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A PRELIMINARY REPORT ON NEW DINOSAUR MATERIAL FROM THE ARUNDEL CLAY (LOWER CRETACEOUS, LATE APTIAN-EARLY ALBIAN) OF MARYLAND.

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Recent collecting activity at a locality in the Arundel Clay (Lower Cretaceous, Late Aptian-Early Albian), of Maryland, has produced a quantity of new dinosaur material. Although most of the finds are isolated bones and teeth, they help to augment our fragmentary knowledge of the dinosaur fauna of the Arundel Clay. Material of interest includes: an associated find of a theropod proximal tibia, pedal phalange, and ungual; 2 very large sauropod femora, indicating the presence of gigantic sauropods in the fauna; and an unusual ornithopod tooth, probably indicating a new taxon in the Arundel. In addition, a collection of theropod teeth, some referrable to very small individuals, have been recovered from the locality.

Introduction

Gallup (1988) stated that little has changed regarding our knowledge of the dinosaurs of the Arundel Clay in the past 90 years. Indeed, the last significant collection assembled before the present was that of A. B. Bibbins in 1894-1896. However, in the 1980's interest in collecting in the Arundel

Clay was revived by local amateurs, who uncovered a promising locality at a commercial clay pit near Muirkirk, Maryland. Many of their finds have been added to the collections of the U.S. National Museum. These new specimens, together with the larger collections amassed by J. B. Hatcher and A. B. Bibbins in the last century, and a few isolated finds made through the years, is all we presently know of the fauna of the Arundel Clay. Unfortunately, that knowledge, based primarily on isolated, often incomplete material, is very fragmentary. Although previous authors have erected taxa based on these remains, current workers are much less certain as to the taxonomic affinities and systematic relationships of the material. Perhaps only one valid genus and species, *Pleurocoelus nanus*, can be recognized, and then not with confidence as it is based on isolated, juvenile remains. With this exception, all other taxa erected by Marsh (1888), as well as those named by Leidy (1865), Lull (1911), Gilmore (1920, 1921) and Russell (1972), are considered nomina dubia by modern workers. The present study will introduce no new taxa, but will add modest new insights concerning the composition of the Arundel fauna, based in large part on the specimens collected in the last few years.

Geology

The Arundel sediments were until recently given formation status and included in the Potomac Group. Revision by Jordan (1983) changed the Potomac Group to the Potomac Formation, and the Arundel Formation to the Arundel Clay (McGee, 1896). The Potomac Formation occurs in a broad belt running northeast from central Virginia to southern New Jersey, but the Arundel Clay is only recognizable in the portion between Washington, D.C. and Baltimore, Maryland. The Potomac Formation represents a fluvial-deltaic complex, with a time transgressive relationship (Doyle and Robbins, 1977), deposition moving from south to north through time, as a result of tectonic movements (Owens and Gohn, 1985). Doyle and Hickey (1976) defined the depositional environment of the Arundel Clay as a swamp or backwater. More recently, Owens and Gohn, (1985) concluded that the environment was that of a forested wetland, with deposition of grey clay in oxbow lakes. The Arundel Clay may represent a local facies and be highly variable in age throughout its occurrence in the Potomac Formation (pers. comm. Robbins).

Brenner (1963) divided the Potomac deposits into 4 palynologic zones, with the Arundel sediments corresponding to Pollen Zone I. Doyle and Hickey

(1976) correlated Pollen Zone 1 as being Late Aptian to Early Albian in age. Robbins (1991) took 3 samples from the Muirkirk clay pit locality for analysis. The sample taken from the base of the clay unit conforms to Pollen Zone I, however, the sample taken from near the supposed dinosaur-bearing horizon, in about the middle of the deposit, revealed traces of Zone II pollen. The sample taken near the top of the clay unit was typical upper Zone I. In order to work out this discrepancy the junior author has taken new samples and we are awaiting their analysis.

Stratigraphic sections of the Muirkirk clay pit locality have been published by Clark (1911) and Brenner (1963). In general, the unit begins with red clays at the base which are overlain by grey clay units, which carry lens of lignitized wood, as well as fossil vertebrates. The grey clay is in turn overlain by brown-grey clay.

Approximate stratigraphic section of Muirkirk clay pit by Robbins (1991).

Top of Hill	Est. Thickness
Brown-gray clay, mottled (Sample # 1245)	40 ft.
Gray clay, some charcoal and iron zones	

Log unit, top -dark gray clay with logs having bark ironstone root casts (Sample #1244)	
middle -dark gray clay with twigs; pyrite	15 ft.
bottom - dark gray clay with sediment filled roots, non-calcareous; sauropod femur	
Rooted underclay	
Gray clay in ironstone unit	
unconformity	----------
Orange sand with gray clayballs	
Darker grey clay with twigs	25 ft.
6" gray clay having turtle scutes (Sample #1243)	

Mottled red clay	30 ft.
Red clay	
Floor of pit	Total thickness 110 ft.

Paleontology

As previous workers have commented (Gilmore 1921, Ostrom 1970) the nature of the fossil record of the Arundel Clay is an extremely fragmentary one, based as it is on isolated, often incomplete material. As Hatcher reported "no two bones or fragments of all that material collected from the Potomac beds [Arundel Clay] in Maryland were found in such relation to one another as to demonstrate that they belonged to the same individual.... the scattered and disarticulated state in which [they were] found, must be constantly borne in mind." (Quoted by Gilmore [1921, p. 582].) These problems make determination of systematic relationships amoung Arundel specimens and affliations with taxa from other formations extremely difficult. However, the discovery in 1989 of a complete, articulated turtle (still in prep), and the more recent find of fragmentary, but apparently associated theropod remains, holds out the hope that more determinable dinosaur material will eventually come to light.

There are several problems associated with preservation and collecting in the Arundel Clay. The original depositional environment, while low energy (as evidenced by the lack of transport abrasion on the bones), was presumably as poor in its preservational characteristics as are modern swamps or wetland forests. Pyrite, leeching from clay lens with a heavy lignite content, is highly corrosive to fossil bone. This may explain the disproportional preservation of teeth and phalanges, as these are not only the most numerous skeletal elements, but also the most robust. Collecting is hampered by a lack of suitable exposures for prospecting. In the past, while active ore mining was in progress localities were probably more numerous. Today, iron ore is not mined in the area and the old localities are no longer exposed. Only brick and commercial clay pits offer a chance to prospect.

History of Collecting

The first recorded find of dinosaur material from the Arundel Clay was the discovery in 1858 of two sauropod teeth by P. T. Tyson, near Bladensburg, Maryland. This was the first record of Sauropoda from N. America. The teeth are in the collections of the Peabody Museum.

In 1887 and 1888 J. B. Hatcher working under the auspices of O. C. Marsh, assembled the largest and most significant collection of Arundel vertebrates to date. Most of this material was recovered from the Muirkirk and Contee area, from iron ore mines at a locality known as Swampoodle. What is striking about Hatcher's locality is the relative abundance of bones, something not seen in other Arundel sites. By far the most numerous material collected was referrable to a juvenile sauropod, *Pleurocoelus nanus* Marsh. Lull (1911) indicated that a catastrophic event was responsible for the over representation of sauropod remains at the site. Also recovered , but represented by far less material, were the first theropod and ornithopod fossils from the formation. Hatcher's collection now resides in the U.S. National Museum.

In 1894, 1895, and 1896 A. B. Bibbins was commissioned by Goucher College to recover fossil cycad trunks from the Potomac formation. While pursuing this objective he also accumulated a collection of fossil vertebrates from several localities of the Arundel Clay. All of his material was originally deposited in the collections of Goucher College, and subsequently transferred to the U.S. National Museum.

The interval between Bibbin's collection in the 1890's and the 1980's has brought little new material to light. When bones were found it was usually a chance find, related to heavy industry. In 1942, an incomplete femur of a moderate-sized sauropod was found while building a filtration plant in N.W. Washington, D.C. Little else of consequence has been found in the intervening years.

In 1988, a local school teacher and paleontologist, P. Kranz, revived amateur interest in collecting dinosaurs in the Arundel Clay, by encouraging amateurs to prospect the Muirkirk clay pit locality. In addition, close cooperation between the management of the clay pit and the Smithsonian Institution has resulted in the recovery of several interesting finds. This locality is not as abundant in bone as was Hatcher's locality, but it represents a more balanced fauna. This locality has produced more ornithopod material than any other Arundel site. Most of the material collected has been accessioned by the U.S. National Museum.

History of Publication

The first publication on an Arundel dinosaur came in 1859, with a short note by C. Johnston on two sauropod teeth discovered by P. T. Tyson the previous year. Johnston erected the name *Astrodon* for the teeth in reference to the star-shaped appearance of the dentine in cross-section. The teeth were later described and figured by Leidy (1865), who formalized the name as *Astrodon johnstoni.*

In 1888 O. C. Marsh published on the large collection recovered by J. B. Hatcher. Marsh recognized 5 dinosaur taxa in the Arundel Clay, erecting 2 new genera and 5 new species based on fragmentary material. The type materialfor the medium-sized theropod, *Allosaurus medius*, included a tooth and various metapodial elements. The type material of the small theropod, *Coelurus gracilis* was an ungual phalanx. The type material for the small sauropod, *Pleurocoelus nanus*, included parts from the skull, axial and appendicular skeleton. However, as Hatcher commented none of these remains can be shown to have been associated. Further complicating matters is the fact that the materials of *Pleurocoelus nanus* represent immature animals, as evidenced by open sutures. The type material of the medium-sized sauropod *Pleurocoelus altus*, is a tibia and incomplete fibula. Finally, Marsh erected what he thought was a new genus and species of stegosaur, *Priconodon crassus*, based on a single tooth. Marsh believed the Arundel fauna to have it's greatest affinities with the Upper Jurassic Morrison fauna..

The next major work on the Arundel fauna was produced by Lull (1911). Lull concurred with Marsh's interpretation of a Jurassic age for the Arundel, retaining all of the previous author's taxa. Lull recognized 8 dinosaur taxa, including 2 new species. The type material of the large theropod, *Creosaurus potens*, was a single vertebral centrum. To establish the new ornithopod species, *Dryosaurus grandis*, Lull removed all the metapodial type material from Marsh's *Allosaurus medius*. Lull also added *Astrodon johnstoni* to his faunal list.

Gilmore (1921) produced the next major revision of the Arundel fauna, and significantly altered or abolished many of the taxa proposed by Marsh and Lull. He was also one of the first authors to question the erection of taxa in the Arundel based on isolated, incomplete remains. Nevertheless, he named a new theropod species, *Ornithomimus grandis*, based on the fragmentary, isolated metapodial type material that Lull had removed from *Allosaurus medius* to *Dryosaurus grandis.* Gilmore argued for a Cretaceous age for the Arundel, and altered Marsh's and Lull's theropod taxa to reflect a Cretaceous affliation, e. g. *Dryptosaurus? medius* and *Dryptosaurus? potens*, while tentitively retaining the Jurassic genus *Coelurus? gracilis*. Gilmore synonymized *Pluerocoelus* with *Astrodon*, creating 3 species;

A. nanus, *A. altus* and *A. johnstoni*. Gilmore retained *Priconodon crassus*, but removed it from Stegosauridae to Ankylosauridae.

No formal review of the Arundel fauna has come out since Gilmore, although Ostrom (1970) briefly reviewed the fauna in relation to the Cloverly Formation. Ostrom pointed out the very meager nature of our knowledge concerning the Arundel material and offered only a generalized assessment of the fauna. The present authors concur with Ostrom's approach.

Although no faunal review has appeared, many modern workers have reviewed the Arundel taxa individually. Molnar (1990) considers materials referred to *Allosaurus medius* and *Creosaurus potens* to be indeterminate. Norman (1990) refers *Coelurus gracilis* to theropoda nomen dubia. Russell (1972) referred *Ornithomimus affinis* to his newly established genus *Archeaornithomimus*. Smith and Galton (1990) restudied this material and concluded that ornithomimid characters were not preserved, and referred the remains to coelurosaurian grade theropoda (Barsbold and Osmolska (1990) reached a similiar conclusion). McIntosh (1990) retains both *Pleurocoelus nanus* and *Pleurocoelus altus* in his species list, but questions the validity of these taxa. Most modern workers synonymize *Astrodon* with *Pleurocoelus*. Coombs and Maryanska (1990) comment on the highly conservative nature of ankylosaurid dentition and do not accept assignments based on dentition. *Priconodon crassus* is considered nomen dubia. In Galton and Jensen (1979) described a fragmentary ornithopod tooth from the Arundel Clay, which they referred to *?Tenontosaurus sp.* The present authors will not comment on the validity of this assignment, as the specimen has been on loan and is not available for study.

DINOSAUR FAUNA OF THE ARUNDEL FORMATION

Listed by Marsh, 1888	Listed by Lull, 1911	Listed by Gilmore, 1921	Listed by Ostrom, 1970	Listed by authors, 1992
Theropoda	**Theropoda**	**Theropoda**	**Theropoda**	**Theropoda**
Allosaurus medius	*Allosaurus medius*	*Dryptosaurus? medius*	*Large Theropod 1*	*Large Theropod*
Coelurus gracilis	*Creosaurus potens*	*Dryptosaurus? potens*	*Large Theropod 2(?)*	*Small Theropod*
	Coelurus gracilis	*Coelurus gracilis*	*Small Theropod*	
		Ornithomimus affinis	*Ornithomimid*	
Sauropoda	**Sauropoda**	**Sauropoda**	**Sauropoda**	**Sauropoda**
Pleurocoelus nanus	*Pleurocoelus nanus*	*Astrodon nanus*	*Sauropod 1*	*Sauropod 1*
Pluerocoelus altus	*Pleurocoelus altus*	*Astrodon altus*	*Sauropod 2(?)*	*Sauropod 2(?)*
	Astrodon johnstoni	*Astrodon johnstoni*		
	Ornithopoda			**Ornithopoda**
	Dryosaurus grandis			*?Tenontosaurus*
				Ornithopod indet.
Stegosauria	**Stegosauria**	**Ankylosauria**	**Ankylosauria**	**Ankylyosauria**
Priconodon crassus	*Priconodon crassus*	*Priconodon crassus*	*Ankylosaurid*	*Nodosaurid*

New Specimens

Only the most interesting specimens will be commented on below. These remarks are not meant as a formal description of the material. In addition, a complete listing of the new specimens recovered from the Muirkirk clay pit will be given. This is included to give the reader an impression of the nature of collecting in the Arundel. Some of the material will be figured.

Theropoda

A recent, apparently associated find, which includes the proximal end of a left tibia, a pedal phalange and an ungual, is the most diagnostic theropod material thus far recovered from the Arundel Clay. The material is still in preparation and has not been cataloged. The tibia which belonged to a medium-sized theropod is quite gracile, although the specimen may have been slightly crushed in the lateral-medial plane. The cnemial crest is very pronounced. There is a prominent facet on the caudolateral surface of the tibia for articulation of the fibula. Presence of a fibular crest is indicated. In general, the tibia of this specimen resembles those of ornithomimids and the Late Cretaceous form *Dryptosaurus aquilunguis.*

A small collection of theropod teeth has been recovered from the Muirkirk clay pit locality, and presents some interesting characteristics. The collection includes both premaxillary and maxillary/dentary teeth, with many crowns intact to the tip. The most consistent feature found in the maxillary/dentary teeth is the restriction of anterrior serrations to the top third of the tooth crown. The smaller teeth also exhibit this feature, but have a carina reaching close to the base of the crown. In the larger teeth the serrations of the anterrior surface terminate abruptly, without any observable decrease in the size of the individual denticles, and are not followed by a carina. Denton (pers. comm.) reports a similar pattern in the teeth of *Dryptosaurus aquilunguis*. A brief analysis of the Arundel clay pit theropod maxillary/dentary teeth was made using methods outlined in Farlow, et. al. (1991). Materials from the Hatcher and Bibbins collections could not be included because of poor preservation of the material. The analysis reveals that the Arundel theropod teeth cluster most closely with those of an unidentified Comanchean theropod, dromaeosaurids, and *Alectrosaurus* (in the figures by Farlow, et. al., 1991). The larger teeth also correlate with those of an unidentified theropod from the Morrison Formation.

Sauropoda

The discovery of a very large, incomplete sauropod femur (at first believed to be a cycad stump, due to heavy iron ore accretion on the specimen) in the Muirkirk clay pit in 1990, followed by an even larger femur later that year, gives us the first evidence of gigantic sauropods from the Arundel Clay. An incomplete femur collected in 1942, and referred to incorrectly by Kranz (1989) as pertaining to a very large individual, is only half the linear dimensions of the more recently discovered femora. The diameter measured across the distal condyles of the two giant femora was 440mm and 480mm respectively (same measurement from a specimen of *Apatosaurus ajax* was 450mm). These new finds denote animals of enormous size. The preserved distal ends of both femora, and the smaller femur from 1942, compare very closely in morphology. Despite, its very large size, the second femur, recovered has a portion of shaft preserved, which appears quite slender when compared with those of other sauropods of similar size. (I.E. TRANSVERSE DIMENSION OF DISTAL PORTI

Ornithopoda

An unusual ornithopod tooth was collected from the clay pit in 1989. The tooth exhibits primitive ornithopod characters such as leaf-shaped serrations, but also shows advanced features, such as canting of the occlusal surface and the presence of a strong ridge orientated parallel to the longitudinal axis of the tooth. Some workers who have viewed the tooth believe it has certain ceratopsian characteristics, and it does agree in some points with the teeth of *Psittacosaurus*. It does not agree closely with the teeth of *Tenontosaurus*, from either the Cloverly (Ostrom, 1970) or the Arundel (Galton and Jensen, 1979). The tooth probably indicates a new taxon in the Arundel fauna, and so is listed as an indeterminate ornithopod in the faunal listing compiled above.

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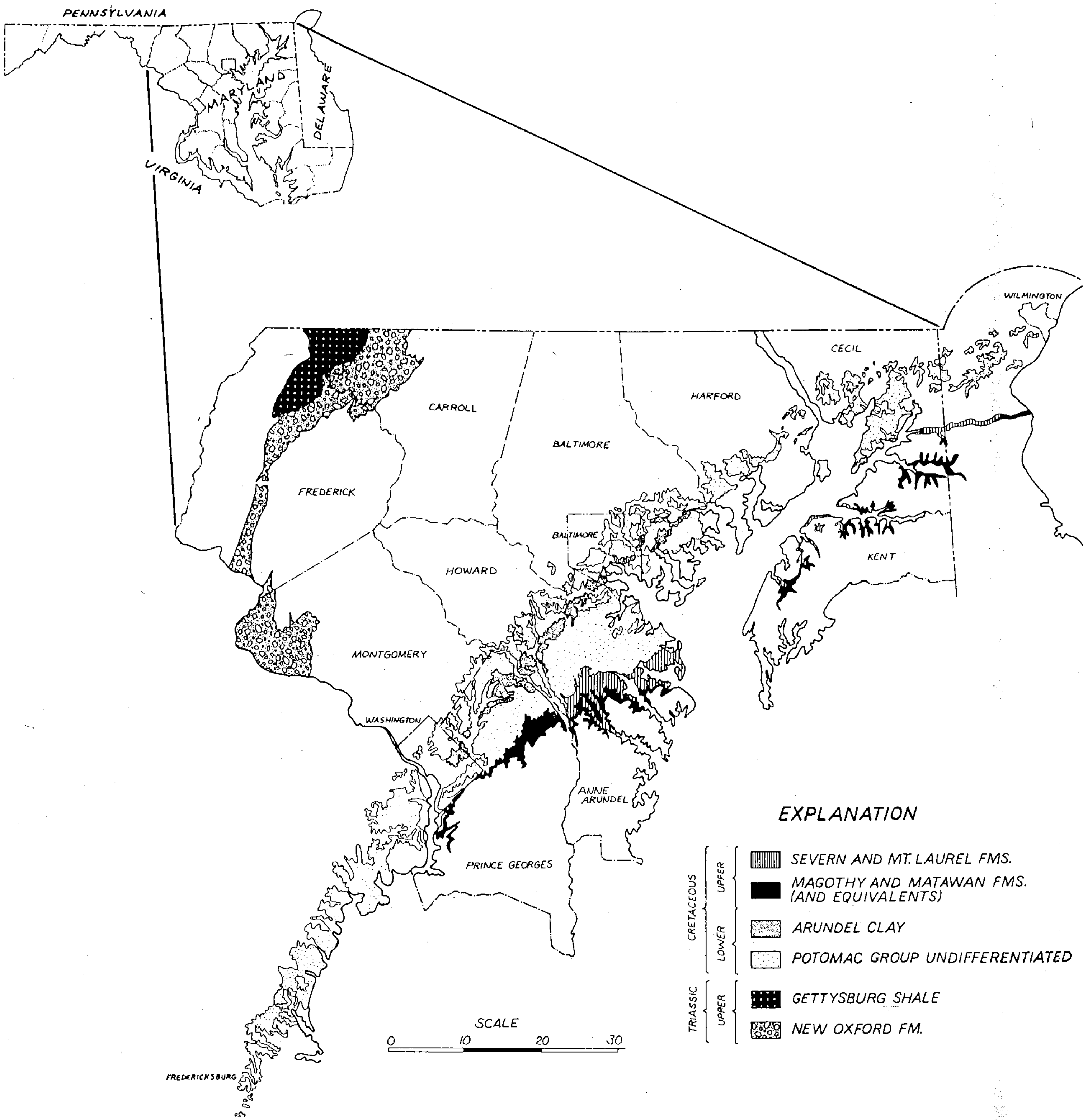

Figure 1. The Mesozoic outcrops of Maryland.

Figure 2. The Muirkirk clay pit locality.

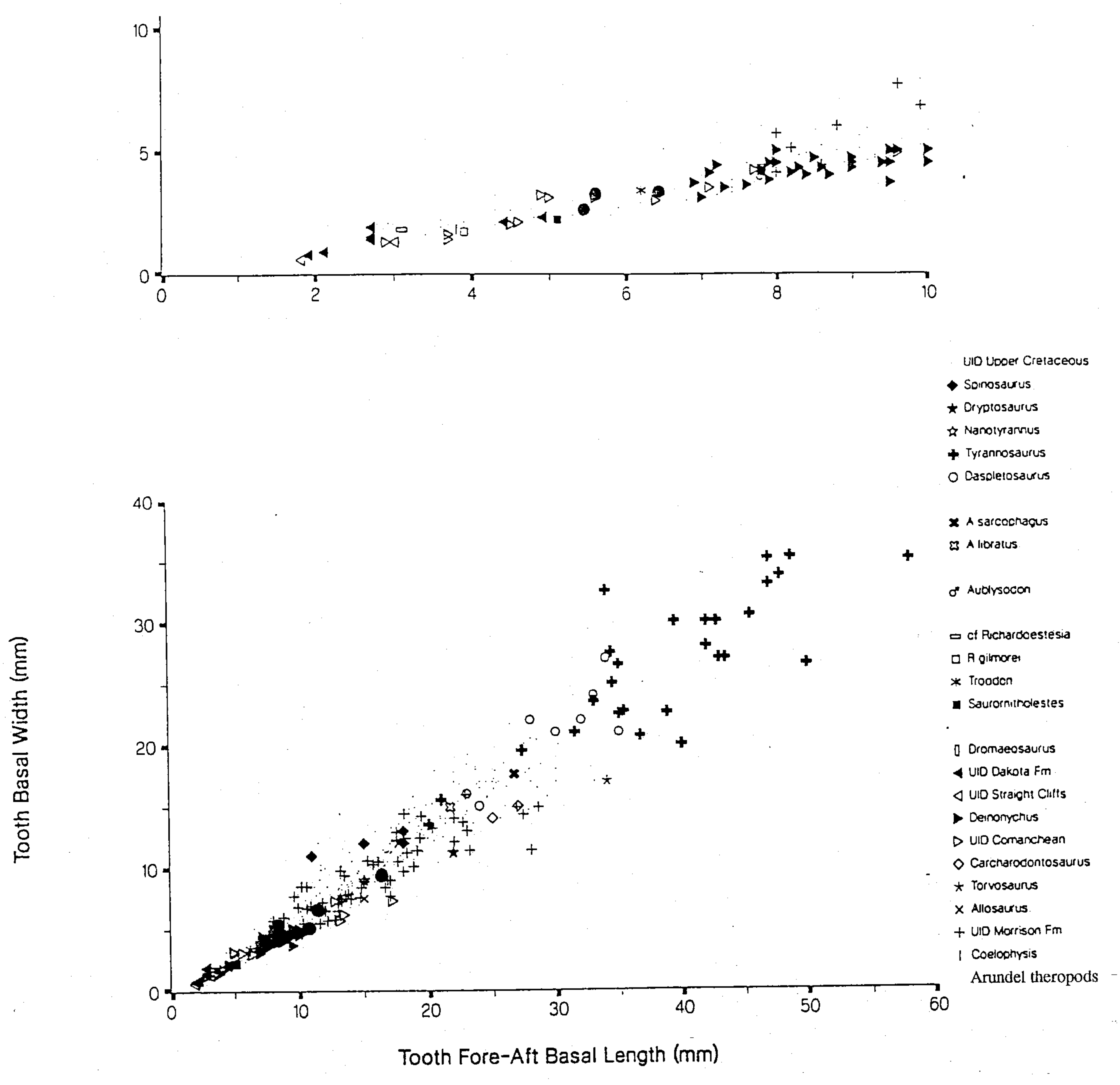

Figure 3. Relationship between tooth basal width and tooth fore-aft basal length in theropods (from Farlow, et. al., 1991).

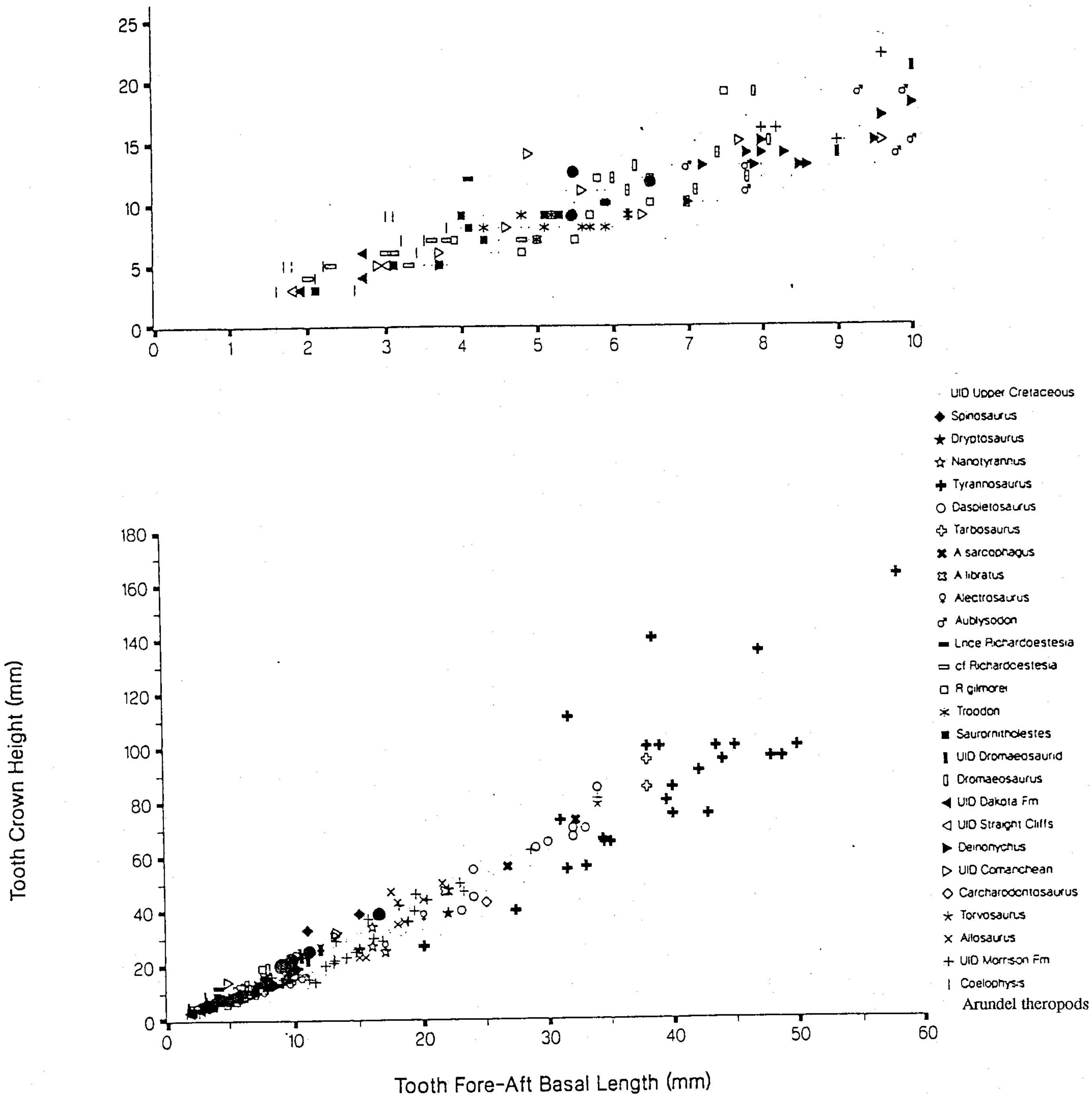

Figure 4. Relationship between tooth crown height and tooth fore-aft basal length in theropods (from Farlow, et. al., 1991).

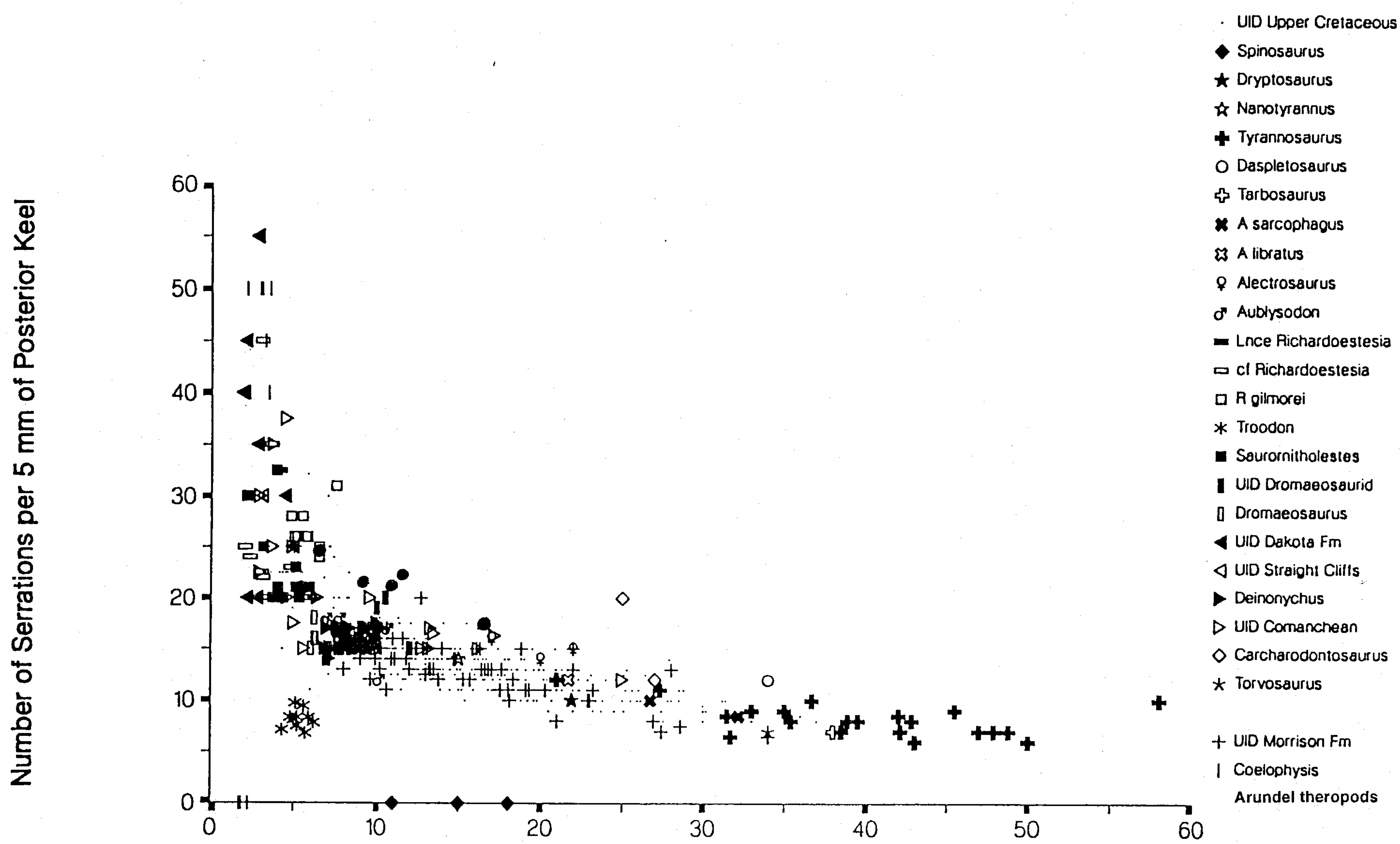

Figure 5. Relationship between posterrior keel serration density and tooth fore-aft basal length in theropods (from Farlow, et. al., 1991).

Figure 6. Theropod proximal tibia (USNM, not cataloged), in lateral view.

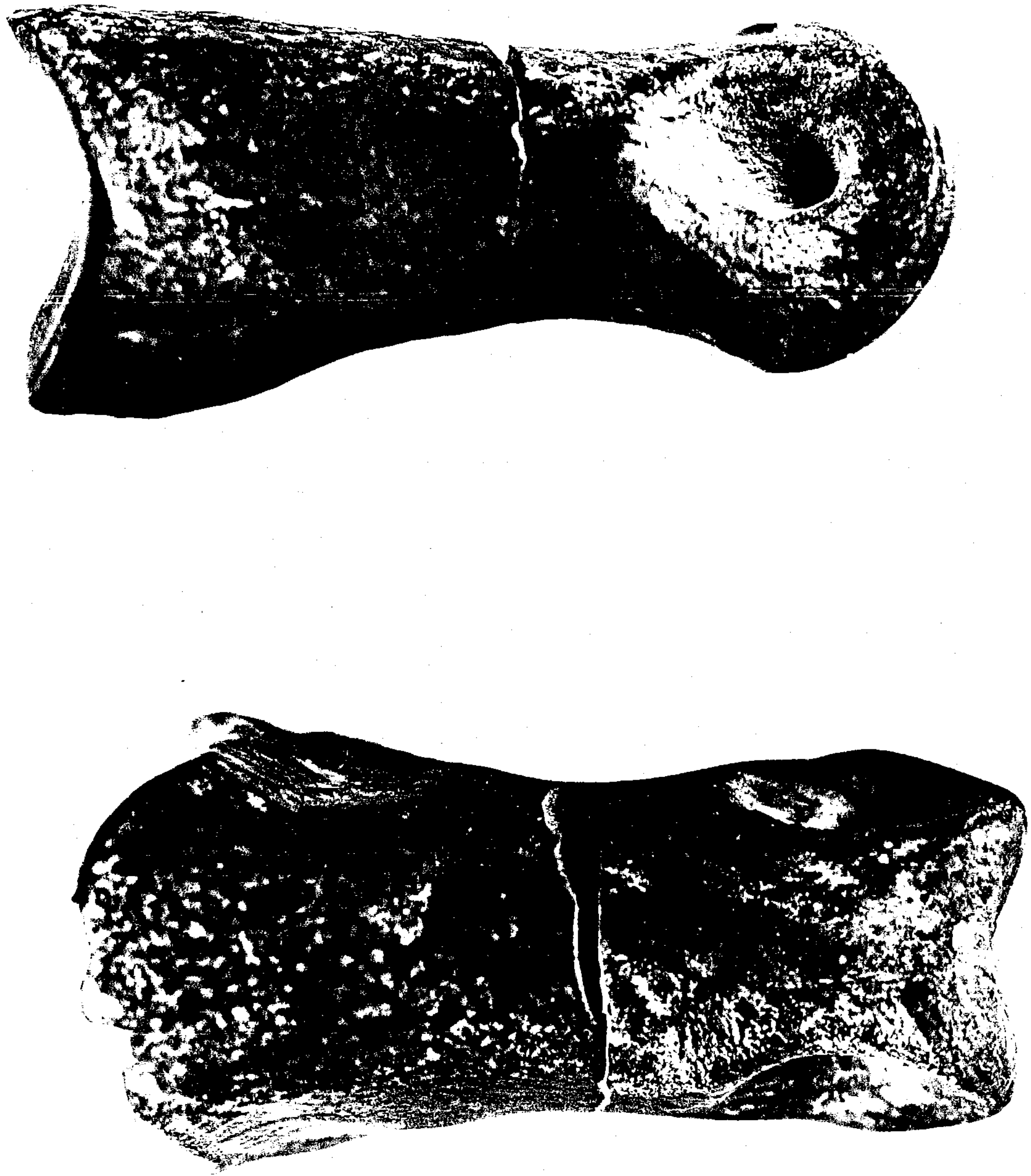

Figure 7. Theropod phalanx (USNM, not cataloged), in side and dorsal views.

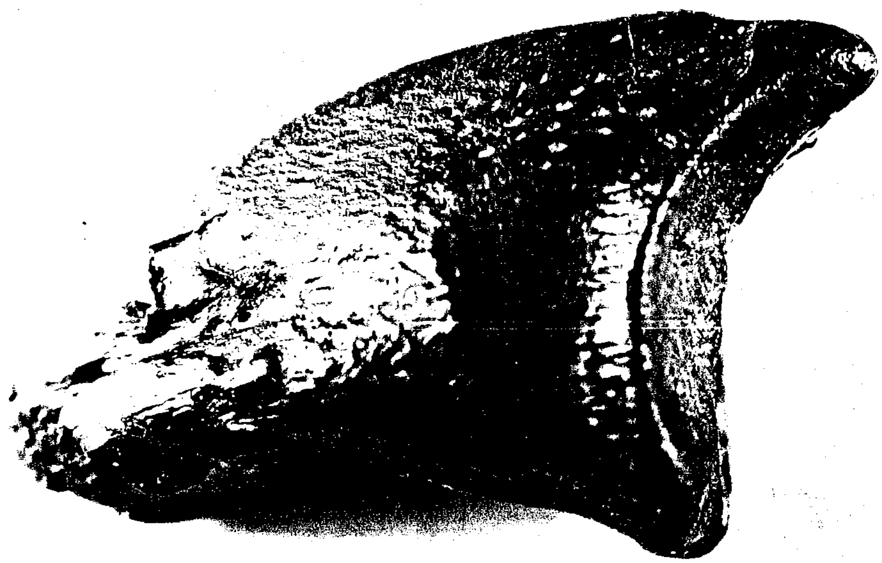

Figure 8. Theropod ungual (USNM, not cataloged), side view.

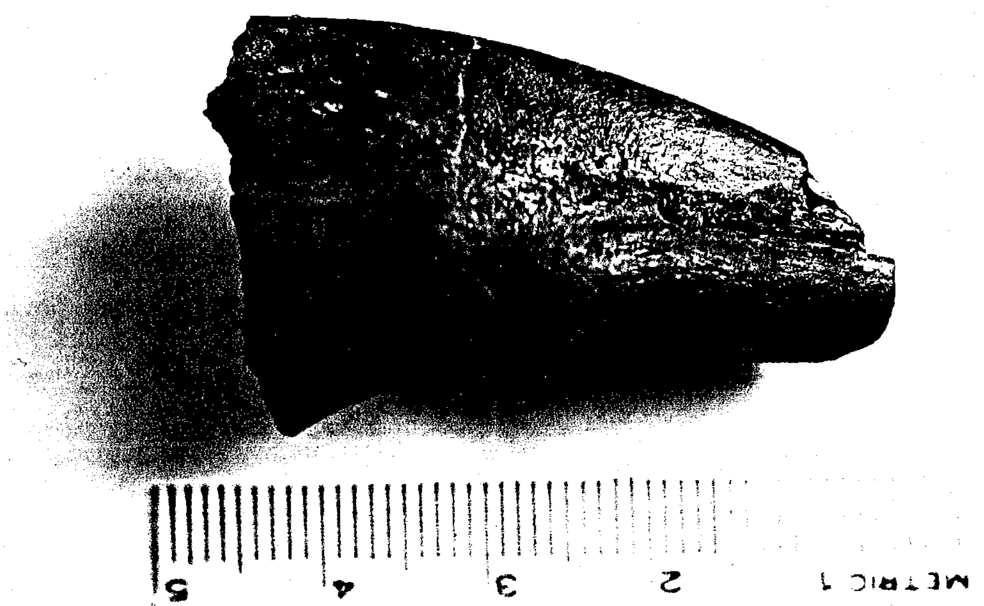

Figure 9. Theropod ungual (USNM 442510), side and dorsal views.

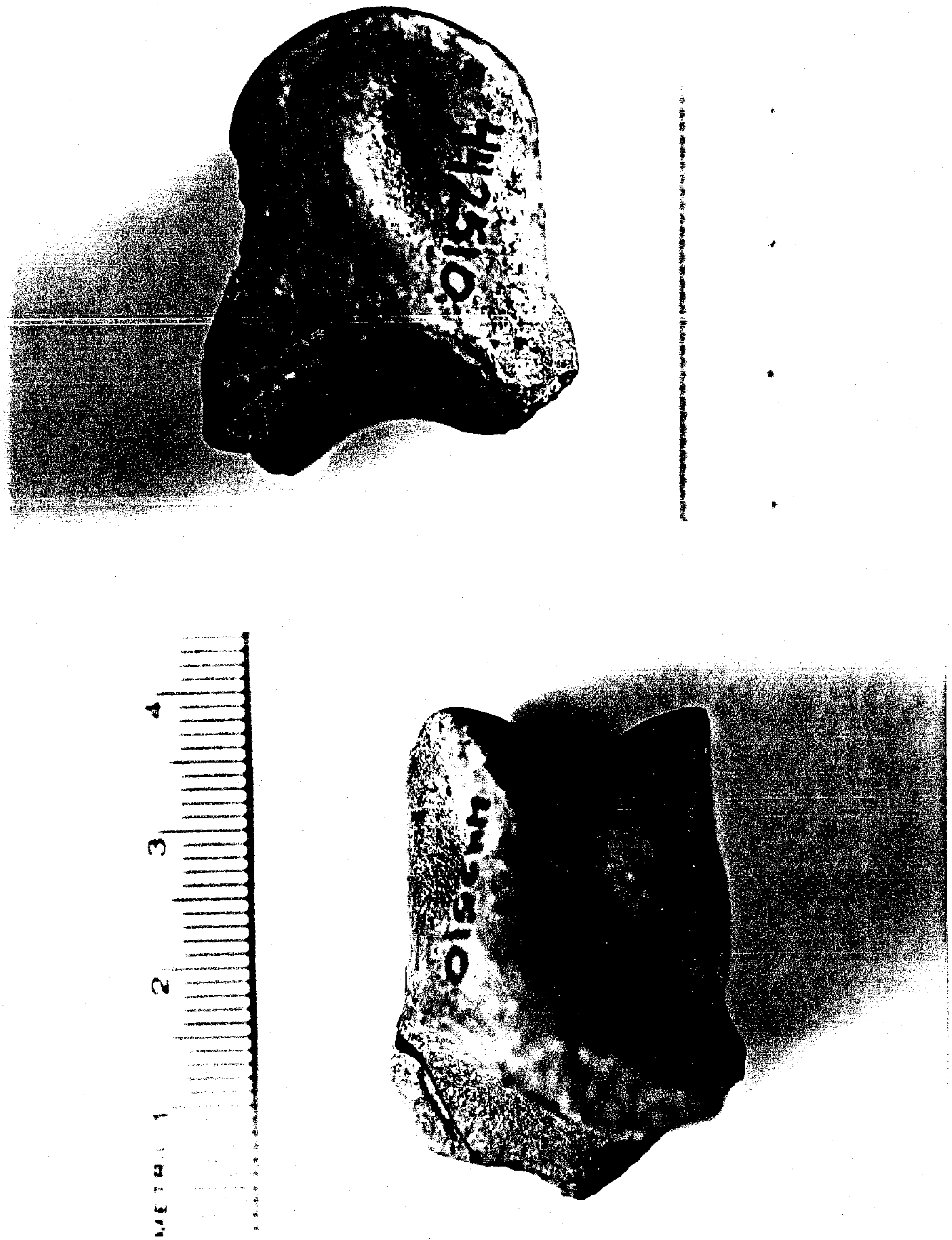

Figure 10. Theropod phalanx (USNM 442521), side and dorsal views.

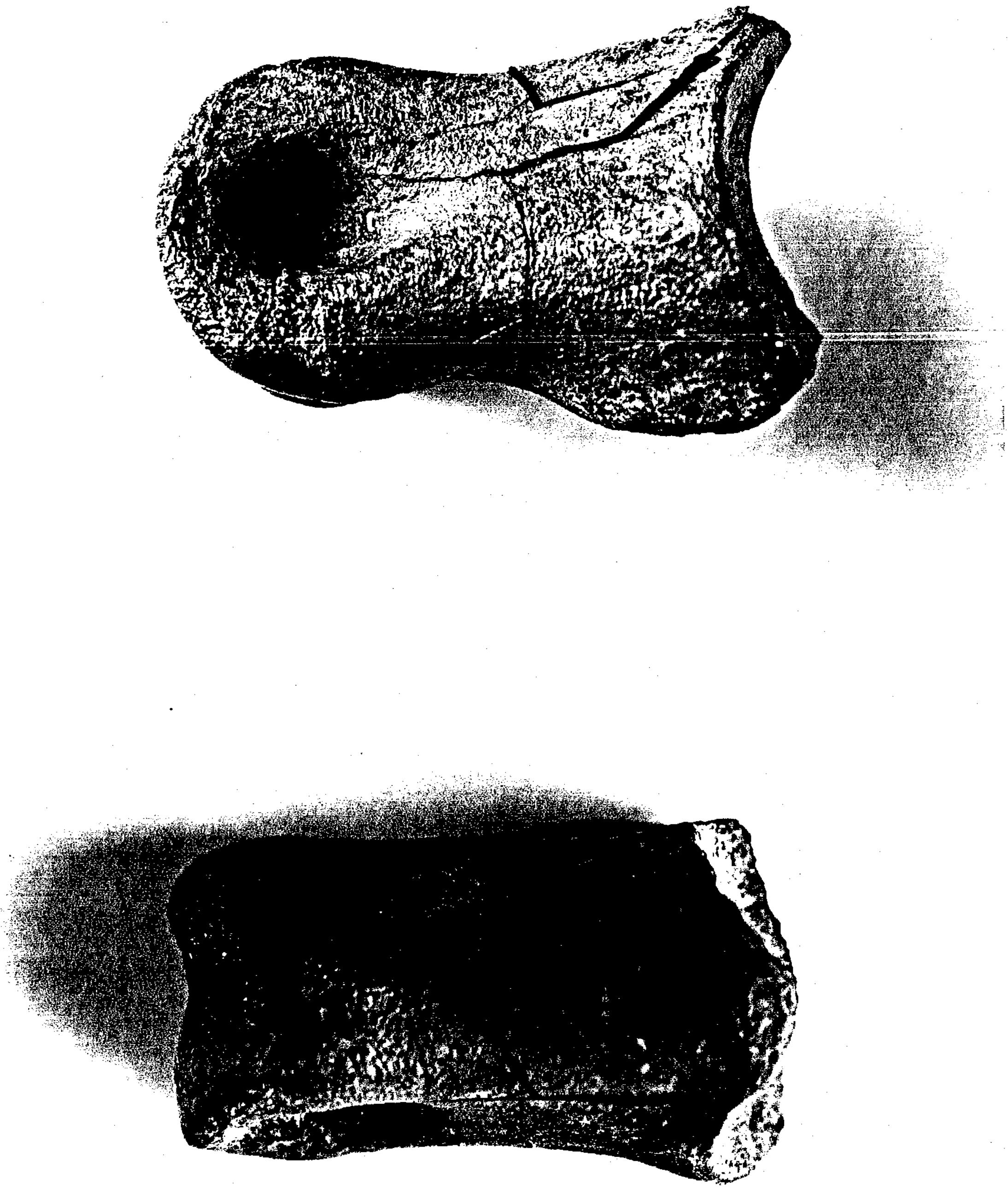

Figure 11. Theropod phalanx (USNM 16748), side and dorsal views.

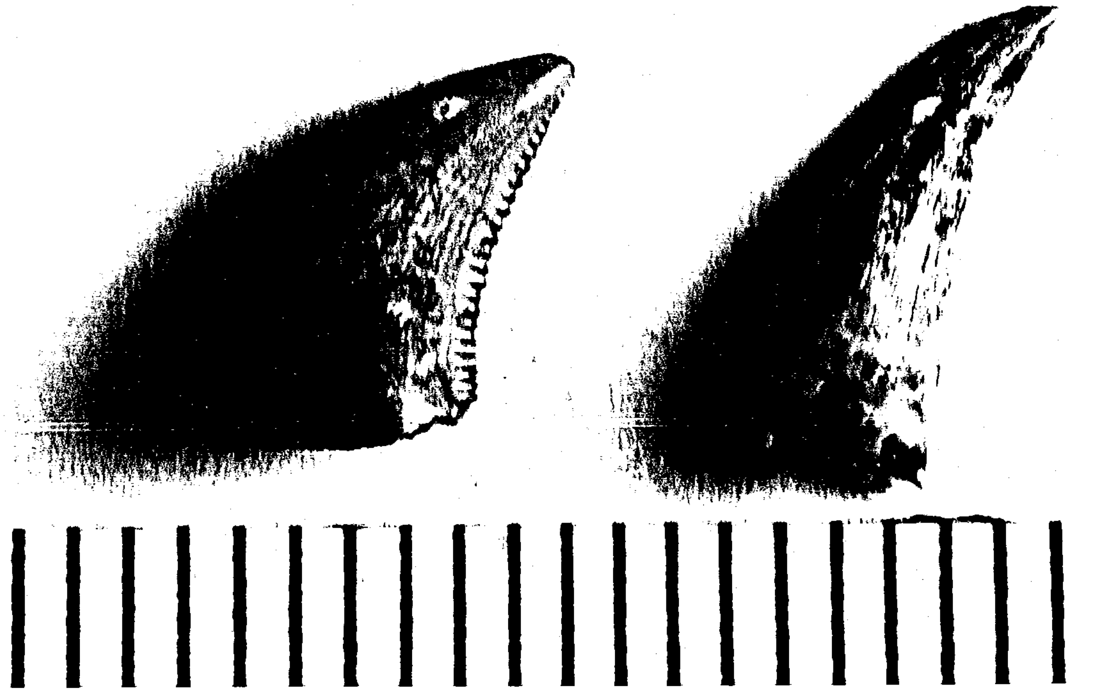

Figure 13. Two theropod teeth (USNM 437630 and USNM 451991), side view.

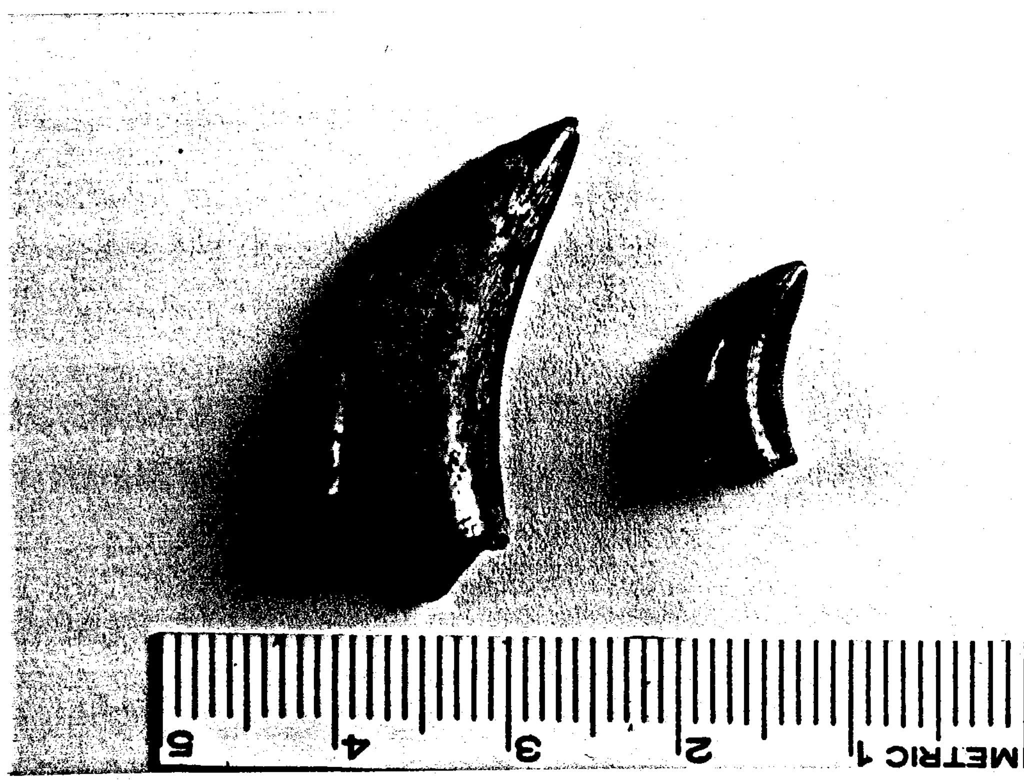

Figure 14. Two theropod teeth (USNM 442406), side view.

Figure 15. Theropod tooth (USNM 437629), side view.

Figure 16. Theropod tooth (USNM 442510), side view.

Figure 17. Theropod tooth (USNM 442442), side view.

Figure 18. Incomplete sauropod femur (USNM 442451), posterrior view.

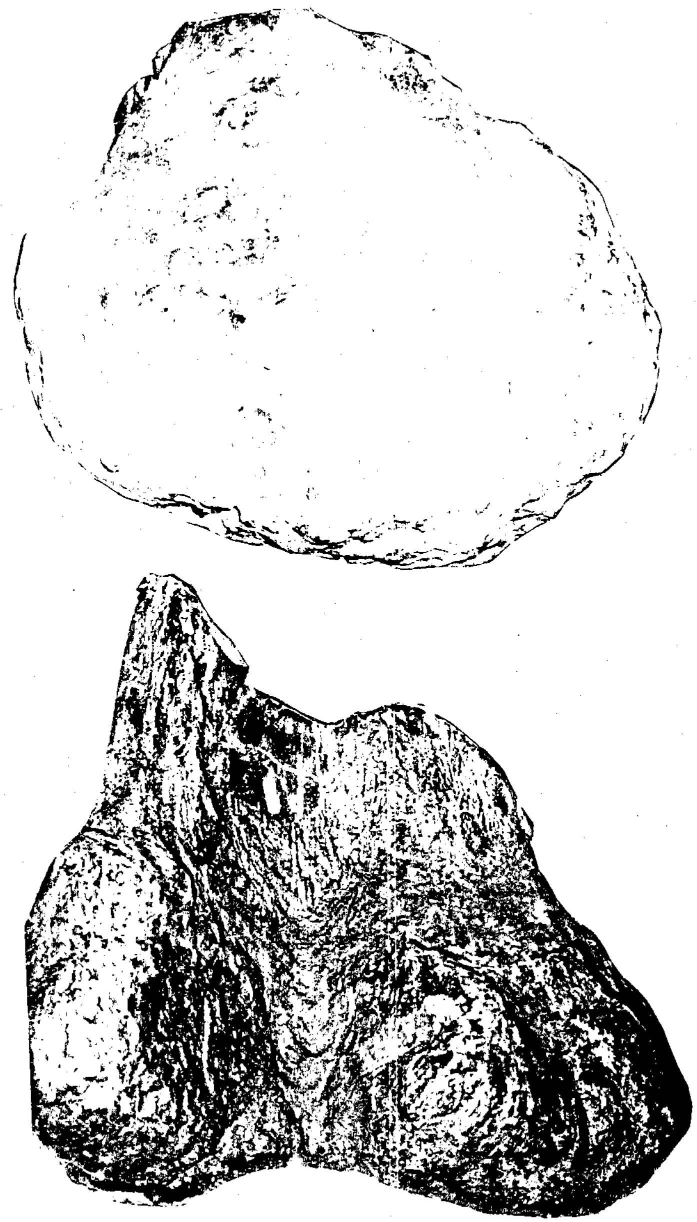

Figure 20. Incomplete sauropod femur (USNM 16710), posterior view.

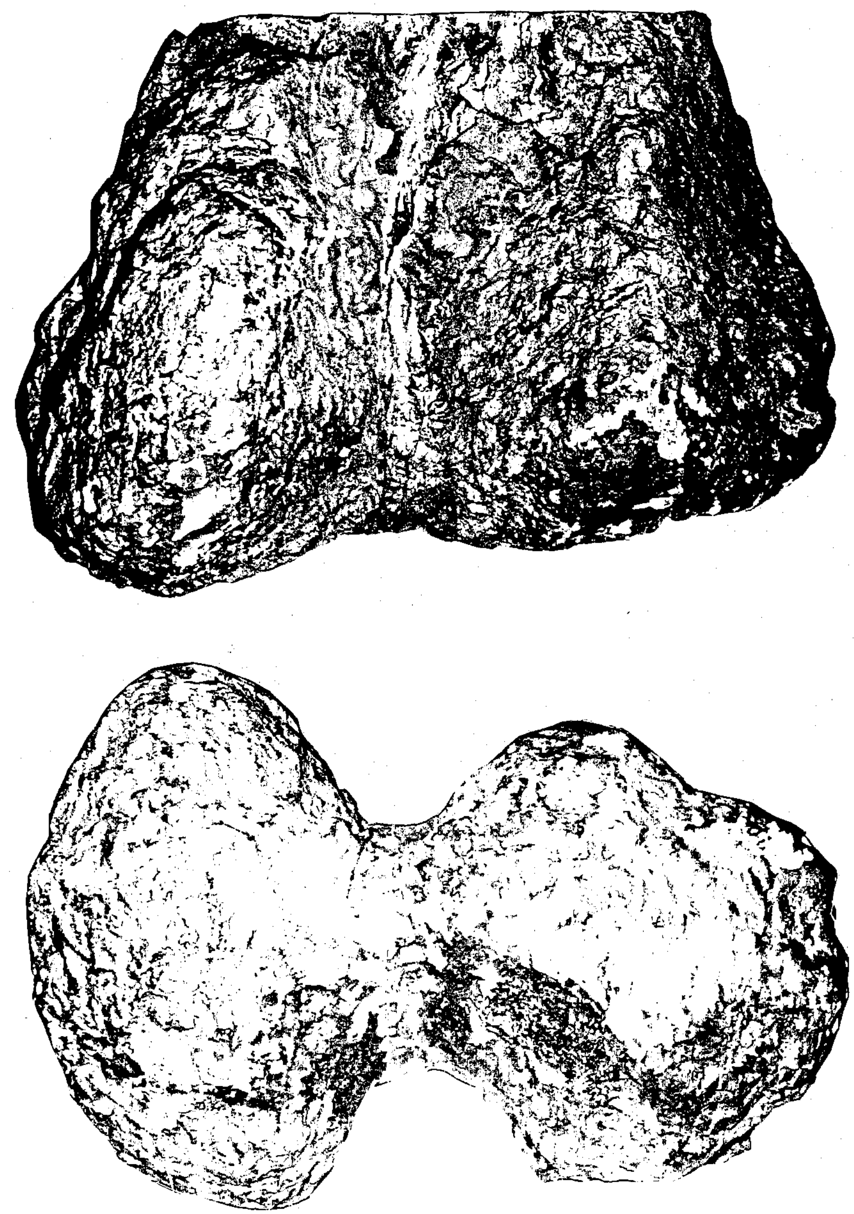

Figure 19. Incomplete sauropod femur (USNM 452029), posterrior, lateral, and ventral views.

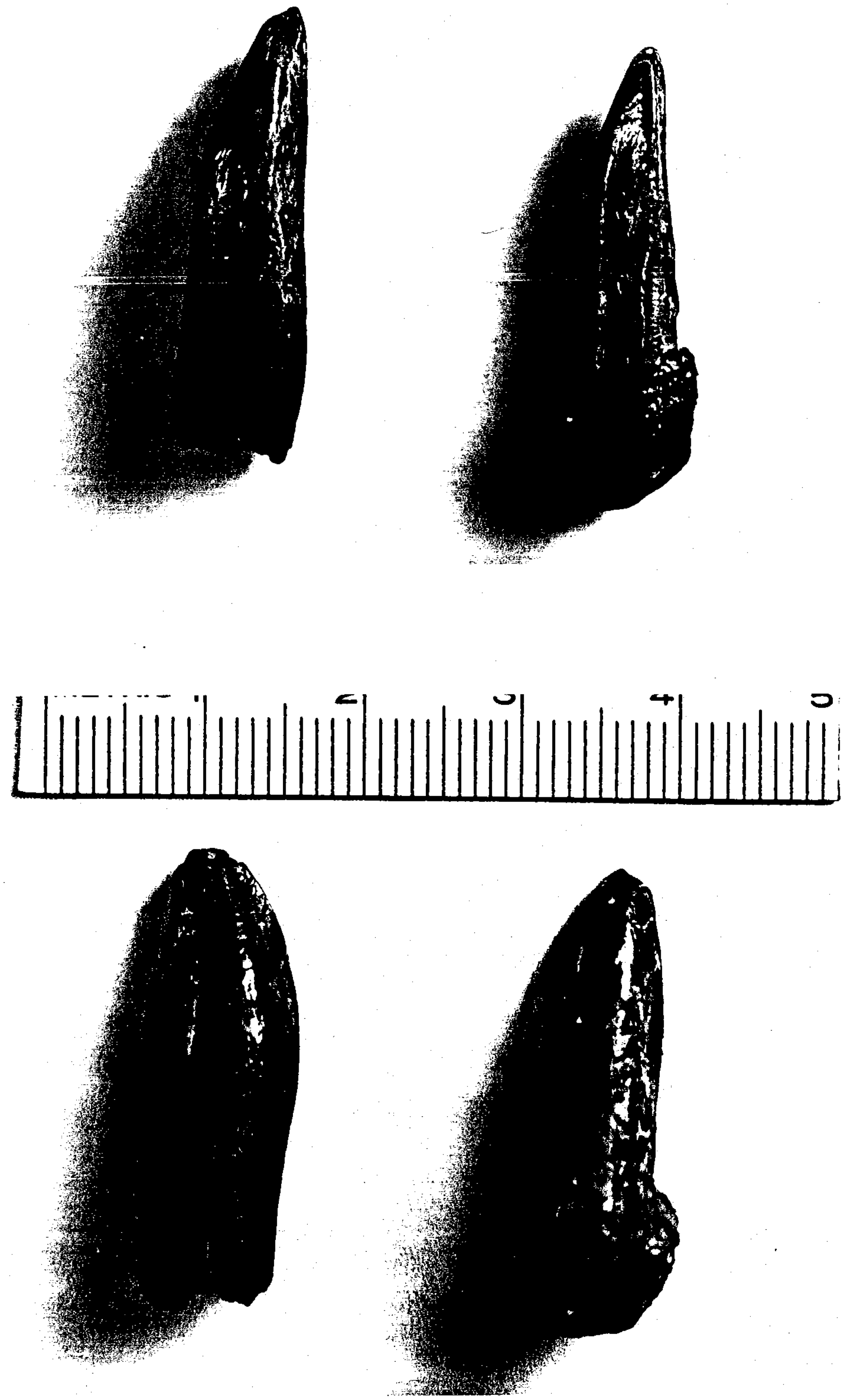

Figure 21. Two sauropod teeth (USNM 442455 and USNM 435228), side view.

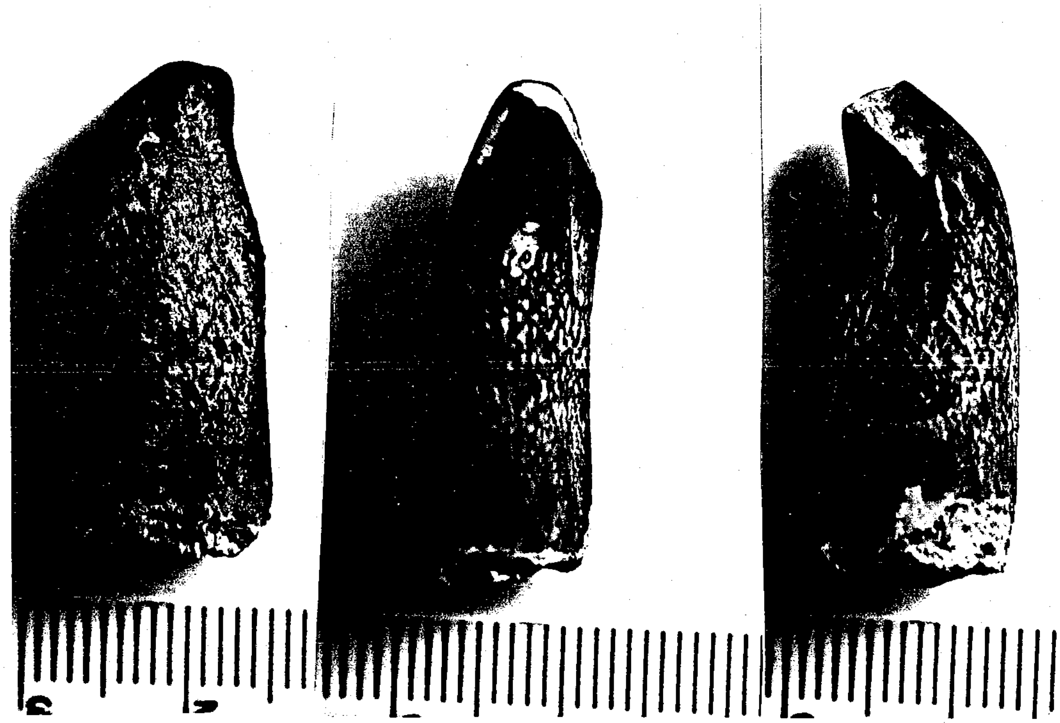

Figure 22. Sauropod tooth (USNM 437986), side view.

Figure 23. Nodosaurid tooth (USNM 437985), side view.

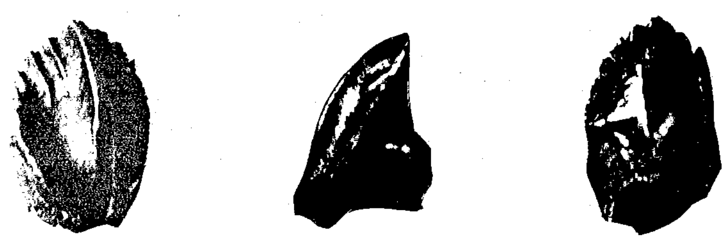

Figure 24. Indeterminate ornithopod tooth (USNM 337984), multiple views.