Discovery of *Ceratosphaeridium* (Acritarcha) from the Ediacaran Doushantuo Formation in Yangtze Gorges, South China and its biostratigraphic implication

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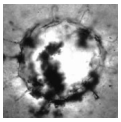

Ceratosphaeridium Grey, 2005 is a key taxon of ECAP (Ediacaran complex acritarch palynoflora) in the Officer and Amadeus basins, South Australia. Recently, several specimens of *Ceratosphaeridium* were fortuitously observed from the Member III of the Ediacaran Doushantuo Formation in the Yangtze Gorges, South China. The discovery of *Ceratosphaeridium* and other associated acritarchs from the Doushantuo Formation suggests that this taxon is widely distributed and with potential for inter-continental correlation of Ediacaran strata. Acritarch assemblages in Member III of the Doushantuo Formation in Yangtze Gorges can now be correlated with the Ediacaran Complex acantrhiomorph palynoflora (ECAP) of South Australia. At present, the ECAP cannot be correlated with the lower microfossil assemblage of the Ediacaran Doushantuo Formation of the Yangtze Gorges (characterized by the key taxon *Tainzhushania* and this interval may be missing in South Australia. • Key words: Ediacaran, Acritarcha, Yangtze Gorges, South Australia, *Ceratosphaeridium*, stratigraphical correlation.

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Acritarchs belong to an informal group of microorganisms with mostly unknown phylogenic origins (Evitt 1963). It is commonly agreed that they are polyphyletic and many are considered to be resting cysts of single-celled, eukaryotic phytoplankton. Since acritarchs are widespread and evolved rapidly, they are widely used for Phanerozoic biostratigraphy. Previous studies suggest that acritarch records in Ediacaran successions show rapid diversification and replacement of taxonomically diverse assemblages over short intervals (Knoll & Ohta 1988, Yin & Liu 1988, Vidal 1990, Knoll 1992, Zang & Walter 1992, Moczydłowska *et al.* 1993, Tiwari & Knoll 1994, Yuan & Hofmann 1998, Zhang *et al.* 1998, Grey 2005, Moczydłowska 2005, Veis *et al.* 2006, Willman *et al.* 2006, Zhou *et al.* 2007, Willman & Moczydłowska 2008). Some Ediacaran acritarch taxa, such as *Papillomembrana compta* and *Tanarium conoideum*, seem to have short stratigraphic ranges and a wide distribution on several palaeocontinents; thus their potential for Ediacaran biostratigraphic subdivision and global correlation is becoming increasingly important. Four assemblage zones of the Ediacaran complex acanthomorphic acritarch palynoflora (ECAP) were identified in the Officer and Amadeus basins, South Australia and Northern Territory, and to a lesser extent on the Stuart Shelf, adjacent to the Adelaide Rift Complex of South Australia (Grey *et al*. 2003, Grey 2005). These distributions were confirmed in subsequent studies by Willman *et al*. (2006) and Willman & Moczydłowska (2008). Among them, the genus *Ceratosphaeridium*, characterized by a single process is one of the most important taxa of ECAP in the Officer and Amadeus basins, South Australia. Recently, several specimens of *Ceratosphaeridium* were fortuitously found from the Ediacaran Doushantuo cherts in the Yangtze Gorges, South China (Fig. 1). Prior to this report, the specimens of genus *Ceratosphaeridium* have only been found in the Officer and Amadeus basins, South Australia. So, the discovery of *Ceratosphaeridium* from the Doushantuo chert suggests that this taxon is widely distributed and with potential for inter-continental correlation of Ediacaran strata.

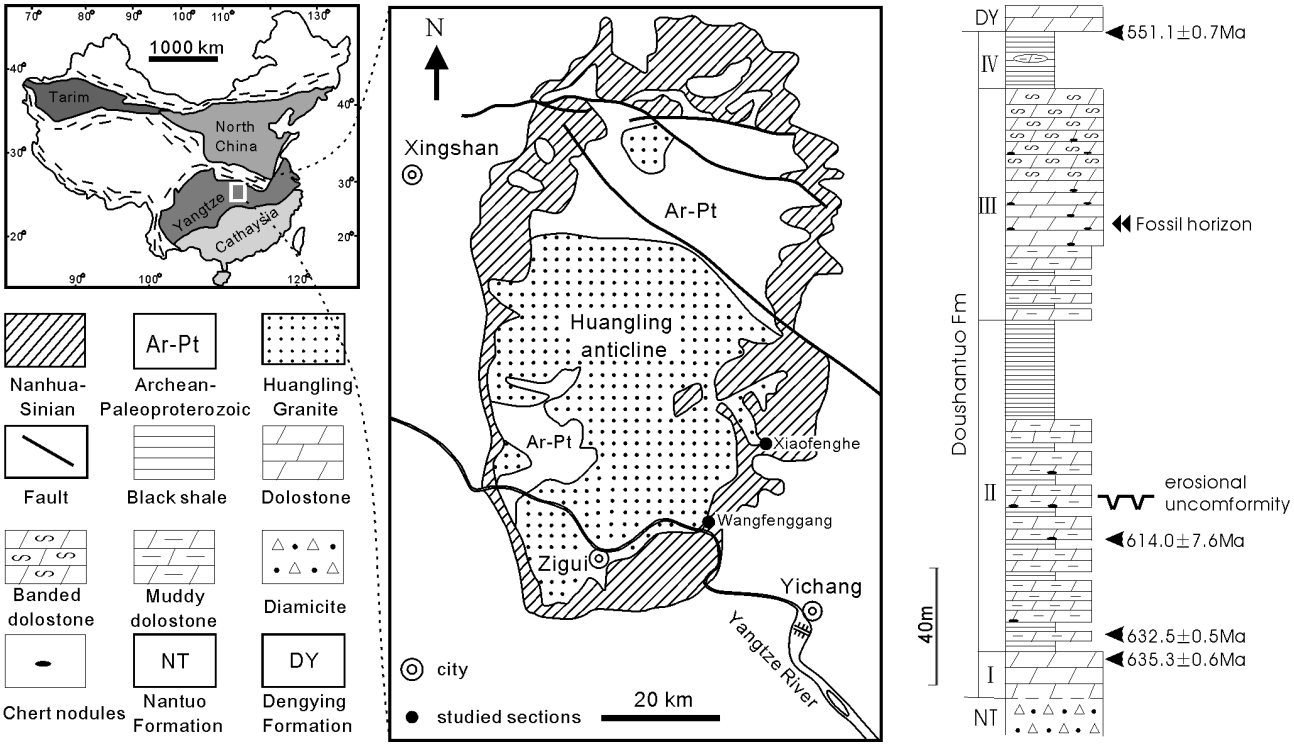

Figure 1. Simplified geologic map of the Yangtze Gorges area and general stratigraphy of the Doushantuo Formation.

Ceratosphaeridium in Yangtze Gorges, South China

Ediacaran stratigraphy of Yangtze Gorges, South China

Due to an abundance of fossils and a long research history, the Ediacaran succession in the Yangtze Gorges, South China, is one of the most important Ediacaran successions in the world. The Ediacaran Doushantuo Formation in South China is underlain by the Cryogenian Nantuo diamictite and overlain by upper Ediacaran dolostone of the Dengying Formation. The age of the Doushantuo Formation has been constrained between 635.2 ± 0.6 Ma and 551.1 ± 0.7 Ma (Fig. 1) by zircon U-Pb ages obtained from interbedded ash beds (Condon *et al.* 2005, Yin *et al.* 2005, Zhang *et al.* 2005). Generally, the Doushantuo Formation in the Yangtze Gorges area consists of four members. These members are, in ascending order, (1) ~5 m thick cap carbonate overlying glacial deposits of the Nantuo Formation; (2) 80–120 m thick black shale intercalated with medium-bedded dolostone and muddy dolostone with abundant chert nodules; one obvious erosional unconformity (younger than 614.0 ± 7.6 Ma; Liu *et al.* 2009a) can be seen in the middle part of this member at many sections (Zhu *et al.* 2007); (3) 40–60 m thick medium-bedded dolostone with chert bands or lenticles and banded dolostone; (4) ~10 m thick black shale with large dolomitic concretions (Fig. 1).

Previous studies indicated that the Doushantuo Formation in the Yangtze Gorges area was deposited in subtidal environments and the chert nodules were formed just below the water-sediment interface during early diagenesis (Xiao 2004). Abundant silicified microfossils, including acritarchs, coccoidal and filamentous cyanobacteria, multicellular algae, embryos and some tubular microfossils have been reported from chert nodules or lenticles in both Member II and III (Zhang *et al.* 1998, Yin 1999, Xiao 2004, Yin *et al.* 2007, Zhou *et al.* 2007, Liu *et al.* 2009b). Black shales of Member IV at Miaohe (see Fig. 1 for location) contain abundant macroscopic carbonaceous compressions (Chen *et al.* 1994, Xiao *et al.* 2002, Tang *et al.* 2008). In addition, large numbers of *Chuaria*-like carbonaceous compressions and a dichotomously branching algal thallus (*Entermorphites* see Zhu & Chen 1984) were found from black shales in Member II at the Jiulongwan section (see Fig. 1 for location, Tang *et al.* 2006). The reported specimens of *Ceratosphaeridium* were found from the lower part of Member III at the Wangfenggang and Xiaofenghe sections (see Fig. 1 for location).

Ceratosphaeridium in the Yangtze Gorges and its taxonomy

The genus *Ceratosphaeridium* was established by Grey (2005) based on specimens found from the Wilari Dolomite

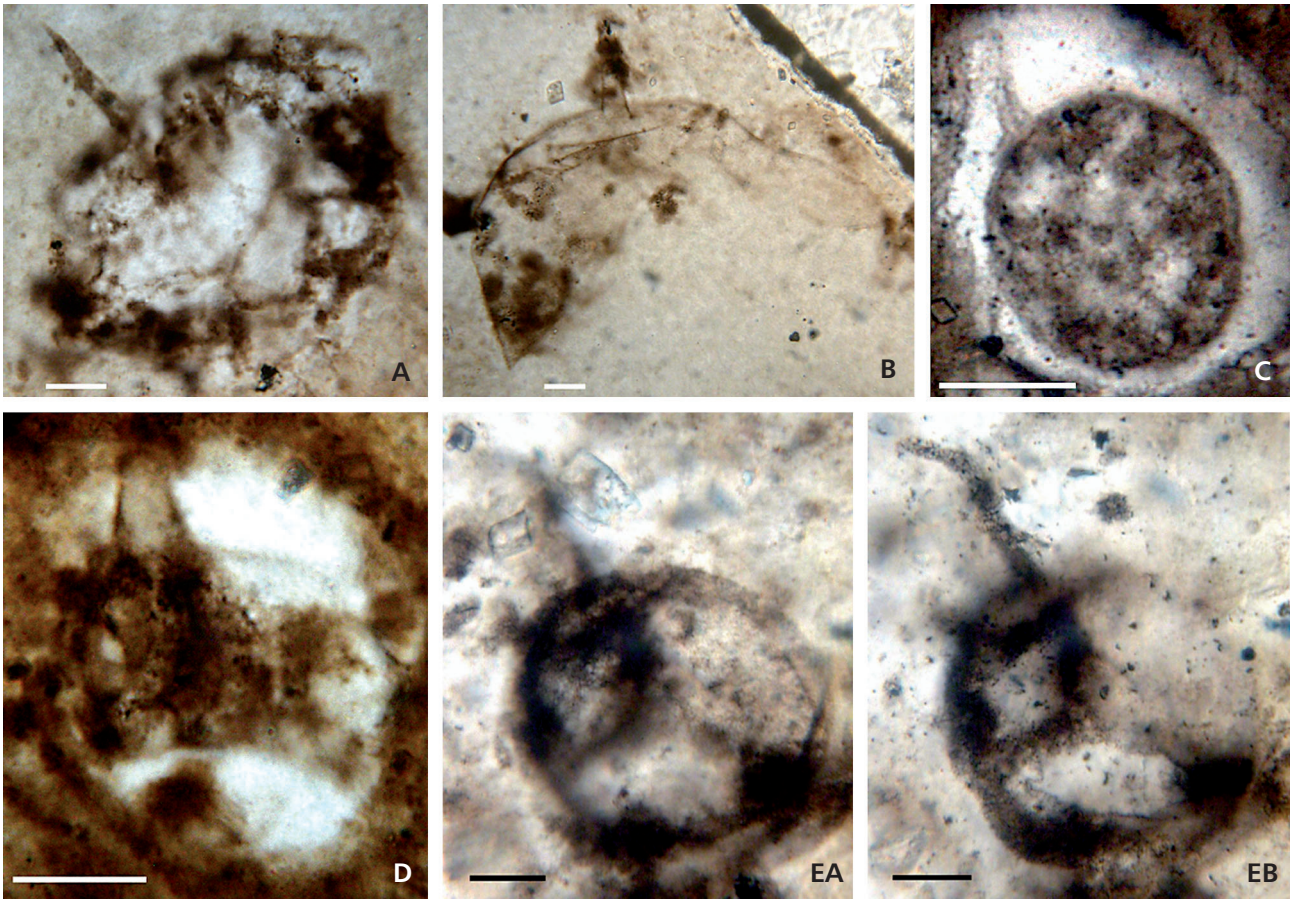

Figure 2. *Ceratosphaeridium glaberosum* Grey, 2005 from the Doushantuo Formation in Yangtze Gorges. • A – WFG367, thin section WFG80816-3-15, coordinates 17 × 86; B – WFG537, thin section WFG8421-72, coordinates 42.4 × 89.6; C – XFH383, thin section X71013-4-092, coordinates 31.6 × 93.6; D – WFG382, thin section WFG80816-3-23, coordinates 41.2 × 97.8; E – XFH340, thin section X71013-4-067, coordinates 41.8 × 100.3, EB is a different focus of EA. Scale bars = 20 μm.

Member and Tanana Formation in the Officer Basin and the Pertatataka Formation in the Amadeus Basin, South Australia. It is characterized by a medium to large vesicle, circular to subcircular in outline (probably originally spherical), bearing a single, prominent, hollow, tapering process, with closed distal end and communicating proximally with thevesicle cavity. The vesicle wall is single-layered, thin, and either granular or smooth. The two species, *Ceratosphaeridium mirabile* (type species) and *C. glaberosum*, are distinguished by whether or not they have grana on the surface of the vesicle. In the case of *C. mirabile*, the whole surface of the vesicle is covered by small, densely scattered grana, but the grana are not present on the process. By contrast, both the vesicle wall and process of *C. glaberosum* is smooth (Grey 2005).

Two distinctive palynofloras, the Ediacaran leiosphere palynoflora (ELP) and the Ediacaran complex acritarch palynoflora (ECAP), were identified in the Officer and Amadeus basins, South Australia (Grey *et al.* 2003, Grey 2005). The ECAP was subdivided into four assemblage zones and each assemblage zone is based on three key species. In ascending order, they are (1) *Appendisphaera barbata-Alicesphaeridium medusoidum-Gyalosphaeridium pulchrum* Assemblage Zone; (2) *Tanarium conoideum-Schizofusa risoria-Variomargosphaeridium litoschum* Assemblage Zone; (3) *Tanarium irregular-Ceratosphaeridium glaberosum-Multifronsphaeridium pelorium* Assemblage Zone; and (4) *Ceratosphaeridium mirabile-Distosphaera australica-Apodastoidas verobturatus* Assemblage Zone (Grey *et al.* 2003, Grey 2005). Obviously, the genus *Ceratosphaeridium* plays an important role in the third and fourth assemblage zones.

So far, nine specimens of *Ceratosphaeridium* have been identified from thin sections of chert nodules in the Chinese successions (Fig. 2). Their vesicles are medium to large, and circular to subcircular in outline. The diameters vary from 42 to 230 μm (average 128 μm, nine measurements). Vesicle walls are generally thin, single-layered with smooth surfaces and a single, prominent process. The process is hollow, tapering with closed ends and freely communicating with the vesicle cavity. The length of processes varies from 15 to 78 μm (average 39 μm, nine

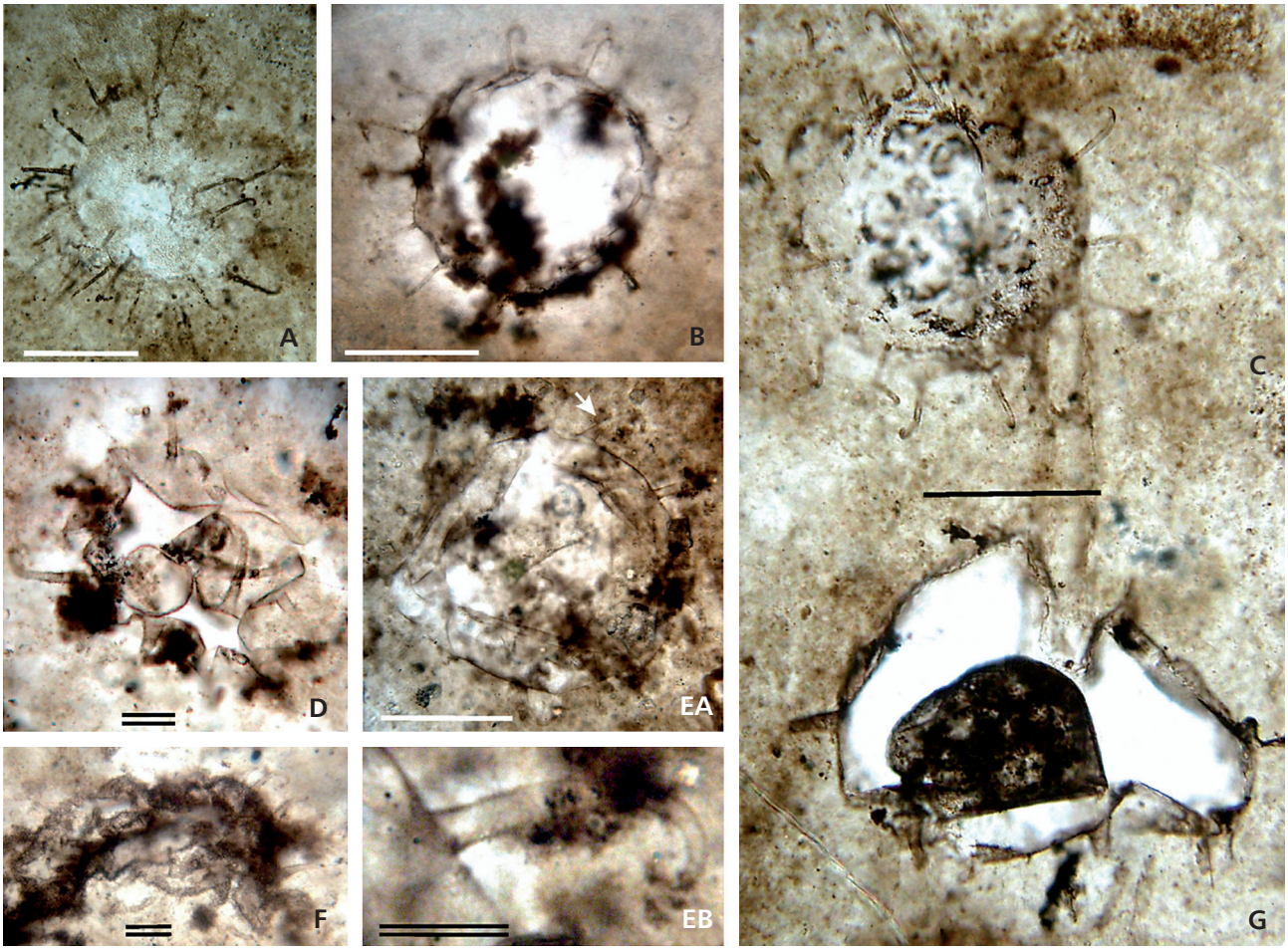

Figure 3. Acritarchs associated with *Ceratosphaeridium glaberosum* Grey, 2005 from the Doushantuo Formation in Yangtze Gorges. • A–C – *Tanarium anozos* Willman & Moczydłowska, 2008. A – WFG095, thin section WFG8421-8b, coordinates 47.5 × 87.7; B – NP III 069, thin section NP III b-8, coordinates 39.4 × 91.9; 3, NP III 052, thin section NP III b-4, coordinates 32.5 × 93.2. • D–G – *Tanarium conoideum* Kolosova, 1991. D – NP III 168, thin section NP III b-23, coordinates 51.9 × 99.9; E – WFG423, thin section WFG80816-3-31, coordinates 34.5 × 88, EB is an enlarged view of marked with arrow in EA; F – XFH332, thin section X71013-4-061, 40.5 × 99.5; G – NP III 053, thin section NP III b-4, coordinates 32.5 × 93.2. Single and double bars represent 100 μm and 25 μm, respectively.

measurements), with a base of 4.5–13 μm in diameter (average 11.8 μm, nine measurements). These characteristics of all specimens are similar to *Ceratosphaeridium glaberosum* Grey, 2005 found from the Officer and Amadeus basins, South Australia (Grey 2005, Willman & Moczydłowska 2008). Thus, all specimens from the Doushantuo Formation are assigned to *Ceratosphaeridium glaberosum*.

The inter-continental biostratigraphic correlation of *Ceratosphaeridium*

Two different acritarch assemblages were identified in the Ediacaran Doushantuo Formation of the Yangtze Gorges, South China, which separately appear in the Member and lower Member III (Yin *et al.* 2009). The carbon isotope composition ($\delta^{13}C_{carb}$) of the Doushantuo Formation shows three prominent negative excursions (EN1–EN3) separated by generally positive values (EP1 and EP2) (Zhou & Xiao 2007, Zhu *et al.* 2007). Two microfossil assemblages of the Doushantuo Formation in the Yangtze Gorges appear generally within the positive values parts (EP1 and EP2) respectively. The lower assemblage is characterized by *Tianzhushania* and a high diversification of large acanthomorphic acritarchs. The upper assemblage is distinguished from the lower assemblage by (1) being devoid of *Tianzhushania*; (2) by the first occurrence of abundant 50–150 μm, smooth-walled spherical microfossils; (3) by the first occurrence of diverse new acanthomorphic acritarchs (they will be reported later); and (4) the first occurrence of tubular microfossils, such as *Sinocyclocylicus guizhouensis* (Yin *et al.* 2009). In particular, *Tanarium* is a key taxon in the upper assemblage.

The lack of easily identifiable and geographically widespread fossils, however, makes it relatively difficult for Ediacaran biostratigraphic correlation between South

China and other continents, although recent studies show that acritarchs and other microfossils are abundant in the Ediacaran rocks and their potential for biostratigraphic subdivision and correlation is becoming increasingly important (Yin 2001, Grey 2005, Willman *et al.* 2006, Willman & Moczydłowska 2008).

Ceratosphaeridium glaberosum is a key species of ECAP in the Officer and Amadeus basins, South Australia, and it mainly appears in the upper ECAP (in both the *Tanarium irregulare-Ceratosphaeridium glaberosum-Multifronsphaeridium pelorium* and *Ceratosphaeridium mirabile-Distosphaera australica-Apodastoidas verobturatus* assemblage zones; Grey 2005). The discovery of *Ceratosphaeridium glaberosum* from Member III (upper acritarch assemblage) of the Doushantuo Formation in the Yangtze Gorges, South China suggests that this taxon is widely distributed and has potential for inter-continental correlation. In addition, the acritarchs *Tanarium conoideum*, *T. anozos* (Fig. 3) and some new taxa (they will be described in a separate paper) have also been found in the Member III of the Doushantuo Formation. Specimens of both *Tanarium conoideum* and *T. anozos* are very abundant in chert nodules; in particular, 77 specimens of *T. anozos* have been observed in one thin section (thin section NP IIIb-23). The taxon *Tanarium conoideum* is a widely distributed species and has found from the Vendian of the Siberian Platform (Moczydłowska 2005), and particularly in the *Tanarium conoideum-Schizofusa risoria-Variomargosphaeridium litoschum* Assemblage Zone of ECAP in South Australia (Grey *et al.* 2003, Grey 2005, Willman & Moczydłowska 2008). Prior to this report, *Tanarium anozos*, which was established by Willman & Moczydłowska (2008), was only found from the Tanana Formation (upper ECAP) in the Giles 1 drillhole of the Officer Basin, South Australia (Willman & Moczydłowska 2008). Thus, the acritarch assemblage in Member III (upper microfossils assemblage) of the Doushantuo Formation in the Yangtze Gorges shows good correlation with the ECAP from South Australia. The fossil assemblage can correlated with lower microfossil assemblage in the Yangtze Gorges may be missing in South Australia.

Conclusions

Ediacaran large acanthomorphic acritarchs are known from several basins, including South China, South Australia, East European Platform, Siberia, northern India and Svalbard (Yin & Li 1978, Yin 1987, Knoll & Ohta 1988, Knoll 1992, Yin & Liu 1988, Yin 1999, Vidal 1990, Zang & Walter 1992, Moczydlowska *et al.* 1993, Tiwari & Knoll 1994, Yuan & Hofmann 1998, Zhang *et al.* 1998, Xiao 2004, Grey 2005, Veis *et al.* 2006, Willman *et al.* 2006, Willman & Moczydlowska 2008, Zhou *et al.* 2007, Vorobeva *et al.* 2009a, b), and their potential for biostratigraphic subdivision and global correlation is becoming increasingly important although they can be limited by facies control, taphonomic biases, and taxonomic problems (Grey *et al.* 2003, Grey 2005, Willman & Moczydlowska 2008, Yin *et al.* 2009, McFadden *et al.* 2009, Vorobeva *et al.* 2009a). The discovery of *Ceratosphaeridium glaberosum* and some other typical taxa of ECAP from the upper acanthomorphic acritarch assemblage in the Yangtze Gorges suggests that only upper Doushantuo acanthomorphic acritarch assemblage is present in South Australia, and lower Doushantuo acanthomorphic acritarch assemblage (the key taxon is *Tianzhushania*) is missing from South Australia. Despite the absence of the lower zone, some large acanthomorphic acritarchs can be used as standard fossils for global biostratigraphic correlation of Ediacaran successions.

Acknowledgments

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