



Triassic and Jurassic vertebrate-dominated trace fossil assemblages of the Cimarron Valley region--Implications for paleoecology and biostratigraphy

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TRIASSIC AND JURASSIC VERTEBRATE-DOMINATED TRACE FOSSIL ASSEMBLAGES OF THE CIMARRON VALLEY REGION: IMPLICATIONS FOR PALEOECOLOGY AND BIOSTRATIGRAPHY

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Abstract—Upper Triassic and Jurassic rocks of the Cimarron valley region of northeastern New Mexico and adjacent parts of Colorado and Oklahoma exhibit abundant, well-preserved ichnofaunas dominated by the tracks of reptiles.

The Late Triassic Dockum Group ichnofaunas, particularly those of the Sloan Canyon Formation, are the most diverse, and include the vertebrate ichnogenes *Apatopus*, *Brachychirotherium*, *Chirotherium*, *Coelurosaurichnus* and *Rhynchosauroides*, at least three invertebrate ichnotaxa including *Scoyenia*, and other distinctive but unnamed traces. The overlying Sheep Pen Sandstone exhibits three trace-bearing horizons that collectively exhibit only three named ichnotaxa, namely *Brachychirotherium*, *Grallator* and *Scoyenia*.

Whereas the Triassic ichnofaunas are exposed in the main Cimarron valley and its tributaries, Jurassic ichnofaunas in the Morrison Formation occur both in this valley and in the Purgatoire valley to the north. Preliminary stratigraphic correlations of Morrison Formation sections suggest that tracks probably occur in the lower part of the formation in both areas.

Because of the scarcity of biostratigraphically useful body fossils in these rocks, the ichnofaunas and associated stratigraphic and sedimentological information enhance our understanding of the paleoecology and probable biostratigraphic correlation of these units.

INTRODUCTION

The vertebrate and invertebrate trace fossils of the Cimarron valley region are among the most remarkable in North America. Upper Triassic rocks in the area expose the largest, continuously mapped, North American vertebrate tracksite known from this time period (Lockley, 1986a). Similarly, the Morrison Formation in the Purgatoire valley to the north also yields the largest mapped trackway assemblage currently known from the Jurassic of North America (Lockley et al., 1986). In addition, the Oklahoma Panhandle exhibits tracks from both periods in close stratigraphic juxtaposition on either side of the complex Triassic-Jurassic unconformity (Fig. 1). The sequence of ichnofaunas in this area is therefore important because it helps establish constraints on the duration of the systemic unconformity between the Triassic Sheep Pen Sandstone and the Jurassic Entrada Sandstone. This paper describes the various known tracksites and discusses the paleoecological and biostratigraphic implications of the ichnofaunas.

The history of study of trace fossils in the Cimarron valley region is limited. Only a few Upper Triassic Sloan Canyon Formation tracks from New Mexico have been examined in a small systematic study of museum specimens from the Peacock Canyon locality (Baird, 1964). All other sites discussed herein have been reinvestigated in the last few years (Lockley, 1986a, b). Our field investigations have focused on mapping extensive river-bed exposures and smaller outcrop sites. While these outcrops are vulnerable to severe erosional damage, as witnessed during the course of study, they currently provide the largest continuous track-bearing exposures hitherto reported in the U.S.A. Because of the threat of further erosion, it is important to map these sites to obtain a census of preservable trackway data.

Ultimately these tracksites afford the opportunity to gain unique paleoecological perspectives on representative Triassic and Jurassic paleocommunities from the Cimarron valley region. Few areas have as many ichnocoenoses in close stratigraphic and geographic proximity. Ichnocoenoses, defined as associations of trace fossils corresponding to biocoenoses, or communities (Häntzschel, 1975), are particularly important, though somewhat neglected, in paleoecological and paleo-environmental research. Their particular importance pertains to the fact that they are in situ records of the dynamic activity of living animals, at very specific locations, during very short intervals of time.

DOCKUM GROUP ICNOLOGY

In the Cimarron valley region, the Upper Triassic Dockum Group consists of the Baldy Hill, Travesser, Sloan Canyon and Sheep Pen

formations, in ascending order. The older Baldy Hill and Travesser formations are not discussed in this report because they lack known tracksites. The Sloan Canyon Formation typically is composed of vari-colored floodplain mudstones and siltstones with local channel sandstones. The overlying Sheep Pen Sandstone consists mainly of fluvial sandstones. Both formations are apparently restricted to the region around the Cimarron valley (Baldwin and Muehlberger, 1959).

Sloan Canyon Formation

The tracksite exposed in the Sloan Canyon Formation at Peacock Canyon, northeastern New Mexico, represents the only Dockum locality from which trace fossils had previously been described. Baird (1964) described *Rhynchosauroides* sp., cf. *Anchisauripus hitchcocki* and *Anomoepus* sp. from two small collections of track-bearing slabs (CMNH 10027A, B; AMNH 6338) curated by the Cleveland and American Museums of Natural History, respectively. However, the extent of the site in the field was unknown to Baird, and a systematic ichnological survey had not been made in the context of field relationships.

Initial field investigations revealed an extensive site (approximately 5,000 m²) with a diverse ichnofauna occurring in at least 12 different track-bearing beds in close stratigraphic succession (Lockley, 1986a, fig. 17; Figs. 2, 3). In addition, the site has yielded phytosaur teeth and other skeletal remains, *Neocalamites*-like plant impressions, root casts, conchostracans and bone-bearing, vertebrate-carnivore coprolites.

A brief overview of the depositional setting was given by Lockley (1986a, in press), who interpreted the site as an exhumed fluvial channel that had incised a sequence of floodplain mudstones (Fig. 3). Several distinctive lithofacies, each with an associated ichnocoenose, have been identified at the Peacock Canyon site.

The channel facies is characterized by white, ripple-marked, cross-laminated, medium-grained, quartzose sandstone. Only the large *Chirotherium* trackways and a few *Brachychirotherium* and therapsid trackways are found within this facies. The trackways are generally aligned either parallel to the exhumed channel or perpendicular to it (Fig. 3).

The overbank facies is composed of whitish gray-green, very thinly bedded, calcareous siltstones and fine sandstones that are laterally contiguous to the channel facies. Small *Rhynchosauroides* sp. tracks are abundant in this facies, and *Coelurosaurichnus* sp. and *Apatopus* occur also. Evidently the overbank facies was most suitable for the preservation of small tracks. This is because the very thin (<1 cm) siltstone and fine sandstone beds are separated by greenish clay drapes. Such

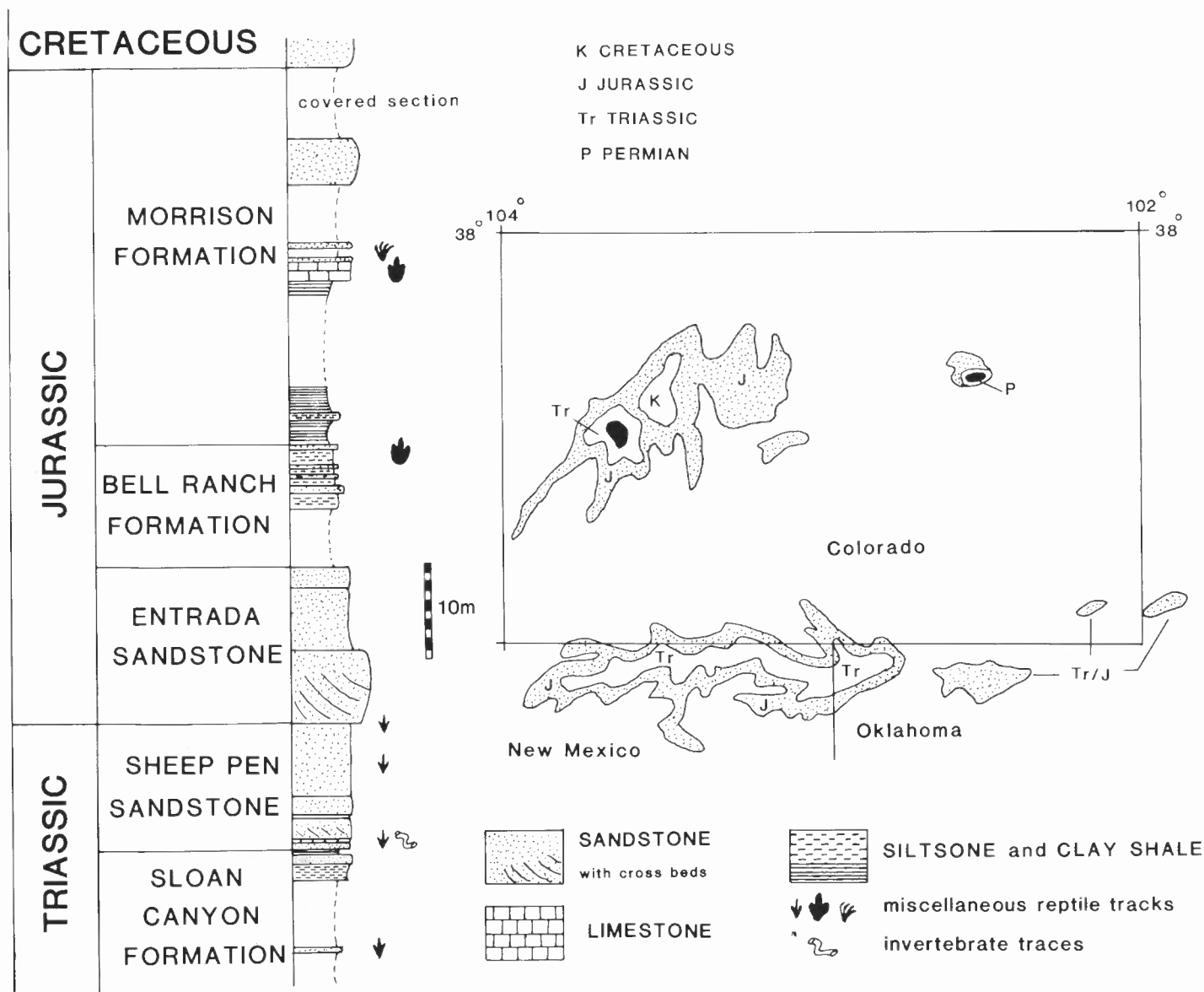


FIGURE 1. Outcrops of Triassic and Jurassic rocks in the Cimarron and Purgatoire valleys, with a representative stratigraphic section based on the Tucker Ranch locality. Note the frequency of track-bearing beds.

thinly bedded sediments are known to enhance the preservation of small, delicate tracks and underprints (Hitchcock, 1858).

Pink-to-salmon, very thinly planar-bedded, mud-cracked, fine calcareous siltstones dip toward the channel with the same inclination as the exhumed northwestern bank of the channel (Fig. 2). These sediments, which exhibit several closely spaced track-bearing horizons dominated by *Brachychirotherium* trackways, are also interpreted as part of the overbank facies assemblage. Because of their dip, and the cyclicity of the sequence, these sediments are interpreted to have accumulated on the flanks of an abandoned channel or pond-like depression subject to periodic wetting and desiccation.

Adjacent to the channel complex, and locally comprising passive channel-fill, are a series of purplish-red and green siltstones and mudstones that exhibit abundant rootcasts and indistinct tracks. These beds, which are interpreted as paleosols, developed on floodplain deposits lateral to the channel, and contain plant, vertebrate and invertebrate body fossils.

Similar occurrences of track and lithologic associations have been noted elsewhere in Upper Triassic rocks. Five localities in the Dockum Group and Chinle Formation yield *Brachychirotherium* traces in as-

sociation with tridactyl, dinosaur-like tracks in fluvial floodplain deposits. Lithologies described for the Milford site in New Jersey (Baird, 1957) resemble the fluvial channel and overbank facies at Peacock Canyon and yield similar vertebrate and invertebrate traces. Both sites are thus interpreted to represent fluvial depositional environments subjected to periodic overbank-flood events.

Ichnology

Archosaurs

Ichnofamily *Chirotheriidae* Abel 1939

Distinctive reptilian trackways allied to the ichnogenus *Chirotherium* Kaup 1835 are presently assigned to four distinct ichnogenera, two of which are represented in the Sloan Canyon Formation. *Chirotheriid* traces range from latest Permian (Conti et al., 1977) to latest Triassic (Lockley, 1986a) with European (Haubold, 1984), North American (Peabody, 1948), African (Olsen and Galton, 1984) and South American (Bonaparte, 1966) occurrences documented. The Sloan Canyon Formation material is important because it is unquestionably assignable to this biostratigraphically significant and widely distributed trace-family.

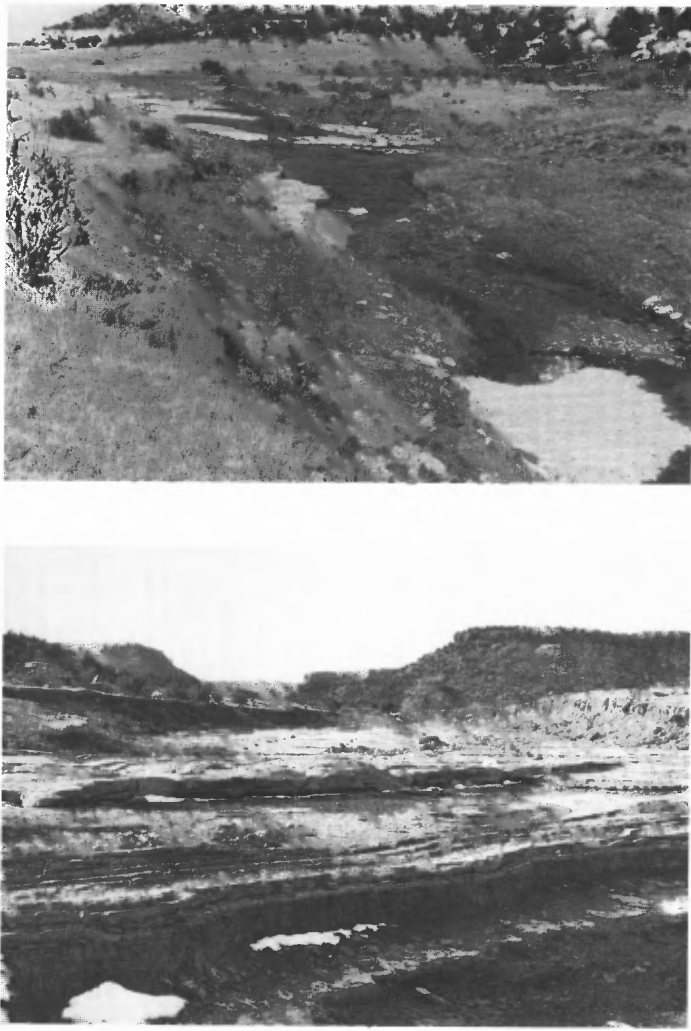


FIGURE 2. The Peacock Canyon tracksite, Sloan Canyon Formation. Above, view looking downstream. Below, view looking upstream showing the track-bearing beds.

All chirotheriid tracks and trackways are preserved as natural impressions (concave epireliefs) or associated underprints (see Häntzschel, 1975 for terminology).

***Brachychirotherium* sp.** (Figs. 4 and 5a)—Characterized by narrow trackways with manus-pes imprint “sets” that display slightly laterally rotated, digitigrade, tetradactyl (four-toed) manus tracks anteriomedially positioned with respect to the larger, anteriorly directed, semiplantigrade pentadactyl (five-toed) pes prints. Pes traces exhibit distinct digital and metatarsophalangeal padding of digits I–IV. Pes digit V is reduced, with coalesced digital and metatarsophalangeal padding obscuring details of its configuration. In the manus, digits II and III are subequal in length and longer than digit IV. Digit I is very short (Fig. 5a). In the pes, digit III is the longest with digits II and IV being subequal. Pes lengths reach a maximum of 180 mm; stride lengths are as much as 1,100 mm. Sharply impressed, undistorted manus impressions closely resemble *Brachychirotherium* (*Otozoum*) sp. figured without associated pes traces by Kuhn (1937), whereas both the manus and pes tracks of the Sloan Canyon form are remarkably similar to *Brachychirotherium coburgense* Aumann 1957 (Aumann, 1957, 1960), both from the middle Keuper (Km3–Km4) of the Germanic basin. Initially described as *?Anomoepus* sp. (Baird, 1964) and recently correctly reassigned (Baird, in Olsen and Galton, 1984, p. 101), this trace taxon is consistent with the ichnogenetic diagnosis given by Demathieu (1985).

***Chirotherium* sp.** (Figs. 4 and 5b)—Trackways composed of manus-

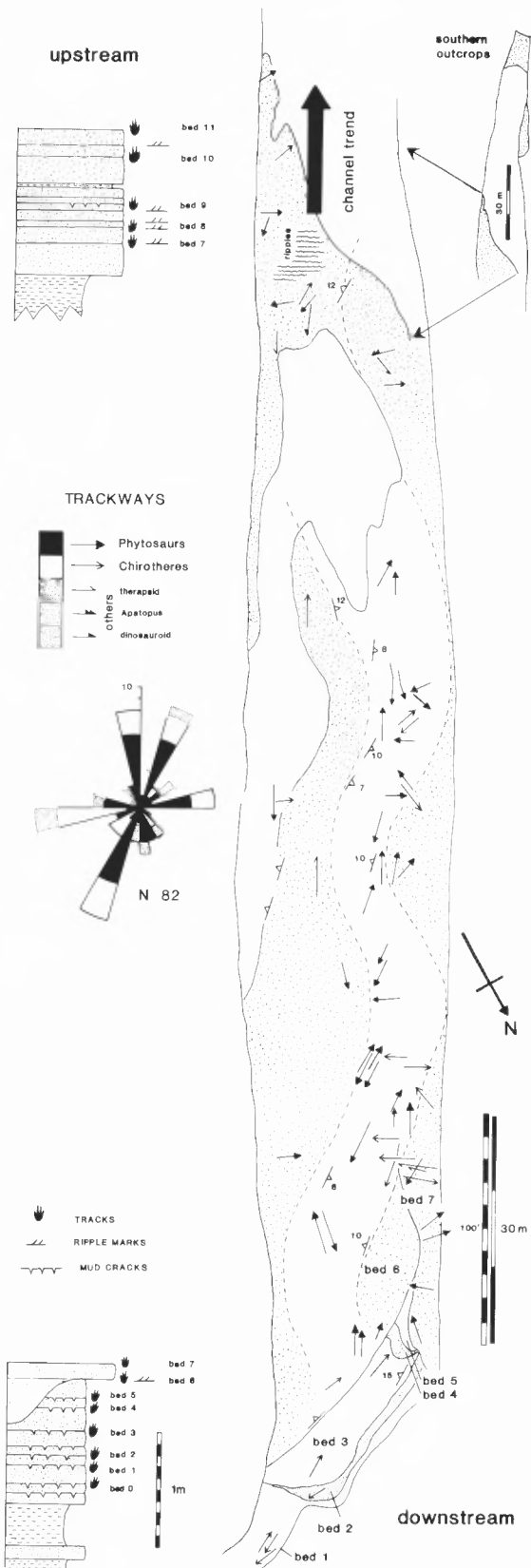


FIGURE 3. Map of the Peacock Canyon tracksite, Sloan Canyon Formation, showing sinuous exhumed channel, with dip symbols and distribution and orientation of reptile trackways. Orientations also summarized in rose diagram. Representative stratigraphic sections from the northern (downstream) and southern (upstream) ends of the site are shown at bottom and top, respectively. Note multiple track-bearing beds referred to in the text, and compare with Figure 2. Most of the trackways are associated with bed 7.

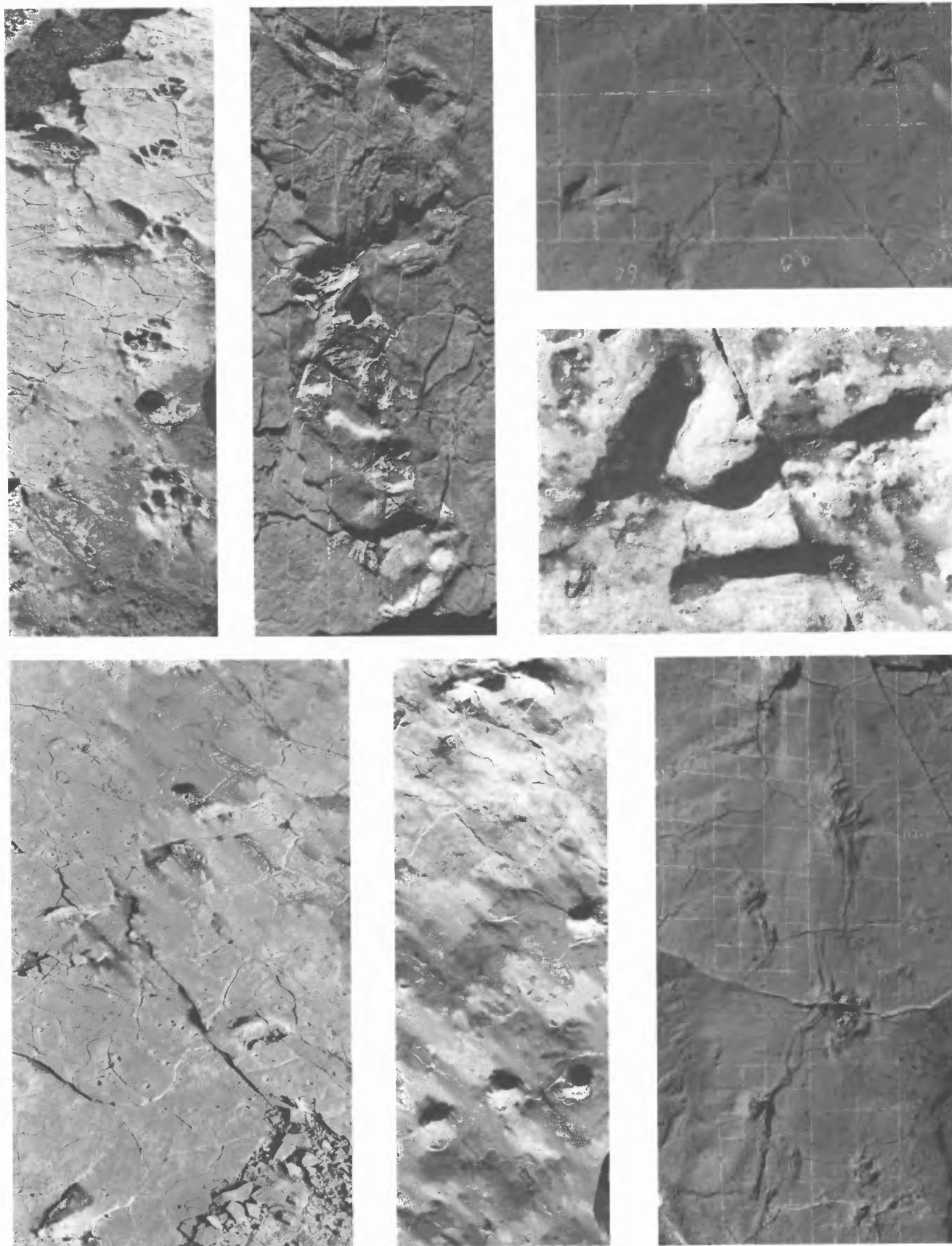


FIGURE 4. Representative tracks and trackways from the Peacock Canyon site, Sloan Canyon Formation. Above (left to right): *Brachychirotherium*, *Chirotherium* and *Coelurosaurichnus* (with detail of latter, middle right). Below (left to right): pavement with many *Rynchosauroides* tracks and a therapsid trackway, detail of other ?therapsid tracks and *Apatopus* trackway. All trackways have 55 cm lens cap or 10 cm chalk grid lines for scale, and are illustrated with line drawings in Figures 5 and 6.

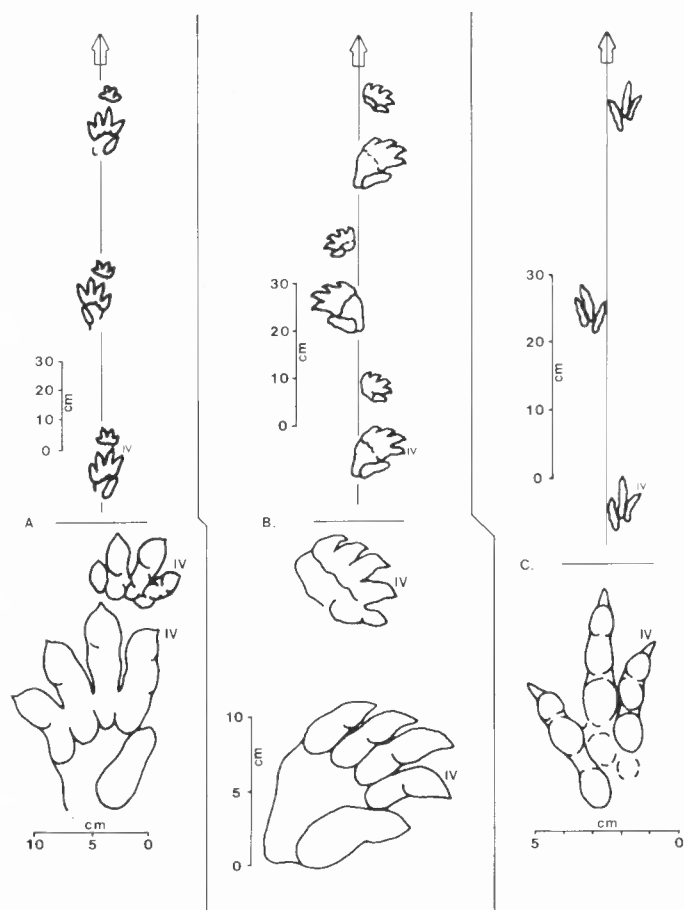


FIGURE 5. Tracks and trackways from Peacock Canyon, Sloan Canyon Formation. A, *Brachychirotherium* sp. trackway (above) and right manus-pes set (below) from UCDTRNM5(UN) and acetate overlays. B, *Chirotherium* sp. trackway (top) and right manus-pes set (below) from composite of UCDTRNM2,3,4(UN) plus acetate overlays. C, *Coelurosaurichnus* sp. trackway (top) and right pes (below) from UCDTRNM15(UN) plus acetate overlays.

pes sets in which both fore and hind feet are commonly much larger than the associated *Brachychirotherium* from the same assemblage. The trackways illustrated by Lockley (1986a, pl. 1 and fig. 16) exhibit pes tracks as much as 30 cm long. Manus-pes sets are also characterized by a considerable degree of outward rotation relative to the trail midline. "Juvenile" trackways of this form are therefore easily distinguishable from *Brachychirotherium* sp. Manus traces are semi-plantigrade, occasionally pentadactyl but more commonly tetradactyl, and imprints indicate an unreduced manus digit V. The length of digit IV is slightly less than III, and both exceed that of II. Digit I is the shortest, and displays no trace of an enlarged pollex. The manus impressions are positioned anteriomedially relative to the fully plantigrade pes tracks due to the outward rotation of the latter. Manus pace-angulation, however, may be as low as 90° (Lockley, 1986a, fig. 16), whereas pes angulation values are typically about 135°. Relative lengths for pes digits I–IV are similar to those cited for the manus, but with "claw impressions" in several trackways. A well-developed pes digit V, with both digital and metatarsophalangeal pad portions, and the appearance of a "beaded" scaled surface (squamation), provide additional support for the ichnogenic assignment.

These are the largest archosaurian tracks known from the Late Triassic of western North America. Bock (1952) commented on the large size of similar tracks in reference to isolated examples of the largely unknown *Chirotherium huberi* from the Lockatong Formation. Unlike Bock's specimens, the Peacock Canyon form is known from a large number of quite extensive trackways. Individual tracks are also com-

parable to the giant chirotheriids, *C. rex* Peabody 1948 and *C. moguinensis (moguinese)* Peabody 1948 from the lower and upper Moenkopi, respectively, and compare more closely with the later, younger ichnospecies.

A largely obscure trackway displaying a single crisp set of manus-pes impressions at Peacock Canyon may represent a third, distinct chirotheriid ichnotaxon, but this cannot be proved without supplementary material.

Dinosauroids

Although three-toed pes tracks are usually interpreted as dinosaurian in origin, a variety of non-dinosaurian thecodonts including ornithomischids and advanced rauisuchians such as *Postosuchus* (Chatterjee, 1985) as well as early true dinosaurs could have produced tridactyl tracks while in a bipedal mode of progression. Hitchcock (1858) observed that underprints often show fewer digit impressions than the actual footprints. Other factors to consider in the attempted differentiation of potential track makers include substrate conditions (depths of tracks), the presence or absence of manus prints, and the overall configuration of digit impressions. For these reasons we use the informal term "dinosauroid" in reference to tridactyliform traces. The Peacock Canyon tridactyl tracks probably represent true dinosaurs, but this cannot be proved at this stage of the investigation.

Coelurosaurichnus sp. (Fig. 4 and 5c)—The tracks and trackway segments excavated and cast from the Peacock Canyon site show crisp tridactyl pes impressions (concave epireleifs) characterized by marked asymmetry with respect to the position of digits II and IV on either side of digit III (see Fig. 5c). Digit IV impressions are more anteriorly situated than digit II impressions. Consequently, metatarsophalangeal pad impressions of digit II form the posterior (proximal) border of the footprint. Pace angulation is low, approximately 163°. This form is comparable to the type *Coelurosaurichnus toscanus* Huene 1941 from the Italian Keuper, recently refigured by Tongiorgi (1980). Material on weathered surfaces has suffered loss of detail. This leads to the possibility of other interpretations, and may account for the identification of tridactyl forms by Baird (1964) as cf. *Anchisauripus hitchcocki* Lull, and by Lucas et al. (1986) as *Grallator* sp.

Synapsida

Therapsids (Figs. 4 and 6a)

A solitary trackway at Peacock Canyon is morphologically distinct from similar-sized archosaur tracks, trails and underprints at this site. It is only vaguely reminiscent of other Late Triassic specimens studied by us, such as the traces of kannemeyeriid dicynodonts (*Pentasauropus* sp.) from the uppermost Chinle Formation of Utah (Lockley, 1986a, fig. 5). As individual traces compare more closely with the French early Middle Triassic ichnogenus *Cynodontypus* Ellenberger 1976, we tentatively refer this trackway to the Therapsida.

Other reptiles

Apatopus sp. (Fig. 4 and 6b)—Trackways found at this site correspond closely with *Apatopus lineatus* (Bock) Baird 1957 (Baird, in press) from the Newark Supergroup, but appear to represent either juveniles of that form or a different ichnospecies. Many quantifiable morphologic similarities exist between the Newark and Dockum examples, with pace angulations, inter-pes distances, relative digit lengths and orientations closely coincident. The two forms differ slightly in the degree of development of pes digit IV. Although digit IV is the longest in the Dockum form, it is relatively short compared with the Newark traces. The wide trackways of both eastern and western forms indicate a sprawling gait, very different from the narrow trackway patterns of chirotheres identified at the Peacock Canyon site (see above).

Rhynchosauroides sp. (Figs. 4 and 6c)—Many thousands of individual dissociated traces and a few manus-pes sets assigned to this ichnogenus (Baird, 1964) are known from this site, but discovery of complete, well impressed and non-interfering trackways remains elusive. We note a degree of size disparity between traces that allows us to distinguish between tracks attributed to adults and juveniles of a

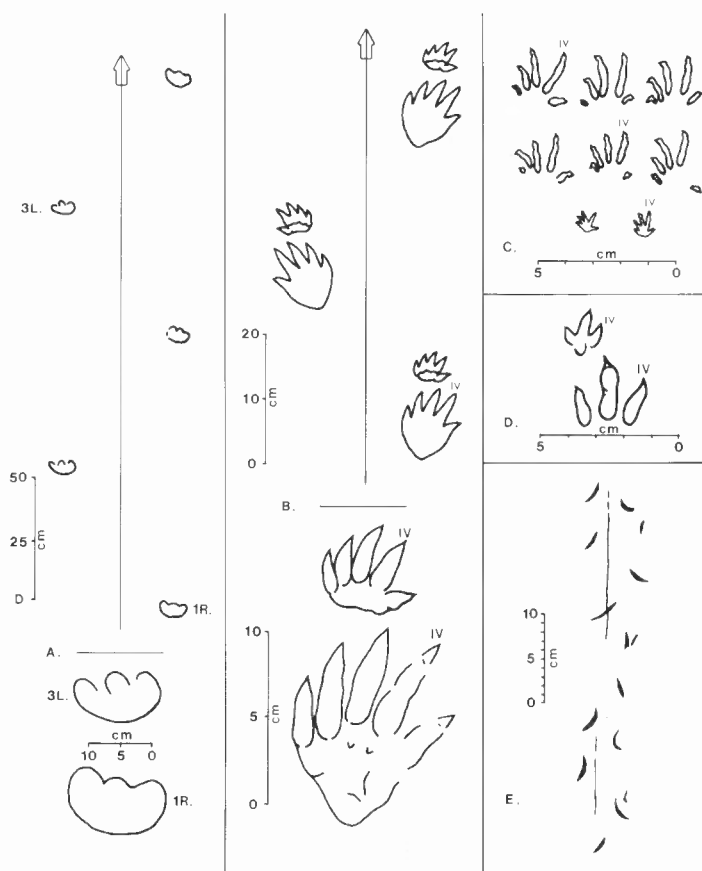


FIGURE 6. Tracks and trackways from Peacock Canyon, Sloan Canyon Formation. A. ?Therapsid trackway (top) and probable pes tracks (below) drawn from acetate overlays. B. *Apatopus* sp. trackway (top) and right manus-pes set (below) from UCDTRNM9(UN) and acetate overlays. C. *Rhynchosauroides* sp. from UCDTRNM10,11,12(UN) plus acetate overlays. D. *Coelurosaurichnus* sp. juvenile manus-pes set from UCDTRNM17(UN). E. cf. *Kouphichnium* sp. drawn from acetate overlay.

single reptilian taxon; for example, the traces figured by Baird approximate the observed maximum size (manus length = 20 mm), whereas we record a minimum manus length of 7 mm for juvenile tracemakers.

Associated with *Rhynchosauroides* sp. are numerous traces of other small reptiles (Baird, 1964, p. 120). The more common of these may represent tracks and trails of hatchling, quadrupedal *Coelurosaurichnus* sp. (Fig. 5d). Additional tracks are relegated to problematica.

Interpretation of the vertebrate ichnocoenosis

Although we are aware of the potential pitfalls of correlating tracks with zoological taxa, it is hoped that a century of Dockum Group vertebrate studies has provided sufficient supporting evidence for our interpretations of the trace data outlined above. In decreasing order of abundance at the Peacock Canyon site:

1. *Rhynchosauroides* sp. tracks are inferred to represent small (.25–1 m in length), sprawling though agile, terrestrial reptilian quadrupeds; probably represent extinct squamates (lizards) or sphenodontids.

2. *Chirotherium* sp. tracks are inferred to represent a moderately large to very large (2 to greater than 4 m in length), quadrupedal reptile. At first sight the trackways resemble those of small sauropods, especially where the outward rotation of pes digits is clearly seen. Although this similarity led us to consider prosauropods as possible trackmakers, the lack of a well developed digit I pollex claw appears to eliminate this group from serious consideration. Baird (1980) inferred that the Lower Jurassic trackway *Navahopus* could be assigned to a prosauropod trackmaker. The Sloan Canyon tracks, however, cannot be assigned to this ichnogenus, so alternative interpretations must be considered. The

pes-claw impressions suggest a carnivore. Although capable of clumsy terrestrial progression, as shown by the wide pace angulations, locomotor specializations of this trackmaker are consistent with an aquatic mode of life, as suggested by Lockley (1986a, in press), who interpreted the trackways as those of phytosaurs.

3. *Brachychirotherium* sp. probably represents a moderately large-sized (1–3 m) fully terrestrial, agile quadruped. A full discussion of the evidence for correlating the trackways with probable trackmakers is outside the scope of this paper. Several authors have debated this issue, concluding either that the trackmakers were aetosaurians or rauisuchians. We prefer to interpret the tracks as those of aetosaurians for the following reasons. Aetosaurs are common in the Late Triassic skeletal record of the western United States and elsewhere, and commonly occur with phytosaur remains. Estimates of hip height from *Brachychirotherium* trackways, using the apparent members method outlined in Leonardi (in press), tends to suggest skeletal proportions consistent with aetosaurian affinity. This conclusion is only tentative.

4. *Coelurosaurichnus* sp. is inferred to represent a small (.3–1.5 m), fully terrestrial thecodontian or early dinosaur. Probably a facultative biped in juvenile stages but an obligatory biped as an adult.

5. *Apatopus* sp. probably represents a moderate sized (1–1.5 m) sprawling terrestrial quadruped. The trackway pattern is less agile (i.e., more sprawling) than the most primitive chirotheriid ichnogenus *Synaptichnium* (Peabody, 1948; Haubold, 1984), thus indicating a very primitive gait. The trackway probably represents a sub-theodontian diapsid. Recent work on primitive and relatively advanced parasuchids strongly suggests, both from structural (Chatterjee, 1978) and functional studies (Parrish, 1986, in press) that the reptilian ichnogenus *Apatopus* does not correspond with phytosaurs. Our studies tend to confirm this view, as does our designation of the large *Chirotherium* as a phytosaur track.

6. Therapsida—probably a moderate sized (1.6 m) quadrupedal terrestrial therapsid of uncertain affinities.

Invertebrate ichnotaxa

We have recognized at least three invertebrate ichnotaxa in the sandstone facies at the Peacock Canyon site. The forms include cf. *Scoyenia*, a large *Kouphichnium*-like form and a smaller *Acanthichnus*-like form. The *Kouphichnium*-like form (Fig. 6e) is similar to the limuloid trace described by Caster (1944) from the Chinle Formation and has the central ?telson marks oriented parallel to the channel axis. The *Acanthichnus*-like form is also characterized by a series of chevron-like bifid V-shaped impressions, but the trail is only about 1 cm wide and lacks a central groove. Hitchcock (1858) described three ichnospecies in the ichnogenus *Acanthichnus*, the largest of which, *A. tardigradus*, resembles the Sloan Canyon form in trackway width and overall configuration. The trackmaker was probably an insect or other arthropod (Hitchcock, 1858; Häntzschel, 1975).

We have observed *Scoyenia*-like traces in association with vertebrate tracks at several other Late Triassic localities, including Sheep Pen Sandstone outcrops described below. The *Acanthichnus*-like form is also known from the Popo Agie Formation in northwestern Colorado, and the *Kouphichnium*-like form is known from the Chinle Formation of the Petrified Forest region.

Sheep Pen Sandstone

The Upper Triassic Sheep Pen Sandstone crops out in the vicinity of the Colorado-Oklahoma-New Mexico tristate area and ten km north of Kenton, Oklahoma reveals three different track-bearing localities. All occur within one km of each other, one in Oklahoma and two in Colorado (Figs. 1, 8–11). The Colorado localities are at the base and in the middle of the formation. The Oklahoma locality is at the top of the formation, immediately below the local disconformity with the overlying white, massive, crossbedded Entrada Sandstone, which is probably of Middle to Late Jurassic age. The three track-bearing horizons in the Sheep Pen Sandstone are conveniently referred to as the lower, middle and upper track beds. McLaughlin (1954, fig. 25) figured the unnamed small, conical hill on the state line in this area; our Figure 7

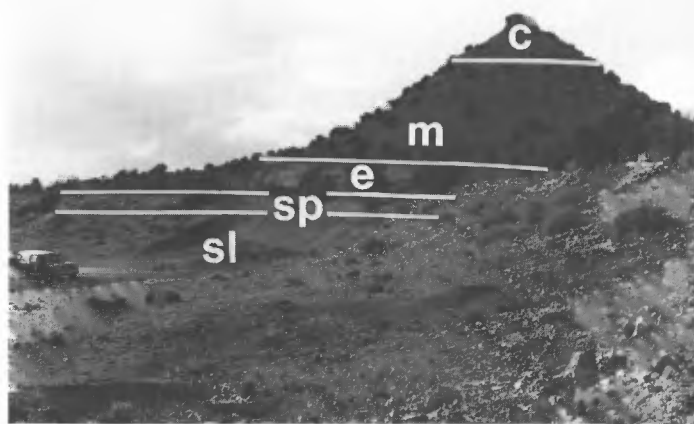


FIGURE 7. Mesozoic section at the Tucker Ranch locality on the Oklahoma-Colorado state line. Abbreviations are: sl = Sloan Canyon Formation, sp = Sheep Pen Sandstone, e = Entrada Sandstone, m = Bell Ranch and Morrison Formations and c = Cretaceous section.

is a different view showing the underlying Triassic strata. In this view the lower track bed is in the foreground, the middle track bed is to the right, just out of the picture, and the upper track bed is to the left, out of the picture.

Lower track bed

Outcrops in the small quarry northeast of Tucker Ranch reveal the well-exposed disconformable contact between the variegated Sloan Canyon Formation mudstones and siltstones and the massive, light-brown, ledgy sandstones of the overlying Sheep Pen Sandstone. The sandstones contain abundant invertebrate traces (Fig. 8), a few isolated dinosaur-like tracks and distinctive sole marks that are indicative of sheet flood scouring. The invertebrate traces represent a low diversity, possibly

monospecific, assemblage of backfilled, unbranched burrows ranging in diameter from 2–20 mm. We provisionally assign the specimens to the ichnospecies *Scoyenia* cf. *S. gracilis* White.

The dinosauroid tracks (Fig. 8) that are preserved as natural casts are assigned to the ichnotaxon *Grallator* (*Grallator*) sp. following Olsen and Galton (1984). The specimens referred to here are of small size (less than 7 cm long) with symmetrical disposition and sub-equal anterior projection of digits II and IV. Trackways are narrow (pace angulation approximately 176°), and, where fully impressed and well-preserved, metatarsophalangeal-pad trace IV is the posteriormost imprint of the proximal margin. We consider this form to be conspecific with specimens from the middle and upper track beds.

Middle track bed

Exposures a few hundred m northwest of the quarry reveal approximately forty tracks preserved as impressions on the surface of a sub-horizontal sandstone bed. The exposure has been mapped to resolve the tracks into at least 10 distinct trackways (Fig. 9), eight of which are attributable to *Grallator* (*Grallator*) sp. and two of which represent *Brachychirotherium* sp. The tridactyl trackmakers are inferred to have been of small to moderate (.6–1.3 m) size. The tracks are preserved as impressions (concave epireliefs) but are generally rather deep and indistinct, often with iron staining. Digits II and IV show greater divarication than in tracks from the lower and upper track beds; however, this probably represents a behavioral response to a soft substrate.

Upper track bed

West of Tucker Ranch, subhorizontal sandstone beds in the uppermost few cm of the formation exhibit several localized exposures with small dinosauroid tracks preserved as epireliefs on the bedding planes (Figs. 8, 10 and 11). The tracks are remarkable for the good preservation of digital pad impressions, and the trackway data they provide. Like the tracks in the lower track bed, they are assigned to the ichnotaxon *Grallator* (*Grallator*) sp. There are a few indications of the presence of larger trackmakers, questionably *Brachychirotherium*, but the impressions are too faint to be assessed with confidence.

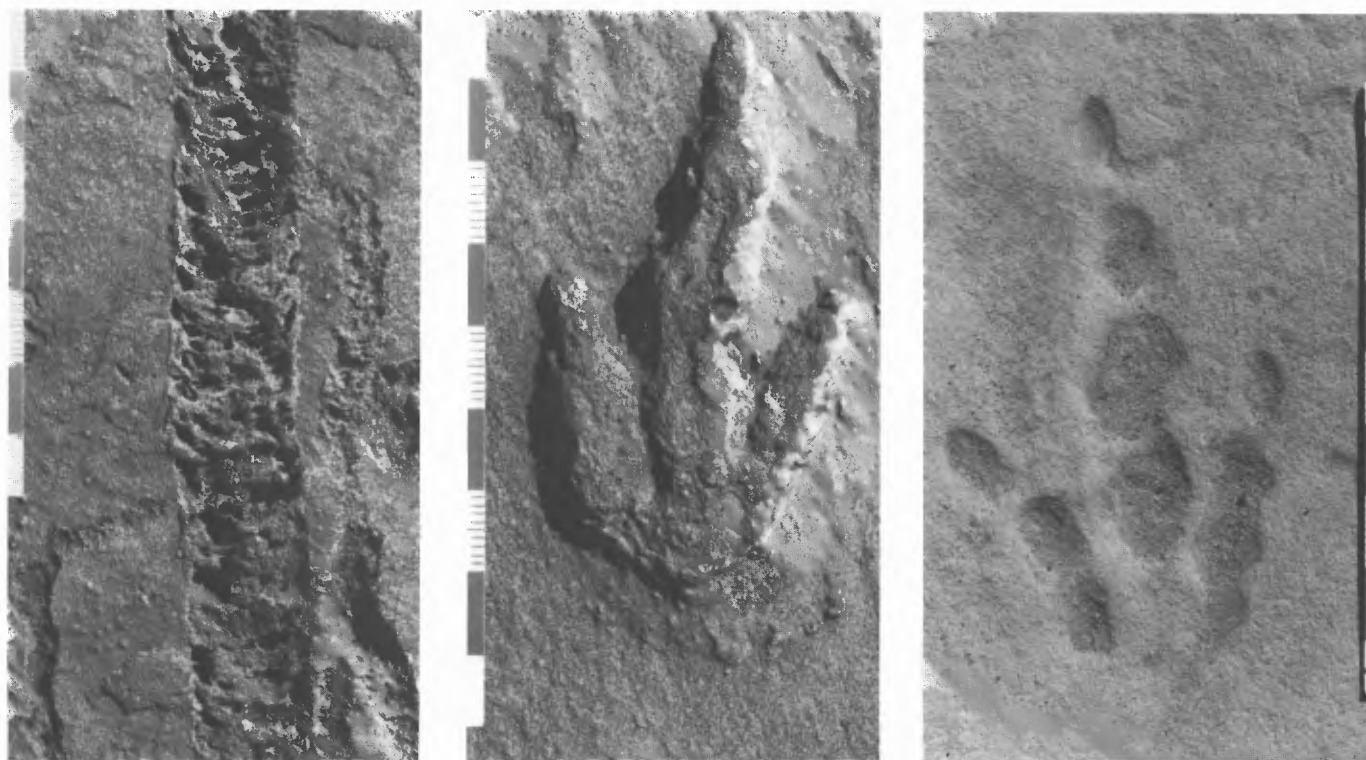


FIGURE 8. Representative trace fossils from the Sheep Pen Formation. Left: *Scoyenia* from the lower track bed. Middle and right: dinosaur tracks [*Grallator* (*Grallator*) sp.] from the lower and upper track beds respectively. Scale cards in cm.

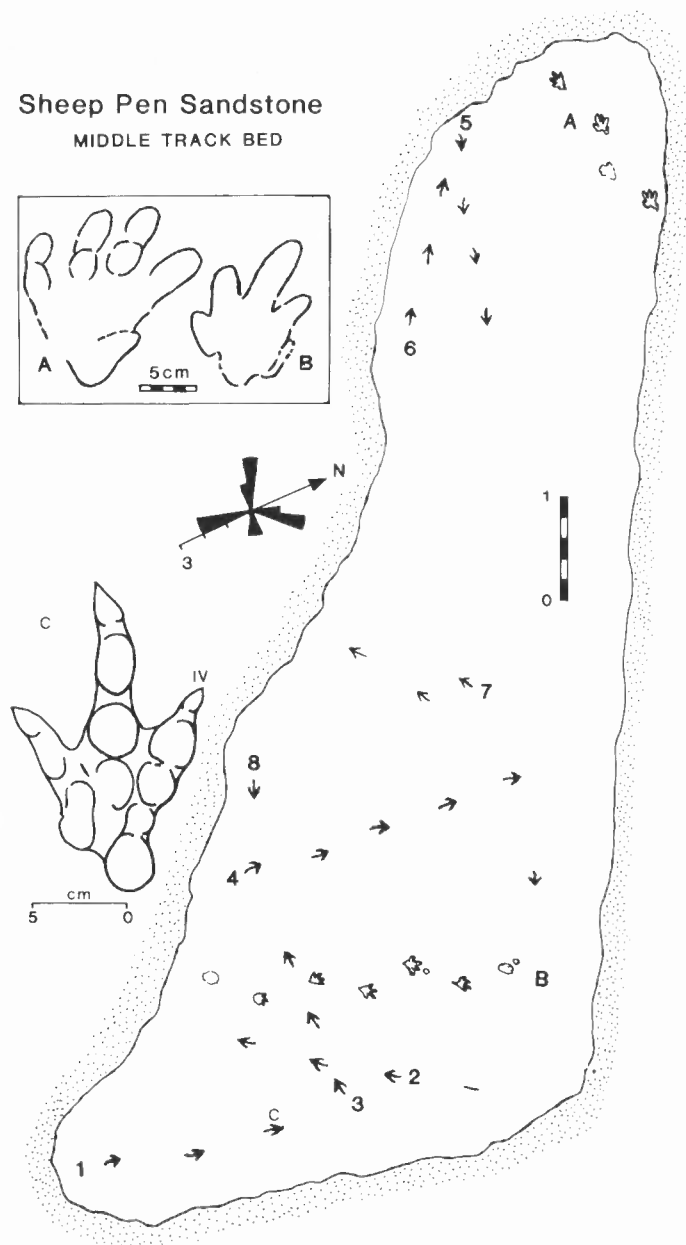


FIGURE 9. Map of vertebrate trackways in the middle track bed, Sheep Pen Sandstone. Inset (top) shows chirothere pes tracks, and rose diagram shows trackway orientations; lower inset (c) shows a *Grallator* (*Grallator*) track drawn from plaster replica.

Interpretation of the Sheep Pen ichnofaunas

All three track-bearing horizons yield very similar dinosaur (or dinosauroid) tracks that are more abundant than any other vertebrate traces. Although the tracks vary in size, there are no obvious grounds for separating them taxonomically. Hence, the ichnofaunas appear very conservative throughout the span of time represented by Sheep Pen deposition. The reasons for the stability and low diversity of the ichnofaunas, compared with those reported from the underlying Sloan Canyon Formation, are unclear. However, although the difference may in part be due to the small areas of the Sheep Pen sites providing a smaller sample, it is evidently not due to differential preservation. The preservation of Sheep Pen tracks and traces, particularly in the lower and upper track beds, is very good (Fig. 8), and it is therefore unlikely that the assemblages are severely biased by preservational deficiencies. This leads to the conclusion that the Sheep Pen ichnofaunas indicate

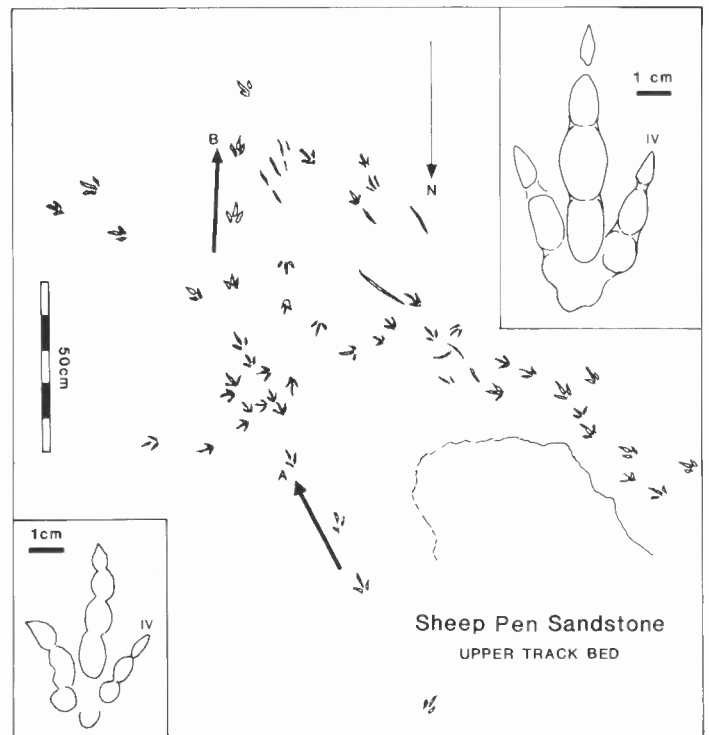


FIGURE 10. Map of dinosaur track distributions in an exposure of the upper track bed, Sheep Pen Sandstone. Trackways A and B are illustrated separately in Figure 11. Insets show size range for *Grallator* (*Grallator*) tracks at this horizon.

ichnocoenoses which are paleoecologically reliable, and quite distinct from those in the Sloan Canyon Formation. One possible explanation for this distinction is found in Benton's (1984) proposal that the middle Norian was a time of worldwide extinction. Full discussion of all possible interpretations is beyond the scope of this paper.

ENTRADA SANDSTONE

A laterally discontinuous sandstone, of variable thickness, between the Late Triassic Dockum Group and overlying Jurassic Bell Ranch-Morrison succession, has been referred to the Entrada Sandstone by some workers, but to the Exeter Sandstone by others (see Lucas et al. [1985] for review). The unit is not discussed in any detail in this paper because of the lack of trace-fossil evidence in the Cimarron valley region. However, bioturbation is known from localities in New Mexico (Lucas et al., 1985, p. 215), and rare dinosaur tracks are known from Colorado and Utah (Lockley, 1986a, p. 22).

BELL RANCH FORMATION ICHNOLOGY

Six km southeast of the Sheep Pen tracksites, brown silty track-bearing exposures of Jurassic age crop out in a small tributary of Carrizo Creek in northwestern Oklahoma. The tracksite, which exhibits three trackways of large dinosaurs, was illustrated by Lockley (1986a, pl. 2 and fig. 16) and assigned to the Morrison Formation. This designation was made in order to stress that the tracks are *not* in the Sloan Canyon Formation as suggested by Gardner-McBee (1980) and implied by Fay (1983) in his map of the area. In the terminology of Baldwin and Muehlberger (1959) the track beds would be in the brown silt member of the Morrison Formation because they overlie the Entrada Sandstone. However, since the track-bearing unit is below the chert and thin-bedded gray clay-shales characteristic of the lower Morrison Formation in the region (Prince, in prep.), we follow Lucas et al. (1985) in regarding this unit as equivalent to the Bell Ranch Formation.

Following the existing designation (Lockley, 1986a, p. 38), two of the trackways can be compared with the ichnogenus *Gypsichnites* (Fig. 12). Traditionally this ichnogenus has been attributed to a large orni-

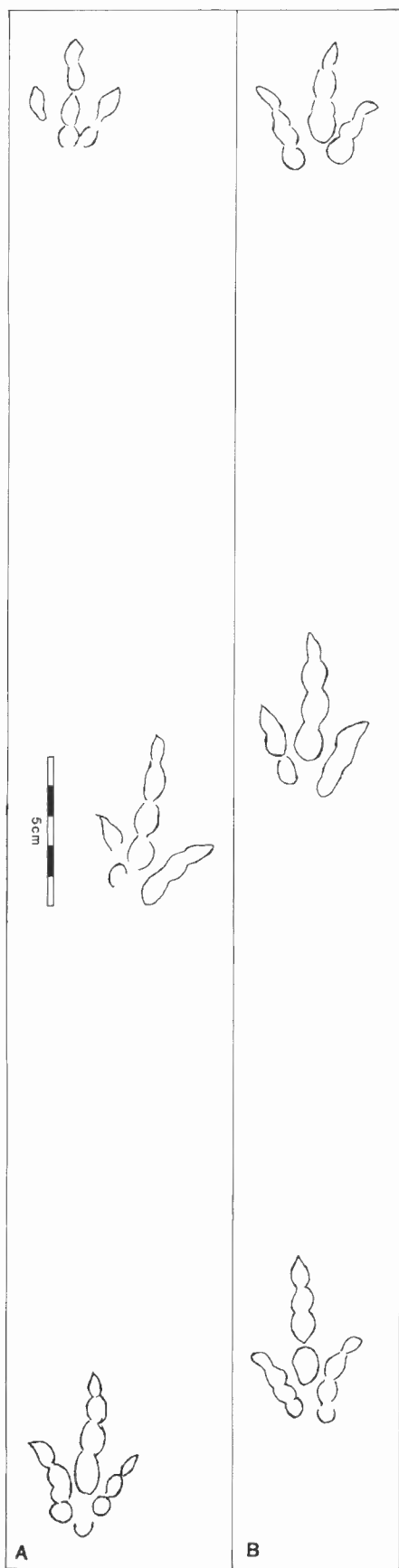


FIGURE 11. Detail of dinosaur trackways [*Grallator (Grallator)* sp.] from the upper track bed, Sheep Pen Sandstone.



FIGURE 12. Dinosaur tracks from the Bell Ranch Formation, Carrizo Creek, Oklahoma.

thopod, whereas the other trackway, in the lower of the two track-bearing beds, appears to represent a theropod.

The original *Gypsichnites* designation (Sternberg, 1932) was based on an incomplete trackway segment from the Cretaceous Gething Formation in Canada. Because the Bell Ranch trackways exhibit a short step, broad, blunt toes and an inward (positive or pigeon-toed) rotation of the pes, the maker was almost certainly a large ornithopod, as inferred by Sternberg for the type material. The tracks measure about 45 cm in length and 40 cm in width with an average stride of about 180–185 cm (range of steps from 88–100 cm).

The somewhat smaller footprints (length 45 cm; width 36 cm) in the lower of the two track-bearing beds comprise a single trackway with a longer stride (215–220 cm) than the "*Gypsichnites*" from the overlying bed. The lack of inward rotation of the pes and slender configuration of the digits suggest theropod affinities (Lockley, 1986a).

MORRISON FORMATION ICHNOLOGY

When excluding the above mentioned Bell Ranch tracks from consideration as a part of the Upper Jurassic Morrison Formation ichnological succession, there are still at least two known tracksites in the Morrison of the Cimarron valley, and two in the Purgatoire valley. The Morrison in this region can be informally subdivided into two units, the lower dominated by clay-shale and limestone, and the upper characterized by varicolored mudstone and thin lenticular sandstone (Prince, in prep.). All of the Morrison tracks reported in this region to date are in the lower unit, whereas most of the significant bone quarries in the Panhandle area appear to be from the upper unit (West, 1978).

Cimarron valley

West (1978) figured a presumed pterodactylan track from beds above the distinctive stromatolitic limestones (Neuhauser et al., 1987) in the lower part of the formation. Based on his illustration (West, 1978, pl. 22; Fig. 13), we reinterpret this as a crocodilian track. This interpretation is consistent with the reevaluation of other Morrison Formation pterosaur tracks by Padian and Olsen (1984) as crocodilians, and with reports of skeletal remains of crocodilians (*Goniopholis*) from this region (Mook, 1964).

The Cimarron valley footprint (Fig. 13) is a pes track that is very close in size to the specimen from the Salt Wash Member of the Morrison in Utah (Stokes, 1957). The specimen figured by West (1978, pl. 22) is a natural cast of a ?right pes, and when redrawn in reversed view (left aspect) is readily comparable with the Utah specimen and a modern crocodile track (*Caiman sclerops*) illustrated by Padian and Olsen (1984). As these authors retained the name *Pteraichnus saltwashensis* for the Utah material, it is appropriate to refer provisionally the Oklahoma material to this ichnospecies. However, because the ichnogenus name is so inappropriate, future revisions are anticipated.

One other possible crocodilian track is known from the Morrison Formation on the east side of the Front Range; this is the isolated tetradactyl specimen from the Canon City area figured by Hatcher (1903, fig. 23). This interpretation is based on the observation that the track does not resemble any which could be inferred to have been made by dinosaurs or other reptiles known to have existed in Morrison time.

Sauropod tracks were also reported from a locality in the Cimarron valley due north of Boise City (Schoff and Stovall, 1943). Langston (1974) referred to these tracks, again noting their sauropod affinity, but reported that they had been destroyed by vandals after having been

removed to the University of Oklahoma. We revisited the locality, now heavily silted over, and confirmed the authenticity of the site. A search is currently underway for archival photographs of these tracks thought to be on file at the Stovall Museum of Science and History, Norman, Oklahoma.

Purgatoire valley

Two Jurassic tracksites are known in the Purgatoire valley. The largest, at Rock Crossing, located about 20 km upstream from Higbee, has recently been described in detail (Lockley et al., 1986). The smaller site, at Higbee, reveals no in situ tracks, but is the site from which the Denver Museum trackway (DMNH 1498) was collected. Both tracksites appear to represent horizons associated with well-developed carbonate facies in the lower part of the Morrison Formation. As such they may be roughly correlative with the track horizon reported by West (1978).

Invertebrate traces encountered at a number of localities in the area include both vertical *Scolithos*-like, and horizontal *Scoyenia*-like burrows that most commonly occur on the top surfaces of the thin sandstones of the upper Morrison. The ichnofauna is too sparse and indeterminate to warrant detailed analysis at this stage of investigation.

PALEOECOLOGICAL AND BIOSTRATIGRAPHIC SIGNIFICANCE OF THE ICHNOFAUNAS

We consider the paleoecological and biostratigraphic implications of the ichnological data together because different tracksites furnish ichnofaunas that represent assemblages having both paleoecological and biostratigraphic significance. For example, the diverse Sloan Canyon ichnocoenosis is representative of the Late Triassic faunas in fluvial settings, but can also be used for correlation to some degree.

Triassic sites

Sloan Canyon Formation

Strictly speaking, the Sloan Canyon ichnofaunas from Peacock Canyon include several distinct ichnocoenoses representing an undetermined but significant span of time. For the purposes of this report they are considered collectively, because of their close stratigraphic proximity, and because a number of ichnotaxa are common to successive track-bearing beds. Further justification of this approach is provided by the observation that most of the mapped assemblage is associated with the restricted stratigraphic interval associated with bed 7 (Fig. 3). Thus, the overall assemblage is primarily a reflection of the bed 7 ichnocoenose.

The assemblage is dominated by *Rhynchosauroides*, with *Chirotherium* sp. and *Brachychirotherium* sp. ranking second and third, respectively, in terms of relative abundance. The other ichnotaxa—*Coelurosaurichnus*, *Apatopus*, the therapsid and invertebrate traces—are much less common. The mixture of forms inferred to be both terrestrial and aquatic, presumably reflects the paleogeographic location of the traces in close proximity to a river channel system that incised floodplain sediments that were subaerially exposed, except during flood events. In this respect the ichnocoenose reflects the known composition of Dockum and other Late Triassic fossil assemblages from North America. Where the overall ichnocoenose differs is in the high proportion of traces attributable to small vertebrates. According to Jacobs and Murry (1980) and Chatterjee (1985), however, there is evidence that the Late Triassic skeletal record is biased toward large forms. This is a common phenomenon, and the ichnocoenose's evidence strongly suggests that this bias is real in the case of Dockum Group faunas.

Although the Peacock Canyon ichnocoenose compares to varying degrees with other trace fossil assemblages from the western U.S.A. (Lockley, 1986a), it compares more closely with the assemblage described from the lower Passaic Formation of Milford, New Jersey (Baird, 1957; Olsen and Baird, 1986). Four of six currently known vertebrate ichnotaxa from the New Mexico site (i.e., *Brachychirotherium*, *Coelurosaurichnus*, *Rhynchosauroides* and *Apatopus*) are shared with the lower Newark Supergroup site. Both sites are also in the *Scoyenia* ichnofacies. Therefore, not only are the Milford trace faunules paleo-

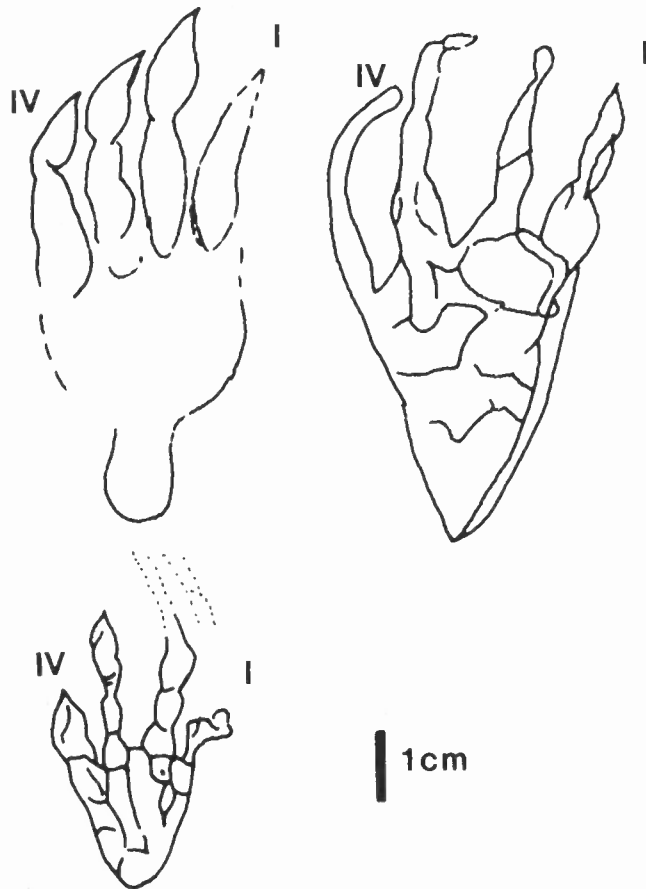


FIGURE 13. Crocodilian tracks from the Morrison Formation. Top left, redrawn after West (1978, pl. 22) and top right redrawn after Padian and Olsen (1984, fig. 2d). Lower track is a modern *Caiman sclerops* redrawn after Padian and Olsen (1984, fig. 2c).

ecologically similar to those from New Mexico, but, as shown below, there is also evidence to suggest that they are age equivalent.

The Milford section has been dated palynologically as early Norian (Olsen and Baird, 1986). Because it is not possible to correlate directly with the New Mexico site using pollen, we follow the tradition of using vertebrates, as is usually done in the western U.S.A. The phytosaur skull recovered by Stovall and Savage (1939), 19 km northeast of the Peacock Canyon site, probably belongs to the "B-Group," *Rutidon* (*Machaeroprotopus*) *tenuis* complex (Long and Ballew, 1985), which is the characteristic morphotype of the upper unit of the Petrified Forest Member of the Chinle Formation. It is difficult to infer the horizon from which Stovall and Savage (1939) collected the phytosaur material; however, our interpretation is that it probably originated from the lower part of the Sloan Canyon succession (cf. Baldwin and Muehlberger, 1959). Thus, we conclude that there is probably not a large stratigraphic separation between the track-bearing and phytosaur-bearing beds.

Although the Petrified Forest and Monitor Butte members of the Chinle are considered by Litwin (1985) to be "probable late Middle to Late Carnian age" based on pollen, Long and Ballew (1985) propose that the vertebrates indicate a probable Norian age for the entire Petrified Forest Member. More recently Ash et al. (1986) have suggested that the Carnian-Norian boundary can be located in the Petrified Forest Member. We therefore conclude that the Sloan Canyon ichnofauna is probably late Carnian to early Norian in age. Having established the North American correlations, it is worth noting that *Brachychirotherium* from the Sloan Canyon site is comparable with tracks from the early Norian portion of the Germanic middle Keuper (Km3-Km4).

Reptile trackways from the two reported sites of the Redonda Formation (upper Dockum Group) of east-central New Mexico (Gregory, 1972) are too poorly known at present to allow detailed comparisons with Cimarron valley forms. *Brachychirotherium* sp. has been identified from museum specimens from Mesa Redonda (Baird, oral commun. and personal observation, 1986), but well-preserved trackways of that form apparently no longer survive (Lucas et al., 1986). Small tridactyliform tracks, however, are known from the locality (Lucas et al., 1986).

Sheep Pen Sandstone

The few *Brachychirotherium* tracks from the Sheep Pen Sandstone are difficult to compare with those from other areas. However, based on stratigraphic position, they probably represent forms which are younger than those from the Peacock Canyon site. Nevertheless, the dinosauroid traces of the younger unit, *Grallator* (*Grallator*) sp., compare more closely morphologically (disregarding size differences) with late Norian-Liassic forms (Olsen, 1980, fig. 20) than with the older traces of *Coelurosaurichnus* sp. in the underlying strata. A similar situation, the stratigraphic juxtaposition of "primitive" and relatively advanced forms, exists in the Chinle Formation (Lockley, 1986a). Thus we conclude, on the basis of the new footprint evidence, that the Sheep Pen Sandstone is probably middle to late Norian in age.

As suggested above, the Sheep Pen ichnofaunas appear to be a reliable census of a low diversity fauna. As such they are quite distinct from the Sloan Canyon Formation ichnocoenoses, and may indicate radical changes in the fauna in early or middle Norian time (Benton, 1984; Ash et al., 1986). These changes may indicate local paleoecological factors, worldwide faunal changes or a combination of both factors.

Jurassic sites

Because tracks from the Jurassic of the western U.S.A. have not been described in detail until recently, the material reported here is of some paleoecological and biostratigraphic importance for the small amount of new information it provides.

Bell Ranch Formation

Lucas et al. (1985, p. 230) point out that the "Bell Ranch and equivalent units have not yielded any identifiable body fossils." However, based on lithology they infer a lacustrine depositional environment that is related to the more saline-like setting of the Todilto Formation. The presence of two types of dinosaur tracks may be considered a useful indication that the Bell Ranch paleoenvironment supported both her-

bivorous and carnivorous dinosaurs. Large mudcracks in the track-bearing beds suggest a fluctuating or ephemeral water body in that area, possibly situated to the west of the track-bearing exposures (Lockley, 1986a). If Lucas et al. (1985) are correct in assigning this unit to the Late Middle Jurassic (Callovian), then the ornithopod tracks are somewhat unusual, because of their large size. Alternately, given the known trend toward increasing size of ornithopods from Jurassic to Cretaceous time (Haubold, 1984), the tracks would suggest a somewhat younger age for the strata.

Morrison Formation

The large volume of trackway data available at the Purgatoire valley site has permitted considerable paleoecological inference (Lockley et al., 1986). Most of the conclusions suggest that the ratio of various dinosaur tracks (sauropod: ornithopod: theropod) is consistent with what is known of the relative abundance of skeletal remains in the formation (Dodson et al., 1980). Thus, the tracksite provides an independent but consistent paleoecological census. Until more is known of the Cimarron valley tracks little can be added, except that the crocodilian tracks from this region add to the ichnological record.

Although Morrison tracks are currently of limited biostratigraphic value on a regional scale, we conclude that the Purgatoire valley and Cimarron valley tracks occur at about the same stratigraphic level. This coincidence may be related to the fact that both occur in lacustrine paleoenvironments; however, this observation may also prove useful in local correlation (Prince, in prep.).

CONCLUSIONS

Despite having received scant attention in the past, trace fossils from the Triassic and Jurassic of the Cimarron valley are well-preserved and quite diverse. Our initial surveys suggest the following distribution of named and distinct ichnotaxa:

Formation	Number of ichnotaxa
Morrison	8
Bell Ranch	2
Sheep Pen	3
Sloan Canyon	10

All the above figures are minimum diversity estimates based only on the localities described in this report. At present, vertebrate traces appear to outnumber substantially those attributed to invertebrates, although the disparity may be due to depositional, observational or preservational biases, since many of the paleoenvironments in question no doubt supported diverse invertebrate faunas.

The vertebrate tracks appear to be quite reliable and useful in providing a census of the vertebrate faunas from the different localities in question, and as a possible biostratigraphic tool for correlation. Although vertebrate tracks have traditionally been regarded as being of limited biostratigraphic value except where no other fossil evidence exists, they are an integral part of the paleontological record and can be just as reliable as body fossils when it comes to correlation in continental successions. This point is illustrated by the Triassic age determinations inferred for the Sloan Canyon and Sheep Pen ichnocoenoses analyzed above. Furthermore, we conclude that ichnocoenoses can shed much light on the paleoecology of various deposits, thus providing census data analogous to paleontological assemblages of body fossils. In most cases, the Cimarron valley ichnocoenoses indicate faunas that were more diverse than any that could be inferred directly from the body fossil evidence.

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