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Stone flowers explained as dinosaur undertracks: unusual ichnites from the Lower Cretaceous Jiaguan Formation, Qijiang District, Chongqing, China

石花形恐龙幻迹:中国重庆綦江区下白垩统夹关组的罕见遗迹化石

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Abstract: Two large footprint features preserved as natural casts on the underside of an overhang in the sand−rich Jiaguan Formation of the Tiger tracksite, Qijiang District, Chongqing, China, are shown to be unusual undertrack features of the type reported from other Cretaceous sites in Korea and North America. A combination of radial and concentric, semi−brittle deformation gives these under-

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tracks a "chopped up" or reticulate appearance which sometimes resembles a segmented flower or cauliflower-like morphology. This has given rise to local folklore references to stone flowers. Such features while of undisputed dinosaurian origin clearly demonstrate extramorphological characteristics.

Key words: dinosaur tracks; undertracks ; Jiaguan Formation; Lower Cretaceous; Qijiang

摘要:在中国重庆綦江区虎山足迹点发现了2个大型恐龙天然足模化石,化石赋存于砂质富集的夹关组的一悬崖底面。它们属于罕见的幻迹,同类足迹也发现于韩国和北美白垩系足迹点。放射状、同心及半脆性形变使这些幻迹具有切断状或网状外观,有时呈现出类似裂断花或菜花的形态。这正是当地"石头开花"民间传说的来源。这些特征表明,造迹者必然是恐龙,同时也清晰地展现了其外形态学特征。

关键词:恐龙足迹;幻迹;夹关组;下白垩统;綦江

中图分类号:P534.53;Q911.28 **文献标志码:**A **文章编号:**1671-2552(2015)05-0885-06

1 Introduction

One of the important modes of preservation for dinosaur tracks is as natural casts. Sauropods tracks preserved as casts (convex hyporeliefs) have already been reported from numerous locations[1-5]. Casts of sauropod tracks appear as rounded bulges protruding from the bases of sandstone beds into the underlying sediment layer (and are sometimes referred to informally as "Brontosaur Bulges")[6-7].

Although a number of sauropod track casts have been previously reported from Lotus tracksite in Qijiang area, the best preserved of these tracks lack adequate morphological features and are difficult to refer to specific ichnotaxa. In 2013, District Bureau of Land Resources found two sauropod natural casts in a sandstone layer of Tiger Mountain (GPS: 29°1´31.00"N, 106°45´54.00"E) which is 1000 m northeast of Lotus tracksite (Fig. 1). The sauropod tracks have been regarded as stone flowers by locals, as were the ornithopod tracks of Lotus tracksite, and demonstrate another instance of track fossils influencing local folklore[8]. Besides, there is a human face-shaped rock (about 30 m high) about 20 m away from the tracks which may have also influenced sites prominence in local folktales.

Institutional abbreviations: TM=Tiger Mountain, Qijiang District, Chongqing, China; SI =isolated sauropod tracks.

2 Geological setting

According to a geologic map of Qijiang area, produced by the Sichuan Provincial Bureau of Geology Aviation Regional Geological Survey Team①, the Tiger tracksite is located at a stratigraphic level within the Cretaceous Jiaguan Formation (Fig. 2). Recent pollen studies suggesting a Barremian-Albian age for the Jiaguan Formation[9]. This age assignment for the Jiaguan Formation is adopted in this paper.

The Tiger tracksite is associated with a sequence more than 700 meters thick consisting of massive sandstones intercalated with thinner mudstone intervals. The sequence is almost equally divided between about 340 m of the Upper Jurassic Pengliazhen Formation at its base, and about 390 m of the Lower Cretaceous Jiaguan Formation in the upper part. The track level is in the lower part of the Jiaguan Formation about 30-40 m above the base of the unit, where the lithology is comprised of purple red quartz sandstone. The track level displays current ripples. The lithology and layers of Tiger tracksite are basically the same as those of Lotus tracksite (for a full description of the Jiaguan Formation see Xing et al.[10-12]).

3 Description of track casts

The Tiger tracksite specimens consist of two natural casts (convex hyporeliefs) of dinosaur tracks (Figs. 3-4), cataloged as TMSI1p-2p. The original tracks remain in situ in the Qijiang National Geological Park, Qijiang District, south of Chongqing, China. The casts show unusual preservation with highly irregular, under- surfaces marked by furrows, grooves and fault- or fracture- like features, with radial components, which give the casts a crenulated or crudely-reticulare appearance. Such features, are characteristic of

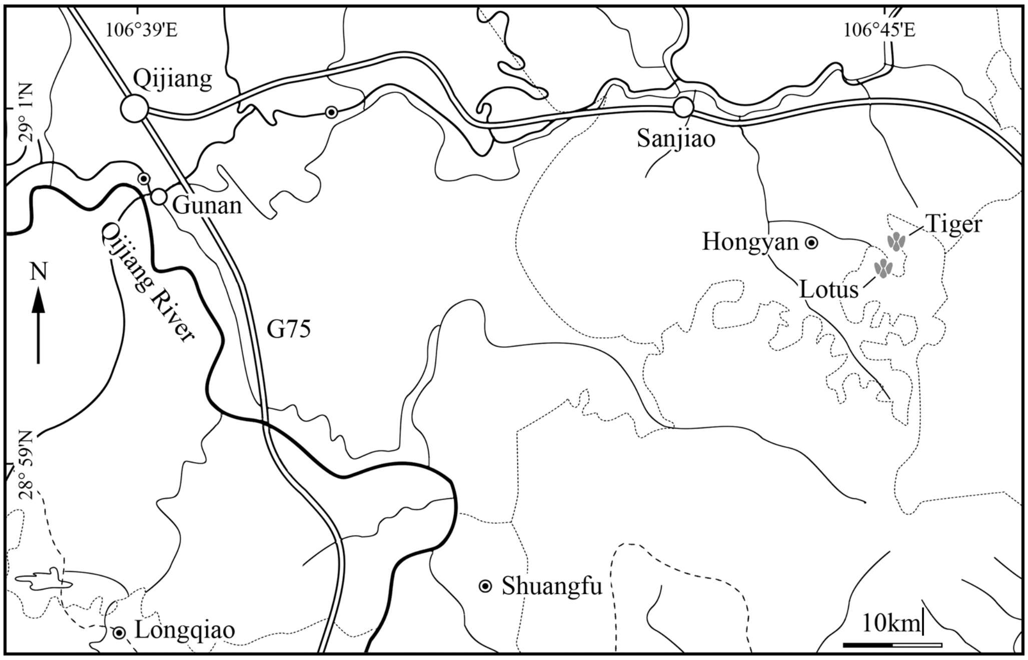

Fig. 1　Geographic map of the dinosaur footprint localities (indicated by the footprint icon)

the radial cracks described in detail by Lockley et al.[13] and Hwang et al.[14]. As noted by these authors, and in the discussion below, such features are a type of undertrack. Nevertheless, as these features are convex hyporeliefs they can also be described as natural casts of undertracks or undertrack casts.

Undertrack cast TMSI1 is the better preserved of the two, in part because the whole outline can be seen. It is approximately 64.5 cm in length, 70.5 cm in width, and 15–20 cm in depth. The L/W ratio of the track cast is 0.9. The irregular, grooved and crenulated surface is typical of casts of under tracks made in certain sedimentary sequences and in the type of track–making scenario described below. TMSI1p has rounded to crudely–semicircular shape, with almost half of the circumference taken up by an arcuate region about 20 cm in radial diameter which is significantly higher in relief (deeper in the original indentation) that the rest of the cast area. The groves and crenulations in this area era significantly more pronounced than in the rest of cast. There is also a raised sub–triangular portion of the cast, opposite the middle of the arcuate area, also characterized by an irregular surface.

Only the a portion of the TMSI2 cast is exposed, while the remainder is obscured. The cast is approximately 70 cm in width, and 27–30 cm in depth. Again, an arcuate rim is exposed, which may possibly bear some relation to claw traces .

4 Interpretation

TMSI1 and TMSI 2 represent casts of undertracks made by large dinosaurs on a sandstone layer, above the interface between sandstone and underlying mudstone exposed on the overhang (Fig. 3). This type of preservation was described by Lockley et al.[13] for ornithopod tracks in the Cretaceous Dakota Group of Colorado and also for ornithopod tracks in the Cretaceous of Korea[14]. If the dinosaurs had walked on the presently exposed interface between the sand and underlying mud diagnostic track morphologies would have been registered more clearly. However, as described by these authors, if a track maker walked on sand layers above the mud–sand interface, the impact

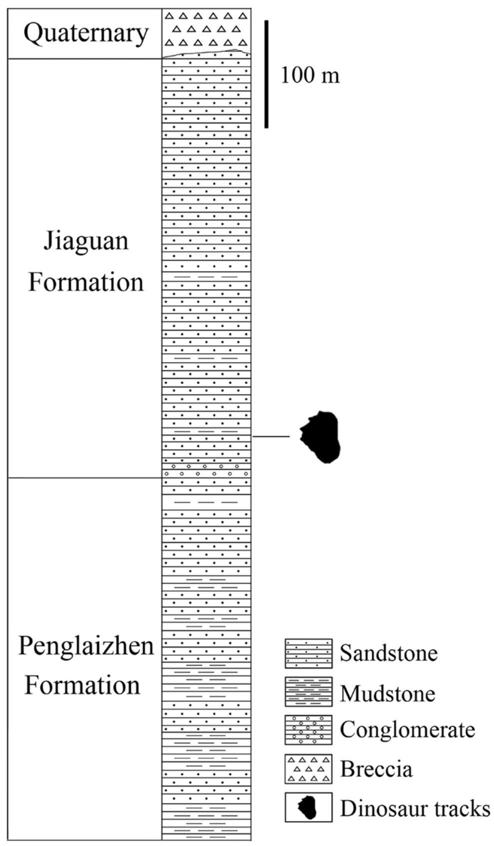

Fig. 2 Upper Jurassic–Lower Cretaceous stratigraphy of Tiger tracksite, Chongqing, China[12]

of the foot falls would cause bulging (undertrack formation) at this interface: i.e., where the sand layer, not the foot, is pushed down into mud (Fig. 4–E). In the present study it is not possible to identify the track maker with certainty. However, the size of the undertracks suggest they may be attributable to sauropods.

Because the mud–sand interface surface area that was deformed by this undertrack formation was forced to expand, the surface was disrupted by extensional forces. Moreover, given that the undertrack–impacted area is more or less circular, the extensional deformation will appear as a series of radial cracks arranged around the downward facing cone (convex hyporelief). These appear somewhat like little horst and graben structures indicating a type of semi–brittle deformation[14]. There is also a concentric component to the deformation, especially when produced by a circular or subcircular foot. This creates, in addition to a circular wall to the undertrack, concentric deformational planes that intersect with the radial planes to produce the reticulate, mosaic, segmented or grid–like deformation pattern (Fig. 4). If the deformation of subsurface layers is slight (shallow), and associated with thin ductile beds, a smooth convex–down dish shaped undertrack will form without any significant extensional radial or concentric cracking. However, if the undertrack is deep, with steeper walls, as in the examples described here, the radial cracking will be pronounced and the sandstone layer will break up, especially in the middle of the undertrack, as described in detail by Hwang et al.[14]. In such cases there may be mixing of the underlying mud with the sandstone in the broken central region of the track. As also described by Hwang et al.[14], if the tracks are deep enough, the foot may penetrate to the mud layer and leave either a complete or incomplete track, depending on how much of the sand layer is pushed aside. In such cases, since the sand layer gets more impacted and broken up in the middle of the track, and may mix with the underlying mud, and even rise into, or close to, the area which is the floor of the actual track, it is to be expected that the central broken area may be shallower than the outer margin of the undertrack. This appears to be the case in TMSI2

Thus, the features seen in TMSI1 and TMSI2 are entirely consistent with previously reported undertrack casts (convex hyporeliefs), and their positive equivalents (concave epireliefs). The details of track morphology are not clear in TMSI1 and TMSI2, but radial cracks typical of undertracks are well developed, as is the broken, segmented, crudely–reticulate, mosaic pattern seen on the underside of the casts. Likewise, as in the Korean examples, the marginal walls of the undertracks are fairly steep, while the central areas are broken.

The distinctive and very unusual Korean undertracks, with prominent radial cracks, described by Hwang et al.[14] had previously been interpreted a number of different ways[15–19]. These interpretations were all incorrect, due to the mistaken assumption that the

Fig. 3　Overview of the Lower Cretaceous dinosaur undertrack casts from Tiger tracksite. The white arrows indicated the casts

features were true tracks. Hwang et al.[14] showed that these were undertracks very similar to those from the Dakota Group of Colorado[13] and others showing similar preservation from the Cretaceous of North America[20]. Song[21] supported this revised interpretation.

5　Conclusion

(1)Tiger tracksite is the second reported tracksite from the Qijiang area, suggesting that more dinosaur tracks likely exist at the same or other horizons.

(2)The site adds to the growing ichnological evidence of the flourishing Early Cretaceous dinosaur faunas of the Jiaguan Formation.

(3)The casts are shown to be undertrack features similar to those reported from the Cretaceous of North America and Korea

(4)Such undertracks are characterized to various degrees by radial cracks and concentric deformation patters which give the casts, a segmented, mosaic crudely-reticulate, flower like appearance.

(5)Such unusual morphologies which gave rise

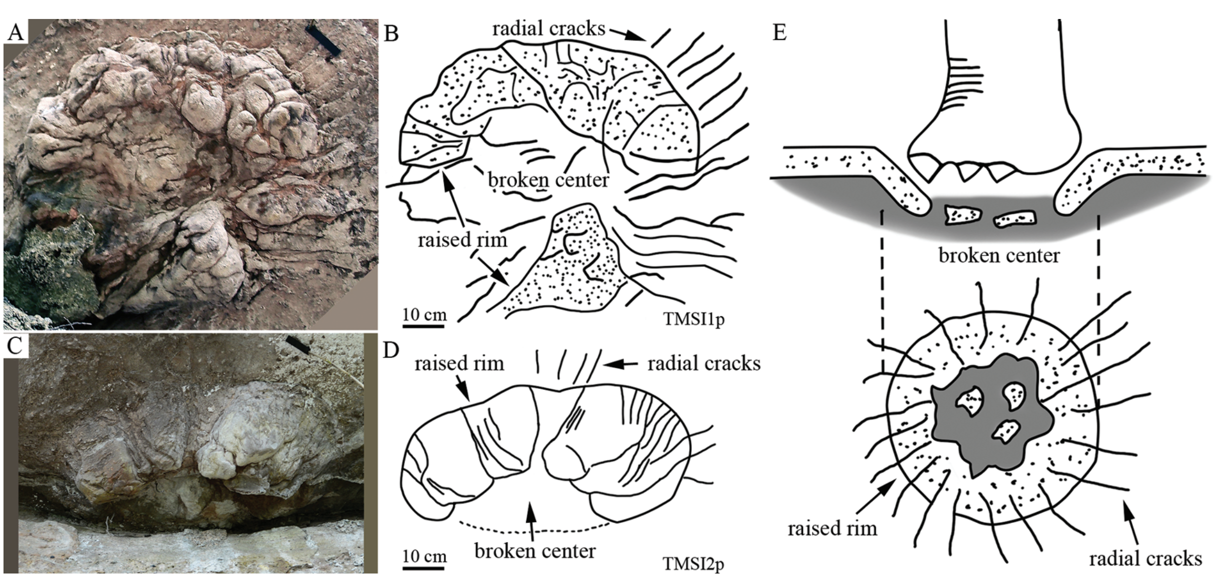

Fig. 4　Photographs (A, C) and interpretative outline drawing (B–E) of the dinosaur undertrack casts from Tiger tracksite. Note development of radial cracks and segmented, mosaic or crudely-reticulate pattern to surfaces. E shows effects of footprint registration on top of a sandstone layer in producing an undertrack on the underside.

to local folklore about "stone flowers" can be explained as extramorphological features of track preservation.

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