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Occurrence of Early Cretaceous *Shimakuroxylon* wood in southeastern China, and its palaeobiogeographic significance

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Abstract

The Mesozoic gymnosperm genus *Shimakuroxylon* Philippe, Boura, Oh et Pons is a peculiar petrified wood taxon which was exclusively recorded from the Jurassic–Early Cretaceous interval in eastern Asia. To date, ten occurrences of this genus were documented in Japan, Indochina and Tibet (southwestern China). However, little is known about the record of *Shimakuroxylon* in eastern China. Here, we describe a new fossil wood specimen from the Lower Cretaceous Laocun Formation in Longyou County of Quzhou City, Zhejiang Province, southeastern China. This fossil specimen exhibits typical *Shimakuroxylon* anatomy with *japonicum*-type (shimakurean) radial tracheid pitting and araucarioid cross-field pitting, representing a new record of *Shimakuroxylon* in eastern Asia. This new finding contributes to our understanding of the fossil wood diversity of the Early Cretaceous xyloflora in southern China, and provides additional data that furthers our knowledge of the palaeobiogeographical distribution of *Shimakuroxylon*. *Shimakuroxylon* is commonly suggested as an indicator of warm and wet climates based on its palaeobiogeographical distribution pattern. However, evidence from plant megafossils and sporopollen suggests the local climate of the study area was warm and arid to semiarid during the Early Cretaceous. It is tentatively suggested that the wood plant might have lived in a warm and humid basin margin with relatively sufficient water supply, though the general environmental background might have been arid to semiarid.

Keywords: *Shimakuroxylon*, Early Cretaceous, Laocun Formation, Zhejiang Province, palaeogeography, palaeoclimate

Introduction

Fossil wood is one of the most significant elements for terrestrial vegetation compositions and continental palaeoenvironment reconstruction in deep time (Philippe *et al.*, 2014). Diverse and rich fossil wood from China have been documented, ranging from the Pennsylvanian to Cenozoic deposits (Zheng *et al.*, 2008). Among these, fossil wood remains found in the northern phytoprovinces are far more abundant and diverse than those in the southern phytoprovinces. With the continuous studies on fossil wood of China, the records of fossil wood from southern phytoprovinces have gradually increased over the past decades, such as those from the Lower Cretaceous in Zhejiang Province, southeastern China (*e.g.*, Tian *et al.*, 2018; Jiang *et al.*, 2020) and Tibet (Yang & Li, 2021), the Upper Jurassic in Shehong of Sichuan Province (*e.g.*, Xie *et al.*, 2023a, 2024a), as well as the Middle Jurassic in Qijiang of Chongqing City (*e.g.*, Xie *et al.*, 2023b, 2024b), Huize of Yunnan Province (*e.g.*, Feng *et al.*, 2015), and Shuanghu County of Tibet (*e.g.*, Xia *et al.*, 2020). It is of note that most of the fossil wood found from the Jurassic and Cretaceous of southern China are referable to those petrified wood taxa which have typical araucarioid cross-filed pitting. However, among the three most common representatives of Mesozoic wood with araucarioid cross-filed pitting, *i.e.*, *Agathoxylon* Hartig, *Brachyoxylon* Hollick & Jeffrey and *Shimakuroxylon* Philippe, Boura, Oh & Pons, the genus *Shimakuroxylon* has rarely been recorded in China (Vezenin-Serra & Pons, 1990). *Shimakuroxylon* is a peculiar petrified wood taxon, which was exclusively recorded from the Jurassic–Early

Cretaceous interval in eastern Asia (Philippe *et al.*, 2014). To date, only a single species has been recognized within this genus, *i.e.*, *Shimakuroxylon japonicum* (Shimakura) Philippe, Boura, Oh & Pons (Philippe *et al.*, 2014).

Recently, a fossil wood specimen with well-preserved anatomical structures was collected from the Lower Cretaceous Laocun Formation in Zhejiang Province, southeastern China. Systematic palaeobotanical investigation indicates that this specimen should be assigned to the genus *Shimakuroxylon*. The new finding provides significant evidence for revealing the fossil wood diversity of the Early Cretaceous in southern China and contributes to further understanding of the palaeobiogeographic distribution of *Shimakuroxylon* worldwide.

Material and methods

The fossil wood specimen studied was collected from the Lower Cretaceous Laocun Formation of the Jiande Group in Xiazhai Village, Hengshan Town, Longyou County, Zhejiang Province (29°12'18.31" N, 119°10'58.36" E) (Fig. 1). The Laocun Formation is well developed in western Zhejiang Province and is considered as one of the major horizons for yielding Early Cretaceous plants remains in southern China (Sun *et al.*, 1995). However, only a few fossil plant taxa have been reported in this formation, represented by *Elatides* Heer, *Sphenolepis* Schenk, *Cupressinocladus* Seward, *Brachyphyllum*

Brongniart, *Pseudofreneopsis* Schenk? and *Otozamites* Braun (Cao, 1999). In the present fossil locality, the Laocun Formation mainly consists of mottled sandstones, intercalated with several layers of the conglomerates, siltstones and tuffaceous sandstones (Wang *et al.*, 2019). With a thickness of 1164 m, the Laocun Formation was lithologically divided into 22 layers. The fossil wood specimen was collected from the tuffaceous sandstone of layer 6 (Wang *et al.*, 2019). Previous zircon U-Pb geochronological study on tuffs from the Laocun Formation in this area gave an age of 138.1 ± 2.3 Ma, which indicates a Valanginian age of the Early Cretaceous (Wang *et al.*, 2019). The specimen with well-preserved anatomical structures was cut into transverse, radial, and tangential planes of sections to produce standard petrographic thin-sections for wood identification (Hass & Rowe, 1999). Software Scope Image 9.0 (H3D) adapted to a Yongxin BM2000 microscope was used to investigate and photograph the thin-sections. The specimen and four thin-sections are housed in the Palaeontological Museum of Liaoning, Shenyang, China, with a catalogue number PMOL-B06661. In the description of fossil wood, we followed the terminology for anatomical structure defined by the IAWA Compendium (IAWA Committee, 2004), supplemented by Philippe and Bamford (2008) and Boura *et al.* (2021).

Systematic palaeontology

Class Pinopsida Burnett 1833

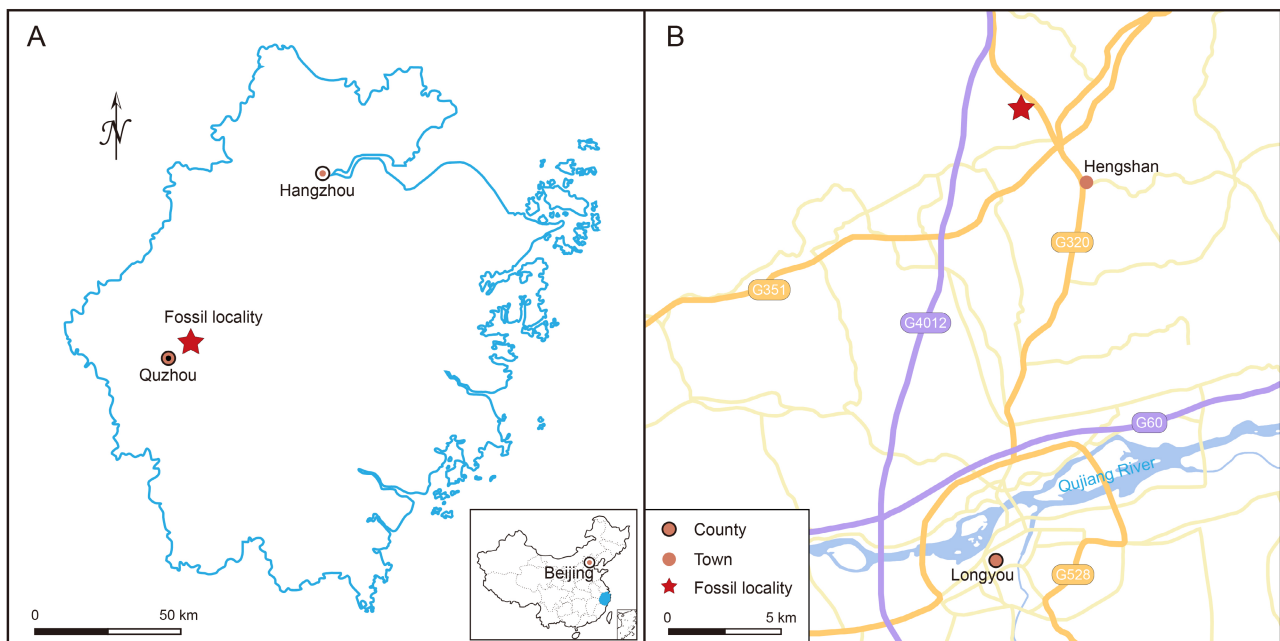


FIGURE 1. Geographic distribution of the fossil locality. **A**, Sketch map of fossil locality (star) for fossil wood in Longyou County of Quzhou City, Zhejiang Province, southeastern China. **B**, Close-up of **A**, showing details of sketch map of fossil wood locality (star).

Order Pinales (= Coniferales) Gorozhankin 1904

Genus *Shimakuroxylon* Philippe, Boura, Oh & Pons, 2014

Shimakuroxylon japonicum (Shimakura) Philippe, Boura, Oh & Pons, 2014 (Fig. 2)

Material. Specimen No. PMOL-B06661. The specimen and slides are housed in the Palaeontological Museum of Liaoning, Shenyang, China.

Locality and horizon. Longyou County of Quzhou City, Zhejiang Province, P.R. China. Laocun Formation, early Cretaceous (Valanginian).

Description. The specimen PMOL-B06661 is preserved as a fragment of secondary xylem. Details of the pith and primary xylem are not available. The wood is homoxylous and pycnoxylic (Fig. 2). In the transverse section, indistinct growth rings are present (Fig. 2A–C). The tracheid cross-sections are commonly rectangular to polygonal, with intercellular spaces present (Fig. 2A–C). No axial parenchyma and resin canals are observed. In the radial section, the bordered pits on the tracheid walls are uniseriate to biseriate (Fig. 2D–G). When uniseriate, the pits are commonly contiguous and oval in shape (Fig. 2D); when biseriate, the pits are occasionally alternate with an elliptical shape (Fig. 2E), but mostly opposite with a square or oval edge at the marginal side (Fig. 2F, G). Cross-field pitting is araucarioid, meaning each cross-field bears about 15 cupressoid alternate pits (Fig. 2H, I). In the tangential section, the ray cells are uniseriate, mostly 2–8 cells high, occasionally up to 14 cells tall (Fig. 2J, K). Both the horizontal and end walls of the ray parenchyma cells are smooth (Fig. 2H, I). Crassulae, axial parenchyma, and resin canals are absent.

Remarks. The fossil wood specimen described herein was assigned to the genus *Shimakuroxylon* Philippe, Boura, Oh & Pons, based on its anatomical characters of typically *japonicum*-type (shimakurean) radial tracheid pitting (*sensu* Boura *et al.*, 2021) and araucarioid cross-field pitting. The genus *Shimakuroxylon* was validly established by Philippe *et al.* (2014) based on specimens from the Outer Zone of Southwest Japan, which was originally described by Shimakura (1936) as *Dadoxylon* (*Araucarioxylon*) *japonicum* Shimakura. To date, only one verified species has been described for this genus, *i.e.*, *Shimakuroxylon japonicum* (Philippe *et al.*, 2014). It should be noted that eight fossil wood species which were initially assigned to *Dadoxylon* Endl., *Baieroxylon* Greguss, *Brachyoxylon* Hollick & Jeffrey, *Mesembrioxylon* Seward, *Protopodocarpoxyton* Eckhold, and *Prototaxoxylon* Kräusel & Dolianiti, were synonymized under the type species *S. japonicum* by

Philippe *et al.* (2014). While these species share the *japonicum*-type (shimakurean) radial tracheid pitting, they do show differences in other wood anatomical details, such as the number of cross-field pits, the height of ray cells, the presence or absence of distinct growth rings, axial parenchyma, and resin ducts. As Philippe *et al.* (2014) mentioned, despite the significant anatomical variability among these specimens, the reassignment of these seven species to *S. japonicum* is generally reasonable and acceptable. Upon further comparison, the present fossil wood specimen from China is mostly similar to the type specimens of *S. japonicum* in the number of cross-field pits, the height of ray cells, and the absence of distinct grow rings, axial parenchyma and resin ducts (Shimakura, 1936). The only difference is that the type materials of *S. japonicum* have triseriate radial tracheid pits, which were not found in the Chinese material. Hence, our specimen described herein was tentatively assigned to *S. japonicum*.

Discussion

Zhejiang Province is considered as one of the most significant fossil localities for Early Cretaceous petrified wood in southern China. To date, four fossil wood species have been reported from this region: *Agathoxylon* (*Araucarioxylon*) *xinchangense* Duan, *Agathoxylon* sp., *Brachyoxylon zhejiangense* Tian, Zhu & Wang and *B. zhoui* Jiang, Tian, Wu & Wang (Duan *et al.*, 2002; Tian *et al.*, 2018; Zhu *et al.*, 2018; Jiang *et al.*, 2020). All these species were described from the Lower Cretaceous (Albian) Guantou Formation in Xinchang and Yongkang Counties, eastern Zhejiang Province. In recent years, Wang *et al.* (2019) briefly reported the occurrence of petrified wood from the Lower Cretaceous (Valanginian) Laocun Formation in Longyou County of Quzhou City, eastern Zhejiang Province. However, due to the poor preservation condition of their fossil wood specimens, Wang *et al.* (2019) only tentatively identified them as *Araucarioxylon* sp. citing araucarian cross-field pitting, but provided no figures, plates, or detailed systematic descriptions. In this study, we discovered new fossil wood materials from the same horizon and locality, exhibiting good anatomical details. Based on credible evidence, we recognized these specimens as *Shimakuroxylon japonicum*. This represents the first credible record of *Shimakuroxylon* in China and provides new insights into the Early Cretaceous palaeoecological flora of Zhejiang Province.

Shimakuroxylon, as one of the significant components of Mesozoic fossil wood flora, is endemic to Eastern Asia, for instance, Japan, Thailand, Cambodia, Vietnam, as well as southwestern China (*i.e.*, Lhasa, central Tibet)

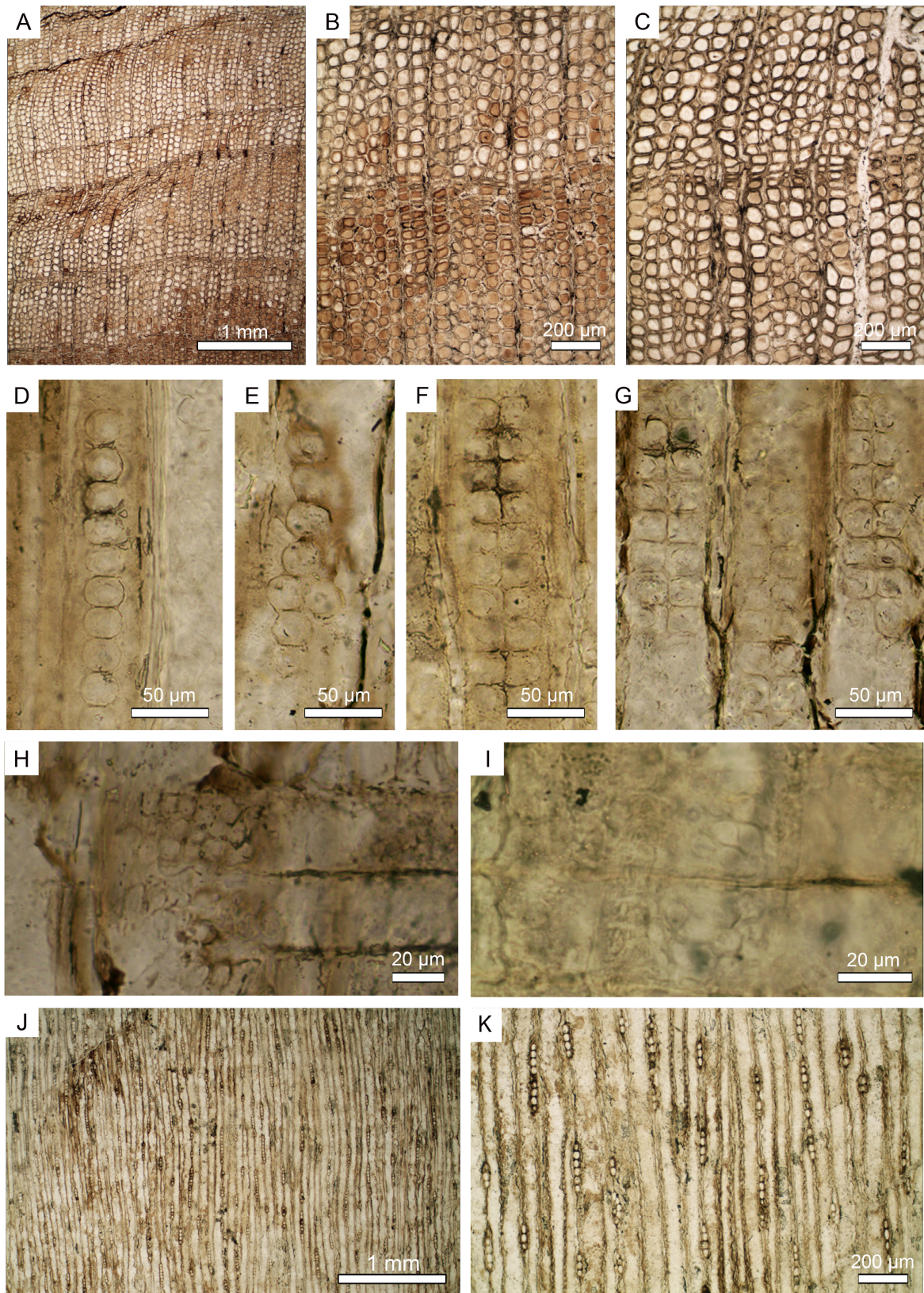


FIGURE 2. *Shimakuroxylon japonicum* (Shimakura) Philippe, Boura, Oh et Pons from the Lower Cretaceous Laocun Formation in Longyou County of Zhejiang Province, China. **A**, Cross section, showing indistinct growth rings. **B**, **C**, Cross section, showing details of indistinct growth rings. **D**, Radial section, showing uniseriate continuous and flattened bordered pits on the tracheid walls. **E**, Radial section, showing locally biseriate alternate bordered pits. **F**, **G**, Radial section, showing biseriate opposite bordered pits on the tracheid walls. **H**, **I**, Radial section, showing araucarioid cross-field pitting. **J**, Tangential section, showing uniseriate rays. **K**, Tangential section, showing details of uniseriate rays, 2–8 cells high.

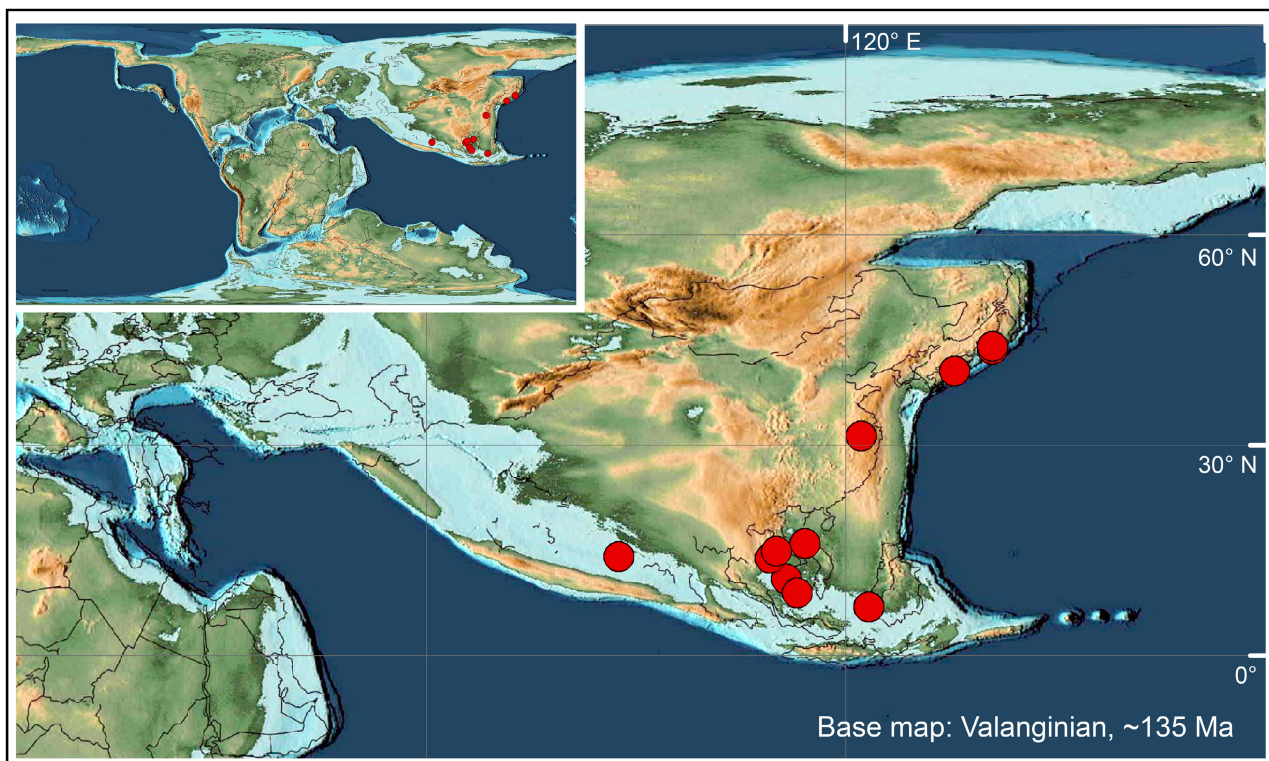


FIGURE 3. Paleobiogeographic map showing the spatio-temporal distribution of *Shimakuroxylon* worldwide. The red dots indicate the occurrences of *Shimakuroxylon* (data from Philippe *et al.*, 2014, with updates). The base paleogeographic map is modified after Scotese (2014): Valanginian (~135 Ma), Early Cretaceous.

(Philippe *et al.*, 2014) (Fig. 3). The genus spans from the Jurassic to the Cretaceous, confined to mid-low latitude regions of the Eastern Asia between palaeolatitudes 12°N and 25°N (Philippe *et al.*, 2014). However, this genus has never been recorded in eastern China. Our new finding represents the first credible record of this peculiar fossil wood taxon in eastern China and extends the known distribution of *Shimakuroxylon* to the eastern part of the Asian continent during the Early Cretaceous. Palaeogeographically, *Shimakuroxylon* distribution is aligned along a tectonically active margin, likely bordered by a system of coastal cordilleras during the Jurassic–Early Cretaceous (Fig. 3). The occurrence of *Shimakuroxylon* in Zhejiang indicates that this genus existed not only on the eastern side, but also on the western side of the coastal cordillera in eastern Asia.

It is widely accepted that the Early Cretaceous floras from southern China belong phyto-geographically to the Euro-Sinian Realm, representing a tropic–subtropical xeric vegetation (Sun *et al.*, 1995). Fossil evidence gained from the plant megafossil (represented by conifers with scaled leaves, *e.g.*, *Elatides*, *Cupressinocladus*, *Brachyphyllum*, *Pseudofreneopsis*) and sporopollen (*Classopollis*) in the Laocun Formation, also indicates a subtropical to tropical hot and relatively semiarid climate (Cao, 1999). It is noted that according to several lines of evidence, Philippe *et al.*

(2014) proposed that the distribution of *Shimakuroxylon* was ecologically constrained to year-round warm and at least seasonally wet climates. The occurrence of *Shimakuroxylon* in Longyou, thus, may imply that a warm and wet climate with seasonality was prevailing in this region during the Early Cretaceous. A mild seasonality is supported by the characters of tree growth rings in Longyou wood. However, a warm and wet climate condition is obviously inconsistent with that gained from megafossil and sporopollen. Sedimentological evidence from Wang *et al.* (2019) suggests that the fossil wood from Longyou was deposited in a fluvial fan and/or lakeside environment. This implies that the wood plant might have thrived in a warm and humid basin margin with relatively sufficient water supply, although the general environmental background might be arid to semiarid. Nevertheless, the finding of fossil wood *Shimakuroxylon* in the Laocun Formation offers new evidence to further understanding for the local climate of Longyou during the Valanginian Stage of the Early Cretaceous.

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