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Saurischian track assemblages from the Lower Cretaceous Shenhuangshan Formation in the Yuanma Basin, Southern China

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ABSTRACT

Cretaceous dinosaur tracks from Hunan Province are historically significant as the basis for three ichnotaxa: *Xiangxipus chenxiensis*, *Xiangxipus youngi*, and *Hunanpus jiuquwanensis* all representing theropodan tracks, described from a single site in 1982. Although the type locality has since been destroyed, the type specimen and replicas remained available for restudy in 2006, when paratype *Hunanpus* tracks and sauropod footprints were described from a second, nearby locality. Material from both localities is here re-described in detail. It is proposed that while *Xiangxipus chenxiensis* can be regarded as a distinct ichnospecies, probably representing an ornithomimid trackmaker, *Xiangxipus youngi* cannot be accommodated in the same ichnogenus. We consider it similar to the ichnogenus *Wupus* from the Lower Cretaceous of Sichuan Province, and therefore of possible avian affinity. We also find no justification for regarding *Hunanpus jiuquwanensis* as generically distinct from the widespread ichnogenus *Grallator*, and therefore rename it *Grallator jiuquwanensis* comb. nov. The Hunan track record is generally consistent with the sparse record of theropod skeletal remains in the province, but adds evidence of sauropods that was previously lacking.

1. Introduction

The Mesozoic vertebrate record from Hunan Province, in South China, is poor, and the Jurassic record is completely unknown. However, Mesozoic exposures have provided two important records, including skeletal remains of the sail-backed poposauroid *Lotosaurus* from the Middle Triassic of Sangzhi County, Zhangjiajie City (Zhang, 1975), and fragments of large and small theropods, ornithopods, and sauropodomorphs from Upper Cretaceous rudaceous rock in Tianyuan District, Zhuzhou City (Tong et al., 2009).

The Yuanma (Yuanling-Mayang) Basin, in western Hunan Province, contains red continental clastic rocks and provides one of the most important copper mines in Hunan. The Jiuquwan copper mine is located in a copper-rich sector of Cretaceous sandstone, and covers 9.8 km^2 in the middle of the Yuanma Basin, 25 km northeast of Mayang County. In 1979, the Investigation Team of Hunan Bureau of Geology found and collected a group of tridactyl dinosaur tracks (Zeng, 1982a) (Fig. 1) at Jiuquwan site I (GPS: 27°55′24.29″N, 110° 4′35.90″E) and described the ichnotaxa *Xiangxipus chenxiensis*, *Xiangxipus youngi*, and *Hunanpus jiuquwanensis* (Zeng, 1982a and b). Matsukawa et al. (2006) reported theropod and isolated sauropod tracks from nearby Jiuquwan site II (GPS: 27°55′41.36″N, 110° 4′49.93″E). In 2015, the main author investigated these track sites and found that Jiuquwan site I had been destroyed by mining, while site II still preserves a few theropod and sauropod tracks.

Dinosaur tracks have influenced folklore throughout China (Xing et al., 2011, 2015a). Exploitation of the Jiuquwan copper mine dates back to the Western Zhou Dynasty (1046–771 BC) (Edit Group of Mayang Copper Mine Annals, 2006) or to the Spring and Autumn period (771–476 BC) (Li, 1998). Though there is no direct

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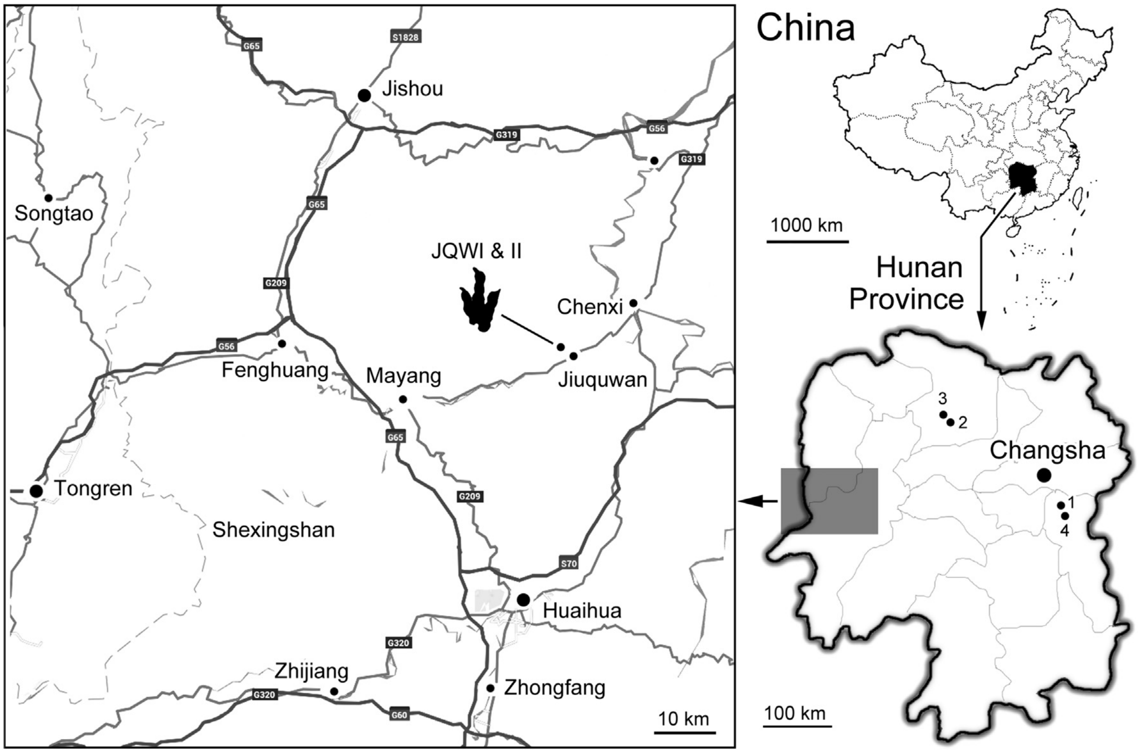

Fig. 1. Map showing the position of the Jiuquwan footprint locality discussed in this text. The Early Cretaceous Dinosaur records from Hunan Province: 1, Shexingshan site; 2, Lemashan site; 3, Wapengshan site; 4, Yangjia site.

evidence that the ancient inhabitants had discovered the dinosaur tracks, the tracks, particularly the tridactyl tracks, likely played a role in shaping local folk tales of the Jin Ji (Golden Chicken).

Abbreviations

L/R = Left/right; T = Theropod; S = Sauropod; AT = anterior triangle; UCM = University of Colorado Museum, USA; JQWI = Jiuquwan tracksite I, Mayang, Hunan Province, China; JQWII = Jiuquwan tracksite II, Mayang, Hunan Province, China; HV = Vertebrate collections from Hunan Museum of Geology, Changsha, China

2. Geological setting

The Xiaodong Formation was originally considered Upper Cretaceous (Bureau of Geology and Mineral Resources of Hunan Province, 1988). Then, it was classified as part of the Lower Cretaceous Shenhuangshan Formation (Li, 1997; Zheng et al., 1998) (Fig. 2). Evidence from conchostracan fossils appears to favor an early stage of the Upper Cretaceous (Chen, 1989, 2003). Li (1997) suggested that the conchostracans of Shenhuangshan Formation consisted of *Tenuestheria*, *Dictyestheria*, *Halysestheria*. This conchostracan assemblage is most likely to be of Early Cretaceous age (cf. Niu, 1986). On the other hand, based on the LA-ICP-MS U–Pb dating of zircons from Xinshi basalt of Shenhuangshan Formation, Ma et al. (2012) considered the age to 132.7 ± 1.2 Ma. Generally, based on ostracod, stonewort, plant and bivalve fossils, the Shenhuangshan Formation is considered to represent a late stage of the Lower Cretaceous (Albian) (Li, 1997).

3. Materials and methods

The record of *Xiangxipus* and *Hunanpus* from JQWI (Zeng, 1982a) consists of a total of nine tracks cataloged as JQWI-HV003-0–8 (Fig. 3). For consistency this same numbering scheme was followed by Matsukawa et al. (2006, fig 5), and is followed again here. Tracks 4, 5 and 8 in this sequence are also preserved as replica at the University of Colorado Museum (UCM) mold and replica 214.4. Zeng (1982a) only described eight tracks, however photogrammetric images shows a ninth incomplete track, which begins a trackway series with HV003-3–6. This ninth incomplete track is cataloged as HV003-0. All the tracks are preserved in a brick-red calcareous argillaceous siltstone slab, spanning roughly 3 × 1 m.

Photogrammetric images of HV003-1–8 were produced from multiple digital photographs (Canon EOS 5D Mark III), which were converted into scaled, highly accurate 3D textured mesh models using Agisoft Photoscan Professional v. 1.0.4. The mesh models were then imported into Cloud Compare v. 2.5.3., where the models were rendered with accurately scaled color topographic profiles.

According to investigation records, three quarters of the JQWII track surface that was exposed in 1999 was covered by new buildings in 2001 (Fig. 4). Theropod and isolated sauropod tracks from JQWII are preserved in a purple-red silty mudstone surface (Fig. 4), that spans roughly 2 m^2. The sauropod tracks are isolated, and a tridactyl theropod trackway and an isolated tridactyl track also occur (Matsukawa et al., 2006, fig 5). The first two tracks in the theropod trackway sequence are also preserved as UCM replica 214.35. All tracks were cleaned up, traced and photographed.

4. Systematic ichnology

4.1. Theropod tracks

Zeng (1982a) described two new ichnogenera and three new ichnospecies based on JQWI specimens. The theropod tracks from JQWI and II sites can be divided into three morphotypes:

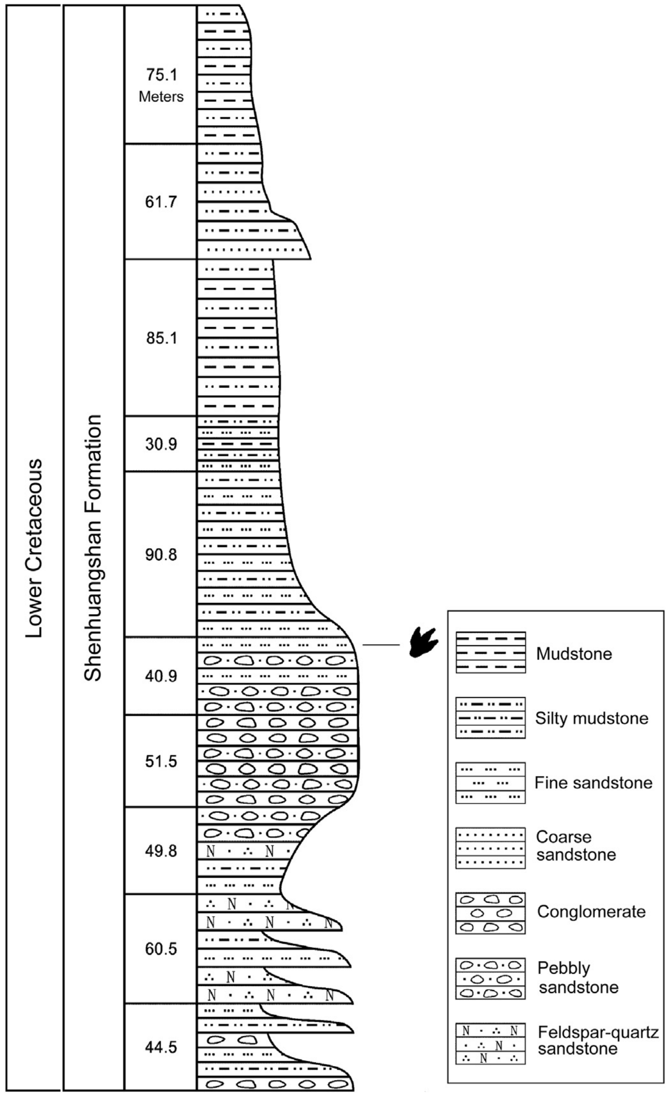

Fig. 2. Stratigraphic section of the Lower Cretaceous sedimentary sequences in the Jiuquwan area with the position of the footprint level.

4.1.1. Xiangxipus *tracks*

Theropoda Marsh, 1881
Xiangxipus Zeng, 1982a
Xiangxipus chenxiensis Zeng, 1982a

Holotype. A complete natural mold of a pes track, cataloged as JQWI-HV003-4 from the Jiuquwan I tracksite (Figs. 3 and 5; Table 1), and the other **s**pecimens JQWI-HV003-0, 3, 5 and 6 in the same trackway. The specimen is stored in the Hunan Museum of Geology, Changsha, China.

Type horizon and locality. Shenhuangshan Formation, Lower Cretaceous (Albian). Jiuquwan I tracksite, Mayang County, Hunan Province, China.

Emended diagnosis. A medium-sized, slender-toed tridactyl footprint, pes L/W ratio of 0.8, with weak mesaxony (0.33). A metatarsophalangeal pad traces from digit IV is located lateral to the long axis of digit III. The footprint is nearly symmetrical, with a wide (97°) divarication angle. Step length is roughly three times footprint length. Mean pace angulation is relatively high, about 159°.

Description. The *Xiangxipus chenxiensis* trackway includes five tracks: JQWI-HV003-0, 3–6. HV003-0 and HV003-3 are incomplete. HV003-4 is the best-preserved example. It has a length/width ratio of 1.0. Digit IV is the longest, and the digits II and III are nearly equal in length. The metatarsophalangeal pad of digit IV is located lateral to the long axis of digit III. Distal claw traces are also clearly visible. The phalangeal pads of all three digits are undifferentiated and indistinct. The divarication angle between digits II–IV (90°) is high. Pace angulations of the trackway are between 149° and 164°, and the footprint length to pace length ratio is 1:3.

In morphology, HV003-5 and 6 are similar to HV003-4. Of note, digit II of HV003-5 and digit IV of HV003-6 both show double traces, possibly due to the wet and soft sediments in which they were made. The same sediment condition may have led to the elongated claw mark of digit III in HV003-4. The Jiuquwan II tracksite presents an incomplete slender-toed tridactyl track cataloged as JQWII-TI1, it is 14.6 cm long and morphologically similar with HV003-4 (Fig. 6).

Speed and body length. The stride length relative to pes length of the type trackway of *Xiangxipus chenxiensis* permits a calculation of speed (v) using the formula of Alexander (1976): $v = 0.25g^{0.5} \times SL^{1.67} \times h^{-1.17}$ where g is the gravitational acceleration in m/s, SL id the stride length, and h is the hip height. Hip height is estimated at 4.5 times foot length, using the ratio for large theropods proposed by Thulborn (1990). We estimate a speed of ~1.29 m/s or ~4.64 km/h. The body length of the track maker of the *Xiangxipus chenxiensis* is approximately 2.2 m, calculated using the average hip height to bodylength ratio of 1:2.63 (Xing et al., 2009).

Comparisons: The average length/width ratio of the anterior triangle of *Xiangxipus chenxiensis* tracks is 0.33 (N = 3), which suggests they are weakly mesaxonic tracks (Lockley, 2009). The bivariate analysis of the length/width ratio vs. anterior triangle ratio (AT) shows that, *Xiangxipus chenxiensis* JQWI-HV003-4–6 is remarkably different from *Eubrontes* tracks from Lower Cretaceous China (Fig. 7). Regarding morphology, the *Xiangxipus chenxiensis* tracks are distinctive in having very widely splayed toes. Matsukawa et al. (2006) and Lockley et al. (2011) suggested assigning the trackmaker of *Xiangxipus chenxiensis* to the Ornithomimipodidae.

Xiangxipus is morphologically consistent with Ornithomimipodidae (Lockley et al., 2011), having 1) slender-toed, tridactyl, gracile tracks; 2) a width longer than length; 3) wide divarication between traces of digits II and IV; and 4) a narrow trackway. However, the following typical Ornithomimipodidae characteristics are absent: 1) digit II trace often separated from the digit III and IV traces; 2) the heel pad trace is usually centrally located, connected to traces of digits III and IV, and typically separated from the proximal phalangeal pad trace of digit III by a notable constriction. Lack of separation between digit II and digits III and IV may be a preservational feature, while deflection of the heel pad trace towards digit IV is a distinctive morphological feature of *Xiangxipus*.

Ornithomimosauria radiated widely in the Late Cretaceous, though their existence can be traced back to at least the Early Cretaceous. Early Cretaceous ornithomimosaurians include the European *Pelecanimimus* from Calizas de La Huérguina Formation (Upper Hauterivian–Lower Barremian) (Pérez-Moreno et al., 1994) and the Chinese *Shenzhousaurus* from Yixian Formation (Barremian–Aptian) (Ji et al., 2003). Ornithomimipodidae (Lockley et al., 2011) includes *Ornithomimipus* from the Upper Cretaceous of Canada (Sternberg, 1926) and the Upper Cretaceous of Colorado and Utah (Lockley et al., 2011), and perhaps other ichnogenera with ornithomimisaur affinities: *Irenichnites* (Sternberg, 1932) and *Columbosauripus* (Sternberg, 1932) from the Lower Cretaceous of Canada, and *Magnoavipes* from the “mid” Cretaceous of Colorado

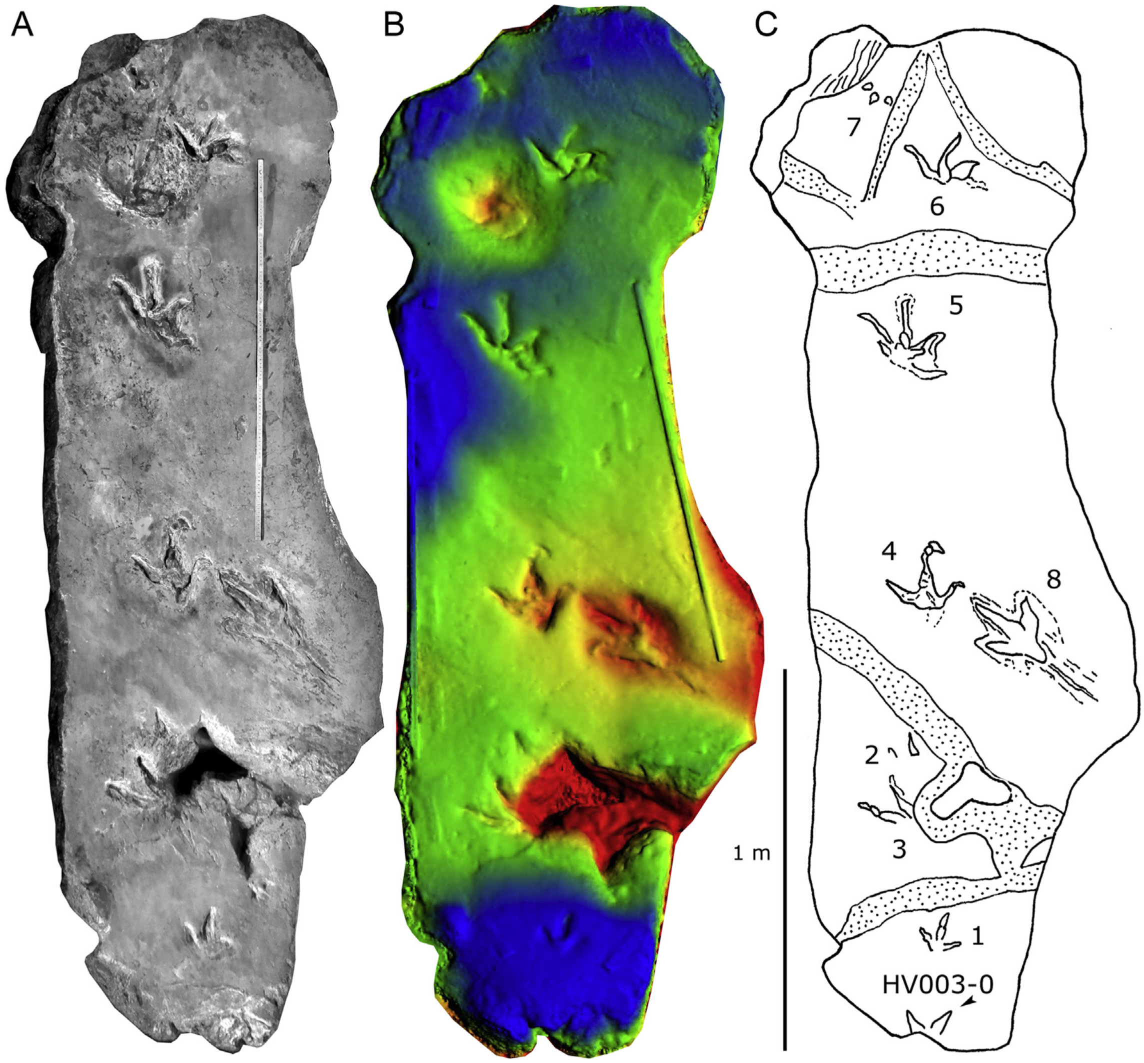

Fig. 3. Photograph (A), 3D height map (B) and map (C) of large track-rich block from the Jiuquwan I footprint locality showing *Xiangxipus chenxiensis* trackway JQWI-HV003-0, 3, 4, 5, 6, *Grallator jiuquwanensis* (Zeng, 1982a) comb. nov. JQWI-HV003-8 and cf. *Wupus* isp. JQWI-HV003-1, 2 and 7. C after Matsukawa et al., 2006.

(Lockley et al., 2001), New Mexico (Kappus and Cornell, 2003), Texas (Lee, 1997), and Alaska (Fiorillo et al., 2011).

Xiangxipus implies that medium-sized ornithomimosaurs may have already been present in late Early Cretaceous (Albian) of Central China, adding to the documented diversity of the local dinosaur fauna. *Xiangxipus* is approximately 2.2 m long, slightly longer than *Shenzhousaurus* which is 1.6 m (Ji et al., 2003), and far shorter than *Beishanlong* which is 7 m (Makovicky et al., 2010).

4.1.2. Grallatorid tracks

Theropoda Marsh, 1881
Grallatoridae Lull, 1904
Grallator sensu Gierlinski, 1994
Grallator jiuquwanensis (Zeng, 1982a) comb. nov.

Holotype. A complete natural mold of a pes track, cataloged as JQWI-HV003-8 from the Jiuquwan I tracksite (Figs. 3 and 5; Table 1). The specimen is stored in the Hunan Museum of Geology, Changsha, China
Paratype. Trackway JQWII-T1 (consisting of three tracks) (Fig 6; Table 1). The specimen is preserved at the Jiuquwan II tracksite, Mayang, China, with a replica of the first two tracks in the University of Colorado collections (UCM 214.35).
Type horizon and locality. Shenhuangshan Formation, Lower Cretaceous (Albian). Jiuquwan I tracksite, Mayang County, Hunan Province, China.
Emended diagnosis. A medium-sized tridactyl theropod footprint, pes L/W ratio of 1.5, with moderate mesaxony (0.53). A strong indentation behind digit II. The length of digit III trace comprising 55% of the track length. The footprint reveals a relatively narrow (58°) divarication angle. Step length is roughly 3.3 times footprint length. Mean pace angulation is high, about 167°.
Description. JQWI-HV003-8 is a 26.2 cm-long isolated track and has a length/width ratio of 1.5. Digit IV is the longest, and digit II is shortest in length. There is a strong indentation behind digit II. The proximal end of digit II is located near the mediomedial of digit IV (~40% of the length). The length of the digit III trace comprises 55% of the track length. The metatarsophalangeal pad of digit IV is developed and located near to the long axis of digit III. Distal claw traces are also clearly visible, especially that of digit II. The phalangeal pads of the three digits are coalesced and less distinct. The divarication of digits II–IV (58°) is relatively narrow.

Fig. 4. Photograph of Jiuquwan I site.

The JQWII-T1 paratype trackway from Jiuquwan II tracksite includes three tracks: JQWII-T1-L1–L2. T1-R1 is the best-preserved example. JQWII-T1 (19.5 cm in length) is slightly smaller than JQWI-HV003-8 but basically the same in morphology. The proximal end of digit II is located near the medial of digit IV (~37% of the length, N = 3). Pace angulations of the trackway is 167°, and the footprint length to pace length ratio is 1:3.3.

Speed and body length. Based on the previously described formula (Alexander, 1976; Thulborn, 1990; Xing et al., 2009), JQWII-T1 offers an estimated speed of ~1.4 m/s or ~5.04 km/h and the body length of the track maker is approximately 2.3 m.

Comparisons. At first sight *Hunanpus* is typical of many small theropod tracks of the type typically assigned to *Grallator.* Lockley et al. (2013 and 2014) provisionally accepted *Hunanpus* as a valid ichnogenus pending further study. However, although this ichnogenus has been known for more than 30 years it has never been recognized elsewhere outside the JQWI and JQWII sites. By contrast small theropod tracks attributable to *Grallator* sensu lato have been found at many Lower Cretaceous distributed widely across China (Lockley et al., 2014). Given that Zeng (1982a) provided no explanation of why *Hunanpus* was diagnostically distinct from typical *Grallator* tracks we suggest that it is better transferred into the latter, and far-better-known genus as *Grallator jiuquwanensis* (Zeng, 1982a) comb. nov. The best-described and best-preserved Lower Cretaceous theropod tracks from China originated from the Shandong assemblages at Huanglonggou (Lockley et al., 2015a). These have been assigned to a spectrum of grallatorid morphotypes, ranging from small (morphotype B) with a mean length of 12.5 cm to medium sized (morphotype A) with lengths between ~20 and ~30 cm. The corresponding AT ratios are 1.43 and 1.86 indicating weaker mesaxony in large forms. Type *Hunanpus* (JQWI-HV003-8 ML 26.2 cm) is similar in size and shape (AT 0.53) to Huanglongou morphotype A, with *Hunanpus* paratype trackway JQWI-HV003-8 (mean ML 19.5 cm, AT 0.43) also falling very close to the lower end of the morphotype A size range. Bivariate analysis of the length/width ratio vs. anterior triangle ratio (AT) confirms that JQWI-HV003-8 is quite similar to other theropod tracks like *Grallator*, *Eubrontes* and possibly *Megalosauripus* type tracks from the Lower Cretaceous China with relatively high L/W and AT ratios (Fig. 7). *Megalosauripus* differs from *Eubrontes* in the relatively short digit III trace comprising 60% of the track length (Lockley et al., 1998). JQWI-HV003-8 and the JQWII-T1 trackway also possess such ratios, but we consider this simply a result of widespread convergence in theropod footprint morphology. Given that *Megalosauripus* is a problematic ichnogenus (Lockley et al., 1998), with well-defined samples of large tracks (ML often >40 cm) mostly confined to the late Jurassic of North America, Europe and Uzbekistan, we consider it prudent to regard *Hunanpus jiuquwanensis* as indistinguishable from *Grallator* sensu lato.

4.1.3. Wupus *tracks*

Wupus Xing et al., 2007
cf. *Wupus* isp.

Materials. Three tracks: JQWI-HV003-1, 2 and 7 (Figs. 3 and 5; Table 1). JQWI-HV003-2 is incomplete and probably forms a step with HV003-1. The specimens are stored in the Hunan Museum of Geology, Changsha, China.

Type horizon and locality. Shenhuangshan Formation, Lower Cretaceous (Albian). Jiuquwan I tracksite, Mayang County, Hunan Province, China.

Description and Comparisons. JQWI-HV003-1 is 10 cm long, well preserved, and has a length/width ratio of 0.8. The length:width ratio of the anterior triangle is 0.51. Three digits traces are separate from each other. Digit III is the longest, and digit II is the shortest. Distal claw traces are also clearly visible. The metatarsophalangeal pad is distinct. The phalangeal pads of three digits are coalesced and less distinct. The divarication of digits II–IV (112°) is wide. JQWI-HV003-2 only preserved the tip of digit III.

Zeng (1982a) named HV003-1 and 2 as another species of *Xiangxipus*: *X. youngi*. However, because HV003-1 and 2 are very different from *Xiangxipus chenxiensis* in size and morphology, there is little justification for including them in the same

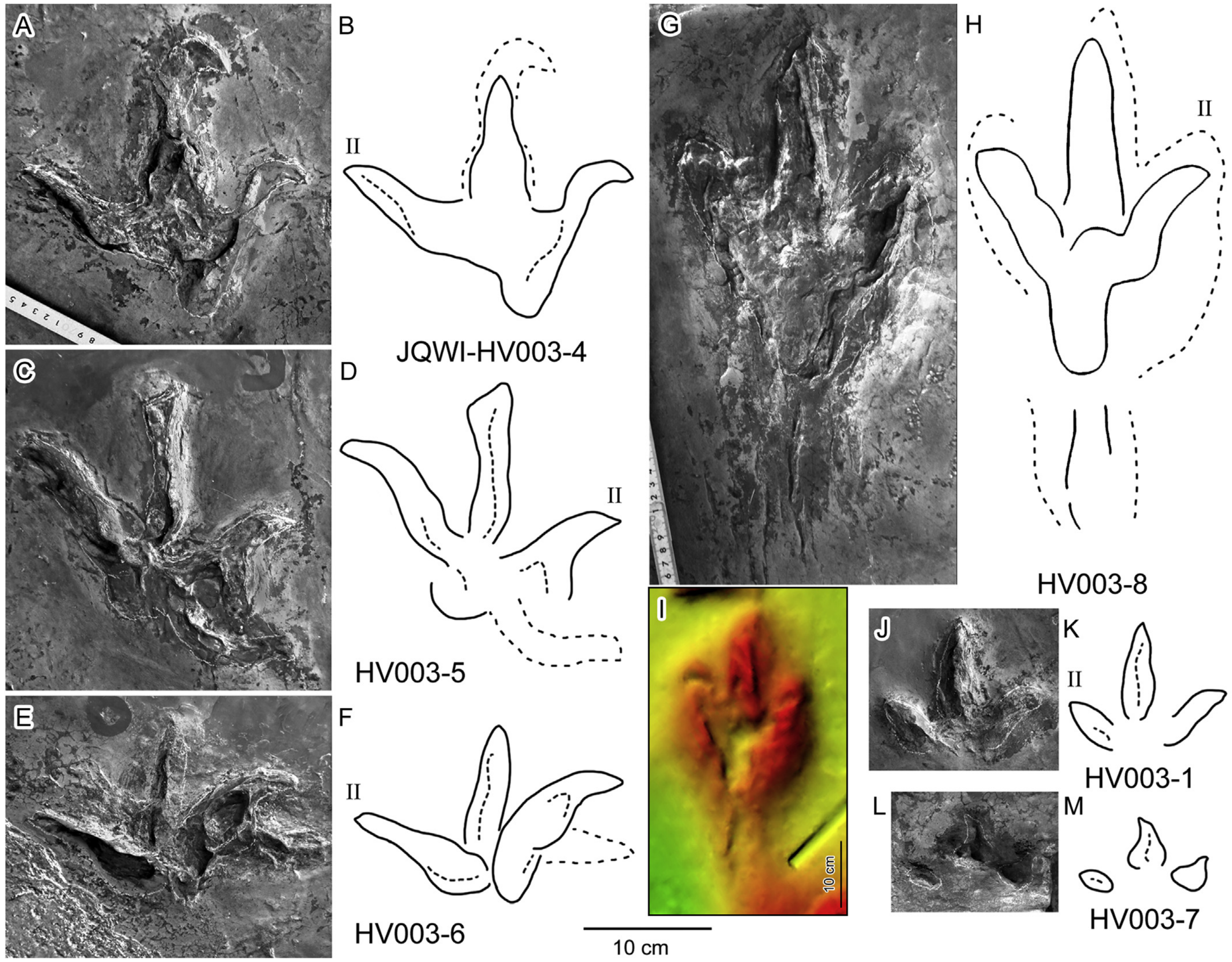

Fig. 5. Photograph (A, C, E, G, J, L) and interpretative outline drawings (B, D, F, H, K, M) of theropod tracks from Jiuquwan I site. A–F, details of *Xiangxipus chenxiensis* trackway. G–I, *Grallator jiuquwanensis* (Zeng, 1982a) comb. nov. with I showing 3D height map.

ichnogenus. Among Early Cretaceous theropod tracks, HV003-1 is similar to *Wupus* from the Jiaguan Formation (Aptian–Albian) of China (Xing et al., 2007, 2015b) and to *Limiavipes* from the Gates Formation (lower Albian) of western Canada (McCrea et al., 2014). All these taxa have a footprint width greater than length; three, moderately thick, functional pedal digits; normally short pace; and a strong rotation towards the midline of the step. In this respect the track morphotype is convergent with *Anomoepus*, which is traditionally attributed to an ornithischian trackmaker. However there is insufficient evidence to support using this ichnogenus label. In *Wupus* and *Limiavipes*, length/width ratio and the length/width ratio of the anterior triangle are 0.9 and 0.46, 0.8 and 0.46, respectively. HV003-1 is more similar to *Wupus* largely because of relatively thick toes. Due to the small sample size, it is difficult to discern systematic features, and thus the material is referred to cf. *Wupus* isp.

JQWI-HV003-7 is poorly preserved and its morphology is greatly affected by preservation factors. The trackmaker left deep tracks with proximal enlargement in wet, soft sediment. Zeng (1982a) referred HV003-7 to *Xiangxipus chenxiensis*, which was inappropriate in terms of size and morphology. Sharp claw mark shows affinity with an avian or non-avian theropod. We therefore refer HV003-7 to theropod indet.

Table 1
Measurements (in cm) of the Saurischian (theropod–sauropod) tracks from JQWI and II tracksites, Hunan Province, China.

Number.	ML	MW	ML/MW	PL	SL	PA	II-IV	AT
JQWI-HV003-0	–	–	–	58.8	117.5	163°	–	–
JQWI-HV003-3	–	–	–	60.0	124.7	164°	–	–
JQWI-HV003-4	21.9	22.6	1.0	66.0	109.0	149°	90°	0.37
JQWI-HV003-5	18.9	22.6	0.8	47.0	–	–	94°	0.36
JQWI-HV003-6	13.9	21.2	0.7	–	–	–	106°	0.27
Mean (0, 3–6)	18.2	22.1	0.8	58.0	117.0	159°	97°	0.33
JQWI-HV003-1	10.0	12.2	0.8	–	–	–	112°	0.51
JQWI-HV003-7	6.0	10.2	0.6	–	–	–	135°	0.40
JQWI-HV003-8	26.2	18.0	1.5	–	–	–	58°	0.53
JQWII-T1-L1	19.5	12.8	1.5	62.5	129.5	167°	54°	0.43
JQWII-T1-R1	20.0	12.5	1.6	67.8	–	–	48°	0.47
JQWII-T1-L2	19.0	14.5	1.3	–	–	–	60°	0.40
Mean T1	19.5	13.3	1.5	65.2	129.5	167°	54°	0.43
JQWII-TI1	14.6	–	–	–	–	–	–	–
JQWII-SI1m	14.0	24.2	0.6	–	–	–	–	–
JQWII-SI1p	34.5	27.3	1.3	–	–	–	–	–
JQWII-SI2m	17.6	25.5	0.7	–	–	–	–	–
JQWII-SI3m	17.5	26.5	0.7	–	–	–	–	–

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; AT: anterior triangle length-width ratio; ML/MW is dimensionless.

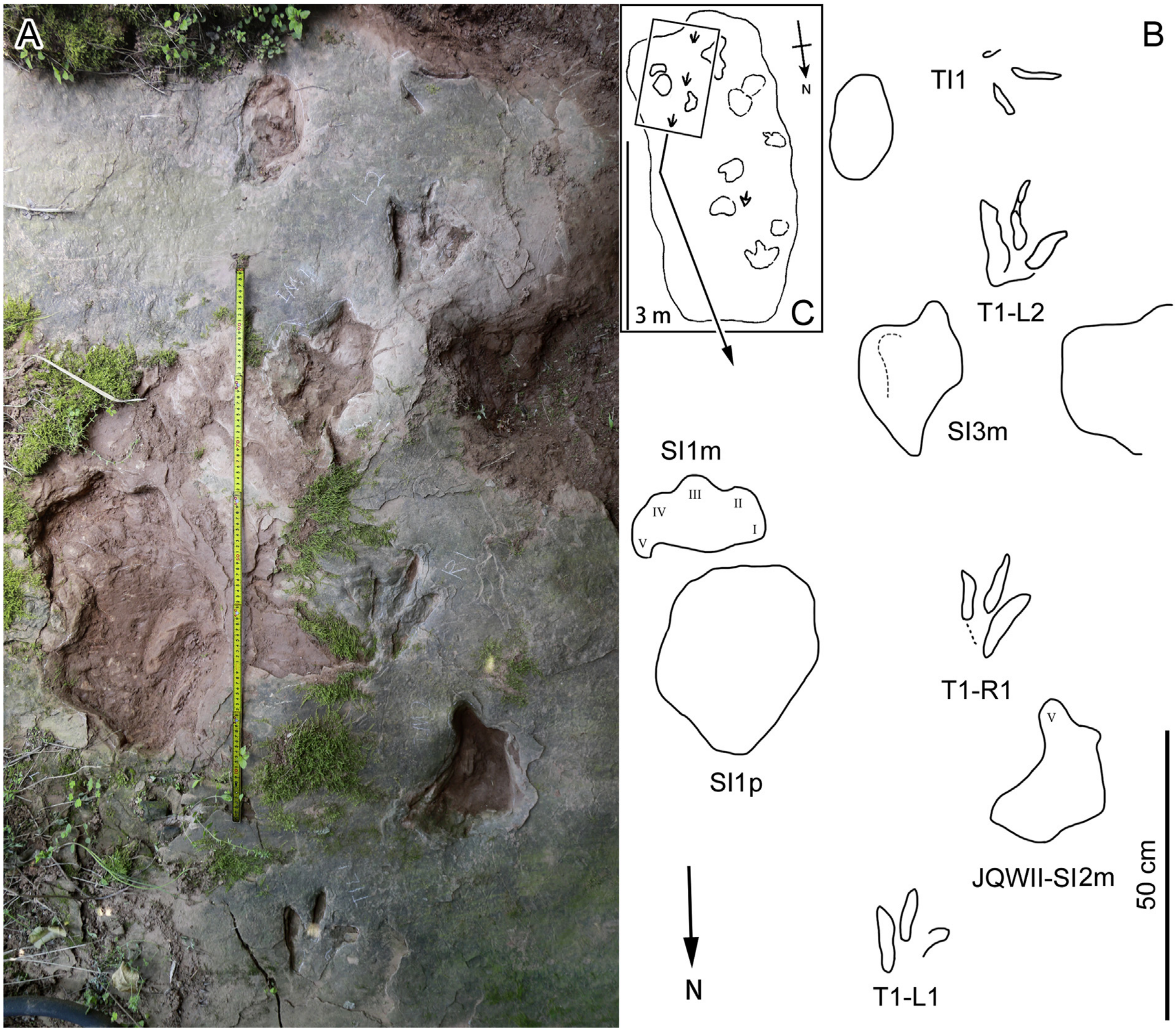

Fig. 6. Photograph (A) and interpretative outline drawing (B) of Jiuquwan II site with theropod trackway JQWII-T1 *Grallator jiuquwanensis* (Zeng, 1982a) comb. nov., isolated theropod track JQWII-TI1 *Xiangxipus chenxiensis* and isolated sauropod tracks SI *Brontopodus* isp. (C) after Matsukawa et al., 2006.

4.2. Sauropod tracks

Sauropoda Marsh, 1878
Brontopodus Farlow et al., 1989
Brontopodus isp.

Materials. Pes and manus traces of a pair of sauropod tracks cataloged as JQWII-SI1m and 1p, and manus tracks of two isolated sauropod tracks JQWII-SI2m and 3m (Fig 6; Table 1). The specimen are preserved at the Jiuquwan II tracksite, Mayang, China.
Type horizon and locality. Shenhuangshan Formation, Lower Cretaceous (Albian). Jiuquwan II tracksite, Mayang County, Hunan Province, China.
Description and Comparisons. JQWII-SI1m and 1p are well-preserved. The length/width ratios of the manus and pes impressions are 0.6 and 1.3 respectively. The U-shaped manus imprint shows oval impressions of digits I and V and a concavity between digit II and III. III and IV can be observed. The pes impression is oval, while the claw traces are indistinct. The metatarsophalangeal region is smooth. JQWII-SI2m and 3m share the same morphologies as JQWII-SI1m.

Most sauropod trackways in China are wide- (or medium-) gauge and are therefore referred to the ichnogenus *Brontopodus* (Lockley et al., 2002). *Brontopodus* was erected and described on the basis of trackways from the Early Cretaceous Glen Rose Formation of Texas (Farlow et al., 1989). Matsukawa et al. (2006) considered sauropod tracks from the Jiuquwan II tracksite morphologically similar to typical *Brontopodus*. We agree with this interpretation and further suggest that JQWII-SI1m and 1p tracks are consistent with the characteristics of *Brontopodus* type tracks; these features include: pes tracks that are longer than wide, large and U-shaped manus prints, and a high degree of heteropody (ratio of manus to pes size) (1:3). But the lack of trackway makes gauge difficult to determine, so we provisionally refer the Jiuquwan II sauropod tracks to *Brontopodus* isp.

5. The Early Cretaceous dinosaur fauna from Hunan Province

Other Early Cretaceous dinosaur records in Hunan Province in addition to these of Jiuquwan tracks include:

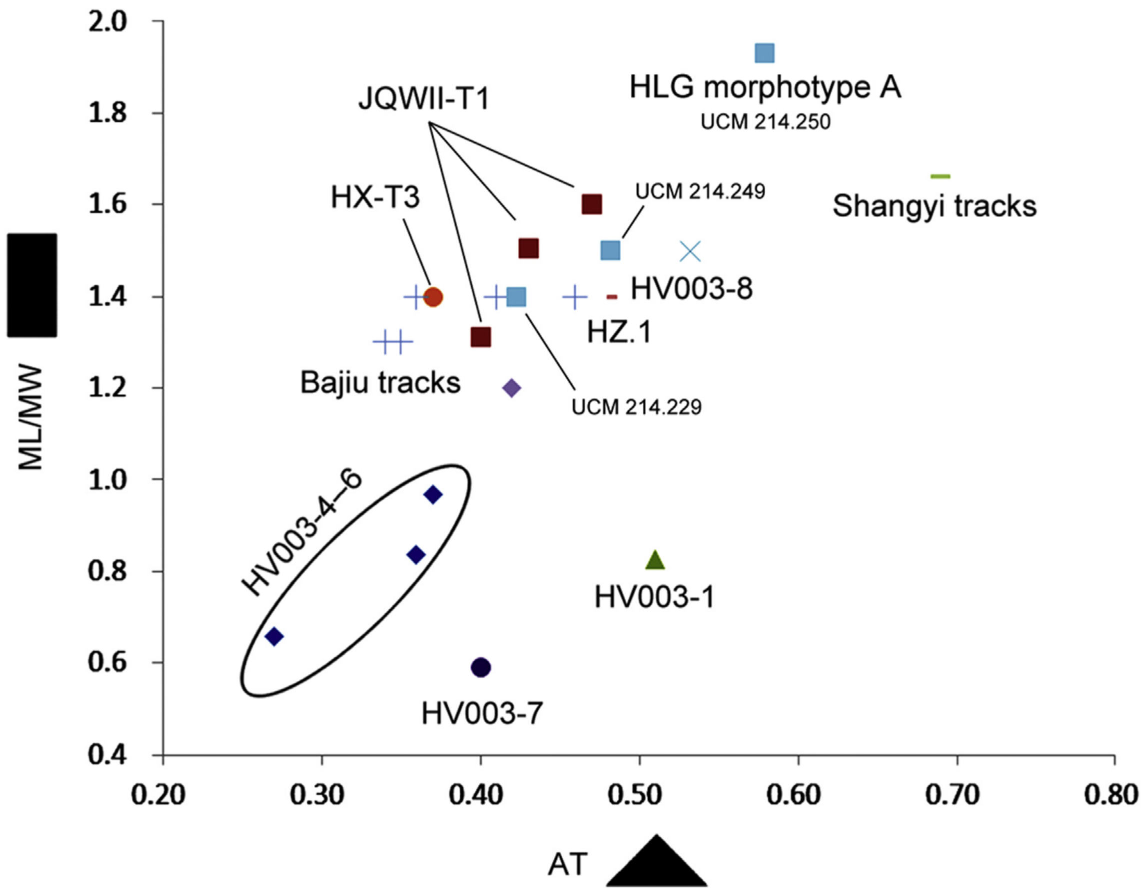

Fig. 7. Bivariate analysis of the length/width ratio vs. AT (anterior triangle length-width ratio) of Jiuquwan theropod tracks and other tridactyl theropod ichnotaxa from the Lower Cretaceous of China.

1) Dongjing Formation (Barremian–Aptian, Li, 1997)

Shexingshan site, from You County, Zhuzhou City, southeast Hunan. When mapping the Bahechong-Liaogongpu Cretaceous section in You County, the Investigation Team of Hunan Bureau of Geology found theropod, Mesosuchia (Crocodylia), and Cryptodira (turtle) fragments in 1974, but did not describe them in details (Chu, 1978; Bureau of Geology and mineral; Resources of Hunan Province, 1988). Dong (1979) identified these specimens and considered two teeth and one toe belonging to coelurosaurids.

2) Lanlong Formation (Albian, Li, 1997)

Lemashan site, from Taoyuan County, Changde City, northwest Hunan. The Investigation Team of Hunan Bureau of Geology found megalosaurid and coelurosaur fragments in 1965, when mapping Lemashan section, but did not describe them in detail (Chu, 1978; Bureau of Geology and mineral; Resources of Hunan Province, 1988). Dong (1979) identified these specimens and considered the teeth belonging to a megalosaurid.

3) Shenhuangshan Formation (Albian, Li, 1997)

Wapengshan site, from Taoyuan County, Changde City, northwest Hunan. The Investigation Team of Hunan Bureau of Geology found Coelurosaur fragments in 1972 when mapping Wapengshan section, but did not describe them in detail (Chu, 1978; Bureau of Geology and mineral; Resources of Hunan Province, 1988). A similar discovery was made in Yangjia, You County, Zhuzhou City (Bureau of Geology and mineral; Resources of Hunan Province, 1988).

Dinosaur skeletal fossils from Lower Cretaceous formations in Hunan only consist of small and medium-sized theropods while the track records attest to a diverse array of small and large theropods and sauropods. These findings indicate that saurischians dominated the Early Cretaceous formations in Hunan. This is consistent with records from Sichuan Province, also part of South China, such as the track records from Jiaguan Formation (Xing et al., 2015b; Lockley et al., 2015b, c).

6. Conclusions

The original descriptions of *Xiangxipus chenxiensis*, *Xiangxipus youngi*, and *Hunanpus jiuquwanensis* Zeng (1982a) from the Shenhuangshan Formation in the Yuanma Basin were problematic and here re-evaluated in the light of present knowledge of Early Cretaceous ichnofaunas in China.

Xiangxipus chenxiensis probably represents an ornithomimid theropod as suggested by Matsukawa et al. (2006). *Xiangxipus youngi* cannot be accommodated in the same ichnogenus as *X. chenxiensis*. It is most similar to *Wupus* or *Limnavipes* and so may be of avian theropod affinity. *Hunanpus jiuquwanensis* is indistinguishable from *Grallator sensu lato*, and so we transfer the ichnospecies to *Grallator jiuquwanensis* comb. nov. The sauropod track Brontopodus also occurs in the sample.

Thus, the Hunan tetrapod ichnofauna is saurischian dominated including morphotypes tentatively referred to the ichnogenera *Xiangpus*, *Grallator*, *Wupus* and *Brontopdus*. In comparison tetrapod skeletal remains from the Cretaceous of Hunan Province includes theropod (coelurosaurid and megalosaurid), crocodilian and turtle elements. Thus the track record adds evidence of sauropods and suggests the presence of an avian theropod.

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