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中国甘肃省中铺地区下白垩统河口群的兽脚类与蜥脚类足迹组合*

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提要　近年来，中国西北部兰州-民和盆地的中铺地区河口群发现了一批恐龙骨骼化石和足迹化石。中铺地区的蜥脚类与兽脚类足迹组合相对丰富，但大多数标本保存较差。大夏足迹点发现了保存较好的类似亚洲足迹的跷脚龙类足迹(*Asianopodus*-like grallatorid tracks)，足迹有着中趾弱前凸(weak mesaxony)。李家沟一号点的足迹组合包括了较大的兽脚类足迹和大型的、非三趾型四足类足迹，后者可能是蜥脚类足迹。李家沟二号点的足迹为多层的蜥脚类足迹，这表明了这类恐龙的活跃性，巨龙类的骨骸也可能来自同一层位。虽然中铺足迹组合不如同属河口群的盐锅峡足迹组合那么具有多样化与得以充分暴露，但依然体现了该地区以及中国早白垩世地层的典型足迹组合。

关键词　亚洲足迹　蜥脚类　兽脚类　恐龙足迹　下白垩统　甘肃省

THEROPOD AND SAUROPOD TRACK ASSEMBLAGES FROM THE LOWER CRETACEOUS HEKOU GROUP OF ZHONGPU，GANSU PROVINCE，CHINA

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Abstract　In recent years，several sites with fossil dinosaur bones and tracks were found in the Hekou Group of the Zhongpu area from the Lanzhou-Minhe Basin in northwestern China. Theropod and sauropod track assemblages from the Zhongpu area are relatively abundant，although poorly preserved in most cases. The Daxia tracksite reveals

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moderately well preserved, small *Asianopodus*-like grallatorid tracks with weak mesaxony. The Lijiagou tracksite 1 assemblage reveals larger theropod tracks and poorly defined tracks of large non-tridactyl quadrupeds, probably sauropods. The Lijiagou tracksite 2 assemblage reveals multiple track-bearing levels indicating the activity of sauropods, possibly titanosaurs known by skeletal remains from the same unit. The assemblages are similar to others in the region and typical for the Lower Cretaceous of China, though less diverse than those of the large, well-exposed Hekou Group ichnofaunas from the Yanguoxia tracksites.

Key words *Asianopodus*, Sauropoda, Theropoda, dinosaur tracks, Lower Cretaceous, Gansu Province

1 INTRODUCTION

In recent years, the Lanzhou-Minhe Basin in northwestern China has yielded impressive assemblages of dinosaur fossil bones and tracksites. The tracks are primarily found in the Yanguoxia area, within the main area of the Liujiaxia Dinosaur National Geopark. These dinosaur tracks are taxonomically diverse, and represent sauropods, non-avian theropods (both tridactyl and didactyl forms), ornithopods, and birds (Li *et al.*, 2006; Zhang *et al.*, 2006; Xing *et al.*, 2013a). Skeletal fossils are found at several sites, including the Zhongpu area, where the bones of large titanosauriforms, such as *Huanghetitan liujiaxiaensis* (You *et al.*, 2006) and *Daxiatitan binglingi* (You *et al.*, 2008), have been found, along with remains of iguanodontians, such as *Lanzhousaurus magnidens* (You *et al.*, 2005). Within the Zhongpu area, there have also been several as-yet-unpublished discoveries of dinosaurs, fishes and turtles (pers. obvs., 2013).

In 2008, a geological survey team from the Fossil Research and Development Center of the Third Geology and Mineral Resources Exploration Academy of Gansu Province discovered two tracksites in the Zhongpu area, and in 2013, Xing L D, Lockley M G, Marty D and Peng C investigated another new tracksite. Herein, we offer a detailed description of these so far unexplored Daxia and Lijiagou tracksite 2 sites. Tracks from the Daxia tracksite have been collected and are housed in the Fossil Research and Development Center of the Third Geology and Mineral Resources Exploration Academy of Gansu (GSLTZP), all others were left in the field.

2 INSTITUTIONAL ABBREVIATIONS

GSLTZP = Fossil Research and Development Center of the Third Geology and Mineral Resources Exploration Academy of Gansu Province, China; I = Isolated; L/R= Left/Right; S = Sauropod, T = Theropod, ZPI, ZPII = Lijiagou tracksites I and II, Zhongpu, Gansu, China.

3 GEOLOGICAL SETTING

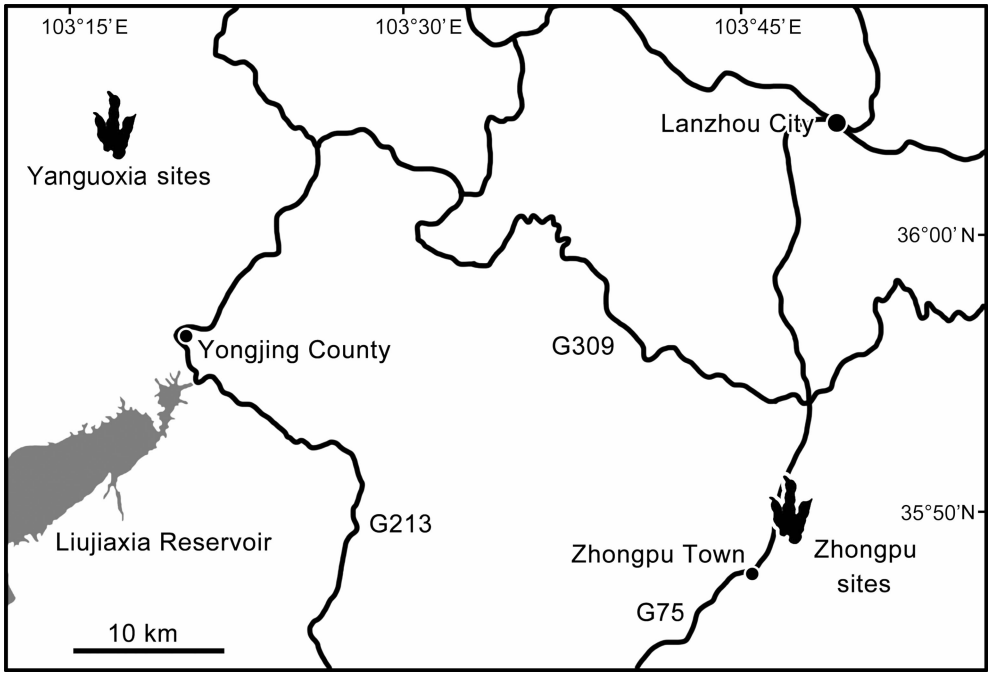
The Zhongpu area is located in the Lanzhou-Minhe Basin (text-fig. 1), at the border of Gansu Province and Qinghai Province, and encompasses a total area of 11 300 km^2 of the Lanzhou-Minhe Basin is a fault basin that developed from the Middle Qilian uplift zone. The red clastic rocks that dominate the basin are a single lithological unit, 3 482 m thick, and have long been regarded as part of the Hekou Group (Gansu Provincial Bureau of Geology and Mineral Resources, 1997; Chen, 2013; Chen *et al.*, 2013). These sediments are Early Cretaceous in age (Tang *et al.*, 2008). The dinosaur-track-containing stratum of the Zhongpu area is slightly lower than that represented at the Yanguoxia tracksites. Furthermore, the Zhongpu area is dominated by fluvial facies sediments (Chen *et al.*, 2013), while the Yanguoxia area sediments are those of shallow shore lacustrine facies.

4 DINOSAUR TRACKS

4.1 Theropod tracks from the Daxia tracksite

GSLTZP(08)-03-01 and 02 are small sized

(11.8—13.7 cm) tridactyl tracks (Text-fig. 2; Table Ⅰ), from thin layers of brownish yellow argillaceous siltstone. They were discovered while preparing the stratum around the Daxiatitan fossil site. Each track is preserved as a mold and as a cast.



Text-figure 1　Geographical setting showing the location (footprint icon) of the Zhongpu and Yanguoxia tracksites in Gansu Province, China.

GSLTZP (08)-03-01 is slightly larger than GSLTZP (08)-03-02, but has the same general morphology. Both tracks appear to have been left by the same kind of trackmaker. GSLTZP (08)-03-02 is the best preserved. Digit III is directed forward and it is the longest. Digit IV is shorter than digit II. Due to preservation, only digit IV has a laterally directed claw mark. Digit II has two phalangeal pads, but pad impressions of other digits are indistinct. A circular to oval metatarsophalangeal pad is present. It is well-developed, robust (average diameter 2.6 cm) and positioned in line with the long axis of digit III. The digits have a high divarication angle (54°) between digit II and IV. The divarication angle between digits III and IV is larger than that between digits II and III.

GSLTZP(08)-03-01 and 02 are similar to the tracks described by Lockley *et al*. (2011, fig. 8) from the Upper Cretaceous of Colorado. They are characterized by their small size and a general theropod (grallatorid) shape, with only faintly-separated digit pad traces, giving the overall digit traces an elongate cigar-shaped outline. Unlike typical *Grallator* tracks, which are slender and elongated with strong mesaxony and distinct digital pad traces (Lockley, 2009), the Daxia tracks are more transverse with a weaker mesaxony, and fainter digital pad traces. The lack of clearly-separated digital pad impressions may indicate that the trackmaker's foot was fleshier. However, it may also indicate that the tracks are undertracks, although if this is the case, we infer that the true track level would be only a few millimeters above the thin veneer of sediment seen covering the exposed surface. GSLTZP (08)-03-01 and 02, by the distinct separation of the metatarsophalangeal pad from the digits the tracks resemble *Asianopodus* (Matsukawa *et al*., 2005) although the metatarsophalangeal pad is not strongly enlarged. Similarities with the theropod ichnogenus *Changpeipus* are the position of the metatarsophalangeal pad being in line with digit III sometimes forming a distinct "heel" (Xing *et al*., 2014). It is difficult to discern whether GSLTZP (08)-03-01 and 02 are left or right tracks, however, in both cases there are relatively small traces of a small pad, immediately

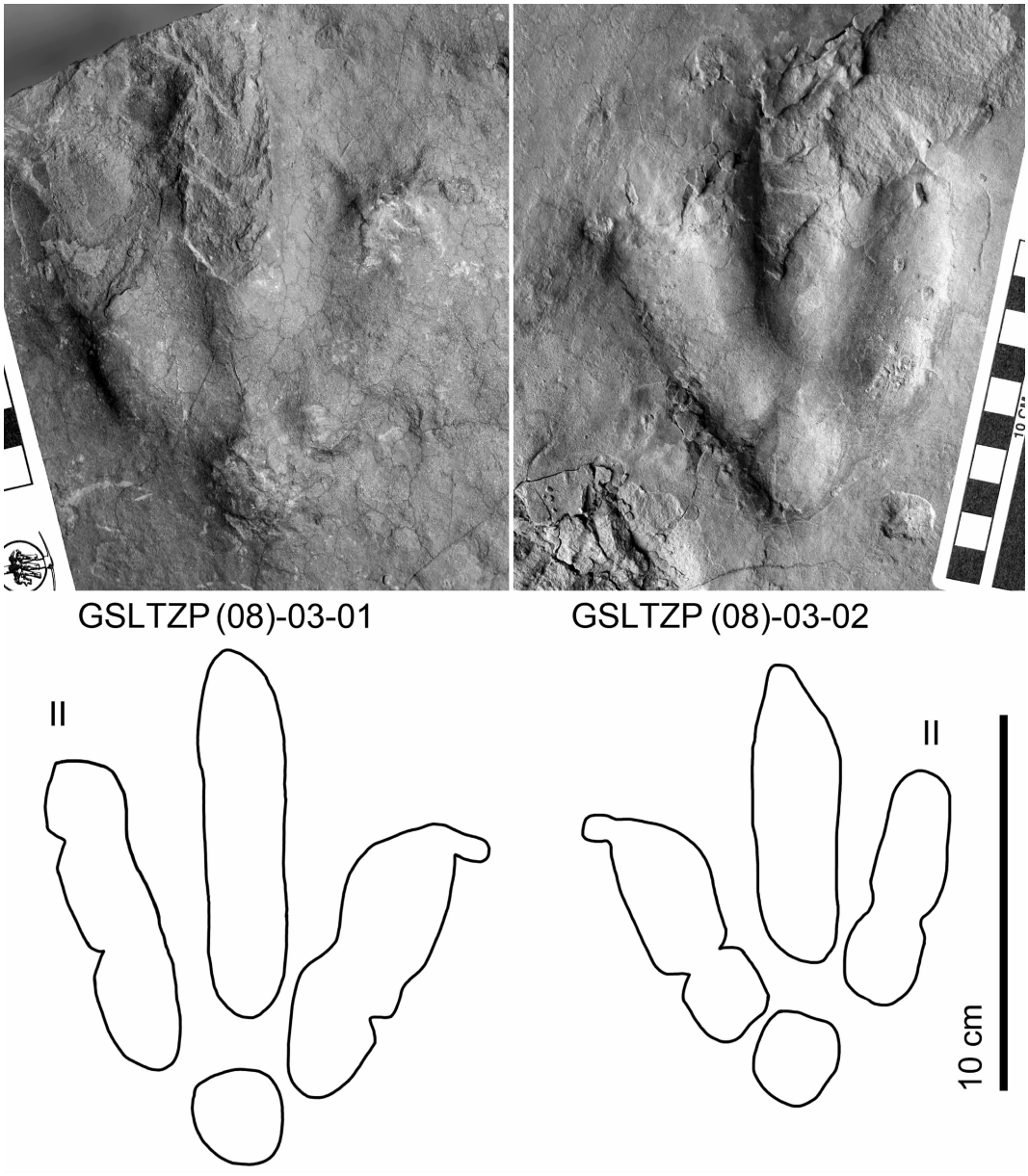
anterior to the metatarsophalangeal pad that seems to indicate digit IV and this may indicate that GSLTZP (08)-03-01 is right track, and the 02 is left track (text-fig. 2).

4.2 Dinosaur tracks from Lijiagou tracksite I

Tracks from this site occur on an inclined sandstone surface that has been subject to considerable erosion, and therefore the outline of many tracks is indistinct and cannot be easily identified.

4.2.1 Theropod tracks

ZPI-TL1-TL3 is a trackway that includes five successive tracks (text-figs. 3, 4; Table Ⅰ) with an average length of 41.9 cm and an average divarication angle of 52°. The mean stride length is 121.4 cm. The mean pace angulation of 143° indicates a trackmaker with a narrow stance typical of theropods. TL2 is the best preserved track in the trackway. TL2 is tridactyl with a digit III that is directed forward and that is the longest digit. The claw marks of digit II and digit III are sharp. The metatarsophalangeal pad is well developed, close to the axis of digit III, and oriented towards digit IV, forming an extended "heel". The phalangeal



Text-figure 2 Photographs and outline drawings of theropod tracks (natural molds) from the Daxia tracksite, Zhongpu area, China.
Register Number: GSLTZP (08)-03-01, GSLTZP(08)-03-02.

Table Ⅰ　Measurements (in cm) of the dinosaur tracks from the Zhongpu area

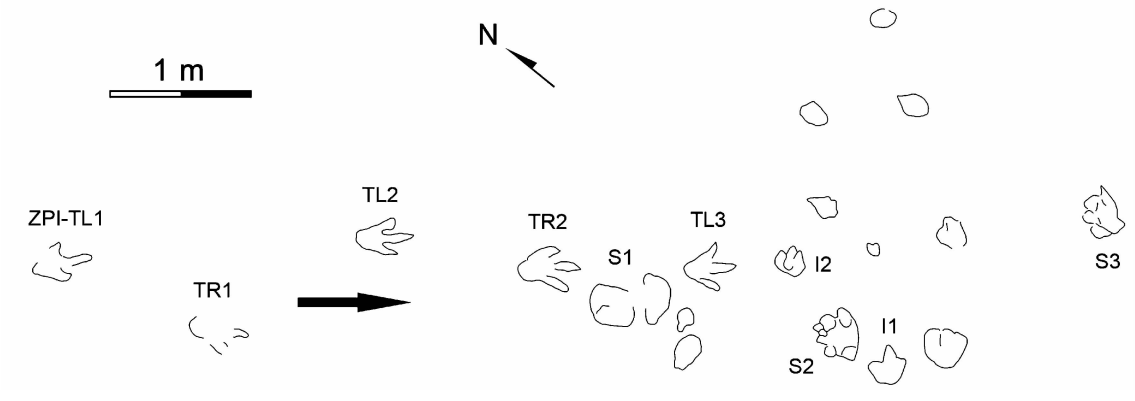
Number.	ML	MW	LDII	LDIII	LDIV	II-III	III-IV	II-IV	PL	SL	PA	L/W	M
GSLTZP(08)-03-01	13.7	10.2	8.8	9.8	8.1	21°	33°	54°	—	—	—	1.3	0.36
GSLTZP(08)-03-02	11.8	8.5	6.3	8.0	6.6	24°	30°	54°	—	—	—	1.4	0.41
Mean	12.8	9.4	7.6	8.9	7.4	23°	32°	54°	—	—	—	1.4	0.39
ZPI-TL1	47.9	28.3	—	—	—	—	—	—	120.0	231.5	—	1.7	—
ZPI-TR1	44.3	—	—	—	—	—	—	—	133.0	237.4	122°	—	—
ZPI-TL2	38.4	22.5	12.7	20.9	12.7	23°	24°	47°	118.5	231.2	138°	1.7	0.55
ZPI-TR2	43.7	25.0	23.8	24.8	18.4	21°	21°	42°	114.0	—	168°	1.7	0.47
ZPI-TL3	35.0	29.5	16.3	18.6	15.0	31°	35°	66°	—	—	—	1.2	0.39
Mean	41.9	26.3	17.6	21.4	15.4	25°	27°	52°	121.4	233.4	143°	1.6	0.47
ZPI-I1	27.5	24.1	—	—	—	—	—	73°	—	—	—	1.1	—
ZPI-I2	19.7	12.3	—	—	—	—	—	—	—	—	—	1.6	—
ZPI-S2	33.7	27.5	—	—	—	—	—	—	—	—	—	1.2	—
ZPI-S3	29.5	25.1	—	—	—	—	—	—	—	—	—	1.2	—
ZPII-S1	106.0	79.0	—	—	—	—	—	—	—	—	—	1.3	—
ZPII-S2	72.0	58.0	—	—	—	—	—	—	—	—	—	1.2	—
ZPII-S5	51.0	46.0	—	—	—	—	—	—	—	—	—	1.1	—

Abbreviations: LD II: length of digit II; LD III: length of digit III; LD IV: length of digit IV; ML: maximum length; MW: maximum width; PA: Pace angulation; PL: Pace length; SL: Stride length; II-III: angle between digits II and III; III-IV: angle between digits III and IV; II-IV: angle between digits II and IV; L/W: Maximum length/ Maximum width. M: mesaxony (length/width ratio for the anterior triangle)

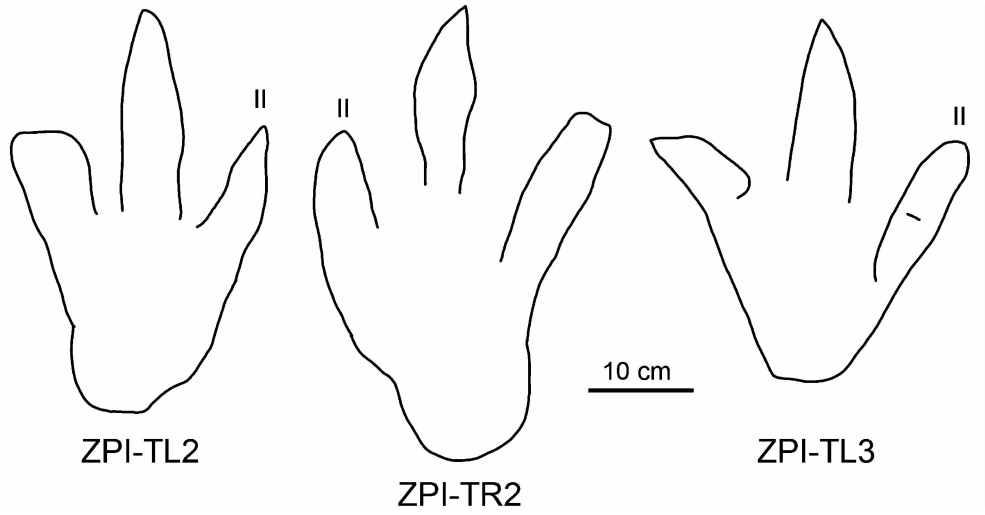
pads of the digits are indistinct. The divarication angle between digits II and digit III are almost equal to that between digits III and digit IV, and that between digits II and IV is 47°.

ZPI-TL1 and TR1 are incomplete. ZPI-TR2 is larger than TL2 or TL3 due to the longer "heel" impression, and ZPI-TL3 has larger divarication angles compared to those of TL2 and TR2. These variabilities in track morphology are likely related due to differences in substrate properties (moisture content) and/or trackmaker behaviour (foot kinematics) (e.g., Xing *et al.*, 2014).

In general, ZPI tracks resemble the large, typical theropod tracks from the Yanguoxia tracksite (Zhang *et al.*, 2006: morphotype 1), that are tridactyl tracks, approximately 32 cm long, with a divarication angle of 61° and trackways showing an average pace angulation of 160°. Furthermore, the metatarsophalangeal pad is close to the axis of digit III and oriented towards digit IV. The average pes



Text-figure 3　Map of the track-bearing level at Lijiagou tracksite I with a theropod trackway segment



Text-figure 4 Outline drawing of selected theropod tracks from Lijiagou tracksite I

length of the largest theropod trackways from Yanguoxia is 42 cm (N = 2). While most Yanguoxia large theropod tracks are between 30—35 cm long (unpublished data).

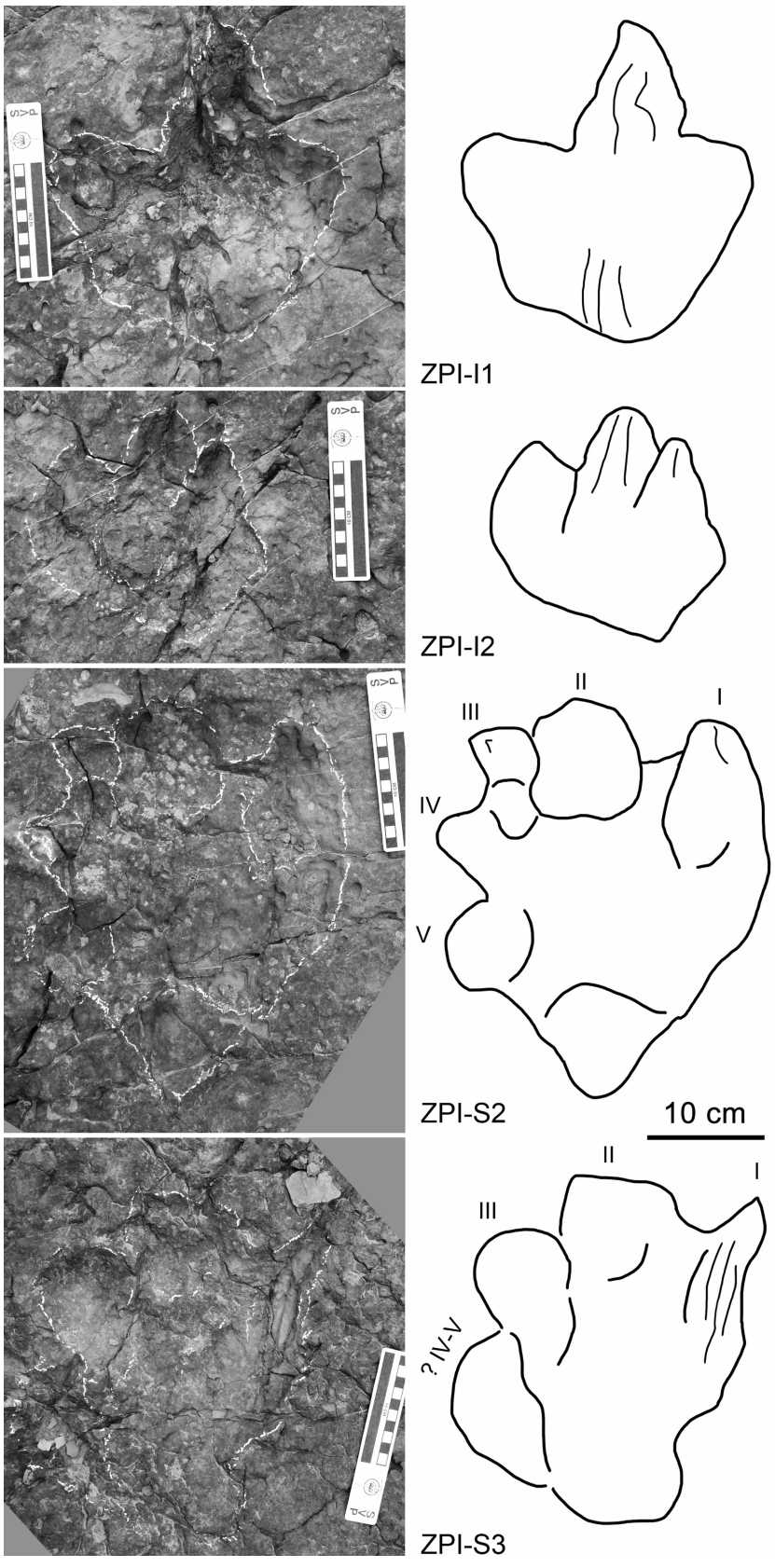
The mean length: width (L/W) ratio of the anterior triangle of the ZPI tracks is 0.47 (N=3), suggesting that they are weakly mesaxonic tracks and may belong to the *Eubrontes* morphotype (Lockley, 2009). The L/W ratio of the anterior triangle of the Daxia tracksite theropod tracks is even lower, 0.39 (N = 2). The L/W ratio of the large theropod tracks from the Yanguoxia tracksite is 0.52 (N = 2), again, suggesting that the Yanguoxia specimens resemble the ZPI tracks. The ZPI tracks are slightly more elongated than the Daxia tracksite specimens, and it cannot be excluded that they were left by different trackmakers, even though differential preservation (substrate vs. kinematics) may also be a reason fort his variability.

4.2.2 Possible Theropod tracks

ZPI-I1 and ZPI-I2 are isolated tridactyl tracks from the Lijiagou tracksite I (text-figs. 3, 5; Table Ⅰ), that are poorly preserved. The middle digit III of ZPI-I1 is directed forward, and it is the longest, and deepest digit. It shows a distinct displacement rim that is linked to particular (wet and soft) substrate conditions. The left digit has a comparable strong posterior indentation suggesting that it is a theropod track. However, the length/width ratio of ZPI-I1 is 1.1, that is less than for typical theropod tracks [such as types of *Eubrontes* (1.7), *Anchisauripus* (1.9) and *Grallator* (2.6), Lockley, 2009]. The three digits of ZPI-I2 are almost parallel to each other. The middle digit is directed forward and the longest. Wet and soft substrate likely led to the deformation of the digit impressions, and made the three digits appear to be almost parallelly oriented. The terminal middle digit and the terminal right digit are deeper, and deep grooves suggest that sharp claw marks are probably registered. In general, ZPI-I1 and ZPI-I2 are consistent with theropod trackmakers.

4.2.3 Medium-sized tracks of quadrupeds

Tracks ZPI-S2 and ZPI-S3 (text-figs. 3, 5; Table Ⅰ) are not part of a discernable trackway configuration, and they are clearly not tridactyl. The average length is 31.6 cm, the length/width ratio is 1.2. ZPI-S2 is better-preserved, than ZPI-S3 with three indentations at its anteromedial margin, corresponding to the predicted typical positions of digits I - III in sauropod tracks. In digit I the claw mark is the deepest, after digit II. In digit II the claw mark are round and blunt. Digit III is small, but the claw mark is the sharpest. The lateral side of the track has two faint indentations, which might represent digits IV and V. The inferred trace of digit V is a round impression, probably representing a blunt pad or callosity. The heel is developed, located on the axis of digit II. ZPI-S3



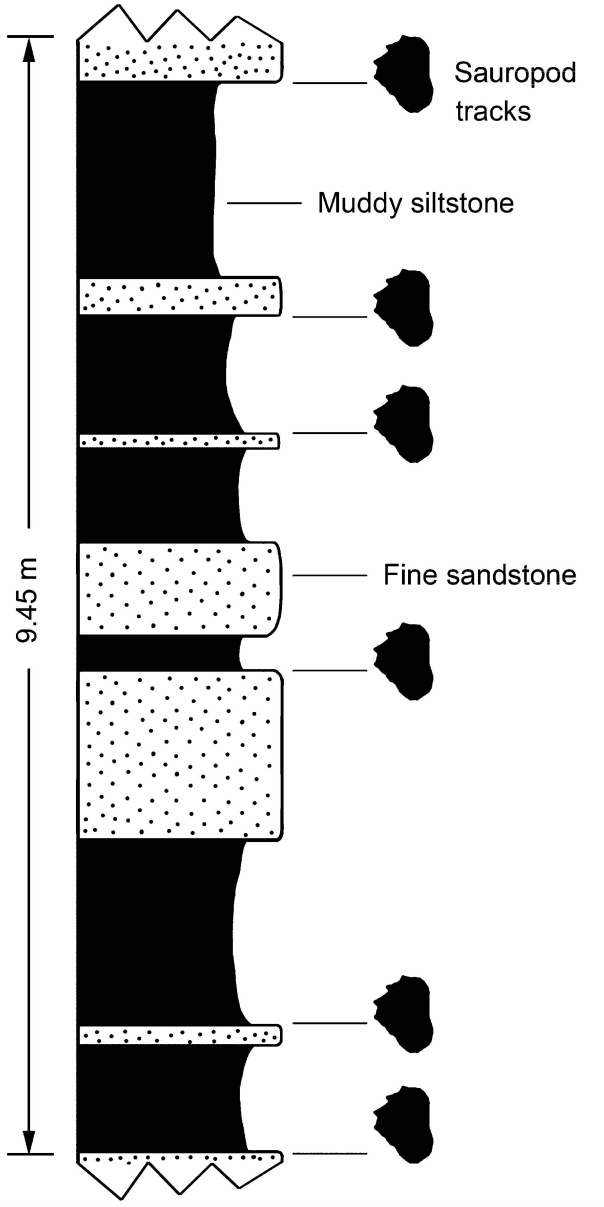
Text-figure 5　Photographs and outline drawings of possible theropod tracks and medium-sized tracks (natural molds, impressions) of quadrupeds (? sauropods) from Lijiagou tracksite I, Zhongpu area, China.

is poorly-preserved, but generally resembles ZPI-S2, at least in size. The inferred digit I trace has probably claw drag mark. The inferred digit II trace is the largest. The inferred digit III trace is round and blunt and may overlap with the digit IV trace. ZPI-S1 is a round impression similar to S2 and S3 in size, but lacks details.

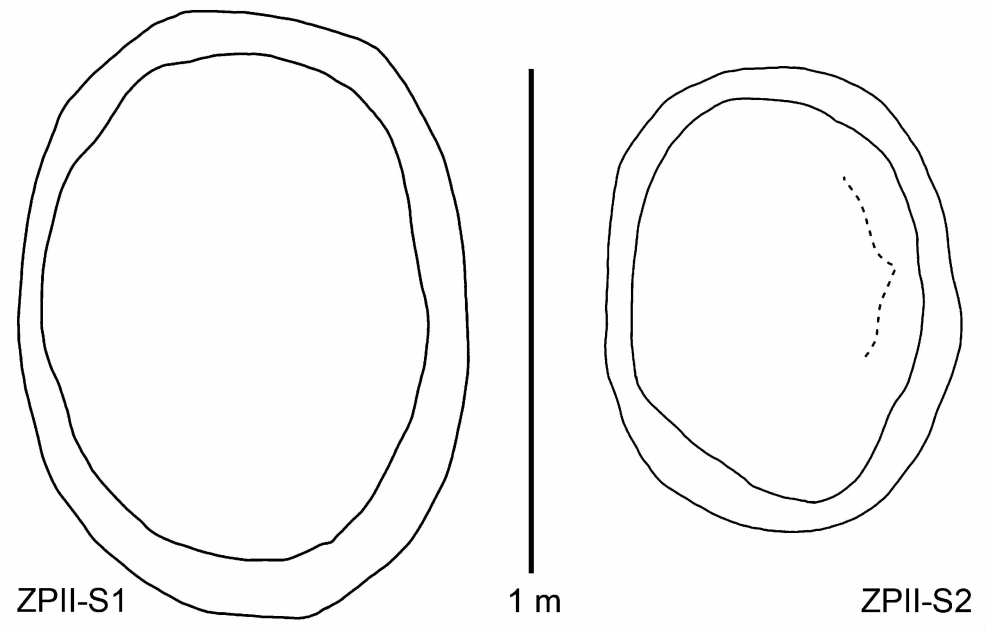
In morphology, ZPI-S2 and ZPI-S3 are similar to the medium-sized tracks from Malingshan, Jiangsu Province (Xing *et al.*, 2010a), Linshu, Shandong Province (Xing *et al.*, 2013b), Zhucheng, Shandong Province (Xing *et al.*, 2010b), Yanqing, Beijing (Zhang *et al.*, 2012), Litan, Yanguoxia (Xing *et al.*, in press). For example, in Linshu specimens the average length is 27.1 cm. However, most previously-discovered medium-sized tracks of quadrupeds are not ideally-preserved, frequently being round or blunt tridactyl/tetradactyl impressions. Traces of digits I – III of ZPI-S2 and ZPI-S3 are similar to other medium-sized tracks of quadrupeds from China. While smaller digit IV and round digit V traces support comparison with such tracks. More significantly, the morphological interpretations, although difficult when tracks are not well preserved, are consistent with other track evidence of non-tridactyl quadrupeds (sauropods) nearby; see following section.

4.3 Sauropod tracks from Lijiagou tracksite II

The Lijiagou tracksite II was discovered in 2013 and reveals only sauropod tracks. The lithology is generally consistent with site I. A 9.45 meter section was measured in which we identified at least six levels with sauropod tracks (text-fig. 6). Herein we describe the two levels from the No. 6 informal formation-level unit with the best-preserved tracks (Zhang *et al.*, 2003). ZPII-S1 and S2 are typical large sauropod pes tracks that are preserved as natural molds (text-fig. 7). The lengths range between 72 to 106 cm, the average length/width ratio is 1.4. The tracks are severely weathered, with interior and external diameters only roughly discernable, and with some evidence for a former sediment displacement rim outside the track. Small (approximately 25 cm long and 39 cm wide) concave indentations are present anterior to S1 and S2, and are probably partial manus tracks. The substantial difference in size between S1 and S2 indicates that these tracks were left by different producers. The large sauropod pes tracks at the Yanguoxia tracksite I average 88.6 cm in length and 73.8 cm in width and can be assigned to the ichnogenus *Brontopodus* (Zhang *et al.*, 2006). ZPII-S1 and S2 resemble the Yanguoxia tracks in size, however, other characteristics are not



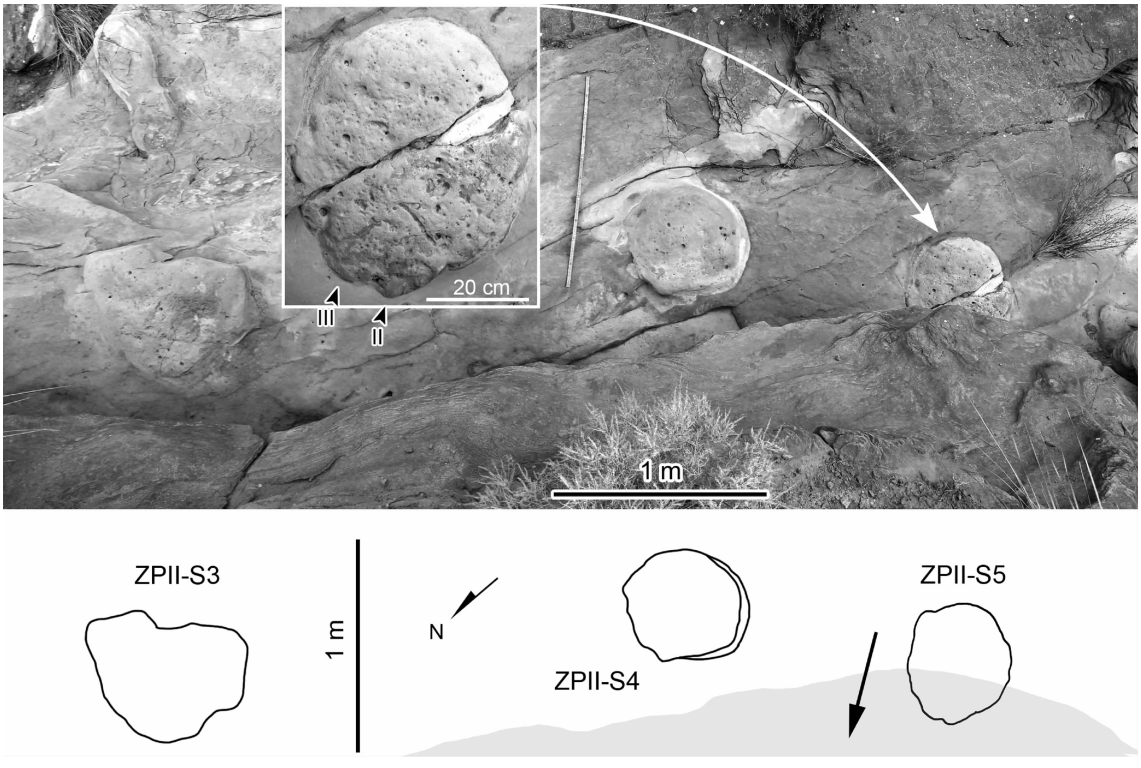
Text-figure 6 Local stratigraphic section of Lower Cretaceous Hekou Group strata logged at the Lijiagou tracksite II, showing the position of multiple track-bearing levels.



Text-figure 7　Outline drawing of sauropod tracks from Lijiagou tracksite II

discernable, and the tracks cannot, therefore, be assigned to a particular ichnogenus.

The surface with ZPII-S3-S5 is positioned one meter below the surface with ZPII-S1 and S2 (text-fig. 8). These tracks are also not part of any discernible trackway and are heavily weathered, subrounded casts. ZPII-S5 is the best preserved, with a length/width ratio of 1.1. ZPII-S5 possesses two indentations at its anteromedial margin, which may correspond to the positions of digits II and III in typical sauropod tracks.



Text-figure 8　Photograph and outline drawing of sauropod tracks from Lijiagou tracksite II

5 DISCUSSION

The assemblages from the Zhongpu area are dominated by theropod and sauropod tracks. The relative abundance and the rarity of ornithopod tracks likely indicates that the locality was strongly influenced by an arid climate (Lockley *et al.*, 2002). Such assemblages are common in the Early Cretaceous of China and are known from Chabu, Otogo, Banner, Inner Mongolia (Li *et al.*, 2011), Malingshan, Jiangsu Province (Xing *et al.*, 2010a), and Linshu, Shandong Province (Xing *et al.*, 2013b). Although ornithopod tracks are present in the Yanguoxia assemblage, the quantity of these tracks is small compared with those of sauropods and theropods (Zhang *et al.*, 2006). So, although the track-bearing horizon of the Zhongpu area is below that of the Yanguoxia area, the track profiles are generally consistent.

Remarkably, the sauropod tracks from Zhongpu area comprise at leat two different size classes. This assemblage is similar to the sauropod track assemblage from Yanqing, Beijing (Zhang *et al.*, 2012; unpublished data) and Linshu, Shandong Province (Xing *et al.*, 2013b). It suggests that the Early Cretaceous dinosaur fauna of the Zhongpu area is similar to that of other equivalently aged Chinese deposits. Sauropod tracks were recorded in six layers of siltstone at the Lijiagou tracksite II, and this suggests locally abundant, probably titanosauriform trackmakers, that could have included *Huanghetitan liujiaxiaensis* (You *et al.*, 2006) and *Daxiatitan binglingi* (You *et al.*, 2008). No theropod fossils have yet been discovered in the Zhongpu area, but the track record suggests a strong presence of medium-sized to large theropod dinosaurs as well.

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