GEOLOGICAL NOTE

First American Record of the Jurassic Ichnospecies *Deltapodus brodricki* and a Review of the Fossil Record of Stegosaurian Footprints

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ABSTRACT

We describe the first American stegosaur track of the ichnospecies *Deltapodus brodricki*, collected in the Upper Jurassic Morrison Formation of San Juan County, southeastern Utah, United States. The track is preserved as a natural cast on the underside of a slab of fluvial sandstone and consists of a well-preserved pes track and the eroded remains of a manus track. Previously, *Deltapodus* was known only from the Middle Jurassic Yorkshire coast of England and the Upper Jurassic of Portugal and Spain. The new discovery thus substantially extends the geographic record of this ichnospecies and highlights the similarities between the Late Jurassic dinosaur faunas of North America and those of Western Europe.

Introduction

Fossil dinosaur tracks and trackways are abundant and well known for all major dinosaur groups except for stegosaurs, whose tracks are only poorly known and are largely limited to Europe (Thulborn 1990; Whyte and Romano 1994, 2001; Lockley and Hunt 1998; Long 1998; Gierlinski and Sabath 2002, forthcoming; Garcia-Ramos et al. 2006; Whyte et al. 2007; Lockley et al., forthcoming; Mateus and Milàn, forthcoming). In May 2008, the Dinosaur Institute's Thornbury Dinosaur Expedition discovered a sandstone slab containing a deep natural cast of a stegosaur pes track and the eroded remains of an associated manus track in the Brushy Basin Member of the Upper Jurassic Morrison Formation, south of Blanding (San Juan County, Utah; fig. 1). The distinct morphology of this track allows identification of it as belonging to the ichnospecies *Deltapodus brodricki* (Whyte and Romano 1994), originally described from the Middle Jurassic of Yorkshire (England) and interpreted first as of sauropod origin (Whyte and Romano 1994) but subsequently reinterpreted as thyreophoran (Lockley and Meyer 2000) and stegosaurian (Whyte and Romano 2001).

Several specimens of *Deltapodus* have been collected from Middle Jurassic flood plain deposits of the Yorkshire coast (Whyte et al. 2007), and loose natural casts of this ichnogenus have been described from the Upper Jurassic of Asturias (Garcia-Ramos et al. 2006; Lockley et al., forthcoming) and the similar Upper Jurassic deposits of Lourinhã (Mateus and Milàn, forthcoming), in Spain and Portugal, respectively, yet no evidence of this ichnotaxon was known outside of western Europe. This article reviews the scant ichnofossil record of stegosaurians and demonstrates the existence of *Deltapodus* in the Upper Jurassic of North America.

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Description

The new track is preserved as a natural cast on the underside of a sandstone slab, originating from a fluvial sandstone bed interbedded with the red and

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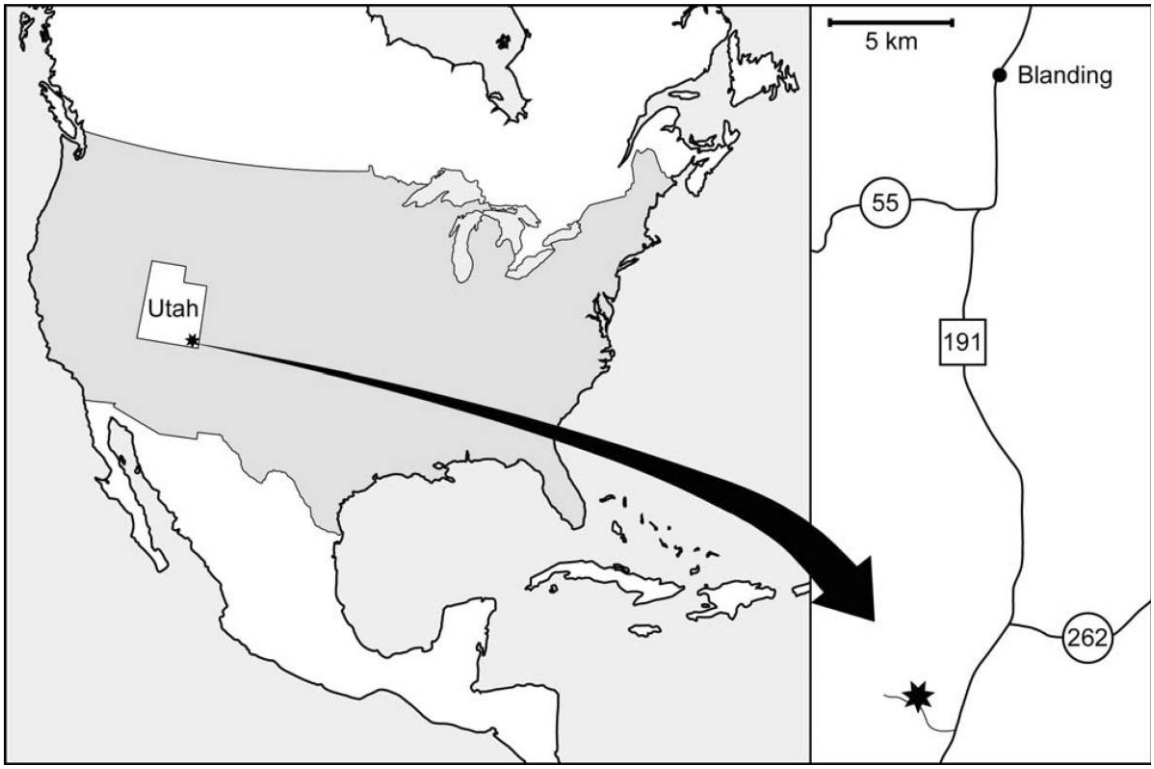

Figure 1. Geographic location of LACM 7708/154065. The track was found in the Brushy Basin Member of the Morrison Formation, at a site (37°23′37.68″N, 109°31′3.72″W) approximately 35 km south of Blanding, San Juan County, Utah.

green floodplain clays of the Upper Jurassic Brushy Basin Member of the Morrison Formation. The slab was found in a wash, clearly fallen down from a cliff face exposing the footprint bed. Preserved on the slab are a well-preserved cast of a pes and the eroded remains of a manus impression (fig. 2). The pes track is subtriangular in outline (31 cm long and 22 cm wide), mesaxonic (middle digit is the largest), and tridactyl, in which the greatest width of the track is measured across the digit impressions. The impressions of the digits are short and blunt. The cast is 23 cm deep, measured from the original tracking surface, and the foot made a slight rotation as it was impressed down and dragged up through the sediment, slightly deforming the walls of the natural cast. Although the manus track is broken off and its remains are largely weathered, it can be determined that it was approximately 20 cm wide and 10 cm long, and traces of an inwardly directed pollex claw are visible. The narrow crescentic shape seems to be characteristic of the *Deltapodus* manus track (fig. 2*B*, 2*D*). The pes track was collected and is now part of the collection of the Dinosaur Institute at the Natural History Museum of Los Angeles County (LACM 7708/154065).

The Fossil Record of Stegosaurian Footprints

Stegosaur tracks are rare, and their identification has been largely based on comparison with the anatomy of the stegosaurian manus and pes (fig. 3*A*). The manus of stegosaurs is functionally tetradactyl, with four short reduced digits arranged in semicircular pattern and only digit I bearing an enlarged claw (Gilmore 1914; Thulborn 1990). The foot of these dinosaurs is tridactyl and mesaxonic, with digits II and IV of subequal length. The digits are short and terminate in rounded hooflike unguals (Gilmore 1914; Thulborn 1990).

Based on this morphology, *Deltapodus* tracks from Western Europe have been interpreted as belonging to stegosaurs (Whyte and Romano 2001). This ichnogenus is characterized by entaxonic, crescent-shaped manus impression that is approximately twice as wide as long and may have the impression of an inward-directed pollex claw. The

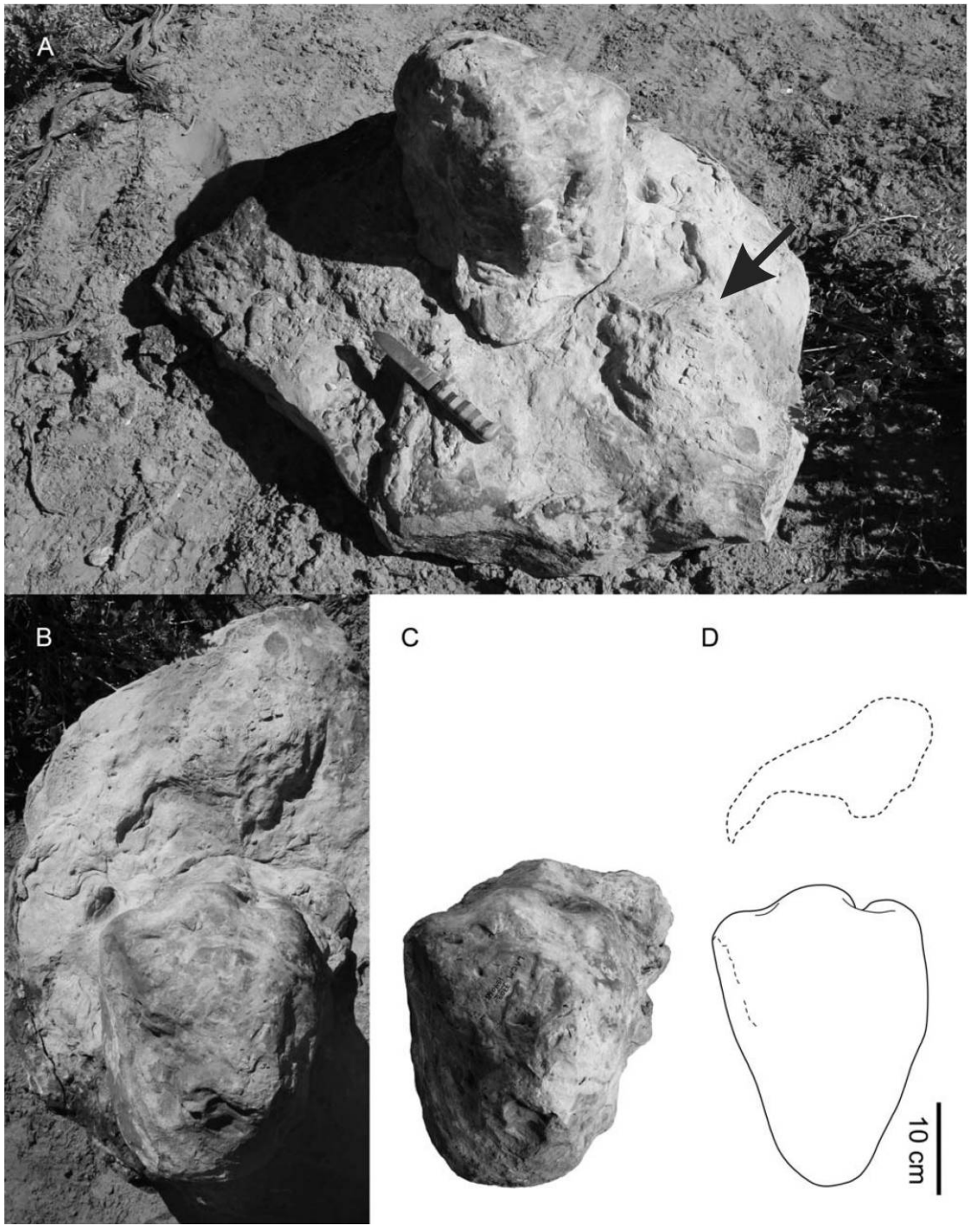

Figure 2. *A*, New track as it was found preserved as a deep natural cast on the underside of a sandstone slab. The broken-off and badly eroded remains of the manus track are visible in front of the pes (*arrow*). *B*, Track (pes and manus) seen from directly above, showing the subtriangular shape of the pes track and its three short blunt digits. The heel area of the track has rotated slightly during the impression and lifting of the foot, giving the heel a broader appearance in this view. *C*, Collected cast of the pes track (LACM 7708/154065). *D*, Interpretative drawing of the track. The drawing is made from the bottom of the track, reflecting the true shape of the foot. The eroded remains of the manus track are indicated by broken lines.

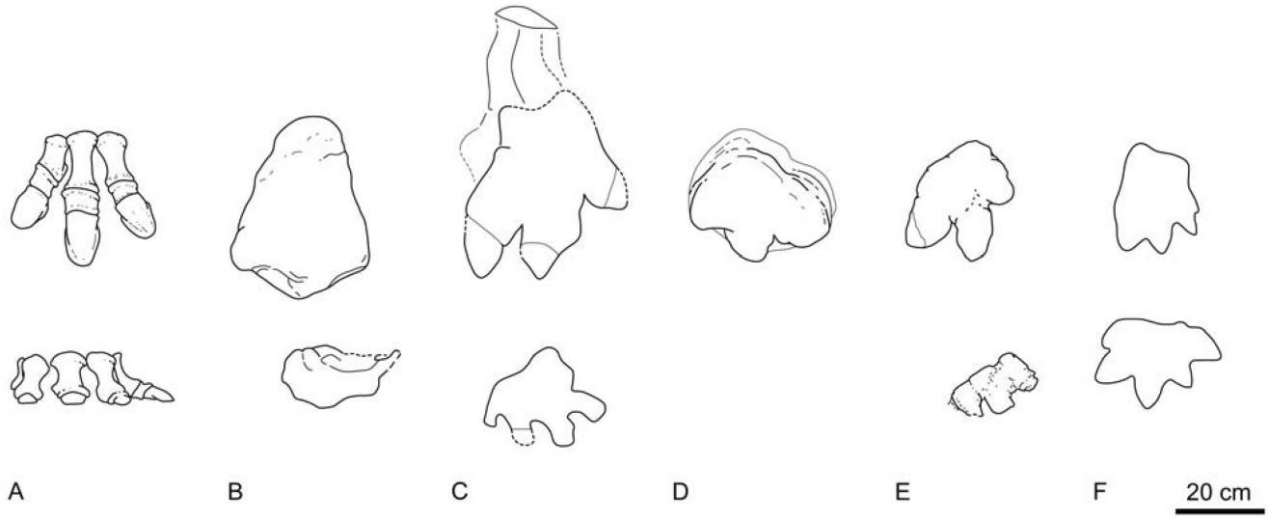

Figure 3. Pedal skeleton of *Stegosaurus* and purported stegosaur tracks, all drawn to same scale. *A*, Pes (*above*) and manual skeleton (*below*) of *Stegosaurus*. The manus has short reduced digits arranged in a crescent shape with only a large inward directed pollex claw; the pes consists of three short broad digits terminating in rounded hooflike unguals (Gilmore 1914). *B*, Drawing from field photographs of holotype of *Deltapodus brodricki*, from the Middle Jurassic of England. A latex mold and plaster cast is stored in the Palaeoecological Collection, Department of Earth Sciences, University of Sheffield (F00768; Whyte and Romano 1994). Compare to figure 2. *C*, Drawing of manus and pes track of *Stegopodus czerkasi* from the Salt Wash Member of the Morrison Formation. Originals are stored in University of Colorado–Museum of Western Colorado joint collection (CU-MWC 195.1 and CU-MWC 195.2), Utah (Lockley and Hunt 1998). *D*, Pes track from the Morrison formation at Como Bluff, Wyoming (Bakker 1996). *E*, Drawing of manus and pes tracks from the Late Jurassic of Poland. Original is stored at the Museum of Material Culture History, Starachowice, Poland (MHKM GG/2; Gierlinski and Sabath 2002). *F*, drawing of manus and pes tracks from the Early Cretaceous Broome Sandstone of Australia (Long 1998).

pes of *Deltapodus* is generally triangular in outline, tridactyl, and mesaxonic, with impressions of short, bluntly rounded digits and a maximum width across the base of the digit impressions (fig. 3*B*). The heel impression is also elongate, making the tracks about twice as long as wide (Whyte and Romano 1994). Recently, Gierlinski and Sabath (forthcoming) suggested that *Deltapodus* tracks were made by other thyreophorean trackmakers than stegosaurs, but based on the tridactyl configuration of the stegosaur foot, compared to the evidently tridactyl shape of well-preserved *Deltapodus* specimens, we follow the notion (Whyte and Romano 2001) that *Deltapodus* is stegosaurian. The morphology of the newly discovered Morrison track is remarkably similar to that of *Deltapodus*. In LACM 7708/154065, the pes is also triangular, mesaxonic, and tridactyl; the digital impressions are short and blunt; and the pedal track is widest at the level of the digits. Likewise, the manus track associated with LACM 7708/154065 is entaxonic, crescent shaped, and approximately twice as wide as long, and it appears to preserve traces of an inwardly directed pollex claw. LACM 7708/154065 can thus be directly placed within the ichnospecies *Deltapodus brodericki* (figs. 2, 3*B*).

Few other tracks have been proposed to be of stegosaurian origin. Lockley and Hunt (1998) erected the name *Stegopodus czerkasi* for the natural cast of a supposed stegosaur manus track and associated pes track found in the Morrison Formation, north of Moab, Utah. *Stegopodus* is characterized by having a tetradactyl manus track only slightly wider than long, with short and blunt but well-defined digits. The associated pes track is tridactyl, with relatively long digits terminating in blunt claw impressions (fig. 3*C*; Lockley and Hunt 1998). *Stegopodus* differs from *Deltapodus* in that the manus track shows four separate digits, is subcircular in outline, and has no impression of a pollex claw, even though the track is entaxonic with a pronounced digit I. The pes track is asymmetric with relatively long digits and is only slightly longer than wide. Bakker (1996) interpreted another

tridactyl pes track from the Morrison Formation at Como Bluff, Wyoming, to be from a stegosaur (fig. 3*D*); however, this track differs significantly from both pes tracks of *Deltapodus* and *Stegopodus* in that it is wider than it is long and has longer, broader digits. The stegosaurian affinities of this track are doubtful, and the track may be better interpreted as a distorted pes track from an ornithopod dinosaur (Lockley and Hunt 1998). A pes track with an associated manus track from the Upper Jurassic of Poland (fig. 3*E*) resembles the track described by Bakker (1996) and is likewise suggested to be of stegosaurian origin (Gierlinski and Sabath 2002). Like the track from the Morrison Formation at Como Bluff, the polish pes track has three relatively long, broad digits. In contrast to the track from Como Bluff, this one is slightly longer than it is wide, 27 cm long and 24 cm wide (Gierlinski and Sabath 2002), but its overall dimensions and shape still fall outside the morphology of *Deltapodus*. Recently, a number of alleged stegosaur tracks including diminutive tracks of putative hatchlings have been discovered in the Upper Jurassic Morrison Formation of Colorado (M. T. Mossbrucker, pers. comm., 2008). However, whether these tracks belong to *Deltapodus* has yet to be determined.

Outside Western Europe and North America, stegosaur tracks have only been described from the Early Cretaceous Broome Sandstone of Australia (Long 1998). These tracks consist of crescent-shaped, five-fingered manus tracks and broad tridactyl pes tracks (fig. 3*F*). The Australian tracks differ from *Deltapodus* in having manus tracks with five short and well-defined digits, and no inward directed pollex claw, and pes tracks that are broader and squarer in outline than those of the latter ichnogenus. Further, the manus track is proportionally much larger than the manus tracks in *Deltapodus* and other purported stegosaur tracks.

Conclusion

LACM 7708/154065 is the only track that indisputably documents the presence of *Deltapodus brodericki* outside Western Europe. This new record greatly extends the geographic range of this ichnospecies and highlights once again the similarity of the Late Jurassic dinosaur faunas of North America and Western Europe (Garcia-Ramos et al. 2006; Mateus 2006; Escaso et al. 2007; Foster 2007; Lockley et al., forthcoming).

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