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Trace element and strontium isotope constraints on sedimentary environment of Ediacaran carbonates in southern Anhui, South China

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ABSTRACT

Two units of sedimentary carbonates in association with Neoproterozoic glaciations occur in the Lantian Formation of the Ediacaran system, equivalent to the Doushantuo Formation elsewhere in South China. Trace elements and strontium isotopes in the carbonates were analyzed by stepwise dissolutions with different strengths of acid. The results show that the carbonate component dissolved in 0.5 M acetic acid (Dissolution I) is principally composed of calcite and almost free from non-carbonate contamination. Thus its element and isotope compositions can be used to unravel the geochemical feature of water from which the carbonates precipitated. The strontium concentrations and isotope ratios, REE + Y concentrations and patterns of Dissolution I from the carbonates are similar to each other between the two units. They exhibit high strontium concentrations and high $^{87}Sr/^{86}Sr$ ratios, depletion of LREE relative to MREE and HREE, minor positive La anomalies, subtle negative Ce, Gd and Er anomalies, and near-chondritic Y/Ho ratios. These indicate that the Lantian carbonates were precipitated from the similar nature of basin water, which is devoid of trace element composition typical of normal marine carbonates but similar to those in freshwater carbonates. The negative Ce anomalies in the carbonates of the two units suggest oxygenation of the precipitation water. Therefore, the Lantian carbonates would form in a continental marginal basin, with predominant contributions from freshwater and high sedimentary rates. Since the Doushantuo–Lantian carbonate secessions may probably correspond to the chemical sediments of post-Marinoan and post-Gaskiers, it is hypothesized that the freshwater would originate from locally deglacial meltwater with significant inputs from continental weathering.

1. Introduction

Chemical sedimentary rocks, such as carbonates, banded iron formation, cherts and phosphates, were precipitated from waters of oceanic, continental and marginal basins. At thermodynamic equilibrium, they can serve as useful proxies for the geochemical records of elements and isotopes in the basin water from which these rocks originate. In particular, stable carbon isotopes, radiogenic strontium isotopes, and trace elements in sedimentary carbonates provide important sources of information on their depositional environments (e.g., Brenchley et al., 2003; Bolhar and Van Kranendonk, 2007; Li et al., 2007; Frimmel, 2009). Sedimentary carbonates of the Ediacaran system overlying the Middle–Late Neoproterozoic glacigenic diamictites on the earth commonly show negative carbon isotope excursions (Calver, 2000; McKirdy et al., 2001; Brenchley et al., 2003; Yoshioka et al., 2003; Porter et al., 2004; Condon et al., 2005; Halverson et al., 2005; Peral et al., 2007), and they are generally considered as chemical precipitates from seawater. However, the newest study of Y and rare earth elements (REE) geochemistry for Neoproterozoic carbonate successions in southwestern and central Africa suggests the strong influence of river-born particles on the REE + Y distribution in the analyzed carbonates, implying that many of the successions developed in near-shore environments (Frimmel, 2009). This has challenged the common paradigm that the Ediacaran carbonates formed in normal marine environments. Extreme instability of atmosphere and ocean chemistry is expected to occur due to deglaciation of the Marinoan and Gaskiers ice ages. This possibly has geochemical impacts on paleobiological evolution (Fike et al., 2006; Canfield et al., 2007; McFadden et al., 2008; Shen et al., 2008), but it is unclear if oxidation of the Ediacaran seawater is associated with the deglaciations.

Many studies of carbon isotopes have been devoted to Ediacaran carbonates in South China (e.g., Shen, 2002; Jiang et al., 2003, 2007; Condon et al., 2005; Shen et al., 2005; Zhang et al., 2005; Zhou and Xiao, 2007; Wang et al., 2008). The results show negative carbon isotope excursions similar to those observed elsewhere in the world (Zhu et al., 2007). Komiya et al. (2008) analyzed the rare earth elements of carbonate minerals from the Doushantuo Formation of the Ediacaran system to the Shuijintuo Formation of Lower Cambrian in the Yangtze Gorge, South China. The results show negative Ce and

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Eu anomalies in the shale-normalized REE + Y patterns, with the degree of anomalies varying with the stratigraphy. This suggests the variable extents of oxygenation state in the Ediacaran seawater. Based on high $^{87}Sr/^{86}Sr$ and low $^{88}Sr/^{86}Sr$ ratios for the cap carbonate of the Doushantuo Formation that deposited immediately above the Marinoan-related Nantuo tillite, Ohno et al. (2008) suggest that surface seawater was mixed with a large amount of freshwater from the continental crust during the extreme global warming after the glacial event.

Middle–Late Neoproterozoic sedimentary successions in South China contain multiple Marinoan diamictites (Condon et al., 2005; Zhang et al., 2005), the lowest unit of which is called the Nantuo tillite. This tillite is overlain by the Doushantuo Formation, consisting mostly of carbonates, black shales and phosphate deposits. Sedimentology and paleogeography of the Doushantuo Formation have been extensively studied, suggesting different sedimentary facies along an environmental gradient from the carbonate platform to deep basin facies (Wang and Li, 2003; Shen et al., 2005; Jiang et al., 2007). The Nantuo-equivalent glacigenic diamictite is named the Leigongwu Formation in southern Anhui, equivalent to the Marinoan diamictites elsewhere in the world (Wang and Li, 2003; Vernhet et al., 2006). The Lantian Formation sharply and disconformably overlies the Leigongwu diamictites. Biostratigraphic, chemostratigraphic and geochronological studies have demonstrated that the Lantian Formation is equivalent to the Doushantuo Formation elsewhere in South China (Chu et al., 2005; Condon et al., 2005; Yuan et al., 1999).

Two distinct units of carbonates occur in the Lantian Formation in southern Anhui. The carbonate in the lower unit, with $\delta^{13}C$ values of -5.2 to -3.6‰ (Zhou et al., 2001), directly follows the Leigongwu Formation. The carbonate in the upper unit has $\delta^{13}C$ values of -10.2 to -8.5‰ for carbonate and from -35.3 to -26.9‰ for organic carbon (Wang, 2004), comparing well with $\delta^{13}C$ values for mid-late Ediacaran carbonates elsewhere in South China and the world (Zhou et al., 2001; Wang, 2004; Halverson et al., 2005; Fike et al., 2006; Le Guerroue et al., 2006a,b; Zhou and Xiao, 2007; Zhu et al., 2007). Although the carbonate in the upper unit is associated with the large negative $\delta^{13}C$ excursions, it overlies black shales and mudstone without glaciomarine diamictites as observed elsewhere (Corsetti and Kaufman, 2003; Jiang et al., 2003; Condon et al., 2005; Melezhik et al., 2005; Zhang et al., 2005). It is possible that the depositional environments of the Doushantuo–Lantian carbonates are restricted shallow coastal settings in which seawater was diluted by freshwater through influx of deglacial meltwater, or huge continental basins that were separated from the open ocean. Resolution of this difference is important because the largest and most diverse assemblage of multicellular metaphytes occur in these Formations (Yuan et al., 1999, 2002). Therefore, it is intriguing whether the Lantian carbonates have the trace element composition atypical of marine deposition. This paper reports our study of trace elements and strontium isotopes in carbonates from the Lantian Formation in southern Anhui.

2. Geological setting

South China consists of the Yangtze and Cathaysia Blocks that were converged along the Jiangnan Orogen (Fig. 1). Subduction of oceanic crust during the Late Mesoproterozoic is commonly assumed for island arc magmatism and subsequent amalgamation between the two blocks (Charvet et al., 1996; Wang and Li, 2003), with the closure of backarc basins and arc–continent collision in the Early Neoproterozoic between them (Li et al., 2002, 2008; Vernhet et al., 2006; Zheng et al., 2008a).

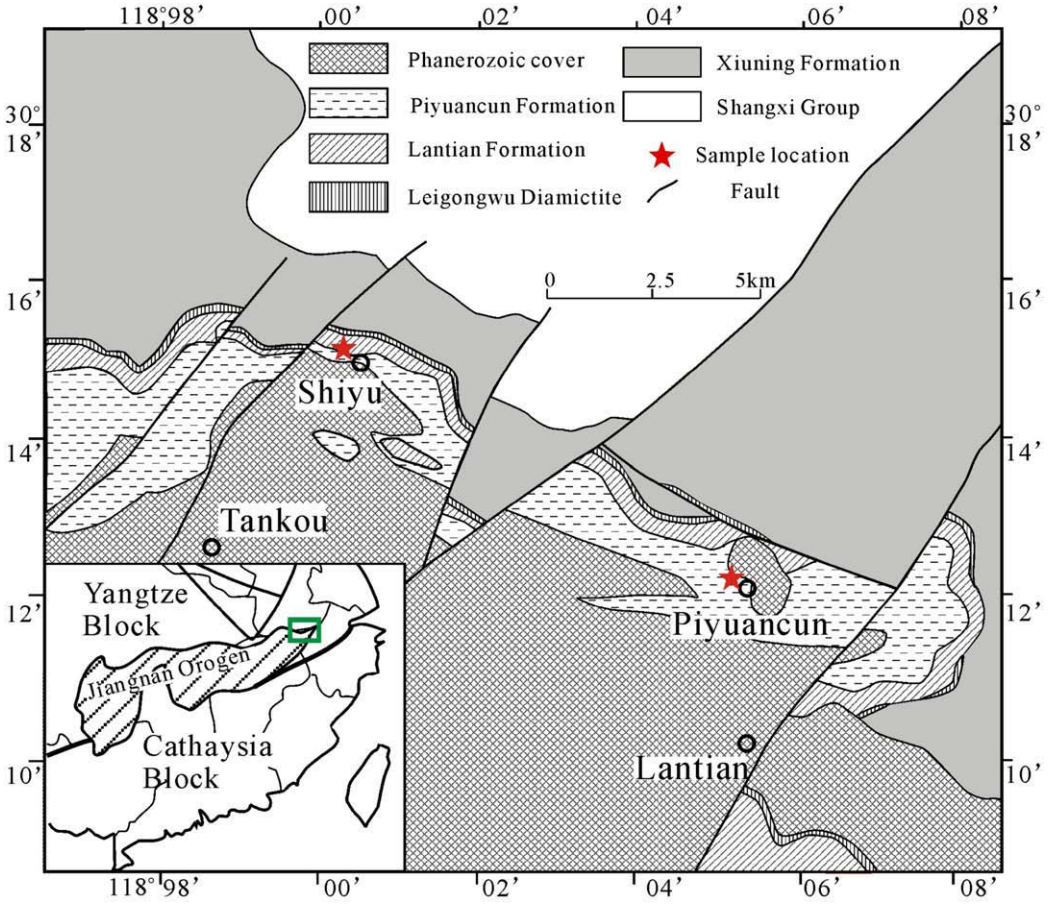

Fig. 1. Simplified geological map showing the occurrence of Late Neoproterozoic sedimentary rocks in southern Anhui (inset) between the Yangtze and Cathaysia Blocks in South China. Star denotes the sample locality.