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First record of *Cercidiphylloxylon* (Cercidiphyllaceae) from the Palaeocene of Fushun, NE China

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Abstract *Cercidiphylloxylon spenceri* (Brett) Pearson is described from the Lizigou Formation, Palaeocene in China. The growth rings are distinct; pores are diffuse, solitary, with somewhat angular outlines in cross section; vessel elements long with long scalariform perforation plates; intervessel pitting is opposite to scalariform; fiber-tracheids are present; axial parenchyma is scarce; rays are mostly biseriate and heterogeneous. All wood characters of the fossil specimen fall into the range of those of extant *Cercidiphyllum* (Cercidiphyllaceae). The finding is one of the earliest fossil wood records of Cercidiphyllaceae.

Key words *Cercidiphylloxylon*, *Cercidiphyllum*, fossil wood, Fushun, Palaeocene.

Cercidiphyllaceae with a single extant genus *Cercidiphyllum* is regarded as a member of the core eudicots (Soltis & Soltis, 1997, 2004; Soltis et al., 1997, 2007; Fishbein et al., 2001; APG II, 2003; APG III, 2009; Shipunov, 2007; Jian et al., 2008). Its systematic position has been suggested to be in the Hamamelidales (Cronquist, 1981; Thorne, 2000), Trochodendrales (Dahlgren, 1980; Endress, 1986), Cercidiphyllales in the Hamamelidae (Takhtajan, 1969, 1997, 2009), or Saxifragales (Soltis & Soltis, 1997; Fishbein et al., 2001; APG II, 2003; Shipunov, 2007; Soltis et al., 2007).

Cercidiphyllum has two extant species. *Cercidiphyllum japonicum* grows in Shanxi, Henan, Shaanxi, Gansu, Zhejiang, Jiangxi, Hebei, and Sichuan Provinces of China and also in north Honshu, Shikoku, Kyushu, and Hokkaido of Japan. *Cercidiphyllum magnificum* is found in the Japanese alps, Nikko region, and Iwate of Honshu, Japan (Lindquist, 1954; Numata, 1974; DFRPSAAS, 1979; Guan, 1979; Spongberg, 1979).

The fossil leaves and fruits of *Cercidiphyllum* were reported in western North America from the Oligocene to the Miocene, in Europe from the Oligocene to the Pliocene, and in eastern Asia from the Miocene to the Pleistocene (Jähnichen et al., 1980; Kvaček & Konzalová, 1996; Meyer & Manchester, 1997; Kvaček, 2008; Manchester et al., 2008).

Fossil woods similar to Cercidiphyllaceae are generally known under the name *Cercidiphylloxylon* which has two currently recognized species, *Cercidiphylloxylon spenceri* from the Palaeocene of Mull, Scotland (Crawley, 1989), the Early Eocene of London Clay, England (Brett, 1956), and the Eocene Clarno Formation of Oregon, USA (Scott & Wheeler, 1982; Wheeler & Manchester, 2002) and *Cercidiphylloxylon kadanese* from the Late Oligocene of the Czech Republic (Prakash et al., 1971; Sakala & Privé-Gill, 2004).

In this paper, we describe a new record of *Cercidiphylloxylon spenceri* from the Palaeocene of Fushun in NE China.

1 Material and methods

The calcified wood (specimen no. FS036) was collected from Lizigou Formation of the Fushun Group in the Xilutian opencast coal mine (41°50′ N, 123°51′ E), Fushun, Liaoning Province, NE China. The age of the Lizigou Formation has been considered as Late Palaeocene based on palynological correlations (Sung & Tsao, 1976), and the sequentially underlying formation, the Laohutai Formation, has been considered as Early Paleocene. The overlying formations (Guchengzi, Jijuntun, and Xilutian formations) have been judged to be Eocene (Hong et al., 1980).

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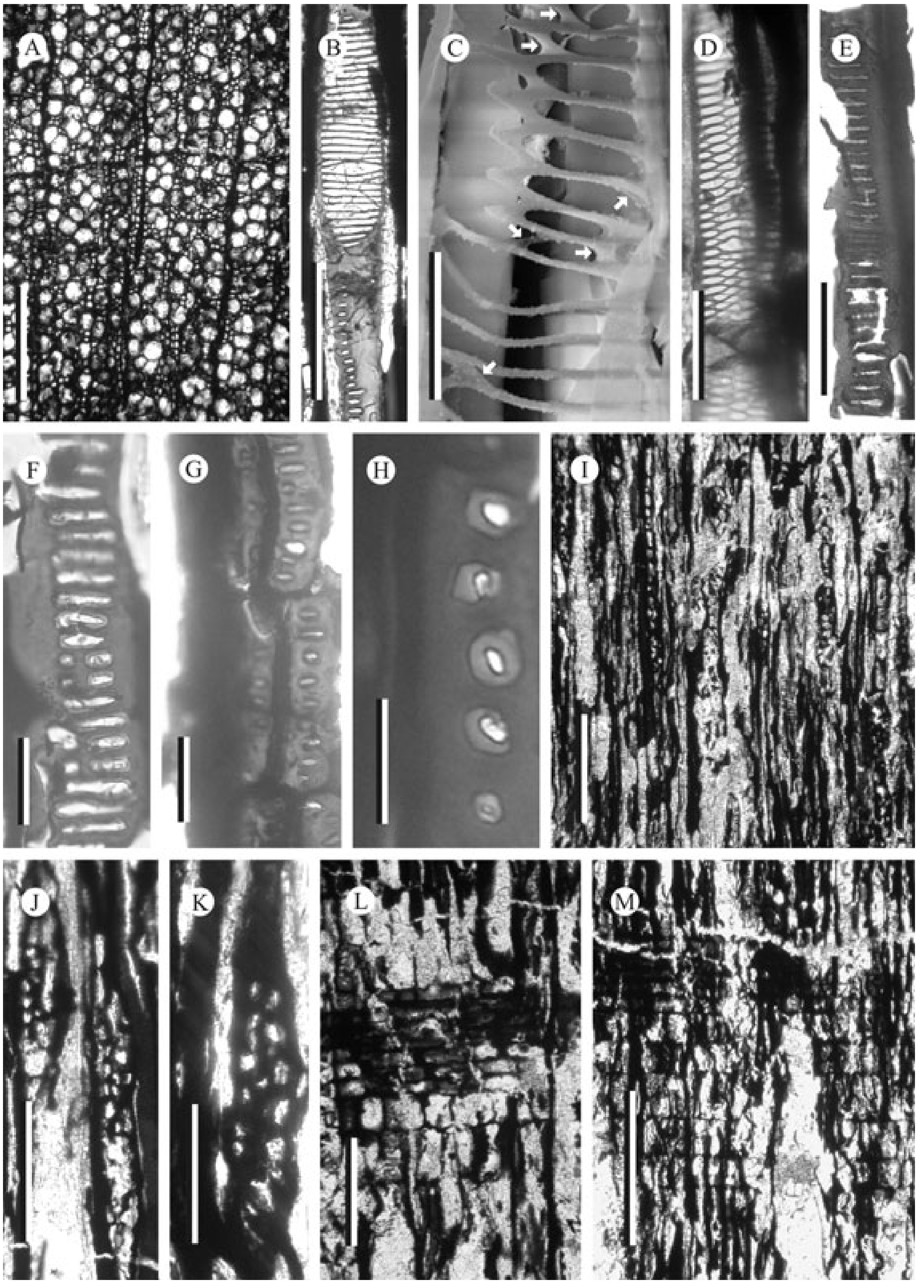

Fig. 1. *Cercidiphyllum spenceri*. **A**, Cross section. Growth rings distinct. Diffuse porous. Vessels solitary, and angular in the outline. **B**, Perforation plates scalariform, RLS. **C**, Perforation plate scalariform, and the probable membrane remnants (arrows), RLS. **D**, Perforation plate reticulate, RLS. **E**, **F**, Intervessel pits, opposite to scalariform, radial section (RLS). **G**, Vessel-ray pits scalariform, RLS. **H**, Fiber-tracheid with distinctly bordered pits, tangential section. **I**, Rays 1–2 cells wide, tangential section. **J**, **K**, Rays 3 cells wide. **L**, **M**, Rays heterocellular, with 1–8 marginal rows of upright cells, RLS. Scale bars = 500 μm in **A**; 100 μm in **B**; 50 μm in **C–E**, **G**; 25 μm in **F**, **J**, **K**; 10 μm in **H**; 100 μm in **L**; and 200 μm in **I**, **M**.

Transverse, radial, and tangential sections of the sample were prepared using the standard methods (Hass & Rowe, 1999), and the peel method (Zhu, 1983; Galtier & Phillips, 1999). The vessel elements, tracheids, fibers, and parenchyma of fossil wood were separated in 40% HF for 30 s, then in 10% HCl for 20 min. The specimen and the sections are deposited in the National Museum of Plant History of China, Institute of Botany, Chinese Academy of Sciences, Beijing, China. The modern wood slides of *Cercidiphyllum japonicum* for comparison were provided by the Wood Herbarium, Research Institute of Wood Industry, the Chinese Academy

Table 1 Wood comparison between *Cercidiphyllum* and *Cercidiphylloxylon*

	Cercidiphyllum japonicum	*Cercidiphyllum magnificum*†	*Cercidiphylloxylon spenceri*	*Cercidiphylloxylon kadanese*	Fossil specimen from Fushun
Growth rings	Present	Present	Present	Present	Present
Vessel density (/mm^2)	ca. 176	>200	<180	60–165	153–196
Vessel diameter (μm)	25–64	20–50	22–70	25–88	37–76
Bar no./Scalariform Perforation plate	20–50	ca. 50	20–55	25–45	21–46
Intervessel pitting	Opposite to scalariform	Opposite to scalariform	Opposite to scalariform	Scalariform	Opposite to scalariform
Axial parenchyma	Present, diffuse sparse	Present, near the growth rings	Present, diffuse or scanty paratracheal?	Present, diffuse or sparse, paratracheal	Scanty
Ray width (cells)	1–3	1–2	1–2(–3)	1–4	1–3
Ray margins (cells)	1–4	1–8	1–9	1–8	1–8
Fiber-tracheids	Present	Present	Present	Libriform fibers?	Present
Age	Extant	Extant	Palaeocene to Eocene	Oligocene	Palaeocene
Reference	Metcalfe & Chalk, 1950; Cheng et al., 1992		Crawley, 1989; Brett, 1956; Scott & Wheeler, 1982; Wheeler & Manchester, 2002	Prakash et al., 1971; Sakala & Privé-Gill, 2004	This paper

†The wood features of this species provided by Forestry and Forest Products Research Institute in their online wood database (http://f030091.ffpri.affrc.go.jp/index-E.html).

of Forestry, Beijing, China. The terminology used for the descriptions follows the recommendations of the IAWA List of Microscopic Features for Hardwood Identification (IAWA Committee, 1989). The InsideWood (2004–) website was used to obtain lists of extant and fossil dicots with the combination of characters observed in the fossil wood (Appendix 1).

2 Results

Systematics
Family: Cercidiphyllaceae
Genus: *Cercidiphylloxylon* Prakash et al. 1971
Species: *Cercidiphylloxylon spenceri* (Brett) Pearson 1987

Description Growth rings 0.6–**1.0**–1.6 mm wide, distinct, marked by slightly wider vessels in early wood than in late wood and a narrow band of radially narrow fibers (Fig. 1: A). Wood diffuse-porous (Fig. 1: A). Vessels exclusively solitary, occasionally in the tangential and radial pairs, apparently due to overlapping of end walls. Vessels usually angular in outline, but also elliptical to rounded in the transverse section.Vessels more than 1000 μm long, with tangential diameter of 37–**54**–76 μm, and radial diameter of 24–**54**–79 μm. Vessel frequency 153–**169**–196 per mm^2 (Fig. 1: A). Vessel walls 2–**3**–5 μm thick. Perforation plates scalariform (Fig. 1: B, C), occasionally reticulate (2%, Fig. 1: D), with 21–**33**–46 bars, among them 17–23 bars per 0.1 mm long. Vessel pits on longitudinal walls, rare, opposite to scalariform (Fig. 1: E, F). Vessel-ray pits similar to the intervessel pits (Fig. 1: G). Fiber-tracheids quadrangular to polygonal in cross section, thin- to thick-walled (2–**4**–6 μm), with bordered pits (Fig. 1: H), 4–**6**–8 μm wide. Axial parenchyma diffuse and rare. Rays 1–3 seriate, most 2 cells wide, heterocellular (Fig. 1: I–M), with 5–**8**–11 rays per mm. Rays often with alternating uniseriate and multiseriate portion. Uniseriate portions composed of upright cells, with 1–8 marginal rows of upright cells (Fig. 1: L, M), and 146–**406**–697 μm high. Uniseriate rays composed of upright cells or both upright and procumbent cells (Fig. 1: I).

3 Discussion

3.1 Comparisons with *Cercidiphylloxylon*

The fossil specimen studied is characterized by distinct growth rings, diffuse porous, small angular pores, long vessel members, scalariform perforation plates with 21–46 bars, intervessel pitting opposite to scalariform, axial parenchyma scarce, rays heterogeneous, 1–3 cells wide.

The combined features of wood are in accord with those of *Cercidiphylloxylon*, which has diffuse-porous wood with mostly solitary vessels that are angular in outline with scalariform perforation plates having 20–50 bars; intervessel pitting from scalariform to alternate and opposite; rare axial parenchyma; and heterocellular, 1–3-seriate rays (Prakash et al., 1971; Sakala & Privé-Gill, 2004). So we could assign our fossil specimen to *Cercidiphylloxylon*.

Cercidiphylloxylon spenceri and *C. kadanese* are distinguished from each other by ray width which is mostly 1–2 cells wide, occasionally 3 in the former,

Table 2 Wood comparison between fossil specimen and some modern taxa with similar wood structures

	Fossil from Fushun	*Cercidiphyllum japonicum*	*Cercidiphyllum magnificum*	*Illicium*	*Hamamelis*	*Corylopsis*	*Liquidambar*	*Exbucklandia*	*Daphniphyllum*
Growth rings	Distinct	Distinct	Distinct	Distinct	Distinct	Distinct	Distinct	Distinct	Absent or distinct in some taxa†
Vessel diameter (μm)	37–76	25–64	20–50	31–80	No data	>50	25–90	>50	30–60
Bar no./Scalariform perforation plates	21–46, and 17–23 bars mm	20–50	ca. 50	>150†	7–28, mostly <20†	25–57	12–25, and 15 bars per mm†	19–54	25–92 (mean bar no. >37)†
Intervessel pitting	Opposite to scalariform	Opposite to scalariform	Opposite to scalariform	Opposite to scalariform	Scalariform	Scalariform	Opposite to scalariform	Opposite to scalariform	Opposite to scalariform
Axial parenchyma	Scanty	Present, diffuse sparse	Present, diffuse sparse	Diffuse and scanty	Scanty	Scanty	Scanty	Scanty	Apotracheal, parenchyma strand of 8 cells†
Ray width (cells)	1–3	1–3	1–2	1–3(−4)	1	1 or 2†	Up to 4 seriate, commonly 2 or 3 seriate	1(−2)†	1–3, mostly 2
Ray margins (cells)	1–8	1–4	1–8	No data	2–4	6 or 7	1–3	2†	No data
Ray/mm	5–11	5–11	5–13	10–14	>12	7–18	7–12	12<	ca. 14†
Reference	This paper	Metcalfe & Chalk, 1950; Cheng et al., 1992		Metcalfe & Chalk, 1950; Poole et al., 2000	Tang, 1943; Metcalfe & Chalk, 1950; Cheng et al., 1992	Tang, 1943; Metcalfe & Chalk, 1950	Tang, 1943; Metcalfe & Chalk, 1950; Sakala & Privé-Gill, 2004	Tang, 1943; Metcalfe & Chalk, 1950; InsideWood, 2004–	Tang, 1932; Metcalfe & Chalk, 1950; Carlquist, 1982; Suzuki & Noshiro, 1988; Cheng et al., 1992; InsideWood, 2004–

†Character differences between fossil specimen and its related living genera.

and mostly 2–3 cells wide, occasionally 4 in the latter (Table 1; Prakash et al., 1971; Crawley, 1989; Sakala & Privé-Gill, 2004). This Paleocene studied wood has mainly 1–2-seriate, occasional 3-seriate rays; similar to *C. spenceri* rather than *C. kadanese*. Therefore, we propose to assign our wood to *C. spenceri*.

3.2 Comparisons with extant woods

This combination of wood features falls into the range of *Cercidiphyllum* (Metcalfe & Chalk, 1950; InsideWood, 2004–) although Tang (1943) and Cheng et al. (1992) pointed out that the gross wood characters are similar among *Cercidiphyllum*, *Illicium* L., *Hamamelis* Gronov and L., *Corylopsis* Sieb. and Zucc., *Liquidambar* L., *Exbucklandia* Brown, and *Daphniphyllum* Bl.

The fossil specimen can be separated from *Illicium* by the number of bars in the scalariform perforation plates which is 21–46 bars in the former, but 150 bars in the latter (Table 2; Metcalfe & Chalk, 1950). The fossil wood also differs from *Hamamelis* which has fewer than 20 bars (Table 2; Tang, 1943; Cheng et al., 1992). The fossil is different from *Corylopsis* in that the biseriate parts of the ray are as wide as uniseriate parts in the former, while wider in the latter (Table 2; Scott & Wheeler, 1982). The vessel perforations in the fossil have 21–46 bars, that are spaced about 17–23 bars per 0.1 mm; in *Liquidambar,* the vessel perforations have 12–25, bars, spaced about 15 bars per 0.1 mm (Table 2; Metcalfe & Chalk, 1950; Cheng et al., 1992; Sakala & Privé-Gill, 2004). The fossil specimen differs from *Exbucklandia* by the ray seriation which is 1–3 cells wide in the fossil, but uniseriate in *Exbucklandia* (Table 2; Metcalfe & Chalk, 1950; InsideWood, 2004–). The fossil specimen can be distinguished from *Daphniphyllum*, by more distinct growth rings (Table 2; Carlquist, 1982; Suzuki & Noshiro, 1988; Cheng et al., 1992; InsideWood, 2004–), except for *Daphniphyllum himalense* Muell.-Arg., *Daphniphyllum teijsmanni* Zollinger and *Daphniphyllum macropodum* Miq. The fossil specimen can be distinguished from these three species by scanty parenchyma and perforation plates with 21–46 bars; these three species possess parenchyma strands of 8 cells and perforation plates with 25–92 bars (Table 2; Carlquist, 1982; Suzuki & Noshiro, 1988; Cheng et al., 1992; InsideWood, 2004–).

The wood anatomy of the fossil studied here is very similar to that of *Cercidiphyllum*. The wood structures of both *Cercidiphyllum japonicum* (Metcalfe & Chalk, 1950; Cheng et al., 1992) and *Cercidiphyllum magnificum*, provided by the Forestry and Forest Products Research Institute in the online wood database (http://f030091.ffpri.affrc.go.jp/index-E.html), are very similar (Table 1). Considering the fossil plant is more than 55 Myr old (Palaeocene in age), and the anatomical similarity with some of the other extant genera mentioned above, we prefer to assign it to *Cercidiphylloxylon* rather than to extant *Cercidiphyllum*.

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Supporting Information

The following supporting information is available for this article:

Appendix S1. Identification of Paleocene wood specimen in Fushun using the online database InsideWood [http://insidewood.lib.ncsu.edu].

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