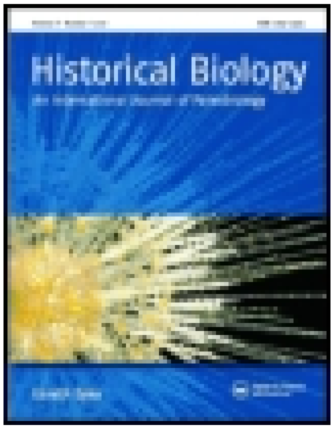



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# A new sauropodomorph ichnogenus from the Lower Jurassic of Sichuan, China fills a gap in the track record

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A dinosaur tracksite in the Lower Jurassic Ziliujing Formation of Sichuan Province, China consists of a spectacular sub-vertical exposure, with multiple track-bearing levels and trackways showing parallel and bimodal orientations. Based on well-preserved material, the new ichnogenus and ichnospecies, *Liujianpus shunan* ichnogen. nov. ichnosp. nov. is erected to accommodate distinctive sauropodomorph trackways occurring in this assemblage. *Liujianpus* has a unique combination of features, some relating to the early Jurassic basal sauropodomorph (prosauropod in traditional usage) ichnogenus *Otozoum*, others to the sauropod ichnogenus *Brontopodus*. Despite such a mix of basal sauropodomorph- and sauropod-like features, the trackmaker of *Liujianpus* is likely a basal sauropodomorph. This identification is consistent with the occurrence of basal sauropodomorph skeletons from geographically and chronologically close localities. The other distinct morphotype from the tracksite is linked to a sauropod trackmaker. As such, the ichnofauna consisting of two distinct foot morphotypes reflects the diversity of sauropodomorph dinosaurs in the Early Jurassic of Asia.

**Keywords:** Sauropodomorph tracks; *Liujianpus*; Ziliujing Formation; Lower Jurassic; Sichuan Province; China



## 1. Introduction

Although skeletal remains of sauropodomorph dinosaurs are well known, and locally abundant in the early Mesozoic of East Asia (Young 1951; Dong 1992; Barrett et al. 2005), their tracks are scarcely known (Lockley et al. 2002) and have not been described in detail. Documented tracks were mostly attributed to sauropods, whereas diagnostic basal sauropodomorph tracks have not been reported from East Asia thus far. This situation is in contrast to the track record of other regions, notably North America, Europe and southern Africa, where the basal sauropodomorph track record is well documented and of considerable significance in the history of ichnology.

### *1.1. Global distribution of basal sauropodomorph tracks*

The first ichnogenus currently confidently attributed to prosauropods was *Otozoum*, which was named by Hitchcock (1847) from the Lower Jurassic Portland Sandstone of New England. However, Hitchcock did not link *Otozoum* with a prosauropod trackmaker since that group was unknown at the time. Subsequently, Lull (1904, 1953) assigned *Otozoum* as a prosauropod track and erected the ichnofamily Otozoidae in a revision of Hitchcock (1847, 1848, 1858). Recent work by Rainforth (2003), Lockley et al. (2006a) and others unanimously support the basal sauropodomorph affinity for *Otozoum*.

Ellenberger (1970, 1972, 1974) named the ichnogenus *Pseudotetrasauropus* from the Lower Jurassic of southern Africa. Features similar to *Otozoum* let some workers infer a basal sauropodomorph affinity for this ichnotaxon (Ellenberger and Ellenberger 1958; Ellenberger et al. 1969; Ellenberger 1970, 1972; Lockley and Meyer 2000; D'Orazi Porchetti and Nicosia 2004, 2007 ; Lockley et al. 2006a). However, Rainforth (2003) considered a crurotarsan origin based on the derived phalangeal formula. Olsen and Galton (1984) interpreted *Pseudotetrasauropus* as a bipedal *Brachychirotherium* suggesting a crocodylian-stem affinity as well. The latter authors revised the ichnotaxonomy of *Pseudotetrasauropus* and other southern African ichnogenera based on a survey of the literature, but without first-hand observations of the original African materials. Although they synonymised many of the southern African ichnogenera with North American ichnotaxa, *Otozoum* and *Pseudotetrasauropus* are now considered distinct (Lockley and Meyer 2000; Rainforth 2003; D'Orazi Porchetti and Nicosia 2004; Lockley et al. 2006a; Gierliński, 2009).

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At present, the plexus of tracks attributed to basal sauropodomorphs includes *Otozoum*, *Pseudotetrasauropus*, *Evazoum* and *Kalosauropus* and has been dubbed the *OPEK* plexus (Lockley et al. 2006a), which belongs to the ichnofamily Otozoidae (Lockley et al. 2006a; Lockley and Lucas 2013). *Lavinipes cheminii* described by Avanzini et al. (2003) could probably also be assigned to this plexus since it is generally similar to *Otozoum*, although not preserved with sufficient detail to show the complex pads so characteristic of *Otozoum*. The former two OPEK plexus ichnogenera (*Otozoum* and *Pseudotetrasauropus*) are based on large type specimens, and include large robust forms that represent quadrupedal as well as bipedal trackmakers. In contrast, the two latter ichnogenera represent small bipeds, which were probably gracile animals.

In contrast to the long history of research on basal sauropodomorph tracks, the study of true sauropod tracks did not begin until the 1930s (Bird 1939, 1985) and it was not until 1989 that the ichnogenus *Brontopodus* was named for large sauropod tracks from the Cretaceous of Texas (Farlow et al. 1989). Since then, most additional sauropod track reports, as well as newly proposed ichnogenera have pertained to late Mesozoic (Late Jurassic-Late Cretaceous) tracks.

Although sauropods are known from the Late Triassic (Buffetaut et al. 2000, 2002), there have been relatively few reports of sauropod or sauropodomorph tracks from Triassic and Lower/Middle Jurassic strata, and few of these are represented by newly named ichnotaxa. The oldest distinctive sauropodomorph ichnogenus attributable to a robust quadruped is *Eosauropus* (Lockley et al. 2006b) named for well-preserved material from the Late Triassic of New Mexico (previously informally referred to the ichnogenus *Tetrasauropus*; Ellenberger 1972). In North America, *Eosauropus* is often represented by poorly preserved trackways, presumably made under substrate conditions not suitable for optimal preservation (Lockley et al. 2011). One set of tracks resembling poorly preserved *Eosauropus* (or *Otozoum*) has been tentatively identified from China (Xing et al. 2014a).

Other reports of Early and Middle Jurassic sauropod tracks come from Morocco (Ishigaki 1988; Gierliński et al. 2009), Italy (e.g. Leonardi and Mietto 2000), Poland (e.g. Gierliński et al. 2004; Gierliński, 2009) and Portugal (Santos et al. 1994), respectively. In the former case, the tracks, which remain unnamed, are Early Jurassic in age and resemble those described here, whereas in the later case, the tracks (*Polyonyx gomesi*) are Middle Jurassic in age and are morphologically distinct from any Lower Jurassic forms (Santos et al. 2009). Only two previous reports of sauropod tracks from the Lower Jurassic of China are known: (a) from the Zhenzhucheng Formation of the Dazu region of Sichuan (Matsukawa et al. 2006) illustrated by Lockley and Matsukawa (2009); and (b) from the Ziliujing Formation of Zigong City, Sichuan (Xing et al. 2014b).

### *1.2. Sauropodomorph trackways from Gulin County*

At the southern border of the Sichuan Basin, the Gulin area protrudes into northern Guizhou Province as a peninsular-shaped region. In May 2009, Yiguang Chen and Jianming Tang, the engineers from No. 113 Geological Team, Sichuan Bureau of Geology and Mineral Resources, discovered a group of dinosaur tracks at Heping (meaning 'peace') brickfield near Zhongshan Village, Jiaoyuan (meaning 'pepper garden') Township, Gulin County. During 2010–2014, the senior author has made six visits to investigate the tracksite. The purpose of this paper is to describe a large assemblage of sauropodomorph trackways from a locality near Gulin County in the Lower Jurassic Ziliujing Formation in Sichuan Province, China, and discuss their ichnotaxonomic status and paleobiological significance. This paper elaborates on a very preliminary note on the site by Xing (2010). Co-occurring theropod tracks and trackways from the same locality are described in a different study (Xing, Lockley, Zhang et al. in press).

**Institutional and other abbreviations:** JY = Jiaoyuan tracksite; UCM = University of Colorado Museum of Natural History, Boulder, Colorado, USA; ZLJ = World Dinosaur Valley Park, Yunnan Province, China; S = Sauropod; I = Isolated; M = Manus; P = Pes; L = Left; R = Right

## 2. Geographic and geologic setting

The Jiaoyuan tracksite is situated at latitude N 24°02′ 32.78″ and longitude E 105°48′53.05″ in a small, relatively remote valley 30 km south southeast of Gulin County, in Sichuan Province (Figure 1). The main tracksite consists of an outcrop consisting of bedding planes that dip steeply at 70° to the southeast (Figure 2). Quarrying operations to extract siltstones and mudstones for a local brick factory have ceased now. The main track-bearing surface approximately faces south. Long parallel trackways are conspicuous, especially in the western sector of the exposed surface where the upper exposures are to the north and the lower exposures to the south. Close inspection of this main western outcrop reveals that some of these trackways extend in opposite directions indicating a bimodal orientation to the overall assemblage (Figure 3). This western sector is divided from an eastern sector by local outcrops of the overlying beds. As noted further in the text, a few accessible tracks in the lower part of the eastern sector have been studied. At the base of the western outcrop, this is a relatively small exposure of a track-bearing sandstone unit overlying the main surface. A single sauropodomorph trackway is exposed on the surface of this overlying unit.

Heim (1930) referred the lower part of the red beds of the Sichuan Basin to the 'Ziliujing Series'. When classifying the strata of eastern Sichuan, Yi (1958)

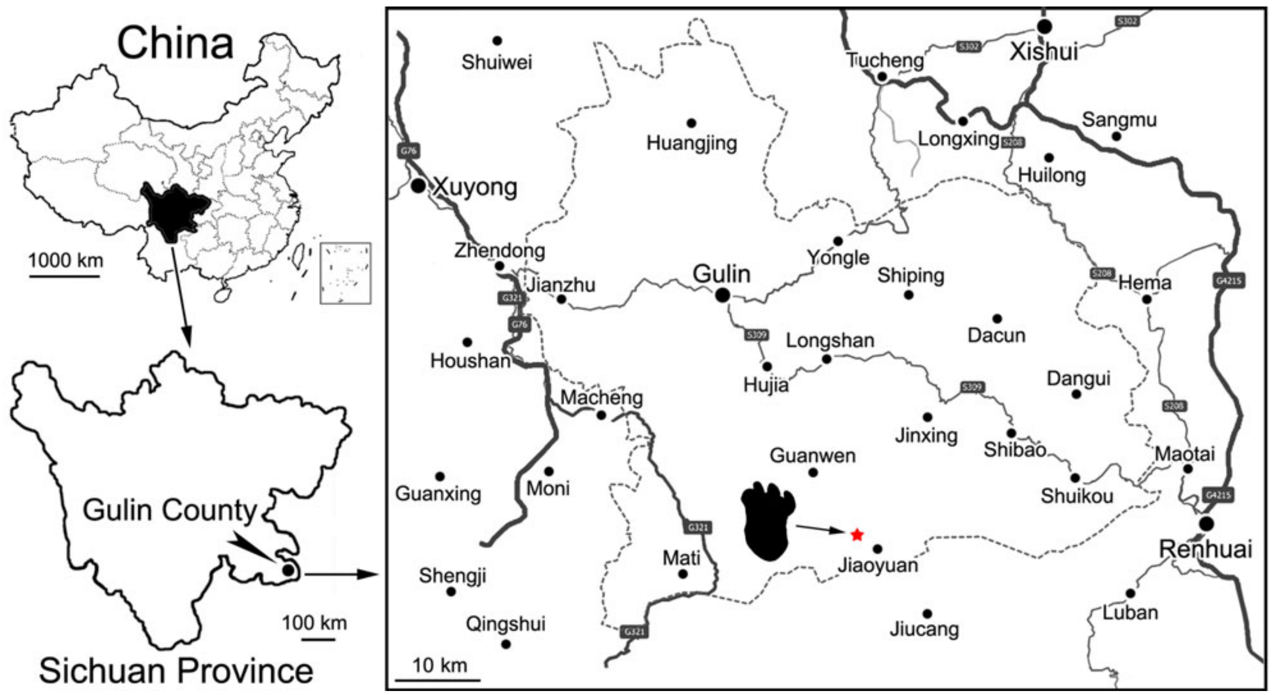


Figure 1. Map showing the location of the Jiaoyuan tracksite near Gulin in Sichuan Province China.

referred the beds as the ‘Ziliujing Group’. In 1979, the term Ziliujing Formation was proposed for the lower Zhenzhuchong Member. Meanwhile, the upper Lianggaoshan Member was designated as the Dongyue-miao, Maanshan and Daanzhai Members (Dong 1980).

The Jiaoyuan tracksite is in the Lower Jurassic Daanzhai Member of the Ziliujing (former spelling: Tseliutsing) Formation (Gu et al. 1997). The Ziliujing Formation rests on the Lower Jurassic Zhenzhuchong Formation and is conformably overlain by the Middle Jurassic Xintiangou Formation.

The Ziliujing Formation is characterised by the occurrence of abundant small-sized bivalves dominated by *Apseudocardinia* (Cai and Liu 1978). Based on the presence of *Unio huangbogouensis*, *U. lufengensis*, *U. ningxiaensis* and *Cuneopsis jingyouensis* (Ma 1984), the formation is inferred to be Lower Jurassic in age. The sporopollenin and ostracod fossils also support this assessment (Peng et al. 2005).


Figure 2. Photograph of the Jiaoyuan tracksite showing a spectacular deeply dipping surface with conspicuous parallel and bimodally distributed trackways. A and B corresponding to part of the JYS1 and JYS3 trackways (Figure 5), and JYS11 trackway (Figure 8), respectively.

The *Lufengosaurus* vertebrate fauna found in the Daanzhai Member of the Ziliujing Formation includes *Lufengosaurus* sp. from the Zigong area, Sichuan Province (Dong 1984) and the Weixin area, Yunnan Province (The first division of The Regional Geological Survey Team, Guizhou Geological Bureau 1979). The Middle Jurassic Xintiangou Formation contains fragmentary sauropod material, but basal sauropodomorph body fossils have not been found in the formation at the time of writing (Peng et al. 2005). However, although basal sauropodomorph body fossils mostly flourished in the Lower Jurassic strata of Asia, only *Yunnanosaurus youngi* occurs in the Middle Jurassic (Lu et al. 2007).

The main tracksite occurs as part of a sequence dominated by friable siltstones and resistant sandstones (Figure 4), in which a minimum of eight track-bearing levels have been identified. The measured section has a total thickness of almost 100 metres, in which there are only two relatively well-developed sandstone units: a lower one at the base of the exposure, about 4 metres thick, and not well exposed, in which tracks could not be identified, and a well-exposed, upper unit, also about 4 metres thick. These are referred to informally as the lower and upper sandstone units, with the upper units

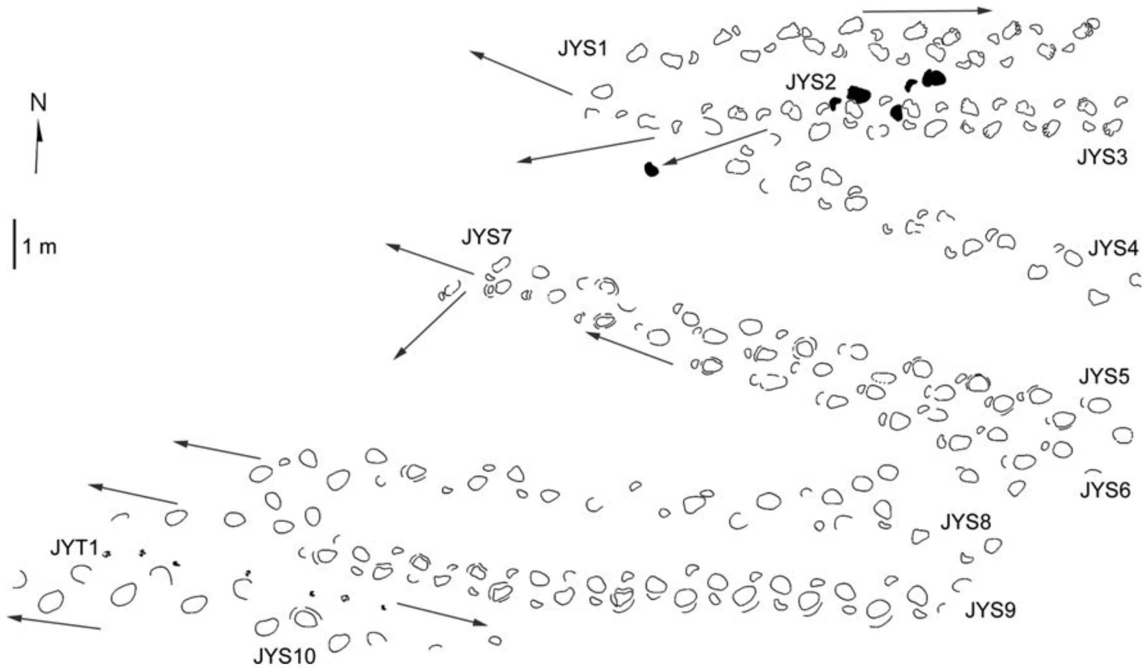


Figure 3. Map of main track-bearing surface with sauropodomorph trackways JYS1-10.



being of particular importance because of the rich track assemblage. All other sandstone units are between 5 and 50 cm in thickness, resulting in a total thickness of sandstones of about 10 metres, or ~10% of the total section. Some surfaces reveal ripple marks and desiccation cracks.

## 3. Methods

Due to the steepnessof the main tracksite (~70° dip to the south), two experienced climbers were employed to set ropes and assist with gaining access to the site. This permitted examination of the tracks at close quarters and enabled chalk outlines, tracings, photographs and molds to be made. Once outlines of the tracks in the uppermost sector of the outcrop had been chalked, a large sheet of transparent plastic was used to trace most of the trackway segments in this sector. Due to the size of the outcrop, it was not feasible to map (trace) the configuration of trackways across the entire outcrop, especially in the lower sector where the trackways are longer, therefore portions of the map were filled in using photographs taken by Xing (2010).

During our field expedition in August 2013, four trackway segments (JYSI–IV) in the upper part of the tracksite were mapped, and the procedure was repeated again in the fall of 2013. In addition, a further method was employed on the poorly preserved lower trackways. Using a professional Canon SLR camera EOS-1D X and super-telephoto lens EF 800 mm f/5.6L IS USM the site was photographed perpendicular to the surface from the terraced fields opposite the tracksite. The photographs were merged using Adobe Photoshop CS6, and the distribution pattern was mapped.

Ideally, this type of site should be accurately mapped using Lidar Scanning, photogrammetry or other similar methods capable of producing three-dimensional images of large areas. However, obtaining such images is only possible with specialised equipment and access to a suitable location or platform from which to operate the scanning and photogrammetic equipment. Under ideal circumstances, photogrammetric images might be obtained if a vantage point such as a balloon, platform or helicopter were to be situated perpendicular to the surface a few tens of metres away. Such positioning was practically impossible at such a remote site, where clear weather is atypical. Moreover, photogrammetic imaging is compromised by shadows in the tracks. Even if the above was possible, in order to adequately describe the tracks, it is still necessary to climb on the surface to set scales, reference points, inspect details of track morphology, obtain close-up photographs and moulds.

Using tracings obtained from both the main surface, and a second surface one metre above, we obtained following measurements of manus and pes imprints and trackways: Track length and width, rotation, pes–pes and manus–manus pace angulation, step, stride and inner and outer trackway width. The sauropodomorph trackway parameters follow those of Marty (2008, Figures 2.10 and 2.11). Trackways were numbered JYS1 to JYS10 with ‘JY’ indicating the Jiaoyuan tracksite and ‘S’ the sauropod

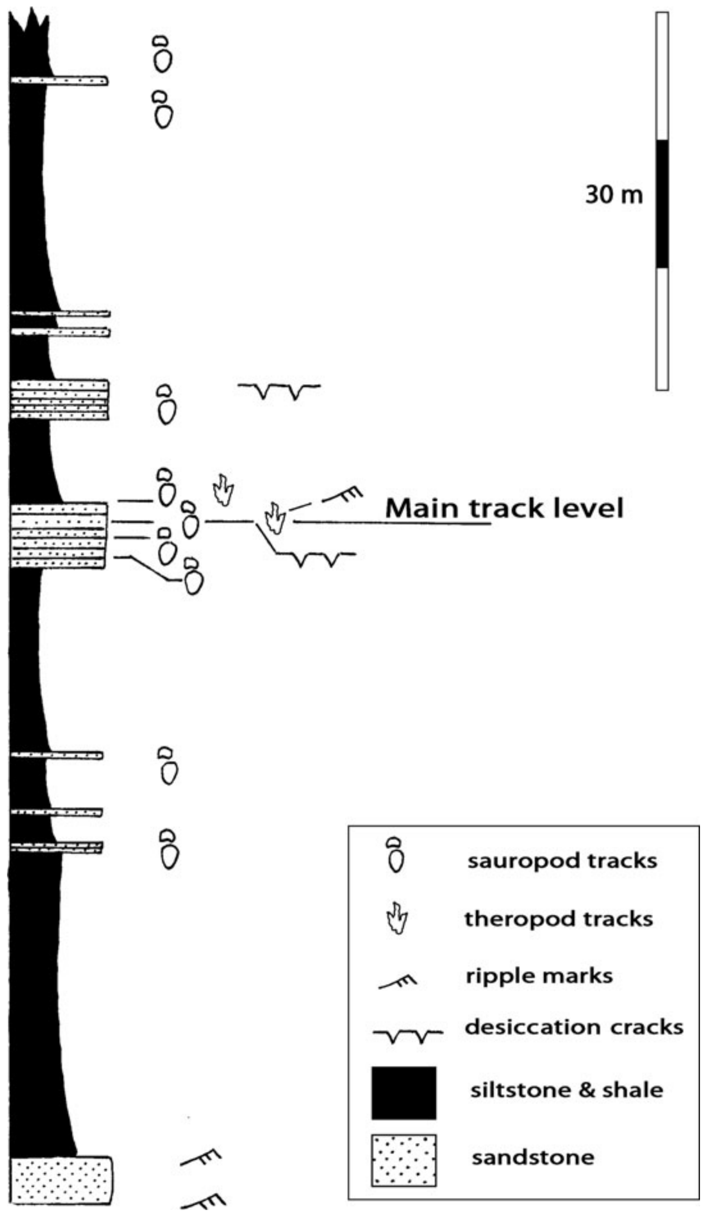


Figure 4. Stratigraphic section showing position of upper track-bearing sandstone unit and other track-bearing levels.

trackmaker. Tracings were also used to make overlay images, as proposed by Baird (1957). In this method, tracings of multiple tracks from the same trackway were overlain to give a composite, idealised image. A replica of a pes imprint UCM 178.18 was made using latex.

## 4. Description of the trackways

The trackways are conspicuous and generally deep and continuous over much of the main surface (Figures 2 and 3). The majority occur on a surface within the upper sandstone unit, but one easily accessible trackway occurs on a surface one metre above the main surface on the uppermost surface of the upper sandstone bed (Figure 4). There are at least two trackway morphotypes present. The first morphotype (A), found on the main track-bearing surface, is characterised by an oval, outwardly rotated pes with four pes claw traces sub-parallel to the footprint axis, and a semicircular to pentadactyl manus (Figures 5–9). The second morphotype (B) is a more typical sauropod morphotype characterised by an oval to sub-triangular, outwardly rotated pes, some with outwardly rotated claw traces, and a semicircular, outwardly rotated manus (Figures 10–11). A good example of this morphotype is the trackway found on the upper surface, just above the main track level. Some of these differences may be due to variation in trackmaker size and quality of trackway preservation.

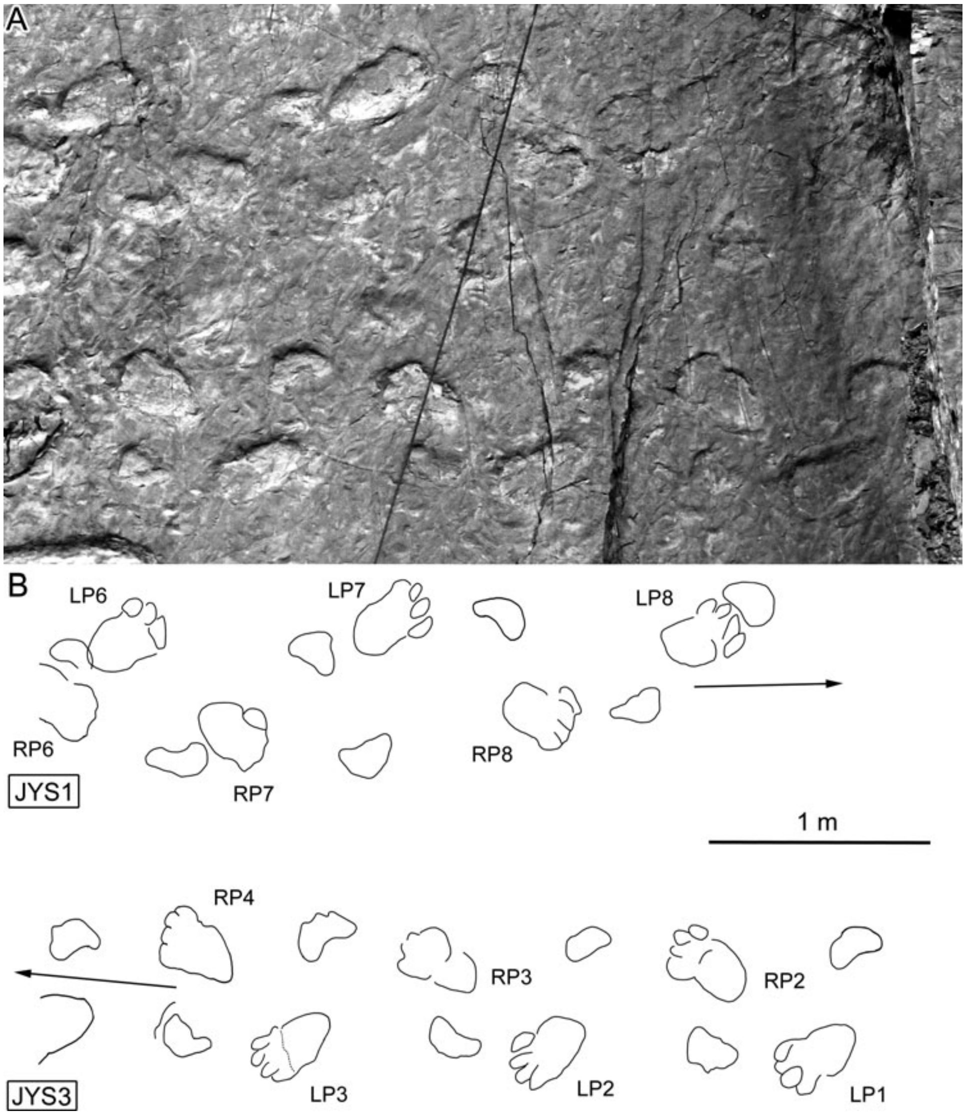


Figure 5. Photograph (A) and interpretative outline drawing (B) of trackways JYS1 (holotype) and JYS3 (paratype).



### *4.1. Systematic paleontology*

*Liujianpus* ichnogen nov. Figures 5–9

*Type ichnospecies: Liujianpus shunan* (monospecific)

*Horizon and locality:* Daanzhai Member of Ziliujing Formation (Lower Jurassic), Jiaoyuan near Gulin County, Sichuan Province China (latitude N 24° 02′ 32.78″ and longitude E 105° 48′53.05″).

*Etymology:* after LIU Jian, a famous Chinese mountaineer and explorer, who helped with technical climbing at this and other sites, and *pus* meaning 'foot'.

*Diagnosis*. Trackway of large quadruped with elongate, tetradactyl, outwardly rotated pes with length of digit III > IV = II > I and a sole area divided by a transverse crease. Manus pentadactyl to semi-circular and strongly rotated outward. Differs from other sauropodomorph tracks by the presence of four nearly equidimensional, elongate pes digit traces oriented subparallel to the pes axis and a sub-circular manus with five discrete blunt digit traces. Combines some features of otozoid tracks with those of sauropod tracks such as *Brontopodus*.

*Liujianpus shunan* ichnosp nov

*Holotype:* Trackway JYS1 comprising 15 pes and 14 manus tracks including JYS1-LP7 and LM7 (replica UCM 178.18) (Figures 3, 5–8, 9A) (Table 1).

*Paratype:* Trackway JYS3 with 16 pes and 15 manus tracks (Figures 3, 5, 6–9B) (Table 2).

*Horizon and locality:* As for the ichnogenus.

*Etymology:* the specific name '*shunan*' refers the southern part of the Sichuan Province.

*Diagnosis:* As for the ichnogenus.

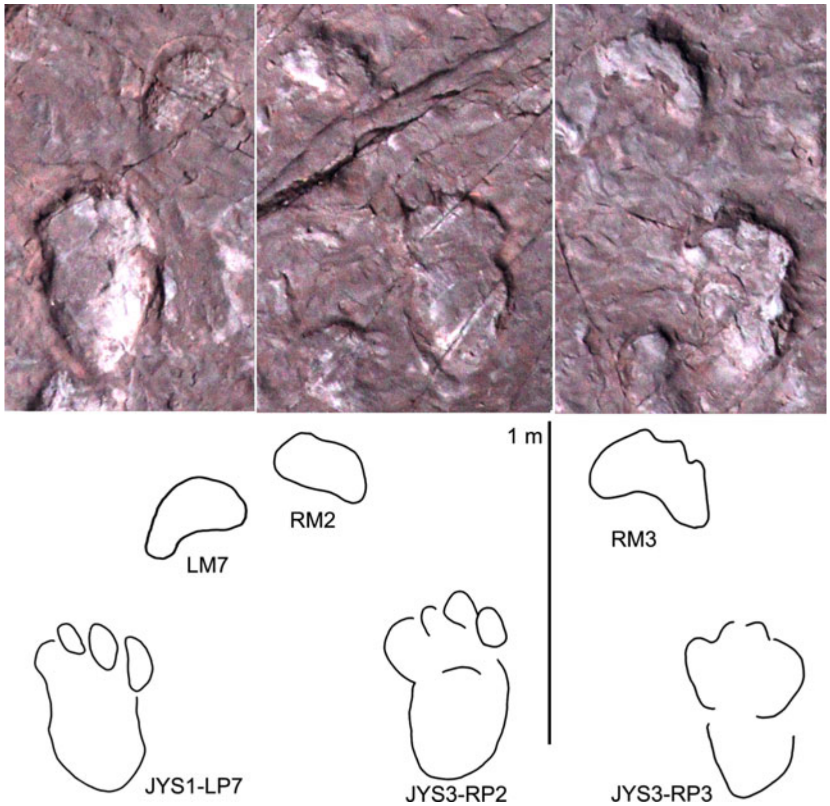


Figure 6. Photographs and interpretative outline drawing of manus-pes tracks JYS1-LP7, LM7 (holotype), JYS3-RP2, RM2 and JYS3-RP3, RM3 (paratype).

### *4.1.1. Description*

The pes imprints are tetradactyl with their length (l) and width (w) ranging from about 37–40 cm and 26–28 cm, respectively (average l/w ratios 1.32–1.54). They are outward-rotated, terminating anteriorly in four equidimensional, slightly curved digit traces that are oriented sub parallel to the pes axis (Figures 5–9). Pes sole area divided by a transverse crease, situated almost midway along the length of the tracks: i.e. about 40–45% of pes length from the anterior margin of the footprint. On the medial border, this crease terminates in a distinctive notch behind digit I. Pes claw traces make up about 25–30% of pes length.

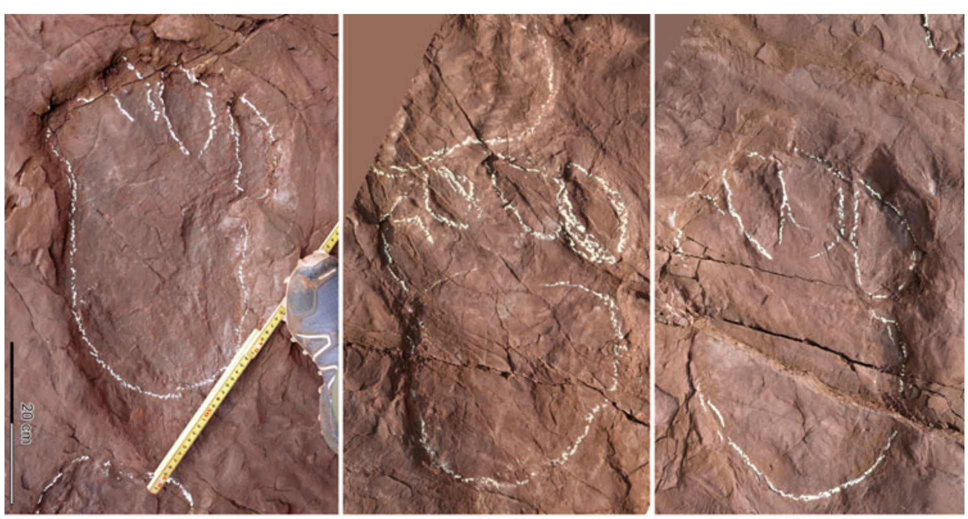


Figure 7. Photographs of pes tracks JYS1-LP7, LP8; JYS3-LP1.

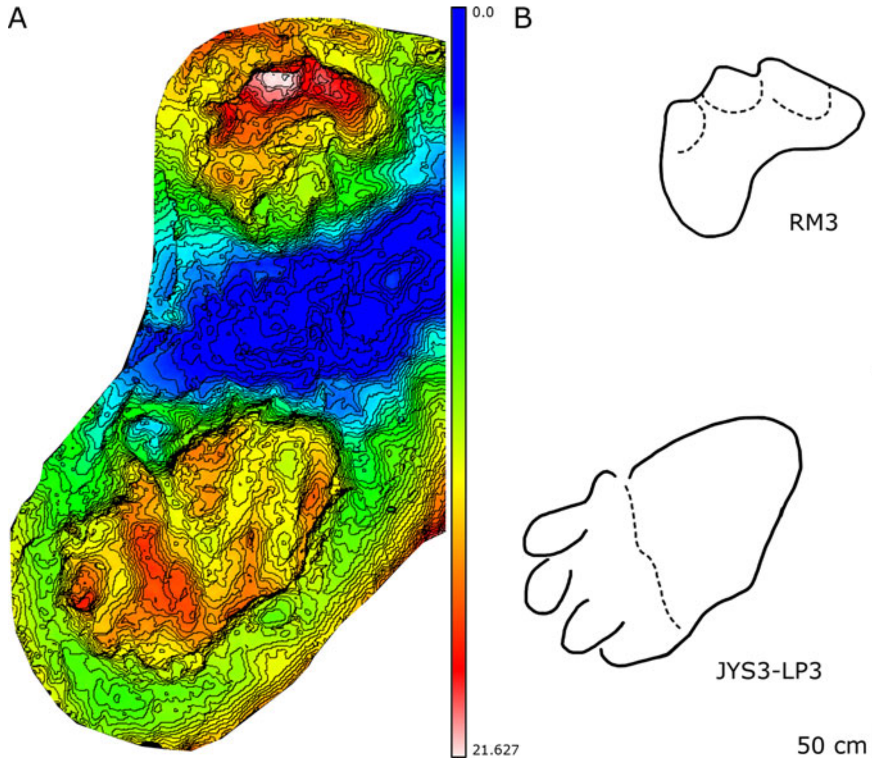


Figure 8. The 3D height map (A), and interpretative outline drawing (B) of the JYS3-LP3 and RM3.

Manus pentadactyl to semi-circular, wider than long, with length (l) between 15 and 18 cm and width (w) about 25 cm, (l/w ratios 0.60–0.74), subcircular to pentadactyl in outline.

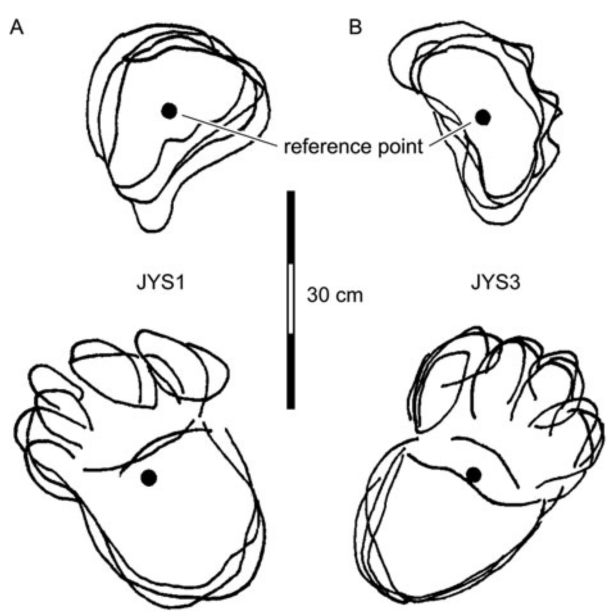


Figure 9. Composite manus pes outlines based on trackways JYS1 (A, holotype) and JYS3 (B, paratype).

Trackway narrow with pes inner trackway width 6–12 cm and pes outer trackway width ~75 cm. Inner trackway width greater for manus than for pes (~24–28 cm), but outer trackway width slightly less (63–70 cm). Outward rotation of the pes averages 38–40°, outward rotation of the manus ~52°. Pes pace angulation averages between 112 and 117°, manus pace angulation averages 105–111°. Pes step and stride averaging about 70–86 cm and 120–145 cm, respectively, manus step and stride averaging about 75–77 cm and 118–123 cm, respectively.

### 4.1.2. *Brontopodus-type*

An isolated trackway (JYS11) (Figure 10) of a small sauropodomorph from the upper surface of the upper sandstone appears to show all the features of a typical sauropod trackway such as *Brontopodus*-type (Table 3), except that it is relatively narrow gauge. It is small, with a mean pes length and width of 26.4 and 18.7 cm, respectively (l/w 1.41) and corresponding mean manus length and width of 10.4 and 18.3, respectively (l/w 0.57), mean outward rotation for the pes is 34° and mean pace angulation is 109°. These values are all similar to those recorded for trackways JYS1 and JYS3 from the main track-bearing surface (Tables 1 and 2). However, these are generalised, non-diagnostic features. Trackway JYS11 shows almost no pes or manus digit traces except in a few

Table 2. Measurements for *Liujianpus* paratype trackway JYS3.

| Track ID | Length | Width | Pes rot | Pace angle | Step | Stride |
|---|---|---|---|---|---|---|
| JYS3-LP1 | 40.5 | 26.0 | 42° | – | – | – |
| JYS3-LM1 | 16.5 | 24.0 | 62° | – | – | – |
| JYS3-RP2 | 42.5 | 27.0 | 40° | 110° | 65.5 | 124.0 |
| JYS3-RM2 | 12.0 | 22.0 | 58° | 110° | 75.5 | 120.0 |
| JYS3-LP2 | 38.0 | 27.0 | 45° | 112° | 84.5 | 126.0 |
| JYS3-LM2 | 13.5 | 25.0 | 68° | 112° | 76.0 | 115.0 |
| JYS3-RP3 | 40.0 | 26.5 | 30° | 114° | 65.0 | 109.0 |
| JYS3-RM3 | 18.0 | 29.5 | 64° | – | 75.5 | – |
| JYS3-LP3 | 40.0 | 24.0 | 43° | – | 65.0 | – |
| Mean-P | 40.2 | 26.1 | 40° | 112° | 70.0 | 119.7 |
| Mean-M | 15.0 | 25.1 | 63° | 111° | 75.5 | 117.5 |

cases where the trace of a manus pollex (digit I) appears to be present.

An easily accessible small pes JYSI-1 (Figure 11) with a maximum length of 26 cm and width of 18 cm (l/w 1.44) is exposed on the lower part of the main track surface in the eastern sector of the outcrop. This track was replicated and is preserved as UCM 178.19. The track shows strong outward rotation of the traces of digits I–III, but the trace of digit III is inconspicuous and there is no clear trace of digits IV and V. The trackway is incomplete. As the JYS11 trackway, JYSI-1 can be assigned to the *Brontopodus*-type track.

## 5. Discussion

The diagnostic features of *Liujianpus* are the four elongate slightly curved, equidimensional pes claw traces aligned sub-parallel to the pes axis and the pentadactyl blunt manus. The relative lengths of the pes digit traces III > IV = II > I are also diagnostic and can be shown to recur in consecutive right and left footprints in multiple trackways (Figures 5–9). Likewise, the distinctive transverse crease, ending medially in a notch behind the trace of digit I on the pes, is distinctive and seen in multiple tracks. Such a combination of features has not been reported from other sauropodomorph footprints, except for those in Ishigaki (1988).

Thus, the closest match for the tracks from Jiaoyuan are those illustrated by Ishigaki (1988, Figures 11 and 23) from the reliably dated Lower Jurassic Assif n Sremt (Sremt Assifn) site in Morocco. Although these tracks show the notch behind digit 1 quite clearly, Ishigaki (1988) did not describe these tracks in detail. Based on the illustrations: (1) the Moroccan tracks represent a quadruped; (2) they represent large animals (pes length and width 75 and 61 cm, respectively) making them almost twice the size of the Sichuan tracks; (3) the outward rotation of the pes is similar as are the relative digit lengths (III > IV = II > 1) and (4) the medial notch behind pes digit I seems to divide the track transversely as in the Sichuan footprints. The most significant difference is that the manus in the Moroccan trackways is less outwardly rotated and relatively smaller and divided into two impressions giving it a bilobed shape.

*Otozoum* from the Early Jurassic of North America (Hitchcock 1847, 1848, 1858; Lull 1904, 1953) has several similarities to *Liujianpus*, most notably in the relative lengths of the pes digits (III > IV = II > I). However, unlike *Liujianpus*, *Otozoum* has highly segmented pes digits with as many as three digital pads on the distal portions of the digits, which are clearly separated by the interdigital hypices that extend posteriorly for as much as 40–50% of pes length. Also, the inner digit traces of *Liujianpus* (digits I and II) are longer: i.e. more anteriorly

Table 1. Measurements for *Liujianpus* holotype trackway JYS1. Specimens JYS1-LP7 and LM7 are holotype.

| Track ID | Length | Width | Pes rot | Pace angle | Step | Stride |
|---|---|---|---|---|---|---|
| JYS1-RP7 | 36.0 | 28.5 | 40° | – | – | – |
| JYS1-RM7 | 17.0 | 25.0 | 65° | – | – | – |
| JYS1-LP7 | 42.0 | 27.5 | 40° | 110° | 90.0 | 143.0 |
| JYS1-LM7 | 24.0 | 25.5 | 45° | 105° | 86.0 | 128.0 |
| JYS1-RP8 | 33.5 | 29.0 | 32° | 124° | 82.0 | 146.0 |
| JYS1-RM8 | 14.5 | 24.5 | 61° | 105° | 75.0 | 118.0 |
| JYS1-LP8 | 37.0 | 27.5 | 30° | – | 88.0 | – |
| JYS1-LM8 | 17.5 | 24.0 | 37° | – | 71.0 | – |
| Mean-P | 37.1 | 28.1 | 38° | 117° | 86.0 | 144.5 |
| Mean-M | 18.3 | 24.6 | 52° | 105° | 77.3 | 123.0 |

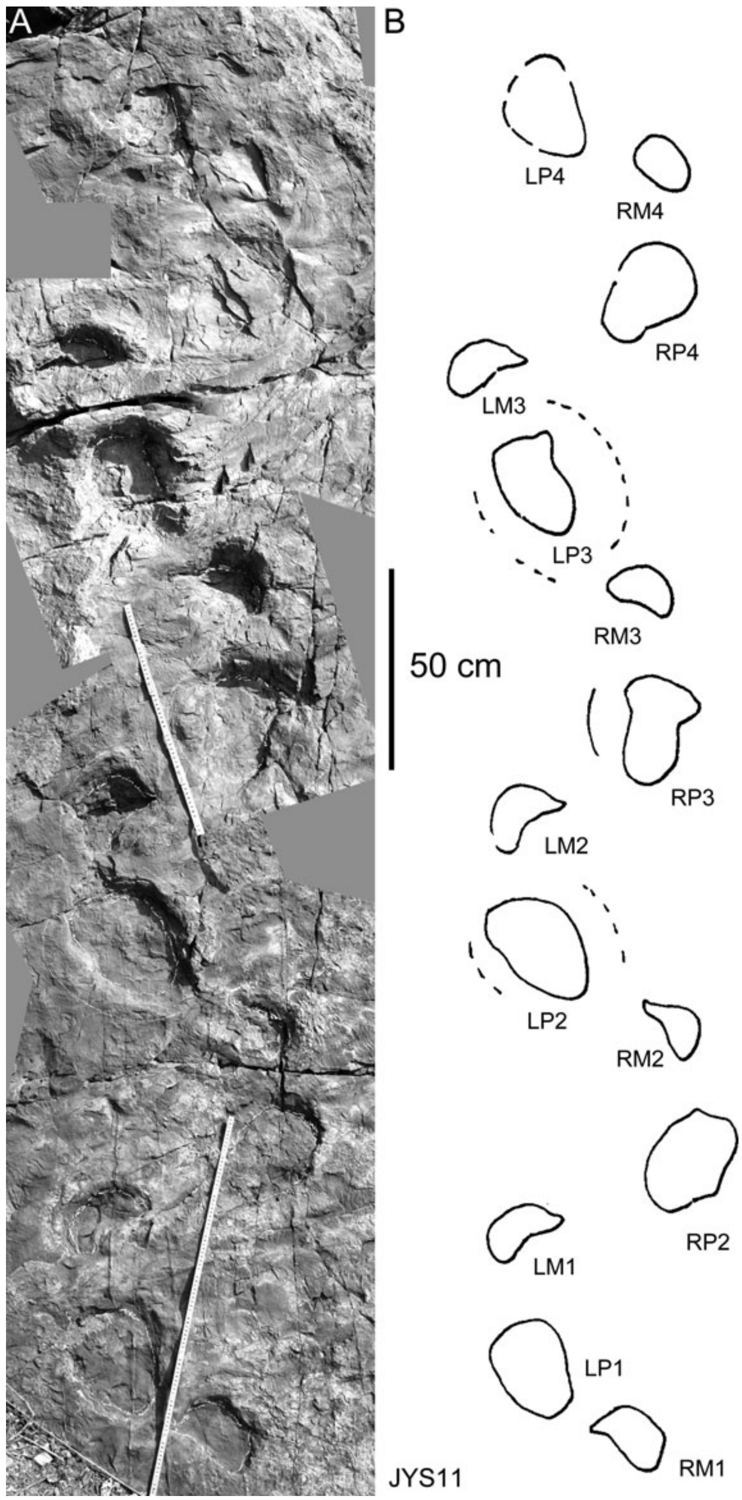


Figure 10. Photograph (A) and interpretative outline drawing (B) of small sauropod trackway JYS11 from the Jiaoyuan tracksite.

developed than in *Otozoum*, and the pes is far more strongly outwardly rotated. *Otozoum* trackways indicate bipedal progression except in rare cases including the holotype (Lull 1953; Rainforth 2003; Lockley et al. 2006a). Moreover, the rarely preserved manus is small in comparison with *Liujianpus*, more gracile and has well-separated digit traces. Also, in *Otozoum*, it is positioned laterally rather than anteriorly to the pes. Avanzini et al. (2003) claimed that *Lavinipes* was very similar to *Otozoum*, except that it evidently represented a fully

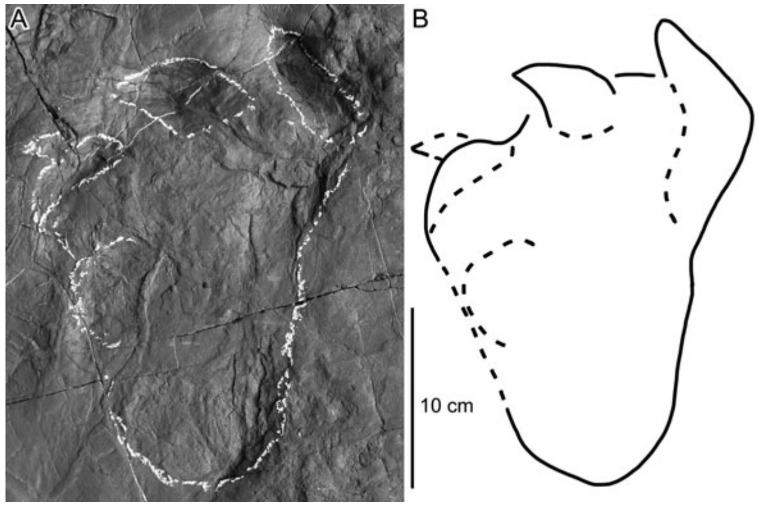


Figure 11. Photograph (A) and outline drawing (B) of small sauropod pes track JYSI-1 from the Jiaoyuan tracksite.

quadrupedal trackmaker. In this regard, *Liujianpus* is closer to *Lavinipes* in representing a quadruped with a manus larger than in *Otozoum*. However, the differences in the pes digit size and outward rotation between *Liujianpus* and *Lavinipes* are just as pronounced as those outlined earlier between *Liujianpus* and *Otozoum*.

*Liujianpus* is similar to typical *Brontopodus* or *Brontopodus*-like sauropod trackways in a number of general, mostly non-diagnostic, features. Most notable are the similarities in the oval, elephantine, outwardly rotated, fleshy pes, with large anterior claw traces and the semicircular outwardly rotated manus. Pace angulation values are similar to those reported for typical sauropod trackways (vid. Farlow et al. 1989). However, the digit configuration and orientation of *Liujianpus* is quite different. Notably, digit I is the shortest and digit III the longest, with digit IV being well developed. This is in contrast to the typical sauropod configuration where digit I is the longest, with digits II–V being progressively shorter (I > II > III > IV > V). In *Liujianpus*, digit I is less conspicuous, and, contrary to *Brontopodus*, digits IV and V lack claw traces. The different configuration III > IV = II > I of digit traces and their orientation subparallel to the footprint long-axis strongly supports a distinct ichnogenus *Liujiangpus*.

Although some of the *Liujianpus* manus tracks are semicircular to crescent shaped without distinct digit traces, unlike many sauropod tracks, a significant number show distinct traces of all five manus digits (Figure 5). Such configurations are rare in sauropod tracks and are again more reminiscent of the basal sauropodomorph track *Otozoum*. However, as noted earlier, *Otozoum* manus tracks are rare and smaller, with more clearly differentiated digits yhasn in *Liujianpus*.

Table 3. Measurements for sauropod trackway JYS11.

| Track ID | Length | Width | Pes rot | Pace angle | Step | Stride |
|---|---|---|---|---|---|---|
| JYS11-RM1 | 10.5 | 18.5 | – | – | – | – |
| JYS11-LP1 | 24.5 | 19.0 | 35° | – | – | – |
| JYS11-LM1 | 10.5 | 20.0 | – | – | – | – |
| JYS11-RP2 | 27.0 | 18.5 | 35° | 105° | 66.0 | 105.0 |
| JYS11-RM2 | 9.0 | 18.5 | – | – | – | – |
| JYS11-lp2 | 29.5 | 19.0 | 44° | 107° | 66.0 | 109.0 |
| JYS11-lm2 | 12.0 | 20.0 | – | – | – | – |
| JYS11-rp3 | 25.0 | 19.0 | 17° | 112° | 65.0 | 116.0 |
| JYS11-rm3 | 10.5 | 17.0 | – | – | – | – |
| JYS11-lp3 | 25.5 | 17.5 | 30° | 112° | 69.0 | 110.0 |
| JYS11-lm3 | 10.5 | 19.0 | – | – | – | – |
| JYS11-rp4 | 27.0 | 19.0 | 43 | 109° | 59.0 | 96.0 |
| JYS11-rm4 | 10.0 | 15.0 | – | – | – | – |
| JYS11-lp4 | 26.0 | 19.0 | 40° | – | 55.0 | – |
| Mean-P | 26.4 | 18.7 | 34° | 109° | 63.3 | 107.2 |
| Mean-M | 10.4 | 18.3 | – | – | – | – |

Table 4. Comparison between *Otozoum*, *Liujianpus* and *Brontopodus* indicates which features are characteristic of prosauropods (p) or sauropods (s).

| Ichnogenus | Trackway pattern | General pes shape | Pes digit traces | Pes digit lengths | Pes–manus rotations | Manus outline | Manus digit traces |
|---|---|---|---|---|---|---|---|
| *Otozoum* | p | p | p | p | p | p | p |
| *Liujianpus* | s | s | p | p | s | p/s | p |
| *Brontopodus* | s | s | s | s | s | s | s |

Note: The diagnostic morphological features of *Liujianpus* are equally divided between those characteristic of prosauropods and those typical of prosauropods.

*Liujianpus* shows a combination of features shared with both *Otozoum* and *Brontopodus*. Therefore, it cannot be assigned to either of them, and is considered here as a new ichnogenus (Table 4). To date, the closest match for overall trackway configuration and pes track morphology comes from the unnamed Moroccan material reported by Ishigaki (1988).

The discovery of a large sample of sauropodomorph tracks combining morphological features of well-known basal sauropodomorph and sauropod ichnogenera indicates that the morphological diversity of sauropodomorph tracks, and their relationship to the evolution of the sauropodomorph pes, is still not fully understood. Moreover, the occurrence of such intermediate morphologies has implications for the evolution and diversification of sauropodomorphs, especially in the early Mesozoic.

Fortunately, sauropodomorph dinosaurs are well known in southern China from the early Jurassic. For example, the basal sauropodomorph *Lufengosaurus* (Young 1941) is abundant in Yunnan Province, and its pedal morphology (Figure 12) is consistent with the *Liujianpus* morphotype. *Lufengosaurus* co-occurs with other basal sauropodomorph such as *Yunnanosaurus huangi* and various Early Jurassic sauropods such as *Chinshakiangosaurus* and *Jingshanosaurus.* According to Upchurch et al. (2007), *Chinshakiangosaurus* possesses an unusual combination of basal sauropodomorph and sauropod features. Thus, the Jiaoyuan footprints seem also just as useful as skeletal remains in inferring intermediate or mixed characteristics of early sauropodomorph morphology in the Early Jurassic of Asia.

Remarkably, some complete sauropodomorph skeletons were discovered in the Lower Jurassic Dongyuemiao Member of the Ziliujing Formation in Gongxian County in the southern Sichuan Basin, which were named *Gongxianosaurus shibeiensis* (He et al. 1998). *Gongxianosaurus* is approximately 14 metres in body length. He et al. (1998) and Luo and Wang (2000) assigned the specimens to early sauropods according to the ratio of fore limbs to hind limbs was 70–75%. The Gongxian specimens were assigned to basal sauropodomorph based on characteristics such as the amphiplatyan–amphicoelous vertebrae and an ilium with typical basal sauropodomorph morphology. The phalangeal formula is 2-3-4-5-1 (Dong Z.M. pers. comm.). A recent analysis by Apaldetti et al. (2011) suggests that *Gongxianosaurus* was more basal than *Vulcanodon*, *Tazoudasaurus* and *Isanosaurus*, but more derived than the early sauropods *Antetonitrus*, *Lessemsaurus*, *Blikana-*


Figure 12. Well-preserved *Lufengosaurus huenei* pes skeleton ZLJ 0023 from Lower Jurassic Lufeng Basin, Yunnan Province for comparison.

*saurus*, *Camelotia* and *Melanorosaurus*. In general, the combined characteristics of Basal sauropodomorph and Sauropoda are reflected in *Gongxianosaurus*, just as they are in *Liujianpus*.

Most sauropod trackways in China are wide- (or medium-) gauge and are therefore referred to the ichnogenus *Brontopodus* (Lockley et al., 2002). Xing et al. (2010, 2013, 2015) also assigned the Early Cretaceous narrow-gauge, medium-sized/small-sized sauropod trackways from the Nanguzhai tracksite, Jishan tracksite and the Qianjiadian tracksite to *Parabrontopodus* isp. However, the Jiaoyuan JYS11 trackway lacks a strong outward rotation of the manus, which is a typical characteristic in Chinese medium-sized/small-sized *Parabrontopodus* tracks (Xing, Lockley, Bonnan et al in press). Therefore, the characteristics of Jiaoyuan JYS11 trackway are more closer to the *Brontopodus*-type tracks. Lastly, the presence of a small *Brontopodus*-like trackway in close association with the assemblage of much larger *Liujianpus* indicates that small and large sauropodomorphs may have co-existed.

## 6. Conclusion

1. The Jiaoyuan track site reveals the largest sauropodomorph trackway assemblage currently known from the Early Mesozoic (probably Lower Jurassic) of China, and indeed from all of Asia.
2. The site consists of multiple sub parallel and bimodally oriented trackways on a steep, near vertical wall.
3. The trackways include at least two morphotypes: a *Brontopodus*-type form of presumed 'true' sauropod affinity, and a new sauropodomorph ichnotaxon, *Liujianpus shunan* ichnogen. nov. ichnosp. nov. of probable basal sauropodomorph affinity.
4. *Liujianpus* combines features of *Brontopodus, Otozoum* and the *Otozoum*-like European sauropodomorph track *Lavinipes*, but is morphologically distinct from all three in pes digit and manus track morphology.
5. It is somewhat similar to an unnamed Early Jurassic track from Morocco.
6. The combination of morphological features attributed to both basal sauropodomorph and sauropods expands the range of sauropodomorph known footprint morphologies.
7. The footprint morphotypes may be linked with foot morphologies intermediate between basal sauropodomorph and sauropods, which is consistent with the skeletal record of sauropodomorphs in the Early Jurassic of Asia.



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