Lucas, S.G., and Heckert, A.B., eds., 2000, Dinosaurs of New Mexico. New Mexico Museum of Natural History and Science Bulletin No. 17.

CRETACEOUS DINOSAURS IN NEW MEXICO

SPENCER G. LUCAS[1], ANDREW B. HECKERT[2], and ROBERT M. SULLIVAN[3]

[1]New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104;
[2]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131-1116,
[3]The State Museum of Pennsylvania, Third and North Streets, P.O. Box 1026 Harrisburg, PA 17108-1026

Abstract—New Mexico's most extensive fossil record of dinosaurs is from rocks of Cretaceous age. The Early Cretaceous record is confined to tracks of late Albian age, principally from northeastern NM. They are primarily of ornithopods (*Caririchnium, Amblydactylus*) and lesser numbers of theropods. They provide circumstantial evidence of social behavior in ornithopods and, because of the lack of sauropod tracks, suggest the extirpation of North American sauropods took place during the late Albian.

New Mexico's record of Late Cretaceous dinosaurs includes a few tracksites (notably including the holotype of *Tyrannosauripus* from the late Maastrichtian of the Raton basin) and an extensive body fossil record from rocks of late Turonian, late Santonian, Campanian and Maastrichtian age. Highlights of this record include: (1) *Zuniceratops* from the late Turonian Moreno Hill Formation, the oldest North American ceratopsian with brow horns, which suggests a possible North American origin of ceratopsids; (2) hadrosaur, ceratopsian and theropod fossils from the late Santonian Crevasse Canyon Formation and early Campanian Menefee Formation that are mostly fragmentary and isolated but that indicate a need to collect further this largely unsampled interval; (3) an extensive late Campanian record from the Fruitland and Kirtland formations in the San Juan Basin that provides strong evidence of Asian-North American interchange of Campanian dinosaurs; and (4) a possible Paleocene dinosaur record from the San Juan Basin.

INTRODUCTION

New Mexico has an extensive fossil record of Cretaceous dinosaurs that can be readily divided into Early Cretaceous occurrences of dinosaur footprints and Late Cretaceous occurrences dominated by body fossils with a few footprints and skin impressions (Fig. 1). Collection and study of New Mexico's Cretaceous dinosaurs began in the 1880s and continues, unabated, to the present. This century-plus of research, combined with the great extent of fossiliferous Cretaceous outcrops, has produced a diverse and scientifically significant record of Cretaceous dinosaurs. Here, we both review this record and add selected new records of Cretaceous dinosaurs from New Mexico. Here, KU = Museum of Natural History, University of Kansas, Lawrence; and NMMNH = New Mexico Museum of Natural History and Science, Albuquerque.

EARLY CRETACEOUS

New Mexico's Early Cretaceous history can be divided into three phases: (1) a Neocomian interval when essentially no deposition took place across the state (the only possible exception is in the Little Hatchet Mountains of Grant-Hidalgo counties, where possible Neocomian marine strata are preserved: Lucas and Lawton, 2000); (2) a late Aptian-middle Albian interval, during which both nonmarine and marine deposition took place in the Chihuahua trough (a rift basin) in extreme southwestern New Mexico (Lucas and Estep, 1998, 2000); and (3) a late Albian phase, when marine and paralic deposits accumulated across much of eastern and part of southwestern New Mexico (Lucas and Estep, 2000).

Early Cretaceous dinosaurs from New Mexico come from deposits of the third phase and consist of tracks of ornithopods and theropods (Fig. 2); no body fossils of Early Cretaceous dinosaurs are known from the state. These tracks come from localities in northeastern New Mexico (Colfax, Harding and Union counties: Fig. 1); Hunt and Lucas (1998) provided a comprehensive review of these sites, upon which we base a brief summary (see also Lockley et al., 2000).

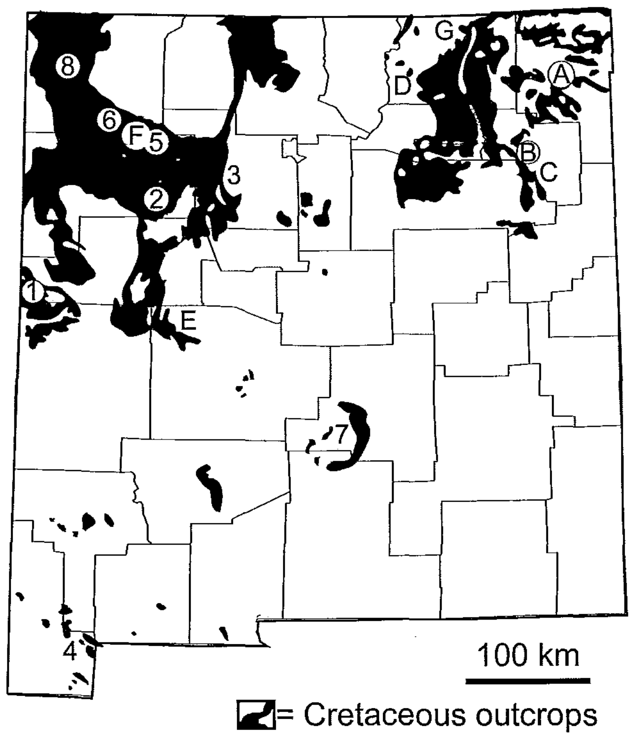

FIGURE 1. Cretaceous dinosaur localities, including both tracksites (letters) and body fossils (numbers). Tracksites: **A**, Clayton Lake State Park; **B**, Mosquero Creek; **C**, Mills Canyon; **D**, Farley; **E**, Jalarosa Creek; **F**, Fossil Forest; **G**, Raton. Body fossils: **1**, Moreno Hill Formation; **2**, Crevasse Canyon Formation; **3**, Menefee Formation; **4**, Ringbone Formation; **5**, Fruitland Formation; **6**, Kirtland Formation; **7**, McRae Formation; **8**, Ojo Alamo Sandstone.

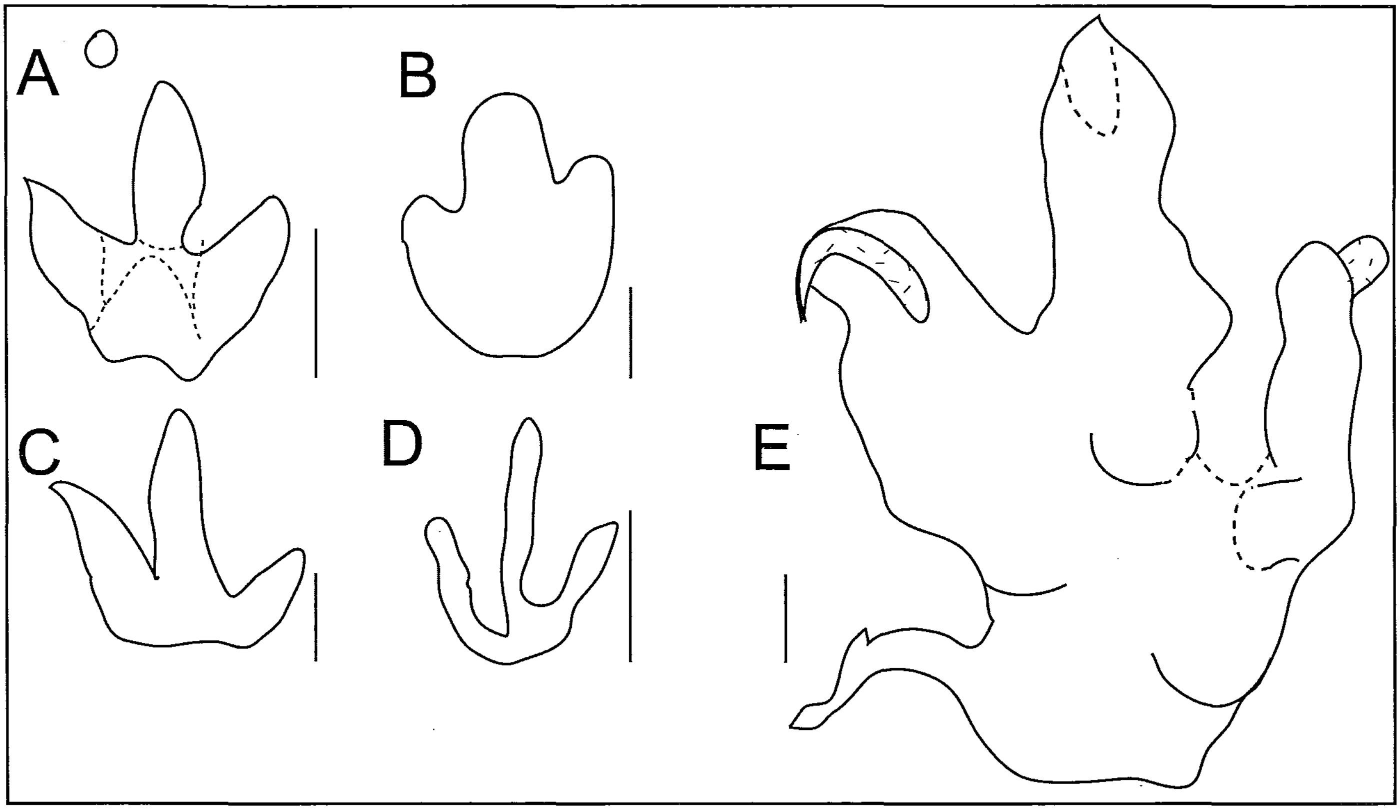

FIGURE 2. Principal dinosaurian ichnotaxa from the Cretaceous of New Mexico. **A**, *Caririchnium leonardii*; **B**, *Amblydactylus* sp.; **C**, large theropod; **D**, small theropod; and **E**, *Tyrannosauripus pillmorei*. Tracks (A-D) are most common in Lower Cretaceous strata, (E) is known only from its type locality in the uppermost Cretaceous. Scale bars are 10 cm long. (C) and (E) are drawn to the same scale.

Clayton Lake State Park

More than 400 dinosaur tracks are present in the uppermost Mesa Rica Sandstone and lowermost Pajarito Formation in the spillway of the dam at Clayton Lake State Park, Union County (Gillette and Thomas, 1985, 1989; Lucas et al., 1986; Bennett, 1993; Lockley and Hunt, 1995; Hunt and Lucas, 1996, 1998). The dinosaur tracks represent two morphotypes of ornithopods (*Caririchnium leonardii* and *Amblydactylus* sp.) and two or more theropod morphotypes (*Grallator* spp. and *?Magnoavipes* sp.) (Fig. 2).

Mosquero Creek

At least 81 trackways of individual ornithopod dinosaurs (ichnogenera *Caririchnium* and *Amblydactylus*) are present in the uppermost Mesa Rica Sandstone near Mosquero Creek, Harding County (Lucas et al., 1987a; Lockley and Hunt, 1995; J.E. Cotton et al., 1996, 1997; W.D. Cotton et al., 1997, 1998). The vast majority of the trackways (55) are parallel to each other and have been interpreted as evidence of gregarious behavior.

Mills Canyon

Hunt and Watts (1996) reported ornithopod tracks from near Mills in Harding County. These tracks can be assigned to *Caririchnium leonardii*, and are from the uppermost Mesa Rica Sandstone.

Farley

We report here a new dinosaur track locality in the Mesa Rica Sandstone north of Farley in Colfax County (NW1/4 SW1/4 sec. 15, T26N, R27E—NMMNH locality 4258), discovered by Fred, Francis, and Donny Fernandez on their ranch. Locally, the Mesa Rica Sandstone is about 10 m thick, and the tracks occur on a ripple-laminated sandstone bedding plane in the approximate middle of the unit. About 20 tracks, all of a large ornithopod, are present, and show no preferred orientation (Fig. 3). The tracks are relatively large (25-35 cm long), have thick blunt toes, bilobed or flat heels, and can be assigned to *Caririchnium leonardii* (NMMNH P-31622 and P-31623 are casts from this site).

Other Sites

As Hunt and Lucas (1998) noted, there are several other tracksites in the Mesa Rica Sandstone in Union and Harding counties, as well as a possible site in Quay County. However, these have not yet been studied.

Significance

There are two reasons why the Early Cretaceous dinosaur footprints from northeastern New Mexico are significant:

1. They provide circumstantial evidence of group behavior in ornithopod dinosaurs (W.D. Cotton et al., 1997, 1998). Parallel trackways and speed clustering support the idea that ornithopods sometimes walked in groups across Early Cretaceous substrates in northeastern New Mexico.

2. The Mesa Rica Sandstone and Pajarito Formation are of late Albian age (ammonite zone of *Mortoniceras equidistans* and slightly younger: Lucas and Hunt, 2000). The dinosaur track fauna is dominated by ornithopods, and devoid of sauropod tracks. Older Lower Cretaceous units in the western United States, especially the early Albian Glen Rose Formation in Texas and DeQueen Formation in Arkansas, have track faunas dominated by sauropods and devoid of ornithopods (Lucas and Hunt, 1989). This suggests the extirpation of North American sauropods during the late Albian, a concept that is further borne out by the lack of sauropod body fossils from this interval and the suceeding

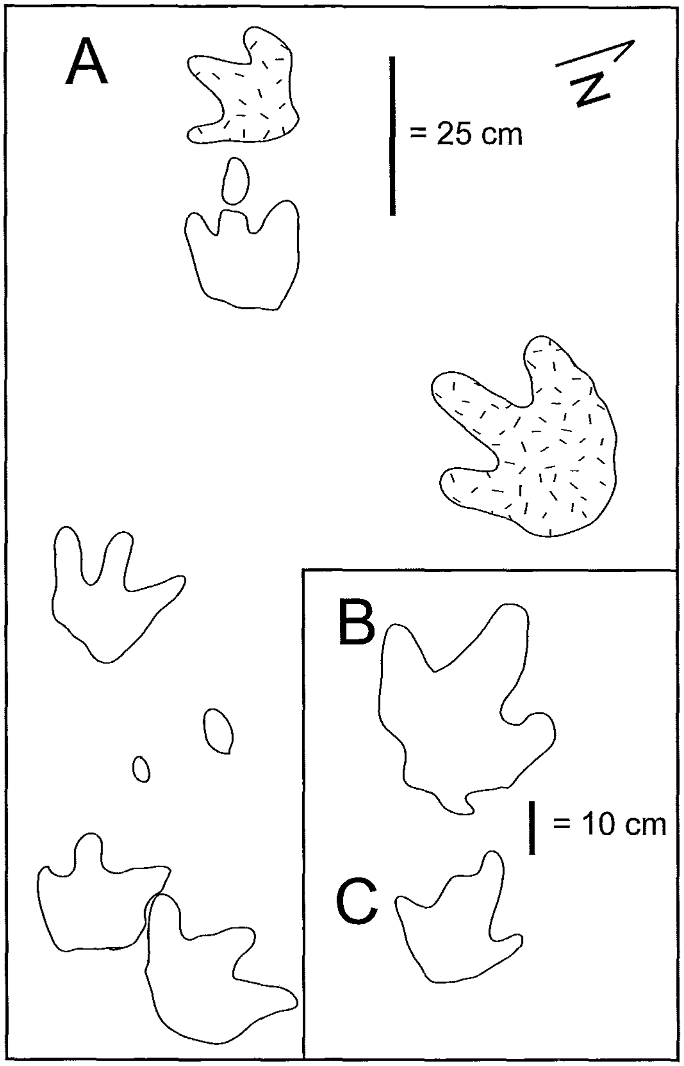

FIGURE 3. Selected tracks of ornithopod dinosaurs from the Farley locality, Colfax County, New Mexico. **A**, Overview of relatively randomly-oriented tracks; **B-C**, detail of two tracks.

Cenomanian-Santonian. Sauropod reintroduction to North America during the late Campanian, probably as a result of an immigration event from South America, thus establishes a "sauropod hiatus" in North American from the late Albian to the late Campanian (Lucas and Hunt, 1989; Sullivan and Lucas, 2000a).

Lockley et al. (1992) proposed the term "dinosaur freeway" megatracksite to refer to about 30 dinosaur tracksites that occur in upper Albian strata along the Rocky Mountain Front Range and on the southern High Plains of Colorado, Oklahoma, and New Mexico. However, the term "dinosaur freeway" megatracksite is, at best, a misnomer based on imprecise stratigraphy. The many sites that supposedly make up this "megatracksite" occur throughout a stratigraphic interval, not at the same exact stratigraphic level. Furthermore, the Mesa Rica Sandstone and stratigraphically equivalent units, while homotaxial, represent the transgression of the Western Interior Seaway, and are thus time-transgressive as well, so that trackways in deposits laterally equivalent to each other from east-to-west were generated at different times. Thus, no megatracksite is present, and the "dinosaur freeway" is best abandoned as a concept based on poor stratigraphic resolution.

LATE CRETACEOUS

New Mexico's most extensive record of dinosaurs comes from its Upper Cretaceous strata. This record consists of a few tracksites and skin impressions as well as a diverse and prolific body-fossil record from several formations. Here we review the skin impression and tracksite records, then discuss the body fossil record in ascending stratigraphic (temporal) order (Fig. 4).

Late Cretaceous Skin Impressions

In 1990, Gorge T. Basabilvazo, then a graduate student at New Mexico State University, discovered dinosaur skin impressions and associated skeletal remains in the Little Hatchet Mountains. These fossils, all from a single dinosaur individual, were located in a sandstone bed of the middle member of the Ringbone Formation near Playas Peak. They are now housed in the New Mexico Museum of Natural History, where they are catalogued as NMMNH P-2611.

Anderson et al. (1998) described NMMNH P-2611, which is part of the tail skeleton and skin impressions from the tail region of a duckbill dinosaur (hadrosaur). This association is important, because the skin impressions are in the rock encasing the bones, so they clearly are from the same individual hadrosaur; many putative dinosaur skin impressions in the literature lack a clear association with bone, so their identity as skin impressions is not certain.

The skeletal elements of NMMNH P-2611 are 20 articulated vertebral centra, several disarticulated centra, and ossified tendons, all from the mid- to distal caudal region. They identify the dinosaur as a hadrosaur, but in the absence of cranial remains a more precise identification is not possible. The skin impressions are six discrete patches of apical, circular to ovate tubercles. The tubercles range in size from 3 x 12 mm to 10 x 16 mm on the short and long axes, respectively. All of the tubercles have radiating ridges and grooves that converge at their apices.

The middle member of the Ringbone Formation was deposited in a relatively deep lake during the late Campanian, about 71 Ma (Basabilvazo, 1991). The sandstone bed that contained NMMNH P-2611 probably represents the distal portion of a deltaic channel near the lake margin. Evidently, part of a hadrosaur carcass was rapidly buried in such a setting, but we do not precisely understand the relatively unique conditions that preserved the skin impressions.

Recently, one of us (SGL) re-examined an earlier report of supposed hadrosaur skin impression from the Fruitland Formation in the San Juan Basin (Hall et al., 1988). This specimen, KU 11276, is housed at the University of Kansas and was collected from the Fruitland Formation of the San Juan Basin in the 1980s. This specimen consists of a 6 by 7 cm-wide patch of densely packed tubercles preserved in negative relief (Fig. 5). While not as well-preserved as the impressions of NMMNH P-2611, the tubercles are of approximately the same size and also arranged in an array of irregular 4- to 6-sided polygons with subrounded corners. Based on its similarity to the Ringbone hadrosaur skin impression, the impression from the San Juan Basin does indeed appear to be that of hadrosaur skin, as suggested by Hall et al. (1988).

The skin impressions of New Mexican hadrosaurs resemble those of other hadrosaurs (e.g., Lull and Wright, 1942) but are notable for their exquisite detail, especially in the case of NMMNH P-2611. The function of the tubercles in hadrosaur skin is unclear, but the ridges and grooves would have increased the surface area of the skin to provide more efficient heat exchange. The tubercles would have also increased the resistance of the skin to tearing and puncturing.

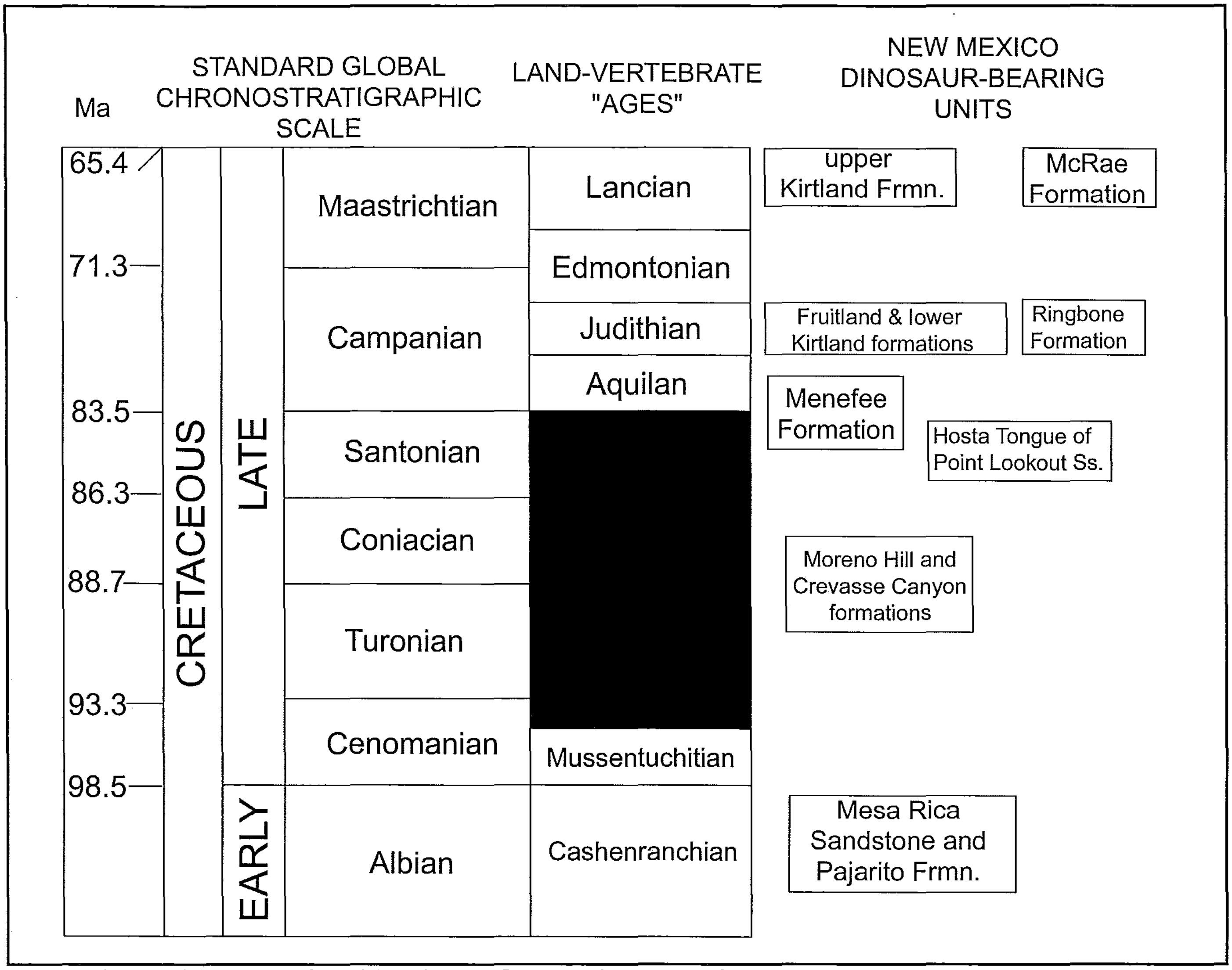

FIGURE 4. Stratigraphic summary of New Mexico's Upper Cretaceous dinosaur record.

Late Cretaceous Tracksites

There are three records of Upper Cretaceous dinosaur tracks from New Mexico:

1. Heckert and Lucas (1998) reported ornithopod tracks (*Caririchnium* sp.) from middle Cenomanian strata of the Dakota Formation at Jaralosa Creek in Socorro County.

2. Wolberg et al. (1988) reported large ornithopod tracks from the Campanian Fruitland Formation in the San Juan Basin.

3. Lockley and Hunt (1994) named the new ichnotaxon *Tyrannosauripus pillmorei* for a track from the Maastrichtian portion of the Raton Formation in the Raton Basin. This is believed to be a track of *Tyrannosaurus rex* and was associated with a hadrosaur track.

New Mexico's Late Cretaceous record of dinosaur tracks is too limited to allow broad inferences to be drawn. Nevertheless, all tracksites yield ornithopod (presumably hadrosaur) tracks, which reflects the dominance of ornithopod tracks in the Late Cretaceous North American record and corresponds well to the hadrosaur-dominated body fossil record of New Mexico's Upper Cretaceous strata. Further, the track of *Tyrannosaurus* is a relatively unusual record.

Late Cretaceous Body Fossils

Late Cretaceous body fossils are known from diverse localities throughout the central and western portion of the state (Fig. 1). Although the extensive dinosaur faunas of the Kirtland-Fruitland formations in the San Juan Basin in northwestern New Mexico are the best known, numerous other localities have produced important dinosaurs of Late Cretaceous age. These include the Moreno Hill Formation in west-central New Mexico, the Point Lookout Sandstone in central New Mexico, the Crevasse Canyon and Menefee formations in the San Juan Basin, the Ringbone Formation in southwestern New Mexico, and the McRae Formation in central New Mexico.

Moreno Hill Formation

The oldest Late Cretaceous dinosaur body fossils from New Mexico are from the middle Turonian Moreno Hill Formation, McKinley County (Wolfe et al., 1997; Wolfe and Kirkland, 1998; Wolfe, 2000). The dinosaurs from this unit are under study and mostly undescribed. They include therizinosauroids?, dromaeosaurids, tyrannosaurids, hadrosaurs and the ceratopsian *Zuniceratops christopheri*. Particularly significant is *Zuniceratops*,

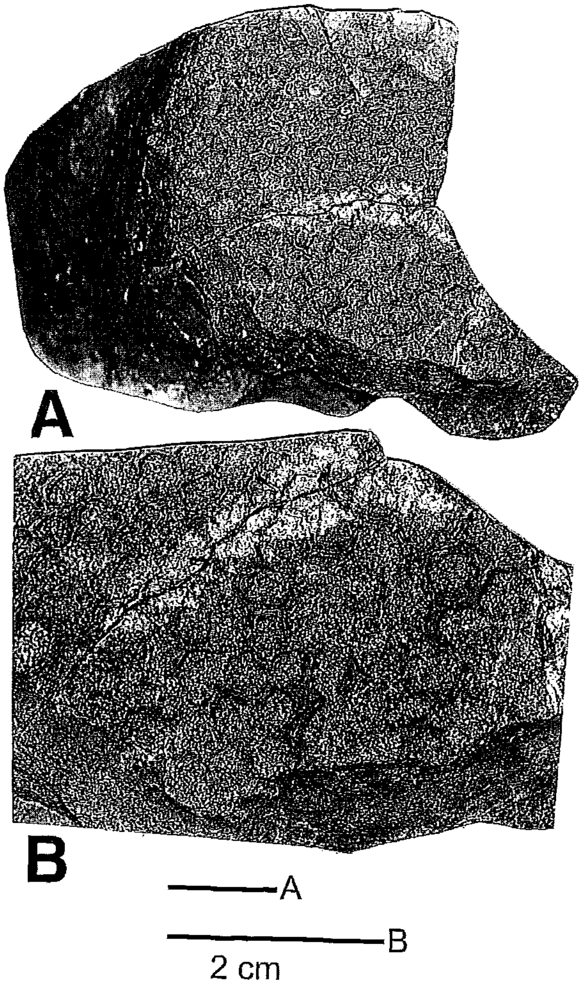

FIGURE 5. KU 11276 (University of Kansas, Lawrence), skin impression of a hadrosaur from the Fruitland Formation, San Juan Basin, New Mexico. A, entire specimen; B, close-up view of central portion of (A).

because it is the oldest North American ceratopsian with brow horns. It displays a mosaic of derived features of ceratopsids, and more primitive features that identify *Zuniceratops* as a possible North American representative of basal ceratopsids (Wolfe, 2000). It thus raises the possibility of a North American origin for the Ceratopsidae (Wolfe and Kirkland, 1998).

Crevasse Canyon Formation

Lucas et al. (1988) and Hunt and Lucas (1993) documented a hadrosaur maxilla and some indeterminate dinosaur fossils from the lower Santonian Gibson Coal Member of the Crevasse Canyon Formation in north-central New Mexico. This unit merits further field investigation.

Point Lookout Sandstone

Lucas et al. (1988) documented some isolated dinosaur teeth and bones from the Santonian Hosta Tongue of the Point Lookout Sandstone in central New Mexico. Taxa represented are Dromaeosauridae, Tyrannosauridae and Hadrosauridae. These fossils are transported remains in a shoreface sandstone deposit.

Menefee Formation

Hunt and Lucas (1993) and Williamson (1997) documented dinosaur fossils from the upper Santonian-lower Campanian Menefee Formation in north-central New Mexico. Two distinct stratigraphic intervals yield dinosaurs. The older interval, in the upper Santonian Cleary Coal Member, has yielded fragmentary remains of hadrosaurs, ankylosaurs and a tyrannosaurid? theropod (Hunt and Lucas, 1993). The younger interval, in the lower Campanian Allison Member, has yielded a partial skeleton of a pachyrhinosaurine ceratopsian, a dromaeosaurid theropod (cf. *Saurornitholestes* sp.) and hadrosaur bones (Hunt and Lucas, 1993; Williamson, 1997). Much more field investigation is needed here.

Ringbone Formation

In Hidalgo and Grant counties in southwestern New Mexico, the Campanian Ringbone Formation yields fragmentary remains of hadrosaurs and tyrannosaurid theropods (Hunt and Lucas, 1993; Lucas et al., 1990, 2000). Particularly significant are the associated hadrosaur tail and skin impressions discussed above (Anderson et al., 1998).

The dinosaur (and other) fossils from the Ringbone Formation do not provide a precise correlation. However, an Ar^{40}/Ar^{39} age of an ash bed, which immediately overlies the Ringbone Formation in the Little Hatchet Mountains, is 71.44 ± 0.19 Ma (Lawton et al., 1993). This suggests that the underlying Ringbone Formation is of late Campanian age, as is its Arizona equivalent, the Fort Crittenden Formation, and their Sonoran equivalent, part of the Cabullona Group (Lucas et al., 1995).

Fruitland Formation

One of the most extensive dinosaur faunas in New Mexico is that of the upper Campanian Fruitland Formation in the San Juan Basin (Lucas, 1981; Lucas et al., 1987b; Hunt and Lucas, 1992, 1993). The dinosaurs from this unit include: cf. *Ornithomimus* sp., Ornithomimidae indeterminate, Dromaeosauridae indeterminate, Troodontidae indeterminate, the tyrannosaurids ?*Albertosaurus libratus*, ?*Albertosaurus* sp., a new tyrannosaurid, a nodosaurid, an indeterminate ankylosaur, an indeterminate pachycephalosaur, the ceratopsian *Pentaceratops sternbergii*, an indeterminate ceratopsid, the hypsilophodontid ?*Thescelosaurus* sp. and the hadrosaurids *Parasaurolophus cyrtocristatus* and ?*Corythosaurus* sp.

This dinosaur fauna has a well-established Campanian age, based on: (1) the lateral equivalence of the Fruitland Formation to upper Campanian, ammonite-bearing marginal marine/marine strata of the Pictured Cliffs Sandstone and Lewis Shale; and (2) Ar^{40}/Ar^{39} ages of 75.56±0.41 for an ash in the lower Fruitland and 74.11±0.62 for an ash bed near the base of the overlying Kirtland Formation (Fassett and Steiner, 1997). These data make the Fruitland dinosaur fauna one of the more tightly cross-correlated Late Cretaceous dinosaur faunas. Highly significant also is the Fruitland Formation skeleton of *Parasaurolophus cyrtocristatus*, the most complete specimen known of this genus of hadrosaur (Ostrom, 1963; Sullivan and Williamson, 1999).

Lower-upper Kirtland Formation

The Bisti, Hunter Wash, Farmington, and De-na-zin members of the Kirtland Formation are of late Campanian age based on Ar^{40}/Ar^{39} ages of ash beds that range from 74.11±0.62 Ma to 73.04±0.25 Ma (Fassett and Steiner, 1997). Their combined dinosaur fauna is: the sauropod dinosaur *Alamosaurus sanjuanensis*, the ornithomimids cf. *Struthiomimus* sp. and *Ornithomimus* *antiquus*, an indeterminate dromaeosaur, *Saurornitholestes langstoni*, the tyrannosaurids *Albertosaurus* sp., *Aublysodon* cf. *A. mirandus* and *Daspletosaurus* new species, a nodosaurid, the ankylosaurid *Nodocephalosaurus kirtlandensis*, new species of the pachycephalosaur *Prenocephale*, the ceratopsid *Pentaceratops sternbergii*, and the hadrosaurids *Anasazisaurus horneri*, *Naashoibitosaurus ostromi* and *Parasaurolophus tubicen* (Lucas et al., 1987b; Hunt and Lucas, 1992, 1993; Sullivan, 1997, 1999; Sullivan and Williamson, 1999; Williamson, 1999; Sullivan and Lucas, 2000a,b). Most of these dinosaurs are from the De-na-zin Member and reflect renewed collecting in this unit during the late 1990s. Also, more precise stratigraphy has led to the realization that several dinosaur taxa attributed by previous workers (Lehman, 1981; Lucas et al., 1987b; Hunt and Lucas, 1992, 1993) to the Naashoibito Member actually came from the underlying De-na-zin Member (see below).

Recent discoveries in the De-na-zin Member include taxa with close Asian affinities, including the ankylosaur *Nodocephalosaurus*, the pachycephalosaur *Prenocephale*, and the theropod *Saurornitholestes* (Sullivan, 1999, 2000; Sullivan and Lucas, 2000b). They suggest substantial interchange between Asian and North American dinosaurs during the late Campanian.

Naashoibito Member of Kirtland Formation

The uppermost interval of the Kirtland Formation, the Naashoibito Member of Baltz et al. (1966) (=lower-middle Ojo Alamo Sandstone of Bauer, 1916 and some subsequent workers), contains a limited, but distinctive dinosaur fauna, the age of which is still debated. These dinosaurs are: indeterminate ornithomimid, dromaeosaurid, and saurornithoidids, ?*Albertosaurus* sp., cf. *Tyrannosaurus* sp., the sauropod *Alamosaurus sanjuanensis*, indeterminate ankylosaurid and nodosaurids, the ceratopsians *Torosaurus* cf. *T. latus* and *Pentaceratops* and at least one indeterminate hadrosaurid (note that this list eliminates taxa mistakenly attributed to the Naashoibito Member by Lehman, 1981; Lucas et al., 1987b, and Hunt and Lucas, 1992, 1993). No radiometric ages or direct cross-correlation to marine biostratigraphy can be made for this fauna. Thus, three opinions have been advanced as to its precise age:

1. The conventional view is that the Naashoibito fauna is of Maastrichtian age, or Lancian in terms of vertebrate biochronology (Lehman, 1981; Lucas, 1981; Lucas et al., 1987b; Hunt and Lucas, 1992, 1993; Kirkland et al., 1998). This is based on the presence of *Torosaurus*, *Tyrannosaurus* (known only from one tooth!) and *Alamosaurus* (now known also from Campanian strata). Mammals from the Naashoibito Member, especially the multituberculate *Essonodon browni*, further support this age assignment.

2. The reasonable alternative is to argue that the Naashoibito fauna is late Campanian, discounting the identifications of Lancian-age indicators such as *Torosaurus* and *Tyrannosaurus* as having been based on inadequate material (Sullivan, 1987).

3. The unreasonable alternative is to regard the Naashoibito dinosaurs as Paleocene in age (Fassett, 1982; Fassett and Steiner, 1997). This is based on an upublished record of "Paleocene" pollen from the uppermost De-Na-Zin Member (J.E. Fassett, written comm., 2000).

McRae Formation

East of Elephant Butte Reservoir in Sierra County, central New Mexico, the Hall Lake Member of the McRae Formation yields a limited dinosaur fauna (Lozinsky et al., 1984; Wolberg et al., 1986; Gillette et al., 1986; Lucas et al., 1998). The dinosaurs are *Alamosaurus* sp., *Tyrannosaurus rex*, an indeterminate ankylosaur, an indeterminate ceratopsid and *Torosaurus latus*. All authors have concluded that this dinosaur fauna is of Lancian age.

Ojo Alamo Sandstone

The stratigraphically highest dinosaurs in the San Juan Basin are from the Ojo Alamo Sandstone *sensu* Baltz et al. (1966). Fassett et al. (1987) reviewed the known records to conclude that almost all were of fragmentary and/or abraded bones that arguably were reworked from underlying strata. The only exception is the large hadrosaur femur found along the San Juan River west of Farmington. This bone is discussed at length by Fassett et al. (2000) and Fassett and Lucas (2000), who argue that it is not reworked and is stratigraphically above Paleocene pollen, thus making it a *bona fide* Paleocene dinosaur.

Recent work by Lucas and Sullivan at Betonnie Tsosie Arroyo has revealed a substantial number of dinosaur fossils (tyrannosaurid, ceratopsid, hadrosaurid, *Albertasaurua/Daspletosaurus*, *Alamosaurus*) in strata that some have assigned, on a lithostratigraphic basis, to the Ojo Alamo Sandstone *sensu* Baltz et al. (1966). However, these strata can be demonstrated to be a sandy facies laterally equivalent to the Naashoibito Member (Lucas and Sullivan, 2000). Indeed, some of the other dinosaur bones found in the "Ojo Alamo Sandstone" may be in an equivalent facies. Thus, not all strata assigned on a lithologic basis (and correctly so) to the Ojo Alamo Sandstone *sensu* Baltz et al. (1966) are Paleocene; Cretaceous, dinosaur-bearing rocks are also part of the Ojo Alamo Sandstone.

Significance

Various aspects of the significance of New Mexico's Late Cretaceous dinosaur body fossils have already been touched upon here. In sum, the New Mexico record is a particularly dense one for Campanian time, perhaps one of the most potentially complete late Campanian dinosaur records in North America. The New Mexican dinosaurs include relatively unique records of ceratopsids (*Zuniceratops*, *Pentaceratops*), hadrosaurids (*Parasaurolophus*), ankylosaurids (*Nodocephalosaurus*), and the last North American sauropod (*Alamosaurus*). The possibility of Paleocene dinosaurs also demands further study.

ACKNOWLEDGMENTS

This paper has benefited from our past collaboration with a number of colleagues, including J. Fassett, A. Hunt, M. Lockley, and T. Williamson. J. Harris read an earlier version of the paper.

REFERENCES

Anderson, B.G., Barrick, R.E., Lucas, S.G., Heckert, A.B. and Basabilvazo, G.T., 1998, Dinosaur skin impressions from the Upper Cretaceous Ringbone Formation, southwestern New Mexico: Journal of Vertebrate Paleontology , v. 18, p. 739-745.

Baltz, E.H., Ash, S.R. and Anderson, Y., 1966, History of nomenclature and stratigraphy of rocks adjacent to the Cretaceous-Tertiary boundary, western San Juan Basin, New Mexico: U.S. Geological Survey, Professional Paper 524-D, 23 p.

Basabilvazo, G.T., 1991, Stratigraphy, depositional environments, and sediment dispersal pathways of the Upper Cretaceous Ringbone Formation in the Little Hatchet Mountains of southwestern New Mexico [M.S. thesis]: Las Cruces, New Mexico State University, 158 pp.

Bauer, C.M., 1916, Stratigraphy of a part of the Chaco River Valley: U.S. Geological Survey, Professional Paper 98, p. 271-278.

Bennett, S.C., 1993, Reinterpretation of problematical tracks at Clayton Lake State Park, New Mexico: Not one pterosaur, but several crocodiles: Ichnos, v. 2, p. 37-42.

Cotton, J.E., Cotton, W.D. and Hunt, A.P., 1996, Evidence for herding behavior in ornithopod dinosaurs from the Dakota Sandstone of northeastern New Mexico: New Mexico Geology, v. 18, p. 57.

Cotton, J.E., Cotton, W.D. and Hunt, A.P., 1997, Further evidence for herding behavior in ornithopod dinosaurs from the Dakota Sandstone of north-east New Mexico: New Mexico Geology, v. 19, p. 59.

Cotton, W.D., Cotton, J.E. and Hunt, A.P., 1997, Social behavior of Cretaceous ornithopod dinosaurs of New Mexico: New Mexico Museum of Natural History and Science, Bulletin 11, p. 45-50.

Cotton, W.D., Cotton, J.E. and Hunt, A.P., 1998, Evidence for social behavior in ornithopod dinosaurs from the Dakota Group of northeastern New Mexico, U. S. A.: Ichnos, v. 6, p. 141-149.

Fassett, J.E., 1982, Dinosaurs in the San Juan Basin, New Mexico, may have survived the event that resulted in creation of an iridium-enriched zone near the Cretaceous-Tertiary boundary: Geological Society of America, Special Paper 190, p. 435-447.

Fassett, J.E., Lucas, S.G. and O'Neill, F.M., 1987, Dinosaurs, pollen and spores, and the age of the Ojo Alamo Sandstone, San Juan Basin, New Mexico: Geological Society of America, Special Paper 209, p. 17-34.

Fassett, J.E. and Steiner, M., 1997, Precise age of C33N-C32R magnetic-polarity reversal, San Juan Basin, New Mexico and Colorado: New Mexico Geological Society, Guidebook 48, p. 239-247.

Fassett, J.E., Lucas, S.G., Zielinski, R.A. and Budahn, J.R., 2000, Compelling new evidence for Paleocene dinosaurs in the Ojo Alamo Sandstone, San Juan Basin, New Mexico and Colorado, USA; *in* Catastrophic events and mass extinctions: Impacts and beyond: LPI Contribution no. 1053, Lunar and Planetary Institute, Houston, Texas, p. 45-46.

Gillette, D.D. and Thomas, D.A., 1985, Dinosaur tracks in the Dakota Formation (Aptian-Albian) at Clayton Lake State Park, Union County, New Mexico: New Mexico Geological Society, Guidebook 36, p. 283-288.

Gillette, D.D. and Thomas, D.A., 1989, Problematic tracks and traces of late Albian (Early Cretaceous) age, Clayton Lake State Park, New Mexico, USA; *in* Gillette, D.D. and Lockley, M.G., eds., Dinosaur tracks and traces: Cambridge University Press, p. 337-342.

Gillette, D.D., Wolberg, D.L. and Hunt, A.P., 1986, *Tyrannosaurus rex* from the McRae Formation (Lancian, Upper Cretaceous), Elephant Butte Reservoir, Sierra County, New Mexico: New Mexico Geological Society, Guidebook 37, p. 235-238.

Hall, J.P., Wolberg, D.L., and West, S., 1988, Dinosaur-skin impressions from the Fruitland Formation (Campanian-Maastrichtian) of the Fossil Forest, San Juan Basin, San Juan County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 122, p. 23-27.

Heckert, A.B. and Lucas, S.G, 1998, A new dinosaur footprint locality from the Dakota Sandstone (Upper Cretaceous: Cenomanian) in west-central New Mexico: New Mexico Museum of Natural History and Science, Bulletin 14, p. 169-171.

Hunt, A.P. and Lucas, S.G., 1992, Stratigraphy, paleontology and age of the Fruitland and Kirtland formations (Upper Cretaceous), San Juan Basin, New Mexico: New Mexico Geological Society, Guidebook 43, p. 217-239.

Hunt, A.P. and Lucas, S.G., 1993, Cretaceous vertebrates of New Mexico: New Mexico Museum of Natural History and Science, Bulletin 2, p. 77-91.

Hunt, A. P. and Lucas, S. G., 1996, A reevaluation of the vertebrate ichnofauna of the Mesa Rica Sandstone and Pajarito formations (Lower Cretaceous: late Albian), Clayton Lake State Park, New Mexico: New Mexico Geology, v. 18, p. 57.

Hunt, A.P. and Lucas, S.G., 1998, Tetrapod ichnofaunas from the Lower Cretaceous of northeastern New Mexico, USA: New Mexico Museum of Natural History and Science, Bulletin 14, p. 163-167.

Hunt, A.P. and Watts, B.R., 1996, Evidence of gregarious behavior in dinosaurs from a new tracksite, Mesa Rica Sandstone, (Lower Cretaceous), northeastern New Mexico: New Mexico Geology, v. 18, p. 56-57.

Kirkland, J.I., Lucas, S.G. and Estep, J.W., 1998 Cretaceous dinosaurs of the Colorado Plateau: New Mexico Museum of Natural History and Science Bulletin 14, p. 79-89.

Lawton, T.F., Basabilvazo, G.T., Hodgson, S.A., Wilson, D.A., Mack, G.H., McIntosh, W.C., Lucas, S.G. and Kietzke, K.K., 1993, Laramide stratigraphy of the Little Hatchet Mountains, southwestern New Mexico: New Mexico Geology, v. 15, p. 9-15.

Lehman, T.M., 1981, The Alamo Wash Local Fauna: a new look at the old Ojo Alamo Fauna; *in* Lucas, S.G., Rigby, J.K. Jr. and Kues, B.S., eds., Advances in San Juan Basin paleontology: Albuquerque, University of New Mexico Press, p. 189-221.

Lockley, M.G. and Hunt, A.P., 1994, A track of the giant theropod *Tyrannosaurus* from close to the Cretaceous/Tertiary boundary, northern New Mexico: Ichnos, v. 3, p. 1-6.

Lockley, M. G., Holbrook, J., Hunt, A.P., Matsukawa, M. and Meyer, C., 1992, The dinosaur freeway: A preliminary report on the Cretaceous megatracksite, Dakota Group, Rocky Mountain Front Range and Highplains; Colorado, Oklahoma and New Mexico; *in* Flores, R., ed., Mesozoic of the Western Interior, SEPM Midyear Meeting Fieldtrip Guidebook, p. 39-54

Lockley, M.G., Lucas, S.G. and Hunt, A.P., 2000, Dinosaur tracksites in New Mexico: A review: New Mexico Museum of Natural History and Science, Bulletin 17.

Lozinsky, R.P., Hunt, A.P., Wolberg, D.L. and Lucas, S.G., 1984, Late Cretaceous (Lancian) dinosaurs from the McRae Formation, Sierra County, New Mexico: New Mexico Geology, v. 6, p. 72-77.

Lucas, S.G., 1981, Dinosaur communities of the San Juan Basin: A case for lateral variations in the composition of Late Cretaceous dinosaur communities; *in* Lucas, S.G., Rigby, J.K. Jr., and Kues, B.S., eds., Advances in San Juan Basin paleontology: Albuquerque, University of New Mexico Press, p. 337-393.

Lucas, S.G. and Estep, J.W., 1998, Lithostratigraphy and biostratigraphy of the Lower-middle Cretaceous Bisbee Group, southwestern New Mexico, USA: New Mexico Museum of Natural History and Science, Bulletin 14, p. 39-55.

Lucas, S.G. and Estep, J.W., 2000, Lower Cretaceous stratigraphy, correlation and paleogeography of New Mexico: New Mexico Museum of Natural History and Science, Bulletin 16, p. 45-61.

Lucas, S.G. and Hunt, A.P., 1989, *Alamosaurus* and the sauropod hiatus in the Cretaceous of the North American Western Interior: Geological Society of America, Special Paper 238, p. 75-85.

Lucas, S.G. and Hunt, A.P., 2000, The Lower Cretaceous ammonite *Mortoniceras equidistans* (Cragin) from the Mesa Rica Sandstone, Quay County, New Mexico: New Mexico Museum of Natural History and Science, Bulletin16, p. 97-100.

Lucas, S.G. and Lawton, T.F., 2000, Stratigraphy of the Bisbee Group (Jurassic-Cretaceous), Little Hatchet Mountains, New Mexico: New Mexico Geological Society, Guidebook 51, in press.

Lucas, S.G. and Sullivan, R.M., 2000, Stratigraphy and vertebrate biostratigraphy across the Cretaceous-Tertiary boundary, Betonnie Tsosie Wash, San Juan Basin, New Mexico: New Mexico Museum of Natural History and Science, Bulletin 17.

Lucas, S.G., Basabilvazo, G. and Lawton, T.F., 1990, Late Cretaceous dinosaurs from the Ringbone Formation, southwestern New Mexico: Cretaceous Research, v. 11, p. 343-349.

Lucas, S.G., Hunt, A.P. and Pence, R., 1988, Some Late Cretaceous reptiles from New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 122, p. 49-60.

Lucas, S.G., Kues, B.S. and González-León, C.M., 1995, Paleontology of the Upper Cretaceous Cabullona Group, northeastern Sonora: Geological Society of America, Special Paper 301, p. 143-165.

Lucas, S.G., Mack, G.H. and Estep, J.W., 1998, The ceratopsian dinosaur *Torosaurus* from the Upper Crtaceous McRae Formation, Sierra County, New Mexico: New Mexico Geological Society, Guidebook 49, p. 223-227.

Lucas, S.G., Estep, J.W., Boucher, L.D. and Anderson, B.G., 2000, Cretaceous stratigraphy, biostratigraphy and depositional environments near Virden, Hidalgo County, New Mexico: New Mexico Museum of Natural History and Science, Bulletin 16, p. 107-119.

Lucas, S.G., Holbrook, J., Sullivan, R.M. and Hayden, S.N., 1987a, Dinosaur footprints from the Cretaceous Pajarito Formation, Harding County, New Mexico: New Mexico Geological Society, Guidebook 38, p. 31-32.

Lucas, S.G., Hunt, A.P., Kietzke, K.K. and Wolberg, D.L., 1986, Cretaceous stratigraphy and biostratigraphy, Clayton Lake State Park, Union, County, New Mexico: New Mexico Geology, v. 8, p. 60-65.

Lucas, S.G., Mateer, N.J., Hunt, A.P. and O'Neill, F.M., 1987b, Dinosaurs, the age of the Fruitland and Kirtland Formations, and the Cretaceous-Tertiary boundary in the San Juan Basin, New Mexico: Geological Society of America, Special Paper 209, p. 35-50.

Lull, R.S. and Wright, N.E., 1942, Hadrosaurian dinosaurs of North America: Geological Society of America, Special Paper 40, 242 pp.

Ostrom, J.H., 1963, *Parasaurolophus cyrtocristatus* a crested hadrosaurian dinosaur from New Mexico: Fieldiana Geology, v. 14, p. 143-168.

Sullivan, R.M., 1987, A reassessment of reptilian diversity across the Cretaceous-Tertiary boundary: Natural History Museum of Los Angeles County, Contributions in Science, no. 391, 26 p.

Sullivan, R.M., 1997, A juvenile *Ornithomimus antiquus* (Dinosauria: Theropoda: Ornithomimosauria), from the Upper Cretaceous Kirtland Formation (De-na-zin Member), San Juan Basin, New Mexico: New Mexico Geological Society, Guidebook 48, p. 249-253.

Sullivan, R.M., 1999, *Nodocephalosaurus kirtlandensis*, gen. et sp. nov., a new ankylosaurid dinosaur (Ornithischia: Ankylosauria) from the Upper Cretaceous Kirtland Formation (upper Campanian), San Juan Basin, New Mexico: Journal of Vertebrate Paleontology, v. 19, p. 126-139.

Sullivan, R.M., 2000, *Prenocephale edmontonensis* (Brown and Schlaikjer) new comb. and *P. brevis* (Lambe) new comb. (Dinosauria: Ornithischia: Pachycephalosauria) from the Upper Cretaceous of North America: New Mexico Museum of Natural History and Science, Bulletin 17.

Sullivan, R.M. and Lucas, S.G., 2000a, *Alamosaurus* (Dinosauria: Sauropoda) from the late Campanian of New Mexico and its significance: Journal of Vertebrate Paleontology, v. 20, p. 400-403.

Sullivan, R.M. and Lucas, S.G., 2000b, First occurrence of *Saurornitholestes* (Theropoda: Dromaeosauridae) from the Upper Cretaceous of New Mexico: New Mexico Museum of Natural History and Science, Bulletin 17.

Sullivan, R. M. and Williamson, T. E., 1999, A new skull of *Parasaurolophus* (Dinosauria: Hadrosauridae) from the Kirtland Formation of New Mexico and a revision of the genus. New Mexico Museum of Natural History Bulletin 15, 52 p.

Williamson, T. E., 1997, A new Late Cretaceous (early Campanian) vertebrate fauna from the Allison Member, Menefee Formation, San Juan Basin, New Mexico: New Mexico Museum of Natural History, Bulletin 11, p. 51-59.

Williamson, T. E., 1999, A partial skull of a pachycephalosaurian dinosaur from the Upper Cretaceous Kirtland Formation, San Juan Basin, northwestern New Mexico: New Mexico Geology, v. 21, p. 44

Wolberg, D.L., Hall, J.P. and Bellis, D., 1988, First record of dinosaur footprints from the Fruitland Formation, San Juan Basin, San Juan County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 122, p. 33-34.

Wolberg, D.L., Lozinsky, R.P. and Hunt, A.P., 1986, Late Cretaceous (Maastrichtian - Lancian) vertebrate paleontology of the McRae Formation, Elephant Butte area, Sierra County, New Mexico: New Mexico Geological Society, Guidebook 37, p. 227-234.

Wolfe, D.G., 2000, New information on the skull of *Zuniceratops christopheri*, a neoceratopsian dinosaur from the Cretaceous Moreno Hill Formation, New Mexico: New Mexico Museum of Natural History and Science, Bulletin 17.

Wolfe, D. G. and Kirkland, J. I., 1998 *Zuniceratops christopheri* n. gen. & n. sp., a ceratopsian dinosaur from the Moreno Hill Formation (Cretaceous, Turonian) of west-central New Mexico: New Mexico Museum of Natural History and Science, Bulletin 14, p. 303-318.

Wolfe, D.G., Kirkland, J.I., Denton, R. and Anderson, B.G. 1997 A new terrestrial vertebrate record from the Moreno Hill Formation (Turonian, Cretaceous), west-central New Mexico: Journal of Vertebrate Paleontology, vol. 17, supplement to no. 3, p. 85A.