Tail-Drag Marks and Dinosaur Footprints from the Upper Cretaceous Toreva Formation, Northeastern Arizona

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The first Late Cretaceous dinosaur tracksite recorded from Arizona, preserving over 100 footprints, also preserves sinuous grooves here interpreted to be impressions left by the tail of a large vertebrate as it dragged through sediment now assigned to the Toreva Formation. Although no footprints are preserved that can be referred unambiguously to the individual or individuals that produced the tail-drag marks, the dynamic nature of the surface upon which the tracks were made, likely a river or stream shoreline, could have easily resulted in their disturbance or obliteration. As best as can be determined on the basis of a depauperate marine fauna from the lower part of the unit, and on the basis of a substantial hiatus that separates the lower and upper parts, the site is probably middle Coniacian in age. These tracks and drag marks add significantly to the exceptionally rare record of terrestrial vertebrates known from the Toreva Formation.

INTRODUCTION

Dinosaur tracks and trackways are well known throughout Mesozoic formations in several western states, but in Arizona relatively few sites have been reported (e.g., Irby, 1993, 1996; Lockley and Hunt, 1995; Nations et al., 1996; Lockley et al., 2000). The occurrence of another tracksite in the northeastern part of the state is here noted because of the presence of several unambiguous tail-drag marks, together with numerous dinosaur footprints. This site also represents the first dinosaur tracksite in Arizona of Late Cretaceous age.

Eight prominent sinuous drag marks and at least 113 variably-sized tridactyl footprints representative of both ornithopod and theropod dinosaurs occur at the site. Although the sinuosity and morphology of these grooves leaves little doubt that they represent tail-drag marks, there are no footprints straddling the grooves, or otherwise directly associated with them, that may be referred unambiguously to the individuals that made them. Therefore, evidence that the drag marks were made specifically by dinosaurs is inconclusive. However, there are several dinosaur footprints that intersect portions of the drag marks.

The site, which can be accessed only with written permission of the Navajo Nation, was discovered by a hunter who reported it to the Navajo Nation Minerals Department at Window Rock, Arizona. In 1991, Navajo Nation geologist R. Cook took the first author to the site, which is located in a remote area of the Navajo Reservation on Black Mesa, Apache County, northeastern Arizona (Fig. 1). The exact locality, MNA 1489, is on file in the Department of Geology, Museum of Northern Arizona (MNA), Flagstaff. The track-bearing bedding surface occurs on an outcrop of sandstone about 15 m long by 6 m wide within a modern stream bed on forested land at approximately 2220 m elevation. Approximately 40 m downstream from the main site is another smaller outcrop with four additional tail-drag marks, but no footprints.

The objectives of this report are: (1) to document and describe this dinosaur tracksite primarily because so little evidence of terrestrial vertebrates has been reported from the Toreva Formation (see below); (2) to add to the record of the relatively few dinosaur footprint sites currently known from the Cenomanian of North America and, in particular, Arizona (see Lockley et al., 2000); and (3) to record another rare occurrence of tail-drag marks in association with dinosaur footprints.

PREVIOUS WORK

Reports of dinosaur tail-drag marks are rare. It is assumed that dinosaurs typically held their tails off the ground when moving about (Thulborn, 1990). The classic example of tail-drag marks are the *Gigandipus* trackways in the Lower Jurassic Turner Falls Formation of the Connecticut Valley, Massachusetts, which include large tridactyl tracks directly associated with sinuous and continuous tail-drag grooves (Hitchcock, 1858; Lull, 1953; Thulborn, 1990). Tail-drag marks with footprints also have been reported in: (1) the Cretaceous (Campanian) Blackhawk Formation within coal mines near Price, Utah (Parker and Balsley, 1989); (2) the Cretaceous (Aptian-Albanian) Dakota Formation at Clayton Lake State Park, New Mexico (Gillette and Thomas, 1985); (3) the Lower Cretaceous Glen Rose Formation at Glen Rose, Texas (Bird, 1941, 1944); (4) the Early Cretaceous of Spain (Viera and Aguirrezabala, 1984; Casanovas Cladellas et al., 1993); (5) the Middle Jurassic Entrada Sandstone of the Grand Staircase National Monument, Utah (Foster et al., 2000); (6) Lower Jurassic deposits of Lesotho, South Africa, (Ellenberger, 1974); (7) Jurassic coal measures of Queensland, Australia (Bryan and Jones, 1946); (8) the Middle Jurassic of Morocco (Jenny et al., 1981); and (9) the Chinese Upper Triassic to Jurassic strata of the Sichuan Basin (Yang and Yang, 1987) and Upper Jurassic Penglaizhen Formation of Yuechi, Sichuan (Zhen et al., 1983). As noted, however, it cannot be determined unequivocally whether the Toreva drag marks were made by dinosaurs, or by some other large tetrapod such as a champsosaur or crocodilian. On the other hand, it is important to note that there are reports of questionable dinosaur tail-drag marks that, like those noted herein, do not provide conclusive evidence of the individual that made them (e.g., Dalla Vecchia et al., 2000, p. 263; E. Rainforth, 2001, pers. commun.).

STRATIGRAPHY AND AGE

The tail-drag marks and dinosaur footprints occur in the Toreva Formation of the Mesa Verde Group (Repenning and Page, 1956) near Balakai Point, which forms the

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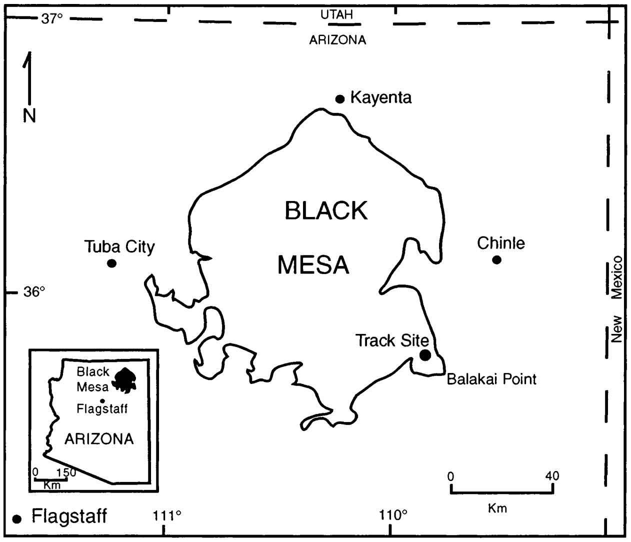

FIGURE 1—Locality map showing the track site on Black Mesa, northeastern Arizona.

southeastern-most part of Black Mesa, in Apache County, Arizona (Fig. 1). The Toreva Formation overlies and intertongues with the Mancos Shale, and is divided into three members that Repenning and Page (1956) interpreted as representing deposition into a large bay during regression of the Cretaceous seaway (see also Franczyk, 1988). The lower, cliff-forming, sandstone member represents regressive, wave-dominated, shoreline (delta-front) marine deposition (Franczyk, 1988). Overlying the lower sandstone member is a middle carbonaceous member. This middle, slope-forming member includes coal, carbonaceous silt, and lenticular sands that represent delta-plain depositional environments such as swamps, lagoons, distributary, interdistributary, and crevasse-splay channels that prograded across the delta-front deposits (Repenning and Page, 1956; Franczyk, 1988). The upper sandstone member consists of arkosic sands deposited in a continental fluvial environment (Franczyk, 1988, p. 16). Continued regression of the seaway resulted in further fluvial deposition of the overlying Wepo Formation (Repenning and Page, 1956; Franczyk, 1988).

Approximately 0.9 km ENE of the track site, the upper portion of the escarpment that marks the edge of the mesa includes ~ 20 m of cliff-forming sandstone above the Mancos Shale, that is overlain by ~ 8 m of poorly indurated, slope-forming sandstone and siltstone, comprising the local top of the mesa. These two units are interpreted to be the lower sandstone and middle carbonaceous members, respectively. In the immediate vicinity of the tracksite, and stratigraphically above it, is an orange-colored, very coarse-grained, cross-bedded sandstone interpreted to be the upper sandstone member based on descriptions of this unit by Repenning and Page (1956).

The main tracksite discussed herein occurs in a large slab of fine- to medium-grained, well-indurated sandstone, of a generally pinkish color on unweathered surfaces, that crops out in a modern stream channel (Fig 2). Its stratigraphic position is interpreted to occur within the lowermost part of the upper sandstone member. Another, smaller slab of this same lithology crops out ~ 40 m downstream and also shows distinct tail-drag impressions. The surrounding terrain otherwise is covered by piñon-juniper forest.

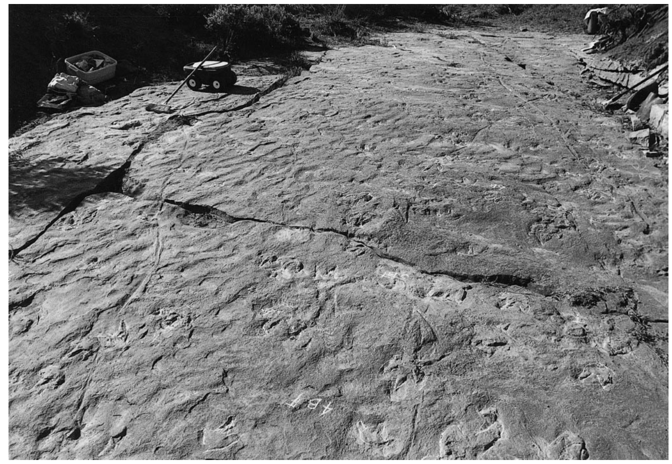

FIGURE 2—Oblique view of study area, looking south, showing tail-drag marks, dinosaur footprints, and ripple marks.

Based on the presence of rare but diagnostic molluscs, Eaton et al. (1987), Franczyk (1988), and Kirkland (1991) suggested that the lower sandstone member of the Toreva Formation was late middle Turonian in age (*Prionocyhclus hyatti* NA Ammonite Zone). Eaton et al. (1987) and Franczyk (1988) noted that the lower and upper parts of the Toreva were deposited during the Greenhorn and Niobrara cyclothems, respectively, and that a substantial hiatus representing most of the late Turonian and early Coniacian separates them. The lower part of the upper sandstone member, and therefore the age of the tracksite, is likely middle Coniacian, or about 87–88 Ma (based on time scale of Gradstein et al., 1995). Prior to this report, no record of terrestrial vertebrates other than a single dinosaur footprint (MNA V3299) was known from the Toreva Formation. Marine vertebrates, also rare in this unit, include chondrichthyan and osteichthyan fish remains and fragmentary turtle bones, all of which are housed in the collections at the MNA Department of Geology.

METHODOLOGY

Volunteer workers helped prepare the site for mapping by sweeping the area of loose sand and silt, removing brush from joints and eroded sections, highlighting the footprints with chalk, and establishing a meter-square grid system for photography. Each square meter was photographed for the compilation of a photomosaic of the site, and a detailed map was produced from the photomosaic (Fig. 3). The footprints consist primarily of digital impressions, and only one footprint length was suitable for measurement because most are somewhat degraded. The azimuths of the drag marks and of the footprints (taken from the midline of digit III) were recorded and plotted on Rose diagrams, and the lengths of the drag marks were measured (Table 1). RTV silicone rubber casts were made *in situ* of two of the more distinctive footprints, and plaster molds of these two footprints were prepared in the MNA laboratory.

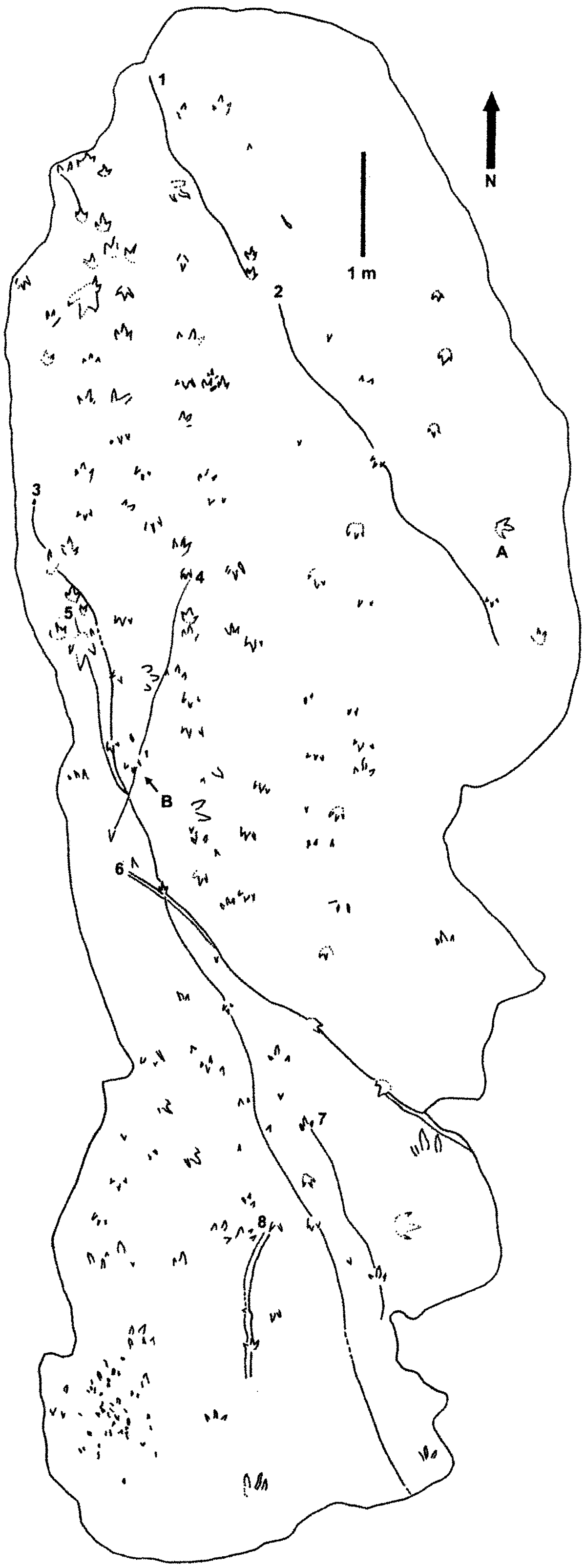

FIGURE 3—Map of tracksite. Tail-drag marks are numbered from north to south; also note footprints A and B.

TABLE 1—Shape, approximate length, and average azimuth of sinuous tail-drag marks.

Number	Morphology	Length	Average azimuth
1	Narrow, V-shaped	22.2 m	156°
2	Narrow, V-shaped	4.0 m	147°
3	Narrow, V-shaped	10.4 m	155°
4	Narrow, V-shaped	2.5 m	192°
5	Narrow, V-shaped	1.8 m	165°
6	Narrow, V-shaped to broad, U-shaped	4.3 m	125°
7	Narrow, V-shaped	2.1 m	155°
8	Broad, U-shaped	1.5 m	182°

DESCRIPTIONS

Tail-drag marks

For descriptive purposes, the 8 sinuous grooves are numbered from north to south (Fig. 3), and Table 1 provides their lengths and azimuth values. The trend of the tail-drag marks, as indicated by the Rose diagram (Fig. 4A), is NNW-SSE, although the actual direction of travel of the individual that made them cannot be determined without directly associated footprints. Four additional tail-drag marks occur on a second, smaller outcrop of sandstone located ~ 40 m downstream from the larger outcrop. They range in length from 2.9 to 3.5 m and very likely are preserved on the same bedding surface as those on the main slab, based on lithology and physical characteristics. They, too, show no direct association with footprints.

All of the tail-drag marks are lined on both sides with "expulsion rims" (per Dalla Vecchia et al., 2000) created as the tail plowed through the soft sediment. They all also show evidence of having been overstepped sometime after they were formed (Figs. 5, 6). All tail-drag marks are less than 2 cm deep; some are narrow (~1 to 3 cm) and V-shaped (e.g., Fig. 3, drag mark 2), while others are broad (~5 to 7 cm) and U-shaped (e.g., Fig. 3, drag marks 6 and 8; also see Table 1).

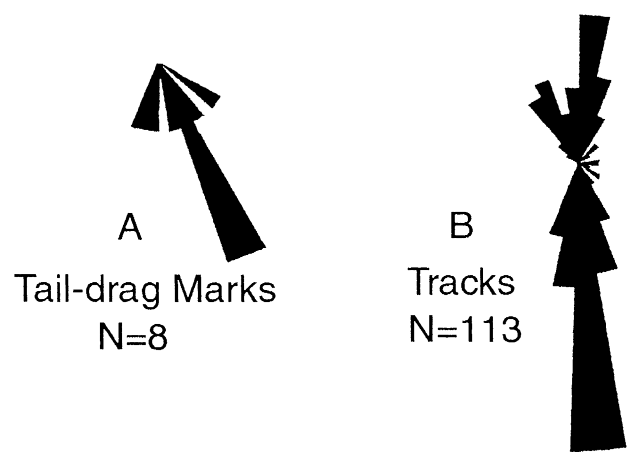

FIGURE 4—Rose diagrams indicating general direction of tail-drag marks (A) and of footprints (B).

FIGURE 5—Photo showing expulsion rims and sinuous nature of tail-drag marks. View is to the south.

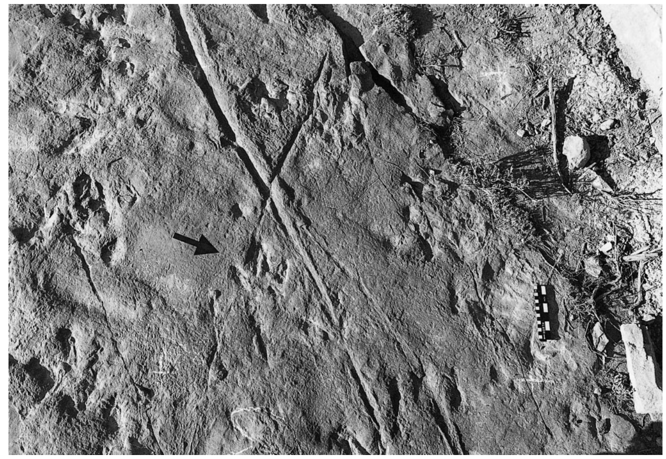

FIGURE 6—Tail-drag number 4 (thin trail crossing large trail number 3; see Fig.3) overstepped by footprint B (black arrow, also see Fig. 7B).

Footprints

Tridactyl, somewhat degraded prints of both theropod and ornithopod dinosaurs occur at the site (Fig. 7). Claw marks are associated with some of the theropod prints, and the ornithopods are distinguishable by their U-shaped prints (Thulborn, 1990, p. 220). The footprints are subdigitigrade to digitigrade (Leonardi, 1987), and one print is preserved well enough to measure (Fig. 7A: 23.3 cm length, 29.1 cm width). There is no evidence of hallux impressions (see Irby, 1995). Several tracks are preserved in inverted relief, appearing as natural casts of the footprint rather than natural molds. The Rose diagram for the footprints (Fig. 4B) indicates a mostly southerly direction of travel, which does not differ significantly from the direction noted above for the tail-drag marks.

DISCUSSION

The sinuous nature of the drag marks, the "expulsion rims" that line them, and the presence of numerous footprints on the same bedding plane provide clear indications that the grooves are not sole or tool markings, but are indeed traces "produced during directed locomotion . . . by an animal having part of its body in continuous contact with the substrate surface" (Boggs, 1987, p. 176). The grooves are remarkably similar to those produced by various varanid lizards (as described and figured in Farlow and Pianka, 2000), although it is not here implied that varanids were the track makers. On the other hand, tail-drag marks made by the extant American alligator, as discussed and figured in Reineck and Howard (1978), are less sinuous than those described here, although the cross-sectional shape is quite similar. Evidence that these traces are not the result of invertebrate burrowing rests on the combination of their length and width, the presence of expulsion rims, and their regular, directed, conspicuously sinusoidal nature. *Planolites*-like invertebrate traces more often exhibit a randomly wandering sinuosity, rather than a regular, directed sinusoidal pattern (Albright, pers. observation).

Both ornithopod and theropod footprints occur on the

FIGURE 7—Plaster molds of ornithopod footprint (A) and theropod footprint (B). Track A measures 23.2 cm length and 29.1 cm width. Scale bar equals 10 cm.

same bedding plane as do the tail-drag marks, but none can be associated unambiguously with the individual that made the sinuous grooves. Therefore, it is not known if the grooves were made by one of the dinosaurs represented by the footprints or by some other large tetrapod such as a champsosaur or crocodilian. However, the inability to directly associate the tail-drag marks with footprints of the individuals that produced them, although intriguing, is not overly problematic given the dynamic nature of the surface upon which the tracks and trails occur. In addition to the tail-drag marks and footprints, the surface of the outcrop also shows ripple marks (Fig. 2), indicating that shallow water at least occasionally washed the site. This, together with the fluvial rather than lacustrine or estuarine nature of the environment of deposition, further suggests that the tracks were made along the shoreline of a stream or river—an obvious corridor for mass movement of a terrestrial to semi-aquatic vertebrate fauna, in turn resulting in regular trampling of previously-made tracks. There are several examples at this site where footprints overstepped the drag marks, indicating that many of the preserved tracks were produced some time after the tail grooves. That the tracks are somewhat degraded points toward an extended period of subaerial exposure after their formation; water movement sufficient to produce ripple marks would have obliterated the tracks if the site had been washed over shortly after they were made.

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