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A diversified vertebrate ichnite fauna from the Feitianshan Formation (Lower Cretaceous) of southwestern Sichuan, China

Lida Xing [a,*], Martin G. Lockley [b], Geng Yang [c], Jun Cao [c], Richard T. McCrea [d], Hendrik Klein [e], Jianping Zhang [a], W. Scott Persons IV [f], Hui Dai [g]

[a] School of the Earth Sciences and Resources, China University of Geosciences, Beijing 100083, China
[b] Dinosaur Tracks Museum, University of Colorado Denver, PO Box 173364, Denver CO 80217, USA
[c] Regional Geological Survey Team, Sichuan Bureau of Geological Exploration and Development of Mineral Resources, Chengdu, China
[d] Peace Region Palaeontology Research Centre, Box 1540, Tumbler Ridge, British Columbia V0C 2W0, Canada
[e] Saurierwelt Paläontologisches Museum, Alte Richt 7, D-92318 Neumarkt, Germany
[f] Department of Biological Sciences, University of Alberta 11455 Saskatchewan Drive, Edmonton, Alberta T6G 2E9, Canada
[g] No.208 Hydrogeological and Engineering Geological Team, Chongqing Bureau of Geological and Mineral Resource Exploration and Development, Chongqing 400700, China

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A B S T R A C T

The Bajiu tracksite exposed on a fine sandstone surface at the top of the Feitianshan Formation, close the contact with the overlying Xiaoba Formation, reveals a saurischian dominated ichnofauna consisting of four sauropod and at least eight theropod trackways. The sauropod trackways display a medium-wide gauge pattern characteristic of titanosauriforms, while the theropod trackways can be subdivided into two distinct morphotypes. One is similar to the ichnogenera *Eubrontes* and *Megalosauripus*, the other (cf. *Dromaeopodus*) appears to represent a functionally didactyl dromaeosaur where pedal digit II is represented only by an oval basal pad. A single swim track is possibly attributable to a turtle or crocodylian. Such sauropod-theropod dominated ichnofaunas are consistently typical of the red-bed tracksites in the region and useful for characterizing a fauna that is otherwise poorly known from body fossils. The stratigraphic position and late occurrence of the (typical Jurassic) *Eubrontes-Megalosauripus* morphotype is well known from other Cretaceous localities in China and seems to reflect a peculiarity in the theropod faunas of East Asia.

1. Introduction

The southwestern area of Sichuan Province, which consists of the Liangshan autonomous prefecture and Panzhihua City, is commonly known as the Panxi (Panzhihua–Xichang) region. Aside from the Sichuan Basin, the Panxi region contains the most extensive Jurassic and Cretaceous deposits in Sichuan Province. Nevertheless, until recently, the Panxi region has yielded an impoverished paleobiological record (Wang, Liang, Kan, & Li, 2008). Wang (1988) reported skeletal remains of prosauropods from the Lower Jurassic Yimen Formation, and Li, Yang, Liu, and Wang (2010) described the mamenchisaurid sauropod dinosaur *Tonganosaurus* from the Yimen Formation of Huili County. In Xing, Lockley, Li et al. (2013) described *Kayentapus*-like footprints from the Middle Jurassic Xincun Formation at the Shansong tracksite in Huidong County. Also the Lower Cretaceous Feitianshan Formation of Zhaojue County has yielded a sauropod trackway from the Jiefanggou tracksite (Xing, Lockley, Yang et al., 2015), as well as recently-reported theropod, sauropod, ornithopod, and pterosaur tracks from Zhaojue tracksites (Xing & Lockley, 2014; Xing, Lockley, Zhang et al., 2013, Xing, Lockley, Zhang et al., 2014, Xing, Lockley, Marty et al., 2015).

Between April and May 2014, when a regional geological survey team from the Sichuan Bureau of Geological Exploration and Development of Mineral Resources explored the Lianghekou, Bier, Mishi, and Zhaojue regions in Sichuan, they discovered the Bajiu tracksite (GPS: 28°10′52.45″N, 102°36′3.81″E) near Bajiu Township, Xide County, Liangshan (Fig. 1).

1.1. Institutional abbreviations

BJA, B, and C = Area A B, and C from Bajiu tracksite, Xide County, Liangshan, China.

* Corresponding author.
E-mail address: xinglida@gmail.com (L. Xing).

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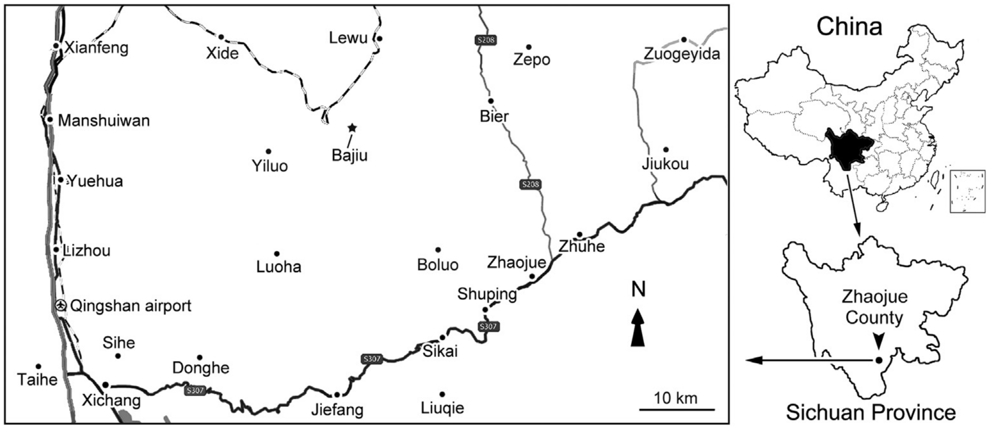

Fig. 1. Geographic map showing the location (star icon) of the dinosaur tracksites in Bajiu area, Sichuan Province, China.

2. Geological setting

2.1. Feitianshan Formation

The Mishi (Xichang)-Jiangzhou Basin (Luo, 1999) is the largest basin in the Panxi region. Based on biostratigraphic indicators (ostracods and stoneworts), the Cretaceous formations of the Mishi–Jiangzhou Basin have been divided into the Lower Cretaceous Feitianshan and Xiaoba formations, and the Upper Cretaceous–Paleogene Leidashu Formation (Gu & Liu, 1997; SBGED, 2014) which are conformable with each other.

In the Zhaojue–Xide area, the Lower Cretaceous Feitianshan Formation is 339.35 m thick and formed by purplish red medium- and fine-grained calcareous feldspathic quartzose sandstones and siltstones interbedded with mudstones. Individual sandstone beds are typically 30 cm–1.5 m thick, (thin-to very thick-bedded, *sensu* McKee & Wier, 1953) with the thickest layers being more than 2 m thick (very thick-bedded, in this classification). There is a thin basal layer of gravel at the bottom of the Feitianshan Formation. The sandstone usually forms large cross bedded units. *Scoyenia* ichnofacies traces from the Zhaojue tracksite indicate intermittent emergence and shallow flooding in low-energy non-marine facies, typical for river floodplains or lakeshore regions (Yang, Zhang, & Yang, 2004; Xing, Lockley, Zhang et al., 2014). The Feitianshan Formation appears equivalent to the Tianmashan Formation or Chengqiangyan Formation from the Sichuan Basin based on stratigraphic correlation and sedimentary facies analysis (CGCMS, 1982). When Tamai et al. (2004) discussed the paleomagnetics of the

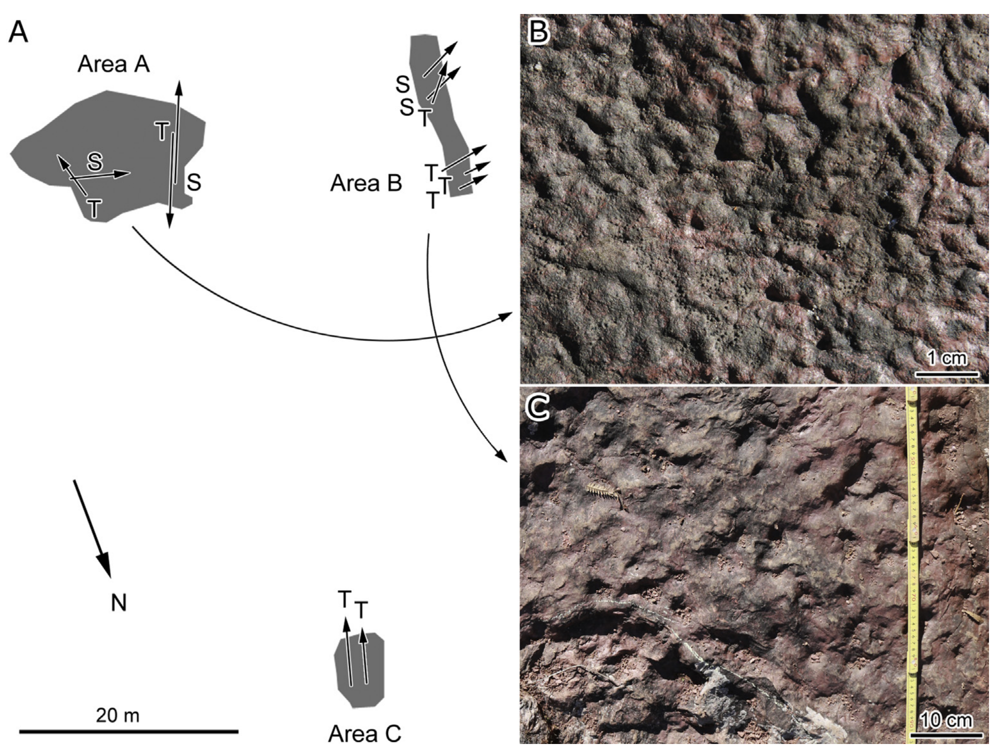

Fig. 2. (A) Distribution of tracksites showing areas A, B, and C. (B) Microbial mats from area A. (C) ripple marks from area B. Arrows show walking direction reflected in main trackways. S = sauropod trackway; T = theropod trackway.

Sichuan and Yunnan fragments of the Yangtze Block, they proposed a Berriasian to Barremian age for the Feitianshan Formation.

The Bajiu tracksite is an exposed purplish-red, fine sandstone surface at the top of the Feitianshan Formation and near the boundary between the Feitianshan Formation and the Xiaoba Formation. The outcrop is about 80 m^2 and divided into three areas: A, B and C, each ~30 m away from one another (Fig. 2A). Area A has clearly identifiable microbial mat structures (Fig. 2B). Area B is 28 m southeast to area A with obvious ripple marks (Fig.2C). Area C is 27 m north to area A without any notable structure.

2.2. Microbial mats

Microbial mat fossils are observable as wrinkle, or popcorn-like structures comprised of a series of oval, strip or crescent bulges on top of the sandstone surfaces (Fig. 2B). Such wrinkle structure refers to the most common microbially induced sedimentary structures (Noffke, Knoll, & Grotzinger, 2002). There are various explanations for the formation of such wrinkle structures, but nearly all are based on the assumption of a once dense microbial mat on the surface of the sediment (Hagadorn & Bottjer, 1997; Noffke et al., 2002; Dai et al., 2015). These bear a close resemblance to similar features recognized in the Lower Cretaceous Cedar Mountain Formation of eastern Utah (Lockley et al., 2014a, Fig. 9).

Numerous wrinkle structures exist on the trackway surfaces of Area A. For example, in BJA-T4-R1, wrinkle structures that have been intensely deformed due to compression can be seen at the edge (displacement impression) of digit II, as well as compacted wrinkle structures inside digit IV, indicating that the T4-R1were left after the microbial mats covered the sediment. Desiccation and lithification caused by the microbial mats were helpful in preserving the tracks. However, continuous growth of the microbial mats may have altered the original track forms (Marty, Strasser, & Meyer, 2009; Dai et al., 2015).

3. Materials and methods

The bedding planes of the Bajiu tracksite have a dip of ~15°. BJA is the largest outcrop, but at least half of it is covered by a fragmented overlying sandstone layer, which includes some track casts. BJB was exposed by a mountain stream that washed off the overlying soil. This track surface is a narrow strip, exposed in the middle of the stream course, with a few trackway segments represented, but no clear trackway patterns traceable for any distance. BJC may have been exposed for a long time and thus weathered heavily.

All tracks were photographed, outlined with chalk, and traced on large sheets of transparent plastic. Videotaping was employed to convert the full-size tracing maps into a digital format. In addition, some well-preserved track casts were collected and are stored at the Sichuan Bureau of Geological Exploration and Development of Mineral Resources.

Photogrammetric images were produced from multiple digital photographs which were convertedinto scaled, highly accurate 3D textured mesh models using Agisoft Photoscan (http://www.agisoft.ru/) (Falkingham, 2012). The mesh models werethen imported into Cloud compare (http://www. danielgm.net/cc/) where the models were rendered with accurately scaled color topographic profiles (Falkingham, 2012).

Following the standard procedures of Leonardi (1987) and Lockley and Hunt (1995), Maximum Length (ML), Maximum width (MW), divarication angle (II–IV), pace length (PL), stride length (SL), pace angulation (PA) and rotation of tracks (R) were measured. Following the methods of Olsen (1980), Weems (1992), and Lockley (2009), mesaxony of tridactyl tracks were measured. Mesaxony refers to the degree to which the central digit (III) protrudes anteriorly beyond the medial (II) and lateral (IV) digits. It can be defined as the ratio of the height of the anterior triangle (from base to apex at tip of digit III) to base (i.e., width between tips of digits II and IV): namely anterior apex height or length/posterior base or width (W) of triangle (= L/W).

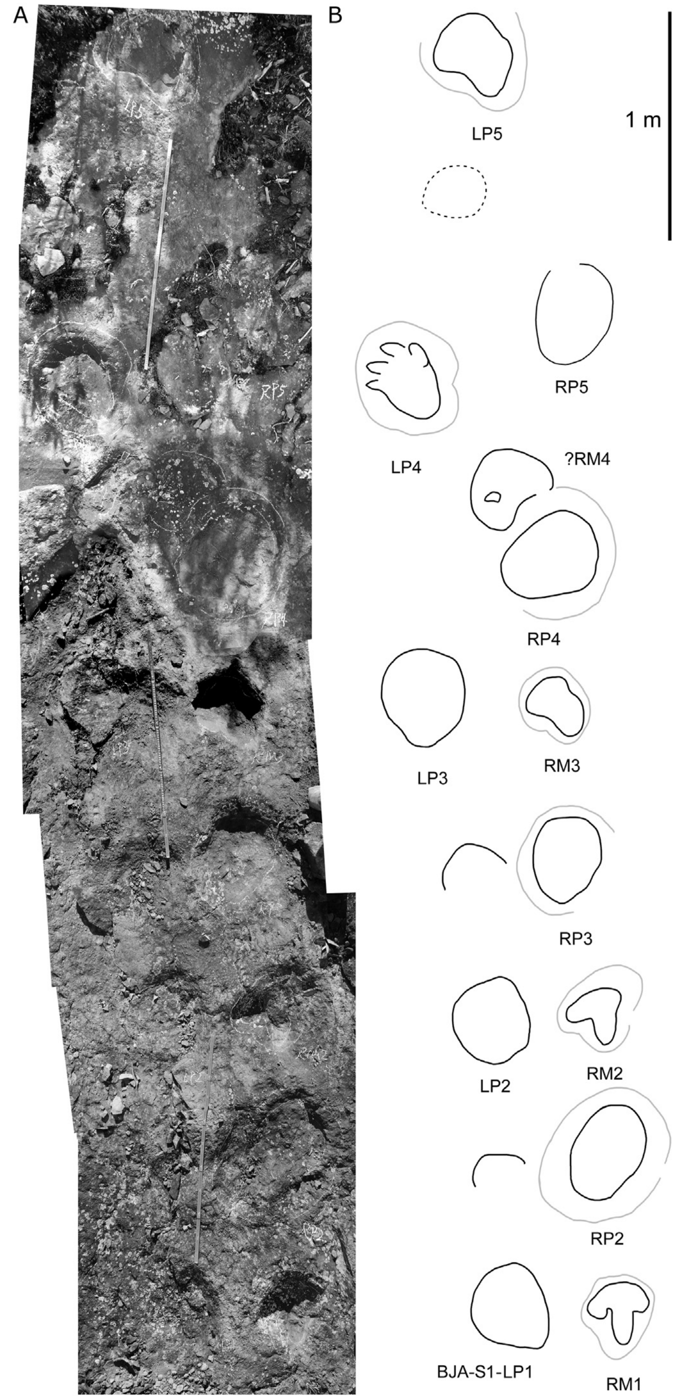

Fig. 3. Photograph (A) and interpretative outline drawing (B) of sauropod trackway BJA-S1 from Bajiu area, Sichuan Province, China.

Gauge (trackway width) of the quadruped trackways was calculated for pes and manus tracks using the ratios WAP/P'ML and WAM/M'ML (see Marty, 2008 and Marty et al., 2010). This calculation is based on pace and stride length on the condition that the width of the angulation pattern crosses the stride at a right angle and at the approximate midpoint of the stride (Marty, 2008). If the

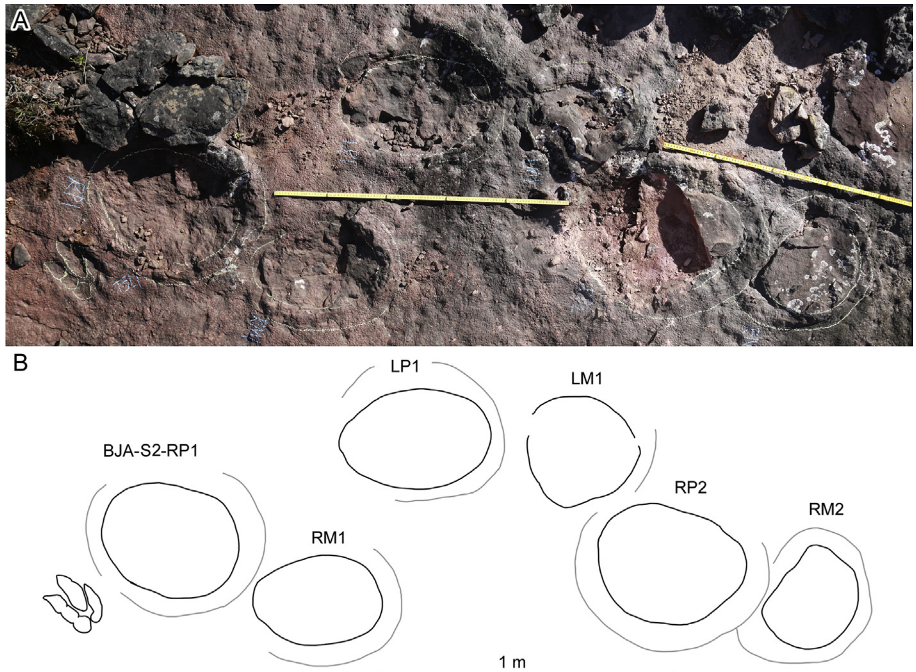

Fig. 4. Photograph (A) and interpretative outline drawing (B) of sauropod trackway BJA-S2 from Bajiu area, Sichuan Province, China. Direction of progression from left to right. Notice co-occurring theropod track at left.

(WAP/P'ML)-ratio is 1.0, the medial margin of the pes tracks probably touch, or are very close to, the trackway midline. If the ratio is less than 1.0, tracks intersect the trackway midline, and are considered narrow-gauge rather than wide gauge (see Farlow, 1992). It was proposed (Marty, 2008) that a value of 1.0 could be used to arbitrarily distinguish narrow-gauge from medium-gauge trackways, while the value 1.2 was selected as a divide between medium-gauge and wide-gauge trackways, and a value above than 2.0 is classified as very wide-gauge (Marty, 2008).

4. Systematic ichnology of the Xiaohutian tracksite

4.1. Sauropod tracks

4.1.1. Description

BJA area has two trackways cataloged as BJA-S1 and S2 (Figs. 3–4; Table 1). The former consist of nine pes and manus prints and the latter is comprised of three sets of pes-manus prints and an incomplete isolated footprint cataloged as BJA-SI1p (Fig. 5). BJB area has two trackways cataloged as BJB-S3 and S4 (Fig. 6; Table 1). The former is composed of four pes and two manus prints, and the latter shows two pes prints, one manus print, and four isolated footprints.

BJA-S1 is moderately preserved, the mean lengths of the manus and pes are 20.6 and 40.1 cm, respectively. The average length/width ratios of the manus and pes impressions are 0.8 and 1.2 respectively. WAP/P'ML = 1.6, indicating wide-gauge according to Marty (2008). The manus impressions of BJA-S1 lie slightly anteromedially to the pes impressions. The best-preserved manus and pes examples are LP4, RM2 and RM3. The semi-circular to crescent shaped manus imprints are diagnostic of sauropods and show the antero-medial digit I and the postero-lateral digit V impressions in their characteristic positions, separated by the concave posterior margin of the trace. The other digit traces are indistinct, as is typically the case in sauropod manus tracks. The pes impression is oval, digits I–IV have distinct digit marks, and the digit I–III claw traces are the best-developed. The metatarsophalangeal region is smoothly rounded. The manus impression is rotated approximately 43° outward from the trackway axis, which is a higher value than recorded for the outward rotation of the pes impressions (approximately 37°). The average PA from both manus and pes is 96°.

RM1 and RM2 are V-shaped manus imprints and show distinct digits I and V, but the digits II–IV are indistinct with the metacarpophalangeal region being deeply impressed. The elongated digit I and V traces might be formed by the trackmaker dragging its forefeet on relatively soft and wet ground. Such relatively elongated digit I and V traces are also present in unnamed prints from the Lower Cretaceous of Italy (Dalla Vecchia, 1999). The measured rotation and pace angulation values apparently change with RP4 (i.e., after BJA-S1-LP3: see Table 1). However, given the difficulty of measuring pes rotation with great accuracy where preservation is suboptimal, the significance of these local differences is unclear.

BJA-S2 (Fig. 4) is moderately well preserved, with mean manus and pes lengths of 28.2 and 49.8 cm, respectively. The average length/width ratios of the manus and pes impressions are 0.8 and 1.4 respectively. WAP/P'ML = 1.0, indicating a medium-gauge trackway (Marty, 2008). Tracks other than RP1 are more or less filled by sediments, obscuring most morphological details. The manus impression is rotated approximately 20° outward from the trackway axis, which is less than the outward rotation of the pes impressions (approximately 57°). The average PA from both manus and pes is 116°.BJA-SI1p (Fig. 5) is an isolated track, with only a front edge but no posterior portion being preserved. The section of the anterior track (Fig. 5C–D) shows 3 claw marks. They are most likely to reflect the claws from digits I–III based on their size and morphology (see Farlow, Pittman, & Hawthorne, 1989).

BJB-S3 (Fig. 6) is relatively well-preserved, the mean lengths of the manus and pes being 34.5 cm and 57.9 cm, respectively. The average length/width ratios of the manus and pes impressions are 0.9 and 1.0 respectively. The WAP/P'ML ratio is 2.0, a value that

Table 1
Measurements (in cm and degrees) of sauropod trackways from the Bajiu tracksite, Sichuan Province, China.

Number	ML	MW	R	PL	SL	PA	ML/MW	WAP	WAP/P'ML	WAM	WAM/M'MW
BJA-S1-RP1	–	–	–	–	–	–	–	–	–	–	–
BJA-S1-RM1	22.5	27.0	37°	–	132.0	96°	0.8	–	–	51.6	1.9
BJA-S1-LP1	43.0	37.0	39°	111.0	138.0	102°	1.2	53.2	1.2	–	–
BJA-S1-LM1	–	–	–	–	–	94°	–	–	–	53.0	
BJA-S1-RP2	<49.0	31.0	41°	111.0	142.0	109°	1.6	47.9	–	–	–
BJA-S1-RM2	22.0	25.0	44°	–	137.0	98°	0.9	–	–	50.4	2.0
BJA-S1-LP2	40.0	36.0	22°	94.0	152.0	112°	1.1	52.9	1.3	–	–
BJA-S1-LM2	–	–	–	–	–	–	–	–	–	–	–
BJA-S1-RP3	39.0	29.0	24°	96.0	121.0	92°	1.3	68.0	1.7	–	–
BJA-S1-RM3	17.0	25.0	48°	–	100.0	–	0.7	–	–	–	–
BJA-S1-LP3	40.0	33.0	23°	97.0	136.0	91°	1.2	69.9	1.7	–	–
BJA-S1-LM3	–	–	–	–	–	–	–	–	–	–	–
BJA-S1-RP4	44.0	36.0	63°	121.0	–	73°	1.2	76.5	1.7	–	–
BJA-S1-RM4	21.0	30.0	–	–	–	–	0.7	–	–	–	–
BJA-S1-LP4	41.0	32.0	50°	–	138.0	91°	1.3	69.4	1.7	–	–
BJA-S1-LM4	–	–	–	–	–	–	–	–	–	–	–
BJA-S1-RP5	–	–	–	–	–	–	–	–	–	–	–
BJA-S1-RM5	–	–	–	–	–	–	–	–	–	–	–
BJA-S1-LP5	34.0	28.0	–	–	–	–	1.2	–	–	–	–
Mean(M)	20.6	26.8	43°	–	123.0	96°	0.8	–	–	51.7	2.0
Mean(P)	40.1	32.8	37°	105.0	137.8	96°	1.2	62.5	1.6	–	–
BJA-S2-RP1	48.0	37.0	20°	93.5	161.5	116°	1.3	49.3	1.0	–	–
BJA-S2-RM1	30.0	41.0	57°	120.0	178.0	116°	0.7	–	–	55.9	1.4
BJA-S2-LP1	51.5	32.0	–	92.0	–	–	1.6	–	–	–	–
BJA-S2-LM1	24.0	34.0	–	108.0	–	–	0.7	–	–	–	–
BJA-S2-RP2	50.0	39.0	–	–	–	–	1.3	–	–	–	–
BJA-S2-RM2	30.5	36.0	–	–	–	–	0.8	–	–	–	–
Mean(M)	28.2	37.0	20°	114.0	178.0	116°	0.8	–	–	55.9	1.4
Mean(P)	49.8	36.0	57°	92.8	161.5	116°	1.4	49.3	1.0	–	–
BJB-S3-RP1	61.5	61.0	–	–	180.0	–	1.0	–	–	–	–
BJB-S3-RM1	34.5	37.0	–	–	–	–	0.9	–	–	–	–
BJB-S3-LP2	–	–	–	–	–	–	–	–	–	–	–
BJB-S3-LM2	34.2	38.0	–	164.0	–	–	0.9	–	–	–	–
BJB-S3-RP2	55.0	54.0	18°	137.0	183.0	84°	1.0	111.4	2.0	–	–
BJB-S3-LP2	56.0	53.5	–	161.0	–	–	1.0	–	–	–	–
BJB-S3-RP3	59.0	57.0	–	–	–	–	1.0	–	–	–	–
Mean(M)	34.4	37.5	–	164.0	–	–	0.9	–	–	–	–
Mean(P)	57.9	56.4	18°	149.0	181.5	84°	1.0	111.4	2.0	–	–
BJB-S4-RP1	>50.0	44.0	–	134.0	–	–	–	–	–	–	–
BJB-S4-LM1	38.0	38.0	–	–	–	–	1.0	–	–	–	–
BJB-S4-LP1	55.0	44.0	–	–	–	–	1.3	–	–	–	–
Mean(M)	38.0	38.0	–	–	–	–	1.0	–	–	–	–
Mean(P)	55.0	44.0	–	134.0	–	–	–	–	–	–	–

Abbreviations: ML: Maximum length; MW: Maximum; R: Rotation; PL: Pace length; SL: Stride length; PA: Pace angulation; WAP: Width of the angulation pattern of the pes (calculated value); WAM: Width of the angulation pattern of the manus (calculated value); ML/MW, WAP/P'ML and WAM/M'MW are dimensionless.

indicates a distinct wide-gauge (Marty, 2008). BJB-S3-LP2 is the best preserved with a length/width ratio of 1.0. The metatarso-phalangeal region is smoothly curved. The corresponding manus print LM2 is poorly preserved, and forms a roughly circular imprint, with a length/width ratio of 0.9. No other morphological features are observable. BJB-S4 consists only of a single step and is similar to S1 in overall morphology but slightly smaller; the mean pes length is 55.0 cm. In addition, a few isolated sauropod tracks BJB areas. All of them are not well-preserved, but the entire morphologies are similar with BJB-S3.

4.1.2. Comparison and discussion

The pes and manus morphology and trackway configuration of the Zhaojue large quadruped trackways is typical of sauropods (Lockley, 1999, 2001; Lockley & Hunt, 1995). Most sauropod trackways in China are wide- (or medium-) gauge and are therefore referred to the ichnogenus *Brontopodus* (Lockley et al., 2002). Far less common narrow-gauge trackways have been referred to *Parabrontopodus* (Xing, Harris, & Jia, 2010, Xing, Lockley, Marty et al., 2013). The Bajiu sauropod trackways fall between medium and wide-gauge, with a WAP/P'ML ratio of 1.0–2.0 (Marty, 2008).

Morphologically, the configuration of the Bajiu sauropod trackways is consistent with the characteristics of *Brontopodus* type tracks from the Lower Cretaceous of North America (Farlow et al., 1989; Lockley, Farlow, & Meyer, 1994). These features are 1) wide-gauge (BJA-S2 is medium-gauge); 2) pes tracks that are longer than wide, large and outwardly directed; 3) semi-circular -shaped manus prints; and 4) a high degree of heteropody (ratio of manus to pes size). The mean heteropody of the well-preserved BJA-S1 sauropod tracks is 1:2. This is close to *Brontopodus birdi* (1:3) but significantly less than in the narrow-gauge ichnotaxa *Breviparopus* (1:3.6) or *Parabrontopodus* (1:4 or 1:5) (Lockley et al., 1994).

It is unusual but not unheard-of to find significantly different narrow-gauge and wide-gauge trackways at the same tracksite. Factors affecting gauge may include the speed of the trackmaker (Xing et al., 2010; Castanera, Pascual, Canudo, Hernandez, & Barco, 2012) and the quality of preservation. Reliable calculations of trackway width should differentiate between true tracks with well-defined outlines and steep walls, and undertracks with very low angle margins. The latter may falsely reduce the apparent inner trackway width and estimation of gauge (Xing, Peng et al., 2015). Preservation might also be responsible for the relatively narrow trackway pattern seen in BJA-S2.

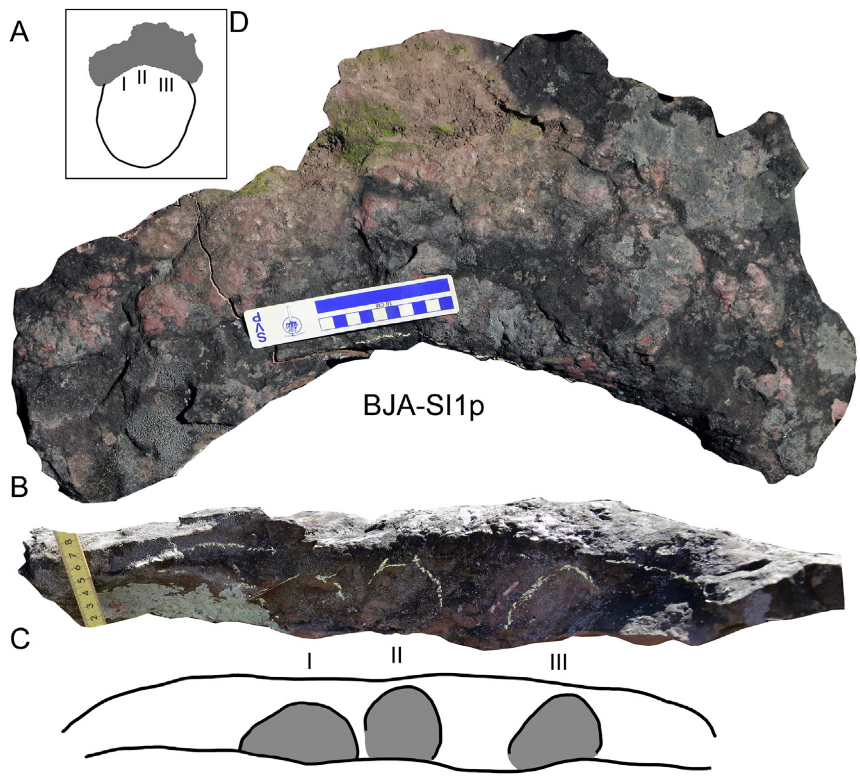

Fig. 5. Isolated sauropod pes BJA-SI1p from Bajiu area, Sichuan Province, China. A: dorsal view, B: cross section view; C, interpretative outline drawing from B; D, reconstruction of the track.

The wide-gauge of the *Brontopodus*-type trackways suggests that the tracks were left by titanosauriform sauropods (Wilson & Carrano, 1999; Lockley et al., 2002). Zhaojue Sauropod trackways from the Feitianshan Formation of Zhaojue County are also classified as being between medium-gauge and wide-gauge, with a WAP/P'ML ratio of 1.0–1.3 (Xing, Lockley, Zhang et al., 2014), which is lower than that of the Bajiu sauropod trackways, especially BJA-S1 and BJB-S4. This evidence of wider-gauge trackways, typical of titanosauriforms, at the top of the Feitianshan Formation, is intriguing, but too limited to suggest a trend.

4.2. Theropod tracks

4.2.1. Description

The Bajiu tracksites show six trackways comprising three, five, two, two, four and three tracks, respectively, cataloged as BJB-T1, BJA-T2, T3, T4, BJC-T5, and T6; and at least nine more isolated theropod tracks cataloged as BJA-TI1–3, BJB-TI1–3, and BJC-TI1–3 (Figs. 7–9; Table 2). The tracks can be divided into two morphotypes:

Morphotype A. BJA-T4-R1 and BJC-T5-L2 are the best preserved. BJA-T4-R1 is 25.2 cm long, with a length/width ratio of 1.4. Digit III projects the farthest anteriorly, followed by digits II and IV. Two distinct metatarsophalangeal pad traces can be seen: a smaller one posterior to digit II and a larger one posterior to digit IV. The former is adjacent to the trace of the first, proximal pad of digit II but separated by a distinct crease. The latter is round and blunt and positioned near the axis of digit III, but closer to digit IV. The digits have relatively wide divarication angles between digits II and IV (52°). Digit pads are mostly indistinct due to the filling of the impressions (Fig. 8), however in BJC-T5-L2, the digit impressions (concave hyporeliefs) show well-preserved pad impressions that have a formula (including metatarsophalangeal pads II and IV) of x-3-3-4-x. Each digit trace ends in a sharp claw mark. Except of BJB-TI1 and TI3, the theropod tracks have basically the same morphology as BJA-T4-R1 and BJC-T5-L2. Some tracks from the BJA site were affected by microbial mat growth as may have been the case for the displacement rim of digit II from BJA-T4-R1.

BJA-TI2 is the smallest track in the sample and only 8.6 cm in length. It is worth noting that BJA-TI2 and BJB-TI2 have fairly large divarication angles between II–IV (100°–101°) and neither of them retains metatarsophalangeal pads. Superficially the track resembles *Anomoepus*, and based on size and divarication, it probably does not represent the same type of trackmaker as the larger theropod tracks. Possibly it should be referred to a third morphotype with ornithischian affinities, however, this cannot be proved with confidence.

Morphotype B is represented only by BJB-TI1 and TI3, that appear to be didactyl tracks left by bipeds (Fig. 9). BJB-TI1 is better preserved and is 24.8 cm long. The pes track has two slender, elongated impressions of digits III and IV, a short, round impression, apparently representing the proximal part of digit II, and a round, developed heel area. The impressions of digits III and IV are subparallel and subequal in length, and possess three digit pads each, excluding the metatarsal phalangeal "heel" pad of digit IV, as well as sharp claw impressions. The suboval heel pad accounts for 32% of the whole length. Digit II pad impressions are close to the medial edge of the heel pad impression but are sparated by a distinct interspace. TI3 is 17.4 cm long and appears generally similar to BJB-TI1 in characteristics except that the digit II impression is positioned closer to the anteromedial margin of the heel pad.

4.2.2. Comparison and discussion

Morphotype A is typical of theropod tracks, it is characterized by weak to moderate mesaxony (range 0.34–0.53), which is typical for footprints of the ichno- or morphofamily Eubrontidae Lull, 1904. Furthermore, the most striking character of

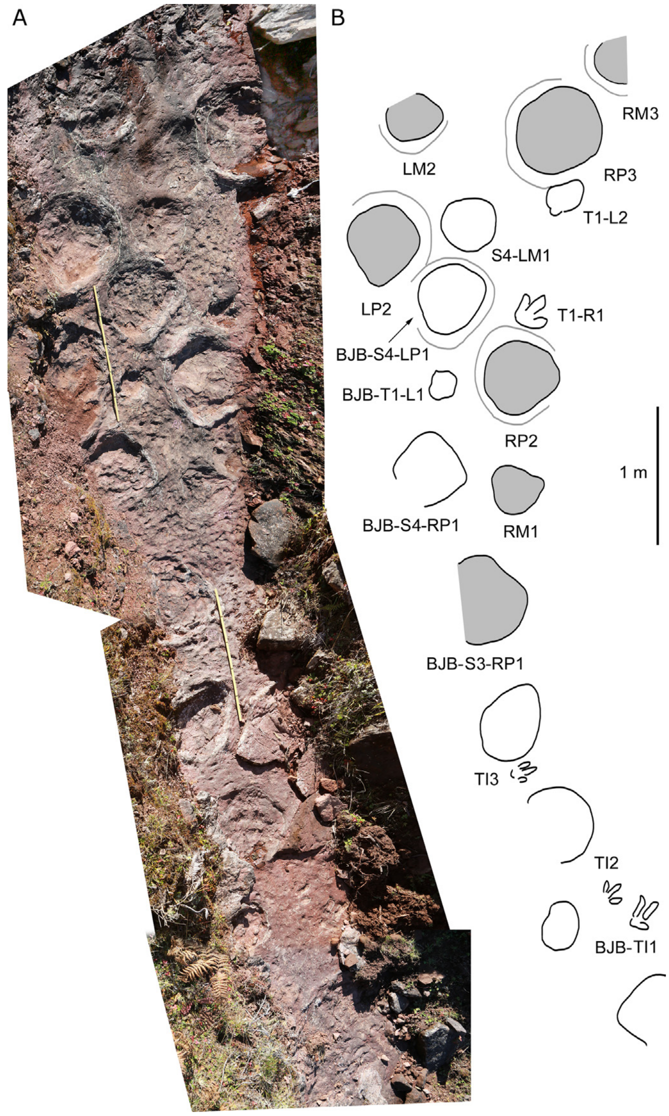

Fig. 6. Photograph (A) and interpretative outline drawing (B) of sauropod and theropod tracks from Bajiu area B, Sichuan Province, China.

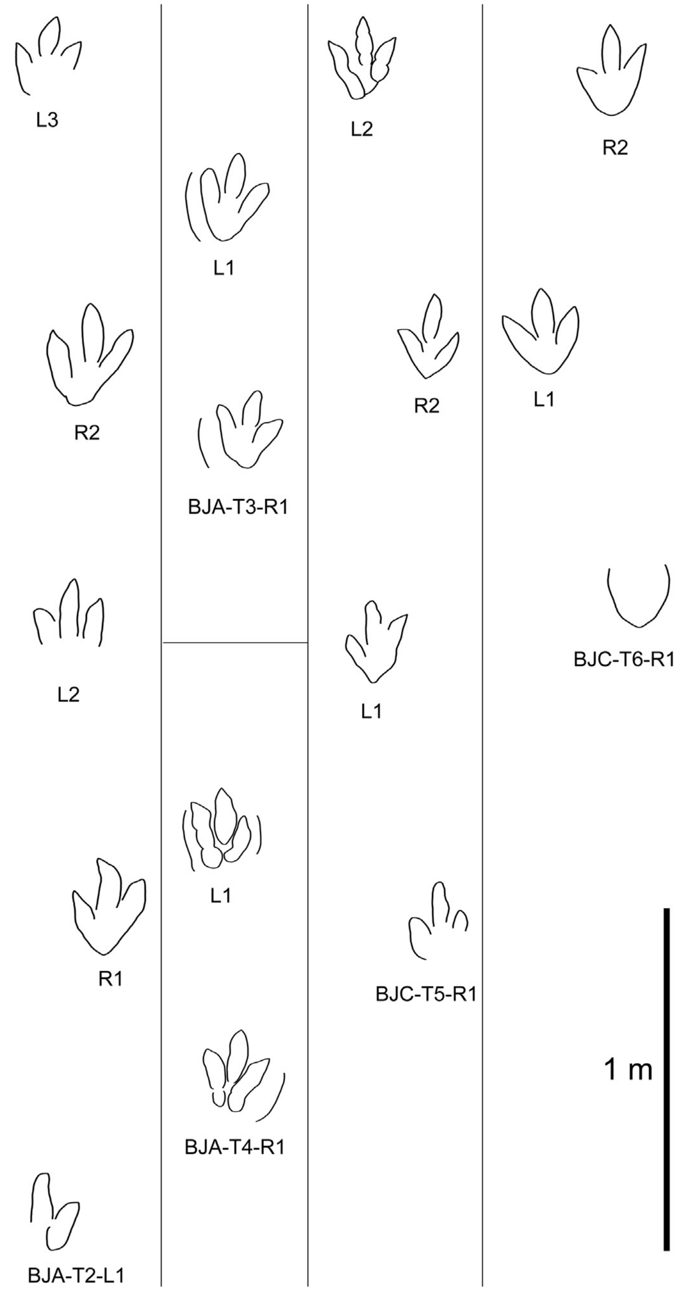

Fig. 7. Interpretative outline drawings of theropod trackways from Bajiu area, Sichuan Province, China.

Morphotype A is the presence of a distinct metatarsophalangeal pad trace posterior to digit II. This character is common in *Eubrontes* tracks, such as the type specimen of *Eubrontes* AC 15/3 (Olsen, Smith, & McDonald, 1998). The relatively large metatarsophalangeal area is also similar to that seen in the Upper Jurassic theropod ichnogenus *Megalosauripus* (Lockley, Meyer, dos Santos, 1998). On the other hand, the dimensions of the "heel" portion might be due to substrate conditions and/or pes posture. All in all this demonstrates that morphotypes very similar to the Jurassic ichnotaxa *Eubrontes*, *Megalosauripus*, *Anchisauripus*, and *Grallator* (Olsen et al., 1998) are widely distributed in Lower Cretaceous deposits of China (Lockley et al., 2013; Xing, Lockley, Marty et al., 2015). However, Early Cretaceous *Eubrontes* tracks generally have larger digit divarication angles than Early Jurassic representatives (Xing, Lockley, Klein et al., 2014); but see Gierlinski & Ahlberg, 1994 and Lucas et al., 2006 for Triassic *Eubrontes* with relatively wide digit divarication.

Morphotype B conforms to the general morphology of typical deinonychosaurian tracks. Deinonychosaurian ichnotaxa comprise four ichnogenera (*Velociraptorichnus*, *Dromaeopodus*, *Dromaeosauripus* and *Menglongipus*) (Xing, Lockley, Marty et al., 2013). The medium–large- sized tracks include *Dromaeosauripus hamanensis* (Kim, Kim, & Lockley, 2008), *Dromaeosauripus yongjingensis* (Xing, Li et al., 2013), and *Dromaeopodus shandongensis* (Li et al., 2007). Some deinonychosaurian tracks have differently been assigned to *Dromaeosauripus* and *Dromaeopodus* (see *Dromaeopodus* of Cowan, Lockley, & Gierlinski, 2010 = *Dromaeosauripus* of Lockley, Gierlinski et al., 2014). Deinonychosaurian tracks are also recorded from Xiaoba Formation of the Panxi region and belong to the *Velociraptorichnus* morphotype (Xing et al., in press). BJB-TI1 is most similar to *D. shandongensis* in its large heel area and the digit II trace. However, the limited number of Bajiu specimens does not permit a detailed comparison and discussion. Therefore, the tracks are tentatively referred to cf. *Dromaeopodus*.

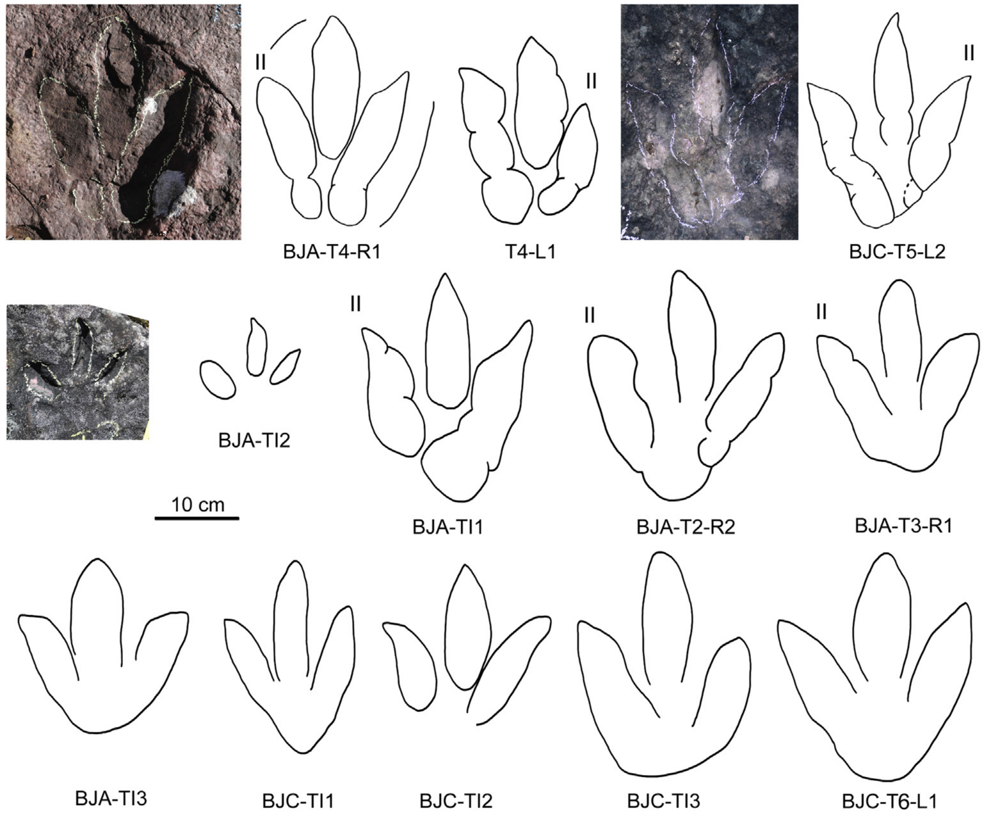

Fig. 8. Interpretative outline drawings and partially corresponding photographs of well-preserved theropod tracks from Bajiu area, Sichuan Province, China.

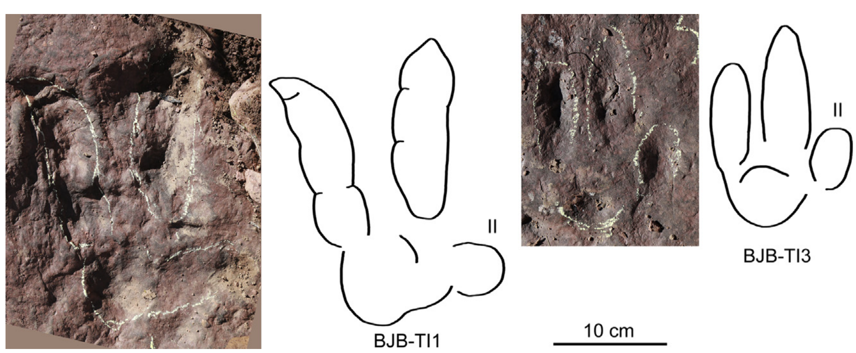

Fig. 9. Photograph and interpretative outline drawing of deinonychosaurian tracks from Bajiu area, Sichuan Province, China.

4.3. Probable swim track

A single isolated track, cataloged as BJA-TU1, is a natural cast without a corresponding mold nearby. The track is 20.6 cm long and 4.6 cm wide, with a length/width ratio of 4.5. It has three distinct, elongated claw marks, probably representing digits I–III. The longest and deepest claw mark is in the middle (Fig. 10). The track appears to have been made in a soft muddy substrate.

Swim tracks attributable to turtle, crocodilian or pterosaurs may be difficult to differentiate, even though some criteria such as size, relative digit length and presence or absence of web traces may give some clues (Lockley, Cart et al., 2014). Lockley, Xing, Li, Li, and Matsukawa (2012) summarized three discoveries of turtle tracks in the Lower Cretaceous of China. These are specimens from the following localities: (1) the Chabu tracksite in the Jingchuan Formation of Nei Mongol, (2) the Zhucheng tracksite in the Longwangzhuang Formation of Shandong Province, and (3) the Huangyangquan tracksite in the Tugulu Group of the Wuerhe district in the Xinjiang Uyghur Autonomous Region. Xing, Avanzini et al. (2014) described turtle tracks from Huangyangquan in detail and suggested that they were similar to the ichnogenera *Chelonipus* and *Emydhipus*. Moreover, new observations on the holotype of *Laiyangpus liui* (Li, J.J., pers. comm.) shows that these tracks, which were previously considered to be those of theropods (Young, 1960), or crocodylians (Lockley, Li, Matsukawa, & Li, 2010) are most likely turtle tracks.

Although BJA-TU1 is an isolated specimen, it is morphologically similar to turtle swim tracks (Avanzini et al., 2005), such as MGCM.G3.RM1 from the Huangyangquan tracksite (Xing, Avanzini et al., 2014). MGCM.G3.RM1 is slightly smaller, 18.9 cm long and 2.6 cm wide than BJA-TU1. In addition, G3.RM1 has a corresponding extremely small manus print RP1.

Table 2
Measurements (in cm and degrees) of theropod tracks from the Bajiu tracksite, Sichuan Province, China.

Number	ML	MW	II-IV	PL	SL	PA	M	ML/MW
BJB-T1-L1	23.0	17.0	–	93.5	166.0	150°	–	1.4
BJB-T1-R1	25.0	23.0	67°	84.0	–	–	–	1.1
BJB-T1-L2	26.0	22.0	–	–	–	–	–	1.2
Mean	24.7	20.7	67°	88.8	166.0	150°	–	1.2
BJA-T2-L1	22.5	–	–	83.3	168.0	165°	–	–
BJA-T2-R1	24.3	18.0	52°	86.0	165.0	172°	–	1.4
BJA-T2-L2	–	20.0	–	79.0	167.6	170°	–	–
BJA-T2-R2	27.8	21.0	59°	88.5	–	–	0.35	1.3
BJA-T2-L3	26.2	20.5	58°	–	–	–	–	1.3
Mean	25.2	19.9	56°	84.2	166.9	169°	0.35	1.3
BJA-T3-R1	23.0	17.5	60°	70.5	–	–	0.36	1.3
BJA-T3-L1	26.0	16.5	52°	–	–	–	–	1.6
Mean	24.5	17.0	56°	70.5	–	–	0.36	1.4
BJA-T4-R1	25.2	17.5	52°	69.0	–	–	0.48	1.4
BJA-T4-L1	22.5	17.0	50°	–	–	–	0.43	1.3
Mean	23.9	17.3	51°	69.0	–	–	0.46	1.4
BJC-T5-R1	26.5	16.5	–	83.0	171.0	155°	–	1.6
BJC-T5-L1	25.0	18.0	56°	92.0	175.0	153°	–	1.4
BJC-T5-R2	25.0	17.5	65°	88.0	–	–	–	1.4
BJC-T5-L2	26.0	19.5	58°	–	–	–	0.41	1.3
Mean	25.6	17.9	60°	87.7	173.0	154°	0.41	1.4
BJC-T6-R1	–	–	–	79.0	151.0	147°	–	–
BJC-T6-L1	27.0	22.0	58°	80.0	–	–	0.34	1.2
BJC-T6-R2	27.0	21.0	62°	–	–	–	–	1.3
Mean	27.0	21.5	60°	79.5	151.0	147°	0.34	1.3
BJA-TI1	27.4	20.1	50°	–	–	–	0.44	1.4
BJA-TI2	8.6	12.0	100°	–	–	–	0.35	0.7
BJA-TI3	20.8	20.1	71°	–	–	–	0.36	1.0
BJB-TI1	24.8	14.5	31°	–	–	–	–	1.7
BJB-TI2	14.0	17.0	101°	–	–	–	–	0.8
BJB-TI3	17.4	5.9	18°	–	–	–	–	2.9
BJC-TI1	24.0	16.0	48°	–	–	–	0.44	1.5
BJC-TI2	22.0	29.0	77°	–	–	–	0.37	0.8
BJC-TI3	27.5	19.0	57°	–	–	–	0.53	1.4

Abbreviations: ML: Maximum length; MW: Maximum (measured as the distance between the tips of digits II and IV); II-IV: angle between digits II and IV; PL: Pace length; SL: Stride length; PA: Pace angulation; M: Mesaxony; ML/MW is dimensionless.

Similar tracks also include pterosaur pes swim tracks, such as described by Lockley and Wright (2003), Kim, Kim, Kim, and Lockley (2006), Lockley, Cart et al. (2014). Most pterosaur pes swim tracks have four digit marks (e.g. Lockley & Wright, 2003; Lockley, Cart et al., 2014). Digit IV marks of turtle tracks are often shorter and smaller, and in particular, turtle swim tracks usually register only the traces of digits I–III (e.g. Avanzini et al., 2005). Swim tracks described by McCrea, Pemberton, and Currie (2004) as *Albertosuchipes* (UALVP 134) from the Paleocene of Canada (Fig. 11), bear a striking resemblance to BJA-TU1, and have been attributed to a crocodilian. However, unlike the Canadian material which consists of a partial trackway, with manus and pes traces, the Chinese track is an isolated cast, which therefore provides rather less useful information.

5. Conclusions

A plethora of dinosaur tracks has been found in recent years in the Lower Cretaceous Feitianshan Formation of the Panxi region, including Zhaojue tracksite I, II and IIN (Xing, Li et al., 2013; Xing, Lockley, Li et al. 2013; Xing, Lockley, Marty et al., 2013; Xing, Lockley, Zhang et al., 2013; Xing, Lockley, Marty et al., 2015; Xing & Lockley, 2014), the Jiefanggou tracksite (Xing, Lockley, Yang et al., 2015), and the Yangmozu tracksite(unpublished data). The Yangmozu tracksite is considered the stratigraphically lowest, occurring just above the Upper Jurassic Guanggou Formation. It has yielded theropod tracks such as those of the *Grallator*-type and *Minisauripus*; the Zhaojue tracksites and Jiefanggou tracksite are in the middle of the Feitianshan Formation and produce non-avian theropod (*Grallator*-type, *Eubrontes-Megalosauripus* type, *Siamopodus*), sauropod (*Brontopodus*), ornithopod (*Caririchnium*, *Ornithopodichnus*) and pterosaur tracks (*Pteraichnus*) (Xing, Lockley, Zhang et al., 2013, Xing, Lockley, Zhang et al., 2014; Xing, Lockley, Marty et al., 2015; Xing & Lockley, 2014).

The Bajiu tracksite is at the top of the Feitianshan Formation,

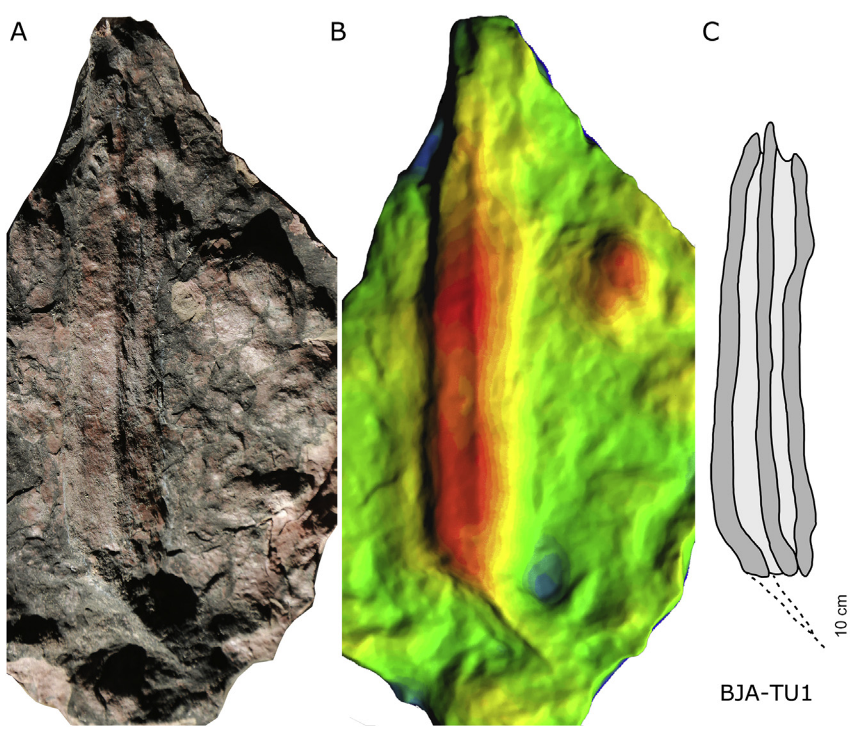

Fig. 10. Photograph (A), 3D height map (B) and interpretative outline drawing (C) of possible turtle track from Bajiu area, Sichuan Province, China.

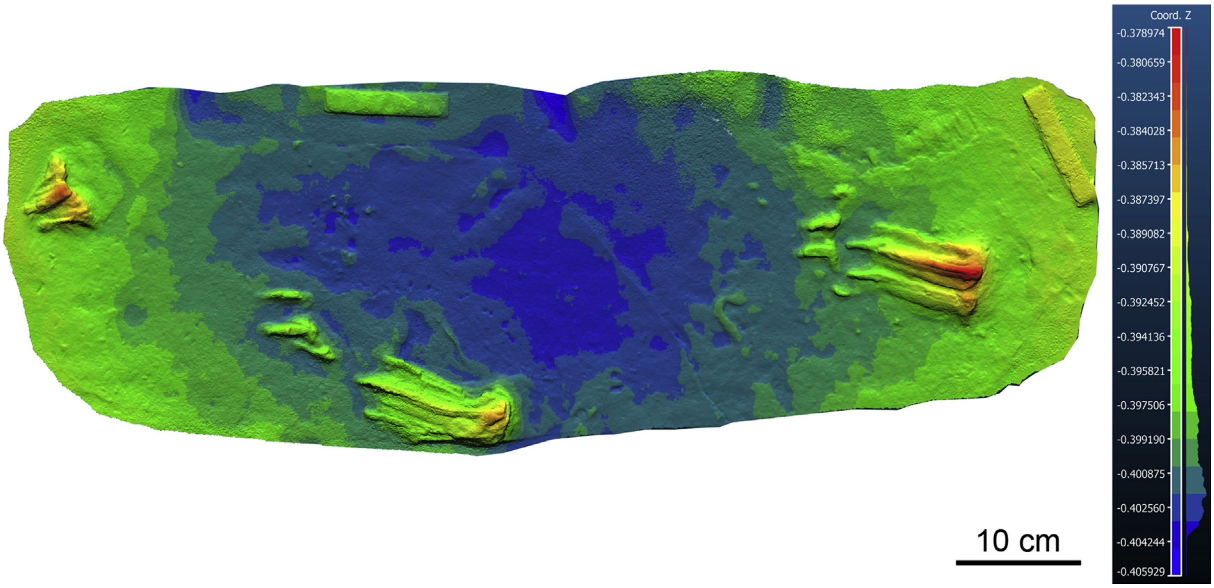

Fig. 11. 3D height map of *Albertosuchipes* (UALVP 134) from the Paleocene of Canada.

and has produced non-avian theropod (*Eubrontes-Megalosauripus* type and deinonychosaurian tracks), sauropod (*Brontopodus*), and a possible turtle or crocodilian track. Both the deinonychosaurian tracks cf. *Dromaeopodus*, and the turtle or crocodilian track are the first of these morphotypes reported from the Feitianshan Formation, enhancing the diversity of the Berriasian to Barremian age fauna (Feitianshan Formation, Tamai et al., 2004).

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