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THE OLDEST LATE TRIASSIC FOOTPRINT ASSEMBLAGE FROM NORTH AMERICA (PEKIN FORMATION, DEEP RIVER BASIN, NORTH CAROLINA, USA)

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ABSTRACT

An assemblage of reptile footprints from the abandoned Pomona Terra-cotta and the active Boren quarries in the middle Pekin Formation of the Sanford subbasin of the Deep River basin is the oldest track faunule recognized to date in strata of Late Triassic age in Eastern North America. The most common taxon is a possibly new genus of pentadactyl ichnite similar to, but distinct from, *Brachychirotherium*. It may lack manus impressions, has a strong tendency to be functionally tridactyl, and has an extremely shallow digit V impression. At least one track is over 30 cm in length. Also present is the quadrupedal, probably phytosaurian ichnite *Apatopus lineatus*, based on a trackway, and several small (<15 cm) bipedal and tridactyl forms that are probably dinosaurian. Other more poorly preserved forms are present. Apart from *Apatopus*, none of the tracks fit into recognized Newark ichnotaxa. The age of this track assemblage is early Tuvalian (early Late Carnian of the Late Triassic), based on associated tetrapod skeletal and macro- and micro-floral remains. This middle Pekin footprint assemblage is thus distinctly different, and older than all other Newark Supergroup footprint assemblages. It is important because it represents a transitional stage between the well known Middle Triassic assemblages and the more typically Newarkian Late Triassic assemblages. The apparently dinosaurian ichnites from this horizon are therefore arguably among the oldest in the world.

INTRODUCTION

Footprints comprise by far the most common evidence of tetrapods in the Newark Supergroup of eastern North America. They have been the subject of fairly continuous research since the first dinosaur footprint was described by Edward Hitchcock in 1836 (Hitchcock, 1836; Olsen and others, 1997), and they provide a rich source of biostratigraphic, paleoecological, behavioral, and physiological information (e.g., Olsen and Galton, 1977; Olsen, 1988; Lockley, 1991; Farlow, 1981; Farlow and Chapman, 1997). Despite the over 160 years of study devoted to Newark Supergroup tetrapod footprints, the assemblages from the Early Jurassic age strata have received most of the attention, with antecedent 30 million years of Newark track assemblages receiving relatively short shrift. Indeed, it is within only the last 45 years that the Triassic-age assemblages have been recognized as distinct in composition (Baird, 1957; Olsen and Baird, 1986; Fraser and Olsen, 1996) with most of the occurrences still being known from superficial descriptions (e.g. Olsen. 1988; Olsen and others, 1989). Here we describe the oldest known Late Triassic age footprint assemblage in the Newark Supergroup, that from the middle Pekin Formation of the Deep River Basin of North Carolina.

GEOLOGICAL PROVENANCE

The Deep River basin of North and South Carolina is the southernmost exposed of a extensive series of rift basins formed during the

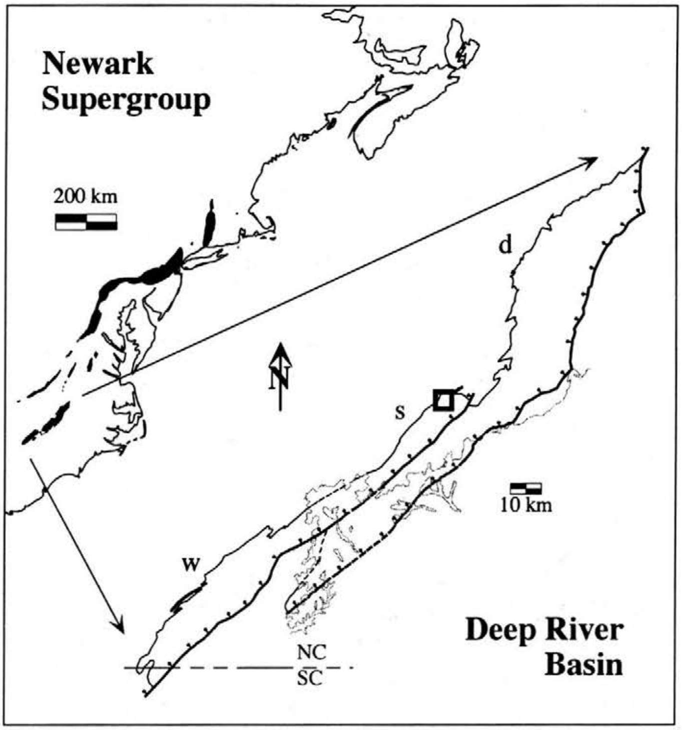

Figure 1. Deep River basin of North and South Carolina and Newark Supergroup of eastern North America. Box shows position of footprint localities (see Figure 2): d, Durham subbasin; s, Sanford subbasin; w, Wadesboro subbasin. Gray line shows limit of Coastal Plain.

Triassic and Early Jurassic break up of Pangea (Figure 1). The footprint assemblage described herein, comes from the Pekin Formation of the northern part of the Sanford subbasin of the Deep River Basin, which is the oldest formation recognized in the basin. Presently, the Pekin Formation is placed within the Chatham Group of the Newark Supergroup (Weems and Olsen, 1997) and comprises tectonostratigraphic sequence II (TS II), the oldest, widespread rift sequence in the Central Atlantic Margin rifts (Olsen, 1997).

All of the footprints described here come from two quarries called the Pomona Terra-cotta Co. quarry (now abandoned) and the Boren Clay Products quarry developed in the lower part of the middle Pekin Formation (Figure 2). As described by Reinemund (1955), the Pekin Formation in the northern Sanford subbasin, in the vicinity of these quarries, is about 530 - 550 m thick (Figure 3). Its basal beds tend to consist of about 90 m of gray or brown conglomerate and sandstone followed by mostly lenticular beds of red, brown or purple claystone, siltstone, sandstone, and locally conglomeratic arkosic sandstone. A gray sandstone and siltstone sequence is exposed near the top of the section in the main part of the Boren quarry and this interval is a marker bed mapped throughout the northern Sanford subbasin by Reinemund (1955) (Figure 2). Its position, according to Reinemund, is about 210 m above the base of the section. It is this unit that produced the well known plant assemblages described by Hope and Patterson (1969), Delevoryas and Hope, (1975), and Axsmith and others, (1995), among others. All of the footprints occur below this bed, probably within about 100 m.

Most of the footprints were found in the north end of the Pomona quarry, here termed Pomona A, during the 1970's. In Pomona A, the Pekin Formation itself consists of red bioturbated mudstone with tabular beds of ripple cross-laminated siltstone and fine sandstone (Table 1;

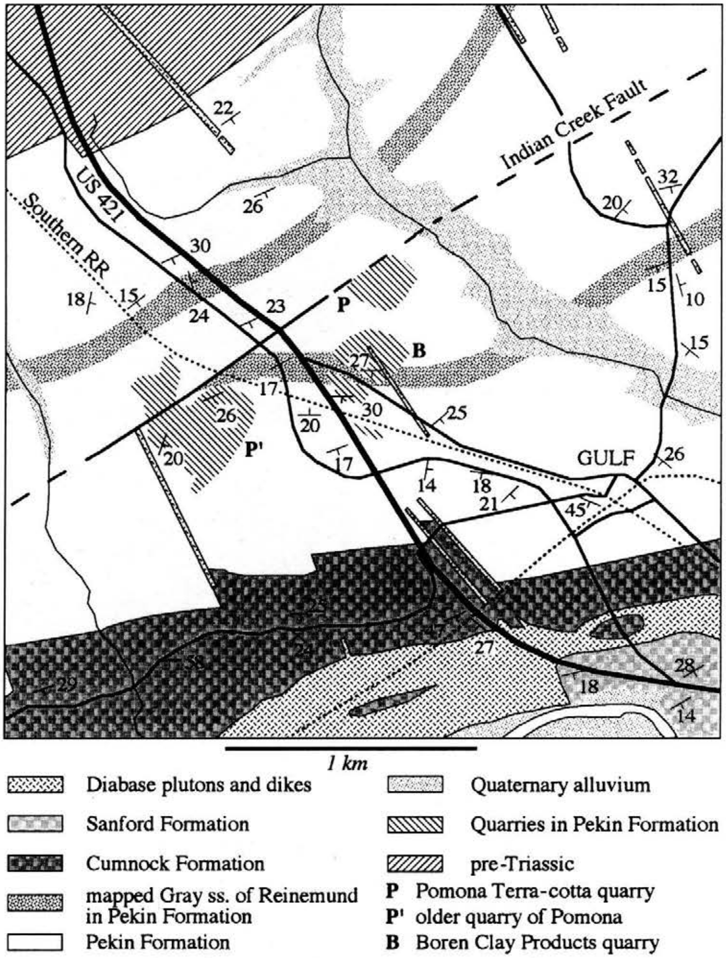

Figure 2. Map of geology in vicinity of middle Pekin Formation footprint localities. Maps are based on digitally superposed images of the U.S.G.S. 7.5 minute Goldston Quadrangles and maps of Reinemund (1955; plate 1-central, and plate 4).

Figure 4). A distinctive mudstone with plant foliage, fish scales and other fossils (Figure 5; Table 1) occurs below the main footprint-bearing unit that consists of a greenish-purple, ripple cross laminated silty sandstone. Most of the footprints from Pomona A, however were found in rubble. The important assemblage of tetrapod bones described by Baird and Patterson (1968) and Huber et al. (1993) (Table 2) apparently comes from the southern side of the Pomona quarry, here termed Pomona B. During the 1970's Pomona B was being filled in and the existing exposures did not allow for the section to be measured in detail. One track was found in 1989 in rubble from the Boren Pit.

The projected trace of the Indian Creek fault shown by Reinemund (1955) should pass through the Pomona quarry, and it should have between 100 and 250 m of normal displacement. However, a fault of this magnitude was not observed by PEO in either the Pomona or Boren quarry over 15 years of visits, and hence the fault presumably passes to the immediate east of the Pomona quarry, as it is shown in Figure 2. However, several small faults were seen in the Pomona and Boren quarries. From their narrow gouge zones, the similarity of facies on both sides of the faults, and the lack of major

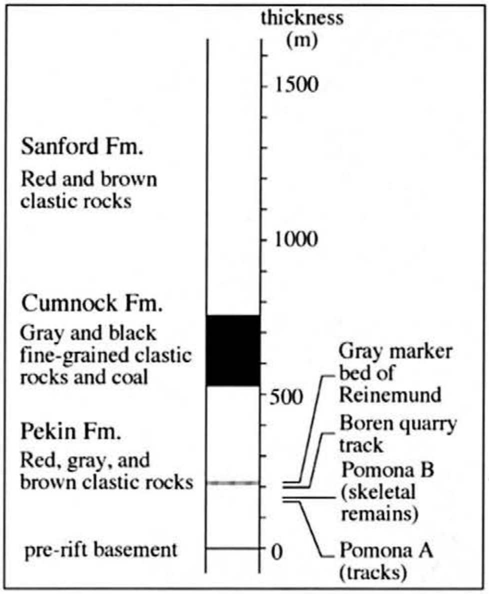

Figure 3. Section of Triassic rocks in northern part of Sanford subbasin: based on Reinemund (1955).

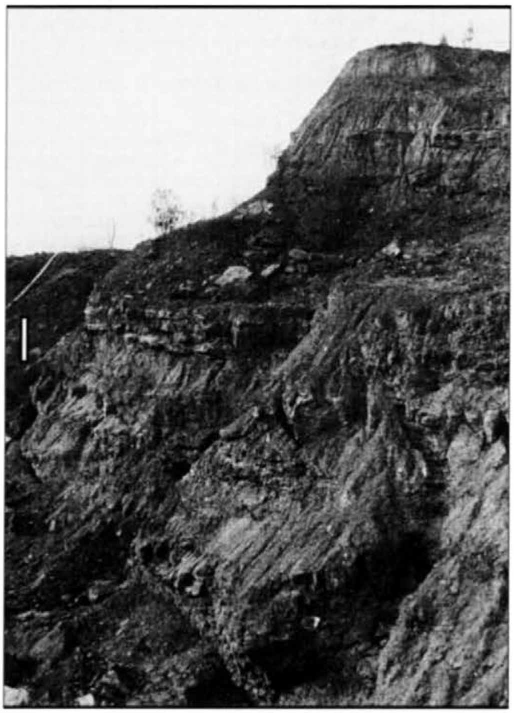

Figure 4. Exposure of footprint-bearing strata at north end of Pomona A. White bar is 1 m and is positioned just below main footprint-producing unit (Table 1).

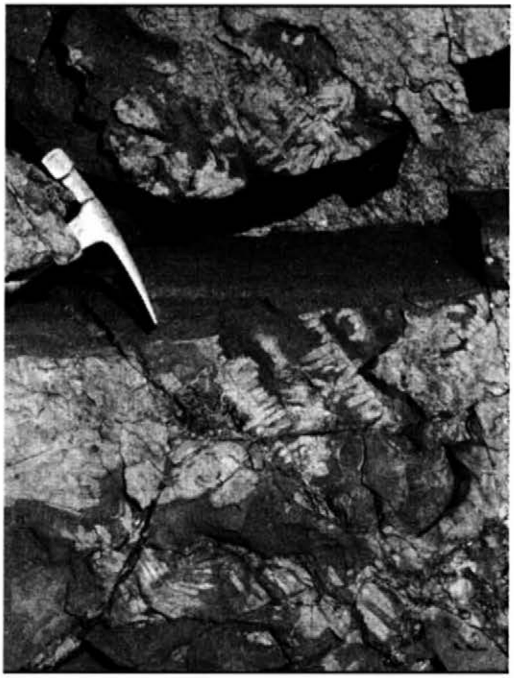

Figure 5. Plant foliage (mostly cycadeoid) preserved as red clay films in red mudstone from within the main track bearing-unit (Table 1).

repetition of strata, these faults probably have displacements of a few meters. Unfortunately, one of these small faults separates the Pomona A section from the Pomona B section, and this and the other small faults make it impossible to compile a complete section from the plant-bearing gray sandstone marker bed in the Boren quarry through the main footprint-bearing units in the Pomona quarry, given the exposures present in the 1970's.

The tabular geometry of the footprint bearing unit in Pomona A and the presence of conchostracans in the plant-bearing strata of the Boren quarry (Olsen et al, 1989) suggests some ponded water. In combination with the presence of tilted beds of ripple-cross laminated sandstone and lenticular cross-bedded sandstones, the environment of deposition was probably shallow lacustrine, paludal, marginal lacustrine, and fluvial during the deposition of the units exposed in the Pomona and Boren quarries. The absence of caliche and evaporites and the intense bioturbation and abundant plant foliage (even in red

Table 1. Measured section at footprint-producing area on the north side of the Pomona Terra-cotta quarry. Section measured December 29, 1977. * denotes main track-bearing unit.

thickness	lithological description	fossils, other
normal fault		
+1 m	red hackly mudstone	?*Scoyenia*
0.5 m	purple-brown, green up hard siltstone	roots
0.9 m	deep purple, light purple up mudstone	hematitic nodules
0.4 m	green-purple hard siltstone and fine sandstone	footprints, roots, *Scoyenia*
3.0 m	red fissile siltstone	roots
1.0 m*	greenish-purple and red, hard, flaggy siltstone and fine sandstone	footprints, plant foliage, roots, *Scoyenia*
1.8 m	red massive mudstone, fissile upward	fish scales, coprolites, reptile teeth, plant foliage, *Scoyenia*
0.2 m	green and red, hard, massive mudstone	
1.9 m	red, greenish up, faintly lamina teconchoidally fracturing, siltstones	
+1m	green and red poorly bedded mudstone	roots, casts of *in situ* plant stems
covered		

Table 2. Vertebrate osteological remains and tracks (*) from the Pomona Terracotta and Borden quarries.

Taxon	Reference	Horizon
Synapsida		
Kannemeyeriidae		
Placerias cf. *P. hesternus*	Huber *et al.*, 1993	Pomona A
Reptilia	Baird & Patterson, 1968	Pomona A
Phytosauria		Pomona B
Phytosauria indet.		Borden
**Apatopus lineatus*	this report	Pomona B Borden
Archosauria		
Suchia		
Longosuchus cf. *L. meadei*	Huber *et al.*, 1993	Pomona A
Rauisuchia indet.	Huber *et al.*, 1993	Pomona A
?Suchia		
*cf. *Brachychirotherium* sp.	this report	Pomona B
?Dinosauria		
*undetermined	this report	Pomona A Pomona B

units) suggests persistently humid conditions.

FOOTPRINT ASSEMBLAGE

Tracks from Pomona A include *Apatopus lineatus*, abundant cf. *Brachychirotherium* spp., small three-toed dinosaurian tracks, and several unidentified forms. Most of the tracks could not be recovered and have been destroyed. A trackway consisting of a natural cast of three successive manus-pes sets on a large transported block demonstrates the presence of *Apatopus lineatus* Baird 1957 (Figure 6). According to Baird (1957), *Apatopus lineatus* is diagnosed as a

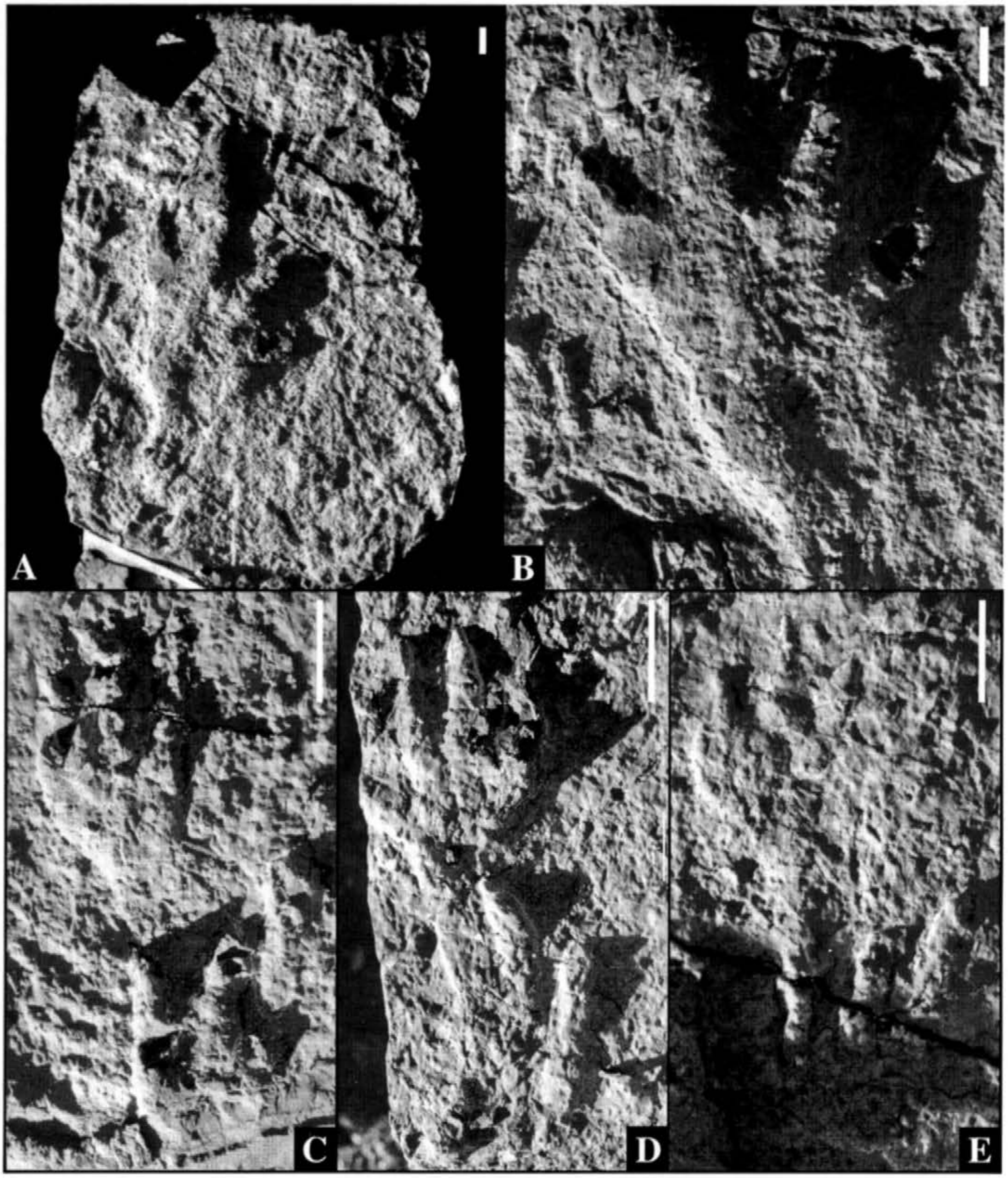

Figure 6. Large slab with natural casts of *Apatopus lineatus* and very large brachychirothere-like possible example of new genus 1; slab not collected. A, photograph of entire slab digitally corrected for parallax; B, possible example of new genus 1; C-E, successive manus-pes sets of *Apatopus lineatus*. Scale for all is 5 cm.

quadrupedal ichnite with a long, narrow pentadactyl pes with the digits in increasing length V, I, II, III, IV, and a short manus symmetrical around digit III. Usually only digits I, II, and III of the pes impress distinctly, and this is the case with the Pekin trackway (Figures 6, 7). Individual manus-pes sets (Figure 6 C-E) are indistinguishable from the type material described by Baird (1957, Plate 3, Figure 1). In addition, Baird's (1957, Figure 8) figured trackway, based on dissociated blocks, is matched closely by the Pomona trackway (Figure 7), which is

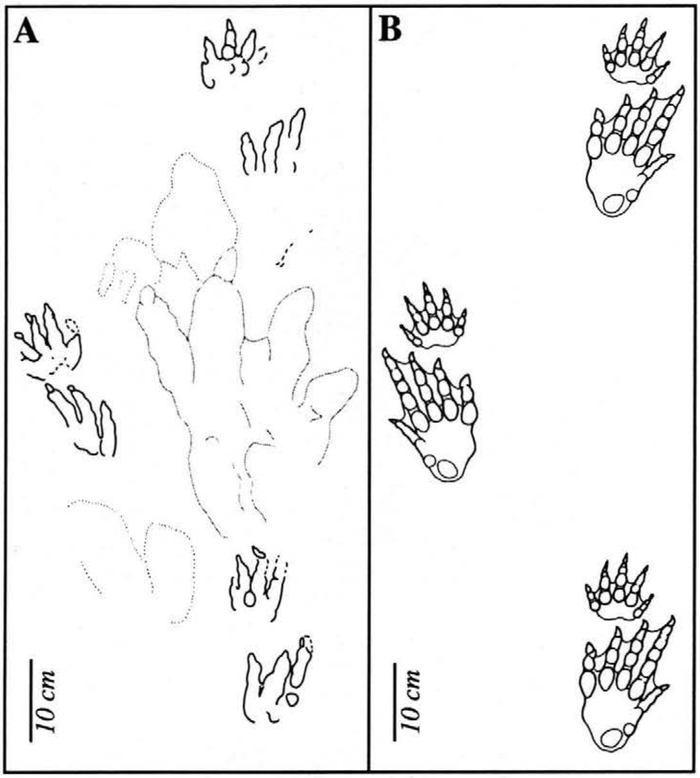

Figure 7. Outline drawing of trackway of *Apatopus lineatus* (A) compared to type trackway as reconstructed by Baird 1957 (B). B is redrawn from Baird (1957).

confirmation of his reconstruction.

Baird (1957) assigned *Apatopus lineatus* to the Phytosauria because of general similarities between the trackway of *Apatopus* and living crocodilians, the correspondence between the reconstructed skeleton of *Apatopus* and the reconstructed pes and manus, and the overlapping stratigraphic ranges of phytosaurs. Parrish (1986) has questioned this assignment on functional grounds, but has produced a forward model of a phytosaur track based on known osteology (his Figure 4.9) that is as close to *Apatopus* as can be expected given the limitations of the method. We argue that a functional argument is inherently weaker than one based on anatomical similarity, and therefore concur with Baird's (1957) original assignment.

The most abundant footprints from Pomona A are somewhat similar to *Brachychirotherium* in having a pentadactyl pes with the digit III being longest, and digit V being very reduced (e.g. Haubold, 1971) (Figures 8, 9). However, unlike *Brachychirotherium*, the impression of digit V is very weak and far posterior of its normal position (Fig 8), and digit I is small with the pes being functionally nearly tridactyl. In addition, none of the specimens from the Pekin Formation has an unequivocal manus impression. In the nearly tridactyl form of the pes and absence of a manus impression, the Pomona A forms resembles *Parachirotherium postchirotheroides* from the Gipskeuper (Early Carnian age) of Bayreuth, in Germany. As figured by Kuhn (in Haubold, 1971; 1986), however, digit V is too far anterior. As exemplified by the clearest example (Figures 8A, 9A) the track is different than any described form and probably should be named a new genus, which we call new genus 1 for this paper. However, we cannot name a new taxon at present, because, none of the specimens or casts of new genus 1 reside in institutions.

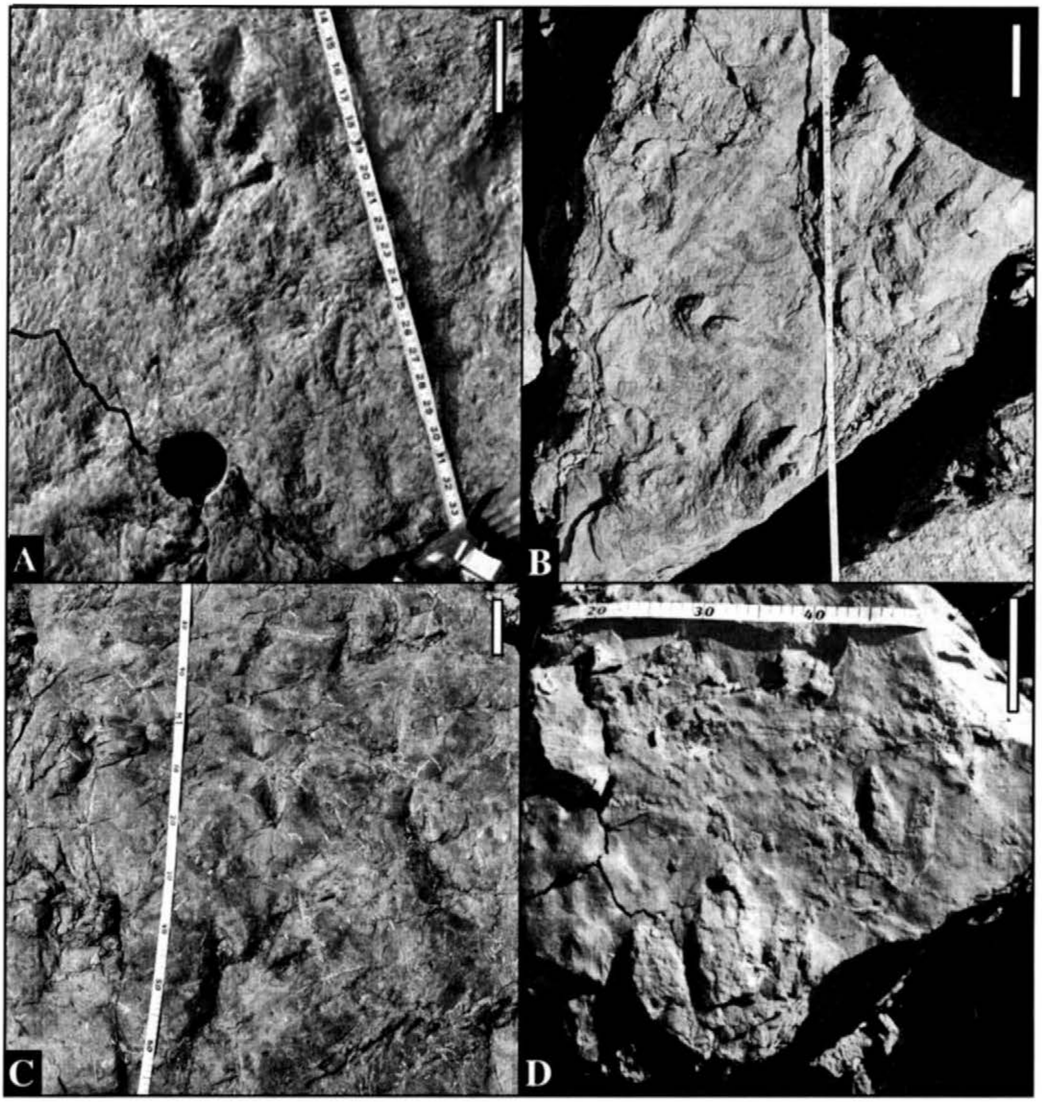

Figure 8. Slabs of footprints from Pomona A: A, new genus 1 and vague undetermined tracks (slab in collection of James L. Mashburn of Sanford, North Carolina); B, slab with natural casts of trackway of undetermined? brachychirothere with possible manus (not collected); C, large slab with deep but sloppy trackway of new genus 1 (not collected); D, natural casts of partial? brachychirothere and good dinosaurian pes (not collected). Scale for all is 10 cm.

The absence of clear pads precludes a detailed osteological reconstruction of the pes of new genus 1. However, it is clear that the track maker had a reduced digit V, a short digit I, and a long metatarsal axis. The pes skeleton of *Postosuchus kirkpatricki* (Chatterjee, 1985) is comparable to new genus 1, and it is interesting that Chatterjee has reconstructed *Postosuchus* as bipedal, which agrees with the new genus. In addition, the probably rauisuchian teeth from Pomona B could be a postosuchid. However, *Postosuchus* has a temporal range (Carnian and Norian) much greater than new genus 1 would seem to have. More track material with better defined pads is needed for rigorous analysis, however.

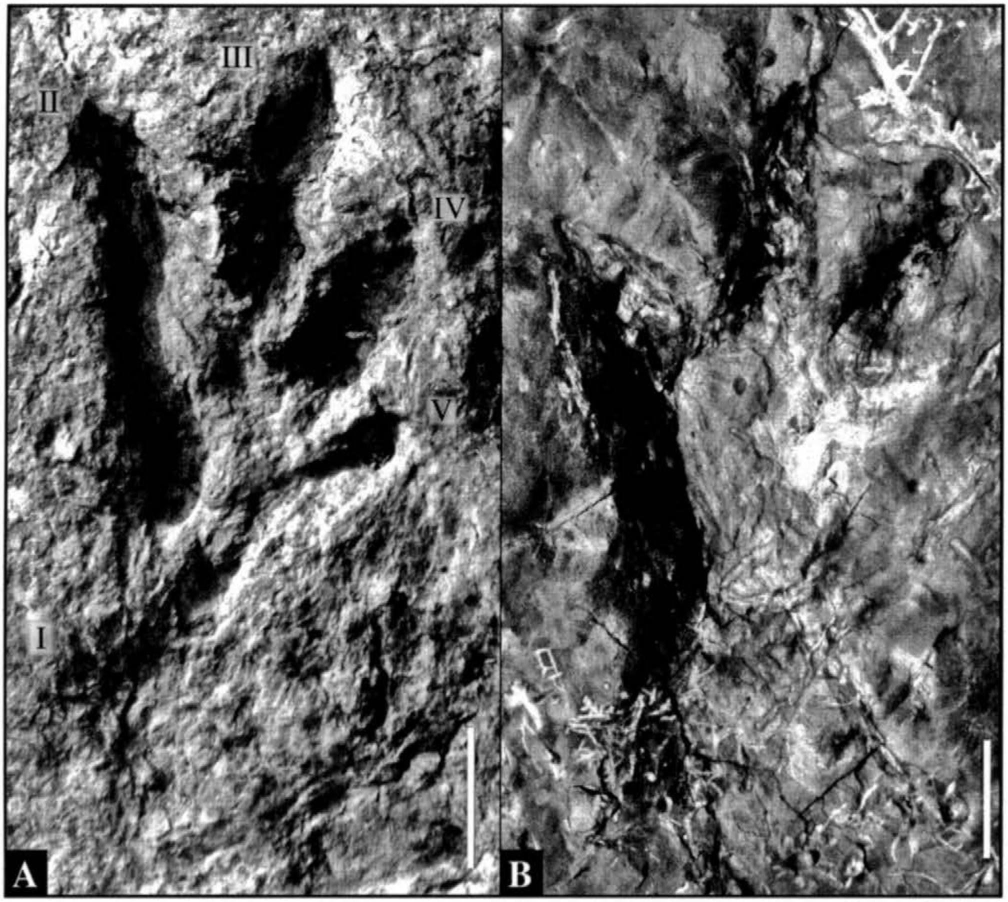

Figure 9. New genus 1: A, detail from slab in Figure 8A (note digit labels); B, detail of lower track shown in Figure 8C. Scale is 5 cm.

On the same slab as the *Apatopus* trackway (Figure 6A, B) is a natural cast of a very large (~35 cm) pentadactyl pes. Again, there is no manus impression, but this form differs from new genus 1 in having a proportionally longer digit I, shorter digit III, and more anterior and distinct digit V. Superficially the pes is comparable to large chirotheriids and brachychirotheriids (e.g. Haubold. 1971). It is possible, however, that the differences between this very large form and new genus 1 could be due to ontogenetic allometric changes similar to those seen in Early Jurassic theropod dinosaur tracks (Olsen and others, 1997). Without specimens of intermediate size, it is impossible to test this hypothesis.

Tridactyl ichnites, represented by one trackway, are present at Pomona A and the Boren quarries (Fig 8D, 10). Two of these have vague possible manus impressions, but without trackway confirmation, the association could be fortuitous. All the tridactyl forms have a widely splayed pes, with proportions and size similar to the Jurassic ichnogenus *Anomoepus* (see Lull, 1953). However, none of the Pekin tridactyl ichnites have the characteristic placement of the metatarsal phalangeal pad of digit IV directly in line with the axis of digit III. There is no sign of the distinctive pentadactyl manus of *Anomoepus* as well. The three-toed pes and bipedal trackway may be shared-derived characters of the Dinosauria. Because none of the Pekin tridactyl forms have distinct phalangeal pads we do not attempt further analysis, except to note

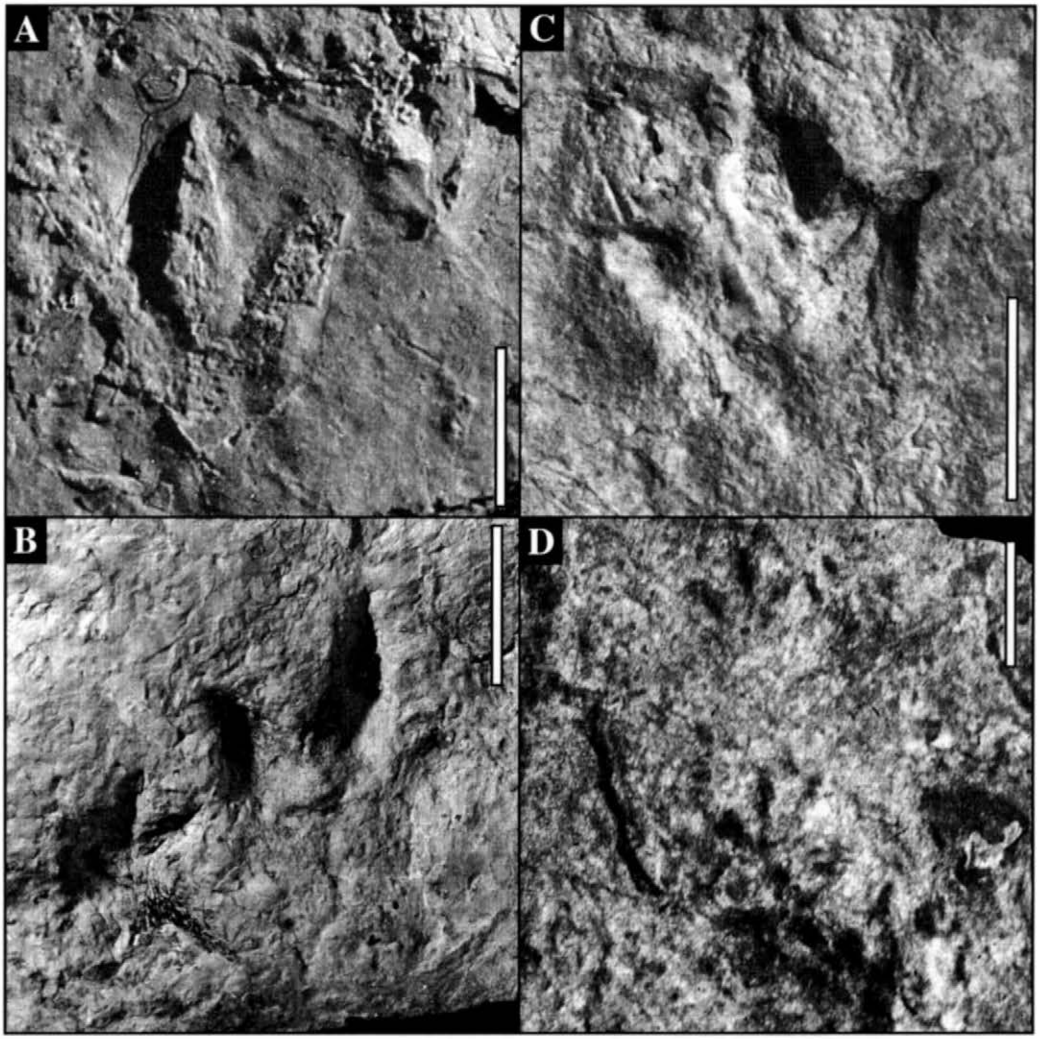

Figure 10. Dinosaurian tracks from Pomona A and the Boren quarry: A, detail of track shown in Figure 8D, right; B, pes and possible manus (Yale Peabody Museum 55875); C, natural cast of right pes from the Boren quarry (not collected); D, part of large slab of vague natural casts of dinosaurian pedes (not collected). Scale is 5 cm.

that they are plausibly, but not definitively dinosaurian.

There are a number of other traces from Pomona A that indicate the presence of other ichnotaxa (e.g. Fig 8D, left). However, these are all to poor to warrant detailed description. They indicate significant additional diversity in this assemblage.

ASSOCIATED FAUNAL AND FLORAL REMAINS AND AGE

Pomona B has produced an important although fragmentary tetrapod skeletal assemblage (Baird and Patterson, 1968). Based on the small fault offset between Pomona A and Pomona B, the footprint assemblage is no more than 40 m below the unit that produced the tetrapod assemblage, and probably significantly less. Most distinctive is the rotund dicynodont synapsid *Placerias* cf. *P. hesternus* and aetosaur scutes assignable to *Longosuchus meadi*. According to J. L. Mashburn and D. Baird (1974, pers. comm.) the *Placerias*, at least, were originally articulated specimens prior to blasting. Based on correlation with the Chinle group and the European section, these indicate an early Tuvalian (early Late Carnian) age (Huber and others, 1993). Also present are indeterminate phytosaur material and indeterminate, probable rauisuchian teeth. This assemblage comprises the type for the Sanfordian land vertebrate faunachron of Huber et al. (1993), which correlates to the Otischalkian land vertebrate faunachron of the Chinle Group of the western United States.

A palynoflorule from the basal Pekin Formation of the Sanford basin (Cornet, 1977) and the Boren quarry has produced an extensive floral assemblage (Hope and Patterson, 1969; Delevoryas and Hope, 1975; Olsen and others, 1989; Axsmith and others, 1995) that suggests correlation of the lower to middle Pekin Formation with tectonostratigraphic sequence II (TS II, Olsen, 1997) of the Richmond and Taylorsville basins. The vertebrate assemblage also suggests a correlation with TS II of the Fundy basin of the Canadian Maritimes and the Argana Basin of Morocco (i.e. Timezgadiwine Formation).

COMPARISONS TO OTHER ASSEMBLAGES

There are two accounts of footprints from the Newark Supergroup that are probably older than the Middle Pekin assemblage. The oldest is from the Honeycomb Point Formation of the Fundy basin of New Brunswick, Canada (Olsen, 1997), but these ichnites are very poor and have never been described. Shaler and Woodworth (1899) figure outline drawing of footprints from the "Productive Coal Measures" of the Richmond basin. These strata belong to the lower part of TS II and are probably older than the footprint assemblage from the middle Pekin. The drawings are, however, inadequate for comparison to other tracks and the whereabouts of the specimens is unknown.

Abundant and diverse footprint material has been recovered from tectonostratigraphic sequence III (TS III) in many other Newark Supergroup basins. Nonetheless, the only undoubted member to the Pekin footprint assemblage shared by younger Newark Supergroup faunules is *Apatopus lineatus*. The oldest assemblage that has been described in TS III is that from the upper Stockton and lower Lockatong Formation of the Newark basin of New York, New Jersey, and Pennsylvania (Olsen and Flynn, 1989; Olsen, 1988; Baird and Olsen, 1986) and the roughly coeval tracks from the Cow Branch Formation of the Dan River basin of North Carolina and Virginia (Olsen and others, 1978; Baird and Olsen, 1986; Fraser and Olsen, 1996). All of these are Late Carnian (late Tuvalian) in age and are associated with tetrapod skeletal taxa of the Conewagian land vertebrate faunachron (Huber and others, 1993). The Late Carnian age assemblages are basically the same as early and middle Norian assemblages (also in TS III) that are known from many localities and many Newark Supergroup basins (Baird, 1954; Baird, 1957; Olsen and Baird, 1986; Olsen, 1988; Olsen et al; 1989). These are dominated by *Brachychirotherium*, *Apatopus*, *Rhynchosauroides* and dinosaurian taxa, notably *Atreipus* and *Grallator*, and are associated with skeletal forms of Neshanician and lower Cliftonian land vertebrate faunachrons (Huber and others, 1993).

Otischalkian strata of the Chile Group have produced very little footprint material (Lucas and Huber, 1997) and the younger Chinle assemblages have nothing in common with the Pekin track faunule. A greater diversity of footprints is known from the European lower Keuper (km1-km3), notably with the lower Gipkeuper (km2) that produced *Parachirotherium postchirotheroides*.

The Argana and Ourika basins of Morocco have also produced a poorly known assemblage of footprints, which at first glance appears potentially similar to that from Pomona A (Biron and Dutuit, 1981). *Apatopus lineatus* appears to be present in the Ourika basin (Biron, 1981) along with tetra-or pentadactyl tracks (*Quadridigitatus dubius* of Biron) and a few unnamed tridactyl forms. Biron named two tri- tetra-or pentadactyl tracks, *Tridactylus manchouensis* and *Anomoepus moghrebensis*, that were recovered from the Timezgadiwine Formation of the Argana basin (comprising TS II of Olsen, 1997). These could be poorly preserved examples of new genus 1, however restudy and collection of new material is clearly needed. The age of the Timezgadiwine Formation is early Tuvalian (Late Carnian) and that of the tracks in the Ourika basin is constrained only to Carnian on the basis of pollen and spore assemblages (Cousminer and Manspeizer, 1976).

IMPORTANCE OF THE PEKIN ASSEMBLAGE

The footprint assemblage from the Pekin Formation of the Deep River basin is the oldest in eastern North America that is based on material good enough to analyze. Coming from strata of early Tuvalian age, it is the same age as the oldest known dinosaurs (Lucas and Long, 1992; Lucas and Huber, 1997). King and Benton (1996), suggest that all published records of dinosaur footprints of Middle Triassic age are doubtful, and therefore the tracks of dinosaurian aspect of the Pekin assemblage are among the oldest in the world. That said, it is also true that since both saurischians and ornithischians are present in late Tuvalian age strata, early Tuvalian, or even late Middle Triassic age dinosaurs plausibly existed. In addition, the feet of the earliest known dinosaurs, such as *Herrerasaurus*, retain very primitive proportions with both long digits I and IV (Novas, 1993). Therefore, it is likely that it may be quite difficult to recognize the pes of very early dinosaurs because they might resemble a brachychirothere more than a *Grallator.*

Newarkian late Tuvalian (Late Carnian) to late Norian age track assemblages are well known and could even be called stereotypical. They differ substantially from Middle Triassic age footprint assemblages described by Demathieu (1970), Demathieu and Gand (1972), and Demathieu and Weidmann (1981) in having abundant unquestioned dinosaurian tracks and a broader range of quadrupedal ichnites. The middle Pekin faunule is intermediate in age and composition between the much better known Middle Triassic and late Triassic assemblages, and is thus critical to an understanding of the origin of dinosaur-dominated communities of the later Mesozoic. For this reason, a concerted effort should be made to collect more and better material from this key interval, especially from active quarries.

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