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An exceptionally preserved conifer wood *Metapodocarpoxylon* from the Jurassic of northeastern Qinghai-Xizang (Tibetan) Plateau, and its palaeobiogeographic and palaeoclimatic significances

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Abstract

The Early-Middle Jurassic impression/compression macroflora and the palynoflora from the Qaidam Basin in the northeastern Qinghai-Xizang (Tibetan) Plateau have been well studied; however, fossil wood from this region has not been previously documented systematically. Here, we describe an anatomically well-preserved fossil wood specimen from the Lower Jurassic Huoshaoshan Formation at the Dameigou section in northern Qinghai Province, northwestern China. This fossil exhibits typical *Metapodocarpoxylon* Dupéron-Laudoueneix et Pons anatomy with usually araucarian radial tracheid pits and variable cross-field pits, representing a new record for *Metapodocarpoxylon* in the Qaidam Basin. This discovery indicates that trees with this type of wood anatomy were not confined to northern Gondwana but also grew in more northerly regions in Laurasia. The wood displays distinct growth rings, with abundant, well-formed earlywood and narrow latewood. This observation, along with previous interpretations based on macroflora, palynoflora and sedimentological data, suggests that a warm and humid climate with mild seasonality prevailed in the region during the Early Jurassic.

1. Introduction

Located on the northeastern margin of the Qinghai-Xizang (Tibetan) Plateau, the Qaidam Basin is renowned for its extensively developed Mesozoic and Cenozoic terrestrial deposits with abundant hydrocarbon source rocks of Jurassic age (Zhang *et al.* 1998; Ritts *et al.* 1999). These deposits also represent the most complete Lower–Middle Jurassic plant-bearing sequences of Northern China (Li *et al.* 1988; Zhou, 1995; Wang *et al.* 2005). Based on these plant fossils, a series of palaeobotanical studies have been carried out since the 1950s, demonstrating that highly diverse vegetation grew in this basin during the Early–Middle Jurassic, including bryophytes, ferns, cycads, bennettitaleans, ginkgos and conifers (e.g., Sze, 1959; Li *et al.* 1988; Wang *et al.* 2005; Zhang *et al.* 2024). Fossil wood is regarded as one of the most important types of plant fossils with informative significance for exploring the vegetation composition and palaeoclimate variations (Wang *et al.* 2017); however, detailed systematic studies of fossil wood material from the Qaidam Basin have been absent so far.

Since the beginning of the 20th Century, a number of fossil wood specimens have been described from Pennsylvanian–Cenozoic deposits in China (Zheng *et al.* 2008), with the Jurassic and Lower Cretaceous fossil wood record being extraordinarily diversified (Zheng *et al.* 2008; Wang *et al.* 2009; Yang *et al.* 2013). Up to now, about 20 genera and 40 species of fossil wood have been described from the Jurassic of China (Zheng *et al.* 2008; Wang *et al.* 2009; Xie *et al.* 2023, 2024). However, as mentioned above, so far little is known about fossil wood from the Qaidam Basin, although some sedimentological studies mentioned the occurrences of fossil wood (Ritts, 1998; Ritts *et al.* 1999; Li *et al.* 2016; Lu *et al.* 2020), but without providing detailed systematic investigations.

During recent fieldwork in the Dachaidan area of Qinghai Province, a specimen of permineralized fossil wood was collected from the Lower Jurassic Huoshaoshan Formation. In the present study, this well-preserved fossil specimen is investigated in detail, to describe its anatomy and carry out taxonomic determination, to interpret the palaeoclimatic signals preserved in the tree growth rings of the wood, and to shed new light onto the palaeobiogeography of the Gondwana type of *Metapodocarpoxylon* wood. The fossil wood here is recognized as *Metapodocarpoxylon libanoticum* (Edwards) Dupéron-Laudoueneix et

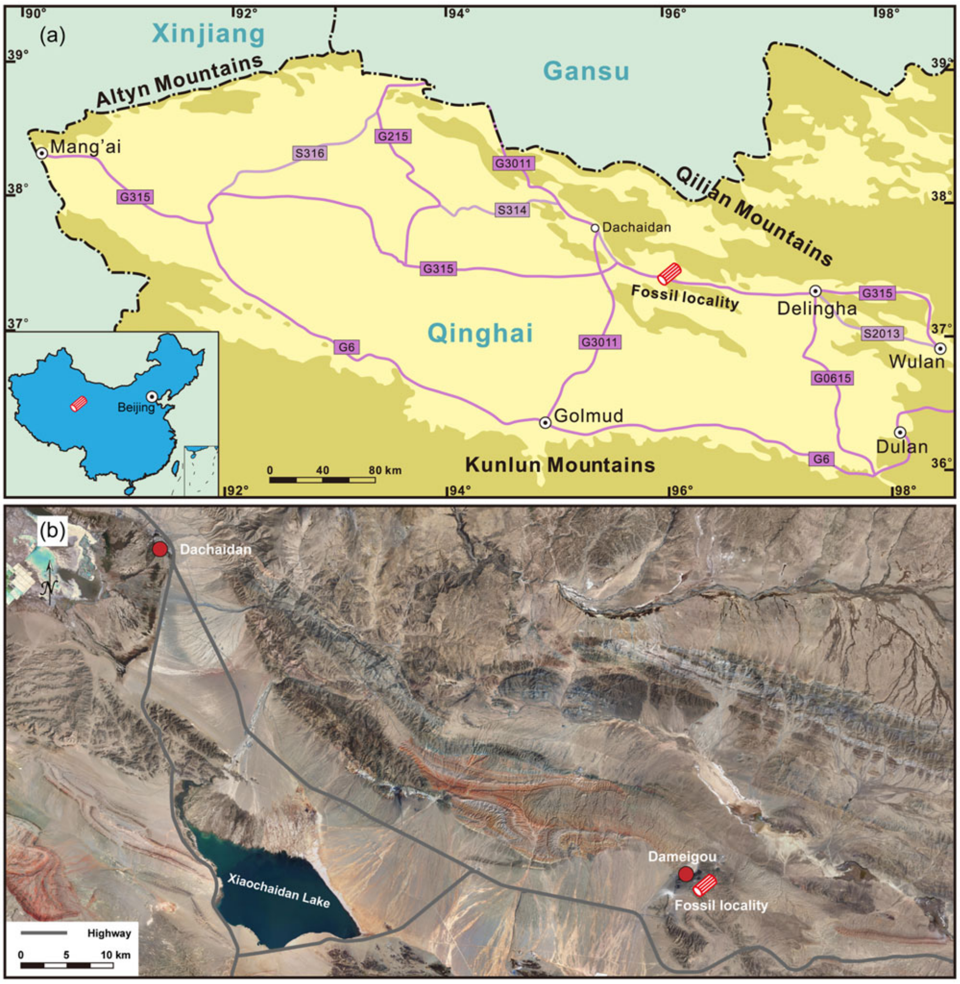

Figure 1. (a) Sketch map of fossil wood locality at Dameigou section in Dachaidan Town, Delingha City, Qinghai Province, China. (b) Close-up of (a), showing details of fossil wood locality; the base satellite image is according to the National Platform for Common GeoSpatial Information Services.

Pons, so far only known from the Jurassic and Cretaceous deposits in Northern Gondwana regions (e.g., Bamford *et al.* 2002; Philippe *et al.* 2003; El-Noamani *et al.* 2021), thus representing the first record of *Metapodocarpoxylon* in Laurasia.

2. Geological setting and stratigraphy

Located at the northeastern margin of the Qinghai-Xizang (Tibetan) Plateau, the Qaidam Basin covers an area of ~120,000 km^2 (36°–39° N, 91°–98° E). The basin is surrounded by the Altyn Mountains in the northwest, the Qilian Mountains in the northeast and the Kunlun Mountains in the south (Fang *et al.* 2007; Fig. 1). During the Mesozoic, the Qaidam Basin was tectonically influenced by the evolution of the Meso-Tethys, Neo-Tethys and Mongol-Okhotsk Ocean, as well as the collisions of related blocks (Ritts & Biffi, 2001; Kravchinsky *et al.* 2002; Kapp *et al.* 2007; Gehrels *et al.* 2011). The basement of the Qaidam Basin is pre-Paleozoic crystalline rocks and Paleozoic non-metamorphic or shallow metamorphic rocks (Wang *et al.* 2005; Gong *et al.* 2012; Liu *et al.* 2014). After a series of tectonic evolutionary stages, the intermontane basin developed terrestrial deposition from the Jurassic onwards, consisting of Mesozoic-Cenozoic sediments in a fluvial-lacustrine depositional environment, with a thickness of 3–16 km (Ritts & Biffi, 2001; Xia *et al.* 2001; Zhuang *et al.* 2011; Jian *et al.* 2013; Ren *et al.* 2017; Zhou *et al.* 2022).

The Jurassic strata mainly crop out at the northern margin of the Qaidam Basin in the Yuqia, Dameigou, Baishushan, and Wanggaxiu areas (Li *et al.* 1988; Zhang *et al.* 1998; Wang *et al.* 2005). In these areas, the Jurassic deposits have been divided into seven formations: the Lower Jurassic Xiaomeigou Formation, Huoshaoshan Formation, Tianshuigou Formation and Yinmagou Formation, as well as the Middle Jurassic Dameigou Formation, Shimengou Formation and Caishiling Formation in ascending chronostratigraphic order (Zhang *et al.* 1998; Wang *et al.* 2005; Zhou *et al.* 2022). Specifically, the Lower Jurassic is only well-exposed in the Dameigou section, representing a relatively complete Jurassic succession in the Qaidam Basin (Zhang *et al.* 1998; Wang *et al.* 2005; Zhou *et al.* 2022).

The fossil wood specimen studied here was collected from the Huoshaoshan Formation at Dameigou section (37°30′43″ N, 96°2′17″ E) in Dachaidan Town, Delingha City, Qinghai Province, China. This formation is composed of conglomerates, sandstones, mudstones and coal seams, representing a braided delta plain depositional environment (Fig. 2) (Jin *et al.* 2006; Yang *et al.* 2007; Yu *et al.* 2017; Lu *et al.* 2020; Zhao *et al.* 2020). In general, the age of the Huoshaoshan Formation is regarded as Early Jurassic (Pliensbachian), based on evidence from lithology, chronostratigraphy (detrital zircon U-Pb dating and carbon isotope chemostratigraphy), cyclostratigraphy (based on cyclostratigraphcial analysis of rock colour datasets) and biostratigraphy (palaeobotany and palynology) (Zhang *et al.* 1998; Wang *et al.* 2005,

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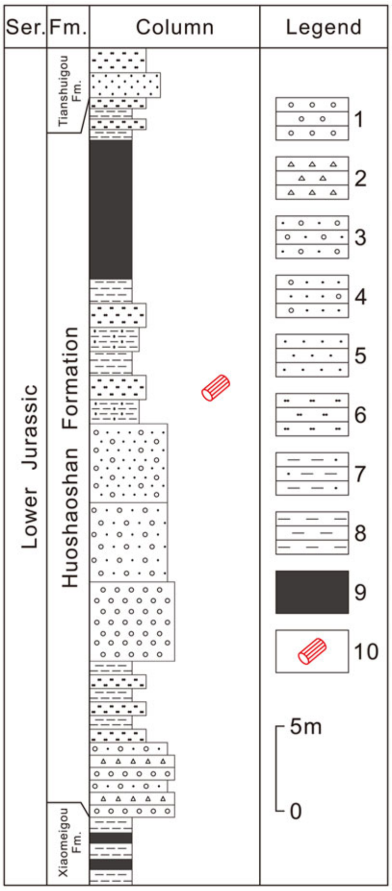

Figure 2. Stratigraphic column and fossil wood horizon of the Lower Jurassic Huoshaoshan Formation at Dameigou section in the Qaidam Basin, China (according to lithological descriptions of Zhang *et al.* 1998). 1. Conglomerate; 2. Breccia; 3. Glutenite; 4. Conglomeratic sandstone; 5. Sandstone; 6. Siltstone; 7. Sandy mudstone; 8. Mudstone; 9. Coal seam; 10. Fossil wood.

Yu *et al.* 2017; Lu *et al.* 2020; Zhou *et al.* 2023; Li *et al.* 2024). The fossil macroflora of the Huoshaoshan Formation is composed of sphenophytes (e.g., *Neocalamites* Halle, *Equisetites* Sternberg), ferns (e.g., *Cladophlebis* Brongniart), cycads (e.g., *Ctenis* Lindley et Hutton, *Anomozamites* Schimper emend. Harris), ginkgophytes (e.g., *Ginkgoites* Seward emend. Florin, *Sphenobaiera* Florin) and conifers (e.g., *Podozamites* A. Braun, *Elatocladus* Halle emend. Harris) (Li *et al.* 1988; Zhang *et al.* 1998). The palynoflora is represented by a *Protoconiferus funarius–Chasmatosporites hians* assemblage (Wang *et al.* 2005).

3. Material and methods

For obtaining standard petrographic thin sections for wood identification, the fossil wood specimen was cut transversely, radially and tangentially in the three planes of section. Thin sections were investigated and observed under a Zeiss Imager M2 microscope; images were photographed with an Axiocam 506 colour digital camera and software ZEN 2 pro adapted to the microscope. The fossil specimen and 16 thin sections are deposited at the Nanjing Institute of Geology and Paleontology, Chinese Academy of Sciences (NIGPAS) with Catalog Number PB204109. For the description of fossil wood, we followed the terminology for wood anatomical structure defined by the International Association of Wood Anatomists (IAWA) list of microscopic features for softwood identification (IAWA Committee, 2004), supplemented by Philippe & Bamford (2008), and Boura *et al.* (2021).

4. Results

4.a. Systematic palaeobotany

Class: Pinopsida Burnett 1833

Order: Pinales (=Coniferales) Gorozhankin 1904

Family: Unknown

Genus: *Metapodocarpoxylon* Dupéron-Laudoueneix et Pons 1985

Species: *M. libanoticum* (Edwards) Dupéron-Laudoueneix et Pons 1985 (Figs. 3, 4)

Locality: Dachaidan Town, Delingha City, Qinghai Province, China.

Material studied: One specimen PB204109 with 16 thin sections (PB204109-a to PB204109-p).

Horizon and age: Huoshaoshan Formation, Early Jurassic (Pliensbachian).

Repository: The specimens and slides are housed in the Paleobotanical Collection, NIGPAS, Nanjing, China.

Description: This description is based on secondary xylem. Bark, pith and primary xylem are not preserved. In transverse section, growth rings are distinct (Fig. 3a, b, red arrows). The earlywood band has a mean width of 2.51 mm (2.09–2.97 mm; median = 2.50 mm; n = 5). Earlywood tracheids are large, thin-walled, with an oval to polygonal shape in cross section (Fig. 3b, c). Earlywood cells measure on average 67 µm (31–109 µm; median = 65 µm; n = 163) in radial diameter (height, the growth direction of tree growth rings), and on average 64 µm (29–101 µm; median = 63 µm; n = 163) in tangential diameter (width). The latewood is composed of narrow bands of tracheids, usually 3 rows wide; the latewood tracheids are somewhat thicker-walled than those of the earlywood tracheids (Fig. 3b). The latewood band has a mean width of 87 µm (70–120 µm; median = 84 µm; n = 5). Latewood cells measure on average 22 µm (15–38 µm; median = 20 µm; n = 28) in radial diameter (height, the growth direction of tree growth rings), and on average 50 µm (20–72 µm; median = 52 µm; n = 28) in tangential diameter (width). The cross-sectional shape of tracheids in the latewood is narrow, from narrowly elliptical to narrowly polygonal (Fig. 3b). The abrupt transition between earlywood and latewood is characterized by size differences of the tracheids in radial diameter and wall thickness (Fig. 3a, b, red arrows). Axial parenchyma cells are present (Fig. 3c, red arrows), whereas the resin canals are absent.

In radial section, tracheidal pits are uniseriate and biseriate; when uniseriate, they are usually contiguous and compressed (Fig. 3d–f, black arrows), and rarely distant (Fig. 3g); when biseriate, the arrangement of radial tracheid pits is alternating (Fig. 3d–f, red arrows). These pits are generally oblate in outline. Crassulae were not observed. Cross-field pits vary in size and borders (oculipores and oopores). Each cross-field usually bears one to two pits (Figs. 3h, 4a–d). These pits are oculipores with an oblique slit-like aperture (podocarpoid) (Figs. 3h, 4a, d, white arrows), or oculipores with a broad elliptic aperture (taxodioid) (Fig. 4c, d, blue arrows), or oopores (Figs. 3h, 4b, red arrows). The rays consist of parenchymatous cells with thin, smooth horizontal and end walls (Figs. 3h, 4a–d). Helical thickenings are not present.

In tangential section, rays are homogenous, parenchymatous and uniseriate (Fig. 4e–i). The rays are variable in height, ranging from very low to very high, 3–35 cells high, mostly low, 3–13 cells tall (n = 291) (Fig. 5). Tangential tracheid pits are occasionally

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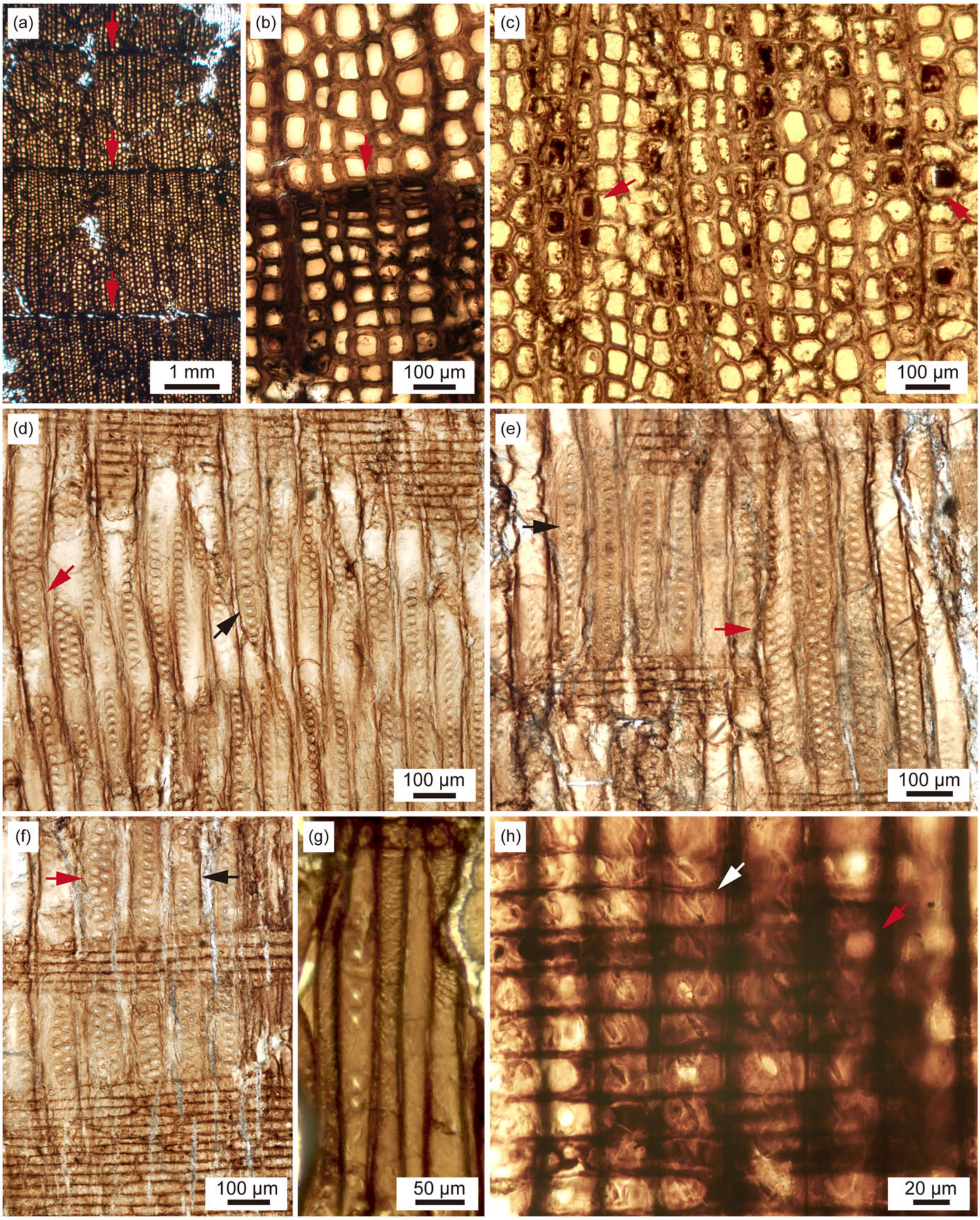

Figure 3. *Metapodocarpoxylon libanoticum* from the Lower Jurassic Huoshaoshan Formation at Dameigou section in the Qaidam Basin, China; all photographs were taken of transverse (PB204109-a–b) and radial (PB204109-c, f, o) sections of specimen PB204109. (a) Transverse section, showing distinct growth rings (red arrows); PB204109-a; (b) Close-up of (a), transverse section, showing details of a distinct growth ring (red arrow); PB204109-a; (c) Transverse section, showing shapes of tracheids, and axial parenchyma cells (red arrows); PB204109-b; (d–f) Radial section, showing uniseriate contiguous and compressed (black arrows), as well as biseriate alternate radial tracheid pits (red arrows); PB204109-c; (g) Radial section, showing rarely uniseriate distant radial tracheid pits; PB204109-f; (h) Radial section, showing cross-field bearing one podocarpoid pit (white arrow), or one oopore (red arrow); PB204109-o.

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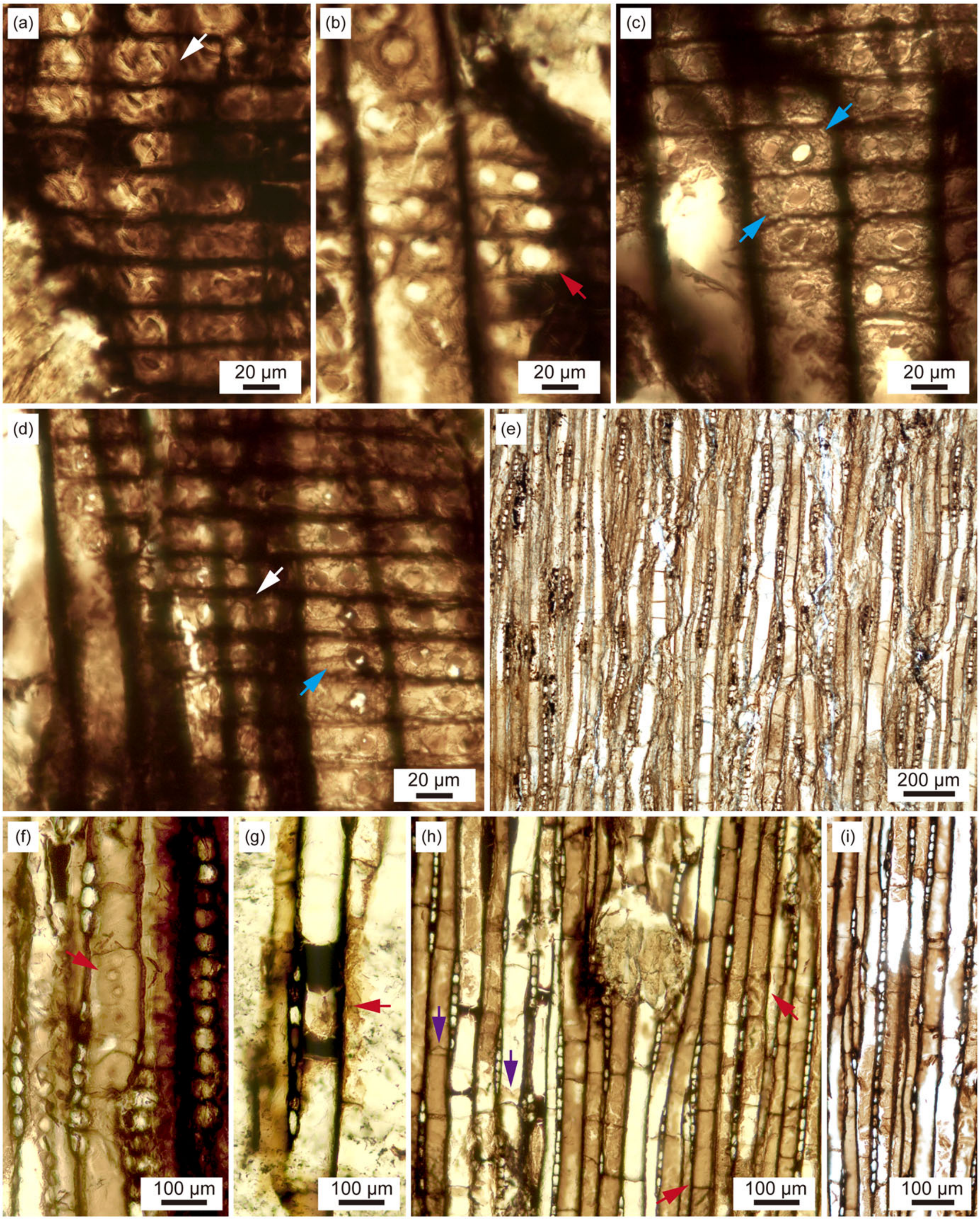

Figure 4. *Metapodocarpoxylon libanoticum* from the Lower Jurassic Huoshaoshan Formation at Dameigou section in the Qaidam Basin, China; all photographs were taken of radial (PB204109-c, e, o) and tangential (PB204109-p) sections of specimen PB204109. (a) Radial section, showing cross-field bearing two podocarpoid pits (white arrow); PB204109-o; (b) Radial section, showing cross-field bearing one oopore (red arrow); PB204109-e; (c) Radial section, showing cross-field bearing two taxodioid pits (blue arrows); PB204109-c; (d) Radial section, showing cross-field bearing one taxodioid pit (blue arrow), or one podocarpoid pit (white arrow); PB204109-c; (e) Tangential section, showing uniseriate rays; PB204109-p; (f) Tangential section, showing uniseriate tangential tracheid pits (red arrow); PB204109-p; (g) Tangential section, showing an axial parenchyma cell (red arrow); PB204109-p; (h) Tangential section, showing axial parenchyma cells (red arrows) and septa in tracheids (purple arrows); PB204109-p; (i) Tangential section, showing a high ray; PB204109-p.

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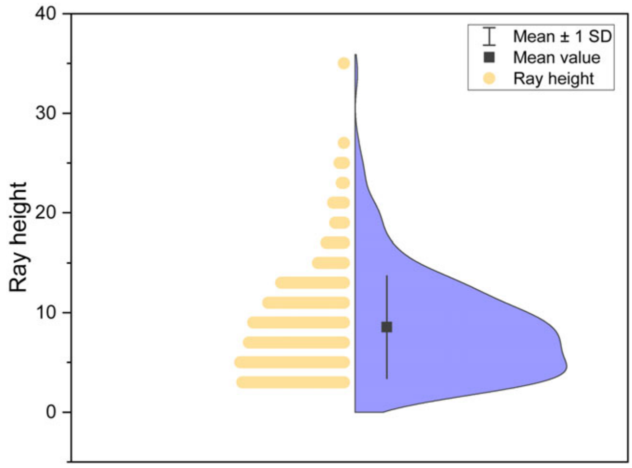

Figure 5. Ray cell heights in 291 rays as observed in a tangential section (PB204109-p) of *Metapodocarpoxylon libanoticum* from the Lower Jurassic Huoshaoshan Formation at Dameigou section in the Qaidam Basin, China; specimen PB204109.

present; they are uniseriate, contiguous and circular (Fig. 4f, red arrow). Axial parenchyma cells are present, with smooth end walls (Fig. 4g, h, red arrows). Abundant septa are preserved in tracheids (Fig. 4e, h, purple arrows). Resin canals are not observed.

4.b. Growth ring characteristics of Metapodocarpoxylon libanoticum

As mentioned above, distinct growth rings (GR1 to GR5) are observed in our fossil specimen PB204109, *M. libanoticum* (Fig. 6). On average, the earlywood band has a width of 2.51 mm on average (2.09–2.97 mm; median = 2.50 mm; n = 5). Earlywood cells measure on average 67 µm (31–109 µm; median = 65 µm; n = 163) in radial diameter (height), and on average 64 µm (29–101 µm; median = 63 µm; n = 163) in tangential diameter (width). The latewood consists of narrow bands of tracheids, usually 3 rows wide. The latewood band has a mean width of 87 µm (70–120 µm; median = 84 µm; n = 5). Latewood cells measure on average 22 µm (15–38 µm; median = 20 µm; n = 28) in radial diameter (height), and on average 50 µm (20–72 µm; median = 52 µm; n = 28) in tangential diameter (width). The transition between earlywood and latewood is abrupt.

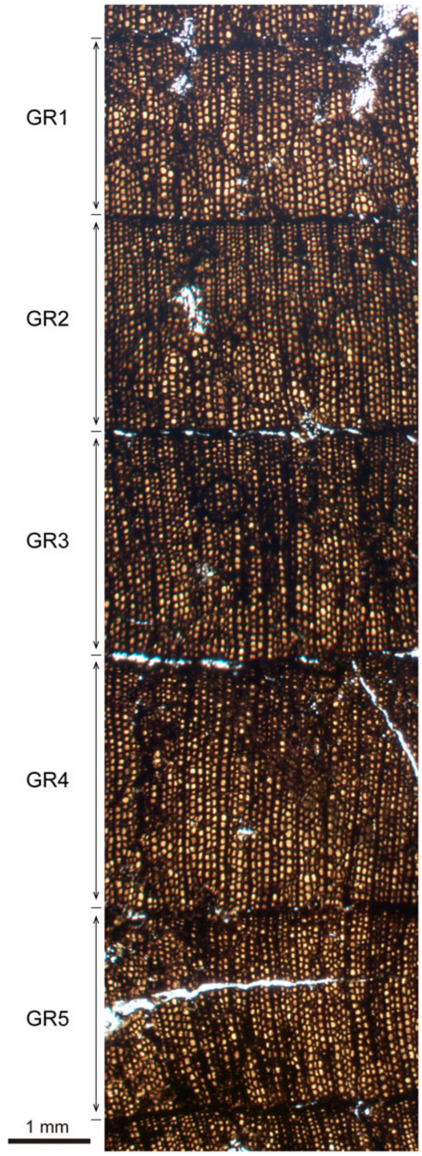

Figure 6. Growth rings (GR1–GR5) in *Metapodocarpoxylon libanoticum* from the Lower Jurassic Huoshaoshan Formation at Dameigou section in the Qaidam Basin, China; specimen PB204109 with thin-section PB204109-a. All growth rings are distinct with narrow latewood, usually 3 rows wide.

5. Discussion

5.a. Taxonomic assignment and comparisons

In general, five different arrangements of radial tracheid pits are known from Mesozoic conifer-like wood: araucarian, abietinean, brachyoxylean (mixed), shimakurean (*japonicum*-type) and xenoxylean radial tracheid pitting (Philippe & Bamford, 2008; Philippe *et al.* 2014; Boura *et al.* 2021). In our study, the bordered pits on the radial tracheid walls in fossil specimen PB204109 from the Huoshaoshan Formation in Dachaidan are usually araucarian radial tracheid pits. The characters of cross-field pits, tracheids and ray cells in our specimen are represented by these aspects, such as each cross-field usually bearing 1–2 podocarpoid pits, taxodioid pits or oopores, abundant septa in tracheids, and all ray cell walls thin and unpitted. These anatomical characters demonstrate that the fossil wood PB204109 can be systematically assigned to the genus *Metapodocarpoxylon* Dupéron-Laudoueneix et Pons (Dupéron-Laudoueneix & Pons, 1985; Bamford *et al.* 2002; Philippe & Bamford, 2008).

Metapodocarpoxylon was first established by Dupéron-Laudoueneix and Pons in 1985 when reviewing an old fossil wood specimen (type slides and duplicated thin-sections) from the Lower Cretaceous of Lebanon, which was originally described as *Mesembrioxylon libanoticum* Edwards (Edwards, 1929). Dupéron-Laudoueneix and Pons formally defined *Metapodocarpoxylon* as "homoxylous wood without resin canals; radial tracheid pitting usually araucarian type; each cross-field with one oopore, or 1–2 podocarpoid oculipores, or many transition forms; homogenous rays with smooth walls; axial parenchyma present; thyllosis septa in tracheids" (Dupéron-Laudoueneix & Pons, 1985; Philippe & Bamford, 2008). Following this definition, a bunch of fossil wood taxa were subsequently reassigned to its type species *M. libanoticum* (Edwards) Dupéron-Laudoueneix et Pons, such as *M. libanoticum* Edwards, *Protophyllocladoxylon chudeaui* Batton,

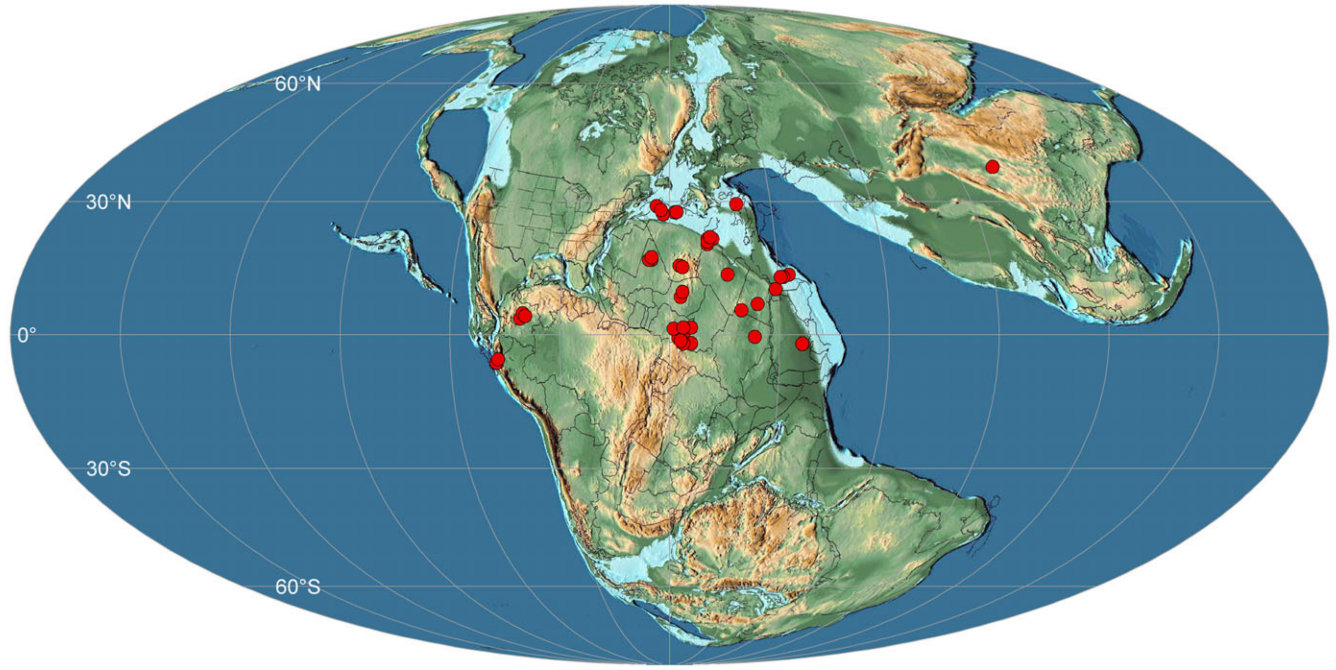

Figure 7. Palaeobiogeographic map showing the spatio–temporal distribution of *Metapodocarpoxylon* worldwide. The red dots indicate the occurrence of *Metapodocarpoxylon* (data from Philippe *et al.* 2003, 2004, with updates). The base palaeogeographic map is modified after Scotese (2014): Toarcian (~180 Ma), Early Jurassic.

P. curitiense Pons, *P. diphtericum* Batton et Boureau, *P. leuchsii* Kräusel, *P. libanoticum* (Edwards) Kräusel, *P. maurianum* Gazeau, *P. rosablancaense* Pons, *P. subdiphtericum* Duperon-Laudoueneix and *Xenoxylon saadawi* Youssef (Philippe *et al.* 2003; Philippe & Wilde, 2020). Most of these reassignments refer to species previously assigned into the genus *Protophyllocladoxylon* Kräusel. The reason is that the difference between *Metapodocarpoxylon* and *Protophyllocladoxylon* is very small; that is, the cross-field pits of *Metapodocarpoxylon* exhibit both oopores and oculipores, whereas those of *Protophyllocladoxylon* are only oopores (Kräusel, 1939; Dupéron-Laudoueneix & Pons, 1985; Philippe & Bamford, 2008; Philippe & Wilde, 2020). Concerning the anatomical character of oopores and oculipores in the cross-fields in our fossil wood specimen, its assignment to the genus *Metapodocarpoxylon* mentioned above is reliable, instead of *Protophyllocladoxylon*.

Metapodocarpoxylon is monospecific, and only one species, *M. libanoticum* has been described so far, although about 40 occurrences of *Metapodocarpoxylon* have so far been reported from Gondwana (Dupéron-Laudoueneix & Pons, 1985; Philippe *et al.* 2003; El-Noamani *et al.* 2021). In general, the previously reported specimens of *M. libanoticum* obtain low rays, which is similar to the rays in our specimen (uniseriate, mostly 3–13 cells high). For example, the type specimen *M. libanoticum* from Lebanon is characterized by having uniseriate rays (1–14 cells high) (Dupéron-Laudoueneix & Pons, 1985). The fossil specimen of *M. libanoticum* from Egypt obtains slightly shorter rays, i.e. mostly 1–7 cells high, very rarely 15 cells high (El-Noamani *et al.* 2021). The fossil wood *M. libanoticum* from Mali exhibits uniseriate rays with mostly seven cells high (1–10 cells high) (Bamford *et al.* 2002). In addition, tangential tracheid pits are observed in the type specimen from Lebanon and our specimen from China. Combined with other generic characters mentioned above, our fossil wood specimen is thus recognized as *M. libanoticum* (Edwards) Dupéron-Laudoueneix et Pons.

5.b. Palaeobiogeography of Metapodocarpoxylon

With the discovery of our new fossil wood material, the occurrence of *M. libanoticum* in the Early Jurassic offers new insights into the palaeobiogeographic distribution of *Metapodocarpoxylon*. During the Mesozoic, *Metapodocarpoxylon* was widespread in Northern Gondwana with a clear latitudinal belt extending from Lebanon westward to Peru (Dupéron-Laudoueneix & Pons, 1985; Bamford *et al.* 2002; Philippe *et al.* 2003; El-Noamani *et al.* 2021) (Fig. 7). The fossil wood *Metapodocarpoxylon* described here from the Huoshaoshan Formation represents the first report of this fossil wood genus in the Qaidam Basin in China.

So far, only a single species of *Metapodocarpoxylon* is recognized worldwide; however, about 40 occurrences of this genus have been documented since the early twentieth century (Fig. 7) (Philippe *et al.* 2003, 2004; El-Noamani *et al.* 2021). So far there are no pre-Jurassic records of *Metapodocarpoxylon*. When the current study of *Metapodocarpoxylon* is considered, it implies that this genus would have originated in the Early Jurassic. In the Middle Jurassic, there are seven occurrences of *Metapodocarpoxylon* from Morocco (Gazeau, 1970; Dupéron-Laudoueneix & Pons, 1985) and Israel (Philippe *et al.* 2003). In the Late Jurassic, five occurrences of this genus have been reported from Colombia (Pons, 1982), Algeria (Benest *et al.* 1999; Philippe *et al.* 2003), Tunisia (Barale *et al.* 1998, 2000) and Lebanon (Edwards, 1929).

During the Early Cretaceous, *Metapodocarpoxylon* reached a significant period of prosperity in geographic distribution, as 28 occurrences have been documented from Italy (Biondi, 1980), Colombia (Pons, 1978; 1988), Ecuador (Philippe *et al.* 2003), Peru (Philippe *et al.* 2003), Morocco (Attims & Crémier, 1969), Tunisia (Barale *et al.* 1998; Philippe *et al.* 1999; Philippe *et al.* 2003), Algeria (Philippe *et al.* 2003), Mali (Dupéron-Laudoueneix & Pons, 1985; Bellion *et al.* 1992; Bamford *et al.* 2002), Niger (Batton, 1965), Nigeria (Philippe *et al.* 2003), Cameroon (Batton & Boureau, 1965; Dupéron-Laudoueneix, 1976, 1991*a*, 1991b; Flynn *et al.* 1988;

Brunet *et al.* 1990; Dejax & Brunet, 1995), Sudan (Philippe *et al.* 2003), Lebanon (Philippe *et al.* 2003) and Saudi Arabia (Philippe *et al.* 2003).

Recently, a study on the Cretaceous terrestrial biota of northern Africa offered new evidence for the Late Cretaceous record of *Metapodocarpoxylon* in Egypt (El-Noamani *et al.* 2021). In addition, some records of *Metapodocarpoxylon* are reported from Middle Jurassic to Lower Cretaceous strata in Libya (Philippe *et al.* 2003), and Upper Jurassic to Lower Cretaceous strata in Egypt (Youssef, 2002), without a finer stratigraphic resolution.

Based on the occurrences of *Metapodocarpoxylon* reported so far, this genus had probably a wide occurrence in the Middle Jurassic–Cretaceous deposits of northern Gondwana, along with the only record in the Early Jurassic sediments of Laurasia presented in this study. It seems that *Metapodocarpoxylon* may have originated in Laurasia during the Early Jurassic, then migrated to Gondwana maybe owing to some possible climatic changes. However, we realize that this hypothesis may need support from other robust evidence owing to the limited fossil material of *Metapodocarpoxylon* in our current fossil locality. Thus, further analysis of additional and so far understudied occurrences of fossil wood from the Mesozoic, especially in the Middle East and other regions, would undoubtedly enhance our knowledge of the palaeogeographic patterns observed in *Metapodocarpoxylon*. Nevertheless, our new finding does extend the palaeobiogeographic range of *Metapodocarpoxylon* northward and eastward from northern Gondwana regions to Laurasia.

5.c. Palaeoclimatic implications of Metapodocarpoxylon

In the *Metapodocarpoxylon* wood from the Qaidam Basin, distinct growth rings with abrupt transitions between earlywood and latewood were well-developed when this tree was growing (Fig. 6). The latewood contains narrow bands of tracheids, usually 3 rows wide. These true growth rings with narrow latewood in our fossil wood *M. libanoticum* suggest that this tree's growth conditions were slightly variable concerning mild seasonality during the whole year, and demonstrate that it enjoyed a long and optimal growth season of the year, then underwent slower growth for a short time. Moreover, Philippe *et al.* (2003) proposed that *Metapodocarpoxylon* trees grew in the summer-wet climatic zone in a palaeoclimatological map drawn by Rees *et al.* (1999) based on the occurrences of this genus. Following modern Köppen-Geiger climate classification, this summer-wet climate can be found in the Tropical Monsoon Climate, Humid Subtropical Climate and Temperate Climate zones (cf. Kottek *et al.* 2006), which is characterized by a distinct pattern of precipitation, that is, most rainfall occurs during the warmer months of the year. Putting them all together, we can assume that the *Metapodocarpoxylon* tree in the Qaidam Basin was growing in a usually warm and humid environment with mild seasonality during the Early Jurassic.

Palynological studies also play a significant role in demonstrating that a warm and humid climate prevailed throughout deposition of the Huoshaoshan Formation. The palynoflora of the Pliensbachian in the Qaidam Basin is represented by an assemblage of *Protoconiferus funarius–Chasmatosporites hians*, with a high mesophyte index and a zero thermophyte/xerophyte index (Wang *et al.* 2005). The dominant Pinaceae pollen indicates a temperate climate, and other plants demonstrate a humid tropical–subtropical climate. This climate condition is also consistent with the leaf flora assemblage in the Huoshaoshan Formation, which is dominated by ferns and conifers, along with some cycads and ginkgophytes, indicating a temperate and humid climate (Li *et al.* 1988; Zhang *et al.* 1998).

A warm and humid climate during the Early Jurassic in the Qaidam Basin is also supported by some recent geochemical investigations, based on chemical weathering parameters (e.g., chemical index of alteration, chemical index of weathering, as well as plagioclase index of alteration and clay mineral assemblages), and element geochemistry indices (e.g., Rb/Sr, K_2O/Na_2O, $Na_2O/A1_2O_3$, Na_2O/TiO_2 ratios, TOC and $\delta^{13}C_{org}$ values) (Hu *et al.* 2020; Lu *et al.* 2020; Zhou *et al.* 2022, 2023).

Integrating the evidence of the present fossil wood, together with other data including leaf, sporopollen and sediments, the Early Jurassic deposit of the Huoshaoshan Formation of the Qaidam basin is interpreted as a warm and humid climate environment with mild seasonality.

Data availability. All the related data are described in the study.

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