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Lacustrine sedimentary record of early Aptian carbon cycle perturbation in western Liaoning, China

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ABSTRACT

The early Aptian abrupt carbon isotope excursion in marine carbonate and sedimentary organic matter reflects a major perturbation in the global carbon cycle. However, until now almost all the evidences of this event came from marine deposits. Here we present organic-carbon isotope ($\delta^{13}C_{org}$) data from the non-marine Jehol Group in western Liaoning, China. The lacustrine $\delta^{13}C_{org}$ curve is marked by a relative long-lasting $\delta^{13}C_{org}$ minimum followed by two stages of positive $\delta^{13}C_{org}$ excursions that are well correlated with contemporaneous marine records. The carbon isotope correlation shows that the lacustrine strata of the Jehol Group were deposited at the same time of the early Aptian Oceanic Anoxic Event (OAE1a). The relative long-lasting $\delta^{13}C_{org}$ minimum supports the hypothesis that volcanic CO_2 emission may have played the main role in triggering the negative $\delta^{13}C$ excursion and global warming at the onset of this event. In addition, the onset of $\delta^{13}C_{org}$ minimum is concomitant with the radiation of the Jehol Biota, implying that the evolutionary radiation of the Jehol Biota may have been closely related with the increase in atmospheric CO_2 and temperature.

1. Introduction

The early Aptian is characterized by dramatic fluctuations in the carbon isotope ($\delta^{13}C$) records of marine carbonates and sedimentary organic matter. It is marked by a positive $\delta^{13}C$ excursion that is preceded by a pronounced negative $\delta^{13}C$ excursion (Menegatti et al., 1998). This carbon isotope excursion has been identified in marine deposits at various localities around the globe and is thought to reflect globally significant perturbations in the carbon cycle (e.g. Bellanca et al., 2002; van Breugel et al., 2007; Dumitrescu & Brassell, 2006; de Gea, Castro, Aguado, Ruiz-Ortiz, & Company, 2003; Kuhnt, Holbourn, & Moullade, 2011; Luciani, Cobianchi, & Jenkyns, 2001; Millán, Weissert, Fernández-Mendiola, & García-Mondéjar, 2009; Stein et al., 2011; Weissert & Erba, 2004; Yamamoto et al., 2013). It triggered a series of environmental changes and bio-events, notably the Oceanic Anoxic Event 1a (Jenkyns, 1980, 2010; Schlanger & Jenkyns, 1976), the drowning of carbonate platforms (Föllmi, Godet, Bodin, & Linder, 2006; Föllmi, Weissert, Bisping, & Funk, 1994; Huck et al., 2010; Weissert, Lini, Föllmi, & Kuhn, 1998; Wissler, Funk, & Weissert, 2003), and the nannoconids crisis (Erba, 1994, 2004; Erba, Bottini, Weissert, & Keller, 2010; Larson & Erba, 1999; Millán et al., 2009). Given the global significance of the perturbations, their record is not only confined to marine carbonates and sedimentary organic matter but is also reported in terrestrial woody materials that are preserved in coastal or marine environments (Ando, Kakegawa, Takashima, & Saito, 2002; Gröcke, Hesselbo, & Jenkyns, 1999; Heimhofer, Hochuli, Burla, Andersen, & Weissert, 2003), and should extend to large and deep lakes (Jenkyns, 2010). However, this last environment has until now remained almost unexplored except for the $\delta^{13}C$ records from Xiagou Formation, NW China (Suarez, Ludvigson, González, Al-Suwaidi, & You, 2013). The lacustrine Jehol Group in western Liaoning, northeastern China may be another case in point. Recent radiometric dating and palaeomagnetic correlations show that these lacustrine strata cover the interval of the early Aptian carbon cycle perturbation event (e.g. Chang, Zhang, Renne, & Fang, 2009; He et al., 2004; Smith et al., 1995; Swisher, Wang, Wang, Xu, & Wang, 1999; Yang, Li, & Jiang, 2007; Zhu, Pan, Shi, Liu, & Li, 2007). More important, the lacustrine deposits of Jehol Group recorded the most important and largest radiation of the Jehol Biota (the second phase of Jehol radiation) involving dinosaurs, birds,

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pterosaurs, mammals, and early angiosperms (Zhou, 2006; Zhou, Barrett, & Hilton, 2003). Furthermore, the organic constituent of the lacustrine deposits is characterized by low thermal alteration which suggests primary $\delta^{13}C_{org}$ compositions (Li, Song, Zou, Wang, & Ji, 2008) and presents a unique opportunity to explore the early Aptian global carbon cycle from a lacustrine perspective and its impact on Jehol ecosystem in northeastern China.

2. Geological settings

The western Liaoning area occupied a palaeolatitude of approximately 40–45° N during the late Mesozoic (Zhou et al., 2003, Fig. 1A). In the Early Cretaceous, a series of basins and lakes were formed in western Liaoning due to increased tectonic and magmatic activity. The lacustrine sedimentary strata formed by these lakes are called Jehol Group (Gu, 1962). The Jehol Group consists of, in ascending order, the Yixian, Jiufotang, and Fuxin Formations (Sha, 2007). The Yixian and Jiufotang formations outcrop well in Yixian and Beipiao counties. The Jiufotang Formation conformably overlies the Yixian Formation. The Yixian Formation is mainly composed of lava flows, igneous intrusions, and several siliciclastic lacustrine sedimentary beds. The upper most and lower most lacustrine bed of Yixian Formation are Jingangshan Bed and Jianshangou Bed respectively (Chen et al., 2005). Dakangpu Bed and Zhuanchengzi Bed represent the lacustrine beds which were deposited in the middle part of the Yixian Formation though the relative position of these two beds is still in dispute (Chen et al., 2005; Zhao et al., 2010). The Jiufotang Formation is mainly composed of siliciclastic lacustrine deposits. Recent radiometric dates and palaeomagnetic correlations show that the Yixian and Jiufotang formations were deposited during the late Barremian to early Aptian (e.g. Chang et al., 2009; He et al., 2004; Smith et al., 1995; Swisher et al., 1999; Yang et al., 2007; Zhu et al., 2007). In addition, the lacustrine deposits of Yixian and Jiufotang formations have yielded a huge variety of well-preserved fossils of Jehol Biota, which includes plants, insects, conchostracans, ostracods, shrimps, bivalves, gastropods, fishes, amphibians, reptiles, birds, non-avian dinosaurs, and mammals (e.g. Chang, Chen, Wang, Wang, & Miao, 2003; Sha, 2007; Zhou et al., 2003).

3. Material and methods

Black shale and mudstone are the dominant lithology of lacustrine sedimentary beds of the Yixian and Jiufotang formations in Yixian and Beipiao area (Figs. 2 and 3A). A total of 76 black shale and mudstone samples were collected from the outcrops. Samples from the Yixian Formation were collected at Sihetun (Jianshangou Bed), Wangjiagou (Dakangpu Bed), and Zaocishan (Jingangshan Bed) (Fig. 1C). Samples from the Jiufotang Formation were collected at Pijiagou (Fig. 1C). The rock samples were cut and polished to remove all visible signs of superficial alteration and veins and then ground to powder with a mortar and pestle. The powdered samples

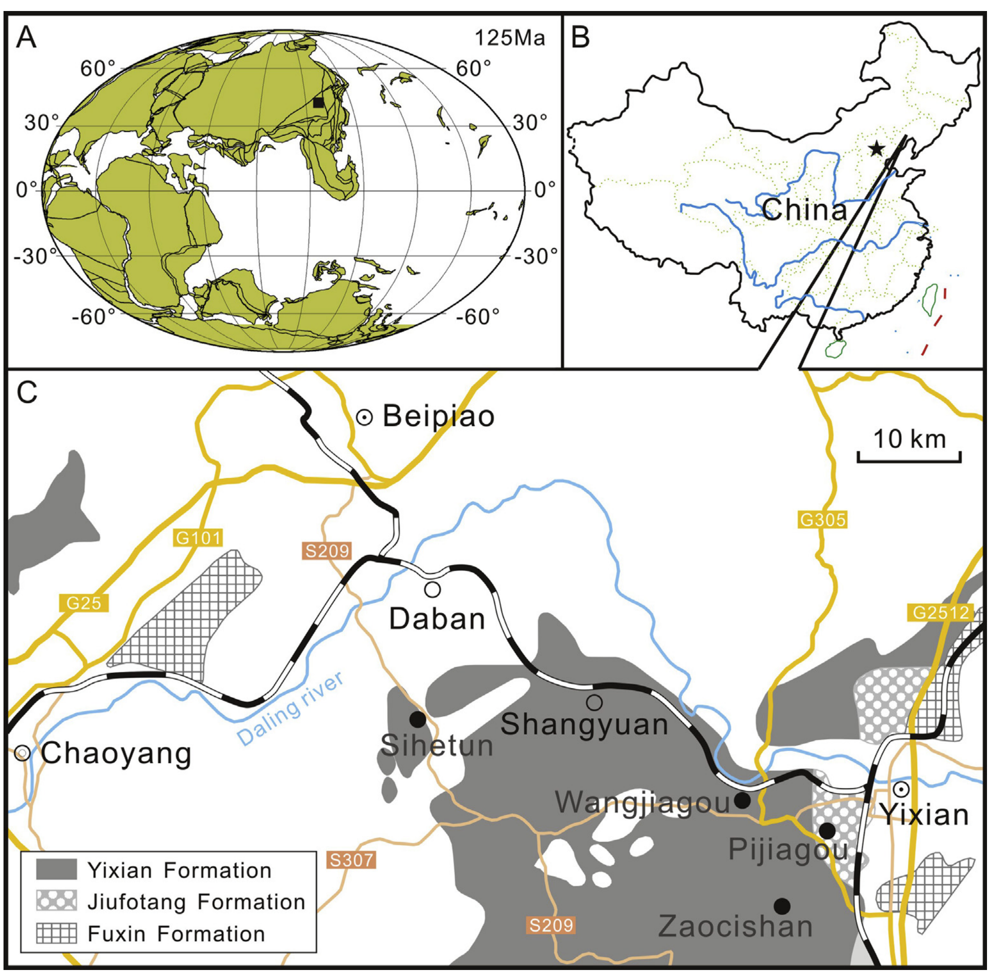

Fig. 1. A) Palaeogeographic position of the studied area (black square), the palaeogeographic map is downloaded from the www.odsn.de website; B) Geographic position of the studied area; C) Geographic distribution of the Jehol Group and location of the studied sections (black circle).