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Biogeochemical changes across the Ediacaran–Cambrian transition in South China

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ABSTRACT

The late Neoproterozoic successions of South China comprise some of the most complete and well-preserved records of the Ediacaran–Cambrian transition. The articles in this special issue provide a snapshot of ongoing research that is helping us to understand early stages in the development of the modern Earth system. These studies illustrate the transitional character of the Ediacaran–Cambrian interval from the evolution and early extinctions of the first bilaterian metazoans during the Ediacaran Period to their dominance of pelagic and benthic realms by the end of the early Cambrian. Geochemical data reveal a noisy transition of increasing baseline $\delta^{13}C$ values punctuated by extreme isotopic oscillations. It is evident that highly negative $\delta^{13}C$ values and large amplitude $\delta^{13}C$ swings ceased once modern marine ecosystems had become firmly established by ~520 Ma. We postulate that sub-surface bioturbation helped to strengthen the relationship between benthic oxidation state and P-retention, thus tightening an important negative feedback that helps to stabilize productivity, climate and oxygen levels in the modern Earth system. The disappearance of negative excursions after ~520 Ma might also suggest a key role for methanogenesis which would have declined following the rise of in-sediment sulphur cycling due to bioturbation. Further insight into this fascinating interval is needed before we can disentangle the complex interactions between biological evolution and biogeochemical cycling during the emergence of the modern Earth system.

1. Introduction

Over the past decade, our understanding of the events leading up to the expansion and diversification of animal life has improved dramatically. As a result, we know that early animal evolution was accompanied by extraordinary perturbations to climate, carbon cycling, chemical weathering and tectonics as well as changes to the composition of the atmosphere and oceans. Fossil finds and geochemical data from well preserved marine successions of the South China (Yangtze) Craton have fueled much of this progress, and include the first convincing fossilized animals (Xiao et al., 1998); the first putative bilaterian fossils (e.g. herein); the first evidence for predation on animals (Hua et al., 2005); and one of the most complete bio- and chemo-stratigraphic archives of the Ediacaran Period (Zhu, 2010). The contributions in this special issue were solicited to bring the reader up-to-date with recent developments concerning the biostratigraphy, chemostratigraphy and facies evolution through this key interval in South China.

Armed with this new information, as well as recently published data from elsewhere in the world, we can begin to discuss the role that early animals played in tightening and accelerating the stabilizing, negative feedbacks which define the modern Earth system. During the Ediacaran–Cambrian transition, complex interactions between biological evolution and the surface environment led to a reorganization of biogeochemical cycling that was to lead to the long-term stability of Earth's climate and atmospheric composition during the rest of the Phanerozoic Eon.

2. Advances in Ediacaran–Cambrian biostratigraphy and palaeobiology

The lower Ediacaran fossil record is characterized worldwide by a group of relatively large acanthomorphic (spiny) acritarchs (LSA's). On the South China craton, such acritarchs first appear in strata of the lower Doushantuo Formation dated to about 630 Ma (Yin et al., 2007). However, in Australia, lowermost Ediacaran acritarchs are of the simple leiosphere type with large spiny varieties appearing only in strata deposited after the

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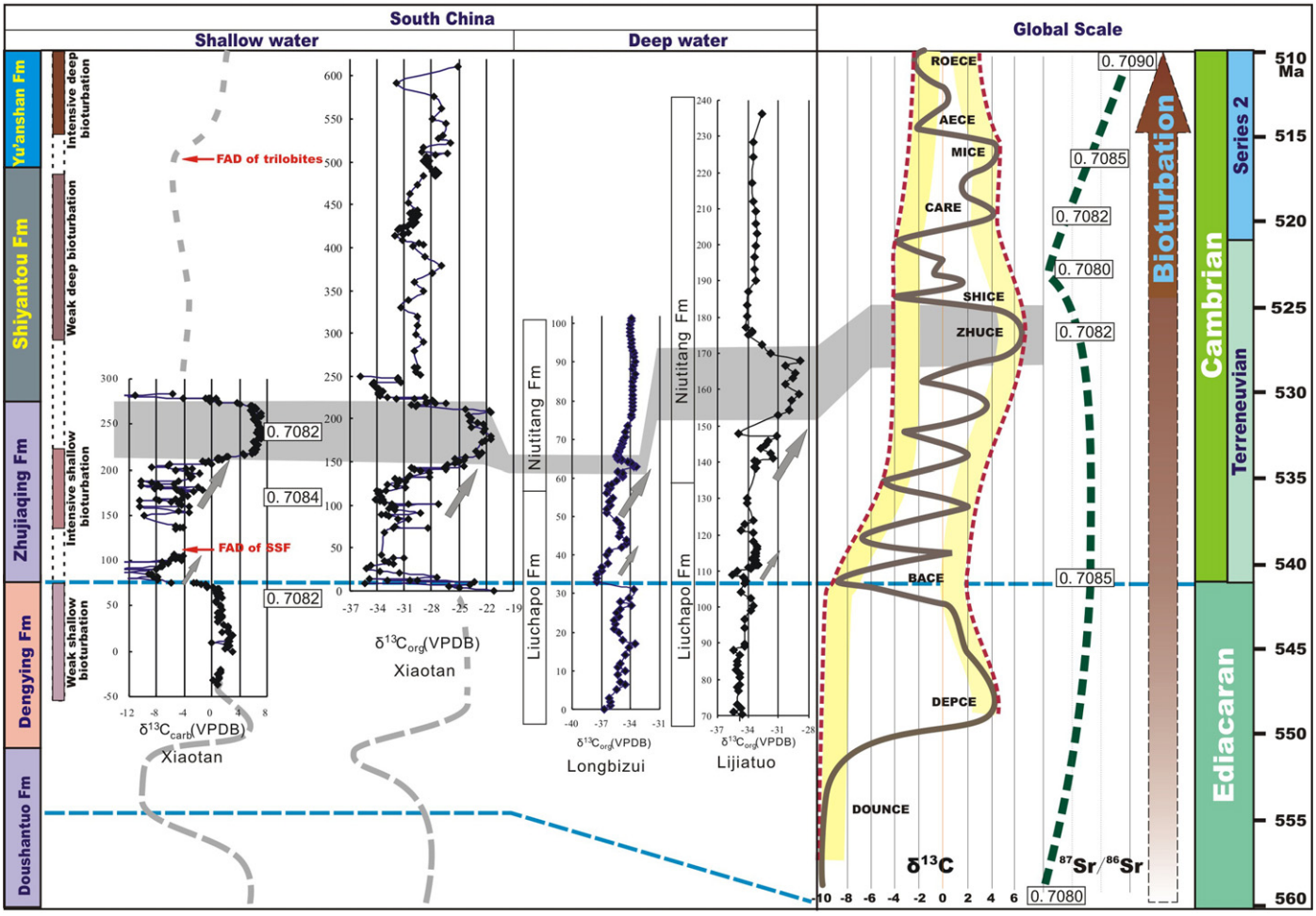

Fig. 1. Integrated stratigraphic record of the Ediacaran–Cambrian transition in South China (compiled from data in this special issue), unpublished qualitative bioturbation data from the Xiaotan section, NE Yunnan, and global carbon isotope curves (Zhu, 2010; Maloof et al., 2010). Note decrease in amplitude of $\delta^{13}C$ excursions, and increasing baseline $\delta^{13}C$ values through the transition in China and worldwide.

"Acraman" meteorite impact (Grey et al., 2003). Whether the abrupt appearance of LSAs in Australia marks evolutionary diversification following extinction (Grey et al., 2003), an opportunistic invasion of LSAs from elsewhere or merely a taphonomic artifact has remained uncertain. New data provided by Liu et al. add robust evidence to this debate.

It is difficult to separate evolutionary from taphonomic phenomena in Precambrian acritarch studies because of the various ways in which acritarchs can be preserved in the rock record. Indeed, acritarch biozones had until recently only been recognized from acid-maceration studies of drill-core samples in Australia (Grey, 2005). Vorob'eva et al. (2009) were the first to recognize Neoproterozoic acritarch biozones outside Australia with three assemblages from the Vychedga Formation in NE Baltica, the upper two of which are considered to be Ediacaran in age. Intriguingly, the middle and upper assemblages resembled Grey's zones (1) and (2–5), respectively.

Liu et al. also find two distinct acritarch assemblages, which they refer to Grey's zones (1) and (2–5) based on taxonomic similarities. The lower zone is dominated by *Tianzhushania spinosa*, specimens of which have been interpreted as the diapause cysts of animal embryos (Yin et al., 2007) and so may represent the oldest fossil evidence for animal life. The upper zone, characterized by the *Tanarium anozos–Tanarium conoideum* assemblage, shares a number of species with the Ediacaran complex acritarch palynoflora (ECAP) from Australia. Interestingly, the two assemblages are separated and bracketed in South China by negative $\delta^{13}C$ excursions.

The last of these, the DOUNCE, can be correlated with the global 'Shuram-Wonoka' excursion, which heralds the extinction of Ediacaran LSA"s worldwide (Fig. 1).

The Doushantuo Formation is also well known for the presence of phosphatised animal embryos (Xiao et al., 1998), which are sometimes found contained within LSAs (Yin et al., 2007). Although the presence of true animals among these early Ediacaran microfossils is disputed (e.g. Huldtgren et al., 2011; Xiao et al., 2012), two articles in this issue present additional evidence for a metazoan, and possibly even bilaterian heritage. Firstly, Petryshyn et al. describe new specimens of the putative bilaterian *Vernanimalcula guizhouena* (Chen et al., 2004). Their careful measurements support the case for a biological origin for the supposedly bilaterian features of these fossils and call for further study. In the same issue, Yin et al. report an exhaustive series of scanning electronic microscopy (SEM) and state-of-the-art propagation phase contrast synchrotron X-ray microtomography (PPC-SR-μCT) analyses. Their demonstration of polar lobes in the Doushantuo embryos supports the presence of bilaterian embryos in the Doushantuo phosphorite and illustrates the conservative nature of some aspects of bilaterian embryonic development.

Subsequent metazoan biodiversification can also be traced in South China where the small shelly fossil (SSF) record is of global import. The Dengying Formation that overlies the Doushantuo