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GIANT THEROPOD TRACKS FROM THE CRETACEOUS DAKOTA GROUP OF NORTHEASTERN NEW MEXICO

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Abstract —Giant theropod tracks from the Cretaceous Dakota Group of Union County, northeastern New Mexico measure up to about 1 meter long, with heel drag traces, and 50 cm wide, with a stride of 3.7 meters. These are the largest tracks yet reported from this stratigraphic unit, and are associated with a typical assemblage of ornithopod tracks (*Caririchnium*) . The tracks are deep with heel traces or metatarsal impressions, but with no obvious hallux trace. Digit III lengths and whole track lengths are variable and probably exaggerated by forward motion of the foot exiting the substrate. However track width measurements provided by the impressions of digits II and IV are reliable and consistent, and allow measurement of the angle at which the foot penetrated the substrate.

The track is possibly that of an ornithomimid and may be related to *Magnoavipes*. This ichnogenus is relatively common in the Dakota Group, and normally does not exceed a length and width of about 25-30 cm. This suggests the possibility of more than one theropod species, with a common small form and a rarer large form. An additional tracksite is also reported that yields only ornithopod tracks.

INTRODUCTION

More than 60 tracksites are now known from the Cretaceous (late Albian-early Cenomanian) Dakota Group of eastern Colorado and eastern New Mexico. These tracksites form part of the so called "Dinosaur Freeway" which represents a "regionally extensive" package or sequence of beds in sequence 3 of the Dakota Group (Jones. 1988; Lockley, 1991; Lockley et al., 1988, 1992; Lockley and Pittman 1989; Lockley and Hunt, 1995; Weimer, 1989). Recent studies in southeastern Colorado (Schumacher, 2003; Kukihara, 2006; Kukihara et al., 2004, 2005a, b, c) have shown that many more Dakota Group tracksites are still being discovered, some of which are yielding new ichnotaxa, not previously reported from the is group.

This paper is a further contribution to this trend. We herein report on two tracksites north of Clayton Lake State Park (Gillette and Thomas, 1985, 1989; Lucas et al., 1989; Lockley and Hunt, 1995) that yield typical ornithopod tracks (*Caririchnium*) (Fig. 1). However one site reveals a very unusual large theropod track that may be different from anything previously reported from the Dakota Group.

GEOLOGICAL SETTING

Both sites described here are relatively small and associated with outcrops of horizontal Dakota Group sandstones. Because neither site reveals much vertical section it was not possible to identify the exact stratigraphic levels of the tracks with certainty. However, as noted by Lockley et al. (1992) many of the track-bearing layers in southeastern Colorado and northeastern New Mexico are associated with the transition from the upper part of the Mesa Rica Sandstone into the lower part of the Pajarito Formation. Track beds occur at this level at Clayton Lake State Park which is the nearest previously known tracksite, located only a few tens of kilometers to the south (Lucas et al. (1989). In this region, tracksites are often found associated with flat exposures, at or near the top of bluffs, or on the open prairie where the softer shales and thin sandstones of the Pajarito Formation have eroded down to the level of the top of the more resistant Mesa Rica Sandstone.

To date, all studies have inferred a late Albian age for the track-bearing beds in this Mesa Rica-Pajarito transition zone (Lucas et al., 1989; Lockley et al., 1992). As noted above this track bearing zone is associated with the onset of the T6 transgression (*sensu* Kauffman, 1977), which corresponds to the early transgressive systems tract of Dakota Group sequence 3 (*sensu* Weimer, 1989). The sequence stratigraphy and facies architecture of this region has been studied by Holbrook (1996, 2001) and others (Holbrook et al., 1992, 2006; Scott et al., 2004) leading to refined understanding of the relationships between track-bearing units and the sequence stratigraphy (Lockley et al., this volume).

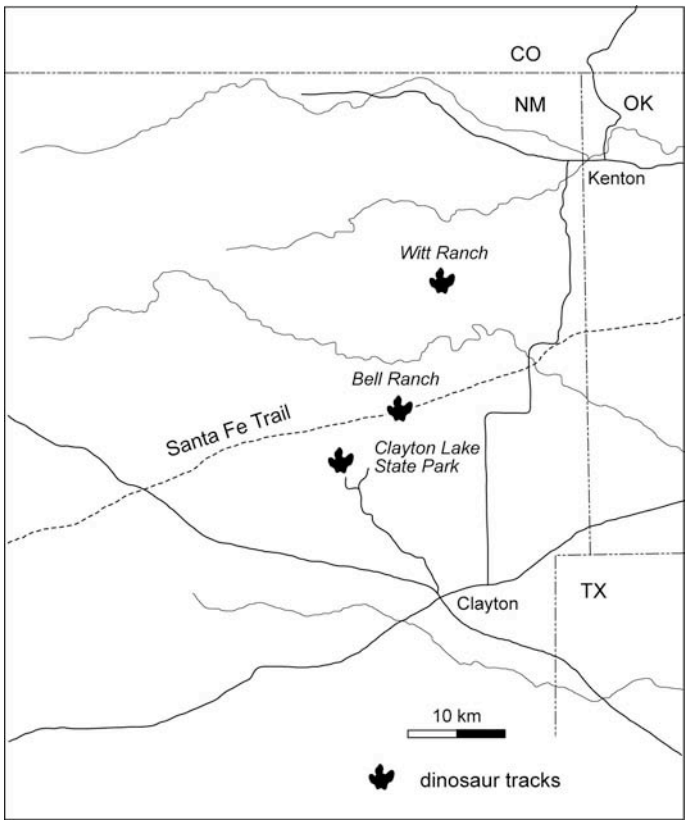

FIGURE 1. Locality map for new dinosaur tracksites north of Clayton Lake State Park, northeastern New Mexico.

DESCRIPTION OF TRACKS AND TRACKSITES

The Witt Ranch tracksite

The Witt Ranch tracksite reveals about 30-35 identifiable tracks in an area of approximately 6 x 6 (= 36 m^2). Thus, he track density is quite high: about 1 per m^2. The trackways represent at least 10 individuals (Figs

TABLE 1. Measurements of trackways from the Witt Ranch Site. Trackway 1 represents a theropod, and the No. 2 track is preserved as a replica (CU 209.36) in the University of Colorado at Denver, Dinosaur Tracks Museum collections. (*) indicates length measurement with heel trace: see text for details. All other trackways represent ornithopods.

Trackway #	Track length cm	Track width cm	Step cm	Track type / notes
1	100 *	50	180-190	Theropod
2	28	28	81	Ornithopod
3	c. 47	47	99	Ornithopod
4	44	47	88	Ornithopod
5	24	23	59	Ornithopod + manus
6	c.36	27	c. 85	Theropod
7	33	32	-	Ornithopod
8	c. 18	c.22	-	Ornithopod
9	27	27	97	Ornithopod
10	30	c.30	-	Ornithopod + manus
Mean for ornithopods	2-10	31.9	31.4	84.8

2-3). Nine trackways were identified as those of ornithopods (Table 1), and one was identified as that of a theropod. The trackways appear to have no obvious preferred orientations.

The Bell Ranch tracksite

The Bell Ranch tracksite reveals only one trackway consisting of eight poorly preserved ornithopod tracks (Fig 4) and an isolated track at another stratigraphic level. The outline of the tracks is not suitable for obtaining reliable length and width measurements. However, we measured an average step of about 67 cm and an average stride of 133 cm. The outcrop in this area consists of extensive sandstone bedding planes with no other evidence of tracks. Thus, the track density is low in contrast to the Witt Ranch site.

ORNITHOPOD TRACKS

All of the tracks from the Bell Ranch site and nine trackways from the Witt Ranch site are identified as those of ornithopods. They are indistinguishable from tracks assigned to the ichnogenus *Caririchnium* (Lockley 1987), which are the most common found on the Dinosaur Freeway (Lockley et al., 1992; Kukihara et al., 2005a). As indicated in Table 1, the ornithopod pes tracks range from 24 cm long and 23 cm wide to 47 cm long and 47 cm wide. Thus, they are about equally as long as wide (mean length 31.9, mean width 31.4 cm). Corresponding step lengths are 59 and 99 cm, respectively, for the largest and smallest trackmakers (mean 84.8 cm). Only two trackways (5 and 10) show typical sub-circular manus tracks situated anterior to the pes tracks. One example is illustrated in Figure 5. In all respects these trackways are typical of *Caririchnium* from most other Dakota Group tracksites.

THEROPOD TRACKS

Three theropod tracks comprise an unusual two-step, three-footprint trackway (Figs. 2, 3 and 5). The tracks, numbered 1, 2 and 3 in the direction of progression, are very deep and are characterized by long posterior heel traces, which show little deviation from the trackway midline. In track 2, which we replicated as University of Colorado at Denver, Dinosaur Tracks museum specimen CU 209.36, the impressions of digits II and IV penetrate the substrate at an angle of about 40-50°. Given the depth of the tracks (up to 25 cm in places), we interpret these posterior traces as heel traces made when the sediment was soft. Although there is partial collapse of sediment around some digit impressions, all impressions are preserved to their full depth, though the walls have converged inward somewhat, notably in digit III.

It is possible that the posterior traces represent metatarsal traces, but this cannot be demonstrated with any confidence. Although the heel traces

FIGURE 2. Photo of Witt Ranch site. Tracks occur in front of individual observer

on tracks 1 and 2 show slight irregular depressions on their lateral margins, we infer that these cannot be hallux traces, because they are on the outer lateral sides of the tracks, not on the inner medial side as would be predicted.

Average track width is 50 cm (range 47-55 cm) and the tracks show a very wide divarication angle (about 105° in track 1 and 135° in track 2). Track 1 is 87 cm long with the heel trace but about 50 cm without. Track 2 is 110 cm long with the heel trace and about 65 cm without. We infer that the most conservative interpretation of track size is that the tracks were about 50 cm long and wide. In general, track width measurements are a consistent and a more accurate indication of foot width than footprint length, which can be distorted by movement of the foot in the direction of progression. The step of the trackmaker is 180 cm between track 1 and 2, and 190 cm between 2 and 3 (stride 370 cm).

The most common Dakota Group theropod track is *Magnoavipes* (Lockley et al., 2001), which is typically about 20-25 cm long and wide, with wide digit divarication, no hallux or heel trace and a relatively long step. Thus, we infer that this track, though *Magnoavipes*-like if the posterior (heel) trace is discounted as extramorphological, probably represents a different ichnotaxon. Few tracks of comparable size have been reported from the Dakota Group or equivalent deposits. Kappus et al. (2003) reported some *Magnoavipes*-like tracks of approximately this size from the Mojado Formation (Sarten Member) of southern New Mexico, but the quality of preservation was too poor to provide measurements that would be useful for detailed morphometric comparison.

Lockley et al. (2001, p. 143-144) reported an anomalously large theropod track from Dinosaur Ridge (foot length and width 38 cm, step

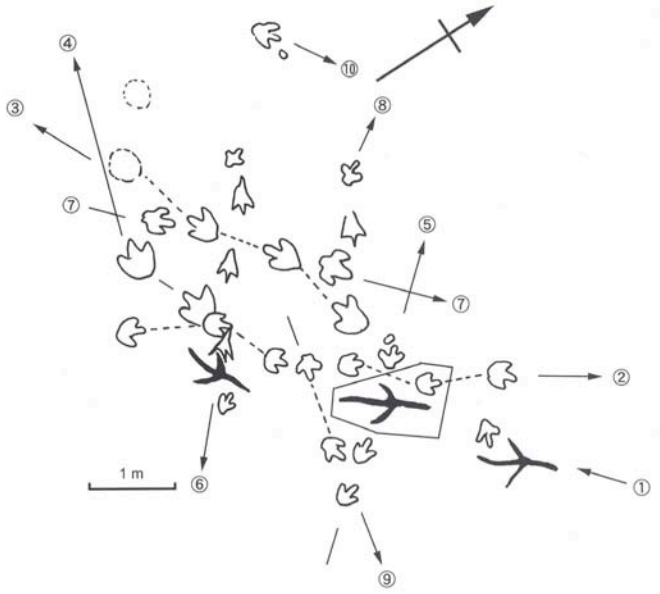

FIGURE 3. Map of Witt Ranch site. Trackway numbers correspond to Table 1

FIGURE 5. Photograph of large theropod trackway

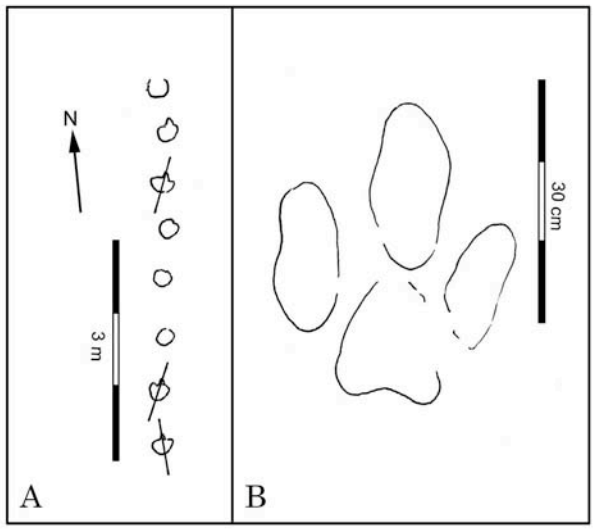

FIGURE 4. **A:** Sketch map of northward trending ornithopod trackway from the Bell Ranch site. **B:** Tracing of isolated ornithopod track from same locality based on tracing T 817.

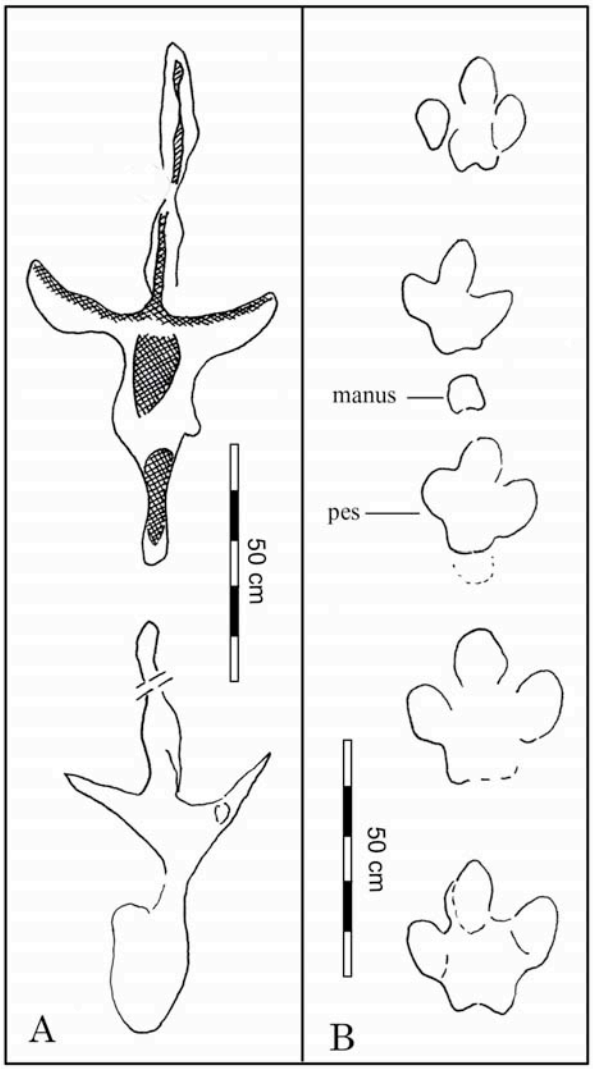

FIGURE 6. **A:** Tracings of giant theropod tracks (1 and 2 in sequence). No. 2 = replica 209.36 in University of Colorado at Denver, Dinosaur Tracks Museum collections. Compare with Figure 3. **B:** size range of various ornithopod tracks based on tracings T 786 and T787: all drawn to same scale. Ornithopod tracks do not show a trackway sequence, but the manus and third pes from top make a pair.

122 cm) and stated that it "may not be *Magnoavipes*" because it is much larger than any of the other 15 trackways in the sample which do not exceed 26-27 cm in length and width, respectively. Another trackway with similar dimensions (approximately 40 cm long, 35 cm wide, with a step of 120 cm) was recently discovered at another locality south of Dinosaur Ridge (Lockley et al., 2005). However in both these cases the tracks measure only about 70-80% of the size of the Witt Ranch tracks. Also in both cases step length is also shorter (about 65%) than the Witt Ranch dimensions. As a result of these comparisons we again infer that the Witt Ranch trackway is unique, and is the largest and most distinctive theropod track yet reported from the Dakota Group. However, despite its distinctive outline and great depth, we consider it premature to suggest a formal name.

DISCUSSION

Large theropod tracks are rare in the Dakota Group. The common theropod track type, *Magnoavipes*, rarely exceeds 27 cm in length and width. Because of its wide digit divarication angles *Magnoavipes* is often interpreted as the track of some type of ornithomimid or struthiomimid dinosaur. This inference is supported by the lack of evidence for any kind of hallux trace. The same logic can be applied to the large Witt Ranch theropod tracks, and leads us to conjecture that they may have been made by a large ornithomimid that differed from the *Magnoavipes* trackmaker in having feet twice as large on average. However, these interpretations are conjectural.

On of the interesting aspects of Dakota Group ichnology is that at the vast majority of known localities, the overwhelmingly dominant dinosaur track types are *Caririchnium* and *Magnoavipes*. This consistency in ichnofaunal composition has led to characterization of Dinosaur Freeway ichnofaunas as a distinctive and regionally homogeneous *Caririchnium* ichnofacies (Lockley et al., 1994; Lockley in press) or *Caririchnium* ichnocoenosis (*sensu* Hunt and Lucas, 2006 in press).

We stress that the concept of an ichnotaxonomically uniform ichnofauna, ichnocoenosis or ichnofacies, does not imply a one-to-one correspondence with actual trackmaker diversity. On the contrary, it is impossible to estimate trackmaker diversity with great accuracy in the vast majority of cases; indeed, it may be practically impossible in all cases. Thus, we are free to speculate that the actual trackmaker diversity may have been higher than the minimum number of distinctive track types (ichnotaxa) indicates. In this case diversity for named dinosaur tracks is only two. However, it has been recently suggested that ornithopod tracks from the southern part of the Dinosaur Freeway are generally smaller than those found to the north, and this could indicate different species of smaller trackmaker at lower latitudes as ecological theory might suggest (Kukihara, 2006). The discovery and documentation of large theropod tracks that differ from typical *Magnoavipes* helps support the inference that dinosaur ichno-diversity is higher than previously supposed (Kukihara et al., 2005a). This result is not particularly surprising given that the Dakota paleoenvironment was suitable for supporting a diverse flora and fauna.

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