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Research paper

Cycas fushunensis sp. nov. (Cycadaceae) from the Eocene of northeast China

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ABSTRACT

A new cycad species, *Cycas fushunensis* sp. nov., is described from the Lutetian Jijuntun Formation at Fushun Coalmine, Liaoning Province, northeast China, based on a well-preserved partial frond containing about 15 leaflets. The fossil is characterized by a single strong vein per leaflet, decurrent leaflet base and haplocheilic stomata, suggesting that the fossil is attributed to the genus *Cycas* of Cycadaceae. Epidermal anatomical comparisons between the fossil and 17 selected modern *Cycas* species further indicate that *C. fushunensis* sp. nov. closely resembles *Cycas panzhihuaensis* Zhou et Yang, an endemic cycad to southwest China, due to characters shared, such as the straight anticlinal walls of both adaxial and abaxial epidermal cells and granular to striate cuticular characters on the internal surface of guard cell periclinal walls. The occurrence of close-to-modern *Cycas* from the early Cenozoic largely casts doubt on a hypothesis of the late Miocene differentiation of modern cycads, suggested by a recent molecular phylogenetic study.

1. Introduction

The genus *Cycas* of the Cycadaceae has about 90 living species distributed in the tropical and subtropical lowlands of Southeast Asia, Madagascar, East Africa, north and northeast Australia, and southwest Pacific (Hill, 1992; Jones, 1993; Shen et al., 1994; Hill et al., 2004a, 2004b; Stanberg and Stevenson, 2012). In China, there are at least 16 extant species living in seasonal dry regions of south and southwest China (Guan et al., 1996). Although the genus is not diverse, the state of its taxonomy is quite confusing and work on its systematics is far from satisfactory (Jones, 1993; Guan et al., 1996; Whitelock, 2002; Hill, 2003; Chen and Liu, 2004). New records of living species are still emerging (e.g., Hill et al., 2004a, 2004b; Singh and Radha, 2008; Agoo and Madulid, 2012). Fortunately, studies on leaf epidermal morphology and stomatal structure using light microscopy (LM) (Greguss, 1957; Pant and Nautiyal, 1963; Greguss, 1965, 1968; Wang and Chen, 1995) and particularly scanning electron microscopy (SEM) (Wang and Chen, 1995) have indicated that foliar epidermal features can be fairly diagnostic in the absence of reproductive cones and seeds. Using principal component analysis under normalized variables, Mickle et al. (2011) demonstrated that foliar epidermal features can likely facilitate the separation of five commonly confused living species of *Cycas*.

Due to their richness and diversity in Mesozoic fossil records cycadophytes have been considered to be an evolutionarily ancient seed plant group (Taylor et al., 2009). However, a recent study of fossil-calibrated phylogenies on living cycads indicated that these modern species evolved from a small number of ancestor species that lived no more than ~12 Ma (late Miocene) (Nagalingum et al., 2011). This conclusion may still need further elaboration as numerous pre-Miocene cycadean records have been documented (e.g. Hill, 1980; Horiuchi and Kimura, 1987; Kvaček, 2002; Erdei et al., 2012), strongly depicting an earlier differentiation of cycadean evolution. Here we report a new Eocene leaf species attributed to *Cycas* from northeast China. The leaf fossil was briefly reported by Liu et al. (1990) and cuticularly studied by Liu (1992), but its taxonomical treatment has not been validly published. In the past decades, new information on the taxonomy of *Cycas* has become available and it is now possible that the fossil can likely be recognized by its distinctive epidermal characters and better compared with living species, particularly *Cycas panzhihuaensis*, a Chinese endemic and the most similar living *Cycas* species to this Eocene species.

2. Material and methods

The Fushun Coalmine is located in an east–west trending exposure of Mesozoic and Cenozoic rocks surrounded by Precambrian terrain (Wu et al., 2002). The well-exposed strata occurring in the coalmine are along the slopes of excavated pits. These continental sequences

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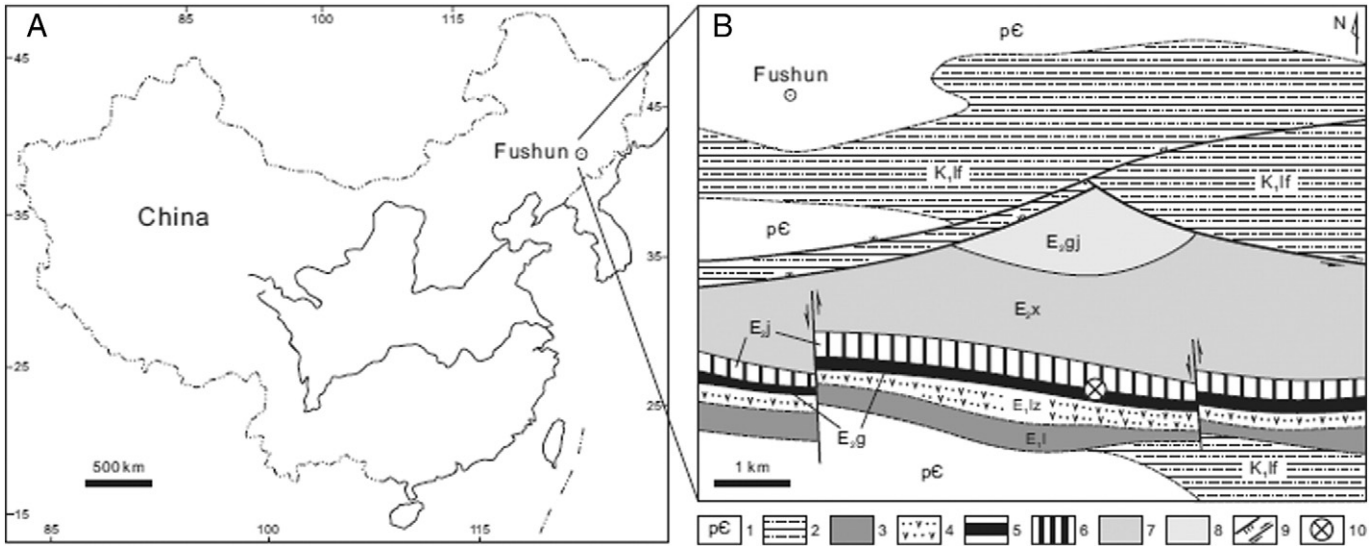

Fig. 1. Map showing the location where the regional stratigraphy in Fushun Coalmine is distributed and the fossil was uncovered. 1. Pre-Cambrian; 2. Lower Cretaceous Longfengkan Formation; 3. Selandian Laohutai Formation; 4. Thanetian Lizigou Formation; 5. Ypresian Guchengzi Formation; 6. Lutetian Jijuntun Formation; 7. Bartonian Xilutian Formation; 8. Priabonian Gengjiajie Formation; 9. Fault; 10. Fossil location in the lower part of the Jijuntun Formation.

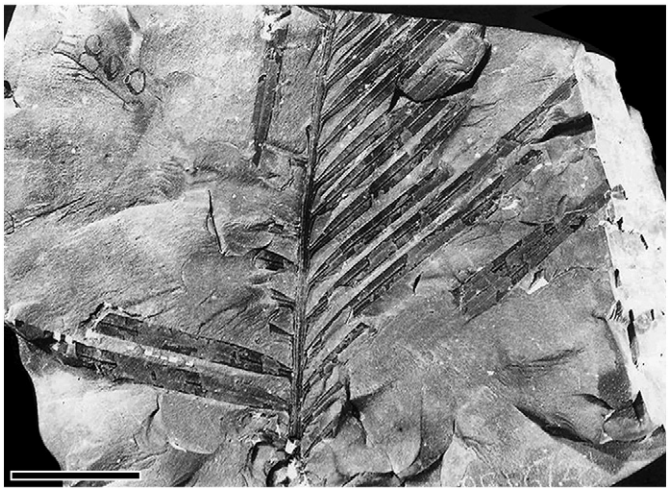

Plate I. Fossil leaf of *Cycas fushunensis* sp. nov. from the Lutetian in Fushun, northeastern China. Holotype PB 16728. Scale bar = 5 cm. One slab specimen, showing the leaf frond with 15 pinnae attached. Note the apex of leaflet is not preserved and the diverging angles on both sides of rachis are different, probably due to the preservation.

consist of fluvio-deltaic and tuffaceous sediments that were deposited in the basin during the early Paleogene (Wu et al., 2002). In ascending order, the sequence is subdivided into the Laohutai, Lizigou, Guchengzi, Jijuntun, Xilutain, and Gengjiajie formations (See Fig. 1). This sedimentary sequence across the Selandian (mid Paleocene) to Priabonian (late Eocene) lacks noticeable unconformities except for the para-conformity between the first two formations (Zhao et al., 1992). The continuous Paleogene strata, although in part of the upper sections, represent one of the best sediments for paleoecological studies in East Asia (Quan et al., 2011, 2012a, 2012b). In addition to the abundant palynological records, the ages of these formations have been constrained by data of either paleomagnetism, isotopes, or insect fossils (Quan et al., 2011).

The plant macrofossils, mainly leaves, are preserved only in the lower part of the oil shale and black shale Jijuntun Formation. Paleomagnetic dating suggests that the fossiliferous layer of the Formation is 47.5 ± 1 Ma, viz. the Lutetian (early Middle Eocene) (Quan et al., 2011). One slab with the compression of a *Cycas* leaf fossil with several attached leaflets and its counterpart were found in the oil shale, in which many other plant taxa, such as *Sabalites*, *Mimosites*, *Firmiana*, *Meliosma*, *Phellodendron*, *Quercus*, *Acer*, *Rhus* and *Betula*, were uncovered (Liu et al., 1996). An updated list of genera in the leaf flora can be seen in the appendix of Quan et al. (2011).

The fossil *Cycas* leaf yielded well preserved cuticles. For a cuticular analysis, small carbonized fragments on the fossil were directly sampled from a centrally located leaflet. After being treated in 47% hydrofluoric acid for two days, the samples were thoroughly washed in distilled water and then macerated in Schulze solution until the organic material was oxidized (Kerp, 1990; Pott and McLoughlin, 2009). For comparisons, modern *Cycas* leaves were obtained from various Chinese herbaria and the Australian species were requested from the National Herbarium of New South Wales (Liu, 1992). The modern cuticles were prepared by treating samples with 20% Cr_2O_3 (Alvin and Boulter, 1974) for up to 96 h. Cross section of the modern samples follows the standard paraffin embedding and sectioning (Ruzin, 1999). For SEM observations, the fossil and modern cuticles were washed in distilled water, mounted abaxially and adaxially on stubs with double-sided tape and air dried. The cuticle was sputter coated and examined with JEOL SEM at 20 kV.

The fossil cuticles, although well-preserved, are quite fragmentary. The terminology for cuticle morphology follows Stockey and Frevel (1997) and Mickle et al. (2011).

3. Systematics

Family: CYCADACEAE Persoon, 1807
Genus: *Cycas* L., 1753
Species: *Cycas fushunensis* Su, Quan et Liu, sp. nov.
Holotype: PB 16728 (Plate I; Plate II, 1–8) and PB 16727 (counterpart).

Plate II. Scanning electron micrographic images of cuticles of *Cycas fushunensis* sp. nov. Scale bar = 100 μm for images 1 and 5; 10 μm for images 2–4, 6–8. 1–2. Adaxial epidermis. 1. Smooth external surface, showing the outline of rectangular adaxial epidermal cells. 2. Internal surface, showing slightly granular periclinal walls of epidermal cells. 3–8. Abaxial epidermis. 3. External surface, showing a slightly sunken stoma. 4. External surface, showing an enlarged round base. 5. Internal surface, showing regularly distributed stomata near the central vein (left of photo). Note the stomata near the central vein parallel the vein course. 6. Internal surface of a haplocheilic stoma, encircled by about nine subsidiary cells. 7. Internal surface, showing granular striae periclinal walls of two guard cells. 8. External surface, showing another slightly sunken stoma with a short opening slit.