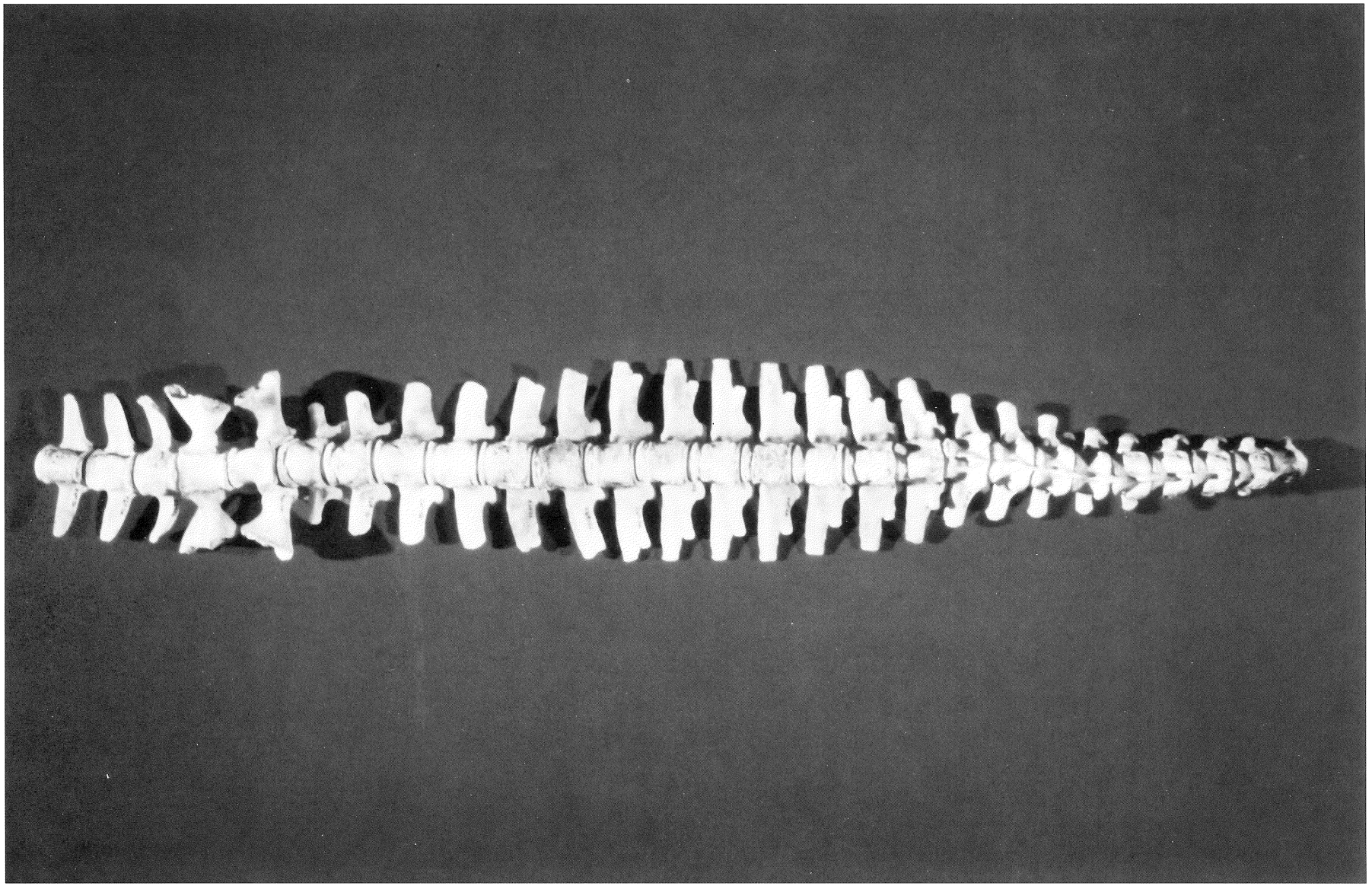

Vertebral column of *Alligator mississippiensis* SMM Z69.26 showing periosteopathy of the dorsal vertebrae. Photo by Robert Spading.

PALEOPATHOLOGY OF THE PALEOCENE CROCODILE *LEIDYOSUCHUS (=BOREALOSUCHUS) FORMIDABILIS*

Glen T. Sawyer

and

Bruce R. Erickson

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PALEOPATHOLOGY OF THE PALEOCENE CROCODILE LEIDYOSUCHUS (= BOREALOSUCHUS) FORMIDABILIS

By

Glen T. Sawyer
Research Associate in Paleontology
and
Bruce R. Erickson
Curator of Paleontology

ABSTRACT

Pathologic conditions in a large suite of bones belonging to the eusuchian crocodile *Leidyosuchus (= Borealosuchus) formidabilis* from the late Paleocene are described. Interpretation of various pathological conditions are presented wherein there is compelling evidence for causes of these conditions and related animal behavior. Frequency tables are presented along with a glossary of descriptive terms.

KEY WORDS: Paleopathology; crocodilians; Paleocene crocodilians; Wannagan Creek Fauna.

INTRODUCTION

A complete understanding of our environment should include an historical perspective. This requires a paleoecological examination of the distant past including a study of the animals, their diseases, and when possible, their behavior.

Skeletal abnormalities of non-humans have long been recognized in fossil vertebrates. Their accounts are generally scattered in the literature and are often treated incidentally, merely as interesting anomalies, with little attempt at serious study. References to crocodilian paleopathology are relatively few even when large samples of specimens such as those of *Diplocynodon* from the Eocene deposits of Grube Messel and des Geiseltales are available. A comparable-size suite of bones of the eusuchian crocodile *Leidyosuchus (= Borealosuchus) formidabilis* from the late Paleocene of North America (Erickson, 1976; 1982) is now available. This assemblage recovered from Wannagan Creek Quarry and the surrounding area constitutes the Wannagan Creek Fauna. Bony tissue pathology from many individuals and most regions of the skeleton are present. Material from 80 individuals, based on actual basicranial count of specimens in the collections of The Science Museum of Minnesota (SMM), includes 3,028 bones and 4,126 osteoscutes. These specimens, which represent a suite of individuals of various age groups, and presumably both sexes, were examined during the present study.

There are problems inherent in an investigation of this type. True pathology must be differentiated from taphonomic alterations that occur when living bone is converted to fossil bone. Most diseases do not leave permanent visible changes in bones. Pathology that occurs in very young and/or fragile bones or that affects blood and/or soft tissues frequently is not reflected in dry bone analysis. For purposes of this study, we have drawn parallels with bone pathology found in living species wherever possible. For example, *Crocodylus niloticus* is compared with the present fossil material because of morphological similarities and the extensive observations of the Nile crocodile by Cott (1961).

The treatment is organized as follows: paleoenvironmental and taphonomic considerations; methods employed in the analysis of the material; description of all pathologic conditions found in the present suite of specimens; interpretation and discussion of results; summary; and a glossary of terms for clarification of definitions. Many of these terms have been applied to human disease (Merbs et al., 1980) but their use seems appropriate here. In paleopathology, a major, reasonably well supported premise is that human diagnoses can often be extrapolated to other genera (Rothschild and Tanke, 1991).

ACKNOWLEDGMENTS

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PALEOENVIRONMENTAL AND TAPHONOMIC CONSIDERATIONS

The Wannagan Creek Fauna containing *Leidyosuchus (= Borealosuchus) formidabilis* occurs in the Late Paleocene Bullion Creek (Tongue River) Formation of western North Dakota and has a Land Mammal Age of Tiffanian 4 with a date of about 60 m.y.b.p. Local floodbasin deposits characterize large floodplain systems in this formation (Royse, 1970; Jacob, 1972). A sequence of layers in one particular floodbasin (Fossil Lake Wannagan, Erickson, in press) indicates that fluvial and lacustrine environments prevailed in the region. Within this basin a basal calcareous shale or marl bed and an overlying lignitic zone developed through the accumulation of plant debris including numerous coalified trees. Above this is a sequence of layers of fine clay and silt. Crocodile remains are generally well-preserved and occur throughout these layers (Erickson, 1982). Bioturbation and the rather mobile bottom conditions that existed at all stages of basin deposition account for displacement and general disarticulation of the bones.

Some hydrodynamic sorting and weathering were also among the principal influences on skeletal modifications and primarily included breakage and plastic deformation. Breakage occurs with greatest frequency as post-mortem fractures. Many "step" or longitudinal fractures, of long bones especially, resulted as drying cracks (Hill, 1979; Haynes, 1983). In most cases these have been further enhanced by the effects of prolonged weathering (Conybeare and Haynes, 1984) as well as by sediment compaction. As such these modifications are clearly taphonomic in origin.

Haynes and Stanford (1984) note modifications that take place when bones are deposited in moist or aquatic habitats as were the present bones. The bones remained moist for a considerable length of time and responded to trampling and scavenging like "fresh" bone. Behrensmeyer et al. (1989) discuss bone modification and occurrence of "fresh" and "green" bone. Little evidence of oxidation is present except in the light colored, sandy shale of the uppermost level of Wannagan Creek Quarry.

Abundant large fishes and turtles provided a local food source. The chelonivorous habits of the crocodile for example are demonstrated by a number of injuries in the form of tooth punctures and abrasions of the shells of turtles (Erickson, 1984; Sawyer and Erickson, 1987). Numerous associated coprolites further establish the basin as a feeding place for the crocodile (Sawyer, 1981). The presence of hatchlings, mixed with juvenile and adult individuals, suggests nearby nesting.

MATERIALS AND METHODS

All elements of *Leidyosuchus (= Borealosuchus) formidabilis* in the collections of The Science Museum of Minnesota that had been prepared as of January 1997, were examined for pathologic alterations. A total of 240 pathologic conditions were found in 25 different elements (Table I). Four bones each had two abnormalities and therefore 236 bones showed pathology. Forty-seven of the 236 are individually described because of distinctive features and the remainder described in groups because of similar alterations. Table II shows elements examined that exhibited no pathology.

Not all of these elements were complete. Since the only abnormalities found in skulls occurred in or near the snout, only skulls with the anterior third intact were counted to determine "total examined". Only the surangular portion of the lower jaw was considered since no jaw pathology was found elsewhere on the mandible. Since most vertebral pathology was present on the centra, only centra were tabulated. The remaining skeletal elements were counted as examined if more than 50% were intact and, in the case of long bones, at least one end was intact as well. Gastralia and dorsal ribs were too fragmented to obtain accurate numbers. A total of 7,154 elements were examined for pathologic abnormalities as a part of this study. This number does not include gastralia or dorsal ribs.

In dry bone analysis it is sometimes difficult to determine whether or not a deviation from expected bony architecture is pathologic or not. Certainly, many taphonomic alterations of bone can occur during preservation (such as plastic deformation). For the purposes of this study, only lesions associated with bony hypertrophy and/or erosion were considered pathologic, except for one well-remodeled, possibly fractured femur (P77.33.7) and three probable "congenital malformations" (osteoscutes P82.12.306, Fig.17A; chevron P79.19.997, Fig. 17B; and P82.12.419). Unfortunately, this definition of pathology will not include acute conditions such as trauma that occurs at the time of death or shortly thereafter. Also, several hundred unaccounted for vertebrae and osteoscutes may have been consumed by many crocodiles as stomach stones (Erickson, 1982). The frequency of bony pathology in this population, therefore, is probably underestimated.

This study is based on gross visual observation. No microscopic studies were done on these specimens. No chemical analyses were performed. Only a few selected elements were x-rayed and this information was not informative. It is possible such studies could find additional pathology and/or help in further differentiation of obvious gross lesions.

Descriptive diagnoses are assigned to each abnormality found and an attempt is made to separate various varieties (Table I and Glossary). Elements are placed in the "fracture" category if circular depressions or holes surrounded by reactive bone were seen (depressed or perforating fractures) or if shaft angulation and/or displacement with callus formation had occurred. The "periosteopathy/osteopathy" category is used when hypertrophy was present involving the periosteum (periosteopathy) and sub-periosteal bone (osteopathy). If the lesion appeared to have localized erosion and/or a canal strongly suggesting a drainage sinus, and therefore an infectious process, the category "osteomyelitis" is used. "Spondyloarthropathy" indicates lesions characterized by erosion of articular surfaces and hypertrophic changes of neighboring bone. One distinctive specimen has a large amount of reactive bone surrounding three vertebrae and is also called "spondy-

loarthropathy" (P70.20.408, Fig. 12). Three elements with discrete abnormal bony surface projections not associated with erosion, as well as two femora and a scapula with probable ossification of muscle attachments, are placed in the "exostosis" category. Three elements with structural distortions not associated with reactive hypertrophy or erosion are called "congenital malformation."

A total of 67 "fractures" were found and separated into various varieties (Table III). Perforating, transverse, comminuted, and oblique types are identified (Glossary).

A well-remodeled femur (P77.33.7) is not categorized by the above descriptive diagnostic criteria because it has no angulation, displacement, or callus. It possibly represents, however, the late stages of bone repair after an oblique fracture years before death and, therefore, is listed under the "fracture" category. Alternately, it is possible that it is not pathologic at all, but merely shows plastic deformation. Phalange P95.13.26 has been remodeled in a similar fashion, but also has angulation present. This provides some evidence in favor of a "fracture" diagnosis for femur P77.33.7. The dorsal rib section (P73.25.115, Fig. 3) and many gastralia have what appears to be calluses with and without angulation. These well-circumscribed lesions entirely surround the shafts and probably represent fractures. "Greenstick fractures" are a possibility here.

The pathologic elements under category "periosteopathy/osteopathy" include specimens with single, or most often multiple, patchy well-demarcated areas on bone surfaces that are elevated and have either rough or smooth surfaces (Table IV). They have minimal or no erosional features, and no draining sinus-like cavities. Some specimens were severely affected by this process so that the multiple lesions appeared to have coalesced (Fig. 7). Articular surfaces show no alterations. Two specimens (humerus P95.13.12, Fig. 8A and ulna P76.28.905) have single patches quite similar to each other. They have smooth surfaces.

Two elements (dorsal rib P89.6.79, Fig. 8B and pubis P.73.25.1) exhibit multiple discrete, localized elevations of the surface with fine, transverse ribbing. This process appears to be distinctive enough to warrant separation into a category termed "ribbed periosteopathy". Visceral surfaces are primarily involved in both specimens.

Two elements with pathologically expanded shafts (radius P74.24.12 and metapodial P71.16.248, Fig. 8C) are termed "fusiform osteopathy". They could represent late stages of bone shaft repair after fracture, but neoplastic, toxic or metabolic etiologies are also possible.

Twenty-eight osteoscutes have "periosteopathy/osteopathy with erosional cavities/canals". Most show numerous grooves and canal openings with both large and small cavities. Scute P79.19.955 (Fig. 9A) is a good example. Generalized surface erosion is often present and, although both surfaces are usually involved, the process appears to be more severe on dorsal surfaces. In addition, some elements show generalized thickening. Multiple etiologies are possible, but parasitic infection is most likely.

Seven elements have pathologic lesions with features suggesting bony infection (osteomyelitis)(Table V). Localized osteolytic cavities are present in four specimens (atlas centrum P83.12.64, Fig. 10A; dorsal vertebra P89.6.214, Fig. 10B; ilium P75.22.480, Fig. 10D; femur P76.28.999, Fig. 10E). Of these four elements, three have mild to minimal nearby reactive bone, while one (femur P76.28.999) has a markedly elevated rough area with a cavity (combined hypertrophy and a localized osteolytic cavity).

Three of the specimens with "osteomyelitis" have apparent sinus drainage canals or cavities (cervical rib P83.12.63, Fig. 10C; radius P75.22.346, Fig. 5; tibia P76.28.55, Fig. 6). Nearby bone hypertrophy is marked in cervical rib P83.12.63. In radius P75.22.346 and tibia P76.28.55, the probable sinuses are associated with evidence of mid-shaft fractures involving angulation and callus formation. In addition, the cortex at the proximal end of radius P75.22.346 is markedly thinned. These features strongly suggest compound fractures with secondary pyogenic osteomyelitis in both specimens. They are classified under "fractures" in Table I, although both have two diagnoses ("fracture" and "osteomyelitis").

"Spondyloarthropathy" is confined to foot elements except for one dorsal rib (P89.6.79, Fig. 8B) and a specimen with three joined dorsal vertebrae (P70.20.408, Fig. 12). Ten metapodials, nine phalanges and one ungual have articular surface erosion and nearby reactive bone hypertrophy. A metatarsal and a phalange (P76.28.3, Fig. 11) were found articulated and, therefore, cataloged as one specimen. This is counted as a metatarsal only and, therefore, Table I shows nine instead of ten phalanges.

The three dorsal vertebrae fused by marked bony proliferation (P70.20.408), also termed "spondyloarthropathy", are counted as one pathologic specimen in Table I.

A discrete abnormal bony surface projection ("exostosis") is present on one dorsal vertebra (P76.33.289, Fig. 15) as a cartilaginous projection in the cotyle (probable chondroma). "Exostoses" are also seen on two femora (P79.19.1120; P70.20.1783, Fig. 14A, B) and one scapula (P76.28.804, Fig. 14C) as projections located at sites of muscle attachments where they may well represent ossification of tendons. On phalange P74.24.29 (Fig. 16) and on ungual P70.20.1692, these discrete lesions are small and bony ("button osteomas"). The prominent irregular exostosis on the posterolateral crest of scapula P76.28.804 may be attributed to trauma because of the location of the lesion, but ossification of tendons is more likely.

One chevron (P79.19.997, Fig. 17B) and two osteoscutes (P82.12.306, Fig. 17A; P82.12.419) show significant deviations from normally expected bony architecture and no reactive hypertrophy or erosion. These are labeled "malformations".

DESCRIPTION OF PATHOLOGIC CONDITIONS

SKULL P84.19.3 (Fig. 1)

Perforating fracture - On the dorsolateral surface of the right maxilla, at the level of the second and third alveoli, a cavity measures 2.2 cm across in anteroposterior direction and 3.3 cm in a dorsoventral direction. The depth is about 1.5 cm. Margins of the cavity consist of periosteal reactive bone hypertrophy with elevated portions that are either smooth or roughened on the surface. This reactive bone area extends 1.0 cm to 1.5 cm from the edge of the cavity.

SKULL P78.14.133

Perforating fracture - The lesion is on the dorsal surface of the nasals at mid-length along the midline and at the level of the seventh maxillary teeth. A circular depression with a smooth, slightly irregular bottom has broken through in one area into the nasal cavity. The posterior edge of the depression cannot be determined with certainty and therefore precise anteroposterior measurement is uncertain, but is at least 3.5 cm. The width is approximately 3.0 cm.

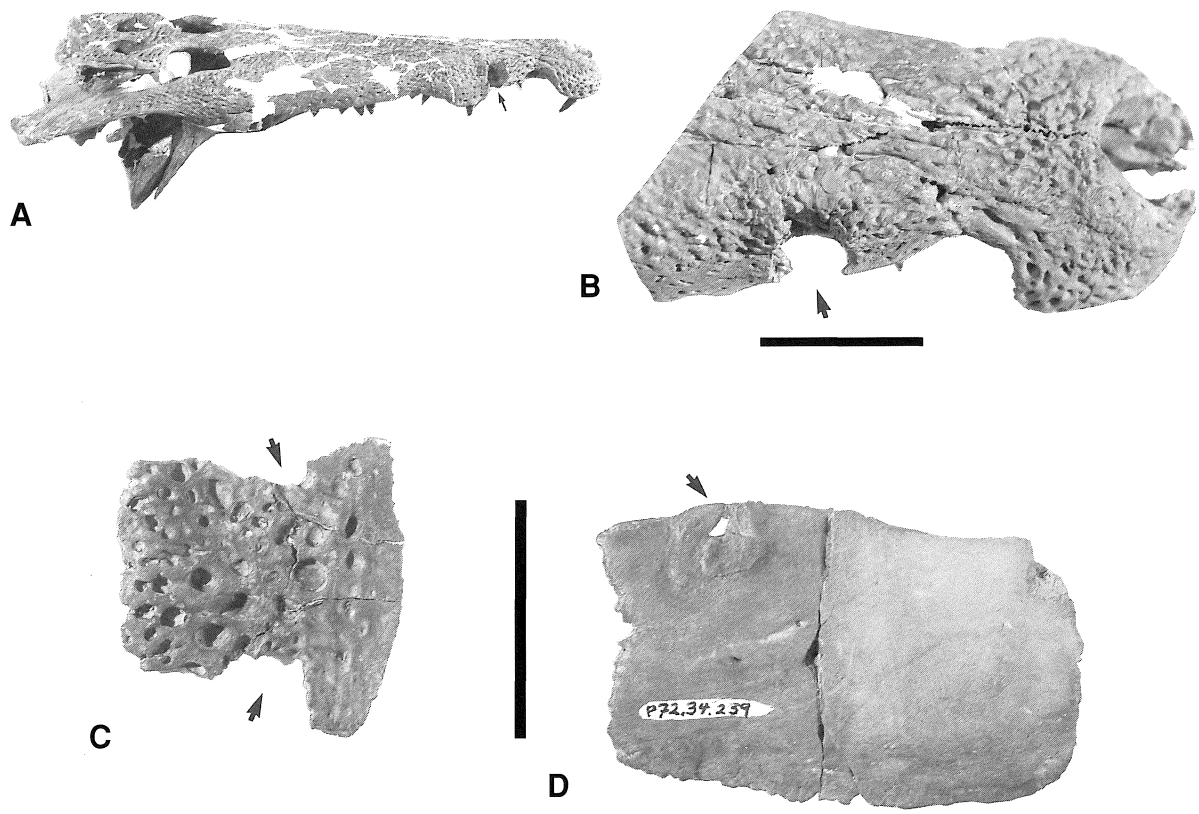

Figure 1. Perforating fractures in *Leidyosuchus (= Borealosuchus) formidabilis.* A, lateral and B, rostral views of skull P84.19.3; C, osteoscute P82.12.373 in dorsal view; D, osteoscute P72.34.239 in ventral view. Arrows indicate fractures. Scale bars equal 5 cm. Skull length equals 580 cm.

LEFT SURANGULAR P79.19.1026 (Fig. 10F)

Probable perforating fracture - This lesion is located on the lateral surface dorsal to the lateral mandibular fenestra. The cavity is an oval opening with smooth, rounded edges. The length of the opening is 2.2 cm, the width is 0.8 cm and the depth approximately 1.0 cm. The cavity has an expanded interior, especially ventrally and posteriorly.

ATLAS P83.12.64 (Missing intercentrum and neurocentra)(Fig. 10A)

Possible osteomyelitis - The anterior surface of the atlas centrum at the base of the odontoid process has two areas of localized osteolysis. The largest cavity measures approximately 7.0 mm by 13.0 mm, with a depth of 5.0 mm. The second is less well developed in that it is narrower and shallower. Both cavities are surrounded by small areas of irregular reactive bone.

FIRST DORSAL VERTEBRA P76.33.289 (Fig. 15)

Exostosis (probable chondroma) - The lesion is located deep within the cotyle of the anterior face of the centrum, slightly to the right of center. It has an irregular, raised surface and measures approximately 8.0 mm by 11.0 mm. This appears to be a cartilaginous projection.

DORSAL VERTEBRA P75.22.518

Periosteopathy - There is a mild amount of irregular, elevated hypertrophic bone in a roughened patch on the centrum. It is not present on the condyle, cotyle, parapophysis, or floor of the neural canal. The almost complete neural arch also shows no pathology.

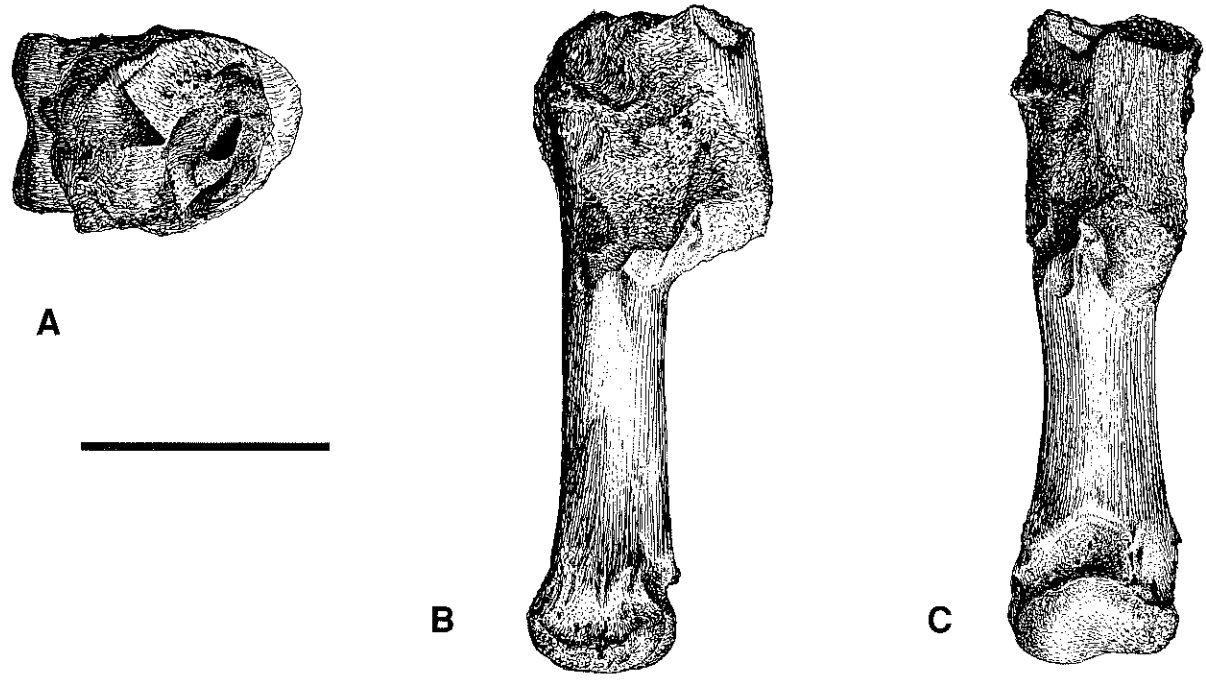

Figure 2. Metapodial of *Leidyosuchus (= Borealosuchus) formidabilis* P76.28.53 with transverse fracture. A, section through lesion showing two lumina; B, lateral view; C, anterior view. Scale bar equals 2 cm.

DORSAL VERTEBRAL CENTRUM P70.20.1775 (Fig. 7A, B)

Periosteopathy - This specimen shows marked irregular hypertrophic bone surrounding the centrum from the pedicle of the neural arch on one side to the pedicle of the neural arch on the other side. This process spares the condyle, cotyle, and floor of the neural canal. It appears to be a condition that has become severe with coalescing lesions.

OTHER DORSAL VERTEBRAL CENTRA (47 specimens: P70.20.1752 (Fig. 7C, D); P72.34.96; P73.25.73; P74.24.6; P75.22.107; P75.22.110; P75.22.351; P76.28.474; P76.28.863; P76.28.936; P76.28.980; P76.28.1014; P76.33.392; P79.19.109; P79.19.772; P79.19.781; P79.19.782; P79.19.807; P79.19.816; P79.19.817; P79.19.900; P79.19.987; P79.19.990; P79.19.991; P79.19.992; P79.19.993; P79.19.1095; P80.10.344 (2 elements); P82.12.5; P83.12.99; P89.6.56; P89.6.161; P91.17.198; P91.17.201; P93.22.61; P93.22.146; P93.22.148; P93.22.168; P95.13.18; P95.13.19; P95.13.20; P95.13.21; P95.13.22; P95.13.23; P95.13.24; P95.13.25)

Periosteopathy - These elements have a pathologic condition that is similar to, but less severe than, the lesions on P75.22.518 and P70.20.1775.

DORSAL VERTEBRA P89.6.214 (Fig. 10B)

Possible osteomyelitis - The left side of the neural arch at the base of the neural and lateral spines has an osteolytic cavity measuring 9.0 mm in depth. The cavity is 6.0 mm wide, 11.0 mm long, and has relatively smooth edges with only mild reactive bone evident.

3 DORSAL VERTEBRAE P70.20.408 (Fig. 12)

Spondyloarthropathy - These three posterior dorsal vertebrae are fused by extensive bony proliferation over the lateral and ventral surfaces of the centra. The process preserves the intervertebral spaces.

FIRST SACRAL VERTEBRA P82.12.258 (Missing neural spine, but includes left rib)

Periosteopathy - There are several patches of elevated roughened hypertrophic bone on the ventral surface of the centrum.

CAUDAL VERTEBRA P95.13.6

Transverse fracture - At the base of the right lateral spine a healing callus has formed which kept the fracture in good alignment.

Periosteopathy - Scattered, rough elevated patches of hypertrophic bone are present on the surface of the centrum. This condition does not involve the condyle, cotyle or floor of the neural arch.

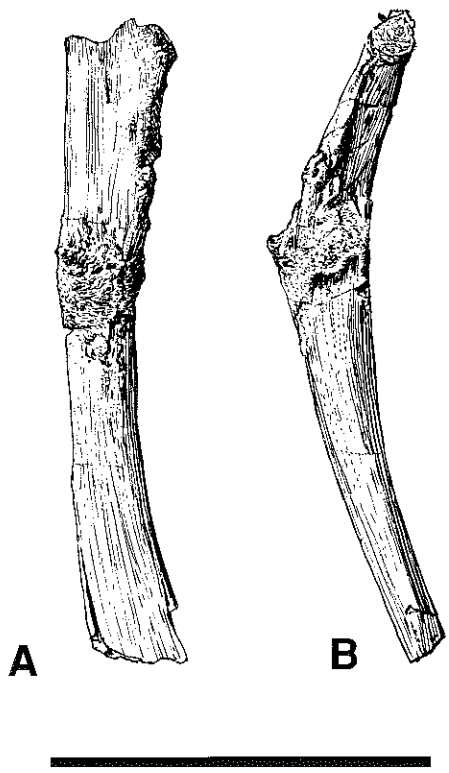

Figure 3. Dorsal rib of *Leidyosuchus (= Borealosuchus) formidabilis* P73.25.115 with greenstick fracture; A, lateral view; B, anterior view. Scale bar equals 5 cm.

CAUDAL VERTEBRAL CENTRUM
P79.19.1001

Periosteopathy - There are patches of hypertrophic bone on both lateral surfaces. No enlargement of the centrum is present. The condyle, cotyle, and chevron facets are not affected.

OTHER CAUDAL VERTEBRAL CENTRA
(22 specimens: P71.16.293; P76.28.847; P76.33.284; P76.33.464; P79.19.649; P79.19.654; P79.19.655; P79.19.669; P79.19.678; P79.19.809; P79.19.859; P79.19.988; P79.19.999; P79.19.1000; P79.19.1002; P79.19.1089; P83.12.42; P91.17.105; P93.14.148; P93.22.98; P95.13.3; P95.13.4)

Periosteopathy - All of these specimens have hypertrophic bone on centrum surfaces but relative sparing of areas where, in other conditions, osteophytes or syndesmophytes might occur.

CHEVRON FRAGMENT P72.34.24
(Branch of haemal arch)

Transverse fracture - The fossil has been broken through a probable callus of a healed fracture.

CHEVRON P83.12.65

Probable transverse fracture - A callus has formed in a branch of the haemal arch.

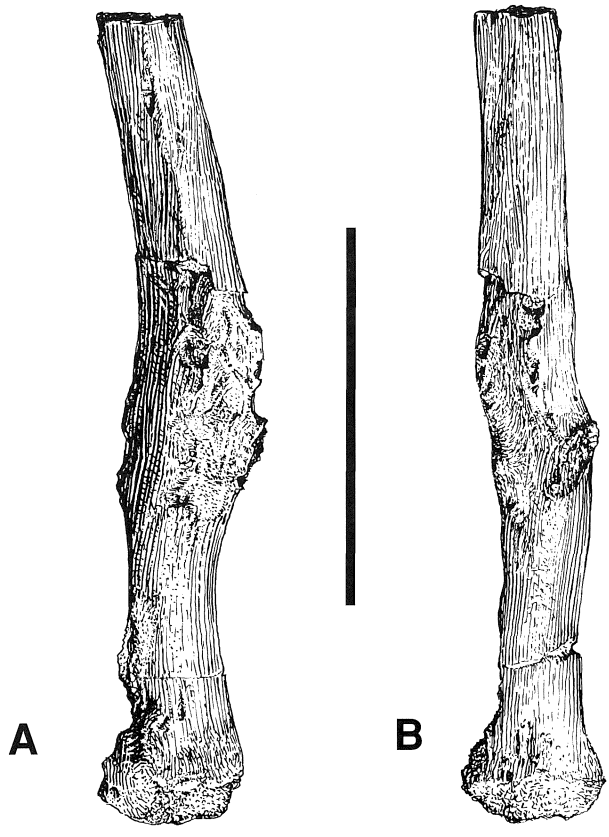

Figure 4. Distal fibula of *Leidyosuchus (= Borealosuchus) formidabilis* P72.34.240 with transverse fracture. A, anterior and B, lateral views. Scale bar equals 5 cm.

CHEVRON P79.19.997 (Fig. 17B)

Possible malformation - There is a severe outward bowing of the right branch of the shaft which is thinned distally. This has resulted in an enlarged haemal arch.

CERVICAL RIB P83.12.63 (Fig. 10C)

Probable osteomyelitis - The anteroventral aspect of the rib shaft has a small aperture (probable sinus drainage canal) surrounded by irregular reactive hypertrophic bone.

DORSAL RIB SECTION P73.25.115 (Fig. 3)

Possible greenstick fracture - There is localized bone hypertrophy of the shaft near the proximal end. Only minimal reaction is present on the visceral aspect.

DORSAL RIB P89.6.79 (Fig. 8B)

Ribbed periosteopathy - On the visceral aspect at mid-shaft there are at least five discrete elevations showing fine transverse ribbing.

Spondyloarthropathy - There is pronounced reactive bone hypertrophy at the distal end and some erosion of the surface that articulates with the intermediate rib segment.

INTERCLAVICLE P70.20.420

Probable depressed fracture - There is an irregular roughened cavity on the proximal expansion (ventral surface). The bone on the bottom of the cavity is extremely thin. The fossil specimen has been broken through the lesion. Nearby bone is irregular and thickened with reactive hypertrophy.

RIGHT SCAPULA P76.28.804 (Fig. 14C)

Exostosis (possible ossified muscle attachments) - The heavy crest on the posterolateral aspect has been enlarged by an irregular, mushroom-shaped, bony proliferation.

RIGHT HUMERUS P95.13.12 (Fig. 8A)

Periosteopathy (smooth surface) - There is a smooth elevation on the dorsal surface, slightly distal to mid-shaft, measuring 4.5 cm long and 2.5 cm wide. The specimen has broken transversely through the lesion to well demonstrate the distinctly lighter shade of the added bone.

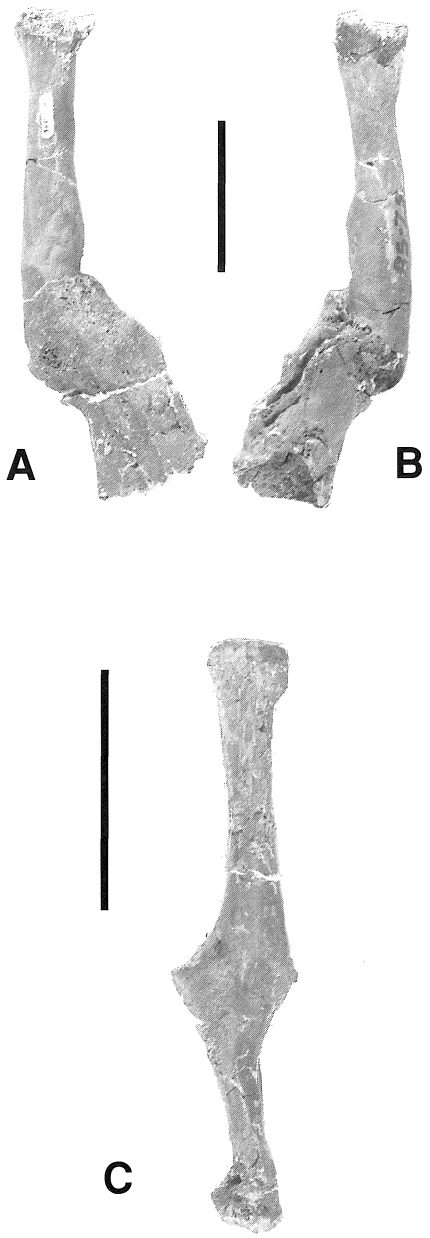

Figure 5. Comminuted fractures of *Leidyosuchus (= Borealosuchus) formidabilis.* A, right radius P75.22.346 in anterior and B, posterior views; C, metapodial P92.2.53. Scale bars equal 5 cm.

RADIUS P74.24.12

Fusiform osteopathy - There is a localized fusiform enlargement of the distal shaft. The "tumor" has a mildly roughened surface. Articular surfaces are intact and no shaft angulation or erosion is present.

RADIUS P77.33.21 (3/4 of proximal end)

Periosteopathy - The lesion is mid-shaft with an elevated, slightly irregular surface measuring 1.5 cm by 1.3 cm.

RADIUS P75.22.346 (missing distal end)(Fig. 5)

Probable comminuted fracture and secondary osteomyelitis - Callus formation and angulation are present as well as a possible sinus drainage cavity, suggesting secondary osteomyelitis. The distal end of the broken shaft displays a markedly enlarged medullary cavity with reflexed edges. The cortex at the distal end is markedly thinned.

ULNA P76.28.905 (3/4 of shaft and missing both ends)

Periosteopathy (smooth surface) - The proximal end has a localized, elevated area with smooth surface. On cross section, this lesion is discolored with a lighter shade compared to the original shaft, which appears intact with regard to both thickness and color. The lesion appears similar to that on humerus P75.13.12.

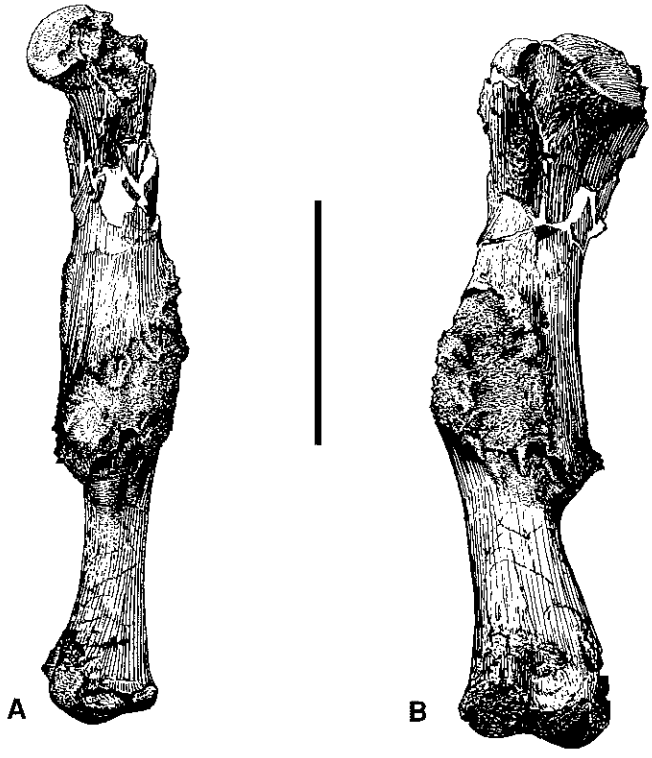

Figure 6. Left tibia of *Leidyosuchus (= Borealosuchus) formidabilis* P76.28.55 showing oblique fracture and secondary osteomyelitis; A, anterior view; B, posterior view. Scale bar equals 5 cm.

ULNAR (2 specimens: P79.19.1007; P76.28.372)

Periosteopathy - Each element has several elevated, well demarcated and roughened areas on the shaft. Articular surfaces are normal.

LEFT ILIUM P75.22.480 (Fig. 10D)

Probable osteomyelitis - In the anterior acetabular portion there is a series of 3-5 lytic features that coalesce. There is only mild surrounding bone reaction.

LEFT PUBIS P73.25.1

Ribbed periosteopathy - On the visceral surface there are discrete elevations with the appearance of a welding bead that have transverse ribbing. This process extends around the shaft to the lateral surface, but this extension is less prominent.

RIGHT FEMUR P77.33.7 (distal 2/3)

Possible oblique fracture - This well remodeled lesion remains as a smooth groove dorsally on the shaft which is 4 cm long and 1.0 cm at greatest width. This groove runs at an angle to the long axis of the bone on the side opposite to the greater trochanter. No shaft angulation, displacement or callus are present.

This element, with its proximal end missing, was found buried perpendicular to ground level and with proximal portion down. This position was possibly due to bioturbation. Another crocodile, for example, could have stepped on one end of the bone on the soft lake bottom, producing the unusual positioning of the femur. This would have occurred postmortem and, if it did occur, was unrelated to the possible well-healed fracture. Another explanation for the bone position includes postmortem gas accumulation in the distal end causing it to float upright before settling into the soft bottom sediments.

LEFT FEMUR P76.28.999 (Fig. 10E)

Possible osteomyelitis - Markedly elevated, rough and irregular bony proliferation surrounds a cavity that is 7.0 mm by 10.0 mm with a depth of 5.0 mm.

Figure 7. Dorsal vertebrae of *Leidyosuchus (= Borealosuchus) formidabilis* showing periosteopathy in A, anterior and B, ventral views of P70.20.1775; C, anterior and D, ventral views of P70.20.1752. Scale bar equals 5 cm. Same condition shown in *Alligator mississippiensis* frontispiece.

TWO FEMORA P79.19.1120 (proximal 2/3); P70.20.1783 (proximal 1/2; head missing) (Fig. 14A, B)

Exostoses (probable ossification of muscle attachments) - Both elements have two separate, well-demarcated areas of irregular, bony surface projections. These occur on the fourth trochanter (where the caudifemoral muscles attach) and on the internal trochanter (possible insertion for a portion of the obturator exterus).

TIBIA P76.28.55 (Fig. 6; Sawyer and Erickson, 1987)

Oblique fracture and probable secondary osteomyelitis - There is a callus formation at midshaft with angulation and override. A periosteal reaction with roughened surface over and near the callus is present. Also, a probable sinus drainage cavity suggests secondary pyogenic infection as might occur with a compound fracture.

FIBULA P72.34.240 (distal 1/2)(Fig. 4)

Transverse fracture - Shaft callus formation and angulation are present.

METAPODIAL P92.2.53 (Fig. 5C)

Comminuted fracture - The lesion is located at mid-shaft with angulation of shaft and callus formation, enlarging the neighboring shaft and forming spike-like projections.

METAPODIALS (6 specimens: P70.20.77; P76.28.53 (Fig. 2); P76.28.374; P76.28.375; P79.19.1012; P95.13.8)

Probable transverse fractures - All specimens have shaft callus formation with displacement/angulation and deformity.

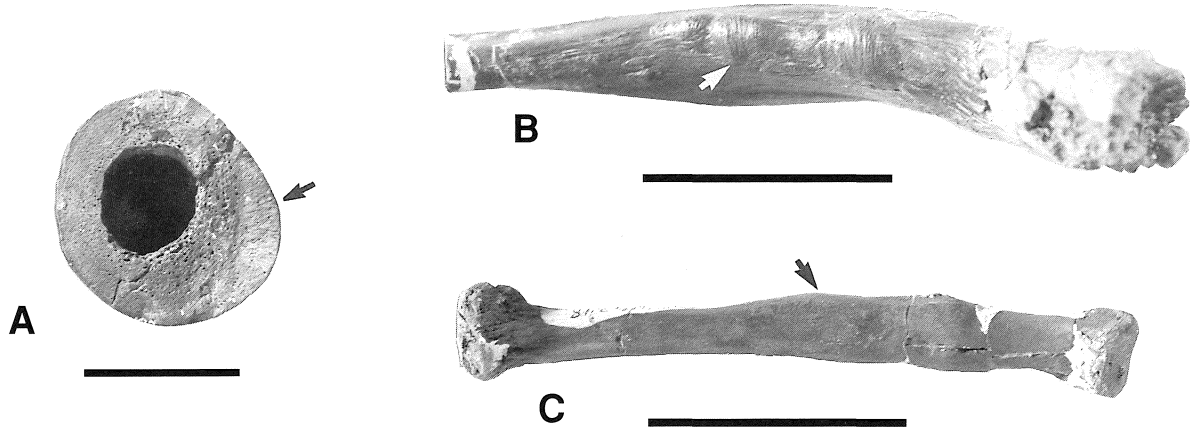

Figure 8. Periosteopathy of *Leidyosuchus (= Borealosuchus) formidabilis*. A, section of humerus P95.13.12 at mid shaft showing localized, smooth periosteopathy. Scale bar equals 2 cm; B, dorsal rib P89.6.79 with ribbed condition and C, metapodial P71.16.248 with fusiform osteopathy. Scale bars equal 5 cm. Arrows indicate pathology.

METAPODIALS (10 specimens: P70.21.242; P72.34.25; P76.10.9; P76.28.364; P76.28.369; P76.28.370; P76.28.886; P79.19.313; P79.19.1006; P79.19.1014)

Periosteopathy - There are well demarcated, often elevated and variably roughened areas on shafts which may be single or multiple. Articular surfaces are spared. Associated, localized hypertrophic shaft enlargement is often present.

METAPODIAL P71.16.248 (Fig. 8C)

Fusiform osteopathy - This element has a fusiform shaft enlargement 6.2 cm long. The total bone length is 12.3 cm. The lesion has a mildly roughened surface and articular surfaces are spared.

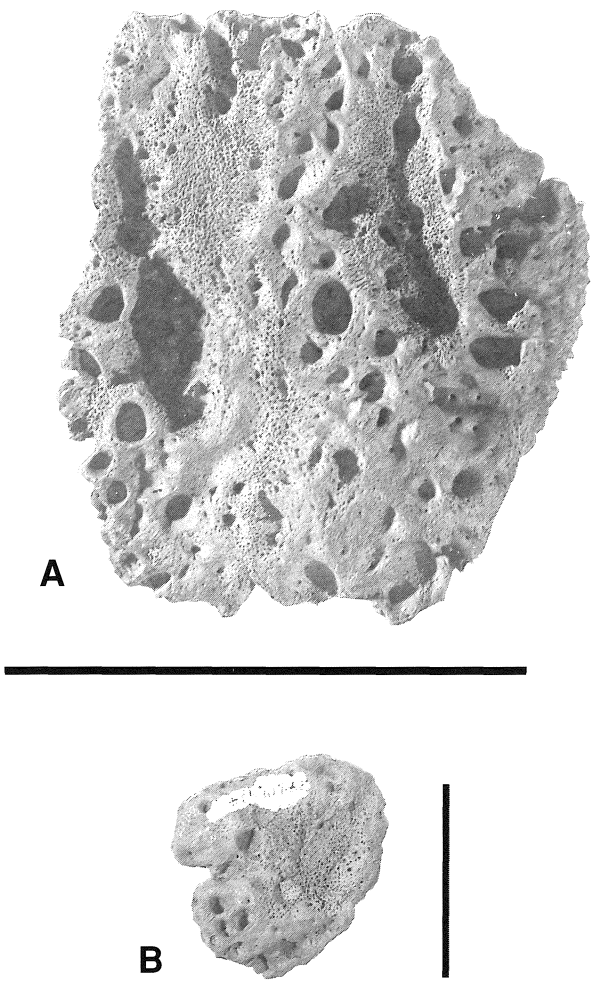

Figure 9. Osteoscutes of *Leidyosuchus (= Borealosuchus) formidabilis*. A, P79.19.955 and B, P79.19.934 in dorsal views showing periosteopathy/osteopathy and cavities/canals. Scale bars equal 5 cm.

METACARPAL V P95.13.9

Spondyloarthropathy - This element has erosion of the proximal articular surface and a mild amount of neighboring reactive bone.

METATARSAL/PHALANGE P76.28.3 (found articulated)(Fig. 11)(Sawyer and Erickson, 1987)

Spondyloarthropathy - There is erosion of adjacent articular surfaces of both elements plus nearby roughened shaft surfaces and osteopathic enlargement involving the distal end of the metatarsal and the proximal end of the phalange.

METAPODIALS (8 specimens: P73.25.118; P75.22.47; P75.22.55; P75.22.517; P76.28.10; P77.33.246; P79.19.1004; P95.13.10)

Spondyloarthropathy - All specimens have erosion of an articular surface. In P75.22.55, the entire proximal end has eroded away. Hypertrophy is present on nearby shaft surfaces and no draining sinus-like cavities are seen. In P95.13.10, the distal end of the shaft is diffusely enlarged. Syndesmophytes are seen and are especially prominent on specimens P73.25.118 and P75.22.517.

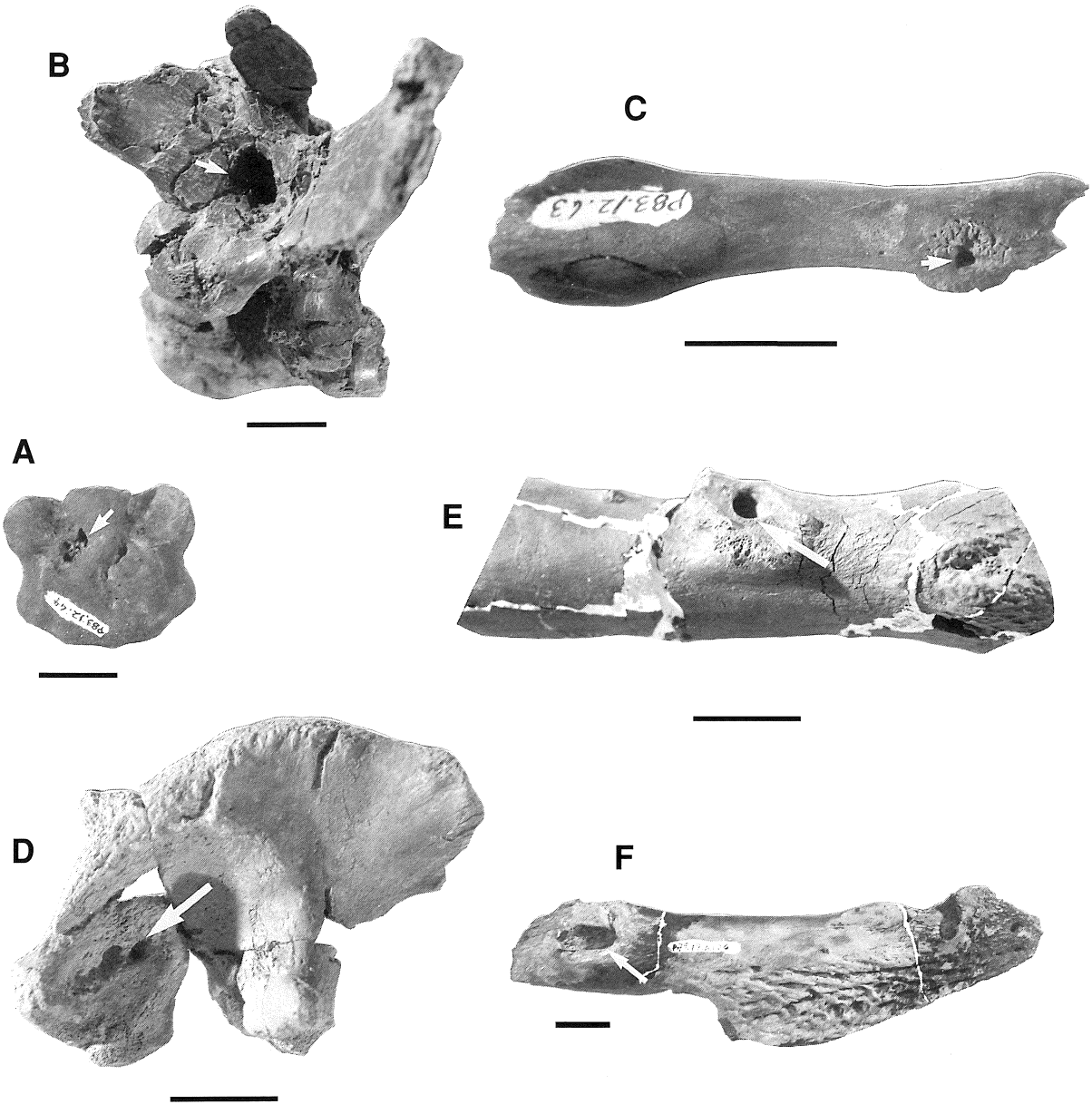

Figure 10. Osteomyelitis in *Leidyosuchus (= Borealosuchus) formidabilis.* A, centrum of atlas P83.12.64 in anterior view; B, dorsal vertebra P89.6.214 in dorsal view; C, cervical rib P83.12.63 in lateral view; D, left ilium P75.22.480 in lateral view; E, left femur P76.28.999 in posterior view; F, left surangular P79.19.1026 in lateral view. Arrows indicate osteolytic cavities. Scale bars equal 2 cm.

PHALANGE P75.22.4

Transverse fracture - Angulation of the shaft is seen with localized bone hypertrophy (probable callus) at the point of angulation near the distal end.

PHALANGE P95.13.26

Oblique fracture - There is mid-shaft angulation. Bone hypertrophy forms an elevated, mildly roughened ridge adjacent to a mid-shaft smooth longitudinal groove. The lesion appears to be considerably remodeled.

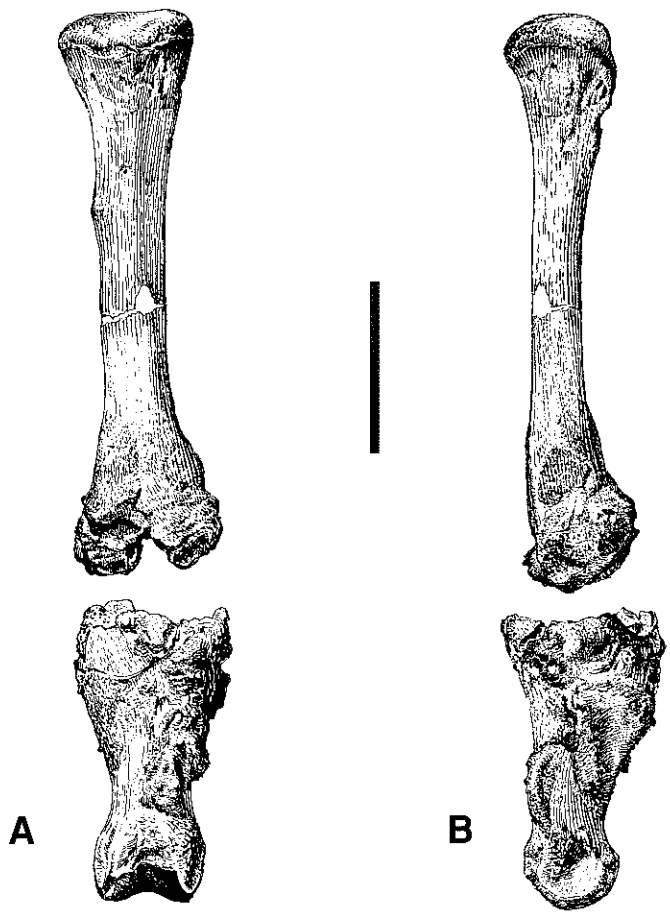

Figure 11. Spondyloarthropathy in *Leidyosuchus (= Borealosuchus) formidabilis* metatarsal/phalange P76.28.3. A, anterior view; B, lateral view. Scale bar equals 2.5 cm.

PHALANGES (13 specimens: P70.20.1716; P72.34.23; P73.25.116; P74.24.326; P76.28.363; P76.28.368; P76.28.861; P77.33.248; P77.33.249; P77.33.250; P79.19.543; P79.19.995; P79.19.1003)

Periosteopathy/osteopathy - All elements have localized well-demarcated, elevated and roughened areas on the shaft. These lesions are often associated with a somewhat smoother elevation of neighboring bone (osteopathy). Articular surfaces appear normal. Lesions may be single or multiple and, if multiple, appear to be distributed randomly. There is no clear preference for proximal, distal or mid-shaft location. The most extensive involvement of this type is seen on specimen P77.33.250.

PHALANGES (9 specimens: P74.24.232; P76.28.362; P76.28.367; P76.28.371; P76.28.838; P76.28.951; P79.19.1008 (Fig. 13B, C, D); P92.2.25; P93.22.23)

Spondyloarthropathy - All elements have articular surface erosion and no draining sinus-like cavities. Four specimens have distal involvement, four have proximal involvement, and one (P79.19.1008) has erosion of both articular surfaces. Irregular roughened, and often elevated, shaft surfaces near the involved articular surfaces are present. Element P79.19.1008 has marked thickening of the entire shaft (Fig.13B, C, D).

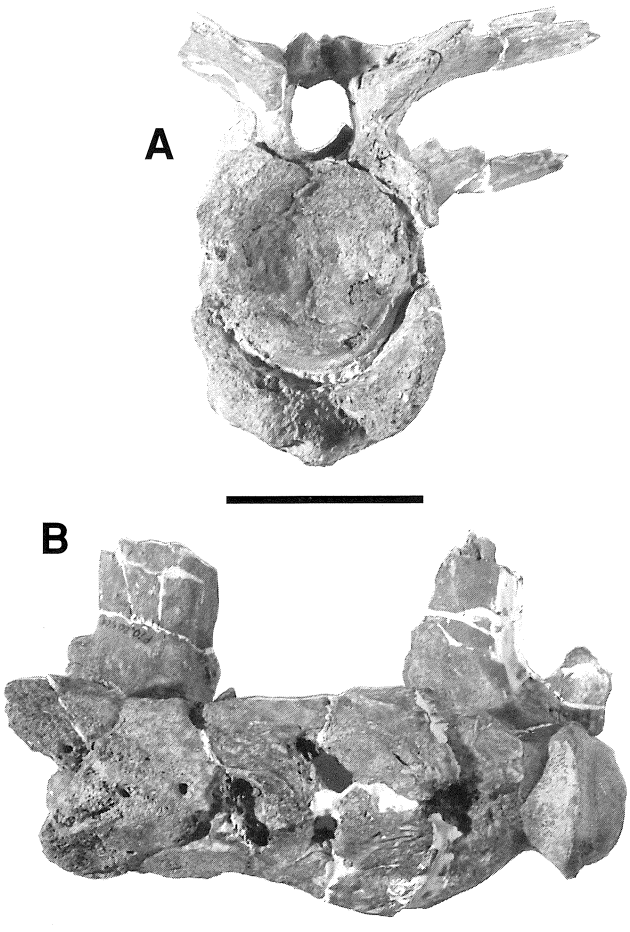

Figure 12. Spondyloarthropathy involving three dorsal vertebrae of *Leidyosuchus (= Borealosuchus) formidabilis* P70.20.408. A, anterior view; B, ventral view. Scale bar equals 5 cm.

PHALANGE P74.24.29 (Fig. 16)

Exostosis - There is a small, prominent and somewhat roughened surface projection on the shaft near the proximal end.

GASTRALIA (3 specimens: P70.20.74; P76.28.450; P95.13.17)

Probable transverse fractures - The elements show bulbous localized enlargements of shafts which probably represent callus formation.

GASTRALIA (19 specimens: P70.20.92; P71.16.274; P74.24.67; P74.24.76; P74.24.87; P79.19.232; P79.19.241; P79.19.245; P79.19.247; P79.19.257; P79.19.1017; P79.20.280; P89.6.104; P91.17.156; P93.22.99; P93.22.106; P93.22.114; P95.13.15; P95.13.16)

Probable transverse fractures - These small specimens have bulbous enlargements of shafts (probable callus formation). Some exhibit angulation at the pathologic site.

UNGUAL P79.19.1005 (Fig. 13A)

Spondyloarthropathy - There is erosion of the articular surface with nearby surface roughness.

UNGUAL P70.20.1692

Exostosis - The projection is located near the base on the medial surface and spares the articular surface.

OSTEOSCUTE (OSTEODERM) P77.33.88

Two perforating fractures - This rectangular, dorsal osteoscute with two sutural borders measures approximately 7.3 cm by 5.6 cm and has two fractures.

The first is a "buttonhole" fracture located 1.0 cm from the edge in the portion of the dorsal surface that is overlapped by the neighboring scute and 1.3 cm from the sutural edge. The aperture measures 0.3 cm across at its widest point.

The second fracture is represented by a crescent-shaped cavity in the edge of the portion of the ventral surface that is overlapped by the neighboring scute. This measures 1.2 cm across at the scute edge.

Both fracture sites are surrounded by hypertrophic bone in the immediate area which are best seen on ventral surfaces.

OSTEOSCUTE (OSTEODERM) P72.34.230

Perforating fracture - This is a rectangular dorsal osteoscute with two sutural borders. A "buttonhole" fracture is located 0.3 cm from the edge in the portion of the dorsal surface that is overlapped by the neighboring scute.

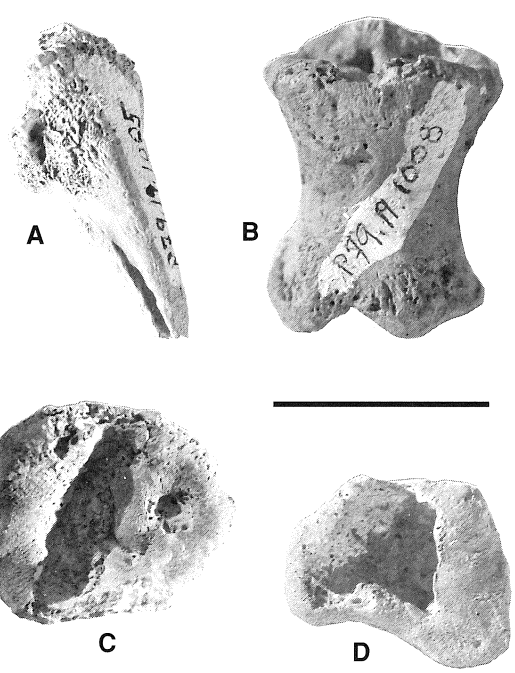

Figure 13. Spondyloarthropathy in *Leidyosuchus (= Borealosuchus) formidabilis*. A, ungual P79.19.1005; B, C, and D, phalange P79.19.1008 in dorsal, proximal and distal views respectively. Scale bars equal 2 cm.

OSTEOSCUTES (OSTEODERMS)(22 specimens: P70.20.105; P71.16.259; P72.34.237; P72.34.239 (Fig. 1D); P74.24.424; P75.22.164; P76.33.441; P79.19.935; P79.19.936; P79.19.937; P79.19.939; P79.19.949; P79.19.961; P79.19.962 ("buttonhole"); P79.19.964; P79.19.966; P79.19.976; P79.19.984; P82.12.373 (Fig. 1C); P82.12.497; P83.12.83; P83.12.116)

Perforating fractures - All scutes here, except P79.19.962, have pathologically notched edges and nearby reactive hypertrophy. Osteoscute P79.19.962 has a "buttonhole fracture" similar to the lesion in osteoscute P72.34.230.

Figure 14. Exostoses in *Leidyosuchus (= Borealosuchus) formidabilis.* A, femur P70.20.1783; B, femur P79.19.1120; C, right scapula P76.28.804. Arrows indicate bony proliferation. Scale bars equal 5 cm.

OSTEOSCUTE (OSTEODERM) P82.12.382

Periosteopathy/osteopathy with cavities/canals - This rectangular dorsal scute measures 6.3 cm by 4.5 cm. There is a shallow pit on the ventral surface with somewhat depressed, irregular edges. It is located near a sutural border and has several associated small canal openings on the ventral surface.

OSTEOSCUTE (OSTEODERM) P79.19.941

Periosteopathy/osteopathy with cavities/canals - Numerous canal openings are present on both dorsal and ventral surfaces. In addition, ventral surface grooves (some curvilinear) are present which sometimes terminate in canal openings and sometimes seem to continue around the edge, producing a notch.

OSTEOSCUTE (OSTEODERM) P79.19.955 (Fig. 9A)

Periosteopathy/osteopathy with cavities/canals - This is a thickened specimen with irregular borders. It is probably a lateral scute. The dorsal surface is severely altered by large cavities and ridges with surface erosion. The ventral surface is unremarkable.

Figure 15. First dorsal vertebra of *Leidyosuchus (= Borealosuchus) formidabilis* P76.33.289 exhibiting exostosis (probable chondroma) near center of the cotyle. Scale bar equals 5 cm.

OSTEOSCUTES (OSTEODERMS)(25 specimens: P71.16.261; P73.25.117; P74.24.494; P76.28.866; P76.33.414 (2 specimens found together); P76.33.439; P76.33.457; P79.19.934 (Fig. 9B); P79.19.940; P79.19.943; P79.19.946; P79.19.953; P79.19.954; P79.19.956; P79.19.963; P79.19.974; P79.19.981; P79.19.985; P82.12.263; P82.12.496; P89.6.117; P93.22.37; P93.22.186; P95.13.13)

Periosteopathy/osteopathy - All, except dorsal osteoscute P74.24.494, are distal lateral or marginal in position. Both dorsal and ventral surfaces are pathologic in all. The dorsal surface is usually more severely involved. Cavities/canals or grooves are seen in all.

OSTEOSCUTE (OSTEODERM) P82.12.306 (Fig. 17A)

Probable malformation - This specimen is a rectangular scute measuring 3.3 cm by 5.2 cm with a normally pitted dorsal surface and a smooth ventral surface. It is remarkable in that the dorsal surface extends out beyond the margin of the ventral surface in a wedge-shaped projection which has pitting on both sides. The overall appearance suggests a nuchal osteoscute, fused at an angle into a dorsal osteoscute.

OSTEOSCUTE (OSTEODERM) P82.12.419

Probable malformation - Two small, broken, bony scute fragments appear fused side to side.

INTERPRETATION AND DISCUSSION

The terminology detailed in the glossary has been long used in describing bone and joint disorders of humans. Bone, whether human or non-human, reacts to noxious stimuli in a limited number of ways. It may either proliferate or erode. Bone density may either increase or decrease. The nature of the structural alteration, its location on or in the bone, and the pattern of distribution of the pathology in the skeleton should be considered when a pathologic diagnosis is made. Etiologic specificity is variable.

Non-human pathologic fossil specimens are often found and described as single elements, not associated with the remainder of the skeleton, or with a suite of bones from the same species. The large number of crocodile elements from the Wannagan Creek site allows an analysis of a population. These elements were usually not articulated, however, so that distribution of pathological conditions in individuals could not be well studied. It should be noted that, in dry bone analysis of this kind, the general health of the individual is usually unknown. Also, an examiner cannot usually know if soft tissue near the bone lesion was diseased. Exceptions exist, however. For example, a compound fracture with signs of infection including a sinus drainage canal in life probably was associated with a pyogenic infection of nearby soft tissue.

Extant human and non-human pathologic studies rarely include dry bone analysis. Paleopathological examination in this regard, therefore, contributes to the understanding of disease as it affects bone. Such studies also contribute to the understanding of the role of disease in biological adaptation and add time-depth (Ortner and Putschar, 1981).

Fractures

Sixty-seven fractures are found in a total of 236 pathologic specimens (28%). Fracture type is detailed in Table III.

Elements most affected by fracture are metapodials, gastralia and osteoscutes. There are, relatively, more fractures distally in limbs. Indeed, our sample may be distorted by a high incidence of amputated digits, as reported elsewhere in *Crocodylus porosus* (Webb and Messel, 1977). If so, the incidence of distal limb trauma could be higher than suggested by our study. Digit amputation, especially occurring at joints, may be undetected in our study of unarticulated, dry bones.

The only pathology found in skulls/jaws is perforating fractures. Only mild reactive hypertrophy is associated with these fractures.

Webb and Messel (1977) studied abnormalities and injuries in an extant *C. porosus* population. Individuals were caught, examined, and then released. They reported that, "in adults, the head usually had distinct puncture marks." This agrees well with our findings in *Leidyosuchus (= Borealosuchus) formidabilis*. They also found that the most common limb injury was an amputated digit (64% of limb injuries). In *Leidyosuchus (= Borealosuchus) formidabilis*, 13% of total fractures were of metapodials and phalanges. (If one just considers limb bones, this percentage rises to 69%.) It therefore appears that traumatic limb injuries tend to be distally located in both the extant species *C. porous* and fossil species.

In the same Webb and Messel study, adult *C. porous* "trunk injuries were usually puncture marks, presumably from other adult *C. porous*". Similarly, we have 24 osteoscutes with distinct perforating fractures. None of these are from the cervical region.

Cott (1961) has extensively studied an extant *Crocodylus niloticus* population. He reported frequent "wounds, scars, fractures, and amputations" in 548 crocodiles. About 20% of these animals had sustained injuries that were most frequent in the tail (70.1%) and the limbs (14.2%). He did not specifically tabulate fracture incidence so his study cannot be directly compared to our dry bone analysis of fossil material. He felt that "it is probable that most of the injuries were inflicted by crocodiles".

In our opinion, fractures in *Leidyosuchus (= Borealosuchus) formidabilis* were most likely a result of intraspecific crocodilian aggressive behavior such as territorial conflicts by males. Others (Cott, 1961; Webb and Messel, 1977; Buffetaut, 1983) have come to similar conclusions.

No vertebral compression fractures are identified.

Periosteopathy/Osteopathy

Recognized in 134 of the 236 pathological specimens, this disorder is the most frequent type of pathology present (57%). Dorsal and caudal vertebrae, metapodials, phalanges, and osteoscutes are especially involved. Table IV details four types, but "periosteopathy" is the predominant variety. It is absent in cervical vertebrae and dorsal are more involved than caudal vertebrae (Table 1). This condition is probably non-specific and, especially if multiple lesions are present, reflects bony skeletal response to a toxic, metabolic or nutritional disorder. If a single lesion is present, trauma and/or overlying inflammatory soft tissue would also be considerations. When bone is close to the surface, trauma is more likely.

We have recognized "periosteopathy" in an extant adult skeleton of *Alligator mississippiensis* (SMM Z69.26, frontispiece). Skeletal distribution and character of lesions in this alligator are similar to those found in this study (Table VI). All dorsal vertebrae have these lesions and 14 of 37 caudal vertebrae have them. No cervical vertebrae, but 5 metapodials and 4 phalanges, are involved. Other crocodilians including *A. mississippiensis* and *Crocodylus siamensis*, both zoo and wild animals, were examined and found to have no "periosteopathy". It appears that this disorder, while probably non-specific, has remained relatively unchanged since the Paleocene. It also is apparent that alligators as well as crocodiles may be affected.

Figure 16. Phalange of *Leidyosuchus (= Borealosuchus) formidabilis* P74.24.29, in lateral view, exhibiting exostosis at the proximal end. Scale bar equals 2 cm.

Twenty-eight osteoscutes have surface erosional cavities and canals. Some of these specimens are also thickened. Although trauma or malnutrition might be etiologic possibilities here, parasitic infection seems most likely. Parasitic infection of body surfaces in extant crocodilians is well known. Webb and Messel (1977) described and illustrated, for example, "parasite tracks" on scute ventral surfaces in a study of *Crocodylus porosus*. It appears similar infestations probably occurred in the Paleocene.

Osteomyelitis

Seven elements show evidence of probable infection. All are individually described here. The skeletal distribution of these lesions appears widespread. Either the infection source was hematogenous or local penetrating wounds (e.g., by a crocodile tooth), with or without compound fracture, introduced infectious organisms. Adjacent, soft tissue abscess could also have spread to bone.

Table V lists the seven elements and associated features. Two of these elements have an associated fracture. In both cases a probable draining sinus is present and there is marked reactive hypertrophy (radius P75.22.346, Fig. 5A, B; tibia P76.28.55, Fig. 6). The fractures were probably compound allowing the introduction of an infectious agent. It should be noted here that none of the 28 "perforating" fractures in this population show any evidence of infection, however. Radius P75.22.346 has a comminuted fracture and tibia P76.28.55 has an oblique fracture.

One element (cervical rib P83.12.63, Fig. 10C) has an apparent sinus drainage canal and marked neighboring reactive bone, but no fracture.

The left femur P76.28.999 (Fig. 10E) has no evidence of fracture, but marked localized hypertrophy. This reactive bone surrounds an osteolytic cavity strongly suggesting infection even though no draining sinus was present.

The last three specimens (atlas/axis P83.12.64, Fig. 10A; dorsal vertebra P89.6.214, Fig. 10B; ilium P75.22.480, Fig. 10D) have only mild bone hypertrophy surrounding osteolytic cavities. In the atlas/axis and the ilium, these cavities are multiple. They appear to coalesce in the ilium. This may well represent hematogenous spread of the infectious agent since the location of the lesions in all three is not in an area one would suspect susceptible to trauma. Putschar (1965) has observed that a traumatic etiology is "less likely" in areas protected by a strong mantle of musculature.

Spondyloarthropathy

This condition has been reported in numerous vertebrates, including *Hyaenidae* (Rothschild and Rothschild, 1994), *Proboscideans* (Rothschild et al. 1994), new world monkeys (Rothschild and Woods, 1993) and humans (Rothschild and Martin, 1993).

This erosive (inflammatory) arthritis in our population occurs primarily in foot elements. One dorsal rib and three dorsal vertebrae are also involved. This is quite similar to reported skeletal distributions characteristic of this disorder in both humans and non-humans (Rothschild and Woods, 1992). The character of individual lesions and their distribution within the skeleton appear the same in all species where this condition has been recognized and have remained unchanged in human populations through time (Rothschild 1995).

Twenty-two of the 236 pathological specimens in this study had evidence of spondyloarthropathy. The incidence of this disease in *Leidyosuchus (= Borealosuchus) formidabilis* is not known, however, since most of the studied elements were not articulated. The severity of joint damage in involved individuals (if similar to human disease) suggests considerable disability. Diseased individuals were possibly forced to somewhat alter activities from active predation to more scavenging (Rothschild and Rothschild, 1994). Ankylosis of dorsal spine segment P70.20.408 is an example (Fig. 12). Based on extensive observations by the writers, frequent scavenging, however, is a normal habit of living crocodilians.

In this study 56 sacrae and 21 ilia were examined and show no evidence of spondyloarthropathy. Zygapophyseal joints and vertebral centra (other than P70.20.408) also show no involvement. Sampling error could partially explain this. Certainly the literature describes frequent involvement of these elements in this disorder (Rothschild and Woods, 1992).

Gilmore (1946) has described and illustrated two fused pathological dorsal vertebrae of *Crocodilus sp.* from the Bridger, Eocene, that appear almost identical to our three fused dorsal vertebrae (P70.20.408). He provided no diagnosis, but his specimen certainly appears to represent another example of spondyloarthropathy in a fossil crocodilian.

Other Arthropathies

Osteoarthritis is not recognized in this population. Indeed, osteoarthritis in Tertiary vertebrates has proven "difficult to document" and, at most, is rare (Rothschild, 1990).

Spondylitis Deformans (Spinal Osteophytosis) also is not present although it is common in some vertebrates such as dinosaurs (Rothschild, 1990).

There is no evidence for rheumatoid arthritis in this fossil assemblage. However, the other major erosive arthritis, spondyloarthropathy, is identified in 21 elements. It is the primary joint disorder in this population.

Exostoses

These abnormal surface projections include a probable chondroma, two "button osteomas", and three elements with probable ossified muscle attachments. The six involved elements were scattered throughout the skeleton and are probably not related to each other. No osteochondromas were recognized.

Malignant tumors are rare in reptiles (Elkan and Cooper, 1976). Indeed, no valid report of a malignant bone has apparently been seen in the fossil record (Rothschild and Tanke, 1991).

Congenital Malformations

Malformations were seen only in 3 specimens (Chevron P79.19.997; Osteoscutes P82.12.306 and P82.12.419).

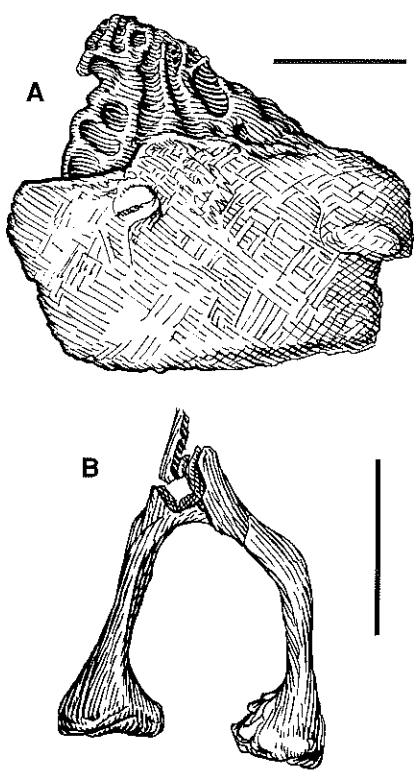

Figure 17. Malformations in *Leidyosuchus (= Borealosuchus) formidabilis.* A, osteoscute P82.12.306; B, chevron P79.19.997. Scale bar equals 2 cm.

SUMMARY

The pathologic conditions of the eusuchian crocodile, *Leidyosuchus (= Borealosuchus) formidabilis*, from the Late Paleocene Wannagan Creek Fauna of North America, are described, analyzed, and discussed. Six distinct pathologic structural varieties are identified. They include fractures, periosteopathy/osteopathy, osteomyelitis, spondyloarthropathy, exostoses, and congenital malformations. Periosteopathy/osteopathy is most frequent, while fractures are second. In both instances, parallels are drawn to extant crocodilians with indistinguishable pathologic structural alterations. These disorders, when pronounced, are likely to have significantly altered the individuals' behavior, especially with regard to feeding habits; however, any assumption about behavior should be made cautiously. The unchanged nature of disease through time since the Paleocene is significant.

TABLE I. Summary of Pathology

Element	Total Pathologic	Total Examined	Fractures	Periosteopathy/Osteopathy	Osteomyelitis	Spondyloarthropathy	Exostoses	Congenital Malformations
Skull (maxilla)	2	29	2					
Mandible (surangular)	1	72	1					
Atlas centrum	1	20			1			
Dorsal vertebra	52	422		49	1	1	1	
Sacrum	1	56		1				
Caudal vertebra	25	268	1	24(1)				
Chevron	3	60	2					1
Cervical rib	1	249			1			
Dorsal rib	2		1	1		(1)		
Interclavicle	1	14	1					
Scapula	1	46					1	
Humerus	1	69		1				
Radius	3	53	1	2	(1)			
Ulna	1	23		1				
Ulnar	2	21		2				
Ilium	1	21			1			
Pubis	1	33		1				
Femur	4	53	1		1		2	
Tibia	1	41	1		(1)			
Fibula	1	42	1					
Metapodial	28	284	7	11		10		
Phalange	25	414	2	13		9	1	
Ungual	2	136				1	1	
Gastralium	22		22					
Osteoscute	54	4,126	24	28				2
No Pathology		602						
Totals:	236	7,154	67	134(1)	5(2)	21(1)	6	3

( ) = second diagnosis

TABLE II. Elements With No Pathology (January, 1997)

Element	Number Examined
Cervical vertebra	351
Hyoid	19
Coracoid	45
Radial	38
Ischium	21
Palpebral	12
Astragulus	50
Calcaneum	36
Coronoid	30
Total	602

TABLE III. Fractures

Type and Element	Number	
A. Perforating		
Skull	2	
Surangular	1	
Interclavicle	1	
Osteoscute	24	
subtotal		28
B. Transverse		
Caudal vertebra	1	
Chevron	2	
Dorsal rib	1	
Fibula	1	
Metapodial	6	
Phalange	1	
Gastralium	22	
subtotal		34
C. Comminuted		
Radius	1	
Metapodial	1	
subtotal		2
D. Oblique		
Femur	1	
Tibia	1	
Phalange	1	
subtotal		3
TOTAL		67

TABLE IV. Periosteopathy/Osteopathy

Type and Element	Number	
A. Periosteopathy		
Dorsal vertebra	49	
First sacral vertebra	1	
Caudal vertebra	24 (1)	
Humerus*	1	
Radius	1	
Ulna*	1	
Ulnar	2	
Metapodial	10	
Phalange	13	
subtotal		102 (1)
B. Ribbed Periosteopathy		
Dorsal rib	1	
Pubis	1	
subtotal		2
C. Fusiform Osteopathy		
Radius	1	
Metapodial	1	
subtotal		2
D. Periosteopathy/Osteopathy with cavities/canals		
Osteoscute	28	
subtotal		28
TOTAL		134 (1)

*Localized smooth periosteopathy
( ) = Second diagnosis

TABLE V. Osteonyelitis

Element	Cat. Number	Associated fracture?	Reactive bone	Lesion description	Location susceptiable to trauma?
Atlas centrum	P83.12.64	no	mild	2 osteolytic cavities	no
Dorsal vertebra	P89.6.214	no	mild	1 osteolytic cavity	no
Cervical rib	P83.12.63	no	marked	1 draining sinus	yes
Radius	P75.22.346	yes	marked	1 draining sinus	yes
Ilium	P75.22.480	no	mild	3-5 osteolytic cavities	no
Femur	P76.28.999	no	marked	1 osteolytic cavity	yes
Tibia	P76.28.55	yes	marked	1 draining sinus	yes

TABLE VI. Periosteopathy in Alligator mississippiensis SMM Z69.26

Element	Number
Skull and mandible	none
Cervical vertebra	none
Dorsal vertebra	all 14
Sacrum	none
Caudal vertebra	14 of 37
Chevron	5 of 25
Cervical and dorsal rib	none
Pectoral girdle	none
Humerus	1
Radius and ulna	none
Pelvic girdle	none
Femur	none
Tibia	1
Fibula	none
Metapodial	5
Phalange	4
Gastralium	none

GLOSSARY

Ankylosing Spondylitis.
A variety of spondyloarthropathy, an inflammatory joint disorder, in which syndesmophytes fuse and bridge vertebral centra. The appearance has suggested a "bamboo spine". An old term, "rheumatoid spondylitis", should not be used since this condition is not related to rheumatoid arthritis.

Arthritis.
Inflammation of a joint, which may or may not result in structural changes that can be observed in dry bone analysis. Inflammatory (erosive) joint disease includes spondyloarthropathy, rheumatoid arthritis, infectious arthritis, and forms of crystalline arthritis such as gout. Osteoarthritis (osteoarthrosis) should be considered non-inflammatory.

Arthropathy.
A general term indicating any disease affecting a joint.

Atrophy.
A general term indicating decrease in size or wasting away of tissue. The term "osteoporosis" implies a generalized loss of bone. In "osteolysis" the bone loss is localized and, if the pathological process is slow/chronic or slows/stops after an acute period, new reactive bone may form adjacent to this localized lesion.

Callus.
Hard tissue/bone that appears at a healing bone fracture site.

Chondroma.
A tumor-like hypertrophic growth of cartilage, either within the cartilage substance or on its surface.

Eburnation.
Articular cartilage thinning so that it appears worn and polished.

Etiology.
The cause or origin of a disease.

Exostosis.
An abnormal surface projection from bone. Varieties include ossification of muscle attachments, chondromas, osteochondromas, and osteomas.

Fracture.
Sudden discontinuity of bone which may be partial or complete and usually has a traumatic etiology. Varieties include: comminuted (the bone is splintered); compound (associated open wound of soft tissues); compression (usually a wedge-shaped vertebral centrum produced by compression); depressed (the bone fragment is depressed below the surface); greenstick (one side of bone is bent while the other side is broken); oblique (the break is in an oblique direction as in the shaft of a long bone); perforating (the bone has been punctured by a pointed object such as a tooth producing a feature sometimes resembling a "buttonhole"); and transverse (the bone has broken at a right angle to its axis).

Hematogenous.
Blood borne.

Hypertrophy.
A general term indicating overgrowth of tissue.

Joint.
The place of union, usually but not always movable, between two or more bones.

Joint Mouse.
A cartilaginous projection (exostosis) on the articular surface of a vertebral centrum. In humans, it has been present in some athletes.

Osteoarthritis (Osteoarthrosis).
A mechanical form of arthritis. Since evidence of inflammation is minimal or absent, especially in dry bone analysis, osteoarthrosis is a better term. Osteophytes (spurs) are present at margins of articular surfaces and, in severe cases, articular surfaces may be grooved and eburnated. No subchondral bone erosion and no joint bridging is seen. In the spine it only affects the zygoapophyseal joints. "Degenerative joint disease" is an old label for this process but, because pathological changes are hypertrophic and not destructive, is probably a poor term.

Osteochondroma.
A cartilage-capped exostosis which may occur on any bone, especially in the metaphyseal region, but does not affect joints. It may be multiple in an individual, is usually asymptomatic, and rarely may undergo malignant degeneration to osteosarcoma. It sometimes has a "mushroom" appearance.

Osteolysis.
Bone destruction or softening.

Osteoma.
A small (usually less than 1.5 cm) benign tumor of bone tissue which occurs either in an intraosseus location (osteoid osteoma) or as an exostosis ("button osteoma").

Osteomyelitis.
Inflammation of the bone, especially of the marrow, caused by a pathogen such as a bacterium, the tuberculosis bacillus, a mycobacterium, or a fungus. Bone destruction (erosion) may be extensive with sinus drainage canals frequent. Reactive, disorganized, and often grossly distorted hypertrophic bone typically surrounds the erosion. Infection may spread by hematogenous route or by contiguous spread from adjacent infected soft tissue. If infection involves a joint it is termed "infectious arthritis".

Osteophyte (spur).
A bony outgrowth from vertebral centrum margins perpendicular to the vertebral column. If numerous, the condition is called osteophytosis (Spondylosis Deformans). Osteophytes also occur at margins of articular surfaces in the appendicular skeleton where it is a characteristic feature of osteoarthritis. Neighboring osteophytes may fuse.

Paleopathology.
The study of any pathological condition that affects pre-historic human or non-human organisms.

Pathology.
The study of any structural deviation from a healthy, normal or efficient condition.

Periostitis (Periosteopathy).
Reactive hypertrophy of the periosteum (superficial layer of bone tissue) which may or may not suggest certain etiologic possibilities. For example, periosteopathy localized to a bone surface in a frequently traumatized location may well be secondary to the trauma. If the term osteitis (osteopathy) is used, it indicates apparent pathological involvement of subperiosteal bone as well.

Reiter's Syndrome.
A condition in humans with symptoms and signs of inflammation of the outer layer of the eye (conjunctivitis) and/or of the genitourinary system. Rashes of skin and/or mucous membrane may be present. This syndrome is often associated with spondyloarthropathy.

Rheumatoid Arthritis.
An inflammatory symmetrical joint disorder that spares axial joints except in the upper cervical region. Bone destruction (erosion) is often pronounced with relatively minimal reactive bone hypertrophy. A favored location is in the marginal area between subchondral bone and the joint capsule attachment. In severe cases subchondral erosion may undermine the articular surface. There probably is no sacroiliac, costovertebral/costotransverse, or zygapophyseal joint involvement. Peripheral joint fusion also probably does not occur. This entity apparently has not been described in the non-human fossil record (Rothschild 1995).

Spondyloarthropathy.

An inflammatory asymmetrical joint disorder most frequently involving the spine and sacroiliac joint but, to a lesser degree, also costovertebral/costotransverse and more peripheral joints. Erosion and bone hypertrophy are mixed. In the spinal column syndesmophytes are present which may produce longitudinal bridging with relative preservation of intervertebral spaces. Zygapophyseal articular surfaces often show erosion and/or fusion. Varieties include ankylosing spondylitis, psoriatic arthritis, arthritis of inflammatory bowel disease, and "reactive arthritis" (a post-infectious phenomenon that includes "Reiter's Syndrome" in humans and infectious agent diarrhea). The most commonly affected peripheral joints affected are wrist, metacarpal phalangeal and metatarsal phalangeal (Rothschild and Woods, 1992; Rothschild and Martin, 1993; Rothschild, 1995).

Spondylosis Deformans (Spinal Osteophytosis).

A chronic pathological process of the spinal column characterized by numerous osteophytes (spurs) which often show coalescence.

Syndesmophyte.

Overgrowth of vertebral centrum margins which cause ossification of portions of the annulus fibrosis. This may cause longitudinal bridging of vertebral centra with fusing. They are seen in all varieties of spondyloarthropathy. Sometimes syndesmophytes are attached to vertebral centra in a more central, non-marginal area.

Tumor.

A mass of tissue in an area where it would not normally occur. It may or may not be inflammatory.

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