BULLETIN
of
GUNMA MUSEUM
of
NATURAL HISTORY

A New Nearly Complete Skeleton of *Camarasaurus*

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Number1 TOMIOKA, 1996

BULLETIN OF GUNMA MUSEUM OF NATURAL HISTORY
Number 1, pages 1–87, 40 photos, 81 figures
Issued 24 December 1996

Received 20 May 1996
Revised manuscript accepted 22 October 1996

Referees

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Cover Photo: Skeleton of *Camarasaurus grandis* GMNH-PV 101

BULLETINS OF GUNMA MUSEUM OF NATURAL HISTORY
are published at irregular intervals by Gunma Museum of Natural History,
1674-1 Kamikuroiwa, Tomioka,
Gunma 370-23, JAPAN.

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ISSN 1342-4092

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A New Nearly Complete Skeleton of *Camarasaurus*

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Abstract

Western Paleontological Laboratories, Inc., has recently completed preparation and mounting of an approximately 65% complete, well-preserved *Camarasaurus* skeleton. This specimen (GMNH-PV 101) most closely resembles *Camarasaurus grandis*. A detailed history of the skeleton is followed by an osteological description. Several characteristics of the specimen provide interesting insights on the genus. They are (1) exceptional preservation of a disarticulated skull and mandible including the intercoronoids; (2) presence of the proatlas and proof of single-headed cervical ribs for the atlas; (3) the coalescence of the last dorsal rib (no. 12) with the ilium; (4) a complete set of caudal vertebrae with narrow transversely expanded neural spines, which has aided in distinguishing sexual dimorphism in a sauropod for the first time; (5) numerous pathologies found throughout the tail, including spina bifida, here reported for the first time as having occurred in dinosaurs; (6) the slenderness of the limb bones; and (7) evidence of scavenging by predators on the limb, foot, and girdle bones.

Introduction

Attempts to establish criteria for species determination in sauropods (Mook 1917, McIntosh 1990) have proved very difficult. The reasons for this are that very few taxa are known from fairly complete articulated skeletons. The loose joint between the atlas and occipital condyle has resulted in the skulls of most specimens being disarticulated and separated from the postcranial skeleton. In a large number of the valid genera, the all-important skull is still unknown. Fortunately, the size and weight of these animals led to highly specialized vertebrae in most genera that provided the greatest structural strength at minimum weight. These vertebrae provide many significant taxonomic characters used to establish generic identity; however, the statistical sample of specimens complete enough to provide characters of specific significance, sexual dimorphism, or individual variation is lacking in most sauropod genera.

It is therefore very encouraging that in the most common North American sauropod genus, *Camarasaurus,* an increasing number of articulated skeletons have been reported in recent years, and, though the sample is still relatively small, it appears that soon it may be large enough to provide meaningful statistics. Until then it is very important that all articulated skeletons be fully reported with as many illustrations as possible, accompanied by adequate measurements. Unlike one of the few other sauropods with multiple articulated skulls and skeletons, the Chinese *Shunosaurus,* which has been reported from a single horizon and locality, *Camarasaurus* has been found in a number of sites in at least six states and in horizons all the way from low in the Kimeridgian up into the Tithonian.

Discovery and Excavation

The present specimen was collected in 1993 by Western Paleontological Laboratories, Inc. (WPL), of Orem, Utah, at a locality not far from the famous American Museum of Natural History's Bone Cabin Quarry (BCQ) in Albany County, northeast of Medicine Bow, Wyoming. In 1990, WPL began to explore the area in and around BCQ. Well-known among paleontologists from the work of the American Museum of Natural History (AMNH) around the start of the twentieth century, BCQ has nevertheless seen little activity since the AMNH left the site in

1905 (Osborn 1904b). Located in cattle country about ten miles north of the famed fossil beds of Como bluff, near Medicine Bow, Wyoming, the locality has produced a broad assortment of Jurassic specimens such as *Stegosaurus, Diplodocus, Apatosaurus, Allosaurus, Ornitholestes, Camptosaurus,* and *Dryosaurus.* Kimeridgian in age, this horizon extends for hundreds of meters to the east and west of BCQ itself, which is located on a small knoll overlooking a draw that descends to the Little Medicine Bow River about two kilometers southwest. The Laramie Plains surround the excavations for several kilometers in all directions (Photo 1).

There are three major dinosaur quarries at this locality: Bone Cabin Quarry, East *Camarasaurus* Quarry '93 (ECQ) east of BCQ, and Stegosaur '99 to the southwest. All three are located in the upper Morrison unit with Bone Cabin Quarry positioned 3 to 7 meters above the base of the upper unit and ECQ about 14 meters as well. The dinosaur bones are in a poorly sorted, angular, fine-to coarse-grained sandstone, composed of 15% black chert at ECQ and up to 40% at BCQ. This gives the sandstone a salt-and-pepper appearance.

In the summer of 1992, Jeffrie Parker, the WPL field manager, discovered a few pieces of fossilized bone eroding from surface sandstone in the middle of a jeep trail about one hundred fifty meters east of BCQ. Further exploration of the find indicated that some of the bone pieces belonged to a sauropod humerus. Also revealed, lying just below the surface, were elements that had not been exposed directly to the elements.

Over the next few days, Parker, Tyler Pinegar, and Stan Pinegar removed sufficient overburden to expose several additional elements, including a nearly complete humerus, five ribs, and three vertebrae (Photo 2). From the shape and size of these elements, the team was able to identify the bones as belonging to *Camarasaurus.* The relative bone size and evidence of articulation suggested that the remains were of a single skeleton. However, since the field season was drawing to a close, the extent of the specimen had to await further exploration the following year. Before leaving the discovery the team covered the exposed elements with burlap, plastic tarps, and loose sand to protect them from the inclement winter weather.

By the spring of 1993, WPL was anxious to continue the exploration of the *Camarasaurus.* Parker and the Pinegar brothers reopened the dinosaur site and enlarged the quarry. The bone-bearing layer was found to dip at about 12 degrees to the south, which necessitated the removal of approximately 1000 cubic meters of overburden from an area measuring approx-



Photo 1. Aerial view of the Camarasaurus *quarry (right) showing the relatively flat terrain surrounding the quarry. Bone Cabin Quarry is the light-colored area in the left of the photo.*



Photo 2. Stan Pinegar (left) and Tyler Pinegar (right) exposing the left and right humerus of the Camarasaurus. *These were the first bones to be discovered of the* Camarasaurus.



Photo 3. Aerial view of the Camarasaurus *quarry showing the size of the excavation. A quarry of this size would not have been possible to create in a single field season had it not been for the "Bobcat" excavator.*

imately 15 meters east-west, 12 meters north-south, and up to three meters in depth (Photo 3). A small earth-moving machine (Bobcat) made this task fairly easy. Early on, Parker piled earth on the abrupt south end of the dig to prevent unsuspecting travelers of the jeep road from plummeting over the edge.

Following the trail of bones in the excavation did not present a problem. The sand matrix containing the bones was clearly definable. Sand and clay deposits alternated above the distinctive target matrix, and below it lay a bed of fine clay. The pattern of bone deposition continued to the southeast, reflecting the scattering action of an ancient river (Photo 4). It became apparent that the bones belonged to a single individual and that much of the skeleton was present. Before complete burial, the corpse had been moved by the action of water but not completely scattered. This hypothesis assisted Parker in efficiently tracing the remains.

WPL decided to commit the necessary effort to complete the work of excavating the *Camarasaurus* during the summer of 1993. Many individuals assisted with the excavation, which Parker supervised throughout the summer. Ron Mjos, a WPL partner, spent a great deal of time at the quarry, as did Stan and Tyler Pinegar, David Hamblin, Lucy McDonald, Landis Buck, Kate Olson, and many other WPL employees and guests. In all, about thirty people participated in some phase of the excavation (Photo 5).

The dig proceeded with few interruptions. The weather generally cooperated over the course of the summer. Although the quarry suffered one substantial flood early in the season, the porous nature of the quarry sediment quickly absorbed the water. Usually conditions were warm and dry, with occasional thunderstorms rolling across the plains (Photos 6, 7).

Occasionally, unexpected visitors stopped by to visit, including a small herd of cattle, the curious pilot of a passing helicopter, and a rattlesnake that fell down the south edge of the quarry, landing next to a couple of startled crew members. The snake, probably more startled than the workers, was escorted away with a shovel and bucket.

The field crew uncovered bones of what has been tentatively identified as a *Diplodocus* skeleton along the southwest and south boundaries of the quarry-namely, dorsals, sacrum, and caudal vertebrae. This additional specimen was partly collected to allow unrestricted access to the *Camarasaurus*. Other discoveries in the quarry include portions of the small ornithopod *Dryosaurus,* a turtle shell, and a superb crocodile skeleton with skull.

Composed largely of silica and calcite, the fossil bone in the quarry was of a good, hard quality, tending toward a deep gray and occasionally roseate color. Some of the elements near the surface show evidence



Photo 4. Jeffrie R. Parker who discovered the Camarasaurus, *giving scale to the excavation site. Note the "flow" of the bones showing stream direction.*

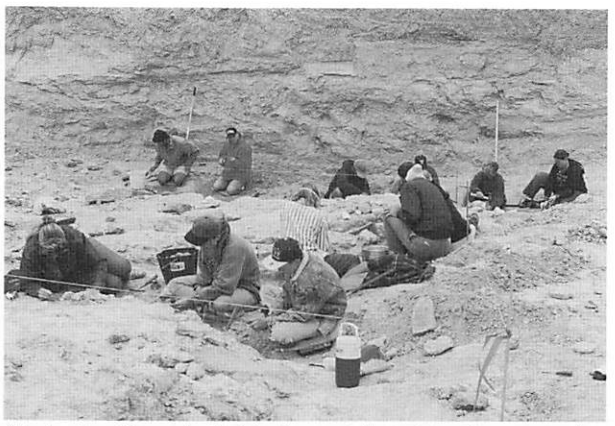


Photo 5. Many individuals contributed to the excavation of the Camarasaurus, *half of them volunteers who helped just for the excitement of digging dinosaurs. Note the height of the back wall. The skeleton lay about three meters down from the surface at its deepest point.*



Photo 6. It was very common to have afternoon rain showers that inconvenienced the field crew and occasionally made the quarry unpleasant to work in.

of freeze-thaw damage, but most of the specimen lay deep enough to have escaped severe weathering.

With the overburden removed by the Bobcat, the team was able to access the bone layer and use hand tools (e.g., awls, utility knives, brushes) to meticulously expose the skeleton (Photos 8, 9). Care was taken to expose bones only as much as necessary to facilitate mapping and removal. WPL carefully mapped the quarry, taking hundreds of photographs and extensively videotaping progress of the excavation. A zero point was established near the northwest corner of the site, from which X and Y lines stretched on cardinal lines (Photo 10). Bone and block coordinates, measured from these lines, were recorded in a field notebook, along with sketches and comments that might aid the laboratory technicians.

The skull of the *Camarasaurus* proved to be the most spectacular part of the find. Nearly complete, it lay within the largest cluster of bones not far from the point of initial discovery. It was carefully and partially exposed in the field and left essentially in situ until it could be safely removed in a large block of matrix.

The field crew worked around large bones or clusters of bones, isolating and mapping them and plastering the blocks of stone-encased bone, which were then lifted out of the ground, often with the help of the Bobcat (Photos 11−13). Smaller bones that could be collected individually were mapped and removed, wrapped in foil, marked for identification, and placed in crates for stable transportation. The rather flat terrain around the quarry provided a very good staging area for the shipment of the bones back to the WPL laboratory. With the specimen and associated matrix weighing between seven and ten tons, several trips with a heavy-duty trailer were required to transport the *Camarasaurus* to the WPL lab.

It was during the 1993 field season that Dr. Yoshikazu Hasegawa, executive director of the Gunma Museum of Natural History (GMNH), and Mr. Hollis Butts from the Heart of Stone Company visited the quarry to inspect the *Camarasaurus*. After the inspection Dr. Hasegawa recommended that GMNH fund the project, which would facilitate the entire preparation and mounting of the *Camarasaurus*.

By the end of August, the extent of the specimen had been defined. In September, removal of large blocks began in earnest. With cold weather swiftly setting in and the crew occasionally working in rain and snow, the dig was successfully completed and the quarry closed by the end of the month.

As may be seen from the quarry map (see map), the skeleton lay on its right side. Both the neck and tail constricted back, pulling the carcass into a U-shaped postmortem condition that is discussed later. The main body of the dinosaur interrupted current



Photo 7. Even though rain made digging difficult, the weather created many beautiful rainbows and cloud formations. The wooden shacks in the picture are crew quarters and the kitchen. They were built and used instead of tents because of the strong winds that often accompanied the rain.



Photo 8. Karen Cloward (staff) and Michelle Beardall (a volunteer) carefully excavating the caudal series. All of the volunteers were very helpful in exposing the dinosaur.



Photo 9. Digging dinosaurs is often hot, labor-intensive work, but the rewards of discovering a dinosaur make the work worth it. Elliot Smith (left) and Wes Elkins (right) spent hours digging trenches around exposed bones.

flow, which formed an eddy. This fortunate occurrence is what probably led to most of the skull bones remaining with the skeleton. A number of skull and tail bones drifted downstream as well as the right tibia, fibula, and pes. A certain amount of soft tissue must have remained attached to the right tibia, fibula, and pes because a number of the elements were found closely associated. The forelimb bones are in close approximation to the body relative to their actual positions in life. The ilium was articulated to the sacrum with the pubes and ischia displaced backward. The right femur is in an approximate position of articulation. Most of the ribs were found near the vertebral column. Remarkably all 53 caudals are present, the same number as in the articulated tail of Carnegie Museum (CM) 11338. This number suggests that the number of caudals may have been stable in *Camarasaurus* rather than varying by a few as previously supposed. Even more remarkable is the fact that the individual elements of the skull and mandible are completely disarticulated, including the separation of teeth from the jaws. Nearly all the skull elements have been preserved uncrushed and are in an excellent state of preservation, with every tooth being found.

The previously published literature on *Camarasaurus* include the brief descriptions of Cope (1877) and Marsh (1878, 1889, 1896). The first comprehensive study is the great monograph of Osborn and Mook (1921) on Cope's *Camarasaurus supremus* material. This monograph included detailed descriptions of the vertebral column and the pectoral and pelvic girdles with all of the bones figured in multiple views. Regrettably, nothing was known of the associations of the vertebral column, resulting in some errors. The Cope collection contained only a few disarticulated skull elements; a few, for the most part, imperfect limb bones; and almost no foot bones.

The second paper is that of Gilmore (1925), published only a few years later, in which he described an almost complete articulated skeleton of a juvenile animal CM 11338. The specimen allowed him to describe the external features of a complete skull and mandible, correct the vertebral formula, provide descriptions of the limb bones with comparative length measurements, and provide specific information concerning the fore and hind feet. The understandable decision to mount that remarkable skeleton as a panel mount as it lay in the quarry, with many bones worked out only partially in relief, had the disadvantage of hiding some details, particularly of the presacral vertebrae and various aspects of the limbs.

A third, recently published, paper by Madsen, McIntosh, and Berman (1995) added to our knowledge

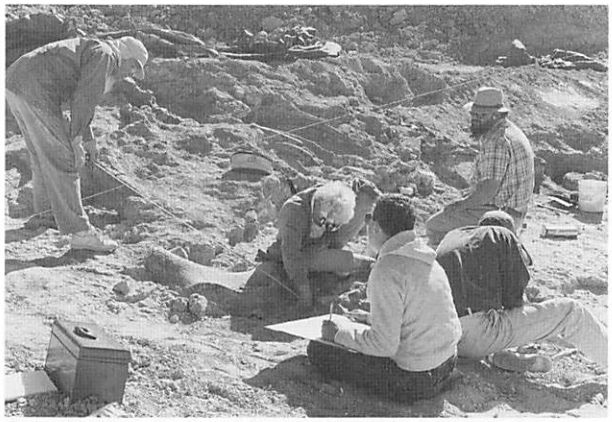


Photo 10. The task of carefully measuring and mapping the skeleton was aided by almost everyone who worked at the quarry. Here Chuck and Ethel Miles help one of the authors (CAM) in mapping part of the caudal series. The completed quarry map helped to solve many questions regarding the skeleton such as the presence and position of the atlas ribs.



Photo 11. Ron Mjos and Stan Pinegar perform the task of jacketing and removing bones. This was hard but rewarding work because it meant that the fragile bones were secure and could now be safely transported to the lab.



Photo 12. Large blocks are very difficult to remove from the quarry. The best way to remove them has to be carefully considered in order to reduce the risk of damage to the bones. Ron Mjos (left) and Jeff Parker (right) are experts at removing large blocks, not damaging a single bone.

of the skull and mandible of *Camarasaurus* by describing in detail all the disarticulated skull bones, figuring each in multiple views. A fourth major source of

information on *Camarasaurus* is the set of plates prepared by O. C. Marsh for his projected but never completed sauropod monograph. This contains figures of all of the limb and girdle bones, as well as of some vertebrae; some skull elements; and some foot bones, all in multiple views. These he referred to his genus *Morosaurus,* which was later shown by Osborn and Mook (1921) to be synonymous with *Camarasaurus.* These plates were finally published without descriptions by Ostrom and McIntosh in 1966.

Many other papers add information to our knowledge of *Camarasaurus.* Some of the most significant include Osborn (1904a) on the sacrum and manus; Holland (1924) on the posterior cervicals; White (1958) on a skull with emphasis on the braincase and teeth; Jensen (1988) on the large part of a skeleton; Brigham Young University (BYU) 9047 of a new species *Cathetosaurus (=Camarasaurus) lewisi;* and finally McIntosh, Miller, Stadtman, and Gillette (1996) with a more detailed description of this skeleton with multiple illustrations.

In light of all the literature cited above, it would be redundant to repeat detailed descriptions of much of the material. Nevertheless, if the present material is to be of use to workers in the future in trying to select those species which are valid, it is very important that numerous figures of the individual bones with detailed measurements and special features of those elements be presented in one all-encompassing work. We have attempted then to accomplish this task with this publication, as well as give brief descriptions and comparisons to other specimens of *Camarasaurus.*

Abbreviations

AMNH: American Museum of Natural History, New York, New York
BCQ: Bone Cabin Quarry, Albany,Wyoming
BYU: Brigham Young University, Earth Science Museum, Provo, Utah
CAM: Clifford A. Miles, WPL, Orem, Utah
CM: Carnegie Museum of Natural History, Pittsburgh, Pennsylvania
DISH: Diffuse idiopathic skeletal hyperostosis
DINO: Dinosaur National Monument, Jensen, Utah
ECQ: East Camarasaurus Quarry, Albany, Wyoming
GMNH: Gunma Museum of Natural History, Gunma, Japan
USNM: National Museum of Natural History, Washington, D.C.
UUVP: University of Utah Vertebrate Paleontology, Salt Lake City, Utah
WIPS: Western Interior Paleontological Society, Denver, Colorado
WPL: Western Paleontological Laboratories, Inc., Orem, Utah
YPM: Yale Peabody Museum, New Haven, Connecticut

*The sauropod fossils from the Cleveland-Lloyd Dinosaur Quarry are conserved at three different Museums: (1) Utah Museum of Natural History, Salt Lake City, Utah; (2) Earth Science Museum, Brigham Young University, Provo, Utah; (3) College of Eastern Utah, Prehistoric Museum, Price, Utah.



Photo 13. The Bobcat was a very useful tool that aided in the removal of large blocks. The greatest risk always involved turning the blocks over, in order to "jacket" the side that was down.

Systematic Paleontology

Order: Sauropoda
Family: Camarasauriidae
Camarasaurus grandis Marsh (1878)

This specimen, Gunma Museum of Natural History (GMNH) 101, is approximately 65% complete, consisting in large part of an articulated skeleton, which is in many ways quite unusual. Preserved are the skull and mandible, cervical vertebrae 1−8, dorsal neural arches 6−12, most of the dorsal ribs, the articulated sacrum lacking centra, a nearly complete set of caudal vertebrae lacking only the centra of nos. 1 and 2, 18 chevrons, part of the right scapula, left coracoid, left humerus and fragments of the right, partial left ulna, partial left manus, right ilium, pubes, ischia and nearly complete right hind limb and pes, head of the left femur, and part of left pes.

Skull and Mandible

(See skull measurement drawings and Photo 14)

Except for the braincase, the skull elements have been completely disarticulated, but most of them are present, undistorted, and in a remarkable state of preservation. Those elements which are missing

include both jugals, both vomers, the left palatine, both stapes, and all of the elements of the sclerotic ring that surrounds the eyeball. Several other elements are less well preserved or incomplete. These include the left postorbital, squamosal, frontal, and quadratojugal as well as the right palatine. Missing from the mandible are both prearticulars; also the left surangular is incomplete. Most of the teeth had fallen out of the jaw elements, but apparently every one has been recovered and carefully arranged by Cliff Miles (CAM) in a manner that we believe to be essentially correct. The state of preservation and lack of distortion of the elements has permitted Ron Mjos of WPL to skillfully reassemble a cast of the skull and mandible. Since a recent publication (Madsen et al. 1995) has treated the individual skull elements exhaustively, it will be unnecessary to describe them in detail here. Instead and for completeness, we have chosen to give a summary outline description of the skull elements to aid in the interpretation of the many figures, which otherwise speak for themselves.

The massive premaxillae with their four large alveoli are particularly well preserved (Figure 1). Three gracile processes arise above the main block-like body of the bone and are complete. These include (1) two tongue-shaped, slender, backwardly directed processes that lock the premaxillae to the maxillae in addition to the lower one also connected to the (missing) vomers; (2) a graceful, long posterodorsal directed nasal process that tapers to fit into the groove of the equally gracile descending premaxillary process of the nasal.

The nasals (Figure 2) broaden posteriorly to abut the frontals and extend down a curving tongue on whose anterior margin abuts the long, stout, diagonal, dorsally directed lacrimal process of the maxilla. On the posterior margin of the nasals are the prefrontals (Figure 3), and below them the head of the lacrimal. The large, laterally facing oval-shaped nares are thus ringed by the premaxillae and nasals above and the maxillae below.

The maxilla possesses a heavy rectangular main body, which contains on its medial face ten alveoli (Figure 4). Behind them are two well-developed depressions, the anterior one for articulation with the palatine, the rear one for a solid suture with the foot of the ectopterygoid. Above on the dorsal margin there arises a sharp triangular-shaped hump into which is implanted the foot or ventral end of the lacrimal (Figure 5), the bones of which are beautifully preserved in this specimen. These slender laminar lacrimals possess, just above midheight, tear-shaped foramina facing posteriorly into the orbit. The lacrimal serves to separate the anteorbital fenestra in front from the orbit behind. The orbit is shaped like an inverted teardrop. Articulating with the posterior margins of the maxilla is the thin forward edge of the recumbent L-shaped straplike quadratojugal (Figure 6). Thus the jugal (missing in this specimen) is excluded from the lower margin of the skull. The frontal (attached to the braincase in GMNH 101), postorbital (Figure 7), and squamosal (Figure 8) are present but damaged on the left side. However, except for the jugal, all of these elements are well preserved on the right side. The dorsal rim of the orbit is formed by the small rectangular prefrontal, above, and behind it the frontal, to which behind is firmly attached (and completing the upper rim of the orbit) the anteriorly directed first of three processes of the triradiate postorbital. A second downwardly directed slender process meets the jugal (missing) to complete the rim of the orbit. The third and backwardly directed process of the postorbital tapers to a point and fits neatly into a groove in the head of the squamosal. On the medial side of the postorbital a vertically oriented lamina (crista antotica) articulates with the latero-sphenoid. The squamosal sends down a hollow sleeve that fits neatly over the head of the quadrate, its lower edge articulating directly with the short, up-wardly directed process of the quadratojugal. These two elements lie over the lateral face of the quadrate, excluding the latter from the posterolateral face of the skull. Together with the postorbital and jugal, the quadratojugal and squamosal complete the rim of the large gourd-shaped lateral temporal fenestra (also called the infratemporal fenestra), which underlies the orbit. The stout vertically directed quadrate extends (Figure 9) forward a large sail-shaped plate (pterygoid process of the quadrate) from the upper two-thirds of the anterior margin of its shaft. On the medial side of this plate, the backwardly

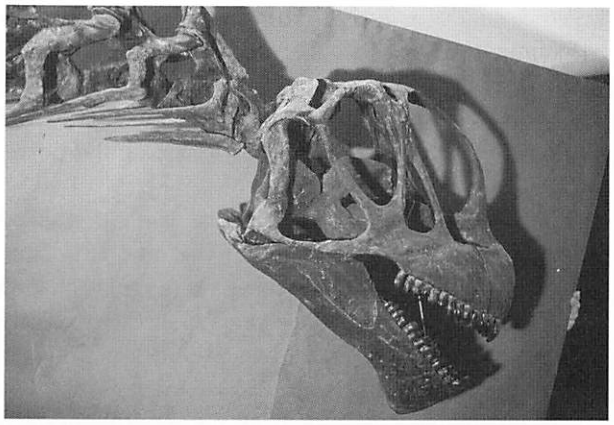


Photo 14. The completed Camarasaurus *skull. This* Camarasaurus *skull is one of the most complete and the largest ever collected.*

directed quadrate process of the pterygoid loosely articulates. Viewed from behind, the posterior face of the quadrate contains a vertically directed trough. A stout condyle is present on the lower quarter of the quadrate for contact with the articular at the posterior end of the mandible.

The braincase (Figure 10) is well preserved except for the anterior portion of the overlying frontals. The dorsal surface of these rectangular-shaped platelike bones is flat, but the ventral surface exhibits a sharp ridge that extends from the outer anterior junction with the prefrontals inward and backward to a point just above where the frontal meets the forward edge of the underlying orbitosphenoid, behind which the large olfactory nerve would have been housed. The suture on the median line between the frontals is evident, and at its posterior termination there lies a prominent circular pineal foramen, the rear half of the rim of which is formed by the parietals, whose suture with the frontals is clear and straight. The suture between the two parietals is not evident, as is often the case, and each is rectangular and broader than long. The inner half of their anterior margin articulates with the frontals, the outer half with the postorbitals, which together with the parietals rim the oval-shaped supratemporal fenestra. Directly behind the parietals is the robust, triangular-shaped supraoccipital bone, on each side of which are the paroccipital processes of the opisthotics. Beneath the supraoccipital is the large, circular foramen magnum, which is also formed by the basioccipital and the exoccipitals, whose sutures with the opisthotics are completely obliterated.

The sidewalls of the braincase are formed by the usual four elements, which, in order from front to rear, are (1) the small orbitosphenoid; (2) the laterosphenoid with its vertically directed lamina (crista antotica), which unites with the postorbital in front; (3) the short solid prootic, which also possesses a lateral lamina (crista prootica) that extends anteroventrally to unite with the crista antotica; and (4) the opisthotic. The openings for the cranial nerves are all apparent and in agreement with their locations on other specimens as described in detail elsewhere (White 1958, Madsen et al. 1995). The floor of the braincase is formed posteriorly by the massive basioccipital, which has a large occipital condyle. In front of the basioccipital lies the basisphenoid, onto whose upper lateral surface the crista antotica attaches. Anteriorly, the triangular forwardly directed parasphenoid emerges, but its suture line with the basisphenoid is obscure. Ventrally the basisphenoid branches into two short stout ventrolaterally directed basipterygoid processes. These fit neatly, but loosely, into a pocket on the upper margin of the rear branch of the pterygoid.

Of the bones making up the vaulted palate, both pterygoids and ectopterygoids are preserved and are in an excellent state of preservation. However, the two vomers are missing, as is the left palatine and the upper half of the right one. The pterygoid (Figure 11), which lies almost vertically, may be divided into three parts: (1) a winglike thin anterior plate that abuts against its mate medially along the midline, the anterior tongue of which progresses forward between the diverging, vertically placed robust vomers; (2) a broad process at midlength is directed ventrally and curves posteriorly at its distal end to articulate with the palatine above and the ectopterygoid below; (3) a shorter posteriorly directed segment of the pterygoid contains the pocket for the basipterygoid process of the basisphenoid on its upper margin and a broad surface on its lateral face for a loose articulation with the quadrate. The sail-shaped palatine (Figure 12) covers the upper margin of the ectopterygoid medially and projects forward from its lower border a strong process that inserts into a depression on the posteromedial face of the maxilla. The curved, strap-like ectopterygoid (Figure 13) has a broad, downwardly directed segment that overlaps the downwardly directed process of the pterygoid as mentioned above. The bone narrows anteriorly with its upper margin abutting the palatine. It curves outward to implant a solid foot into a second depression just behind that of the palatine on the inner face of the maxilla. A small circular fenestra is present, rimmed by the palatine, ectopterygoid, and maxilla, where these three elements almost join.

Except for the missing prearticulars and fragmentary left surangular, all the bones of the mandible are present, most of them in a superb state of preservation. The massive dentary bones (Figure 14) articulate with one another along a broad and loose symphysis. Each dentary contains alveolae for fourteen broad teeth, most of which have fallen out but have been recovered. At midpoint the dentary divides into two segments: a strong medial branch that narrows, rises upward and backward; and a much thinner lateral branch that narrows posteriorly and ventrally. Underlying the lower branch and continuing to the end of the ramus is situated the sturdy elongated angular (Figure 15), which forms the ventral margin of the ramus. Overlying the ventromedial face of the dentary is the very thin splenial (Figure 16). Both splenials are well preserved in this specimen. Above the splenials, articulating with their dorsal edges and covering the back edge of the tooth row, are the thin straplike intercoronoids (supradentaries) (Figure 17)

that are rarely preserved when disarticulated. Both are present in this skull, although neither is complete. Above the angular and behind the dentary lies the large plate of the hatchet-shaped surangular (Figure 18). It narrows posteriorly into a "handle," which, along with the angular, cradles the ventral surface of the articular. The medial face of the surangular is marked by two parallel anteroposterially directed ridges. Above the upper ridge lies the articular face for the dentary; below the lower one is the articular face for the angular. The robust, well-preserved blocklike articulars (Figure 19) are roughly elongated ovals as viewed from above, with a well-developed trough for articulation with the quadrate. Viewed from the side, the lower margin is broadly convex downward.

The skull elements have been carefully compared to those of other *Camarasaurus* skulls, and in particular with those of DINO 28. This skull from the Dinosaur National Monument (DINO) is about the same size as GMNH 101 and is also totally disarticulated. This skull has been referred to *Camarasaurus lentus* (White 1958, Madsen et al. 1995) largely because Gilmore referred the juvenile skeleton CM 11338, also from Dinosaur National Monument, to that species. It is quite likely that only a single species of *Camarasaurus* is present at that site. Comparison of the two skulls failed to reveal any significant differences. The quadratojugal of GMNH 101 is slightly more slender, the occipital condyle is a bit larger, etc. The most obvious difference is the presence of 14 dentary teeth in GMNH 101, one more than in DINO 28. As will be discussed later, these numbers vary slightly among other specimens from DNM, so this feature is likely a matter of individual variation or age. The skull elements of GMNH 101 are also quite similar to those of *Camarasaurus* from the Cleveland-Lloyd Dinosaur Quarry in Utah (Madsen et al. 1995). There appear to be possibly more differences from the so-called "*Camarasaurus*-like skull A," University of Utah Vertebrate Paleontology (UUVP) 10795, also from that quarry. The lacrimals in this specimen are more gracile, the downwardly directed processes of the pterygoids more robust, and the paroccipitals processes directed more laterally rather than ventrolaterally from the center. Even these differences may eventually prove to be due to individual variation only.

Teeth (CAM) (Figure 20)

The dental formula for this *Camarasaurus* is clearly shown as follows:

Upper jaw: premaxillary 4; maxillary 10; total 14

Lower jaw: dentary 14

This dental formula differs slightly from the juvenile skull of CM 11338 described by Gilmore from Dinosaur National Monument. It possessed the following dental formula:

Upper jaw: premaxillary 4; maxillary 8−9; total 12−13

Lower jaw: dentary 13

It appears that the number of teeth in both the upper and lower jaw vary among different individuals. After looking at the dentary of a juvenile *Camarasaurus* (in the possession of WPL, found in sediments the same as and just west of BCQ), which also has 14 tooth aveolae, it is likely that differing dental formulas may be attributed to individual rather than developmental variation.

The teeth of *Camarasaurus* are homodont, larger in size anteriorly, and becoming smaller posteriorly. This is true for both the upper and lower series. The teeth of the upper jaws appear to be more robust than those of the lowers. This robustness is more apparent on the exterior side of the teeth where they are more rounded through the exterior half of the crown. This can only be seen if one has a nearly complete set of teeth.

A total of 66 teeth were found for the *Camarasaurus* skull, which is 10 more than are required for a complete dental formula. Three possibilities exist for the extra teeth: (1) some of the teeth were shed crowns from other individuals; (2) some of the teeth were unerupted, coming in behind functional worn teeth; or (3) a combination of the first two explanations. It is more likely that this third possibility is correct since some of the recovered teeth consist of heavily worn crowns and others appear to be immature teeth showing no wear that would have been unerupted. In any event, all the teeth that were recovered from the area of the skull are considered as candidates belonging to the skull.

Three teeth (right premaxillary 1, right premaxillary 2, and right dentary 7) were removed from the jaws. Their positions were recorded and the teeth placed with the assemblage of other teeth. They were removed to facilitate the final restoration of the skull. After all of the teeth were prepared they were paired as lefts and rights. The pairs were then arranged from largest to smallest (see Table A). The largest pair of teeth are contained in the premaxillaries and not the dentaries. Using this premise, the largest pair of teeth were placed in the number-one position in the premaxillaries. The next largest pair were placed in the number-one position in the lower jaws. This pattern of alternating and placing each pair of teeth from the uppers to lowers working posteriorly continued until all of the pairs were assigned posi-

TABLE A—MEASUREMENTS OF TEETH

(all measurements in millimeters)

ELEMENT		RIGHT LENGTH	RIGHT WIDTH*	LEFT LENGTH	LEFT WIDTH
PREMAXILLA	1	375	33	100	31
	2	70	32	130	29
	3	85	29	105	28
	4	127.5	28	100	28
MAXILLAE	1	120	26	35	28
	2	92.5	28	70	27
	3	57.5	28	82.5	26
	4	70	27	95	25
	5	57.5	23	115	24
	6	75	25	102.5	22
	7	37.5	23	92.5	22
	8	82.5	21	72.5	21
	9	102.5	21	42.5	18
	10	82.5	15	80	18
DENTARY		128	31	145	30
	2	110	28	**	**
	3	100	26	130	29
	4	12	25	110	30
	5	57.5	26	120	27
	6	95	24	97.5	26
	7	40	24	115	27
	8	97.5	24	61	26
	9	64	25	100	23
	10	90	20	90	28
	11	37.5	20	60	21
	12	70	12	45	22
	13	60	12	50	17
	14	65	10	65	16

* The width was taken from the crown only.

** This tooth was found in the dentary and could not be measured.

tions.

Four teeth were found still in the jaws. It appears that they were just erupting. It was decided that three of the remaining loose teeth (left maxillary 3, left maxillary 7, and left maxillary 9) assigned the same positions as the erupting teeth would not be used in the restored skull. The crowns assigned to left maxillary 7 and left maxillary 9 are extremely worn crowns and may not have belonged to this skull. Left maxillary 3 likely came from that position, but because there was an erupting crown showing, it was not used. The fourth erupting tooth did not have a loose individual that would fill the position (left dentary 2). After all of the teeth were assigned positions, we discovered that we had placed the teeth removed earlier back in their original positions. This indicated to us that we had probably placed all of the teeth in their correct positions.

Vertebral Column

Apparently the vertebral column was articulated at the time of burial, from the atlas to the middle of the tail. The posterior caudals were somewhat scattered but apparently all present. The animal lay on its right side, the neck pulled upward and backward due to postmortem contraction of the large ligament that lay in the trough formed by the two metapophyses of the divided neural spines. This condition is common to sauropod carcasses, among them the two articulated *Camarasaurus* skeletons from Dinosaur National Monument CM 11338 and U.S. National Museum (USNM) 13786. The dorsal and sacral vertebrae had been twisted around so that instead of resting on their right sides, the spines were directed straight downward. Erosion destroyed cervicals 9—12 and dorsals 1—5 (see quarry map) and also the centra and lower portions of the neural arches of the remaining dorsals, sacrals, and the first two caudals. Those who collected the skeleton originally believed that dorsal 12 was the first sacral; that sacrals 1—4 were nos. 2—5; and that the fifth and last sacral, only the spine of which remained, was the first caudal. This confusion resulted because dorsal 12 was later found to be fused into the sacral complex, which is quite unusual but not unique. Thus it was originally thought that a total of fifty-four caudals were present. The revised assignment leaves a tail of fifty-three caudals, the same number observed in the articulated tail of the nearly complete juvenile skeleton CM 11338.

The vertebral column of *Camarasaurus* has been described in great detail by Osborn and Mook (1921) so the description presented here will be brief, summarizing the main features that characterize *Camarasaurus* and comparing the bones of GMNH 101 with those of other specimens of *Camarasaurus*.

Cervical Vertebrae

Cervicals 1—8 were found in articulation and in a fairly good state of preservation. The rarely preserved proatlas (Figure 21) consists of two separate elongated strips of bone in the shape of scaline triangles with the longest leg facing dorsally. The right element is preserved with the present specimen. The proatlas, originally termed "post-occipital bones" in sauropods, was first reported in 1883 by Marsh in the paratype of *"Morosaurus" (=Camarasaurus) grandis* Yale Peabody Museum (YPM) 1905 (figured by Ostrom and McIntosh in 1966 erroneously as the prefrontal). The proatlas was subsequently recognized in the so-called *"Morosaurus" agilis* (Marsh 1889) and in a few other specimens. Of the two ventrally facing sides of the proatlas, the forward and shorter one abuts the upper surface of the occipital condyle, and the rear and longer side abuts the upper surface of

the neural arch of the atlas.

The atlas is complete (Figure 22). The intercentrum and two branches of the neural arch (neuropophyses) are firmly fused, and the latter meet and apparently fuse to one another above. This bone is in complete accord with other sauropod atlases, but one important feature should be noted: namely, the presence of distinct facets as pits on the lower outer margin of the posterior face of the intercentrum for articulation of single rib heads. Elements (Figure 23) that are almost certainly atlas ribs are present, the right one in position (see quarry map no. 434 and Photo 15).

The well-preserved axis (Figure 24) features a centrum with a well-developed pleurocoel that is apparently not subdivided by septa. The odontoid process of the atlas is firmly fused on the anterior face of the axis. The posterior end of the centrum exhibits a deep cup. The ventral face features a sagittally oriented sharp ridge. Just in front of the small parapophyses lies an axial intercentrum firmly fused to the centrum. In describing the nearly complete juvenile *Camarasaurus* skeleton CM 11338, Gilmore specifically stated that "no indication is found of a separate axial intercentrum such as exists in the type of *Morosaurus agilis* Marsh." Nevertheless, in this specimen, although it is fully incorporated into the rest of the bone, an axial intercentrum is clearly indicated. The backwardly directed spinous process rises at a moderate 45° to the horizontal, similar to that of *C. grandis* YPM 1905 and DINO 28, a bit more steeply than in several of the more juvenile specimens from Dinosaur National Monument (CM 11338, USNM 13786), but less steep than in *C. lewisi* BYU 9047, and particularly *C. supremus* AMNH 5761.

The remaining cervicals (Figures 25−30) preserved in GMNH 101 increase in length and all other dimensions from cervicals 3 to 8 (see Table B). The

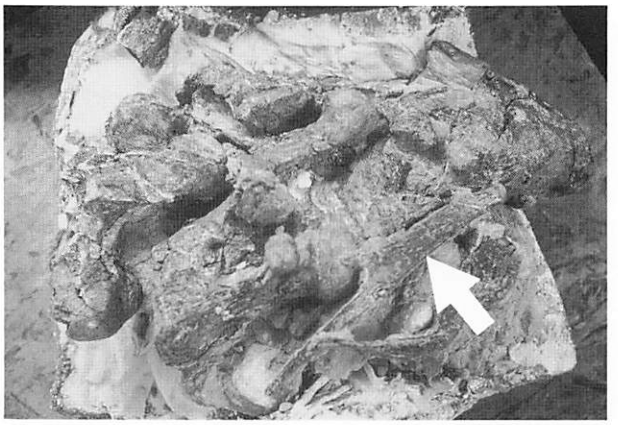


Photo 15. The right atlas rib shown in the position it was found. Add an arrow to photo to show rib location.

more anterior cervicals are better preserved, with increased damage posteriorly, particularly to the diapophyses on the exposed left side. The centra are all strongly opisthocoelous. They all bear elongated deep pleurocoels, which are divided by septa that are not well preserved in many of the posterior cervicals but clearly visible, e.g., in the well-preserved third cervical where the pleurocoel is split into three cavities by a horizontal septum that delineates a lower depression and a diagonal septum dividing the upper 2/3 of the pleurocoel. The ridge on the ventral face of the centrum, so prominent on the axis, survives as a fine line in cervical 3. As is characteristic of *Camarasaurus,* the large prezygapophyses extend well beyond the front of the centrum, in contrast to those of the diplodocids *Diplodocus* and *Apatosaurus.* The neural spines are placed well back on the arch and do not rise as high as in the Diplodociidae. As in *C. grandis* YPM 1905, the bifurcation of the spine begins as an incipient notch on cervical 3, but it is not until cervical 5 that one observes the fully developed U-shaped trough, and even then the cleft is not nearly as

TABLE B− MEASUREMENTS OF CERVICAL VERTEBRAE

(all measurements in millimeters)

ELEMENT	LENGTH		CENTRUM ANTERIOR		CENTRUM POSTERIOR		HEIGHT OVERALL	HEIGHT PRE-	BREADTH SPINE	BREADTH TRANSVERSE
	Total	W/O Ball	Breadth	Height	Breadth	Height	HEIGHT	ZYGAP	TOPS	PROCESSES
Cervical #1	70	70	—	—	80	90	160	—	—	160
Cervical #2	171	100	67	46	99	90	260	115	106	131
Cervical #3	191	150	87	70	107	100	260	150	32	189
Cervical #4	245	200	108	70	130	115	250	165	69	245*
Cervical #5	310	252	130	80	160	115	265	190	70	310
Cervical #6	370	305	148	90	160	135	281	190	80	330*
Cervical #7	405	340	133	100	165*	132*	315	223*	86	352*
Cervical #8	486*	410*	146*	120	155	132	340	205*	120	371*

*RESTORED

TABLE C—COMPARATIVE MEASUREMENTS

GMNH 101; type of C. lewisi *(BYU 9047) ; and* paratype C. *grandis (YPM 1905)*

(all measurements in millimeters)

	LENGTH OF CERVICAL VERTEBRA			BREADTH OF CERVICAL VERTEBRA			HEIGHT OF CERVICAL VERTEBRA		
ELEMENT	GMNH	*C. lewisi*	*C. grandis*	GMNH	*C. lewisi*	*C. grandis*	GMNH	*C. lewisi*	*C. grandis*
CERVICAL 1	70	102	—	80	70	—	160	105	—
CERVICAL 2	200	185	135	99	75	73	260	212	223
CERVICAL 3	191	193	155	107	88	94	260	210	218
CERVICAL 4	245	240	220	130	102	102	250	218	228
CERVICAL 5	310	295	270	160	122	108	265	208	257
CERVICAL 6	370	375	324	160	—	—	281	250	278
CERVICAL 7	405	398	—	—	157	135	315	295	—
CERVICAL 8	INC	460	—	155	141	135	340	210	—

prominent as in the cervicals of the diplodocids. In this respect GMNH-PV 101 *Camarasaurus,* and most of the other specimens of the genus, differ from the deep, narrow bifurcation seen in *C. lewisi* BYU 9047 (see Table C).

Cervical Ribs

The majority of the ribs of cervicals 1 through 8 are present, but most have suffered damage in the very long, slender, backwardly projecting rods of bone. New and most interesting is the pair of single-headed atlas ribs: the right one is complete and the left one nearly so. The left rib had been washed some distance downstream from the skeleton, but the right rib was found almost in position (see map; 434 and Photo 15). These ribs are flattened thin strips of bone directed posteriorly from the thickened knoblike heads. These heads fit into shallow articular cups on the ventrolateral corners of the posterior face of the intercentrum. The ventral border of the strip is relatively straight, but the dorsal border rises to midlength of the bone, then descends sharply to parallel the ventral margin on the narrow posterior of the rib. The lateral surface of the strip is slightly convex from front to rear. A gentle upward bulge rises from just behind the bottom of the rib head, eventually reaching about one-third of the way up the lateral face to midlength, then turns downward and blends into the lateral face. The major feature of the medial surface is a pronounced longitudinal groove that begins about one-third of the way along the strip on the lower part of the face. It proceeds backwards, deepening to a maximum at midlength of the strip and dissipating about 3/4 of the way down the strip.

The presence of atlas ribs has been actively debated over the years. Holland (1906) identified two elements found with the skull, atlas, and axis of *Diplodocus* AMNH 969 as cervical ribs 1 and 2. Although these elements were not found with the atlas and axis of *Apatosaurus louisae* CM 3018, they were restored in a drawing done under Dr. Holland's direction and reproduced in Gilmore's monograph (1936) on that animal. He noted pits for the atlas intercentrum for their articulation. Gilmore (1925), on the other hand, did not find them in the juvenile CM 11338. (The intercentrum of the atlas of *C. grandis* YPM 1905 is missing.) More recently, no atlas rib was found with the *C. lewisi* skeleton BYU 9047. McIntosh, Miller, Stadtman, and Gillette (1996) were unable to recognize rib facets on the atlas. Their presence in GMNH 101 should end the debate.

The atlas rib extends backward beneath the axis and underlaps the anterior end of the centrum of cervical 3. One double-headed axial rib was also found. The cervical ribs from 3 to 8 are fused to their respective vertebrae as in other adult sauropods. They have a short extension in front of the tuberculum, behind which they become very slender. In this specimen, however, they are imperfect behind the distal end of the centrum in cervicals 3 to 6. In the present specimen right cervical rib 7 is also complete and also covers the length of 3 cervicals. A large portion of right rib 8 is also present. The rib head of cervical rib 12 was found and restored to be a more transitional rib showing some of the robust nature we see in the first dorsal rib. These ribs in *C. lentus* CM 11338 are complete, becoming progressively longer and reaching their maximum length on cervical 7. This rib extends back beneath the full length of cervicals 8 and 9. Cervical ribs 8 to 12 progressively decrease in length, with number 12 directed downward as well as backward. It is a much more transitional rib to those of the dorsals than in the diplodocids.

Dorsal Vertebrae (Figures 31—37)

The first five dorsals were completely lost to erosion, which is particularly unfortunate since a major diagnostic character for the species *Camarasaurus grandis* is in the anterior dorsals. In that species the neural arch lies on highly elevated pedicels

TABLE D— MEASUREMENTS OF THE DORSAL NEURAL SPINE CRESTS

(all measurements in millimeters)

EXPLANATION	DORSAL#6	DORSAL#7	DORSAL#8	DORSAL#9	DORSAL#10	DORSAL#11	DORSAL#12
Transverse Breadth	189	170	170	161	159	161	135
Sagittal Breadth	59	85	48	64	66	61	70
Height from median of postzygapophyses to the spine top	195	200	215	210	210	210	200

on the upper surfaces of the centra. In the present specimen, the short broad spines are preserved in dorsals 6—12 and the arches down to and including the zygapophyses. In dorsals 9, 11, and 12 the right diapophyses are also preserved. Dorsals 9 through 12 were found in tight association with dorsals 6 through 8 in situ but not articulated due to erosion. Dorsals 6 through 8 were found with their thoracic ribs articulated (see Table D).

The 6th dorsal spine is the first preserved in the dorsal series. It is the least bifurcated of the anterior dorsals because spine top 7 has only a slight dentation or convection when viewed from the anterior face. On the left side there is a slender, round rod extending down from the metapophyseal to articulate with the lamina arising from the epipophyseal. This rather rugose structure is pillarlike in its construction and supports the bifurcated spine. The same formation can be seen on the left side as well; however, the rod is bent slightly laterally at the midline. An oblong opening is present between the support and the neural spine itself. No lamina is present nor is there any evidence that there was one between this structure and the neural spine. In James A. Jensen's (1988) discussion of *Cathetosaurus (=Camarasaurus) lewisi,* he describes a "diagonal ligament that ran from the metapophyseal to the pre-diapopyseal of the transverse process of the succeeding vertebra." On this specimen, the "ligature" does not articulate to the succeeding vertebra but stays confined to its own vertebra. Also, Jensen can only hypothesize as to the actual structure in *"Cathetosaurus" lewisi*'s dorsals because the ligature is missing. In this specimen it is present on the 6th dorsal on both sides and is definitely bone, not a tendon or ligament.

The 7th dorsal spine shows a very slight dentation when compared to the 6th dorsal and its bifurcation. This very slight dentation can only be viewed from the anterior face. The 7th dorsal also has sites for the lateral supports that were evident on dorsal 6. They must have been larger and more robust than those seen in 6 because the "articulation" site is slightly larger. The lateral faces of the neural spine do not indicate that any laminae are missing between them and the supports. The first real definition of the spine as separate from the laminae that run laterally out from its base to the transverse processes is seen in this dorsal. The spine tapers ventrally on both lateral faces to a point, tapering also in thickness but maintaining a thicker base than the laminae that run laterally from the sides. This thickness gives definition to the spine itself and is accentuated by the rugosity.

The 8th dorsal is very similar to the 7th with the same features, including "articulation" sites for the bone rods. The right side has a small part of the support extending ventrally, approximately 2.5 cm from the metapophyseal. The 9th dorsal shows an apparent change in the support structure. A complete thin lamina of support runs from the metapophseal down to the top or epipophyseal of the postzygapophyses. There is no opening between the neural spine and the support as the lamina is articulated all the way down the side of the neural spine to the postzygapophyses. A deep pleurocel is formed between this lamina and the transverse process. On the right side only a small articulation site remains of where the support began.

The 10th dorsal shows a definite site for the support, approximately 2.0 cm. long. This spine is very rugose and slightly squared on the top. The right side again shows a vague articulation site for the support. The 11th dorsal has an eroded "articulation" site on the metapophyseal that is sagittally oblong. The spine again is very rugose. The 12th dorsal is fused to the sacrum.

All the preserved dorsals appear to possess a hyposphene, but these are not well preserved. Aside from displaying this unusual support feature, little information can be obtained from these vertebrae except to note that the last dorsal to possess a divided spine is no. 6. This is in agreement with all other known specimens in the genus except for *C. lewisi* BYU 9047, where a well-defined notch persists to dorsal 11 and dorsal 12 and exhibits a slight indentation.

Ribs (Figures 39—40)

All the ribs are present except numbers 1 and 2

of the right side. Right dorsal ribs 3 through 9 were in situ connected with their respective dorsals. Right rib 12 was also in place. This made the placing of ribs 10 and 11 relatively easy. Only the 12th right rib was articulated. Comparisons with the right ribs made possible identification of the left ribs, although they were all disarticulated and widely scattered. As is so often the case with sauropod ribs, most of them lacked their lower ends; only left 2 and both number 12's are complete to the end. Right 3 consists of only a small portion of the shaft, and five others (left 3, left 8, right 4, right 6, and right 10) lacked the head and tubercle. The head of left 2 is missing, as is the tip of the tubercle of left rib 5 and the tubercle of right 5. Finally, the upper ends of left 10, right 7, and right 8 were not complete and required some restoration. The most robust rib is left no. 1, which also has the greatest expanse between the head and tubercle. This expanse decreases backward, as does the length of the tubercle (Table E). The ribs bow gently outward. Initially the length increases from rib 1 backward, and then, in the middle of the thoracic cavity, they decrease in length back to the sacrum. Incompleteness of the shafts makes it uncertain which middle rib is the longest.

Viewed from the front, a low ridge extends down the tubercle to meet a similar ridge from the head and centrum some distance down the shaft. This leads to a corresponding concavity on the posterior face. The shafts of the ribs are more rounded and more gracile than in the diplodocids, where the shafts, particularly those in the mid-dorsal area, become flattened and can attain a considerable sagittal breadth. Of more interest are the 12th ribs, which are articulated to the diapophyses of dorsal 12 and extend horizontally outward just below the flaring anterior blade of the ilium. Apparently they do not extend beyond it. This feature allowed dorsal 12 to be incorporated into the sacral complex.

TABLE E– MEASUREMENT OF RIBS

(all measurements in millimeters)

ELEMENT	MEASUREMENTS	
	LENGTH	*SPREAD
Rib-CVR1	288	–
Rib-CVR12	–	365
Rib-L1	–	330
Rib-L2	1313	–
Rib-L4	–	310
Rib-L6	–	283
Rib-L7	–	277
Rib-L9	–	259
Rib-L11	–	205
Rib-R10	–	244
Rib-R11	–	190

* MEASUREMENT IS FROM CAPITULUM TO TUBERCULUM (OUTSIDE EDGES)

A small rib-like element (Figure 41) was found in the dorsal region of GMNH 101 that could not be positively identified. It is likely a fragment of gastralia, since it shows similarities to known gastralia found in *Apatosaurus*.

Sacrum (Figure 42)

One of the more interesting features of this skeleton is seen in the sacrum. As with the dorsals and first two caudals, the centra have been eroded away, but the neural arches and spines, including the transverse processes, are fairly well preserved and articulated with one another and with those of the posterior dorsals and anterior caudals. In most Upper Jurassic sauropods, five vertebrae function as sacrals. Riggs (1903) considered nos. 2, 3, and 4 as primal sacrals with the addition of a modified dorsal or dorsosacral (sacral 1) in front and a modified caudosacral (sacral 5) behind. It is now recognized that nos. 2 and 3 alone form the primary sacrum, and that nos. 4 and 5 are both caudal sacrals. Thus no. 4 is the first vertebra to be added, no. 5 the second, and no. 1 the third. As shown by several juvenile sacra (e.g., that of the type specimen of *Camarasaurus lentus* YPM 1910), all five centra are originally unfused to one another and to their arches. The arches are also not fused to one another except for nos. 2 and 3, which are always united. Their spines are fused for their entire length, although a suture line between them can usually be traced out visually. Not so with their zygapophyses. In all specimens examined by the authors, including those of the youngest individuals, no trace of a suture separating postzygapophyses on 2 and prezygapophyses on 3 can be discerned.

The sacral ribs of all five sacrals are also free in the juvenile. They unite with the transverse processes, arches, and centra in the adult, where they also unite with one another to form the sacral yoke. In most adult specimens the centra of nos. 2 to 5 are fused together, whereas that of the dorsal sacral (sacral no. 1) remains free (for example, in the paratype of *Camarasaurus supremus* AMNH 5761). This lack of fusion is in contrast to many other genera, e.g., *Diplodocus, Haplocanthasaurus, Apatosaurus, Brachiosaurus,* etc., where all five centra fuse in the adult. Nonetheless, the modified rib is fused to its arch and centrum and to that of sacral 2 in the sacral yoke, which in turn articulates with the ilium, thus qualifying it as a functioning sacral. In the present specimen the rib of dorsal 12, the last dorsal, is directed horizontally, barely reaching the anterior tip of the ilium

fusing with it, which suggested to its collectors that dorsal 12 is actually part of the sacrum. A similar situation occurs in the very old individual of *Camarasaurus* AMNH 690 from Bone Cabin Quarry (Osborn 1904).

In the Cretaceous sauropod family *Titanosauridae* a second dorsal vertebra is taken into the sacrum as a full partner, providing a sacral yoke of six vertebrae that is united with the ilia to provide more strength. It is regrettable that the centra are missing in GMNH 101 since it would be useful to know whether those of dorsal 12 and sacral 1 were either fused together or separate.

In the present specimen, as stated above, the centra and sacral yoke formed by the ankylosed sacral ribs have been eroded away. But the spines and diapophyses remain for sacrals 1 to 4, with only the spine being preserved in no. 5. As usual, the spines of nos. 2 and 3 are fused for their entire lengths, and those of nos. 1, 4, and 5 remain free. Viewed from above, the diapophyses of sacral 2 are directed outward and forward from the spine. These unite with those of sacral 3 at the spine and are directed outward and backward from it. The spine of no. 5 has a greater anteroposterior expansion than that of the anterior caudals, as in *C. grandis* YPM 1905, which it very closely resembles.

Caudals (Figures 43−56)

As can be determined from the quarry map, caudals 1 to 20 are articulated to the sacrum and to one another, caudals 21 and 22 have been displaced somewhat, but nos. 23 to 26 are articulated in position. The remaining caudals are somewhat scattered, having drifted downstream, but the complete tail of 53 vertebrae is present. This is the same number as found in the articulated juvenile *Camarasaurus* CM 11338. Thus caudal no. 53 ends in a point, indicating that it does indeed represent the termination of the tail. Although it would not be surprising if the number of caudal vertebrae in *Camarasaurus* was slightly variable, the presence of two complete tails with 53 vertebrae suggests this number may be static. Except for caudals 1−2, which lack the centra, the caudals are for the most part in a remarkable state of preservation and undistorted. Loss of those centra is doubly unfortunate because it does not permit one to know whether caudal 1 possessed chevron facets or whether the first caudal to possess a chevron was no. 2. Unequivocal evidence in this respect is not present in any of the known specimens of *Camarasaurus*, although McIntosh, Miller, Stadtman, and Gillette (1996) have presented strong evidence that a chevron was present on caudal 1 of *C. lewisi* BYU 9047.

The caudal vertebrae of GMNH 101 closely resemble those of both *C. grandis* YPM 1901 and 1905, and *C. lewisi* BYU 9047. The centra of the anterior caudals are gently amphicoelous through to caudal 11, then becom amphiplatyan throughout the rest of the series. All of the caudals are constricted medially with no pleurocoels. The centra are relatively short and their articular faces subcircular. They decrease in length only very slowly in the first half of the tail (see Table F). Chevron facets terminate at caudal 31. When the caudals were articulated on the flat surface of the floor in the lab, it was noticed that the articular faces of caudals 7 and 8 were not parallel. The neural spine of caudal 8 swept anteriorly and not posteriorly, but when the articular faces of the caudals were placed parallel to articulate properly, the neural spine of caudal 8 swept back, forming an even spacing between the neural spines. This would indicate that it is between caudals 7 and 8 that the tail begins a downward sweep.

The transverse processes, shown in juvenile and subadult specimens (e.g., *C. lentus* YPM 1910 and *C. grandis* YPM 1905) to be separate ossifications and therefore caudal ribs rather than diapophyses, are present through caudal 10, and a trace of a rib remains on no. 11. In *C. grandis* YPM 1901, a trace of a caudal rib persists back to caudal 13, but this variability is probably not significant. The anterior ribs arise from the upper half of the lateral face of the centra, are directed outward, and sweep back and up initially. Posteriorly they move into a stronger lateral position and disappear by caudal twelve. The anterior caudal ribs are long and expand at their outer extremities, being much wider through the longitudinal axis than the vertical axis.

Neural arches placed slightly forward of the center of the centrum persist back as far as caudal 43 with zygapophyses, and traces of an arch are present in at least four more. The first three spines proceed upward from the centrum and curve gracefully backward. Viewed from the side, these spines are directed upward and slightly back. They are more or less rectangular and become successively lower and gradually change to a more rhomboidal shape by about no. 17. From no. 30 to 43 they are gradually directed more nearly backward and eventually disappear. The last five caudals are fused together and reduced essentially to a rod, with no. 53 ending in a point, clearly indicating the end of the tail.

A very interesting feature of the spines is the transverse width of the anterior ones. In this specimen and also in the paratype of *C. grandis* YPM 1905, these spines are little expanded transversely, whereas in *C. lewisi* BYU 9047 and the type of *C. grandis* YPM 1905 they are significantly broadened at the top.

TABLE F— MEASUREMENTS OF CAUDAL VERTEBRAE

(all measurements in millimeters)

ELEMENT	LENGTH	CENTRUM ANTERIOR Breadth	CENTRUM ANTERIOR Height	CENTRUM POSTERIOR Breadth	CENTRUM POSTERIOR Height	HEIGHT OVERALL HEIGHT	HEIGHT PRE-ZYGAP	HEIGHT POST-ZYGAP	SPREAD DIAPOPHYSES
Caudal #3	140	*245	245	*225	*220	555	*335	332	*380
Caudal #4	130	230	230	215	215	545	*330	335	—
Caudal #5	153	235	225	210	205	510	*325	310	*370
Caudal #6	158	225	205	205	185	483	*310	275	*340
Caudal #7	150	210	210	198	180	465	300	265	310
Caudal #8	145	202	185	190	190	450	280	265	*295
Caudal #9	138	190	183	180	170	435	260	255	*270
Caudal #10	130	185	180	180	170	419	255	250	190
Caudal #11	130	185	176	164	173	396	250	240	130
Caudal #12	128	165	171	156	175	390	240	240	—
Caudal #13	131	156	165	149	175	379	229	*240	—
Caudal #14	130	147	160	138	168	357	218	235	—
Caudal #15	130	141	158	136	158	330	217	218	—
Caudal #16	132	140	150	130	150	318	205	195	—
Caudal #17	135	133	143	127	145	295	200	185	—
Caudal #18	134	125	140	125	138	274	190	190	—
Caudal #19	133	128	135	125	130	254	183	170	—
Caudal #20	133	125	123	116	122	240	160	167	—
Caudal #21	133	118	118	120	120	229	166	164	—
Caudal #22	129	115	122	113	120	225	165	165	—
Caudal #23	133	107	115	105	112	202	155	152	—
Caudal #24	127	107	107	106	107	192	145	143	—
Caudal #25**	116	110	100	130	118	190	134	**	—
Caudal #26**	120	125	114	93	94	158	**	126	—
Caudal #27	127	93	90	92	93	154	*120	125	—
Caudal #28	120	97	94	90	90	147	120	125	—
Caudal #29	118	84	86	80	80	134	*123	110	—
Caudal #30	119	80	80	75	75	122	*105	102	—
Caudal #31**	91	75	73	76	76	130	97	107	—
Caudal #32**	90	77	80	66	65	110	—	86	—
Caudal #33	106	75	77	75	75	123	*100	104	—
Caudal #34	99	68	65	64	62	100	89	—	—
Caudal #35	96	65	66	60	58	*100	84	—	—
Caudal #36	91	60	60	55	54	84	80	—	—
Caudal #37	81	*55	*54	55	53	90	70	—	—
Caudal #38	81	54	54	48	48	74	70	—	—
Caudal #39	81	46	48	45	46	—	60	—	—
Caudal #40**	78	47	42	40	42	62	52	—	—
Caudal #41	68	36	41	36	38	62	54	—	—
Caudal #42	71	36	35	35	34	—	—	—	—
Caudal #43**	**66	34	38	32	28	50	44	—	—
Caudal #44	55	28	29	25	28	—	—	—	—
Caudal #45	56	30	25	27	24	35	—	—	—
Caudal #46**	58	27	27	26	24	—	—	—	—
Caudal #47	—	—	—	27	28	—	—	—	—
Caudal #48	41	21	25	20	24	—	—	—	—
Caudal #49	33	18	20	15	21	—	—	—	—
Caudal #50**	21	17	18	23	15	—	—	—	—
Caudal #51**	25	23	15	24	16	—	—	—	—
Caudal #52**	35	24	16	18	12	—	—	—	—
Caudal #53	41	12	10	4	2	—	—	—	—

* RESTORED ** PATHOLOGICAL

Because the two *C. grandis* skeletons were found lying next to one another in the same quarry (Marsh Quarry No. 1, Como Bluff, Wyoming) and do not differ from one another in any other respect, they clearly belong to a single species. The difference in the spine width is thus probably due to sexual dimorphism. Although which sex is represented by the wide spine and which by the narrow spine cannot be determined with certainty, it will here be assumed that the wider spine belongs to the male. If this be the case, YPM 1901 and BYU 9047 represent males, whereas the present specimen and YPM 1905 are females.

Pathologies (CAM)

Bone responds to stress in such a way that its shape is altered by mechanical forces from muscle disease processes or developmental abnormalities. This is known as Wolff's Law. *Camarasaurus* GMNH 101 exhibits three interesting types of bone pathologies involving a total of thirteen caudals and one chevron. One type of bone pathology is developmental, the second is degenerative, and the third is a physiological phenomenon.

Developmental pathologies:

Developmental pathologies are found in caudals 40 and 43 in the form of dysraphic anomalies, defects caused by a failure to fuse (Figure 57). The specific form manifest in these caudals appears to be spina bifida occulta. Described here for the first time as having ocurred in dinosaurs (Darren Tanke, Tyrrell Museum, personal communication), these are defects of the dorsovertebral arch in which the neural arch fails to close or develop properly. It is possible that the defect could also be the form of spina bifida known as spina bifida meningocele, but this is difficult to diagnose because no remains of the spinal cord have been preserved to see if the spinal cord actually left the neural groove.

Caudal 39 likely had spina bifida occulta, but the preservation of the bone makes it impossible to make a positive determination.

Caudal 40 has a neural groove that failed to close completely, which left the spinal cord vulnerable. It is likely that this caudal exhibits spina bifida occulta because the neural arch, though not closed, is formed well enough to hold and protect the spinal cord.

Caudal 43 is even more interesting because half of the neural arch failed to form. The half that did form shows no evidence of the neural groove. It consists of a single post of bone arising off the centrum and a long thin caudal spine that exhibits no evidence of either pre-or postzygapophyses. This developmental pathology would not have given any protection to the spinal cord. It would have allowed the soft tissues of the spinal cord to protrude as a fluid-filled sac, making a case for spina bifida meningocele, a more serious form of spina bifida but one which would have allowed the animal to live. The centrum of this caudal also exhibits osseous growth, which, speculatively, could be the result of a posttraumatic event. This error of morphogenesis occurred in the earliest stages of the animal's development. Forms of spina bifida any more severe than seen in GMNH 101 would not have allowed the animal to live any longer than a few days due to the high potential for infection. In humans and other animals, spina bifida occurs in females twice as frequently as in males.

Degenerative pathologies: (Figure 58)

The pathology that is seen in caudals 32, 33, 43, 46, 47, and possibly 50−53 appear to exhibit a condition known as osteoarthritis, also referred to as "degenerative joint disease" or "wear and tear" arthritis. This progressive degradation of articular cartilage led to joint narrowing, subchondral bone thickening, and eventually a nonfunctioning joint. Although it is not primarily an inflammatory process, a mild inflammatory reaction may have occurred within the synovium. The pathology can be seen as excessive bone growth around the edges of the articular faces of the centra. In more extreme manifestations, the centra may fuse, forming a large bone cyst around the joint covering much of vertebrae. Trauma and changes resulting from excessive function were probably the primary cause for these osteoarthritic pathologies.

Caudals 32 and 33 exhibit osteoarthritis primarily between the shared articular face of their centrums. Much of the surface area of the faces of the centrum has been completely reabsorbed. Osseous growth around the outer margins of the damaged joint is also evident. The prezygapophyses of caudal 32 and the postzygapophyses of caudal 33 have been almost completely reabsorbed. Well-developed nutrient foraminae formed on the anterior ventral surface of the centrum, which aided the development of the pathology. These foraminae are clearly seen on caudal 33. This pathology is likely the result of a post traumatic event because of the zygapophyseal joint damage and the intervertebral disk damage.

Caudal 43 shows both spina bifida (discussed above) and an osseous growth (Figure 57). The osseous growth is seen as excessive bone growth around the outer margins of the centrum on both the anterior and posterior faces. The anterior face of the centrum shows the greatest deformity. Caudals 46 and 47 are fused together, showing only a little exterior secondary growth. Caudal 46 is complete, with the anterior third of caudal 47 fused to its centrum. The anterior

middle of caudal 47 was not preserved and had to be restored with the posterior half.

Caudals 49 through 53 are fused as a single rod of bent bone showing almost no exterior osseous growth. Caudal 53 was found separated from caudals 49 through 52, and the articular end of caudal 53 was damaged sufficiently enough from collection to make it difficult to tell for certain whether it was indeed fused. Caudal 53 was restored as if it were originally fused.

Physiological pathologies: (Figure 59)

The physiological phenomenon seen in caudals 25 and 26 can be attributed to diffuse idiopathic skeletal hyperostosis (DISH). It is manifested as a vertebral bridging, which is a fusion of vertebrae by an osseous overgrowth transgressing the intervertebral disk space external to the site of attachment of the annulus fibrosus or disk. The cause for this type of osseous growth has been attributed to a physiological stabilizing mechanism that may have aided in keeping the tail elevated (Rothschild and Berman 1991).

Caudals 25 and 26 exhibit the most extreme osseous growth seen in GMNH 101. The two vertebrae are fused by a very large cyst on the ventral half of their centra. It is evident looking at the dorsal half of the centra that the intervertebral disk was not reabsorbed and the vertebra did not fuse at ends of the centrums, making a good case for diffuse idiopathic skeletal hyperostosis (DISH). The cyst also incorporated their shared chevron and rendered this joint useless.

It is believed by some paleontologists that the large sauropods used their tails as defensive weapons by swinging them with great force at their attackers. It is entirely possible that such a blow could produce the kind of traumatic injury required to degrade the joints and facilitate these different osseous growths.

It is also possible that some of the osseous growths seen in this very old individual are simply the result of wear and tear due to normal use over a long period of time. In any event, as more and more of these pathologies are discovered in the future, a pattern may emerge that will give us clues as to the actual cause of these deformities.

Chevrons (Figure 60)

A total of eighteen chevrons and a fragment of a 19th were recovered, most of them disarticulated. However, as can be deduced from the quarry map, seventeen of these probably belonged to the first twenty-two caudals. When these are arranged in serial order by size and known positions (between caudals 9 and 10 and between caudals 11 and 12), the other fifteen chevrons can be placed quite accurately with a possible error of one or, at most, two slots (see Table G). The position of chevron 18 is somewhat less certain since, judging from the tail of *Camarasaurus lentus* CM 11338, the first thirty-two caudals bore chevrons. This chevron, which was carried further downstream with a jumble of twenty-three posterior caudals, does not vary greatly in size from 17 and so likely belongs somewhere near caudal 22.

TABLE G—MEASUREMENTS OF CHEVRONS

(all measurements in millimeters)

ELEMENT	LENGTH	MAXIMUM WIDTH OF ARTICULAR END
Chevron 2	–	97
Chevron 3	–	90
Chevron 4	360	90
Chevron 5	318	94
Chevron 6	–	100
Chevron 7	296	85
Chevron 8	236	85
Chevron 9	210	73
Chevron 10	190	75
Chevron 11	167	75
Chevron 12	151	80
Chevron 13	134	84
Chevron 14	125	65
Chevron 15	99	83
Chevron 16	83	72
Chevron 17	98	68
Chevron 18	63	55

The chevrons are typical of those of other specimens of *Camarasaurus* in that the first groups are relatively straight rods of bone bowed slightly anteriorly. This curvature increases beyond caudal 10 as they decrease progressively in length so that by no. 25 they are quite short and broadened from front to rear, suggesting a trend toward forked chevrons of the diplodocids. However, they become very small and disappear before reaching this elongated condition to any great extent. The important taxonomic features of these chevrons are (1) although a very old individual, the hemal canal is not bridged over dorsally in contrast with those of *C. lewisi,* where they are bridged over as in the diplodocids; and (2) the two articular heads which articulate with the caudal centra are "normal" in that they face upward to articulate nearly equally with both the centrum in front and that behind. This again contrasts with those of *C. lewisi,* where the front half of the articular head fits into an enlarged chevron facet on the rear of the caudal centrum.

Pectoral Girdle

Of the pectoral elements, only the right scapula (Photos 16–17) and left coracoid (Figure 61) were

recovered, the coracoid being the most complete. In addition, the right sternal plate was also recovered (Photo 18).

The right scapula, being close to the surface of the ground with the medial surface exposed, has been eroded, with a loss of a third of the anterior plate and the posterior edge of the blade. The broad, forwardly and downwardly directed proximal plate is damaged, with a loss of the entire coracoid articulation and glenoid surface. The thin, upper distal end has suffered far less damage; only a portion of the very thin face on the anterior margin is incomplete. The scapula has been crushed and severely fractured. Restoration of the scapula was done to resemble other known *Camarasaurus* scapulae in that the anterior plate is very developed, with the posterior end of the blade splayed and slightly concave medially. By comparison with the scapula of *Camarasaurus grandis* YPM 1901, the present specimen differs in its more slender blade and apparent less-pronounced distal flare. This is in keeping with the relatively more slender limb bones of this specimen (see Table H). In spite of being near the surface and therefore discolored, the left coracoid is nearly complete with a very well defined coracoid foramen and glenoid process. The bone is well preserved except for a small portion of the anteroventral region where it is thinnest. The coracoid is gently convex laterally and concave medially. It is thickest near the glenoid cavity where the dorsal surface articulated with the scapula. The coracoid is not fused to the scapula, and the surface where it met that bone becomes thinner as it proceeds forward, rising a bit from a straight line just above the coracoid foramen that is closed above. The oval-shaped left coracoid exhibits no significant differences from that of *C. grandis* (Ostrom and McIntosh 1966, plate 46).

An incomplete right sternal plate was found nestled on top of the posterior end of the right scapula. At first sight it was supposed that it was the posterior edge of the scapula blade. After being prepared, then compared with the Carnegie Museum specimen's ster-

TABLE H

MEASUREMENTS OF PECTORAL GIRDLE

(all measurements in millimeters)

ELEMENT	GMNH 101
RIGHT SCAPULA—LENGTH	—
Breadth, proximal	—
Breadth of shaft	190
Breadth, distal end	—
LEFT CORACOID—LENGTH	445
Breadth, greatest	590
Margin of glenoid	205

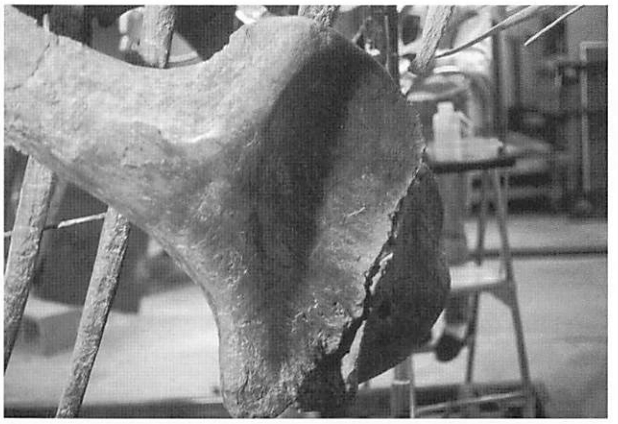


Photo 16. The right scapula attached to the skeleton.

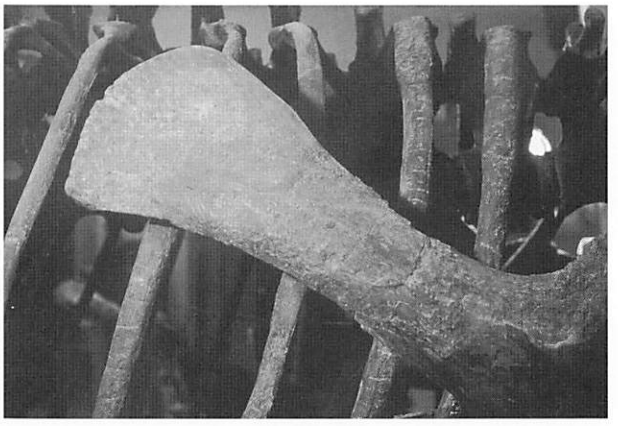


Photo 17. The posterior of the right scapula attached to the skeleton. The posterior fourth of the scapula is restored.

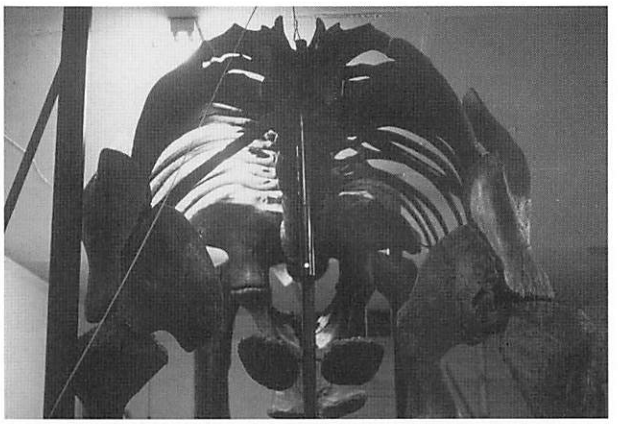


Photo 18. A front view of the main body of the Camarasaurus. *The steel assembly on the left is one of the frames for lifting the body up to the correct height. The sternal plates can be seen in the bottom center of the photo.*

nal plate, it was determined to be the right sternal plate. The lack of articulation of any of the pectoral girdle prevents any new light being shed on the scapula in relation to placement along the thorax.

Forelimb

The parts of the forelimb preserved include the left humerus and distal end of the right, the incomplete left ulna, left "radiale," left metacarpals 1, 2, and the proximal end of 3, as well as a partial claw and two other phalanges. The right humerus with crushed distal end was found near the surface with its eroded edge lying on top of the right scapula. The left humerus (Figure 62), found near the right, is a relatively long slender bone expanded at both ends, more so at the proximal than the distal. Viewed from the front, the lateral margin is fairly straight, expanding slightly outward at both ends. Beginning at the pointed radial condyle, the medial margin proceeds upward along a slightly inclined straight line, causing the shaft to contract in breadth. At midlength the medial margin is concave so that the transverse breadth of the humerus is expanded to a greater breadth than at the distal end. The damaged deltopectoral crest arises at midlength as an outwardly projecting vertical ridge set at a right angle to the anterior face of the bone along its lateral margin. It proceeds upward to the proximal end of the humerus. The result is a concave anterior face in the upper half of the bone. The head of the humerus has a prominent raised knob on the inner third of the medial face at the proximal end. Although part of the deltoid crest was gone, it appears to be well formed down to the center of the shaft. The deltoid crest on the proximolateral edge has very well defined carnosaur tooth marks extending antero-posterior (Figure 62). These marks covering a 15 cm area are approximately .8 cm apart, .3 cm long, and 4.5 cm deep, covering a 15-cm area. Several sites have been identified on this *Camarasaurus* that have similar teeth marks.

The head of the humerus is very rugose. The olecranon fossa is well developed, as would be expected in a mature adult. Two parallel, slightly raised projections near the middle of the lower end of the anterior face mark condyles for the radius and ulna.

The humerus of GMNH 101 is in close accord to that of *C. lewisi* BYU 9047. That of *C. grandis* YPM 1901 has a broader proximal end (see Tables I, J). As can be seen from the enclosed table of measurements, the humero-femoral length ratio is as great or greater than that of any other North American camarasaurs. Although less slender than that of *Brachiosaurus,* the humerus is comparable to that of *Diplodocus* and *Barosaurus,* but much more slender than that of *Apatosaurus.* Similarly the overall relative length of the fore to the hind limb lies between the very long foreleg of *Brachiosaurus* and the short foreleg of the diplodocids.

TABLE I—MEASUREMENTS OF LIMBS

(all measurements in millimeters)

ELEMENT	GMNH 101
RIGHT FEMUR	
Length	1485
Breadth, proximal	405
Breadth, shaft	228
Breadth, distal	400
Least circumference	630
RIGHT TIBIA	
Length	930
Breadth, proximal	340
Breadth, shaft	123
Breadth, distal	270
Least circumference	430
RIGHT FIBULA	
Length	1008
Breadth, proximal	170
Breadth, shaft	100
Breadth, distal	170
Least circumference	158
LEFT HUMERUS	
Length	1130
Breadth, proximal	385
Breadth, shaft	170
Breadth, distal	297
Least circumference	472
LEFT ULNA	
Least breadth	80
Least circumference	270

The bones of the forelimb in the GMNH 101 skeleton are represented only by the left ulna (Figure 63), which lacks both its proximal and its distal end. The preserved portion of the bone resembles that of *C. grandis* YPM 1901 (Ostrom and McIntosh 1966, plate 53). Because of its preservation little can be said about this ulna except for a few general observations. The distal portions of the shaft are round, but proximally it broadens transversely and becomes concave anteriorly for the upper end of the radius.

The forefoot of *Camarasaurus* (Photo 19) is known from a number of specimens. It was first correctly described and figured by Osborn (1904a) based on a right manus of AMNH 823 (erroneously labeled AMNH 965). The carpus of that specimen was compared to two blocklike elements, the larger one fitting closely to the tops of metacarpals I, II, and III, and the smaller one resting on metacarpals IV

and V. The phalangeal formula of this foot is 2-1-1-1-1, with the first digit ending in a large claw. In at least one instance, USNM 13786, a small rudimentary second phalanx was found articulated to phalanx V-1. In *Apatosaurus louisae* (CM 3018), phalanx II-1 exhibits a groove on its distal surface into which a similar rudimentary spherical phalanx was found producing a phalangeal formula of 2-2-1-1-1. A very similar phalanx was found disarticulated with the manus of *Camarasaurus lentus* YPM 1910. Whether this is II-2 or possibly V-2 is not known. Thus the complete phalangeal formula in *Camarasaurus* is either 2-2-1-1-1 or 2-1-1-1-2, or possibly the existence of these rudimentary phalanges may be variable. Otherwise Osborn's illustration of the manus is correct except that the metacarpals there figured probably spread out a bit too much distally. Footprints show that the metacarpals were oriented almost vertically, producing a digitigrade manus.

Controversy also surrounds the correct determination of the two carpal bones. Most authors term the larger medial element the "radiale" and the smaller lateral one the "ulnare." Osborn (1904a) claimed the larger one was a combination of C-1+C-2+C-3 of the second row, whereas the smaller one was the combined C-4+C-5. It is now clear from the almost



Photo 19. A completed left front foot showing the articulation of the elements.

mammal-like close articulation of the carpals with the metacarpals that Osborn was correct.

The "radiale" (Figure 64) is somewhat thick, slightly oblong, and flattened dorsally and ventrally. The proximal diameter is less than that of the distal

TABLE J- COMPARATIVE MEASUREMENTS OF LIMBS

(all measurements in millimeters)

COMPARATIVE MEASUREMENTS OF HUMERI

MEASUREMENTS	*C. grandis* GMNH 101	% OF LENGTH	*C. sp.* AMNH 823	% OF LENGTH	*C. lewisi* BYU 9047	% OF LENGTH	*C. grandis* YPM 1901	% OF LENGTH	*C. lentus* YPM 1910	% OF LENGTH	*C. lentus* CM 11338	% OF LENGTH
Length	1130	100	768	100	1018	100	890	100	545	100	435	100
Breadth, proximal	385	34	287	37	369	36	380	43	250	46	210	48
Breadth, shaft	170	15	128	17	149	15	144	16	95	17		
Breadth, distal	297	26	260	34	281	28	274	31	199	37	160	37
Least circumference	472	42	346	45	450	44	394	44	270	50		

COMPARATIVE MESUREMENTS OF FEMORA

MEASUREMENTS	*C. grandis* GMNH 101	% OF LENGTH	*C. grandis* YPM 1901	% OF LENGTH	*C. lentus* YPM 1910	% OF LENGTH	*C. lentus* CM 11338	% OF LENGTH	*C. lentus* DINO 4514	% OF LENGTH
Length	1485	100	1180	100	750	100	570	100	1470	100
Breadth, proximal	405	27	390	33	246	33	215	38	482	33
Breadth, shaft	228	15	210	18	133	18	100	18	252	16
Breadth, distal	400	27	382	32	229	31	175	31	440	30
Least circumference	630	42	514	44	356	47	269	47	710	48

RATIO: HUMERO-FEMORAL LENGTH

MEASUREMENTS	*C. grandis* GMNH 101	*C. grandis* YPM 1901	*C. lentus* YPM 1910	*C. lentus* CM 11338
Length of Humerus	1130	890	545	435
Length of Femur	1485	1180	750	570
Humerus length / Femur length	0.76	0.75	0.7	0.7

diameter. The proximal face slopes from the medial edge down to the lateral edge, which is considerably thinner and more curved than the medial edge. The medial edge has two somewhat flattened faces that line up flush with the medial side of metacarpal I so as to articulate tightly with the tops of metacarpals I, II, and part of III (see McIntosh, Miller, Stadtman, and Gillette 1996).

The proximal ends of each of the metacarpals are very rugose with deeper grooves anteriorly (Figure 65). The proximal ends of both metacarpals 2 and 3 are triangular in dorsal view. Metacarpal 1 has a nearly triangular proximal end with a broad, flat lateral surface below the proximal end that articulates with the upper portion of the medial face of metacarpal II. The distal end has very defined condyles and is somewhat rugose. Metacarpal II is the longest and most slender of the three, having a flat surface, laterally and medially for contact with metacarpals I and III. Metacarpal II has a lateral surface with the posterior edge broadening laterally at the proximal end for articulation with Metacarpal III. The distal end is rugose and expanded transversely, more than metacarpal I. Metacarpal III has a large, slightly concave lateral surface with the upper anterior edge broadening laterally. The anterior face of metacarpal III is broadened and has an almost flat surface. Only the proximal half of this metacarpal was found.

TABLE K
MEASUREMENTS OF PELVIC GIRDLE
(all measurements in millimeters)

ELEMENT	GMNH 101
RIGHT ILIUM	
Length of right pubic articulation to ischia, articulation	430
Height from acetabular crest to dorsal margin	320
Height of crest to pubic articulation	580
LEFT PUBIS	
Left pubis articular surface for ilium to distal extremity	780
Left pubis breadth of distal extremity	390
RIGHT PUBIS	
Right pubis articular surface for ilium to distal extremity	820
Right pubis breadth of distal extremity	355
LEFT ISCHIUM	
Left ischium articular surface for ilium to distal extremity	875
Left ischium articular surface for pubis to distal extremity	950
Left ischium length of pubic articulation	360
Left ischium breadth of distal extremity	142
RIGHT ISCHIUM	
Right ischium articular surface for ilium to distal extremity	880
Right ischium articular surface for pubis to distal extremity	990
Right ischium length of pubic articulation	330
Right ishium breadth of distal extremity	145

The phalanges that were found were scattered with the rest of the metacarpals. They were intact with minimal fracturing and no crushing (Figure 66). Comparisons with YPM 1910 and Osborn's (1904a) discussion on the manus of AMNH 823 led to the placement of the phalanges as listed. Phalanx II-1 is easily identified by its rather knobby anterior protrusions, the larger one sweeping to the median. The lateral face is convex. A definite concave curve between the two protrusions provides a site for possible articulation with a "button" between the two knobs. The proximal articular surface is slightly concave with a thin lip around the distal edge. A ridge on the distal end of Metacarpal II appears to align laterally with the articular edge of phalanx II-1. Phalanx III-1 is smaller than II-1 and has a boxy appearance. It is more robust medially, tapering laterally to a slight edge. The proximal articular surface is convex. Both dorsal and ventral sides are rather flat, with the anterior end being slightly rugose. The manus ungual I-2 is more elongated and less curved than those of the hind foot. In this specimen the distal end is very rough and perhaps not complete.

Pelvic Girdle

Of the six pelvic elements (Figure 67), the left ilium is missing in GMNH 101 and the other five bones have suffered some damage. They exhibit no significant differences from those of *C. supremus* (Osborn and Mook 1921), where detailed descriptions are given of the individual bones. The right ilium was found with the dorsal edge of the blade directed downward and the ventral surface of the blade exposed. It was somewhat weathered and had moderate fracturing with only the blade preserved. The right ilium lacks the portion behind the ischiadic peduncle and all of the pubic peduncle.

The ilium is a plate oriented in a vertical position. On its medial side are ridges for articulation with the five sacral ribs. In front of these the plate is bent gently outward, forming the typical expanded anterior lobe of sauropod ilia. The pubic peduncle would have been directed downward on the ventral margin a bit forward of the midpoint of the plate. It would have been much longer than the ischiadic peduncle. The preacetabular blade is moderately thick, but behind it the plate becomes very thin, and, although often damaged in other specimens, it is well preserved here (see Table K). The ilium resembles that of *Apatosaurus*, but the preacetabular blade is more expanded vertically. Clearly defined carnosaur tooth marks can be seen along the posterior ridge.

The right pubis (Figure 68) was found lying on top of the right femur. Although slightly crushed and fractured, it is nearly complete, missing only a portion

of the posterior edge. The left pubis (Figure 68) was found lying on a section of the caudal series, crushed and fractured along the ilium articular edge. The distal ends of each pubis are very rugose and slightly expanded. The shafts are quite broad, sweeping concavely toward the ischial articulation, and are relatively shorter than in the diplodocids, whose broad shaft narrows less above the distal end. The ambiens process, so prominent in *Diplodocus* and *Barosaurus,* is not developed. Both pubes are damaged at the proximal ends that connect with the ilia. The nature of the preservation suggests that the missing portion may be attributed to scavenging. There are suggestions of tooth marks, though the marks are not as well defined as on other elements. The remainder of the bones are fairly well preserved and uncrushed.

The left ischium (Figure 69) was found under the proximal end of the left pubis and on top of the anterior caudal series; it is complete although fractured. The right ischium (Figure 69) was found perpendicular to the distal end of the left ischium, lying parallel to the right femur. It is considerably fractured and is missing its pubic articulation. The shafts of each are nearly straight, showing some dorsal arching with only a slight expansion at the distal ends. From the shaft the ischia broaden to articulate with the ilium. There is a wide margin of articulation with the pubes. They are heavily rugose on all margins. The two shafts meet distally edge-to-edge rather than side-to-side as in *Apatosaurus* and were not found coossified. The distal ends are not expanded at all in contrast to *Apatosaurus* and to a lesser degree *Diplodocus* and *Barosaurus.*

Hind Limb (Photo 20)

The hind limb is represented by all three leg bones and a nearly complete pes of the right side, all in a superb state of preservation. In addition there is the head of the left femur and a few bones of the left pes. The left femur head, badly crushed and eroded, was found next to the left coracoid and on top of the right ribs. The well-preserved right femur was found lying under the right pubis (Figure 70). Again, carnosaur tooth marks can be seen. The parallel grooved patterns appear to match those found elsewhere on this specimen; however, the femur has more sites than any other bone. Six distinct areas on the distal end can be identified where bites occurred.

The robust femur has a straight shaft and expanded ends. In cross section the shaft is elliptical. The lateral margin expands a bit outward at the distal end, then continues uniformly upward with a slight bulge outward just before reaching the greater trochanter at the upper end. The median margin has greater curvature, constricting more inward at the distal end, curving upward and more abruptly inward at the head. The transverse breadth of the proximal end exceeds the antero-posterior dimension. The prominent, rounded head rises well above the greater trochanter.



Photo 20. The right hind lower leg mounted on the skeleton. All of the elements are original bone.

As in all sauropods, viewed from above, there is no notch between the head and greater trochanter. As in all but the earliest sauropods, the lesser trochanter has completely vanished. A well-developed vertically directed narrow ridge, located on the posterior face nearly at the medial edge, represents the prominent fourth trochanter. The lower end appears at midshaft and continues upward to about 2/3 the length of the bone. Well-developed tibial and somewhat smaller fibular condyles are present on the distal end of the posterior face. The tibial condyle is located just inside the medial margin, whereas the fibular condyle is medial of the lateral margin. The anterior intercondylar groove is very prominent.

The *Camarasaurus* femur is much more robust (see Table I) than that of *Diplodocus* but narrower transversely and broader sagittally than that of *Brachiosaurus,* where, in addition, the bulge on the upper part of the lateral margin is much more pronounced. The closest resemblance is to that of *Apatosaurus,* but in that animal the head rises only slightly above the greater trochanter. In addition, the upper end of the greater trochanter, instead of showing a bulge, has a gentle outward sweep to give the whole bone a hint of the sigmoid curve of the prosauropod femur. Notable to the GMNH 101 femur is its overall slenderness compared to any other known femur of this genus (see Table J).

The right tibia (Figure 71) was washed down-stream from the skeleton and was deposited with the fibula and several associated foot elements. The tibia is well preserved with minimal crushing and fracturing. It is quite massive, being over half the length of the femur with a .64 ratio. The shaft, straight and robust, expands at both ends transversely with greater expansion at the proximal end. The expansion of the distal end is due largely to the outward curving of the lateral margin of the bone. It too resembles that of *Apatosaurus* but is relatively more robust and possesses a noticeably smaller cnemial crest that arises on the upper part of the lateral margin on the anterior face of the bone. The distal end is very rugose and contoured, matching the contouring of the astragalus. As in all sauropod tibiae, the median half of the posterior face of the distal end is marked by a short vertical column that fits into the dorsal surface of the astragalus, locking it in place. Viewed from the front the distal edge of the tibia is nearly straight.

The fibula (Figure 72) was found next to the tibia. The distal ends of the fibula and tibia were in close proximity, and the astragalus was found next to the distal ends. The straight, slender fibula is a bit longer than the tibia. It is expanded anteroposteriorly at both proximal and distal ends. The shaft at the proximal end does not fit into the groove provided by the cnemial crest and shaft of the tibia as seen in many dinosaur restorations but takes a more lateral position. The distal end is somewhat expanded transversely, with its pointed, inwardly directed projection fitting loosely into the broad concavity on the lateral face of the astragalus. Covering the upper end of the medial surface are triangular muscle scars with the apex of the triangle at the proximal end. The scarring extends down to a slight anterolateral bulge. The bulge that is present at the lower tip of this scar resembles that in *C. grandis* YPM 1905, but is less pronounced than in *C. lentus* YPM 1910. A prominent bulge two-thirds of the way up on the lateral surface marks the attachment for the flexor digitorum longus (Borsuk-Bialynicka 1977, p. 40).

Of the tarsus, only the well-preserved right astragalus remains, although unlike the diplodocids *(Diplodocus, Barosaurus, Apatosaurus),* where there is no ossified calcaneum, this rugose spheroidal element has been found in several other specimens of *Camarasaurus,* namely in *C. lentus* YPM 1910 and CM 11338 and a camarasaur on the cliff face at Dinosaur National Monument, DINO 4109. Madsen (oral communication) reports calcanea from the Cleveland-Lloyd Dinosaur Quarry and another unnamed locality in the San Rafael Swell.

The astragalus (Figure 73) matches completely that of *C. grandis* YPM 1905 (Ostrom and McIntosh 1966, pl. 78). It was found directly below the distal ends of the tibia and fibula, is well preserved, and has no fracturing. It is rugose on almost all surfaces, having a quadrilateral shape on the lower surface. Viewed from the front or back its shape is triangular, with (1) the horizontal leg lying just below the distal margin of the tibia, (2) the short lateral edge proceeding downward from it, and (3) the diagonally directed lower margin of the astragalus slanting upward from the bottom of the lateral apex to the inner margin of the horizontal leg. The distal face itself is convex and does not in any way fit onto the top of the metatarsal, as the carpals do in the forelimb. Thus the joint is very loose.

Despite the commonness of *Camarasaurus,* a complete pes has yet to be described and the phalangeal formula has not yet been determined. In describing the articulated skeleton of *C. lentus* CM 11338, Gilmore (1925) stated that "The hind foot of the left side is the more perfectly preserved. The five metatarsals are articulated and the phalanges of the first three digits are all preserved, but slightly disturbed. It shows that the first three toes of the pes bore terminal claws, with a phalangeal formula of 2, 3, and 4. The other phalanges are missing, while the right foot shows a proximal phalanx on digit IV." He also wrote, "A small rounded ossification attached by matrix to the outer end of the left astragalus may represent either the calcaneum or a tarsal of the distal row." In a partially articulated pes, BYU 9482, Jensen (1988) claims to have found a very small rudimentary claw of digit IV, which was unfortunately lost during collection. In the as-yet-undescribed articulated skeleton of *C. lentus* USNM 13786, the articulated pedes are mounted as found with no phalanges restored. The more nearly complete right pes contains the astragalus; metatarsals I to V and a phalangeal formula of 2-3-3-2-1, with claws on digits I to III; no rudimentary claw on digit IV; and a "button" on digit V. No phalanx was found between III-2 and the claw. In the apparently complete articulated pes of *Apatosaurus* CM 89, the phalangeal formula is 2-3-4-2-1 with the same tiny phalanx on digit V.

In GMNH 101 (Figures 74−81) 26 foot bones were found totally disarticulated with many of them widely scattered throughout the quarry, but some clustered in the general vicinity of the right tibia and fibula, which had been carried far downstream from their original position (see map). In addition to the left "radiale" and right astragalus, there are nine metapodials, four claws, and eleven phalanges. The metapodials include the three left metacarpals already mentioned as well

as the complete right metatarsus and left metatarsal IV. The unguals include left II-1 of the manus and those of digits I, II, III of the right pes. Two pair of proximal phalanges are identified as I-1, II-1 from both pedes. Two more proximal phalanges represent right III-1 and right IV-1, whereas the remaining two belong to the manus. The three intermediate phalanges are identified as right II-2, right III-2, and left II-2.

Unlike the manus, the pes was semiplantigrade with the proximal ends of the five metatarsals arranged in a semicircular pattern. The bones are directed downward and forward, their distal ends diverging from one another much more than do the metacarpals. They accord completely with those of *C. grandis* (Ostrom and McIntosh, 1966, pls. 81 to 85). Footprints confirm that a fleshy pad was present in the heel similar to that observed in elephants. For purposes of description, metatarsals I to IV may be roughly compared to prisms with rectangular ends so that six faces are recognized. In addition to the proximal and distal faces, there are the anterodorsal, lateral, posteroventral, and medial faces. Metatarsal I is the shortest, no. II longer, no. III the longest, no. IV shorter, and no. V shorter still. This contrasts with the diplodocids, where the metatarsals increase in length from no. I to no. IV, and although V is shorter than IV, it is still much longer in comparison with *Camarasaurus*.

The first metatarsal (I) is the most robust, with the proximal end sloping up to meet the astragalus and articulate with metatarsal II. The lateral length is greater than the medial length. The distinct articular surface curves posteriorly with some lobing on the posterior edge.

Metatarsal II is eroded on the anterior face and fractured slightly. The proximal end slopes up laterally and flares distally for articulation with metatarsal III. The shaft flares wider at the distal end. The articular surface for the proximal phalanx is more anterior. The third metatarsal is the longest of the five, with a long slender shaft that is expanded transversely on both ends (see Table L). The anteroproximal face is concave across the front medial edge. There is a broad flat surface laterally for articulation with metatarsal IV. The distal end flares more medially than laterally. Metatarsal IV is shorter than III and swells transversely at both ends. The proximal end is subtriangular in shape. The distal end is more

TABLE L—MEASUREMENTS OF FOOT BONES

(all measurements in millimeters)

ELEMENT	RIGHT			LEFT		
	Length	BREADTH MEASUREMENTS		BREADTH MEASUREMENTS		
		Proximal	Distal	Length	Proximal	Distal
MANUS						
RADIALE	–	–	–	8	–	–
DIGIT I: Metacarpal	–	–	–	280	148	87
DIGIT II: Metacarpal	–	–	–	324	96	94
DIGIT III: Metacarpal	–	–	–	–	92	–
PES						
ASTRAGULAS	148	268	135	–	–	–
DIGIT I: Metatarsal	172	106	122	–	–	–
DIGIT I: Phalanx	52	92	63	–	95	65
DIGIT I: Phalanx	174	65	15	–	–	–
DIGIT II: Metatarsal	193	78	102	–	–	–
DIGIT II: Phalanx	53	88	85	–	82	82
DIGIT II: Phalanx	–	67	60	–	62	58
DIGIT II: Phalanx	135	52	14	–	–	–
DIGIT III: Metatarsal	223	80	87	–	–	–
DIGIT III: Phalanx	42	77	74	–	–	–
DIGIT III: Phalanx	*22	58	50	–	–	–
DIGIT III: Phalanx	97	41	14	–	–	–
DIGIT IV: Metatarsal	204	81	85	208	84	85
DIGIT IV: Phalanx	33	77	57	–	–	–
DIGIT V: Metatarsal	166	66	51	–	–	–

*RESTORED



Photo 21. Initial inspection of a newly opened block by Ron Mjos (left) and Clark Miles (right). Often newly opened blocks revealed bones that were not seen in the field, which was always welcome and added to the completeness of the skeleton.

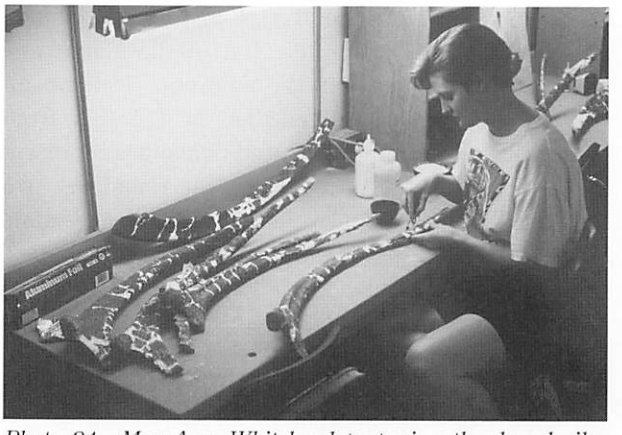


Photo 24. MaryAnn Whitehead preparing the dorsal ribs. Ribs are very fragile. Their long thin length naturally creates greater risk of breakage, so extra care must be taken during preparation.



Photo 22. The right femur jacket, opened and under preparation in the lab. Note the number of fragments. After each section was prepared, they were assembled, completing the femur. The bone to the right of the femur is the left humerus awaiting preparation.

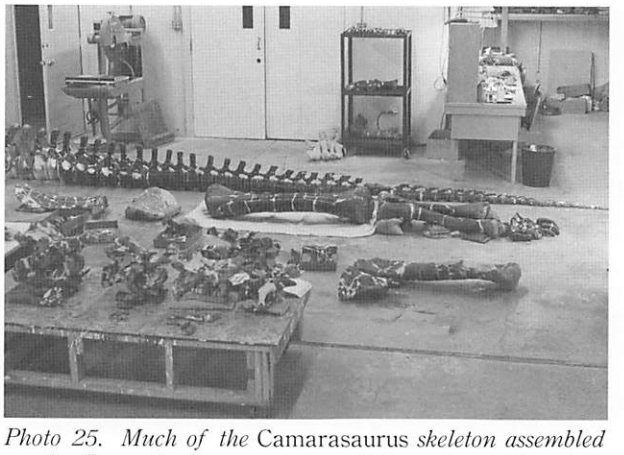


Photo 25. Much of the Camarasaurus *skeleton assembled on the floor. Laying out prepared elements aided in both the study and considerations relating to the mounting of the skeleton.*

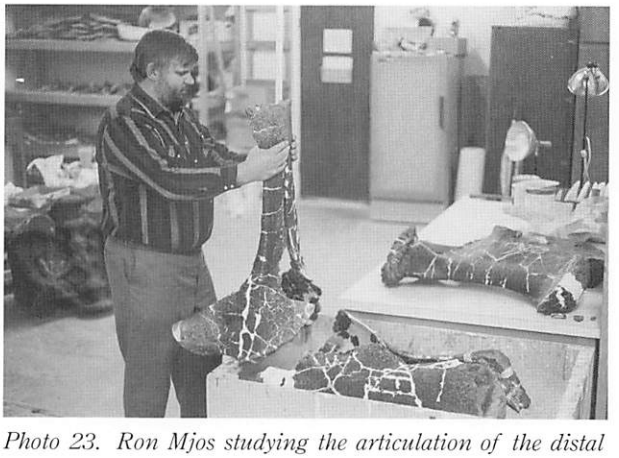


Photo 23. Ron Mjos studying the articulation of the distal ends of the ischia while considering the positions of the ischia to the pubes.

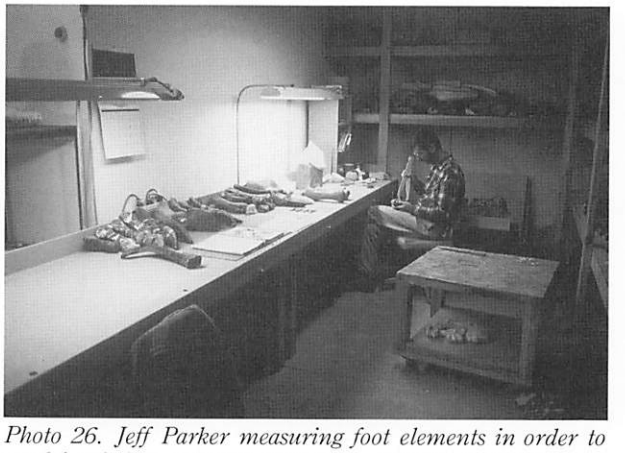


Photo 26. Jeff Parker measuring foot elements in order to model missing, opposite elements. Careful measurements are taken to make sure the models are accurate in every dimension.

rectangular and has only slight protrusions on the posterior distal edge.

Metatarsal V is the most distinctive of all the metatarsals. Its fan-shaped proximal end narrows down to a short shaft that then swells slightly to the convex distal end. The medial surface is nearly flat with the lateral face more convex. This metatarsal articulates to number IV with its greatest span extending anteroposteriorly. It is distally rugose, and there is a small protrusion on the anterior near the ventral margin.

Phalanx I-1 is long medially, with small protrusions dorsally. The distal articular surface slopes down and back posteriorly for articulation with the ungual. The ventral side is rugose. Phalanx II-1 is very broad, more so than I-1. It has a broad, long medial surface and is rounded across the anterior surface to the lateral side. There are small protrusions on the distal ventral edge with some rugosity on the ventral side. Distal phalanx II-2 is small and oblong with a narrow edge medially, expanding laterally to a fairly flat lateral face. A small rugose distal lip curls ventrally back toward the proximal phalanx. Phalanx III-1 is similar in size to phalanx I-1 but has a less-defined proximal edge and is more lobed on the distal end. The medial edge is flat with the dorsal face sloping laterally.

The III-2 phalanx is small and oval and has a thin edge medially, is concave distally, and has a wide flat surface laterally. The distal edge sweeps back to articulate with phalanx III-1. The ventral side is rugose. The distal end is also slightly concave for articulation with a small ungual. Phalanx IV-1 is the smallest of the proximal phalanges with the proximal edge convex and a flat medial face. The dorsal side is rounded, sloping to the lateral side.

The first ungual is very large and robust, having a wider margin of articulation than the distal surface of the phalanx. It is rugose on the proximal face as well as on the ventral posterior surface. The lateral surface of the ungual is more convex than the medial surface. A groove runs the length of the ungual on the lateral face. A small groove closer to the ventral face runs on the medial face. Ungual II is smaller than I, being shorter and not as robust. It is also convex laterally and has a groove on the lateral side.

Ungual III is the smallest of the three, being only half the size of ungual II. It has the same rugosity on the proximal end, and the lateral groove runs the length of the ungual.

All nutrient foramina on the phalanges are ventral. The rugosity and the foramen are very distinctive features on the ventral side of each phalanx. The

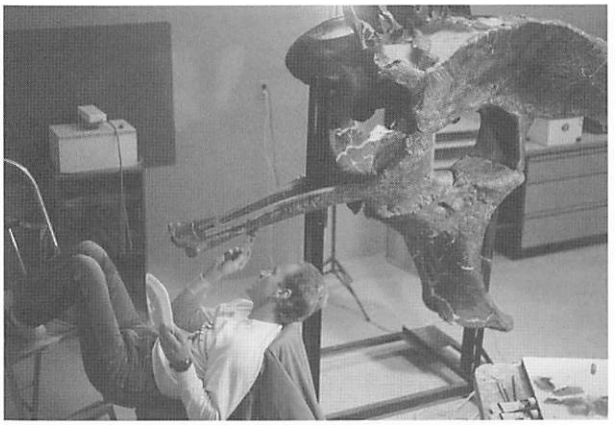


Photo 27. Brian Versey performing color restoration on the ischia. Color restoration gave the skeleton a complete homogeneous look, making it more attractive to view.



Photo 28. Karen Cloward and Delanie Webb hardening the completed teeth and skull elements. Teeth are some of the most fragile fossils to prepare.

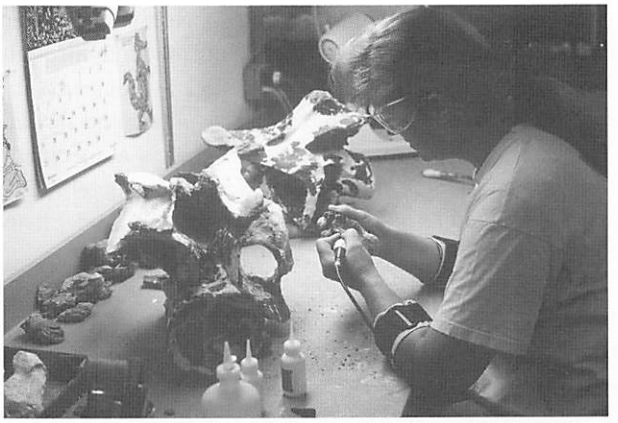


Photo 29. Karen Cloward preparing the cervicals. These bones were particularly difficult because of their very fragmented condition.

distal end of the metatarsals is rugose, and the unguals are distally rugose. Accordingly, the phalanges that are between the two are distally rugose as well. A small groove between the lobing on the posteriorly distal ends of the metatarsals appears to be a nutrient foramen. The phalanges also have their rugose, foramen-bearing sides down. The distal phalanges ride in the center of the proximal ends of the unguals. The unguals' proximal edges are exposed above and below the surface of the phalanges.

Preparation and Mounting (Photos 21−40)

Preparation was directed by Ron Mjos and Cliff Miles. Nine full-and nine part-time employees required 23 months to excavate, prepare, and mount the skeleton. The bones were glued and hardened (Photo 28) using polyvinyl acetate (Vinac), cyano-acrylates, and polyester and epoxy fillers. Difficulties were encountered in the preparation of the midcervical vertebrae, dorsal neural spines, and sacral neural spines due to weathering that had weakened the elements collected near the surface. These bones were broken into hundreds of fragments (Photos 29−30), each of which required careful cleaning and reassembly. It was decided by both GMNH and WPL that all of the skull elements, cervicals 1, 2, and 3, their respective cervical ribs, the right femur, and nine of the pathological caudals would not be used in the mount because of their scientific importance. Casts were used in their place (Photos 31−32).

Mounting was directed by Ron Mjos, who took great care to incorporate as much steel into the skeleton as possible without compromising the integrity of the bones (Photo 33). A T-shaped plate was fashioned to hold the cervical vertebrae in position. The dorsal, sacral, and caudal vertebrae were drilled. The dorsals were drilled with two holes to keep them from rotating, and the caudals were drilled with a single hole, which was reduced in diameter in successively smaller caudals. The limbs have steel incorporated through their long axis. Every rib has steel attached to its medial surface (Photo 34), as do the pubes and ischia. The end result of all the internal steel is a specimen that is very strong and stable. Having the steel internal to the skeleton gives it a very neat and clean appearance.

Using casts from other individuals and modeling bones facilitated restoration of missing elements. Color restoration (Photos 35−37) was performed using acrylic pigments. All surfaces were sealed with polyvinyl acetate and clear fixatives. All of the bones in the skeleton were given a final inspection for any problems before the finish work was complete

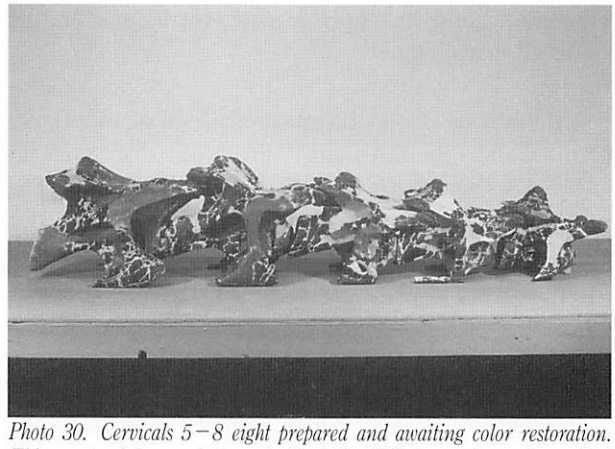


Photo 30. Cervicals 5−8 eight prepared and awaiting color restoration. This group of bones challenged all of the WPL preparators who worked on them. Their highly fragmented nature was due to the fact that they were very near the surface and suffered a great deal of weathering.



Photo 31. Kate Olson setting up skull elements for molding. All of the skull elements were set up as left and right pairs where possible. This aided in more accurate restoration of incomplete elements.

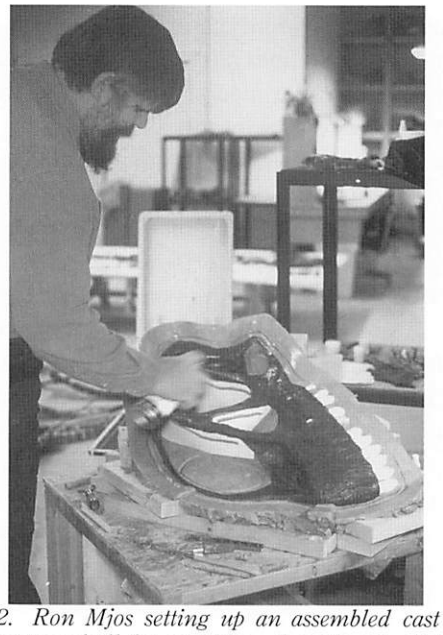


Photo 32. Ron Mjos setting up an assembled cast of the Camarasaurus *skull for molding. A solid cast of the skull is a better candidate for mounting than using assembled individual elements because it is much stronger.*

(Photo 38).

The skeleton was designed to be assembled in ten sections. The main body was lifted with two electric winches that were attached to the base of the skeleton. Two support bars were moved into place and the body lowered onto the supports. Each limb (Photo 39), as well as the neck, was constructed as a single unit. When the limbs are attached they act as stabilizers, giving the skeleton six points of support. Both the neck and tail were assembled using a male-female, pipe-fitted arrangement. The neck is entirely self-supporting. The tail required suspended cables to ensure stability. The skeleton is 13.59 meters long and 3.4 meters high, making it the largest mounted *Camarasaurus* (Photo 40).

Discussion and Conclusions

Some of the more interesting features of skeleton GMNH 101 are (1) the large number and exceptional preservation of the disarticulated elements of the skull and mandible including the intercoronoids; (2) the presence of the proatlas and single-headed ribs of the atlas; (3) the coalescence of the last dorsal rib (no. 12) with the ilium; (4) the complete set of caudal vertebrae without widely transversely expanded neural spines; (5) numerous pathologies found throughout the tail and the fusion of the terminal caudals; (6) the slenderness of the limb bones; and (7) evidence of scavenging by predators on the limb, foot, and pelvic elements.

As for which species *Camarasaurus* GMNH 101 belongs to, careful comparisons of the elements of skull with those of other skulls, particularly of the incomplete paratype of *C. grandis* YPM 1905 and the nearly complete DINO 28, which has been assigned to *C. lentus,* did not reveal any distinguishing characters. The caudal vertebrae closely resemble those of *C. grandis* and *C. lewisi. Camarasaurus* caudals can be separated into two types—here assumed to be the result of sexual dimorphism—those with neural spines broadly expanded in the transverse direction and those with narrowly expanded spines. GMNH 101 belongs to the latter category, along with the paratype of *C. grandis* YPM 1905, in contradistinction to those of the types of *C. grandis* YPM 1901 and *C. lewisi* BYU 9047. The chevrons of GMNH 101 resemble those of *C. grandis* YPM 1901 and 1905, but differ from those of *C. lewisi.*

The unfortunate loss of the centra and lower parts of the neural arches of the anterior dorsal vertebrae of GMNH 101 makes impossible comparisons with *C. grandis* and *C. lentus* in a region where they differ the most. Some insight into differences between these species is afforded by comparative

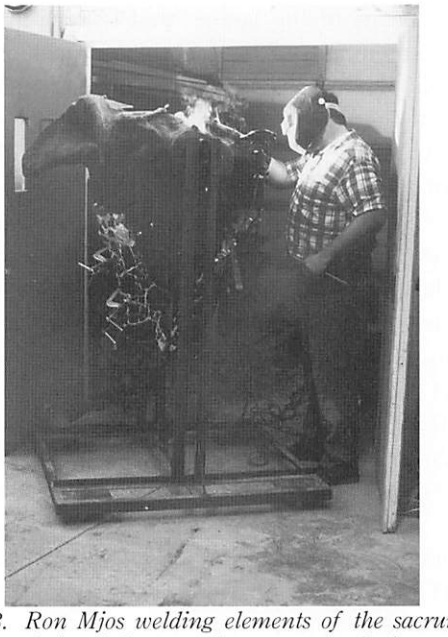


Photo 33. Ron Mjos welding elements of the sacrum, the first part of the skeleton to be mounted. It is necessary that preparators have many different skills in order to successfully mount a skeleton.



Photo 34. Greg Parrent (right) and Brian Versey (left) texturing restored bones. Good textures really help to make the color restoration more convincing.

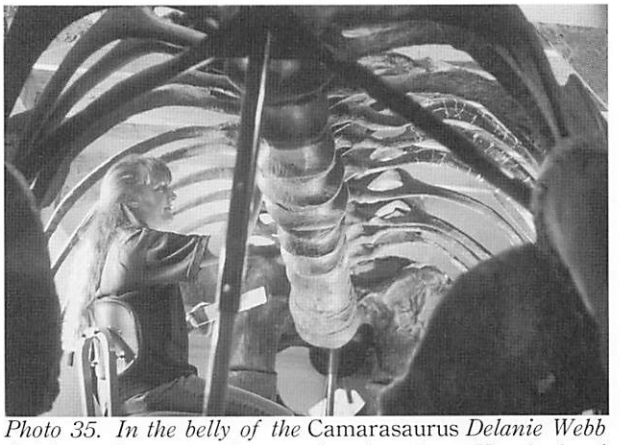


Photo 35. In the belly of the Camarasaurus *Delanie Webb finishes color restoration on dorsal centra. Hundreds of hours were required to complete the job of color restoration.*

measurements of the humeri and femora in Table J, where percentages of the lengths are presented. The most reliable of these percentage measurements is the ratio of the least circumference of the shaft to greatest length. The least reliable is probably the ratio of the proximal breadth of the humerus to its length. This happens because the greatly rounded proximal half of sauropod humeri often become somewhat flattened by compaction with the result that they often are artificially magnified. An example may be seen in YPM 1901. Humeral measurements show GMNH 101 to be of the slender variety, along with AMNH 823 from the nearby Bone Cabin Quarry, *C. grandis* YPM 1901 and *C. lewisi* BYU 9047. The humeri of *C. lentus* YPM 1910 and CM 11338 are more robust, but these are both of subadult animals, a fact that should not be overlooked. In the femur, GMNH 101 is the slenderest of all. Again the circumference to length ratio of 42% compares more closely with 44% of *C. grandis* YPM 1901, as opposed to 47% and 48% in *C. lentus*. A fully adult femur, DINO 4514, from the same quarry as CM 11338 gives a similar ratio, showing that no change occurs ontogenetically.

Thus, although the results are by no means certain, GMNH 101 appears to be closer to *C. grandis* than to *C. lewisi* or *C. lentus*, and we tentatively assign it to that species. The other currently recognized species, *Camarasaurus supremus*, from very high in the Morrison, is also excluded. It has not been altogether certainly separated from *C. lentus*. It is

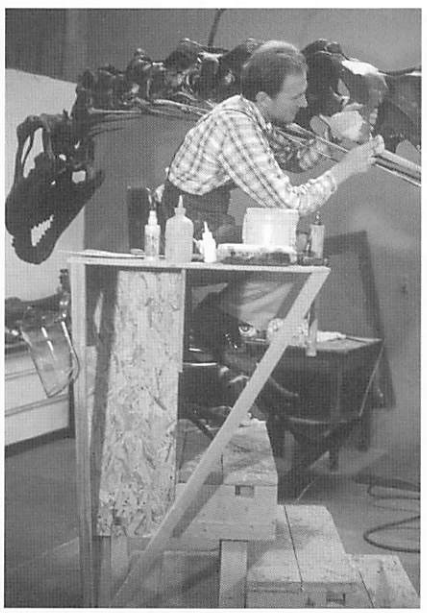


Photo 37. Brian Versey restoring cervical ribs. Camarasaurus *cervical ribs give the neck a very dramatic appearance. They are the longest of any known sauropod.*



Photo 36. Delanie Webb very skillfully performing the color restoration on a restored rib. Her skills made it very difficult to discern original bone from the restoration. This is why it is always best to photograph elements to be studied before color work is finished so there is no question scientifically what is original and what is restored.



Photo 38. Charles McClellan cleaning off the last fragments of adhesive used to bond the bones to the steel. This was the final step before each subassembly was added to the skeleton.

about 12% larger than GMNH 101, itself an old adult (from the fusion of the dorsal rib with the sacrum), whereas GMNH 101 is the largest specimen of those here considered. As stated earlier, we have somewhat arbitrarily assumed that *Camarasaurus* with the less-expanded caudal spines and more slender limbs are female.

Acknowledgments

The authors would like to thank the following individuals, all of whom helped to make this project possible: Helen Beardall, Michelle Beardall, Landis Buck, Hollis Butts (Heart of Stone), Lance Cloward, David Hamblin (WPL), Owen Harding and the Carlin Ranch Corp., Yoshikazu Hasegawa (GMNH), Kim Johnson (WPL), Debi Johnson (WPL), James H. Madsen Jr. (DINOLAB), Charles McClellan (WPL), Lucy McDonald (WPL), Clark Miles (WPL), Ron Mjos (WPL), Kate Olson (WPL), Greg Parrent, Stan Pinegar (WPL), Tyler Pinegar (WPL), Dave Schmude (WIPS), Elliot Smith, Kenneth L. Stadtman (BYU-ESM), Brian K. Versey (WPL), Delanie Webb (WPL), Chris Weege, (WIPS), and Mary Ann Whitehead (WPL).

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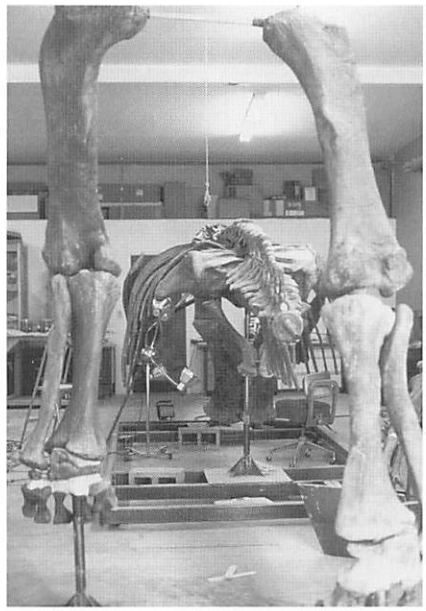


Photo 39. The left and right hind limbs ready for fitting onto the skeleton. They required only minor adjustments for the final fit.

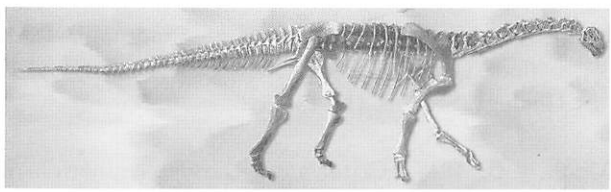


Photo 40. Camarasaurus *GMNH 101, 13.7 meters long.*

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Plates

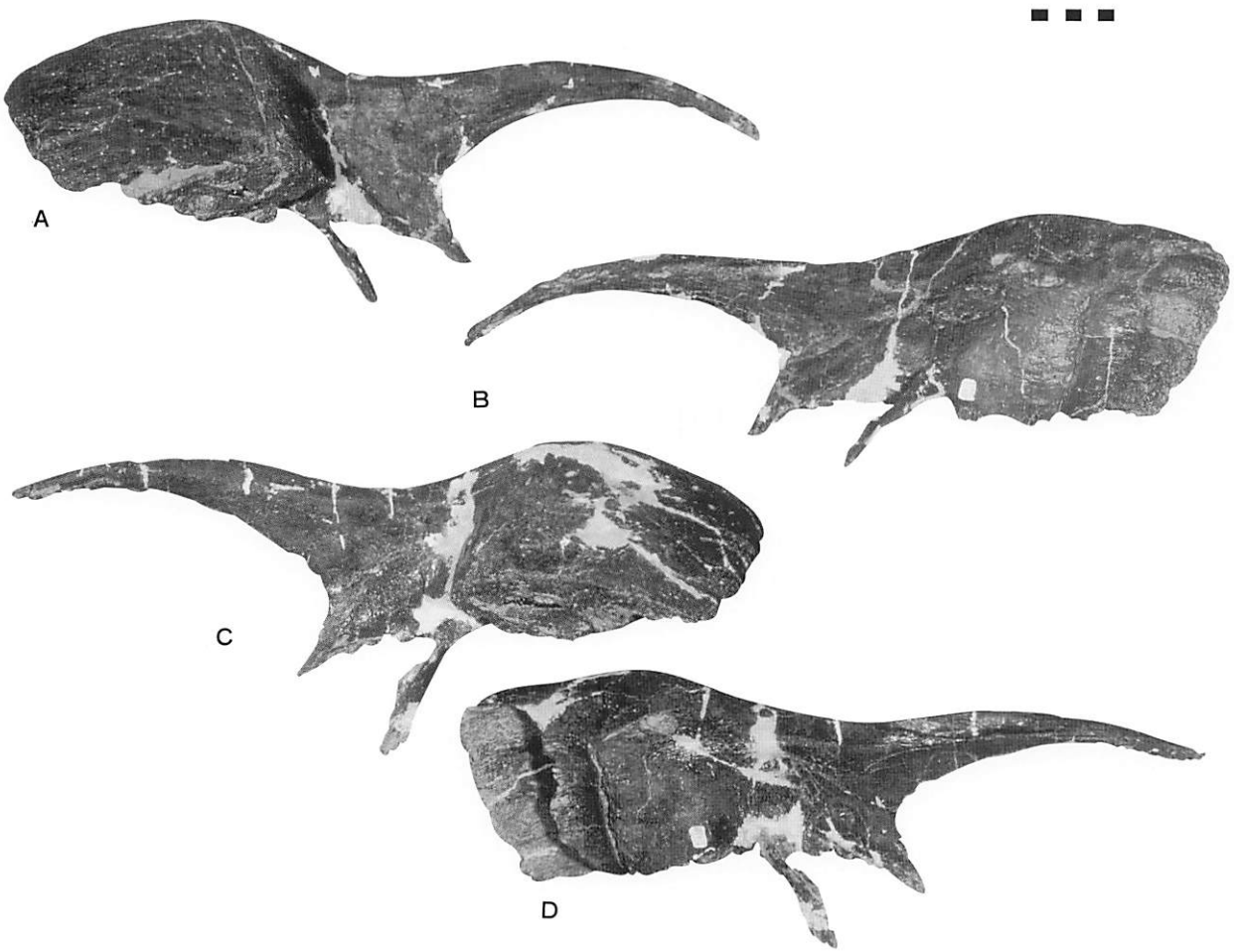


Figure 1. Premaxilla. A. Left, lateral view [Cat. No. 351]; B. Left, medial view [Cat. No. 351]; C. Right, lateral view [Cat. No. 350]; D. Right, medial view [Cat. No. 350]

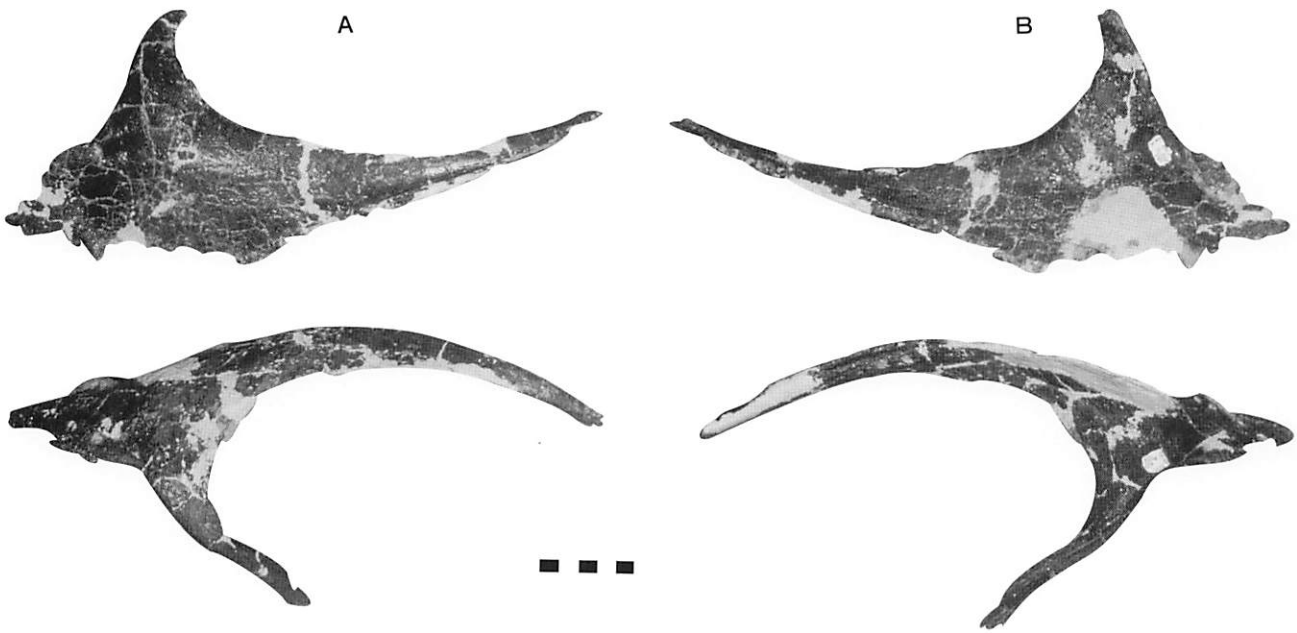


Figure 2. Nasal. A. Left (upper), dorsal view [Cat. No. 355]. Right (lower), dorsal view [Cat. No. 354]; B. Left (upper), ventral view [Cat. No. 355]. Right (lower), ventral view [Cat. No. 354]



Figure 3. Prefrontal. (Left & Right)[Cat. No. 427 & 428]. A. lateral view; B. medial view

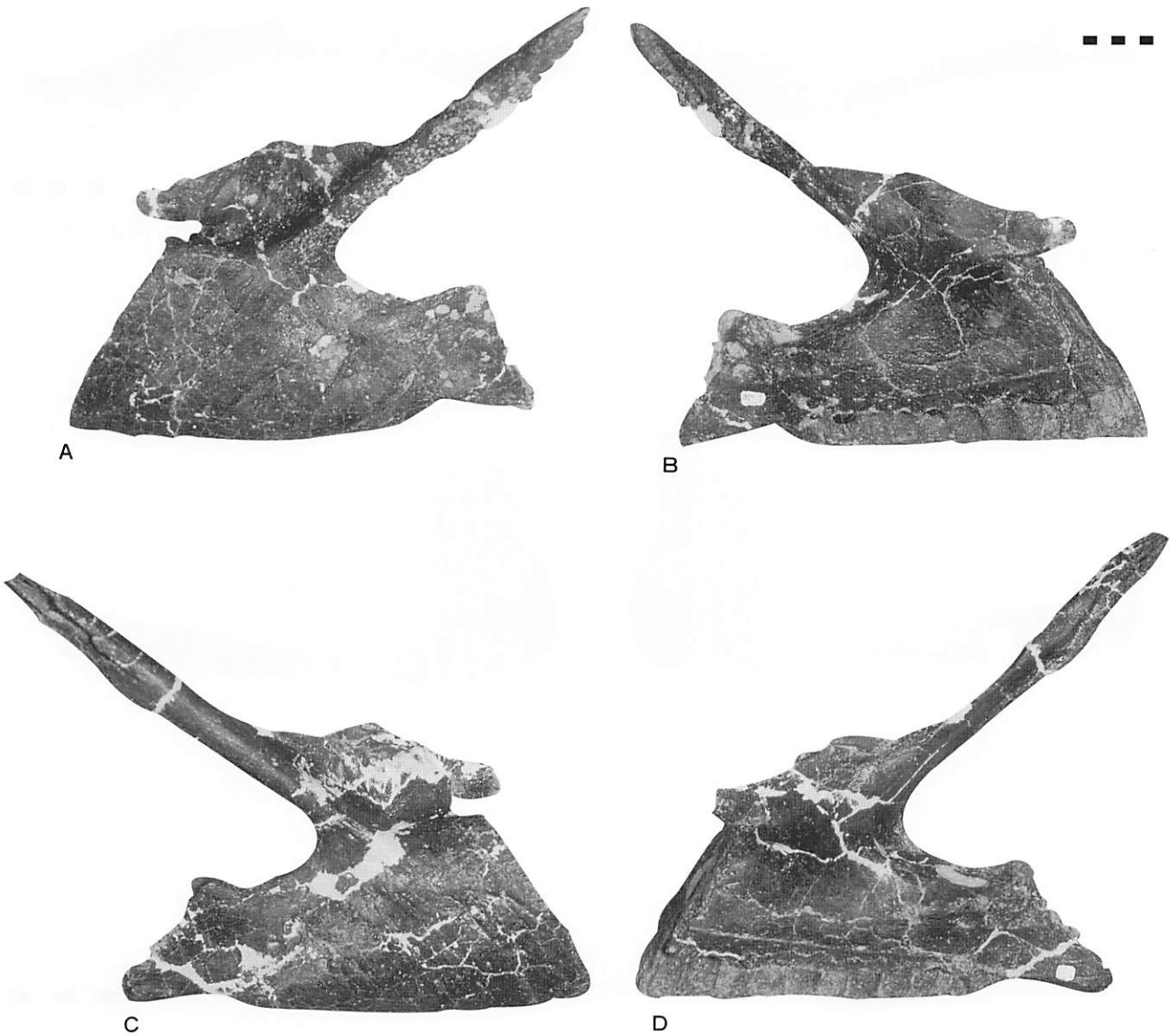


Figure 4. Maxilla. A. Left, lateral view [Cat. No. 353]; B. Left, medial view [Cat. No. 353]; C. Right, lateral view [Cat. No. 352]; D. Right, medial view [Cat. No. 352]

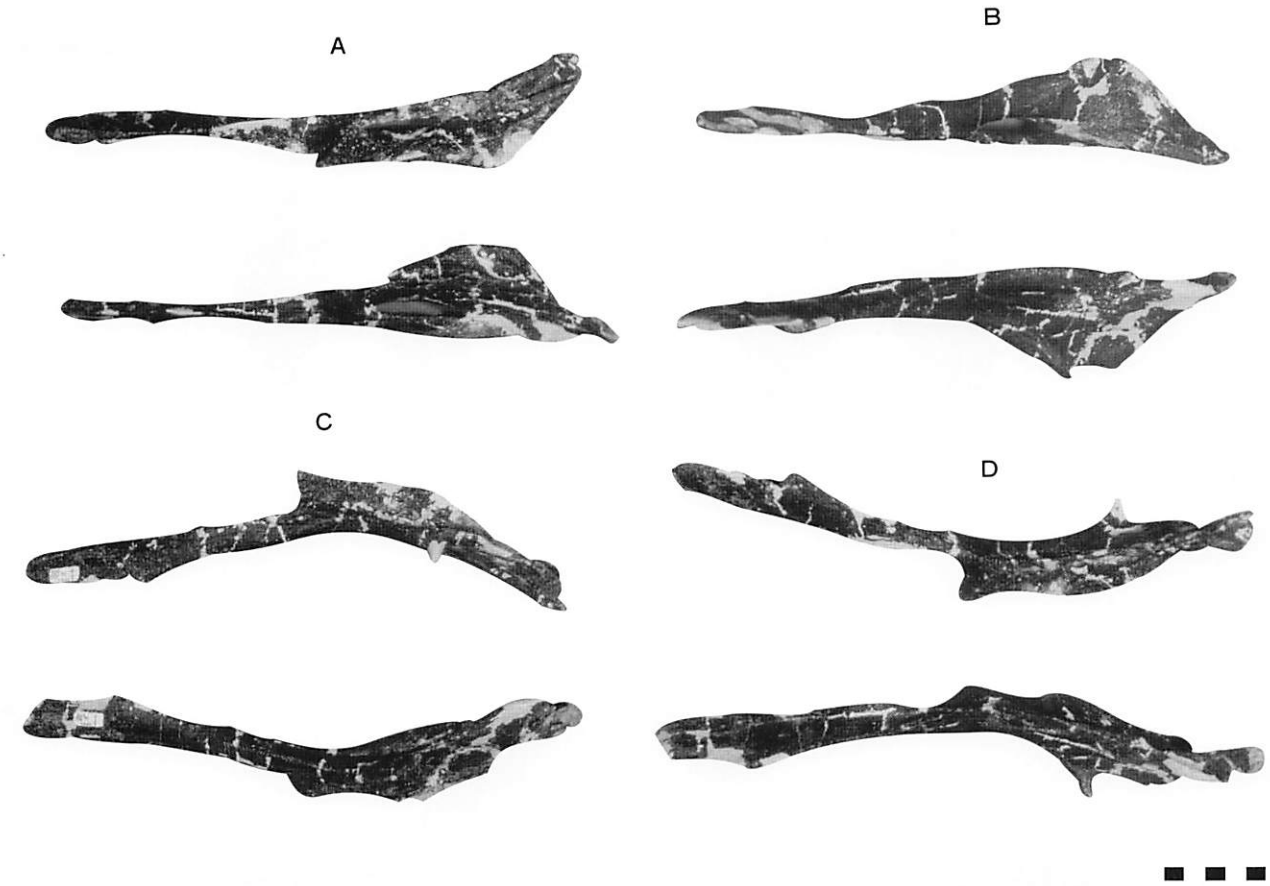


Figure 5. Lacrimal. A. Left & Right, anteromedial views [Cat. No. 430 & 429]; B. Left & Right, posterolateral views; C. Left & Right, posterior views; D. Left & Right, anterior views;

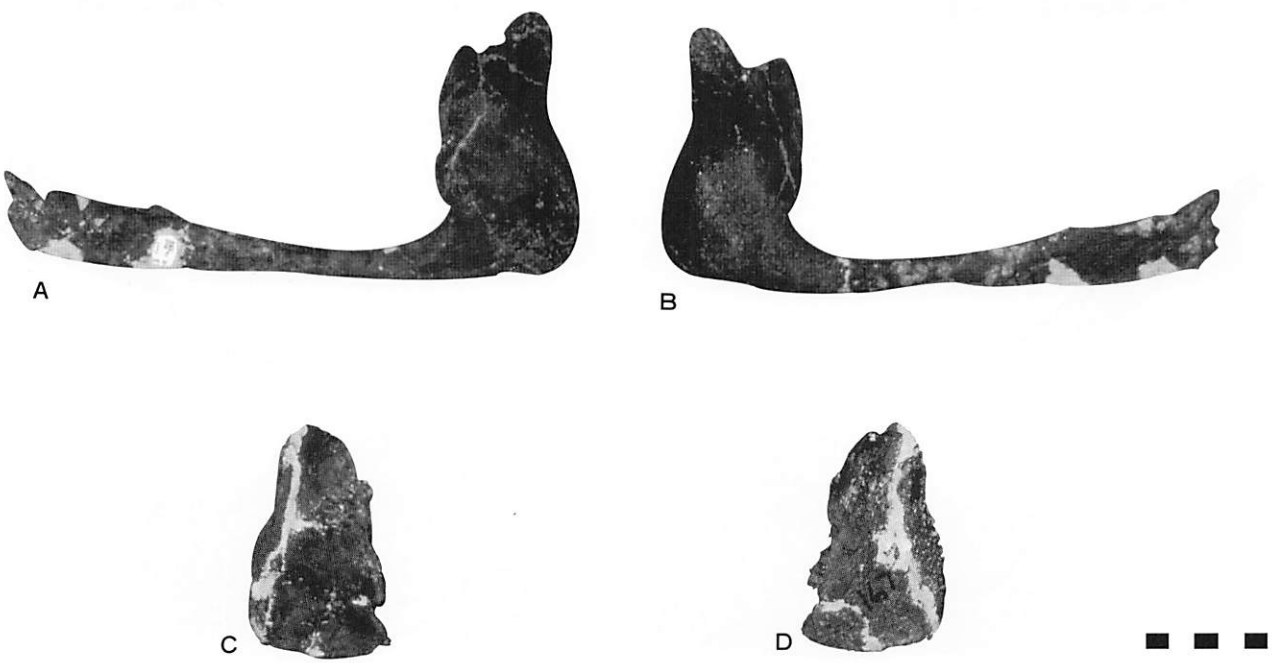


Figure 6. Quadrato jugal
A. Right, medial view [Cat. No. 420]; B. Right, lateral view [Cat. No. 420]; C. Left, medial view [Cat. No. 349]; D. Left, lateral view [Cat. No. 349]

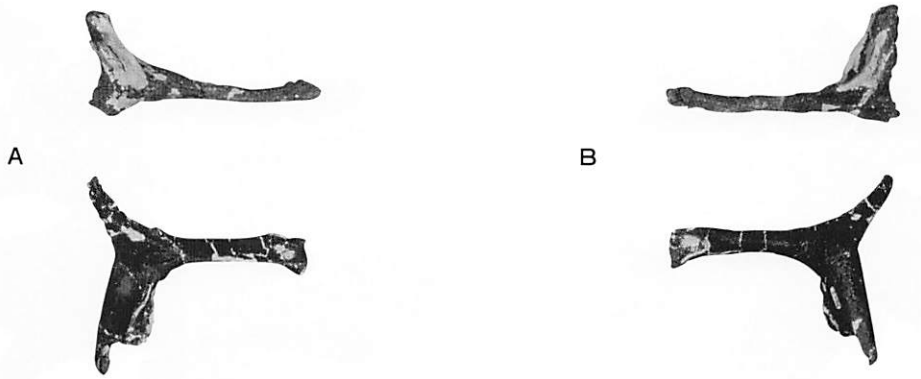


Figure 7. Postorbital. A. Left & Right, lateral views [Cat. No. 435 & 436]; B. medial views

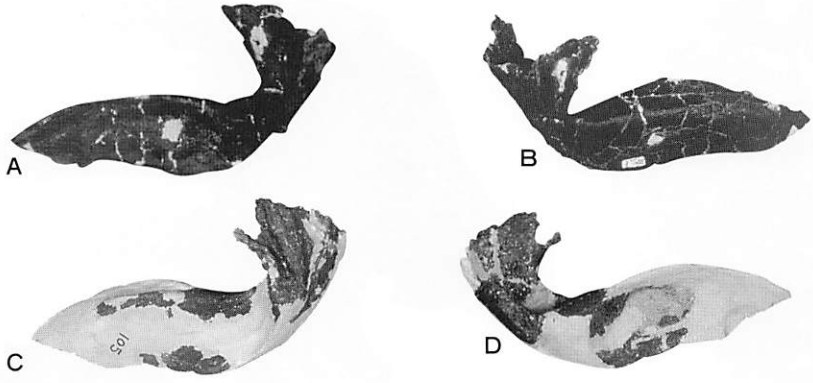


Figure 8. Squamosal. A. Right, medial view [Cat. No. 432]; B. Right, lateral view [Cat. No. 432]; C. Left, lateral view [Cat. No. 449]; D. Left, medial view [Cat. No. 449]

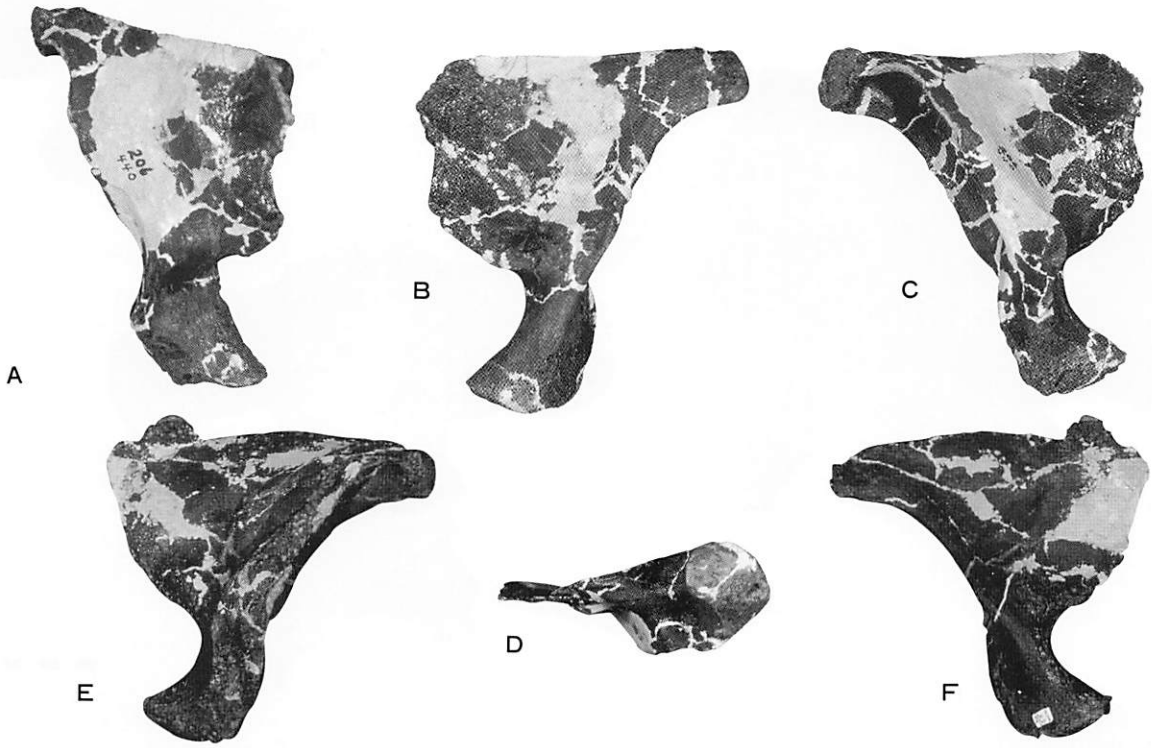


Figure 9. Quadrate. A. Right [Cat. No. 440], anterior view ; B. Right, posterior-medial view C. Right, anterior-lateral view D. Right, ventral view ; E. Left [Cat. No. 417] , anterior view ; F. Left, posterior-medial view

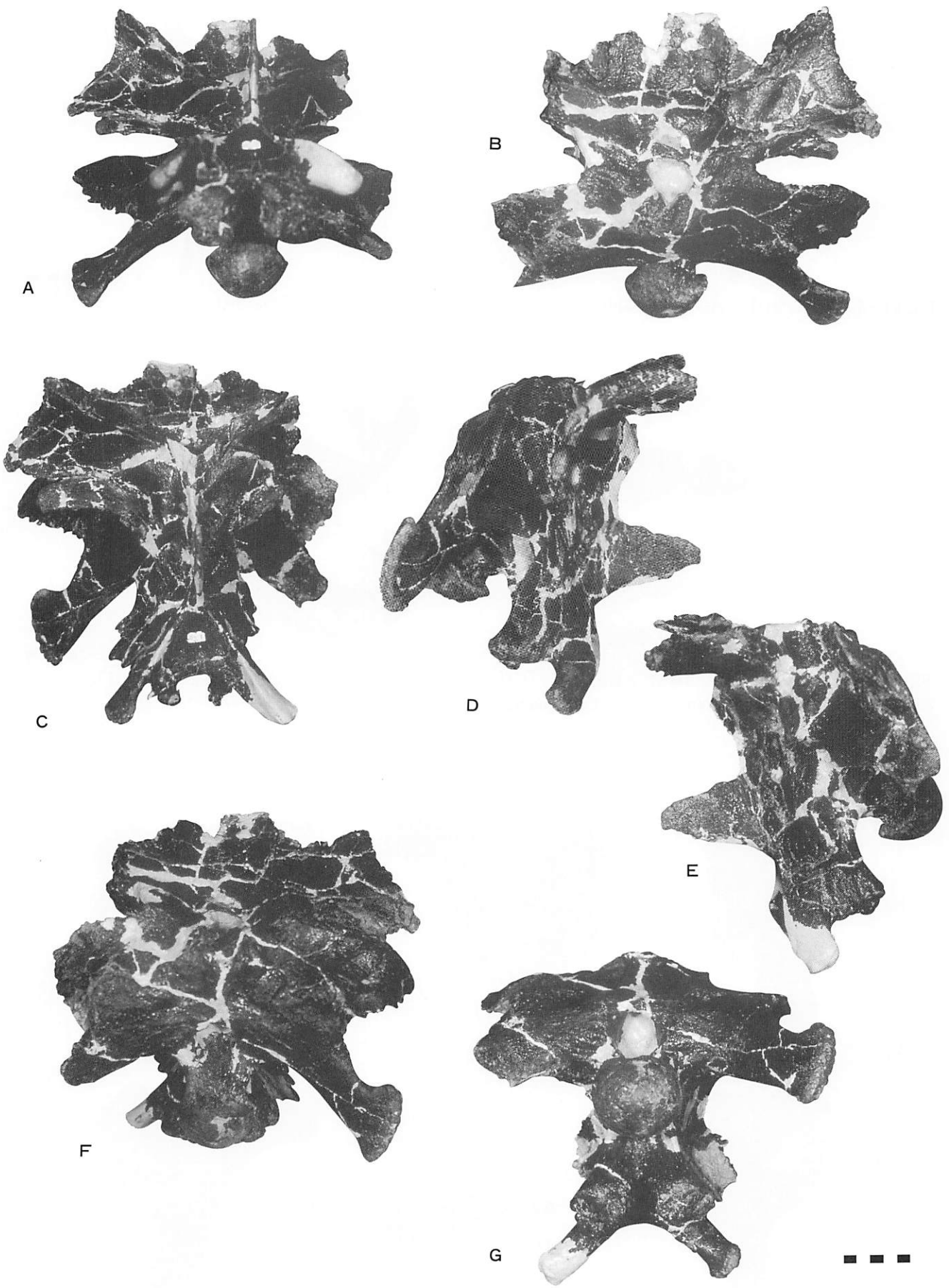


Figure 10. Braincase [Cat. No. 421]. A. Bentral view; B. anterior-dorsal view; C. anterior view; D. right lateral view; E. left lateral view; F. dorsol-posterior view; G. posterior view.

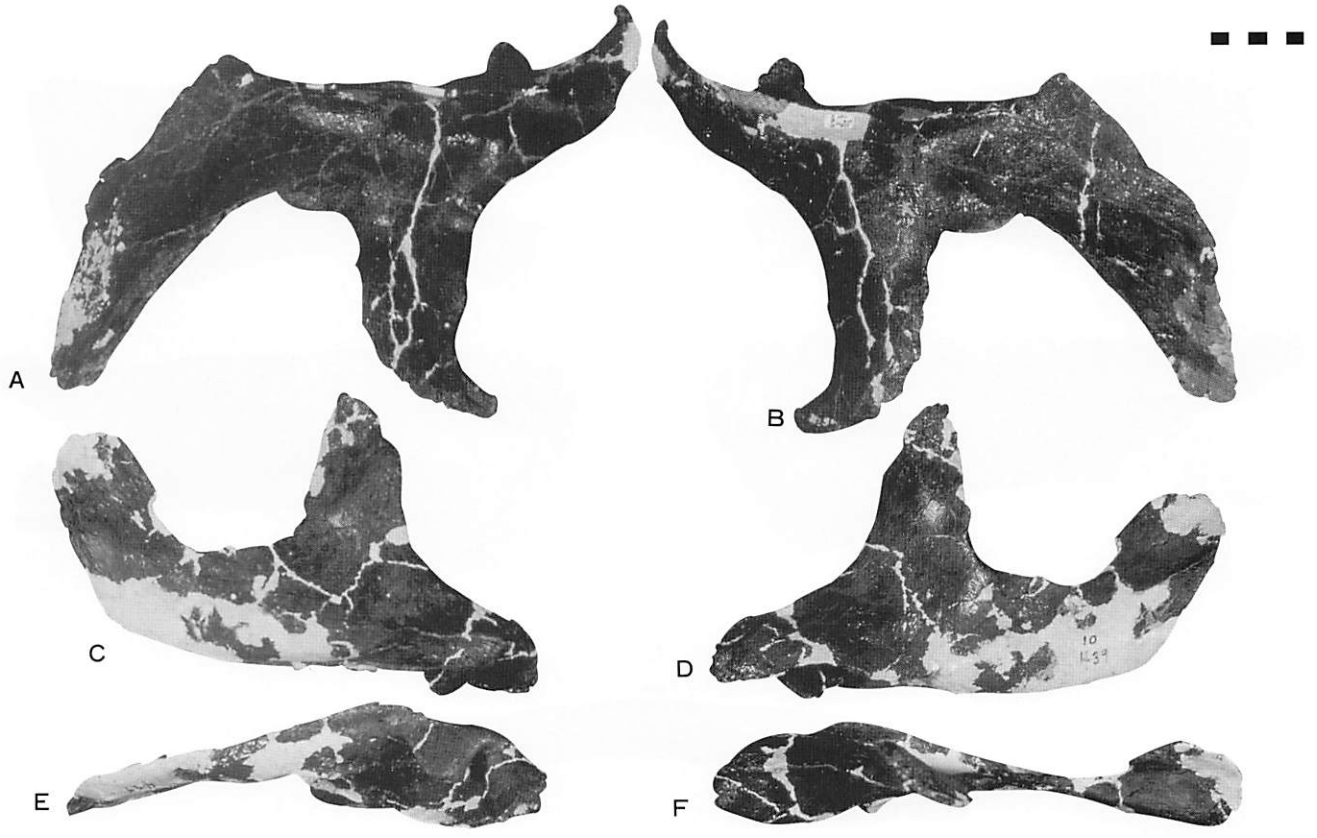


Figure 11. Pterygoid. A. Right, medial view [Cat. No. 418]; B. Right, lateral view [Cat. No. 418]; C.Left, medial view [Cat. No. 439]; D. Left, lateral view [Cat. No. 439]; E. Left, dorsal view [Cat. No. 439]; F. Left, ventral view [Cat. No. 439]

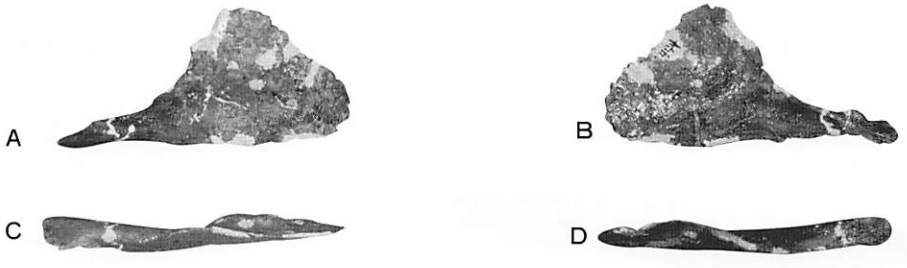


Figure 12. Right Palatine [Cat. No. 444]. A. medial view; B. lateral view; C. ventral view; D. dorsal view

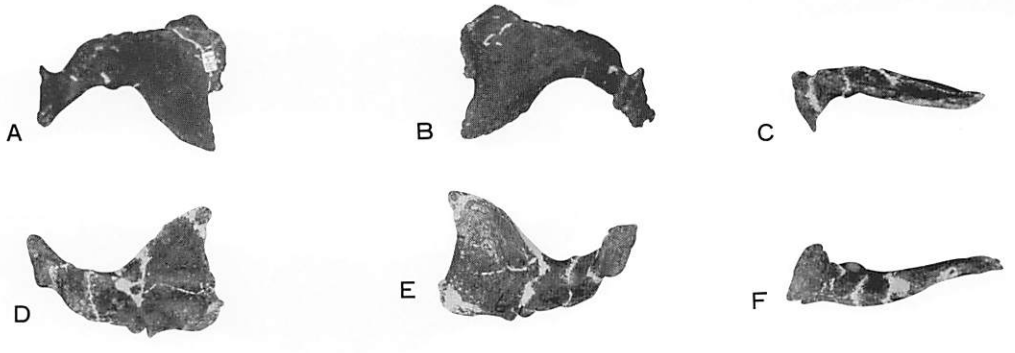


Figure 13. Ectopterygoid. A. Right, medial view [Cat. No. 422]; B. Right, lateral view [Cat. No. 422]; C.lateral view [Cat. No. 421]; D. Left, medial view [Cat. No. 441]; E. dorsal view [Cat. No. 441]; F. ventral view [Cat. No. 441]

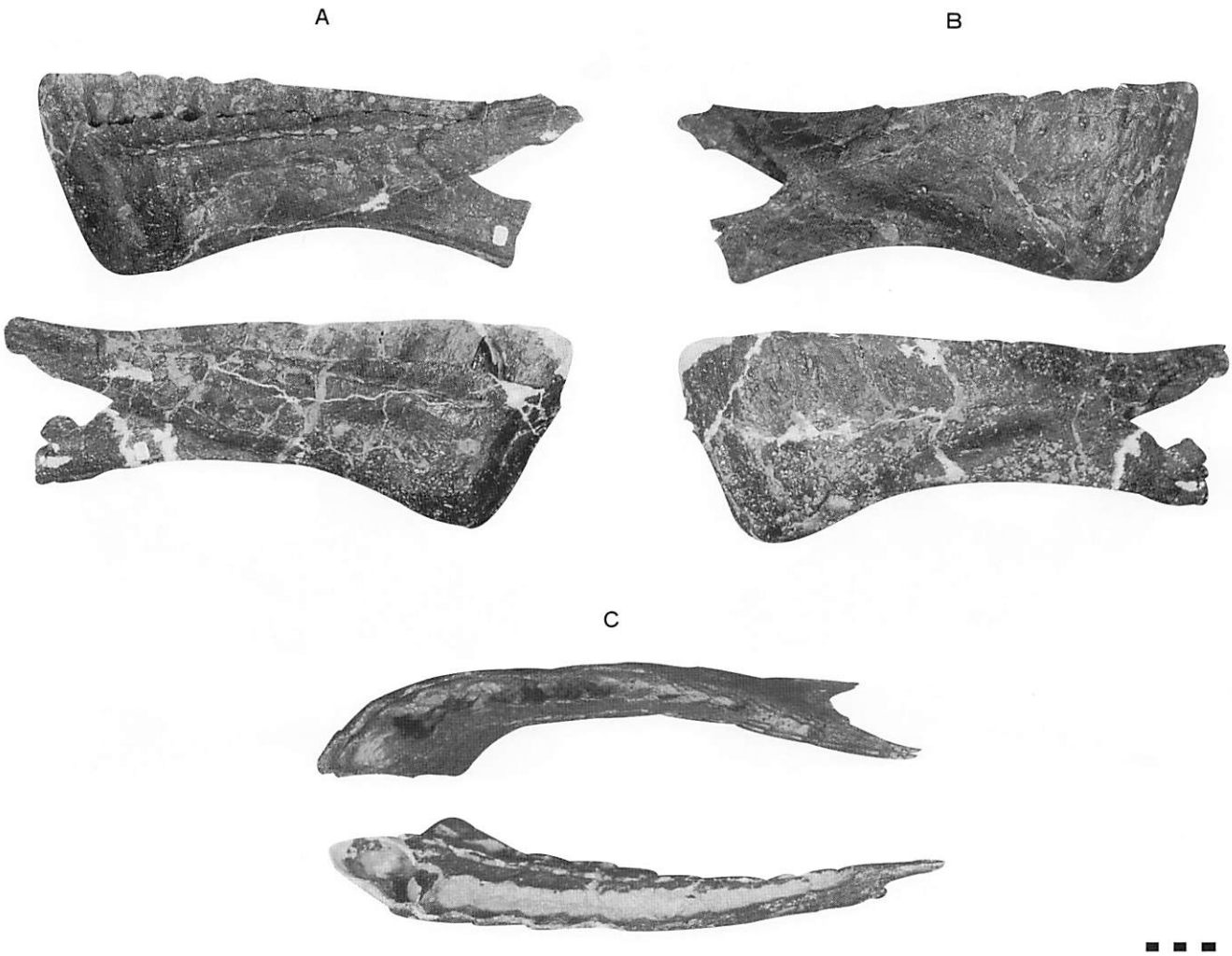


Figure 14. Dentary [Left: Cat. No. 356 & Right: Cat. No. 357]. A. medial views ; B. lateral views ; C. dorsal views

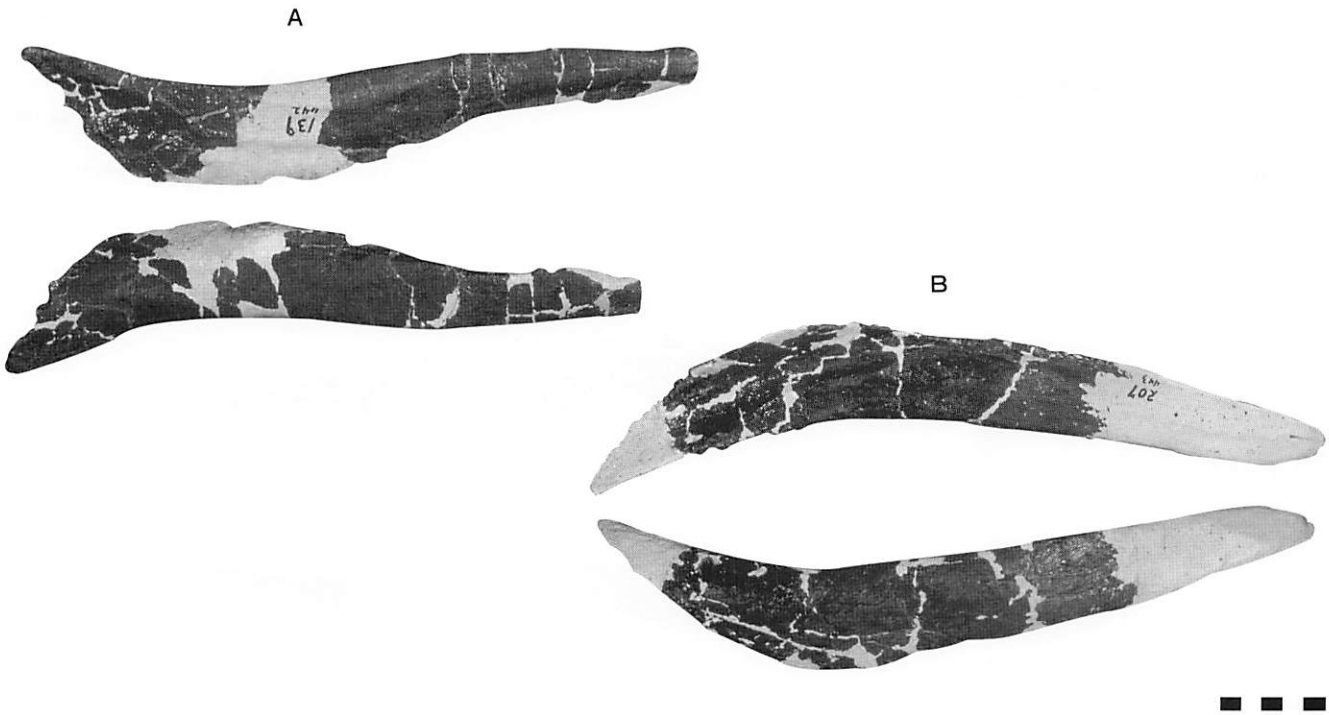


Figure 15. Angulars [Left: Cat. No. 442 & Right: Cat. No. 443]. A. medial views; B. lateral views

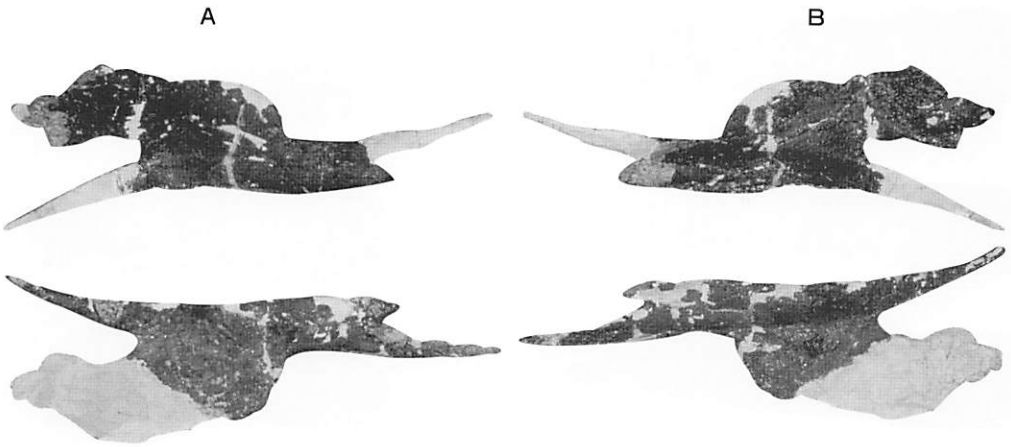


Figure 16. Splenial [Left: Cat No. 450 & Right: Cat. No. 451]. A. medial views; B. lateral views

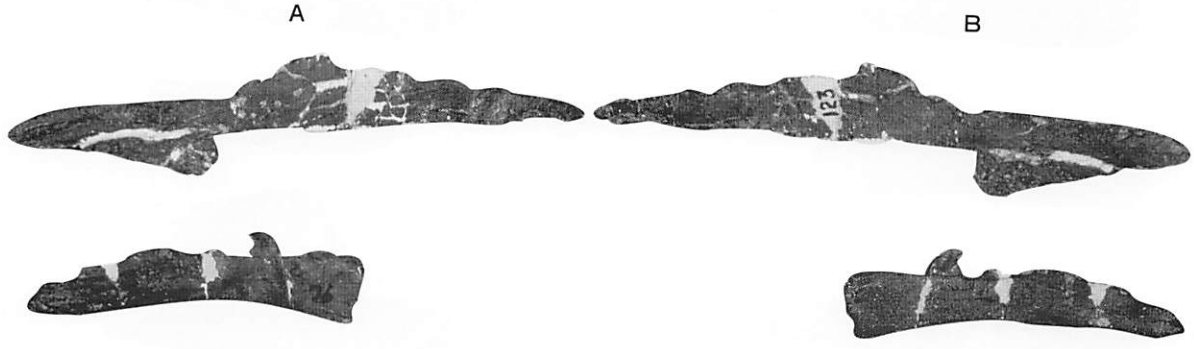


Figure 17. Supradentaries [Left & Right, Cat No. 452 & 453]. A. lateral views; B. medial views

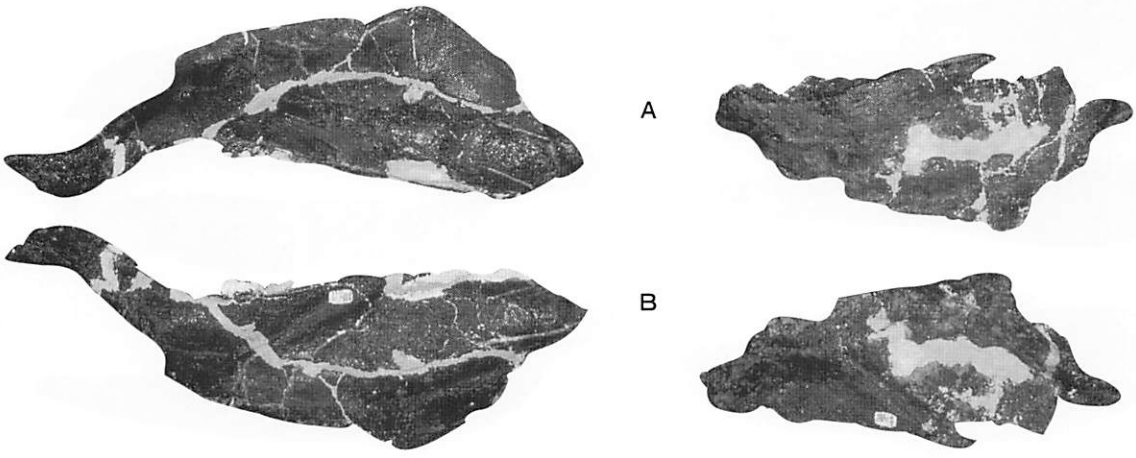


Figure 18. Surangular [Left & Right, Cat. No. 438 & 437]. A. lateral views; B. medial views



Figure 19. Articular. A. Right, dorsal view [Cat. No. 447]; B. ventral view; C. lateral view; D. Left, dorsal view [Cat. No. 426]; E. ventral view; F. Right, medial view [Cat. No. 447]

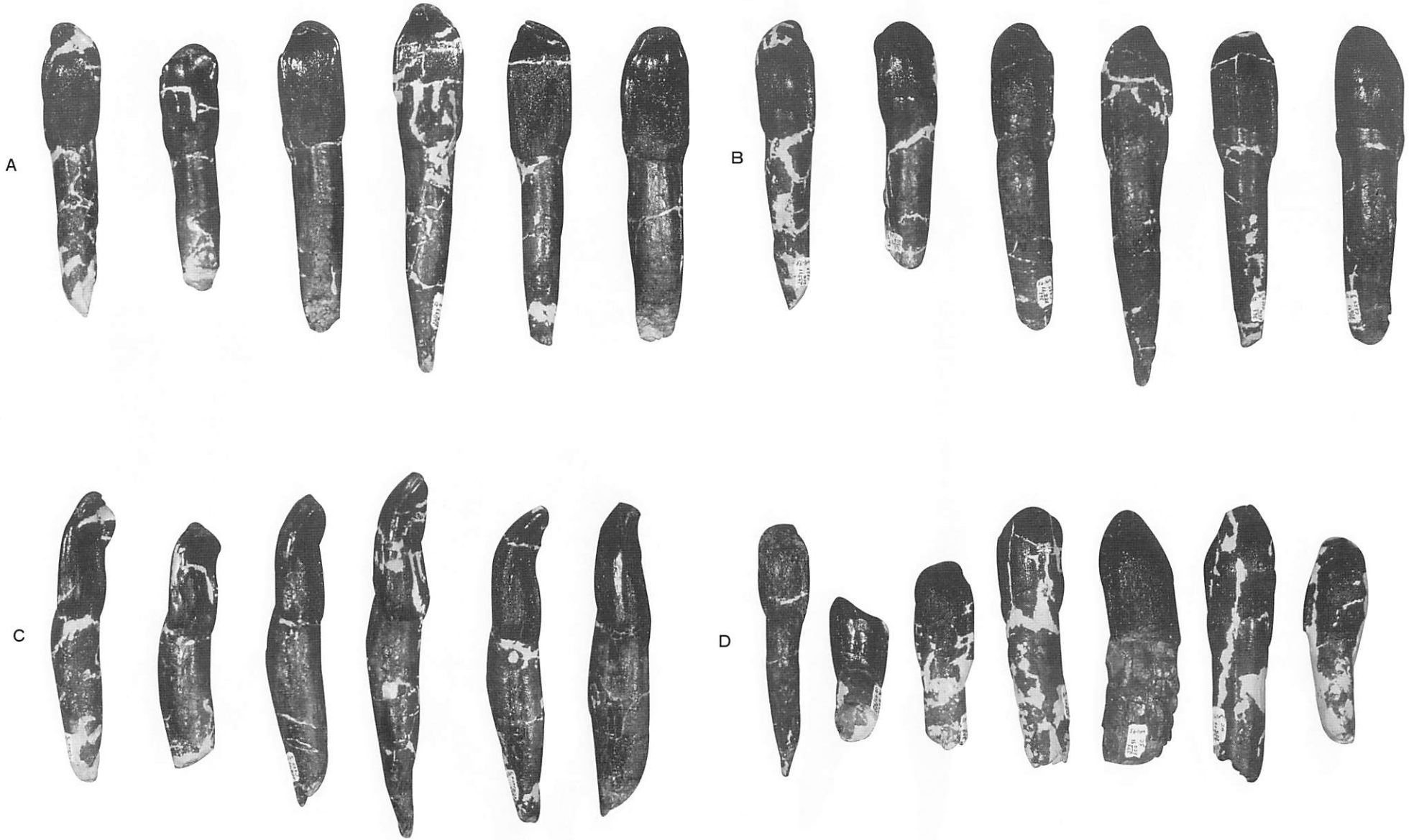


Figure 20. Teeth. A. inside views [Cat. No. 364•365•362•360•363•361]; B. outside views [Cat. No. 364•365•362•360•363•361]; C. side views [Cat. No. 364•365•362•360•363•361]; D. outside views [Cat. No. 366•367•368•374•375•376•377]



Figure 20. continued; E. outside views [Cat. No. 369•370•371•372•373•358•359]; F. inside views [Cat. No. 382•383•384•385•386•387]; G. inside views [Cat. No. •390•389•395•393•388•394•391]; H. inside views [Cat. No. 396•397•398•400•401•402•407]; I. inside views [Cat. No. 378•379•380•381•392]



Figure 21. Proatlas [Cat. No. 424]. A. dorsal view; B. ventral view



Figure 22. Atlas [#1 Cervical, Cat. No. 419]. A. anterior view; B. posterior view; C. dorsal view



Figure 23. Atlas Ribs [Left: Cat. No. 433 & Right: Cat. No. 434] A. medial view; B. lateral view

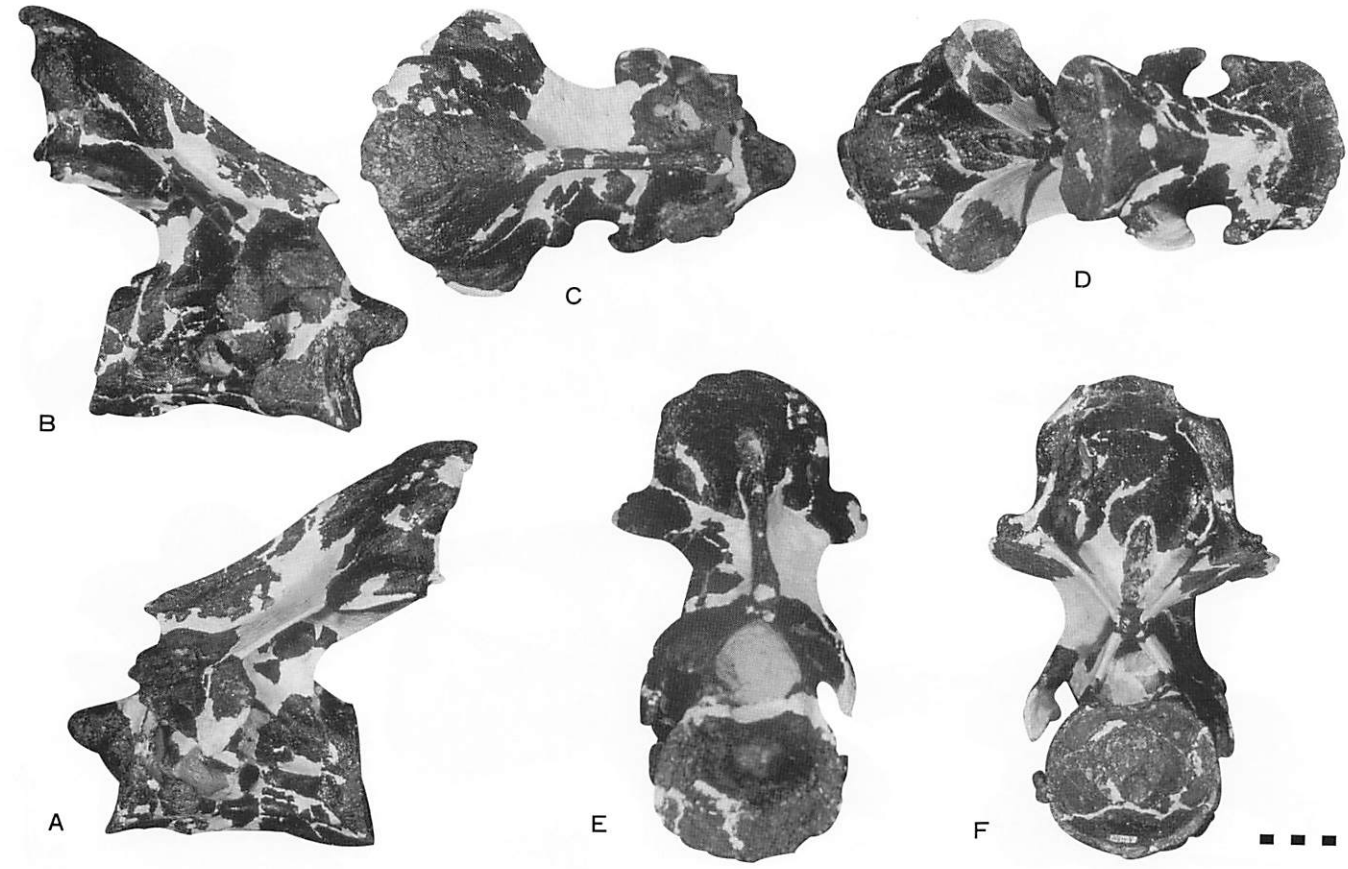


Figure 24. Axis [#2 Cervical, Cat. No. 423]. A. left lateral view; B. right lateral view; C. dorsal view; D. ventral view; E. anterior view; F. posterior view

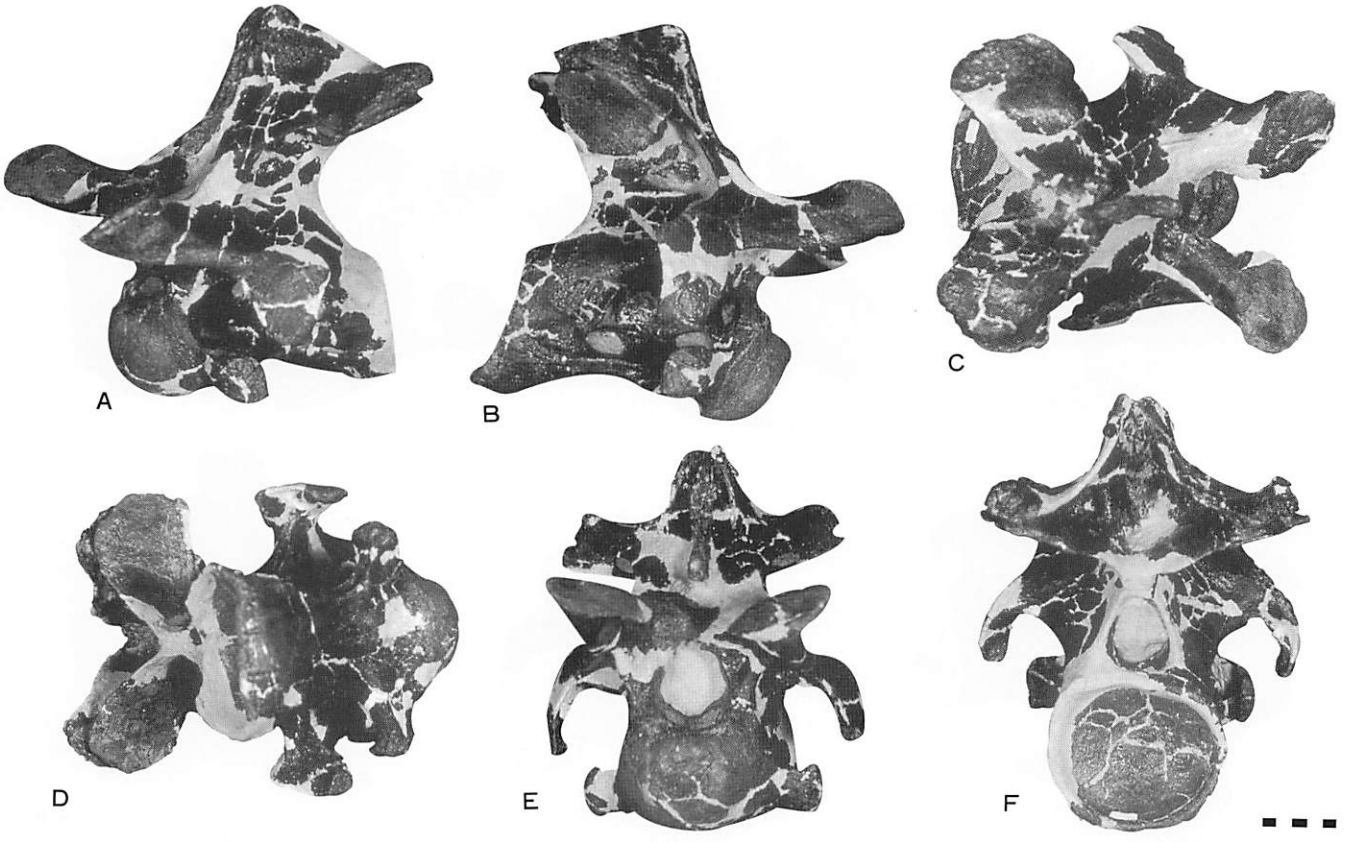


Figure 25. Cervical Vertebra #3 [Cat. No. 425]. A. left lateral view; B. right lateral view; C. dorsal view; D. ventral view; E. anterior view; F. posterior view

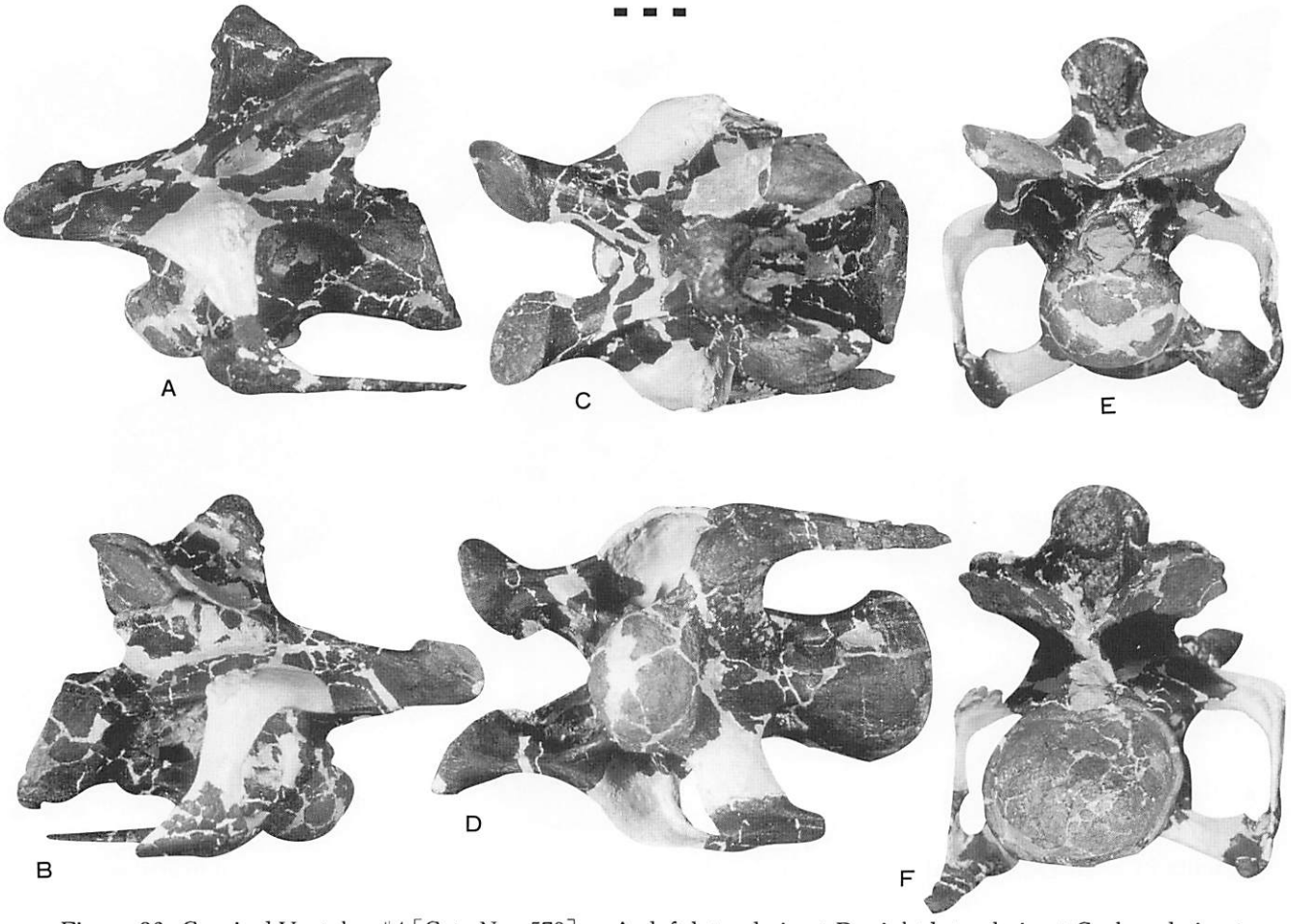


Figure 26. Cervical Vertebra #4 [Cat. No. 579]. A. left lateral view; B. right lateral view; C. dorsal view; D. ventral view; E. anterior view; F. posterior view

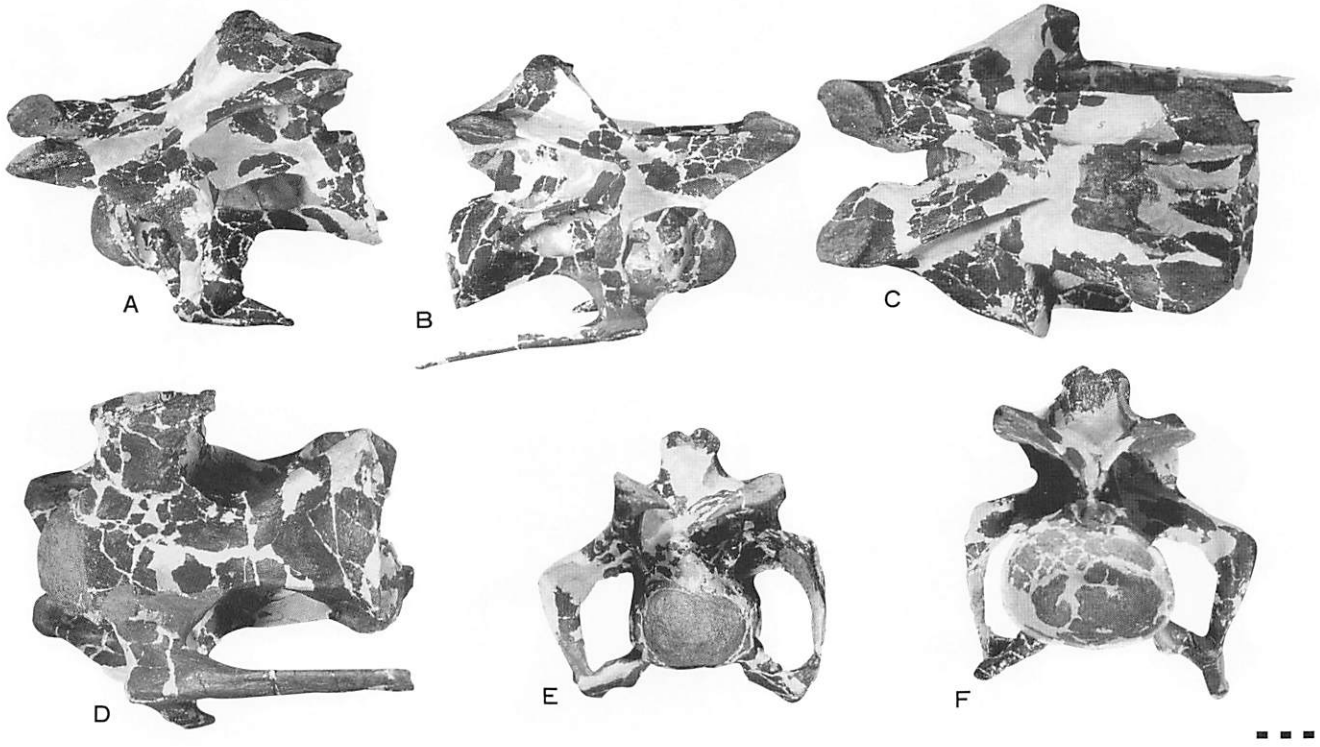


Figure 27: Cervical Vertebra #5 [Cat. No. 580]. A. left lateral view; B. right lateral view; C. dorsal view; D. ventral view; E. anterior view; F. posterior view

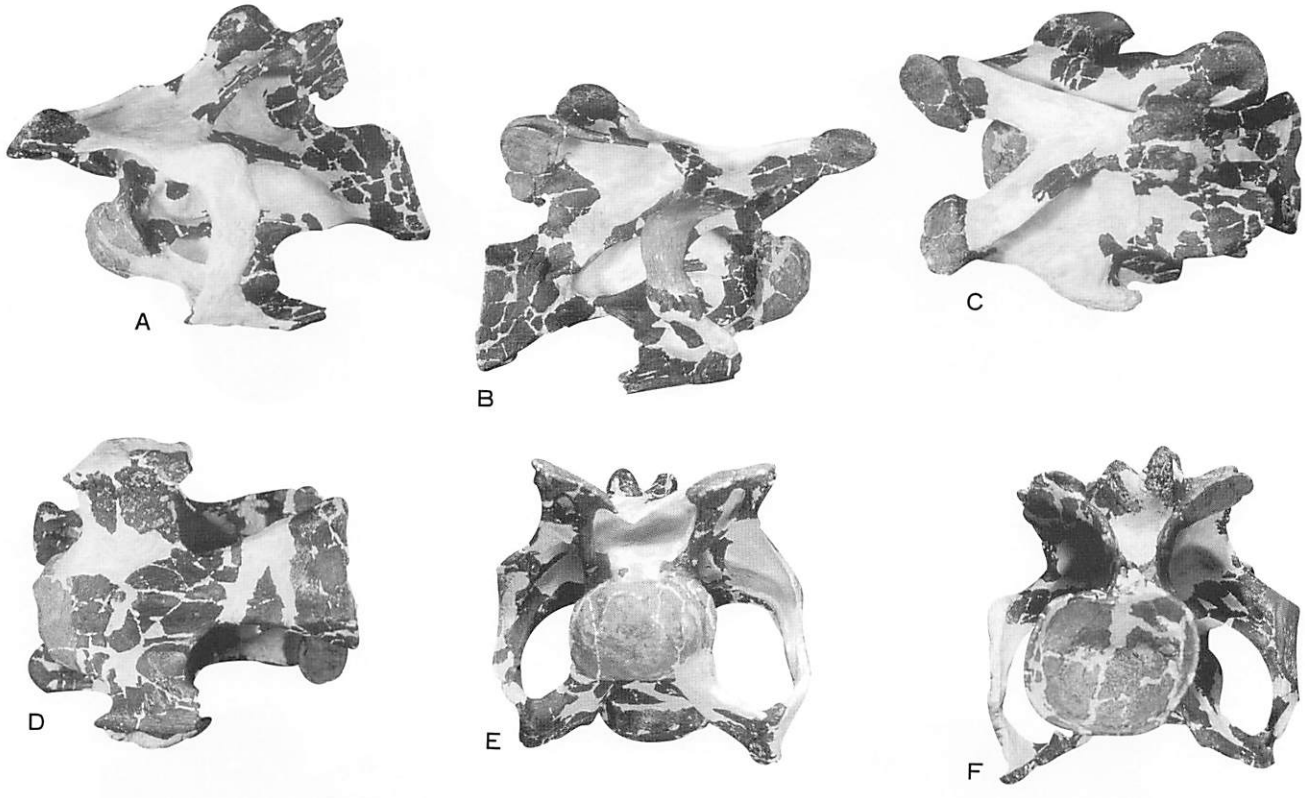


Figure 28: Cervical Vertebra #6 [Cat. No. 581]. A. left lateral view; B. right lateral view; C. dorsal view; D. ventral view; E. anterior view; F. posterior view

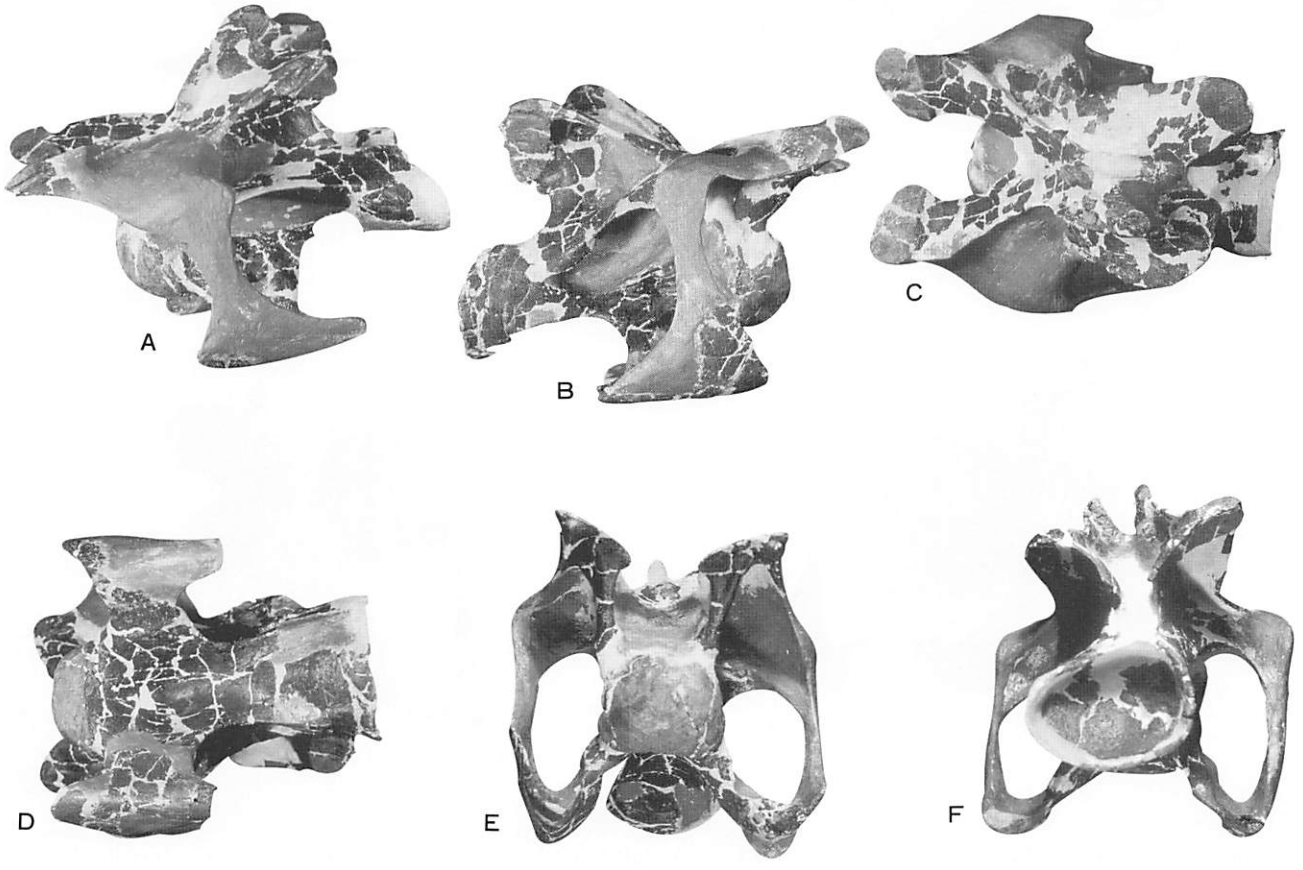


Figure 29: Cervical Vertebra #7 [Cat. No. 582]. A. left lateral view; B. right lateral view; C. dorsal view; D. ventral view; E. anterior view; F. posterior view

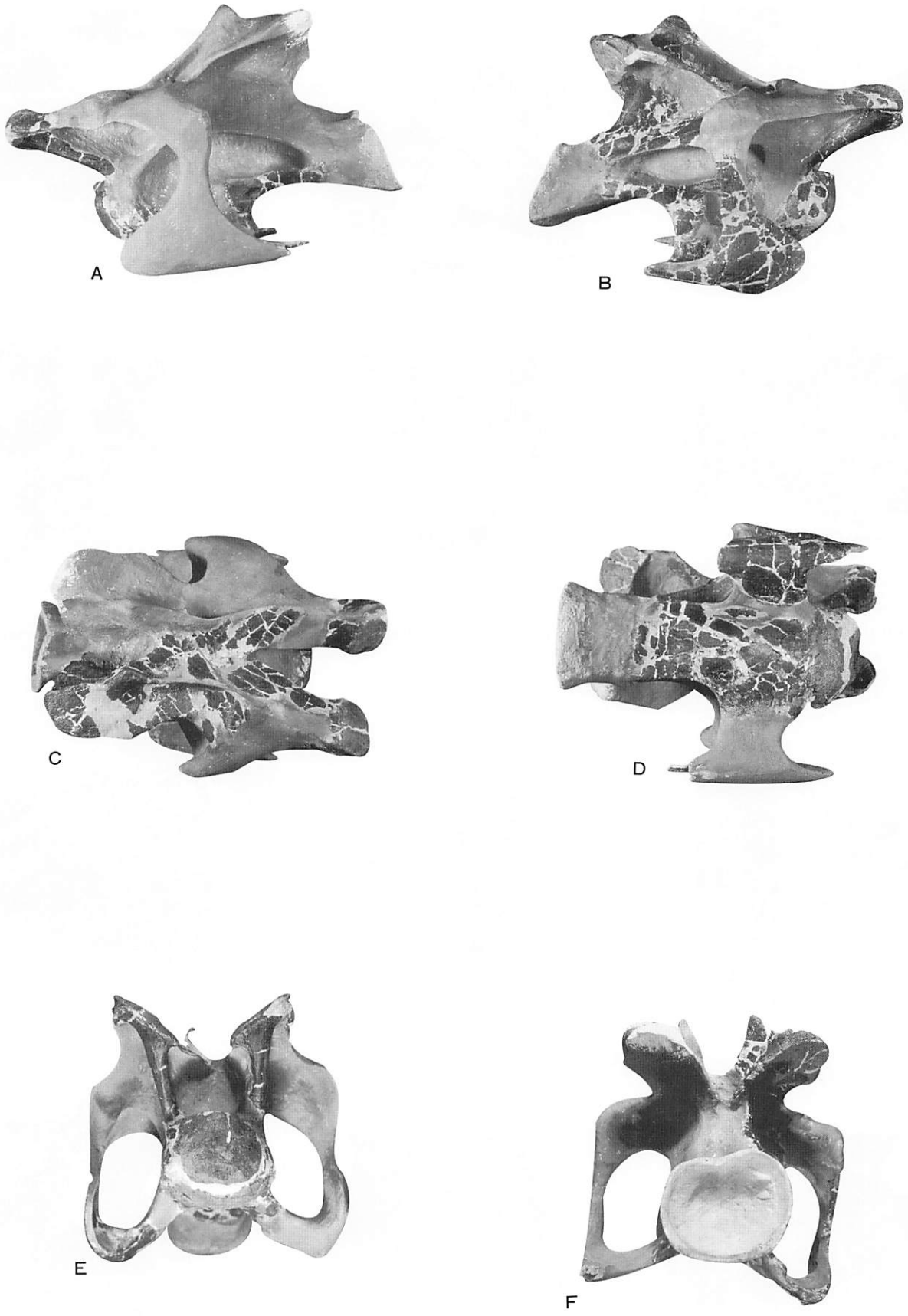


Figure 30: Cervical Vertebra #8 [Cat. No. 583]. A. left lateral view; B. right lateral view; C. dorsal view; D. ventral view; E. anterior view; F. posterior view



Figure 31: Dorsal Vertebra #6 [Cat. No. 587]. A. anterior view ; B. posterior view

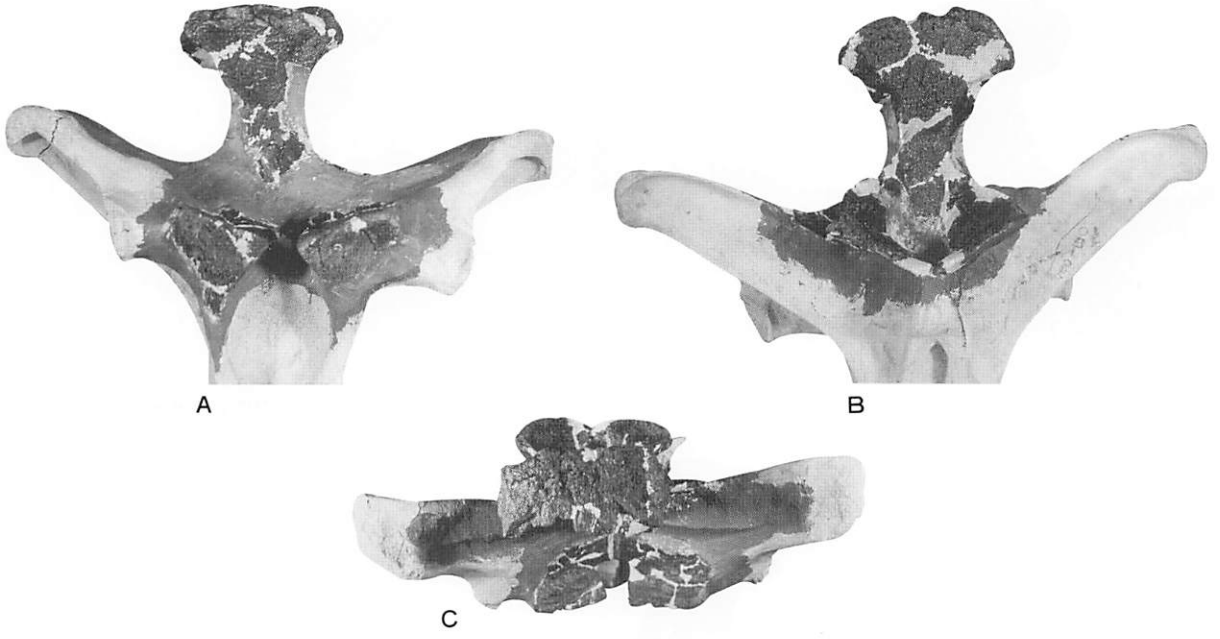


Figure 32: Dorsal Vertebra #7 [Cat. No. 588]. A. anterior view ; B. posterior view; C. dorsal view

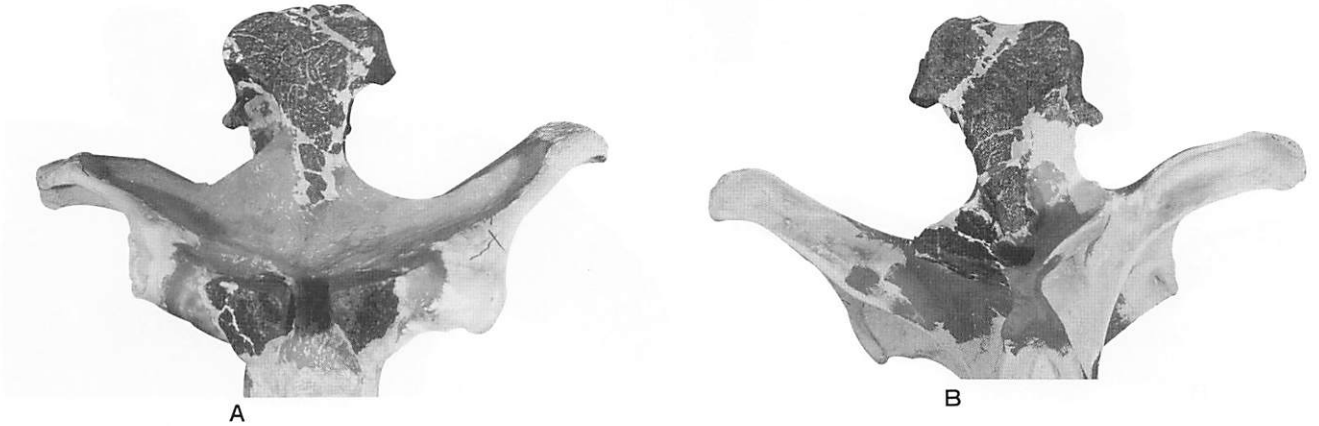


Figure 33: Dorsal Vertebra #8 [Cat. No. 589]. A. anterior view ; B. posterior view

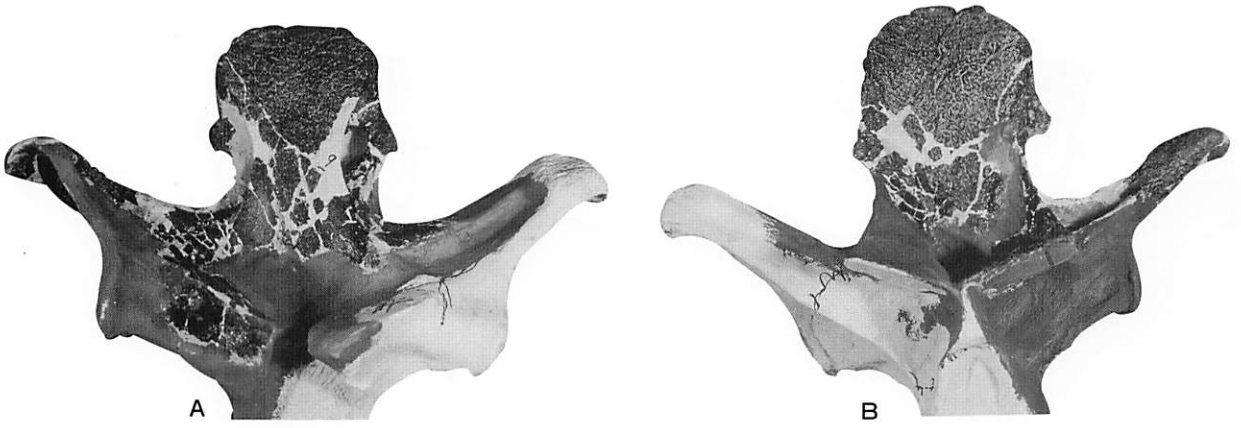


Figure 34: Dorsal Vertebra #9 [Cat. No. 590]. A. anterior view ; B. posterior view

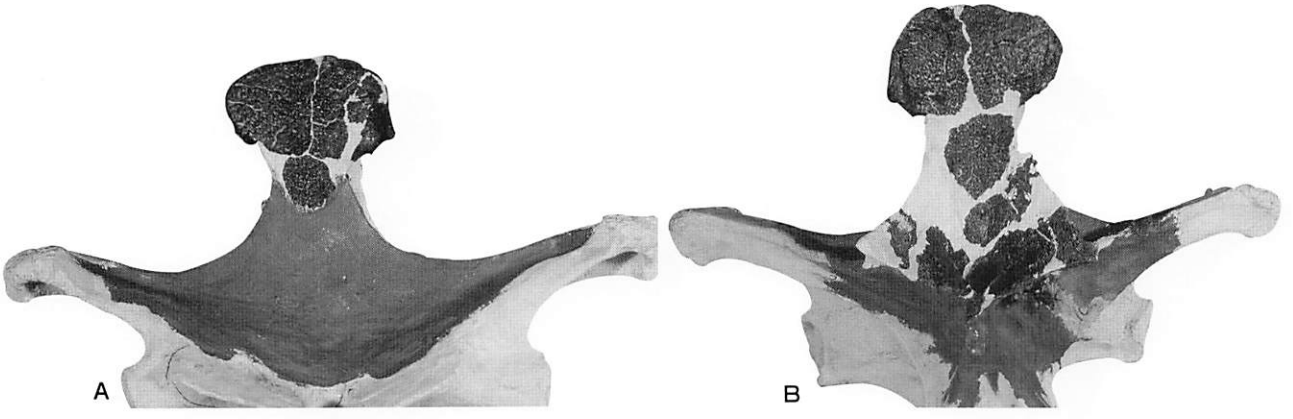


Figure 35: Dorsal Vertebra #10 [Cat. No. 591]. A. anterior view ; B. posterior view

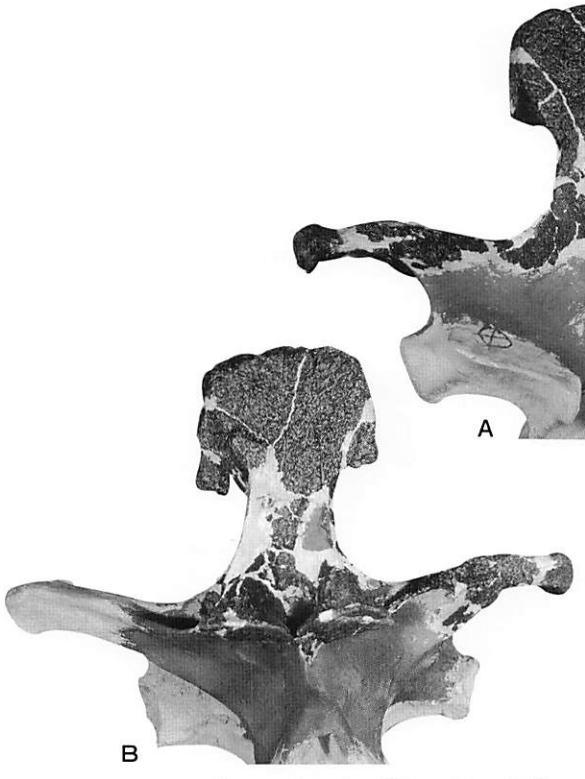


Figure 36: Dorsal Vertebra #11 [Cat. No. 592].
A. anterior view ; B. posterior view

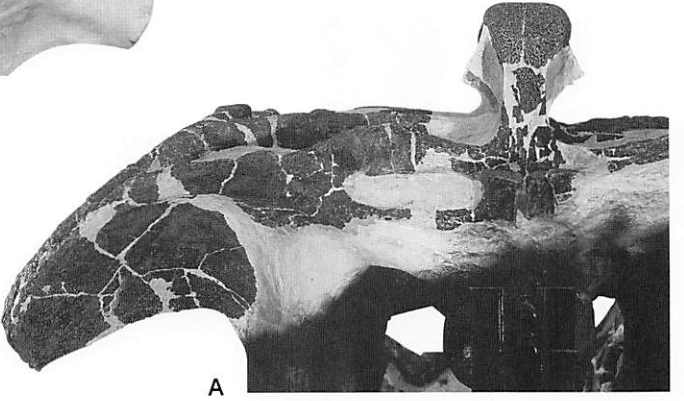


Figure 37: Dorsal Vertebra #12 [Cat. No. 593].
A. anterior view

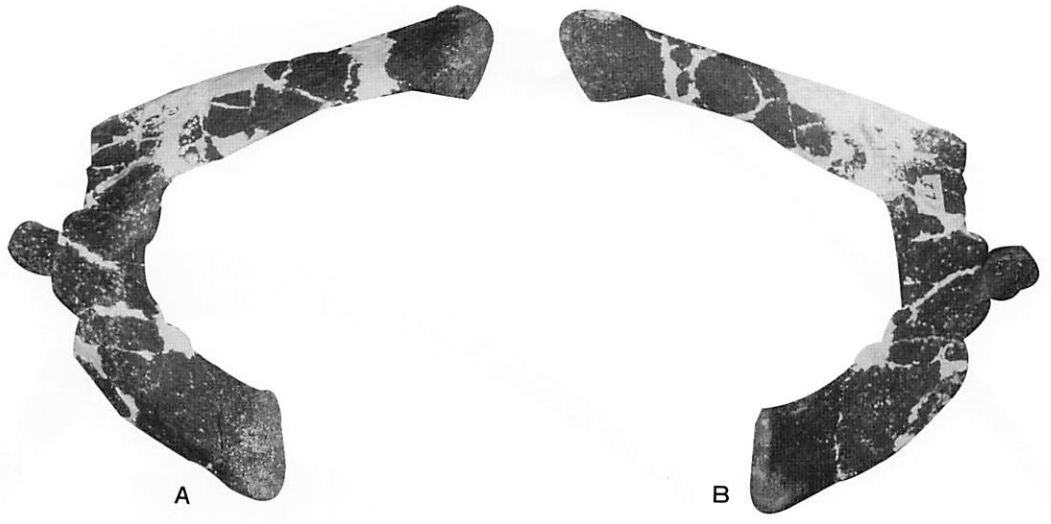


Figure 38: Right cervical Rib #12 [Cat. No. 498]. A. anterior view; B. posterior view



Figure 39: Rib Left #L2, L3[Cat. No. 478, 479]. A. L2 anterior view; B. L2 posterior view; C. L3 anterior view; D. L3 posterior view;



Figure 40. Ribs : Left #3-#11 [Cat. No. 478-488] A-I. posterior views



Figure 40. continued. Ribs : Left #3-#11 [Cat. No. 478-488] J-R, anterior view

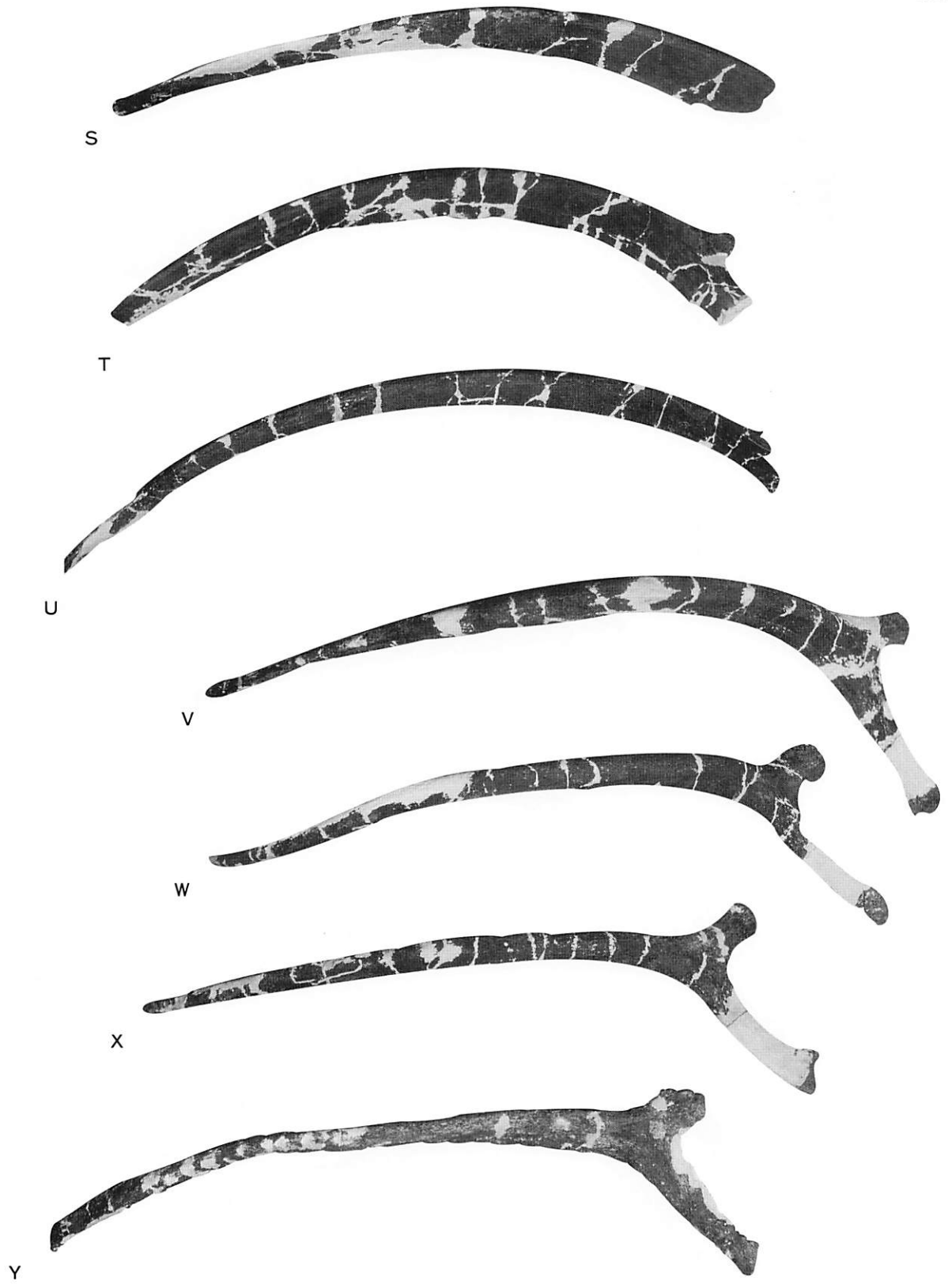


Figure 40. continued. Ribs : Right #5-#11 [Cat. No. 490-495, 497] S-Y, anterior views



Figure 40. continued. Ribs : Right #5-#11 [Cat. No. 490-495, 497] Z-FF, Dosterior views



Figure 41: Gastralia? [Cat. No. 578] A. dorsal view ; B. veatral view

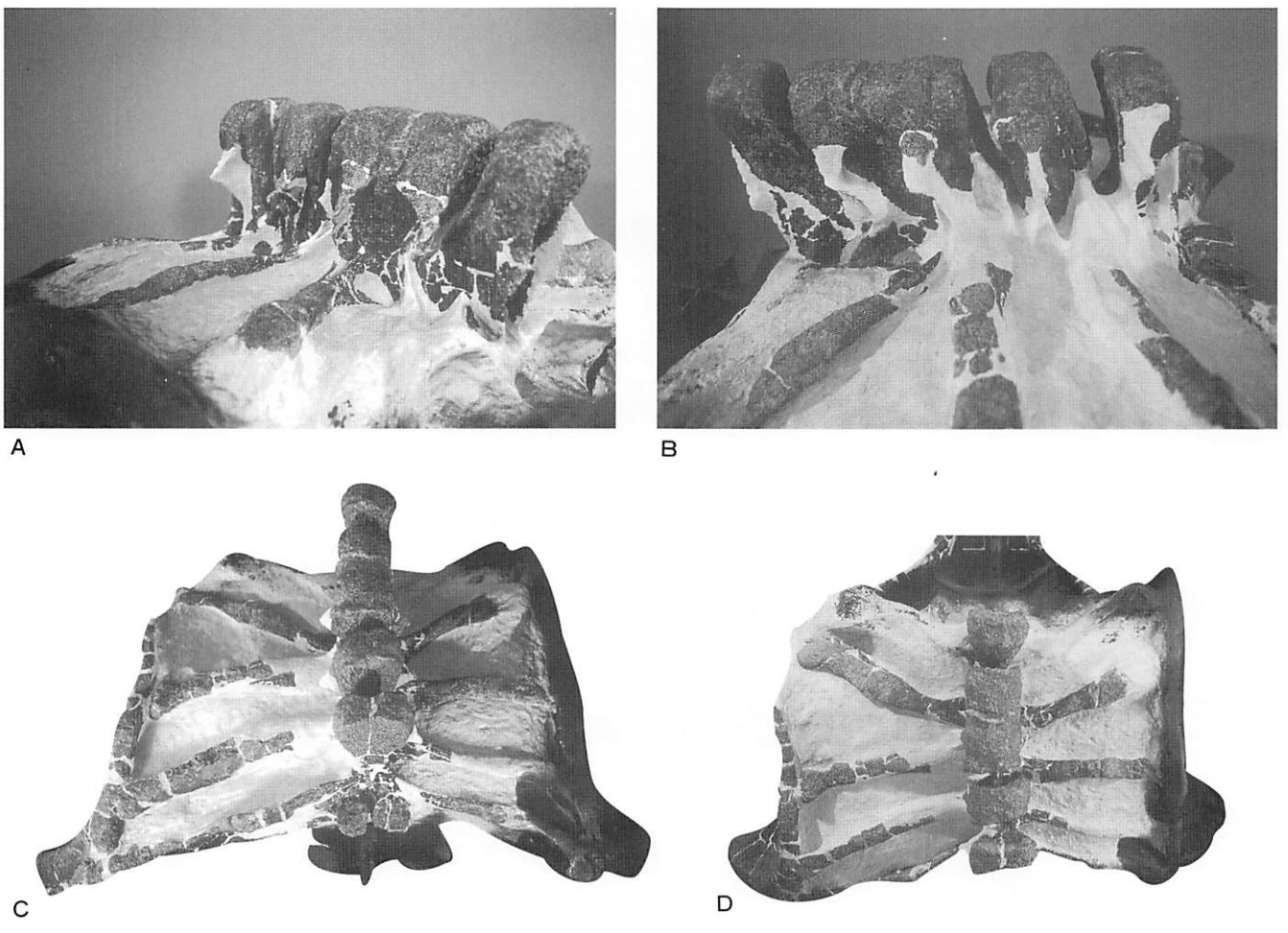


Figure 42: Sacrum. A. left lateral view; B. right lateral view; C. anterior-dorsal view; D. dorsal view.

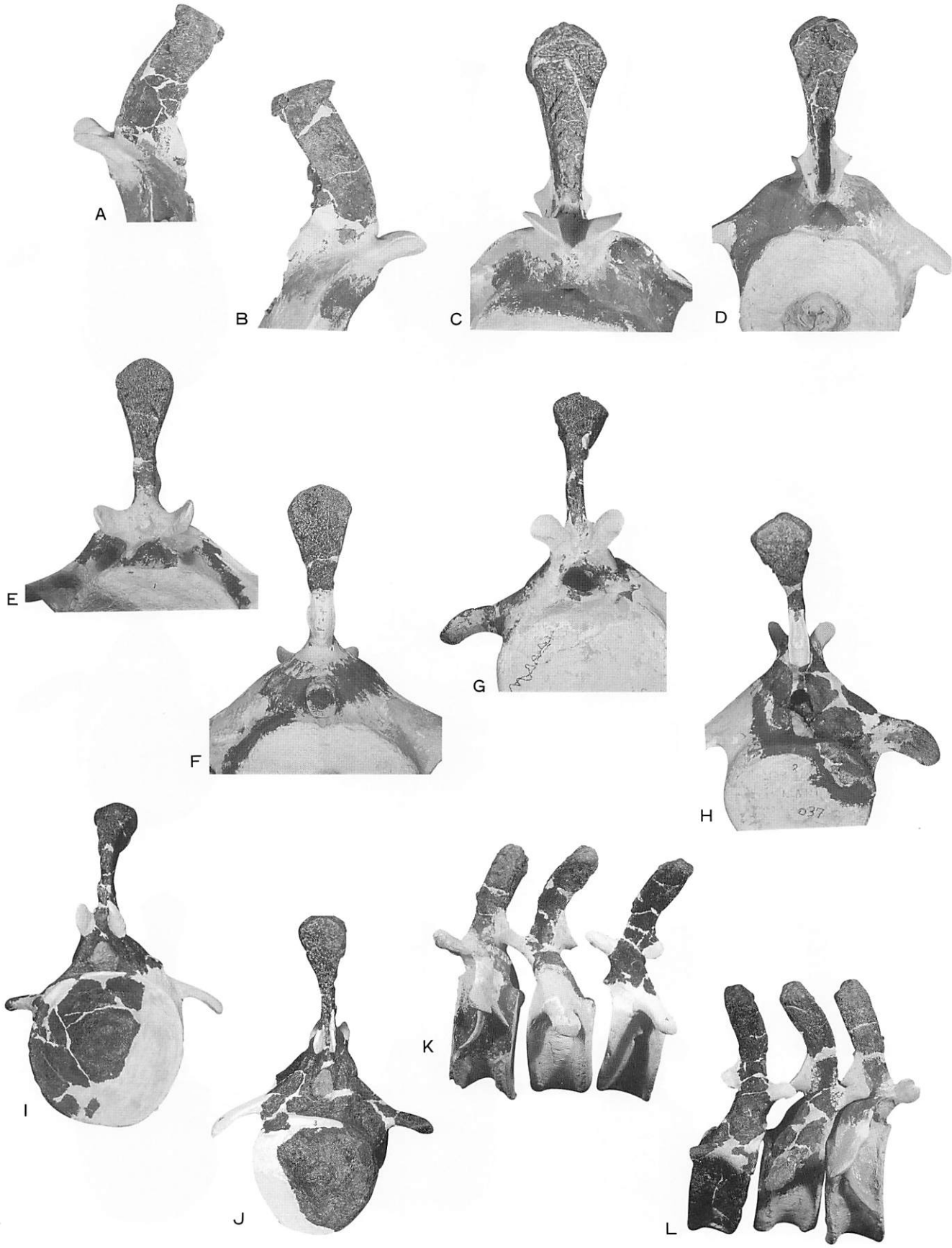


Figure 43: Caudal Sacral. A. left lateral view; B. right lateral view; C. anterior view; D. posterior view; Caudal Vertebrae [Cat. No. #1: 501; #2: 502; #3: 503] (#1: E-F, #2: G-H, #3: I-J). E. anterior view; F. posterior view; G. anterior view; H. posterior view; I. anterior view; J. posterior view; K. Caudal Vertebrae #1·2·3 left lateral view in articulation; L. Caudal Vertebrae #1·2·3 right lateral view in articulation

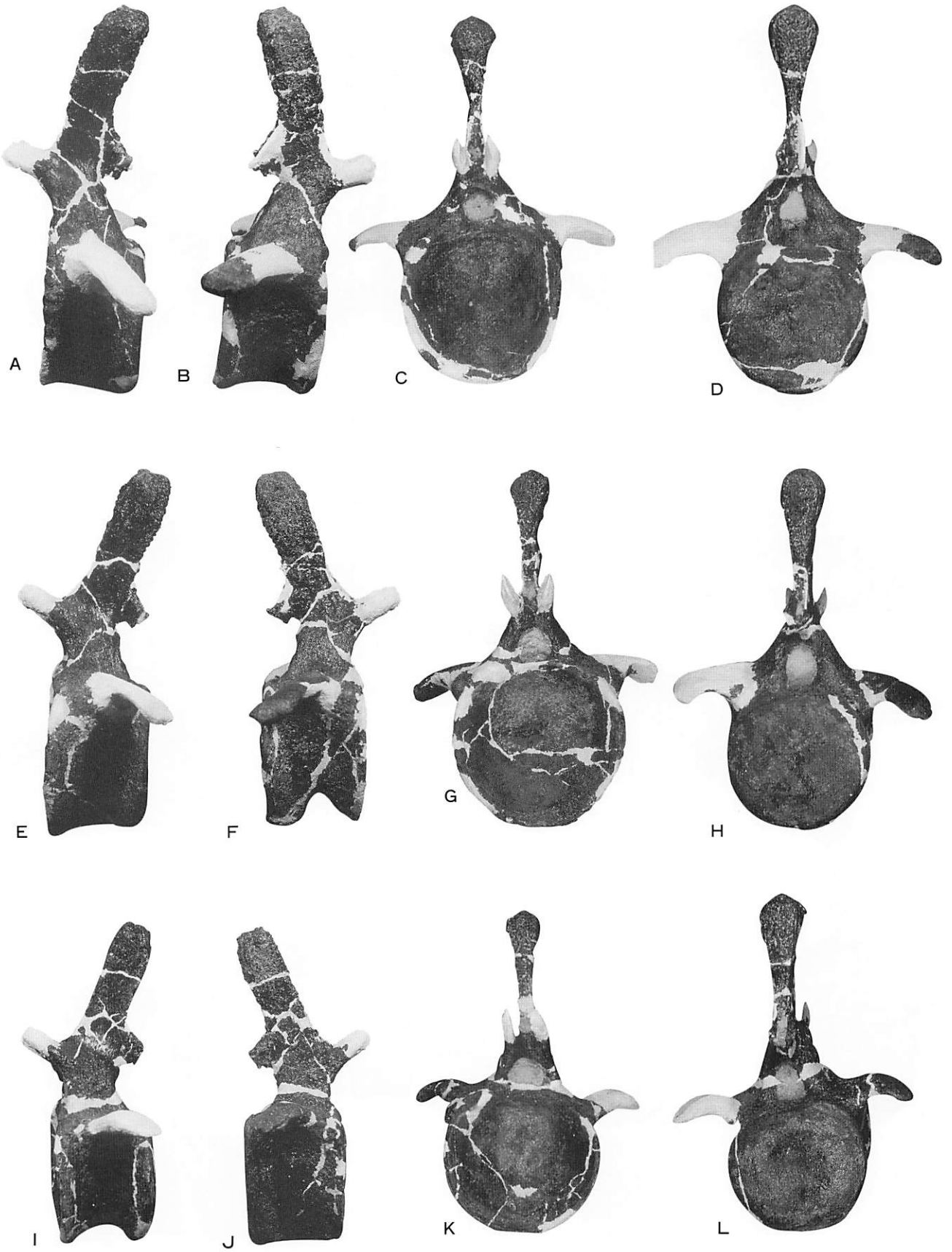


Figure 44: Caudal Vertebrae [Cat. No. #4: 504; #5: 505; #6: 506] (#4: A-D, #5: E-H, #6: I-L); A. left lateral view; B. right lateral view; C. anterior view; D. posterior view; E. left lateral view; F. right lateral view; G. anterior view; H. posterior view; I. left lateral view; J. right lateral view; K. anterior view; L. posterior view

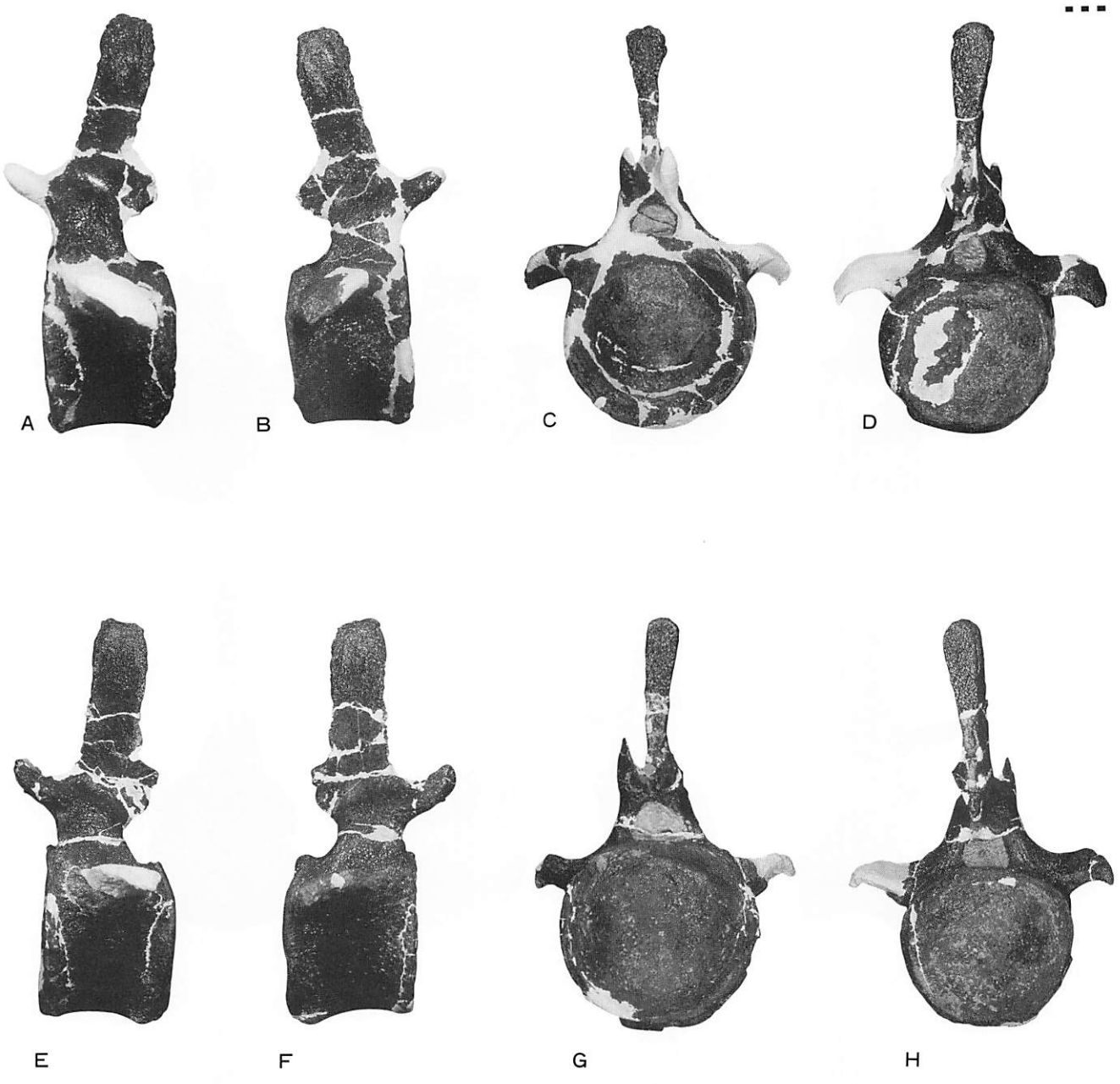


Figure 45: Caudal Vertebrae [Cat. No. #7: 507; #8: 508] (#7: A-D, #8: E-H). A. left lateral view; B. right lateral view; C. anterior view; D. posterior view; E. left lateral view; F. right lateral view; G. anterior view; H. posterior view

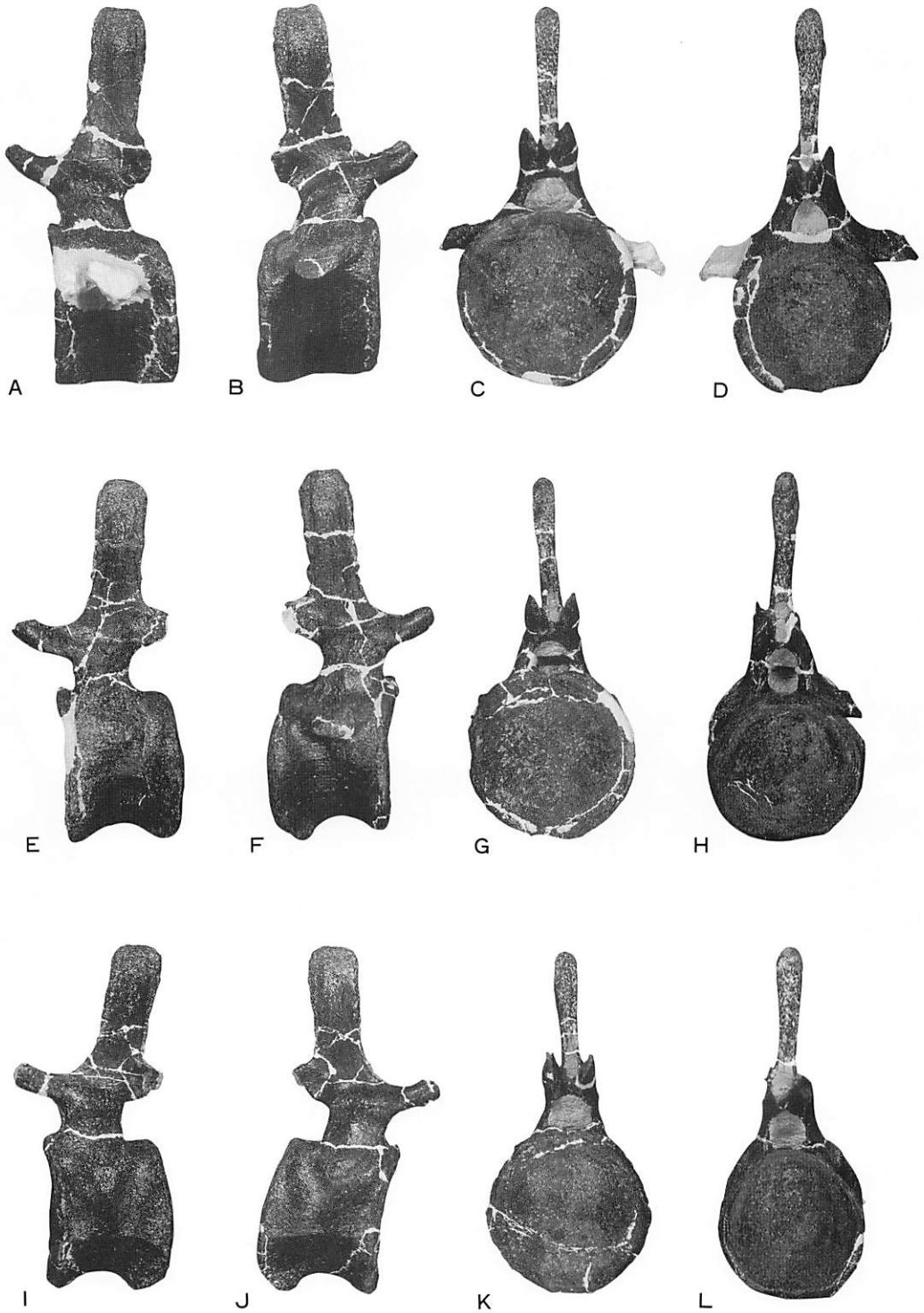


Figure 46: Caudal Vertebrae [Cat. No. #9: 509; #10: 510; #11: 511] (#9:A-D, #10:E-H, #11:I-L). A. left lateral view; B. right lateral view; C. anterior view; D. posterior view; E. left lateral view; F. right lateral view; G. anterior view; H. posterior view; I. left lateral view; J. right lateral view: K. anterior view; L, posterior view

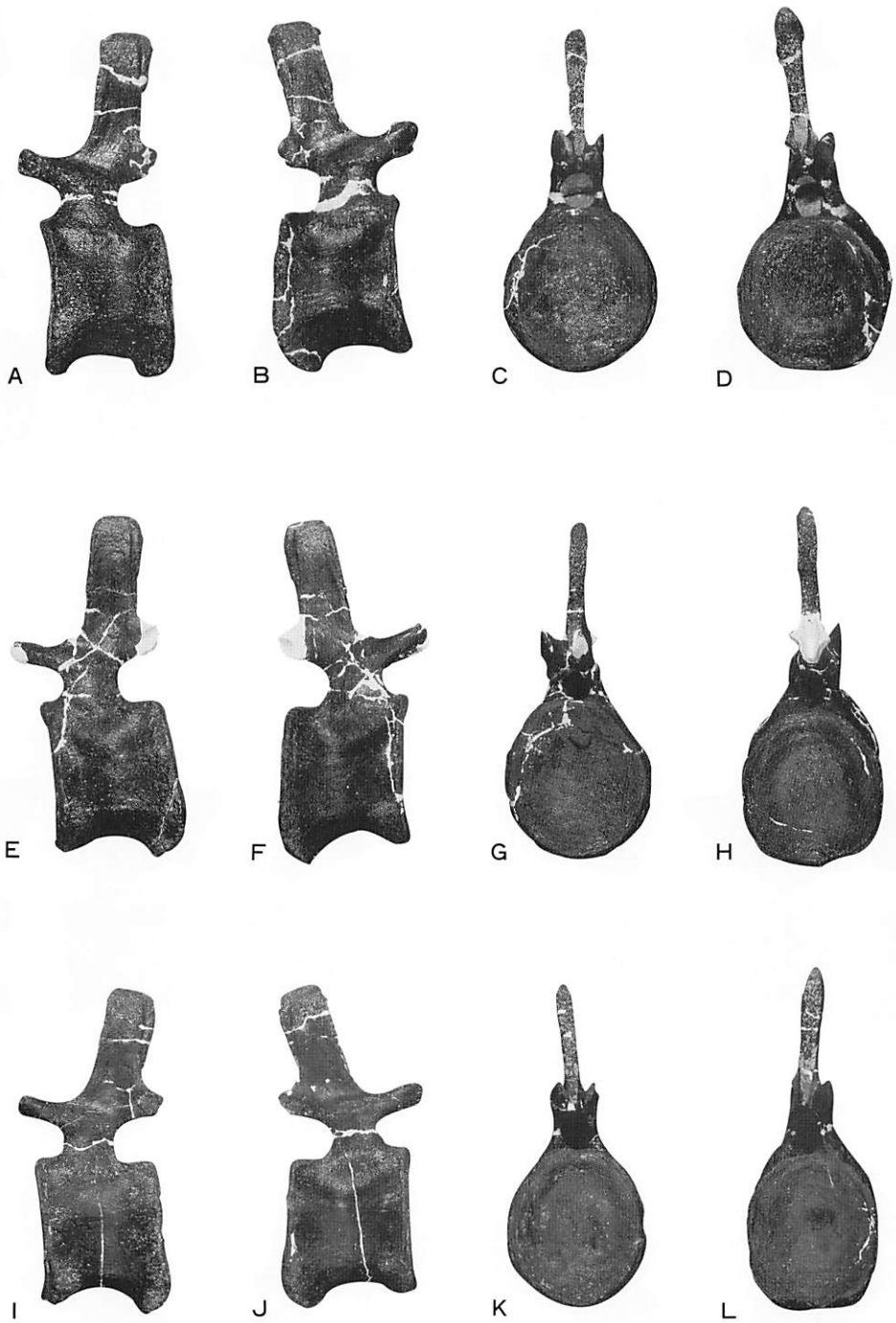


Figure 47: Caudal Vertebrae [Cat. No. #12: 512; #13: 513; #14: 514] (#12: A-D, #13: E-H, #14: I-L). A. left lateral view; B. right lateral view; C. anterior view; D. posterior view; E. left lateral view; F. right lateral view; G. anterior view; H. posterior view; I. left lateral view; J. right lateral view; K. anterior view; L. posterior view

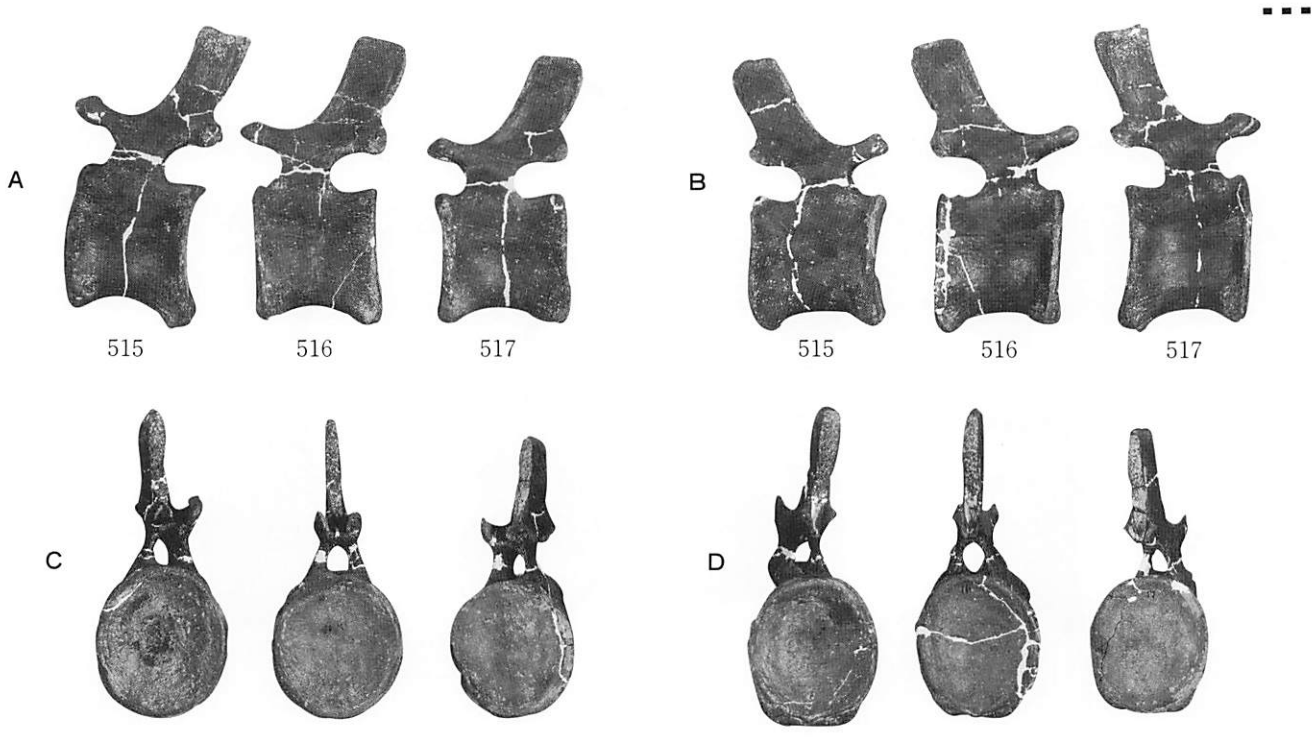


Figure 48: Caudal Vertebrae [Cat. No. 515-517] (#15-#17). A. left lateral views; B. right lateral views; C. anterior views; D. posterior views

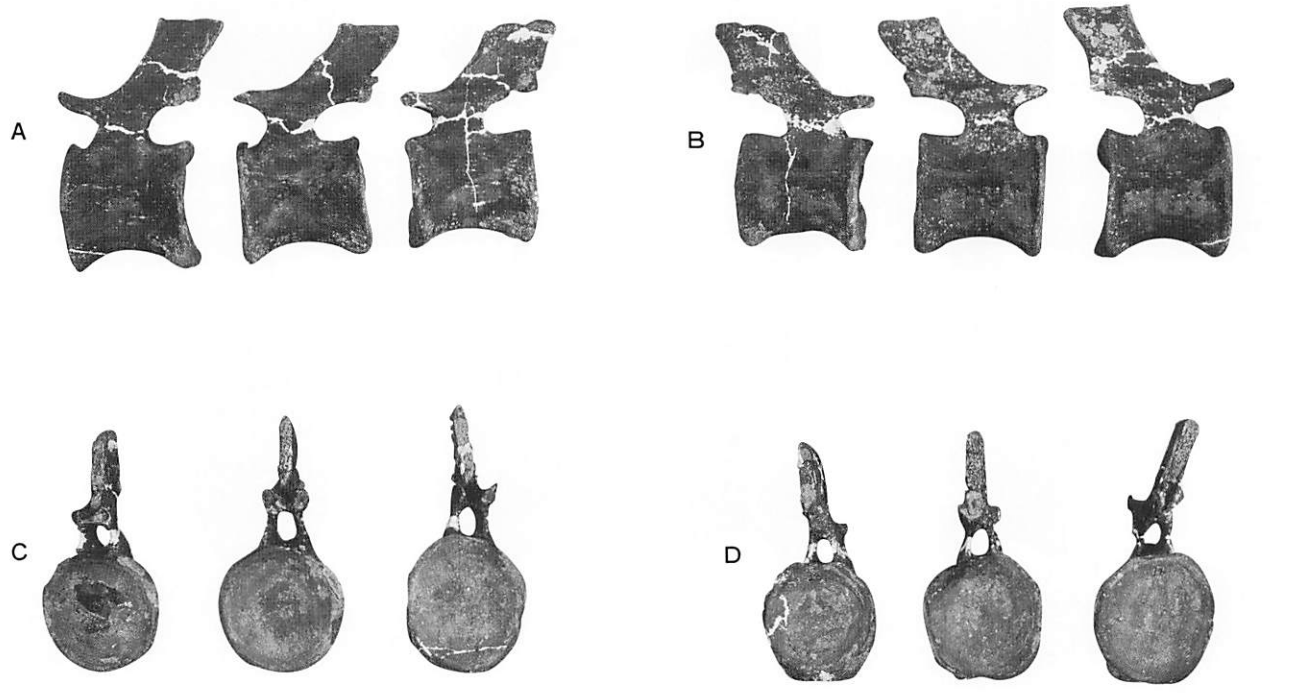


Figure 49: Caudal Vertebrae [Cat. No. 518-520] (#18-#20). A. left lateral views; B. right lateral views; C. anterior views; D. posterior views

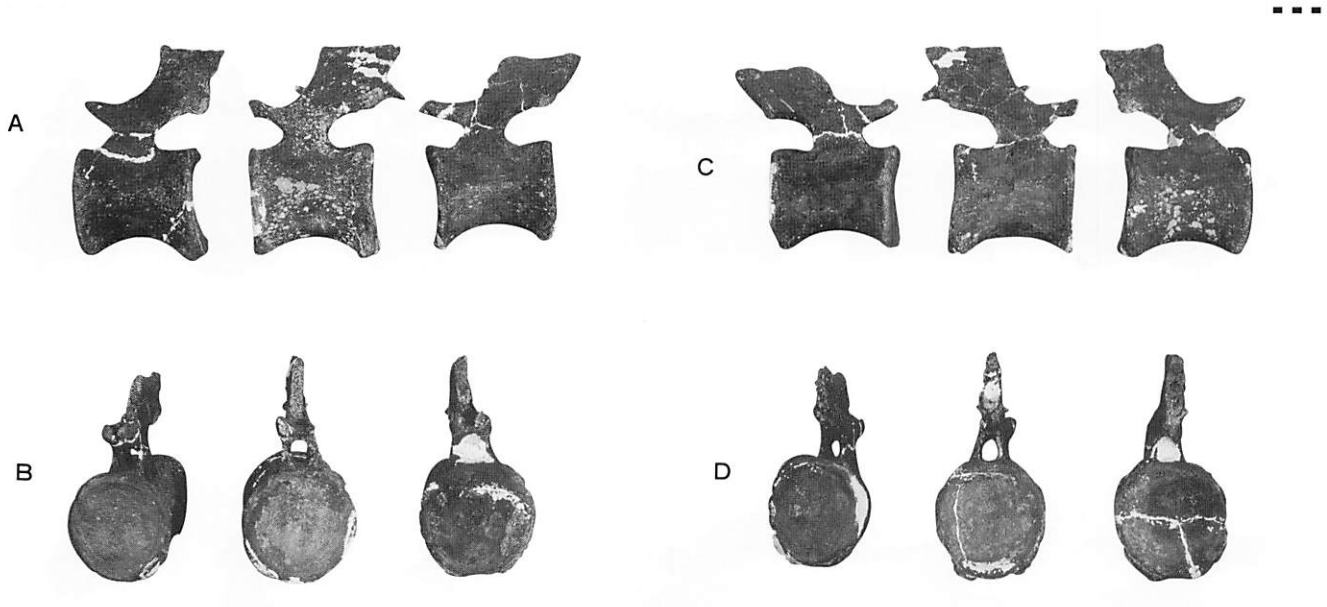


Figure 50: Caudal Vertebrae [Cat. No. 521-523] (#21-#23). A. left lateral views; B. right lateral views; C. anterior views; D. posterior views

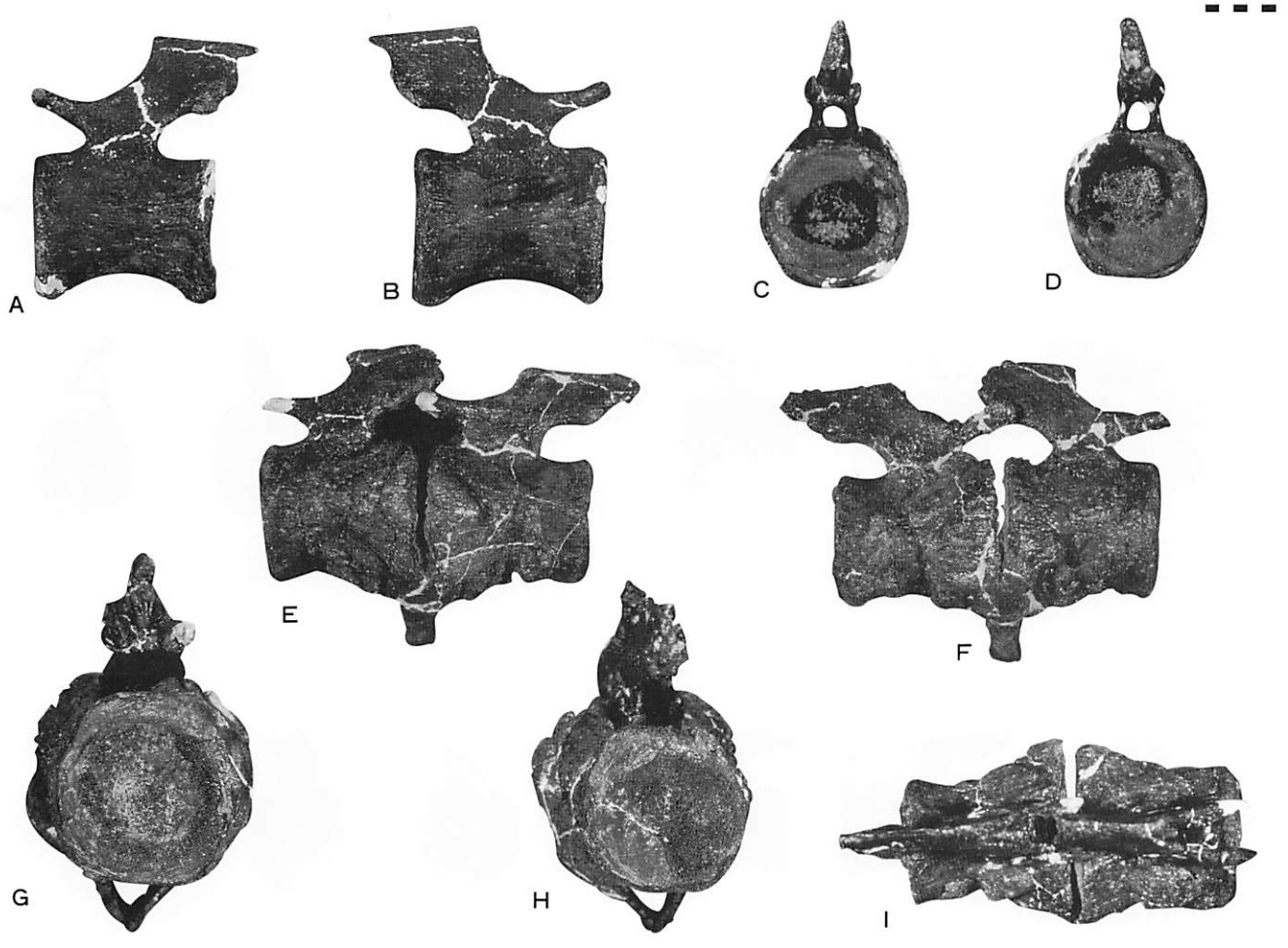


Figure 51: Caudal Vertebrae [Cat. No. #24: 524; #25: 525; #26: 526] (#24: A-D, #25: G, #26: H & I, #25-#26: E & F). A. left lateral view; B. right lateral view; C. anterior view; D. posterior view; E. left lateral view; F. right lateral view; G. anterior view; H. posterior view; I. dorsal view

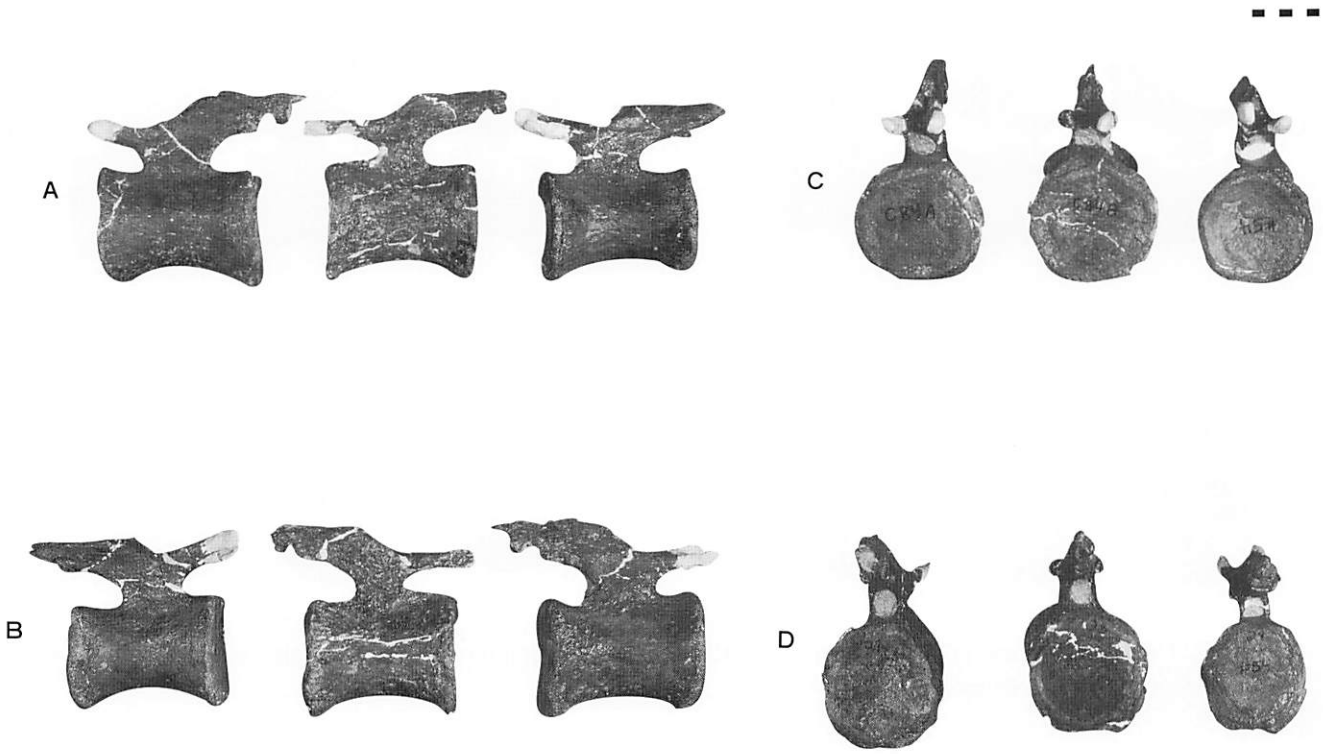


Figure 52: Caudal Vertebrae [Cat. No. 527-529] (#27-#29). A. left lateral views; B. right lateral views; C. anterior views; D. posterior views

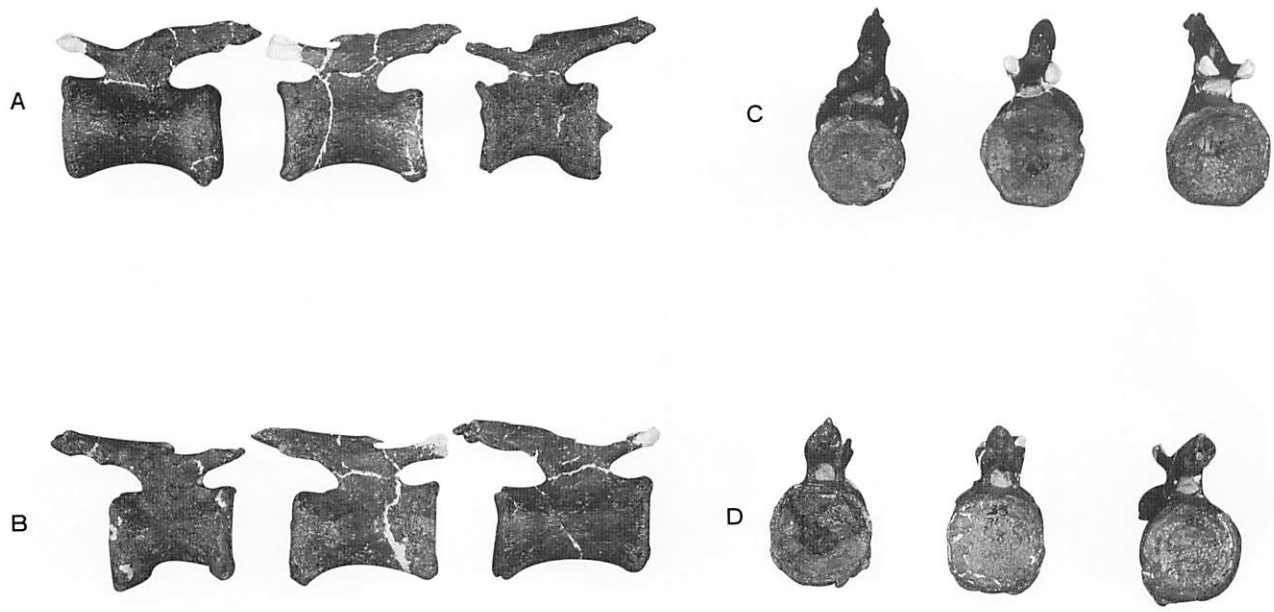


Figure 53: Caudal Vertebrae [Cat. No. 530-532] (#30-#32). A. left lateral views; B. right lateral views; C. anterior views; D. posterior views

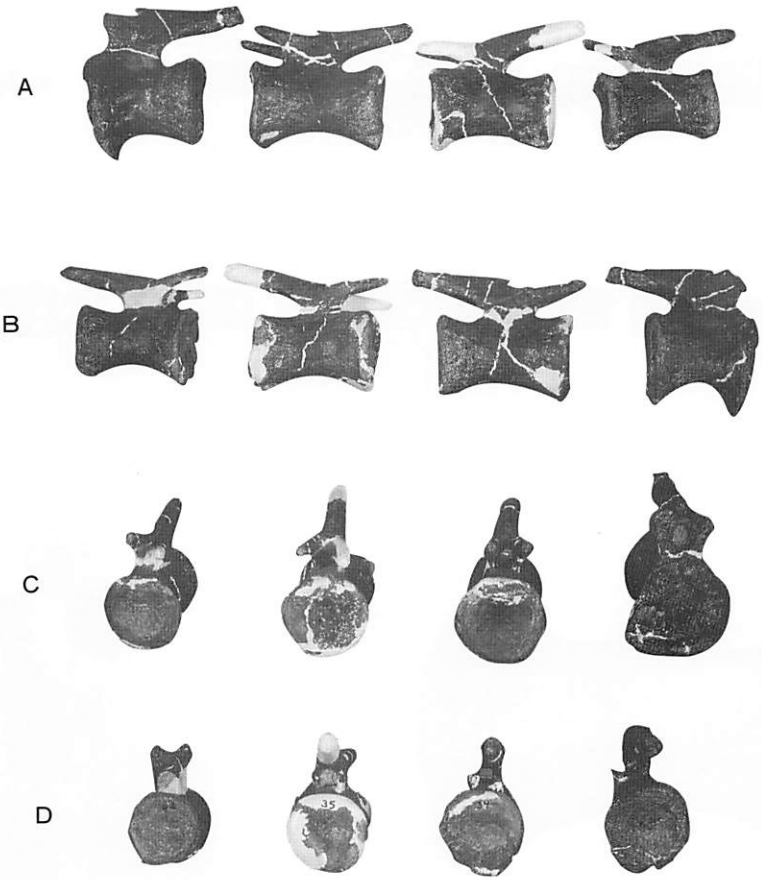


Figure 54: Caudal Vertebrae [Cat. No. 533-536] (#33-#36). A. left lateral views; B. right lateral views; C. anterior views; D. posterior views

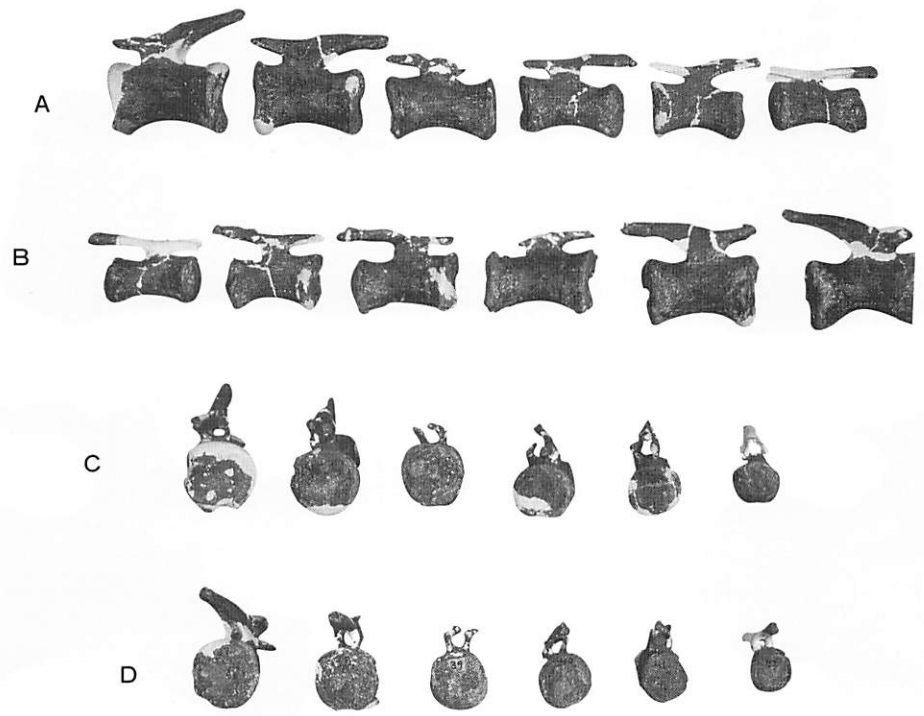


Figure 55: Caudal Vertebrae [Cat. No. 537-542] (#37-#42). A. left lateral views; B. right lateral views; C. anterior views; D. posterior views

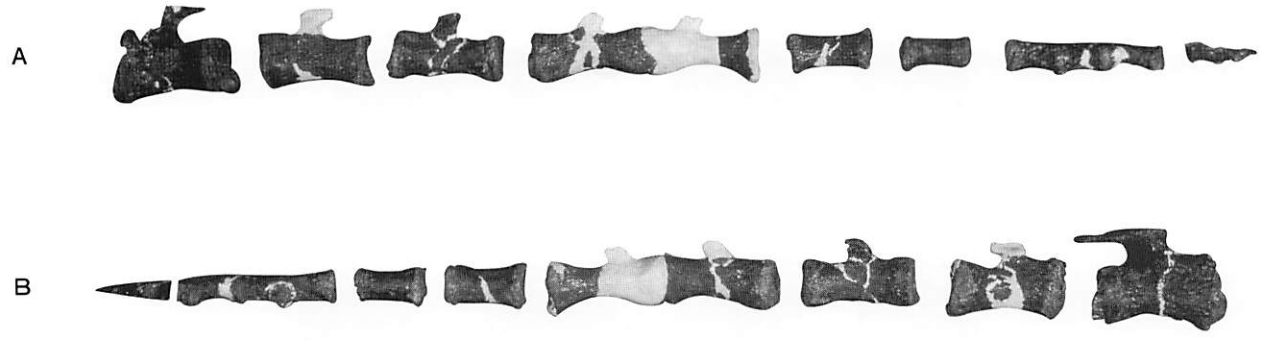


Figure 56: Caudal Vertebrae [Cat. No. 543-553] (#43-#53). A. left lateral views; B. right lateral views

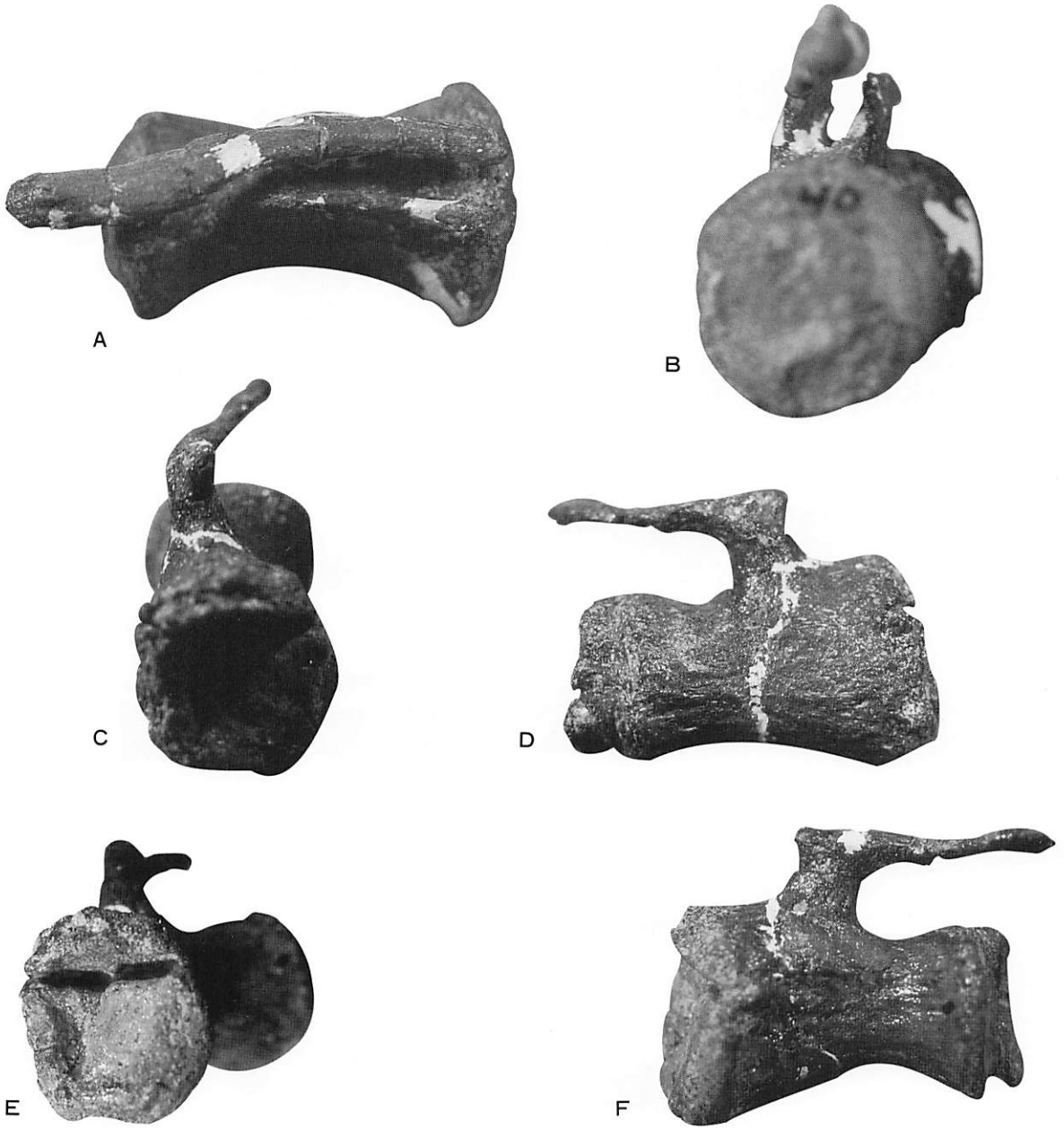


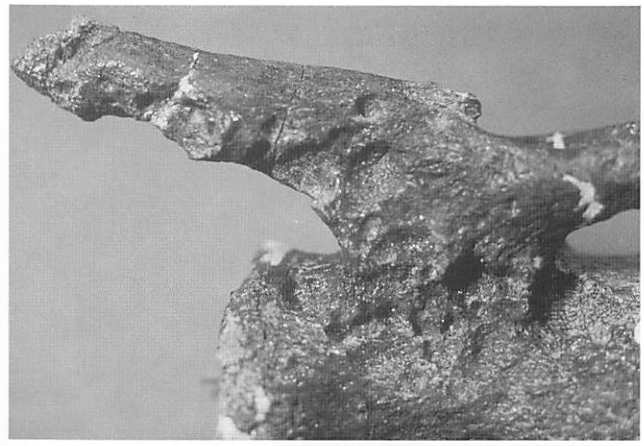
Figure 57: Caudal Vertebrae (#40: A-B & #43: C-F). A & B. various views, spina bifida; C-F. various views, spina bifida



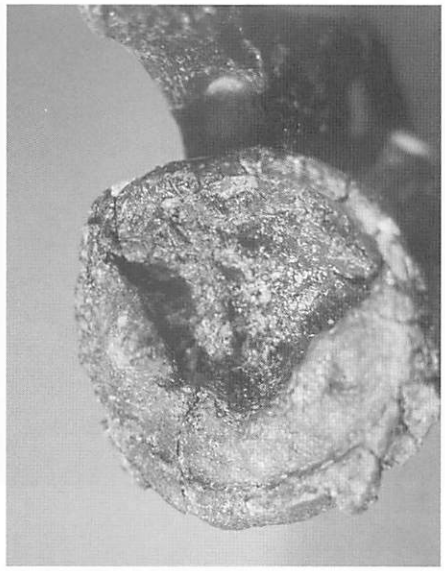
A



B



D



C



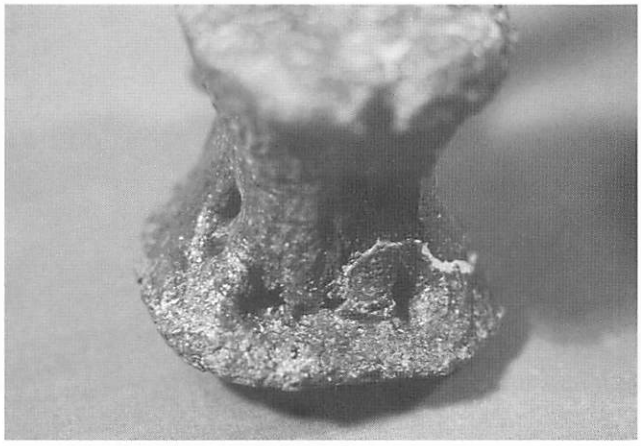
E



G

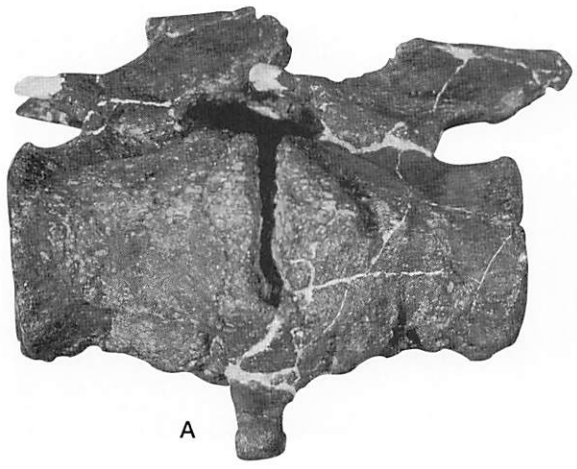


H

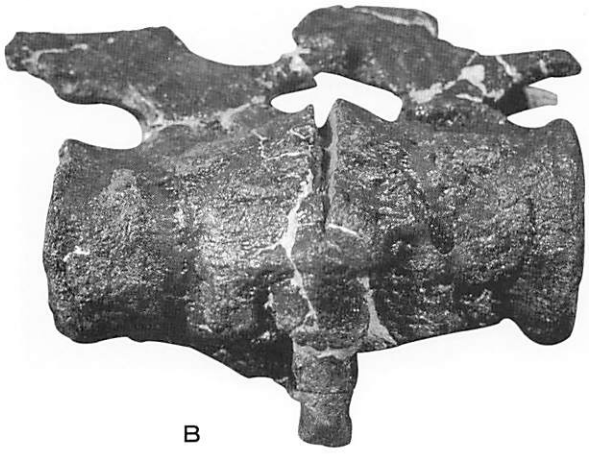


F

Figure 58: Caudal Vertebrae (#32 & #33, #50-#52). A. #33 Caudal, anterior view; B. #32 Caudal, anterior view; C. #32 Caudal, posterior view; D. #32 Caudal, lateral view of neural spine; E. #32 and 33 Caudals, lateral view; F. #33 Caudal, ventral nutrient foramina, G & H. Caudal Vertebrae #50-#52 various.



A



B



C



E



D

Figure 59: Caudal Vertebrae (#25 & #26). A. #25 & #26 Caudals, left lateral view; B. #25 & #26 Caudals, right lateral view; C. #26 Caudal, right lateral view "close up"; D. #25 Caudal, right lateral view "close up"; E. # 25 & #26 Caudals, ventral view

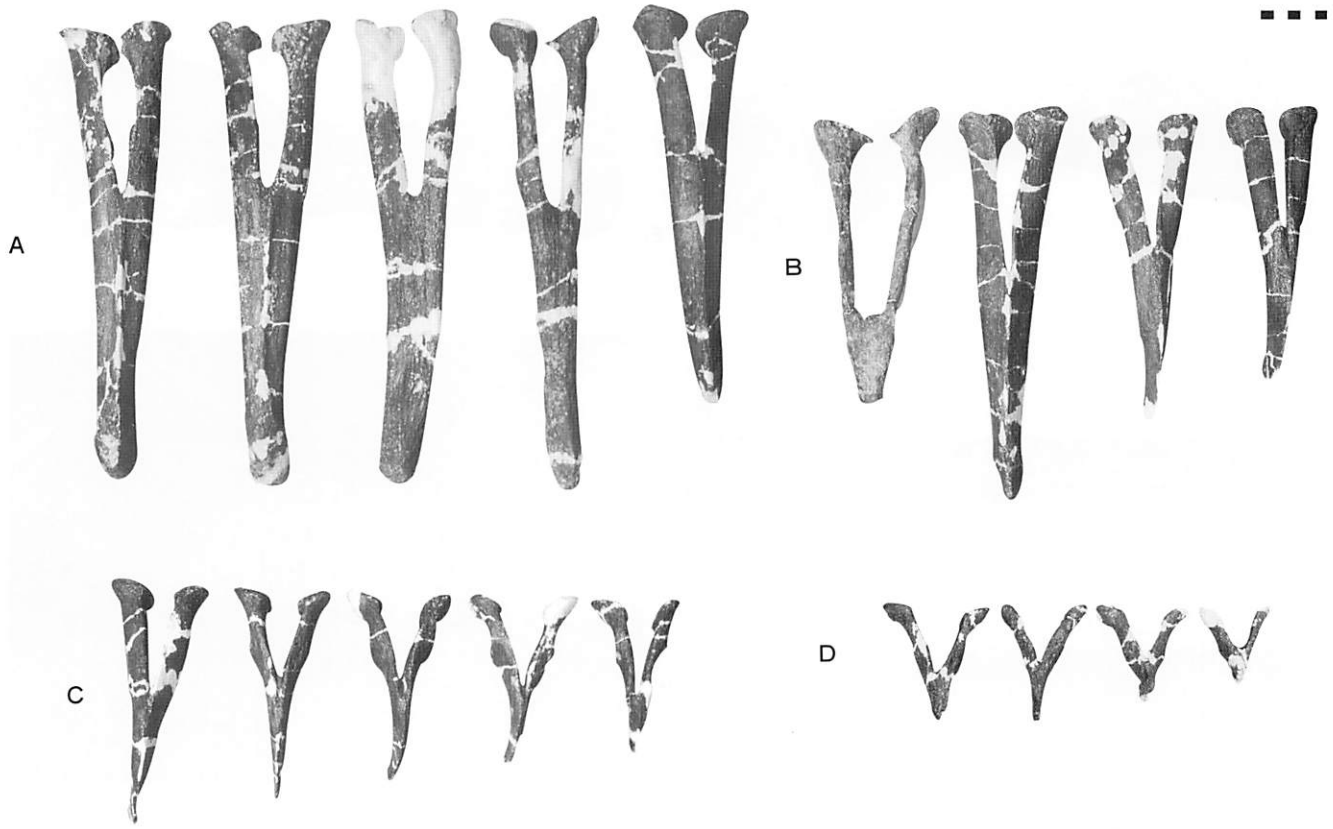


Figure 60: Chevrons [Cat. No. 454-471]. A-D. anterior views

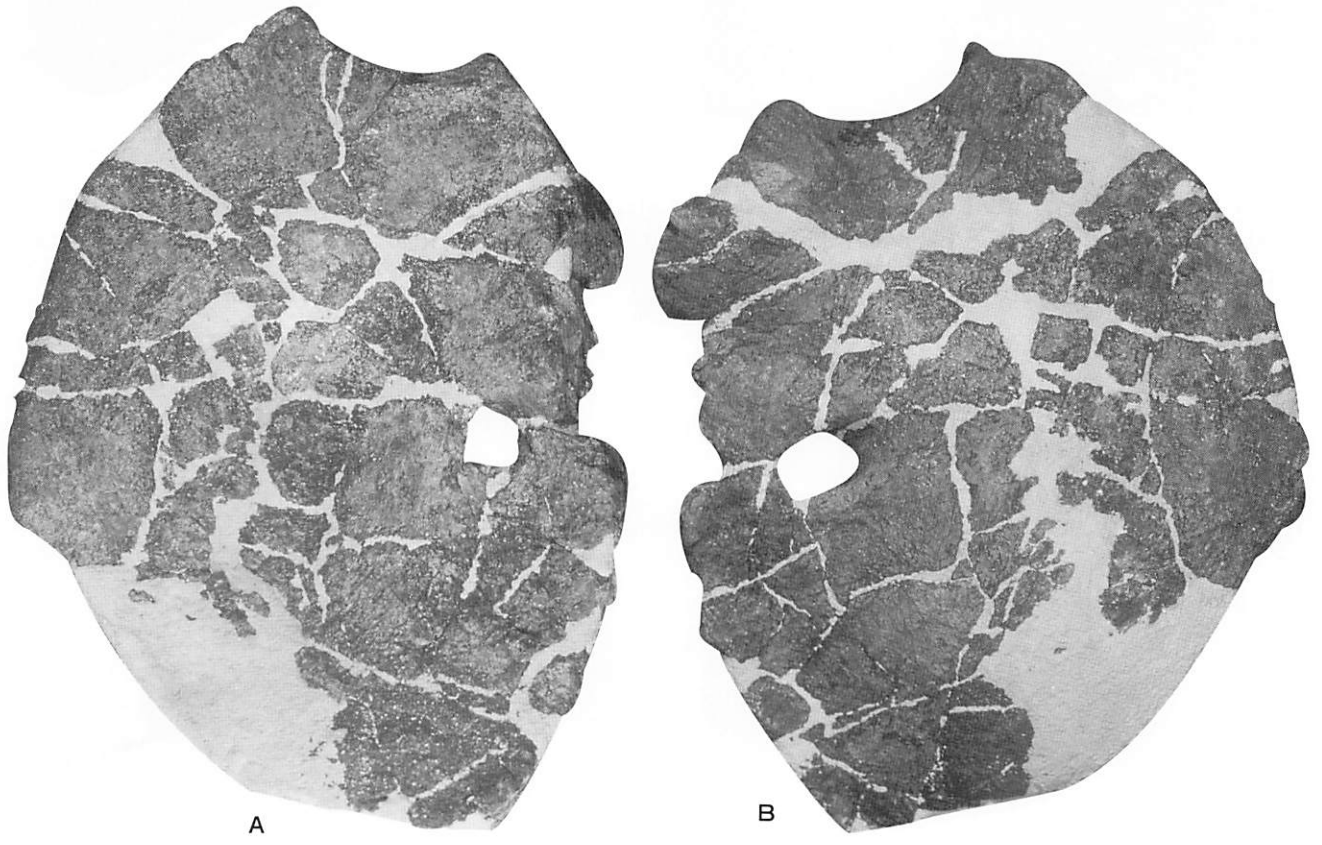


Figure 61: Coracoid. [Cat. No. 477] A. Left Coracoid, medial view; B. Left Coracoid, lateral view

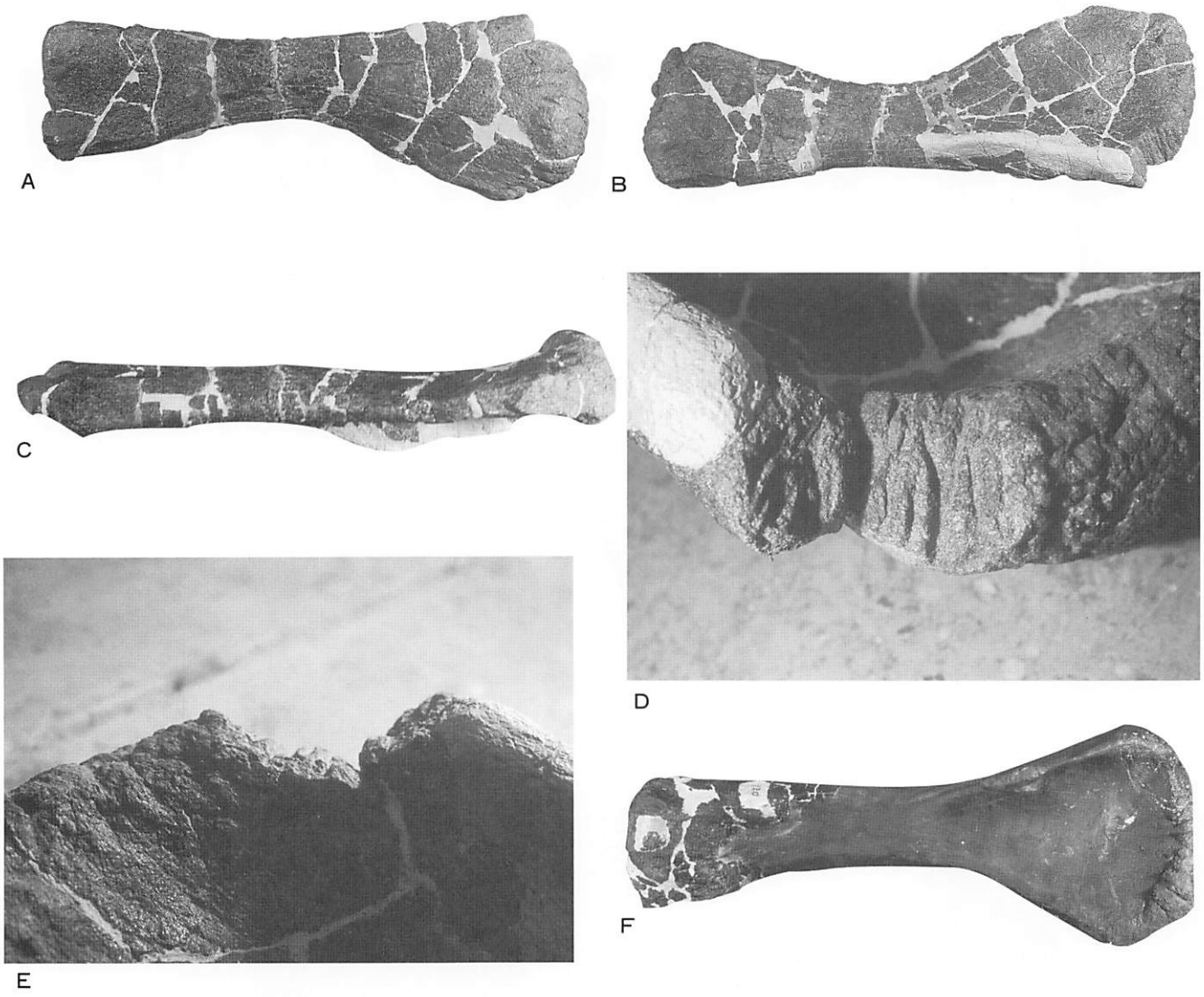


Figure 62: Humerus. A. Left, anterior view; B. Left, posterior view; C. Left, lateral view; D. Left, proximal-lateral view to show the teeth marks; E. Left, proximal-anterior-lateral view to show the teeth marks; F. Right, posterior view

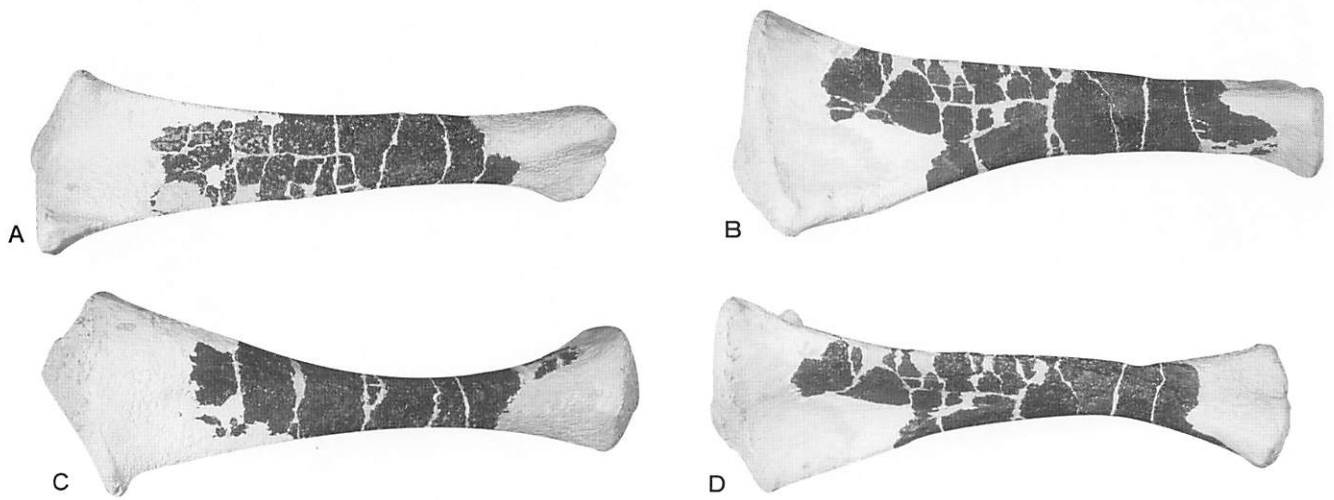


Figure 63: Left Ulna. [Cat.No.341] A. anterior view; B. posterior view; C. lateral view; D. medial view

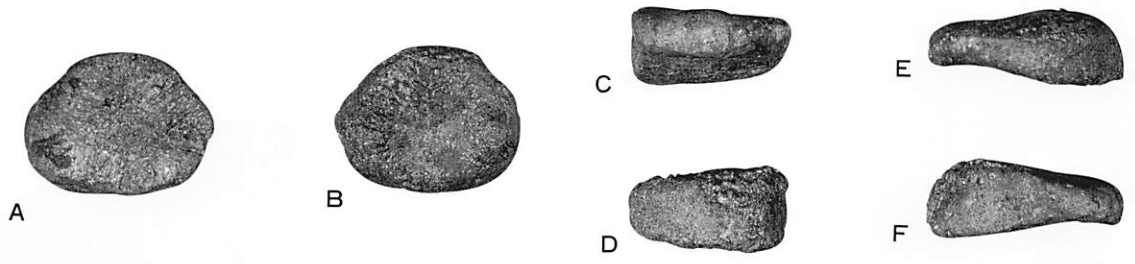


Figure 64 : Radiale. [Cat. No. 445] A. distal view; B. proximal view; C. lateral view; D. medial view; E. posterior view; F. anterior view

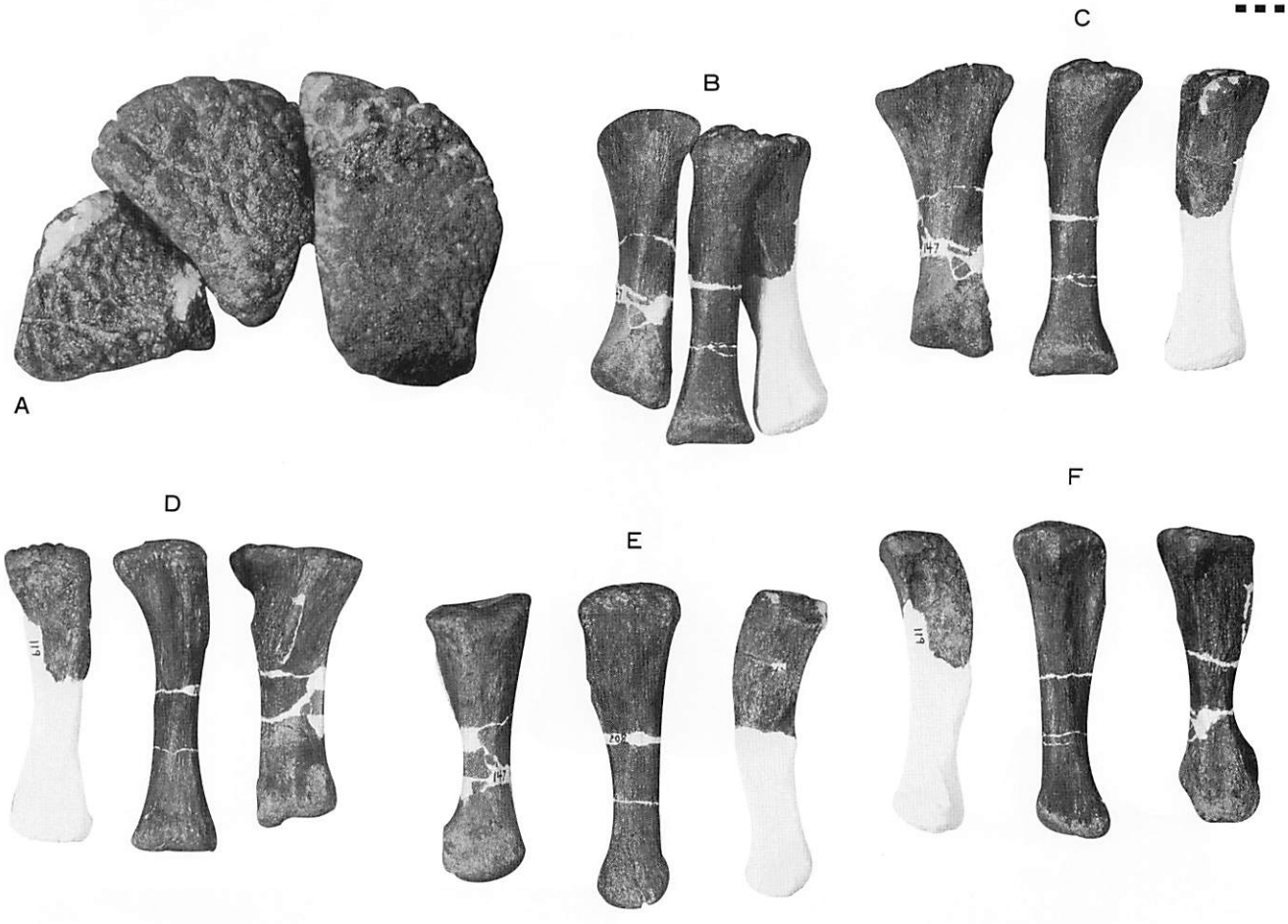


Figure 65 : Left Front Foot. [Cat. No 561-563] A. proximal view (assembled); B. Metacarpals, anterior view; C. Metacarpals, anterior view (separated); D. Metacarpals, posterior view; E. Metacarpals, medial view; F. Metacarpals, lateral view



Figure 66: Phalanges. [Cat. No. 573, 574] A. Front Phalanges, dorsal view; B. Front Phalanges, ventral view; C. Front Phalanges, anterior view; D. Front Phalanges, posterior view

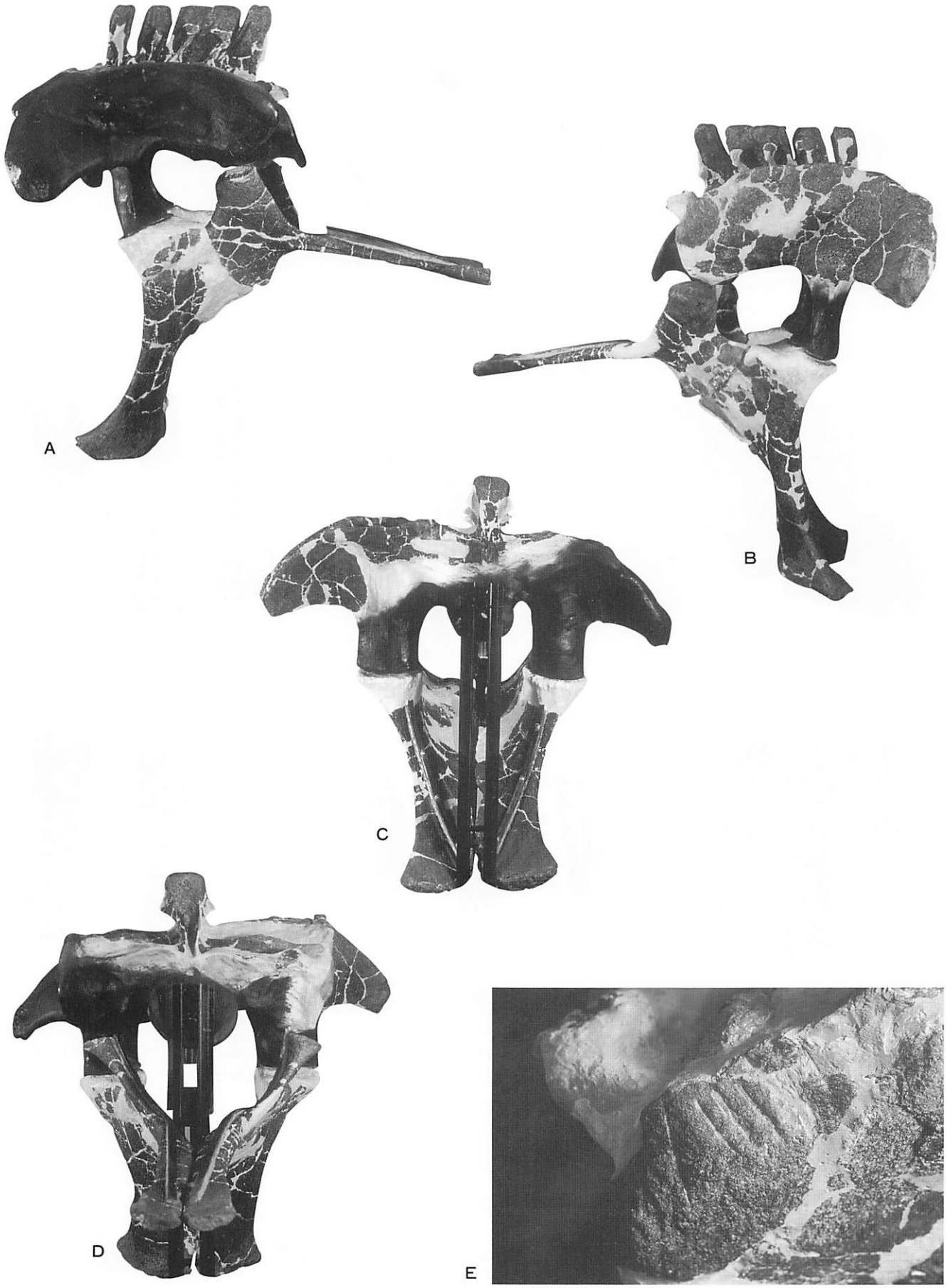


Figure 67: Sacrum. A. left lateral view; B. right lateral view; C. anterior view; D. posterior view; E. Right illium, posterior to show teeth marks.

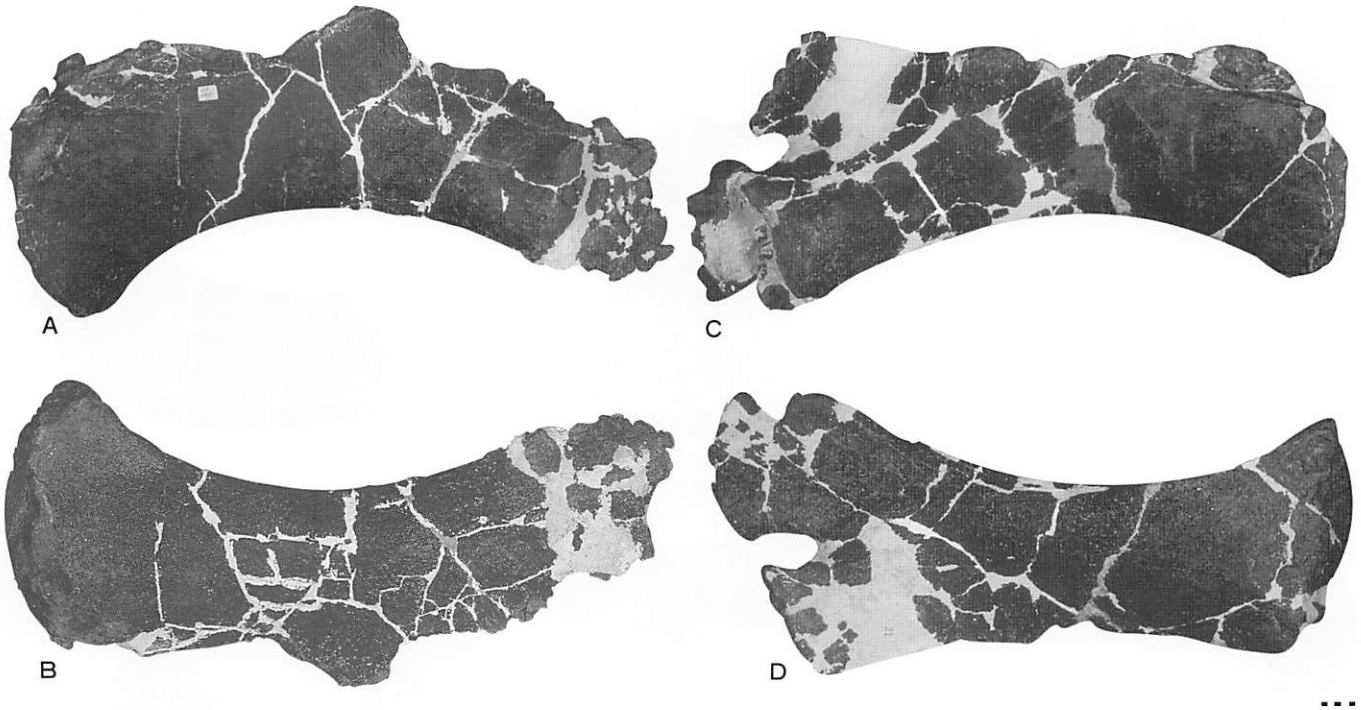


Figure 68: Pubes. [Cat. No.474, 475] A. Left, anterior-medial view; B.Left, posterior-lateral view; C. Right, anterior-medial view; D. posterior-lateral view

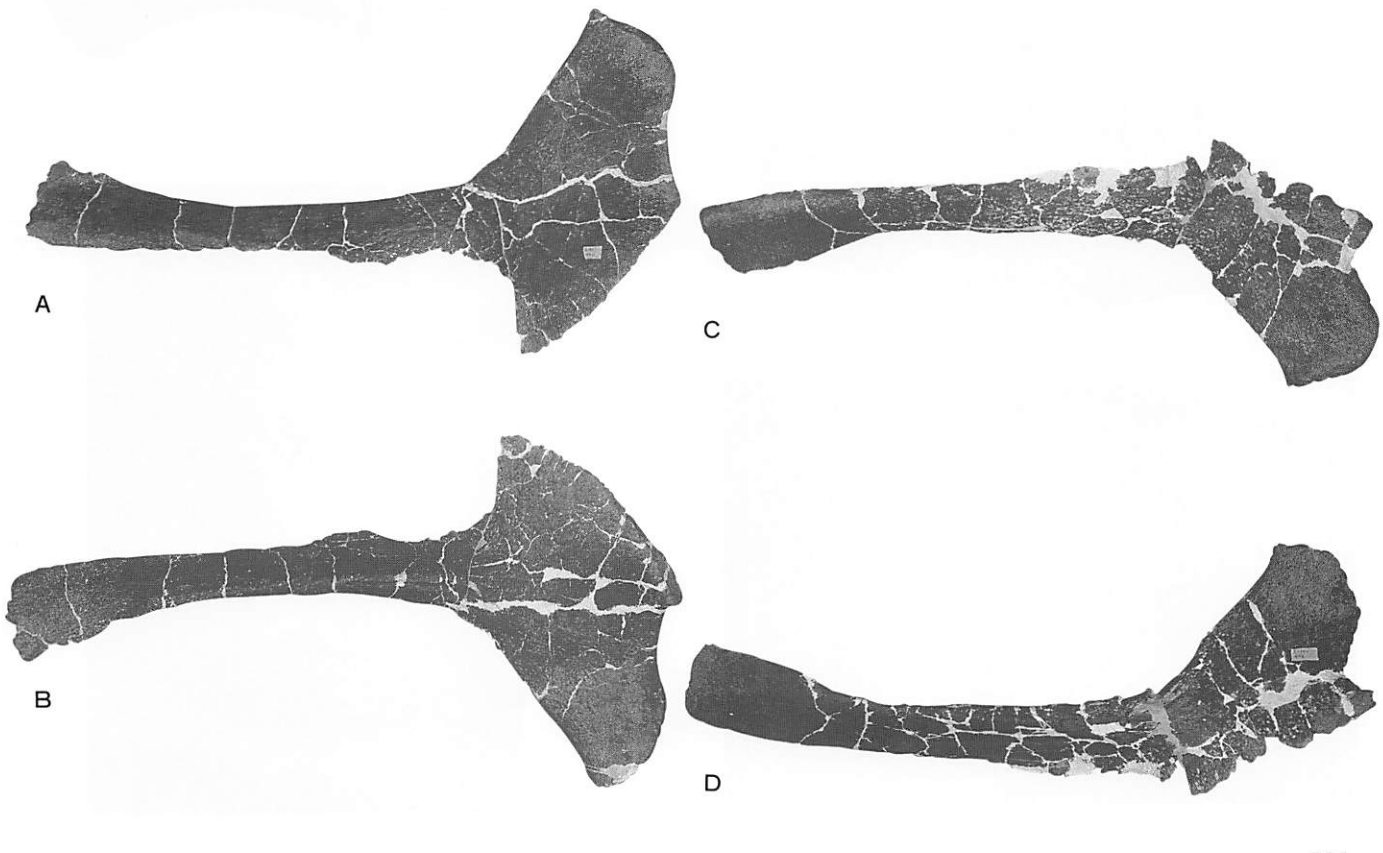


Figure 69: Ischia. [Cat. No. 472, 473] A. Left, medial-dorsal view; B. Left, lateral-ventral view; C. Right, medial-dorsal view; D.Right, lateral-ventral view

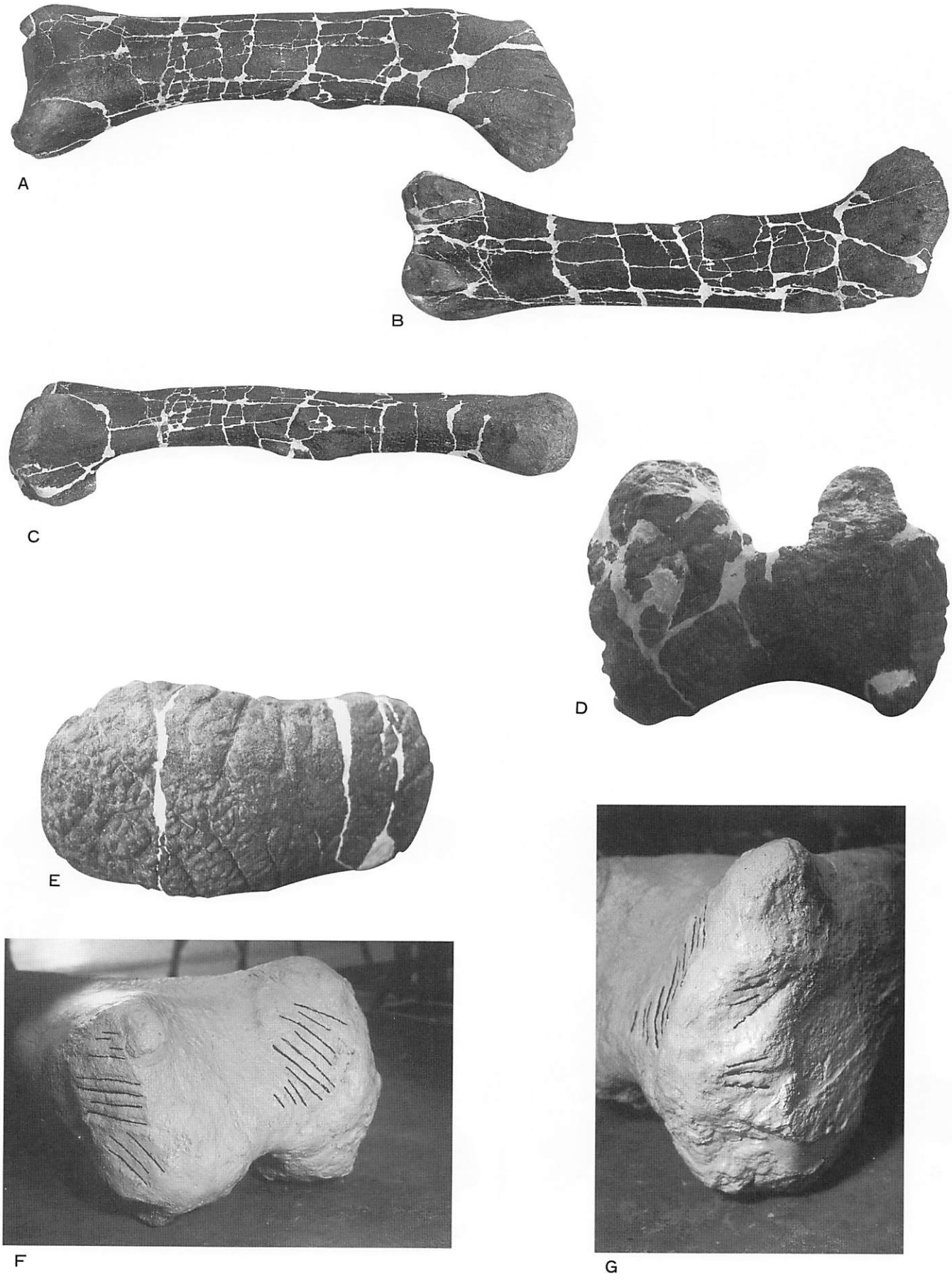


Figure 70: Right Femur [Cat. No. 338]. A. anterior view; B. posterior view; C. medial view; D. Distal view; E. proximal view; F, G. Femur cast to show position of teeth marks.

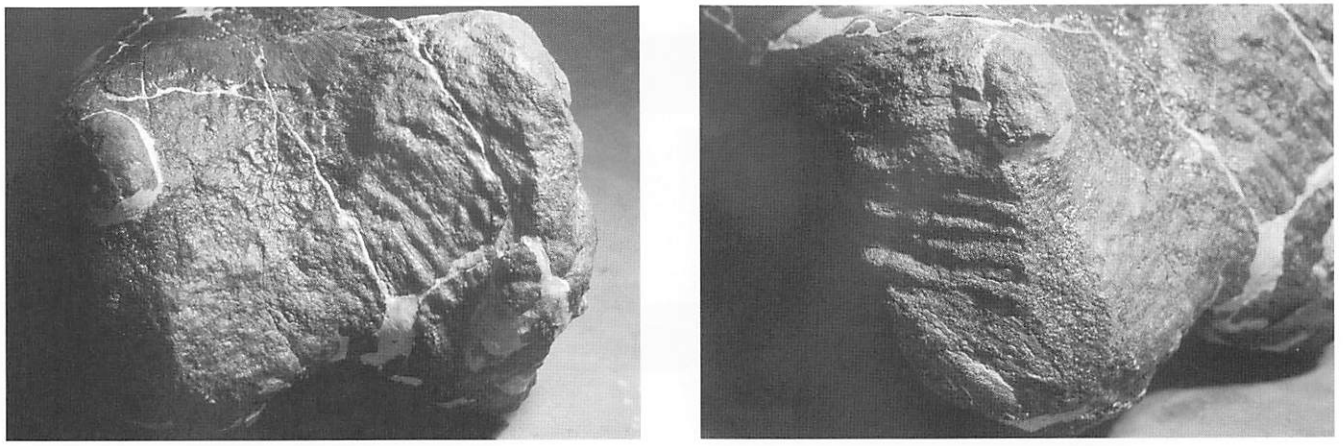


Figure 70. continued. Right Femur. [Cat. No. 338] H,I. distal view, anterior. face up, showing teeth marks.

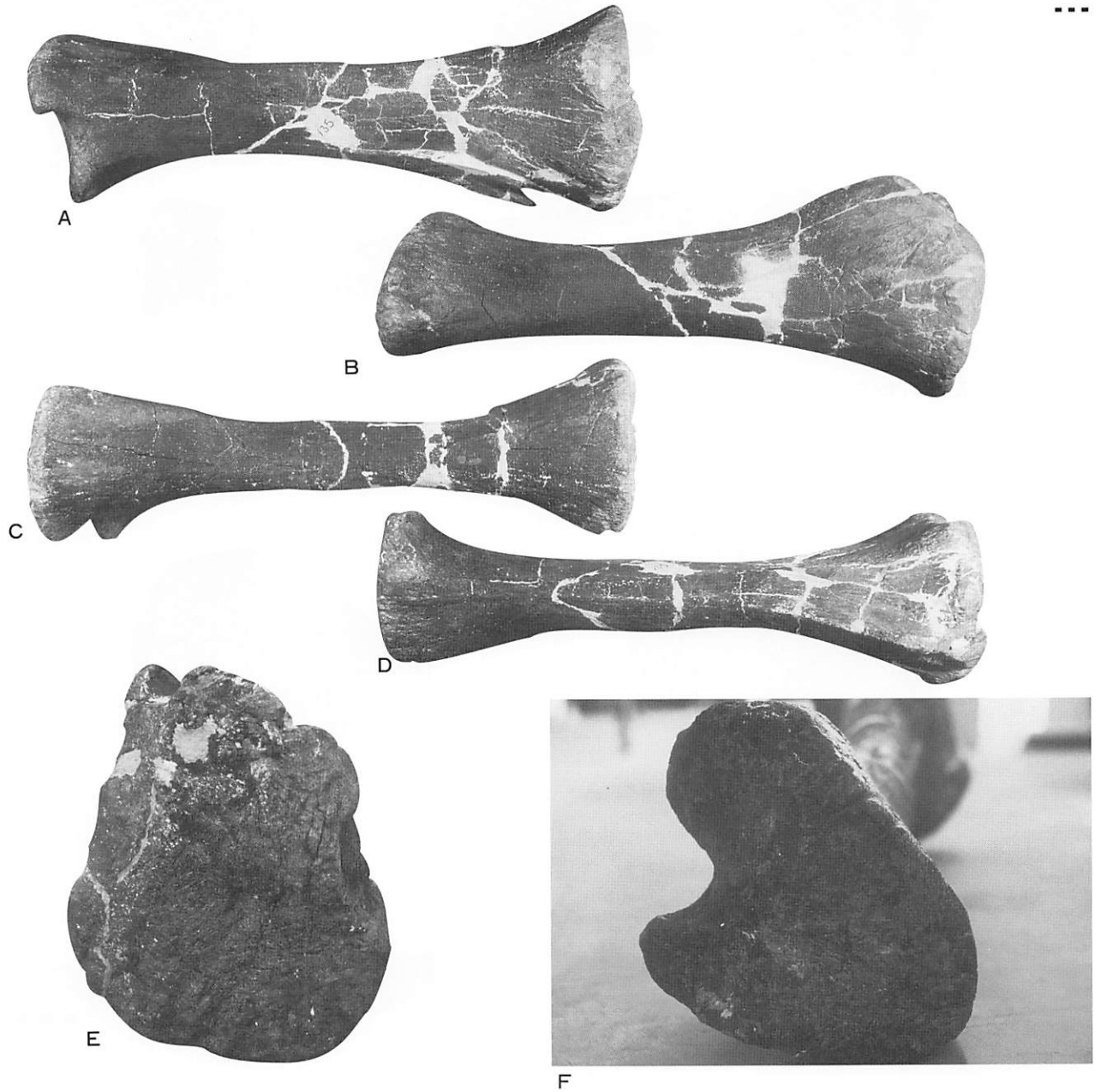


Figure 71: Right Tibia [Cat No. 340]. A. anterior view; B. posterior view; C. medial view; D. lateral view; E. proximal view; F. Distal view



Figure 72: Right Fibula [Cat. No. 342]. A. anterior view; B. posterior view; C. medial view; D. lateral view

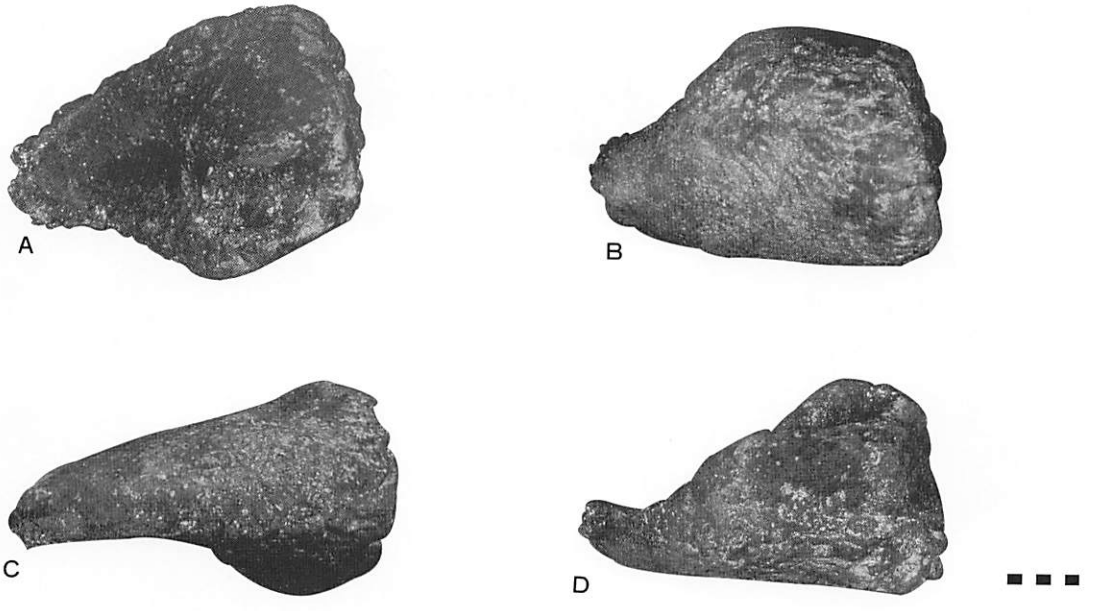


Figure 73: Astragalus [Cat. No. 554]. A. dorsal view; B. ventral view; C. anterior view; D. posterior view

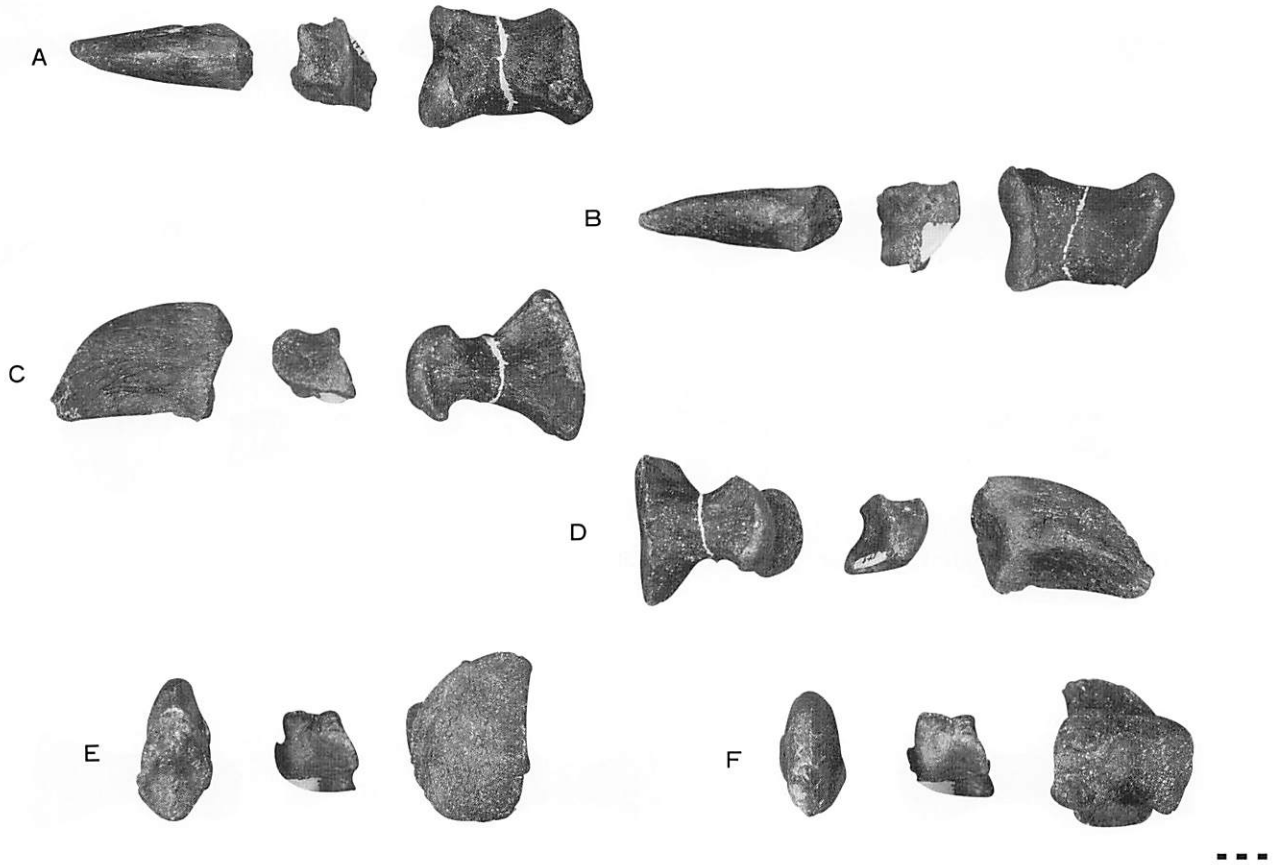


Figure 74: 1st Digit of Right Hind Foot. [Cat. No. 555, 564, 575] A. anterior-dorsal view; B. posterior-ventral view; C. medial view; D. lateral view; E. proximal view; F. distal view

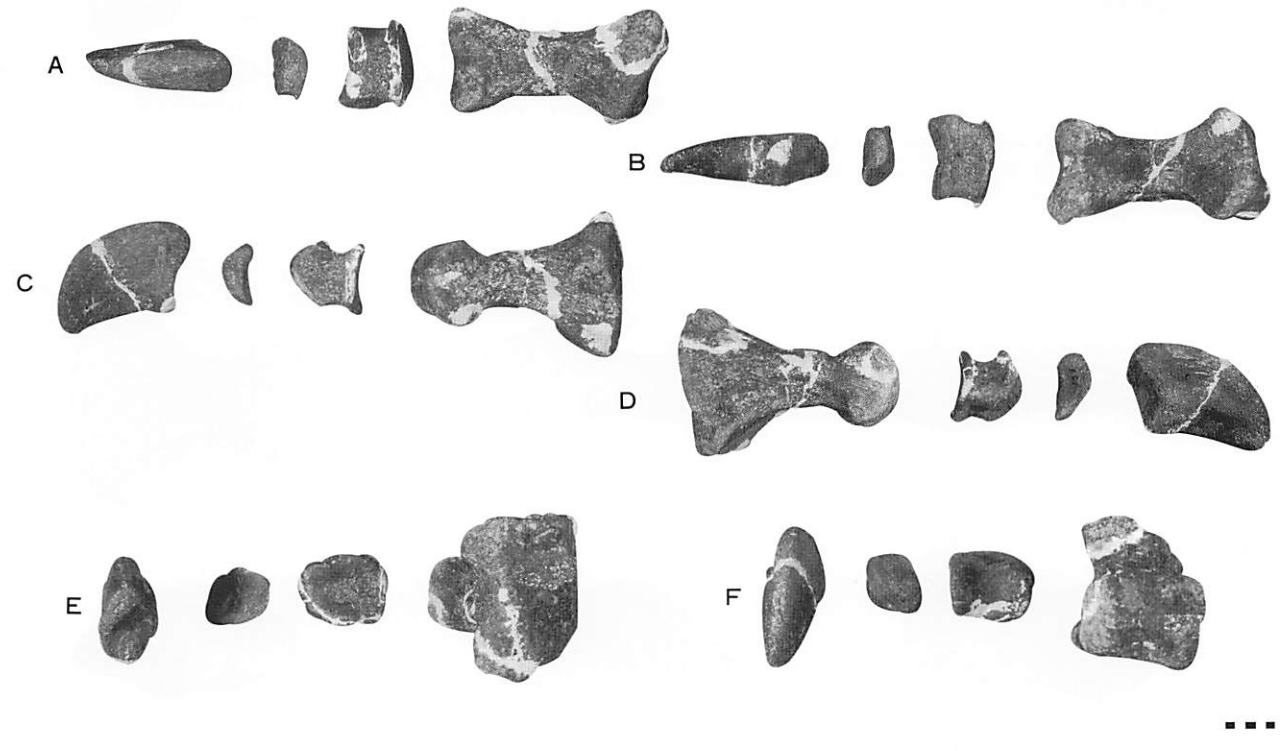


Figure 75: 2nd Digit of Right Hind Foot. [Cat. No. 556, 565, 568, 576] A. anterior-dorsal view; B. posterior-ventral view; C. medial view; D. lateral view; E. proximal view; F. distal view

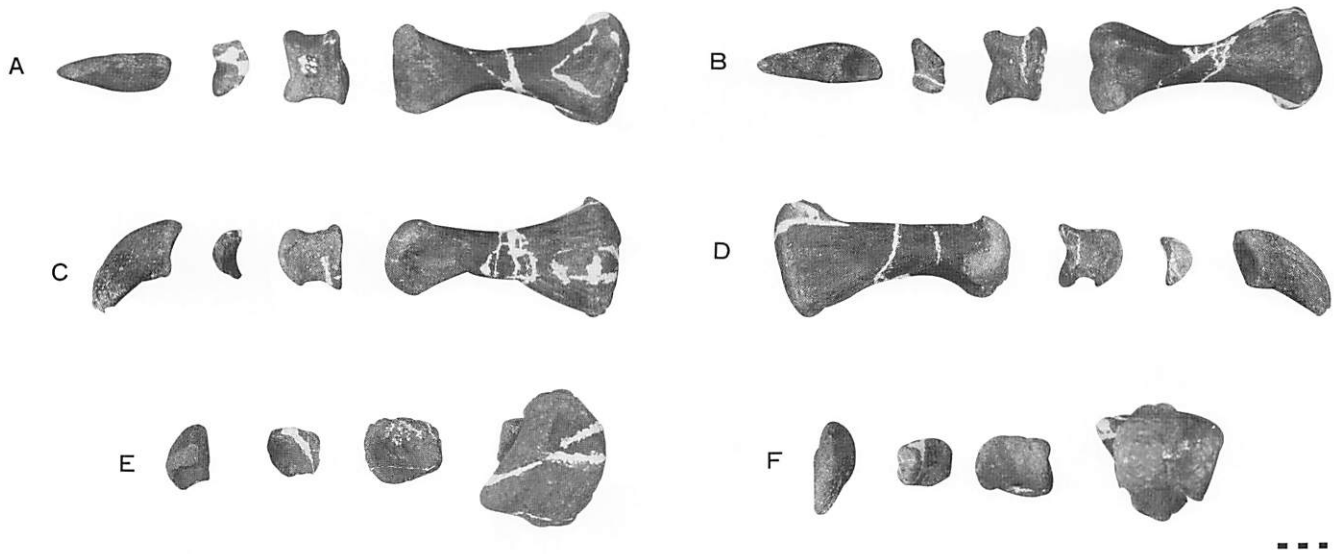


Figure 76: 3rd Digit of Right Hind Foot. [Cat. No.557, 566, 569, 577] A. anterior-dorsal view; B. posterior-ventral view; C. medial view; D. lateral view; E. proximal view; F. distal view

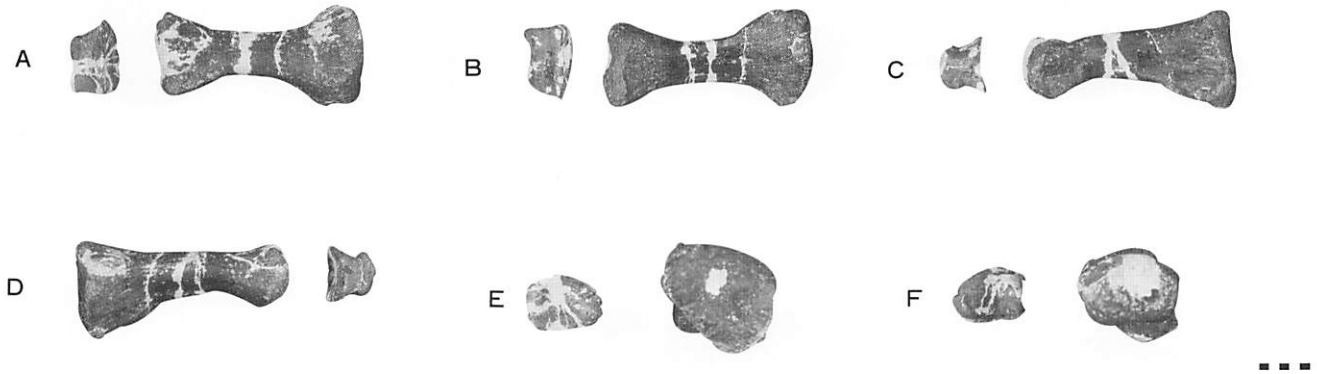


Figure 77: 4th Digit of Right Hind Foot. [Cat.No. 558,567] A. anterior-dorsal view; B. posterior-ventral view; C. medial view; D. lateral view; E. proximal view; F. distal view

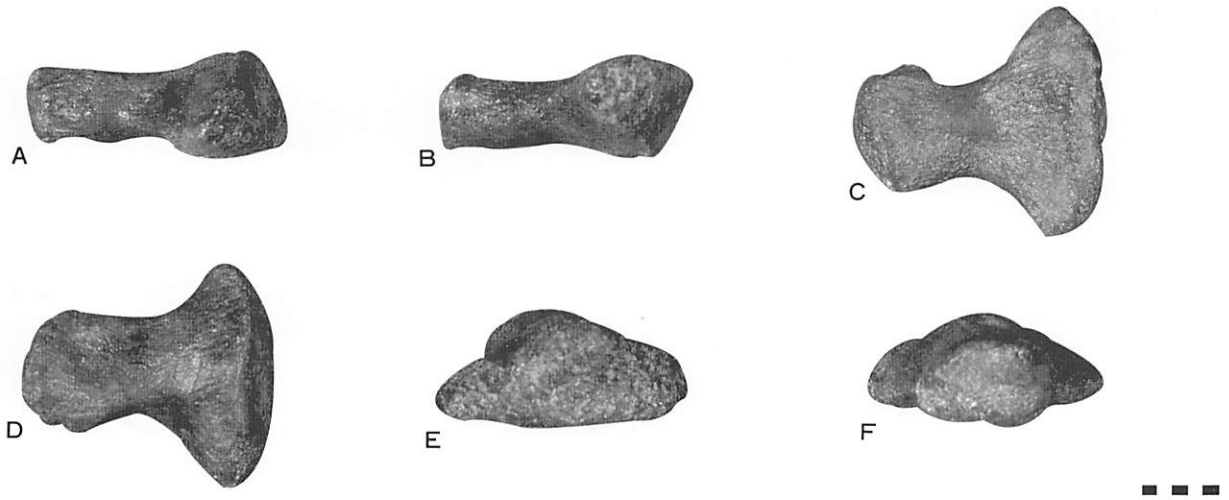


Figure 78: 5th Digit of Right Hind Foot. [Cat.No. 559] A. anterior view; B. posterior view; C. medial view; D. lateral view; E. proximal view; F. distal view



Figure 79: A. Complete Right Hind Foot, anterior-dorsal view; B. Phalanx-Right Foot to show teeth mark; C. Right Hind Leg with Brian Versey.

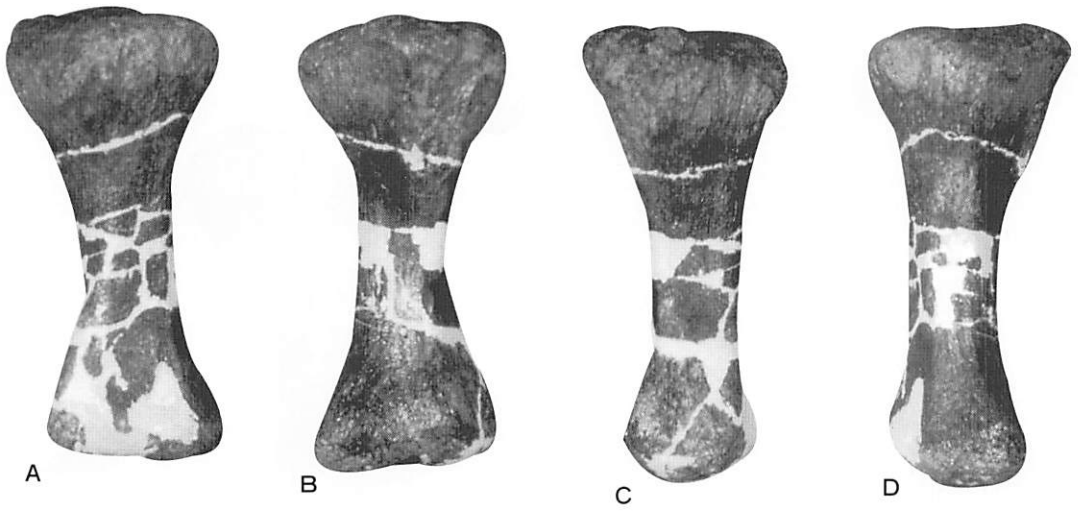


Figure 80: Left Hind Metatarsal (#4). [Cat. No 560] A. anterior view; B. posterior view; C. medial view; D. lateral view

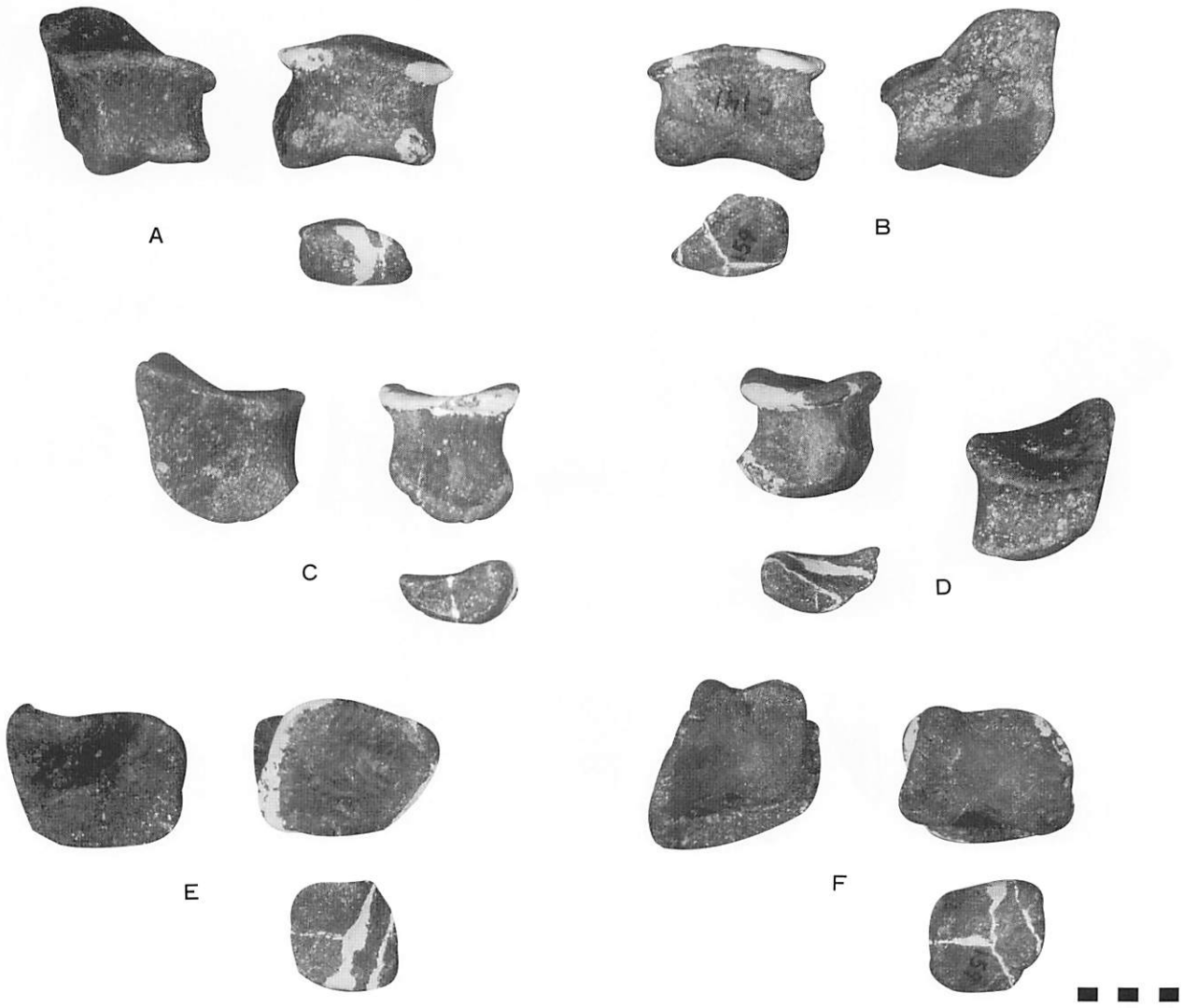
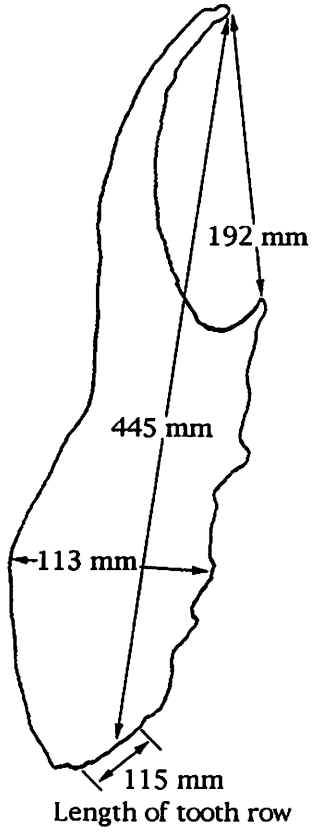


Figure 81: Left Hind Foot Phalanges [Cat. No. 570-572]. A. anterior view; B. posterior view; C. medial view; D. lateral view; E. proximal view, F. distal view

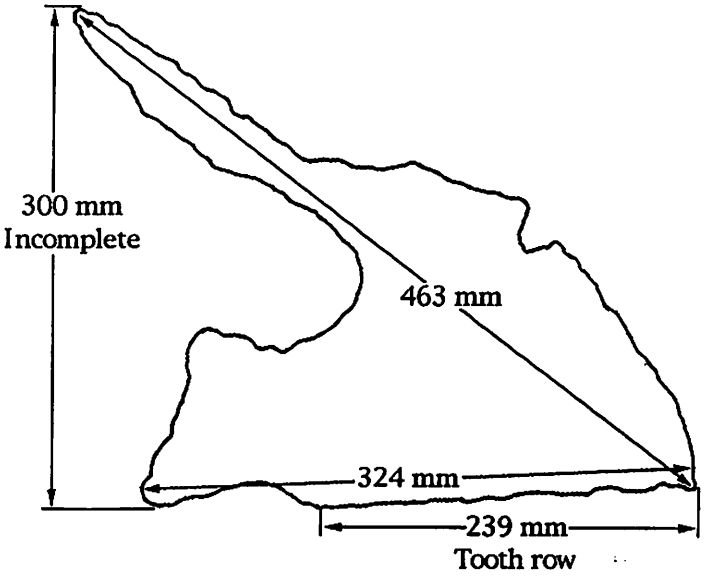
EAST *CAMARASAURUS* QUARRY CATALOG

CATALOG NUMBER	DESCRIPTION	FIELD NUMBER
337	Left Femur Head	227
338	Right Femur	128
339	Left Humerus	129
340	Right Tibia	135
341	Left Ulna	58
342	Right Fibula	151
343	Right Scapula	130
344	Right Humerus	120
345	Tooth	Not mapped
346	Tooth	71
347	Tooth Crown	Not mapped
348	Tooth	99
349	Left Quadratojugal	167
350	Right Premaxillary	225
351	Left Premaxillary	225
352	Right Maxillary	225
353	Left Maxillary	225
354	Right Nasal	225
355	Left Nasal	225
356	Right Dentary	108
357	Left Dentary	71
358	Tooth Crown	225
359	Tooth Crown	225
360	Tooth Crown	225
361	Tooth	225
362	Tooth	225
363	Tooth	225
364	Tooth	225
365	Tooth	225
366	Tooth	225
367	Tooth	225
368	Tooth	225
369	Tooth	225
370	Tooth	225
371	Tooth	225
372	Tooth	225
373	Tooth	2
374	Tooth	3
375	Tooth	5
376	Tooth	4
377	Tooth	6
378	Tooth	20
379	Tooth	183
380	Tooth	19
381	Tooth	16
382	Tooth	114
383	Tooth	18
384	Tooth	17
385	Tooth	22
386	Tooth	156
387	Tooth	190
388	Tooth	12
389	Tooth	14
390	Tooth	15
391	Tooth	160
392	Tooth	9
393	Tooth	10
394	Tooth	21
395	Tooth	161
396	Tooth	162
397	Tooth	163
398	Tooth	164
399	Tooth	165
400	Tooth	166
401	Tooth	67
402	Tooth	191
403	Tooth	Not mapped
404	Tooth	Not mapped
405	Tooth	Not mapped
406	Tooth	108
407	Tooth	7
408	Tooth	8
409	Tooth	109
410	Tooth	110
411	Tooth	111
412	Tooth	112
413	Tooth	11
414	Tooth	11
415	Tooth	113
416	Tooth	13
417	Left Quadrate	77
418	Right Pterygoid	225
419	Atlas Vertebra	225
420	Right Quadratojugal	225
421	Braincase	225
422	Right Ectopterygoid	225
423	Second Cervical	225
424	Proatlas	225
425	Third Cervical	225
426	Left Articular	150
427	Left Pre Frontal–Attached to Braincase	225
428	Right Pre Frontal–Attached to Braincase	225
429	Left Lacrimal	225
430	Right Lacrimal	225
431	Prezyg. Cervical #12	178
432	Right Squamosal–Attached to Braincase	225
433	Left Cervical Rib #1	226
434	Right Cervical Rib #1	225
435	Left Postorbital	206
436	Right Postorbital–Attached to Braincase	225
437	Left Surangular	Not mapped
438	Right Surangular	123
439	Left Pterygoid	10
440	Right Quadrate	206
441	Left Ectopterygoid	6
442	Right Angular	139
443	Left Angular	207
444	Right Palatine	Not mapped
445	Radiali	146
446	Tooth	Not mapped
447	Right Articular	96
448	Tooth	97
449	Left Squamosal	105
450	Right Splenial	73
451	Left Splenial	85
452	Right Supradentary	76
453	Left Supradentary	123
454	Chevron	224
455	Chevron	11B
456	Chevron	116D
457	Chevron	115F
458	Chevron	35G
459	Chevron	80A
460	Chevron	35C
461	Chevron	70I
462	Chevron	36J
463	Chevron	36K
464	Chevron	12L
465	Chevron	36M
466	Chevron	79N
467	Chevron	36O
468	Chevron	36P
469	Chevron	2R
470	Chevron	12Q
471	Chevron	91S
472	Right Ischuim	114
473	Left Ischium	45
474	Right Pubis	121
475	Left Pubis	35
476	Right Ilium	220
477	Left Coracoid	145

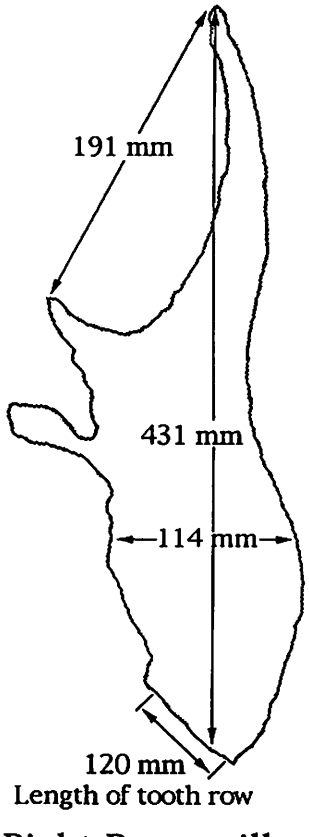
478	Rib - Left #1	221
479	Rib - Left #2	143
480	Rib - Left #3	131
481	Rib - Left #4	132
482	Rib - Left #5	155
483	Rib - Left #6	177
484	Rib - Left #7	186
485	Rib - Left #8	154
486	Rib - Left #9	185
487	Rib - Left #10	157
488	Rib - Left #11	152
489	Rib - Right #4	227A
490	Rib - Right #5	227B
491	Rib - Right #6	227C
492	Rib - Right #7	227D
493	Rib - Right #8	211,227E
494	Rib - Right #9	210,227F
495	Rib - Right #10	209,227G
496	Rib - Right (fragment)	57
497	Rib - Right #11	153
498	Right Cervical Rib #12	221
499	Allosaurus Tooth	55
500	Unknown Rib Fragment	68
501	Caudal #1	223
502	Caudal #2	223
503	Caudal #3	223
504	Caudal #4	223
505	Caudal #5	223
506	Caudal #6	223
507	Caudal #7	124
508	Caudal #8	124
509	Caudal #9	124
510	Caudal #10	124
511	Caudal #11	124
512	Caudal #12	124
513	Caudal #13	124
514	Caudal #14	36
515	Caudal #15	36
516	Caudal #16	36
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518	Caudal #18	36
519	Caudal #19	36
520	Caudal #20	36
521	Caudal #21	64
522	Caudal #22	226
523	Caudal #23	12
524	Caudal #24	12
525	Caudal #25	12
526	Caudal #26	12
527	Caudal #27	54
528	Caudal #28	116
529	Caudal #29	84B
530	Caudal #30	84A
531	Caudal #31	66
532	Caudal #32	64
533	Caudal #33	65
534	Caudal #34	65
535	Caudal #35	69
536	Caudal #36	63A&C
537	Caudal #37	93B
538	Caudal #38	123
539	Caudal #39	71B
540	Caudal #40	70
541	Caudal #41	118A
542	Caudal #42	70A&76
543	Caudal #43	88
544	Caudal #44	118B
545	Caudal #45	101
546	Caudal #46	118D
547	Caudal #47	118D
548	Caudal #48	118C
549	Caudal #49	71A
550	Caudal #50	98&103
551	Caudal #51	98&103
552	Caudal #52	98&103
553	Caudal #53	102
554	Astragalus	140
555	Right Metatarsal #1	117
556	Right Metatarsal #2	79
557	Right Metatarsal #3	38
558	Right Metatarsal $4	178
559	Right Metatarsal #5	136
560	Left Metatarsal #4	122
561	Left Metacarpal #1	147
562	Left Metacarpal #2	208
563	Left Metacarpal #3	119
564	Right Rear Proximal Phalanx #1	149
565	Right Rear Proximal Phalanx #2	178
566	Right Rear Proximal Phalanx #3	188
567	Right Rear Proximal Phalanx #4	138
568	Right Rear Distal Phalanx #2	137
569	Right Rear Distal Phalanx #3	93A
570	Left Rear Proximal Phalanx #2	C141
571	Left Rear Distal Phalanx #2	159
572	Left Rear Proximal Phalanx #1	86
573	Metacarpal Phalanx	176
574	Metacarpal Phalanx	139
575	Right Rear Ungal #1	148
576	Right Rear Ungal #2	180
577	Right Rear Ungal #3	56
578	Gastralia?	227
579	Cervical #4	221
580	Cervical #5	221
581	Cervical #6	221
582	Cervical #7	221
583	Cervical #8	221
584	Cervical Rib	133
585	Cervical Rib	134
586	Caudal Sacral	220
587	Dorsal #6	227
588	Dorsal #7	227
589	Dorsal #8	227
590	Dorsal #9	227
591	Dorsal #10	220
592	Dorsal #11	220
593	Dorsal #12	220
594	Unknown	63
595	Cervical Centrum Fragments	127 Group
596	Unknown	142
597	Unknown	158
598	Unknown	95
599	Cervical Rib #2	181
600	Fused Sacrals	220
601	Unknown	89
602	Unknown	73
603	Possible Denticle	



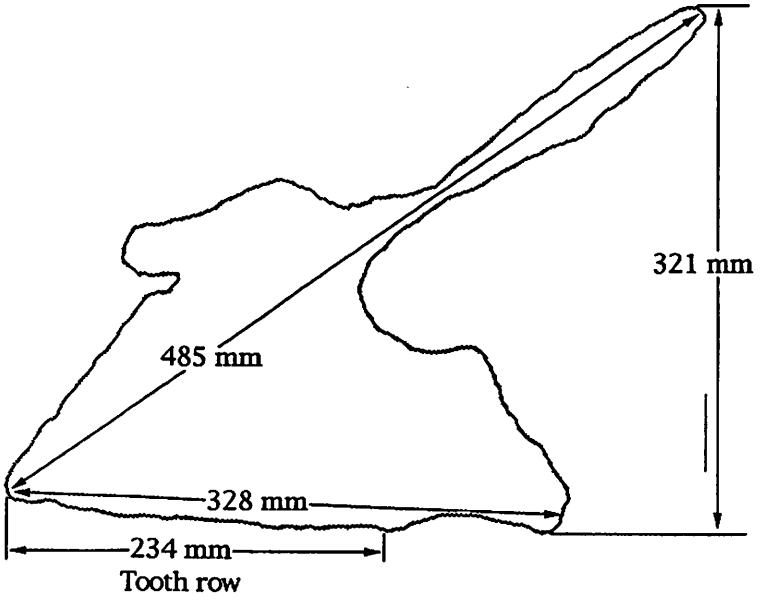
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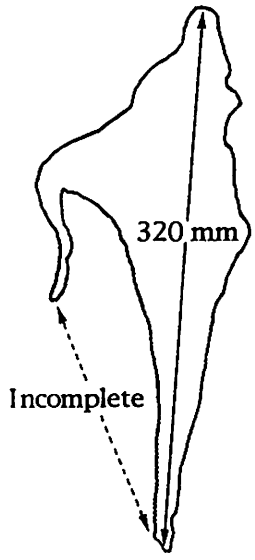
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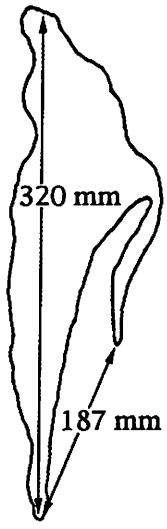
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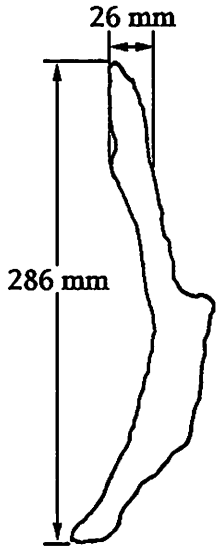
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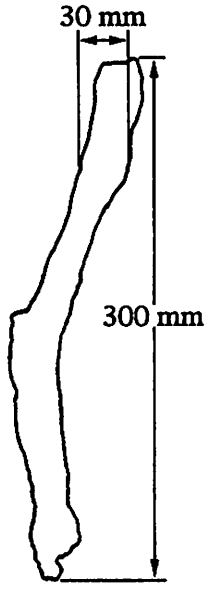
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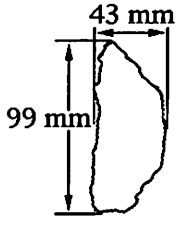
Right Nasal



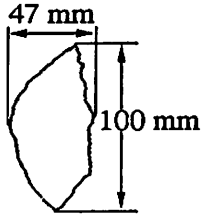
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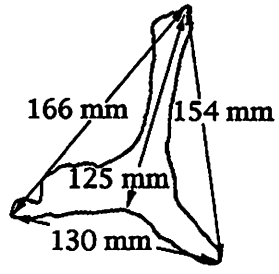
Right Lacrimal



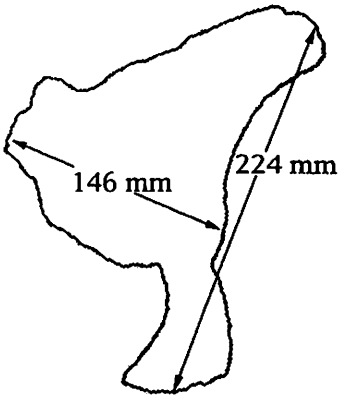
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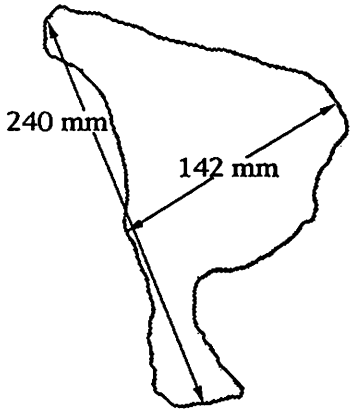
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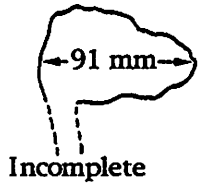
Right Postorbital



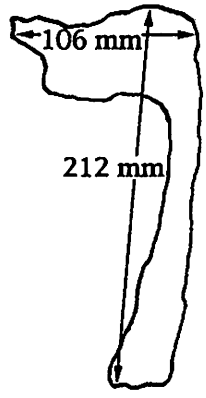
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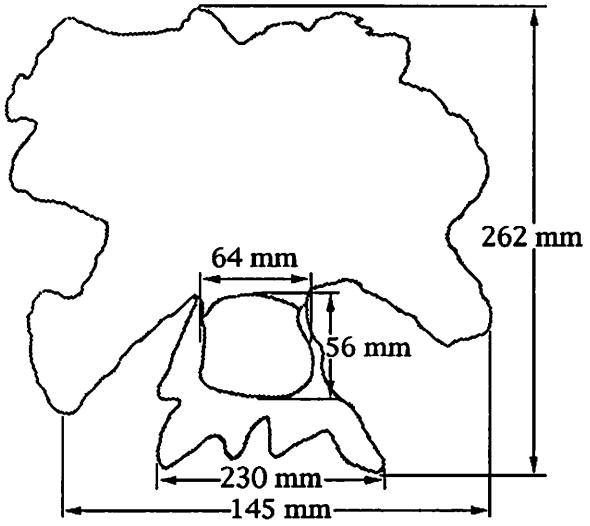
Right Quadrate



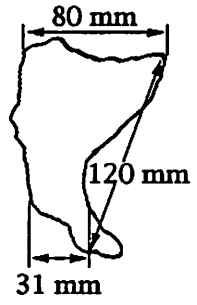
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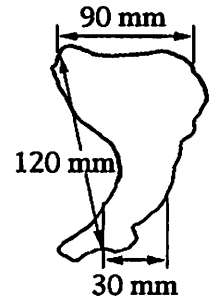
Right Quadratejugal



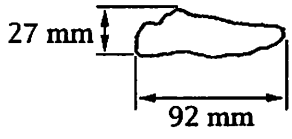
Brain Case



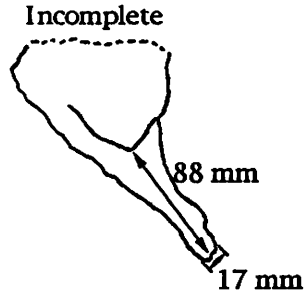
Left
Ectopterygoid



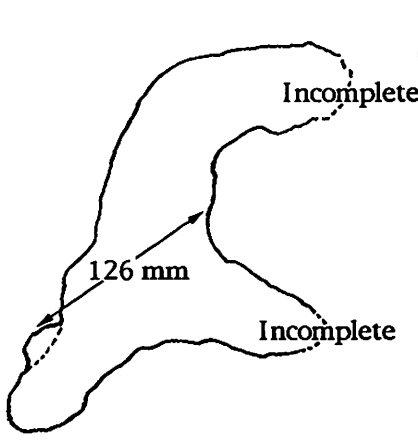
Right
Ectopterygoid



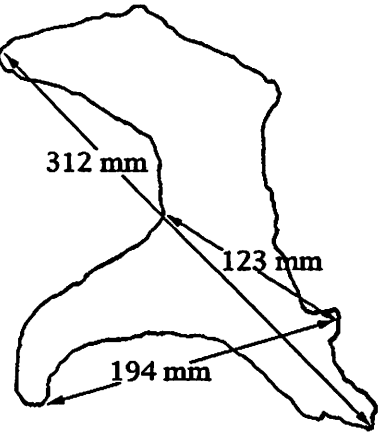
Pro Atlas



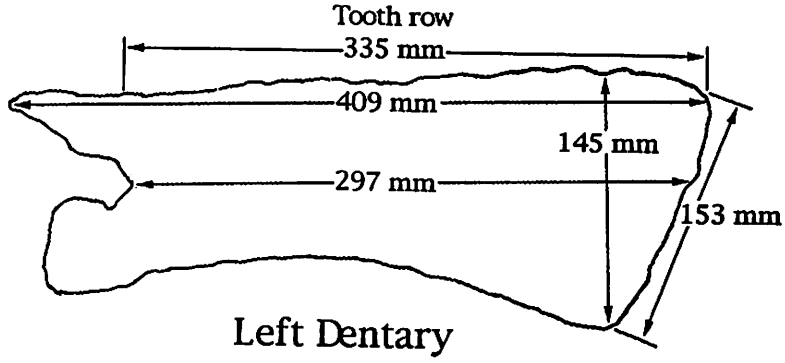
Right Palatine



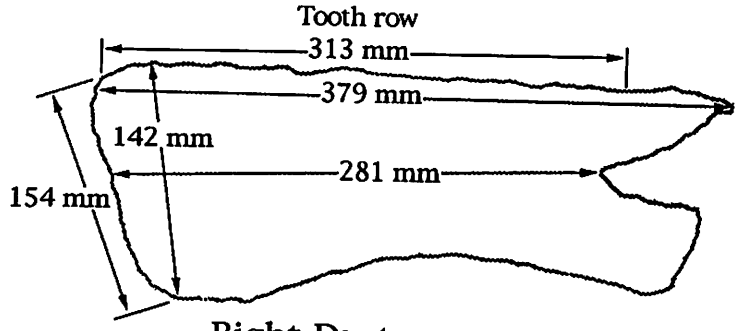
Left Pterygoid



Right Pterygoid



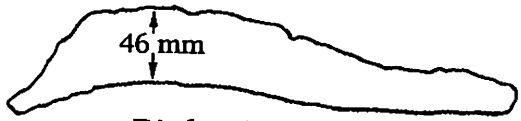
Left Dentary



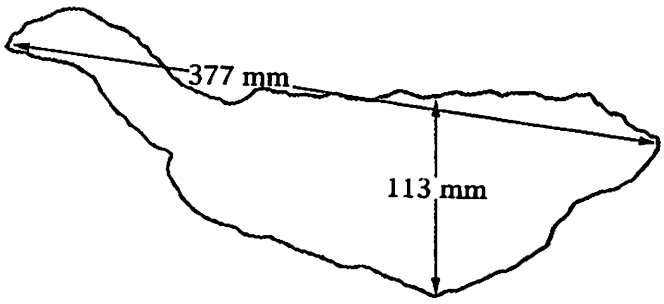
Right Dentary



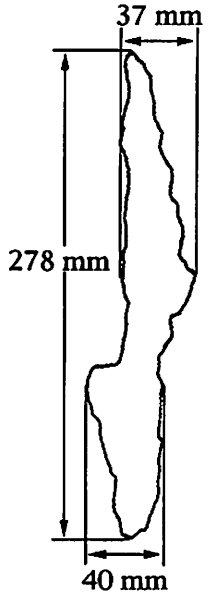
Left Angular



Right Angular



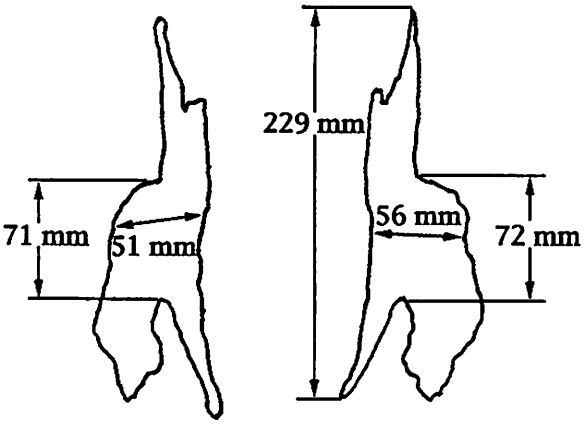
Right Surangular



Left
Intercoronoid
(Supradentary)

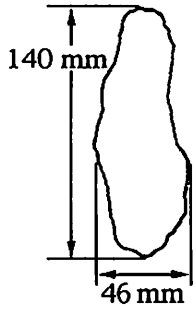


Right
Intercoronoid
(Supradentary)

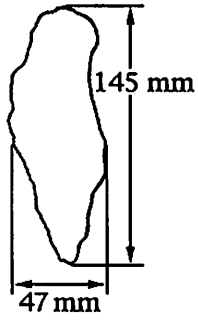


Left
Splenial

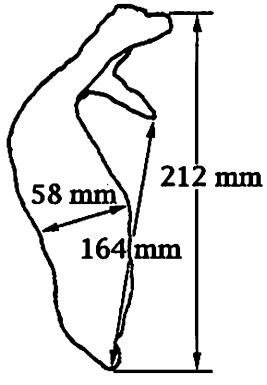
Right
Splenial



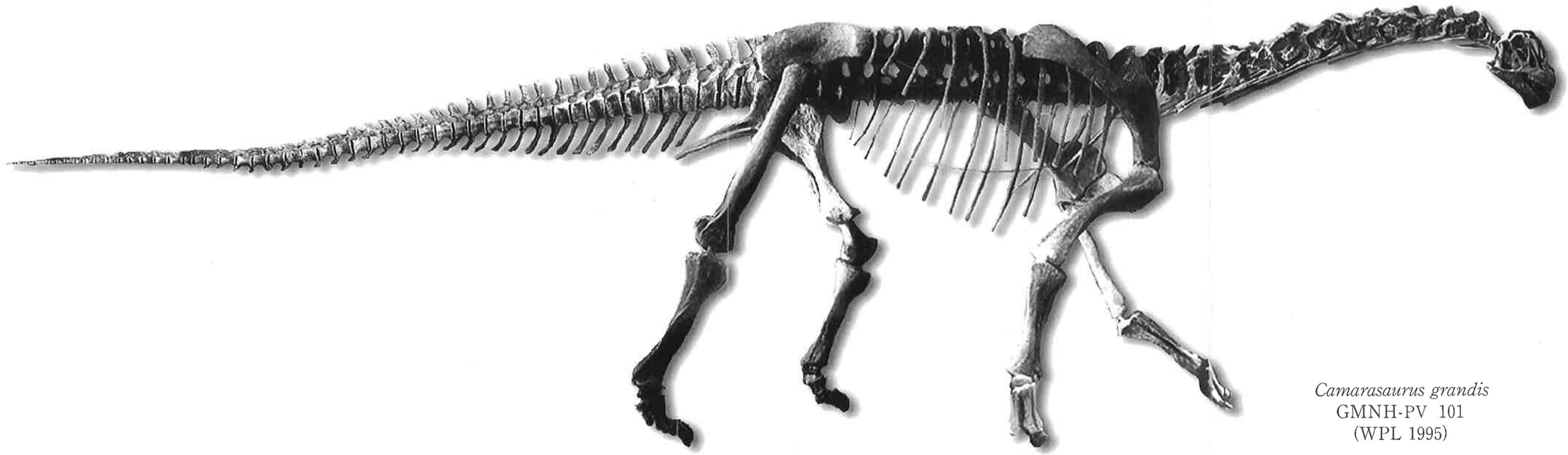
Left
Articular



Right
Articular



Right
Squamosal



Camarasaurus grandis
GMNH-PV 101
(WPL 1995)

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EAST CAMARASAURUS QUARRY
ALBANY COUNTY WYOMING
1993 EXCAVATION

Excavation Director: Jeffrie R. Parker
Excavators: Jeffrie R. Parker, Stanford J. Pinegar, R. Tyler Pinegar, David W. Hamblin, Lucille A. McDonald, Ronald G. Mjos, Karen C. Cloward, Helen B. Beardall, J. Lance Cloward, Michelle S. Beardall, Clifford A. Miles, Clark J. Miles, Kathryn E. Olson, Landus Buck, Elliot P. Smith, West Elkin, Mary A. Whitehead
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Final Quarry Map: Clifford A. Miles, Karen C. Cloward, Brian K. Versey
Preparation Director: Ronald G. Mjos
Preparators: Ronald G. Mjos, Clifford A. Miles, Karen C. Cloward, Charles E. McClellan, Brian K. Versey, Jeffrie R.Parker, Mary A. Whitehead, Clark J. Miles, Delanie A.Webb, Elliot P. Smith, Kathryn E. Olson, Dustin G. Smith, J. Gregory Parrent, Patricia A. Palmer

