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Ediacaran chemostratigraphy and paleoceanography at a shallow marine setting in northwestern Hunan Province, South China

Yoko Kunimitsu[a,*], Yusuke Setsuda[b,2], Seishiro Furuyama[a,1], Wei Wang[c,3], Akihiro Kano[a,1]

[a] Division of Evolution of Earth Environment, Graduate School of Social and Cultural Studies, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan
[b] Graduate School of Science, University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113-0033, Japan
[c] Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China

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ABSTRACT

The geochemical and lithological features of the Ediacaran strata at Yangjiaping in northwestern Hunan Province, South China, record information about the depositional environments, redox conditions, and carbon cycling in a shallow-water setting in this region. The chemostratigraphic profile of the inorganic carbon isotope reveals three negative anomaly intervals in the Ediacaran section that comprises the thick (~360 m) Doushantuo and the thin (~110 m) Dengying Formations. Two of the three intervals, at the base of the Doushantuo Formation and the PC/C boundary, correspond to the global trend. Another anomaly interval in the uppermost 120 m of the Doushantuo Formation appears large-amplitude fluctuations of the inorganic carbon isotope, as well of the oxygen isotope. This interval can be correlated to one of the anomaly intervals of the Three George section, either at the upper, or at the middle Doushantuo Formation. The latter correlation scheme implies association with the Gaskiers glaciation, and demands a substantial hiatus at the Doushantuo/Dengying boundary. Decoupling between organic and inorganic carbon isotopes was recognized in two intervals of the lower Doushantuo Formation and the upper Doushantuo to the lower Dengying Formations. The lower and upper intervals were likely attribute to unusual carbon cycling, reflecting from development and diminishing of the dissolved organic carbon (DOC) reservoir, respectively. Shallow-water sedimentary facies and high organic carbon isotopic values are characteristic of the Yangjiaping section, especially in the oolitic facies of the middle Doushantuo Formation and in the supratidal facies of the lower Dengying Formation. In these intervals, Yangjiaping was in an isolated lagoonal setting where the carbon cycle was independent of that of the open ocean in the South China region.

1. Introduction

The Ediacaran Period, which followed the Marinoan Snowball Earth glaciation (i.e., after 635 Ma; Condon et al., 2005) and was characterized by extreme climatic change (Hoffman et al., 1998; Hoffman and Schrag, 2002) and the evolution of multicellular animals (Li et al., 1998; Chen et al., 2004; Payne et al., 2009), has been subjected to intensive geological, paleontological, and geochemical studies (e.g., Lambert et al., 1987; Li et al., 1998; Zhu et al., 2003; Halverson et al., 2005; Halverson and Hurtgen, 2007; Canfield et al., 2008). The Doushantuo Formation, the lower Ediacaran in the South China block, is especially important in terms of the occurrence of abundant fossil embryos of metazoans (Xiao et al., 1998, 2007; Xiao and Knoll, 1999; Chen et al., 2000, 2002), including the possibly oldest one known (Yin et al., 2007). Therefore, this formation is being actively studied in order to reconstruct the paleoceanographic background of animal evolution.

The carbon isotopic stratigraphy, initially used for stratigraphic correlation (Lambert et al., 1987; Knoll and Walter, 1992; Kaufman and Knoll, 1995; Shen and Schidlowski, 2000; Zhou and Xiao, 2007), is key to reconstruct the Ediacaran oceanography (Yang et al., 1999; Shen et al., 2005; Ling et al., 2007). However, the inorganic carbon isotopic data from the Ediacaran sections in the South China block show substantial variation, depending on the depositional setting, with higher values in shallow platform sediments and lower values in the deep basin (Jiang et al., 2007).

This potential depth gradient in the carbon isotope record might be reflected in unusual carbon cycle features in the Ediacaran ocean, as has already been suggested on the basis of comparisons of inorganic and organic carbon isotopic fluctuation patterns (Rothman et al., 2003; Guo et al., 2007; Peltier et al., 2007).

* Corresponding author. Tel.: +81 92 802 5655; fax: +81 92 802 5662.
E-mail addresses: 9232y0k0@live.jp (Y. Kunimitsu), setta@eps.s.u-tokyo.ac.jp (Y. Setsuda), holocene2007@gmail.com (S. Furuyama), weiwang@nigpas.ac.cn (W. Wang), kano@scs.kyushu-u.ac.jp (A. Kano).
[1] Tel.: +81 92 802 5655; fax: +81 92 802 5662.
[2] Tel.: +81 3 5841 4281.
[3] Tel.: +86 25 83282 267.

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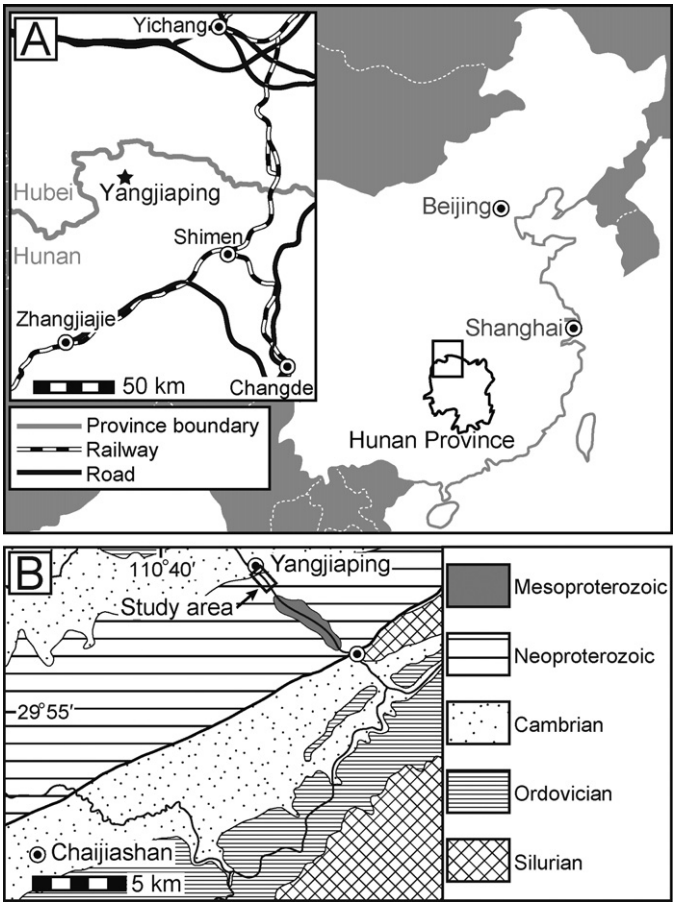

Fig. 1. Locality (A) and geological map (B) of the Yangjiaping section.

Among studied carbon isotope sections in the South China area, both inorganic and organic carbon isotope data have been reported for only a few (e.g., McFadden et al., 2008; Li et al., 2010; Kano et al., 2011), and these data from the entire Ediacaran section have rarely been examined (e.g., Guo et al., 2007). Moreover, most data from shallow-water sections were collected from the Three Gorges area in Hubei Province (e.g., Lambert et al., 1987; Yang et al., 1999; Jiang et al., 2003, 2007, 2010; Condon et al., 2005; Shen et al., 2005; Sawaki et al., 2010).

We investigated the Yangjiaping section, northwestern Hunan Province, another well-known shallow-water section in the South China block (Vernhet, 2007). Here, we discuss chemostratigraphic correlations, carbon cycling, and depositional environments, throughout the section on the basis of lithological observations and carbon isotopic and trace elemental analyses. We also discuss regional paleoceanographic changes in the South China block by comparing our results with data reported from other sections.

2. Geological setting

The Yangjiaping section is 80 km northwest of Shimen County in northwestern Hunan Province, China (Fig. 1A), in the northern limb of the Dongshanfeng anticlinorium (Yin et al., 2003). This section comprises a 600-m-thick sequence (Fig. 1B), which covers the interval from late Cryogenian to earliest Cambrian (655–542 Ma; Amthor et al., 2003; Zhang et al., 2008) (Fig. 2A and B). The section, which exposes outer shelf facies (Vernhet, 2007; Vernhet and Reijmer, 2010), has previously been investigated lithologically, sedimentologically, and chronologically (Lu et al., 1985; Lu and Qu, 1987; Yin et al., 2003; Zhou et al., 2004).

In the South China block, the uppermost Cryogenian unit consists of tillites of the Nantuo Formation, which was deposited during the Marinoan glaciation (Condon et al., 2005). This formation is useful for stratigraphic correlation because it extends across almost the entire South China block. The overlying Ediacaran system is composed of the Doushantuo and Dengying Formations.

The lowermost Doushantuo Formation consists of dolostone of a few meters thick (Lambert et al., 1987; Jiang et al., 2003; Shen et al., 2005) and has been globally correlated with the post-Marinoan cap carbonate (Williams, 1979; Kaufman et al., 1997; Hoffman et al., 1998; Halverson et al., 2005; Shields, 2005). The lithology and thickness of the Doushantuo Formation are highly variable, depending on the depositional setting (Jiang et al., 2011); platform settings, it is thick and calcareous, whereas it is thin and cherty in basin settings (Zhu et al., 2003). The formation is also well known for its fossil embryos from the Weng'an section in Guizhou Province (e.g., Xiao et al., 1998; Chen et al., 2000, 2002).

Because of the importance of the Doushantuo Formation for yielding abundant well-preserved fossils, much attention has been paid to its age determination. An ash bed in the lowermost part of the formation in the Three Gorges area (Hubei Province) has yielded a zircon U–Pb age of 635 Ma (Condon et al., 2005), which currently defines the boundary age between the Cryogenian and the Ediacaran. The fossil-bearing phosphates of the upper Doushantuo Formation in the Weng'an area have been dated to 584–599 Ma by Lu–Hf and Pb–Pb geochronometry methods (Barfod et al., 2002). Zircon U–Pb dating indicates an age of 551 Ma for the ash bed in the uppermost Doushantuo Formation (Condon et al., 2005).

In platform settings, the Doushantuo Formation is covered by the Dengying Formation, which generally consists of dolostone, dolomitic shale, and limestone. However, there is remarkable variation in the lithology and thickness of this carbonate sequence, and in basin settings the Dengjing Formation changes laterally into cherty facies (called the Liuchapo Formation) (Zhou and Xiao, 2007). The Dengying Formation is overlain by Cambrian black shale.

3. Study materials and methods

Samples were collected from 163 horizons of the Yangjiaping section (YJP3–83, YJP101–120, and YJP201–262), covering the interval from the Nantuo Formation to the Cambrian black shale (Muchang Formation; Fig. 2B). Thin sections were made from each sample. Mineral, elemental, and stable isotopic compositions were measured using powdered samples, prepared after excluding veins and weathered parts. Mineral compositions were identified by X-ray diffraction (XRD) analysis at Hiroshima University (MultiFlex; Rigaku, Tokyo) and Kyushu University (RINT-2000V; Rigaku) at an operating power of 40.0 kV and 40 mA and a scan speed of 1.0°/min covering the 2θ range from 24.0° to 35.0°. Identification of some minerals was further confirmed by using the dispersive laser Raman spectrometer (NRS-3100; JASCO) at Kyushu University.

Carbonate minerals in powdered samples were dissolved in 5% acetic acid, and the solutions were analyzed by atomic absorption spectrometry (AA-646; Simadzu) at Hiroshima University to estimate elemental compositions of Mn, Sr, and Fe in the carbonate fraction. A La–Cs solution (La = 1%, Cs = 0.5%, and 1 M HNO_3) with a volume 1/10 that of the sample solution was added to minimize interference resulting mainly from dissolved silica and phosphate (Nyagah and Wandiga, 1979). The measurement error of this method was 10% or less.

The carbonate-containing samples were also analyzed for inorganic carbon and oxygen isotopic composition by using a mass spectrometry system (DeltaPlus and GasBench II; Thermo Finnigan MAT). First, an appropriate amount (0.5–5 mg) of powdered sample, depending on the carbonate content, was reacted with 0.02 mL