

FIRST REPORT ON REPTILE TRACKS FROM THE MOENKOPI FORMATION (LOWER-?MIDDLE TRIASSIC) IN DINOSAUR NATIONAL MONUMENT, UTAH

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Abstract—On the Colorado Plateau, numerous Mesozoic stratigraphic units, including the Navajo and Entrada formations, preserve abundant tracks that contrast with their extremely poor body fossil records. This is also true of the Moenkopi Formation, which also preserves abundant tracks attributed to reptiles. Here we report the first occurrence of tetrapod tracks from the Moenkopi Formation in Dinosaur National Monument in northeastern Utah. The Moenkopi Formation in this area can be divided into four informal “members” with all of the currently known tracksites in Dinosaur National Monument occurring low within the third member. Tracks consist of both footprints and swim tracks and are preserved in the “racetrack” exposures in the western portion of the monument. These traces show morphological characteristics suggesting they were produced under a variety of conditions ranging from subaqueous to subaerial. Footprints are chirotheriid in overall morphology with some resemblance to *Protochirotherium* and *Synaptichnium*. Due to the relative paucity of skeletal remains from the Moenkopi Formation these and other tracks from this unit provide important information about the paleoecology of Early-Middle Triassic reptiles.

INTRODUCTION

The Lower-Middle Triassic Moenkopi and Red Peak formations, which crop out throughout western North America, contain ubiquitous occurrences of tetrapod tracks attributed to reptiles (Peabody, 1948; Klein and Lucas, 2010; Lovelace and Lovelace, 2012). Although reptile skeletal remains from these formations are rare to non-existent, and largely restricted to the Holbrook Member in Arizona (e.g., Heckert et al., 2005; Nesbitt, 2005) and the Anton Chico Member in New Mexico (Schoch et al., 2010), this track assemblage indicates that a medium-high diversity reptile fauna must have existed in this region during Early-Middle Triassic times. Tracks thus provide valuable insights into the composition, geographic distribution, and paleoecology of Early-Middle Triassic reptiles in North America that cannot be obtained from the body fossil record alone.

Tetrapod tracks from the Moenkopi Formation were first discovered in the Red Fleet Reservoir region west of Dinosaur National Monument (DNM) and north of Vernal by a field crew from the University of California Museum of Paleontology in the 1940s. These consisted of an unidentified trackway showing an undulating tail mark and several extensive surfaces bearing numerous marks interpreted as swim tracks (Peabody, 1956). Additional specimens from these track sites are now housed at the Utah Field House of Natural History in Vernal as well as at the University of Colorado Museum in Boulder.

Here we report on three new track localities from the Moenkopi Formation located within DNM (Fig. 1). DNM 481 was discovered in 2010 by Madeline Weigner and Jacob Grosskopf (Geologist-in-Parks GeoCorps interns) in the “racetrack” exposure along the nose of Split Mountain in the Green River District of DNM. DNM 485 and 486 were discovered later by one of us (TJT) in 2011 along this same exposure. Two tracksites occur near the Sound of Silence

trail (DNM 481, DNM 485) and another near the Desert Voices trail (DNM 486). The only other record of vertebrate fossils from the Moenkopi Formation at DNM is the putative occurrence of “amphibian bone” near Vivas Cake Hill by Untermann and Untermann (1954), but more specific locality data are lacking and no repository was indicated by those authors.

Institutional abbreviations. DINO: Acronym for museum catalog numbers, Dinosaur National Monument; DNM: Acronym for fossil locality numbers, Dinosaur National Monument, Vernal, Utah.; UGS: Utah Geological Survey, Salt Lake City, Utah.

GEOLOGIC SETTING

The Moenkopi Formation has been the subject of several stratigraphic studies throughout the Colorado Plateau where it is interpreted to have been deposited under a variety of paleoenvironmental regimes ranging from fluvial to deltaic to shallow marine (e.g., Stewart et al., 1972; Blakey, 1974). Ammonite assemblages from marine units in central and southwestern Utah indicate the formation in that region was deposited during the Early Triassic (Lucas et al., 2007; Brayard et al., 2013). In northern Utah it can be correlated with the Mahogany Member of the Ankareh Formation (Dubiel, 1994) but on the eastern flank of the Uinta Mountains it has remained an undifferentiated sequence of red beds. At DNM, the best and most accessible exposures of the Moenkopi Formation are in the “racetrack,” the broad belt of outcrop associated with the west-plunging Split Mountain anticline.

Locally within DNM the Moenkopi Formation can be divided into several informal “members.” These are, in ascending order, (1) a basal, rhythmically bedded red and gray silty interval that may be equivalent, in part, to the Dinwoody Formation; (2) a medial interval characterized by

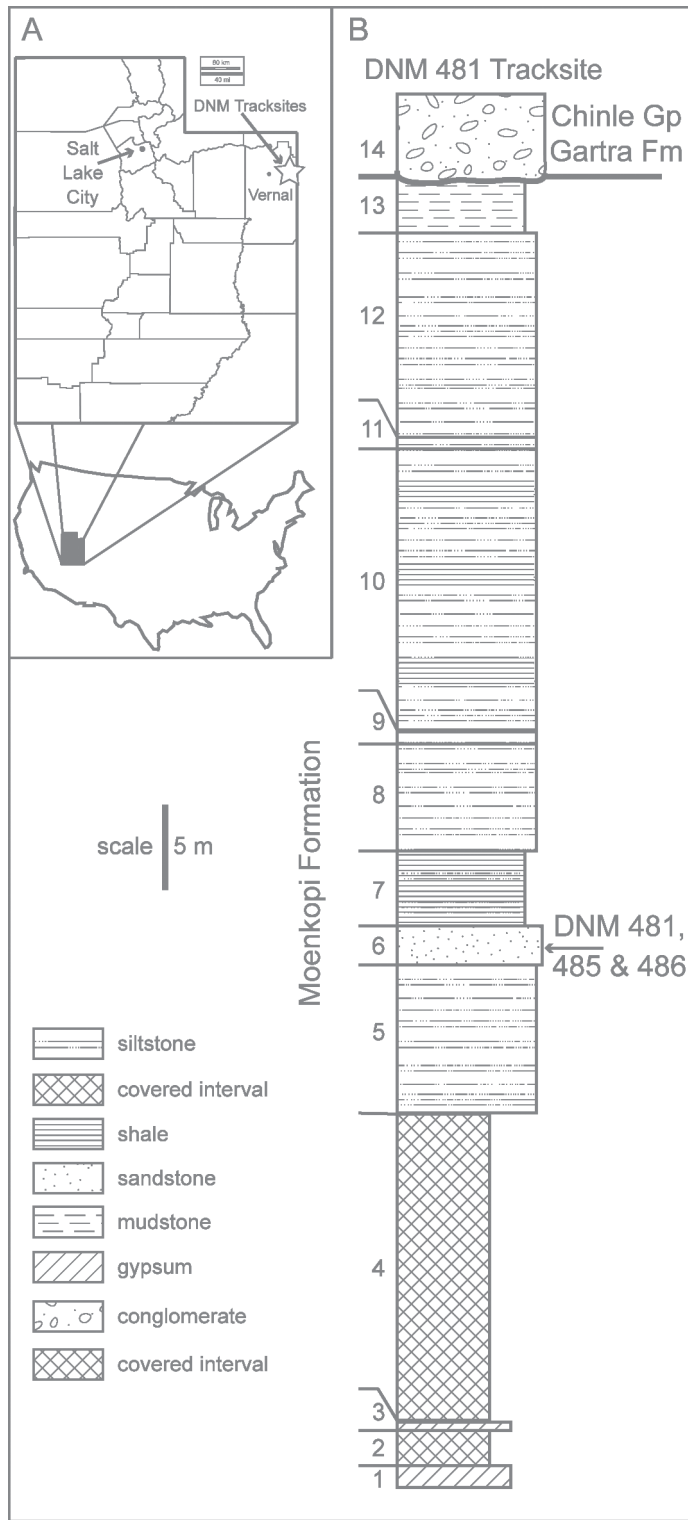


FIGURE 1. A, Map showing the location of Dinosaur National Monument track localities. B, Stratigraphic section measured at the DNM 481 and 485 tracksites near the Sound of Silence trail.

mm- to m-scale interbeds of gypsum in orange siltstone; and an upper interval characterized basally (3) by orange, silty beds lacking gypsum that grade upward into (4) thicker, grayish-red siltstone-dominated beds. Locally the gypsiferous interval includes thin (~m scale) beds of vuggy limestone. This interval has been tentatively correlated to the Thaynes Formation to the west (e.g., Stewart et al., 1972) but could also be equivalent to the Alcova Limestone in Wyoming which is most likely Lower Triassic in age being constrained by vertebrate paleontologi-

cal interpretations but may also be lower-most Middle Triassic (Storrs, 1991). Previously reported Moenkopi Formation sections in the vicinity of DNM range in thickness from 475-970 ft (145-296 m), but most are not recorded in great detail, so higher-resolution correlations are lacking at this time. Complete description and correlation of several measured sections of the Moenkopi Formation in DNM and vicinity will be presented at a later date.

The DNM tracksites occur low in the third member, just a few meters above the uppermost bedded gypsum (Fig. 1). The very fine-grained sandstones preserving the tracks also include abundant climbing ripples, some ripple lamination, and, at DNM 481 in particular, asymmetrical ripples indicating westerly paleoflow. The tracksites are generally localized slightly below a ledge-forming, silt- and fine-grained sandstone that forms a prominent bench throughout much of the "racetrack" in the Split Mountain anticline (units 8-9 in Figure 1). The tracks reported by Peabody (1956) in the Red Fleet Reservoir area north of Vernal are much lower stratigraphically, occurring below the lowest bedded gypsum.

TRACKSITES AND TRACKS

Currently, tetrapod tracks from the Moenkopi Formation are known from three sites within Dinosaur National Monument. Two tracksites occur near the Sound of Silence trail (DNM 481, DNM 485) and another near the Desert Voices trail (DNM 486). DNM 481 preserves footprints of walking tetrapods, whereas tracks at DNM 485 and 486 are swim tracks produced by buoyant or semi-buoyant tetrapods under subaqueous conditions. Tracks are generally preserved in convex hyporelief on the underside of very fine-grained sandstones. At DNM 481, the slabs are relatively thin (~2.4-5 cm thick), whereas at DNM 485 and 486 the beds are closer to 10 cm thick. For a detailed discussion on the morphologies and geographic extent of Early-Middle Triassic swim tracks from western North America see Thomson and Lovelace (this volume). All of these sites also preserve invertebrate traces that await further identification and study. Collected specimens are repositied at DNM and cataloged with DINO numbers as listed in Table 1. Detailed locality information is available in the files at Dinosaur National Monument.

DNM 481

Footprints from DNM 481 consist of several manus/pes sets characterized by digits with hooked distal ends (Fig. 2B), resulting from rotation of the foot in a very soft substrate and tracks with rounded digits which lack hooked distal ends (Fig. 2C-G). Tracks lacking hooked digits are interpreted as also having been produced in a soft, yet more cohesive, substrate that was able to resist the twisting of the foot during locomotion. Thus, it appears that the track surface at this locality is at least slightly time-averaged, allowing for the diachronous passing of numerous individuals and the presence of a range of substrate conditions over a period of perhaps days to weeks. Decreasing water content of a slowly drying substrate with the subsequent deposition of the track-casting sediment prior to mudcrack formation is the best scenario for the preservation of this track surface (*sensu* Scrivner and Bottjer, 1986).

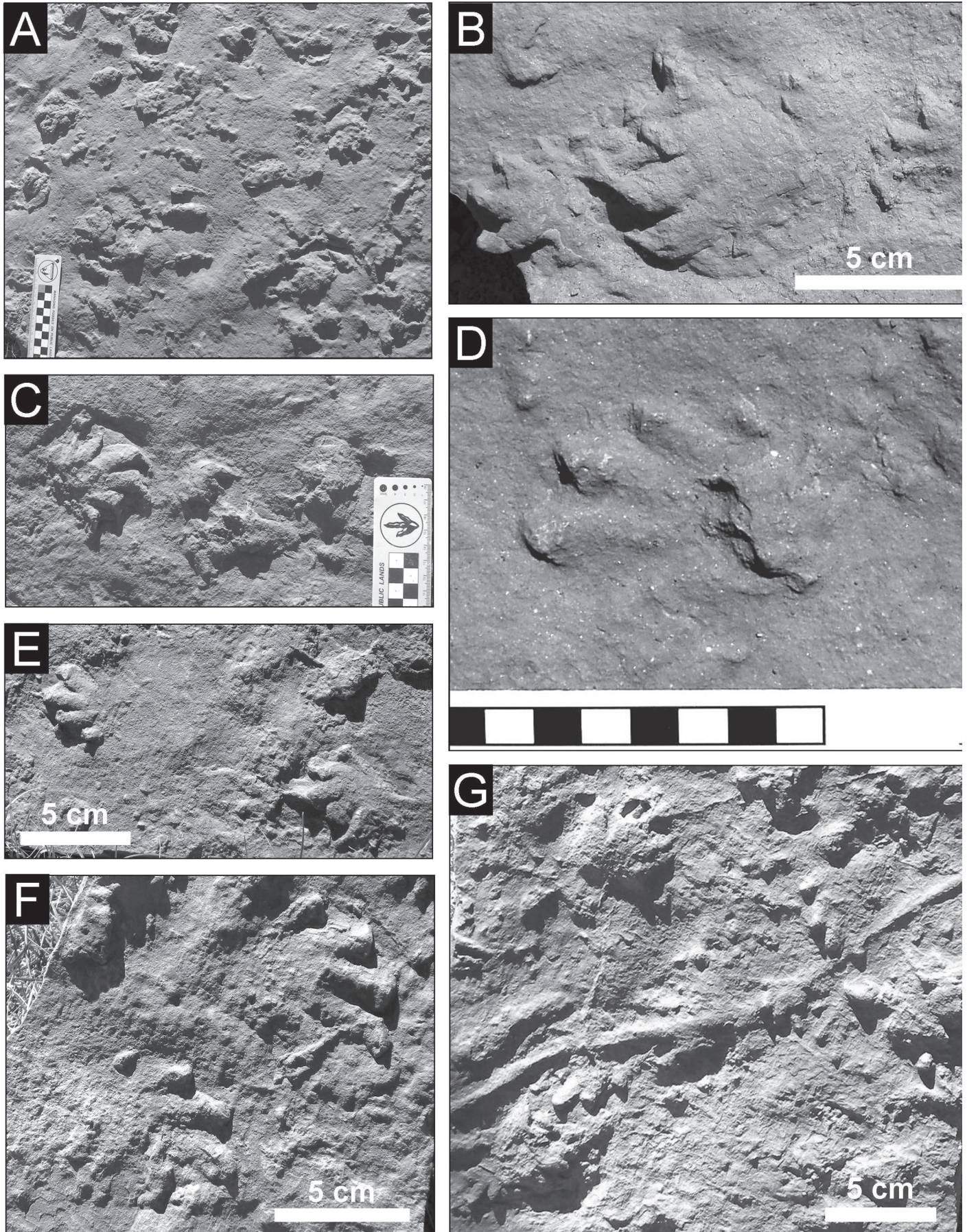


FIGURE 2. Track specimens from DNM 481. **A**, (DINO 43789) Overview of trampled track surface; **B**, (DINO 43795) Pes-manus set and preceding manus imprint of a trackway showing digits with hooked distal ends indicating rotation of the foot in a soft substrate; **C-E**, (DINO 43792, 43790, 43794) Tracks showing rounded digits indicating a lack of foot rotation in a firm substrate; **F**, (DINO 43796) Tracks showing digits with only slightly hooked distal ends indicating substrate conditions allowing for minimal rotation of the foot; **G**, (DINO 43791) Tracks with a possible tail drag mark.

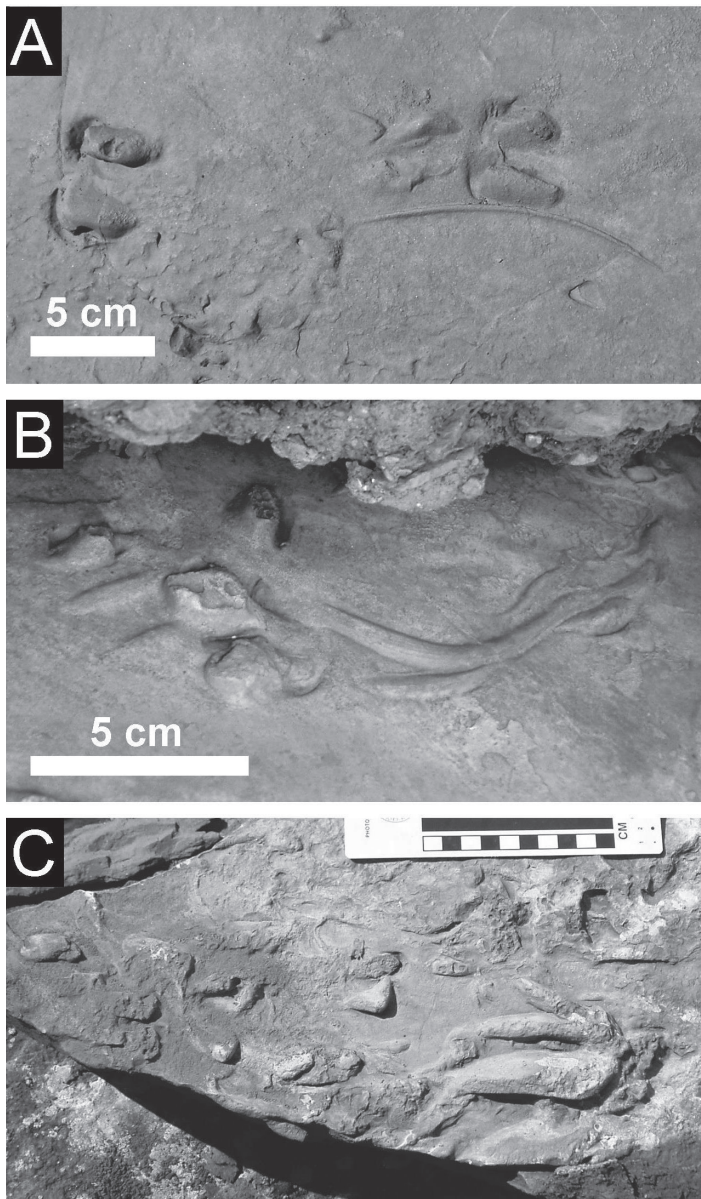


FIGURE 3. Swim tracks. **A**, Two-digit footmarks from DNM 485 with an associated drag mark; **B**, Three-digit sinuous mark from DNM 485; **C**, (DINO 43801) Footmark with three pointed digits associated with smaller, one-digit footmarks from DNM 486.

Pes imprints are typically about 5 cm in length and width, whereas the smaller manus imprints are approximately 2.5 cm in length and 3 cm in width. The digits are rounded and up to 1 cm in width. Some of these tracks (e.g., Fig. 2B) are chirotheriid in shape and their dimensions and overall morphology resemble the Early Triassic ichnogenus *Protochirotherium* isp. from the Detfurth Formation in Germany (Fichter and Kunz, 2004), the Wióry Formation in Poland (Klein and Niedzwiedzki, 2012), and the Timezgadiouine Formation in Morocco (Klein et al., 2010). Others (e.g., Fig. 2D) are similar in size and shape to specimens of the ichnogenus *Synaptichnium* from the Early Triassic Wupatki and Middle Triassic Holbrook members of the Moenkopi Formation in northeastern Arizona (Klein and Lucas, 2010), and the Middle Triassic Voltago Conglomerate and Recoaro Limestone of northern Italy (Avanzini and Miotto, 2008). *Protochirotherium*, a characteristic ichnotaxon of the Lower Triassic (Klein et al., 2013), has thus far not been

Table 1 - Collected Specimens

Locality	Specimen Number	Fossil Type
DNM 481	DINO 43789	chirotheriid tracks
	DINO 43790	chirotheriid tracks
	DINO 43791	chirotheriid tracks & tail drag mark
	DINO 43792	reptile tracks
	DINO 43793	chirotheriid tracks
	DINO 43794	chirotheriid tracks
	DINO 43795	chirotheriid tracks
	DINO 43796	chirotheriid tracks
	DINO 43797	chirotheriid tracks
	DINO 43798	chirotheriid tracks
	DINO 43799	invertebrate trace fossil
DNM 485	DINO 43800	swim tracks
DNM 486	DINO 43801	swim tracks
	DINO 43802	swim tracks

TABLE 1. List of collected specimens from DNM 481, 485, and 486.

recognized from North American strata, but *Synaptichnium* is known from other Moenkopi deposits (Klein and Lucas, 2010). Both ichnotaxa have been ascribed to archosauriform reptiles (Klein and Niedzwiedzki, 2012) which are known from skeletal remains in Arizona (e.g., *Arizonasaurus babbitti*, Nesbitt, 2003) and some scrappy material in New Mexico (Schoch et al., 2010). Indeterminate ichnotaxa other than chirotheriids may also be present on the track surfaces, and we emphasize that the identification of ichnotaxa described here is tentative. A more detailed analysis and ichnotaxonomic study of the collected specimens and field material is needed to potentially assign them to an ichnogenus with any confidence.

DNM 485

Within about 25 meters of DNM 481 and at the same stratigraphic level is DNM 485, which preserves multiple swim tracks. The site contains medium- and small-sized swim tracks with digit marks up to 2 cm in width, some with posterior overhangs. There are two large float blocks immediately below the site that display swim tracks. The first block was flipped over, revealing about 10 small, two-digit footmarks with longitudinal striations and posterior overhangs as well as a possible tail drag mark (Fig. 3A). The track surface also contains a few slightly larger footmarks that are poorly preserved and do not show any taxonomically informative morphology. The second block was too large to flip; however, part of the track surface was exposed underneath, showing a swim track ~15 cm long (Fig. 3B). This swim track is composed of three rounded digit marks, with the middle digit mark comprising the entire length of the track and the lateral digits contributing intermittently. A similar sinuous footmark occurs at Little Dragon (UGS

42Ga1352) in Grand Staircase-Escalante National Monument, Utah (Thomson and Lovelace, this volume, fig. 9b), although the individual digit marks that comprise that track are much thinner and more pointed as opposed to rounded.

DNM 486

At Split Mountain, an in situ track surface is exposed, albeit very small, with several footmarks preserved. Longitudinal striations and posterior overhangs are visible on many footmarks with individual digit widths ranging from 1 to 2 cm. A single float block found at the site shows a footmark with three pointed digits along with several other smaller, single digit footmarks (Fig. 3C).

SUMMARY

This is a preliminary report on the first occurrence of tetrapod tracks from the Early-Middle Triassic Moenkopi Formation within DNM in northeastern Utah as well the general stratigraphic context of the tracksites. The tracks range from footprints with rounded digits to scrape marks interpreted as swim tracks and reflect a range of substrate conditions most likely controlled by water content. Footprints at DNM 481 were probably produced under subaerial conditions, whereas the swim tracks at DNM 485 and 486 required a buoyant or semi-buoyant trackmaker in subaqueous conditions. Further study of the invertebrate trace fossils at these localities and finer-scale stratigraphic work will help to elucidate paleoenvironmental interpretations. Because body fossils from the Moenkopi Formation are rare to non-existent, especially in the area around DNM, these tracks provide valuable insight into the presence and paleoecology of Early-Middle Triassic reptiles in this region.

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APPENDIX

Measured Section at DNM 481

Section measured 8-9 August, 2013 by A.B. Heckert with assistance from A.A. Harrison and J.T. Voris. Base of section is at base of hill at UTM zone 12T 0644997E, 4478784N and the top is at UTM zone 12 0644949E, 4478690N, using NAD27 for the continental US. Rock colors follow Goddard et al. (1984).

Upper Triassic**Chinle Group****Gartra Formation**

- 14 Base Gartra—quartzose sandstone and conglomerate, neither sampled nor measured, forms a cliff. Not measured

Unconformity (Tr-3 unconformity of Pipingos and O'Sullivan, 1978)**Moenkopi Formation****Lower-?Middle Triassic**

- 13 Prominent altered (reduced) bentonitic (?) band consisting of mudstone with minor siltstone; greenish gray (5GY6/1) and grayish yellow (5Y8/4) with pale greenish yellow (10Y8/2) reduction spots. 0.5-0.7 m
- 12 Mudstone, grayish brown (5YR3/2) with light olive gray (5Y6/1) reduction spots; silty and slightly micaceous; not calcareous. 3.3 m
- 11 Siltstone, light brown (5YR6/4-5YR5/6); slightly micaceous; slightly calcareous. Slope forming interval with siltstone ledges; ledges are composed of silt to very fine sand of similar colors with bluish reduction spots. Top (7A) is ledge-forming siltstone; light gray (N7) weathers to (10YR5/4). 12.0 m
- 10 Orange siltstone ledge, like unit 4 but with less distinct bedding, micaceous, calcareous. Light brown (5YR5/6) to moderate yellowish brown (10YR5/4). 0.7 m
- 9 Similar to unit 3, interbeds of "orange silt" and "chocolate shale." Siltstone is slightly sandy and micaceous, forms a prominent ledge at 14.7 meters above base of unit. "Shale" is light brown (5YR6/4-5YR5/6); calcareous; forms a brownish slope. "Orange silt" is siltstone; light brown (5YR6/4) to moderate orange pink (5YR8/4). 16.5 m

- 8 Siltstone (light brown 5YR5/6) and sandstone (very fine-grained quartz arenite); in beds 5-40 cm thick; calcareous; forms prominent ledge. This unit is a primary marker horizon for much of the "racetrack" around Split Mountain. 6.3 m
- 7 Begin intervals of interbedded "chocolate shale" and "orange siltstone" (siltstone to very-fine grained wacke). "Shale" is a silty mudstone; moderate brown (5YR3/4) with light gray (N6) to medium gray (N7) spots; flecks of mica; slightly calcareous; silty; usually "exposed" by burrowing animals. Siltstone is light brown (5YR6/4) to (5YR5/6); slightly calcareous. 4.4 m
- 6 Sandstone, very-fine grained to fine grained, subrounded to subangular, very well sorted; calcareous. **Track bearing interval for DNM 481, 485, and, probably, 486.** Tracks in basal sand; many climbing ripples, some asymmetric ripples with paleoflow to the west. 3.0 m
- 5 Siltstone; light brown (5YR5/6) to moderate brown (5YR4/4); slightly micaceous; very calcareous, blocky but mostly covered. 8.7+ m
- 4 Mostly covered siltstone; gypsiferous; probably similar to unit 5 above. ~ 18 m
- 3 Massive gypsum with wavy laminations and minor interbeds of mudstone; moderate white (N9) to very light gray (N8) and light brown (5YR5/6). 0.5 m
- 2 Mostly covered by colluvium, additional gypsum evident in wash. Very pale orange (10YR8/2) and light brown (5YR5/6). 5.0 m
- 1 Gypsum and mudstone; white (N9) to grayish pink (5R8/2) fresh, weathers to pale reddish brown (10R5/4) and light brown (5YR6/4). 1.3 m