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# *Gigantopteris* Schenk ex Yabe in the Capitanian–Wuchiapingian (middle-late Permian) flora of central Shanxi in North China: Palaeobiogeographical and palaeoecological implications

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ABSTRACT

The concept of the Cathaysian Flora was originally based on fossils from the Permian of central Shanxi Province in North China but is now recognized to be valid for the flora of much of East Asia during the Carboniferous and Permian periods. Although *Gigantopteris* Schenck ex Yabe is characteristic and often distinctive of the Cathaysian Flora in general, it has previously not been recorded in Shanxi Province within the central part of the North China. Recent investigations on the Capitanian–Wuchiapingian (middle-late Permian) flora of the Taiyuan East Hill Coalfield in Shanxi have yielded well-preserved specimens of *Gigantopteris dictyophylloides* Gu and Zhi within the Upper Shihhotse Formation, contained within continental red-beds interpreted as representing a floodplain environment. Discovery of *G. dictyophylloides* extends the palaeogeographic distribution of the genus and shows that the Permian flora of Shanxi is more typical of the Cathaysian Flora than previously thought. Results also provide new information on the ecology of *G. dictyophylloides* based on assessments of its occurrence within depositional sedimentary facies from which we conclude that this species thrived in alluvial–fluvial sediments on the North China Block. We also conclude that the red beds of the Upper Shihhotse Formation that yield gigantopterids most likely formed under a seasonally dry climate rather than a vague statement that these red beds were formed generally under arid conditions as previously thought.

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## 1. Introduction

Although originally based on the late Palaeozoic flora of Shanxi Province in North China (Halle, 1927, 1935), the Cathaysian Flora is now recognized for much of Carboniferous–Permian floras of China and East Asia and includes the endemic taxa *Lepidodendron oculus-felis* (Abbado) Zeiller, *Lobatannularia* Kawasaki, *Conchophyllum* Schenk, *Tingia* Halle, *Gigantopteris* Schenk ex Yabe (Wang, 2009), *Gigantonoclea* Koidzumi; *Fascipteris* Gu and Zhi, *Emplectopteris* Halle, and *Emplectopteridium* Kawasaki (Shen, 1995). Since Halle's (1927) pioneering palaeobotanical research of the Permian regional flora from Shanxi the flora has been extensively investigated (e.g. Sze, 1953a, 1953b, 1954, 1955a, 1955b; Lee, 1955, 1963; Zhao et al., 1987; Kong et al., 1995, 1996; He et al., 1995; Wang, 1983a, 1983b, 1992, 1999; Wang et al., 1996; Shen, 1995; Glasspool et al., 2003, 2004a,b) and is now recognized as including all of the genera considered characteristic of the Cathaysian Flora with the exception of *Gigantopteris*. The absence of *Gigantopteris* is unusual considering its seemingly ubiquitous occurrence elsewhere within Cathaysia, a fact that previously led to the Cathaysian Flora being called the *Gigantopteris* flora (Halle, 1935; Koidzumi, 1936; Shen, 1995; Wang et al., 1996).

In the present article we investigate the Capitanian–Wuchiapingian (middle-late Permian) flora of the Upper Shihhotse Formation in Shanxi Province (Fig. 1) and document well-preserved specimens of *Gigantopteris dictyophylloides* Gu and Zhi. This represents the first identification of the genus from Shanxi Province and shows that the Shanxi regional flora was more typical of the Cathaysian Flora in general and that the genus was palaeobiogeographically more widespread within Cathaysia than previously recognized. Our results also allow us to consider its spatial distribution and palaeoecological setting of Cathaysian gigantopterids within the North

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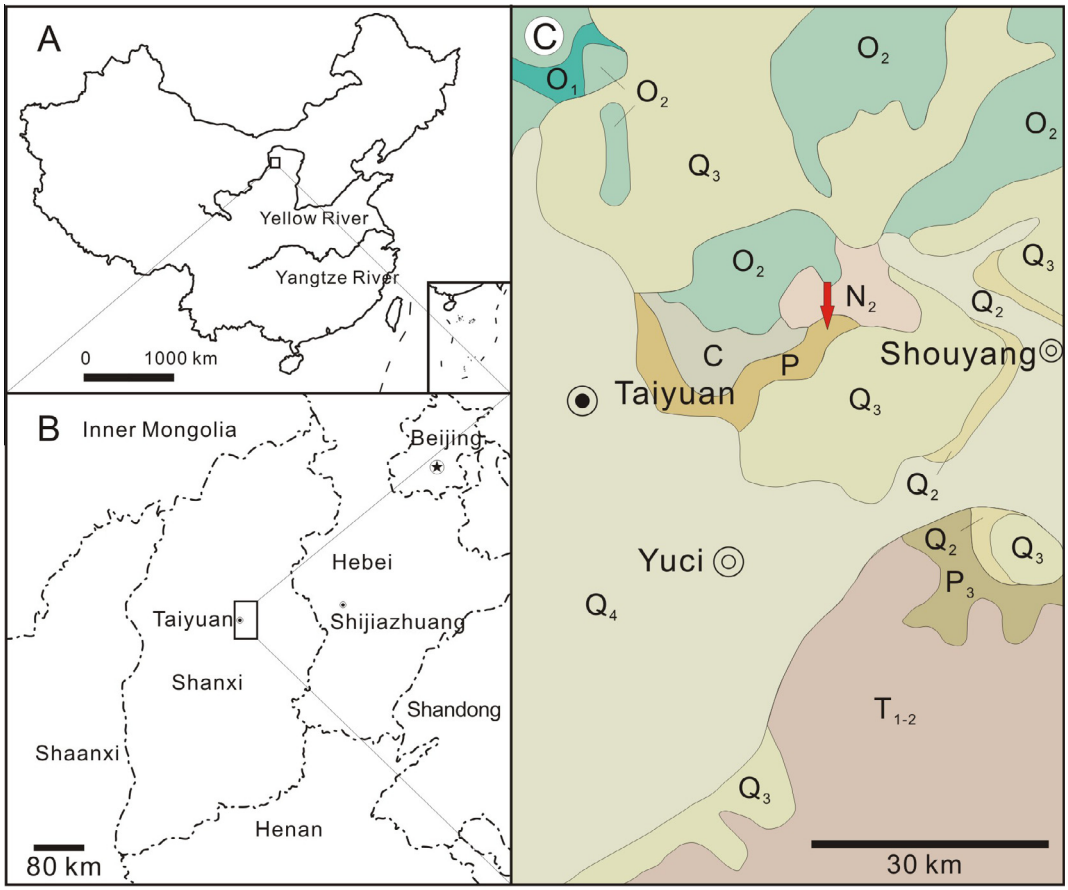


**Fig. 1.** Locality of *Gigantopteris* in Shanxi. (A) Chinese map, square indicates proximate location of research area; (B) map enlarge from (A), square indicates research area; (C) geological map of central Shanxi province with red arrow indicating location of outcrop; $O_1$: Ordovician Liangjiashan Fm.; $O_2$: Ordovician Fengfeng Fm.; C: Carboniferous Taiyuan Fm.; P: Permian; $P_3$: Late Permian, Sunjiagou Fm.; $T_{1-2}$: Early and Middle Triassic; $N_2$:Neogene; $Q_2$: Quaternary, loess deposit; $Q_3$: Quaternary, loess deposit; $Q_4$: Quaternary, fluvial deposit. (The geological map is modified after Geological Map of Shanxi Province of the Peoples Republic of China 1:500,000.)

China Block during the Capitanian–Wuchiapingian by analyzing their occurrences within sedimentary depositional environments.

## 2. Material and methods

Specimens were collected from Mengjiagou village in Shouyang district (Fig. 1) of the Taiyuan East Hill Coalfield in Shanxi Province, occurring in the Upper Shihhotse Formation (Wang and Pfefferkorn, 2010). The sedimentary succession, shown in Fig. 2a and summarized in Table 1, is dominated by red-beds (arrows in Fig. 2a) that comprise sandstones, siltstones and claystones interbedded with paler colored sandstones, siltones and claystones. The sedimentary succession is interpreted as having been deposited under fluvial conditions (Cheng, 1992) progressing from the bottom to the top from overbank to point bar deposits and above this to alternating deposition of fluvial channel sandstones with occasional gravel bases and finer grained overbank (floodplain) deposits of siltstones and claystones (Table 1).

The specimens documented here were collected from bed 6 (Fig. 1b; Table 1) with is indicated by yellow lines in Fig. 2b, occurring in a 0.5 m thick yellowish colored claystone and siltstone between two red beds (Fig. 2a and b). The fossil plants constitute a leaf horizon in which the fossils are well preserved in fine grained sediment allowing detailed features of their morphology to be identified; the fossil plants are relatively complete suggesting that they have not been subjected to transportation and were growing in close proximity to the depositional location although a more detailed taphonomic analysis is not presently available.

Fossil plants associated with *Gigantopteris* in Bed 6 at Mengjiagou include the characteristic Cathaysian genera *Lobatannularia*, *Annularia*, *Tingia*, *Pecopteris*, *Cladophlebis*, *Sphenopteris*, *Fascipteris*, *Gigantonoclea*, *Neuropteridium*, *Taeniopteris* and *Nystroemia* (Wang and Pfefferkorn, 2010). Gigantopteris is a rare constituent of the assemblage in this horizon and to date approximately 20 specimens of this genus have been collected.

Specimens were photographed with a Nikon D800 digital camera with a 60 mm macro lens and are deposited at Nanjing Institute of Geology and Palaeontology (Chinese Academy of Sciences) under the registration number PB21949.

## 3. Results

A well preserved specimen is selected to figure here showing the distinctive venation characters and leaf margin of the genus *Gigantopteris* (Fig. 3). The specimen preserves the right half of a large leaf including part of the primary vein, and the incomplete specimen is approximately 80 mm long by 47 mm wide. The dentate margin bears at least two teeth. Each secondary vein stretches into one tooth, approaching the apex, fading away at the leaf margin. The primary vein is rather thick and straight. The secondary vein is moderately thin in comparison to the primary vein and arises from it at a cute angle of ca. 60°, tapering upward. Tertiary veins are much thinner than secondary veins, departing from the secondary vein at an angle of about 70–80°, with a slightly decurrent base, regularly spaced, and arranged in a sub-opposite pattern. Close inspection reveals the tertiary veins dichotomise at their

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