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

TRIASSIC DINOSAURS IN NEW MEXICO

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

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

Abstract—New Mexico is unique among Western states in possessing an extensive and diverse record of Triassic dinosaurs. This record is the world's most complete for understanding Triassic theropod evolution from Adamanian (latest Carnian) through Apachean (latest Norian-Rhaetian) time. New Mexico's record of Triassic theropods includes superposed faunas of Adamanian and Revueltian age, as well as the *Coelophysis* Lagerstätte of Apachean age. Holotype theropods from the Triassic of New Mexico include *Coelophysis bauri* (Cope), *Eucoelophysis baldwini* Sullivan and Lucas, and *Gojirasaurus quayi* Carpenter. Theropod ichnofossils include a single track from strata of Adamanian age in west-central New Mexico and numerous tracksites of Apachean age in the east-central and northeastern part of the state, all of which are dominantly theropod tracks assigned to the ichnogenus *Grallator*.

Other Triassic dinosaurs from New Mexico include isolated ornithischian teeth of both Adamanian and Revueltian age. Adamanian teeth include those assigned to *Tecovasaurus* from the Bluewater Creek Formation of west-central New Mexico and a diverse fauna, including a potentially new taxon, from the Los Esteros Member of the Santa Rosa Formation in north-central New Mexico. Revueltian teeth include the type specimens of *Revueltosaurus callenderi* Hunt and *Lucianosaurus wildi* Hunt and Lucas, both derived from the Bull Canyon Formation in east-central New Mexico. Records of Triassic prosauropods from New Mexico are limited to a single vertebral centrum of Revueltian age and tracks assigned to the ichnogenera *Pseudotetrasauropus* and *Tetrasauropus* from strata of Apachean age.

INTRODUCTION

New Mexico has a rich fossil record of Upper Triassic dinosaurs. These records, from strata of the Chinle Group, are known from across the northern half of the state (Fig. 1) and range in age from Adamanian (latest Carnian, approx. 228-218 Ma) through Revueltian (early-mid Norian, 218-208? Ma) to Apachean (latest Norian-Rhaetian?, 208?-202 Ma) (Fig. 2). The theropod record is especially rich, and is indeed the most complete record of Triassic theropod evolution in the world (Heckert and Lucas, 2000a). Other dinosaur records from the Upper Triassic are more fragmentary, but include diagnostic teeth of as many as six taxa of early ornithischians, including two holotypes. These, combined with a diverse track record, make New Mexico's Triassic dinosaur record one of the best in the world. Hunt (1994) and Hunt et al. (1995) have noted that most Chinle Group dinosaur occurrences are in distal floodplain or paleosol facies assemblages, so that the existing Chinle fossil record is biased away from dinosaur-bearing facies, although collecting efforts in the last two decades have attempted to rectify this bias.

Here, we review the fossil record of New Mexican dinosaurs in chronostratigraphic order (using the biochronology of Lucas, 1998) and comment on its significance. To identify different grades of theropods, we refer most theropods to the Herrerasauridae (*sensu* Novas, 1996), Ceratosauria *sensu lato*, or Coelophysoidea. In general, "ceratosaurs" are theropods that are more derived than herrerasaurids but not closely related to *Coelophysis*, *Syntarsus*, or *Eucoelophysis*. It is very likely that at least some of these records represent basal members of more advanced theropod clades, so "Ceratosauria" in this sense is not monophyletic. Coelophysoids include *Coelophysis*, *Syntarsus*, and *Eucoelophysis*. This assemblage is almost certainly monophyletic. The remaining Triassic dinosaurs from New Mexico are dominated by basal ornithischians, which we have made no effort to organize phylogenetically due to their scanty remains. We note, however, that isolated teeth of ornithischians are characterized by labio-lingual asymmetry, a constriction near the base of the

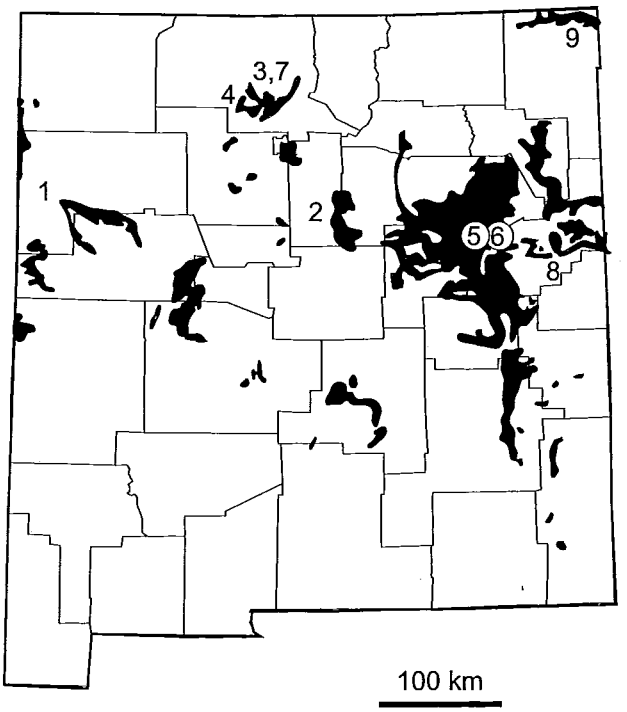

FIGURE 1. Outcrop map of Triassic strata in New Mexico showing fossil localities mentioned in the text. Localities are: (1) Fort Wingate; (2) Lamy; (3) Arroyo Seco (4) Gallina; (5) Bull Canyon; (6) Revuelto Creek; (7) Ghost Ranch; (8) Apache Canyon; (9) Sloan and Peacock Canyons.

age		lvf	faunas
Late Triassic	Rhaetian	Apachean	(9) Sloan &Peacock Canyons (8) Apache Canyon (7) Ghost Ranch
	Norian	Revueltian	(6) Revuelto Creek (5) Bull Canyon (4) Gallina (3) Arroyo Seco
	Carnian	Adamanian	(2) Lamy (1) Fort Wingate
		Otischalkian	Salitral Fm

FIGURE 2. Generalized biochronology of the Triassic dinosaur record in New Mexico. lvf = land vertebrate faunachrons, after Lucas (1998). Numbers of faunas refer to location map in Figure 1 and do not imply stratigraphic succession within a given lvf.

crown, and the presence of denticles inclined approximately 45° from the edge of the tooth (e.g., Sereno, 1991, 1998; Hunt and Lucas, 1994). New Mexico's prosauropod record is both depauperate and indeterminate.

In this paper, AMNH = American Museum of Natural History, New York; MNA = Museum of Northern Arizona, Flagstaff; NMMNH = New Mexico Museum of Natural History and Science, Albuquerque; UCMP = University of California Museum of Paleontology, Berkeley.

OTISCHALKIAN DINOSAURS

The oldest Late Triassic land-vertebrate faunachron (LVF) is the Otischalkian, which spans from early to early-late Carnian (Lucas, 1998). Demonstrably Otischalkian dinosaurs worldwide are fragmentary and rare, limited to *Pekinosaurus olseni* Hunt and Lucas from the Newark Supergroup and *Alwalkeria maleriensis* (Chatterjee) from the Maleri Formation of India (Hunt and Lucas, 1994; Heckert and Lucas, 1999). The only potentially Otischalkian dinosaur from New Mexico is an isolated theropod centrum from the Salitral Formation in north-central New Mexico (Hunt and Lucas, 1990; Fig. 3A-C), although this record could conceivably be of Adamanian age.

ADAMANIAN DINOSAURS

New Mexico's Adamanian dinosaur record includes a diverse body fossil record and a single track from Fort Wingate and more fragmentary records from the Los Esteros Member of the Santa Rosa Formation and the Garita Creek Formation in north-central New Mexico. These are New Mexico's oldest diagnostic dinosaur records.

Fort Wingate

New Mexico's most extensive Adamanian (latest Carnian) dinosaur record comes from the Bluewater Creek Formation in McKinley County, west-central New Mexico. A single tridactyl track (MNA V3303) from MNA locality 530 very low in the Bluewater Creek Formation was preliminarily described as an ornithischian by Hasiotis et al. (1994). We have re-examined this fossil and determined that it is indistinguishable from known specimens of *Grallator* (Heckert and Lucas, 2000b). *Grallator* is widely considered to represent the track of a theropod (e.g., Olsen et al., 1998). This is the oldest dinosaur track in the state, and one of the oldest dinosaur tracks anywhere.

Heckert (1997a,b) and Heckert and Lucas (2000b) described a moderately diverse, albeit fragmentary, body fossil assemblage from a single locality (NMMNH locality 2739) low in the Bluewater Creek Formation. This assemblage includes two fragmentary theropods as well as teeth assigned to *Tecovasaurus*, New Mexico's oldest ornithischian record. The theropods are not generically determinate, although they both appear to be more derived than the herrerasaurids. The second theropod, known only from a few fragmentary but highly derived centra, appears similar to theropod centra recently discovered in the Blue Mesa Member of the Petrified Forest Formation (NMMNH L-3764) in the Blue Hills of eastern Arizona by Stan Krzyzanowski.

Lamy

Hunt and Lucas (1995) described theropod metapodials and ornithischian teeth from the Los Esteros Member of the Santa Rosa Formation near Lamy, in Santa Fe County, north-central New Mexico. They also described fragmentary dinosaur material from the overlying Garita Creek Formation nearby (Hunt and Lucas, 1995). Here, we describe these and other remains in more detail.

There are three theropod specimens from the Los Esteros Member of the Santa Rosa Formation in the vicinity of Lamy. NMMNH P-25749 (Fig. 3D-I) consists of the proximal end of the left pubis, proximal end of the left femur and miscellaneous elements that are concreted against the pubis. The femur may have been folded against the pubis medially, but has since been separated.

The femur of NMMNH P-25749 (Fig. 3D-E) is crushed and slightly eroded but preserves important features that clearly indicate its identity. It is bowed anteromedially, as in most coelophysoids. The upper part of the shaft is compressed lateromedially, and much of this is probably due to crushing. The femoral head is offset and the proximal-most end is eroded. There is no evidence of a groove as in *Eucoelophysis* (Sullivan and Lucas, 1999). The lesser trochanter is broken along its proximal surface, however, most of it is preserved, and clearly indicates that it is robust, forming a major surface attachment on the upper lateral part of the femora immediately distal to the head.

The proximal end of the left pubis is well-preserved, but distally the element is covered by concreted sediment and other unidentified elements that belong to part of the left and/or right femoral shafts (Fig. 3F-I). The surface of the proximal end of the left pubis is rugose, and the articular surfaces (iliac and acetabular facets) are not well-defined. However, the acetabular facet is depressed, and the superior region that corresponds to the iliac facet is flat by contrast. Along the inferior margin, there is a protuberance that is the ischial facet (Sullivan and Lucas, 1999, fig. 4d-e). There is no ischio-acetabular groove between it and the superiorly-situated acetabular facet. However, medial to the ischial facet lies another ventrally-sheared protuberance that appears to join the incomplete pubo-ischiac plate. It consists of a thin surface that is broken along its ventral surface. Based on the alignment of the broken ventral surface of the pubo-ischiac plate and its correspondence with the medially-situated protuberance, there was apparently a well-developed obturator foramen.

Comparisons to *Chindesaurus bryansmalli* Long and Murry cannot be made with any confidence due to the inadequate description given by Long and Murry (1995) with respect to the pubic and femoral elements. However, based on illustrations of the

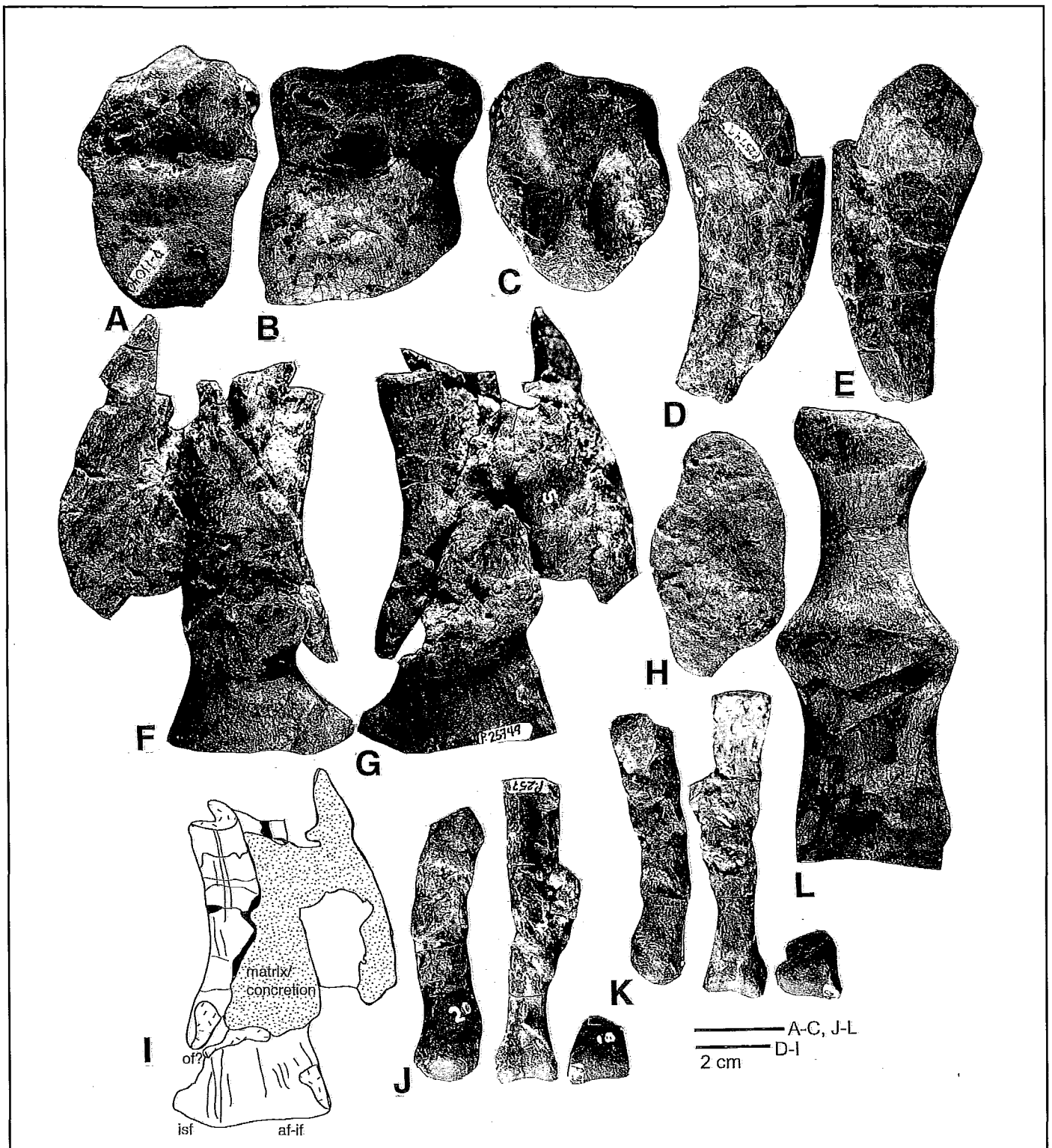

FIGURE 3. Representative late Carnian (Otischalkian?-Adamanian) theropod fossils from the Upper Triassic series of New Mexico. **A-C**, NMMNH P-11040, theropod? vertebra from NMMNH locality 913, Salitral Formation, north-central New Mexico; **D-I**, P-25749, theropod, NMMNH locality 149, Los Esteros Member, Santa Rosa Formation. **D-E**, head of left femur in anterior and posterior views; **F-H**, photographs of incomplete right pubis in medial (**F**), lateral (**G**), and proximal (**H**) views; **I**, interpretative sketch of G at 4/5 size; **J-K**, NMMNH P-25790, podials from NMMNH locality 149 in anterior, **J**, and posterior, **K**, views; **L**, P-13066, two fused sacral centra from NMMNH locality 588, Los Esteros Member, Santa Rosa Formation.

femoral head (Long and Murry, 1995, fig. 187a-b), NMMNH P-25749 is more like that of *Eucoelophysis* and not like *Chindesaurus*, which has a more angular, square shape. Thus, NMMNH P-25749 conforms with "coelophysoid" morphology and is not an herrerasaurid.

Another Los Esteros Member theropod specimen is NMMNH P-25790, from NMMNH locality 149. It consists of five incomplete metatarsals, phalanx, and shaft fragments. It is uncer-

tain that all of the elements pertain to a single individual. However, we identify three incomplete elements as the distal ends of the left fourth, third, and second tarsometatarsals. These elements seem to articulate distally and are illustrated here (Fig. 3J-K). They conform in size to the holotype tarsometatarsals of *Eucoelophysis baldwini* illustrated by Sullivan and Lucas (1999). The shaft portions of metatarsals 4 and 3 are concreted and are distorted by postmortem crushing. They are nearly the same size as the holotype of *Eucoelophysis baldwini*, but there are no autapomorphic characters that would allow assignment to that taxon. Still, these elements support a coelophysoid identification, although a herrerasaurid referral remains possible. The other associated tarsometatarsal and phalangeal fragments are unidentifiable.

The final theropod specimen from the Los Esteros Member of the Santa Rosa Formation is NMMNH P-13006, from NMMNH locality 585. This specimen consists of two incomplete, fused, sacral centra with portions of the synsacrum preserved in a concretion (Fig. 3L). The hollow nature of the centra support assignment to the Theropoda, but this specimen is unprepared, and the morphology of the synsacrum is obscured by matrix. Only the ventral surfaces of the vertebrae are visible. The vertebrae have a relatively pronounced hourglass shape with broad articular facets across the centra. The dorsal surface is broken, and the bone that is exposed is irregular and impossible to decipher in its present condition. The specimen may pertain to a large coelophysoid or herrerasaur.

According to our current understanding of ornithischian dinosaurs, several teeth from NMMNH locality 1171 in the Los Esteros Member of the Santa Rosa Formation can be assigned to two existing species and while others probably represent a new species of *Revueltosaurus*. Specifically, NMMNH P-32626 is a nearly complete tooth of *Pekinosaurus galtoni*. This tooth crown is almost as mesio-distally long as it is tall, with fine denticles arranged at 45-60° angles to the edge of the tooth. This tooth lacks a cingulum and conforms to the description and illustrated specimens of *Pekinosaurus* (Hunt and Lucas, 1994, fig. 12.3H-J). Additional ornithischian teeth from NMMNH 1171 (NMMNH P-32622, 32624, 32625) are taller, strongly asymmetric in mesial and distal views yet nearly symmetric in lingual view, and possess fine denticles on narrow surfaces mesial and distal to a pronounced median ridge. In these respects, these teeth conform closely to the published description and illustrations of *Galtonia gibbidens* (Cope) provided by Hunt and Lucas (1994: fig. 12.4A-F).

Hunt and Lucas (1995) only recognized a single taxon of ornithischian from NMMNH L-1171, based on tall ornithischian teeth with moderately large denticles on the mesial and distal edges with a prominent lingual cingulum. These teeth are identical to teeth from the Blue Mesa Member of the Blue Hills in eastern Arizona illustrated by Long and Murry (1995, figs. 193F-G, 194) but, *contra* Long and Murry (1995), are distinct from *Revueltosaurus callenderi* Hunt. Specifically, these teeth possess coarser denticles, a prominent lingual cingulum near the base of the tooth crown, and a slightly asymmetric distribution of denticles, with fewer denticles distally and more mesially. Additionally, premaxillary? teeth of this ornithischian are much taller and more strongly recurved than those of *R. callenderi*. Notably, these teeth are considerably larger than the associated teeth of *Pekinosaurus* and *Galtonia* and thus almost certainly represent a distinct morphotype. Indeed, these are the largest known Carnian (Otischalkian or Adamanian) ornithischian dinosaur teeth.

Clearly, the possibility exists that one or more of the ornithischian taxa based on teeth are distinguished by differences in tooth morphology attributable to differing position, ontogeny, and intraspecific variation. This is a particular concern at NMMNH locality 1171, where three distinct morphotypes occur as isolated teeth. However, this concern is moderated by the knowledge that locality 1171 appears to be a fairly typical Chinle microvertebrate site, with numerous taxa preserved very incompletely. Thus, we choose to continue to use the ornithischian dinosaur taxonomy of Hunt and Lucas (1994) to describe these distinct morphotypes.

These teeth are particularly significant because they facilitate correlation of Upper Triassic strata. *Pekinosaurus olseni* was previously known only from a single record of Otischalkian age, whereas the holotype and referred specimens of *Galtonia* were known from strata of Adamanian age (Hunt and Lucas, 1994). Therefore, the presence of both taxa in the Los Esteros member is the first record of their co-occurrence, and suggests that one or both have a stratigraphic range that extends through much of the Carnian. The larger, new taxon is more biostratigraphically and biologically important because it: (1) indicates the presence of moderately large (approximately 1 cm crown height) ornithischian dinosaurs in the Adamanian, and (2) facilitates correlation of the Adamanian Los Esteros member with the Blue Mesa Member of the Petrified Forest Formation in the Blue Hills of Arizona, also of undoubted Adamanian age.

The theropod from the Garita Creek Formation consists of centra, metapodials, and an ungual phalanx in the collections of the Museum of Comparative Zoology at Harvard (Hunt and Lucas, 1995). This taxon is, like the Fort Wingate theropods, too fragmentary to assign to a genus (Hunt et al., 1998).

REVUELTIAN DINOSAURS

New Mexico's record of Revueltian dinosaurs is particularly diverse, and includes numerous theropods from the Painted Desert Formation in Arroyo Seco and at Gallina, as well as a diverse fauna from the Bull Canyon Formation at Revuelto Creek and Bull Canyon in the east-central portion of the state. Generally, the presence of abundant scutes of the aetosaur *Typothorax coccinarum* from theropod-bearing localities or closely correlative strata indicates a Revueltian age for most of these records.

Arroyo Seco

David Baldwin's original material that formed the basis of Cope's types of *Coelophysis* (=*Coelurus*) was derived from "Arroyo Seco" and "Gallina," Rio Arriba County, New Mexico (Colbert, 1989). We have long maintained that most, if not all, of this material was derived from the Petrified Forest Formation (e.g., Hunt and Lucas, 1991, 1993b; Sullivan, 1994; Sullivan et al., 1996). This argument is further borne out by the holotype of *Eucoelophysis baldwini*, which is from this stratigraphic level and to which at least part of Baldwin's material can be referred (Sullivan and Lucas, 1999).

The most recent additions to the Revueltian theropod fauna of Arroyo Seco are the theropods from the Snyder quarry, approximately 8 km northwest of the type locality of *Eucoelophysis* (Heckert et al., 2000). The smaller of these theropods is referable to *Eucoelophysis*, but remains distinct, particularly in details of the femur, from *E. baldwini*, and thus is recognized as a distinct and, as yet, unnamed species (Heckert et al., 2000). A second, larger theropod is known from the quarry as well, but only from a single fused tibia-fibula-astragalus-calcaneum that is clearly distinct from the tibiae and fibulae of the smaller theropod. Thus, the Revueltian theropod fauna of Arroyo Seco includes *Eucoelophysis baldwini*, *Eucoelophysis* n. sp., and another, larger theropod.

Gallina

At least some of Cope's (1887) type material of *Coelophysis* was collected by David Baldwin in the vicinity of Gallina, New Mexico (Colbert, 1989; Lucas and Hunt, 1992; Hunt and Lucas,

1993b; Sullivan et al., 1996). Unfortunately, all original association of these bones has been lost, so that the original type material of *Coelophysis* from Gallina and Arroyo Seco is completely and hopelessly intermixed. The only fossiliferous Triassic strata present in the vicinity of Gallina are badlands of the Petrified Forest Formation, where the general area of Baldwin's localities has been re-located (Lucas and Hunt, 1992; Hunt and Lucas, 1993b). Therefore, it seems probable that this unit yielded at least some of Cope's type material. Thus, at this time, it is only possible to say that there is a strong probability that Triassic theropods can be found in the Petrified Forest Formation near Gallina. This is the type locality of the aetosaur *Typothorax coccinarum*, which is an index taxon of the Revueltian LVF, indicating that the Gallina theropod(s) collected by Baldwin are also of Revueltian age.

Bull Canyon

Exposures of the Bull Canyon Formation near its type section in Guadalupe County, east-central New Mexico, have yielded two Triassic theropod specimens. Hunt (1994) identified a herrerasaur from the Bull Canyon Formation in Bull Canyon. This is herrerasaurid B of Hunt et al. (1998). Hunt (1994) and Hunt et al. (1998) note that this theropod is limited to the upper exposures of the Bull Canyon Formation, so it is the youngest known herrerasaur. Here we illustrate and describe two proximal femora from the Bull Canyon Formation.

NMMNH P-4126, the proximal end of a left femur from NMMNH locality 4126 (Fig. 4A-C), and NMMNH P-4415 (Fig 4D-F), the proximal end of a right femur from NMMNH locality 134, are distinct in that they are, in part, characterized by a squared-off femoral head with a pronounced medial offset. These characters compare readily to the holotype of *Chindesaurus bryansmalli* (see Long and Murry, 1995, fig. 187). Indeed, Long and Murry referred NMMNH P-4415 to *Chindesaurus bryansmalli* when they named that taxon. The Bull Canyon Formation is clearly of Revueltian age, making these some of the youngest known herrerasaurids.

Revuelto Creek

Bull Canyon Formation badlands developed in the drainage of Revuelto Creek, Quay County, east-central New Mexico, have yielded a diverse dinosaur assemblage in recent years. Dinosaurs from Revuelto Creek include both theropods and basal ornithischians. The theropod record from Revuelto Creek includes some of the youngest known herrerasaurids as well as at least one ceratosaur, *Gojirasaurus quayi* Carpenter. Although fragmentary, these theropods and the theropod from Bull Canyon are important because they document: (1) the youngest occurrences of herrerasaurids worldwide (Hunt et al., 1998; Heckert and Lucas, 1999, 2000a); and (2) some of the larger known Triassic theropods (Carpenter, 1997).

Hunt (1994) identified an herrerasaurid from Revuelto Creek, which Hunt et al. (1998) listed as "herrerasaurid C." This fragmentary taxon appears dinosaurian, but is not generically diagnostic at this time, *contra* Murry and Long (1989) and Long and Murry (1995), who assign it to *Chindesaurus bryansmalli*. Instead, this specimen only documents the presence of herrerasaurs in the Bull Canyon Formation at Revuelto Creek (Hunt et al., 1998).

Isolated centra from the Bull Canyon Formation appear to represent fragmentary herrerasaurids and coelophysoids. In particular, vertebrae assigned to NMMNH P-4882 from NMMNH locality 177 may represent both an herrerasaurid and a coelophysoid (Fig. 4G-J). The larger of the two vertebrae may be a sacral vertebra of *Chindesaurus bryansmalli*. It is amphicoelous, hourglass-shaped, and has shallow pleurocoels on each side (Fig. 4G-H). Furthermore, the outer edge of the articular surfaces are striated and conform to the holotype vertebra of *Chindesaurus bryansmalli* illustrated by Long and Murry (1995, fig. 177). The second vertebra differs from *Chindesaurus* in that it is not hourglass-shaped, the centrum is taller than wide, and laterally constricted (Fig. 4I-J). Pleurocoels are lacking. The specimen appears to be a caudal of a coelophysoid theropod. (The ventral surface is nearly flat with two distinct lateral ridges that are positioned anteriorly). This specimen also superficially resembles the enigmatic archosauromorph *Vancleavea campi* Long and Murry (see Long and Murry, 1995, p. 196, fig. 197m).

Another Bull Canyon Formation specimen, NMMNH P-16844 from NMMNH locality 463, consists of an incomplete dorsal vertebra of a theropod (Fig. 4K-N). The centrum is a classic, spool-shaped amphiplatyan theropod centrum. Ventrally, it has a distinctive hourglass shape. Laterally, it has a single shallow pleurocoel. The neural spine and processes are broken. The specimen generally conforms to the holotype vertebrae of *Chindesaurus bryansmalli* (Long and Murry, 1995, fig. 178). However, the articular surfaces of both ends are slightly taller than wide.

Parrish and Carpenter (1986) first described a large (by Triassic standards) theropod from the Bull Canyon Formation. Carpenter and Parrish (1985), Hunt and Lucas (1989), Lucas and Hunt (1989), Parrish (1989), and Long and Murry (1995) also mentioned this theropod in various contributions. Hunt et al. (1998) identified this as "herrerasaurid A" from the Bull Canyon Formation. Carpenter (1997) formally named this taxon *Gojirasaurus quayi* and assigned it to the Ceratosauria on the basis of numerous characters of the vertebrae. *Gojirasaurus* is known from fragmentary ribs, centra, a scapula, a pubis, a tibia, and a metatarsal (Carpenter, 1997). Based on the tibia, Carpenter (1997) estimated a body length of 5.5 m, which would make this one of the largest Upper Triassic theropods, rivaled only by the two nearly complete specimens of *Liliensternus* from the Knollenmergel in Germany.

Revuelto Creek encompasses the type locality of two ornithischian dinosaurs as well. *Revueltosaurus callenderi* Hunt, 1989 is the largest Triassic ornithischian, and is known from numerous premaxillary? and maxillary-dentary teeth. Tooth crowns of *Revueltosaurus* routinely exceed 1 cm in height, and thus are the largest Triassic ornithischian teeth known (Hunt and Lucas, 1994; Hunt et al., 1998). Based on comparison to Triassic theropods, *Revueltosaurus* probably was on the order of 2-3 m body length.

A second ornithischian, *Lucianosaurus wildi* Hunt and Lucas, was discovered near Luciano Mesa in the general vicinity of Revuelto Creek. This highly autapomorphic taxon possesses small, low-crowned teeth with a distinct, posterior cusp. These teeth are only 1-2 mm long and less than 2 mm high, and thus are typical of the size of Triassic ornithischians (Hunt and Lucas, 1994). To date, *Lucianosaurus* is known only from the holotype and topotype specimens (Fig. 5).

APACHEAN DINOSAURS

Unlike the underlying rocks of the Chinle Group, rocks of Apachean age preserve more dinosaur footprint records than body fossils. Still, Apachean (late Norian-Rhaetian?) dinosaurs from New Mexico include the *Coelophysis* Lagerstätte at Ghost Ranch as well as the abundant tracks from multiple localities in eastern New Mexico, most notably Apache Canyon (east-central New Mexico) and several localities near Peacock Canyon in the northeastern corner of the state. Importantly, the New Mexican record of theropod tracks contains only *Grallator* and, possibly, closely related forms (*sensu* Leonardi and Lockley, 1995; also see Olsen et al., 1998; Hunt et al., 2000) (Fig. 6). There are no records of *Eubrontes* in these rocks, supporting their assignment to the uppermost Triassic as opposed to the lowest Jurassic (Silvestri and Szajna, 1993; Heckert and Lucas, 1999, 2000a; Lockley et al., 2000).

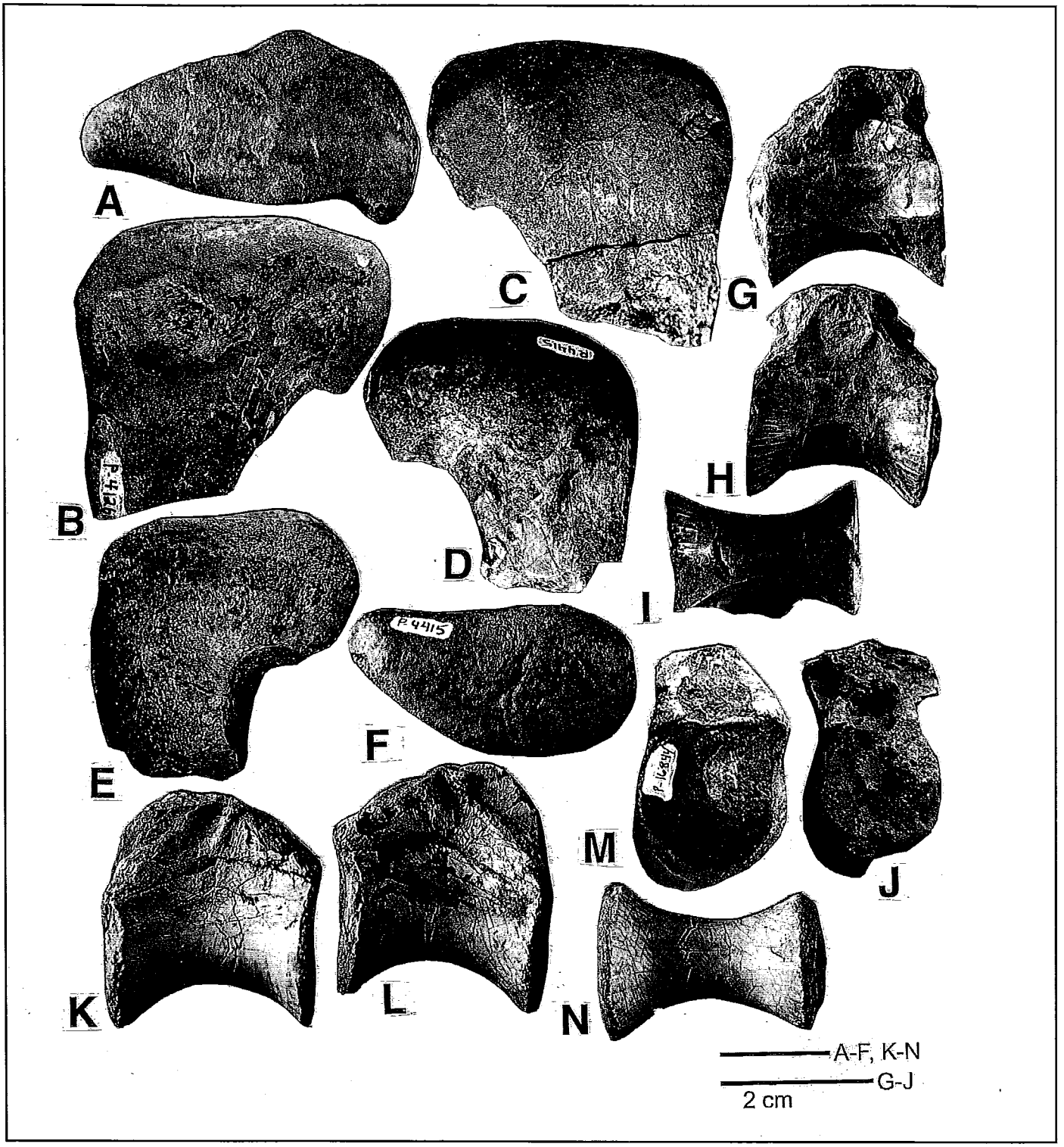

FIGURE 4. Representative early-mid Norian (Revueltian) theropod fossils from the Upper Triassic series of New Mexico. **A-C**, NMMNH P-4126, proximal end of theropod left femur from NMMNH locality 4126, Bull Canyon Formation, in proximal (**A**), posterior (**B**), and anterior (**C**) views; **D-F**, NMMNH P-4415, proximal end of left theropod femur from NMMNH locality 134, Bull Canyon Formation, in anterior (**D**), posterior (**E**) and proximal (**F**) views; **G-J**, NMMNH P-4882, theropod dorsal vertebra, NMMNH locality 177, Bull Canyon Formation, in lateral (**G-H**), ventral (**I**), and articular (**J**) views; **K-N**, NMMNH P-16844, herrerasaur vertebra from NMMNH locality 463, Bull Canyon Formation, in lateral (**K-L**), articular (**M**) and ventral (**N**) views.

Tracks assigned to *Pseudotetrasauropus* and *Tetrasauropus* (Fig. 6) from these localities may be the tracks of prosauropods, and would thus be the only confirmed prosauropod fossils in the state (Hunt et al. 1998; Lockley et al., 2000). All records of Apachean dinosaur fossils in the state are correlated by the presence of skulls of the phytosaur *Redondasaurus* in homotaxial strata. *Redondasaurus* is an index taxon of the Apachean LVF (Lucas, 1998). These are thus the youngest Triassic records of New Mexican dinosaurs and

also mark the stratigraphically lowest strata in the Chinle where dinosaurs are more common than other archosaurs.

Ghost Ranch

In 1947, George Whitaker, working with Edwin Colbert of the AMNH, discovered the *Coelophysis* Lagerstätte in the Rock Point Formation at Ghost Ranch. To date, at least 29 large blocks have been excavated from the quarry and preparation undertaken at a variety of North American museums (Colbert, 1989; Downs, 2000). To cover the history of study, stratigraphy, and taxonomic confusion associated with this quarry exceeds the scope of this paper, although we will address key questions regarding the stratigraphy and age of this deposit.

Various authors (e.g., Schwartz and Gillette, 1986, 1994; Colbert, 1989) have erroneously attributed the Whitaker quarry to the Petrified Forest Formation. Hunt and Lucas (1991, 1993a,b), Lucas and Hunt (1992), Sullivan et al. (1996), and others have amply demonstrated that the Whitaker quarry is stratigraphically high in the Rock Point Formation, approximately 30 m above the uppermost exposures of the Petrified Forest Formation. Indeed, the quarry is less than 40 m below the overlying Middle Jurassic Slick Rock Member of the Entrada Sandstone. This, the co-occurrence of the phytosaur *Redondasaurus* with the Whitaker quarry theropod, and the total lack of scutes of the aetosaur *Typothorax coccinarum* in the quarry, strongly support an Apachean age.

Also, we will simply highlight the fact that the Whitaker quarry theropod is potentially one of the best known, but currently poorly understood, non-avian theropods (see also Downs, 2000). The only other theropods for which we have even remotely comparable numbers of specimens area *Allosaurus* (Madsen, 1976) and *Syntarsus* (Raath, 1977). Even with many blocks incompletely prepared, the total number of known *Coelophysis* specimens probably exceeds 100 and may be substantially higher. Unfortunately, a modern, comprehensive treatment of the Whitaker quarry fauna is lacking at this time and a critical osteological study remains to be completed despite the efforts of Colbert (1989). Thus, a monographic treatment of this theropod along the lines of Madsen (1976), Raath (1977), Harris (1997), Tykoski (1998), and Madsen and Welles (2000) is sorely needed.

Apache Canyon-Mesa Redonda

Numerous Upper Triassic dinosaur tracks are present in exposures of the Redonda Formation at Mesa Redonda and in Apache Canyon, Quay County New Mexico. Most of these tracks are referable to *Grallator* or closely allied forms and thus probably represent the tracks of small theropod dinosaurs (Hunt et al., 1989, 2000; Hunt and Lucas, 1993a). Additional tracks assigned to *Pseudotetrasauropus* probably represent a prosauropod trackmaker, although this association is less clear (Hunt et al., 1989; Hunt and Lucas, 1993a; Lockley and Hunt, 1995).

Dry Cimarron/Peacock Canyon

Uppermost Chinle Group outcrops in the Dry Cimarron Valley of Union County, northeastern New Mexico, produce numerous dinosaur tracks, principally from the Sloan Canyon and Sheep Pen Formations. Exposures of the Sloan Canyon Formation in Peacock Canyon, Union County, northeastern New Mexico are locally fossiliferous and contain abundant dinosaur tracks of both *Grallator* and *Tetrasauropus* (Baird, 1964; Lockley, 1986; Conrad et al., 1987; Hunt and Lucas, 1993a; Lockley et al., 2000). A similar locality in the overlying Upper Triassic Sheep Pen Formation in the Dry Cimarron contains a similar ichnofauna (Conrad et al., 1987; Lockley et al., 1993). Likewise, Lockley and Hunt (1993)

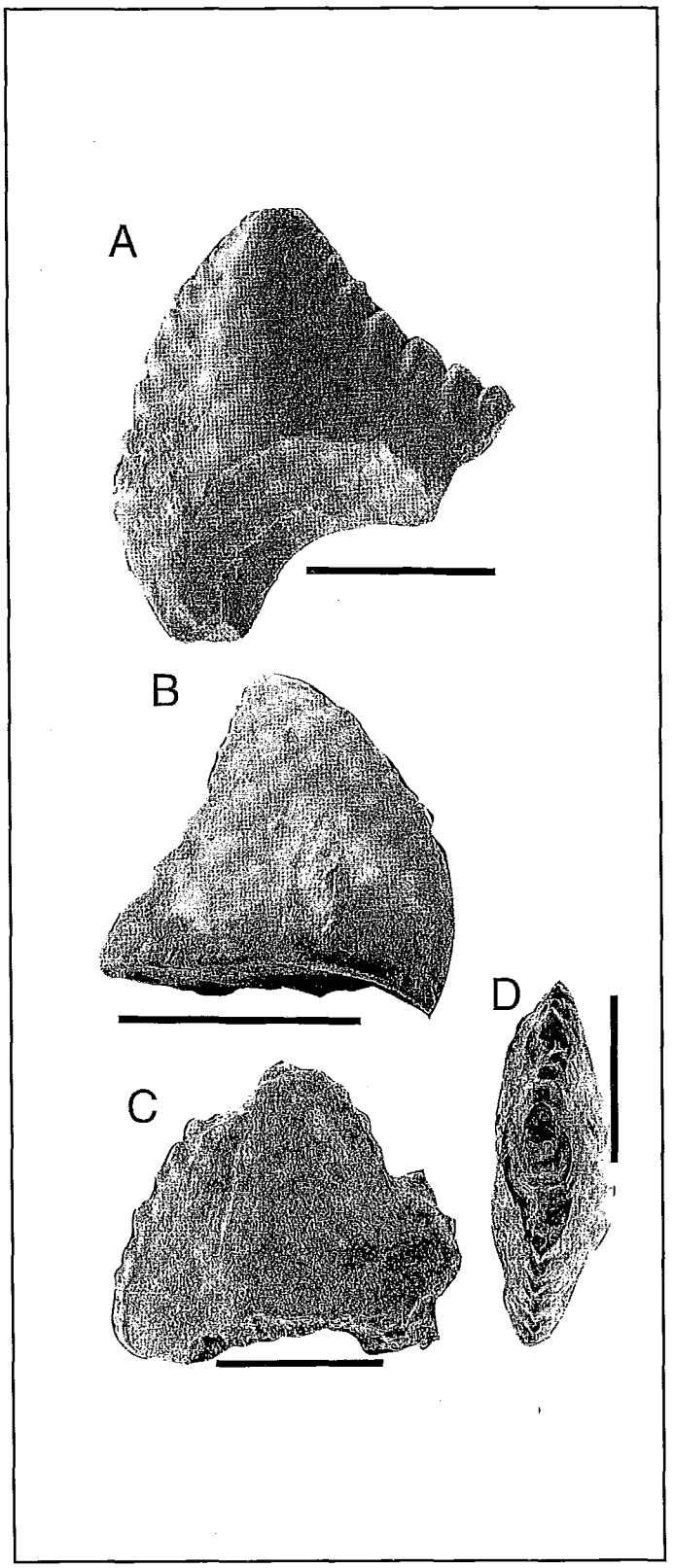

FIGURE 5. Scanning electron microscope photographs of ornithischian dinosaurs. A, NMMNH P-18402, *Tecovasaurus* sp. from the Bluewater Creek Formation near Fort Wingate, west-central New Mexico, in labial view; B, NMMNH P-18192, holotype of *Tecovasaurus murryi* from the Tecovas Formation of Texas for comparison; C-D, *Lucianosaurus wildi*, holotype tooth from the Bull Canyon Formation, east-central New Mexico, in C, labial, and D, occlusal views. Scale bars are one mm.

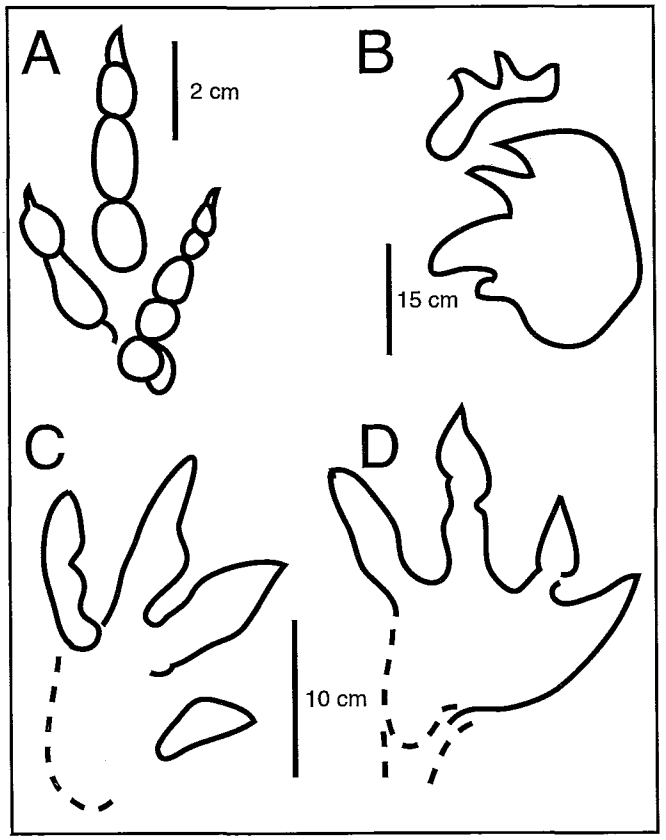

FIGURE 6. Triassic dinosaurian ichnogenera in New Mexico. **A**, *Grallator*, **B**, *Tetrasauropus*, **C-D**, *Pseudotetrasauropus*. (A after Olsen et al., 1998; B-D after Lockley et al., 2000).

reported trackways of *Grallator* and *Tetrasauropus* from the Sloan Canyon Formation at its type locality, and Lockley et al. (1993, 2000) reported *Grallator* and *Pseudotetrasauropus* from the Sheep Pen Formation in Sloan Canyon.

PROBLEMATIC DINOSAURS

In addition to the Otischalkian theropod caudal mentioned previously, there are a number of problematic Triassic dinosaur occurrences from throughout the state. Some of these are fragmentary remains that are probably dinosaurian, whereas others consist of records misidentified as dinosaurs by previous workers.

Heckert (1999) reported a partial theropod tibia from the Bluewater Creek Formation in the Lucero uplift. This specimen is of demonstrable Adamanian age, and appears to represent the proximal tibia of an herrerasaurid. However, the identification remains tentative at this time. Hunt et al. (1998) noted that centra assigned to *Spinosuchus* are known from the Los Esteros Member of the Santa Rosa Formation in central New Mexico, but this taxon requires repreparation and redescription and may not represent a dinosaur. Hunt et al. (1998) also noted that a dinosaur from the San Pedro Arroyo Formation reported near Socorro by Case (1916) was based on a phytosaur femur.

Specimens of the putative ornithomimosaur *Shuvosaurus inexpectatus* Chatterjee, 1993 from Revueltian strata in New Mexico support Long and Murry's (1995) suggestion that this is actually the skull of a rauisuchian, probably *Chatterjeea* (Hunt et al., 1998). Hunt et al. (1998) also cited C. Gow (1993, pers. comm.) as identifying a single prosauropod centrum from the Bull Canyon Formation in east-central New Mexico. Hunt (1994) and Hunt et al. (1998) noted the presence here of a derived theropod with nearly completely conjoined pubes in the Barranca Creek badlands of the Bull Canyon Formation in Quay County.

Finally, Hunt et al. (1998) note that various centra from the Bull Canyon Formation assigned to *Chindesaurus bryansmalli* by Long and Murry (1995) are variously over- or misidentified. Specifically, they state: "Three other specimens referred by Long & Murry (1995) to *Chindesaurus* (NMMNH P-4415, P-16656, P-17325, P-22494) are incorrectly identified and actually pertain to the new herrerasaurid A [=*Gojirasaurus* Carpenter], a theropod? and an indeterminate herrerasaurid, respectively" (Hunt et al., 1998, p. 518). As stated previously, we believe that Long and Murry's assignment of NMMNH P-4415 to *Chindesaurus* is reasonable, although we otherwise agree with Hunt et al. (1998).

SIGNIFICANCE

New Mexico's record of Triassic dinosaurs is remarkable for its abundance, diversity, and stratigraphic succession of both body and trace fossils (Fig. 7). Certainly, the *Coelophysis* Lagerstätte offers more potential to provide information on the variation and anatomy of a theropod dinosaur than any other locality in the world. In addition to this record, New Mexico also has a surprising diversity of Triassic dinosaur records, including numerous different herrerasaurid and coelophysid theropods, and many as six species of ornithischians. Importantly, these records can be stratigraphically ordered from Adamanian through Apachean time, thus providing one of the most comprehensive timelines of Triassic dinosaur evolution. Additionally, although the Adamanian and putative Otischalkian dinosaurs from New Mexico are among the world's oldest dinosaurian taxa, Revueltian records of theropods from New Mexico include some of the youngest known herrerasaurids. The trace fossil record of Triassic dinosaurs is depauperate in the older portion of the section, but Apachean ichnofaunas demonstrate the presence of abundant small theropods and provide the only strong evidence for prosauropod dinosaurs in New Mexico at this time. Importantly, it is only in the youngest Triassic strata of the state where dinosaurs become numerically more common than other archosaurs, in spite of recent attempts to focus collecting efforts on dinosaur-producing facies in older strata.

ACKNOWLEDGMENTS

The collaboration of numerous individuals, particularly A.P. Hunt, has greatly improved our understanding of the Triassic dinosaur record. Intensive collecting efforts by the New Mexico Friends of Paleontology since 1986 have profoundly improved the record of New Mexico's Triassic dinosaurs. Phil Bircheff discovered and collected the dinosaurs from NMMNH locality 1171. Deb Hill allowed us access to study MNA V 3303.

REFERENCES

Baird, D.E., 1964, Dockum (Late Triassic) reptile footprints from New Mexico: Journal of Paleontology, v. 38, p. 118-125.

Carpenter, K., 1997, A giant coelophysoid (Ceratosauria) theropod from the Upper Triassic of New Mexico, U.S.A.: Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, v. 205, p. 189-206.

Carpenter, K. and Parrish, J.M.,1985, Late Triassic vertebrates from

Revuelto Creek, Quay County, New Mexico: New Mexico Geological Society, Guidebook 36, p. 197-198.

Case, E.C., 1916, Further evidence bearing on the age of the red beds in the Rio Grande Valley, New Mexico: Science, v. 77, p. 708-709.

Chatterjee, S., 1993, *Shuvosaurus*, a new theropod: National Geographic Research and Exploration, v. 9, p. 274-285.

Colbert, E.H., 1989, The Triassic dinosaur *Coelophysis*: Museum of Northern Arizona, Bulletin 57, 160 p.

Conrad, K., Lockley, M. G., and Prince, N. K., 1987, Triassic and Jurassic vertebrate-dominated trace fossil assemblages of the Cimarron Valley region: Implications for paleoecology and biostratigraphy: New Mexico Geological Society, Guidebook 38, p. 127-138.

Cope, E.D., 1887, The dinosaurian genus *Coelurus*: American Naturalist, v. 21, p. 367-369.

Downs, A., 2000, *Coelophysis bauri* and *Syntarsus rhodesiensis* compared, with comments on the preparation and preservation of fossils from the Ghost Ranch *Coelophysis* quarry: New Mexico Museum of Natural History and Science, Bulletin 17.

Harris, J.D., 1997, A reanalysis of *Acrocanthosaurus atokensis*, its phylogenetic status, and paleobiogeographic implications, based on a new specimen from Texas: New Mexico Museum of Natural History and Science, Bulletin 13, 75 p.

Hasiotis, S.T., Dubiel, R.F., Conrad, K.I. and Lockley, M.G., 1994, Footprint evidence of North America's earliest dinosaur, Upper Triassic Heckert, A.B. and Lucas, S.G., 2000b, The dinosaur fauna of the Upper Triassic Bluewater Creek Formation (Adamanian:latest Carnian), Fort Wingate and vicinity, west-central New Mexico: New Mexico Museum of Natural History and Science, Bulletin 18.

Heckert, A.B., Zeigler, K., Lucas, S.G., Rinehart, L.F. and Harris, J.D., 2000, Preliminary description of coelophysoids from the Upper Triassic (Revueltian: early-mid Norian) Snyder quarry, north-central New Mexico: New Mexico Museum of Natural History and Science, Bulletin 17.

Hunt, A.P., 1989, A new ?ornithischian dinosaur from the Bull Canyon Formation (Upper Triassic) of east-central New Mexico: *in* Lucas, S.G. and Hunt, A.P., eds., Dawn of the age of dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 355-358.

Hunt, A.P., 1994, Vertebrate paleontology and biostratigraphy of the Bull Canyon Formation (Chinle Group, Upper Triassic) with a revision of the families Metoposauridae (Amphibia:Temnospondyli) and Parasuchidae (Reptilia:Archosauria) [Ph.D. dissertation]: Albuquerque, University of New Mexico, 404 p.

Hunt, A.P. and Lucas, S.G., 1989, Large podokesaurid dinosaur from the Upper Triassic Bull Canyon Formation, east-central New Mexico: New Mexico Journal of Science, v. 29, p. 118.

Hunt, A.P. and Lucas, S.G., 1990, Paleontology and biochronology of the Guidebook 46: 243-246.

Hunt, A.P., Lucas, S.G. and Kietzke, K.K., 1989, Dinosaur footprints from the Redonda Member of the Chinle Formation (Upper Triassic), east central New Mexico; *in* Gillette, D.D. and Lockley, M.G., eds., Dinosaur tracks and traces, Cambridge, Cambridge University Press, p. 277-280.

Hunt, A.P., Heckert, A.B., Lucas, S.G., Sealey, P.L. and Lockley, M.G., 1995, Vertebrate taphofacies of the Upper Triassic (Rhaetian) Redonda Formation, east-central New Mexico: New Mexico Geology, v. 17(2), p. 32.

Hunt, A.P., Lucas, S.G., Heckert, A.B., Sullivan, R.M. and Lockley, M.G., 1998, Late Triassic dinosaurs from the western United States: Geobios, v. 31, p. 511-531.

Hunt, A.P., Lucas, S.G., Lockley, M.G. and Heckert, A.B., 2000, Occurrence of the dinosaurian ichnogenus *Grallator* in the Redonda Formation (Upper Triassic: Norian) of eastern New Mexico: New Mexico Museum of Natural History and Science, Bulletin 17.

Leonardi, G., and Lockley, M.G., 1995, A proposal to abandon the ichnogenus *Coelurosaurichnus* Huene, 1941 - junior synonym of *Grallator*: Journal of Vertebrate Paleontology, v. 15 (supplement to no. 3), p. 40A.

Lockley, M.G., 1986, A guide to dinosaur tracksites of the Colorado Plateau and American Southwest: University of Colorado, Denver, Geology Department Magazine, Special Issue No. 1, 56 p.

Lockley, M. G. and Hunt, A. P., 1993, A new Late Triassic tracksite from

age		western New Mexico	north-central New Mexico	east-central New Mexico	northeastern New Mexico	Dinosaurian taxa
Late Triassic	Apachean		Rock Point Formation	Redonda Formation	Sheep Pen Formation Sloan Canyon Formation	*Coelophysis* *Grallator* *Pseudotetrasauropus* *Tetrasauropus*
	Revueltian		Petrified Forest Formation	Bull Canyon Formation		*Eucoelophysis* *Gojirasaurus* *Revueltosaurus* *Lucianosaurus*
	Adamanian	Bluewater Creek Formation		Garita Creek Formation		*Galtonia* *Pekinosaurus* *Tecovasaurus*
	Otis.		Salitral Formation?			

FIGURE 7. Correlation of New Mexican dinosaur-bearing Triassic strata. Chronology follows Figure 2.

the Sloan Canyon Formation (type section), Cimarron Valley, New Mexico: New Mexico Museum of Natural History and Science, Bulletin 3, p. 279-283.

Lockley, M.G., and Hunt, A.P., 1995, Dinosaur tracks and other fossil footprints of the western United States. Columbia University Press, 338 p.

Lockley, M. G., Santos, V. F. and Hunt, A. P., 1993, A new Late Triassic tracksite in the Sheep Pen Sandstone, Sloan Canyon, New Mexico: New Mexico Museum of Natural History and Science, Bulletin 3, p. 285-288.

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.

Long, R.A., and Murry, P.A., 1995, Late Triassic (Carnian and Norian) Tetrapods from the southwestern United States: New Mexico Museum of Natural History and Science Bulletin 4, 254 p.

Lucas, S.G., 1998, Global Triassic tetrapod biostratigraphy and biochronology: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 143, p. 347-384.

Lucas, S.G. and Hunt, A.P., 1989, Revised Triassic stratigraphy in the Tucumcari basin, east-central New Mexico; *in* Lucas, S.G. and Hunt, A.P., eds., Dawn of the age of dinosaurs in the American Southwest:: Albuquerque, New Mexico Museum of Natural History, p. 150-170.

Lucas, S.G. and Hunt, A.P., 1992, Triassic stratigraphy and paleontology, Chama Basin and adjacent areas, north-central New Mexico: New Mexico Geological Society, Guidebook 43, p. 151-172.

Madsen, J.H. Jr., 1976, *Allosaurus fragilis*: a revised osteology: Utah Geological Survey, Bulletin 109, 163 p.

Madsen, J.H. Jr., and Welles, S.P., 2000, *Ceratosaurus nasicornis* (Dinosauria, Theropoda), a revised osteology: Utah Geological Survey, Miscellaneous Publication 00-02, 80 p.

Murry, P.A. and Long, R.A., 1989, Geology and paleontology of the Chinle Formation, Petrified Forest National Park and vicinity, Arizona, and a discussion of vertebrate fossils of the southwestern Upper Triassic; *in* Lucas, S.G. and Hunt, A.P., eds., Dawn of the age of dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 29-64.

Novas, F.E., 1996, Dinosaur monophyly: Journal of Vertebrate Paleontology, v. 16, p. 723-741.

Olsen, P.E., Smith, J.B. and McDonald, N.G., 1998, Type material of the type species of the classic theropod footprint genera *Eubrontes*, *Anchisauripus*, and *Grallator* (Early Jurassic, Hartford and Deerfield basins, Connecticut and Massachusetts, U.S.A.): Journal of Vertebrate Paleontology, v. 18, p. 586-601.

Parrish, J.M., 1989, Late Triassic tetrapods of the North American Southwest; *in* Lucas, S.G. and Hunt, A.P., eds., Dawn of the age of dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 360-374.

Parrish, J.M. and Carpenter, K., 1986, A new vertebrate fauna from the Dockum Formation (Late Triassic) of eastern New Mexico; *in* Padian, K., ed., The beginning of the age of dinosaurs: faunal change across the Triassic-Jurassic boundary: Cambridge, Cambridge University Press, p. 151-160.

Raath, M., 1977, The anatomy of the Triassic theropod *Syntarsus rhodesiensis* (Saurischia:Podokesauridae) and a consideration of its biology [Ph.D. dissertation]: Grahamstown, South Africa, Rhodes University, 353 p.

Schwartz, H.L and Gillette, D.D., 1986, Microstratigraphy and sedimentology of the *Coelophysis* Quarry (Upper Triassic, Chinle Formation) at Ghost Ranch, Abiquiu, New Mexico: Fourth North American Paleontological Convention, Abstracts with Progams, p. A41.

Schwartz, H.L., and Gillette, D.D., 1994, Geology and taphonomy of the *Coelophysis* quarry, Upper Triassic Chinle Formation, Ghost Ranch, New Mexico: Journal of Paleontology, v. 68, p. 1118-1130

Sereno, P.C., 1991, *Lesothosaurus*, "fabrosaurids," and the early evolution of Ornithischia: Journal of Vertebrate Paleontology, v. 11, p. 168-197.

Sereno, P.C., 1998, A rationale for phylogenetic definitions, with application to the higher-level taxonomy of Dinosauria: Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, v. 210, p. 41-83.

Silvestri, S.M., and Szajna, M.J., 1993, Biostratigraphy of vertebrate footprints in the Late Triassic section of the Newark basin, Pennsylvania: reassessment of stratigraphic ranges: New Mexico Museum of Natural History, Bulletin 3, p. 439-445.

Sullivan, R.M., 1994, Topotypic material of *Coelophysis bauri* (Cope) and the *Coelophysis-Rioarribasaurus-Syntarsus* problem: Journal of Vertebrate Paleontology, v. 14 (supplement to no. 3), p. 48A.

Sullivan, R.M., and Lucas, S.G., 1999, *Eucoelophysis baldwini*, a new theropod dinosaur from the Upper Triassic of New Mexico, and the status of the original types of *Coelophysis*: Journal of Vertebrate Paleontology, v. 19, p. 81-90.

Sullivan, R.M., Lucas, S.G., Heckert, A.B., and Hunt, A.P., 1996, The type locality of *Coelophysis*, a Late Triassic dinosaur from north-central New Mexico (USA): Paläontologische Zeitschrift, v. 70, p. 245-255.

Tykoski, R.S., 1998, The osteology of *Syntarsus kayentakatae* and its implications for ceratosaurid phylogeny [M.S. thesis]: Austin, University of Texas , 217 p.