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LARGE HADROSAURINE DINOSAURS FROM THE LATEST CAMPANIAN OF COAHUILA, MEXICO

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Abstract—In 2001, a large hadrosaurine preserving extensive cranial and post-cranial material (PASAC-1) was discovered in an excavation in the Sabinas Basin near the town of Sabinas, Coahuila, Mexico. The specimen can be compared to the anterior portion of a large hadrosaurid skull (IGM 6685) recovered from the central Parras Basin in 1987. Both specimens are from uppermost Campanian strata, and appear to belong to the same taxon as they are both of the same large size and share a similar down-turned dentary. Distinctive characteristics of the Sabinas specimen include a dorsally recurved ischium (also present in *Hadrosaurus foulkii*), a subrectangular maxilla, and sharply down-turned anterior dentary (also present in *Kritosaurus navajovius,* AMNH 5799). We hypothesize that these Mexican hadrosaurines can be assigned to *Kritosaurus*, but are indeterminate as to species. The 1.3 m length of the femur of the Sabinas specimen suggests an estimated length of 11 m based on comparisons with other hadrosaurids, making *Kritosaurus* as large as the largest well-documented North American hadrosaurine, *Edmontosaurus regalis*. Reexamination of the type skull of *Kritosaurus* reveals new information from the premaxilla and the skull posterior to the narial opening that suggests *Kritosaurus* is a valid taxon. Biogeography and time separate *Kritosaurus* and *Gryposaurus*, whereas *Kritosaurus* (southern North America) and *Edmontosaurus* (northern North America) had non-overlapping biogeographic ranges in the latest Cretaceous.

INTRODUCTION

Many Late Cretaceous dinosaur skeletal localities have been found in the state of Coahuila, Mexico along the west side of the ancestral Gulf of Mexico (Fig. 1). The Geological Institute of the University of Mexico (IGLUNAM) has overseen the majority of investigations within the Cerro del Pueblo Formation of the Difunta Group (Hernandez-Rivera and Espinosa-Arrubarrena, 1990; Hernandez, 1992, 1995; Hernandez and Kirkland, 1993; Hernandez-Rivera, 1996, 1997; Kirkland et al., 2000). IGLUNAM has identified hadrosaurids (both hadrosaurines and lambeosaurines), ceratopsians, ankylosaurs, tyrannosaurids, ornithomimids, dromaeosaurids, and oviraptosaurs in Coahuila. However, to date, few specimens preserve enough diagnostic character states that allow genus level identification.

During the late 1980s, IGLUNAM excavated the remains of a dinosaur near the village of Presa de San Antonio in the central Parras Basin (Fig. 1) (Hernandez-Rivera and Espinosa-Arrubarena, 1990; Hernandez, 1995); the first dinosaur skeleton from Mexico to be mounted (Fig. 2). This specimen, although fairly complete, lacked a skull, but was identified as the hadrosaurine *Kritosaurus* sp. based on comparisons to data provided by Lull and Wright (1942) for "*Kritosaurus" incurvimanus* and data from Brett-Surman's (1975) thesis on the appendicular skeletons of hadrosaurids (Serrano- Brañas, 1997). During the IGLUNAM excavations, Jose Lopez Espinosa of Presa de San Antonio discovered an isolated sandstone block preserving the front portion of a skull from a much larger hadrosaurine (IGM 6685) only a few hundred meters away. This partial skull was the basis for the smaller skull reconstructed for the mounted skeleton (Fig. 2). The specimen is also displayed at the Geological Museum in Mexico City.

To the east, in the area of Rincon Colorado (Fig. 1), IGLUNAM and the Coahuila Paleontological Commission established a series of dinosaur quarries in the Cerro del Pueblo Formation at the base of the Difunta Group around a hill that became known as Cerro de los Dinosaurios (Hernandez and Kirkland, 1993; Kirkland et al., 2000). They periodically worked at these sites through the 1990s with the help of volunteers from the Dinamation International Society. In 1994, this area was set aside as a special fossil preserve by IGLUNAM, the National Institute of Archaeology and History (INAH), and the Secretary of Public Education for Coahuila. Interpretive trails were developed, and a small museum was erected at the village of Rincon Colorado (Fig. 3).

The newly established Museo del Desierto in Saltillo, Mexico continued research on the Cerro del Pueblo Formation, discovering many new dinosaur localities during an on-going collaboration with the Royal Tyrrell Museum and the Utah Museum of Natural History (UMNH). Renewed excavations at the Cerro de los Dinosaurios Quarry 7 (Fig. 3) resulted in the recovery of the skull of a new genus of lambeosaurine hadrosaur currently under study at the UMNH (Gates et al., 2005).

The Cerro del Pueblo Formation consists of coastal floodplain and shallow marginal marine strata preserving complexly interbedded freshwater, brackish, and marine facies that were deposited rapidly at rates exceeding 500 m per million years (Kirkland, et al., 2000, Eberth et al., 2004). The salinity under which different facies were deposited is readily determined by examination of the associated molluscan fossils. Freshwater, brackish, and marine molluscan assemblages are readily identified in nearly every rock unit of the Cerro del Pueblo Formation and rarely show any mixing of mollusks characteristic of different salinities (Kirkland et al., 2000). The majority of dinosaur sites are associated with brackish water facies as determined by the abundance of brackish water mollusks co-occurring with the dinosaur bones (Fig. 3).

In May 2001, Juan Pablo Garcia–de la Garza discovered a large dinosaur just southwest of Sabinas, Coahuila Mexico (Figs. 1, 4). The Association of Amateur Paleontologists of Sabinas (PASAC) excavated the bones in the spring of 2001 and sent the bones to the IGLUNAM in Mexico City for study under the direction of Rene Hernandez-Rivera. All of the bones were identified as coming from one individual hadrosaurine dinosaur, based on the preservation of a diagnostic hadrosaurine ischium together with the size of the preserved elements and the lack of overlapping parts (Fig. 5). Scientists at IGLUNAM believe the specimen represents the

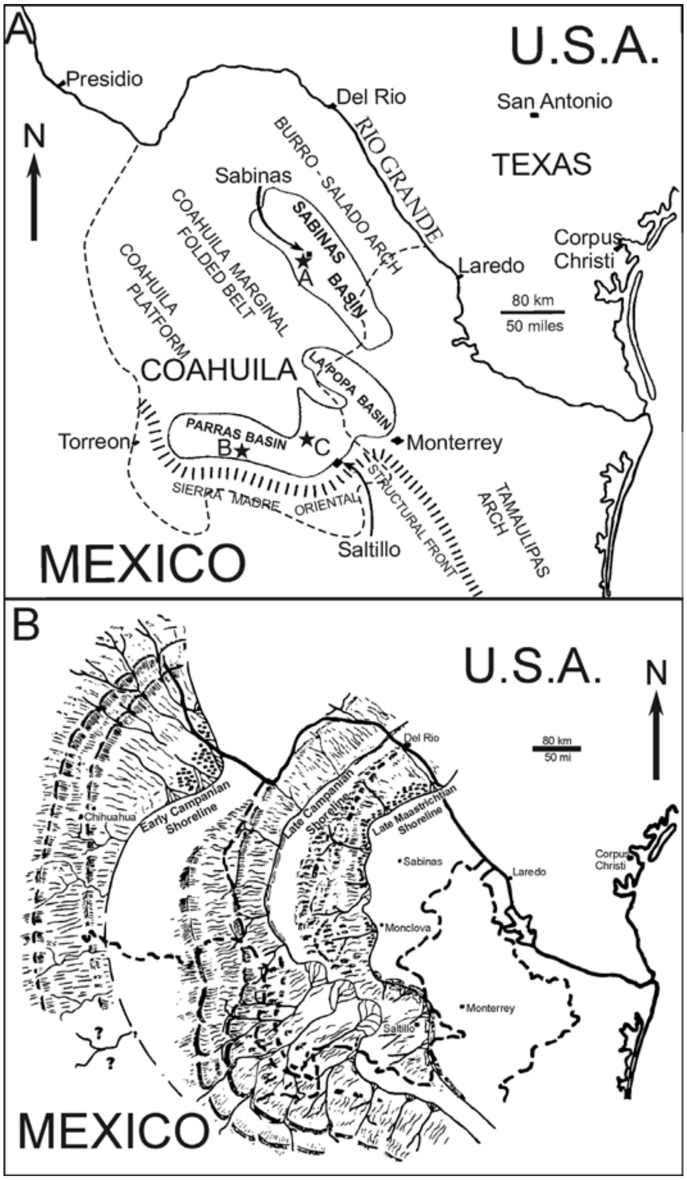


FIGURE 1. **A,** Locality map showing the geographic and geological setting of the Late Campanian of northeasteren Mexico. A. Sabinas hadrosaurine site, B. Presa de San Antonio hadrosaurine locality, C. Rincon Colorado localities at Cerro de los Dinosaurios. Boundary of the state of Coahuila indicated by dashed-line. After Murray et al. (1962). **B,** Latest Cretaceous paleogeography in northeastern Mexico. Modified after Weidie et al. (1972). Note that in the latest Campanian the shoreline was east of Sabinas.

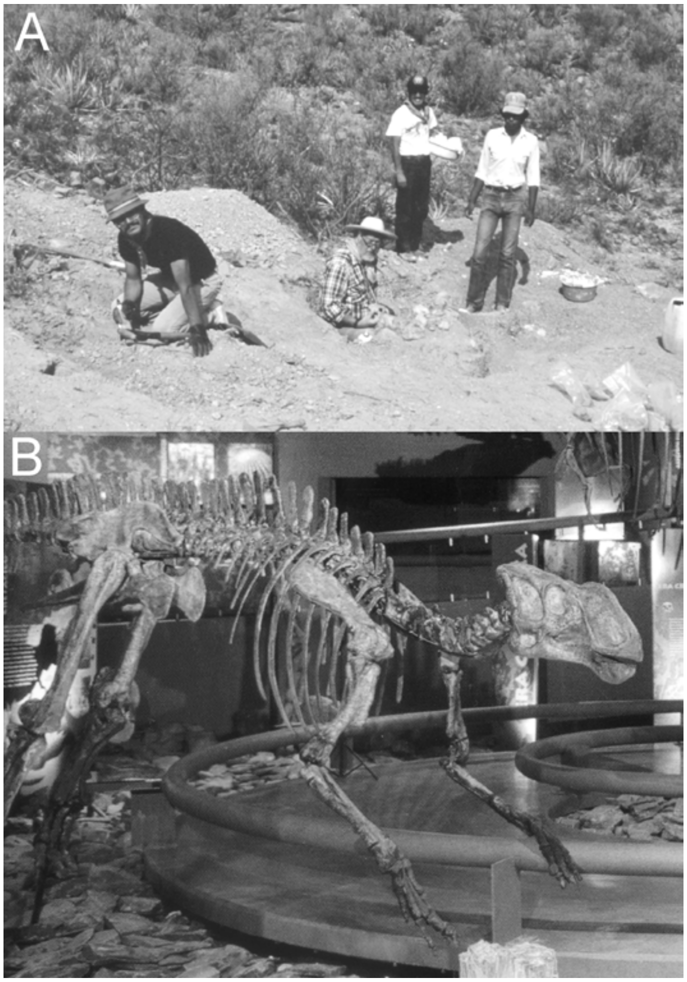


FIGURE 2. **A,** 1988 field team excavating a hadrosaur at Presa de San Antonio; from right to left Louis Espinosa-Arrubarrena, Shelton Applegate, Rene Hernandez-Rivera, all of UNAM; Jose Lopez-Espinosa of Presa San Antonio. **B,** The resulting skeleton as mounted by Rene Hernandez-Rivera at Museo del Desierto in Saltillo, Coahuila. Note that the skull is a reconstruction based on *Gryposaurus*.

most complete individual dinosaur yet recovered from Mexico.

The excavation site is stratigraphically low in the Olmos Formation (Maldonado-Koerdell, 1956; Lopez-Ramos, 1988; Espinoza, 1989) near the base of an eastward dipping low slope. Here, the rocks are poorly exposed due to extensive cover of desert scrub and grasses (Fig. 3). These rocks are nearly correlative with the uppermost Campanian Cerro del Pueblo Formation in the Parras Basin (see below). The bones were deposited on an interval of gravelly mudstone with laterally extensive carbonate nodule beds 10-30 cm thick. Clasts in this bed include carbonate and phosphate pebbles, molds of freshwater snails, and abundant plant fragments. These beds are very poorly sorted and may represent crevasse splays, although a source channel was not recognized.

The bones are preserved at the base of a 2-3 m thick interval of olive-gray silty claystone containing scattered centimeter-scale carbonate nodules. JK identified a diverse assemblage of freshwater gastropods in these beds that include physids, lymnaeids, viviparids, and ornate neretids indicating of a fully terrestrial setting. Microvertebrate remains found in association with the bones include the fresh water rhinobatoid ray *Myledaphus bipartus*, the amioid *Melvius* sp., gar scales, crocodilian teeth, and tyrannosaurid teeth.

Cross-bedded sandstone preserving large petrified logs caps the slope to the west of the site. This may represent the Zone 2 crossed-bedded sandstones of Robeck et al. (1956). If so, then the dinosaur site occurs in the upper 10 m of Zone 1, which makes up approximately the basal 40 m of the Olmos Formation.

Although extensive hadrosaurine remains have been collected from the Presa de San Antonio and Rincon Colorado areas, the Sabinas hadrosaurine is the largest and most northern hadrosaurine skeleton excavated in Mexico. Additionally, there have been no individual hadrosaurine skeletons as complete excavated anywhere in the United States south of Utah. Several cast skeletons have been mounted including one on exhibit in Sabinas, Mexico (Fig. 6).

The purpose of this paper is to illustrate, provide a preliminary description, and discuss the possible phylogenetic relationships of the Sabinas and Presa de San Antonio hadrosaurines. The overlapping dentaries of the Sabinas (PASAC – 1) and slightly younger Presa de San Antonio (IGM 6685) skulls are nearly identical in size and shape and may or may not pertain to the same species. JK and GP had the opportunity to study all the original hadrosaurine fossils at IGLUNAM with our Mexican colleagues,

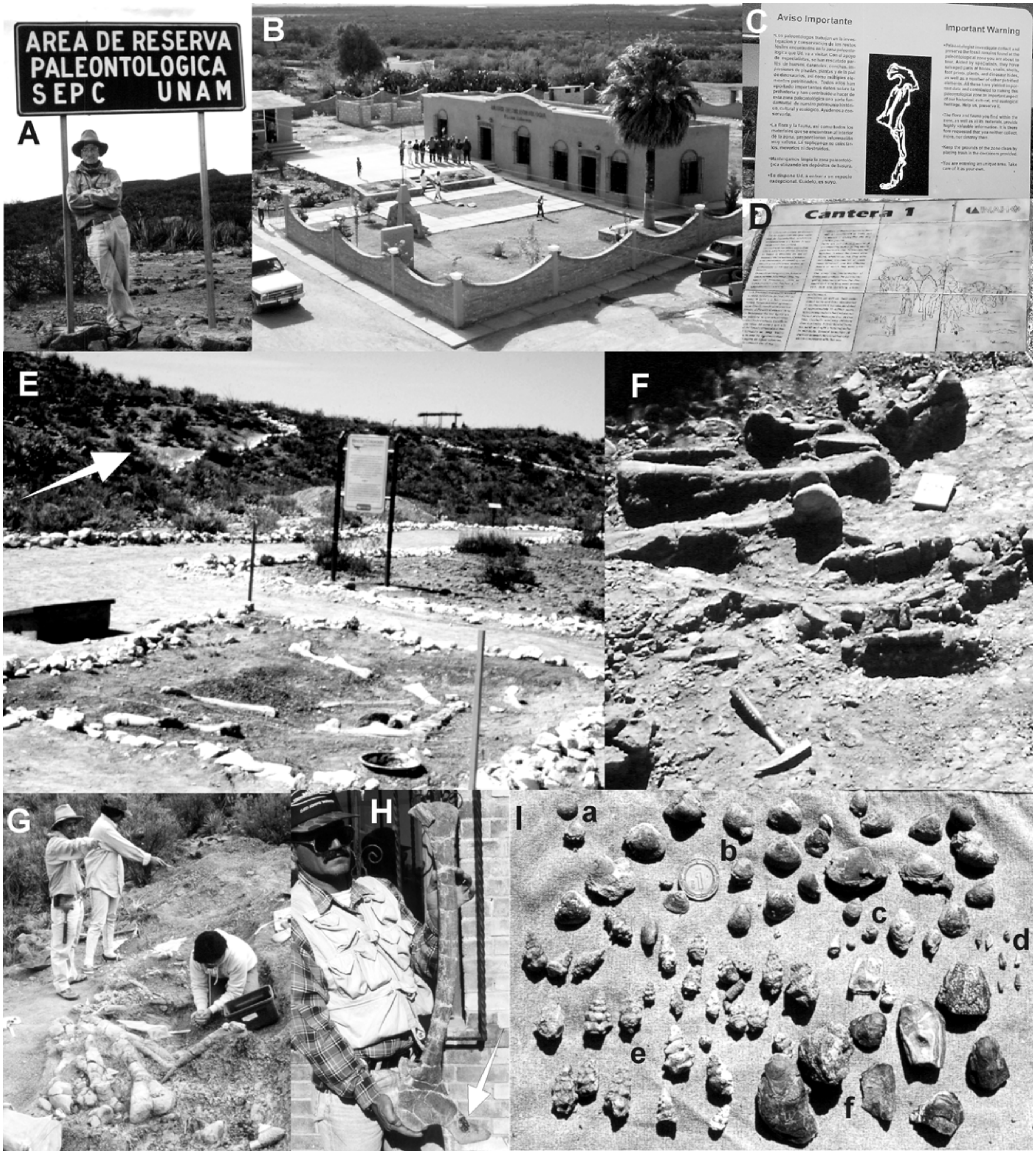


FIGURE 3. **A,** Rene Hernandez-Rivera and original sign designating the Rincon Colorado Paleontological Preserve. **B,** Paleontological Museum at Rincon Colorado with new school visible to left. **C,** Sign at beginning of interpretive trail at Cerro de los Dinosaurios warning the public not to disturb fossils at the site. **D,** Example of an interpretive sign engraved into Saltillo tile on interpretive trail. Cantera 1 = Quarry 1. **E,** Beginning of interpretive trail at Cerro de los Dinosaurios with reconstruction of Quarry 1 in foreground and spoils pile for Quarry 7 indicated by arrow just visible behind sign in background. **F,** Associated hind limb elements of hadrosaurid at Quarry 7. Rock hammer for scale. **G,** Rene Hernandez-Rivera directing excavations by Coahuila Paleontological Commision and Dinamation International Society at Quarry 7 in 1994. **H,** Carlos Rene Delgado de Jesus holding lambeosaurine hadrosaurid ischium encrusted by oyster (arrow) from Quarry 7. **I,** Common brackish water invertebrates from the Cerro del Pueblo Formation. a) *Nerita* sp.; b) *Aphrodina tippana* (Conrad); c) miscellaneous unidentified gastropods; d) *Cerithium pueblensis* Wolleben; e) *Cerithium nodosa* Wolleben; f) *Flemingostrea subspatulata* (Forbes). Scale one peso (new pesos).

FIGURE 4. Sabinas Hadrosaur Site. **A,** Overview of site. Hernandez-Rivera and Garcia de la Garza with members of Sabinas Paleontological Association in arroyo at initial discovery site. Overall area of excavations indicated by white polygon (Fig. 5). White arrow indicates concretionary zone below bone-bearing interval. View to west. **B,** Gravelly matrix of concretion level just below-bone bearing interval. U.S. quarter for scale. **C,** Fresh water gastropods from bone-bearing level: a) lymnaeid gastropod; b) viviparid gastropod. U.S. penny for scale. **D,** Large petrified log typical of Zone 2 in sandstone bed capping hill.

and JK had the opportunity to study all the excavation sites discussed herein. Cast of the Presa de San Antonio skull section and casts of all the preserved skull elements are reposited at UMNH. In conducting this research, JK and RH have had the opportunity to study first hand all of the specimens discussed herein, with the exception of *Lophorothon* and *Shantungosaurus*, during research trips to the Royal Ontario Museum, Canadian Museum of Nature, American Museum of Natural History, and the New Mexico Museum of Natural History and Science. New information on the holotype of *Kritosaurus* resulting from this research is also reported.

INSTITUTIONAL ABBREVIATIONS

AMNH, American Museum of Natural History, New York; BYU, Brigham Young University, Earth Science Museum, Provo, Utah; CMN, Canadian Museum of Nature (National Museum of Canada), Ottawa; IGM, Museo de Paleontología, Instituto de Geología, UNAM, Mexico City; NMMNH, New Mexico Museum of Natural History and Science, Albuquerque; PASAC, Paleontological Association of Sabinas, Coahuila, Sabinas; ROM, Royal Ontario Museum, Toronto.

AGE OF DINOSAUR-BEARING STRATA IN COAHUILA, MEXICO

Wolleben (1977) considered the age of the Cerro del Pueblo Formation to be early Maastrichtian based on the first occurrence of the index bivalve *Exogyra costata* Say and the ammonite *Sphenodiscus* near its lower contact with the underlying Parras Shale. However, biostratigraphically correlating North America with the type Campanian-Maastrichtian of Europe indicates the Campanian/Maastrichtian boundary should be placed stratigraphically higher (Cobban, Kennedy, and Scott, 1992). Cobban, Kennedy, and Scott (1992) have recognized that the common scaphitid ammonite *Jeletzkytes nodosus* Owen and heteromorph ammonite *Nostoceras hyatti* Stephenson are present at the top of the Campanian stage in Europe, and noted that the ammonites also range up into the *Baculites jenseni* ammonite Zone in the Western Interior of the United States. These same ammonites occur in the Nocatoch Sand of the Navarro Group of Texas (Stephenson, 1941). Neither of these ammonites nor identifiable *Baculites* species occur in the Cerro del Pueblo Formation. The important index fossils, *Inoceramus vanuxemi* Meek and Hayden and *Sphenodiscus pleurosepta* Conrad occur in the Cerro del Pueblo Formation, in the western interior and in central Texas. The upper part of the range of *I. vanuxemi* overlaps the base of the range of *S. pleurosepta* through the *Baculites reesidei* and *Baculites jenseni* Zones of the United States Western Interior and in the Nocatoch Sand in Texas (Stephenson, 1941; Kauffman et al., 1993). Therefore, Kirkland et al. (2000) considered the Cerro del Pueblo Formation to be latest Campanian in age, suggesting it might span as much as one million years given an average of 0.5 my/baculite zone; ranging from 72.3-71.3 + 0.5 by using data from Obradovich (1993).

The placement of the Campanian/Maastrichtian boundary in the middle of the next overlying ammonite zone (*Baculites elaisi* Zone) based

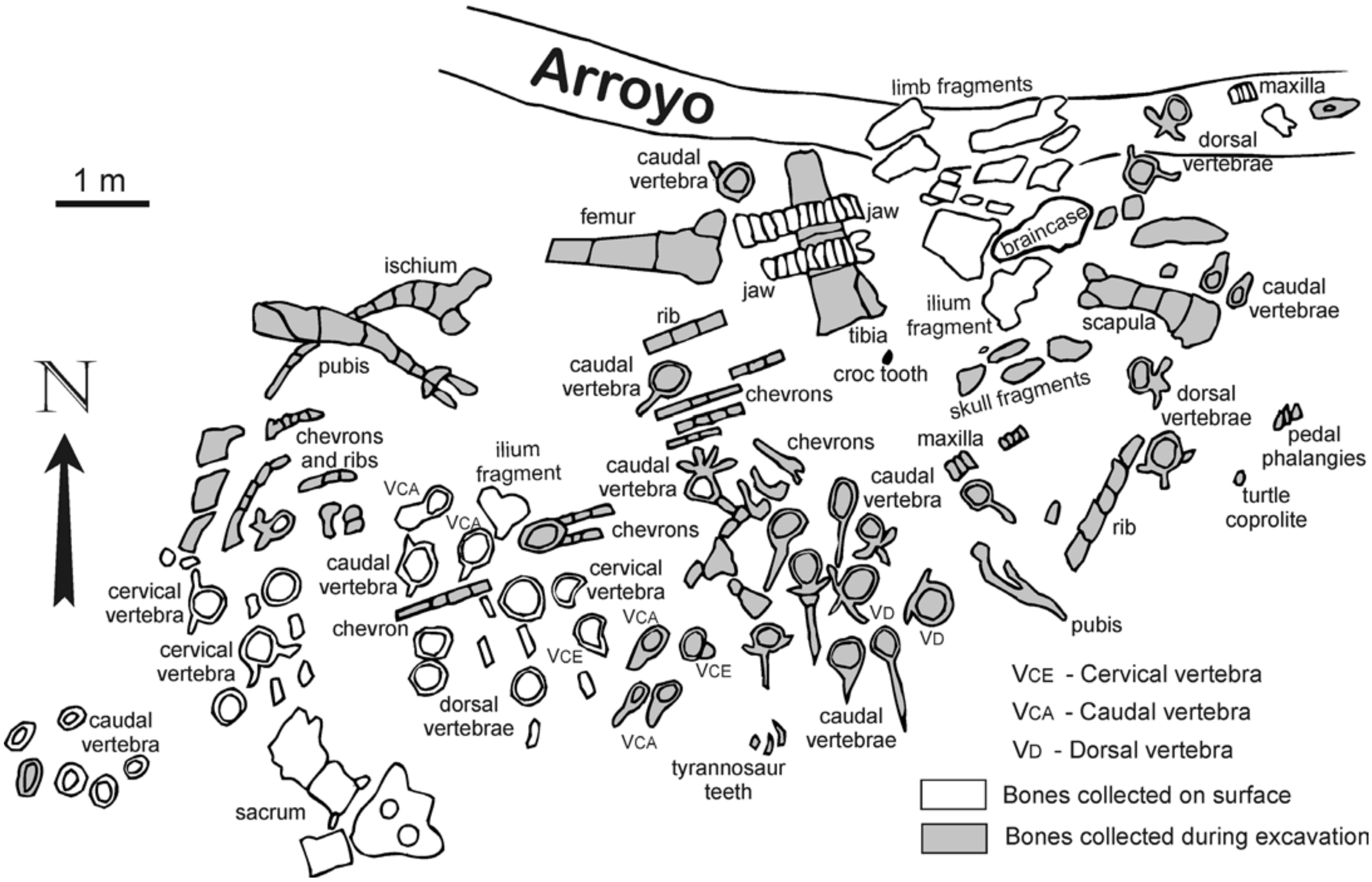


FIGURE 5. Sabinas Hadrosaur Site quarry map compiled by Juan Pablo Garcia de la Garza.

on comparisons to the paleomagnetic time scale (Hicks, Obradovich, and Tauxe, 1999) adds further support for a latest Campanian age for the Cerro del Pueblo Formation. Eberth et al. (2004), utilized magnetostratigraphy to verify the biostratigraphic interpretations of Kirkland et al. (2000), and more accurately placed the Campanian/Maastrichtian boundary in the upper Cerro Huerto Formation.

The Olmos Formation has also been correlated to the Nacatoch Sand with heteromorph ammonites (Tyler and Ambrose, 1986) and the presence of *Exogyra ponderosa* in the underlying San Miguel Formation (Espinosa, 1989). These rocks may range slightly younger, but as the *Baculites reesidei* through *Baculites baculus* Zones probably span less than two million years (Obradovich, 1993), these beds are similar in age. Thus, its age should also be considered as latest Campanian as opposed to earliest Maastrichtian (Fig. 7).

Relative to the most significant dinosaur-bearing strata in the United States and Canada, the dinosaur bearing strata in northern Mexico would seem to correlate best with the Kirtland Formation in the San Juan Basin (Sullivan and Lucas, 2003) and the lower Horseshoe Canyon Formation in southern Alberta (Eberth et al., 2004, Eberth, 2006, personal commun.).

THE SABINAS HADROSAUR

Locality

The Sabinas hadrosaurine excavation site is near El Mezquite, about 4 km southwest of Sabinas, Coahuila Mexico; latitude 27° 48' 43", longitude 101° 8' 83" (Figs.1, 4) in the lower part of Olmos Formation in zone 1 above coal-bearing layers (Robeck et al., 1956).

Material

The specimen (PASAC 1) is housed in Sabinas, Coahuila, Mexico. It includes left and right dentaries, left maxilla, partial left and right quadrates, left quadratojugal, right postorbital, braincase, left pterygoid, partial ectopterygoid, atlas, 21 presacral vertebrae, sacrum, 23 caudal vertebrae, fragments of neural spines, 7 chevrons, 15 fragments of ribs, left scapula, left coracoid, distal end of the left radius, parts of the left ilium, right pubis, right ischium, left and right femurs, left tibia, distal end of the right fibula, 1 proximal and 3 distal ends of metatarsals. None of the bones examined display any sign of significant compactional distortion. The specimen preserves the dental batteries, pectoral and pelvis girdles diagnostic of the Hadrosauridae, and the unbooted, distal ischium diagnostic of the Hadrosaurinae (Horner et al., 2004).

Description

Braincase

The braincase was exposed at the surface of the excavation and exhibits some peripheral breakage (Fig. 8 A-E). For example, the frontals are broken away exposing a natural mold of the anterior dorsal surface of the endocranium. The braincase measures 356 mm anteroposteriorly from the parasphenoid rostrum to the exoccipitals. It measures 245 mm dorsoventrally from the parietal crest to the basitubera. It is widest across the paroccipital processes (220 mm) and tapers anteriorly. However, we suspected that, although the paroccipital processes appear to be symmetrical, their lateral ends are missing. Otherwise, the braincase would be unique among hadrosaurids in having very short and massive paroccipital pro-

FIGURE 6. The mounted skeleton of the Sabinas hadrosaur as exhibited in Sabinas Mexico with Juan Pablo Garcia for scale. Anterior portions of skull based on large hadrosaurine skull from Presa de San Antonio and forelimbs based on large forelimb fossils from Baja California.

cesses. The foramen magnum is deep, and the angle of descent of the exoccipitals to the foramen magnum is about 45°. The occipital condyle is 68 mm across. There is a large hourglass depression on the caudal portion of basisphenoid and rostral portion of basioccipital. There is a lamina between the pterygoid processes that is broken so further comparisons are not possible. The parasphenoid rostrum is massive and anterodorsally oriented. The parietal crest is tall and thin.

Maxilla

Only the right maxilla (Fig. 8 P-Q, S) is preserved. The anterior 10-12 cm is missing, based on the number of nutritive foramina and comparison with the dentaries. The dorsal process may be damaged. As preserved, the maxilla is 380 mm long and 145 mm tall. It is massively constructed and subrectangular in lateral view as opposed to all other hadrosaurine taxa we have examined. The medial surface is flat with the dorsal process extending up dorsally from this surface without being inset. There are 44 nutrient foramina preserved in a horizontal row that is not strongly arched as in all other hadrosaurine taxa that we have examined. Laterally, the rostral half of the maxilla is nearly horizontal and high, does not angle ventrally, and does not have a prominent premaxillary shelf. The jugal articulation is not distinctive but seems to reside anterior to the dorsal process. The ectopterygoid shelf is wide and slightly depressed with the ectopterygoid ridge extending laterally about 20 mm. A thin ridge that runs the length of the posterior half of the maxilla distinguishes the medial edge of the ectopterygoid shelf. The palatine process is long and half as tall as the pterygoid process, which is broken posteriorly but is still high and distinctive. As is common among hadrosaurines, the ectopterygoid process is round and blunt.

Postorbital

A partial right postorbital is preserved (Fig. 8 F-G). It is large and robust, evenly rounded laterally and dorsally, flattened medially, and slightly depressed posterior to the orbit. The anterior portion is broken, so the articulation facets cannot be discerned. Therefore, the participation of the frontals in the orbital rim is uncertain. The jugal process is broken and is sub-triangular in cross-section at the break. There is a large deep articulation facet for the laterosphenoid medial to the jugal process. The squamosal process is oval (4.5 mm high by 28 mm wide) in cross-section, but broken.

Quadratojugal

The left quadratojugal is preserved (Fig. 8 N). The dorsal portion is missing. There is a shallow depression on the anterior lateral face for the overlapping jugal. The ventral margin tapers.

Quadrate

The upper two-thirds of the left quadrate (Fig. 8 H-J) and the lower one-half of the right quadrate (Fig. 8 K-M) are preserved, thus we estimate a composite length of 490 mm. The lateral wing is sinusoidal in lateral view. There is no sign of a rugose ridge on the posterodorsal margin as in *Gryposaurus*. The medial extent of the pterygoid wing cannot be determined because of breakage in both elements. The quadratojugal articulation is long ventrally, but the amount of participation of the quadratojugal in the region is uncertain. Dorsally, the articular surface with the squamosal is slender and subtriangular and ventrally, the articular surface for the surangular is about 40 mm above this and is much more massive, with the inner condyle for the articular directed somewhat anteriorly.

Pterygoid

Much of a left pterygoid is preserved (Fig. 8 O), but it is missing most of the palatine ramus and posterior alar projection. It appears to be vertically expanded as in *Brachylophosaurus* and *Gryposaurus*, reflecting the development of a deep narial area of the skull (Heaton, 1972).

Dentary

Both dentaries are preserved, however, the left dentary is better preserved (Fig. 8 R, T-U), whereas the right dentary is broken into several pieces. The left dentary is only missing the anterior portion supporting the dental battery. It is 680 mm long, 152 mm deep ventral to the tooth row, and 295 mm tall at coranoid process. The splenial extends over 75% of the distance of the tooth row and gently tapers anteriorly. The surangular terminates at the dorsal portion of the coranoid process. There are approximately 53 tooth files. The dentary flexes sharply downward 26° at the anterior end of the tooth row and then straightens as it descends ventrally. It tapers gradually in lateral view between the anterior end of tooth row and the symphysis.

Vertebrae

The intercentrum of the atlas is well preserved (Fig. 9 A). It forms a broad, open U-shape that would have cupped the lower third of the occipital condyle. There is no axis preserved with this specimen.

Most of the remaining cervical vertebrae are relatively well preserved (Fig. 9 B-K). All are strongly opisthocoelus as with all hadrosaurids. There is a short neural spine on all preserved cervical vertebrae. Posteriorly, the cervical vertebrae get larger and proportionately shorter (Table 1). The parapophyses are centrally located on the centra. They are short on the anterior cervical vertebrae and form a pocket in the side of the centra on middle and posterior cervical vertebrae. The diapophyses are more anterior and at the level of the neural canal. They are short on anterior centra and long and flexed ventrally on posterior centra. The postzygapophyseal processses are long and robust, curving backward behind each centra and spreading posteriorly. The postzygapophyses face lateroventrally and the prezygapophyses face mediolaterally, as in other hadrosaurids.

The neural arch is broken off most of the dorsal vertebrae. One moderately intact anterior centrum is missing part of one transverse process and the neural spine (Fig, 9 L, M). The centrum is moderately opisthocoelus and is oval in anterior view. The transverse processes angle upward with about an 84° angle between them, are inclined posteriorly, and are T-shaped in cross-section.

The sacrum is broken into 3 major pieces and is much better preserved ventrally than dorsally (Fig. 9 N). It is composed of eight centra, and the sacral yoke is divided just posterior to the third vertebra. The sacrum is about 810 mm long as reconstructed. There is no ventral groove.

Most of the caudal vertebrae recovered have the neural spine broken off. Two lack chevron facets and are considered to be the most anterior of the preserved caudal vertebrae. The largest of these lacks the neural spine and may be the first caudal vertebra (Fig. 9 O, P). The centrum is short anteroposteriorly and nearly as wide as high (Table 1). It is widest just ventral to the neural canal at the level of the caudal ribs which appear to be short. The possible second caudal vertebra (Fig. 9 Q, R) is similar overall, but possesses steeper sides and longer sloping caudal ribs. It is the only

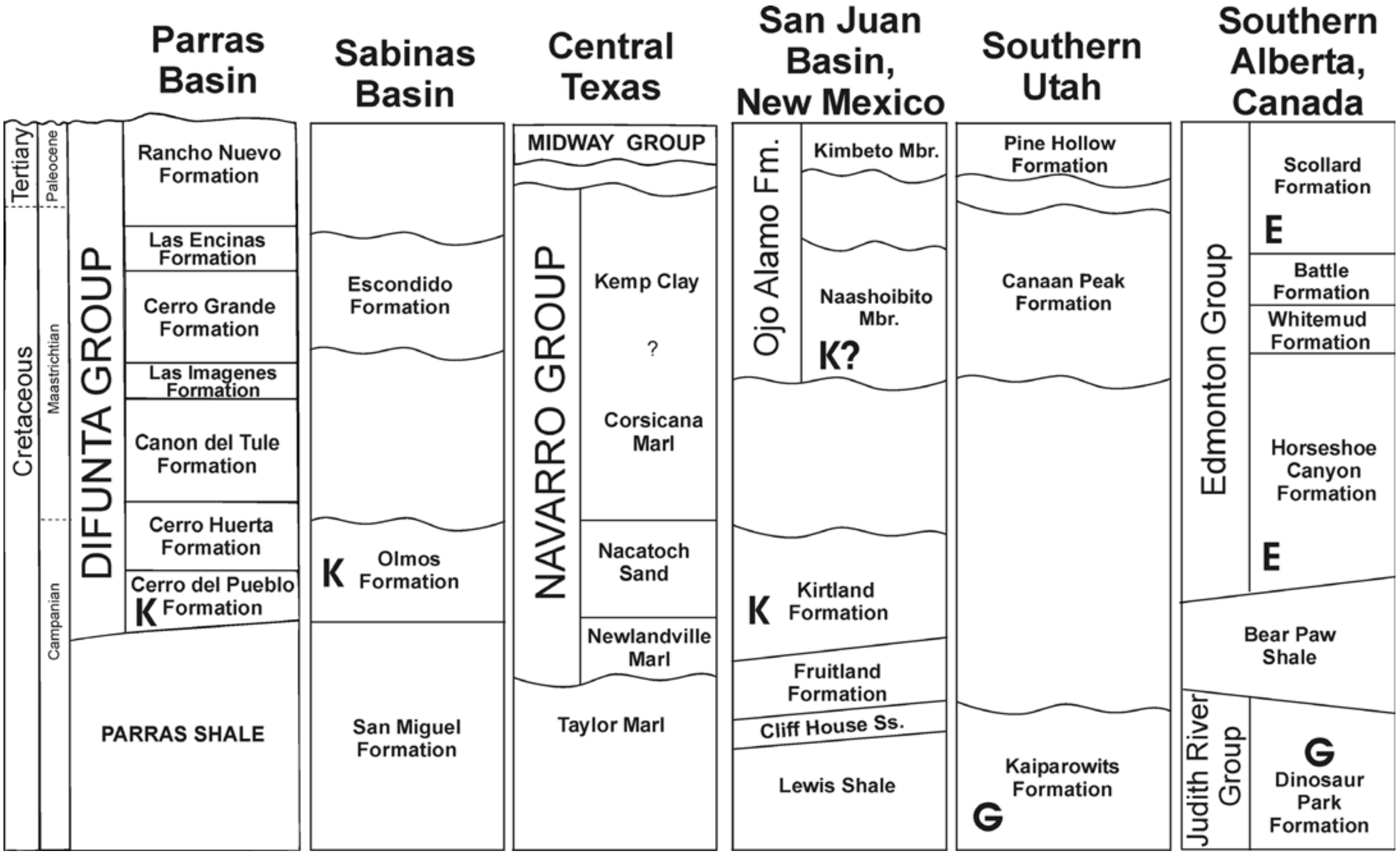


FIGURE 7. Correlation chart for strata discussed in this report. Stratigraphic nomenclature for the Difunta Group in the central Parras Basin after Murray et al. (1962) in Kirkland et al. (2000), for the Sabinas Basin, after Tyler and Ambrose (1986) and Espinoza (1989), for central Texas after Stephenson (1941) modified from data of Cobban et al. (1992), and for the San Juan Basin, New Mexico after Sullivan and Lucas (2003), southern Utah after Eaton (1991) and Roberts et al. (2005), and southern Alberta from Eberth (1997a, b), Eberth and Hamblin (1993) and Roberts et al. (2005). G indicates formation contains *Gryposaurus,* K indicates formation contains *Kritosaurus*, and E indicates formation contains *Edmontosaurus*.

caudal vertebra with a completely intact neural spine. The spine inclines posteriorly, is elongate and fairly thick, and expands anteroposteriorly toward the rounded end of the spine. The pre- and postzygapopheses are closely appressed to the spine near its base. Another anterior caudal vertebra (Fig. 9 S, T) has chevron facets and a long, more inclined neural spine that is missing its distal end. This vertebra is more elongate than the more anterior caudal vertebrae and has less closely appressed zygapophyses. Mid-caudal centra (eg. Fig. 9 U, V) have more hexangular articular surfaces and are more equidimensional overall.

The ribs preserved with this skeleton are fragmentary, and the few chevrons do not add appreciably to the description.

Pectoral Girdle

The left scapula and left coracoid are preserved. The scapula (Fig. 10 B) is missing the distal end of the blade, and the deltoid ridge is broken. As preserved, it is 812 mm long with a minimum width of 130 mm. The blade extends posteriorly with a straight dorsal margin and only gradually expands along its length. Articulation of the glenoid and contact with coracoid are subequal in length.

The left coracoid (Fig. 10 C-E) has the anterior margin and coracoid process broken off. It is 99 mm thick at the contact between the scapular articulation and the glenoid fossa. Laterally, the large coracoid foramen is oval and opens well away from the scapular articulation, while medially, the coracoid foramen is circular and opens at the margin of the scapular articulation, where a groove extends the articulation. The glenoid forms a right angle with the articular surface for scapula. There is a large subtriangular pit on the surface of the glenoid that may be pathologic.

Pelvic Girdle

Two large fragments of the left ilium, the right pubis and the right ischium are preserved (Fig. 10 A). A large fragment of the preacetabular process is preserved. It is long and slender. There is also a large portion of the medial ilium preserved, which includes a portion of the acetabulum, the ischial peduncle, and the antitrochanter (supraacetabular process). This fragment is massively built and has a laterally directed antitrochanter that extends anteriorly from above the ischial peduncle anterior of the center of the acetabulum.

The margins of the pubic blade of the pubis are damaged and most of the pubic process broken off. Repairs were made to the margins of the pubic blade that obscure its actual shape. There does appear to be a relatively long pubic neck. The iliac peduncle is more robust than the ischial peduncle.

The right ischium is complete, well preserved, with absolutely no evidence of distortion. It has a maximum length of 1234 mm. The iliac and pubic peduncles are subequal in size, a character unique among hadrosaurs. The obturator notch is well developed. The ischial shaft is distinctly and continuously curved dorsally for its entire length. It is flattened on both the lateral and medial sides and tapers gradually to a small round termination at its end.

Hind Limbs

Both femora, the left tibia, the distal end of the right fibula, and one proximal and three distal ends of metatarsals are preserved in this specimen. The femur (Fig. 10 F-J) is 1300 mm in length, and the tibia is 1070 mm long (femur to tibia ratio of 1.21). The shaft is straight and slightly

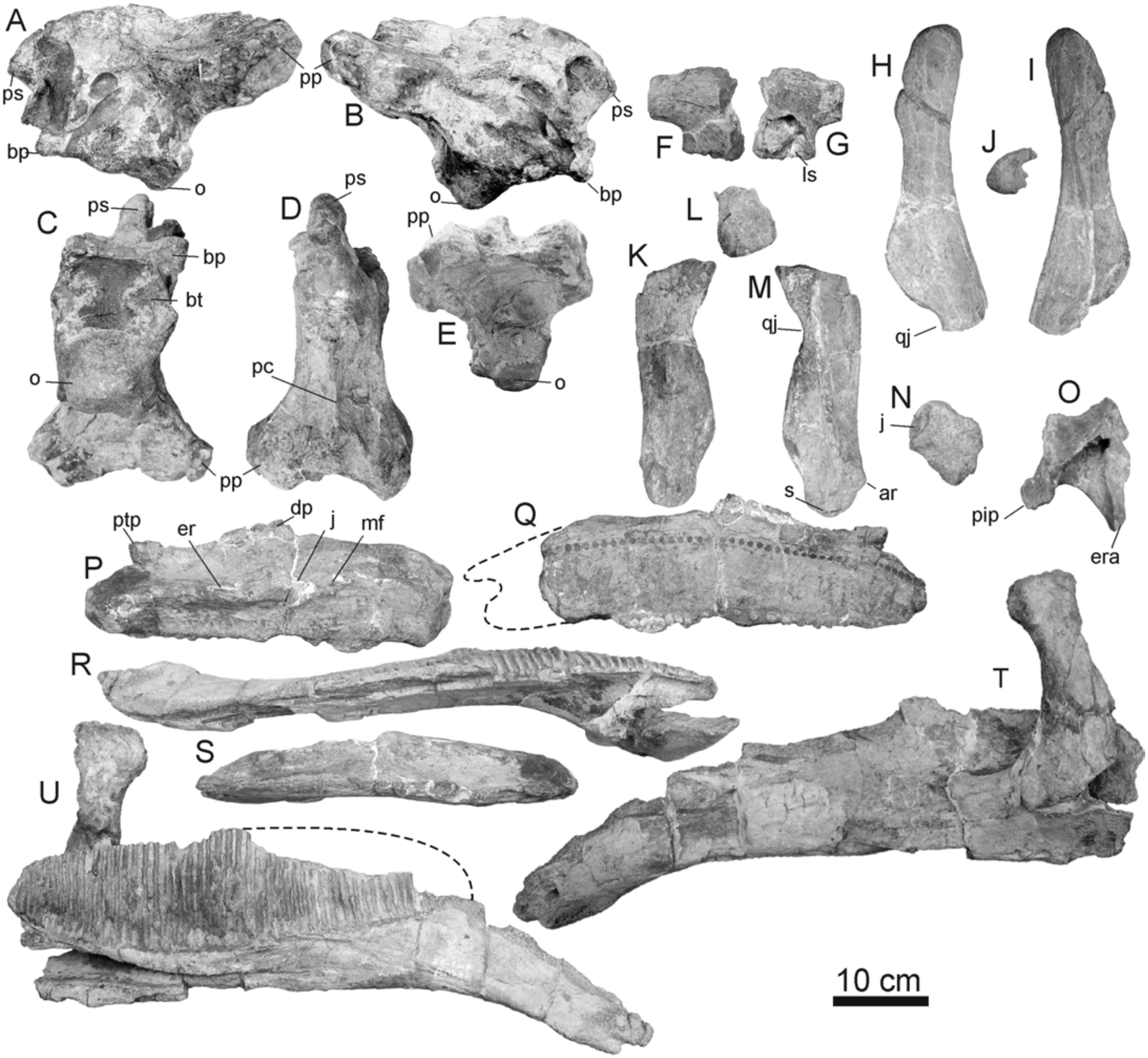


FIGURE 8. Skull bones (PASAC –1). **A-E,** Braincase, A. left lateral view, B. right lateral view, C. ventral view, D. dorsal view, E. posterior view; **F-G,** Right postorbital, F. lateral view, G. medial view; **H-J,** Dorsal portion of left quadrate, H. lateral view, I. medial view, J. dorsal end; **K-M,** Ventral portion of right quadrate, K. lateral view, L. posterior end, M. medial view; **N**, Quadratojugal; lateral view; **O,** Left pterygoid, medial view; **P-Q, S,** Right maxilla. P. lateral view, Q. medial view, S. dorsal view; **R, T-U,** Left dentary, R. dorsal view, T. lateral view, U. medial view. **Ab.** ar. condyle for articular. bp. basipterygoid process, bt. basitubera, dp. dorsal process, er. ectopterygoid ridge, era. ectopterygoid ramus, j. articulation with jugal, ls, articulation for laterosphenoid, mf. maxillary foramen, o. occipital condyle, pc. parietal crest, pip. posterio-inferior projection of quadrate ramus, pp. paroccipital process, ps. parasphenoid rostrum, ptp. pterygoid process, qj. articulation with quadratojugal, s. condyle for surangular condyle for articular. Dashed-line indicates missing portions of bone.

compressed anteroposteriorly. The fourth trochanter is located at mid shaft and is massive, well rounded, and slightly pendent. The femoral head is well developed. The greater trochanter is obvious and the anterior ridge representing the lesser trochanter appears to be fused to it. Distally, the outer condyle is larger and longer anteroposteriorly. The anterior intercondylar groove, while constricted, is not closed.

The left tibia (Fig. 10 K-N) is typical for hadrosaurids. Proximally, it is expanded anteroposteriorly, and distally, it is expanded medio-laterally. The cnemial crest is well developed on the medial side. The outer condyle is larger than the inner condyle, and they are separated by a well-developed intercondylar groove. This broad proximal end tapers gradually to about mid shaft. The inner malleolus is significantly higher than the outer malleolus.

The distal portion of the fibula (Fig. 10 O, P) is expanded into a flattened and densely and deeply grooved distal end. The medial side in contact with the tibia is flattened.The partial metatarsals are uninformative

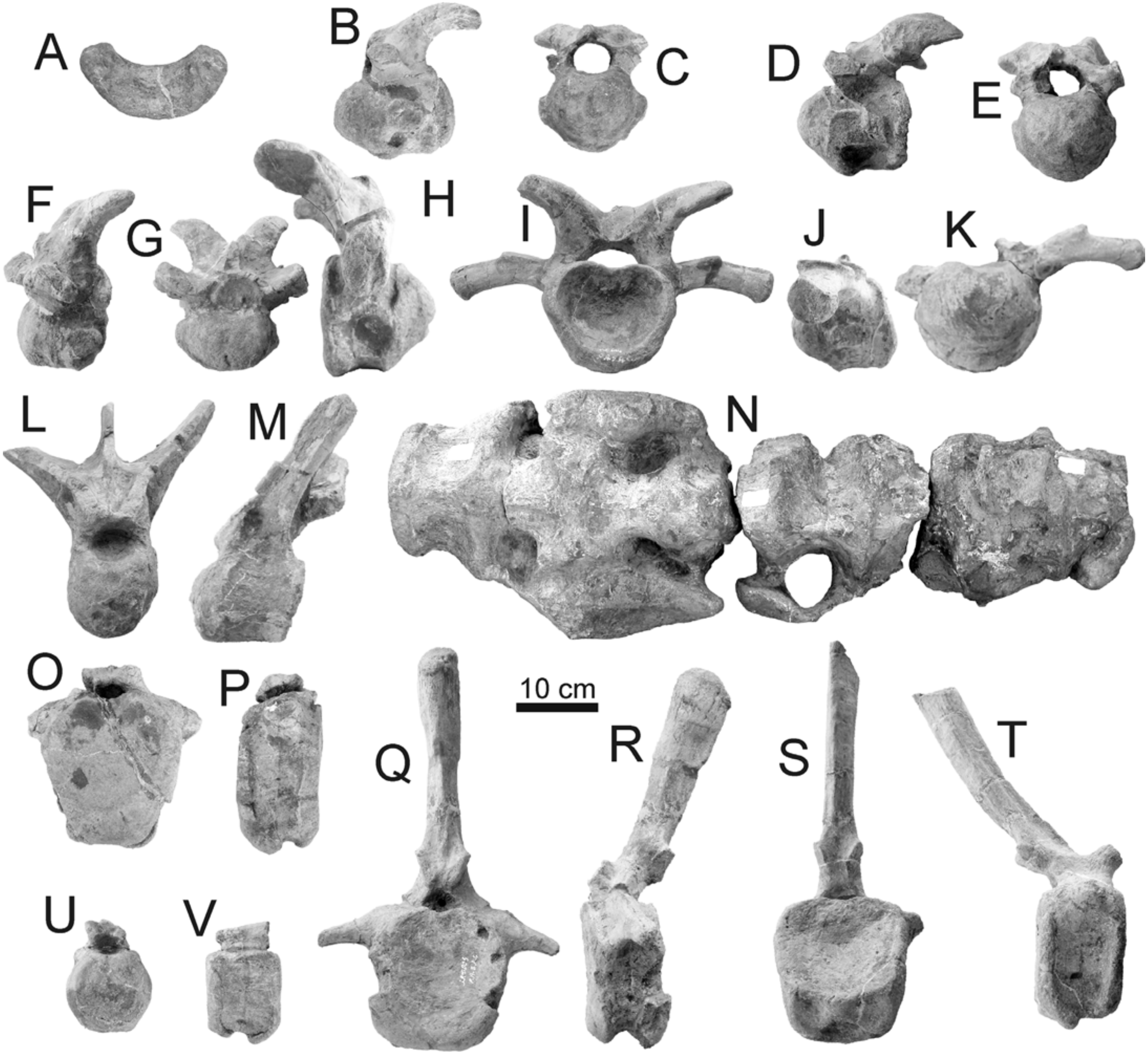


FIGURE 9. Vertebrae (PASAC –1). **A,** Atlas, anterior view, **B-C,** Anterior cervical vertebra, B. left lateral view, C. anterior view; **D-E,** Anterior cervical vertebra, D. left lateral view, E. anterior view; **F-G,** Medial cervical vertebra, F. left lateral view, G. anterior view; **H-I,** Posterior cervical vertebra, H. right lateral view, I. posterior view; **J-K,** Posterior cervical vertebra, J. right lateral view, K. anterior view; **L-M,** Anterior dorsal vertebra, L. anterior view, M. left lateral view; **N,** Sacrum, ventral view; **O-P,** First caudal centrum, O. anterior view, P. right lateral view; **Q-R,** Second caudal vertebra, Q. posterior view, R. left lateral view; **S-T,** Anterior caudal vertebra, S. posterior view, T right lateral view; **U-V,** Medial caudal vertebra, U. anterior view, V. left lateral view.

beyond reflecting the large size of the animal.

ANTERIOR PORTION OF SKULL FROM PRESA DE SAN ANTONIO

Locality

Jose Lopez Espinosa found the sandstone block containing the specimen (IGM 6685) about 1 km north of Presa de San Antonio, Coahuila, Mexico in the uppermost Campanian (Kirkland et al., 2000; Eberth, et al. 2004) Cerro del Pueblo Formation in the central Parras Basin (Fig. 1).

Material

The specimen (IGM 6685) was preserved in a sandstone block that enclosed the anterior-most portion of a skull and lower jaws, which had been preserved in articulation (Fig. 11). The bones include paired premaxillae, predentary, and the anterior portions of the right and left dentaries. A thin arrowhead-shaped piece of unidentified bone lies on the right dentary behind the premaxilla.

Description

Premaxilla

The premaxillae are fully fused to one another and fairly complete, missing only the posterior parts of the lateral and dorsal processes. They are robust and rugose along the oral margin. The lateral edge of the oral

TABLE 1. Measurements of selected vertebrae from the Sabinas hadrosaurine.

VERTEBRAL MEASUREMENTS in mm PASAC - 1

Approximate Vert Position	Identification in Fig. 9	Width of Centrum	Height of Centrum	Length of Centrum	Maximum Height	Maximum Width
ant. cervical	B,C	138.3	105.1	133.0	156.1	
ant. cervical	D,E	133.6	103.0	132.7	170.0	~148.8
mid. cervical	F,G	138.6	115.2	95.6	156.1	185.0
pos. cervical	H,I	165.0	129.1	127.0	226.0	434.0
pos. cervical	J,K	169.6	122.2	118.0		~436.0
ant. dorsal	L,M	123.0	101.2	122.5		~314.0
1st caudal ?	O,P	174.2	176.2	86.4		
2nd caudal ?	Q,R	171.0	172.0	87.4	487.0	311.4
ant. caudal	S,T	131.1	134.8	85.4		~173.2
mid. caudal	U,V	109.6	101.5	87.6		109.6

margin flares ventrolaterally, and the premaxillary lip is deep with the oral margin slightly overlapping this depression rostrally. The dorsal process extends dorsocaudally tapering gently before the broken surface. Much of the lateral process is not visible through matrix. From the symphysis outward, there are two pairs of round to conical shaped premaxillary oral denticles set inside the cutting surface. A third, more lateral pair of denticles extends posteriorly to form a raised ridge that coincides with the lateral cutting edge. In dorsal view, the oral margin is rounded like that of *Gryposaurus*.

Dentary

About 13 cm of the tooth row is preserved on the right and left dentaries anterior to the break. The dentaries are 138 mm deep below tooth row. The predentary shelf sharply angles ventrally at the anterior end of the tooth row, and straightens as it tapers toward the symphysis, as seen in the Sabinas basin specimen. The diastema is approximately 100 mm long.

Predentary

The predentary is massive and about 212 mm long from the symphysis to the end of the predentary process. The ventral process probably forks as in other taxa but is obscured by matrix. The oral margin appears to be adenticulate. In dorsal view, the oral margin is evenly rounded. Laterally, the predentary processes form a broad, depressed dorsal shelf that is about 43 mm wide and slightly inclined laterally. The caudal edge of these processes is forked with the ventral arm significantly longer than the dorsal arm.

DISCUSSION

Comparisons With Other Hadrosaurine Taxa

Research into the relationships of the Sabinas and Presa de San Antonio hadrosaurines is still ongoing, but some important conclusions can be made. Because of its large size, the Sabinas hadrosaurine was at first compared to the even larger Chinese hadrosaurine *Shantungosaurus giganteus* (Hu, 1973). *Shantungosaurus* differs in its massively constructed straight lower jaw and in having 10 sacral vertebrae versus the 8 sacral vertebrae preserved in the Sabinas hadrosaurine. Additionally, *Shantungosaurus* has a straight ischium with a more enclosed obturator process. Finally, *Shantungosaurus* appears to have a postorbital constructed more like that of *Edmontosaurus* (Hu, 1973).

Edmontosaurus (Lambe, 1920; Versluys, 1923), and the closely related *Anatotitan* (Chapman and.Brett-Surman, 1990), have a distinctive postorbital that is expanded and deeply pocketed behind the orbit with a thin jugal process that is inclined rather than erect. The dentary is straight with a much longer diastema than the Sabinas or Presa de San Antonio jaws. Likewise, *Edmontosaurus* and *Anatotitan* have a more delicate, denticulate, predentary that is squared-off in dorsal view. They also possess a proportionally shorter quadrate, lower pterygoid, and a more strongly arched maxilla. The ischium is straight rather than recurved. The largest example of *Edmontosaurus regalis* (ROM 801) examined had a femur length of 1260 mm; nearly the same size as the Sabinas hadrosaurine (Fig. 12).

The Sabinas hadrosaurine can be easily differentiated from *Prosaurolophus* (Brown, 1916; Horner, 1992) and *Saurolophus* (Brown, 1913), on the basis of its elongate quadrate, ventrally recurved dentary, and short diastema between the predentary and the anterior end of the tooth row (Fig. 13). The Presa de San Antonio skull has a much more massive predentary and premaxilla, which also has a strongly recurved lip and extends more dorsally indicating a deeper skull anteriorly. The postorbitals are more robust and the maxillae are not as long and slender. The ischium is distinctly recurved in the Sabinas hadrosaurine and straight in *Prosaurolophus* and *Saurolophus*.

Anasazisaurus (Hunt and Lucas, 1993; Williamson, 2000; Lucas et al., this volume) has a distinctive nasal that is pulled back with a distinct lateral pocket (Fig. 13) similar to that developed in *Lophorothon* (Langston, 1960) and *Prosaurolophus* (Brown, 1916). The predentary of *Anasazisaurus* is lightly constructed and strongly denticulate (Williamson, 2000), unlike that in the type of *Kritosaurus* and in the Presa de San Antonio skull section (IGM 6685).

The dentary recurves less and the diastema is longer in *Brachylophosaurus* (Sternberg, 1953; Horner, 1988) and the closely related *Maiasaura* (Horner, 1983; Trexler, 1995). Additionally, both of these taxa possess a denticulate premaxilla with a short lateral process that is much more delicately constructed and squared off in dorsal view. Both of these genera also have straight ischia.

The dentary is most like that of *Gryposaurus* (Lambe, 1914; Parks, 1920). The dentary in *Gryposaurus* appears to have a more gradual downward flexure anterior to the tooth row. However, if one accepts the muzzle from Presa de San Antonio as being the same species as the Sabinas specimen, its massive predentary compares best to *Kritosaurus*. *Gryposaurus* has a more delicate denticulate predentary, although the apparent absence of denticles in *Kritosaurus navajovius* and the Presa de San Antonio specimen may be a result of their larger size due to an unsubstantiated loss of these denticles late in ontogeny. The ventral curve in the anterior dentary of *Gryposaurus* begins anterior to the tooth row and curves more continuously, unlike that observed in either the Sabinas or Presa de San Antonio hadrosaurines. The maxilla of *Gryposaurus*, as in other hadrosaurines, is triangular in lateral view, and the row of accessory foramen is strongly arched, with an obvious "step" laterally, where the premaxilla articulated. In comparison, the maxilla of the Sabinas hadrosaurine is distinct in being sub-rectangular with a much less arched row of accessory foramen and lacking the well-developed "step" where the premaxilla articulates. The

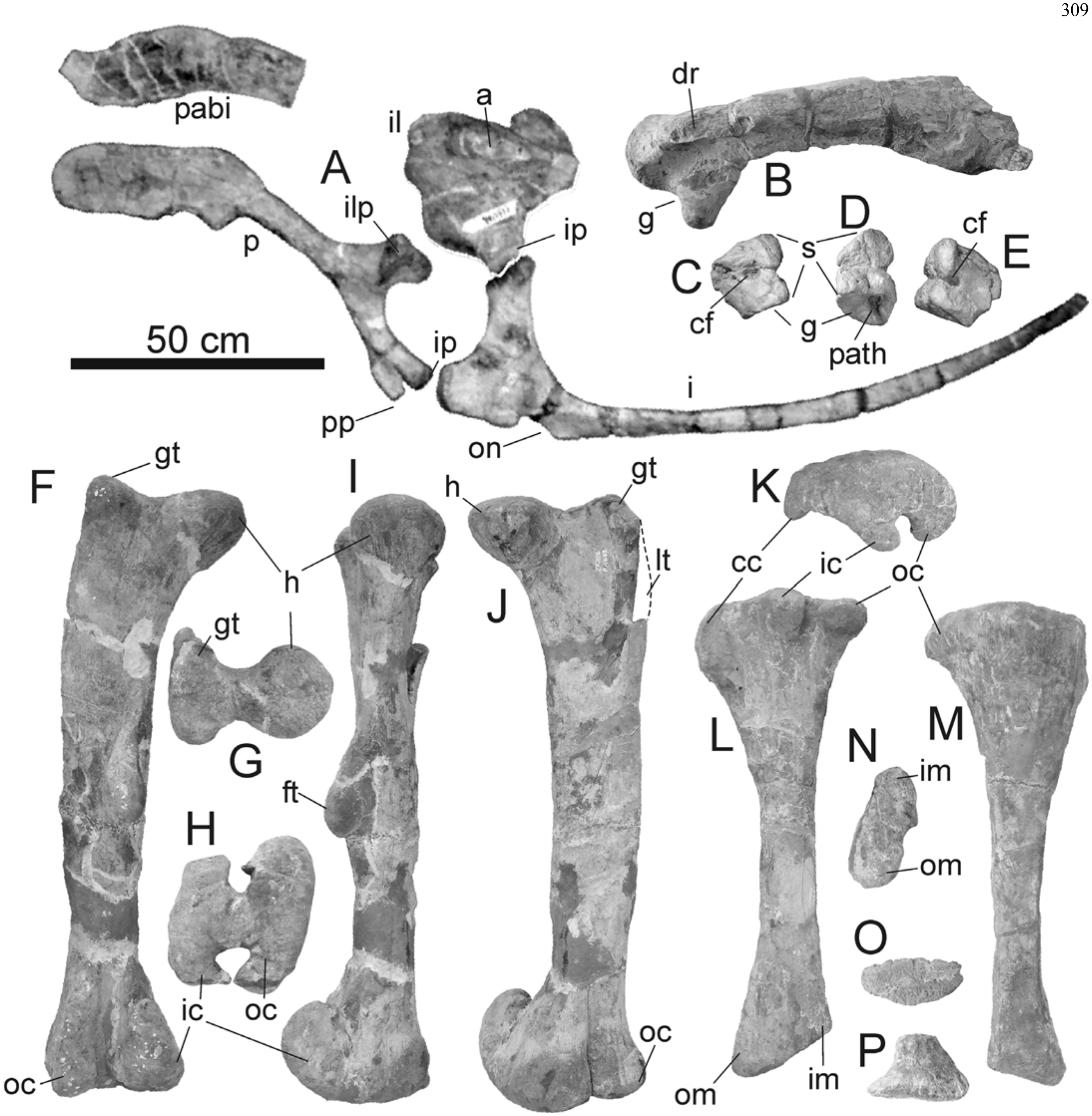


FIGURE 10. Appendicular skeleton (PASAC –1). **A,** Pelvis with fragments of left ilium in lateral view, right pubis in medial view, and right ischium in lateral view; **B,** Left scapula, lateral view; **C-E,** Left coracoid, C. lateral view, D. articular surface, E. medial surface; **F-J,** Left femur, F. posterior view, G. proximal end, H. distal end, I. medial view, J. anterior view; **K-N,** Left tibia, K. proximal end, L. lateral view, M. medial view; N. distal end; **O-P,** Distal end of right fibula, O. proximal end, P. lateral view. Ab: a. antitrochanter, cc. cnemial crest, cf. coracoid foramen, dr. deltoid ridge, ft. fourth trochanter, g. glenoid, gt. greater trochanter, h. femur head, i. ischium, ic. inner condyle, il. ilium, im. inner malleolus, ip, ischial peduncle, lt. lesser trochanter, oc. outer condyle, om. outer malleolus, on. obturator notch, p. pubis, path. pathology, pp. prepubic rod, pabi. preacetabular blade of ilium, s. scapular contact. Dashed-line indicates missing portions of bone.

dorsal border of the scapular blade is relatively straight in the Sabinas hadrosaurine and is curved in *Gryposaurus incurvimanus* (Parks, 1920). Additionally, *Gryposaurus incurvimanus* differs in having a coracoid with a much shorter glenoid relative to the articular surface for the scapula and in having a straight ischium. *Gryposaurus* specimens from the Kaiparowits Formation in southern Utah under study by TG, likewise share straight ischia. Unfortunately, the post-cranial skeleton of the type of *Gryposaurus notabilis* (NMC 2278) remains in plaster jackets, unprepared.

The only described hadrosaurine with an upturned ischium is *Hadrosaurus foulkii* (Leidy, 1858, 1865; Prieto-Marquez et al., 2006). In this taxon, the ischium turns upward, but seems to do so to a lesser degree than in the Sabinas hadrosaurine (Fig. 14). Recently, this taxon was considered a *nomen dubium*, and although recognizably a member of the Hadrosaurinae, its relationships with the other members of this group can-

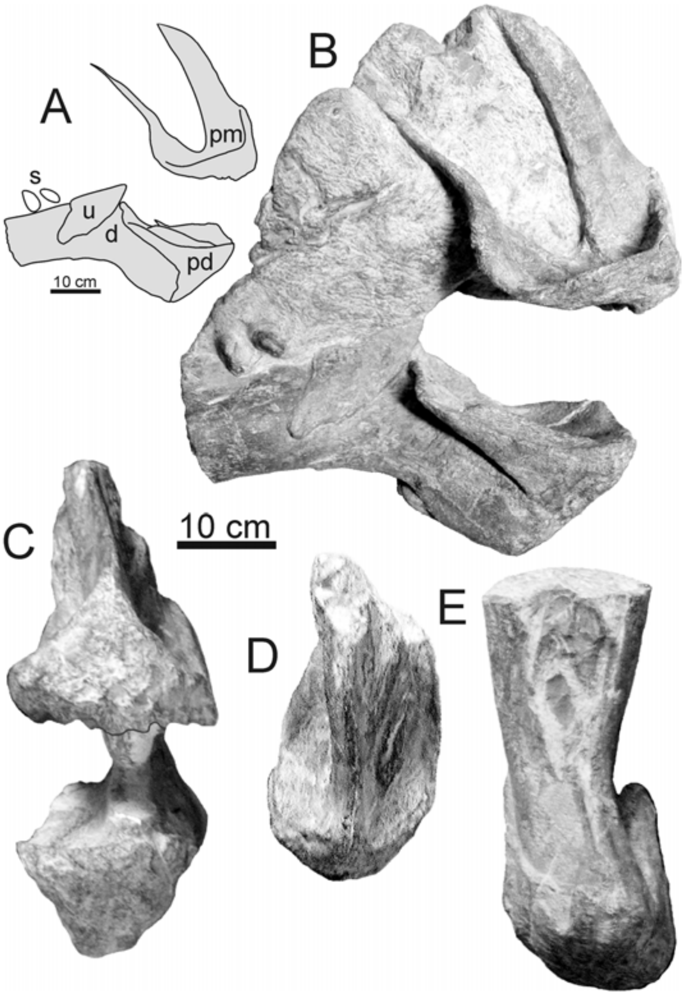


FIGURE 11. Presa de San Antonio muzzle (IGM 6685). **A,** Diagram of right lateral view (B) with bones in gray. **B,** Right lateral view, **C,** Anterior view, **D,** Dorsal view of premaxillae, **E,** Ventral view of predentary and anterior dentaries. Ab: d. dentary, pd. predentary, pm. premaxilla, s. brackish water snails, u. unknown thin bone.

not be determined as the remains of the only known specimen are incomplete (Prieto-Marquez et al., 2006). However, *Hadrosaurus* has a significantly longer tibia in proportion to the length of the femur, and the glenoid forms an acute angle with the articular surface for scapula. Thus, although *Hadrosaurus* may be related to the Sabinas hadrosaurine, it probably represents a distinct genus.

The holotype of *Kritosaurus* (AMNH 5799), represented only by an incomplete skull and axis, appears to be most similar to the Sabinas and Presa de San Antonio hadrosaurines (Fig. 15). The most obvious features shared between these two taxa include a massively developed predentary, elongate, slender quadrates, and dentaries that flex down sharply at the anterior end of the tooth row. Unfortunately, the original specimen of *Kritosaurus* has the front portion of the skull artfully reconstructed and it is exhibited under glass, so it cannot be directly studied. The braincase appears to be beautifully preserved and prepared, but direct comparisons with the distinct braincase of the Sabinas specimen (PASAC – 1) are difficult under these conditions. The characteristic, rectangular maxilla of the Sabinas specimen appears to be most similar to the posterior portion of the *Kritosaurus* type specimen. However, the anterior portions of the type specimen's maxilla are completely obscured by reconstruction and the steel armature supporting the skull (Fig. 16). We suggest that the only way to fully diagnose the holotype of *Kritosaurus navajovius*, is to take it off exhibit and make a high resolution CAT scan of the specimen.

The type, and only example, of *Naashoibitosaurus* (NMMNH P-16106) may represent a juvenile specimen of *Kritosaurus* (Williamson, 2000), but is difficult to determine at the present time (Fig. 15). It is missing most of its the lower jaws and its premaxilla, both critical elements in diagnosing *Kritosaurus*. The nasal of *Naashoibitosaurus* is distinct from *Gryposaurus* in not being strongly arched and in bearing weak lateral depressions on the proximal, lateral surfaces. The maxilla appears to be morphologically intermediate between the condition in *Gryposaurus* and the Sabinas hadrosaurine and may reflect an earlier ontogenetic stage. Unfortunately, *Naashoibitosaurus* does not appear to be very useful in developing an understanding of the Sabinas and Presa de San Antonio hadrosaurines.

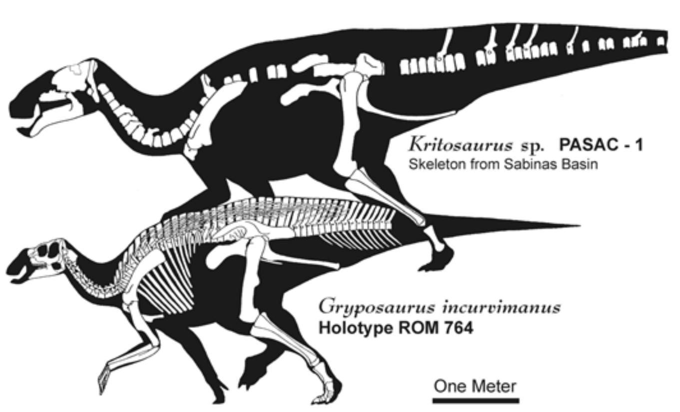


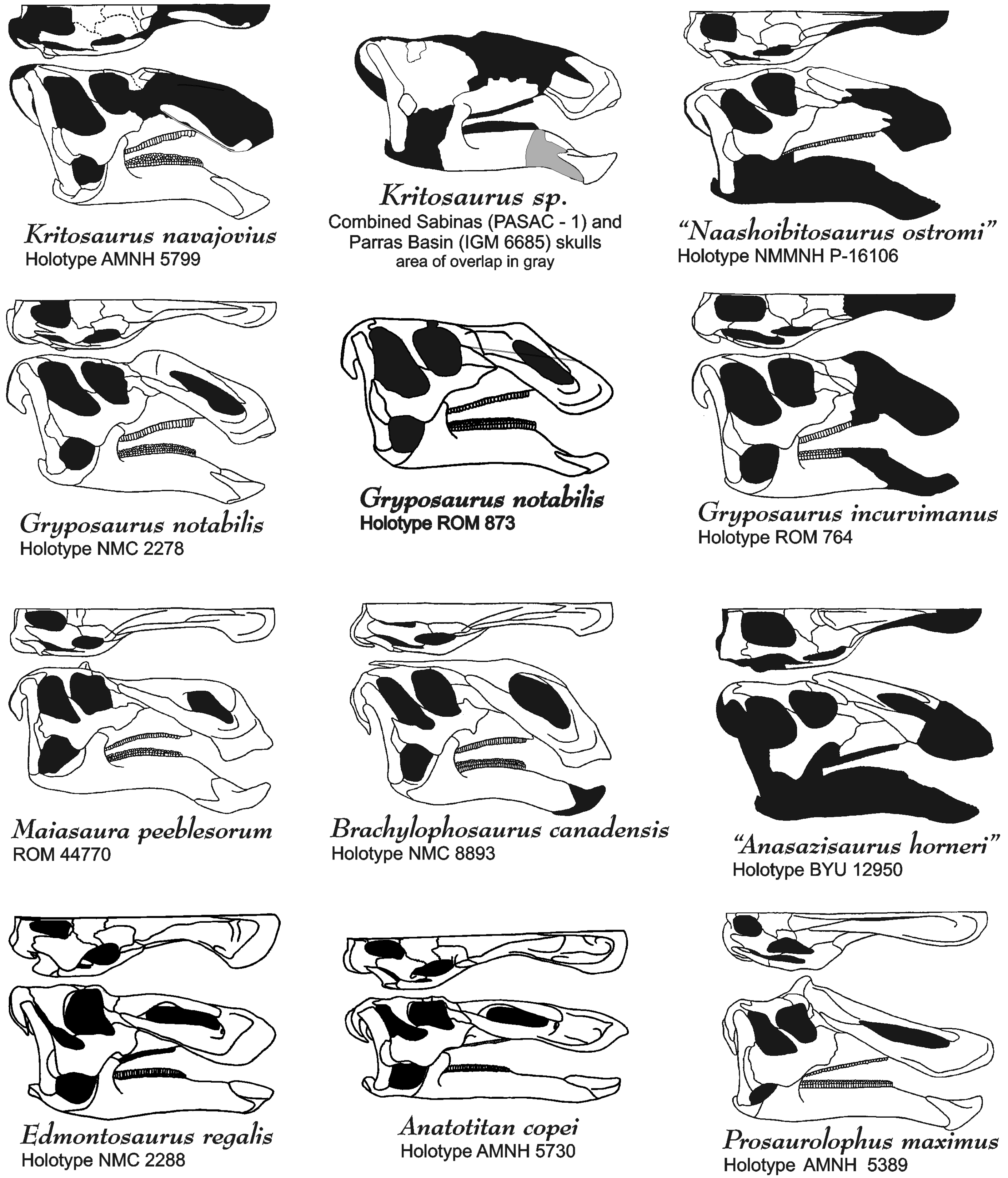
FIGURE 12. Reconstructed skeleton of the Sabinas hadrosaurine compared to the holotype of *Gryposaurus incurvimanus*. In both only the actual preserved bones are indicated.

We identify the large hadrosaurines from Sabinas and Presa de San Antonio as *Kritosaurus*, although, about 20% larger than the holotype of *Kritosaurus navajovius* (AMNH 5799). At this point, we refrain from assigning the specimens to species. Continued field research in the southwestern United States and Mexico will certainly uncover additional, more informative specimens permitting a detailed phylogenetic study of *Kritosaurus* to be undertaken.

The Sabinas hadrosaurine is the only specimen of *Kritosaurus* for which there is extensive post-crania. Additionally, although post-cranial material is well known for *Gryposaurus*, the jackets containing the post-cranial skeleton of the holotype at the Canadian Museum of Nature have never been opened. The most notable features that sets the Sabinas hadrosaurine apart from all other hadrosaurines known from western North America are its rectangular maxilla and distinctive upturned ischium. The discovery of a similar ischium in the San Juan Basin of New Mexico would provide support for our identification of these large hadrosaurines from Coahuila, Mexico as *Kritosaurus* sp.

The Case For *Kritosaurus*

The relationship of *Kritosaurus* and *Gryposaurus* has been a matter of controversy for many years (Fig. 13). Gilmore (1916) apparently recognized the similarities soon after *Gryposaurus* was first described. Parks (1920), Lull and Wright (1942), and most subsequent authors have synonymized *Gryposaurus* with *Kritosaurus*. Baird and Horner (1977) suggested a synonymy of *Hadrosaurus*, *Kritosaurus*, and *Gryposaurus*. Horner (1988) recognized the distinction of *Kritosaurus* based on two additional skulls from the type area. Hunt and Lucas (1993), in reviewing these fossils, reported that the holotype of *Kritosaurus* was not diagnostic and named the two new skulls *Anasazisaurus* and *Naashoibitosaurus*. Williamson (2000) subsequently synonymized these two taxa with *Kritosaurus*, while Wagner (2001) most recently synonymized all of these with *Kritosaurus*, once again. Horner et al, (2004) recognized *Anasazisaurus* and *Naashoibitosaurus* as distinct species, but consider *Kritosaurus* to be a *nomen dubium*, while Prieto-Marquez et al. (2006) seem to accept *Kritosaurus* as a valid taxon.



Kritosaurus navajovius
Holotype AMNH 5799

Kritosaurus sp.
Combined Sabinas (PASAC - 1) and
Parras Basin (IGM 6685) skulls
area of overlap in gray

“Naashoibitosaurus ostromi”
Holotype NMMNH P-16106

Gryposaurus notabilis
Holotype NMC 2278

Gryposaurus notabilis
Holotype ROM 873

Gryposaurus incurvimanus
Holotype ROM 764

Maiasaura peeblesorum
ROM 44770

Brachylophosaurus canadensis
Holotype NMC 8893

“Anasazisaurus horneri”
Holotype BYU 12950

Edmontosaurus regalis
Holotype NMC 2288

Anatotitan copei
Holotype AMNH 5730

Prosaurolophus maximus
Holotype AMNH 5389

FIGURE 13. Comparison of various hadrosaurine skulls discussed herein.

FIGURE 14. Claudia Serrano holding the ischium of the Sabinas hadrosaurine with the darkened ischium from *Hadrosaurus* (Leidy, 1865) superimposed over it.

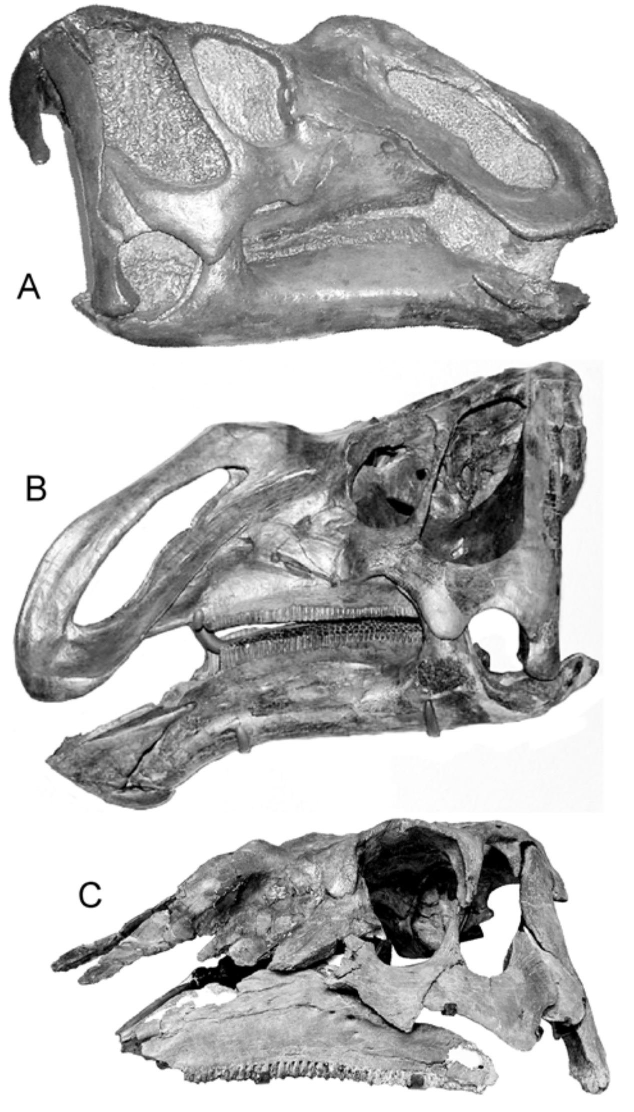


FIGURE 15. Holotype skulls of *Gryposaurus*, *Kritosaurus* and *Naashoibitosaurus*. **A,** *Gryposaurus* (NMC 2278), **B,** *Kritosaurus* (AMNH 5799), **C,** *Naashoibitosaurus* (NMMNH P-16106). Shown at similar size without scale.

Our research on these fossils substantiates the validity of the genus *Kritosaurus* and its distinctiveness relative to the genus *Gryposaurus* and the genus *Hadrosaurus*. Our comparisons of the *Kritosaurus* specimens from Mexico with the holotype specimen on exhibit at the AMNH emphasize some of the features on the holotype that may be diagnostic for *Kritosaurus*. These are a massive, adenticulate predentary, dentaries that sharply flex at the anterior end of the dental battery, and a subrectangular maxilla. Additionally, a dorsally recurved ischium would be diagnostic postcranially.

Barnum Brown's Skull Scraps From *Kritosaurus*

Brown (1910) noted that the anterior portion of the type skull (AMNH 5799) of *Kritosaurus* was poorly preserved and that many fragments could not be put into his reconstruction. Additionally, Brown (personal commun. to Sinclair and Grangier, 1914) assumed the float bones he identified as belonging to the narial region to be crushed due to their extraordinary forms (Williamson, 2000). Within a few years, the skull had been reconstructed with nasals based on those in *Gryposaurus* (Gilmore, 1916). Williamson (2000) identified one piece from the box of fragments that was not incorporated into the skull reconstruction as a medial section of the nasal. RH and JK, during a visit to the AMNH, examined this box of fragments and found a few pieces that went together to form larger sections of bone. One piece could be fit onto the front of Williamson's "nasal" and another large piece seemed to represent the upper posterior part of the nasal. Hernandez et al. (2003) noted that with the nasal reconstructed in this way, it was distinctly different from that of *Gryposaurus* and supported the recognition of these taxa as distinct.

While preparing this manuscript, one of us (SN) identified another of the bone fragments as representing the mirror image of Williamson's (2000) nasal fragment. Unfortunately, this suggested that the nasal was constructed very differently from any other described hadrosaurine nasal. Finally, after long consideration, TG recognized that the majority of these bone fragments represented parts of the ventral premaxilla and, in particular, much of the left and right lateral processes of the premaxilla (Fig. 17). The bone section previously identified as the posterior portion of the nasal (Hernandez et al. 2003) is more problematic. We interpret it to represent a section of the skull from the area posterior to the narial opening. To further illustrate its confoundedness, we are still debating whether this bone fragment may alternatively represent more of the prefrontal or anterior jugal rather than the nasal. More repair and study needs to be performed on these fragments.

This interpretation is reasonable, if one considers that Barnum Brown found the completely articulated skull weathering out of the ground with the complete lower jaws and the skull posterior to the maxilla and frontals preserved in place. We interpret these fragments of bone found as float by Brown to be elements of the skull just anterior to this portion of the skull (i.e., the premaxillae and nasals). Therefore, the anterior and dorsal portions of the premaxillae and the anterior portions of the nasals would have been completely destroyed due to erosion (Fig. 17 G). This hypothesis can be tested by the recovery of an additional adult skull of *Kritosaurus* from the San Juan Basin, New Mexico and further study of these interesting pieces of float bone from the holotype.

BIOGEOGRAPHIC CONSIDERATIONS

We consider the biogeographic separation of *Kritosaurus* and *Gryposaurus* as lending support to the recognition of these taxa as separate genera (Fig. 15). *Gryposaurus* is part of the northern *Corythosaurus* fauna and *Kritosaurus* is the name-bearer of the southern *Kritosaurus* fauna (Lehman, 1997). *Gryposaurus* is known from southern Utah north into western Canada, and *Kritosaurus* is now recognized from northern New Mexico south into southern Coahuila, Mexico (Fig. 7).

However, in addition to being segregated geographically, they are separated in time. Sullivan and Lucas (2003) defined a new North American land animal age, the Kirtlandian (late Late Campanian), that spans the

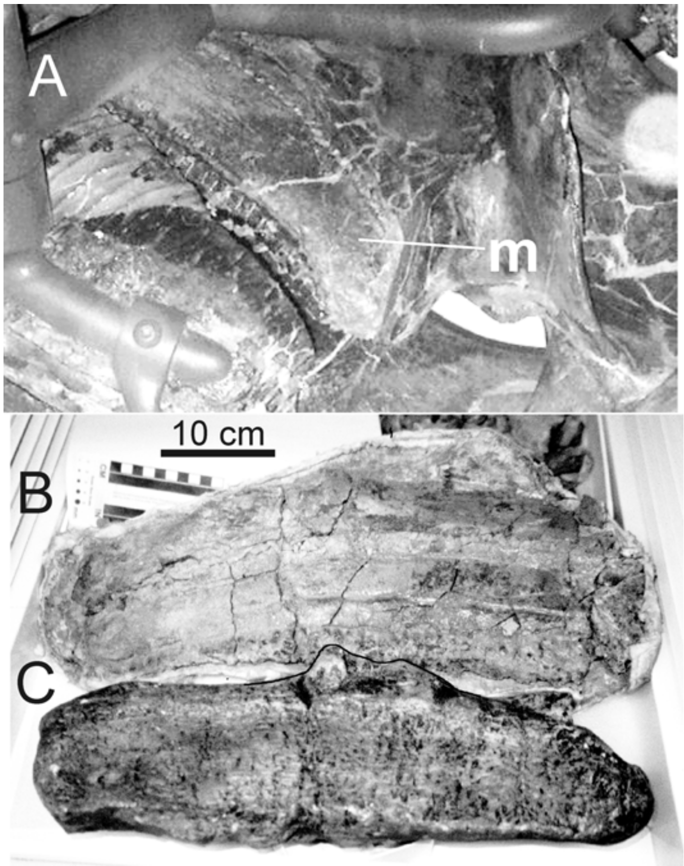


FIGURE 16. Comparison of *Kritosaurus* maxilla. **A,** Ventral view of holotype AMNH 5799 as exhibited showing medial view of posterior one half of right maxilla (m). Pipe about 25 mm in diameter. **B,** AMNH 5797 in jacket. **C,** Cast of right maxilla, PASAC –1.

interval between the Judithian (early Late Campanian) and the Edmontonian (Early Maastrichtian). The Kirtlandian is defined on the range of *Pentaceratops*, which occurs in the Fruitland and Kirtland Formations and in the Mesaverde Group of western Colorado (Lucas et al., this volume). It should be noted that the co-occurring hadrosaurines in these rocks have not been identified. Based on the latest radiometric date correlations, the Fruitland Formation may overlap the upper-most Kaiparowits Formation in southern Utah, which yields *Gryposaurus* (Roberts et al., 2005). *Kritosaurus* is only identified from the Kirtland Formation and not the Fruitland Formation (Williamson, 2000).

Sullivan and Lucas (2003) reported that the Kirtlandian correlated to the marine Bearpaw Shale in southern Alberta. Recent research in this region has shown that the lower part of the Horseshoe Canyon Formation overlying the Bearpaw is latest Campanian (Eberth et al., 2004, Eberth, 2006, personal commun.), and therefore, the basal Edmontonian is actually latest Campanian, as opposed to early Maastrichtian. As the *Kritosaurus* specimen from the Sabinas would appear to be latest Campanian in age (see above), the range of *Kritosaurus* would appear to extend upward into the Edmontonian. Ryan (2003) reported the range of the large *Edmontosaurus regalis* as being in the lower half of the Horseshoe Canyon Formation.

Wagner (2001) reported *Kritosaurus* sp. cf. *K. navajovius* from the Maastrichtian Javalina Formation at Big Bend National Park, Texas, and Sinclair and Granger (1914) collected a maxilla (AMNH 5797) in 1913 that compares well with *Kritosaurus* (Fig. 16) from the Maastrichtian Naashoibito Member of the Ojo Alamo Sandstone, San Juan Basin, New Mexico (Williamson, 2000). These occurrences indicate that *Kritosaurus* or another similar hadrosaurine, lived in the southwestern United States in the later Maastrichtian, while other species of *Edmontosaurus* and the related *Anatotitan* were living in the northern United States and Canada.

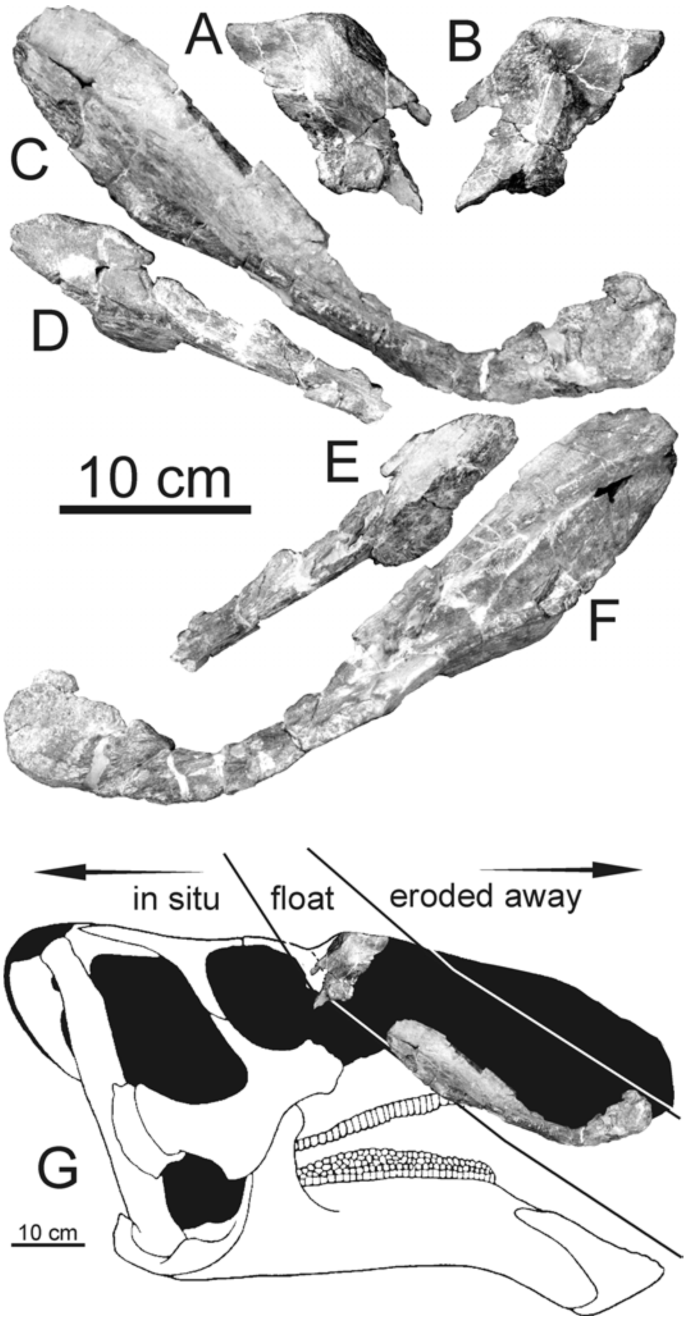


FIGURE 17. Larger bone fragments associated with holotype of *Kritosaurus navajovius* (AMNH 5799). **A-B,** Unspecified bone from area posterior of narial opening. Orientation unknown, but position as interpreted for posterior portion of left nasal. A. lateral view, B. medial view. **C, F,** Lower portion of right premaxilla. C. lateral view, F. medial view. **D-E,** Lower posterior portion of right premaxilla. D. medial view, E. lateral view. **G,** Reconstructed skull of holotype of *Kritosaurus* showing hypothesized orientation of bone fragments and hypothesis as to preservational condition of the skull when discovered by Barnum Brown in 1913.

Thus, while *Edmontosaurus* was roaming Canada, *Kritosaurus* was roaming New Mexico and northern Mexico. The profound differences in the jaw structure of these two genera likely reflect different feeding strategies due to the vegetation that they were feeding on. This is supported by documented dominance of conifers in the north and angiosperms in the south (Lehman, 1997; Lehman and Wheeler, 2001).

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