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Proliferation of shallow-water radiolarians coinciding with enhanced oceanic productivity in reducing conditions during the Middle Permian, South China: evidence from the Gufeng Formation of western Hubei Province

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ABSTRACT

The Middle Permian is a critical period when a possible cooling regime prevailed and massive deep-water cherty sediments were deposited in the South China Craton. An integration of radiolarian paleoecologic and geochemical studies from the Middle Permian Gufeng cherty succession of western Hubei Province, South China tests the relationships among oceanic productivity, redox conditions, and radiolarian responses as well as origin of the cherts. A total of 21 species and six undetermined species in 10 radiolarian genera are identified from the Gufeng Formation in the northern margin basin of the Yangtze Platform of the South China Craton. Three radiolarian *Pseudoalbaillella globosa*, *Follicucullus monacanthus*, and *Follicucullus scholasticus* zones were established and constrained the Gufeng Formation as Roadian to Middle Capitanian in age. The Gufeng cherts embrace a biologic and hydrothermal origin in the northern marginal basin and southern margin basin (the Nanpanjiang Basin) of the South China Craton, respectively. The high oceanic primary productivity in surface oceans resulted in the widespread reducing conditions in the bottom water column. Such high oceanic productivity event slightly predated the Middle Permian Kamura cooling event of the Panthalassian Ocean. Both the elevated continent weathering due to pre-eruptive crustal uplift of the Emeishan flood volcanism and active oceanic upwelling may have stimulated high oceanic productivity and facilitated the deposition of the Gufeng cherts. All radiolarians bloomed in relatively oxic conditions. Only shallow-water radiolarians, mainly spherical forms, proliferated in the reducing conditions, which also coincided with an enhanced oceanic productivity. The abundance of spherical radiolarians therefore is an ideal proxy indicating oceanic primary productivity.

1. Introduction

The Permian Period (298.9 to 252.2 Ma) is one of the most critical intervals in the Earth's history, during which global tectonics together with environments and faunal communities underwent immense turbulence. The supercontinent Pangaea distributed from the North to South Poles and was surrounded by a superocean, namely the Panthalassa (Fig. 1A). Two pronounced biotic mass extinctions at the ends of the Guadalupian and Lopingian, respectively have resulted in the dramatic changes in the biosphere (Stanley and Yang, 1994). The Middle Permian climatic regime was characterized by a global cooling event, named the 'Kamura event' (Isozaki et al., 2007a, 2011; Isozaki, 2009). During this critical period, enhanced organic carbon burials were reported from the mid-Panthalassian sections (Isozaki et al., 2007b), and the contemporaneous organic-enriched deposits were also widely distributed in North America (Phosphoria Formation), northern Europe (Kuperschiefer Formation), Canadian Arctic (Permian cherts), and South China (Gufeng Formation) (Beauchamp and Baud, 2002; Kametaka et al., 2005; Large et al., 2015), an isolated block floating in the eastern Paleo-Tethys Ocean (Fig. 1A). The Middle Permian therefore is one of five distinct peak periods that witnessed major global nutrient-rich oceans during Phanerozoic history (Large et al., 2015). The Middle Permian successions of South China are usually referred to as the chert-dominated Gufeng Formation (also Kuhfeng, sensu Jin and Hu, 1978) or carbonate-dominated Maokou Formation (Jin and Hu, 1978).

Of these, organic-rich siliciclastic sediment from the Gufeng Formation is usually an ideal proxy indicating paleo-marine conditions, as the similar lithology was argued elsewhere (Tyson, 2005). Moreover, the Gufeng Formation yields abundant radiolarians, which are microzooplanktons of primary consumers in the marine ecosystem. Radiolarians are planktonic protozoa that produce intricate siliceous skeletons, yielding a central capsule dividing the cell into the inner and

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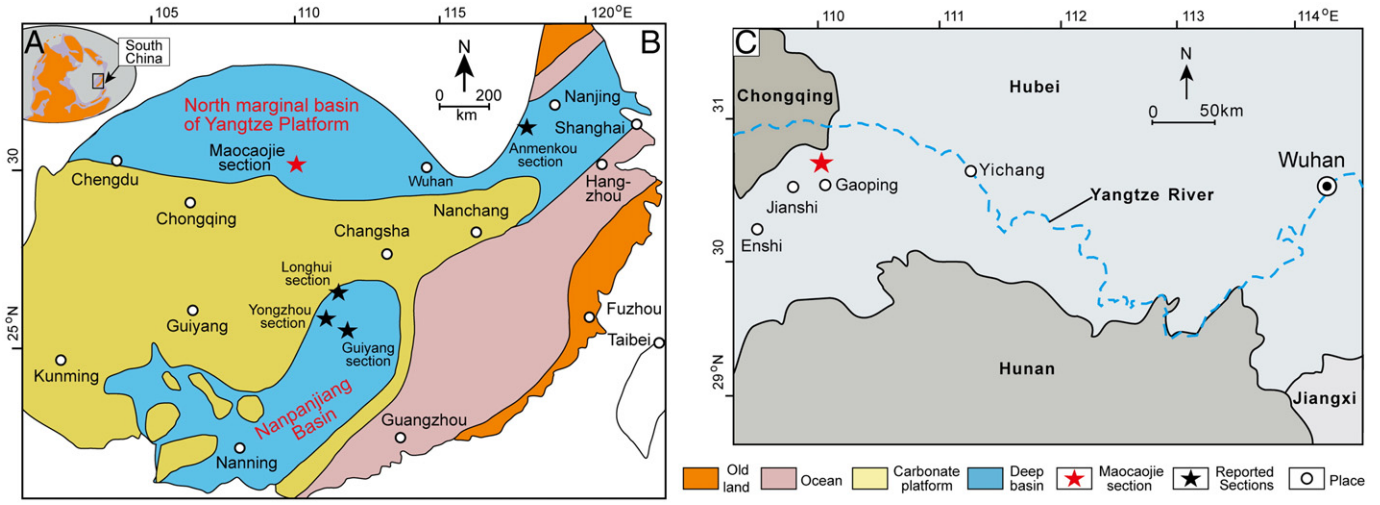

Fig. 1. (A) Global Middle Permian paleogeographic map showing location of the South China block (adapted from Ron Blakey, http://jan.ucc.nau.edu/~rcb7/); (B) Middle Permian paleogeographical configuration of the South China Craton (L. Wang et al., 1994; Y.J. Wang et al., 1994); (C) geographic map showing location of the Maocaojie section, of Jianshi County, western Hubei Province, South China.

outer portions of endoplasm and ectoplasm. They are distributed throughout the water column from the near surface to deeper waters in modern oceans. This clade is also one of the oldest planktonic groups originating in the Early Cambrian and surviving into modern oceans, although a large decrease of both abundance and diversity occurred along with the extinction events in the Earth's history (e.g., Permian–Triassic mass extinction, De Wever et al., 2006; Feng et al., 2007a, 2007b). Radiolarians are heterotrophs that feed on bacteria and algae using a pseudopodial net (Dennett et al., 2002), but many colonial forms also harbor a great number of symbiotic algae and dinoflagellates that contribute to the nutrition of the host (Caron et al., 1995). Thus, radiolarian abundances in marine sediments may assist in assessing paleoproductivity levels due to their dual roles as primary consumers dependent on phytoplankton biomass as well as hosts for symbiotic algae (Du et al., 2012; Jin et al., 2012; Shen et al., 2012; Xiang et al., 2013).

In South China, the Gufeng Formation was comprised of black cherts, siliceous mudstone, and mudstone with some interbeds of limestone. This formation represents a relatively deep shelf basin facies setting, overlying the Kungurian carbonate platform facies deposits, and thus is conspicuous in the field (Jin and Hu, 1978). Radiolarians are commonly present in the Gufeng Formation and its equivalents (Sheng and Wang, 1985; Wang, 1993, 1995; Xia and Zhang, 1998; He et al., 1999; Kuwahara et al., 2007; Yao et al., 2007; Ito et al., 2013a, 2013b), but they were reported mainly from Anhui (He et al., 1999; Ito et al., 2013a; Wang, 1993, 1995) and Jiangsu Provinces (Sheng and Wang, 1985; Kuwahara et al., 2007) in the northern part of the South China Craton, and Guangdong, Guangxi, and Hunan Provinces in the southern part of the same craton (Xia and Zhang, 1998; Wang and Yang, 2003; Kuwahara et al., 2004; Yao et al., 2007; Ito et al., 2013b). Very little (but see Kuwahara et al., 2007, 2008) has been published on radiolarians from the Gufeng Formation of Sichuan and Hubei Provinces, northwestern part of the South China Craton (Fig. 1B).

Besides, no geochemical studies have been undertaken to indicate paleoceanographic conditions and paleo-productivity represented by the Gufeng Formation in South China. Thus, the origin and depositional environment of the Gufeng cherts have long been disputed (Kong and Gong, 1987; Xia et al., 1995; Kametaka et al., 2005). Both hydrothermal and biological origins have been proposed for the source of the Gufeng cherts (Zhu, 1989; Xia et al., 1995; Fu et al., 2004; Kametaka et al., 2005), which are also believed to be deposited in varied environments ranging from platform margin, to basin or rift settings (Liu and Zhu, 1990; Xia et al., 1995; Fu et al., 2004; Kametaka et al., 2005). Moreover, no studies concerning the relationship between oceanic productivity of the Gufeng cherts and the possible Middle Permian cooling event have been conducted in South China.

Herein, we present a detailed study of radiolarian paleoecology and elemental analysis from the Gufeng Formation exposed in the Jianshi area, western Hubei Province, South China (Fig. 1C). The origin of the Gufeng cherts is discussed based on integration of elemental analysis from various sections within the South China Craton. Both microzooplankton paleoecology and geochemical signals also reveal the variations of paleoceanic productivity and redox conditions during the possible Middle Permian global cooling period. The potential mechanism controlling oceanic productivity and deposition of the Gufeng cherts is also discussed in a broad context by integrating the present study and previously published data.

2. Geological setting and stratigraphy

During the Middle Permian, two land areas (also named old lands by Chinese geologists), namely the Cathaysia and Jiangnan continents, were located at the southeastern and northeastern margins of the South China Craton, respectively (Fig. 1B). A large, northeast–southwesterly orientated carbonate platform, namely the Yangtze Platform (L. Wang et al., 1994; Y.J. Wang et al., 1994), was flanked by two relatively deep shelf basins in the northern and southern margins of the craton, respectively (Fig. 1B; L. Wang et al., 1994; Y.J. Wang et al., 1994). The northern marginal basin of the Yangtze Platform was distributed mainly in Sichuan, Hubei, Anhui, and Jiangsu provinces. The southern shelf basin is the Nanpanjiang Basin, which was located in the junction among Guangxi, Guangdong, and Hunan provinces (Fig. 1B).

Of these, the Middle Permian Gufeng Formation successions of these two shelf basins are dominated by black cherts, siliceous shales, and calcareous mudstones with minor interbeds of carbonaceous shale and limestone. This formation is usually underlain by platform facies carbonates of the Qixia/or Maokou Formation in South China. It is also overlain by platform facies carbonates of the Wuxue Formation in Hubei areas or siltstone and shale of the Wangpo Formation and/or the Longtan Formation in Anhui and Jiangsu provinces (Kuwahara et al., 2008). The Gufeng Formation yields abundant fossils of radiolarians, ammonoids, bivalves, brachiopods, and conodonts (Jin and Hu, 1978; Wang, 1993, 1995; Feng and Zhong, 1994; Wang and Qi, 1995; He et al., 1999). Of these, radiolarians are particularly abundant and diverse. Numerous radiolarian zones have been established from the Gufeng Formation (Table 1; He et al., 1999; Wang and Qi, 1995; Wang et al., 1997).

The studied section is located in the Maocaojie village (GPS: 110.00°E, 30.76°N) of Gaoping Town in Jianshi County, about 450 km