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First record of *Deltapodus* tracks from the Early Cretaceous of China

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ABSTRACT

Despite being widely distributed in the Middle–Late Jurassic and earliest Cretaceous of Europe and sparsely distributed in the Late Jurassic of North America, the thyreophoran ichnotaxon *Deltapodus* is represented largely by morphologically suboptimal material. In particular, manus tracks are poorly defined in almost all previously reported specimens, likely due to preservational factors. Nonetheless, two ichnospecies, *D. brodericki* and *D. ibericus*, have been erected based on European material. Here we report the first Chinese examples of *Deltapodus* from the Cretaceous of Xinjiang Uyghur Autonomous Region, China. These specimens are also the youngest unambiguous occurrence of this ichnogenus, and the second reported occurrence from Asia. The specimens have well-defined manus traces with readily identifiable traces of digits I and II, enabling their placement in a new ichnospecies: *Deltapodus curriei* ichnosp. nov. Although not unequivocal in all cases, *Deltapodus* is likely of stegosaurian affinity, given the occurrence of stegosaurian body fossils in related deposits in Xinjiang. *Deltapodus* tracks are far more common and widespread than *Stegopodus* or *Apulosauripus*, the only other ichnogenera with tridactyl pes prints that have been attributed to large thyreophorans.

1. Introduction

Stegosaurian thyreophorans were widely distributed in western China: remains have been discovered in Middle Jurassic–Lower Cretaceous strata in Sichuan (Sichuan basin), Xinjiang (Junggar basin), Tibet (Mangkang basin), and Nei Mongol (Ordos basin) (Maidment and Wei, 2006; Dong, 2009). However, despite reports of ostensibly stegosaurian (cf. *Deltapodus*) tracks from near the Jurassic–Cretaceous boundary, Beijing, China (Zhang et al., 2012) and a poorly described, unattributed but *Deltapodus*-like track from the Upper Cretaceous of India (Mohabey, 1986), unequivocal stegosaur tracks have not previously been reported from Asia. This is partly because distinguishing stegosaurian tracks from those of other thyreophorans is not straight forward, as a recent study of thyreophoran tracks from near the Triassic–Jurassic boundary of the Shenmu area demonstrated (Li et al., 2012). In that study, the well-defined, *Moyenosauripus*-like ichnogenus *Shenmuichnus*, based on shallow tracks, appears *Deltapodus*-like when preserved as deep tracks registered in softer substrates. Therefore, based on present knowledge, confidently attributing many presumably thyreophoran ichnogenera—*Deltapodus*, *Stegopodus*, *Apulosauripus*, and *Shenmuichnus*—to any particular well-defined thyreophoran subgroup is difficult.

The Upper layer of Tugulu Group (unit “c”, a lateral equivalent of the Lianmuqin Formation, ?Berriasian –Barremian, Eberth et al., 2001) in the Wuerhe (formerly Wuerho or Urho) District of the Junggar Basin in Xinjiang Uyghur Autonomous Region, China have produced elements of the well-known, Early Cretaceous *Dsungaripterus*–*Psittacosaurus* fauna (Dong, 2001). This fauna is characterized by an abundance of *Psittacosaurus* (Ceratopsia) and dsungaripterid pterodactyloid pterosaurs; the stegosaurian genus *Wuerhosaurus* and several theropods were also recovered from the same unit (Dong, 1973, 1990; Maidment et al.,

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2008). However, the vertebrate fossils assemblage from the Lower Layer of the Tugulu Group is sparse, consisting only of *Dsungaripterus* isp., *Wuerhosaurus* isp. (Dong Z.M., pers. comm.). In 2009, abundant dinosaur and bird tracks were discovered from this unit near the Huangyangquan reservoir (Xing et al., 2011). Herein, we describe tracks that are stegosaurian in origin, discovered during a subsequent expedition to this same locality in the Wuerhe District.

2. Institutional abbreviations

MGCM = Moguicheng Dinosaur and Bizarre Stone Museum, Xinjiang, China; **MNHM** = Morrison Natural History Museum, Morrison, Colorado, USA; **USNM** = United States National Museum, Washington, USA; **ZDM** = Zigong Dinosaur Museum, Sichuan, China.

3. Geological setting

The Huangyanquan track site is located in the Wuerho district, approximately 110 km northeast of downtown Karamay. The fossil track site lies along the shore of Huangyangquan reservoir (46°4′25″N, 85°34′57″E, WGS 84) (Fig. 1). The Huangyangquan track site is in the Lower layer of the Lower Cretaceous Tugulu Group. Along the southern and eastern margins of the Junggar basin, the Tugulu Group can be divided, in ascending order, into the Qingshuihe, Hutubihe, Shengjinkou, and Lianmuqin formations. However, along the northwestern margin of the basin, including the Wuerhe district, the Tugulu Group is difficult to divide into subunits. Presently, it can only be divided as Upper, Grey-green, and Lower layers, for which correlations with the four southern and eastern units are uncertain (Academy of Prospecting and Developing, Xinjiang Bureau of Petroleum, 1977, 1996, 1997), although Eberth et al. (2001) provided a hypothetical basis. The Lower layer may correlate with the better-defined, stratigraphically low Qingshuihe and/or Hutubihe formations in the southern and eastern portions of the basin (Fig. 2). Lower layer sediments, which are grey, sandy mudstones and light green–grey sandstones, were deposited in deltaic, and lakeshore–semi-deep lake environments (Gu et al., 2003).

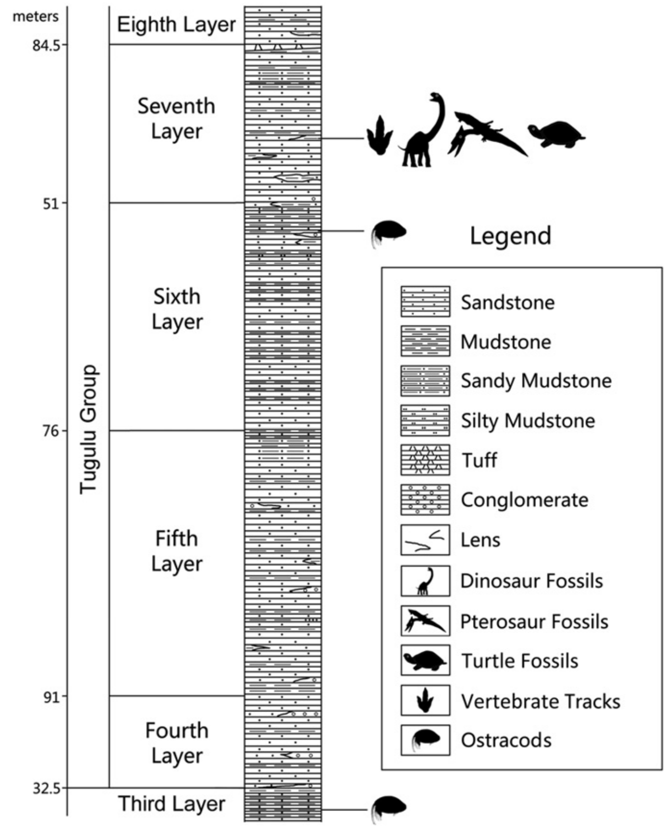

Fig. 2. Stratigraphic section of the Lower layer of the Tugulu Group at the Huangyangquan track site (emended from Qi et al., 1995; Xing et al., 2011).

4. Systematic ichnology

Dinosauria Owen, 1843
Ornithischia Seeley, 1888
Thyreophora Nopcsa, 1915
Deltapodus Whyte and Romano, 1994
Deltapodus curriei ichnosp. nov.

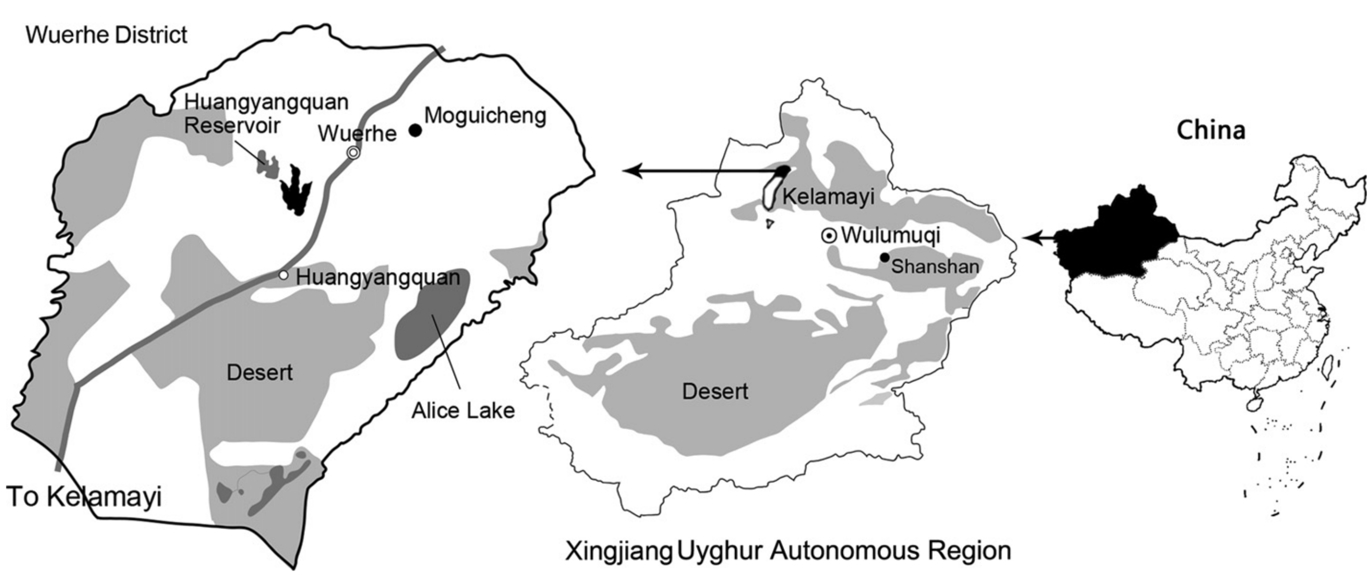

Fig. 1. Map of the Huangyangquan track locality (track icon), Wuerhe District, Xinjiang Uyghur Autonomous Region, China.

Etymology: The specific name is in honour of Dr. Philip J. Currie, a distinguished palaeontologist who contributed greatly to the study of dinosaurs, and the Sino-Canadian Dinosaur Project.

Holotype: A complete manus–pes set of natural-mold tracks, catalogued as MGCM.SA2m and SA2p from the Huangyangquan track site ("m" and "p" appended to the ends of specimen numbers indicate manus and pes, respectively) (Figs. 3 and 4, Table 1). The original specimens remain in the field.

Paratypes: Specimens, MGCM.SA1m and SA1p, SA3m and SA3p, and SA4m and SA4p comprise three manus–pes sets of natural-mold tracks in the same trackway as the holotype (Figs. 3 and 4, Table 1). As with the holotype, these specimens remain in the field.

Referred specimens: Additional specimens include: MGCM.SZ1–SZ17 and SZ20–22–21, manus–pes impression sets reposited at the Moguicheng Dinosaur and Bizarre Stone Museum, Xinjiang, China; MGCM.SB1–2 and MGCM SZ18–19, six manus–pes sets at the Huangyangquan track site; ZDM201103, a pes impression is reposited at the Zigong Dinosaur Museum, Sichuan, China (Figs. 5 and 6, Table 1).

Locality and horizon: Lower layer of Tugulu Group (Qingshuihe–Hutubihe formation equivalent?), Lower Cretaceous. Huangyangquan track site, Wuerhe, Xinjiang Uyghur Autonomous Region, China.

Diagnosis: The manus track is entaxonic and oval-shaped, although somewhat irregular. The manus is approximately twice as wide as long. The impression of manual digit I is distinct and robust. The medial metacarpophalangeal pad region is slightly concave, while the lateral region is slightly convex. The length of the pes track slightly exceeds its width by 35%. The pes tracks have three functional digits (II–IV) that are distinct but short, bluntly rounded impressions. These digit impressions are subequal in length and display a higher degree of entaxony than other species of *Deltapodus*. The heel region is elongate and has smoothly curved margins; the divarication between digits II and III appears slightly greater than that between digits III and IV, but this is difficult to measure accurately in tracks with such short, blunt toe traces. The trackway (both manus and pes) exhibits slight outward rotation.

Description

The material of *D. curriei* comprises a number of manus and pes natural casts in two trackways. The average length:width ratios of the manus and pes impressions in MGCM.SA1–4 are 0.55 (range 0.5–0.6) and 1.55 (range 1.4–1.8), respectively.

The holotype and best preserved specimens, MGCM.SA2m and SA2p (Figs. 3 and 4), are determined to be right prints due to their position in the trackway (Fig. 3) relative to the other trackway prints. Two distinct, blunt projections from the medial side of the manus impression likely are delineations of digits I and II. Digit I is the strongest and deepest; digits I and II have weak, hoof-like ungual impressions. The proximal metacarpophalangeal pad region is slightly concave and similar in depth to digit I.

The pes impression is also well-preserved, with three functional digits. The length of the pes exceeds its width by 35%. Digits II–IV exhibit distinct, short, rounded impressions; digit II is the most robust and deepest and digit III is broader than digit IV. Digit III is only slightly longer than digits II and IV in length. The heel region is elongate, and has smoothly curved margins.

In trackway MGCM.SA, the manus impressions are rotated 21°–29° *outward* from the trackway midline, a somewhat greater

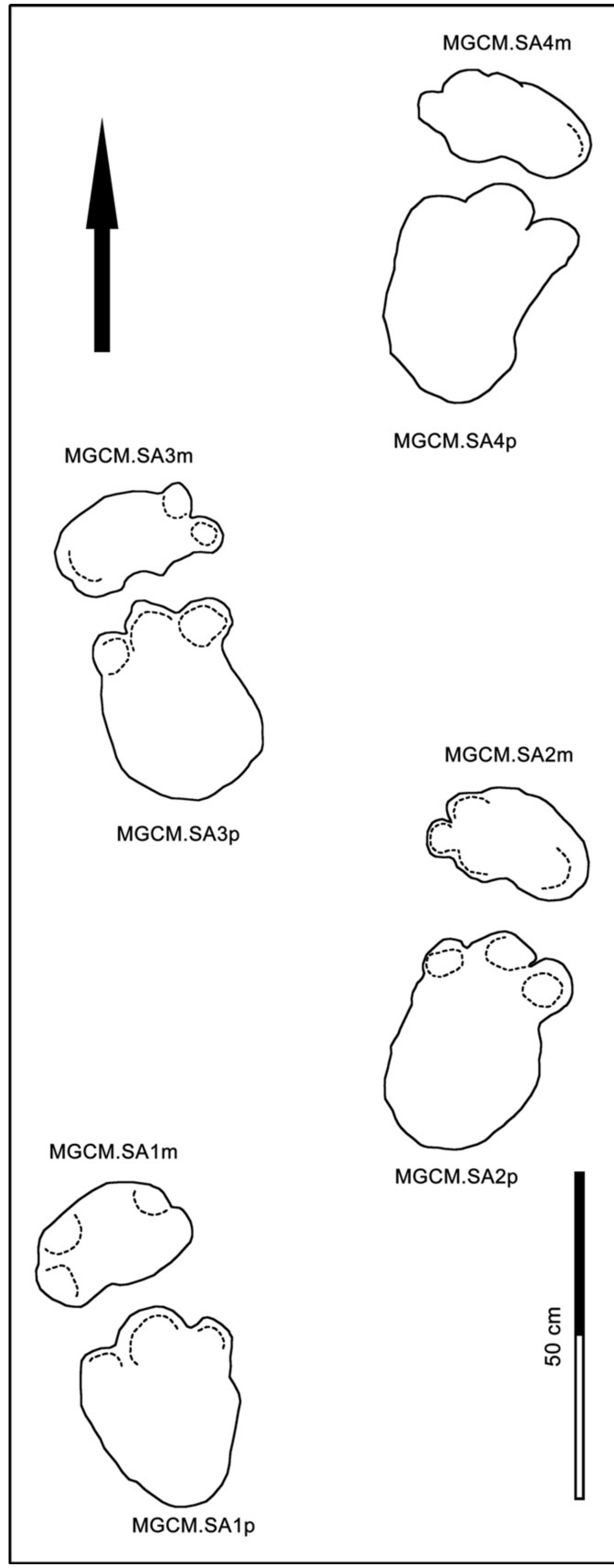

Fig. 3. Schematic diagram of *Deltapodus* trackway MGCM.SA from the Huangyangquan track site (m = manus; p = pes).

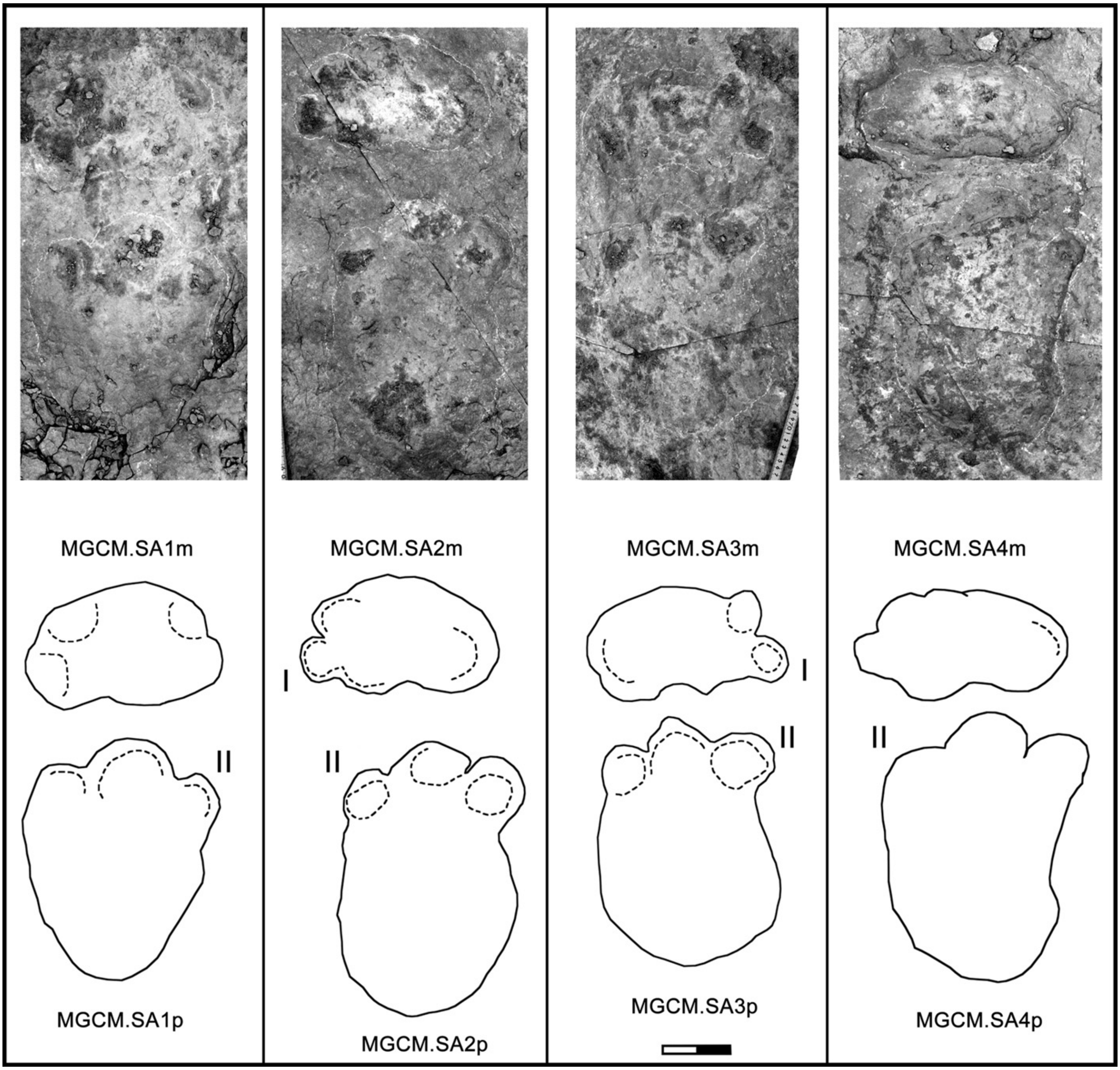

Fig. 4. Photographs and outline drawings of *Deltapodus* tracks MGCM.SA1m and SA1p to SA4m and SA4p from the Huangyangquan track site. Scale bar = 10 cm.

rotation than that of the pes impressions (17°–24°). The centres of the pes impressions are somewhat closer to the trackway midline than the centres of the manus impressions. The average pace angulation of the trackway is 88°. The average distance between each manus–pes pair is 5.3 cm (range 4.3–7.3 cm). The width between pes impressions ranges from 24–26.9 cm, making trackway MGCM.SA a wide-gauge trackway, similar to those of *Deltapodus* and *Apulosauripus*.

The referred specimens MGCM.SZ10p and SZ20m are natural casts (Fig. 5). SZ20m preserves at least eight tubercle slide marks along the anteromedial margin. The longest slide mark is 2.9 cm, and the spacings between the lines ranges from 32–100 mm. Invertebrate traces are preserved within the borders of the tracks in both specimens. Smaller traces are predominantly *Cochlichnus* and *Helminthoidichnites*, whereas the larger traces pertain to as of yet undetermined ichnotaxa (Xing et al., 2011).

MGCM.SZ18p consists of tridactyl footprints bearing exhibiting only rounded digit impressions. The distribution of these three digits is similar to other pes impressions from the same track site. The preservation of three pedal digits rather than the entire pes may be a preservational factor: these tridactyl prints may be undertracks, as the distal ends of the digits in the other specimens are generally more deeply impressed than the rest of the print. Tracks similar to MGCM.SZ18p were also discovered at the Early Cretaceous Yongjing track site in Gansu, China. These tracks were interpreted as having been produced by a swimming ornithopod (Fujita et al., 2012).

Comparisons and discussion

Presently, the global distribution of tracks attributed to stegosaurians includes Africa, Europe, North America, and Australia (Milàn

Table 1
Measured data (in cm) of the *Deltapodus* tracks from Huangyangquan track site, Wuerhe.

MGCM.	R/L	M/C	ML	MW	II–III	III–IV	II–IV	SL	PL	PA	L/W
SA1m	L	M	18.0	28.7	–	–	–	–	–	–	0.6
SA1p	L	M	35.2	24.8	23°	22°	45°	110.5	81	88°	1.4
SA2m	R	M	16.9	28.3	–	–	–	–	–	–	0.6
SA2p	R	M	40.1	22.9	20°	17°	37°	112	78.5	88°	1.8
SA3m	L	M	15.9	27.5	–	–	–	–	–	–	0.6
SA3p	L	M	36.8	24.0	23°	16°	39°	–	83	–	1.5
SA4m	R	M	15.6	29.9	–	–	–	–	–	–	0.5
SA4p	R	M	39.1	26.9	23°	20°	43°	–	–	–	1.5
SB1p	L	M	31.6	20.7	21°	21°	42°	–	–	–	1.5
SB2m	R	M	12.3	20.7	–	–	–	–	–	–	0.6
SB2p	R	M	31.5	19.6	21°	20°	41°	–	–	–	1.6
ZDM201103[b]	R	C	32.1	18.8	19°	16°	35°	–	–	–	1.7
SZ1p	R	C	33.3	18.1	18°	17°	35°	–	–	–	1.8
SZ2p	L	C	34.6	25.0	24°	22°	46°	–	–	–	1.4
SZ3p	R	C	32.9	22.2	23°	17°	40°	–	–	–	1.5
SZ4p	R	C	35.1	23.8	23°	21°	44°	–	–	–	1.5
SZ5p	L	C	27.0	17.4	22°	19°	41°	–	–	–	1.6
SZ6p	R	C	30.6	18.4	22°	16°	38°	–	–	–	1.7
SZ7p	L	C	28.8	17.4	21°	18°	39°	–	–	–	1.7
SZ8p	–	C	>25.9	20.6	–	–	–	–	–	–	–
SZ9p	R	C	30.8	19.4	21°	19°	40°	–	–	–	1.6
SZ10p	R	C	35.6	22.2	20°	18°	38°	–	–	–	1.6
SZ11p	L	C	33.8	19.1	21°	17°	38°	–	–	–	1.8
SZ12p	L	C	29.9	21.2	22°	21°	43°	–	–	–	1.4
SZ13p	–	C	>25.7	21.4	–	–	–	–	–	–	–
SZ14p	R	M	33.9	22.9	25°	20°	45°	–	–	–	1.5
SZ15p	R	C	36.2	24.2	22°	21°	43°	–	–	–	1.5
SZ16p	L	C	35.0	19.9	25°	17°	42°	–	–	–	1.8
SZ17p	L	C	30.8	19.6	18°	14°	32°	–	–	–	1.6
SZ18p	–	M	–	19.3	–	–	–	–	–	–	–
SZ19m	L	M	13.5	27.0	–	–	–	–	–	–	0.5
SZ19p	L	M	31.0	18.8	19°	17°	36°	–	–	–	1.6
SZ20m	R	C	14.6	21.4	–	–	–	–	–	–	0.7
SZ21m	L	C	18.3	25.5	–	–	–	–	–	–	0.7
SZ22m	R	M	10.8	20.3	–	–	–	–	–	–	0.5

Abbreviations: R/L: Right/Left; M/C: Mold/Cast; ML: maximum length; MW: maximum width[a]; PA: Pace angulation; PL: Pace length; SL: Stride length; II–III: angle between digits II and III; III–IV: angle between digits III and IV; II–IV: angle between digits II and IV; L/W: Maximum length/Maximum width.

[a] Dinosaur tracks measured as distance between the tips of digits II and IV.

[b] ZDM specimen belongs to Zigong Dinosaur Museum.

and Chiappe, 2009). These tracks mostly pertain to *Deltapodus* and *Stegopodus*, but also include several unattributed specimens (Fig. 7).

Deltapodus brodricki was originally described from the Middle Jurassic of Yorkshire, England (Whyte and Romano, 1994). The ichnospecies was successively attributed to sauropod (Whyte and Romano, 1994), ankylosaurian or stegosaurian (Lockley and Meyer, 2000), ankylosaurian (Gierliński and Sabath, 2008), and stegosaurian (Whyte and Romano, 2001) track makers. Subsequently, this ichnotaxon was discovered elsewhere in Europe: the Middle Jurassic of the Yorkshire coast, England (Whyte et al., 2007), the Late Jurassic of Asturias, Spain (Garcia-Ramos et al., 2006; Lockley et al., 2008) the Late Jurassic of Lourinhã, Portugal (Mateus and Milàn, 2008), and the Tithonian–Berriasian of Teruel, Spain (Cobos et al., 2010). This suggests that the track makers were abundant in western Europe during the Middle–Late Jurassic and into the earliest Cretaceous. Outside Europe, discoveries include specimens from the Late Jurassic of Utah (Milàn and Chiappe, 2009; Gierliński et al., 2010), the Late Jurassic of Iouaridène, Morocco (Belvedere and Mietto, 2010) and the Jurassic–Cretaceous boundary of China (Zhang et al., 2012). An unnamed but clearly *Deltapodus*-like footprint was also reported from an Upper Cretaceous intratrappean limestone of the Lameta Formation in the Kheda district of India (Mohabey, 1986). Most of the authors that described these other tracks agreed that *Deltapodus* tracks pertain to a stegosaurian track maker (Li et al., 2012). This conclusion was strengthened by Cobos et al. (2010), who demonstrated a close relationship between the distribution of stegosaur (*Dacentrurus*) body fossils and tracks assigned to *Deltapodus ibericus*.

Although *Deltapodus* has been widely accepted as a distinct and relatively widespread ichnogenus, details of its morphology are still poorly known. In particular, the manus of the type (*D. brodericki*), as well as many morphotypes subsequently discovered and illustrated, is poorly known, appearing typically only as a crescentic or kidney-shaped trace that lacks clear digit traces. Li et al. (2012) demonstrated that the tracks (*Shenmuichnus*) of an early Mesozoic (probably Late Triassic–Early Jurassic), quadrupedal ornithischian (?thyreophoran) appear as well-defined, tridactyl pes prints and pentadacyl manus prints when shallow and well-preserved, but may, in contrast, be more *Deltapodus*-like when the prints are deeply impressed and the individual digits are poorly defined.

The relative lengths of the pedal digit traces vary considerably among the four ichnogenera with tridactyl pes prints attributed to large Mesozoic thyreophorans (*Deltapodus*, *Stegopodus*, *Apulosauripus*, and *Shenmuichnus*). As shown by Li et al. (2012), the pes of the *Shenmuichnus* track maker was mesaxonic. The same is true of the pes described in association with the manus originally designated as the *Stegopodus* holotype (Lockley and Hunt, 1998; Gierliński and Sabath, 2008). However, typical *Deltapodus* pedal digit traces display an ectaxonic increase in length from II–IV. As noted above, this configuration is seen in some, but not all, of the Xinjiang specimens, and in the manus–pes set from the Morrison Formation of Colorado (MNHM 1010.1–2: Mossbrucker et al., 2008). We note that, in the large sample of *Deltapodus* tracks from the Jurassic of Asturias, this asymmetry is noticeable, but not highly pronounced. As a result, distinguishing left and right footprint casts, or

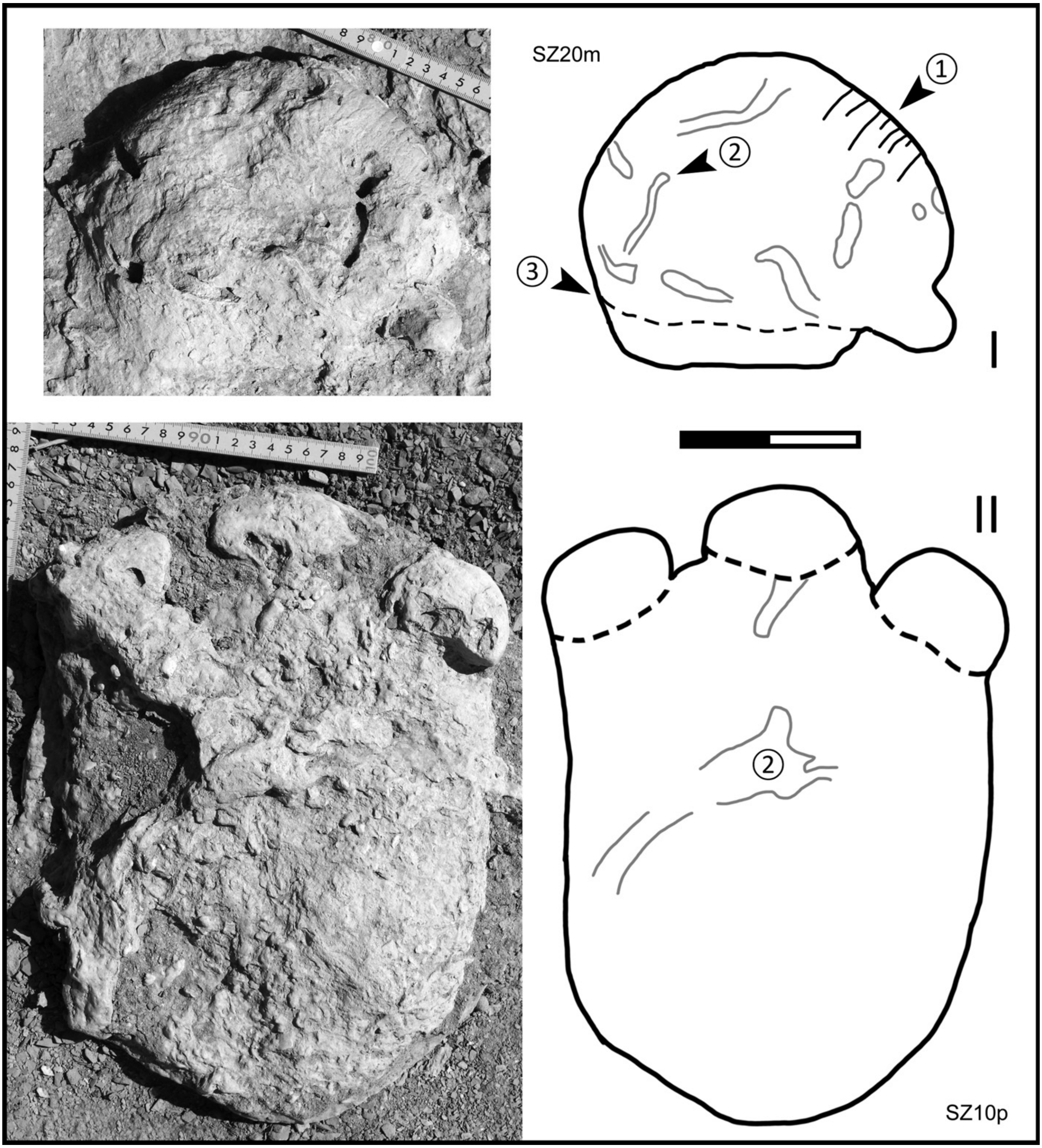

Fig. 5. Photographs and outline drawings of *Deltapodus* tracks MGCM.SZ10p and SZ20m from the Huangyangquan track site showing small-scale features (numbered). (1) = scale scratch lines along the anteromedial side; (2) = invertebrate traces; (3) = elongate metacarpophalangeal region. Scale bar = 10 cm.

differentiating traces of digit II from digit IV consistently, especially in isolated casts (e.g. Lockley et al., 2008, Fig. 11), is difficult. Nevertheless, the evidence that *Deltapodus* tracks were made by an ectaxonic track maker with a somewhat reduced digit II is interesting in light of the entaxonic nature of the foot of *Stegosaurus* as shown by Gierliński and Sabath (2008), who raised legitimate questions about the *Deltapodus* track maker.

The well-defined traces of manual digits I and II differentiates *D. curriei* from *D. brodericki* (Whyte and Romano, 1994), which has a crescentic manus impression that lacks clear digit traces (Whyte and Romano, 1994; Lockley et al., 1994; Whyte and Romano, 2001; Gierliński and Sabath, 2002, 2008; Lockley et al., 2008; Lockley, 2009; Milàn and Chiappe, 2009; Belvedere and Mietto, 2010; Cobos et al., 2010). The well-defined traces of manual digits I and II

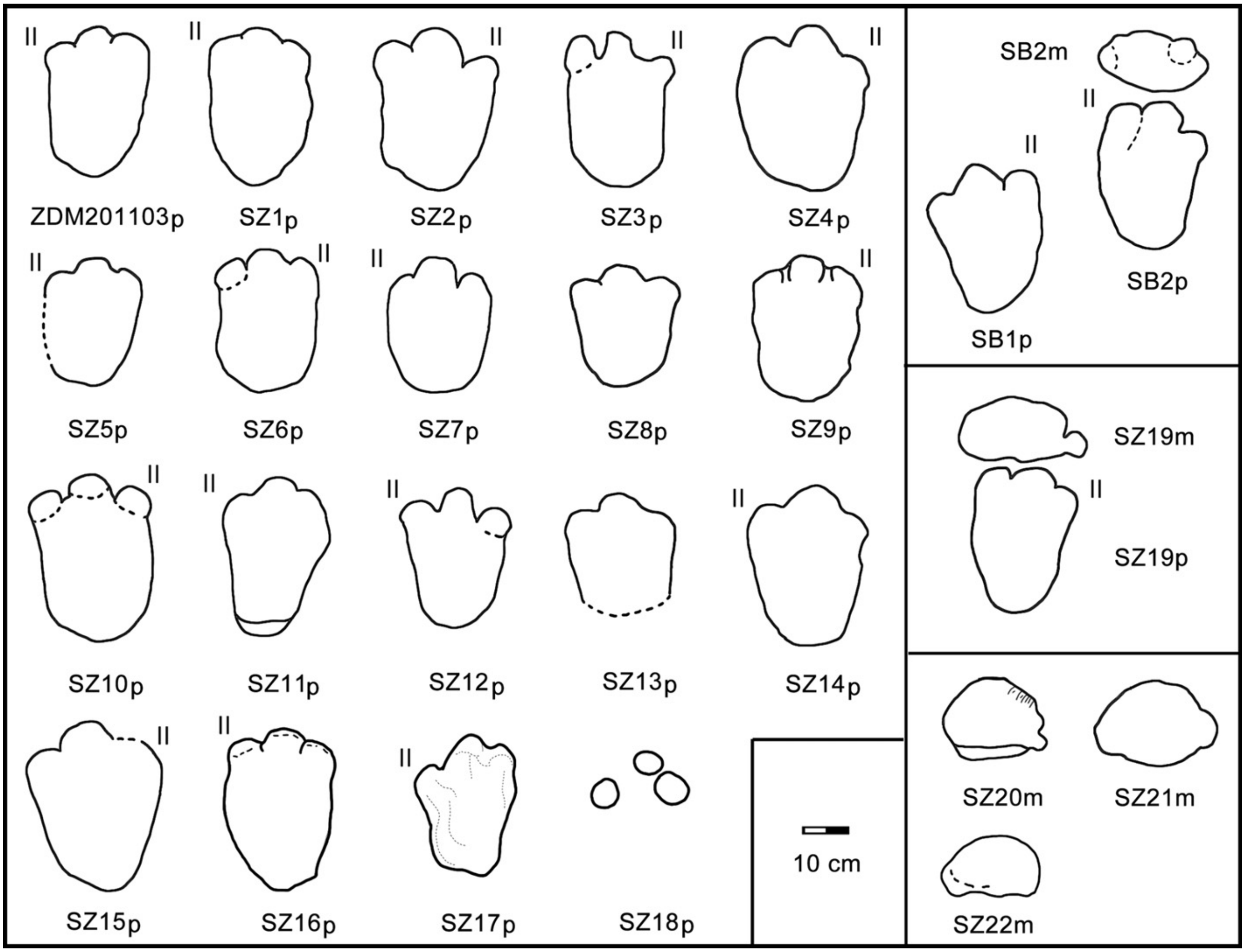

Fig. 6. Outline drawings of *Deltapodus* tracks from the Huangyangquan track site (m = manus; p = pes). Scale bar = 10 cm.

also distinguish the Chinese material from *D. ibericus* described by Cobos et al. (2010). Furthermore, Mateus et al. (2011) described 11 *Deltapodus* tracks from the Late Jurassic of Portugal that are similar in morphology to the Huangyangquan tracks, two of the manus natural casts are semi-lunate in shape, but despite being deeply impressed, they likewise lack free digit impressions. MGCM.SA2m and SA2p also differ from the cf. *Deltapodus* tracks from the uppermost Jurassic Tuchengzi Formation at the Qianjiadian track site in Beijing, China (Zhang et al., 2012) because the outward rotation of the manus is much greater in the latter. The distinctive digit traces in the manus prints of the Huangyangquan specimens justify placing them in a new ichnospecies of *Deltapodus*.

The crescentic manus impression, slightly concave proximal metacarpophalangeal region of the manus, wide and rounded pedal digits, and an elongate posterior region of the pes distinguishes MGCM.SA2m and SA2p from *Stegopodus* (Lockley and Hunt, 1998; Gierliński and Sabath, 2002, 2008). *Stegopodus* tracks have subtriangular manus impressions in which the apex of the triangle forms the posterior end. In addition, *Stegopodus* pes impressions have more strongly tapering toes and lack elongate heel pads (Lockley and Hunt, 1998; Gierliński and Sabath, 2008).

Large manus impressions with discreet digit traces led Gierliński and Sabath (2008) to reconsider *Apulosauripus* as having a probable thyreophoran affinity, rather than the ornithopod affinity originally assigned to it because of its blunt-toed, tridactyl pes (Nicosia et al., 1999). MGCM.SA2m and SA2p are similar to *Apulosauripus* in having a functionally tridactyl pes, a clearly wide-gauge trackway in which the pace angulation of the pes varies from 88° to 120° (Nicosia et al., 1999; Gierliński and Sabath, 2008), but the Chinese material differs by possessing a more elongate heel impression on the pes, and a prominent extension of the manual digit I. However, the Huangyangquan material is similar in the pace angulation of the pes (88° in MGCM.SA2p). Gierliński and Sabath (2008) compared *Apulosauripus* and cf. *Apulosauripus* manus–pes sets from the 'middle' Cretaceous Dakota Group from the Skyline Drive track site in Colorado, USA (Kurtz et al., 2001), which are wide gauge but exhibit only slight outward rotation. However, according to Kurtz et al. (2001), the majorities of the pes tracks are tetradactyl and resemble *Tetrapodosaurus*. This raises the question of whether *Apulosauripus* tracks are poorly preserved and unsuitable as a basis for comparison.

MHKM GG/2, a possibly stegosaurian track from the Late Jurassic of Poland (Gierliński and Sabath, 2002) lacks elongate heel impressions. Unnamed tracks from the Lower Cretaceous Broome Sandstone of Australia (Long, 1998) have elongate heel impressions, but their associated manus impressions possess much more elongate digit impressions than in MGCM.SA2m. However, McCrea et al. (2001, 2011) interpret the Broome Sandstone prints as incompletely preserved tetradactyl pes tracks and documented other tetradactyl pes prints associated with pentadactyl manus prints from the

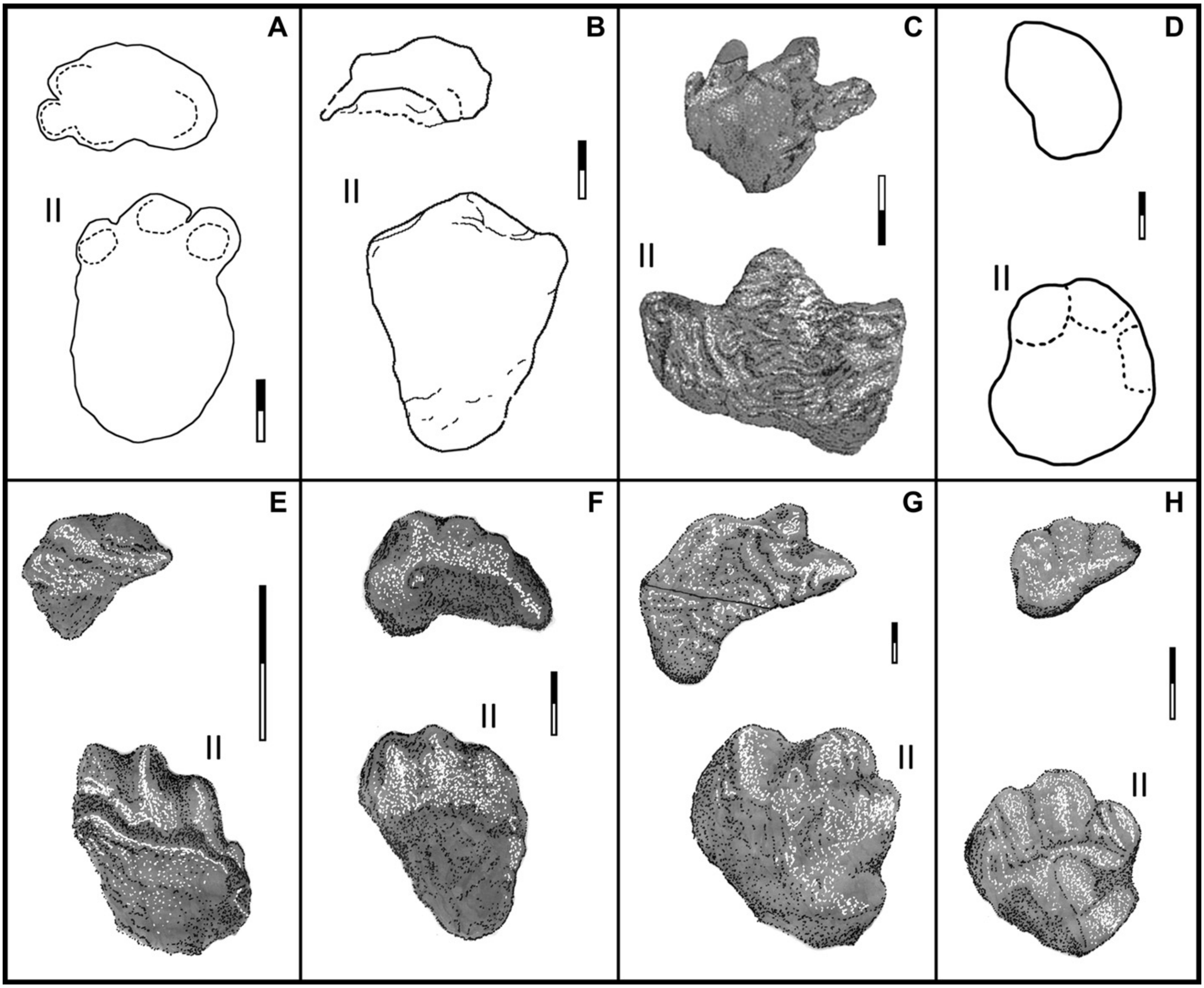

Fig. 7. Comparison between *Deltapodus* and morphologically similar tracks. (A) Huangyangquan *Deltapodus* tracks. (B) *Deltapodus brodricki* (from Whyte and Romano, 1994). (C) *Stegopodus czerkasi*. (D) cf. *Deltapodus* from Beijing, China (from Zhang et al., 2012). (E) *Navahopus falcipollex*. (F) *Deltapodus* isp. (G) cf. *Apulosauripus* isp. (H) *Apulosauripus federicianus*. C, E–H from Gierliński and Sabath (2008). Scale bar = 10 cm.

Broome Sandstone that may be referable to *Tetrapodosaurus* isp. Their observations cast doubt on a stegosaurian interpretation of the Broome tracks.

MGCM.SA2m and SA2p also differ from the *Navahopus falcipollex* from the Navajo Formation (Lower Jurassic) of Kaibito Plateau in Arizona, USA (Baird, 1980), because the outward rotation of the manus is much greater in the latter. Digit impressions I and II of MGCM.SA2m are somewhat similar to those of *Tetrapodosaurus*, but the pes of *Tetrapodosaurus* is tetradactyl. However, *Tetrapodosaurus* pes tracks may appear tridactyl in one part of the trackway and tetradactyl in another part due to variation in substrate consistency (Sternberg, 1932; McCrea and Currie, 1998; McCrea, 2000; Lockley et al., 2006).

5. Stegosauria from Wuerhe district

Mesozoic strata from the Junggar Basin in Xinjiang have produced several thyreophoran taxa: the ankylosaurian *Tianchisaurus* from the Middle Jurassic Toutunhe Formation (Dong, 1993), the stegosaurian *Wuerhosaurus* from the Lower Cretaceous Tugulu Group (Dong, 1973, 1990; reported as the Lianmuqin Formation specifically by Maidment et al., 2008), the stegosaurian *Jiangjunosaurus* from the Upper Jurassic Shishuhgou Formation (Jia et al., 2007), and an unnamed/unattributed stegosaur from the Middle Jurassic Qigu Formation (Wings et al., 2007). No ankylosaurians have been discovered at the Wuerhe district to date.

Wuerhosaurus homheni is the only stegosaur from Wuerhe district and, moreover, the only known thyreophoran from the Tugulu Group in which the tracks reported herein were discovered, albeit from younger strata. This taxon was referred to *Stegosaurus homheni* by Maidment et al. (2008), a genus thought to have gone extinct by the end of the Late Jurassic. No forelimb material was preserved for *S. homheni*, but comparisons can be made to the vertically oriented (standing position), right manual skeleton of *S. sulcatus* (USNM 4937; Senter, 2010, pers. comm.) from the Late Jurassic of Wyoming, USA (Fig. 8). Morphologically, the articulated manus, and in particular digits I and II, of USNM 4937 corresponds well with f MGCM.SA2m. While the entaxonic nature of the manus seems uncontroversial in presumed thyreophoran tracks, the case is not as straight forward in the pes. For example, Gierliński and

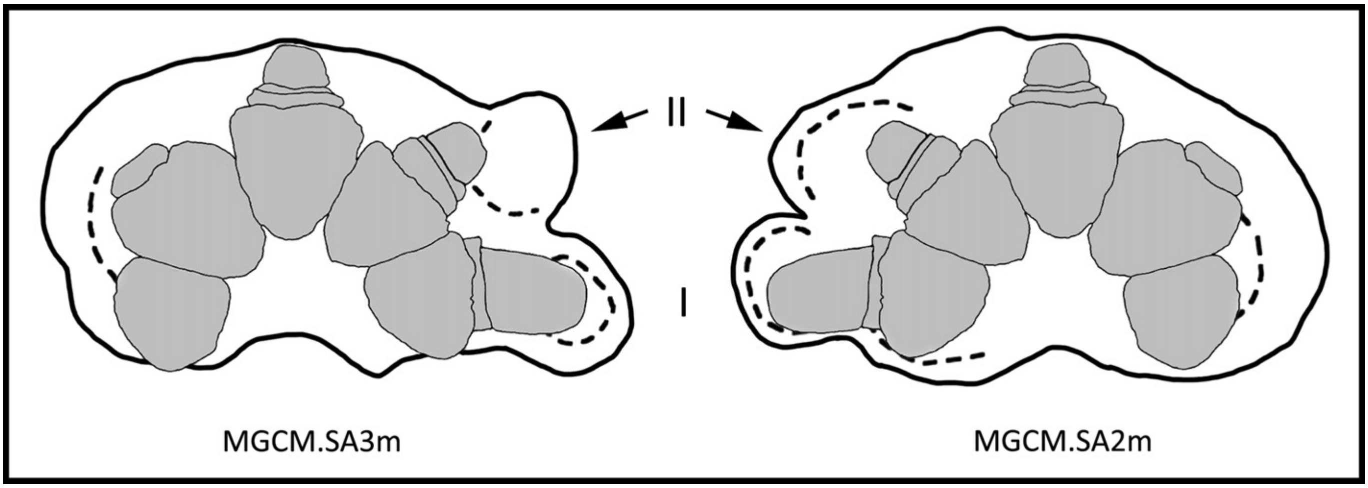

Fig. 8. *Stegosaurus sulcatus* (USNM 4937) manual skeleton in proximal view (based on Senter, 2010) superimposed over schematic diagrams of Huangyangquan track site *Deltapodus* tracks.

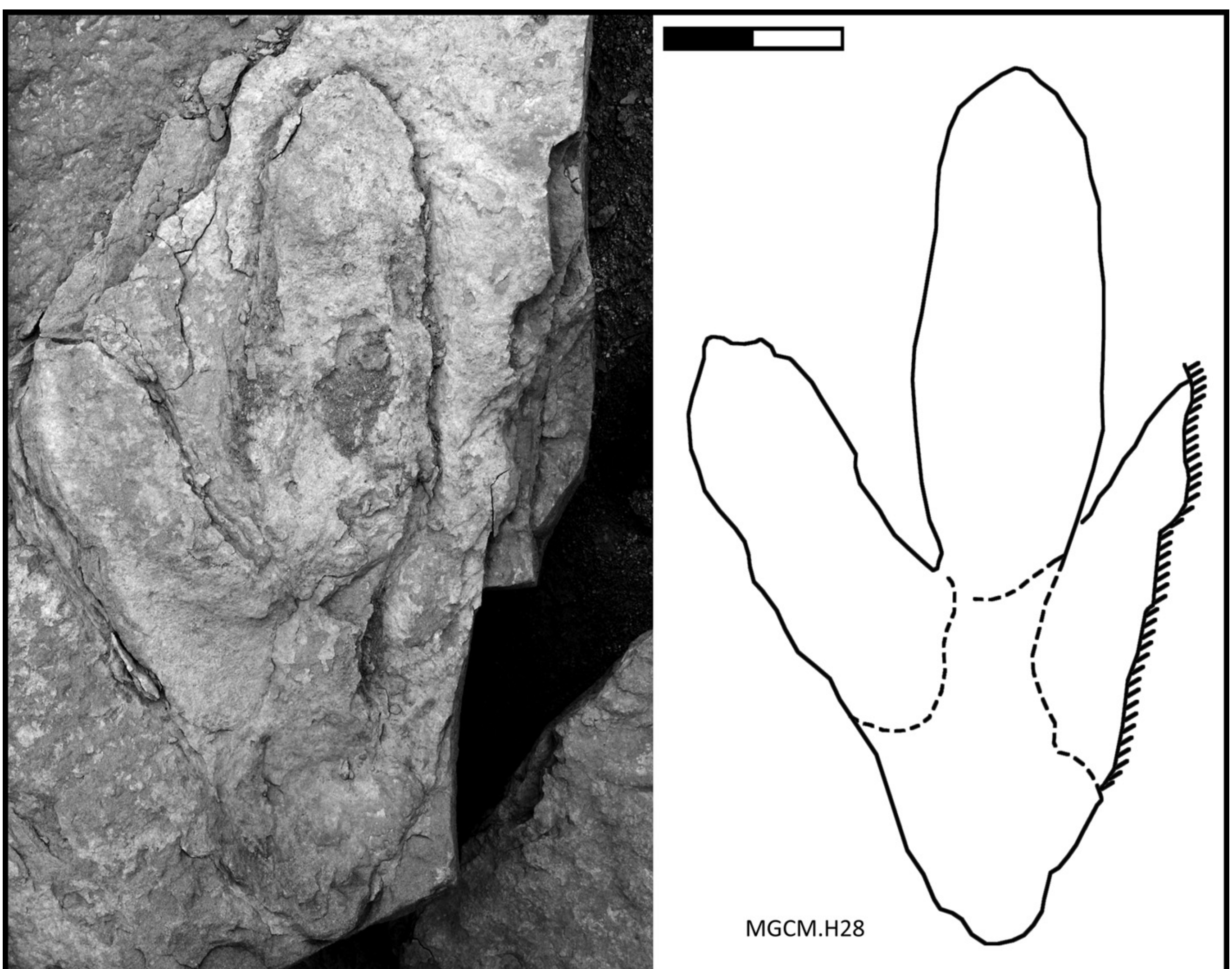

Fig. 9. Photograph and line drawing of new, large theropod track (MGCM.H28) from the Huangyangquan track site. Scale bar = 10 cm.

Sabath (2008, fig. 5) superimposed the pedal skeleton of *Stegosaurus* over a specimen of *Stegopodus czerkasi* (CEUM 20571) to show that the pes of *Stegosaurus* had the potential to leave a slightly entaxonic pes print with short, bluntly rounded digits impressions, as in MGCM.SA2p. Despite the ambiguities, the results demonstrate that MGCM.SA2m could have been produced by a stegosaurian track maker.

Most purported stegosaurian tracks have been found in Middle to Upper Jurassic deposits, and primarily in the latter. Only a few debatably stegosaurian tracks have been reported from the Early Cretaceous (the Broome Sandstone of Australia: Long, 1998; McCrea et al., 2011; Lockley et al., 2012). *Deltapodus curriei* is the first well-supported, Early Cretaceous record of stegosaurian ichnites, and the assemblage described here adds considerably to the sample of thyreophoran tracks from the Mesozoic of Asia.

During the 2010 field season, we discovered limb bone material that may pertain to *Wuerhosaurus* isp. (Dong Z.M., pers. comm.) or another stegosaurian, from the same strata that preserve the track site, and only 4 km away. Although there is no evidence to suggest that the track maker of *Deltapodus curriei* is *Wuerhosaurus* isp., this possible relationship can be tested via this future discovery.

6. New theropod tracks from Huangyangquan track site

In addition to the thyreophoran track sample described here, a single, large theropod track (MGCM.H28; Fig. 9) was also discovered. The track is a sub-symmetrical natural cast of a possible right footprint; the side cannot be determined with certainly because one of the lateral digit traces, likely that of digit II, is broken. The track is ~48 cm long and, based on a half width of 18 cm, approximately 36 cm wide. The sides of the two complete digit casts are parallel-sided, with only vague digital pad impressions and slight tapering at the distal ends. The heel is very narrow. Previously, the largest theropod track from the Huangyangquan track site (MGCM.H6) was ~30.4 cm long and 18.9 cm wide (Xing et al., 2011). The MGCM.H28 track maker pertains to a medium-sized theropod, and adds more data to the ichnofaunal composition of the Huangyangquan track site.

7. Conclusions

Over the last decade, the ichnogenus *Deltapodus* has been reported from many areas in Europe and a few sites in North America, Africa, and Asia. In all cases, these reports have inferred ankylosaurian or, more often, stegosaurian track makers However, until now, no unequivocal *Deltapodus* tracks of Cretaceous age have been reported, though possible occurrences include an unattributed specimen from the Late Cretaceous of India (Mohabey, 1986) and somewhat ambiguous specimens from a Jurassic–Cretaceous boundary sequence near Beijing (Zhang et al., 2012). Thus the occurrences from Xinjiang, described herein, are the most significant reports of thyreophoran ichnites from the Cretaceous of China. The morphology of the Huangyangquan tracks suggests they were made by stegosaurian track makers, an interpretation corroborated by the available skeletal record.

The new Chinese tracks imply that *Deltapodus* track makers were widespread both geographically and temporally. *Deltapodus* presently appears far more common than *Stegopodus*. However, the inference that both *Deltapodus* and *Stegopodus* represent stegosaurian track makers remains tentative. Until now, most reports of *Deltapodus* have been based on material with poorly preserved manus impressions, a problem that the Huangyangquan sample goes some way towards changing. However, the relative lengths of the pedal digit traces are not entirely consistent with known stegosaurian pedal morphology. In contrast, the *Stegopodus* holotype is a well-preserved manus; associated pes tracks do not comprise part of the type material. Nevertheless, Gierliński and Sabath (2008) pointed out reason to infer that stegosaur pes track morphology is potentially diagnostic and different from those of other thyreophoran tracks. Only by understanding the morphologies and variations in larger samples of thyreophoran tracks, such as the Huangyangquan assemblage, in relation to thyreophoran foot morphologies can a basis be established with confidence for using tracks to distinguish thyreophoran clades, such as stegosaurs and ankylosaurs.

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