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Quantitative evaluation of the biostratigraphic distribution of acanthomorphic acritarchs in the Ediacaran Doushantuo Formation in the Yangtze Gorges area, South China

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ABSTRACT

Doushantuo acanthomorphic acritarchs are large morphologically complex organic-walled microfossils broadly constrained between the ~635 Ma Nantuo glaciation and the ~551 Ma Miaohe Biota. They are potential biostratigraphic tools for subdivision and correlation of the Ediacaran System in South China. However, major variations in sedimentary facies and stratigraphic thickness present challenges in understanding the spatial and temporal distribution of these acritarchs. Further, the distribution of acritarchs in the Doushantuo Formation is associated with the presence of early diagenetic chert and phosphate, implying a certain degree of preservational bias and/or environmental control. The purpose of this paper is to document the stratigraphic distribution of Doushantuo acritarchs and to quantitatively evaluate their biostratigraphic significance and possible taphonomic–environmental biases, based on high-resolution paleontological data from six sections over ~100 km in the Yangtze Gorges area, South China.

A total of 1082 acritarch fossils were recorded from 84 chert horizons in the six sections of the study area. These chert horizons are not uniformly distributed throughout the Doushantuo Formation, thus the presence/absence of early diagenetic chert does play a role in controlling the distribution of acritarchs. The sampled chert horizons can be grouped into two stratigraphic intervals in the lower and upper Doushantuo Formation, respectively, based on regional stratigraphic correlation. Quantitative analysis shows that the two intervals are distinct taxonomically and largely independent of taphonomic or facies controls. Thus, the two intervals can be regarded as assemblage biozones. The lower biozone (biozone 1) is numerically dominated by *Tianzhushania spinosa* ($n = 587$; 68.3%) and *Meghystrichosphaeridium magnificum* ($n = 74$; 8.6%), whereas the upper biozone (biozone 2) is dominated by *Ericiasphaera rigida* ($n = 104$; 47.1%) and *Tianzhushania spinosa* ($n = 34$; 14.1%). The three most common genera, *Meghystrichosphaeridium*, *Tianzhushania*, and *Ericiasphaera*, have been identified in all sections. Correspondence analysis (CA), detrended correspondence analysis (DCA), discriminant analysis (DA), and pairwise comparisons of samples (Spearman rank coefficient and Jaccard–Chao index), all consistently support biostratigraphic zonations. Thus, the distribution of the Doushantuo acanthomorphs is primarily controlled by biostratigraphic position of samples, with facies and taphonomic differences playing a secondary role. Our case study suggests that acanthomorphic acritarchs can offer a viable tool for regional correlation of the Ediacaran System.

1. Introduction

Recent efforts to subdivide the Ediacaran Period (635–541 Ma) have been impeded by the lack of radiometric constraints and the overall absence of reliable biostratigraphic markers that could allow for reliable regional and global correlation. Ediacaran acanthomorphic acritarchs (spiny organic-walled microfossils) have long been suggested as a potentially useful biostratigraphic tool for several reasons. First, they are broadly constrained between the termination of the Nantuo glaciation (663–635 Ma) and the first appearance of the Ediacara Biota around 575 Ma (Knoll and Walter, 1992; Grey, 2005; Zhou et al., 2007). Second, acanthomorphic acritarchs have been reported worldwide in Australia (Zang and Walter, 1992; Grey, 2005; Willman et al., 2006; Willman and Moczydłowska, 2008), China (Yuan and Hofmann, 1998; Zhang et al., 1998; Xiao, 2004; Zhou et al., 2007), India (Tiwari and Knoll, 1994), Siberia (Moczydłowska et al., 1993; Moczydłowska, 2005;

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Vorob'eva et al., 2008), Svalbard (Knoll, 1992), Norway (Vidal, 1990), and the East European Platform (Veis et al., 2006; Vorob'eva et al., 2006). Third, the complex morphologies and diversity of acanthomorphic acritarchs allow for precise identification and fine stratigraphic resolution. Further, some Ediacaran acanthomorphs may have affinities with early animals, making their distribution crucial for understanding the evolution of modern biological systems (Yin et al., 2007).

One of the most diverse and best studied acanthomorph assemblages is in the Doushantuo Formation of South China, which is radiometrically constrained between 635.2 ± 0.6 Ma and 551.1 ± 0.7 Ma (Condon et al., 2005). Systematic studies of Doushantuo acritarchs have revealed a diverse assemblage of microfossils in the Yangtze Gorges and Weng'an regions (Yin and Li, 1978; Yin, 1985; Zhao et al., 1988; Yuan and Hofmann, 1998; Zhang et al., 1998; Zhou et al., 2002, 2007; Xiao et al., 2004). The greatest challenge facing regional and global correlation of Ediacaran acanthomorphic acritarchs is related to the taphonomic (preservational) and environmental (depositional/facies associations) differences between basins. For example, the first appearance of silicified acanthomorphic acritarchs occurs within 6 m above the 635 Ma cap carbonate in the Yangtze Gorges area, but the first occurrence of phosphatized acanthomorphs at Weng'an is located above a sequence boundary in the middle Doushantuo (Zhou et al., 2007). In Australia, the first occurrence of Ediacaran acanthomorphs occurs in shales stratigraphically above the Acraman impact ejecta layer, estimated to be ∼580 Ma (Grey et al., 2003; Grey, 2005) or ∼570 Ma (McKirdy et al., 2006).

The inconsistency in the stratigraphic distribution of Ediacaran acanthomorphs in the Yangtze Gorges area, Weng'an, and Australia indicates that global correlation may be complicated by taphonomic/environmental biases associated with different taphonomic windows (chert, phosphorites, and shales). Therefore, in this study, we focus on a single taphonomic window (cherts) at a regional scale (the Yangtze Gorges area) in order to minimize these complications and to test the biostratigraphic significance of acritarchs. This intra-basinal approach allows us to establish time-correlative stratigraphic intervals independent of acritarch-based biostratigraphy by using superposition relationships, regionally traceable stratigraphic cycles, and stable isotope chemostratigraphy. This initial stratigraphic subdivision can then be quantitatively evaluated to test whether acritarchs have biostratigraphic significance. Our study shows that the lower and upper Doushantuo Formation in the Yangtze Gorges area are characterized by different taxonomical abundances and such differences are not related to facies or taphonomy, confirming the biostratigraphic significance of Doushantuo acanthomorphs. However, because the stratigraphic range of many Doushantuo acanthomorphs has not been fully documented, their biostratigraphic significance is best realized by using abundance-assemblage biozonations rather than single-taxon interval biozonations.

2. Geological context

2.1. Paleogeography and tectonics

Ediacaran successions in South China developed on a south-southeast facing (present day position) passive margin on the Yangtze Block after the breakup of Rodinia (Fig. 1; ∼850–750 Ma) (Cao et al., 1989; Wang and Li, 2003). Similar stratigraphic affinities with the Adelaide Rift Complex and the Lesser Himalaya suggest that the Yangtze Block may have been located near Australia and/or northern India during the late Neoproterozoic (Jiang et al., 2003; Li et al., 2003; Wang and Li, 2003). Although the exact timing of rifting events in China is still debated (Jiang et al., 2003; Wang and Li, 2003; Zheng, 2003; Zheng et al., 2004), it has been proposed that the Cryogenian glacial and interglacial successions (750–635 Ma) record a rift–drift transition, and subsequent deposition during the

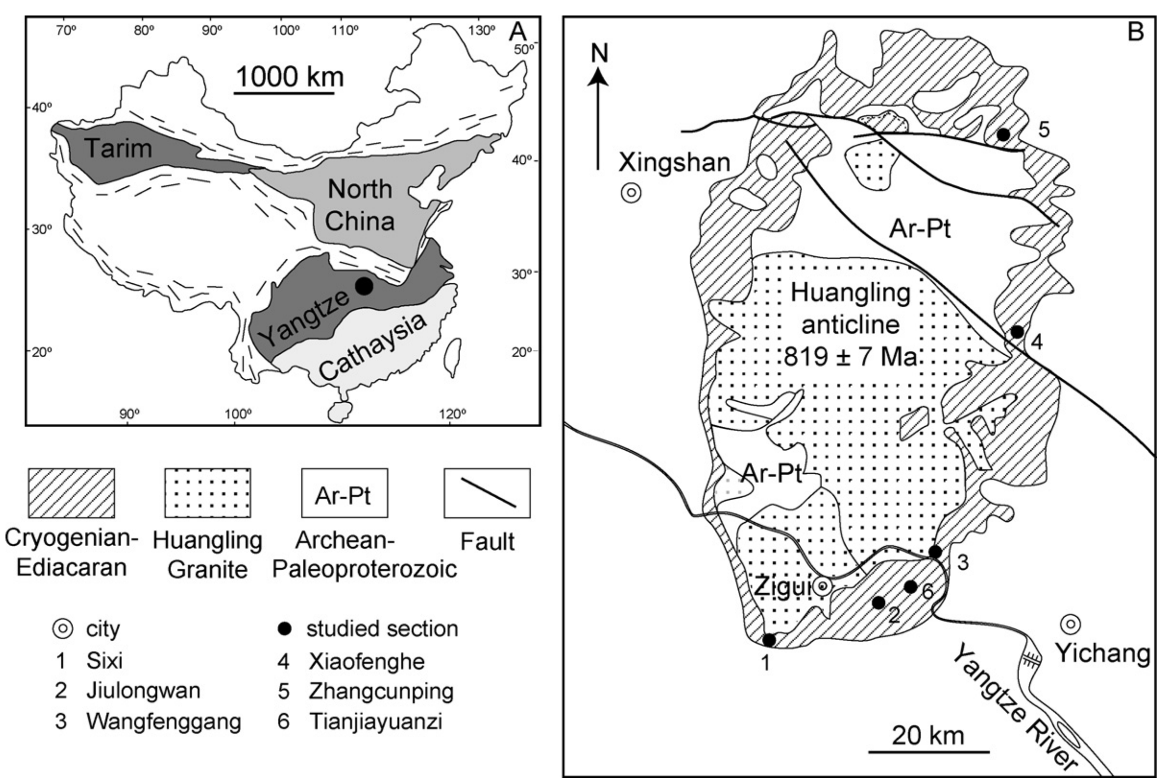

Fig. 1. (A) Map showing the general location of the Yangtze Block and the Yangtze Gorges area (black dot). (B) Simplified geological map of the Yangtze Gorges area (Zhao et al., 1985), showing outcrops of Ediacaran strata around the Huangling anticline and locations of the six studied sections. The Huangling granite in the center of the anticline has been dated at 819 ± 7 Ma (Zhao et al., 1985). (1) Sixi—SX; (2) Jiulongwan—JLW; (3) Wangfenggang—WF; (4) Xiaofenghe—XF; (5) Zhangcunping—ZCP; (6) Tianjiayuanzi—TJYZ.