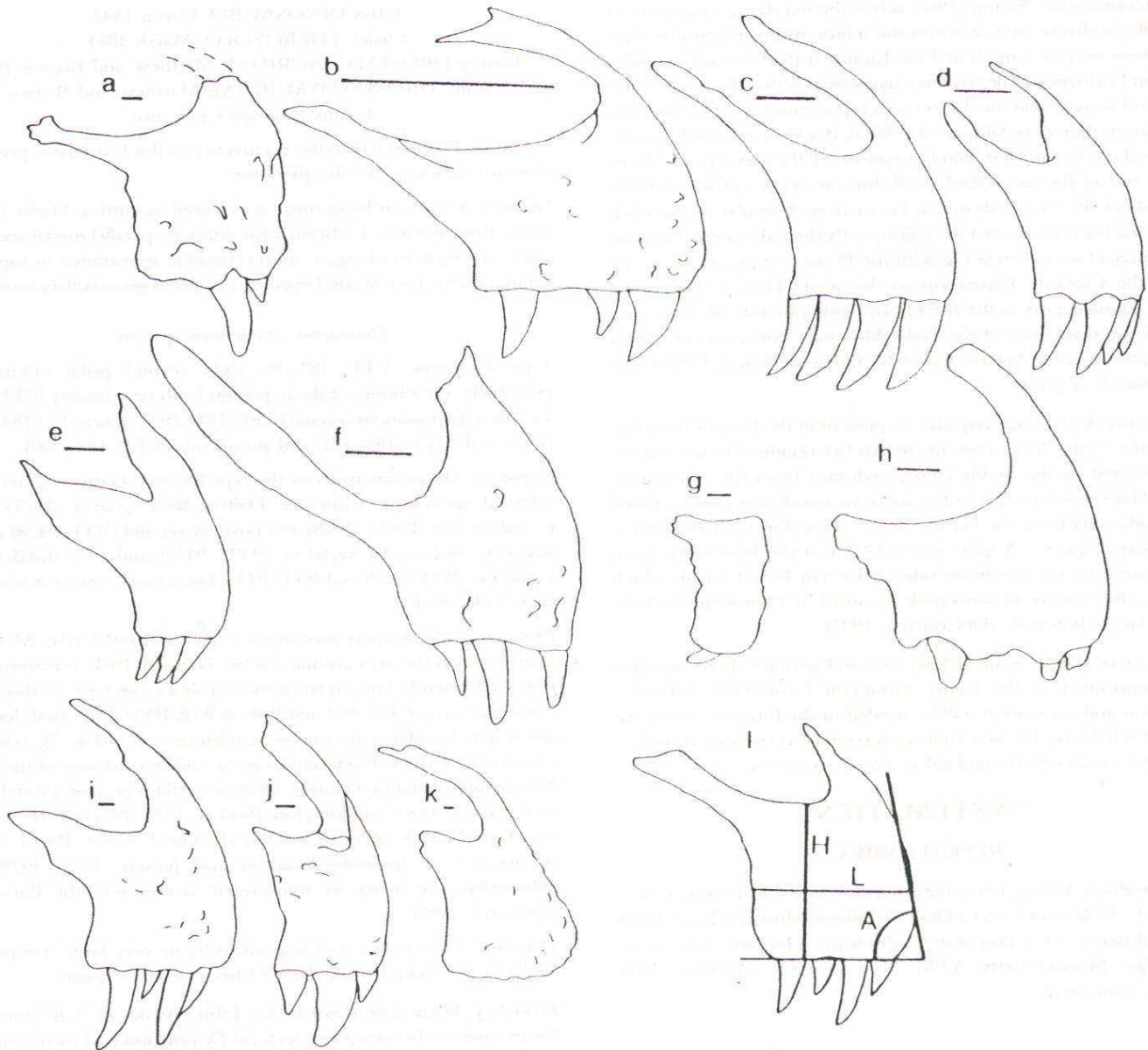


Figure 4. Comparisons of premaxilla of representative theropod dinosaurs. Dromaeosauridae: a) *Utahraptor*, b) *Velociraptor* (after Sues, 1977), c) *Deinonychus* (after Ostrom, 1990), d) *Dromaeosaurus* (after Colbert and Russell, 1969); Troodontidae: e) *Sauromithoides* (after Osmolska and Barsbold, 1990); Theropods from the underlying Upper Jurassic Morrison Formation: f) *Ornitholestes* (after Paul, 1988a), g) *Stokesosaurus* (after Maden, 1974), h) *Marshosaurus* (after Madsen, 1976a), i) *Allosaurus* (after Madsen, 1976b), j) *Ceratosaurus* (after Gilmore, 1920), k) *Torvosaurus* (after Britt, 1991). All drawn to same height from base of tooth row to base of narial opening, scale bars equal 1 cm. l) Idealized premaxilla showing measurements given in text; LH equals the length to height index. A equals the premaxillary angle.

Dromaeosaurus (Colbert and Russell, 1969). Britt (1991) has recorded the length to height index of *Ceratosaurus* as 80, *Allosaurus* as 115, and *Torvosaurus* as 97 (Fig. 4.l).

The nearly vertical anterior margin has a premaxillary angle (Britt, 1991) of approximately 85 degrees (Fig. 4.l). This compares to about 80 degrees in *Deinonychus* (Ostrom, 1969), about 75 degrees in *Velociraptor* (Sues, 1977), and about 74 degrees in *Dromaeosaurus* (Colbert and Russell, 1969) among the dromaeosaurids (Fig. 4). Among theropods from the underlying Morrison Formation the premaxillary angle has been measured as 55 degrees in *Torvosaurus*, 72 degrees in *Allosaurus*, and 80 degrees in *Ceratosaurus* (Britt, 1991), and is estimated to be about 90 degrees in *Stokesosaurus* (Madsen, 1974), about 80

degrees in *Marshosaurus* (Madsen, 1976a), and about 88 degrees in *Ornitholestes* (Paul, 1988). The anterior margin of the premaxilla inclines posteriorly at the height of the base of the narial opening. The base of the superior nasal process is broken off before it extends posteriorly over the narial opening.

The posterior margin of the premaxilla forms the nearly vertical irregular suture with the maxilla which extends below the long, tapering subnarial process. The suture indicates a firm union of the premaxilla with maxilla. A small groove indicates a subnarial foramen for a branch of the sensory nerve V_1 (Romer, 1956) and is located about 20 mm below the lower margin of the subnarial process. The maxilla appears to have overlapped the surface of the premaxilla over

a small triangular area below this groove. At the posterior margin of the narial opening, the subnarial process flares to join with the subnarial process of the nasal, excluding the maxilla from the margin of the narial opening. The lower margin in the narial opening is smooth and broad, curving smoothly down to the suture between the maxilla and subnarial process. The dorsal posterior portion of the main body of the premaxilla is depressed, reflecting the vestibule of the narial opening on the surface of the premaxilla. The external surface of the bone is smooth, but there are numerous fine fractures reflecting crushing of the bone. There is a prominent downward directed fossa about 8 mm across near the anterior margin of the bone at the level of the nares. In addition there is a poorly developed row of foramina 12-15 mm above the lower margin of the bone above the tooth row. Other foramina are few and indistinct, unlike many theropods. In overall form, the premaxilla appears to compare with other described dromaeosaurs (Fig. 4).

Internally there are a pair of large foramina, each about 5-6 mm across toward the anterior margin of the bone about midway up. The more posterior and ventral of these two foramina is the more prominent and extends downward into the bone. The medial symphysis is only about 15 mm wide front to back as it rises above the tooth row. It narrows to about 10 mm at the level of the two large foramina before expanding to cover the entire area between the narial opening and the anterior margin of the bone (Fig. 3). There is a small foramen at the base of the subnarial process about 11 mm below the narial opening. Below this foramen, there is a prominent lozenge-shaped protuberance about 19 mm long just above the subnarial foramina, which represents the maxillary process. The interdental plates are fused to each other and to the bone. They form a triangular extension between each alveolus.

As preserved, the tooth row is 75 mm long and bore four teeth. There is no overlap in the alveoli and, other than the first being set slightly medial of the other teeth, the teeth form a single row. The first tooth is 31 mm long, partially erupted, and nearly unworn; the second tooth is 45 mm long, completely erupted, and worn; the third tooth was broken off in the alveolus prior to burial; and the fourth tooth was shed with the replacement tooth barely visible. Both the first tooth and the second tooth are asymmetric with the anterior carina on the lingual side of the tooth and the posterior carina on the buccal margin of the tooth, forming a highly asymmetric cross section. On the first unworn tooth both the carinae twist about 20 degrees counter-clockwise as they approach the tip of the tooth, much as described for *Dromaeosaurus* (Currie and others, 1991). The external surfaces of the teeth are smooth and strongly convex in cross section. The internal surfaces of the teeth are weakly convex with eight shallow grooves posterior to the anterior carinae. The first tooth has 11-12 serrations per 5 mm on the anterior carina and 12 serrations per 5 mm on the posterior carina. The second tooth has 11 serrations per 5 mm on the anterior carina and 12-13 serrations per 5 mm on the posterior carina. There is only a slight difference in the density of the posterior and anterior denticles, unlike most of the Dromaeosauridae. Denticles on both the anterior and posterior carinae are similar in form and are smaller than those on comparably sized teeth of Jurassic theropods. Laterally they appear as symmetric flat-topped bumps on carinae separated by short shallow grooves perpendicular to carinae. Although proportionally smaller, in form, the denticles on the premaxillary teeth of *Utahraptor* appear to be much closer to those on the premaxillary teeth of *Dromaeosaurus* than to those on the teeth described for other dromaeosaurids (Ostrom, 1969; Currie and others, 1990).

Lachrymal. The right lachrymal (CEU 84v.83) was uncovered along the weathered margin of the Gaston Quarry and had been moderately damaged (Fig. 5). The jugal process was broken off 88 mm from the dorsoposterior margin of the bone and the margins along the jugal process, and along the outer edge above the shallow lateral fossa where broken along the edge. The bone is V-shaped with the jugal process making an angle of about 55 degrees with the dorsal margin. The anterior margin of the bone is deeply excavated by the antorbital fenestra, which forms the evenly curved inner margin of the V.

Unlike many theropods, there is no large, deep, outer pneumatic vacuity in the lachrymal. The conspicuous shallow lateral fossa opens inwards into a small canal about 3 mm in diameter, that extends 7 mm to a point near the inner margin of the lachrymal before turning sharply downward and posteriorly for 5 mm and ending abruptly.

In dorsal view the lachrymal is rectangular in appearance. It is about 18 mm wide (slightly wider at the posterior end) and 53 mm long to the point where it is overlapped by the nasals. The dorsal surface and outer margins are rugose and grooved, suggesting that this surface was overlain by keratin. There is a low flat-topped protrusion on the dorsal surface of the medial posterior corner. It is about 6 mm high and 11 mm wide, and runs along the inner margin for about 18 mm. Another protrusion occurs at about the midpoint of the medial margin. The outer margin of the lachrymal dorsal surface overhangs the shallow lateral fossa, where the outer margin is broken away. There appears to have been a thin (3-4 mm) low ridge running along the outer edge here.

In anterior view, the jugal process inclines outward from the vertical at approximately 25 degrees relative to the dorsal surface of the lachrymal.

The tip of the anterior arm of the lachrymal is broken off, but it preserves the suture where the nasals overlaid the dorsal surface and the suture below on the outer surface where the maxilla overlies it. Medially, along the dorsal side, the contact of the lachrymal with the prefrontal is indistinct; however, toward the posterior margin there are grooves for this contact. The contact between the lachrymal and prefrontal down the medial surface of the preorbital bar is distinct.

Caudal Vertebrae. One mid-caudal and two distal caudals were present in the Dalton Well collection at BYU.

The mid-caudal (BYU 9492; Fig. 6) has a centrum 67.9 mm long with an anterior face 32.2 mm wide and 27.3 mm high. With a L/W ratio of 2.1, it is estimated to be either the tenth or adjacent to the tenth caudal vertebra by comparison with measurements of caudal vertebrae of *Deinonychus* provided by Ostrom (1969). It is about 136% larger than this vertebra in *Deinonychus*. Except for its larger size, the specimen compares well with the eighth caudal vertebra illustrated by Ostrom (1969, fig. 39). Other notable differences are its lack of all evidence of a transverse process, and an even more reduced remnant of the neural spine, which further reflect its more distal position. The centrum is platycoelus with well-developed chevron facets. The neural spine is completely fused to the centrum and there is no visible suture. It is apparent that this vertebra bore the very elongate prezygopophyses characteristic of the Dromaeosauridae (Ostrom, 1990).

The larger distal caudal (BYU 9435) has a centrum 48.3 mm long with an anterior face about 12 mm wide and 12 mm high, with a L/W ratio of 4. By comparison to *Deinonychus* (Ostrom, 1969), it would appear to represent a vertebra distal of at least caudal 25. The smaller distal caudal (BYU 9436) has a centrum 40.7 mm long with an anterior

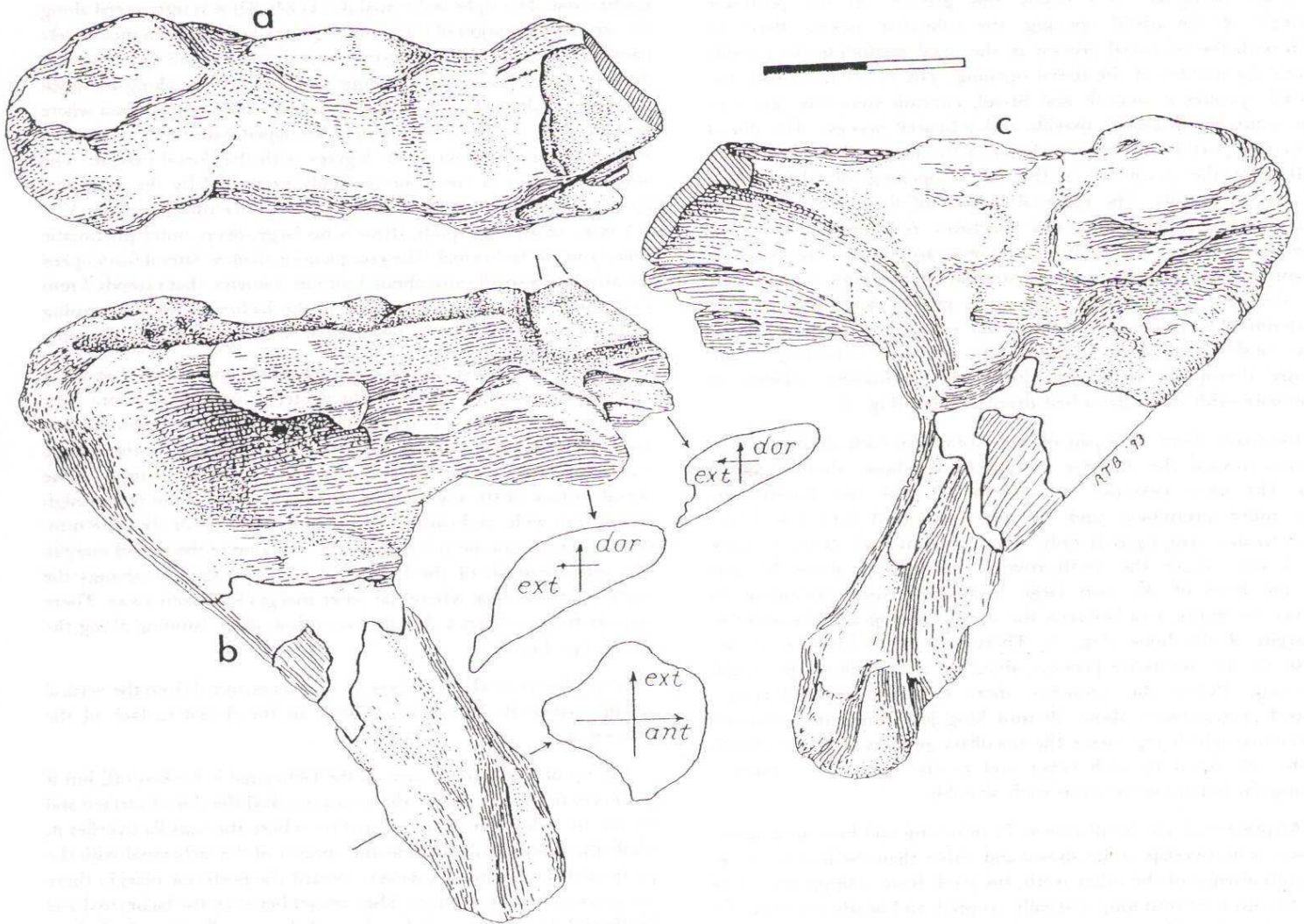
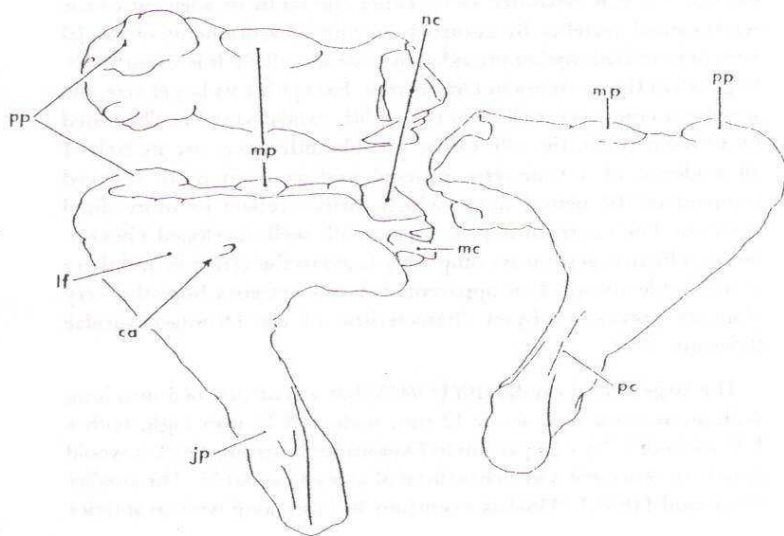


Figure 5. Right lachrymal of *Utahraptor* (CEU 184v.83): a) dorsal view; b) external view; c) internal view. Vertical cross section through maxillary-nasal contacts and horizontal cross section through jugular process shown with orientation arrows (dor – dorsal; ext – external; ant – anterior). Scale bar equals two centimeters. **Figure 5 continued below.** Outlines of dorsal, external and internal views locate the features discussed in the text. Abbreviations: af – antorbital fenestra, ca – canal, jp – jugal process, lf – lateral fossa, mp – medial protrusion, mx – maxillary contact, nc – nasal contact, pfc – prefrontal contact, pp – posterior protrusion.



distal caudal (BYU 9436) has a centrum 40.7 mm long with an anterior face 10.6 mm wide and 11.1 mm high, with a L/W ratio of 3.8. Both vertebrae are platycoelus with shallow ventral grooves. It is difficult to discern distinct chevron facets but this may be due to lack of preservation. The complete neural arch is preserved completely fused to the centrum but the pre- and postzygophyses are missing.

Tibia. The left tibia (CEU 84v.260) has been moderately crushed. The bone has collapsed by brittle fractures, and so the crushing does not seem to have affected the measurements of length or width given here. It is stout and straight shafted (Fig. 7), with a maximum length of 505 mm and a minimum mid-shaft circumference of 200 mm. The circumference/length index is about 40 for *Utahraptor*, less than the 45 of *Torvosaurus* and greater than the average of 34 for *Allosaurus* and 37-38 for *Ceratosaurus* (Britt, 1991). The tibia flares at both ends with a maximum proximal anteroposterior width of 140 mm and a

UTAHRAPTOR OSTROMMAYSI DESCRIBED

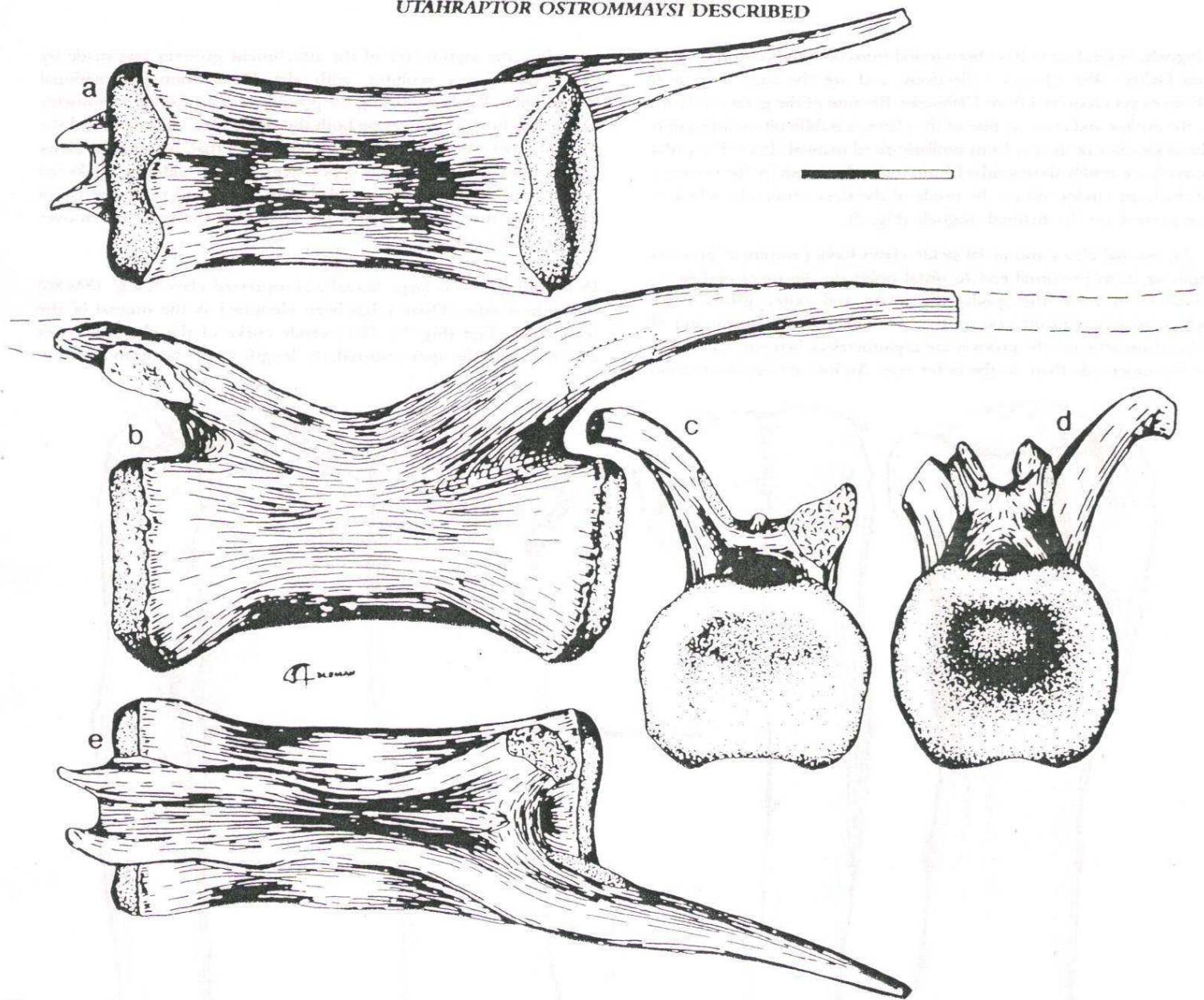


Figure 6. Mid-caudal vertebrae of *Utahraptor* (BYU 9429): a) ventral view; b) lateral view; c) posterior view; d) anterior view; e) dorsal view. Scale bar equals two centimeters.

maximum distal mediolateral width of 145 mm. The shaft of the tibia is hollow and is oval in cross section with a minimum mid-shaft diameter of at least 42 mm.

The proximal end of the tibia is moderately twisted counter-clockwise as viewed proximally and displays the greatest degree of distortion due to compaction. The cnemial crest is prominent, curving around toward the fibula. The fibular process is well developed with a distinct foramen entering the shaft of the tibia externally. While the distal end of the tibia is broad from side to side, at 38 mm it is very narrow fore and aft. In anterior view, the attachment scar for the ascending process of the astragalus is clearly defined (Fig. 7). The scar forms a nearly perfect equilateral triangle covering nearly all of the distal end of the tibia and extending upward for 12 cm at its midline. In the ascending scar, the tibia is clearly similar to that found in the ornithomimids and tyrannosaurids, and is particularly close to the condition seen in *Deinonychus* (Ostrom, 1969; Paul, 1988). In some ways the tibia is somewhat reminiscent of that of *Acrocanthosaurus*, but

Acrocanthosaurus clearly differs in the curved shaft of the tibia and in the asymmetric scar of the ascending process of the astragalus, much as is seen in allosaurs and other large Late Jurassic theropods (Stovall and Langston, 1950).

The length of the *Utahraptor* tibia was somewhat of a surprise to the senior author as it did not measure at twice the length of the tibia from *Deinonychus* (Ostrom, 1969, 1976). However, it was noted that the maximum proximal dimension was approximately twice that of *Deinonychus*. Bakker (personal communication) has suggested that this measurement is compatible with an animal of twice the size of *Deinonychus*, but suggests that the tibia may have been relatively shorter. This suggests a tibia of approximately the same length as the femur, as in other large theropods and differing from *Deinonychus*, which has a shorter femur (Ostrom, 1976). Currie (personal communication) reports that this is not surprising as the length of the tibia increases with negative allometry in comparison with the femur in both ontogenetic and interspecific series of theropods.

Unguals. Several claws have been found from both the Gaston Quarry and Dalton Well Quarry collections, and are the most common elements yet recovered from *Utahraptor*. Because of the great similarity in the outline and cross section of the claws, it is difficult to distinguish the sickle-claw of the pes from similarly-sized manual claws. The pedal unguals are readily distinguished from manual unguals by the presence of the large tendon pit on the inside of the flexor tubercle, which is not present on the manual unguals (Fig. 8).

All manual claws and pedal sickle-claws have prominent grooves running from proximal end to distal point on the inner and outer surfaces. In most theropods, the inner and outer grooves are approximately opposite one another. However, in *Utahraptor* and all other dromaeosaurs the grooves are asymmetrical, being much higher on the inner side than on the outer side. An interesting observation

regarding the asymmetry of the attachment grooves was made by Ray Persinger, a sculptor with the Dinamation International Corporation. While discussing the possible reasons for the asymmetry of the attachment grooves on both the sickle-claw of the pes and the manual claws, Persinger made the observation that, because the claws were so thin from side to side, opposing grooves would have weakened the structural integrity of the blade-like claws and made the claws liable to fracture along the grooves. Offsetting the grooves removes the zone of weakness.

Pedal ungual. One large laterally compressed claw (CEU 184v.86) from the Gaston Quarry has been identified as the ungual of the second left digit (Fig. 9). The outside curve of the claw measures 222 mm; with the apex restored, the length would be up to 240 mm,

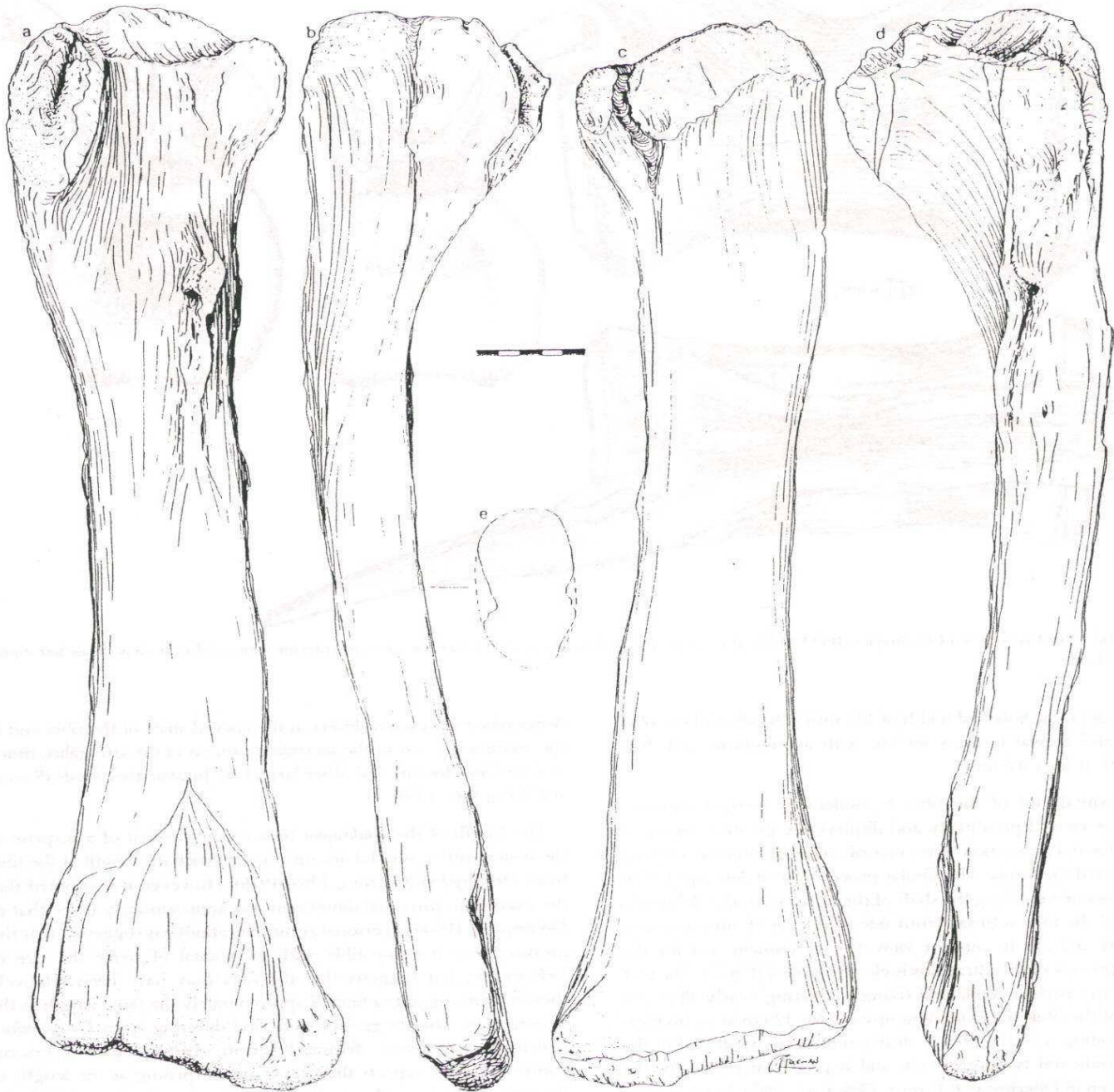


Figure 7. Left tibia of *Utahraptor* (CEU 184v.260): a) anterior view; b) medial view; c) posterior view; d) lateral view; e) cross-section of shaft. Scale bar equals five centimeters.

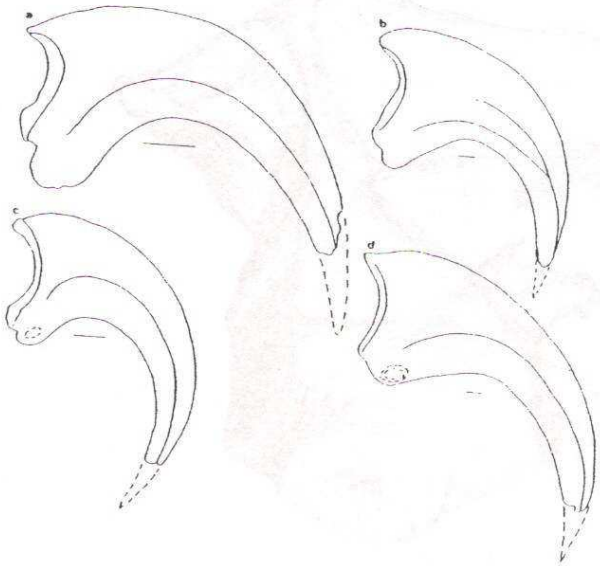


Figure 8. Comparison of pedal and manual unguals of *Utahraptor* and *Deinonychus*; first manual unguals: a) *Deinonychus* based on YPM 5206; b) *Utahraptor* based on CEU 184v.294; second pedal unguals: c) *Deinonychus* based on YPM 5205; d) *Utahraptor* based on CEU 184v.86. All drawn to same height of articular facet. Scale equals one centimeter.

or approximately twice the size of the largest known specimens of *Deinonychus* (Ostrom, 1969). The height of the facet was measured at 70.2 mm and proximal transverse width at 20.6 mm. The facet height appears to be approximately 182% larger than the largest known *Deinonychus* (Ostrom, 1969, YPM 5201). The claw is also somewhat more laterally compressed, although most of this could be an artifact of compaction. The grooves for the attachment of the external claw are asymmetric, with the groove on the lateral side of the ungual lying nearly at the midline, with a much more weakly developed groove lying ventrally to it on the proximal portion of the ungual. The internal groove lies more dorsally so that, toward the apex of the claw, the groove lies nearly on the dorsal surface. Although crushed, it would appear that the articular facet was nearly circular in lateral view and morphologically is very similar to that described for *Deinonychus* (Ostrom, 1969). The large rugose flexor tubercle projects ventrally below the inferior border of the articular facet. The attachment pits for the flexor muscles are asymmetrical with the pit on the external side of the flexor tubercle being well developed at about 12 mm in diameter and 3 mm deep. The curvature of CEU 184v.86 is closer to MCZ 4371 than to YPM 5205 (Ostrom, 1976) (Fig. 10.)

Manual unguals. One large manual ungual (CEU 184v.294) from the Gaston Quarry is less crushed than the pedal ungual described above (Fig. 11). The apex of the claw is distorted from an overlying nodosaur scute and the inner side of the flexor tubercle was damaged when discovered, so that it is impossible to know for certain whether or not there is an enlarged attachment pit for the flexor muscles. However, the claw is morphologically identical to a large manual claw (BYU 13068) from the Dalton Well Quarry, which does not have such a large attachment pit (Fig. 12a-c).

The ungual from the Gaston Quarry (CEU 184v.294) measures 205 mm along its outside diameter and has a facet 74.1 mm high and 19.5 mm wide (W/H 0.26). The large claw from the Dalton Well Quarry is missing approximately the distal one-half. It is somewhat smaller than CEU 184v.294, with a facet 58.2 mm high and 21.8 mm wide (W/H 0.37). As with the pes claw, the grooves for the attachment of the lateral claw sheath are asymmetric from side to side, with the groove on the lateral side of the claw running along the midline of the ungual. A similar weak groove is present ventrally on these claws as well. The articular facets on these claws differ from those of the pedal claw in that, while the dorsal half forms an even curve in lateral view, the ventral half is nearly straight to slightly convex. BYU 13068 has some small distinctive bone calluses, a few millimeters across, on the articular surface of the facet, which are most prominent toward the dorsal margin (Fig. 12a). A prominent flexor tubercle is present below the articular facet and is deflected toward the medial side of the claw relative to the plane of the articular facet. Both of these claws are interpreted as presenting the ungual of digit one from the right manus.

A second small ungual (BYU 8438) was present in the collections from Dalton Well. The distal half of the claw is missing and the claw is weathered, although uncrushed (Fig. 12d-f). The facet measures 14.5 mm wide and 56.4 mm high (W/H 0.25). The ungual is nearly exactly like that of the manual claws described above, except that the flexor tubercle is not so strongly developed. Thus this claw is interpreted as representing the ungual from the second or third digit of the right manus.

One of the most distinctive features of the manual claws is their thinness. The H/W ratios of these claws in *Utahraptor* are from 26 to 37, whereas they range from 45 to 60 in *Deinonychus* (Ostrom, 1969). This indicates that the manual claws of *Utahraptor* had a more significant cutting function as compared to the manual claws of *Deinonychus*. The less circular articular facet in *Utahraptor* may also relate to this functional difference.

CONCLUSIONS

The limited fossil material assigned to *Utahraptor* preserves several diagnostic synapomorphies with other known Dromaeosauridae. The most obvious of these are specializations of the middle to distal caudal vertebrae for stiffening the tail, development of the second ungual into a specialized sickle-like claw, and fused interdental plates (Gauthier, 1986; Paul, 1988b; Ostrom, 1990; Currie and others, 1991). The premaxillary teeth differ from those of nearly all other described dromaeosaurs in their simple blunt serrations. The one known dromaeosaur with serrations like those of *Utahraptor* is *Dromaeosaurus* (Currie and others, 1991). This suggests that, within the Dromaeosauridae, *Utahraptor* may be assigned to the subfamily Dromaeosaurinae rather than the Velociraptorinae.

Utahraptor is the oldest and largest dromaeosaurid yet described. Because of its specialized manual claws, it is not thought to have given rise to any of the other described dromaeosaurs. This indicates that an older common ancestor of the Dromaeosauridae existed in older Early Cretaceous or even Late Jurassic times.

Ecologically *Utahraptor ostrommayisi* must have had a significant role as a major carnivore in the Early Cretaceous faunas of the Arches region. Previously described dromaeosaurids have been documented as being the most sophisticated of predatory dinosaurs known to have existed (Ostrom, 1969, 1990; Paul, 1988b). In addition to having the ability to dispatch vertebrate prey of a size larger than themselves,

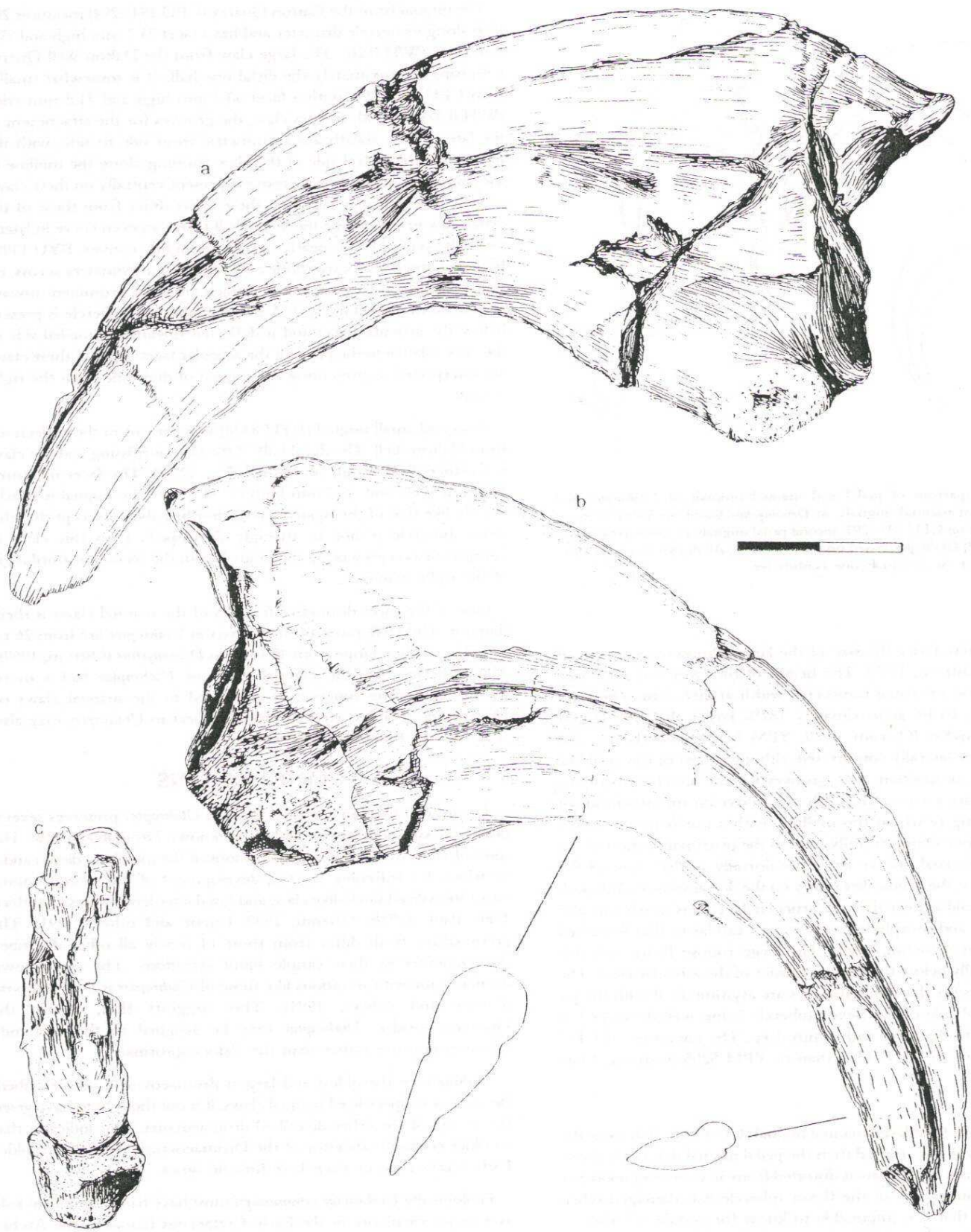


Figure 9. Second ungual of right pes of *Utahraptor* (CEU 184v.86): a) internal lateral view; b) external lateral view with cross sections; c) view of articular facet. Scale bar equals two centimeters.

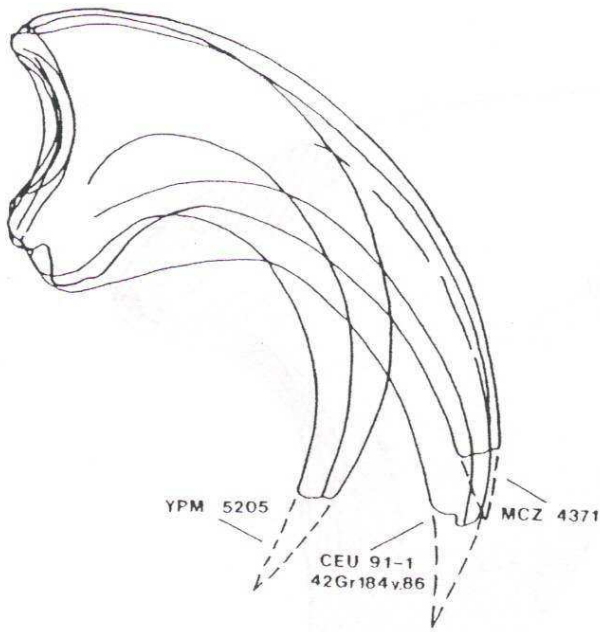


Figure 10. Comparison of the variation in the shape of second pedal unguals of *Deinonychus* with that of *Utahraptor*. All drawn to same height of articular facet.

group hunting may have permitted dromaeosaurs of less than 3.5 m in length and 70 kg to dispatch prey of as much as 8 m in length and 1000-2000 kg in weight. The great size of the *Utahraptor*, estimated at as much as 7 m long and somewhat less than 500 kg in weight; thus it was a polar bear sized carnivore as opposed to a jackal sized carnivore. This indicates that perhaps the smallest of terrestrial vertebrates would have been beneath its notice and that much larger prey may have been included in its diet. If *Utahraptor* hunted in packs, it is conceivable that, in addition to preying on the iguanodonts in the fauna, sauropods up to 20 m long may have been an important part of its diet.

If the interpretation that the tibia was subequal in length to the femur as in other large theropods is correct, it suggests the *Utahraptor* was not proportionally as fast as was *Deinonychus* or *Velociraptor*, which, contrary to many reconstructions, are stubby-legged theropods as compared to ornithomimids, troodontids, and tyrannosaurids (Currie, personal communication). This may simply be a result of its much larger size. It would have been at least as fast as the similar-sized iguanodonts within the fauna and perhaps faster than the co-occurring sauropods. The massiveness of the tibia may also be a reflection of the increased leg strength to employ the full use of the killing sickle-claw on the foot. These proportions suggest that the *Utahraptor* could have slashed with its foot powerfully indeed.

Finally, one of the most distinctive features of *Utahraptor* is its large blade-like manual claws. *Deinonychus* had highly raptorial claws on long arms that were plainly employed in holding the prey at a distance from the body of the animal, while dispatching the subject with the sickle-claw on the foot. It would have been important for the smaller dromaeosaurs to hold on to their prey while they kicked it with their powerful hind legs, simply because, for every action, there is an equal and opposite reaction. It is possible that, if *Deinonychus* or *Velociraptor* were not holding onto their prey, the force of their own kick may

have dislodged them. On the other hand, *Utahraptor*, with its much greater body weight, may have been able to kick out at its prey without the handicap of being thrown off balance by the force imparted by its kick. This would have freed the hand to take on a greater role in killing their prey, hence the much more laterally compressed manual claws of *Utahraptor*.

The presence of a much larger "carnosaur" with *Utahraptor* at the Dalton Well site raises the question as to how the role of large predator was divided between these two large theropods. A great deal of research on this fauna will be needed before this question can be approached.

ACKNOWLEDGEMENTS

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NOTE ADDED IN PROOF

The matching left premaxilla (CEU 184v.300) has recently been recognized from the type locality (CEU 91-1) and, although not fully prepared, the specimen does add information regarding the premaxilla. The specimen is flattened with no teeth preserved. Unlike the right premaxilla (CEU 184v.400), it preserves the complete superior nasal process. The superior nasal process is 18.2 mm deep at its suture with the nasal, and extends posteriorly to a position level with the subnasal process. The elongate narial opening is 35 mm high dorso-ventrally and is estimated to have been about 90 mm long antero-posteriorly.

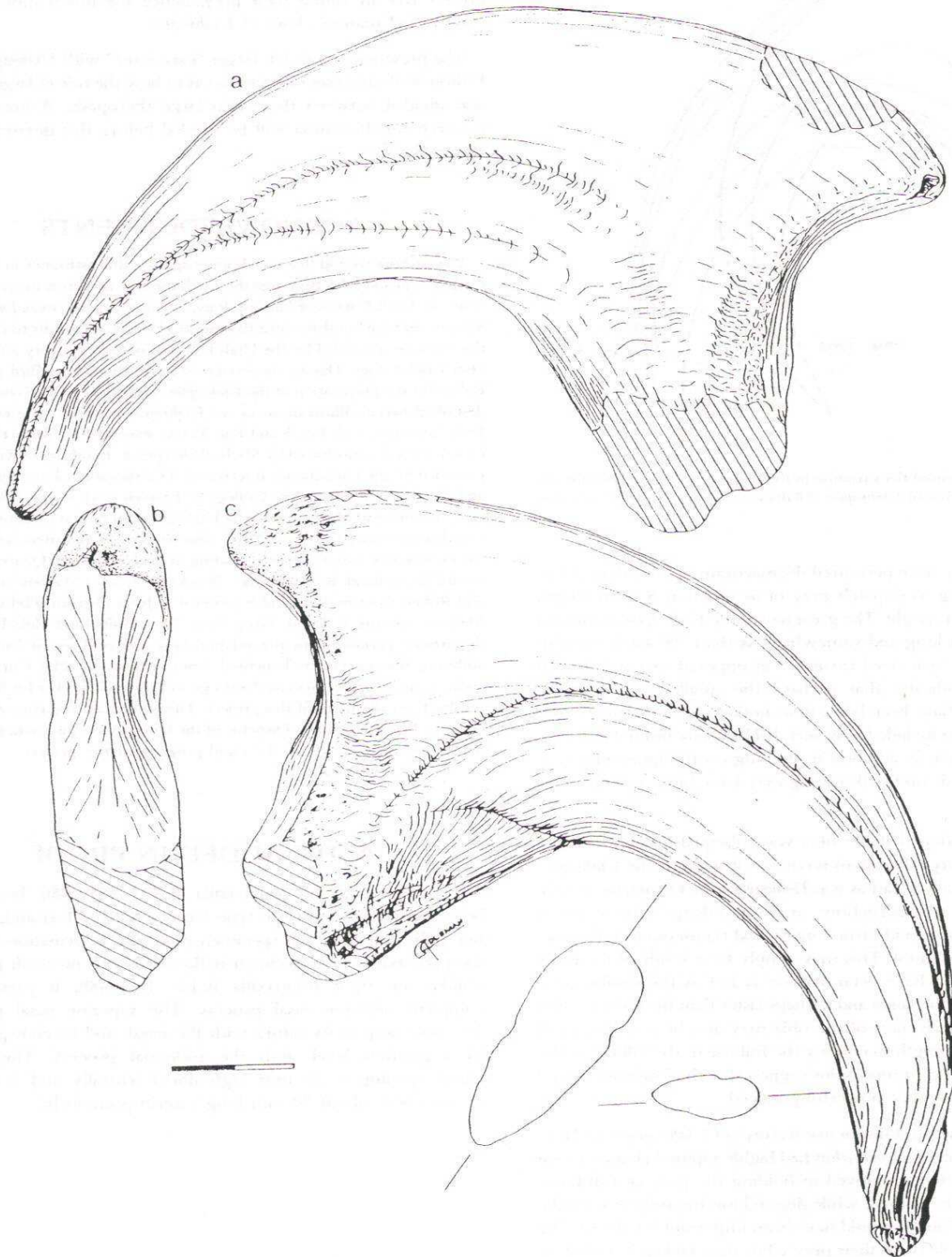


Figure 11. First ungual of left manus of *Utahraptor* (CEU 184v.294): a) external lateral view; b) view of articular facet; c) internal lateral view with cross-sections. Scale bar equals two centimeters.

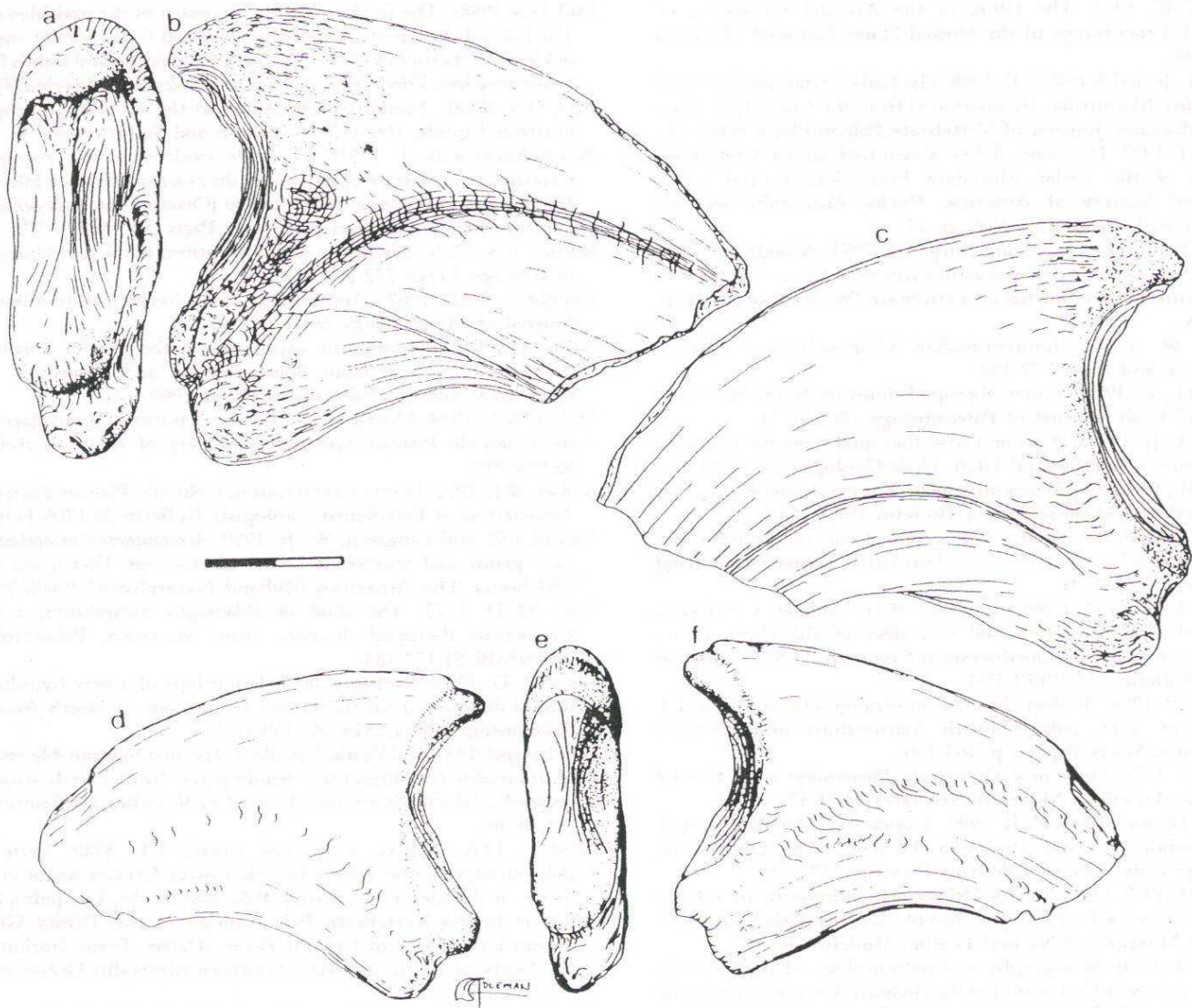


Figure 12. Manual unguals of *Utahraptor* from Dalton Well. First ungual of left manus of *Utahraptor* (BYU 13068): a) view of articular facet; b) internal lateral view; c) external lateral view; possible second ungual of right manus of *Utahraptor* (BYU 9438): d) internal lateral view; e) view of articular facet; f) external lateral view. Scale bar equals two centimeters.

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