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Climatic and environmental indications of carbon and oxygen isotopes from the Lower Cretaceous calcrete and lacustrine carbonates in Southeast and Northwest China

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ABSTRACT

Carbon and oxygen isotopic ratios were determined from ~100 Lower Cretaceous samples from four carbonate-bearing facies in Southeast (SE) and Northwest (NW) China for palaeoclimatic and palaeoenvironmental analyses. The samples were interpreted as sediments within sublithofacies of distal alluvial ponds (SF1), open shallow lakes (SF2), littoral lakes (SF3), and marshes (SF4). Results of analyses show in SE China, $\delta^{13}C$ values range between −5.0‰ and 3.0‰ with a negative trend through time, and $\delta^{18}O$ values are all negative (−19.3‰–−7.4‰); in NW China, $\delta^{13}C$ values range from −4.0‰ to 4.0‰ with periodic change, and $\delta^{18}O$ values range between −18.0‰ and 1.5‰.

Both relatively heavy values and pronounced covariances of most $\delta^{13}C$ and $\delta^{18}O$ indicate semiarid climate and domination of closed brackish lakes, marshes, and ponds in NW and SE China during the Early Cretaceous. Of them, positive $\delta^{13}C$ (0.0‰ to 4.0‰) and relatively heavy $\delta^{18}O$ (−5.0‰ to 1.5‰) values suggest interruptions of arid-evaporation in intermittences of the early Hauterivian in SW Fujian, of the middle Aptian in West Jiuquan basin, of the late Aptian in SW Ordos basin, and of the late Aptian–early Albian in Liupanshan basin. In a short interval of the early Aptian, the hot and humid climate occurred in local SW Zhejiang by high kaolinite content and in West Jiuquan basin by warm flora could be an exception. Particularly, extremely negative $\delta^{18}O$ values (mainly −19.0–−9.0‰) indicate relatively low temperature in SE Fujian in the Berriasian–Barremian, in Liupanshan basin in the late Aptian, in SW Ordos basin in the late Albian, and in West Jiuquan basin in the mid-late Aptian, which is supposed to attribute to the presence of 2500 m–4500 m in elevation. More positive values and more covariance ratios of $\delta^{13}C$ and $\delta^{18}O$ in NW China than in SE China and in mainland China than in America indicate a arider climate in former than in later, probably attributing to the palaeogeography in distance to sea.

A tentative correlation of the Early Cretaceous $\delta^{13}C$ value excursion of calcretes shows a good compatibility between marine OAEs and terrestrial carbonate sediments and between NW China and America continents, implying a global response to carbon cycle in both marine and terrestrial environments. The feature suggests the potential of global correlation and application of terrestrial calcrete $\delta^{13}C$ excursions in pre-Cenozoic.

1. Introduction

Interest in palustrine, alluvial, and pedogenic calcretes and lacustrine carbonates has increased over the last 30 years (e.g., Dan, 1977; Adams, 1980; Arakel and McConchie, 1982; Freytet and Plaziat, 1982; Goudie, 1983; Platt, 1989; Cerling and Quade, 1993; Armenteros et al., 1997; Khadkikar et al., 1998; Alonso-Zarza, 2003; Wright, 2007; Ludvigson et al., 2010), because these materials have been shown to contain significant clues to the climatic and environmental conditions at the time of their formation. Using these materials, many studies have been performed to reconstruct the changes of climate and environment through the Cenozoic (e.g., Read, 1974; Braithwaite, 1983; Mack and James, 1992; Alam et al., 1997; Armenteros et al., 1997; Alonso-Zarza and Calvo, 2000; Armenteros and Huerta, 2006; Khalaf and Gaber, 2008) and the pre-Cenozoic (e.g., Adams, 1980; Freytet and Plaziat, 1982; Platt, 1989; Spötl and Wright, 1992; Wright et al., 1995; Freytet et al., 1997; Dunagan and Driese, 1999; Dunagan and Turner, 2004; Gulbranson, 2004; Ludvigson et al., 2010; Alonso-Zarza et al., 2011). Though for the formation of calcretes and palustrine carbonates, sedimentary, pedogenic, and diagenetic processes must

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interact (Alonso-Zarza, 2003), they have been widespread used to reconstruct the palaeoclimate and palaeoenvironment when the processes little change the stable isotope compositions of the materials.

Geochemical analyses have been applied in previous studies to assess the ancient terrestrial environment and climate. Analyses of carbon and oxygen isotope excursions have been ongoing as early as the viewable study for the materials (e.g., Salomons et al., 1978; Talma and Netterberg, 1983; Salomons and Mook, 1986). The compositions of the stable isotope have provided suitable tools for obtaining information on climate, vegetation, hydrology, lake water chemistry, and for the influence of pedogenic/diagenetic processes, and they have proven to be useful in the reconstruction of palaeoclimate and in the interpretation of the terrestrial palaeoenvironment (e.g., Talma and Netterberg, 1983; Cerling, 1984; Budd et al., 2002; Gulbranson, 2004), palaeovegetation (Cerling et al., 1989, 1997; Khadkikar et al., 2000), and the concentration of atmospheric CO_2 (e.g., Cerling, 1991; Cole and Monger, 1994; Nordt et al., 2002; Retallack, 2005; Breecker et al., 2010; Hong and Lee, 2012). It has been evident that stable isotope data from palustrine carbonates and calcretes are particularly useful in the reconstruction of ancient environments and climates (Alonso-Zarza, 2003).

The correlation of $\delta^{13}C$ excursions has been performed in global marine sediments, and especially in the identification of oceanic anoxic events (OAEs) (Jenkyns, 1980) in the Cretaceous records, but this technique has not been widely used within continental sediments. Recent tentative correlations of $\delta^{13}C$ excursions between marine and continental environments (Cojan et al., 2000; Heimhofer et al., 2003; Magioncalda et al., 2004; Ludvigson et al., 2010) are intriguing. As Ludvigson et al. (2010) noted, the identification of the global Early Cretaceous (Aptian–Albian) $\delta^{13}C$ excursions in purely continental strata opens a new avenue of research by identifying specific stratigraphic intervals that record the terrestrial palaeoclimatic impacts of perturbations of the global carbon cycle (Dumitrescu et al., 2006; Ando et al., 2008). Herein we would like to say that this would open to those that have good carbonate-bearing records in the Cretaceous terrestrial environment.

Unfortunately, the reconstruction of the Cretaceous terrestrial climate and environment and the correlation of $\delta^{13}C$ excursions from calcrete and palustrine carbonates have been largely limited to Euramerica, Africa, and the polar regions. Few studies have been conducted in East Asia, where the Cretaceous continental sediments are widespread, and the carbonate-bearing materials are likely to have been preserved. In this study, we performed carbon and oxygen isotope analyses using two types of terrestrial materials, non-pedogenic calcrete and lacustrine carbonates in SE China and NW China, to reconstruct the terrestrial climate and environmental changes of the Early Cretaceous, and to correlate the $\delta^{13}C$ excursions of concretions between Asia and North America.

2. Geological setting

A number of the middle-late Mesozoic continental sedimentary basins were formed by tectonic extension and flexing in East and SE Asia (e.g., Liu, 1982; Ren, 1990; Okada, 1999; Shu et al., 2008, 2009), and they are classified into rifts/extensional basins, flexural basins and transitional basins (Chen and Dickinson, 1986; Watson et al., 1987).

In SE China, the evolution of the Mesozoic sedimentary basins is subdivided into three stages: the formation of the para-foreland basin from the Late Triassic to the Early Jurassic period, the formation of the rift basin during the Middle Jurassic period, and the formation of a faulting depression basin from the Late Jurassic through the Cretaceous (partly extended to the Palaeogene) (Shu et al., 2008, 2009). Among these basins, the Cretaceous faulting depression basin is more widespread than the others.

Moving from east to west in SE China, the continental Cretaceous sedimentary basins are dominated by volcanic rocks, passing to sediments interbedded with volcanic rocks, and to predominantly sediment (e.g., Li et al., 1987; Lu et al., 2000; Chen et al., 2005; Shu et al., 2009). The Cretaceous sequences with interbedded volcanic and sedimentary rocks (Fig. 1B) were chosen as a research target because they offer the best opportunity to more closely determine the age of the samples, even though the basins are relatively small in size (Ren and Chen, 1989; Yu et al., 2003).

In NW China, the Mesozoic sedimentary basins are dominated by flexural basins, but to the east, the Ordos basin, Liupanshan basin, and the Jiuquan basin, are rift basins.

The composite Ordos basin was constructed on a basement of pre-Cambrian metamorphic rocks, and it comprises three sediment packages: the lower is marine Cambrian–Ordovician, the middle is alternating marine and continental Carboniferous–Triassic, and the upper is continental Jurassic–Tertiary. The later package is extensional/rift (e.g., Chen and Dickinson, 1986; Watson et al., 1987; Okada, 1999). Aeolian facies is widespread over the basin in the Cretaceous, and lacustrine facies are dominant in the southwest.

The Liupanshan basin, southwest to the Ordos basin (Fig. 1C), was formed in the Late Triassic. It is a relatively small and simple depression basin (Zhao, 1990), also known as a pull-apart basin (Watson et al., 1987), that is mainly filled with lacustrine–palustrine and fluvial facies.

The Jiuquan basin lies between the Altyn strike-slip fault and the Qianlianshan orogenic belt (Fig. 1D), and therefore, it was long thought to be a flexing basin. However, oil and gas exploration revealed that it is extensional, and that it is either a pull-apart basin (e.g., Watson et al., 1987; Xie, 1993) or a half-graben/rift confined by S–N faults (e.g., Li, 2003; Li et al., 2006) and filled by facies of fluvial, alluvial fan, lacustrine, and delta (Fu et al., 2003).

3. Stratigraphy

In most of mainland China, the continental Cretaceous strata are difficult to subdivide into stages either because of limitations to the dating of samples of continental spores and pollens, bivalves, plants, ostracods, conchostracans, and some vertebrates, or because of a lack of fossils. The Lower Cretaceous strata are summarised in Table 1 based on former stratigraphic studies and recent U–Pb isotope dating of single zircons from volcanic rocks, and the lithostratigraphic units are introduced as five stratigraphic regions/basins described below.

3.1. SW Zhejiang basins

In SW Zhejiang, the Cretaceous comprises the basins in medium and small size. Among these, the Jinhua–Quzhou basin is relatively large. The Cretaceous stratigraphic system was basically established within this basin. According to prior palaeontological studies of plants, spores, bivalves, and ostracods (e.g., Cao, 1986; Zheng, 1993; Shou, 1995; Zhejiang BGM, 1996; Chen et al., 2006), as well as the volcanic rock and mineral isotope chronology (Li et al., 1987; Li et al., 2011), the Lower Cretaceous is upwardly divided as three groups (Gr): Jiande Gr, Yongkang Gr, and Qujiang Gr, respectively (Table 1).

Four formations comprise the Jiande Group, upward being the Laocun, Huangjian, Shouchang, and Hengshan formations in past (e.g. Zhejiang BGM, 1996; Chen, 2000), and the sequence of the formations was adjusted in Table 1 using volcanic single zircon U–Pb isotope chronology (Li et al., 2011). The Laocun Formation (Fm) is composed of dark-purple muddy siltstone, sandstone and mudrock intercalated/interbedded with tuff and rhyolite with a few fossils of gastropods, ostracods, insects, and plants (e.g., *Cladophlebis* sp.) within mudrocks, and it is dominated by conglomerate in the lower part. This formation is recently revised as the Hauterivian–Barremian age by zircon U–Pb isotope dating (Li et al., 2011). The volcanic Huangjian Fm spans the Aptian age, although it is beyond the scope of this research. The Shouchang Fm is variegated tuffaceous sandstone and shale with two layers of volcanic rocks in the middle and upper part. Some fossils of