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Early Cretaceous sauropod tracks from Zhejian Province, China

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Abstract

The first sauropod tracks from the Lower Cretaceous Shouchang Formation in Zhejiang Province are reported. Based on sauropod track records in East and Southeast Asia, sauropods inhabited fluvi-lacustrine basins under tropical-subtropical and semi-arid climatic setting.

Key words: Sauropod tracks, Early Cretaceous, Zhejiang province, China

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Introduction

Early Cretaceous dinosaur ichnofaunas from Asia suggest a recognizable degree of provincialism (Matsukawa et al., 2006). This was caused by adaptive radiation of track makers in the post Pangean split. In particularly, gracile-toed theropod and ornithopod track ichnofaunas mainly occupied fluvio-lacustrine facies of the mid- latitude Asian continental margin, and robust theropod track ichnofaunas characterized low latitude fluvio-lacustrine facies. Regarding sauropods, however, we can not infer obvious provincialism because Early Cretaceous sauropod tracks have been reported from some areas from south to north a cross the Asian continent. Thus, more information on sauropod track localities is needed in order to understand provincialism.

In 2008, a sauropod trackway site was found in Early Cretaceous strata in Zhejiang Province, China. This discovery contributes to our understanding of sauropod track distribution and provincialism. In this paper, we describe the sauropod tracks and discuss their significance for paleobiogeographical distribution of sauropod in East and Southeast Asia.

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Geological Setting

The discovery of sauropod tracks about 28 km northwest of Lishui City in the southern part of Zhejiang Province, represents the first discovery of sauropod tracks in the province (Fig. 1). The site is located in the bed of a small river in the upper stream area of the Ou Jiang River in Xiaqiao Village. Latitude and longitude are 28˚32'6.24"N, 119˚44'39.18"E. The tracks occur on the surface of a mudstone layer in alternating beds of mudstone and sandstone exposed in an area about 10 m long and 4 m wide (Fig. 2). The bedding surface, which strikes to the west at 80 degrees and dips to the north at 32 degrees, exposes one sauropod trackway and some other isolated sauropod tracks.

The nomarine Cretaceous System in Zhejiang Province is well-developed covering 3/4 of the whole territory of the province, and is recognized as one of Cretaceous type areas in China (Jiang, 1993). There are almost 40 Cretaceous sedimentary basins in Zhejiang Province. The Cretaceous strata in these basins consist of clastics, volcanic rocks and pyroclastic rocks. The clastic rocks include red beds, oil-bearing beds and evaporite rocks. So, these basins represent depositon in lacustrine environments under semi-arid climatic condition. The Cretaceous system in the Laozhu district of Lishui, containing the sauropod tracks, is located in the south central region of the province, and is well developed in Lower, Middle and Upper Cretaceous strata. [Middle Cretaceous is here used in the sense of Hao et al., 1986]. Ages are confirmed on the basis of ostracod biostratigraphy (Hayashi, 2006). The Cretaceous strata are divided into the Moshishan, Shouchang, Guantou and Chaochun formations in ascending order (Fig. 3). Based on ostracod and conchostracan biostratigraphies, and isotope dating the sequence from the Moshishan to Shouchang formations is considered to be assigned to the Lower Cretaceous. The sequence from the Guantou to Chaochuan formation is to be assigned to the Middle Cretaceous [sense Hao et al., 1986], and the Fangyan Formation is to be the Upper Cretaceous. The sauropod tracks occur in lower part of the Shouchang Formation.

Based on Li et al. (1988), the Shouchang Formation shows a mean age of 121.6 Ma and an isochronic (= isotopic) age

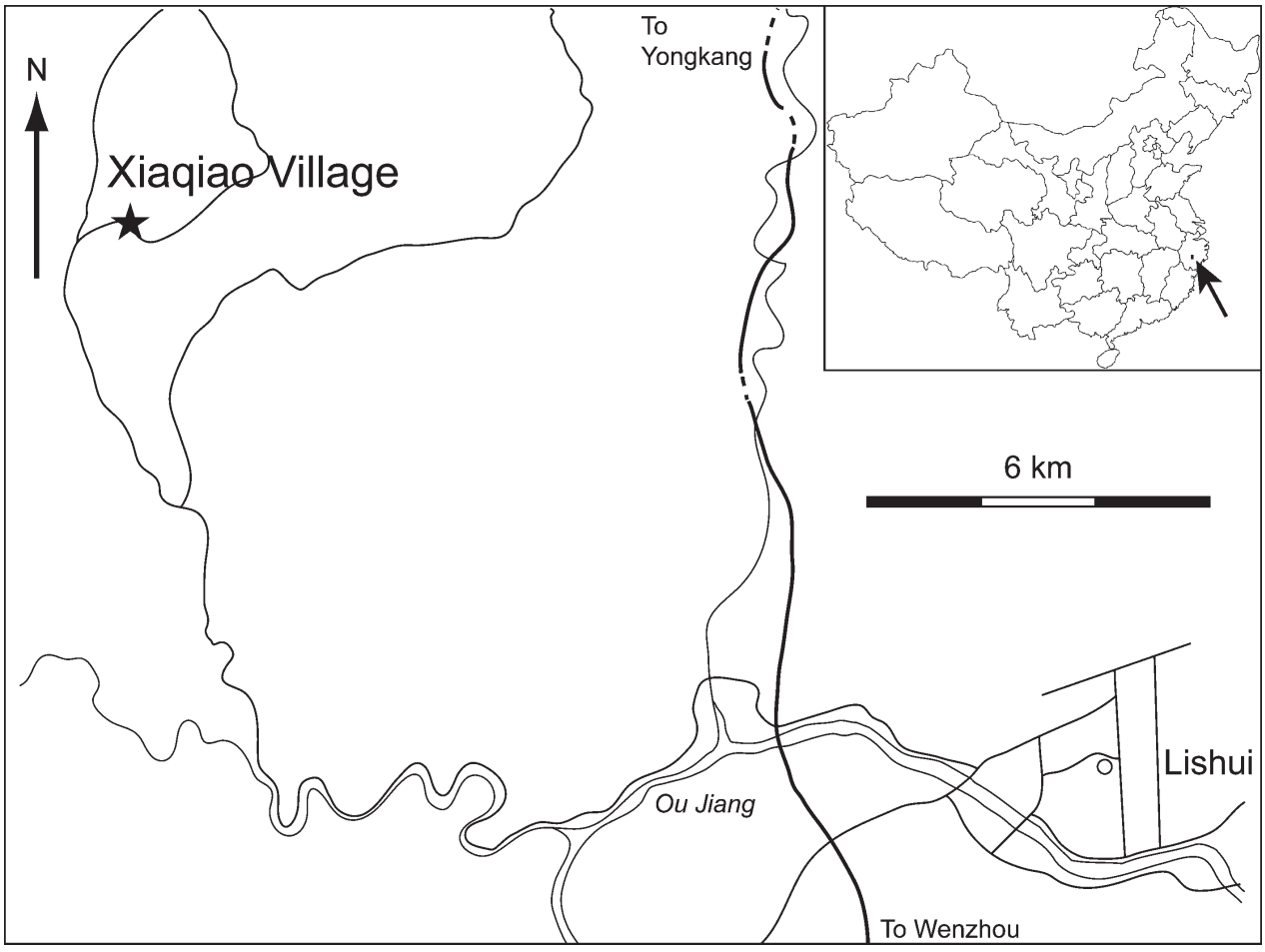

Fig. 1. Map showing locality (star) of the first sauropod tracks in Zhejiang Province.

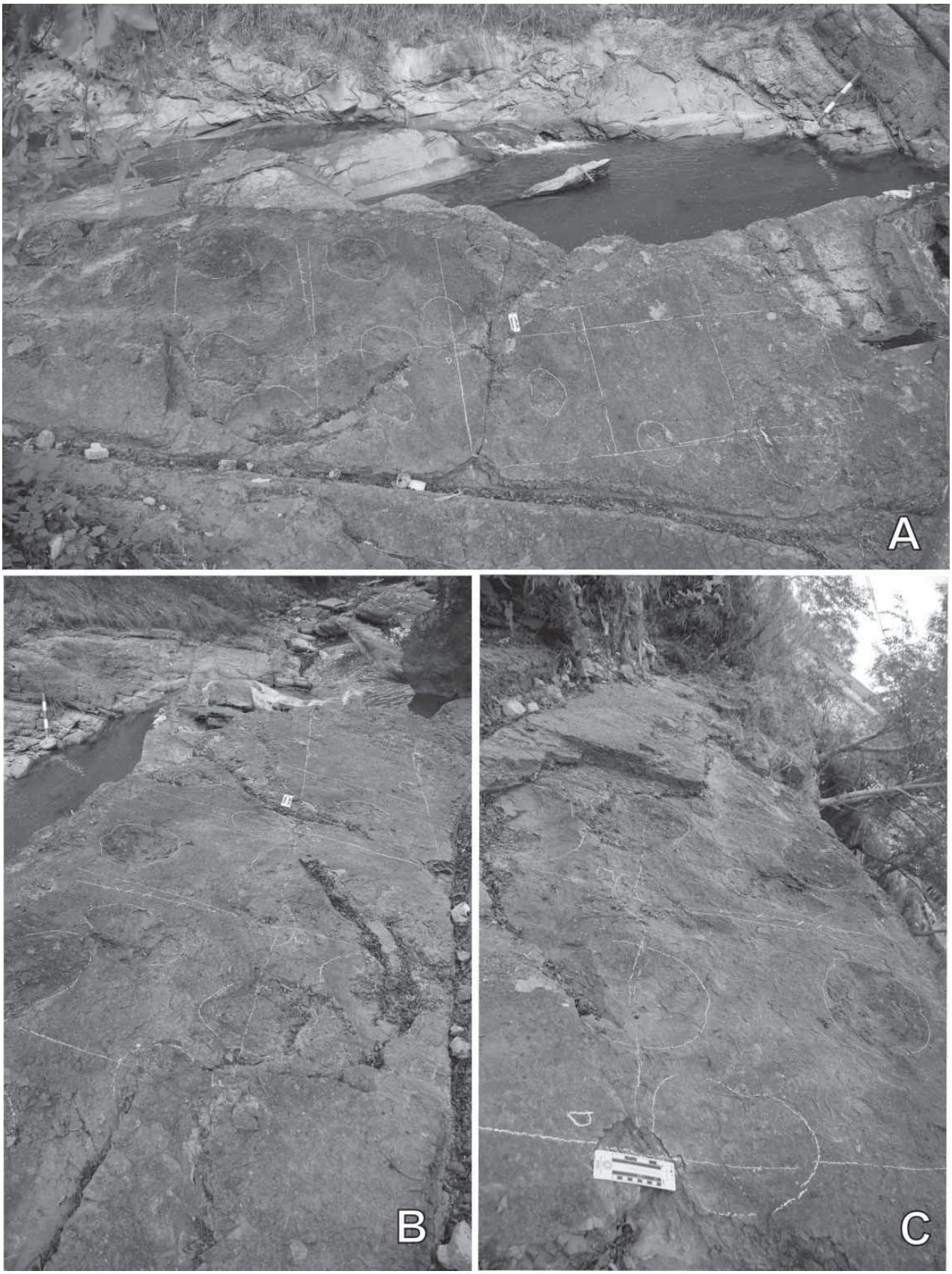

Fig. 2. Sauropod tracks from the Shouchang Formation in Zhejiang Province at Xiaqiao Village. A: view of whole site, B: enlarged eastern part of outcrop, C: enlarged western part of outcrop.

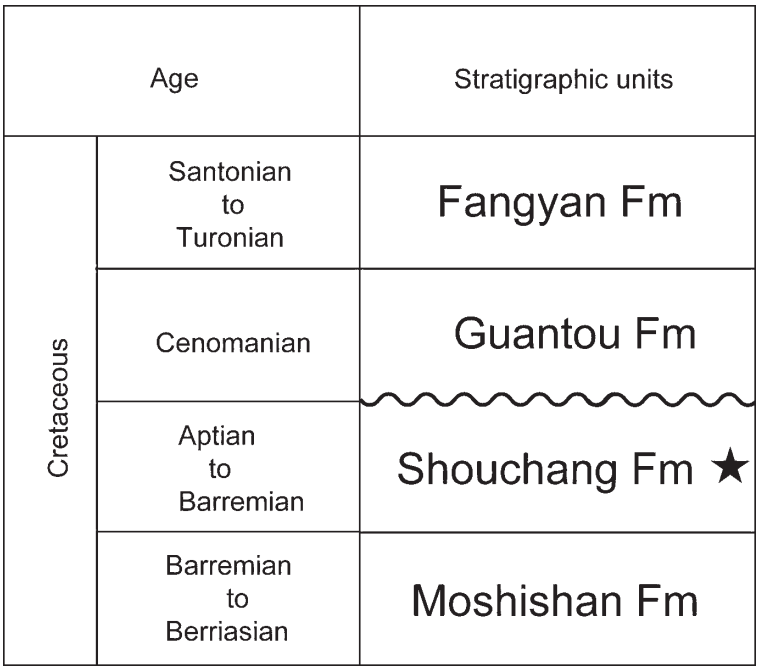

Fig. 3. Stratigraphy of the Cretaceous system in Laozhu district of Lishui area in Zhejinag Province. The sauropod track-bearing Shouchang Formation is marked by star.

of 121.8 Ma as determined by $^{40}Ar/^{39}Ar$ age dating, and shows a mean age value of 121.7 Ma as determined by the Rb-Sr method, and of 124.3 Ma by the zircon – pyroxine uranium / lead technique. So, these data suggest the Shouchang Formation is Aptian in age (Gradstein et al., eds, 2005).

Paleomagnetic data from the Shouchang Formation and a succession from the Guantou to Fangyan formations indicate positive in polarity. The intercalating Henshan Formation between the Shouchang and Guantou formations, which is distributed in Jiande district and lacks in Laozhu district, is, however, negative in polarity (Jiang et al., 1993). The latest negative polarity chron in Early and Middle Cretaceous is the M0r of earliest Aptitan. Therefore, the Shouchang Formation belongs to the M1 chron mainly in Barremian, and the succession from the Guantou to Fangyan formations belong to the KN polarity superchron ranging from Aptian to Santonian (ca. 84-124Ma).

These isochronic dating and paleomagnetic data suggest the Shouchang Formation is Barremian to earliest Aptian in age. The Gantou Formation unconformably overlying the Shouchang Formation has only one isotopic age datum of 99 Ma by the K-Ar method (Jiang et al., 1993). So it is assigned to Cenomanian in age.

The volcanic rocks of the Moshishan Formation in Jinhua City are determined as 140 Ma by K-Ar method. This formation in Laozhu district is equivalent to the Laocun and Huanjian formations of the Jiande Group in Jiande district, which shows age values ranging of 128.7-129.15 Ma and 126-129 Ma respectively (Jiang et al., 1993). Therefore, the Moshishan Formation is considered to be Berriasian to Barremian in age.

Description of sauropod tracks

Eighteen poorly preserved tracks were recognized on the surface of mudstone bed. Although their outlines are unclear, shallow elliptical and kidney like indentations are recognizable (Fig. 4). They suggest these indentations are under tracks of sauropods, with the elliptical indentations suggesting pes and the kidney-like indentations suggesting manus traces. The measurements are as follows: pes length and width range from 36 cm to 48 cm and from 36 cm to 43 cm, respectively, and manus length and width range from 18 cm to 32 cm and from 25 cm to 48 cm, respectively. Because of shallow the poor preservation, we did not obtain reliable trackway measuremnets.

From pes and manus size, these tracks are similar to tracks from the Lower Cretaceous of the Jindong Formation in the Gyeongsang Supergroup in Korea, and to tracks from the Lower Cretaceous of the “Gres superiors” formation in Laos (Matsukawa et al., 2006). They are less than 50 cm in pes length and less than 30 cm in manus length. Pes and

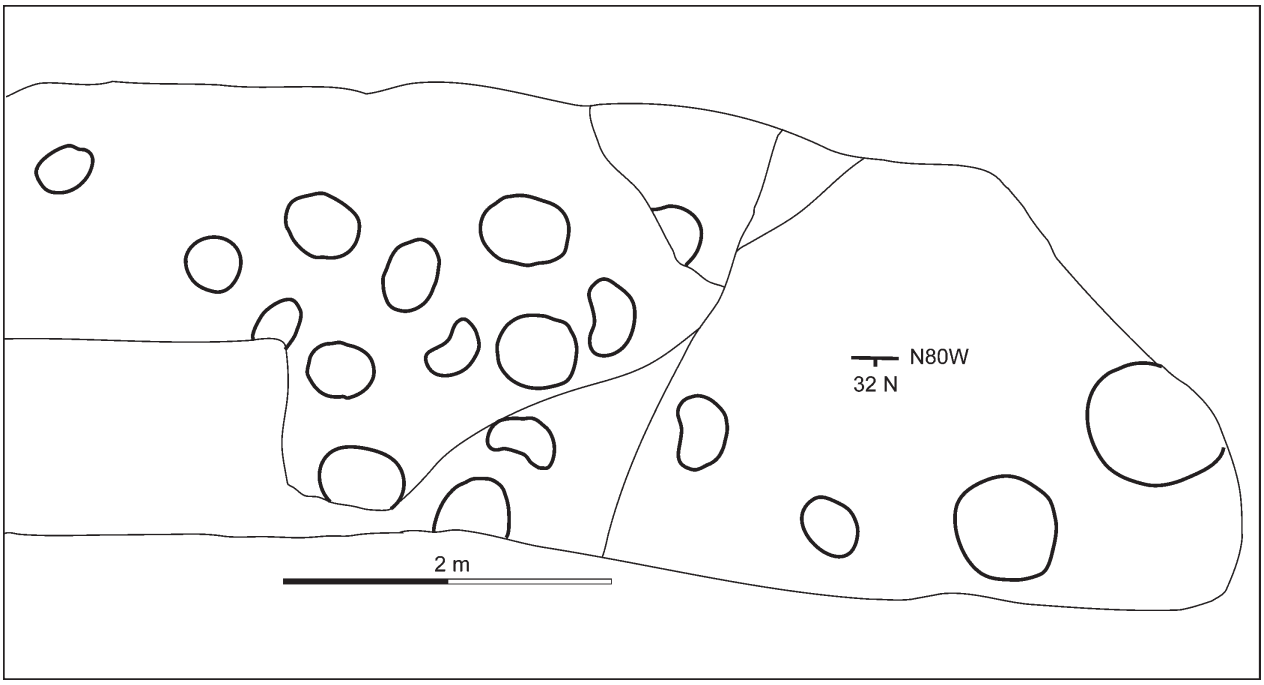

Fig. 4. Map of sauropod track-bearing outcrop at Xiaqiao Village, Zhejinag Province.

manus size of North American sauropods from the Jurassic in Colorado and Utah (Lockley and Hunt, 1995), and the Cretaceous in Texas (Pittman, 1989), from the Cretaceous in Bolivia (Meyer et al., 2001; Lockley et al., 2002), and from the Jurassic of Morrocco (Ishigaki, 1989) are significantly larger than the Zheijiang sauropod track sizes. North American and Morrocco tracks is same cases exceed 100 cm in length.

Discussion

The sauropod track-bearing part of the Shouchang Formation represents the upper part of the first sedimentary cycle in Zhejiang Province (Jiang et al., 1993). The first sequence consists of coarse to fine grained clastics from lower to upper, and intercalations of gypsum-salt rocks in the upper pat. Lava and volcanic-clastics rocks also occur in this lower sequence. So, the Shouchang Formation is considered to be deposited in a lacustrine environments under dry climatic conditions. This means sauropods from Zhejiang Province inhabited lake margins in a semi-arid setting.

To date, Early Cretaceous sauropod tracks are reported from the "Gres superiors" formation in Laos, the Hekou Group in Gansu, the Jingchuang Formation in Nei-Mongolia and the Gyeongsang Supergroup in Korea. As these formations were deposited in fluvio-lacustrine systems, this shows that Early Cretaceous sauropods generally preferred to inhabit such environments. In East and Southeast Asia, sauropd remains including skeletons, teeth and tracks occur in fluvio-lacustrine system from Late Triassic to Late Cretaceous. This means sauropods in East and Southeast Asia inhabited similar environments for a prolonged period of time. This differs from the North American and European sauropod association with platform carbonate facies.

Fig. 5 shows our Early Cretaceous climate model with phytogeographic distributions, distribution of red bed-bearing strata, pyroclastic volcanic strata, evaporite strata and dinosaur-bearing strata. All sauropod track localities fall in areas of tropical-subtropical and arid climate, and of the mixed Tetroi and Ryoseki floras suggesting transition from temperate and moderately humid climate to subtropical or tropical and arid climate. On the basis of floral analyses, Kimura (1979) suggests that the Tetori-type flora was influenced by temperate and moderately humid climates and the Ryoseki-type flora was dominated by subtropical or tropical and arid climates. Then, sauropods in East and Southeast Asia inhabited fluvio-lacustrine basins under tropical-subtropical and arid climate settings.

Conclusions

1. Sauropod tracks were discovered from Lower Cretaceous Shouchang Formation in Zhejiang Province. This is the first sauropod track record in the province.

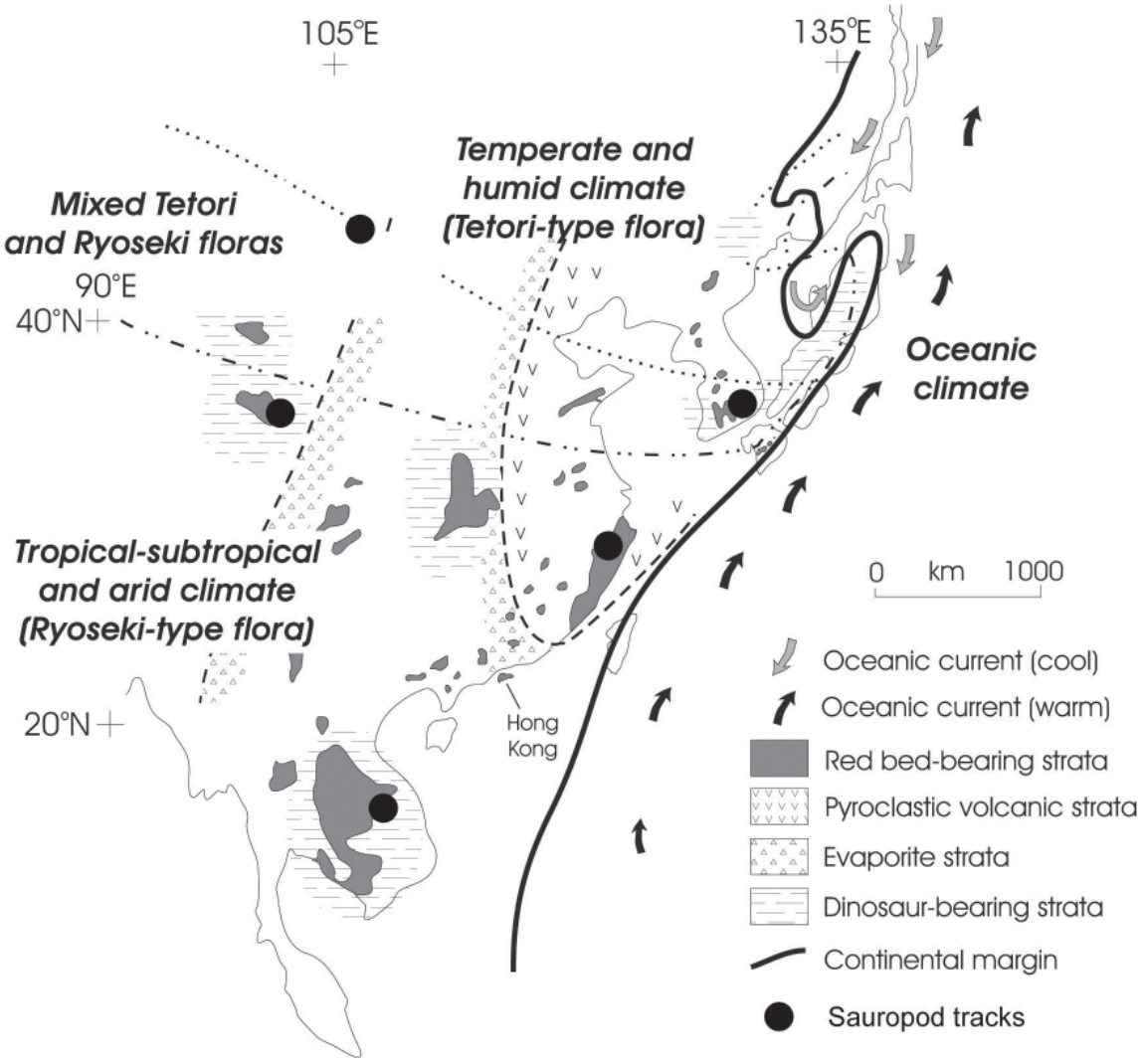

Fig. 5. Sauropod track sites in East and Southeast Asia on map showing Early Cretaceous climate model by Haggart et al. (2006).

2. From track size, sauropod tracks from the Zhejiang Province are similar to sauropod tracks from the Lower Cretaceous of the Jindong Formation, the Gyeongsang Supergroup in Korea, and to tracks from the Lower Cretaceous of the "Gres superiors" formation in Laos. These tracks are generally smaller than many sauropod tracks from North America and Morocco.

3. Based on sauropod track records in East and Southeast Asia, sauropods inhabited fluvi-lacustrine basins under tropical-subtropical and arid climatic condition.

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中国浙江省産の白亜紀前期の竜脚類の足跡

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環境科学分野

要　旨

中国浙江省の下部白亜系の寿昌層下部層から竜脚類の足跡化石が発見された。これは，浙江省での最初の竜脚類の足跡の発見で，不明であった東アジアにおける竜脚類の地理的分布を議論するための貴重な材料になる。

キーワード: 竜脚類の足跡，前期白亜紀，浙江省，中国