BULLETIN OF THE TEXAS MEMORIAL MUSEUM

PART I

The Friesenhahn Cave

BY GLEN L. EVANS

PART II

The Saber-toothed Cat,
Dinobastis serus

BY GRAYSON E. MEADE

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The Friesenhahn Cave

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The Friesenhahn Cave

BY GLEN L. EVANS[1]

Introduction

The Friesenhahn Cave in northern Bexar County is one of the most important sites for late Pleistocene vertebrate fossils yet discovered in Texas. Excavations in the cave's floor deposits yielded an unusually large and varied collection of fossils, including skeletons, partial skeletons, and more than 3,700 isolated teeth and bones. More than 30 genera of mammals, reptiles, amphibians, and birds are represented in the collection. This fossil collection is especially interesting because it represents an ecologic assemblage from a local environment accumulated in a relatively short interval of geologic time, and because it includes important new material from previously little-known species. One of the more interesting fossils recovered was a nearly complete skeleton of the great saber-toothed cat, *Dinobastis*, known previously from only a few teeth and bones. This skeleton of an extinct member of the cat family is the subject of the study by Grayson E. Meade which appears as Part II of this report.

Location and Setting

The Friesenhahn Cave is located on the Alfred Friesenhahn Ranch 21 miles north of San

[1] 2204 Sinclair Ave., Midland, Texas.

Antonio, Texas. It is situated in rocky, gently-sloping terrain on a broad divide between tributary drainages of Cibolo Creek. Physiographically, the area is located in the southeastern part of the Edwards Plateau, a large tableland province covering most of south-central Texas. The Plateau is underlain by a thick series of limestone beds in which great numbers of solution caverns have been developed. Different kinds of native animals frequent some of these caves, especially those which are relatively shallow and which have easily accessible entrances. Many of the Plateau caves undoubtedly were similarly used by the animals of Pleistocene time, but the combination of favorable conditions necessary for concentrating and preserving large quantities of animal bones apparently existed in very few of them. The Friesenhahn Cave is the only richly fossiliferous one among the many that have been explored within the general region.

Description of the Cave

The entrance to the Friesenhahn Cave is a vertical, well-like opening 6 to 10 feet in diameter and 30 feet deep. This opening passes through roof limestones into an underground chamber about 60 feet long and 30 feet wide. The chamber roof is formed by flat-lying lime-

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FIGURE 1

Interior view of main chamber looking northeast toward the old filled opening. Drawing shows the floor fill as it appeared before excavations were commenced in 1949.

PLATE 1

Photograph of cave entrance as seen from the surface.

PLATE 2

Photograph of cave entrance looking upward from floor of main chamber. This opening is a vertical shaft or sinkhole formed in modern times by solution and slumping action along a fracture in flat-bedded limestones.

PLATE 3

Photograph showing deposits of dripstone on the cave wall near the old filled entrance. Such deposits formed at different times in the cave's history, and constitute the cementing material in much of the coarser alluvial fill. Two barking frogs are seen resting on the well-developed tivoli cups in the central area of the photograph. Barking frogs are the most conspicuous element of the cave's modern fauna, which also includes leopard frogs, toads, salamanders, small snakes, cave crickets, daddy longlegs, and a few bats.
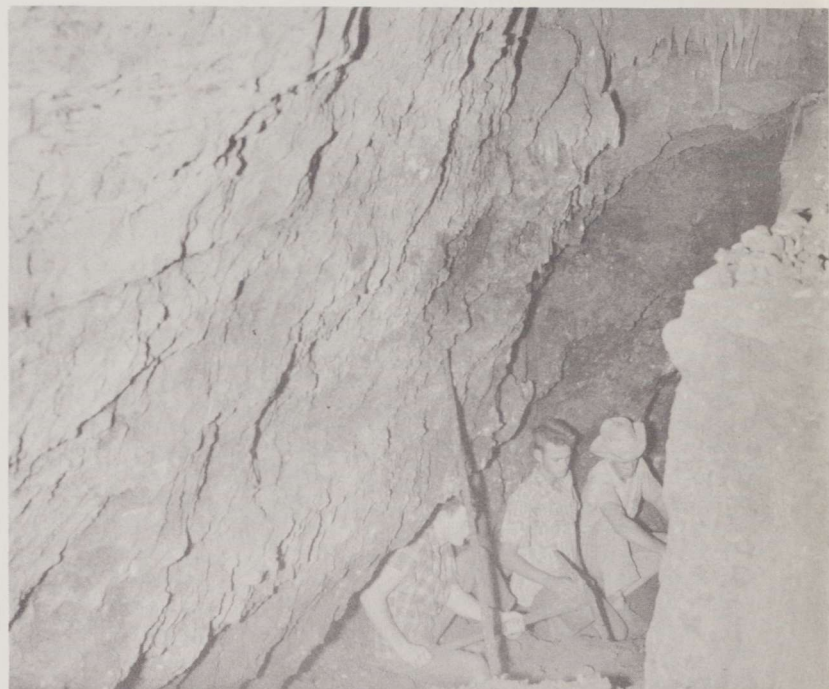

PLATE 4

View of excavations in cave deposits.

stone beds on which small stalactites and other forms of dripstone have developed around fractures and minor solution openings. The bedrock floor and lower walls of the chamber are buried beneath alluvial fill of undetermined thickness, and the surface of this fill extends to within 2 to 6 feet of the roof. Several large stalagmites, one of which is more than 8 feet in diameter, are partly or wholly buried in the fill. These stalagmites formed before alluvial filling took place. They could have grown directly from the cave's bedrock floor, or possibly from a base on fallen limestone blocks.

From the northwest end of the main chamber a constricted opening, or grotto, extends upward at an inclination of 20 to 30 degrees. This grotto is the unfilled part of an ancient opening to the surface, the upper extension of which was completely filled and sealed off by accumulated rock debris and dripstone. The alluvial fill was washed into the cave through this old entrance while it was open to the surface in late Pleistocene time. Coarser rock debris was deposited within and immediately in front of the entrance, while finer-grained silt and clay was deposited in the central and southeast parts of the chamber.

There are several features in the floor deposits which clearly indicate that the cave is a part of a connected cavern system. A sinkhole about 15 feet in diameter has developed in the floor deposits immediately beneath the present vertical entrance. The sunken mass of material must have been displaced into a deeper cavern. Surface water, which occasionally flows through the entrance and falls into the sinkhole, drains freely through the debris into underground passages. An open fracture 8 to 10 feet deep, as well as minor faults and sag features in the bedded clays, also shows that the fill has subsided since the time of deposi-

tion. A filled channel cut into older deposits crosses the cave and passes beneath the exposed part of the cave's southeast wall. Clearly the ephemeral stream which cut and filled this channel flowed into a connecting chamber through an entrance now buried by the cave deposits.

Manner in Which Fossils Accumulated

During a relatively short period in late Pleistocene time the Friesenhahn Cave was almost ideally designed for accumulating and preserving the bones of animals then living in its vicinity. The development of the large, inclined opening to the surface made the cave's main chamber easily accessible to many kinds of animals which habitually utilize such natural shelters. A pond of fresh water stood in the lower part of the main chamber during much of the time that the surface entrance remained open. This convenient watering place undoubtedly attracted many animals into the cave, especially during dry seasons when surface water was scarce or absent in the surrounding area.

Occasionally animals died within the cave. Others were dragged inside as the prey of carnivores which at times used the cave as a den. During periods of heavy rainfall surface waters washed in soil and rock debris, thus burying and preserving the accumulated bones. This process was repeated many times, so that eventually the main chamber was almost filled by a stratified succession of fossiliferous deposits. If such deposition had been lacking the accumulated bones would have decomposed from long exposure to the atmosphere. If, on the other hand, deposition had been very rapid, the main chamber would have been obliterated by filling before many fossils could have accumulated.

The cave entrance gradually became choked by collapsed limestone blocks and coarser rock debris that washed in from the surface. Eventually the upper portion was filled completely. Seeping ground water then deposited dripstone in the voids between the rock fragments and cemented the debris into a solid resistant mass. Thus, the cave was completely sealed, and the bones of Pleistocene animals buried in its floor sediments lay entombed and undisturbed for thousands of years.

A final fortuitous event in the cave's history took place in modern times. A sinkhole was formed by collapse of surface rock layers into a solution-cavity that extended upward from the cave roof. This sinkhole entrance made possible the exploration of the cave and the recovery of fossil bones contained within its sediments. If the sinkhole had not formed the cave could not have been discovered, as all surface indications of the older filled opening had been completely obliterated by weathering.

History of Discovery and Excavation

It is not known who first discovered the Friesenhahn Cave and the fact that it contained vertebrate fossils. The first published

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reference appeared in *The Geology and Mineral Resource of Bexar County*, by E. H. Sellards (Sellards, 1919; 73–74). In this brief account Sellards reported that local residents had entered the cave and collected bones of elephants and other Pleistocene animals. These fossils were submitted to O. P. Hay for identification. Hay (1920) subsequently published a list of 18 species which he had identified from the "Bulverde Cave" and which he considered to be of middle Pleistocene age. Hay chose this name from the village of Bulverde located on Cibolo Creek several miles north of the cave. There are, however, many caves in the vicinity of Bulverde, and none is known by this name to the local residents. For this reason it seems more appropriate to name the cave for the owner of the ranch on which it is located, and the name, Friesenhahn Cave, has been adopted.

The references published by Sellards and Hay indicated that the cave was probably an important fossil locality, but for many years permission to explore the cave could not be obtained. In the summer of 1949, Mr. Alfred Friesenhahn invited a party from the Texas Memorial Museum to excavate the cave deposits and collect whatever fossils were found. Immediately thereafter a field camp was established at the site in preparation for the long-delayed exploration. Excavations were carried on during the summers of 1949 and 1951. The field party consisted of Glen L. Evans, Grayson E. Meade, Charles E. Mear, John White, Carl Moore, and Kenneth Rochat. Dr. E. H. Sellards, then Director of the Texas Memorial Museum, was in general charge of the project.

Preliminary examination of the cave revealed no evidence of previous excavations in

PLATE 6

View of the south wall of Trench 1. Contacts between stratigraphic units are indicated by inked lines.
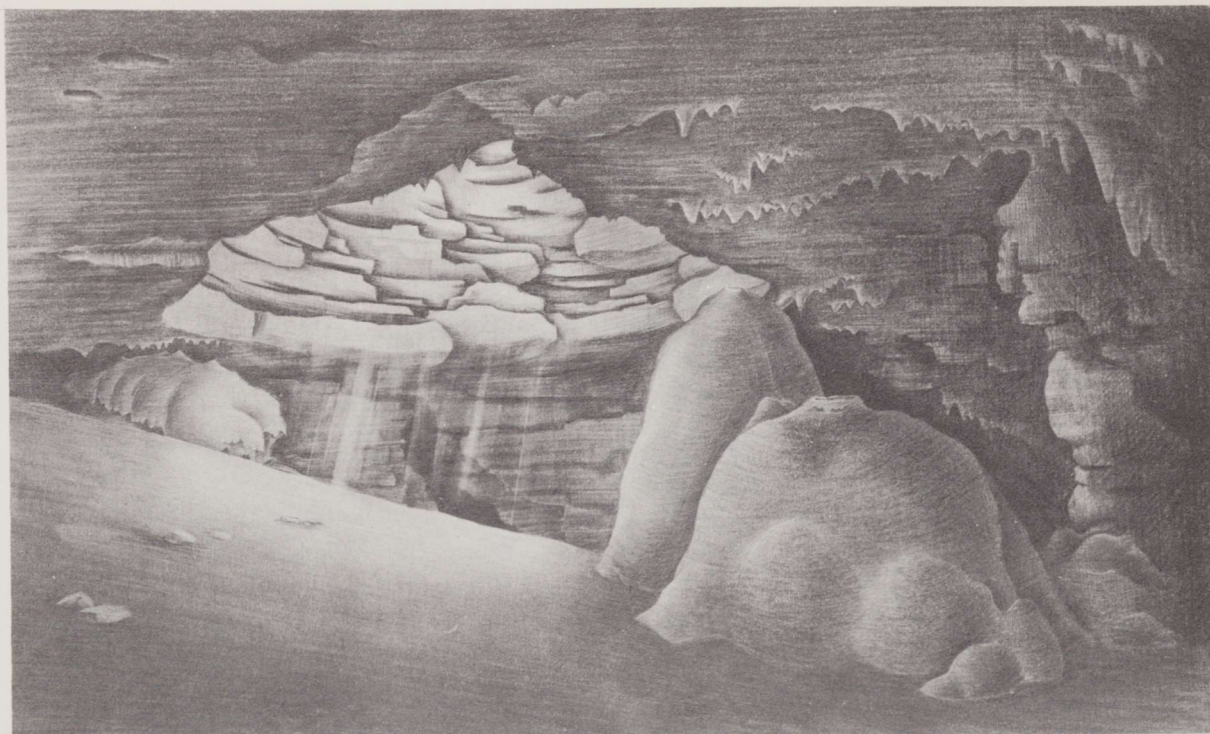
FIGURE 2

Interior view of main chamber looking northeast toward the present cave entrance.

the floor deposits. Apparently the fossils reported by Sellards in 1919 represented a random collection of specimens from the fill surface, principally in the partially lighted area near the entrance, for in the darker parts of the cave numerous bones of elephant and saber-toothed cat were found lying undisturbed at the surface and covered by only a thin increment of dust.

Exploratory tests demonstrated that all cave deposits were richly fossiliferous. Time and facilities were not available, however, for complete excavation of the fossil-bearing sediments. This would have been a major undertaking requiring, among other things, the installation of hoisting equipment for removing large volumes of excavated earth from the

cave. Although only a relatively small part of the total deposits could be excavated, it is believed that the resulting fossil collection is a satisfactory representation of the cave fauna.

Fossil bones are abundantly distributed through the large mass of coarse rock debris in and near the old entrance, but secondary cementation of these deposits made collecting the fossils a slow and tedious process. Consequently, excavations were confined for the most part to trenches dug in the unconsolidated deposits where the fossils could be collected with relatively little difficulty. The several trenches are shown on the floor plan seen in Figure 3. One of these trenches reached a depth of more than 10 feet without penetrating the full thickness of the fossil-bearing sedi-
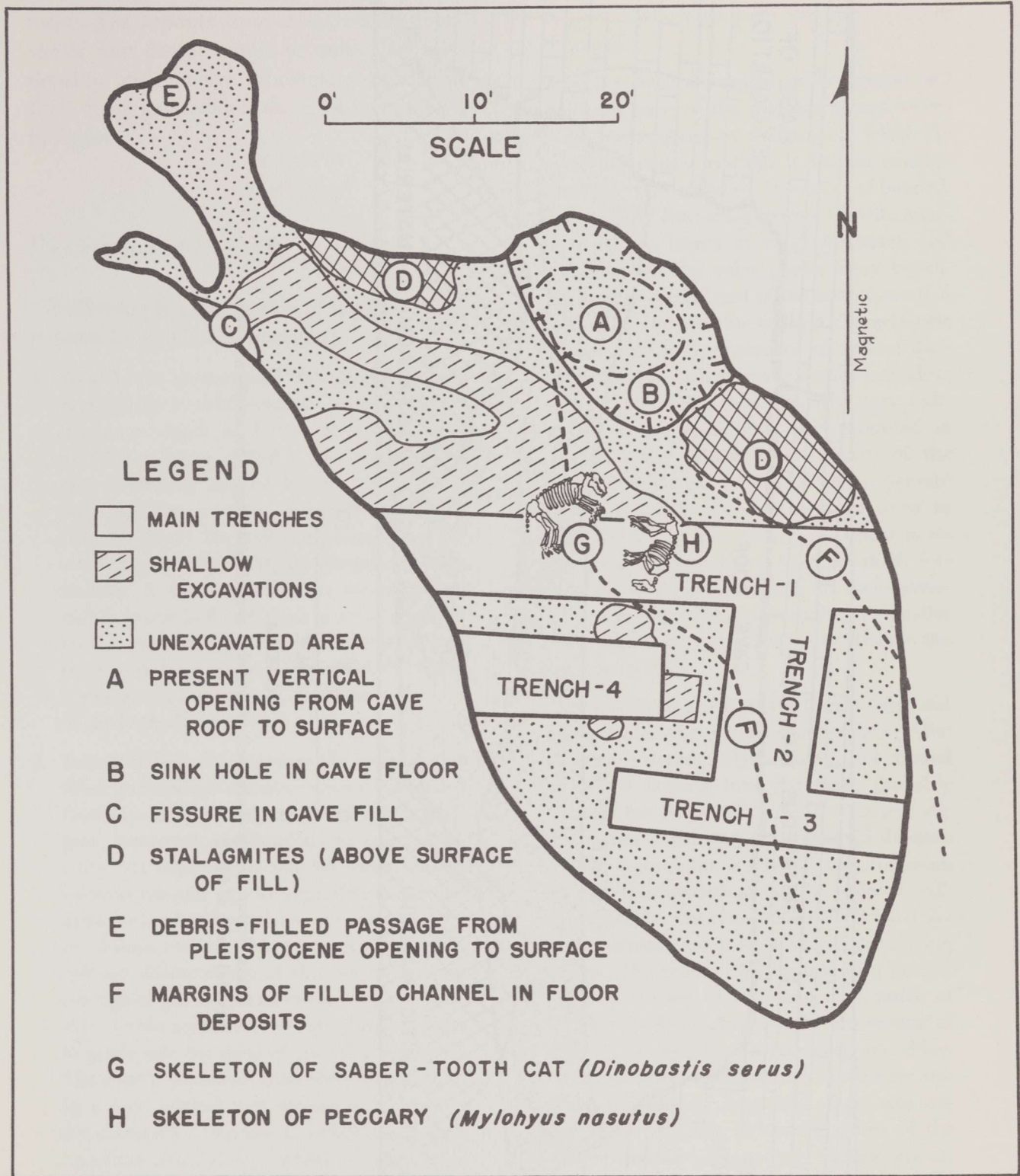
FIGURE 3

Floor plan of Friesenhahn Cave. The heavy outline shows the area of the un-
filled upper portion of the main chamber. Excavations indicate that the filled
lower part of the chamber covers a considerably larger area.

Cross section along south wall of Trench 1 showing stratigraphic relation of the several units of fill.

FIGURE 4

ments. The deposits exposed by trenching consist of four distinct zones or units. The relationship and general lithologic character of these zones are shown in the cross-section seen in Figure 4.

Description of Deposits

Following is a description of the four zones in order from oldest to youngest:

1. Zone 1 was encountered only in the deepest parts of the trenches and was penetrated to a maximum depth of 2 feet. It co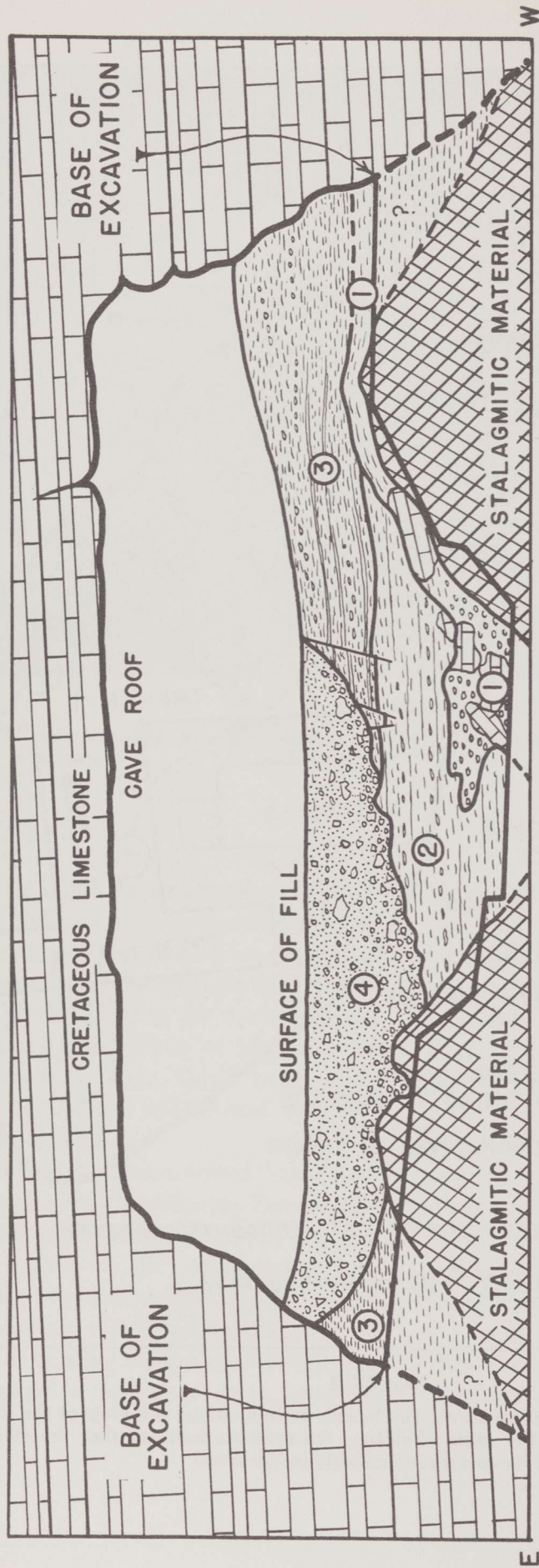nsists of a jumbled mixture of fallen limestone blocks, gravels heavily stained by iron oxides, and deep red clay partially cemented by calcareous dripstone. The unit is separated from the overlying clays by a highly irregular disconformity. A layer of ocherous material one-eighth to one-half inch thick is usually present on this contact. The only vertebrate material recovered from Zone 1 consisted of a few bones of small mammals and some fragments of turtle shell.

2. Zone 2 is best developed in the more deeply filled parts of the chamber where it attains a thickness of at least 4 feet. It consists of slate gray, laminated, and banded clay which obviously was deposited in ponded water. Carbonaceous remains of soft vegetable matter are abundant in bedding planes between clay layers. Numerous very thin partings of limestone grit are characteristic of this zone. The percentage of grit decreases toward the southeast side. To the northwest the entire zone appears to grade into the mass of coarser rock debris. The zone is separated from the overlying unit by a wavy contact that appears to be a minor disconformity. Important vertebrate fossils, including articulated skeletons of an adult and an infant saber-toothed cat, *Dinobastus serus* and a skeleton of the peccary, *Mylohyus nasu-*

tus, were recovered from the upper part of this zone.

3. Zone 3 is well developed in the central and southeast parts of the chamber except where it has been cut out by a channel in which the overlying unit is resting. It has an average thickness of about 3 feet. It consists of banded, conchoidally-fracturing, gritty clay with interbedded thin layers of small limestone and flint gravels. The color grades from bluish-gray in the central part of the cave to mottled reddish-brown near the walls. A characteristic of this zone is the presence of several dark bands rich in carbonaceous matter extending through its entire thickness. The clay sediments of this zone were also deposited in ponded water which covered most of the chamber floor. All of the larger vertebrate species found in the cave deposits occur in Zone 3, and are particularly abundant in its lower part. Although it is the most richly fossiliferous of the several units, the bones generally were not so well preserved and a smaller percentage were found articulated than in the underlying Zone.

4. Zone 4 deposits are from 3 to 10 feet thick, and are restricted to a distinct channel cut into the older cave deposits. The channel was formed by water flowing into the cave, probably through the fissure in which the present entrance has developed. The channel deepens rapidly toward the southeast, and continues beneath the exposed part of the bedrock wall. Undoubtedly, the channel and its Zone 4 deposits extend into a now buried connecting cavern. The channel fill consists of a heterogeneous mixture of rock and clay, much of which was obviously derived from erosion of older cave deposits. Fragmentary and disarticulated fossil bones, many of which were also obviously derived from the older cave deposits, are common in the fill. Bones of the smaller vertebrates, especially rodents, are extremely abundant, and many of these appear to be in primary position.

PLATE 7
View of trench wall showing the channel fill of Zone 4 and its relation to Zones 2 and 3.

PLATE 8
Partially excavated skeleton of the saber-toothed cat, *Dinobastis*, from Zone 2 deposits.

Discussion

The cave deposits and fossils provide a basis for interpreting local conditions prevailing at different stages of the cave's history, and suggest some relations of these conditions to more widespread phenomena. The cave was formed by solution in the limestone country rock of the Edwards Plateau. Solution development probably began in the Tertiary and continued into Pleistocene time. Stream valley dissection of the plateau in the Pleistocene lowered the water table and brought an end to solution action at the level where the cave had developed. After the water had drained out, the cave began to fill with dripstone formations and with blocks of limestone which fell from its roof and walls. How much of the original open space was filled by these deposits could not be determined from the limited excavations. The large size attained by some of the stalagmites indicates, however, that this stage of self-filling lasted for a relatively long time.

The next, and the most interesting, stage in the cave's history began when a large opening developed to the surface in late Pleistocene time. Once this opening developed, filling was greatly accelerated as soil and rock debris was washed into the cave by intermittent flooding from surface run-off. The oldest surface materials recognized in the cave deposits occur in Zone 1 where they are intermixed with fallen rocks and dripstone and rest directly on deposits of the older self-filling stage. The fact that only small vertebrates were found in Zone 1 suggests that the surface materials were introduced during the early development of the opening, before it had attained sufficient size to admit larger animals into the cave.

The pronounced disconformity at the contact between Zone 1 and its overlying sediments is believed to represent a significant gap in the sequence of deposits. A large part of the original Zone 1 deposit obviously was stripped off by running water and redeposited in a lower, unfilled part of the cavern system. Such erosion could have taken place only at times when deeper, connecting parts of the cavern had been partly emptied of water, caused by a lowering of the water table. The lowered base level led inflowing surface water to wash swiftly through the cave and erode the deposits previously accumulated on its floor. A subsequent rise of the water table prevented further drainage into deeper passages. This ended the erosion of Zone 1 and initiated a new stage of deposition.

The fine-grained and thinly bedded sediments which comprise most of Zones 2 and 3 are obviously pond deposits. Throughout the time represented by these two zones the water table stood at a high level, inundating the deeper connecting chambers and, at times, the lower part of the cave floor. Surface water flowing into the cave could not escape through the saturated openings and it accumulated in a pond where the fine-grained sediments were deposited. Numerous partings of limestone grit and very minor disconformities between the thin beds of silt and clay indicate that the pond dried up and reappeared many times during the deposition of the two zones. This intermittent ponding condition was probably caused by minor fluctuations in the water table level and by seasonal variations in the inflow of surface water.

The lithologic differences in Zones 2 and 3 apparently reflect somewhat different depositional conditions within the cave. There is no indication, however, that these units were separated by any considerable hiatus. Rather, they appear to represent a continuing process of filling during a single climatic substage.

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Articulated and well-preserved skeletons found in Zone 2 and in the lower part of Zone 3 suggest a fairly rapid rate of deposition for at least a part of these sediments. Had the skeletons been exposed for a considerable time before burial they almost surely would have been scattered about by scavenger animals. The uppermost part of Zone 3 apparently accumulated at a relatively slow rate. Many of the fossil bones from this zone show advanced decomposition and very slight mineralization, indicating that they were exposed to the atmosphere for a long time before they were ultimately buried in sediments. Indeed, some fossil teeth and the harder, less perishable bones that were never completely buried were found partly exposed at the surface of Zone 3 when excavations were commenced in 1949. The retarded rate of deposition in upper Zone 3 time is believed to have been caused by the gradual filling of the old surface opening which reduced, and eventually completely shut out, inflow of sediment-bearing surface water. For some time thereafter there appears to have been no deposition within the cave.

But eventually surface drainage again found its way into the cave through a new opening near the present surface entrance. The water was not impounded on the cave floor, as had been the case during the preceding stage of deposition. Instead, it flowed through the cave, eroding a pronounced channel into the older ponded deposits. The channel crosses the cave on a rapidly steepening gradient and passes beneath the exposed cave wall into a lower part of the cavern system. Evidently subsidence of the water table after deposition of Zone 3, had reopened the lower cavern enough to receive the inflow from the channel. In time the opening into the deeper cavern was completely filled by Zone 4 channel deposits.

At the present time surface water flows into the cave only in occasional periods of unusually heavy rainfall. As no water course leads to the cave's entrance, the inflow is derived exclusively from sheet wash across the gentle surface slope. Modern deposits are accumulating at a very slow rate and are retained within the sinkhole in the cave floor which lies immediately beneath the present entrance. Surface drainage passes freely through the sinkhole debris into deeper openings, so the remaining area of the cave floor is no longer subject to erosion or deposition. This condition has obtained since the sinkhole first developed some time after the Zone 4 channel filling had been completed.

Notes on Occurrence of the Fossils[1]

Among the larger herbivorous mammals represented in the fauna which would not have been expected to enter the cave of their own accord are elephant, mastodon, camel, horse, *Bison,* tapir, and deer. Quite probably carnivores dragged many of these animals into the cave as prey, and were thus a major factor in the accumulation of the fauna. The carnivores found in association with the herbivorous animals include saber-toothed cats, (*Dinobastis* and *Smilodon* sp., only a canine tooth of the latter being recovered), bear, dire wolf, and coyote. Bones of *Dinobastis* and coyote are especially abundant, indicating that these animals occasionally or regularly used the cave as a den.

One of the most interesting features of the fossil accumulation is the very large number of immature elephant bones found (*Elephas* sp.) as compared to relatively few bones of

[1] See the *Appendix* of Lundelius (1960) for a list of the published studies of elements in the Friesenhahn fauna, and for a preliminary check list of the cave's fauna.

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adult elephants. A comparison of the teeth collected illustrates this disparity. Exclusive of those teeth still in place in jaws and maxillaries, 441 isolated teeth of young individuals were collected, as compared to only 14 complete and fragmentary teeth of adult elephants. A similar ratio between young and adult specimens was also observed in other skeletal parts recovered in the excavations. Most of the immature bones, however, were so badly decomposed that they were not worth preserving. The fossils recovered, and those probably remaining in the unexcavated parts of Zones 2 and 3, represent possibly several hundred young elephants whose remains were accumulated in the Friesenhahn Cave.

Such an exceptional concentration of young elephants cannot be explained as a random accumulation. The condition of the bones, and the fact that they were associated with numerous bones of *Dinobastis,* points clearly to a much more plausible explanation. All of the elephant bones were disarticulated and badly scattered, and some of them contain pits or sheared surfaces which appear to have been made by the sharp teeth of a large carnivore. Among the carnivores represented in the fauna only the saber-toothed cats were large enough to kill the young elephants and drag them into the cave. It seems evident that young elephants were the preferred and principal diet of the great cat, *Dinobastis.*

The American mastodon *(Mammut americanum)* is also present in the cave deposits but is not nearly so abundant as the elephant. Like the elephant, the mastodon is represented almost entirely by young individuals. It is worth noting that all of the large herbivores in the fauna, except the elephant and mastodon, are represented principally by bones of adult individuals.

Although the cave fauna contains most of the familiar late Pleistocene mammals of the general region, the edentates (glyptodonts, ground sloths, and armadillos), commonly present in late Pleistocene deposits of the Coastal Plain and in river deposits throughout Central Texas, are virtually absent from the collection. Only the fragmentary remains of a sloth were found. A possible explanation for this absence is that the edentates preferred to remain near the water courses and rarely invaded the rocky, upland environment in which the cave is located.

The Friesenhahn fauna contains a large number and variety of fossil rodents. At least nine genera have been identified, and part of these have been studied statistically (Kennerly, 1956). Rodent bones occur in all units of the fill but are especially abundant in Zones 3 and 4. Those found in Zone 4 are in part indigenous to the unit, and in part reworked from the older deposits. Some of the rodents represented probably entered the cave in search of food or shelter. Others were probably carried in as the prey of carnivores. Many skeletons of the smaller species found in place in Zone 4 were in very compact, rounded masses, suggesting that they were introduced into the cave as owl pellets.

Turtle bones occur in all levels of the cave fill but are by far the most common in Zone 3. The collection made in 1949 and 1951 includes two genera of turtles represented by 354 complete and fragmentary shells (Milstead, 1956). About 90 per cent of these were found in Zone 3. Almost all the carapaces were separated from the plastrons. The shells were heavily concentrated on the minor disconformities which separate some of the beds of ponded clay. The turtles may have used the cave as a hibernation site, or possibly they were attracted by the intermittent pond in which the sediments were being deposited.

PLATE 9
Partially excavated skeleton of the peccary, *Mylohyus*, from Zone 2 deposits.
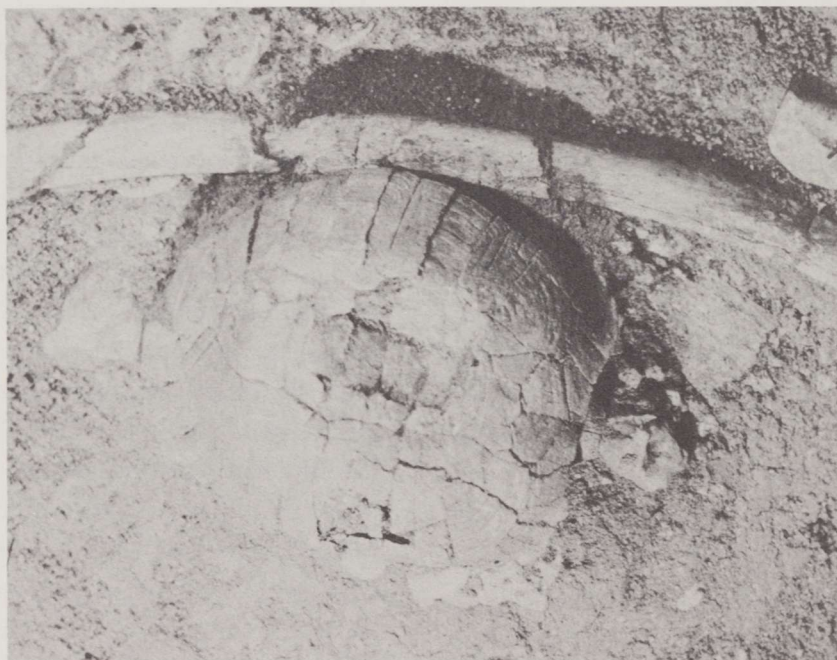

PLATE 10
Turtle shell and mammal rib in place in Zone 3.

The concentration of shells on minor disconformities suggests an increased mortality rate among the turtles at times when the pond dried up and remained dry for a considerable period.

Because of the special interest which attaches to the problem of Paleo-American man, it should be noted that several objects found in the excavations suggest the possibility that he either entered the cave occasionally or lived in the immediate vicinity of its entrance. A few pieces of flaked flint recovered from Zones 2 and 3 closely resemble the flint scrapers which are known to have been fashioned by man. Flint nodules and fragments weathered from local limestone beds are common both in the cave fill and on the surface of the surrounding area. Many of these fragments have been flaked to some degree in the course of erosion and transport. It is not possible to determine with certainty whether the scraperlike objects found in the cave deposits were formed by such natural processes or whether they were made by man.

One valve of a large fresh-water clam shell was found imbedded in the lower part of Zone 4. The nearest stream where such clams could have been expected to live during the time of Zone 4 deposition is several miles from the cave. Consequently, there is no apparent explanation for the presence of this shell unless it was carried into the area by man. If either the shell or the scraper-like flints are related to human activity, they could have been carried into the cave by man or they could have washed in from a nearby surface camp site.

Several pieces of polished bone ranging from about one inch to four inches in length, the ends and edges of which appear to have been cut by a sharp implement, were found in the cave deposits and are considered by some as possible bone artifacts. A more probable explanation, however, is that these bones were cut by the shearing teeth of a large carnivore, probably *Dinobastis*, while devouring its prey, and were polished by passing through the animal's digestive tract. Until more conclusive evidence has been found, the presence of Pleistocene man in the Friesenhahn Cave must be considered a possibility, not an established fact.

Age of Cave Deposits

The age of the fossiliferous cave deposits can be interpreted on the basis of faunal evidence and geological features indicating their relationship to climatic conditions of the times. There appears to be no sound basis for assigning any part of the fossil-bearing sediments to the middle Pleistocene, as was suggested by Hay (1920). Zones 2 and 3 compose the main body of the cave deposits and are by far the most fossiliferous of any tested in the excavations. The occurrence of such typically late Pleistocene genera as *Bison*, *Mammut*, and *Elephas* clearly indicates that these zones originated in the Wisconsin stage of late Pleistocene time. The indicated high stand of the water table during the deposition of these ponded deposits could have existed only during a relatively humid climatic interval. The abundant fossil bones of large herbivorous mammals from these units also attest to a relatively humid climate, as sustained moist conditions would have been necessary to produce enough vegetal food to support such a fauna.

Zone 1 contains fossils which are less definitive in age. This unit, however, is a part of the related sequence of cave deposits and probably originated in an earlier moist substage of the Wisconsin. The disconformity separating

it from the overlying Zones 2 and 3 apparently reflects an intervening dryer substage with attendant lowering of the water table.

Zone 4 yielded fossils consisting in part of vertebrates reworked from the older cave deposits, and in part of smaller forms found in primary position. The indigenous fauna unfortunately does not include species which can be used for conclusive age determinations. The channel and its Zone 4 deposits must have originated during a somewhat dryer interval than the preceding period when the ponded sediments of Zones 2 and 3 were accumulated. On the other hand, the nature of the channel deposits indicates a considerable volume of inflow which suggests somewhat moister climatic conditions than obtain at the present time. There seems to be no reliable means of telling at present whether Zone 4 was deposited during a late substage of the Wisconsin, or whether it is all or in part of post-Pleistocene age.

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PART II

The Saber-toothed Cat
Dinobastis serus

BY GRAYSON E. MEADE

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FIGURE 1
Lateral view of skull (TMM 933–3582)

The Saber-toothed Cat, Dinobastis serus

BY GRAYSON E. MEADE[1]

Introduction and Acknowledgments

One of the most interesting and important of the Pleistocene vertebrate fossils recovered from the Friesenhahn Cave was a nearly complete skeleton of a large, adult saber-toothed cat. This skeleton has been identified as belonging to the genus and species *Dinobastis serus* Cope, previously known by only a few teeth, fragments of limb bones, and a partial cranium. In addition to the adult skeleton, the cave also yielded a remarkable collection of other *Dinobastis* material, including a partial skeleton of an immature individual, a nearly complete infant skeleton, a fine adult skull, and many isolated skeletal parts. These fossils, which are for the most part in a very good state of preservation, have greatly increased our knowledge of one of the least known of the North American Pleistocene saber-toothed cats.

In the preceding section of this report, Evans pointed out that a great number of immature elephants are represented in the Friesenhahn Cave fauna, and he concluded that they were killed and dragged into the cave by *Dinobastis*. This conclusion is not surprising, for the remarkable specialization of the Pleistocene saber-toothed cats appears to have adapted them ideally for preying on elephants. In *Dinobastis*, the specialized saber-teeth were well adapted for biting and tearing the flesh and thick skin of the elephants, and the long and powerfully muscled forequarters provided the great striking and grasping strength necessary to consummate the attack.

The writer wishes to express his appreciation to Dr. W. W. Newcomb, Jr., Director of the Texas Memorial Museum, for valuable assistance in the preparation of the manuscript; to Mr. Hal M. Story, Artist of the Texas Memorial Museum, for the excellent drawings and for most of the photographs used in illustrating this paper; to Mr. Glen L. Evans for his many valuable suggestions and critical reading of the manuscript; and to Mr. Alfred Friesenhahn for permission to excavate the cave and for the many courtesies he and his family extended those of us who participated in the excavation. The late Dr. E. H. Sellards, former Director of the Texas Memorial Museum, kindly shipped the *Dinobastis* material to Calgary, Alberta, Canada, in order that I might study it.

Description of Dinobastis serus

SKULL

Two skulls of *Dinobastis* were found in the Friesenhahn Cave. One (TMM 933–3231)[2] is a partial skull of an adult individual found embedded in dripstone within a few inches of the cervical vertebrae of the articulated skeleton of *Dinobastis* and almost surely belongs to the same individual. The other skull (TMM 933–3582), also of an adult individual, is smaller (See Figure 1). The size differences

[1] 1403 Summit St., Calgary, Alberta, Canada.

[2] Abbreviation used is: TMM—Texas Memorial Museum.
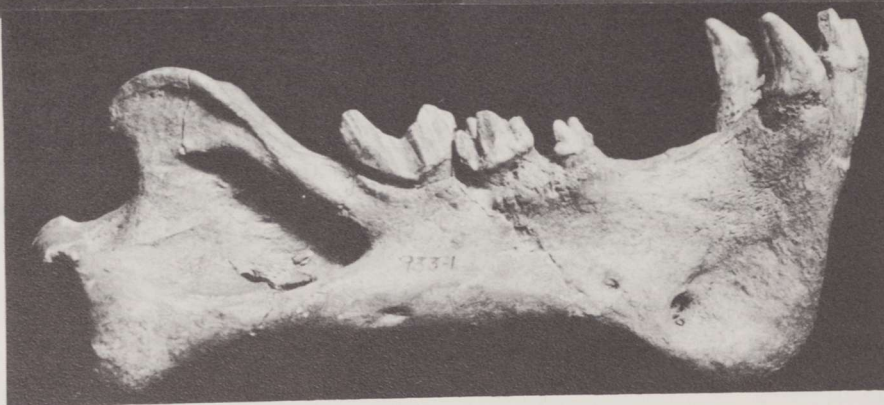
PLATE 1

A. Ventral view of skull (TMM 933–3582)
B. Dorsal view of skull (TMM 933–3582)
C. Lateral view of mandible (TMM 933–1)

between these two skulls, however, are no greater than the variations in skull size within the genus *Smilodon*.[3] If a larger number of skulls of *Dinobastis* were available for comparison one would expect to find that the skulls of *Dinobastis* and *Smilodon* would fall within a similar range of size variation.

The skull belonging to the skeleton is too poorly preserved and incomplete for detailed description. The smaller skull is essentially complete, but imperfect preservation prevents accurate and detailed description of most of the individual elements of the skull as well as the foramina.

The general configuration of the skull closely resembles that of *Smilodon*. The character of many of the individual elements of the skull is partially obscured by the condition of preservation, but so far as can be determined most elements are quite similar to the corresponding parts of *Smilodon*.

The profile of the superior outline of the skull is gently convex as in *Smilodon*, and the sagittal crest is strongly developed with the middle portion slightly elevated above the frontal region. The combined width of the anterior ends of the nasals approximates the width of the anterior nasal openings as in *Smilodon*. Posteriorly, the nasals are nearly the same width as at the anterior extremity and presumably end with an abrupt transverse truncation. The nasal opening is nearly as wide at the base as at the greatest width, which is reached at about the middle height of the opening, and in cross-section resembles the nasal opening of *Smilodon*. In *Panthera atrox* the nasal opening is heart-shaped in cross-section. The parietal elements are rectangular in form as are those of *Smilodon*. The

[3] All comparisons of *Dinobastis serus* to *Smilodon californicus* and *Panthera atrox* are made from Merriam and Stock (1932).

lamboidal crest also resembles that of *Smilodon* in being very prominent, but the crest projects posteriorly more than in either *Smilodon* or *P. atrox*.

The occiput as seen in posterior view is unlike either *Smilodon* or *P. atrox*. It is high, but it is not broadly rounded at the top as is the occiput of *Smilodon*. The occiput is much higher than in *P. atrox*, but resembles this genus in being triangular. The occiput is not so broad at the base, however, as is that of *P. atrox*. The occipital crest is prominent and deep depressions occur between the occipital crest and the great posterior extension of the lamboidal crest. There is a greater overhang of the occipital region in *Dinobastis* than in *Smilodon*. In the basioccipital region a well developed median ridge extends from a point between the condylar foramina almost to the anterior end of the basioccipital as in *Smilodon*. The auditory bullae probably vary greatly in size in different individuals as in *Smilodon*. In one specimen (TMM 933–3582), the auditory bullae are well developed and are larger than the mastoid process. The mastoid process extends downward as far as or farther than the postglenoid process. The premaxilla, in the region between the maxilla and nasals, is a heavier bone than that in either *Smilodon* or *P. atrox*. In the palatine region deep pits are present on the palate adjacent to and opposite the superior carnassial. The length of the zygomatic arch is intermediate between that of *Smilodon* and *P. atrox*. The infraorbital foramina are the only foramina sufficiently preserved for description. They are large, oval in outline, and situated above the superior carnassial.

MANDIBLE

The size and proportions of the lower jaws of *Dinobastis* are similar to those of *Smilodon*
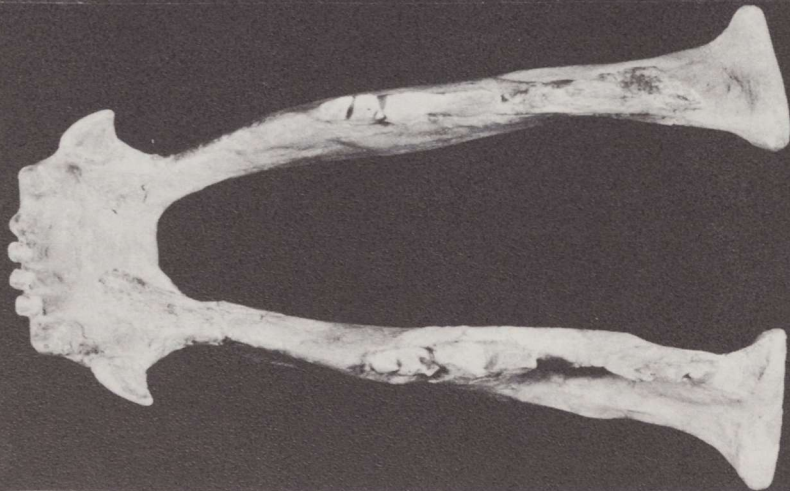
PLATE 2

A. Lateral view of skull.
B. Lateral view of mandible.
C. Dorsal view of mandible.

with strongly developed symphyseal contact, low, rounded coronoid, and a deeply developed masseteric fossa. The lateral flanges are well developed and project below the symphyseal contact. The coronoid process is low and rounded, totally unlike that of *P. atrox* and perhaps even more rounded on its upper surface than that of *Smilodon*. The masseteric fossa is much more prominently developed than in either *Smilodon* or *P. atrox*. The angle, as in *Smilodon*, is nearer the condyle than in the true felines, and it is also situated nearer the external end of the condyle. The posterior edge of the coronoid may not extend quite as far posteriorly as in *Smilodon;* in *P. atrox* the coronoid overhangs the condyle. The articulating surface of the condyle is widest at the inner end and narrows toward the outer end of the condyle.

Dentition. Dental Formula: 3/3, 1/1, 2/2, 1/1.

Superior Dentition. The second and third superior incisors are proportionately larger teeth than in *Smilodon* or *P. atrox*. I 2/ is characterized by a prominent basal cusp on the posterolateral edge. A similar cusp is present on the left I 3/, but is absent on the right. I 3/ is much larger than I 2/ and is about equal in size to the inferior canine. It is characterized by a serrated edge on the lower half of the anterior edge and by a finely serrated edge along the posterior edge of the tooth.

The superior canine is neither as long nor as large as that of *Smilodon*. When the jaw is closed in articulation with the skull, the superior canines extend approximately to the inferior side of the jaw. The anterior and posterior edges of the tooth are serrated. As in *Smilodon* the anterior serrated edge at the upper end is noticeably nearer the inner or median side of the tooth. The posterior cutting edge maintains essentially a median position on the tooth.

P 3/ is a much smaller tooth than in *Smilodon*. It consists of a single backwardly directed cusp with a small tubercle at the posterior basal portion of the tooth.

P 4/ is a specialized cutting tooth with a nearly straight shearing edge along the inner side. The protocone is absent, and so is the antero-internal root, which is present in *Smilodon*. P 4/ consists of the parastyle, paracone, and metacone. The parastyle is well-developed, but does not have a prostyle as is commonly found in *Smilodon*. The paracone and metacone are similar to those of *Smilodon*. The metacone is longer anteroposteriorly than that of *Smilodon*, although the anteroposterior length of the tooth is not as great as that of *Smilodon*.

M 1/ is represented by a small alveolus situated at the posterointernal corner of the superior carnassial.

Inferior Dentition. The inferior canine is a slightly longer tooth than that of *Smilodon*. The anterior and posterior sides of the tooth are straighter and not so recurved as in either *Smilodon* or *P. atrox*. Along the posterior side is a narrow serrated ridge. A similar ridge exists on the inner anterior margin of the tooth, which is weakly developed toward the apex of the tooth and becomes more prominent toward the base. No median lateral ridge is present as in *Smilodon*.

I/3 is similar to that of *Smilodon*, but the lateral ridges are less prominent and the basal cusp is lacking.

P/4 is smaller but has a backward tilt, similar to the corresponding tooth in *Smilodon*. It consists of three cusps, of which the middle is the largest; the anterior and posterior cusps are about equal in size.

The inferior carnassial, M/1, consists of the paraconid and protoconid blades, each about
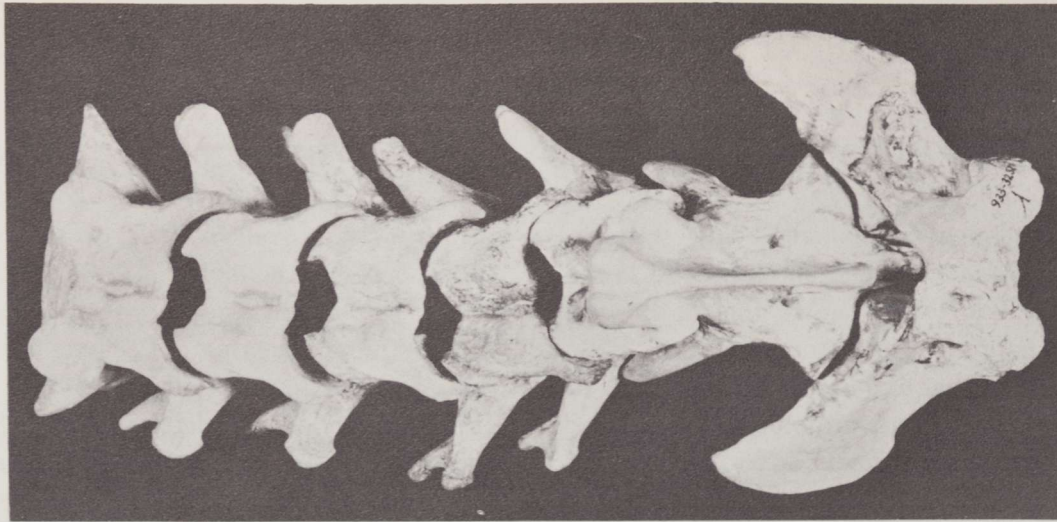
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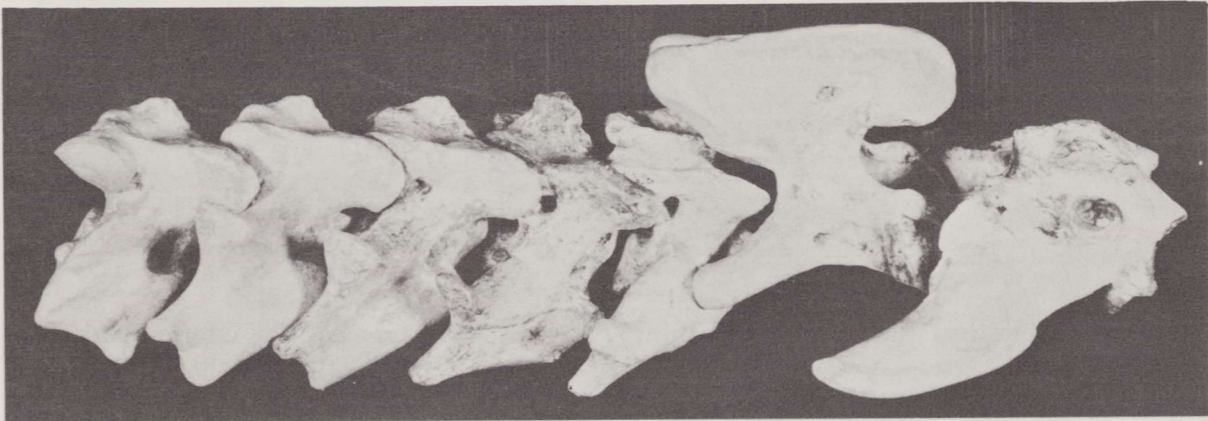
B

C

PLATE 3

A. Dorsal view of atlas, axis, 3rd, 4th, 5th cervical vertebrae; 6th and 7th are restorations.

B. Lateral view of atlas, axis, 3rd, 4th, 5th cervical vertebrae; 6th and 7th are restorations.

C. Lateral view of thoracic vertebrae; right to left, 1st through 10th; 3rd and 4th are restorations.

equal in size. In *Smilodon* the protoconid blade is considerably longer anteroposteriorly than the paraconid blade.

Atlas. The atlas of *Dinobastis* is comparable in size and general shape to the atlas of the average *Smilodon*. As in *Smilodon* the transverse processes are greatly extended posteriorly so as to reach well behind the articulating surfaces for the axis and are pointed at their backward extremities. The processes differ from *Smilodon*, however, in that they have a pronounced inward curve of the posteroexterior margin, and the posterior end is more pointed. The inner surface of the transverse process is perhaps even wider dorsoventrally than in *Smilodon*, and also extends directly backward and outward from the outer end of the articulation for the axis.

The articulating surfaces for the axis, and the anterior articulation for the condyles, are not perfectly preserved, but appear to resemble those of *Smilodon* more closely than they do *P. atrox*. The median tuberosity on the dorsal surface of the neural arch is more prominent that that of *Smilodon*, similar to *P. atrox*. The neural arch is proportionately long in anteroposterior diameter, and the forward margin is not indented. The groove between the posterointernal border of the transverse process and the ventral border of the facet for the axis, where it notches the posterointernal border, is but faintly discernible as in *Smilodon*.

The preservation of the atlas does not permit determination of the true size or shape of the neural canal. The posterior opening of the vertebrarterial canal is situated immediately adjacent to the outer edge of the facet for the axis as in *Smilodon*. The depression in front of the anterior opening of the canal is deep.

Axis. Most of the neural spine is missing, but it is presumably similar to that of *Smilodon*. The anterior articulating surface for the atlas is more like that of *Smilodon* than *P. atrox*. The odontoid process is similar to that of *Smilodon*, but may be a little more pointed anteriorly. The transverse processes are not present on the specimen. The vertebrarterial canal appears to be more posteriorly situated than in either *Smilodon* or *P. atrox*.

Third Cervical Vertebra. The neural spine is so reduced in height that it exists only as a prominent, narrow ridge. On *Smilodon* two tubercles, the hyperapophyses, are frequently present on the dorsal surface between the posterior zygapophyses and may project well beyond the posterior border. These are not so well-developed in *P. atrox* and are but slightly developed in *Dinobastis*. The bony connection between the zygapophyses and the transverse process, lying on the outer side of the vertebrarterial canal, is narrower anteroposteriorly, and the anterior opening of the vertebrarterial canal is situated more posteriorly, than in either *Smilodon* or *P. atrox*. In *P. atrox*, at approximately the middle of the outer surface of the lateral wall of the canal, there is frequently a deep depression of varying size. Lacking in *Smilodon*, this depression is present in *Dinobastis* and is located immediately anterior to the posterior zygapophyses. The transverse process is long and bifurcated at the extremity.

Fourth Cervical Vertebra. A short neural spine is situated in the middle of the neural arch; it rises higher than that of *P. atrox*, but perhaps not so high as in *Smilodon*. The two tubercles, the hyperapophyses, situated posteriorly and between the posterior zygapophyses, are more distinct than in the third cervical vertebra, but not nearly so well-developed as in the fourth cervical vertebra of *Smilodon*. The anterior zygapophyses appear to be directed more toward the inner side and are more concave than in *Smilodon*. The posterior

A

B
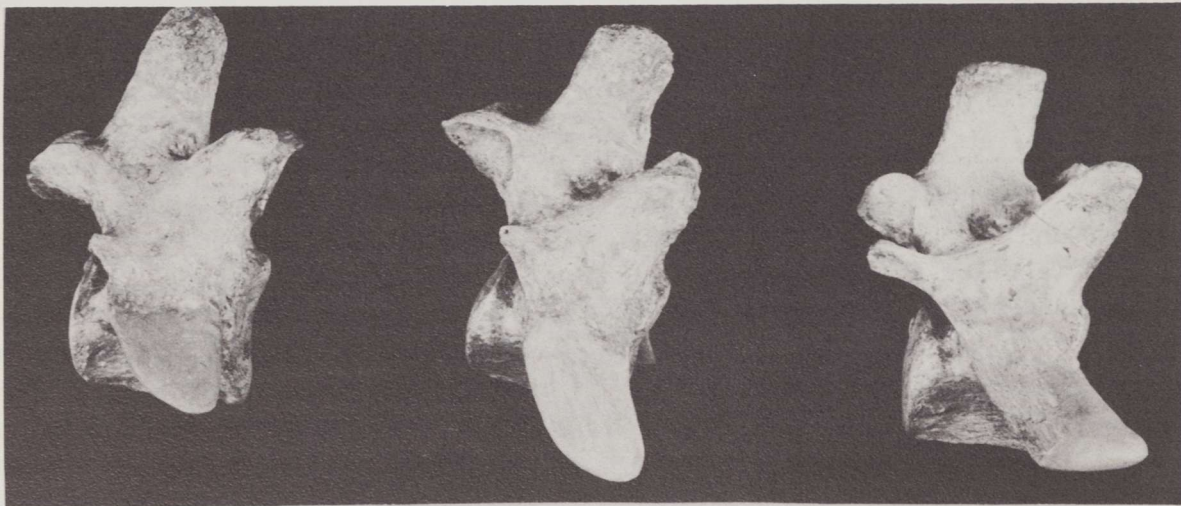
C

PLATE 4

A. Dorsal view of thoracic vertebrae; right to left, 1st through 10th; 3rd and 4th
   are restorations.
B. Lateral view, right to left, of 11th, 12th, and 13th thoracic vertebrae.
C. Lateral view of lumbar vertebrae, right to left, 1st, 2nd, and 3rd.

zygapophyses are large and gently convex on the articulating surfaces.

A large, deep depression is situated at the anterior end of the articulating surface of the posterior zygapophyses. In *P. atrox* a similar depression is situated more anteriorly, but in *Smilodon* it is either less well-developed or absent. The vertebrarterial canal is large and extends laterally farther than in *Smilodon*. The transverse process is long and the bifurcation of the outer end is more pronounced than in either *Smilodon* or *P. atrox*. The posterodorsal portion of the transverse process is greatly upturned and rises to the level of the base of the neural canal at the posterior end of the vertebra. The lower flange or lamella is deep as in *P. atrox* with even greater anterior and posterior projections.

Fifth Cervical Vertebra. The centrum is broader and shallower than in *Smilodon*, but its proportions are much more like that of *P. atrox*. A median keel is present on the ventral surface of the centrum as in the third and fourth cervicals. Viewed from the anterior end, the principal axis of the vertebrarterial canal is inclined about 45 degrees from the vertical, resembling that of *P. atrox*, whereas in *Smilodon* the axis of the canal is more vertical.

The anterior zygapophyses are large, with concave articulating surfaces which are directed inward more than in either *Smilodon* or *P. atrox*. In *Smilodon* the ends of the anterior zygapophyses are carried downward farther in front than in *P. atrox* and reach a level with the anterior upper border of the centrum. In *Dinobastis* the zygapophyses are only carried downward to the extent seen in *P. atrox*. The neural spine is much shorter than in *Smilodon*.

A prominent depression is situated on the outer wall of the neural canal as in *P. atrox*, except that it is more posteriorly located and lies immediately adjacent to the posteroven-tral border of the posterior zygapophysis. The transverse process is long and projects outward and backward in a manner similar to that of *Smilodon*. Much of the inferior lamella is missing, but enough is preserved to show that it is similar to that of *Smilodon* in its posterior projection and that it also extends well below the ventral surface of the centrum.

The sixth and seventh cervical vertebrae are missing from the skeleton.

First Thoracic Vertebra. A median keel is situated on the ventral surface of the centrum, broader and more distinct than in either *Smilodon* or *P. atrox*. A depression extends from this keel to the lateral edges of the centrum. The transverse processes are proportionately long as in *Smilodon* and are directed backward so that the anterior extremities do not extend beyond the plane of the anterior surface of the centrum. The tubercular facet is large and faces more laterally, as in *P. atrox*, than downward as in *Smilodon*. The major portion of the neural spine is missing. The neural canal is large and is more triangular than in either *Smilodon* or *P. atrox*. The anterior zygapophyses are well developed and are directed inward considerably more than in either *Smilodon* or *P. atrox*.

Second Thoracic Vertebra. The ventral surface of the centrum is gently concave anteroposteriorly in the median line, the concavity increasing laterally. The median keel on the ventral surface, so conspicuous in the first thoracic vertebra, is entirely absent in the second. In *Smilodon* a keel is present, but in *P. atrox* the median keel is also absent. The transverse processes are long as in *Smilodon*, and are not directed backward so noticeably as in the first thoracic vertebra. The tubercular facet is large and faces more laterally than in *Smilodon*, and is similar to that of *P. atrox*. The anterior zygapophyses are directed upward, but consid-

erable variation undoubtedly exists as indicated in the variation of the two; the left is broadly concave while the right is flat on the articulating surface. The anterior zygapophyses, however, extend far forward as do those of *Smilodon*.

The anterior edge of the neural spine is thin, but thickens toward the posterior side. The terminal end of the spine widens but little transversely.

The third and fourth thoracic vertebrae are missing from the skeleton.

Fifth Thoracic Vertebra. The ventral surface of the centrum of the fifth thoracic vertebra is shaped like that of the second, but the centrum is deeper and not quite so wide. The transverse processes are long, and the tubercular facets are directed but slightly downward. The anterior zygapophyses are small, and are directed upward and outward. The neural canal is almost circular in outline. The posterior zygapophyses are directed upward and are not so close to the centrum as are those of *Smilodon*. Pronounced lateral depressions are situated on each side of the neural spine and extend dorsally nearly half the length of the spine.

Sixth Thoracic Vertebra. The transverse processes of the sixth thoracic vertebra may rise slightly higher than in the fifth, and the lateral depressions on each side of the neural spine are not as pronounced. The distal end of the neural spine is expanded transversely.

Seventh, Eighth, and Ninth Thoracic Vertebrae. These vertebrae are similar to the fifth and sixth. Lateral depressions are not present on the neural spine, but a small triangular depression with the apex pointed outward is located at the base of the spine and just posterior to the anterior zygapophyses.

Tenth Thoracic Vertebra. The posterior zyg-

apophyses of the tenth thoracic vertebra are wider and the transverse processes extend higher dorsally than in the ninth.

Eleventh Thoracic Vertebrae. The eleventh thoracic vertebra is easily distinguished from the vertebrae preceding or following it. The anterior zygapophyses are slightly concave and are directed upward and forward. Their shape and position are similar to those of the preceding thoracic vertebrae, but the face is concave whereas in the preceding vertebrae the face is usually flat to gently convex. The posterior zygapophyses face outward like those of the remaining vertebrae and not downward as in the preceding vertebrae.

The centrum is proportionately deeper and wider than that of *Smilodon*. On the ventral surface a median ridge is present in *Smilodon*, but such a ridge is absent in both *Dinobastis* and *P. atrox*. A rudimentary lower transverse process on the lateral side of the centrum, similar to that of *P. atrox*, is present in *Dinobastis*, but absent in *Smilodon*.

The anterior zygapophyses scarcely project beyond the anterior face of the centrum in *Dinobastis*. In *Smilodon* they project well beyond the anterior face of the centrum, and in *P. atrox* they usually do not project beyond the face of the centrum.

The anapophysis and metapophysis are well developed. The metapophysis projects upward well above the anterior zygapophysis. The anapophysis projects backward beyond the posterior face of the centrum. The metapophysis-anapophysis region is long in an anteroposterior direction like that of *P. atrox*. It is not so long in *Smilodon*. The neural spine is well developed.

Twelfth Thoracic Vertebra. The centrum of the twelfth thoracic vertebra is proportionately deeper and wider than that of *Smilodon*.

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A faint median keel is present on the ventral surface of the centrum. The anapophysis and metapophysis are well developed. The anapophysis is long and pointed posteriorly and projects far beyond the posterior face of the centrum. The anteroposterior diameter of the anterior zygapophysis-metapophysis region viewed from the outer side is greater in *Dinobastis* than in *P. atrox* and is more nearly comparable to the structure in *Smilodon*. In *Smilodon*, however, there usually exists a ridge which clearly separates the outer wall of the front portion of the anterior zygapophyses from the lateral wall of the metapophysis and anapophysis. No such ridge exists in *Dinobastis* or *P. atrox*. The lateral wall of the anterior zygapophysis, however, is broader than that of *P. atrox*, and extends forward beyond the anterior face of the centrum as in *Smilodon*.

A well developed tubercle is situated immediately above and posterior to the capitular facet.

The anterior zygapophyses are well developed. The ventral portion of the articulating surface is concave on one side and flat on the other. The neural spine is well developed.

Thirteenth Thoracic Vertebra. The centrum of the thirteenth thoracic vertebra of both *Dinobastis* and *Smilodon* has a ventral ridge which does not occur in *P. atrox*. The lateral tuberosities of the centrum appear to be more prominently developed in *Dinobastis* than in either *Smilodon* or *P. atrox*. A neural spine is present. The spine is slender transversely, narrow at the front and widening toward the back. The tip of the spine is slightly expanded transversely, and greatly expanded anteroposteriorly, so that the anterior portion of the tip of the spine produces an overhang. The posterior border of the spine inclines forward like that of *P. atrox*. In *Smilodon* the spine is more erect.

A prominent tubercle is situated posteriorly and above the capitular facet. Such a tubercle is absent in both *Smilodon* and *P. atrox*.

The lateral surface below the metapophysis is similar to that of *Smilodon* and it extends farther anteriorly than it does in *P. atrox*. The anterior and posterior zygapophyses are well developed.

Lumbar Vertebrae. Only the first three lumbar vertebrae are preserved in the skeleton of *Dinobastis*. Presumably the number of lumbar vertebrae is seven, the normal number for *Smilodon* and *P. atrox*.

The centra of the first three lumbar vertebrae are large. Their width is greater than in *Smilodon* and is approximately equal to that of *P. atrox*. The depth of the centrum is about equal to that of *Smilodon* but is slightly less than that of *P. atrox*. The length of the centrum is but slightly less than that of *Smilodon*, considerably less than that of *P. atrox*. The centra have a well developed median ridge on the ventral surface, better developed in the second and third lumbars than in the first. This is generally true of the anterior lumbar vertebrae of *Smilodon*, but in *P. atrox* the first two lumbar vertebrae usually lack a ventral ridge.

The anterior zygapophyses face inward and recurve inward dorsally as in *Smilodon*. This suggests a firm union of the lumbar vertebrae, and a rigidity of this region of the vertebral column equal to that of *Smilodon*. The lumbar region of *P. atrox* exhibits a greater flexibility. The neural spines are relatively heavy and are considerably expanded transversely at the terminal end. The spines of the first three lumbar vertebrae are inclined slightly forward, though they are not so inclined as are those of *P. atrox*. The spines tend to be more erect in *Smilodon*. The metapophyses are comparable to those of *Smilodon*. The anapophysis of the first lumbar vertebra is a relatively long slen-
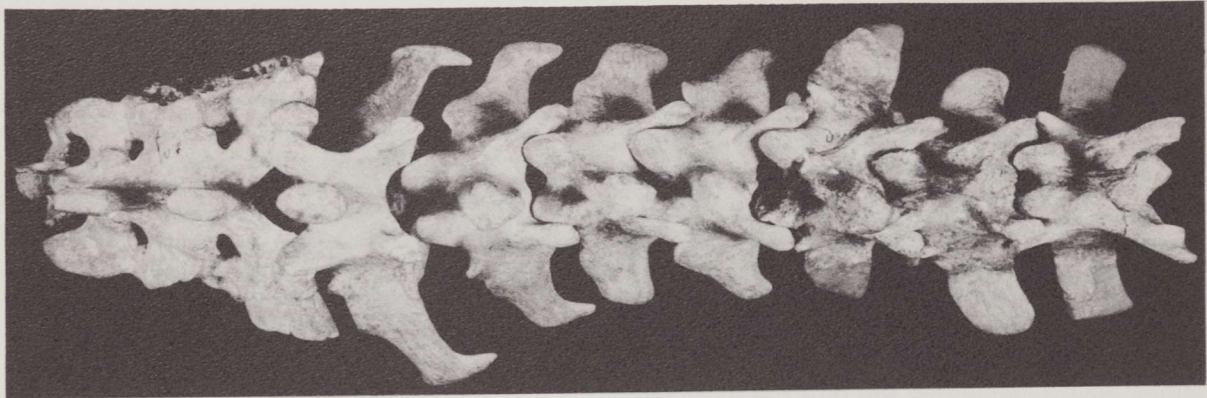
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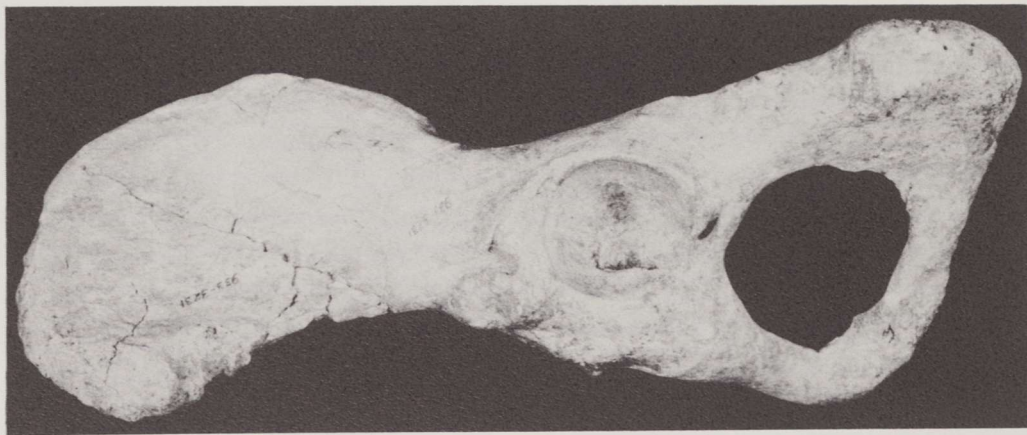
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PLATE 5

A. Dorsal view of 1st, 2nd, and 3rd lumbar vertebrae and sacrum; 4th through 7th are restorations.
B. Lateral view of caudal vertebrae.
C. Lateral view of pelvis.

der process. The process is present on the succeeding two vertebrae but the posterior end of each has been broken and the length cannot be determined. From first to third, however, the base of the anapophysis is situated lower on each succeeding vertebra.

The anapophyses extend backward and outward so that they do not lie as close to the outer wall of the metapophysis of the succeeding vertebra as they generally do in *Smilodon*. The transverse processes, unfortunately, are all too badly damaged for description.

Sacrum. The sacrum of *Dinobastis* is strongly constructed and has a well developed rugose surface on the lateral sides of the first two vertebrae for attachment with the pelvis. The first caudal vertebra is firmly attached to the third sacral vertebra.

In dorsal view the sacrum is seen to narrow posteriorly more than does the sacrum of *Smilodon* or *P. atrox*. The transverse process of the third sacral vertebra of *Dinobastis* projects backward, downward, and slightly inward. The posterior end of this process in *Smilodon* projects outward, but not noticeably beyond the posterior face of the centrum. In *P. atrox* the transverse processes of the third sacral vertebra project much farther laterally than in *Smilodon*, and probably farther posteriorly. These transverse processes in *Dinobastis* are unlike those of either *Smilodon* or *P. atrox* inasmuch as the posterior end of the process has an inward curve and the end projects far beyond the posterior face of the centrum, in fact beyond the middle of the centrum of the first caudal vertebra.

The neural spines of the sacral vertebrae are incomplete, but enough are preserved to show that the spine of the first vertebra is vertical, the second is probably inclined backward, and the third is so inclined as to be almost horizontal. Thus the attitude of the spines is essentially like that of *Smilodon*, for in *P. atrox* they tend to lean forward. The posterior border of the spine of the third sacral vertebra is like that of *Smilodon* also, in that the posterior border rises directly upward and backward from the posterior zygapophyses, whereas in *P. atrox* the posterior border is situated farther forward in reference to the posterior zygapophyses.

The anterior zygapophyses are relatively narrow anteroposteriorly and deep dorsoventrally; wider dorsally and becoming quite narrow ventrally. The united articular processes between the first and second vertebrae are well developed, more as in *P. atrox* and not so reduced as in *Smilodon*. The articular processes between the second and third vertebrae are also well developed. The dorsal sacral foramina appear to be even larger than in *Smilodon*.

An opening into the neural canal is located at the base of the posterior margin of the neural spine of the first vertebra. A similar foramen, though not penetrating to the neural canal, is located at the base of the posterior margin of the second neural spine. On each side of the sacrum a well-defined groove, similar to that in the sacrum of *Smilodon*, extends from the dorsal surface posterior to the anterior zygapophysis laterally around the zygapophysis to the forward side.

The ventral sacral foramina are relatively large. The anterior foramina are about twice the size of the second pair. A third pair of sacral foramina are almost completely enclosed by bone because of the inward projection of the transverse process of the third sacral vertebra. Indeed, were the termini of these processes and lateral parts of the first caudal complete, the foramina might be completely enclosed. Perhaps the sacrum should be considered to consist of four vertebrae in-
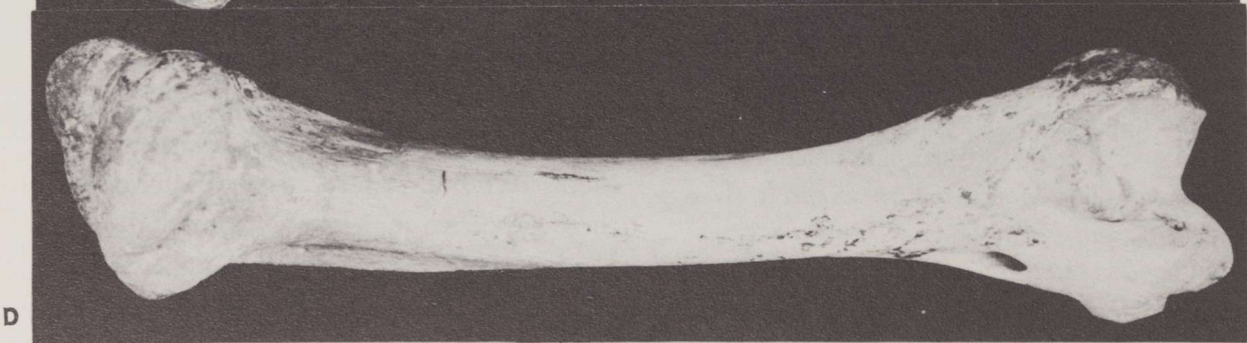
PLATE 6

A. Ventral view of sternum.
B. Left scapula, lateral view.
C. Outer view of right humerus.
D. Posterior view of right humerus.

stead of three, and consequently twelve instead of thirteen caudal vertebrae.

The ventral surface is flattened anteriorly, but posteriorly the surface gradually becomes transversely convex on the third vertebra. There is a faint suggestion of a median keel on the vertebrae.

Caudal Series. The caudal series of *Dinobastis* consists of thirteen vertebrae. The first of these is united with the sacrum, and the terminal two are fused. The centrum of each vertebra is relatively short, except for the first. The tail is short, probably like that of *Smilodon*, and completely unlike the long tail of most felines.

The centrum of the anterior caudals is broad laterally and flattened in a dorsoventral plane. This character is gradually displaced posteriorly and the centra of the terminal caudals are deeper dorso-ventrally than they are wide.

In *Smilodon* the neural arch becomes incomplete in the second caudal vertebra, and in *P. atrox*, the neural arch becomes incomplete more posteriorly. In *Dinobastis* the neural arch is incomplete in the second caudal, and may be incomplete in the first. The condition of preservation of the dorsal surface of the first caudal vertebra makes it impossible to be sure of the structure. If the neural arch is complete, it is at least greatly reduced anteroposteriorly to a very narrow arch.

Sternum. The manubrium and six other sternal elements are preserved. The shape of the manubrium is similar to that of *Smilodon* and *P. atrox*, but the proportions are quite different. The greatest width of the manubrium occurs just anterior to the surfaces for attachment of the first costal cartilage, and is approximately equal to that of *Smilodon* or of *P. atrox*, but the depth is not nearly so great as in either one of these two. The mesosternal elements vary in length and width, but are all relatively deep.

Ribs. The ribs of *Dinobastis* are strongly constructed, and may be longer than those of either *Smilodon* or *P. atrox*, indicating a deeper-chested cat. The tuberculum and capitulum are not separated by such a broad notch as appear in *Smilodon* and *P. atrox*.

Scapula. The preservation of the scapula does not reveal how much suprascapular cartilage may have been ossified at the dorsal extremity of the scapula, but a comparison of measurements of *Dinobastis* with *Smilodon* shows that this element is as large or larger than the average for *Smilodon*.

The scapula of *Dinobastis* is distinctly different from *Smilodon* and *P. atrox*, but as with most other skeletal elements clearly shows an interesting combination of characters in which it more closely resembles *Smilodon* in part, and in part more closely resembles *P. atrox*. As in *Smilodon*, the scapula is relatively narrow from front to back, and high dorsoventrally. The posterior border of the scapula, from a point a short distance above the glenoid fossa, forms a nearly straight line to the junction with the dorsal border, which is characteristic of *P. atrox*, but unlike *Smilodon*.

The upper half of the anterior border of the scapula nearly parallels the posterior border, and produces nearly a right angle where it joins the dorsal border. The dorsal border also forms an angle slightly greater than 90° where it joins the posterior border.

Most of the anterior border appears to be preserved in the left scapula, and the posterior border is preserved in both scapulae.

Humerus. The humerus is long and massively built as in *Smilodon*. The articulating head at the proximal end of the humerus ap-
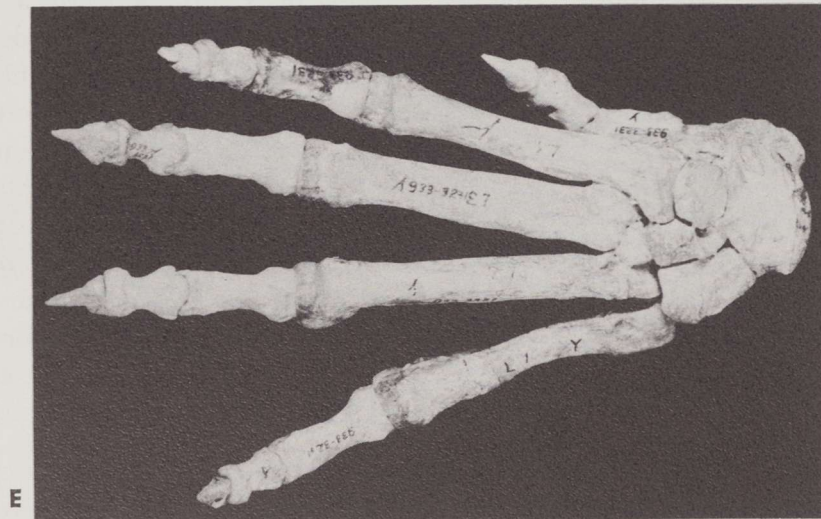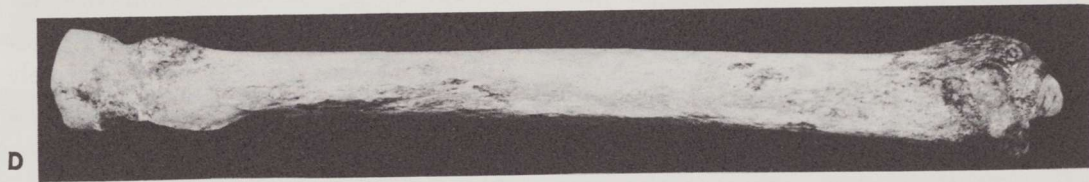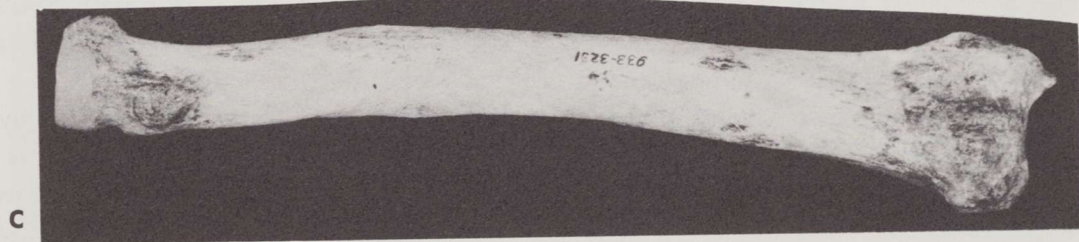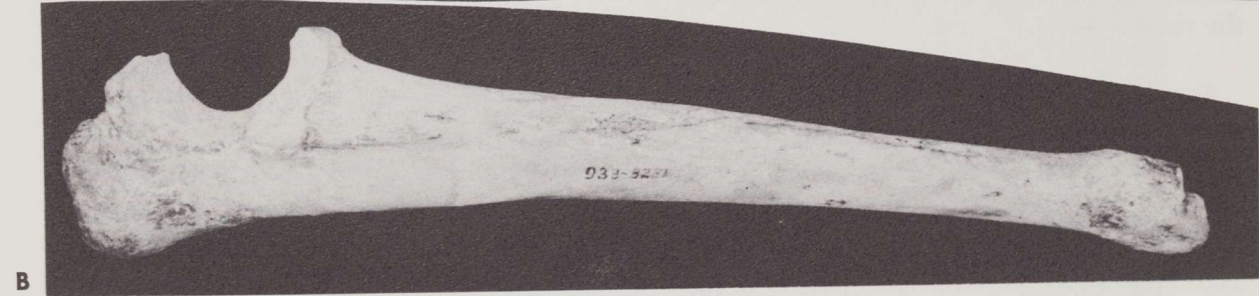
PLATE 7

A. Inner view of right ulna.
B. Radial view of right ulna.
C. Outer view of right radius.

D. Ulnar view of right radius.
E. Dorsal view of left manus.

pears to be wider proportionately than in *Smilodon* and does not extend as far down the posterior side of the shaft. As in *Smilodon* the greater tuberosity extends farther backward along the side of the articulating surface than in *P. atrox*. The greater tuberosity, however, appears to be higher and larger than in either *Smilodon* or *P. atrox*. The lesser tuberosity is better developed, and the bicipital groove, viewed from above, is narrower and deeper than in either *Smilodon* or *P. atrox*. The posterior portion of the crest of the greater tuberosity is much higher above the articulating head of the humerus than in either *Smilodon* or *P. atrox*. From this height the crest descends gradually to the forward edge.

The small tubercle between the bicipital groove and the pectoral ridge is entirely absent in *Dinobastis*. A large entepicondylar foramen is present.

The distal end of the shaft is proportionately wide as in *Smilodon*. The olecranon fossa is wide and shaped like that of *Smilodon*. A separate, small, deep, fossa is located between the posterior end of the inner condyle and the olecranon fossa. This fossa appears to be absent in both *Smilodon* and *P. atrox*. The inner condyle is prominent and appears to extend farther up the anterior side than in either *Smilodon* or *P. atrox*. The outer condyle is much more rounded on the anterior surface, and is longer in a proximodistal direction on the posterior side than in either of these forms.

Ulna. The ulna of *Dinobastis* is longer, but not as heavily built as the ulna of *Smilodon*, and is shorter than the ulna of *P. atrox*. In lateral view the ulna more closely resembles that of *P. atrox* than it does *Smilodon*; the distal end does not curve backward as much as in *P. atrox*, but neither is it as straight as in *Smilodon*. The proximal end displays the posterior curvature as in *P. atrox* and not the es-

sentially straight shaft as seen in *Smilodon*. The angle of slope of the anterior face of the olecranon process is not as steep as that of *Smilodon*. There is a greater overhang on the proximoposterior portion of the olecranon process on the inner side than in either *Smilodon* or *P. atrox*. In anterior view the shaft resembles *P. atrox*. It is not as straight in its longitudinal axis as is the ulna of *Smilodon*. The rugose area for the attachment of the interosseous ligament is better defined than in either *Smilodon* or *P. atrox*.

Radius. The radius of *Dinobastis*, like the ulna, is longer than that of *Smilodon*, and not as heavily built. The shape of the articulating surface of the proximal extremity is more rounded than in *Smilodon*, providing a broader articulating surface for the humerus. The tubercle situated below the head on the anterior surface is decidedly more prominent than in either *Smilodon* or *P. atrox*. The shaft, in ulnar view, is essentially straight as in *P. atrox* and not curved as in *Smilodon*. From the anterior view the shape of the shaft is also more like *P. atrox* than *Smilodon*, the concave contour on the lower ulnar side of the shaft being more pronounced in *Smilodon*. At the distal extremity, the facet for the ulna is large as in *P. atrox*. The articulation for the scapholunar is proportionately long and narrow as in *P. atrox*, and not so short and broad as in *Smilodon*.

Scapholunar. The scapholunar of *Dinobastis* resembles that of *Smilodon* and *P. atrox* in general features, but has some characteristics in which it more closely resembles *Smilodon*, while other characteristics show greater similarity to *P. atrox*.

Viewed from the proximal surface, the articular surface for the radius is seen to be proportionately much greater transversely and much narrower in dorsopalmar direction; and the concavity on the proximal surface is more
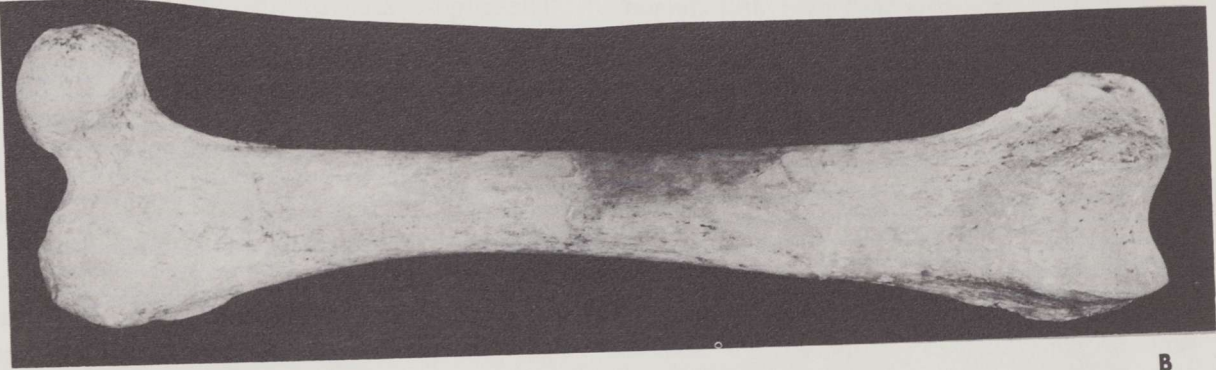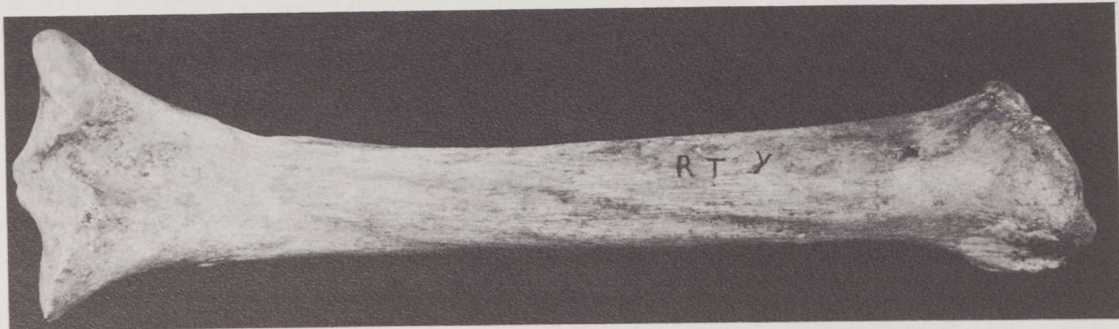
PLATE 8

A. Posterior view of right femur.
B. Anterior view of right femur.
C. Anterior view of right tibia.
D. Posterior view of right tibia.

pronounced than in either *Smilodon* or *P. atrox*.

A pronounced difference is noted in dorsal view between the scapholunar of *Dinobastis* and that of *Smilodon* or *P. atrox*. The depth of the dorsal surface toward the ulnar side and above the articulation for the magnum is greater in *Smilodon* than in *P. atrox*; in *Dinobastis* it is even greater than in *Smilodon*, yet the profile and articulating surfaces for the magnum and unciform are quite like those of *P. atrox*.

In distal view the articulating surfaces for the distal row of carpal elements resemble those of *Smilodon* more than they do *P. atrox*. The articulating surface for the unciform appears to be larger than in either *Smilodon* or *P. atrox* and is directed downward much more than in *Smilodon*.

Metacarpals. The metacarpals are longer than those of *Smilodon*. They are shaped, however, more like those of *P. atrox*. This is particularly noticeable in the triangular shape of the distal ends of Metacarpals II and III. The proximal phalanges are more like those of *P. atrox* in not being as wide at the proximal end as in *Smilodon*. The third metacarpal is the broadest and most heavily built of the metacarpals.

Innominate Bone. The symphyseal union in the pubic region is not as strong as in either *Smilodon* or *P. atrox*. The union does not occur posteriorly as far as the posterior border of the obturator foramen.

The articulating surface within the acetabulum is relatively broad and is more like that of *Smilodon* than *P. atrox*. The ilium is broader at the anterior end and appears to be more gently rounded on the anterodorsal surface than that of either *Smilodon* or *P. atrox*. The external surface of the ilium is not deeply excavated. The ischium is sturdily constructed with a wide body.

Femur. The femur of *Dinobastis* compares in size with that of the average *Smilodon*, but is distinctly shorter and relatively heavier than the femur of *P. atrox*. As in *Smilodon*, the shaft widens from a point near the middle of the femur toward the proximal and distal extremities, and the shaft is slightly bowed in its longitudinal extent. The distal portion of the shaft is similar to that of *Smilodon*; less cylindrical than in *P. atrox*. As in *Smilodon* a nutrient foramen is situated on the inner side of the posterior surface of the shaft midway between the lesser trochanter and the distal articulation.

The greater trochanter does not rise quite to the level of the head. In this respect the femur is more like that of *P. atrox* than *Smilodon*. The outer surface of the trochanter, however, extends down the proximal extremity as in *Smilodon*. Viewed from the anterior side the greater trochanter is not as pointed as it is in *Smilodon*. The anterior face of the femur below the greater trochanter is gently convex, whereas in *P. atrox* this region forms a shallow depression. In *Smilodon* a slight ridge is present. The lesser trochanter is situated some distance below the head as in *Smilodon*. The digital fossa is even larger than in *Smilodon* and the distal end is continuous to the lesser trochanter through a shallow, curving depression. A small rounded tuberosity is present between the head and the fossa, but is less distinct than in *Smilodon*. The patellar surface appears to be similar to that of *Smilodon*. The outer lateral border, however, continues as a prominent ridge a short distance up the shaft.

The inner tibial articulation is decidedly larger than the outer, in contrast to *Smilodon* in which they are about equal in size. The intercondyloid notch widens rather abruptly
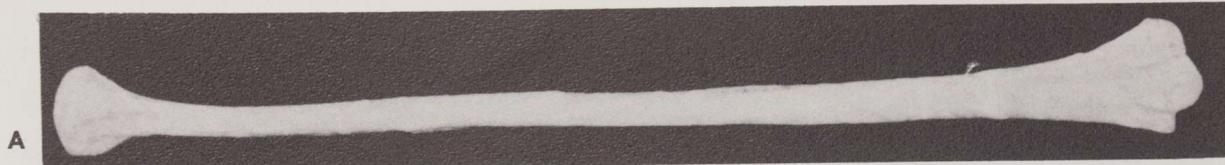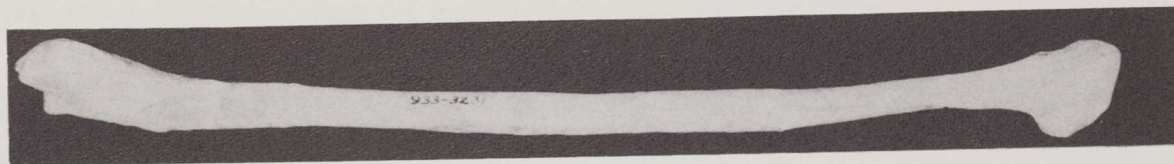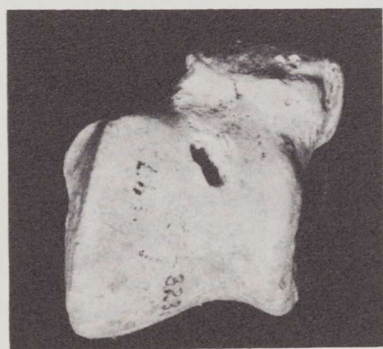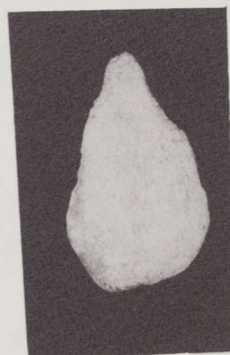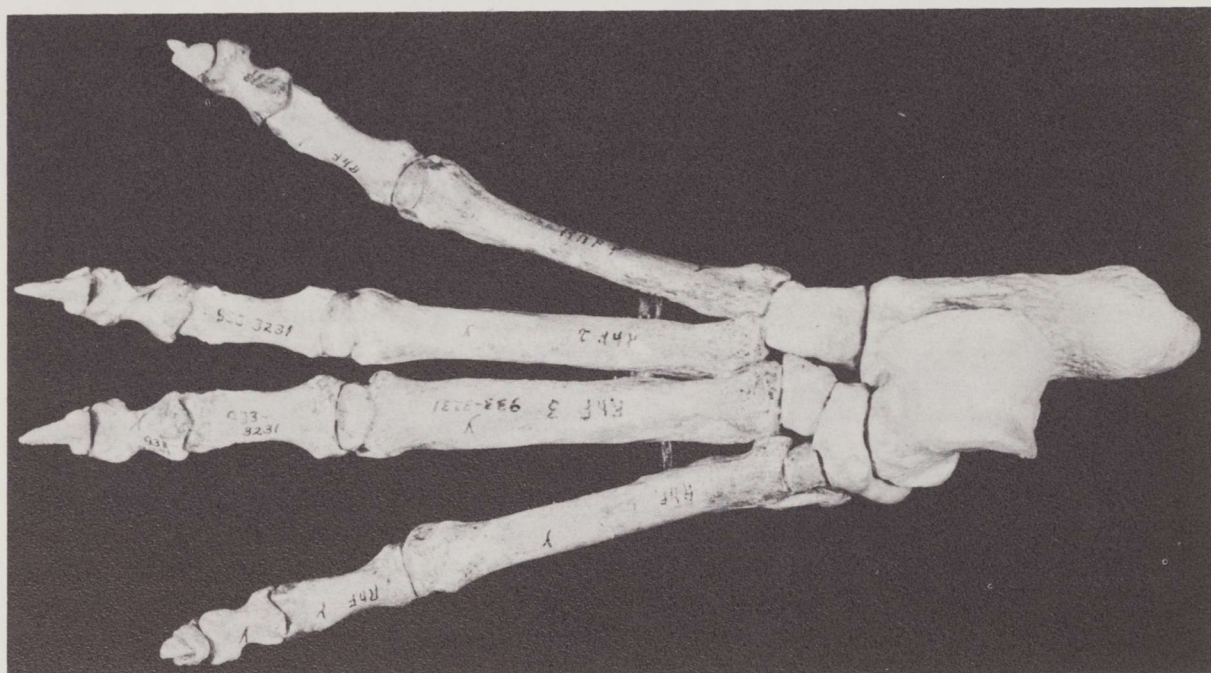
PLATE 9

A. Anterior view of right fibula.
B. Posterior view of right fibula.
C. Tibial view of left astragalus.

D. Anterior view of right patella.
E. Posterior view of right patella.
F. Dorsal view of right pes.

as it nears the patellar surface. The rugose areas at the lower end of the shaft, above the articulating surfaces of the distal end are more pronounced than in either *Smilodon* or *P. atrox*.

Patella. The patella of *Dinobastis* is distinct from that of either *Smilodon* or *P. atrox*, particularly in the shape of the distal tongue. In *Smilodon* the end of the distal tongue is broadly rounded; in *P. atrox* it is pointed. The patella of *Dinobastis* more closely resembles that of *P. atrox*, but it is proportionately much longer and more pointed.

Tibia. The tibia of *Dinobastis* is a relatively long element. The tibia of *Smilodon* is relatively short. The articulating surfaces for the femur appear to be more concave than in either *Smilodon* or *P. atrox,* and the medial separation between the articulating surfaces is much less in *Dinobastis*, and is raised into a more prominent spine than in either *Smilodon* or *P. atrox*. The tubercule for attachment of the ligamentum patellae is relatively broad and the cnemial crest is heavy as in *Smilodon*. Viewed from the side the anterior surface is more concave than in either *Smilodon* or *P. atrox*. As in *Smilodon*, the nutrient foramen on the posterior side is visible in lateral view. The posterior surface below the head is rather deeply and broadly excavated similar to *P. atrox* and unlike that of *Smilodon*. The posterior surface of the shaft is slightly convex, thus resembling *P. atrox* more than *Smilodon*.

Fibula. The proximal end of the fibula of *Dinobastis* is more triangular than in either *Smilodon* or *P. atrox*. The anterior and posterior tuberosities on the proximal end, characteristic of *Smilodon*, are absent in *Dinobastis*. The anteroposterior diameter of the distal end is greater than the transverse diameter. The articulating surface for the astragalus is gently concave.

Astragalus. The astragalus exhibits similarities to that of both *Smilodon* and *P. atrox*, yet is distinct from either. The trochlear surface of the astragalus is more deeply grooved than in *Smilodon* and is similar to that of *P. atrox*. The neck, however, more closely resembles the short-necked astragali of *Smilodon*. Also articulation of the head with the navicular is more like that of *Smilodon* than the true cat. The inner calcaneal facet is similar to that of *Smilodon*. The groove for the interosseous ligament is long, and considerably wider than in either *Smilodon* or *P. atrox*.

Calcaneum. The calcaneum of *Dinobastis* closely resembles that of *Smilodon*. The astragalar facets of the inner side are broadly connected as in *Smilodon*, and the large outer facet for the astragalus also is similar to that of *Smilodon*. The articulating facet for the cuboid is shaped like that in *Smilodon*, and on the inner side is a small flattened surface for the navicular, as in *Smilodon*.

Metatarsals. The metatarsals are long and strongly built. They are approximately equal in length to the maximum metatarsal length of *Smilodon*. The third metatarsal is the widest and most strongly built of the metatarsals. The ungual phalanges have the bony core of the claw encompassed by a well developed hood.

The Phylogenetic Relationships of *Dinobastis serus* Cope

The genus *Dinobastis* was based by Cope (1893) on a few teeth and skeletal elements found in western Oklahoma. The material included "three metacarpals, three phalanges of probably a single digit, and the head of a femur. The teeth include five incisors, two superior canines, and two molars, one of them the superior sectorial in perfect perservation."

Hay (1919) figured an upper canine tooth,

found in the Friesenhahn Cave, and referred it to *Dinobastis*. Hay (1921) described and figured skeletal material from the same locality, which was also assigned to *Dinobastis*.

Savage (1951) briefly discussed two machairodont crania in the Irvington fauna from the San Francisco Bay region, California. He provisionally referred this material to *Dinobastis serus* Cope. One of these crania, however, is probably a species of *Smilodon*.[4] The other cranium, U.C.M.P. 39228, judging from the description given, belongs to the genus *Dinobastis*.

The discovery of a nearly complete skeleton and the remarkable collection of other *Dinobastis* material from the Friesenhahn Cave provides the opportunity for additional diagnosis of this genus, as well as some speculation upon its origins and relationships to other saber-toothed cats.

Dinobastis is now known from the earlier Pleistocene Irvington fauna, the late Pleistocene of the Friesenhahn Cave, and from an unknown stage of the Pleistocene of western Oklahoma.

The generic and specific characters of *Dinobastis* were given by Cope (1893: 896) as follows:

Generic Characters: So far as preserved, the parts agree with those of the genus *Smilodon*, with one exception. This is that the superior sectorial tooth possesses no internal root, not even a rudiment. The protocone is wanting in *Smilodon*, but its corresponding root is present, but in this form the root also has disappeared, so that it may be regarded as representing the last stage of specialization in the cats, a circumstance which is appropriate to its late appearance in time. I therefore suppose the species to represent a genus, to which I give the name *Dinobastis*.

Specific characters: The canine teeth are large, with elongate compressed crowns, a little more convex on the external than the internal face. The cutting edges are finely serrate. The anterior edge differs from that of the *Smilodon neogoeus* in that it turns inward toward the base of the crown, presenting inward. In the S. *neogoeus* this edge is not incurved. The superior sectorial has a large anterior basal lobe and a rudiment of a second at its anterior base. It does not attain the importance of a lobe, as it does in the S. *fatalis*. The part of the crown anterior to the paracone forms about one-fourth of the longitudinal extent of the crown: in the S. *fatalis*, it forms about one-third. The paracone is prominent, and is strongly convex on the external face. The metacone has a nearly straight edge, and its external face displays a shallow vertical groove near the middle. The long diameter of its base is 1.5 as great as that of the paracone. The crowns of the external incisors are oblique, and slightly incurved; they have robust cutting edges, which are finely serrate, and no basal lobes. The incisors 1 and 2 have small conic lobes at the base of the crown, which are well separated from each other at their bases. Those of I. 1 are subequal, while the external of I. 2 is smaller than the internal, and nearer the base of the crown. The crowns proper of 1 and 2 are acutely conic with semicircular section, the posterior face being flat. The edges of I. 2 are feebly crenate; those of I. 1 are smooth.

Merriam and Stock (1932) considered *Dinobastis* a subgenus of *Smilodon*, and on the basis of material known at that time, the subgeneric rank was probably justified. The present study of new and much more complete material from Friesenhahn Cave, however, indicates such variance from other known saber-toothed cats that generic rank is here given to *Dinobastis*.

Additional Diagnosis. Occiput of skull high

[4] Written communication from Dr. Savage. "The cranium, U.C.M.P. 38338, from Irvington, that I indicated (DES 1951, U.C. Bull. 28: pp. 234–235 and Fig. 11) as likely *Dinobastis* is probably a species of *Smilodon*. On the basis of dentitions, we are now sure that both *Smilodon* and *Dinobastis* are represented at Irvington."

and triangular. Second and third superior incisors proportionately larger teeth than in *Smilodon*. Superior canine smaller than that of *Smilodon*. Anteroposterior length of P 4/ less than that of *Smilodon*, but length of metacone longer than that of *Smilodon*. Paraconid and protoconid blades of inferior carnassial approximately equal in size. In appendicular skeleton, forequarters considerably higher than hindquarters.

Appendicular comparisons. Some of the long elements of the appendicular skeleton of *Dinobastis* differ so noticeably in proportion from those of other large extinct Pleistocene cats that a summary of comparisons of the limb elements is given below:

The length of the humerus of *Dinobastis* is intermediate between that of the average for *Smilodon* and *Panthera atrox*. The radius is nearly as long as the average length of radius of *P. atrox*. It is considerably longer than the average for *Smilodon*, and exceeds in length that of the largest *Smilodon*.

The femur is slightly shorter than the average for *Smilodon*, and considerably shorter than that of *P. atrox*. The tibia is shorter than the average for *P. atrox*, and slightly longer than the average for *Smilodon*.

The metacarpals and metatarsals are longer than the average for *Smilodon*. The proportionately longer radius and the shorter femur of *Dinobastis* create considerably different proportions from those in *Smilodon*. *Dinobastis* stood conspicuously higher in the forequarters than in the hindquarters.

The foregoing comparisons of *Dinobastis* with the saber-toothed *Smilodon* and the feline *Panthera atrox*, indicate that *Dinobastis* is a specialized saber-toothed cat structurally closer to *Smilodon* than to any other genus, but with many skeletal features similar to those of the true cat. Unfortunately the preser-vation of the *Dinobastis* skulls does not permit the detailed comparisons that would aid in establishing the true relationships of this genus. However, such obvious features as the elongated, serrated superior canines, and the large forward extending mastoid processes clearly indicate that *Dinobastis* is a true machairodont. Further study is necessary to evaluate fully the significance of the greater similarity of some skeletal features of *Dinobastis to Panthera atrox* than to the saber-toothed *Smilodon*.

There is difference of opinion regarding the phylogeny and taxonomy of the *Felidae*. Whether or not the *Machairodontinae* and the *Felinae* arose from the *Nimravinae*, as seems likely, they did have a common source. In this common source both machairodontine and feline characters should occur. The retention of more of the feline characteristics in *Dinobastis* than are to be found in *Smilodon* indicates a long separate development of the two genera, despite their apparent structural similarities. *Dinobastis* and *Smilodon* represent the terminal stages of two machairodont lines that diverged early in the development of the *Machairodontinae*.

Recognition of the forms ancestral to *Dinobastis* is dependent upon a better understanding of the cranial characteristics of this genus. At present, however, it appears that either *Dinictis* or *Nimravus*, if not directly ancestral to *Dinobastis*, is not far removed structurally from the ancestral form. Between this ancestral form and *Dinobastis* exists a phylogenetic gap into which none of the described North American machairodonts appear to fit. It is quite possible that *Dinobastis* evolved in Eurasia. In this event *Dinobastis* may have arrived in North America in the early Pleistocene, accompanying the elephant upon which he fed.

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TABLE 1

Measurements of Dinobastis *with Comparisons to* Smilodon[1]

	TMM 933–3231	TMM 933–3582
Cranial Measurements: Skull		
Length from anterior end of premaxillary to posterior end of condyle	327.0	289.0
Basal length from anterior end of premaxillary to inferior notch between condyles	315.0	266.0
Length from anterior end of premaxillary to posterior end of inion	362.0	324.0
Length from anterior end of premaxillary to anterior end of posterior nasal opening	--------	142.0
Length from posterior end of glenoid cavity to posterior end of condyles	94.0	108.0
Width of anterior nares	--------	52.0
Greatest width across muzzle at canines	91.0	94.0
Least width between superior borders of orbits	--------	93.0
Greatest width across zygomatic arches	--------	177.0
Anterior palatal width between superior canines	--------	59.0
Posterior palatal width between inner roots of superior carnassials	--------	93.0
Width across palate between posterior alveoli of superior carnassials	--------	108.0
Greatest diameter across condyles	62.0	61.0
Height from base of condyles to top of saggital crest	--------	111.0

Mandible	Dinobastis TMM 933								Smilodon 2002	
	−3231	Rt.	Lt.	−1283	−3533	−2546	−3353	−3397	−72	−104
		−1								
Length from anterior end of symphysis to posterior end of condyle	227.0e	197.0	205.0	204.0	191.0	181.0	--------	--------	230.0	178.3
Length from anterior end of outer flange to posterior end of condyle	208.0e	186.0	191.0	185.0	170.0	163.0	--------	--------	218.8	166.1
Length of symphysis measured along anterior border	67.0e	57.0	57.0	62.5	63.0	--------	--------	--------	72.7	48.7
Least depth of ramus below diastema	49.7a	39.8	42.2	39.4°	40.5°	40.5°	38.0	40.0	38.7	29.6
Depth of ramus below posterior end of M/1	47.5	44.6	42.5	43.4	--------	40.5	39.5	42.3	45.6	36.0
Thickness of ramus below M/1	18.7	18.0	18.5	19.8	19.5	17.7	18.6	19.2	22.5	19.2
Height from inferior border of angle to summit of condyle	45.0	41.8	40.3	40.8	--------	38.7	40.6	--------	37.4	32.3

[1] All measurements are in millimeters. Measurements of the largest and smallest individuals of Smilodon are as listed by Merriam and Stock (1932). astands for approximate, estands for estimated. Measurements are approximate for skull (TMM 933–3231) because of restoration.

° Depth of ramus was measured posterior to P/3. Unless indicated, measurement is anterior to P/3.

Height from inferior border of angle to summit of coronoid process . . .	83.0	76.5	78.5	81.4	--------	71.0	--------	75.0ᵃ	75.2	58.0
Transverse width of condyle	50.5	42.0	40.4	44.0	--------	--------	--------	--------	51.4	38.7
Greatest depth of condyle . .	19.0	18.0	18.0	18.7	--------	15.7	16.8	17.3	18.9	15.8
Greatest width of mandible measured across symphysis and between outer walls of alveoli for lower canines	75.0ᵉ	63.0	63.0ᵉ	64.0ᵉ	--------	--------	--------		56.5	48.1
Greatest width of mandible measured across outer flanges	--------	64.0	66.0ᵉ	50.0ᵉ	--------	--------	--------		58.6	47.5
Greatest width of mandible measured between outer ends of condyles . . .	152.0ᵉ	--------	--------	--------	--------	--------	--------		188.7	147.0

Superior dentition	*Dinobastis* TMM 933				*Smilodon*° 2001	
	–896	–323	–3582	–3231	–24	–148
Length from anterior end of canine alveolus to posterior end of P/4	--------	--------	87.2	108.0	126.3	97.0
Length from anterior end of P 3/ to posterior end of P 4/ .	--------	--------	48.2ᵃ§	48.0	63.7	50.7
Length of diastema from posterior end of alveolus for C to anterior end of alveolus for P 3/	--------	--------	8.3	25.0	18.0	12.4
I 1/, greatest transverse diameter	--------	--------	10.0	7.0	7.6	5.0†
I 2/, greatest transverse diameter	--------	--------	12.0	13.0 Rt. 10.0 Lt.	9.5	7.6
I 3/, greatest transverse diameter	--------	--------	14.5	13.0	13.0	11.1†
C/, anteroposterior diameter of alveolus	--------	--------	32.8	26.5	46.1	38.8
C/, transverse diameter of alveolus	--------	--------	14.0	15.0	22.9	18.0
Length of canine from alveolar border to tip of tooth . . .	--------	--------	--------	68.0	--------	--------
P 3/, anteroposterior diameter	--------	--------	--------	9.0	18.5	15.0†
P 3/, greatest transverse diameter	--------	--------	--------	6.8	10.6	8.4†
P 4/, anteroposterior diameter	36.0	34.7	38.4	39.0	46.0	37.5
P 4/, greatest transverse diameter across protocone . . .	11.2	10.8	13.0	11.5‡	19.3	16.8
P 4/, anteroposterior diameter of base of paracone . . .	12.0	11.5	12.3	13.0	13.7	11.1
P 4/, length from base of paracone to anterior end of tooth .	7.8	8.0	9.0	7.5	10.1	9.2
P 4/, length of metacone blade	15.6	14.4	17.0	16.5	15.2	11.5
Width of incisor series measured between outer sides of third upper incisors	--------	--------	65.5	69.7	63.5	46.3†

	TMM 933								
	–3231	–1928	–1232	–720	–604	–2749	–605	–901	–2580
Length of superior canine measured along inner border from tip to base of enamel	75.0	74.0	69.0	61.0	61.0	64.5	64.5	65.0	65.0

° Measurements of the largest and smallest individuals of Smilodon as listed by Merriam and Stock (1932).

† Indicates measurements of some other specimen than that listed under No. 2001–148.

‡ The protocone is absent in *Dinobastis*. Measurements are transverse diameter of tooth.

§ Measured from alveolar border of P 3/.

Inferior Dentition	-3231			*Dinobastis* TMM 933						*Smilodon* 2002			
		Right	Left	-2041	-322	-1283	-3533	-2456	-608	-3353	-3397	-72	-104
Length from anterior end of C to posterior end of M/1	130.0	117.50				114.5	105.4	108.4				141.8	115.7
Length from anterior end of P/3 to posterior end of M/1		58.0	65.0			67.0	62.0	62.5					
Length from anterior end of P/4 to posterior end of M/1	48.3	47.2	47.6			48.0	47.3	47.3				57.8	52.8
Length of diastema measured between alveoli for C and P/3		43.6				30.5	28.5	29.0					
Length of diastema measured between alveoli for P/3 and P/4		3.6	7.0			9.3	6.0	5.0					
Length measured from posterior border of alveolus for C to anterior border of alveolus for P/4	65.5	55.0				49.6	43.0	44.3					
1/1, greatest transverse diameter		5.8										5.0	
1/2, greatest transverse diameter	6.5	8.3					7.1					7.1	
1/3, greatest transverse diameter	9.8	11.2	11.3				10.2					8.6	8.0
/C, greatest transverse diameter	10.7	11.2	11.4				10.0					10.5	10.4
/C, greatest antero-posterior diameter at base of enamel	15.8	16.1	16.7				15.0					16.0	14.7
P/3, anteroposterior diameter		8.2	9.0					8.8					
P/3, greatest transverse diameter		10.8	11.3					5.6					
P/4, anteroposterior diameter	20.4	18.5	19.2			19.0	19.0	19.2	19.7	18.2	19.4	26.0	23.2
P/4, greatest transverse diameter	9.2	9.0	8.5			9.4	9.2	8.1	8.6	8.5	8.5	12.7	11.3
P/4, basal length of principal cusp	7.4	8.0	7.7			8.2	8.1	6.4	7.5	7.3	7.3	11.6	10.5
M/1, anteroposterior diameter	30.6	28.0	28.0	25.6	26.6	28.1	28.2	27.3		27.2	26.7	32.1	27.4
M/1, greatest transverse diameter	12.8	10.5	10.8	11.8	11.4	11.0	12.8	10.5		10.2	10.1	16.1	14.0
M/1, length of protoconid blade	15.0	13.8	14.0	13.7	13.6	15.0	15.4			14.5	12.3	18.0	16.0

Post-Cranial Measurements:	TMM 933
Atlas	−3231
Greatest width across transverse process	150.0e
Greatest width of anterior end across articulation for condyles of skull	70.0
Greatest width across outer borders of articulation for axis	75.0
Length from anterior end of articulation for condyles to posterior end of articulation for axis	66.5
Length of neural arch along median line	35.0
Greatest length of transverse process, taken oblique to fore and aft axis of vertebra . . .	76.0
Greatest height from ventral surface of inferior arch to dorsal surface of neural arch . .	50.3

Axis

Length of centrum along median line measured parallel to lower surface from posterior end to tip of odontoid process	83.8
Depth of centrum measured normal to floor of neural canal and across posterior epiphysis	27.0
Greatest transverse width across posterior epiphysis of centrum	39.4
Width across articulating surface for atlas	70.2

	TMM 933		
Third to Fifth	−3231		
Cervical vertebrae	3rd Cervical	4th Cervical	5th Cervical
Length from end of anterior zygapophysis to end of posterior zygapophysis	50.6	56.0	55.0
Length of centrum measured normal to posterior face and along median line	38.5	36.4	36.0
Width across anterior zygapophyses	47.0	60.7	59.5
Width across posterior zygapophyses	48.9	48.3	49.4
Greatest width of neural canal at anterior end	19.0	23.0	23.2
Greatest transverse width of posterior epiphysis of centrum . . .	35.0	34.2	35.5
Greatest width across outer ends of transverse processes	116.0	109.0	102.0
Greatest length of transverse process from outer end to end of antero-internal projection of inferior lamella	------	53.0	------
Height from middle of ventral border of posterior epiphysis of centrum to top of neural spine	55.0	67.0°	64.4
Depth of centrum measured normal to floor of neural canal and across posterior epiphysis	27.4	28.2	27.7

° Measured to top of incomplete spine.

First to Tenth Thoracic[*]

	First	Second	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth
Length from end of anterior zygapophysis to end of posterior zygapophysis	42.5	44.0	39.0	——	——	——	45.0	43.0
Length of centrum measured normal to posterior face and along median line	31.6	31.4	30.8	30.0ª	29.0	28.3	29.6	31.3
Greatest width across anterior zygapophysis	63.5	54.0	29.8	27.5	32.0	——	——	27.0
Width across posterior zygapophysis	43.0	40.0	26.0	——	——	——	27.5	31.3
Height of neural canal at anterior end	20.0ª	15.6	17.0	17.4	16.0	17.5	——	16.0
Greatest transverse width of posterior face of centrum across capitular facets	49.0	55.6	51.6	50.0ª	46.6	47.8	48.7	47.5
Depth of centrum measured normal to floor of neural canal and along median line of posterior epiphysis	27.0	27.0	30.5	30.0	30.0	31.0	30.6	30.6
Greatest width across outer ends of transverse processes	100.6	94.8	83.0	80.0	78.6	75.0	76.0	——
Greatest anteroposterior diameter of outer end of transverse process	25.0	22.6	24.0	24.3	25.8	26.0	——	——
Height from middle of ventral border of posterior epiphysis of centrum to top of neural spine	135.0ᵉ	128.0	——	104.0	109.0	——	——	97.0

Eleventh thoracic vertebra

Greatest length from end of anterior zygapophysis to end of posterior zygapophysis	47.3
Length of centrum measured normal to posterior face along median line	32.6
Greatest width across anterior zygapophyses	33.0
Greatest width across posterior zygapophyses	26.5
Greatest transverse width of posterior face of centrum	45.4
Depth of centrum measured normal to floor of neural canal and along median line of posterior epiphysis	29.2
Greatest width measured from outer ends of facets for tubercle of rib	76.8ª
Height from middle of ventral border of posterior epiphysis of centrum to top of neural spine	97.0ª
Length of spine from middle of notch between anterior zygapophyses to top measured parallel to anterior end	66.0ª
Greatest anteroposterior diameter of plate above facet for tubercle of rib	37.7

[*] Third and fourth thoracic vertebrae are missing.

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Twelfth thoracic vertebra   TMM 933
                                                  –3231

Length from end of anterior zygapophyses to end of posterior zygapophyses 57.0
Length of centrum measured normal to posterior face along median line 35.0
Greatest width across posterior zygapophyses 27.9
Greatest width across metapophyses . . . .   62.0[a]
Greatest width across facets for tuberculum of rib 67.4
Greatest width of posterior epiphysis of centrum 47.3
Depth of centrum measured normal to floor of neural canal and along median
line of posterior epiphysis 29.3
Greatest length from end of metapophyses to end of anapophyses 50.6
Height of spine from inferior border of posterior epiphysis of centrum to
top of neural spine . . . .   95.0[a]

Thirteenth thoracic vertebra

Length from end of anterior zygapophysis to end of posterior zygapophysis 60.5
Length of centrum measured normal to posterior face along median line 37.8
Greatest width across posterior zygapophyses 26.0
Greatest width across metapophyses . . . .   62.0[a]
Greatest width of posterior epiphysis of centrum taken immediately above
lateral projection of centrum 48.1
Depth of centrum measured normal to floor of neural canal and along median
line of posterior epiphysis 30.0
Distance from median inferior border of anterior epiphysis to top of neural spine . . .   90.2
Height of spine above roof of neural arch 47.0
Anteroposterior diameter of top of neural spine 27.5

Lumbar vertebrae

	First	Second	Third
Length of centrum measured normal to face of posterior epiphysis and along median line	40.3	41.0	44.7
Greatest length from anterior end of metapophyses to end of posterior zygapophyses	66.5	-----	67.6
Greatest width across metapophyses	56.0[a]	-----	54.0[a]
Greatest width across posterior zygapophyses	27.6	30.0[a]	35.4
Width of posterior epiphysis of centrum	49.6	50.8	52.5
Depth of centrum measured normal to floor of neural canal and across posterior epiphysis	30.4	31.4	33.0
Height from middle ventral border of anterior epiphysis of centrum to top of neural spine	93.4	95.0	96.6

The remaining lumbar vertebrae are missing from the skeleton.

Sacrum   TMM 933
                                             –3231

Greatest length measured parallel to median line 125.0
Greatest width at anterior end and from outer sides of surfaces for ilia . . . .   106.0[a]
Greatest width of third sacral vertebra across transverse processes 67.3
Greatest width between dorsal borders of anterior zygapophyses 54.0
Depth of centrum of first sacral vertebra measured normal to floor of neural canal
and across anterior epiphysis 28.4
Greatest distance from dorsal margin of anterior zygapophysis to ventral border
of surface joining with ilium 80.3
Height from median ventral surface of first sacral vertebra to top of first neural spine . .   83.0[a]

Manubrium

Greatest width 55.0
Greatest depth 23.0
Depth distal end 23.0
Width distal end 29.0
Least depth 21.0

Innominate bone

Length from anterior end of ilium to posterior border of ischium 326.0
Greatest depth of ilium . . . .   107.0[a]
Diameter of acetabulum measured at right angles to long axis of internal notch 47.0
Long diameter of obturator foramen 80.0
Greatest diameter of obturator foramen taken normal to long diameter 62.0

Scapula

	Dinobastis TMM 933	*Smilodon* 2004	
	–3231	R–8	R–7
Greatest length from coracoid process to top of scapula measured along axis of spine	322.0	--------	--------
Greatest width of articulating end measured across glenoid cavity	80.5	87.1	67.0
Greatest transverse diameter across glenoid cavity	46.0	57.9	41.5
Distance from inner border of glenoid cavity to top of spine .	89.0[e]	--------	70.1
Width of scapular blade, measured obliquely across spine . .	161.0	191.0	148.0
Least width of neck across articulating end	66.0	73.2	55.1

Humerus	Dinobastis TMM 933 −3231		−2206	−2506	Smilodon 2005	
	Right	Left			R–1	R–10
Greatest length measured parallel to longitudinal axis	358.0	356.0	340.0	....	385.0	309.0
Greatest transverse diameter of proximal extremity .	74.5	76.0	72.0	67.5	92.4	75.4
Greatest anteroposterior diameter of proximal extremity	104.0	104.0	98.0	91.8	117.6	92.0
Transverse diameter at middle of shaft	33.0	32.0	30.3	28.5	41.7	32.2
Anteroposterior diameter at middle of shaft . . .	49.0	49.0	45.0	39.4	57.7	47.5
Greatest width of distal extremity	82.5	84.4	83.0	....	125.0	98.8
Least anteroposterior diameter of articulating surface for ulna	30.7	30.7	29.5	....	35.4	27.5

Ulna	Dinobastis TMM 933 −3231		Smilodon 2007	
	Right	Left	R–1	R–10
Greatest length measured parallel to longitudinal axis of ulna	376.0	380.0	372.0	287.0
Greatest width of posterior surface of olecranon process	....	59.5	48.8	33.6
Greatest transverse width of greater sigmoid cavity	45.2	45.0	60.2	41.5
Anteroposterior diameter of shaft at proximal end of tendon scar . . .	37.0	37.0	47.6	34.8
Transverse diameter of shaft at proximal end of tendon scar	28.0	24.0	29.9	20.9
Greatest anteroposterior diameter of distal extremity	34.6	34.0	46.6	33.3
Greatest width of distal extremity	23.7	24.0	33.8	20.4

Radius	Dinobastis TMM 933					Smilodon 2006	
	−3231		−485	−2565	−2421	R–1	R–10
	Right	Left					
Length measured along internal border .	323.0	328.0	300.0	307.0	293.0	289.0	235.0
Long diameter of proximal end . . .	37.0[e]	38.5	37.2	39.0	35.3	49.8	41.8
Greatest diameter taken at right angles to long diameter of proximal end	32.0	32.0	30.0	31.4	30.0	42.0	32.2
Width of shaft at middle	30.0	29.0	28.0	26.4	26.7	38.8	26.0
Thickness of shaft at middle	22.0	21.5	19.3	20.2	20.5	22.0	16.5
Greatest width at distal end taken normal to internal face	61.4	57.0	....	56.5	50.8	62.8	50.8
Greatest thickness of distal end . . .	36.7	36.0	....	36.2	35.0	46.7	35.6

[e] Estimated

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Scapholunar   TMM 933
                                                                                                −3231

Greatest transverse diameter measured normal to external border of proximal surface   .   51.8
Greatest dorsopalmar length 37.7
Greatest proximal distal diameter 42.0

	Dinobastis TMM 933				Smilodon 2009	
Femur	−3231		−2658	−2746	−1570	R–1	R–10
Greatest length from top of greater trochanter to distal condyles, measured parallel to long axis of femur . . .	353.0	351.0	338.0	343.0	344.0	408.0	317.0
Transverse diameter of proximal end, outer face of greater trochanter to inner side of head, taken normal to median longitudinal plane	92.0	93.0	89.2	89.1	95.7	108.8	83.0
Greatest anteroposterior diameter of head	42.8	42.4	41.0	42.2	42.4	50.7	39.4
Transverse diameter of shaft at middle .	31.3	31.7	30.0	30.3	30.2	40.4	30.1
Anteroposterior diameter of shaft at middle	28.8	28.7	27.7	27.2	28.4	35.4	26.8
Greatest width of distal extremity . .	73.5	72.0	67.4	69.0	70.8	90.2	65.2
Greatest anteroposterior diameter of the distal extremity, at right angles to longitudinal axis of femur	68.7	71.0	67.0	68.0	69.0	80.3	63.9
Greatest width of intercondylar notch .	15.5	14.8	13.0	14.0	13.5	21.7	14.5
Greatest width of articular surface of inner condyle	32.5	32.0	21.0	31.0	32.5	35.7	26.5

Patella   TMM 933
                                                                                            −3231

	Right	Left
Greatest proximodistal diameter	69.4	69.0
Greatest transverse width	40.0	41.0
Anteroposterior diameter through middle of articulating surface	26.0	25.2

	Dinobastis TMM 933			Smilodon 2010	
Tibia	−3231		−1571	R–1	R–10
	Right	Left			
Greatest length measured parallel to long axis	297.0	297.0	265.0	305.0	241.0
Greatest transverse diameter of proximal end	76.0e	....	71.6	84.4	74.8
Transverse diameter of shaft at middle	27.5	28.0	26.2	26.8	25.7
Greatest transverse diameter of distal end	54.5	55.6	50.1	63.3	50.2
Greatest anteroposterior diameter of distal end	39.0	38.0	30.0	40.8	33.3

Fibula		*Dinobastis* TMM 933		*Smilodon* 2011	
		−3231			
		Right	Left	R–1	R–10
Greatest length		287.0	————	265.0	212.7
Greatest anteroposterior diameter of proximal end		26.0	25.0	39.2	45.9
Greatest anteroposterior diameter of distal end		29.0	29.0	22.8	17.2
Greatest transverse diameter of distal end		14.0	14.0	29.9	24.4
Anteroposterior diameter of shaft at middle		8.5	————	10.7	9.2
Transverse diameter of shaft at middle		10.5	————	11.3	9.4

Astragalus	TMM 933
	−3231
Greatest length	52.5
Greatest width	41.0
Least distance across neck	22.0
Greatest diameter of head	29.6

Calcaneum	
Greatest length	85.0
Greatest width measured across astragalar facets As[1] and As[2]	37.5
Greatest width across cuboid surface measured from astragalar facet As[3] to outer side .	29.7

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