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DINOSAUR AND PTEROSAUR TRACKS IN THE SUMMERVILLE AND BLUFF (JURASSIC) BEDS OF EASTERN UTAH AND NORTHEASTERN ARIZONA

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Abstract—Reexamination of the *Pteraichnus* (pterosaur tracks) type locality in the Four Corners area reveals abundant theropod and brontosaur tracks in the uppermost part of the Bluff sandstone (Recapture Member). These are the first dinosaur tracks reported from these units in this area, and include the theropod track *Megalosauripus*, which is also found in the Summerville near Chama, New Mexico, the Summerville-Bluff transition zone near Blanding, Utah, and the transition zone between the Moab Tongue of the Entrada and the "upper tongue" of the Summerville in the Moab area, Utah. The widespread theropod track assemblage in this facies and widespread distribution of pterosaur tracks in the upper part of the Summerville Formation and correlative pre-Salt Wash beds adds much to our knowledge of a sequence that was previously regarded as completely unfossiliferous, and helps shed light on debates about regional stratigraphic correlation.

INTRODUCTION

Recently there has been considerable debate about placement of the base of the Morrison Formation. Some authors place it at the base of the Salt Wash Member (Gilluly and Reeside, 1928; Anderson and Lucas, 1994). Others place it lower in the succession, below the base of the Bluff Sandstone in the Four Corners area, and below the Tidwell Member in eastern Utah (Peterson, 1994), at a level where the purported J-5 unconformity has been recorded. Much of the debate about the base of the Morrison arises from confusion and controversy about this unconformity. Some authors claim that it cannot be recognized in the field, or that the only regional break of any significance at this time is a regional scour surface at the base of the Salt Wash (Anderson and Lucas, 1994, 1995, 1996).

If a major unconformity exists below the basal Salt Wash scour surface, it might be possible to detect it on the basis of distinctive faunas or ichnofaunas above and below. The Morrison, as defined by Anderson and Lucas (1994–1996) to include the Salt Wash and Brushy Basin Members, contains a distinctive Late Jurassic dinosaur-dominated vertebrate fauna not found in the underlying beds (Tidwell and Bluff). Hence, the age of these pre-Salt Wash beds is not well established.

Recent work however, has shown that fossil footprints are widespread in deposits in the western United States (Lockley and Hunt, 1995), and that the Bluff and Summerville appear to be no exception (Lockley et al., 1996a). Prior to this study tracks were already known from the transition zone between the eolian Moab Tongue Member of the Entrada (Lockley, 1991a, b; Lockley and Hunt, 1995) and the overlying upper tongue of the Summerville in the Moab area (O'Sullivan, 1981). These tracks are so extensive as to constitute a megatracksite that extends over an area of about 2000 km^2 (Lockley, 1991a, b; Lockley and Hunt, 1995). The stimulus for this paper came in 1994, when additional tracksites, yielding similar footprints, were discovered in the Bluff and Summerville beds of the Four Corners area near Teec Nos Pos (Strobell, 1957) and in the Summerville-Bluff transition zone near Blanding.

THE TEEC NOS POS AREA

The *Pteraichnus* type locality

This paper was stimulated, in part, by a restudy of the pterosaurian track ichnospecies *Pteraichnus saltwashensis* first found by Stokes (1957) near Teec Nos Pos. According to Stokes, the tracks occur in the lowest part of the Morrison Formation, but no detailed stratigraphic work was undertaken, nor was the level at which the tracks were found precisely recorded (Stokes, personal commun., 1994). Our studies indicate, however, that *Pteraichnus* occurs in the uppermost part of the Bluff succession (Recapture Member *sensu* Anderson and Lucas, 1995, fig. 4), and that this ichnogenus is widespread in pre-Salt Wash deposits of the Colorado Plateau and adjacent regions (Lockley et al., 1996a).

The tracksite sequence begins with the thinly and evenly bedded, sandy and argillaceous calcareous siltstones of the Summerville Formation (Fig. 1). In the upper part of the sequence are a few fine- to medium-grained, cross-stratified,

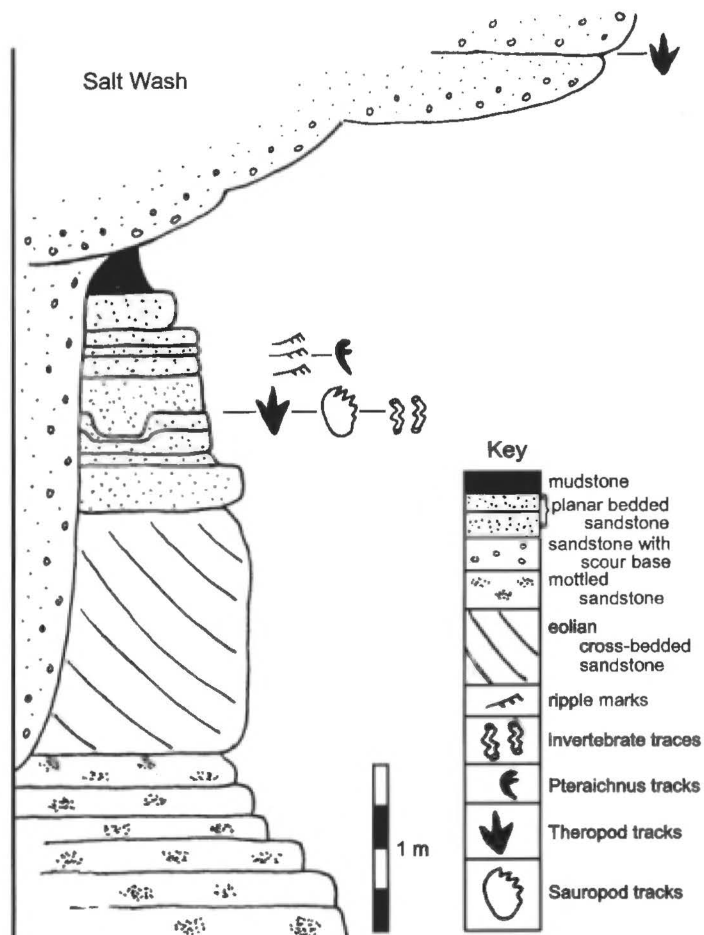

FIGURE 1. Stratigraphic section of the upper part of the Summerville through Bluff and basal Salt Wash sequence, near Teec Nos Pos. Scour surface exaggerated to show maximum down cutting (cf. Strobell, 1957).

eolian sandstone units. According to Strobell (1957), these sandstone units are related to the Cow Springs Sandstone (Harshbarger, 1951), but he pointed out that there is "both grading and intertonguing" of the Bluff and Summerville. The main body of the Bluff Sandstone, though much thinner than in the type area, consists of a cliff-forming unit only about 3 m thick. Parts of this succession reveal intercalated, thinly bedded sandstones characterized by dark reddish-brown claystone partings with small-scale, symmetric, oscillation ripples (wavelength 1–2 cm), invertebrate bioturbation (cf. *Rhizocorallium*) and both small (*Pteraichnus*) and large (sauropod and theropod) vertebrate tracks. Strobell (1957) noted that the top of the Summerville can be placed at the highest dark reddish-brown claystone parting. This would be the Recapture Member of the Bluff according to Anderson and Lucas (1995). We note therefore that the main track-bearing layers are part of the Recapture succession that sits above typical eolian Bluff Sandstone, immediately below the scour surface that marks the base of the Salt Wash. As shown below the track assemblage is different from that found in the Salt Wash Member of the Morrison elsewhere on the Colorado Plateau.

Stokes (personal commun., 1994) collected the type specimen of *P. saltwashensis* from the northwest flank of the Carrizo Mountains, 26 km southwest of the Four Corners, and believed that they came from the lowest part of the Salt Wash Member. He informed the senior author of the precise location where he found the specimen and indicated that at that time (in the 1950s) he observed no other tracks at the locality. Prior to communicating with Stokes, one of us (M.G.L.) tried to locate the locality using geological maps and found *Pteraichnus* tracks (Fig. 2) and abundant dinosaur footprints in the upper part of the Bluff-Summerville sequence (Fig. 1) at a locality about a kilometer east of where Stokes had apparently found the pterosaur tracks. Only one trackway was found in the Salt Wash Member at this new locality. After further communication with Stokes, we were able to locate his original locality, about 1.6 km to the west, and discovered abundant tracks in the top of the Summerville through Bluff sequence, at the same horizon as at the new locality. Again, only one isolated theropod trackway was found at a higher stratigraphic level in the Salt Wash.

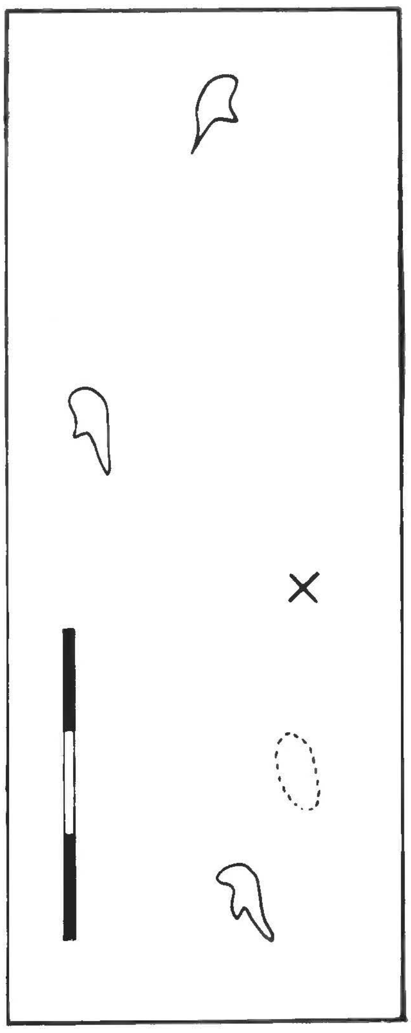

FIGURE 2. A partial *Pteraichnus* trackway from the top of the Summerville-Bluff sequence near the *Pteraichnus* type locality, near Teec Nos Pos. Scale bar 30 cm. X marks inferred position of missing right manus in trackway sequence (see text).

According to Strobell (1957) in "the northern edge of the Carrizo Mountains area, beds at the base of the Morrison formation intertongue slightly with the uppermost beds of the Bluff sandstone" and in "some places the (Morrison) channels completely cut out the Bluff sandstone." We observed similar relationships in the section measured at the new locality, where we found pterosaur tracks only a fraction of a meter below the channeled base of the Salt Wash, and we have noted areas where the channeling cuts down into the Bluff Sandstone. The stratigraphic position of the pterosaur tracks, in the terminology of Anderson and Lucas (1995), would be in the Recapture Member.

Thus, it is possible either that Stokes had a slightly different interpretation of the base of the Morrison, and that the tracks actually came from the Bluff (Recapture) sequence as we report for the new locality, or, perhaps he found another track layer higher in the sequence that really was in the Salt Wash Member. Based on our discovery, and virtually all other occurrences of Jurassic pterosaur tracks so far reported (Lockley et al., 1995, 1996), we place the track beds below the Morrison. If this proves to be correct, then the name *Pteraichnus saltwashensis* is misleading in its stratigraphic implication. The Stokes interpretation, however, may be correct only for the type locality. Though there are pterosaur body fossils in the Morrison Formation, their tracks are not abundant, as they are in pre-Salt Wash deposits.

GENERAL ICHNOLOGY

Methods

In our field studies we have identified all tracks and trackway segments, the horizons from which they originated, and made standard measurements such as track length and width, step, stride and trackway orientation. Many tracks were recorded by tracing the outlines of individual footprints, and a record of selected tracks was obtained by making latex molds. The replicas made from these molds are assigned specimen numbers in the Joint University of Colorado at Denver-Museum of Western Colorado (CU-MWC) collection.

Pteraichnus tracks

Although the *Pteraichnus* specimen shown in Figure 2 is not particularly well-preserved, it shows several of the diagnostic features of this ichnogenus, including the tridactyl manus with the longest digit impression directed posteriorly. The manus tracks are also more deeply impressed than the pes (Lockley et al., 1995). The trackway illustrated herein consists of three manus tracks and a faint pes track. The manus tracks are arranged left 1, left 2, right 2, with right 1 missing due to erosion of the track-bearing surface (X in Fig. 2). Manus length is about 8 cm and width about 4 cm. Step is on the order of 31 cm and stride about 48 cm. These dimensions compare quite closely with the measurements obtained by Stokes (1957) for the type material. The trackway is oriented westward (toward 280°) more or less parallel to the trend of wave-ripple crests. Assuming that waves broke parallel to the shoreline, such evidence suggests an E–W trending shoreline in this area.

Theropod tracks (*Megalosauripus*)

Some natural casts of theropod tracks were observed in association with the laterally continuous, tabular beds immediately overlying the thick, cross-bedded eolian unit that represents the main expression of the Bluff Sandstone at the Teec Nos Pos locality (Fig. 1). These beds are immediately below the *Pteraichnus*-bearing thin-bedded sandstones with clay partings and small-scale wave ripples, and are therefore slightly older than the *Pteraichnus* tracks assigned to the upper part of the Bluff-Summerville sequence.

Some of the theropod track casts observed in this study are natural casts that are exceptionally well-preserved (Fig. 3). They show the typical morphology of two, three and four digital phalangeal pads on digits II, III and IV, respectively. To date we have only observed one trackway *in situ*, consisting of tracks 42 cm long by 28 cm wide with a step of about 100 cm (stride 190 cm) and orientation towards due north. The step is relatively short for the size of the animal, and the trackway is wide. Such features are typical of *Megalosauripus* trackways (Lockley et al., 1996b, fig. 5).

Detailed measurements of well-preserved tracks reveal that they are generally large (40–45 cm long), and much longer than wide (ratio about

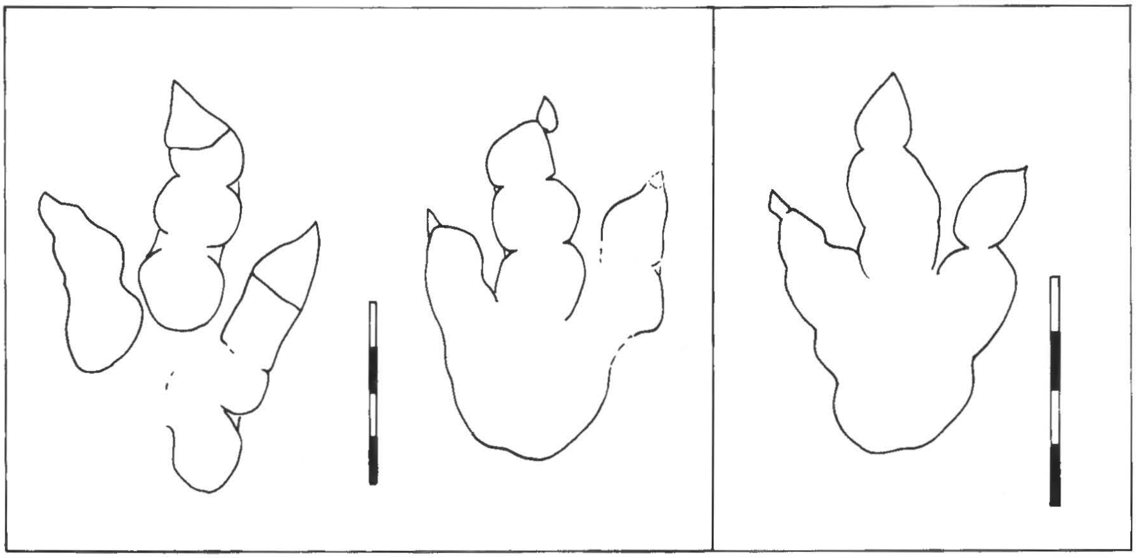

FIGURE 3. Theropod (*Megalosauripus*) tracks from the Summerville-Bluff sequence at the Teec Nos Pos localities (left and center), with comparable track from the Butler Wash locality (right). Scale bars 20 cm.

3:2). This same ratio is noted in tracks from the Summerville-Bluff transition zone at the Butler Wash locality near Blanding and in tracks from the Moab megatracksite, and leads us to conclude that tracks from both localities belong to the same ichnotaxon. When compared with *Eubrontes*, a typical large theropod track from the Lower Jurassic (e.g., Miller et al., 1989), the Bluff-Summerville *Megalosauripus* tracks are significantly different in several respects (Fig. 4).

Megalosauripus tracks are more elongate than *Eubrontes*. More significantly, they have a much more elongate heel than *Eubrontes*, leading to a very different ratio between the length of digit III and overall footprint length. As shown in Figure 4, the heel area makes up 40% of footprint length (digit III = 60%), whereas in *Eubrontes* the heel makes up only 29% (digit III = 71%). There are also differences in the shape of the phalangeal pads of these two track types. *Megalosauripus* tracks show equidimensional pads on digit III, whereas in *Eubrontes* the distal and penultimate pads are larger than the proximal pad, giving the digit a broad, fusiform, spindle shape. These distinctive morphological characteristics have led to recognition of the need for a formal revision of *Megalosauripus* (Lockley et al., 1996b; and Lockley et al., in prep.).

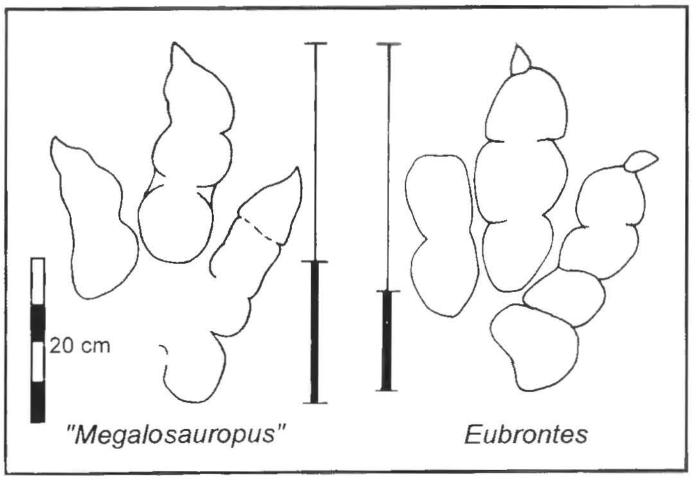

FIGURE 4. Comparison of *Megalosauripus* specimen CU-MWC 188.25 (left), from the Bluff-Summerville near Teec Nos Pos, with Lower Jurassic *Eubrontes* (right), modified after Miller et al. (1989), reveals significant morphological differences in the ratio of the lengths of digit III and the whole footprint. Scale bar 20 cm.

Theropod tracks from the Salt Wash, Teec Nos Pos area

A few much smaller theropod tracks have been found in the Salt Wash Member of the Morrison Formation at the Teec Nos Pos localities. The first is a single left footprint about 25 cm long and 20 cm wide (Fig. 5), with relatively narrow digit impressions, found just above the scour surface at the new *Pteraichnus* locality (Fig. 1). The second locality is near the original *Pteraichnus* type locality and consists of a segment of trackway in beds about 9 m above the track-bearing beds in the Bluff-Summerville sequence. This second Salt Wash tracksite consists of tracks about 33 cm long by 24 cm wide, with a step of 95 cm and an orientation towards 245°. The tracks are not sufficiently well preserved to show pad impressions or to warrant illustration.

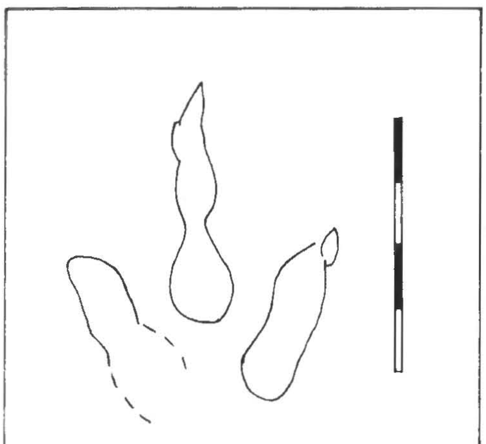

FIGURE 5. An isolated theropod track from the Salt Wash Member of the Morrison Formation at the newly discovered Teec Nos Pos locality. Scale bar 20 cm.

Brontosaur tracks

Both Teec Nos Pos localities have yielded brontosaur tracks from the same Bluff-Summerville beds that produced the theropod tracks. Many of the tracks appear in cross section as large, bulbous convex-downward depressions. Several tracks however, are preserved as perfect natural casts, either on the underside of ledges, or as detached casts in the float below this level. Three of the best tracks are illustrated in Figure 6. The first forms part of a trackway from the new locality, in which the pes is about 55 cm long and 40 cm wide, with a step of 113 cm and a trackway orientation of about 65°.

The other two illustrated sauropod tracks also represent natural casts, found as detached blocks at the original pterosaur tracks type locality. One is

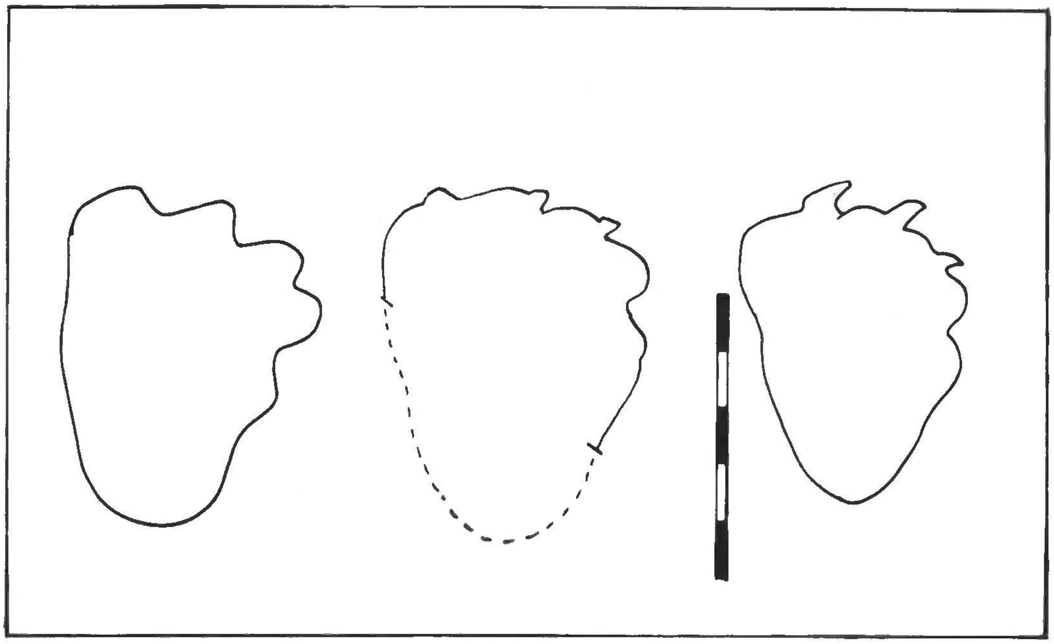

FIGURE 6. Sauropod tracks from the upper part of the Summerville-Bluff sequence Teec Nos Pas area (CU-MWC 188.31, 188.29, 188.28, respectively, from left to right). Scale bar 50 cm.

a complete cast (also measuring 55 cm by 40 cm) showing excellent detail of toe impressions, and the second is an incomplete cast representing a slightly larger individual (pes length about 60 cm; width 46 cm). Until recently there have been very few reports of Jurassic sauropod tracks preserved as natural casts, and equally few reports of footprints in which toe impressions are well preserved (Meyer et al., 1994). The tracks reported here are therefore very significant because of the details of toe morphology that they reveal. For example, it is clear that the trackmakers had relatively small claws on digits I, II and III, and only rounded callosities comprising digits IV and V. In this respect the tracks show subtle differences from *Brontopodus*, the well-known sauropod ichnogenus from the Cretaceous of Texas, which appears to reveal a claw impression associated with the distal end of digit IV (Farlow et al., 1989). Similarly, large sauropod track casts from the Salt Wash Member near Bullfrog, Utah, reveal very large claw impressions on digits I and II, but appear to have rounded callosities associated with digits III, IV and V (Meyer et al., 1994; Lockley and Hunt, 1995, fig. 4.55). Further work is needed to determine the extent to which such difference in the size of claws and the distribution of claws, callosities and pads is a function of differences in sauropod foot morphology, and to what extent it might be attributable to differences in preservation. Clearly, the discovery of new, well-preserved material helps to swell a rapidly expanding data base (Lockley et al., 1994). The occurrence of well-preserved sauropod tracks with relatively small claw impressions might suggest that in some species the claws were largely enclosed in flesh. Extreme examples of the former morphology might help explain the occurrence of sauropod trackways in which claw impressions are absent or obscure.

THE BUTLER WASH LOCALITY

During summer 1994, tracks were discovered in the Summerville-Bluff sequence in a small tributary of Butler Wash about 15 km southwest of Blanding, Utah. The tracks occur at five stratigraphic levels in a 2.5 m sequence of thinly and evenly bedded reddish and buff-to-white sandstones immediately overlain by the main body of the Bluff Sandstone (Fig. 7). One of the theropod tracks (Fig. 3), from level 1 compares very closely in morphology and size with the tracks from the Teec Nos Pos localities. Measurements of tracks are given in Table 1 (compare with Fig. 7).

The data show a range of track size from 47 by 34 to 23 by 16 cm. The largest tracks are therefore about the same size as those from the Teec Nos Pos locality, and we attribute them to *Megalosauripus*. The smaller track is probably attributable to "*Therangospodus*" (quotations indicate that name is a label derived from an unpublished thesis: see Lockley 1996a, for details). The size range of tracks is also very similar to that found in the Moab Tongue-Summerville transition zone megatracksite near Moab.

DISCUSSION

The similarity of theropod tracks at the Teec Nos Pos, Butler Wash and Moab megatracksites localities is quite striking. Although theropod footprints from the Moab megatracksite (Lockley 1991b; Lockley and Hunt, 1995) have not been described in detail, it is clear that the tracks are the same as those reported from Butler Wash and the Teec Nos Pos area (Lockley et al., 1996b). Also, in all cases these *Megalosauripus* and "*Therangospodus*" tracks are associated with facies that represent the interfingering of coastal dunes with flat, evenly-bedded, argillaceous marginal marine sands. Thus, the theropod tracks indicate a distinctive ichnofacies (defined as recurrent associations of particular track types, or track associations in similar facies; Lockley et al., 1994b).

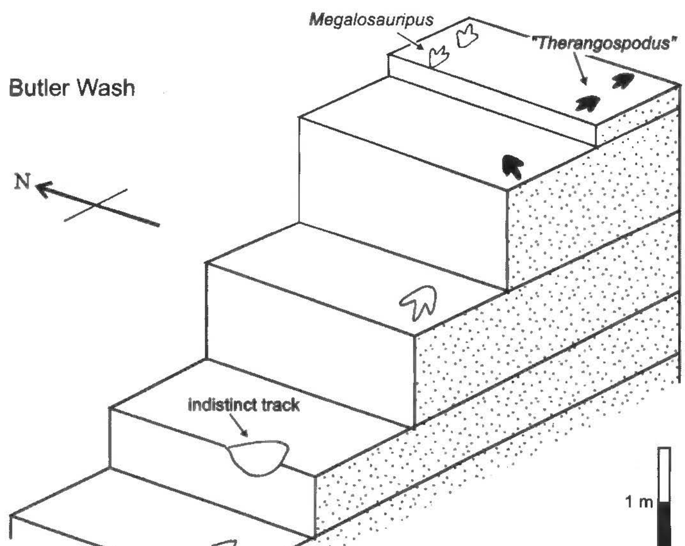

FIGURE 7. Stratigraphic section of the track-bearing Summerville-Bluff sequence at the Butler Wash locality. Track surfaces have been designated 1–5, from oldest to youngest, corresponding to numbers in Table 1.

TABLE 1. Dinosaur track measurements from the Summerville–Bluff sequence, Butler Wash, Utah.

Track level.	length :	width.	step :	stride.	Orientation	Meg./ Ther. *
level 5	23	16	92	178	260 °	Ther.
level 5	47	34	120	-	30 °	Meg.
level 4	(26)	19	-	200 °	Ther.	
level 3	-oval depression is probable theropod underprint-					
level 2	(40)	34	-	-	250 °	Ther.
level 1	33	33	-	-	270 °	Ther.

* provisionally identified as *Megalosauripus* (= Meg.) or "*Therangospodus*" (= Ther.).

In terms of their stratigraphic position in relation to the basal Salt Wash scour surface, the Butler Wash and Moab megatracksite localities are situated lower in the succession than the Teec Nos Pos locality. This may help explain why the latter locality also yields sauropod and pterosaur tracks, the former also being characteristic of the uppermost parts of the Tidwell Member of the Summerville (Lockley and Hunt, 1995) and of the Salt Wash and Brushy Basin Members of the Morrison. *Pteraichnus* usually occurs high in the Summerville or equivalent pre-Salt Wash successions (Lockley et al., 1995, 1996a). Although the Teec Nos Pos tracks may be younger than those from Moab and Butler Wash, the latter still represent a relatively late stage in Summerville deposition, when the Moab Tongue and Bluff ergs were prograding onto the margins of the Summerville marine embayment. Locally, the Butler Wash locality can be regarded as a phase of trackmaking prior to advance of the Bluff erg into the area, whereas the Moab and Teec Nos Pos localities represent phases of marine encroachment and reworking into areas recently occupied by ergs.

Finally, we note a marked change in the ichnofauna progressing upsection from pre-Salt Wash deposits into the Salt Wash Member. At Boundary Butte, is a distinctive ichnofauna of small tridactyl tracks assigned to the ?ornithopodan ichnogenus *Dinehichnus* (Lockley et al., in press). Similar tracks are found the basal Salt Wash near Grand Junction, Colorado. The tracks described herein from the Salt Wash at the two localities near Teec Nos Pos (Fig. 5) both differ in morphology (and size) from *Megalosauripus* and *Therangospodus*. These two ichnogenera are not found in an assemblage of small tridactyl theropod and ?ornithopod footprints in the basal Morrison beds at Como Bluff (Southwell et al., 1996). Thus we conclude that a significant change in the ichnofauna accompanies the stratigraphic transition from pre-Salt Wash (pre-Morrison) deposits (*sensu* Anderson and Lucas (1996), to the Salt Wash/Morrison proper. This change is evidently due to an amelioration of the climate and the establishment of habitats suitable for a more diverse ichnofauna in which small trackmakers become more common. This shift may be related to the drifting of Morrison terrains out of low, subtropical latitudes (cf. Anderson and Lucas, 1996).

ACKNOWLEDGMENTS

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