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# Sauropod Trackway Reflecting an Unusual Walking Pattern from the Early Cretaceous of Shandong Province, China

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**ABSTRACT**

The trackway of a quadrupedal dinosaur from the Early Cretaceous (Albian) Qingquan tracksite (Tancheng, Shandong Province) is redescribed, and the trackmaker is identified as a sauropod. The trackway makes a slight turn towards the northwest and is characterized by an extremely narrow gauge pattern and an unusual configuration, i.e., a conspicuous difference between the position of the left and right manus tracks with respect to the position of the preceding pes track. Left manus tracks are located on the inside of the trackway, very close (and sometimes even in connection) to the opposite right pes tracks. So far, the Qingquan trackway is possibly the only extremely narrow-gauge sauropod trackway known from China. However, it is not clear to what extent this extremely narrow gauge pattern is related to the turning or a special behavior, or even linked to an injury ("limping trackway"). We tentatively attribute the Qingquan trackway to cf. *Parabrontopodus*, even though it has a rather low heteropody that is significantly lower than in *Parabrontopodus* and not typical for narrow-gauge sauropod trackways, but occurs in the wide-gauge ichnotaxon *Brontopodus*. Because of this discrepancy, the Qingquan trackway cannot readily be attributed to a more basal sauropod, which is generally considered the producer of narrow-gauge trackways. Therefore, the identification of a distinct sauropod group is not possible presently. The only skeletal remains of sauropods from the Lower Cretaceous of Shandong Province belong to the large titanosauriform, *Euhelopus zdanskyi*.

**KEYWORDS**
Sauropod track; Trackway configuration; Locomotion; Trackway gauge; Early Cretaceous; Tancheng

## Introduction

Large tracks of sauropod dinosaurs are characteristic trace fossils and can generally easily be recognized and identified as such if they are reasonably well-preserved. Sauropod tracks have been discovered in Mesozoic rocks throughout China (e.g., Lockley et al., 2002; Xing et al., 2010). Zhen et al. (1996) reported several large (pes length up to 82 cm) sauropod tracks from Lower Cretaceous deposits of Donghai County, Jiangsu Province, but without providing any detailed descriptions or figures. Large sauropod tracks from the Cretaceous have also been discovered from Chabu in Inner Mongolia, Chuxiong in Yunnan Province (Lockley et al., 2002), Yanguoxia in Gansu Province (Zhang et al., 2006), and Donghai in Jiangsu Province (Xing et al., 2010). The largest pes tracks from the Chabu No. 2 tracksite range between 75–80 cm in length and 55–60 cm in width. The pes tracks from Donghai range from about 76–92 cm in length and 77–79 cm in width (Xing et al., 2010).

Two dinosaur tracksites are already known from Tancheng County (Xing et al., 2010) (Fig. 1). The distance between the Qingquan tracksite from Tancheng County and the Nanguzhai tracksite from Donghai County is only 11 km, and both are within the Malingshan area.

Previously, the age of the Qingquan tracksite had not been determined. The oldest published description of the tracks comes from the local county annals, and simply states that: the tracksite is situated at Qingquan Village, Quanyuan Township, 500 m northwestward of Malingshan. Hou Lianhai from the Institute of Vertebrate Paleontology and Paleoanthropology identified these tracks as hadrosaur tracks (Song and Wang, 2006).

In 2012, Kuang et al. (2013) recognized that the tracks were not those of hadrosaurs, but sauropods instead. In 2013, Xing, Liu, Kuang, et al. (2013) undertook a more detailed analysis of the tracksite, and here we present a redescription of the trackway and an interpretation of its particular configuration linked to a slight turn.

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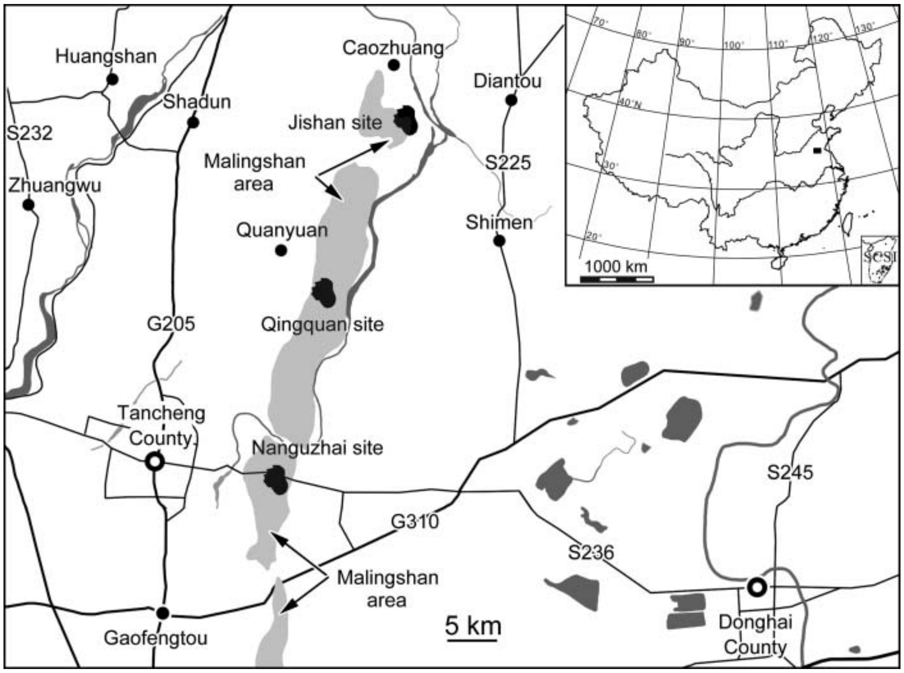


Figure 1. Location of the Qingquan, and the Jishan and Nanguzhai sauropod tracksites (indicated by sauropod pes track icons) in Shandong Province, China.

## Geographical and geological setting

The Qingquan tracksite (118°28′08″E, 34°42′26″N) is located in the Tianjialou Formation of the Dasheng Group, within the Yishu fault belt (the middle segment of the Tanlu fault zone) (Wang et al., 2000). Within the Yishu fault belt, the Lower Cretaceous strata are made up of fluvial deposits with fine-grained sediments and well-developed fluviatile sedimentary bedding structures (Jiangsu Bureau of Geology and Mineral Resources, 1984; Shandong Provincial Bureau of Geology and Mineral Resources, 1991).

The track-bearing surface is located on a steep mountainside (46°) north of Qingquan Temple, on the western part of the Malingshan Syncline. The tracksite lies 30 km NE of Tancheng County in Shandong Province, in the Yishu fault belt, and close to the Nanguzhai tracksite in Donghai County of the Jiangsu Province (Fig. 1), which is also located in the Yishu fault belt. Both these tracksites are located at approximately the same stratigraphic position, even though a precise correlation is not possible.

Above the Lower Cretaceous pyroclastic rocks of the Qinshan Group (Shi et al., 2003) lies a series of clastic, terrestrial deposits with purplish polymictic conglomerates, fine sandstones, and occasionally yellow-green siltites that is partially mixed with volcanic deposits (Si, 2002). Although there is controversy within the geologic literature about the subdivision and formational history of the Dasheng Group (Li and Zhao, 1992; Si, 2002; Liu et al., 2003), it is generally agreed that the lower part of the Tianjalou Formation of the Dasheng Group corresponds with the upper part of the Shiqianzhuang Formation of the Qingshan Group (Tang et al., 2008), having been deposited within the Aptian–Albian (about 120–100 Ma). Being located within the upper part of the Dasheng Group, and in the middle-upper part of the Lower Cretaceous series, the Qingquan tracksite can possibly be attributed to the Albian, about 110–100 Ma ago.

The sauropod trackway is preserved in a layer of fine sandstone including irregular gypsum crystals, which suggests arid climatic conditions at or near the time of track formation. Later, the tracks were filled and covered up with a thin layer (5 cm thick) of purplish-grey fine sandstone, that is characterized by a dense network of polygonal desiccation cracks with a diameter of about 4–5 cm (Figs. 2 and 3). Above this lies a thicker (approximately 30 cm) layer of cross-bedded sandstone with components ranging in size from very fine to coarse. And no other tracks have been found on this upper sandstone surface. On the track level, slightly sinusoidal ripple marks are preserved and oriented approximately NW-SE. These sedimentary characters are consistent with the environment of a fluvial channel of a braided-river system.

## Methodology

Weathering due to prolonged exposure has not yet significantly damaged the Qingquan tracksite (abbreviated

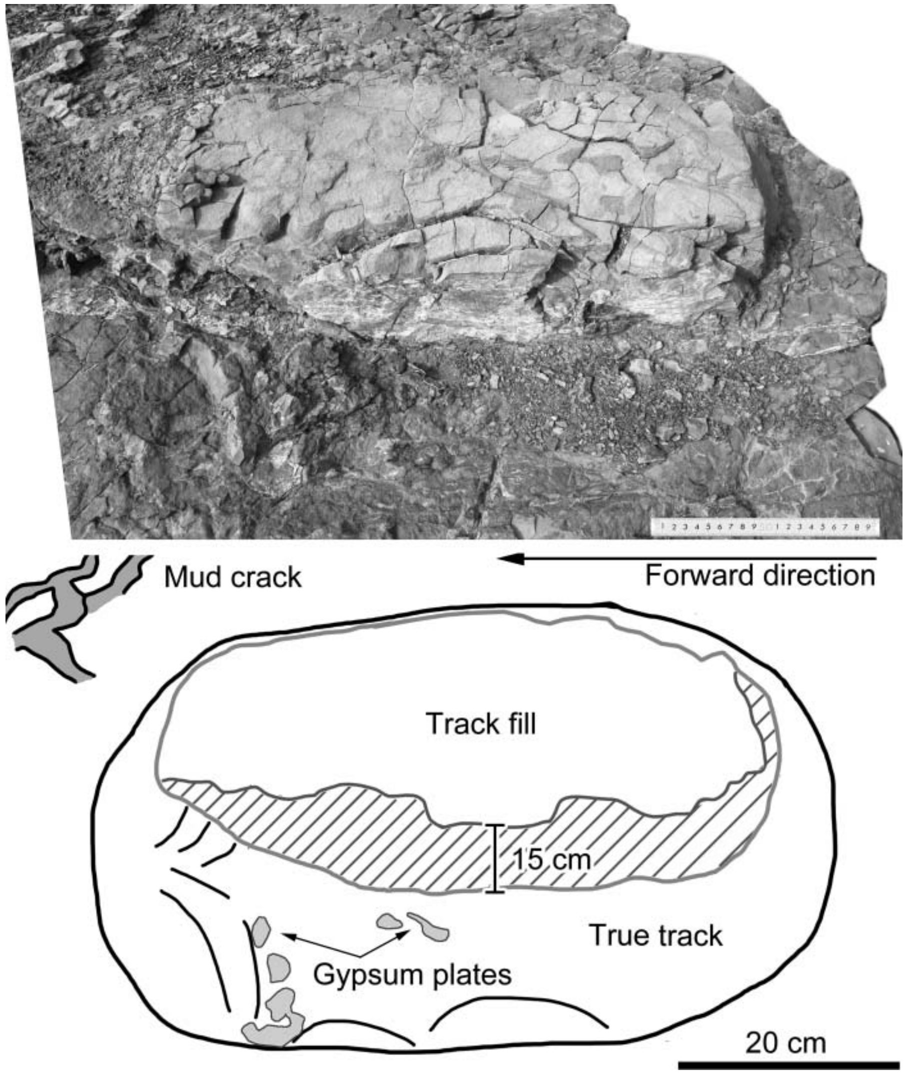


**Figure 2.** Low-angle light photograph and outline drawing of Qingquan sauropod track QQ-S1-LP1.

QQ in labels of imprints), and most of the tracks are even still covered and protected by the track fills and the overlying layer. To better observe the morphology of some of the tracks, the track fills of QQ-S1-LP1, LM1, RP1, and RM1 were removed. Due to the steeply inclined track surface (46°), it was not possible to measure the entire trackway. Only the lowermost six pes-manus track pairs were measured (Table 1), and traced on transparent plastic and acetate sheets at a scale of 1:1. Thus, the upper part of the trackway outline drawing as shown in Figure 3 (the tracks after RP3/RM3) is schematic only as it is based on the photograph. Similarly, the trackway parameters could only be measured for the first five steps but not for the entire trackway.

Trackway gauge (trackway width) was quantified for pes and manus tracks by using the ratio between the width of the angulation pattern of the pes (WAP) or manus (WAM) and the maximum pes length (P'ML) or manus width (M'MW), respectively (according to Marty, 2008; Marty et al., 2010a). The (WAP/P'ML)-ratio and (WAM/M'MW)-ratio were calculated from pace and stride length, assuming that the width of the angulation pattern intersects the stride under a right angle and at the approximate midpoint of the stride (Marty, 2008). If the [WAP/P'ML]-ratio equals 1.0, the pes tracks are likely to touch the trackway midline. If the ratio is smaller than 1.0, tracks intersect the trackway midline, which corresponds to the definition of narrow-gauge (see Farlow, 1992). Accordingly, a value of 1.0 separates narrow-gauge from medium-gauge trackways, whereas the value 1.2 is arbitrarily fixed between medium-gauge and wide-gauge trackways, and trackways with a value higher than 2.0 are considered to be very wide-gauge (Marty, 2008). Marty (2008) has also shown that the (WAP/P'ML) and (WAM/M'MW)-ratios can be well compared with the "trackway ratio" proposed by Romano et al. (2007) for the quantification of trackway gauge. Therefore, the "trackway ratio" is not calculated here.

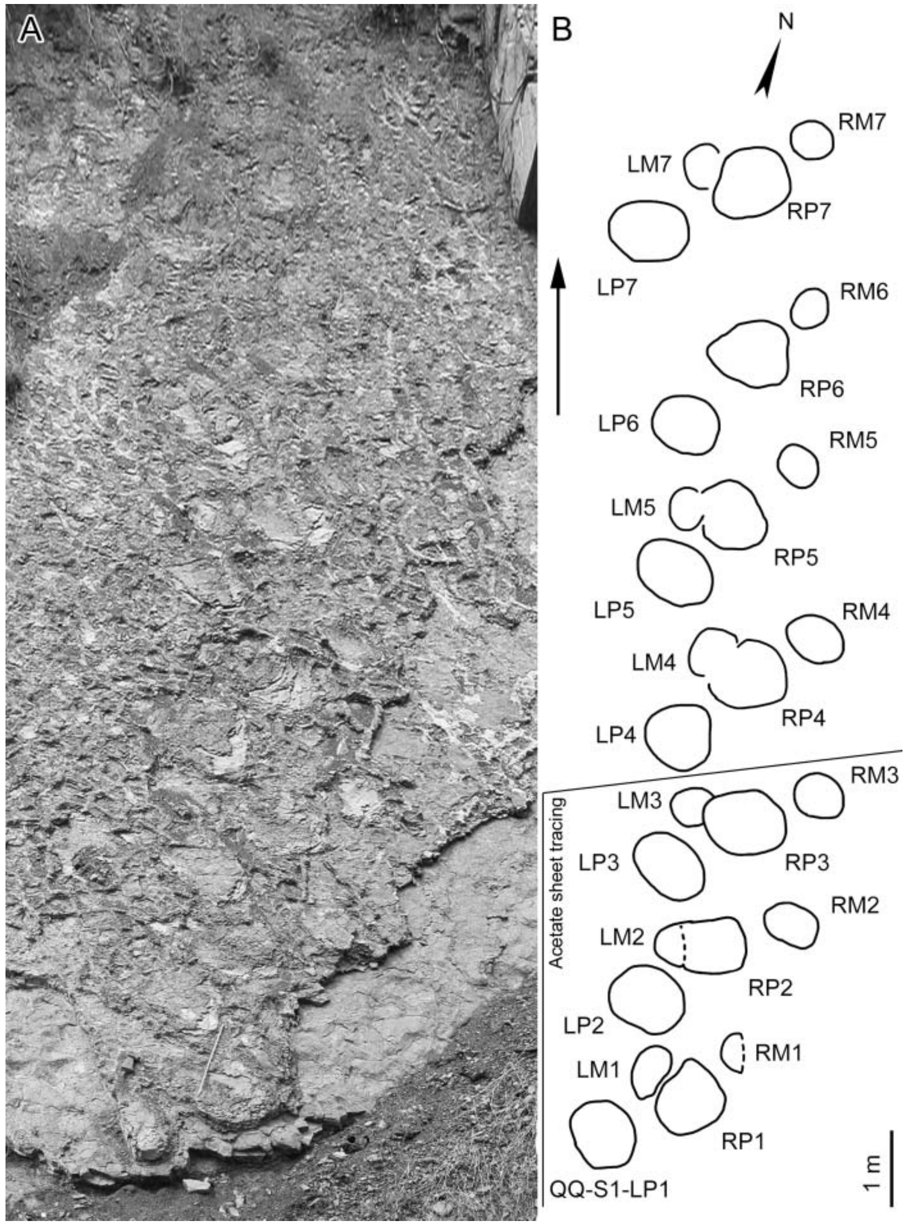


**Figure 3.** The sauropod trackway QQ1from the Qingquan tracksite (map). **A**. Photograph. **B**. Outline drawing based on 1:1 acetate sheet drawing of the tracks LP1–RM3, and schematic outline drawing (not representing real distances) based on the photograph shown in A for LP4–RM7.

## Description of tracks and trackways

### *Trackway QQ-S1*

The sauropod trackway QQ-S1 of the Qingquan tracksite consists of 14 pes-manus track pairs, cataloged as QQ-S1-LP1–RP7 and LM1–RM7 (Figs. 3 and 4; Table 1). All tracks remain in the field.

QQ-S1 is best described as the trackway of a quadruped (*sensu* Marty et al., 2006), even though one single manus track (LM6) seems to be missing. However, its presumed position is high up in the site, where direct observations were not possible. Thus, this track may be overprinted by RP6 or still be covered by the overlying sediment layer.

Between LP1 and LP3, the trackway is making a slight turn towards the northwest. The trackway is characterized by a conspicuous difference between the position of the left and right manus tracks with respect to the position of the preceding pes tracks, occurring all along the trackway. The left manus tracks are located on the inside of the trackway, very close to the opposite right pes track, and sometimes even in touch with (or overstepped by) the opposite pes track (LM2–RP2; LM3–RP3). The right manus tracks, on the other hand, are located more or less in the prolongation of the subsequent pes' long axis and well in front of the subsequent pes, i.e., they show no partial overprinting by the subsequent pes, and they

**Table 1.** Measurements (in cm) of the sauropod trackway QQ1 from the Qinquan tracksite. Abbreviations: WAP: Width of the angulation pattern of the pes (calculated value); WAM: Width of the angulation pattern of the manus (calculated value); WAP/PL and WAM/MW are dimensionless. The "L" and "R" in the trackway number stand for left and right tracks, respectively.

| | Track parameters and ratios | | | | | | | | Trackway parameters and ratios | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pes tracks | | | | Manus tracks | | | | Pes tracks | | | Manus tracks | | | | | | |
| Trackway number | Length (P'ML) | Width (P'MW) | Length/ width | Rotation | Length (M'ML) | Width (M'MW) | Length/ width | Rotation | Stride length | Pace length | Pace angulation | Stride length | Pace length | Pace angulation | WAP | WAM | WAP/ P'ML | WAM/ M'MW |
| QQ-S1-LP1 | 84.0 | 66.0 | 1.3 | 37° | — | — | — | — | 166.8 | 107.8 | 89° | — | — | — | — | — | — | — |
| QQ-S1-LM1 | — | — | — | — | 38.7 | 62.8 | 0.6 | 71° | — | — | — | 148.9 | — | — | — | — | — | — |
| QQ-S1-RP1 | 81.0 | 68.6 | 1.2 | 40° | — | — | — | — | 182.1 | 130.5 | 109° | — | — | — | 84.3 | — | 1.0 | — |
| QQ-S1-RM1 | — | — | — | — | — | — | — | 59° | — | — | — | — | — | — | — | — | — | — |
| QQ-S1-LP2 | 86.0 | 73.7 | 1.2 | 68° | — | — | — | — | 155.2 | 92.5 | 104° | — | — | — | 61.9 | — | 0.7 | — |
| QQ-S1-LM2 | — | — | — | — | 35.7 | 52.4 | 0.7 | 90° | — | — | — | 158.5 | 139.6 | 58° | — | — | — | — |
| QQ-S1-RP2 | 82.0 | 69.2 | 1.2 | 60° | — | — | — | — | 148.6 | 103.3 | 95° | — | — | — | 58.5 | — | 0.7 | — |
| QQ-S1-RM2 | — | — | — | — | 44.1 | 65.7 | 0.7 | 50° | — | — | — | 152.8 | 180.1 | 55° | — | 134.4 | — | 2.0 |
| QQ-S1-LP3 | 89.7 | 63.1 | 1.4 | 48° | — | — | — | — | — | 102.1 | — | — | — | — | 68.9 | — | 0.8 | — |
| QQ-S1-LM3 | — | — | — | — | 48.8 | 47.8 | 1.0 | 80° | — | — | — | — | 147.4 | — | — | 140.3 | — | 2.9 |
| QQ-S1-RP3 | 81.0 | 74.5 | 1.1 | 69° | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| QQ-S1-RM3 | — | — | — | — | 52.1 | 61.5 | 0.9 | 60° | — | — | — | — | — | — | — | — | — | — |
| Mean | 84.0 | 69.2 | 1.2 | 54° | 43.9 | 58.0 | 0.8 | 68° | 163.2 | 107.2 | 99° | 153.4 | 155.7 | 57° | 68.4 | 137.4 | 0.8 | 2.5 |

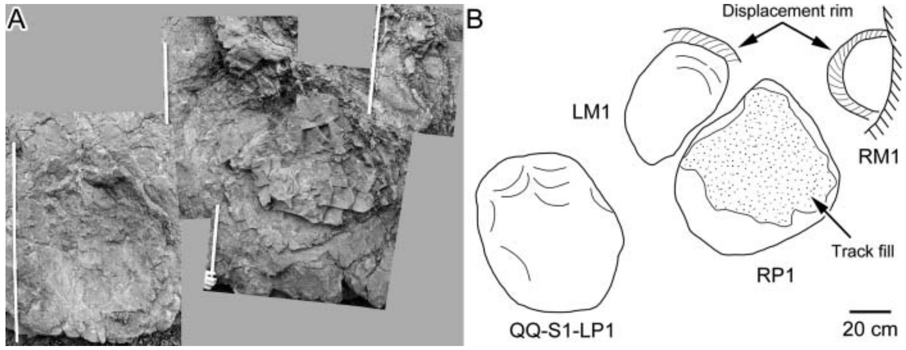


**Figure 4.** Photographs and outline drawings of the Qingquan sauropod tracks QQ-S1-LP1, LM1, RP1, and RM1.

are generally located quite far outside of the trackway, in a large distance to the left pes tracks.

The pes tracks are clearly intersecting the trackway midline, and also the mean (WAP/P'ML)-ratio of 0.8 indicates that the QQ-SI trackway is very narrow gauge.

### *Description of individual tracks*

All tracks of the QQ-S1 trackway are quite deep and surrounded by sediment displacement rims around the internal region that contains the true track *sensu stricto* (Fig. 2). Most of the tracks still bear the track fill, and in this case, the true track cannot directly be observed.

The pes track LP1 and the manus track LM1 are the best-preserved (Fig. 4). LP1 is oval in shape, has a length of 84 cm, a width of 66 cm, and a length:width ratio of 1.3. No digit or claw impressions are preserved. The metatarsophalangeal region is slightly curved. The minimum distance between LP1 and LM1 is 25.5 cm. LM1 is semicircular in shape, has a length of approximately 39 cm, a width of 68 cm, and a length:width ratio of 0.6. It lacks any discernible digit or claw impressions, and it is surrounded by an incomplete medial displacement rim. The medial part of the track is significantly deeper than the lateral and posterior part, and the metacarpophalangeal region is posteriorly concave.

QQ-S1-RP1 and RM1 are similar to QQ-S1-LP1 and LM1 regarding general morphology. However, RM1 is partially eroded. Remarkably, the medial region of RP1 is located merely 4 cm from the metacarpophalangeal region of LM1. RP1 and LM1 are located so close to each other that the border could only be discerned after the track fill was removed. RP1 is even slightly overprinting LM1.

The left manus tracks are rotated outwards relative to the trackway axis with a mean value of 80°. This is clearly higher than the outward rotation of the pes tracks (mean value of 54°). The axis of the right manus tracks is almost parallel to the trackway axis. The mean pace angulation is 57° for the manus and 99° for the pes tracks.

There are five poorly-preserved round impressions located outside of the QQS1 trackway (not figured here), with a diameter of approximately 32 cm. These are likely smaller sauropod pes tracks, indicating that smaller individuals were also present. This is consistent with other tracksites from the Malinshan region where different sauropod track sizes usually coexist (Xing et al., 2013).

## Discussion

### *Ichnotaxonomy and differential diagnosis*

The pes and manus track morphology and also their large size is typical for trackways attributed to sauropods (e.g., Farlow, 1992; Meyer et al., 1994; Lockley, 1999, 2001; Santos et al., 2009; Marty et al., 2010a), even though the trackway configuration, notably the position of the left manus tracks, is rather unusual.

As indicated by its very low (WAP/P'ML)-ratio of 0.8 (Table 1), the trackway QQ1 is extremely narrow-gauge, and commonly such trackways are attributed to the ichnotaxa *Parabrontopodus* or *Breviparopus* (Lockley et al., 1994b; Fig. 5). Marty et al., (2010a) considered both narrow-gauge ichnotaxa *Parabrontopodus* and *Breviparopus* to be valid, even though they have recommended the latter to be formally used until better preserved tracks are found than those currently exposed.

*Parabrontopodus* is described as (1) narrow sauropod trackway of medium to large size (track length about 50–90 cm), (2) no space between trackway midline and inside margin of pes tracks, (3) pes tracks longer than wide with long axis rotated outward, (4) pes claw impressions corresponding to digits I, II, and III with strong outward rotation, and (5) manus tracks semicircular and small in comparison with pes tracks (i.e., pronounced heteropody) (Lockley et al., 1994a).

*Breviparopus* is characterized by (1) a clearly narrow-gauge, (2) pes tracks intersecting the trackway midline, (3) manus tracks positioned in a larger distance to the trackway midline than the pes tracks, and (4) pes tracks with a slightly oval shape (Dutuit and Ouazzou, 1980; Marty et al., 2010a).

Santos et al. (2009; table 3) have proposed the ichno-morphotype or plexus "*Breviparopus/Parabrontopodus*—like," characterized by a (1) narrow—gauge trackway, (2) wide pes prints with anteriorly (or slightly outwardly) directed claw or digit marks, (3) crescent shaped manus prints, and (4) a high heteropody.

There is no uniform use of these ichnotaxa and names in the different ichnological studies, and the ichnotaxonomy of narrow-gauge sauropod trackways is in need of revision. Because *Breviparopus*, originally introduced by Dutuit and Ouazzou (1980), was never formally erected, presently *Parabrontopodus* (Lockley et al., 1994) is the valid ichnogenus. Both might be synonymous and *Breviparopus* as the older name would have priority after being described in accordance with ICZN rules.

The Qingquan sauropod trackway QQ1 partly matches the "*Breviparopus/Parabrontopodus*—like" ichno-morphotype of Santos et al. (2009) in the narrow gauge pattern and the wide crescent-shaped manus imprints, and regarding the general descriptions of *Parabrontopodus* and *Breviparopus* is closer to *Breviparopus*. However, the QQ1 trackway has a rather low heteropody of 1:2.5, significantly lower than in both *Breviparopus* (1:3.6) and *Parabrontopodus* (1:4 or 1:5), but close to the wide-gauge ichnotaxon *Brontopodus* (1:3). Furthermore, in comparison with the "*Breviparopus/Parabrontopodus-like"* pattern described by Santos et al. (2009), it lacks the anteriorly or outwardly directed digit marks. This, however, could be a preservational feature.

The nearby and coeval sauropod tracksite at Jishan exhibits wide gauge trackways with a low heteropody (1:1.5; Xing et al., 2013), whereas the tracksite near Nanguzhai has large sauropod pes-manus track pairs with a heteropody of about 1:2.7, similar to the Qingquan sauropod trackway QQ1.

Most other sauropod trackways known from China are wide (or medium) gauge and therefore referred to the ichnotaxon *Brontopodus* (e.g., Lockley et al., 2002; Li et al., 2011; Xing et al., 2013). Only a few sauropod trackways with medium-sized tracks are narrow gauge, and are referred to the ichnotaxon *Parabrontopodus*, (e.g., Xing et al., 2010; Xing et al., 2013). The Qingquan sauropod trackway is possibly the only extremely narrow-gauge sauropod trackway thus far, and for this reason also differs from other Chinese sauropod trackways. However, it is not clear, how much this extremely narrow gauge is related to the turning, a special behavior such as walking along a slope, or even linked to an injury. Also, the presence of undertracks, which might falsify true track size and gauge calculations, cannot be excluded. The factors affecting gauge may include the speed of the trackmaker (Xing et al., 2010; Castanera et al., 2012) and the quality of preservation. This latter factor is important to differentiate between true tracks with well-defined outlines, steep walls, and undertracks with very low angle margins, which may reduce the inner trackway width and estimation of gauge. Unfortunately, effective statistical evaluation is difficult due to the poor exposed QQ1 trackway. Therefore, we tentatively attribute the QQ1 trackway to cf. *Parabrontopodus*, even though its heteropody is much lower than in *Parabrontopodus*, and not typical for a narrow-gauge sauropod trackway.

## Locomotion and locomotion speed

Because of its unusual interior position and extreme outward rotation (supination) of the left manus tracks, the QQ-S1 trackway potentially is an interesting trackway for future studies that aim to reconstruct sauropod locomotion. At the beginning of the trackway, this (for sauropod trackways) unusual configuration may be related to a slight turn, and could be interpreted as an "off-tracking"-like phenomenon (see Ishigaki and Matsumoto, 2009). However, the turn is not very pronounced, and this unusual configuration also persists after the turn. Therefore, it cannot be excluded that it is linked to another particular behavior of the animal (e.g., interactions with other animals: for example, with turn of the neck and right front/hind legs to the right, particular substrate properties), to an abnormal gait (see also Lockley et al., 1994b), or to movement along a slope. The latter might be indicated by the right-shifted manus tracks relative to the pes tracks. Similarly, the very narrow-gauge of the trackway cannot only be related to the turn, as it also persists afterwards in the straight part at the end of the trackway.

Assuming a foot-length:hip height ratio in the range of 4.0–5.9:1, the relative stride length (SL/h) may be used to determine whether the animal is walking (SL/h < = 2.0), trotting (2<SL<2.9), or running (SL/h > = 2.9) (Alexander, 1976; Thulborn, 1982, 1989, 1990). The SL/h of the Qingquan sauropod trackway is between 0.33–0.49 and accordingly suggests a very slow walking. Using the equation to estimate speed from trackways (Alexander, 1976), the mean locomotion speed of the trackmaker is between 0.97–1.55 km/h. This is slow in comparison with other locomotion speeds estimated from sauropod trackways (e.g., Day et al., 2002; Marty et al., 2003, 2010a; Marty 2008; Xing et al., 2010), and notably to the ones estimated for the type trackways of *Parabrontopodus* (6.8 km/h; Lockley et al., 1986) and *Breviparopus* (4 km/h; Marty et al., 2010a). The unusual gait reflected in the trackway configuration of QQ1with the right and

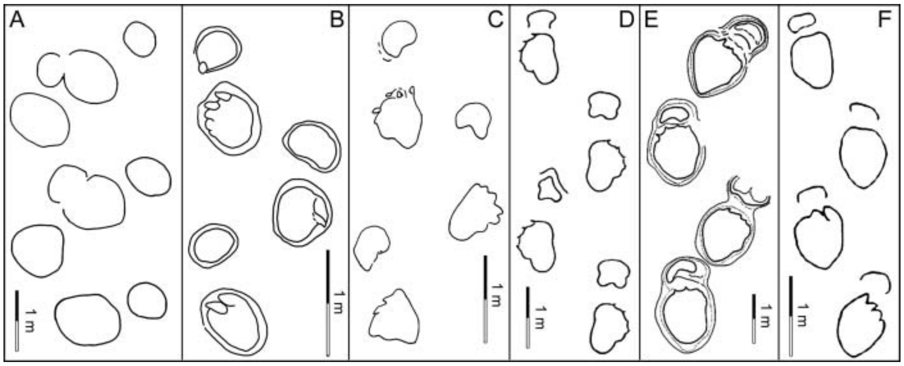


Figure 5. Late Jurassic to Early Cretaceous sauropod trackways not drawn to scale. **A**. Qingquan sauropod trackway (this study). **B**. Early Cretaceous *Brontopodus* isp. (Xing et al., 2013) from Jishan sites, Shangdong, China. **C**. Early Cretaceous *Brontopodus* ichno-morphotype (Zhang et al., 2006) from Yanguoxia sites, Gansu, China. **D**. Early Cretaceous *Brontopodus birdi* (after Farlow et al., 1989) from Paluxy River Valley, USA. **E**. Late Jurassic *Breviparopus* (Dutuit and Ouazzou 1980; illustrated after outline drawing in Ishigaki, 1989, fig. 9.5.) from the High Atlas Mountains, Morocco. **F**. Late Jurassic *Parabrontopodus* (Lockley et al., 1986; fig. 7b) from the Purgatoire River, Colorado, USA.

left pes being extremely close to each other, while the posterior metacarpophalangeal region of the left manus is in contact with the medial part of the right pes, may explain these low values. On the other hand, equations for calculating speed are derived from "normal" gaits and therefore cannot be approved unrestrictedly to a different behavior. Finally, it can also not be excluded that the trackmaker was standing still for a moment at a given point, notably at the beginning of the trackway. At the end of the trackway, increasing distances between LP6/RP6 and LP7/RP7 (Fig. 3) suggest that speed did increase again.

## Trackmaker identification

In Shandong Province, only skeletal remains of a large titanosauriform, *Euhelopus zdanskyi*, have been found so far in Lower Cretaceous strata (Wiman, 1929; Wilson and Upchurch, 2009), and they are slightly older (Barremian–Aptian, ca. 130–112 Ma) than the Qingquan tracksite (Aptian-Albian 110–100 Ma). Therefore, the Qingquan tracksite slightly extends the known temporal range of large sauropods within the Shandong Province.

According to Wiman (1929; plate IV, figs. 1, 4, 5) the hip height of *Euhelopus* is approximately 2.7 m, but it may be slightly higher (2.8–2.9 m), as the leg has strongly declining, instead of more erect (as assumed by Wiman, 1929), metatarsals. With a mean pes length of 84 cm of QQ1, and assuming a foot-length:hip height ratio in the range of 4.0–5.9:1 (Alexander, 1976; Thulborn, 1989, 1990), the hip height of the QQ1 trackmaker may be estimated at 3.4–5.0 m, which is slightly to considerably higher than in *Euhelopus zdanskyi*.

Wilson and Carrano (1999) suggested that more derived sauropods such as the titanosaurs were the trackmakers of wide-gauge trackways while narrow-gauge trackways were attributed to more basal sauropods, basal macronarians or Diplodocoidea *sensu* Wilson and Sereno (1998). Accordingly, based on its extremely narrow gauge, the trackway QQ1 cannot confidently be attributed to a titanosauriform sauropod, but instead could easily be attributed to a more basal sauropod. However, this is in contradiction with the skeletal record, and it cannot be excluded that the extremely narrow gauge of the trackway QQ1 rather is related to an unusual behavior than to the trackmaker constitution. Farlow (personal communication 2004 in Wright 2005) also noticed that some *Brontopodus* trackways of the Paluxy River have a narrow gauge along some trackway segments. Change from wide to narrow gauge along a single trackway was also described by Leonardi and Avanzini (1994) from the Early Jurassic of northern Italy, and by Marty et al. (2010b) from the Late Jurassic of NW Switzerland. Therefore, the QQ1 trackway is no evidence for sauropod diversity in the Early Cretaceous of the Shandong Province being higher than previously known from the skeletal record.

## Conclusions

(1) The Qingquan sauropod trackway QQ1 has a very unusual trackway configuration with left manus tracks located very close to the opposite pes tracks. For this reason, the trackway may be important for future studies of sauropod locomotion and gait reconstructions.
(2) Narrow-gauge trackways are rare in China, and so far, QQ1 is possibly the only "extremely narrow-gauge" trackway. Alternatively, the unusual trackway configuration including the narrow gauge

maybe related to a special behaviour, or even linked to an injury ("limping trackway").

(3) The QQ1 trackway is tentatively attributed to cf. *Parabrontopodus*, even though it has a rather low heteropody that is significantly lower than in *Parabrontopodus* and not typical for narrow-gauge sauropod trackways, but close to the wide-gauge ichnotaxon *Brontopodus*.

(4) Due to this low heteropody, the QQ1 trackway cannot readily be attributed to a basal sauropod trackmaker.

(5) The Qingquan tracksite extends the temporal range of sauropods in the Early Cretaceous of Shandong Province.

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