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THEROPOD- AND PROSAUROPOD-DOMINATED ICHNOFAUNAS FROM THE NAVAJO-NUGGET SANDSTONE (LOWER JURASSIC) AT DINOSAUR NATIONAL MONUMENT: IMPLICATIONS FOR PROSAUROPOD BEHAVIOR AND ECOLOGY

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Abstract—Several track-bearing units from the Navajo-Nugget Sandstone were reported from Dinosaur National Monument in the early 1990s, but not described in detail. Herein, details of these units are given showing that at least 260 tracks have been recorded from 5 mapped horizons between about 8 and 35 meters below the top of the unit. The tracks, which occur in inter-dune deposits, consist exclusively of saurischian tracks attributed to the ichnogenera *Grallator* (*sensu lato*) and *Otozoum,* representing theropods and prosauropods, respectively. *Otozoum* makes up ~16% of the total sample of ~125 trackways and at one horizon reveals several parallel trackways, suggesting that the *Otozoum* trackmaker may have been gregarious.

INTRODUCTION

Dinosaur National Monument (DNM) is most famous for producing vertebrate skeletal remains of Late Jurassic age (Foster, 2007, and references therein) However, vertebrate tracks are also known from the area, especially in the Upper Triassic and Lower Jurassic strata (Lockley et al., 1992a, b, c). Almost all track discoveries (>20 localities) were made in 1990-1992 by the University of Colorado Denver Dinosaur Trackers group as the result of a National Park Service (NPS) sponsored survey (see Acknowledgments). Most of the results were published in NPS literature (Lockley et al., 1990, 1991, 1992a, b) and in most cases the emphasis was on Late Triassic sites (Lockley et al., 1992c), some of which were described and interpreted in more detail in subsequent publications (Lockley and Hunt, 1995; Lockley, 2006).

Towards the end of the project a number of tracksites were discovered in the Glen Canyon Group, at the western end of DNM, close to the Visitor's Center (Figs. 1-3), but they were not reported in detail. These are in a predominantly eolian unit known as the Navajo or Navajo-Nugget Sandstone (also referred to as the Glen Canyon Sandstone on all U.S. Geological Survey geological quadrangle maps for the area). The basal part of this sequence, probably equivalent to the Wingate Sandstone, contains tracks such as *Brachychirotherium* (Lockley et al., 1990) that indicate a Late Triassic age. However, as noted by Lockley et al. (1992b), higher in the succession the ichnofaunas are dominated by theropod tracks (*Grallator sensu lato*) and the presumed prosauropod track *Otozoum*. These ichnogenera are inferred to indicate an Early Jurassic age.

Three stratigraphic sections were measured for a locality designated UCD 92-17, located at the western end of the monument, and the sections, numbered as UCD 92-17.1, UCD 92-17.2 and UCD 92-17.3, cover a distance of about 1 km from west to east. A total of 13 surfaces with tracks (tracksites) were recorded with 6, 4 and 3 horizons, respectively, in the three sections from west to east (Fig. 4). Five of these 13 surfaces were mapped, but the maps were not previously published. Therefore, herein these maps are presented and interpreted for the first time.

DESCRIPTION OF TRACKSITES

Sites in the UCD 92-17.1 Through UCD 92-17.3 Sections

As shown in Figure 3, six tracksite levels were recorded in the UCD 92-17.1 section. The lowest horizon (UCD 92 -17.1a) is about 20 m below the base of the Carmel Formation (Fig. 3). Tracks from this level were not mapped. Horizon UCD 92 -17.1b is about 10 m above 17.1a and reveals two surfaces that were mapped, both of which reveal only tridactyl theropod tracks (*Grallator*). Horizon UCD 92 -17.1c is about 2 m above 17.1b, and exposes one surface that was mapped, revealing both theropod and *Otozoum* tracks.

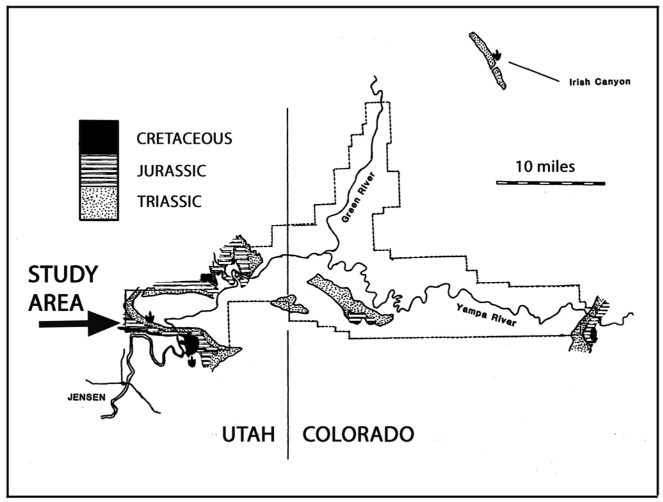

FIGURE 1. Location of study area at western end of Dinosaur National Monument.

UCD 92-17.1.b west (Fig. 3)

This site reveals a total of 82 tracks inferred to represent 59 trackways (Table 1), all of theropods (*Grallator*). About a quarter of the sample provided reliable length and width measurements (mean of 19.2 and 13.6 cm, respectively) with a mean step length of 65.3 cm for those trackway segments that were identified. Trackway orientations are highly variable with three notable concentrations in the NW, SW and SE sectors.

UCD 92-17.1.b east (Fig. 3)

This site is essentially an eastward continuation of UCD 92.17.1.b west. A total of 31 tracks inferred to represent 25 trackways (Table 2) were recorded. The mean length and width (20.0 and 13.7 cm, respectively) indicate similar-sized tracks to those recorded to the west. Only three step measurements were recorded with a mean of 79.7 cm (Table 2). There is also a stronger preferred trackway orientation to the SW than seen on the surface to the west. Tracings of 14 tracks from horizon UCD 92-17.1b are shown in Figure 5.

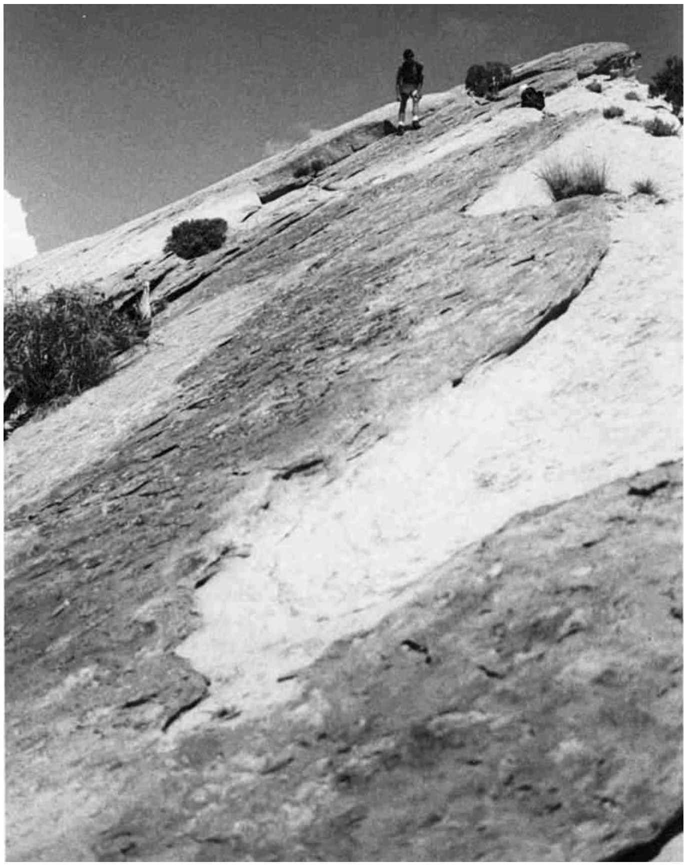

FIGURE 2. Photo of main outcrop at locality designated as UCD-92.17.

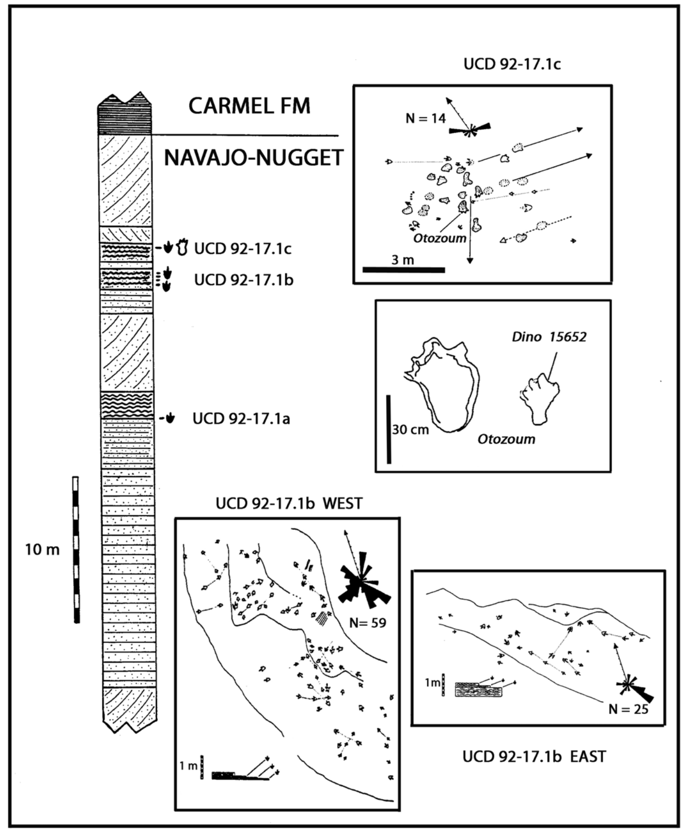

FIGURE 3. Stratigraphic section UCD 92-17.1(a-c) with maps of three surfaces. Black three toed and white four toed track symbols respectively indicate horizons with *Grallator* and *Otozoum* occurrences.

UCD 92.17.1c (Fig. 3)

This site reveals a total of 36 tracks comprising 15 trackways, of which 11 are inferred to represent theropods (*Grallator*) and four are prosauropods (*Otozoum*). A few theropod tracks provided useful length and width measurements (mean 16.5 and 9.6 cm, respectively: Table 3), but it was not possible to measure the *Otozoum* tracks accurately, due to their indistinct outlines. Trackway orientations have a bimodal trend NW-SE. A natural cast of *Otozoum* (Dino 15652) was collected from this site. It is illustrated in Figure 3 and is described in more detail below.

UCD 92-17.2 (Fig. 4)

No surfaces at this site were mapped. However, in this section it is possible to identify tracks at the same horizons as in section UCD 92-17.1. The lowest horizon also appears to reveal *Otozoum* tracks at a lower level ~35 m below the Carmel that are laterally equivalent to *Otozoum* horizons in section UCD 92-17.3. Two tridactyl tracks (Dino 15658 and 15659: Fig. 5) were replicated from this section

UCD 92-17.3 (Fig. 4)

The most easterly section studied reveals three horizons about 34.5, 33.5 and 33.0 meters below the base of the Carmel Formation. The upper and lower surfaces were mapped. The lower level is shown in Figure 6 and the upper in Figure 7.

The lower mapped level (Fig. 6) reveals at least 76 tracks comprising one tridactyl trackway and 15 *Otozoum* trackways. Although at least three trackways consist of oval depressions, from which direction of travel cannot be determined, 12 provide unequivocal evidence of the direction of progression, and indicate a preferred direction to the NW-NNW. Trackways, 1, 3, 4 and 9 are subparallel and may represent a group of 4 individuals heading NW. Likewise, trackways 5-8 may also represent 4 individuals heading NNW.

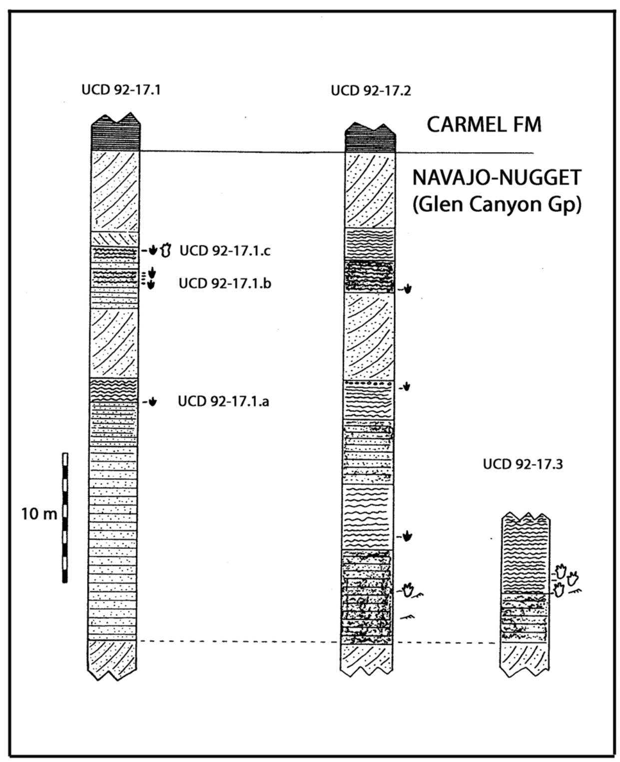

FIGURE 4. Stratigraphic sections UCD 92-17.1 through UCD 92-17.3, after Lockley et al. (1992). Compare with Figures 3, 6 and 7. Black three-toed and white four-toed track symbols respectively indicate horizons with *Grallator* and *Otozoum* occurrences.

TABLE 1. Measurement for 59 trackways (and tracks) from site UCD 92.17.1b (west).

Number	Length	Width	Step	Orient	Number	Length	Width	Step	Orient
1	-	-	62	166	**31**	-	-	-	136
2	17.5	11.0	55	258	**32**	32.0	28.0	-	18
3	16.5	12.5	59	243	**33**	19.0	-	-	318
4	-	-	80	168	**34**	14.0	11.0	-	18
5	-	-	39	135	**35**	-	-	-	30
6	13.0	9.5	-	103	**36**	-	-	-	46
7	14.0	10.0	69	253	**37**	-	-	-	226
8	17.5	11.0	-	278	**38**	-	-	-	153
9	22.0	14.0	70	68	**39**	-	-	-	303
10	-	-	53	163	**40**	-	-	-	48
11	-	-	57	170	**41**	-	-	-	18
12	-	-	93	328	**42**	-	-	-	288
13	-	-	53	288	**43**	-	-	-	314
14	-	-	-	233	**44**	-	-	-	314
15	-	-	-	140	**45**	-	-	-	108
16	-	-	-	150	**46**	-	-	-	265
17	-	-	43	253	**47**	-	-	-	280
18	-	-	-	55	**48**	-	-	-	108
19	18.0	16.0	-	260	**49**	-	-	-	143
20	-	-	-	160	**50**	-	-	-	143
21	24.0	17.0	-	328	**51**	-	-	-	53
22	19.0	12.0	-	108	**52**	-	-	-	233
23	20.0	12.0	-	218	**53**	-	-	-	178
24	15.0	-	-	253	**54**	-	-	-	178
25	22.0	13.0	-	18	**55**	-	-	-	335
26	23.0	13.0	-	78	**56**	-	-	-	233
27	-	-	-	198	**57**	-	-	-	198
28	-	-	-	223	**58**	-	-	-	250
29	-	-	-	223	**59**	-	-	-	10
30	-	-	-	193	**Mean**	**19.2**	**13.6**	**65.3**	**-**

The upper mapped level (Fig. 7) reveals a total of 34 tracks including 14 tridactyl tracks (*Grallator*) representing 8 trackways with variable direction. The remaining 20 tracks are indistinct oval depressions inferred to represent *Otozoum* tracks that are difficult to resolve into trackway patterns with any confidence.

SYNTHESIS OF TRACKWAY DATA

A total of 13 track-bearing horizons were identified in three sections with a lateral distribution of about 1 km and a vertical succession between about 35 and 8 m below the base of the Carmel Formation. Correlation of several track-bearing beds is possible between the sections. Due to the steep dip of the beds and differential erosion between horizons, many of the track–bearing surfaces are exposed to view. The redder, more-friable, impure, horizontally- and thinly-bedded sandstones represent the track-bearing inter-dune deposits and contrast with the massive, white, crossed bedded eolian sandstones without recognized dinosaur track-bearing levels.

The five mapped surfaces revealed a total of ~260 tracks representing ~125 trackways. Of this total there are a minimum of 20 *Otozoum* trackways, with the remainder representing ~105 theropod trackways. Thus, the prosauropods make up about 20/125 of the total census (=16%). Trackway orientations are variable but with a preference of NW and SE orientations.

DISCUSSION

Otozoum was first reported from the Navajo Sandstone in the early 1990s (Lockley et al., 1992a, b), and has since been recorded from many other locations (Lockley and Hunt, 1995; Rainforth, 2003). Most

TABLE 2. Measurement for 25 trackways (and tracks) from site UCD 92.17.1b (east).

Number	Length	Width	Step	Orientation
1	23.0	16.0	80	129
2	24.0	15.0	74	152
3	-	-	85	144
4	-	-	-	233
5	14.5	9.0	-	143
6	-	-	-	143
7	22.0	16.5	-	228
8	17.0	11.0	-	213
9	-	-	-	283
10	-	-	-	283
11	-	-	-	123
12	-	-	-	68
13	-	-	-	338
14	15.5	10.5	-	103
15	24.0	17.5	-	258
16	-	-	-	168
17	-	-	-	158
18	-	-	-	18
19	-	-	-	188
20	-	-	-	150
21	-	-	-	140
22	-	-	-	25
23	-	-	-	308
24	-	-	-	128
25	-	-	-	70
Mean	**20.0**	**13.65**	**79.7**	**-**

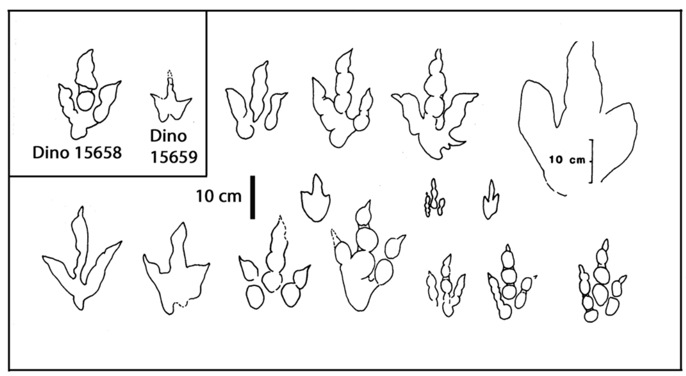

FIGURE 5. Theropod tracks from stratigraphic sections UCD 92-17.1 and 92-17.2 (inset).

reports are of sites of small size with only a few trackways with variable orientations. *Otozoum* is rarely found in the underlying Kayenta Formation (Lockley et al., 2004). In a few cases, such as the Kayenta example just cited, parallel trackways are suggestive of gregarious behavior. Such inferences are supported by the UCD 92-17.1c lower level site map (Fig. 6), which unequivocally shows the *Otozoum* trackmaker to have been abundant in Navajo inter-dune environments. Such indications of environmental preference support the inference that the *Otozoum* trackmaker preferred arid and semiarid desert habitats (Lockley and Hunt, 1995; Rainforth, 2003).

However, despite the apparent abundance of *Otozoum* in the Navajo Sandstone and its equivalents (the Navajo-Nugget), this ichnite is not always easy to identify, although most pes tracks are similar in size: i.e., with foot lengths of ~25-35 cm. Well-preserved *Otozoum* has well

TABLE 3. Measurement for 15 trackways (and tracks) from site UCD 92.17.1c. Tracks 1-4 are identified as *Otozoum*. Tracks 5-15 are tridactyl (*Grallator*).

Number	Length	Width	Step	Orientation
1 *Otozoum*	-	-	-	205
2 *Otozoum*	-	-	-	95
3 *Otozoum*	-	-	-	95
4 *Otozoum*	-	-	-	275
5	20.0	11.0	-	145
6	21.0	12.5	-	295
7	-	-	-	158
8	9.0	4.0	-	245
9	-	-	-	120
10	16.0	11.0	-	280
11	-	-	-	105
12	-	-	-	290
13	-	-	-	295
14	-	-	-	75
15	-	-	-	-
Mean	**16.5**	**9.6**	-	-

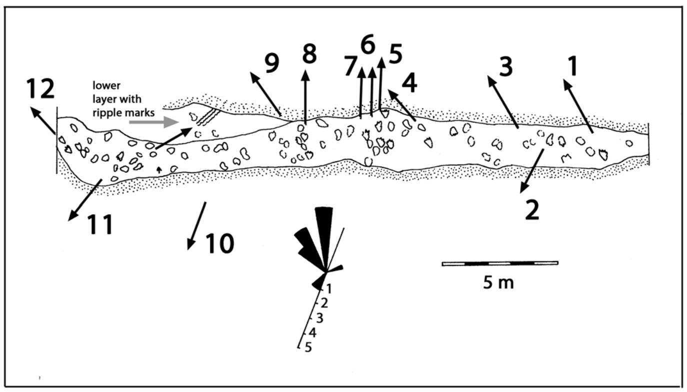

FIGURE 6. Map of surface from section UCD 92-17.3 showing at least 12 *Otozoum* trackways with recognizable orientations.

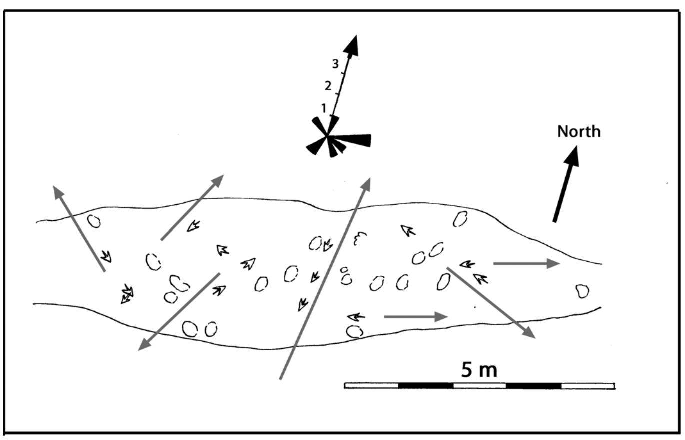

FIGURE 7. Map of surface from section UCD 92-17.3 showing at least 8 theropod trackways with recognizable orientations.

defined digital pads and all four pes digits are easily recognized: e.g., specimens from the Moab area (Lockley and Hunt, 1995, fig 4.17). Manus tracks are rare (Lockley et al., 2006). However, in most cases the preservation of *Otozoum* tracks in sandy substrates is sub-optimal, and the tracks often appear only as oval depressions with the distal claw impressions partially preserved or not even visible. The specimens shown in Figures 3 and 8, however, are fairly typical of some of the natural casts that weather out of the Navajo. As shown in Figure 8, four toe impressions are clear, and the heel is quite narrow compared with the anterior portion of the footprint cast. A very similar, 30 cm long track was reported by Kayser (1964) from the Navajo Nugget of Wyoming (Fig. 9), although until now it had never been identified as *Otozoum*.

FIGURE 8. *Otozoum* track cast (Dino 15652).

FIGURE 9. *Otozoum* track natural cast from Wyoming after Kayser (1964, fig. 11a). Track is ~30 cm long.

A number of authors have noted that vertebrate ichnofaunas from Early Jurassic eolian facies in the western USA are locally abundant but still poorly known (e.g., Faul and Roberts, 1951; Stokes, 1978; Lockley and Hunt, 1995). Prior to 1992, vertebrate tracks had not been reported from the Navajo-Nugget of the Dinosaur National Monument area in any detail although Untermann and Untermann (1949, Table 1, p. 688) mention "Basal layers probably waterlain [that] contain occasional 4-toed dinosaur tracks." This statement, which could refer to a number of possible vertebrate track morphotypes, including *Otozoum*, is repeated almost verbatim by Untermann and Untermann (1950). The present account provides details not included in the initial publications (Lockley et al., 1992a, b). Recently a significant new ichnofauna was discovered from the dune facies of this area, only about 3 km west of the sites described herein from UCD locality 92-17. Englemann et al. (2010) reported abundant tracks assigned to the ichnogenus *Brasilichnium* and interpreted as the tracks of a synapsid. These trackmakers were small, typically the size of domestic cats, and in almost all cases their tracks are found associated with dune foresets, rather than in inter-dune areas. The combination of evidence from this small area suggests that the Navajo-Nugget represents a number of distinct dune and inter-dune deposits, each with a characteristic suite of vertebrate traces, which in turn reflect the environmental diversity and ecology of this Early Jurassic erg system.

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