The oldest vertebrate trace fossils from Comb Ridge (Bears Ears National Monument, southeastern Utah)

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Abstract

Vertebrate trace fossils are common in Upper Triassic deposits across the American southwest. These ichnofauna are dominated by *Grallator*, *Brachychirotherium*, and *Pseudotetrasauropus*, and lack ichnotaxa traditionally considered to be Early Jurassic in age, such as *Eubrontes* and *Anomoepus*. While known from Indian Creek and Lisbon Valley, Utah, vertebrate trace fossils have not been previously reported from Comb Ridge, Utah. This is significant considering that lithostratigraphic work has been ongoing at Comb Ridge since the 1990s in the elsewhere fossiliferous 'Big Indian Rock Beds', in the US Highway 163 roadcut that transects Comb Ridge. 2016 fieldwork by the Museums of Western Colorado: Dinosaur Journey recovered two sandstone slabs that had been dislodged from a river channel sand in the Church Rock Member of the Chinle Formation. The slabs preserve the first documented Triassic vertebrate trace fossils from Comb Ridge: a single pes impression of the ichnogenus *Grallator*, and several manus and at least one pes impression of a small archosaur. We tentatively refer this second track set to the ichnogenus *Brachychirotherium.* Taken together, these specimens provide evidence for a more diverse vertebrate fauna in the Church Rock Member of the Chinle Formation at Comb Ridge than indicated by the current body fossil record.

Institutional Abbreviations: MNA, Museum of Northern Arizona; MWC, Museums of Western Colorado

Introduction

The Chinle Formation at Comb Ridge, Utah has received only cursory paleontological and geological research in the past century (Stewart et al., 1972; Lucas et al., 1997; Molina-Garza et al., 2003; Martz et al., 2014; Gay and St. Aude, 2015). Ongoing fieldwork by teams lead by RG have begun documenting numerous fossil localities in the Chinle Formation across the western face of Comb Ridge, but until recently these sites have produced only invertebrate (unionid bivalves and molluscs) or vertebrate remains (Gay et al., 2016). This changed during the summer of 2016 when the authors discovered a new locality in the Church Rock Member of the Chinle Formation that preserved the first unambiguous vertebrate trace fossil remains from the Chinle of Comb Ridge.

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Unlike the Chinle Formation, the Navajo Sandstone at Comb Ridge has received significant ichnological attention. This may be due in part to the easier access to exposures, as the Navajo is exposed on the gently-sloping eastern face as opposed to the nearly vertical western one. The tracks that have previously been identified from Comb Ridge have almost all been from rocks that are firmly Jurassic in age and include a typical Jurassic ichnofauna, such as *Eubrontes*, *Otozoum*, and *Anomoepus*, along with the Triassic-Jurassic ichnotaxon *Grallator* (Loope et al., 2004; Lockley et al., 2006).

Triassic-aged rocks, such as the Chinle, Dolores, Nugget, and Wingate Formations in Utah, northern Arizona, and western Colorado have produced abundant vertebrate trace fossils, including those referable to *Grallator* (Riggs, 1904; Bunker, 1957; Parrish and Lockley, 1984; Conrad and Lockley, 1986; Hamblin and Foster, 2000; Foster et al., 2001; Gaston et al., 2003; Santucci et al., 2006; Milner and Lockley 2006, Hunt and Lucas, 2007; Martz et al., 2014). Comparatively *Brachychirotherium* is rarer (Hamblin and Foster 2000, Sprinkel et al. 2011, Martz et al., 2014; Irmis et al. 2015) though it too is known from southeastern Utah (Martz et al., 2014). These ichnotaxa have traditionally been interpreted as having been made by small theropod dinosaurs (Olsen et al., 1998) and aetosaurs respectively (Heckert et al, 2010), though some authors have suggested that grallatoroid traces may have been made by several unrelated animals with similar pedal morphology (Farlow et al., 2014).

Materials and Methods

Specimens were collected as float just below MNA Loc. 1776. Craftsman metal sliding calipers and a metric tape measure were used to measure specimens. Specimens were photographed using a Nikon D5200, while locality photos were taken using a Samsung Galaxy S6 and a Nikon D5100. Data for the geologic map in this contribution were collected from USGS Bluff SW 7.5’ topographic map and aerial photography of the same, along with on-the-ground observations on 6/24/2016 and 9/2/2016. Locality data is on file and available to qualified researchers at the Museum of Northern Arizona. The specimens described here were collected under Bureau of Land Management paleontology permit UT14-001S issued to RG and are reposited at the Museum of Northern Arizona.

Locality and Geological Setting

MNA Loc. 1776, ‘Rocky Mountain Oysters’, is located within the ‘Bread Bowl’ area of Comb Ridge in southeastern Utah (Figures 1, 2). The entirety of the slope-forming portion of the ‘Bread Bowl’ exposures are from the Church Rock Member of the Chinle Formation and are dominated by reddish-brown mudstones and shales. The embayment or bowl in the western face of Comb Ridge also has several prominent ledge-forming units. The lower unit is a two-to-three meter thick reddish channel sandstone with prominent vertebrate burrows filled in with white sandstone (Figure 3). The second, higher ledge-forming unit is a channel-fill coquina deposit with numerous vertebrate (including phytosaur) remains throughout. MNA Loc. 1776 is located in a drainage on the north side of the bowl, below the first ledge-forming unit. The fine-grained red sandstone is a match for the lithology of the lower unit but not the coquina (which was represented by abundant debris at the site) nor the overlying Wingate Sandstone (which has larger grain sizes and a more orange hue). The presence of mud cracks on MNA V10984, while not conclusive, conforms with the presence of mud cracks on several overhanging surfaces on the lower ledge forming unit. As a result, and due to the presence of likely vertebrate burrows within the lower unit, we conclude that these two slabs originated from the lower ledge forming unit.

Specimens

MNA V10984, a single slab containing one right pes impression referable to *Grallator*. MNA V10985, a single slab containing two manus and at least one pes impressions referable to *Brachychirotherium*.

Description of Specimens

MNA V10984 is a mostly complete, probable *Grallator* right pes preserved in a mudcracked surface (Figure 4). The total length from heel to tip of digit III is 13.3 cm while the length of digit IV is 8.0 cm. Damage to digit II (DII) occurred during collection when the block broke across DII and the majority of it flaked away. Nonetheless we have measured the angle of divarication between digits II and IV on MNA V10984 at ~90 degrees.

MNA V10984 exhibits the classic tridactyl arrangement seen in the pedal morphology of many theropod dinosaurs. Although digit II was damaged during removal from the field, and the highly bioturbated undertrack surface obscures clear toe pad impressions, several key features point to a probable *Grallator* identification. The angle of divarication of digits II-IV (DII-DIV) at ~90 degrees, digit III exhibiting longest measurable length, and the lack of metatarsal impressions are all classic *Grallator* features that align with synapomorphies of Dinosauromorpha (Brusatte et al., 2010) and with *Grallator* measurements with wider-than-average angles of DII-DIV divarication (Williams et al., 2006). We acknowledge the difficulty in assigning footprint ichnotaxa to specific clades, especially given the preservation of MNA V10984, though here we use synapomorphies as a reliable method of attributing pedal morphology to track morphology (Olsen, 1995, Carrano and Wilson, 2001, Brusatte et al., 2010).

MNA V10985 consists of two manus impressions, both moderately well preserved, not in association with any pes impression. There is also one well-preserved right pes impression, though the individual digit pads cannot be discerned within the impression and digit I is faint or incomplete. A second, possible pes impression (side indeterminate) is also present that preserves impressions of digit II and digit III (Figure 5) with a total preserved length of ~8.2 cm as measured along the longest preserved digit. Manus 1, a probable right manus, measures 2.47 cm in length along the longest digit and 3.4 cm in width (Figure 6), while manus 2, a possible right manus, is 3.1 cm in length along the longest digit and 4.0 cm wide (Figure 7). Pes 1 (P1) includes a unambiguous metatarsal impression and measures 10.65 cm from the posterior end of the metatarsal to the tip of the longest digit, digit III, and a maximum width across the digits (tip of DI to tip of DV) of 7.5 cm (Figure 8). Pes 2 is difficult to measure, owing to its incomplete preservation and faint impression. These indicate that it may be an undertrack from a surface ‘above’ the track surface exposed on the block.

Overall both P1 and M1 compare very favorably to those figured as *Brachychirotherium* by Heckert et al. (2010), though they are roughly 50% smaller (Figure 9, 10) and generally conform to the morphology of known *Brachychirotherium* tracks in that the pes has five digits with DI being set posterior to DII-V and DIII being the longest of the five pedal digits. It is worth noting that MNA V10985 also possesses features characteristic of manual and pedal morphology seen in basal dinosauromorphs, such as a straight posterior margin of the manus and parallel digits (Brusatte et al., 2010).

Discussion

While both MNA V10984 and V10985 are referable to the ichnogenera *Brachychirotherium* and *Grallator*, respectively, there are noticeable differences between the Comb Ridge specimens and those reported elsewhere. MNA V10985 represents a smaller and more gracile version of *Brachychirotherium* compared to similar tracks seen elsewhere in Triassic rocks of Utah (Hamblin et al. 2000; Sprinkel et al. 2011; Martz et al. 2014; Irmis et al. 2015). We hypothesize that these two differences are likely related. A smaller, more gracile animal would have less weight to impress on each digit, reducing the disturbance to the substrate.

MNA V10984 is likewise different from other *Grallator* tracks reported elsewhere in the state of Utah. The LDS tracksite (Williams et al., 2006) *Grallator* tracks have angles of divarication between 62 and 108 degrees between DII and DIV, which is generally larger than most *Grallator* specimens. Hitchcock’s *Grallator* specimens have DII-DIV divarication angles of 26 to 46 degrees (Hitchcock, 1858, Lull, 1953). Williams et al. (2006) conclude that the wide variation in the angle of divarication between digits II and IV seen in many specimens of *Grallator* are due to the interactions between the animal’s foot and the substrate, as proposed by other authors (Gatesy et al., 1999, Milan and Bromley, 2005, Milan, 2006). This may explain the relatively wide spread of DII-DIV in MNA V10984. This seems likely as the mud cracks present in the slab also cross the track surface (Figure 10), indicating that the track was made while the surface was saturated.

Both MNA V10984 and V10985 are significant because they are likely to have been made by taxa that are not represented by body fossils thus far at Comb Ridge. Although there has been recent acknowledgement of similarities between basal suchian and dinosaurian pedal morphology and, potentially, their corresponding tracks (Farlow et al., 2014), traditionally *Grallator* is considered to have been made by a gracile theropod dinosaur (Lull, 1953; Olsen et al., 1998; Gatesy et al., 1999; Milner et al., 2006; Lepore, 2007; Milner et al., 2009). The wide angle of digit II to digit IV divarication in MNA V10984 rules out a basal suchian trackmaker, for which forms like *Poposaurus* fall around 25 degrees in pedal skeletal morphology (Farlow et al., 2014). Given the wide DII-DIV angle of divarication and the length of digit III, both of which compare favorably to *Grallator* measurements (Lull, 1953, Williams et al., 2006), we refer to this specimen as probable *Grallator*. Yet, unambiguous body fossils of theropod dinosaurs, dinosauromorphs, basal suchians, or other plausible grallatoroid track makers are currently unknown from Comb Ridge. Additionally no remains firmly assigned to Aetosauria - a plausible group representative of the *Brachychirotherium* track maker (Heckert et al., 2010, Lucas and Heckert, 2011) - have yet been found at Comb Ridge.

Although these two track blocks do not provide evidence of novel ichnotaxa, they do nonetheless expand the Chinle fauna at Comb Ridge. These tracks are notable given the presence of an exceptionally rich microvertebrate site close (<2 km) to MNA Loc. 1776 (Gay et al., 2016). Further exploration of these ledge-forming units in the Church Rock Member of the Chinle Formation around the Bears Ears area will doubtless lead to additional trace fossil localities being discovered.

Acknowledgments

This work was supported by a grant from the Canyonlands Natural History Association. The authors would like to thank Dylan DeWitt for helping recover MNA V10984 and Andrew RC Milner for pointing us in the right direction for identifying MNA V10985. The authors would also like to extend their heartfelt thanks to ReBecca Hunt-Foster at the BLM Moab office for assistance with permitting, Dave and Janet Gillette at the Museum of Northern Arizona for repository assistance, access to specimens under their care, and their feedback on an earlier version of this manuscript. Julia McHugh for her discussions with RG on the Comb Ridge project, and the Museums of Western Colorado for logistical support for fieldwork in the Bears Ears area in 2016. Adam Marsh provided valuable feedback on this manuscript that we have gratefully accepted and incorporated into the current version.

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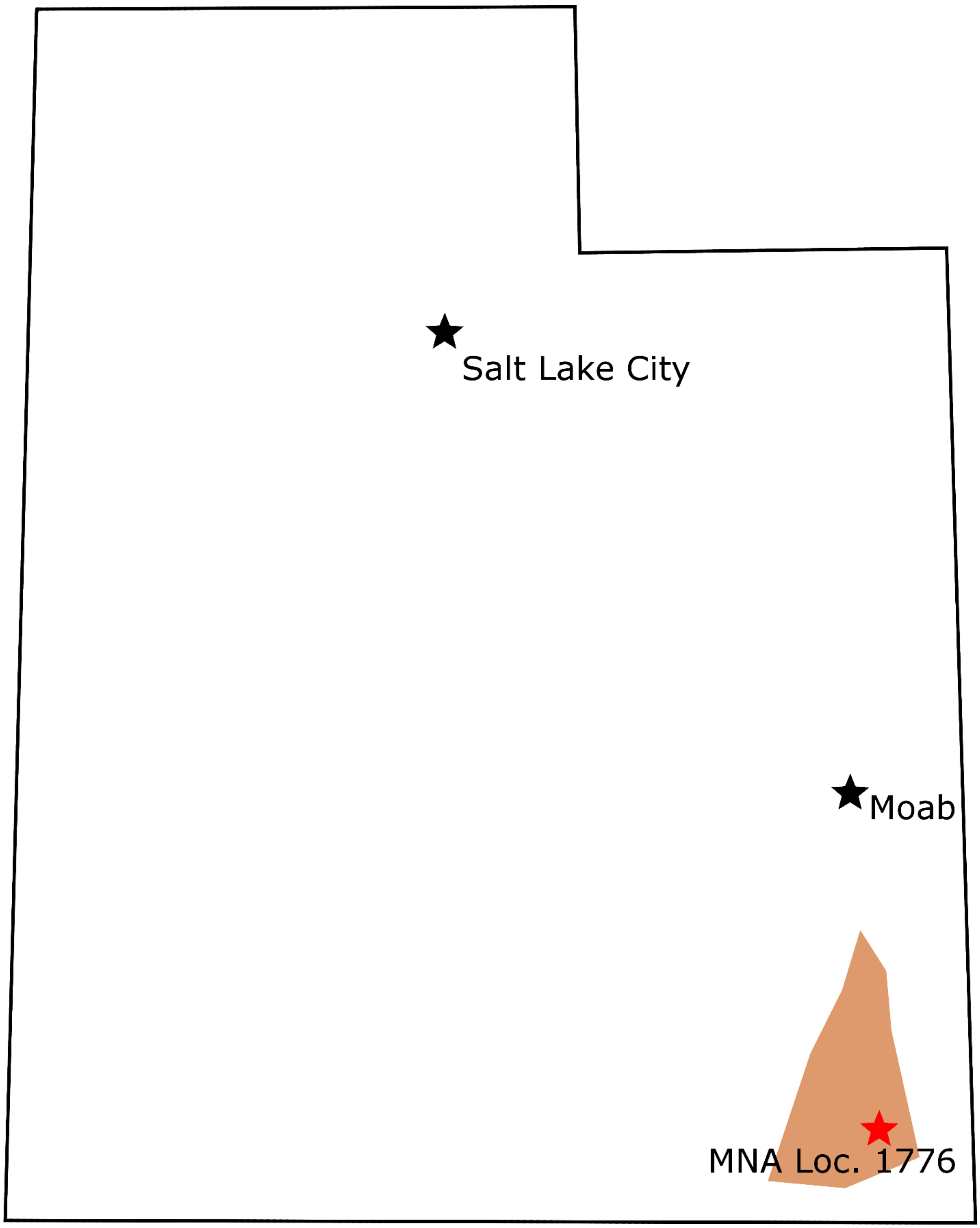

Figure 1: Location of MNA Loc. 1776 in the State of Utah. Tan area indicates Bears Ears region.

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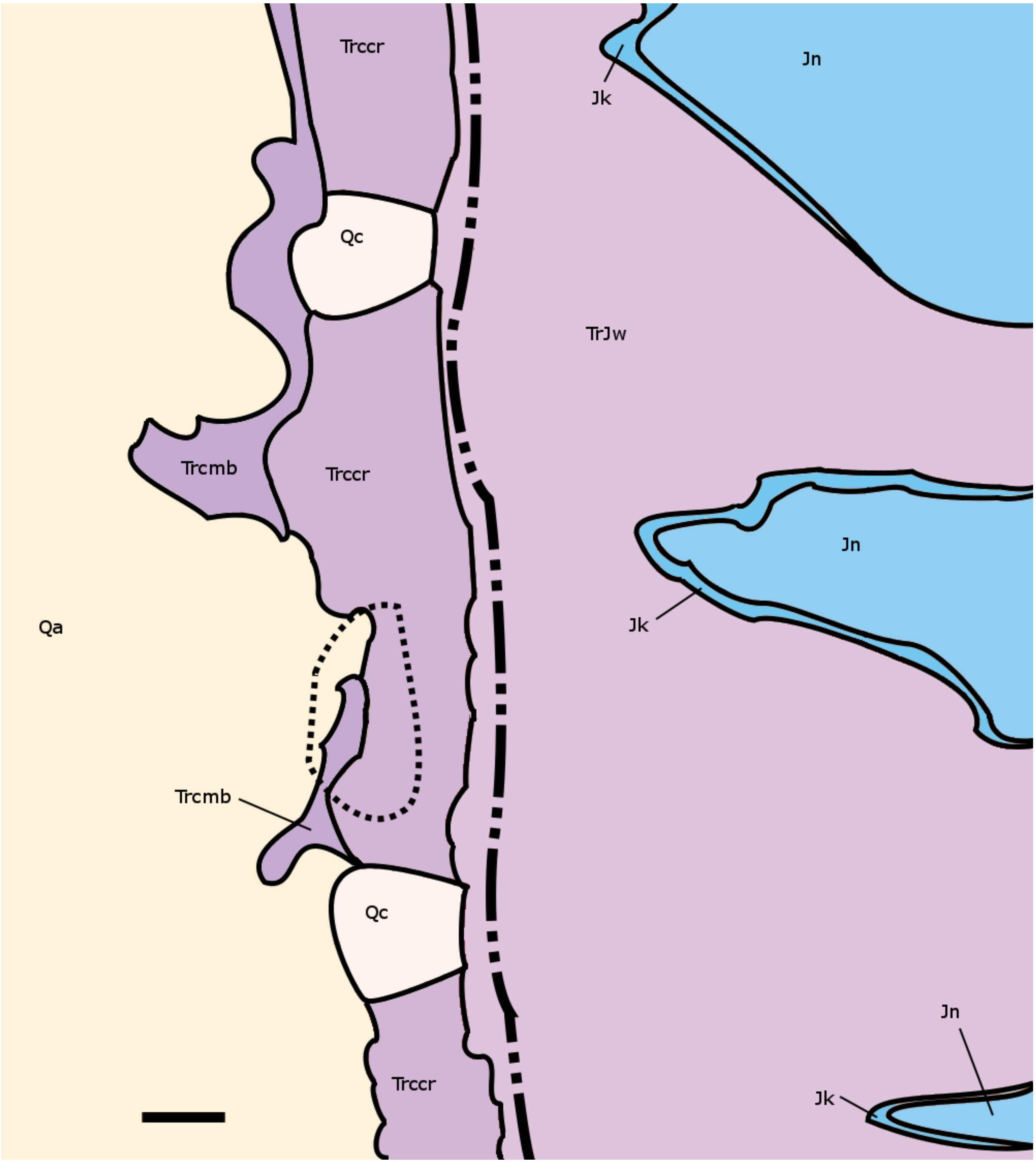

Figure 2: Generalized geologic map of MNA Loc. 1776, which is located in the 'Bread Bowl' area (small dashed line). Dashed and dotted line indicates the ridgeline of Comb Ridge. Trcmb, Monitor Butte Member, Chinle Formation; Trccr, Church Rock Member, Chinle Formation; TrJw, Wingate Sandstone; Jk, Kayenta Formation; Jn, Navajo Sandstone; Qa; Alluvium; Qc; Colluvium. Scale bar = 0.1 km, north is to top of image.

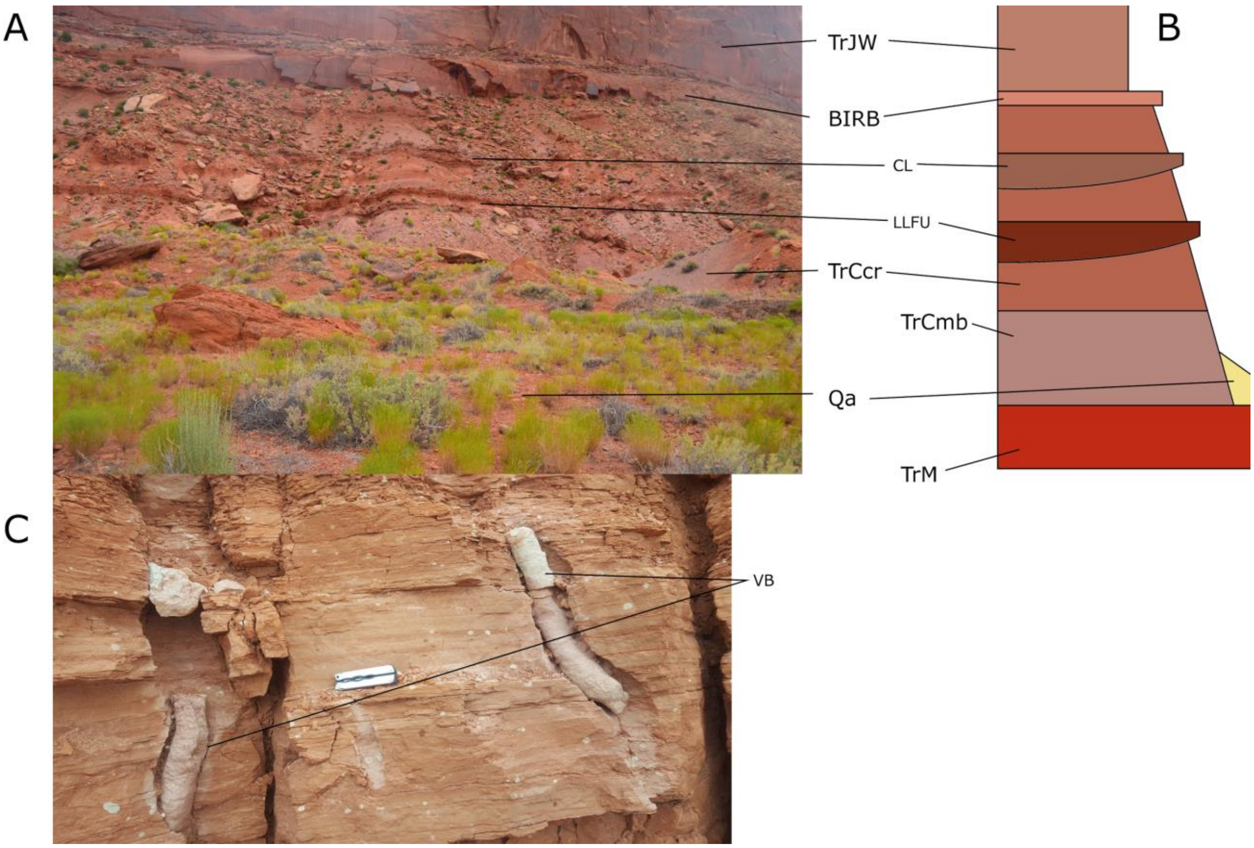

Figure 3: A) Photograph of Bread Bowl area with ledge forming units visible. BIRB; "Big Indian Rock beds"; CL; coquina layer; LLFU; lower ledge-forming unit; TrM, Moenkopi Formation, TrCcr, Church Rock Member, Chinle Formation; TrJW, Wingate Sandstone; Qa; Alluvium. B) Generalized stratigraphic column of the same area. C) Vertebrate burrows in the lower ledge forming unit.

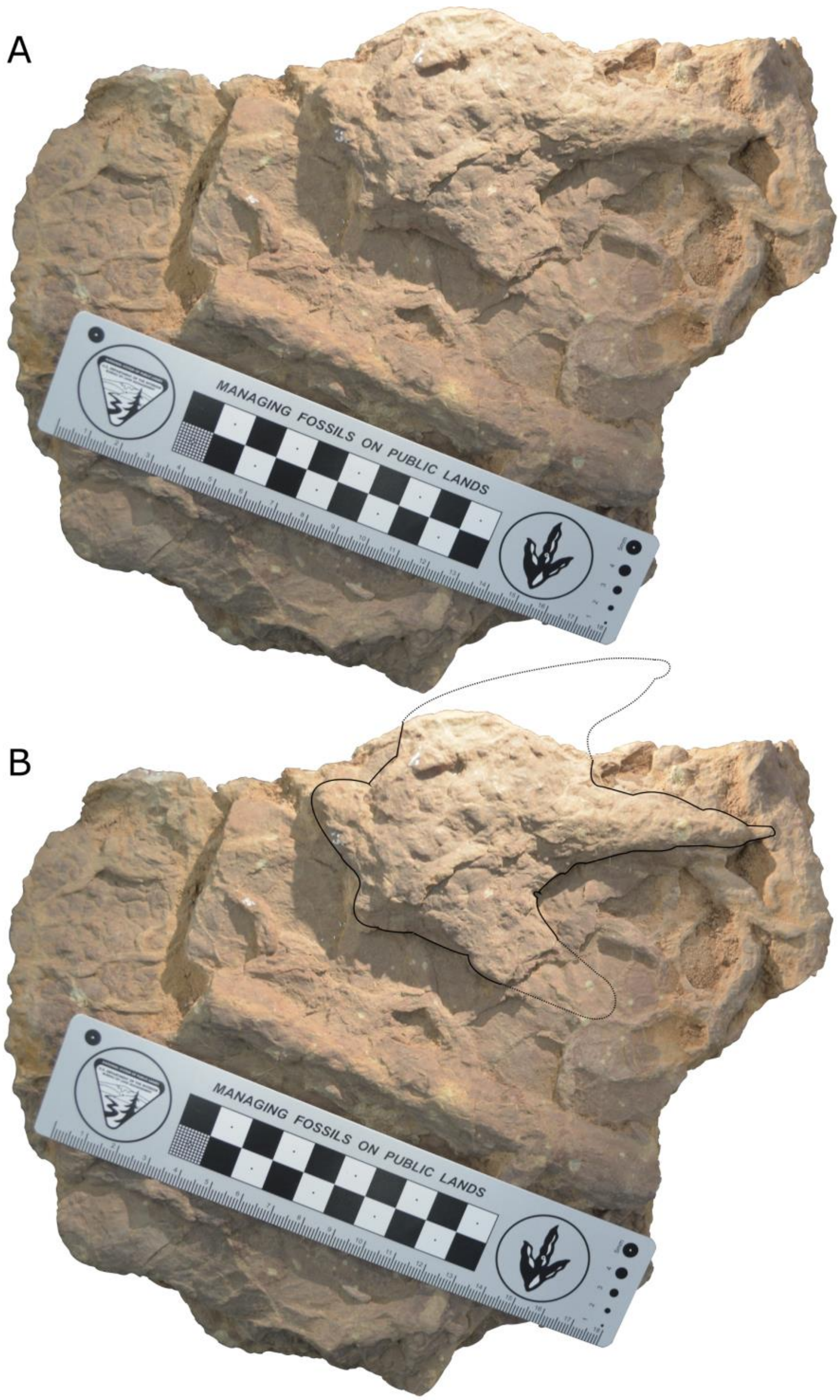

Figure 4: A) MNA V10984, *Grallator* trace and mudcracks. B) MNA V10984, *Grallator* trace (outlined) with mudcracks. Dashed lines indicates where DII was present when discovered and the approximate presumed extent of DIV. Scale bar squares = 1 cm each.

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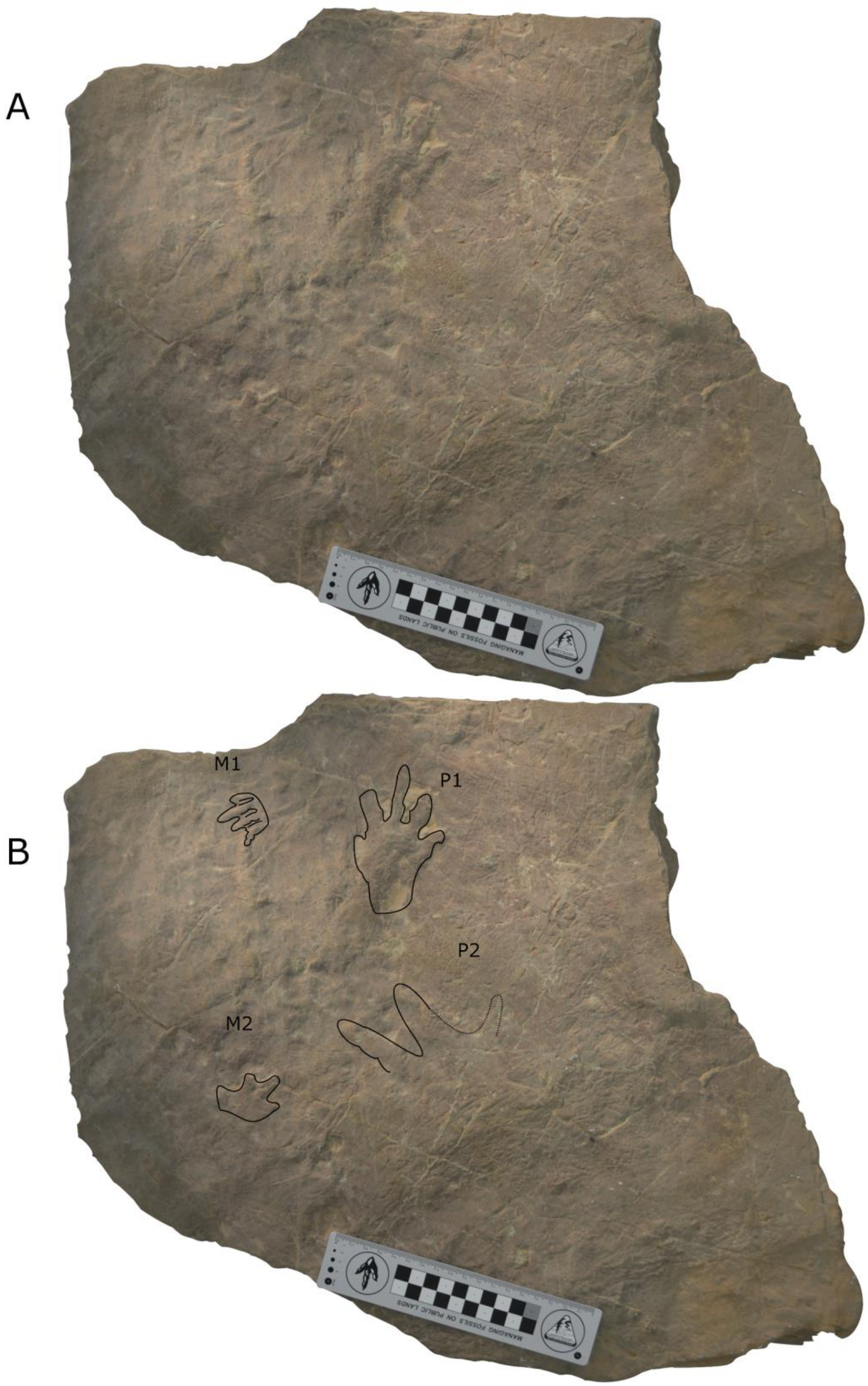

Figure 5: A) MNA V10985. B) MNA V10985 with tracks outlined. M1, manus print 1; M2, manus print 2; P1, pes print 1; P2, pes print 2. Scale bar squares = 1 cm each.

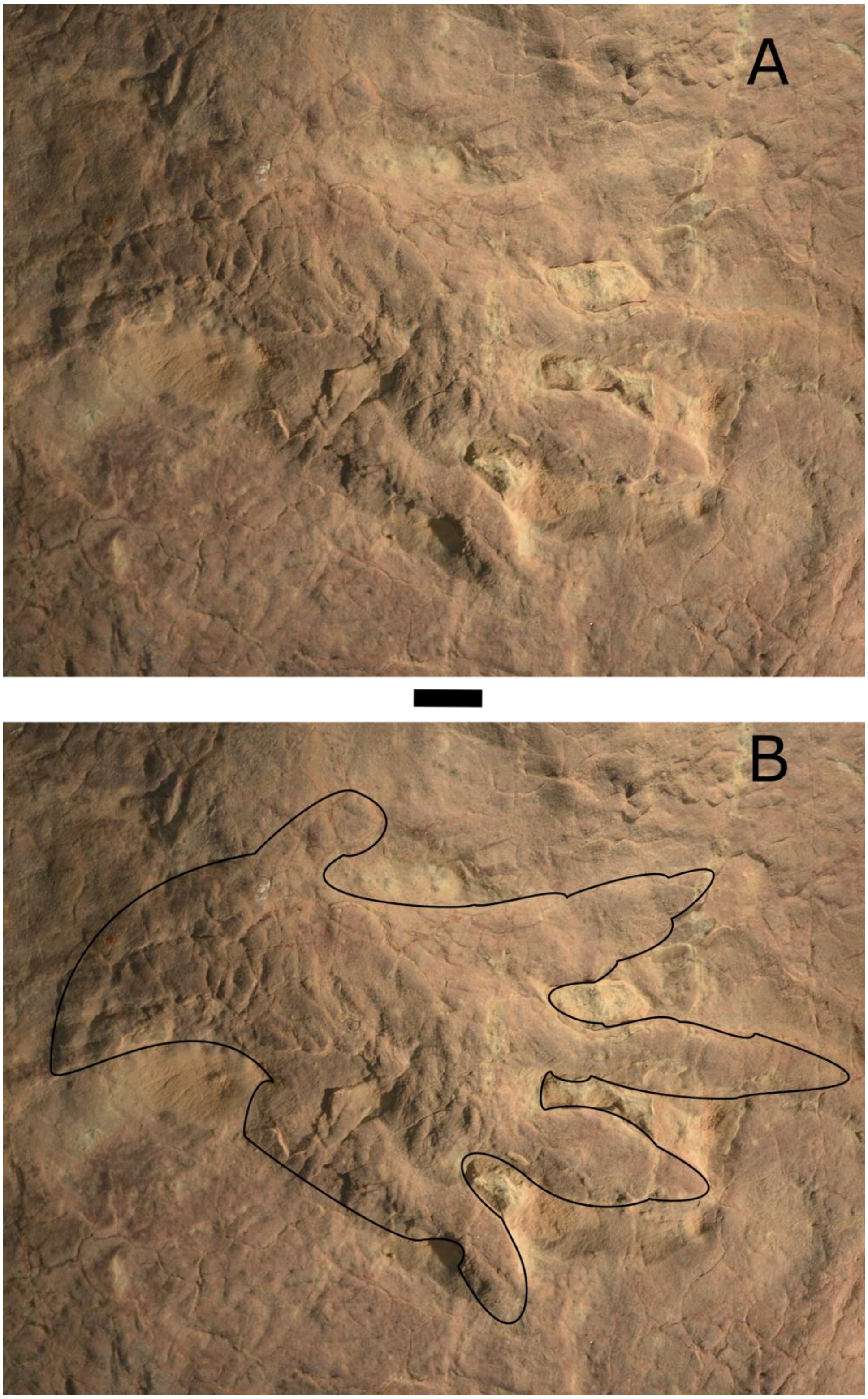

Figure 6: A) Close-up of P1, MNA V10985. B) Close-up of P1, MNA V10985 with the trace outlined. Scale bar = 1 cm.

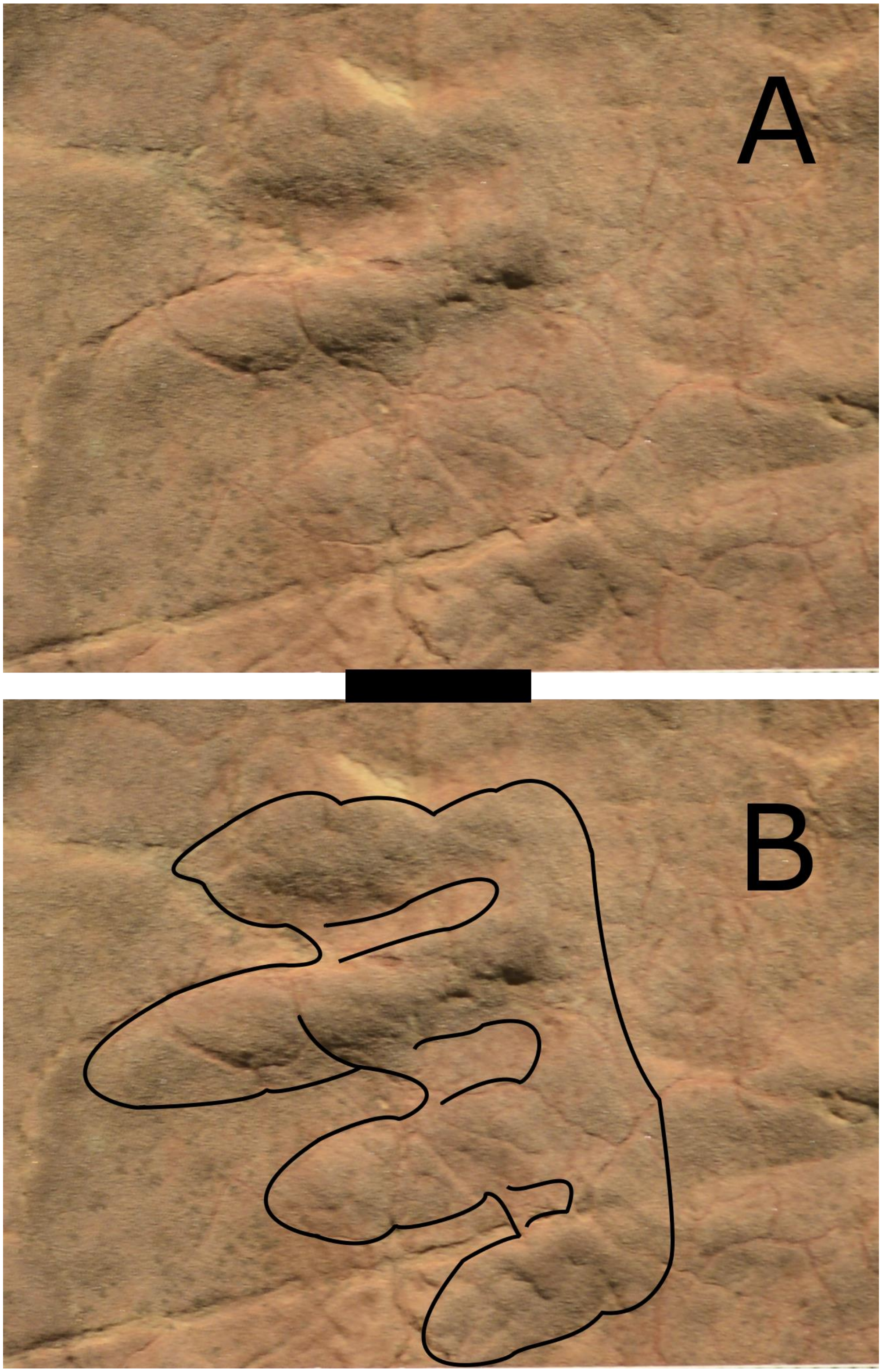

Figure 7: A) Close-up of M1, MNA V10985. B) Close up of M1 with the track and features outlined, MNA V10985. Scale bar = 1 cm.

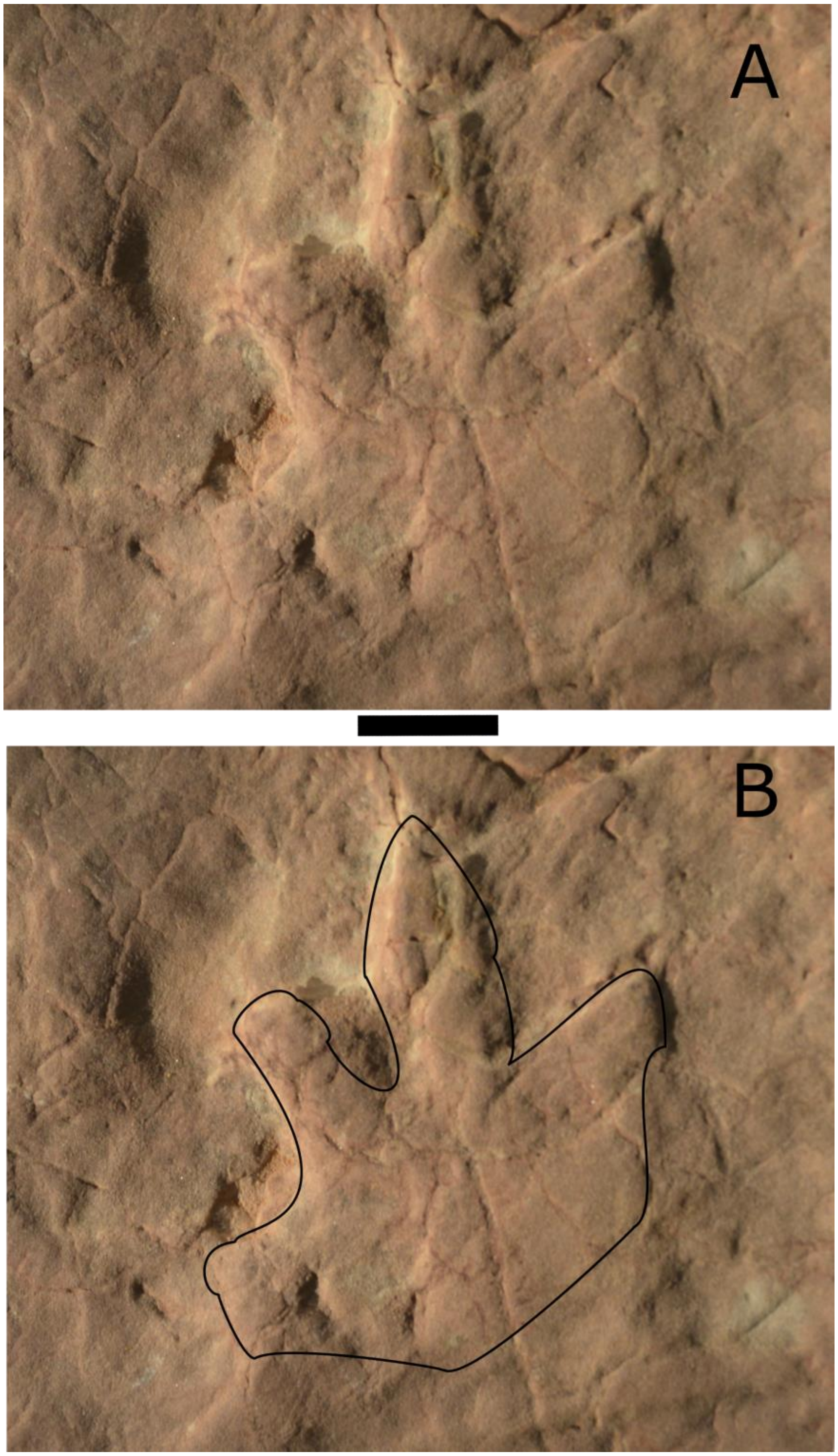

Figure 8: A) Close up of M2, MNA V10985. B) Close of M2 with track outlined, MNA V10985. Scale bar = 1 cm.

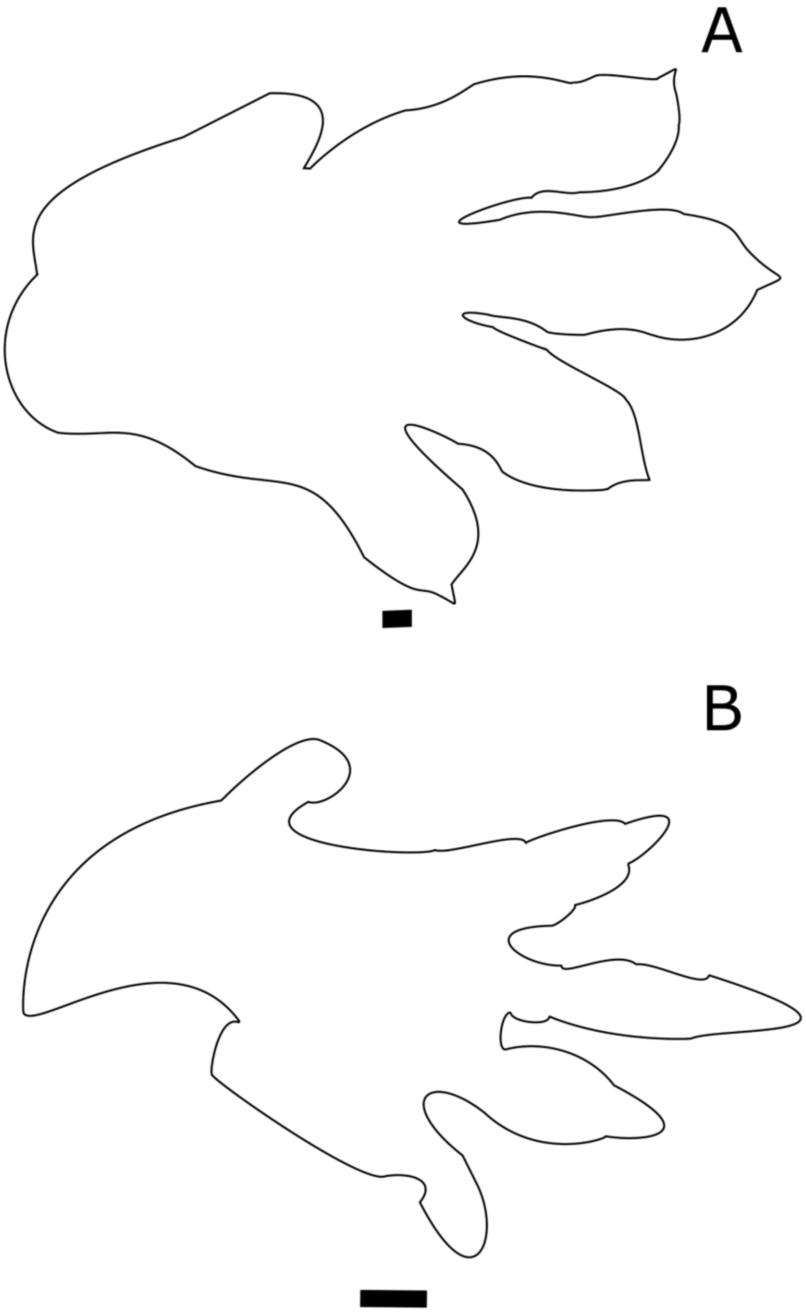

Figure 9: A comparison between a *Brachychirotherium* pes track (modified from Heckert et al., 2010) (A) and P1 of MNA V10985 (B). Scale bar 1 = cm for each track.

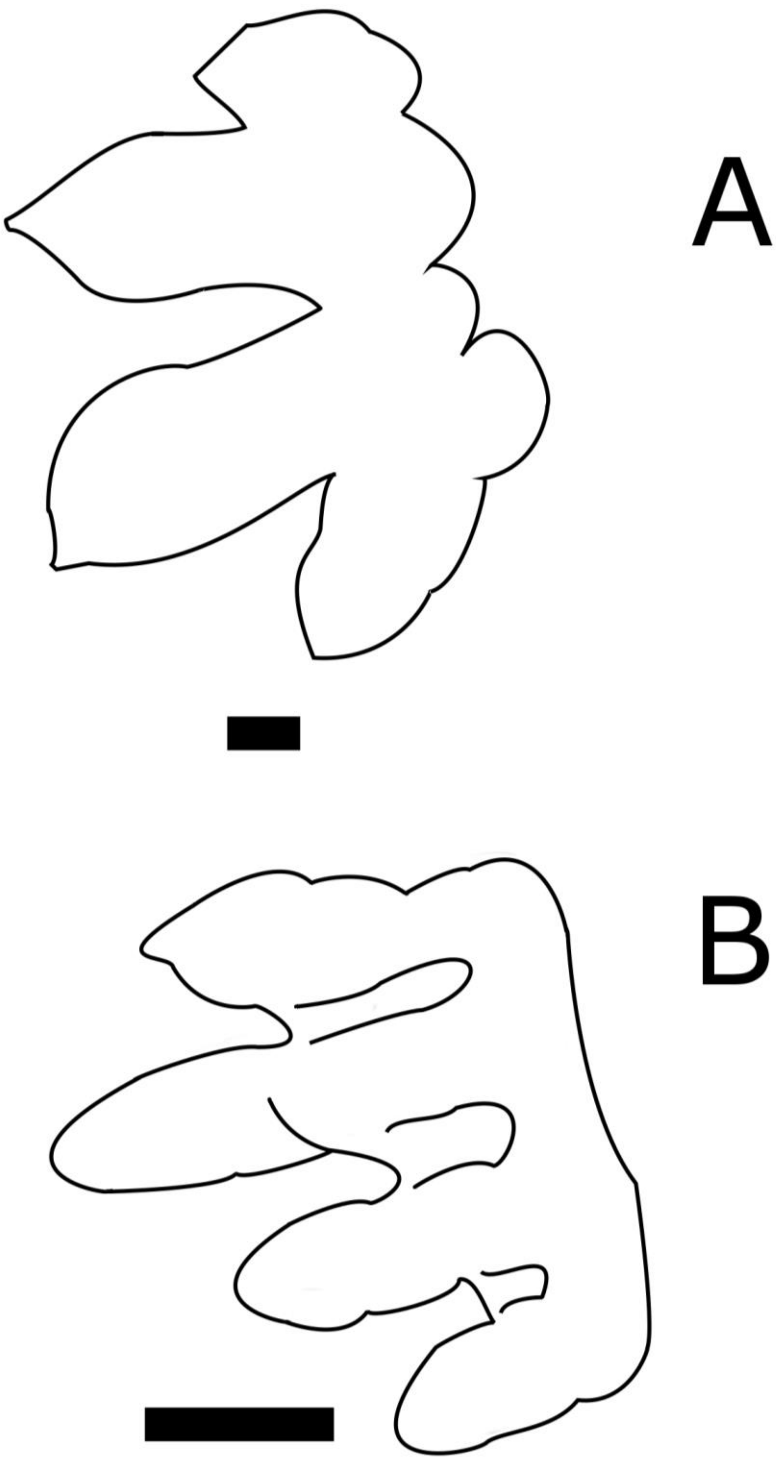

Figure 10: A comparison between a *Brachychirotherium* manus track (modified from Heckert et al., 2010) (A) and M1 of MNA V10985 (B). Scale bar 1 = cm for each track.