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Research paper

A polyxylic Cycad trunk from the Middle Jurassic of western Liaoning, China, and its evolutionary implications

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ABSTRACT

A new fossil cycad stem *Sinocycadoxylon liianum* gen. et sp. nov. is described based on a well-preserved petrified specimen collected from the Middle Jurassic of Beipiao, Liaoning Province, China. The stem is composed of a small pith, a polyxylic vascular cylinder and cortex. The pith is parenchymatous with medullary vascular bundles, transfusion cells and mucilage canals. The polyxylic vascular cylinder consists of sixteen centrifugal rings and one centripetal vascular ring, all with distinct growth rings in secondary xylem. The presence of polyxyly with growth rings distinguishes this new genus from all fossil and extant Cycadales. The primary xylem is mesarch. Secondary xylem tracheids have araucarioid radial pitting. The rays are uni- or multiseriate and the latter are usually accompanied by mucilage canals and transfusion cells. This polyxylic stem is believed to be related to the Encephalartoideae of Zamiaceae. The new find provides new insights into cycad evolution which is consistent with former phylogenetic analyses indicating that Cycadales originated form Medullosales.

1. Introduction

The fossil record of cycads can be traced back to the Early Permian (Zhu and Du, 1981; Gao and Thomas, 1989), even possibly the late Carboniferous (Leary, 1990). Although there is a great discontinuity in the early evolution of this group, it is generally believed that cycads might have originated from Paleozoic pteridosperms, with Medullosales being their nearest ancestors (Delevoryas, 1982; Crane, 1985; Doyle and Donoghue, 1986; Stewart and Rothwell, 1993; Taylor et al., 2009). Cycads reached their peak diversity during the Mesozoic, as is evidenced by numerous species of fossil megasporophylls and ovalate strobili, as well as vegetative shoots, leaves and trunks (Crane, 1988; Norstog and Nicholls, 1997; Cantrill, 2000; Li et al., 2005; Zheng et al., 2005; Hermsen et al., 2006; Wang et al., 2006a, 2009). During the Cretaceous they appear to have started to decline somewhat in diversity. At present cycads constitute a small group of gymnosperms, composed of eleven genera and 300 species, distributed sporadically in tropical and subtropical regions of the Americas, Africa, Southeast Asia, and Australia (Greguss, 1968; Johnson and Wilson, 1990; Pant, 1999; Hill et al., 2004; Hermsen et al., 2006).

Although there are many differences among living Cycadales, such as in their external morphology, development, reproductive organs and foliage, the eleven extant genera all share certain anatomical traits of their trunks that distinguish them from other gymnosperms. These characteristic features include a well-developed pith, a relatively narrow vascular cylinder, a well-developed cortical zone, mucilage canals in the pith and cortex, and girdling leaf traces. The vascular cylinder surrounding the pith belongs either to the monoxylic or polyxylic type. The monoxylic type has a single vascular ring which consists of secondary xylem and phloem, and the polyxylic type shows a succession of concentrical vascular rings each one composed of centrifugal secondary xylem and phloem (as examples of polyxylic stems, *Cycas rumphii* and *Encephalartos tombifolius* with 22 and 24 vascular rings respectively). In all living polyxylic cycads the vascular rings are composed of secondary xylem and phloem and they are not related to growth rings.

At least nine cycad genera with polyxylic stems are known from the fossil record: *Fascisvarioxylon* from the Jurassic of India (Jain, 1964), *Sanchucycas* from the Lower Cretaceous of Japan (Nishida et al., 1991), *Brunoa* from the Upper Cretaceous of Argentina (Artabe et al., 2004), *Worsdellia* and *Neochamberlainia* from the Upper Cretaceous of Argentina (Artabe et al., 2005). *Bororoa* and *Menucoa* from the Paleogene (Paleocene) of Argentina (Petriella, 1969, 1972), and *Lioxylon* from the Middle Jurassic of China (Zhang et al., 2006b; Zheng et al., 2008a). In general anatomical features they are similar to living polyxylic cycads (*Cycas*, *Encephalartos*, *Lepidozamia*, *Macrozamia*). In the present paper, a new polyxylic fossil cycad trunk is reported which differs from any living and previously known fossil polyxylic cycads.

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2. Geological setting, material and methods

The fossil cycad trunk described here was collected from the Middle Jurassic Tiaojishan Formation at Duanmagou village, Changgao Town, Beipiao City, Liaoning Province (Fig. 1). In this area the Middle Jurassic strata are characterized by a series of terrestrial pyroclastic rocks, including the Haifanggou and Tiaojishan formations (previous Lanqi Formation), roughly equivalent to the Aalenian–Bajocian and Bathonian–Callovian, respectively (Wang et al., 2004). The Tiaojishan Formation is represented by intermediate extrusive and pyroclastic rocks, with intercalations of basic volcanic and three plant-bearing beds of sedimentary rocks (Fig. 2) up to 2420 m thick (Wang et al., 2004). Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) dating of volcanic rocks at the upper boundary of the Tiaojishan Formation in western Liaoning–northern Hebei suggests an age of 153–165 Ma, i.e. late Middle Jurassic to Late Jurassic (Liu et al., 2006; Zhang et al., 2008). The Tiaojishan Formation is characterized by a variety of fossil plant remains, including foliage impression/compressions (e.g., *Todites*, *Coniopteris*, *Hausmannia*, *Nilssonia*, *Ctenis*, *Ptilophyllum*, *Pterophyllum*, *Williamsoniella*, *Pseudoctenis*, *Zamites*, etc.), fern rhizomes (*Ashicaulis* and *Millerocaulis*), cycad stems (*Lioxylon*), female cone (*Araucaria*), as well as diverse conifer woods (e.g., *Haplomyeloxylon*, *Pinoxylon*, *Sahnioxylon*, *Scotoxylon*, *Protopodocarpoxylon*, *Taxodioxylon* and *Xenoxylon*) (Zhang and Zheng, 1987, 1991; Ding et al., 2000; Zhang et al., 2000; Matsumoto et al., 2006; Wang et al., 2006b; Zhang et al., 2006a, 2006b; Cheng and Li, 2007; Cheng et al., 2007; Jiang et al., 2008; Zheng et al., 2008a, 2008b; Yang et al., 2010; Cheng, 2011), and the floral assemblage indicates a Middle Jurassic age (Zhang and Zheng, 1987).

The present specimen was collected from the Taizishan Bed, from the upper strata of the Tiaojishan Formation (Fig. 2). It was buried in pyroclastic rocks and the original trunk is silicified. It is more than 1 m long and 68.5 cm in diameter. Although very little of the cortex is preserved, the vascular cylinder and pith are well preserved.

For studying the anatomy, thin-sections were made using the conventional cutting and polishing methods for optical microscopic observation. All slides were observed under an optical microscope (Olympus BX 51) and photographed using an Olympus microscope digital camera (DP72). Because of the large diameter of the specimen, we also used a special large cutting machine to make a transverse polished surface of the whole stem.

3. Systematics

Sinocycadoxylon Zhang et Yang, gen. nov.

Type species: ***Sinocycadoxylon*** *liianum* Zhang et Yang, sp. nov.

Diagnosis: Polyxylic stem with distinct growth rings in secondary xylem. Small pith parenchymatous, with mucilage canals, transfusion cells and medullary vascular bundles. Cylindrical vascular system with many rings of centrifugal secondary xylem and phloem, and one centripetal vascular ring. Primary xylem mesarch. Secondary rays uniseriate or multiseriate with mucilage canals and transfusion cells.

Etymology: The generic name is a combination of Sino (China), cycad, and xylon (wood).

Discussion: Polyxylic stems are characterized by growth rings in the secondary xylem, a complete centripetal vascular ring, and primary xylem-mesarch and medullary vascular bundles. Our pycnoxylic-like wood was compared to other polyxylic woods, such as ***Sanchucycas*** (Nishida et al., 1991), ***Neochamberlainia*** (Artabe et al., 2005; Artabe et al., 2010), ***Worsdellia*** and ***Brunoa*** (Artabe et al., 2004) from the Cretaceous, ***Bororoa*** (Petriella, 1972) and ***Menucoa*** (Petriella, 1969) from the Cenozoic. Medullary vascular bundles occur in ***Worsdellia***, ***Neochamberlainia***, and ***Menucoa*** like in ***Sinocycadoxylon***, but the latter differs in having a complete vascular ring of centripetal secondary xylem. Among fossil cycad stems, a complete vascular ring of centripetal xylem occurs only in ***Fascisvarioxylon*** (Jain, 1964) and ***Lioxylon*** (Zhang et al., 2006b), but they have only a single centrifugal xylem ring. The present wood has a centripetal vascular ring, whereas centripetal secondary xylem occurs separately or scarcely in other fossil cycads. The present wood has well-developed secondary xylem with distinct growth rings which have never been described from any other polyxylic fossil cycad wood.

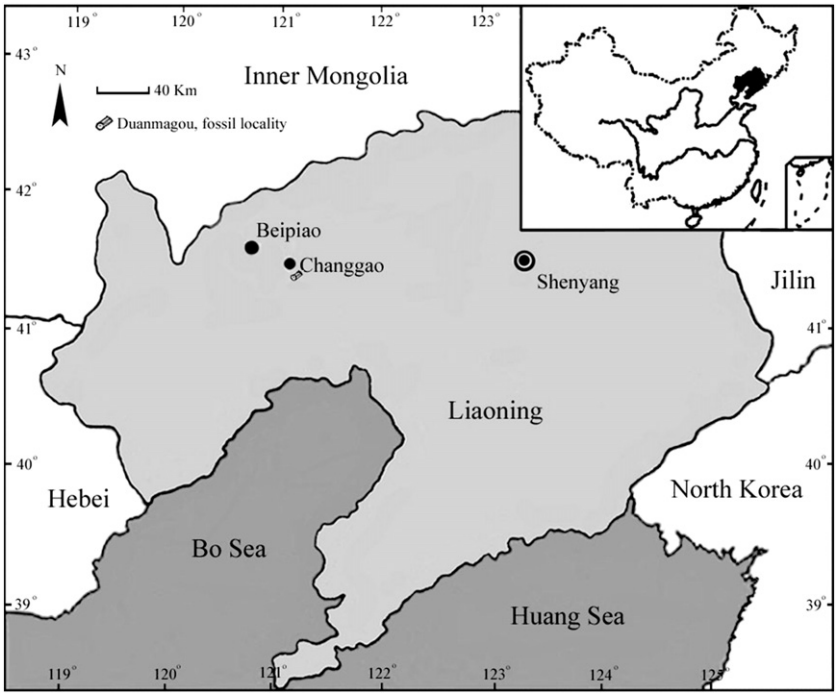

Fig. 1. A sketch map of the fossil locality and adjacent areas in western Liaoning, Northeast China.