SCIENTIFIC REPORTS

OPEN

A Jurassic wood providing insights into the earliest step in *Ginkgo* wood evolution

Received: 06 June 2016
Accepted: 07 November 2016
Published: 16 December 2016

Zikun Jiang[1], Yongdong Wang[2], Marc Philippe[3], Wu Zhang[4], Ning Tian[5] & Shaolin Zheng[4]

The fossil record of *Ginkgo* leaf and reproductive organs has been well dated to the Mid-Jurassic (170 Myr). However, the fossil wood record that can safely be assigned to Ginkgoales has not yet been reported from strata predating the late Early Cretaceous (ca. 100 Myr). Here, we report a new fossil wood from the Mid-Late Jurassic transition deposit (153–165 Myr) of northeastern China. The new fossil wood specimen displays several *Ginkgo* features, including inflated axial parenchyma and intrusive tracheid tips. Because it is only slightly younger than the oldest recorded *Ginkgo* reproductive organs (the Yima Formation, 170 Myr), this fossil wood very probably represents the oldest bona fide fossil *Ginkgo* wood and the missing ancestral form of *Ginkgo* wood evolution.

The maidenhair tree or *Ginkgo* is often described as a "living fossil". It is one of the very few extant plant genera that can be traced back to the Jurassic, at approximately 170 Myr ago. Since *Ginkgo apodes* Zhou and Zheng[1], the "missing link" in *Ginkgo* evolution, has been reported from North-Eastern China, the genus has a quite complete fossil record lineage with different organs documented, including leaves, pollen, reproductive structures, and long and dwarf shoots. Such a complete record lineage is of great interest for phylogenetical studies and for deciphering the potential role of developmental heterochronies in the evolution of Ginkgoales[2].

A tree is made of wood, which forms more than 80% of its biomass. Wood ecophysiology is recognized as a first-order factor in plant evolution[3]. Unfortunately, the fossil wood record for *Ginkgo* is very scanty[4,5], with no established data predating the late Early Cretaceous, i.e., ca. 100 Myr[6,7].

Some woods older than the Cretaceous with supposed and putative relationship links to the Ginkgoales were described as a variety of taxa, such as *Baieroxylon* Greguss, *Plaeoginkgoxylon* Feng, Wang *et* Roessler, *Primoginkgoxylon* Süß, *Proginkgoxylon* Zheng *et* Zhang and *Protoginkgoxylon* Zheng *et* Zhang *ex* Khudaiberdyev[5,8–13]. This profusion of works indicates the strong and lasting interest that the palaeobotany community has in *Ginkgo* wood evolution[5,14,15].

These fossil records predating the Cretaceous are supposedly linked to the Ginkgoales; however, there is no evidence of a direct and certain systematic relationship with *Ginkgo*. Such relationships are hypothesized for isolated secondary xylem pieces, mostly on the basis of the occurrence of tracheid bunches, with their tips bent alongside the rays (intrusive tracheids), according to Greguss[8]. However, assigning Palaeozoic, Triassic or Jurassic woods to Ginkgoales represents a challenging task because there is no consensus with regards to Palaeozoic Ginkgophytes systematics or wood anatomy[16], and the use of a single xylological feature (intrusive tracheids) is risky[17], whereas several other features (e.g., mostly araucarian radial pitting) strongly depart from modern *Ginkgo* wood anatomy. To sum up, *Ginkgo* wood anatomy before the Early Cretaceous is still a matter of hypothesis.

Here, we report a new Middle to Late Jurassic fossil wood from northeastern China. While the leaf and reproductive structures of northeastern China-based *Ginkgo apodes* filled a 100 Myr gap in the fossil record of *Ginkgo* leaf and sexual organs[18], the present fossil wood, at 153–165 Myr ago, is only slightly younger than *Ginkgo yimaensis* but represents the oldest known *Ginkgo* wood species[19]. It thus documents the earliest *Ginkgo* wood anatomy and establishes what could be called the missing "ancestral form" or the dawn for *Ginkgo* wood evolution.

In northeastern China, one of the major fossil wood localities is located in Changgao Town of Beipiao City, western Liaoning, including Lamaying, Shebudaigou, Taizishan, Toudaogou and Renjiagou villages. The fossil

[1]Chinese Academy of Geological Sciences, Beijing 100037, China. [2]State Key Laboratory of Palaeobiology & Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China. [3]UMR 5023 of the CNRS and Université Lyon 1, 7 rue Dubois, F69622 Villeurbanne, France. [4]Shenyang Institute of Geology and Mineral Resources, Shenyang, 110034, China. [5]College of Palaeontology, Shenyang Normal University, Shenyang, 110034, China. Correspondence and requests for materials should be addressed to Y.W. (email: ydwang@nigpas.ac.cn)

wood specimen was collected near Toudaogou village (121°00′–121°09′ E, 41°43′–41°47′ N) in Changgao Town of Beipiao City. The fossil wood locality and geological sections of the Tiaojishan Formation in Beipiao, western Liaoning, northeastern China are described by Wang *et al.*[20].

Stratigraphically, the fossil wood specimen was preserved in the Tiaojishan Formation (previous known as the Lanqi Formation). This formation is widely distributed in western Liaoning Province and the neighbouring northern part of Hebei Province. The Tiaojishan Formation is usually considered to be Middle Jurassic in age, based on palaeontological assemblages[21,22]. Recent isotopic dating of 40Ar/39Ar in volcanic rock revealed, however, a transition between the late Middle Jurassic and the early Late Jurassic ages (approximately 153 Ma to 165 Ma) for the Tiaojishan Formation[23,24].

The Tiaojishan Formation is 2000 m thick and is lithologically composed of intermediate lava and pyroclastic rocks, intercalated with basic volcanic rocks and sedimentary deposits[25,26], with plant-bearing beds made of fine-grained sandstones intercalated with shales. These beds contain abundant well-preserved fossil plants, including leaf foliages, seeds and fruits, permineralized rhizomes and fossil wood[20]. Many anatomically preserved plant specimens were recently reported from the Tiaojishan Formation, including fern rhizomes *Ashicaulis*[27–30], cycad stem *Lioxylon*[31] and conifers *Araucariopitys*, *Pinoxylon*, *Sciadopityoxylon* and *Xenoxylon*[20,32] (Fig. 1).

Results

Systematic palaeontology.

Class: Ginkgopsida
Order: Ginkgoales
Family: incertae sedis
Genus: *Ginkgoxylon* Saporta
Type species: *Ginkgoxylon gruetii* Pons *et* Vozenin-Serra

Ginkgoxylon liaoningense sp. nov. Jiang, Wang, Philippe *et* Zhang
(Fig. 2a–f; Fig. 3a–j)

Type specimen: PB22285 and slides. (housed at the palaeobotanical collection of Nanjing Institute of Geology and Palaeontology, CAS).
Type locality: Toudaogou village, Beipiao City, Liaoning Province, China.
Type horizon: Tiaojishan Formation, Middle to Late Jurassic.
Etymology: after the fossil location in Liaoning Province.
Diagnosis: Tracheidoxyl with *Ginkgoxylon* features, including strongly inflated axial parenchyma chains, idioblasts, intrusive tracheid tips, ordered cupressoid oculipores in cross-fields, opposite pairs of radial pits separated by Sanio's rims and an irregular aspect of the cross-section; similar to *G. chinense* Zhang, Zheng *et* Shang, but with approximately half the radial pits being contiguous and some imbricate biseriate alternate radial pits.

Description. The specimen PB22285 is preserved as a tracheidoxyl, with well-marked growth rings. The transition from early wood to late wood is gradual, with an intermediate type occupying most of the ring (Fig. 2a). The axial cells in cross-section are irregular in size and shape (Fig. 2b), and the tracheids are mostly quadrate to elliptical in the early wood, and more regularly narrowly rectangular in the late wood. Intercellular spaces are often distinct (Fig. 2b, red arrows), and the tracheid wall is thick, even in the early wood, suggesting a compression wood type. The tracheid walls are destroyed in some fungi infected areas (Fig. 2b, black arrows).

In a tangential section (Fig. 2c–f), xylem rays are homogeneous, relatively low, (1) 2–4 (15) cells high and are often associated with inflated axial parenchyma (Fig. 2d,f, red arrows). The tracheid tips are often contiguous to the ray margin or associated to inflated axial parenchyma (Fig. 2c,e).

In the radial section (Fig. 3a–j), some tracheid bunches are present, with storied tips bent alongside wood rays, and the tips sometimes overlap one another (Fig. 3a,b, red arrows). The tracheid radial pits are mostly uniseriate, round and distant (Fig. 3c, red arrow), sometimes contiguous and somewhat flattened, and locally biseriate. The pattern of biseriate pits is variable, from alternate crowded (Fig. 3d, red arrow) to sub-opposite crowded (Fig. 3d, black arrow) or opposite distant (Fig. 3e, red arrow), sometimes with Sanio's rims (Fig. 3f, black arrows). Ray cells in each crossing field yield 4–6 tracheids in the early wood, and ray cell transverse walls are thin and unpitted (Fig. 3g, black arrows), often resiniferous (Fig. 3g, red arrow); cross-fields with (1) 2–4 cupressoid oculipores, with an oblique aperture (Fig. 3h, red arrow). Oculipores are ordered in columns and lines. The axial parenchyma are abundant and well distributed within the ring, with possible crystalliferous chambers (Fig. 3i, black arrow). Trabeculae are locally preserved (Fig. 3j, red arrow), whereas resin canals are not observed.

Comparison. Except for *Protoginkgoxylon*, most fossil wood genera with some *Ginkgo* type features are used for specimens with a strongly araucarian radial pitting. *Baieroxylon* Greguss has idioblasts but no inflated axial parenchyma chain. *Palaeoginkgoxylon* Feng, Wang *et* Roessler, based on a Permian type, has mixed pitting, but with opposite pairs only locally[5]. This is also the case for *Ginkgophytoxylon* Vozenin-Serra, Broutin *et* Toutin-Morin, which was erected based on a type from the Permian of France[33]. *Ginkgomyeloxylon* Giraud *et* Hankel, although diagnosed as having a "*Ginkgo* type of wood", is based on a type with strongly araucarian radial pitting[15,34]. Similarly, *Ginkgoxylpropinquus* Savidge, despite its diagnosis, is based on a type with *Steinkerne*-preserved araucarian radial pitting[35]. This could probably also be the case for *Primoginkgoxylon* Süß, which has thick-walled idioblasts and uninflated axial parenchyma[12].

Protoginkgoxylon was validly recognized by Zheng and Zhang[36] based on Permian material (see supplementary note). The type material of *Protoginkgoxylon* Zheng *et* Zhang has idioblasts and axial parenchyma, but this

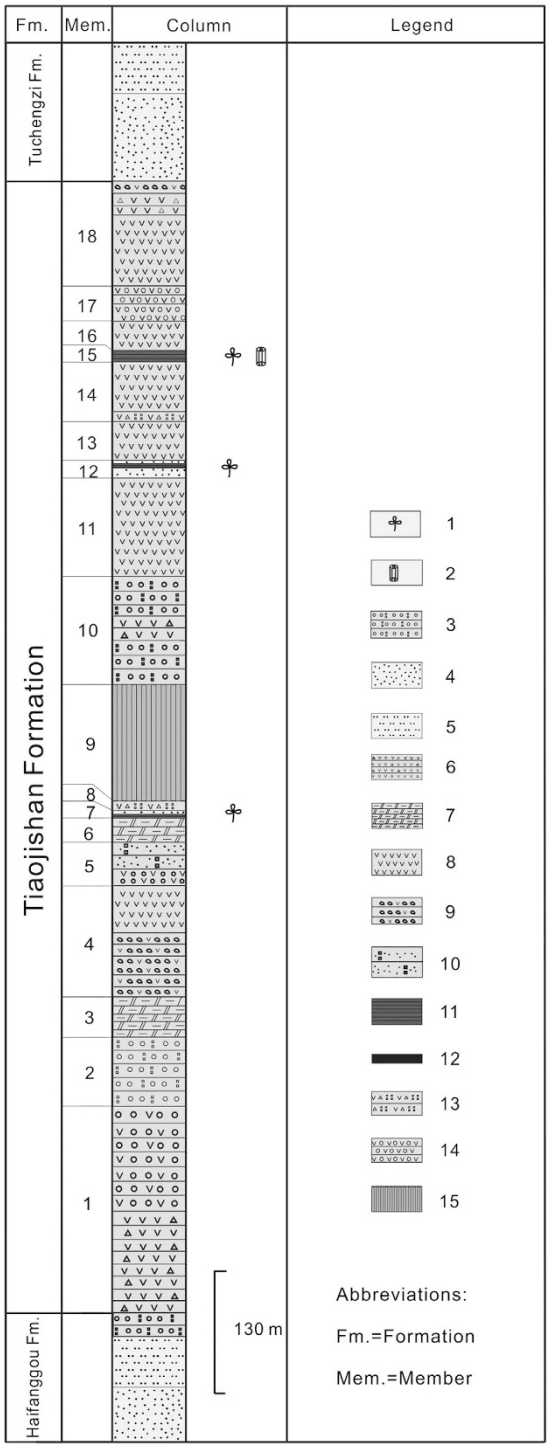

Figure 1. Stratigraphic column of the Tiaojishan Formation in Beipiao, Liaoning Province, China (Drawing based on lithological descriptions of Wang *et al*.[22]). 1. Plant fossils; 2. Fossil wood; 3. Andesitic conglomerate; 4. Sandstone; 5. Siltstone; 6. Andesitic brecciated lava; 7. Andesitic lava breccias; 8. Andesite; 9. Andesite agglomerate; 10. Conglomeratic tuffaceous sandstone; 11. Shale; 12. Coal seam; 13. Andesitic brecciated tuff; 14. Tuffaceous conglomerate; 15. Quaternary sediments.

is only slightly inflated, never reaching 3–4 tracheids in width as observed in our material. Its radial pitting is described as of the "protopinoid-type", but the protologue illustrates a pitting much more araucarian than our material. It never shows opposite pit pairs separated by Sanio's rim. Although they display some *Ginkgo*-like features, the other species included in *Protoginkgoxylon* Zheng *et* Zhang similarly differ from the material studied

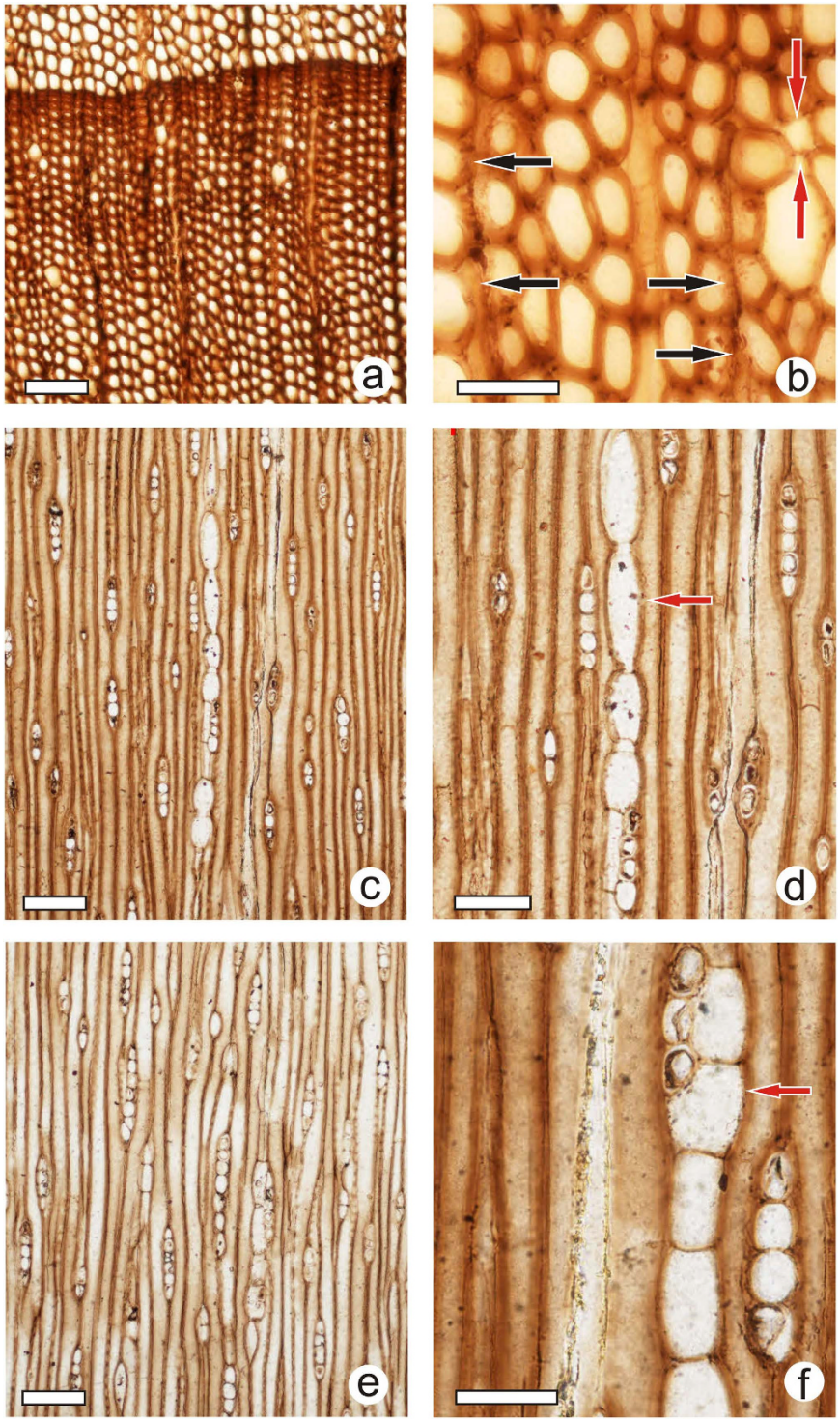

Figure 2. ***Ginkgoxylon liaoningense*** **sp. nov. from western Liaoning, China.** (**a**) Transverse section with a well-marked growth ring. Scale bar = 100 μm. (**b**) Transverse section with intercellular spaces (red arrows) and locally destroyed walls (black arrows), possibly resulting from a fungal attack. Scale bar = 40 μm. (**c**) Tangential section; note the tracheid tip contiguous to the ray margin. Scale bar = 100 μm. (**d**) Tangential section with inflated axial parenchyma associated to a ray (red arrow). Scale bar = 60 μm. (**e**) Tangential section with tracheid tips associated to inflated axial parenchyma or to ray parenchyma. Scale bar = 100 μm. (**f**) Tangential section with inflated axial parenchyma associated to a three-cell ray (red arrow). Scale bar = 40 μm.

here by their mixed type of radial pitting being much more araucarian, with usually more than half of the pits being contiguous and/or alternate.

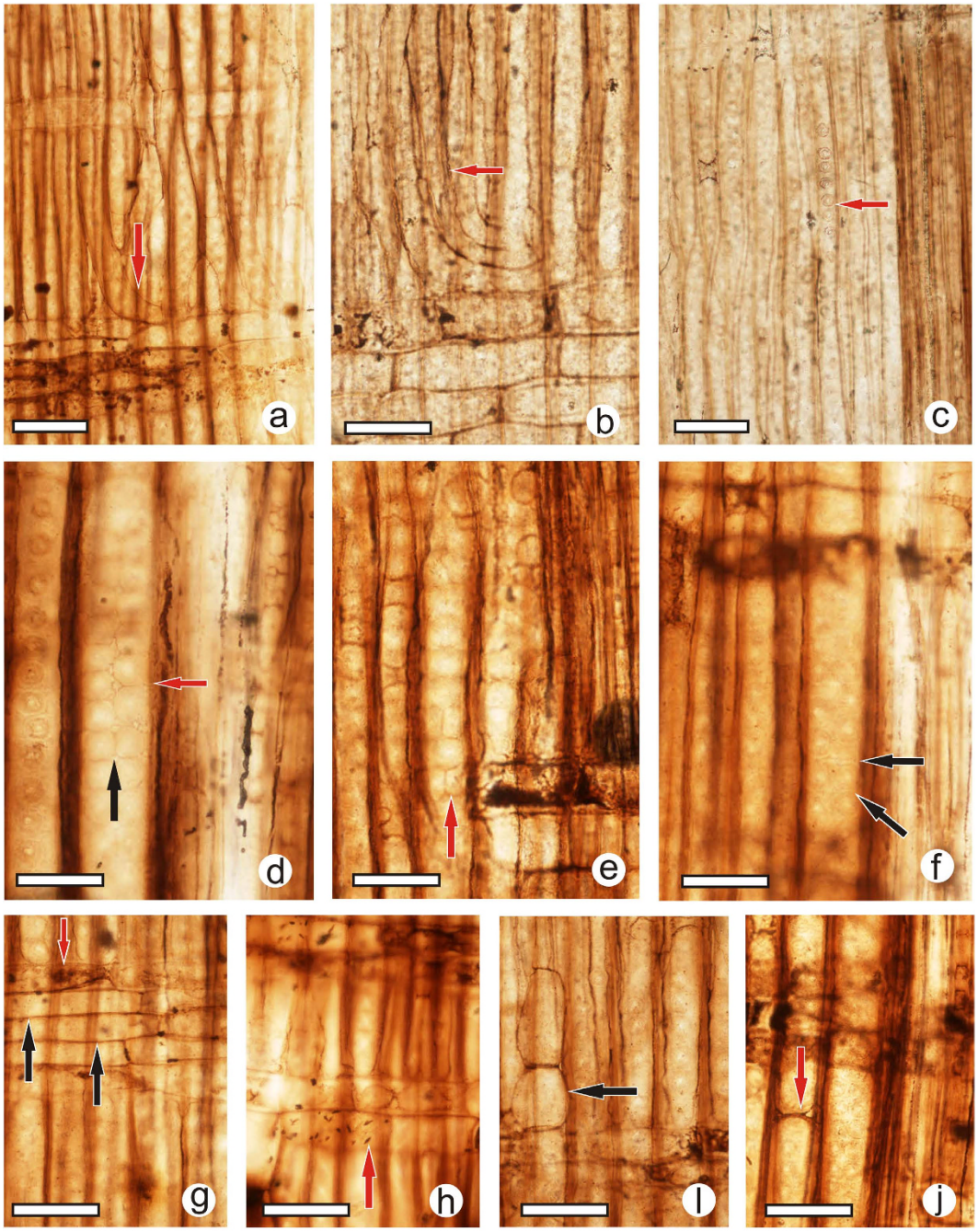

Figure 3. ***Ginkgoxylon liaoningense*** **sp. nov. from western Liaoning, China.** (**a**) A tracheid bunch (red arrow) with tips bent alongside wood rays. Scale bar = 80 μm. (**b**) A tracheid bunch (red arrow) with storied tips overlapping one another. Scale bar = 40 μm. (**c**) Tracheid radial pits (red arrow), mostly uniseriate, round and distant. Scale bar = 80 μm. (**d**) Tracheid radial pits contiguous and biseriate, either alternate (red arrow) or subopposite (black arrow). Scale bar = 40 μm. (**e**) Pairs of opposite tracheid radial pits within a uniseriate contiguous pit chain (red arrow). Scale bar = 40 μm. (**f**) Sanio's rims (black arrows). Scale bar = 40 μm. (**g**) Ray cells, possible resiniferous content (red arrow) cells, and ray cell transverse walls (black arrows). Scale bar = 40 μm. (**h**) Cross-fields. Note that the cross-fields are (1) 2–4 cupressoid oculipores, with an oblique aperture (red arrow). Scale bar = 40 μm. (**i**) Axial parenchyma, with a possible crystalliferous chamber (black arrow). Scale bar = 40 μm. (**j**) A trabecula (red arrow). Scale bar = 40 μm.

Anatomically, our new fossil wood material combines strongly inflated axial parenchyma chains (in addition to idioblasts), intrusive tracheid tips, cupressoid oculipores in its cross-fields, opposite pairs separated by Sanio's rims and an irregular aspect of the cross-section. This combination of features is typical for *Ginkgo*[37] and for *Ginkgoxylon* Saporta[11]. The diagnosis of *Ginkgoxylon* as emended by Khudaiberdyev[9] does not preclude the

inclusion of our material in this genus. Thus, although radial pitting includes a significant share of the araucarian type of radial pitting (approximately 40% to 50%), we assign the present fossil wood material to *Ginkgoxylon*. Within this genus, our material is most similar to the species of *Ginkgoxylon chinense* Zhang, Zheng *et* Shang from the late Early Cretaceous of Liaoning, but it is rather unique because of its partly araucarian radial pitting. Therefore, a new species is proposed for the present fossil wood material from the Jurassic of Beipiao, western Liaoning, China. A comparison of the xyological characters of fossil wood genera linked to Ginkopsida taxa is shown in Supplementary Table S1.

Discussion

Ginkgoales has only one living species, *Ginkgo biloba*; however, this plant group has an extensive and diverse fossil record. This is evidenced by the numerous fossil leaf taxa, e.g., *Baiera* Braun, *Eretmophyllum* Thomas, *Ginkgoidium* Yokoyama, *Ginkgoites* Seward, *Ginkgoitocladus* Krassilov, *Glossophyllum* Kraeusel, *Pseudotorellia* Florin, and *Sphenobaiera* Florin[38]. Compared with these diverse leaf taxa, we still have a very limited knowledge of the history of Ginkgoales wood diversity. In contrast to most other gymnosperms and angiosperms, the wood of *Ginkgo* is particularly prone to degradation and hence, is less likely to get fossilized[39]. Although some fossil wood taxa have been documented based on Paleozoic material, which may be related to Ginkgoales, the fossil wood record of Ginkgoales will probably remain a matter of discussion for a long time.

Modern *Ginkgo* sometimes has a mixed type of radial pitting, especially in an area with disturbed growth. The amount of mixed radial pitting observed here is consequently not considered to preclude a relationship with *Ginkgo*. Because there is only one representative of the genus today, the past variability in *Ginkgo* wood anatomy was probably greater.

Wood with *Ginkgo biloba*-like anatomy is rare in the fossil record[6,40]. It is striking that the present fossil wood material in the Tiaojishan Formation, western Liaoning is found in association with several *Ginkgo* foliage species, including *G. huttonii*, *G. lepida* and G. *sibirica*[41,42]. In the same strata, however, *Ginkgoites* (with *G. tasiakouensis*) and *Sphenobaiera* (with *S. colchica* and *S. paucipartita*) also occur, and thus a link between the studied wood material and a particular foliage species cannot safely be hypothesized. Geologically, our fossil material is only slightly younger than *Ginkgo yimaensis*. *Ginkgo yimaensis* is probably the oldest *Ginkgo* with modern ovulate organs[18] at ca. 170 Myr.

There are some other *Ginkgoxylon* species that have been described and putatively dated as Jurassic. *Ginkgoxylon quangnamense* Serra was reported based on material found *ex-situ* in Vietnam[43]. It might be Early Jurassic in age[44]; however, this generic identification must be confirmed because the type material was poorly preserved[43]. The case is similar with *Ginkgoxylon dixitii* Biradar *et* Mahabale from Andhra Pradesh of India[45]. This wood originates from the Kota Formation, which was long thought to be Early Jurassic in age; however, a recent palynological study demonstrated an Early Cretaceous age[46]. A *Ginkgoxylon* sp. was described from the Tendaguru strata in Tanzania[47]. This deposit is only partly Jurassic in age, and the fossil wood material originates from strata that possibly belong to the Aptian (Early Cretaceous)[47].

With *Ginkgoxylon liaoningense* (Middle to Late Jurassic transition), we now have an ancestral form for a species series, continuing with *G. chinense* Zhang, Zheng *et* Shang (Aptian, Early Cretaceous), *G. gruettii* Pons *et* Vozenin-Serra (Cenomanian, Late Cretaceous), and *Ginkgo beckii* Scott, Barghoorn *et* Prakash (Miocene). Anatomical changes in this series are gradual and mostly limited to the radial pitting becoming more and more abietinean.

In conclusion, the fossil material described here from the Tiaojishan Formation in western Liaoning, China, dated as the Middle to Late Jurassic transition in age, is the oldest well-dated occurrence of the genus *Ginkgoxylon*. Although its anatomy departs slightly from that of the modern *Ginkgo*, it displays all its characteristic features. It differs only in having a more mixed type of radial pitting, which also occurs, albeit locally, in modern *Ginkgo* wood. The xylem structures of *Ginkgoxylon liaoningense* illustrates the basal state of *Ginkgo* wood anatomy and will contribute to the understanding of *Ginkgo* evolution.

Methods

The fossil specimen used in this study was preserved as silicified wood. The techniques used for the investigation are the classical thin section method for silicified wood described in Jones and Rowe[48]. Nomenclatural and taxonomical positions follow those of Philippe[10], Bamford and Philippe[49] and Philippe and Bamford[11]. Photographs were taken with ACT-1C DXM1200C software adapted to a Nikon E600 transmitted light microscope. All fossil wood specimens and slides to which this study refers are housed in the Palaeobotany collection of the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, in Nanjing (China), with registration numbers PB22285.

References

1. Zhou, Z. Y. & Zheng, S. L. The missing link in *Ginkgo* evolution. *Nature* **423,** 821–822 (2003).
2. Kvaček, J., Falcon-Lang, H. & Dašková, J. A new Late Cretaceous ginkgoalean reproductive strtucture *Nehvizdyella* gen. nov. from the Czech Republic and its whole-plant reconstruction. *American Journal of Botany* **92,** 1958–1969 (2005).
3. Pittermann, J., Stuart, S. A., Dawson, T. E. & Moreau, A. Cenozoic climate changes shaped the evolutionary ecophysiology of the Cupressaceae conifers. *PNAS* **109,** 9647–9652 (2013).
4. Süß, H. Zwei neue fossile Hölzer der Morphogattung *Ginkgoxylon* Saporta emend. Süß aus tertiären Schichten der Insel Lesbos, Griechenland, mit einer Übersicht über Fossilien mit ginkgoaler Holzstruktur. *Feddes Repertorium* **114,** 301–319 (2003).
5. Feng, Z., Wang, J. & Rößler, R. *Palaeoginkgoxylon zhoui*, a new ginkgophyte wood from the Guadalupian (Permian) of China and its evolutionary implications. *Review of Palaeobotany and Palynology* **162,** 146–158 (2010).
6. Pons, D. & Vozenin-Serra, C. Un nouveau bois de Ginkgoales du Cénomanien de l'Anjou, France. *Courier Forschungsinstitut Senckenberg* **147,** 199–213 (1992).
7. Zhang, W., Zheng, S. L. & Shang, P. A new species of Ginkgoalean wood (*Ginkgoxylon chinense* Zhang *et* Zheng sp. nov.) from the Lower Cretaceous of Liaoning, China. *Acta Palaeontologica Sinica* **39** (sup.), 220–225 (2000).

8. Greguss, P. Permische fossile Hölzer aus Ungarn. *Palaeontogr. Abt. B* **109,** 131–146 (1961).
9. Khudaiberdyev, R. Wood of *Ginkgo* from the Upper Cretaceous of South-West Kyzylkum. *Doklady. Akademia Nauk SSSR* **145,** 422–424 (1962).
10. Philippe, M. Nomenclature générique des trachéidoxyles mésozoïques à champs araucarioïdes. *Taxon* **42,** 74–80 (1993).
11. Philippe, M. & Bamford, M. A key to morphogenera used for Mesozoic conifer-like woods. *Review of Palaeobotany and Palynology* **148,** 184–207 (2008).
12. Süß, H., Rößler, R., Boppré, M. & Fischer, O. W. Drei neue fossile Hölzer der Morphogattung *Primoginkgoxylon* gen. nov. aus der Trias von Kenia. *Feddes Repertorium* **120(5/6),** 273–292 (2009).
13. Zheng, S. L. *et al. Fossil woods of China* (ed. Zheng, S. L. *et al.*) 1–356 (China Forestry Publishing House, 2008).
14. Pastro, B. T., Degani, S. I., Guerra, S. M. & Schultz, C.-L. Lenhos de Ginkgophyta em florestas petrificadas no Triassico superior Sul-Rio-Grandense, Brasil. *Revista Brasileira Paleontologia* **12(2),** 139–148 (2009).
15. Gnaedinger, S. Ginkgoalean woods from the Jurassic of Argentina: taxonomic considerations and palaeogeographical distribution. *Geobios* **45,** 187–198 (2012).
16. Bauer, K., Kustatscher, E. & Krings, M. The ginkgophytes from the German Kupferschiefer (Permian), with considerations on the taxonomic history and use of *Baiera* and *Sphenobaiera*. *Bulletin of Geosciences* **88(3),** 539–556 (2013).
17. Süß, H. & Kelber, K.-P. Eine neue Art der Morphogattung *Baieroxylon* Greguss aus dem Keuper von Franken, Deutschland. *Feddes Repertorium* **122,** 257–267 (2011).
18. Zheng, S. L. & Zhou Z. Y. A new Mesozoic *Ginkgo* from western Liaoning, China and its evolutionary significance. *Review of Palaeobotany and Palynology* **131,** 91–103 (2004).
19. Zhou, Z. Y. & Zhang, B. L. A Middle Jurassic *Ginkgo* with ovule-bearing organs from Henan, China. *Palaeontographica* (*B*) **211,** 113–133 (1989).
20. Wang, Y. D., Saiki, K., Zhang, W. & Zheng, S. L. Biodiversity and palaeoclimate of the Middle Jurassic floras from the Tiaojishan Formation in western Liaoning, China. *Progress in Natural Sciences* **16,** 222–230 (2006).
21. Zhang, W. & Zheng, S. L. Early Mesozoic fossil plants in western Liaoning, northeast China (in Chinese). *Mesozoic Stratigraphy and Palaeontology of Western Liaoning* (*3*) (ed. Yu, X. H. *et al.*) 239–338 (in Chinese) (Geological Publishing House, 1987).
22. Wang, W. L. *et al. Mesozoic stratigraphy and palaeontology of Western Liaoning, vol 1*. (in Chinese with English abstract). (Geological Publishing House, 1989).
23. Chang, S., Zhang, H. C., Renne, P. R. & Fang Y. High-precision $^{40}Ar/^{39}Ar$ age constraints on the basal Lanqi Formation and its implications for the origin of angiosperm plants. *Earth and Planetary Science Letters* **279(3**–4), 1–10 (2009).
24. Zhang, H., Wang, M. X. & Liu, X. M. Constraints on the upper boundary age of the Tiaojishan Formation volcanic rocks in West Liaoning-North Hebei by LA-LCP-MS dating. *Science Bulletin* **58(22),** 3574–3584 (2008).
25. Xu, K. *et al. Jurassic in Northern China VII. Northeast Stratigraphic Division*. 1–261 (Petroleum Industry Press, 2003).
26. Jiang B. Y., Yao X. G., Niu Y. Z., Rao X. & Li Q. J. *Outline of the Jurassic and Cretaceous systems in western Liaoning*. 1–84 (in English, with Chinese translation) (University of Science and Technology of China Press, 2010).
27. Tian, N., Wang, Y. D., Zhang, W., Jiang, Z. K. & Dilcher, D. L. *Ashicaulis beipiaoensis* sp. nov., a new Osmundaceous fern species from the Middle Jurassic of Liaoning Province, Northeastern China. *International Journal of Plant Sciences* **174(3),** 328–339 (2013).
28. Tian, N., Wang, Y. D., Zhang, W. & Jiang, Z. K. A new structurally preserved fern rhizome of Osmundaceae (Filicales) *Ashicaulis wangii* sp. nov. from the Jurassic of Western Liaoning and its significances for palaeobiogeography and evolution. *Science China*, *Earth Sciences* **57(4),** 671–681 (2014).
29. Tian, N. *et al.* A specialized new species of *Ashicaulis* (Osmundaceae, Filicales) from the Jurassic of Liaoning, NE China. *Journal of Plant Research* **127,** 209–219 (2014).
30. Tian, N., Wang, Y. D., Dong, M., Li, L. Q. & Jiang, Z. K. A systematic overview of fossil osmundalean ferns in China: Diversity variation, distribution pattern, and evolutionary implications. *Palaeoworld* **25(2),** 149–169 (2016).
31. Zhang, W., Wang, Y. D., Saiki, K., Li, N. & Zheng, S. L. A structurally preserved Cycad-like stem, *Lioxylon* gen. et sp. nov., from the Jurassic in western Liaoning, China. *Progress in Natural Science* **26** (Special issue), 236–248 (2006).
32. Jiang, Z. K., Wang, Y. D., Zheng, S. L., Zhang, W. & Tian, N. Occurrence of *Sciadopitys*-like fossil wood (conifer) in the Jurassic of western Liaoning and its evolutionary implications. *Chinese Science Bulletin* **57(6),** 569–572 (2012).
33. Vozenin-Serra, C., Broutin, J. & Toutin-Morin, N. Bois permiens du sud-ouest de l'Espagne et du sud-est de la France. Implications pour la taxonomie des gymnospermes paléozoïques et la phylogénie des Ginkgophytes. *Palaeontographica Abteilung B* **221,** 1–26 (1991).
34. Giraud, B. & Haenkel, O. Nouveaux bois fossiles des dépôts du Karoo du Bassin de Luwegu (Tanzanie méridionale). *Annales de Paléontologie* **72(1),** 1–27 (1986).
35. Savidge, R. A. Xylotomic evidence for two new conifers and a *Ginkgo* within the Late Triassic Chinle Formation of Petrified Forest National Park, Arizona, USA. In Parker, W. G., Ash, S. R., Irmis, R. B. (Eds.), *A Century of Research at Petrified Forest National Park: Geology and Paleontology*. Museum of Northern Arizona special publications **62**, 147–149 (2006).
36. Zheng, S. L. & Zhang, W. Late Paleozoic ginkgoalean woods from northern China. *Acta Palaeontologica Sinica* **39,** 119–126 Supl (2000).
37. Süß, H. Zur Problematik des Nachweises fossiler *Ginkgo*-Holzreste. *Zeitschrifft für geologischen Wissenchaften* **16,** 335–336 (1988).
38. Zhou, Z. Y. Mesozoic ginkgoalean megafossils: a systematic review A. *Ginkgo biloba-A global treasure from biology to medicine* (ed. Hori, T. *et al.*) 183–206 (Springer Verlag, 1997).
39. Scott, R. A., Barghoorn, E. S. & Prakash, U., Wood of *Ginkgo* in the Tertiary of Western North America. *American Journal of Botany* **49(10),** 1095–1101 (1962).
40. Taylor, T. N., Taylor, E. L. & Krings, M. *Paleobotany. The biology and evolution of fossil plants*. 1–1230 (Academic Press, Elsevier, 2009).
41. Van Konijnenburg-van Cittert, J. H. A. *In situ* gymnosperm fructifications from the Jurassic flora of Yorkshire. *Acta Bot. Neerl.* **20,** 1–96 (1971).
42. Heer, O. Beiträge zur Jura-Flora Ostsibiriens and Amurlandes. *Mémoires de l'Académie Impériale des Sciences de St.-Pétersbourg* **25(6),** 1–122 (1876).
43. Serra, C. Sur un nouveau bois de Ginkgoales récolté dans le Ho-Gia (Province du Quang-nam). *Archives Géologiques du. Vietnam* **10,** 93–103 (1967).
44. Philippe, M. Radiation précoce des conifères Taxodiaceae et bois affines du Jurassique de France. *Lethaia* **27,** 67–75 (1994).
45. Philippe, M. *et al.* Biogeography of Gondwanan terrestrial biota during the Jurassic - Early Cretaceous as seen from fossil wood evidence. *Review of Palaeobotany and Palynology* **129,** 141–173 (2004).
46. Rajanikanth, A. & Chinnappa, C. Continental Jurassic of peninsular India – a floristic and stratigraphic riddle. *9th International Congress on the Jurassic System, 6th to 9th January 2014 in Jaipur, India* (2014).
47. Kahlert, E., Schultka, S. & Süß, H. Die mesophytische Flora der Saurierlagerstätte am Tendaguru (Tansania). Erste Ergebnisse. *Mitteilungen Museum Naturkunde Berlin*, *Geowissenschaftliche Reihe* **2,** 185–199 (1999).
48. Jones, T. P. & Rowe, N. P. *Fossil plants and spores: modern techniques*. 1–396 (Geological Society, 1999).
49. Bamford, M. & Philippe, M. Gondwanan Jurassic – Early Cretaceous homoxylous woods: a nomenclatural revision of the genera with taxonomical notes. *Review of Palaeobotany and Palynology* **113,** 287–289 (2001).

Acknowledgements
This work was financially supported by the Strategic Priority Research Program (B) of the Chinese Academy of Sciences (XDB18030502), the State Key Program of Research and Development of Ministry of Science and Technology, China (2016YFC0600406); the National Natural Sciences Foundation of China (NSFC 41402004, 41272010, 41572014, and 41302004), the Team Program of Scientific Innovation and Interdisciplinary Cooperation of CAS. This is a contribution to IGCP 632.

Author Contributions
Z.J., Y.W., and M.P. designed and performed research; Z.J., Y.W., M.P. and W.Z. wrote the manuscript. Z.J., N.T. and S.Z. prepared the figures and table; All authors commented on and approved this version of the manuscript.

Additional Information
Supplementary information accompanies this paper at http://www.nature.com/srep

Competing financial interests: The authors declare no competing financial interests.

How to cite this article: Jiang, Z. *et al.* A Jurassic wood providing insights into the earliest step in *Ginkgo* wood evolution. *Sci. Rep.* **6**, 38191; doi: 10.1038/srep38191 (2016).

Publisher's note: Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.