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PALAEO
Palaeogeography, Palaeoclimatology, Palaeoecology 254 (2007) 7 – 61
www.elsevier.com/locate/palaeo

Integrated Ediacaran (Sinian) chronostratigraphy of South China

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Accepted 5 March 2007

Abstract

The Ediacaran Period was a critical time in the history of life and Earth. Understanding the complex interactions between geological and biological events during this interval requires high-resolution chronostratigraphy. Thanks to its uniquely favorable palaeogeographic setting, South China is an ideal region for constructing a framework for global chronostratigraphic correlation of Ediacaran strata. Here, continuous Ediacaran successions contain both siliciclastic and carbonate rocks that range from shallow to deep marine and contain rich fossil assemblages showing a variety of preservation styles. As part of the present study, 62 reference sections distributed throughout the Yangtze Platform were investigated. Analyses of the sedimentary facies and sequence stratigraphy of more than 40 sections revealed four major sequences in the shallow marine facies. Three major sequence boundaries occur respectively in the middle and upper parts of the Doushantuo Formation and in the middle part of the Dengying Formation. Subdivision and correlation of the Ediacaran successions of the Yangtze Platform based on sequence stratigraphy is congruent with the carbon isotope chemostratigraphy of 12 reference sections (1075 samples). The sequence boundary (SB2) in the middle part of the Doushantuo Formation is suggested here as the Lower (Xiadongian)/Upper (Yangtzean) series boundary of the Ediacaran which coincides with several globally recognizable events, namely 1) the end of the Neoproterozoic glaciations, 2) the first appearance of animals, 3) the sudden increase in the diversity of acanthomorphic acritarchs, and 4) a negative $\delta^{13}C$ excursion. The Ediacaran System of South China may be subdivided into five stages. Furthermore, the criteria for defining these stages may be applicable throughout the world. Also, the composite carbon isotope profile of the Ediacaran of South China can be used as a global reference for chronostratigraphic subdivision and correlation. In addition to the globally recognizable, negative $\delta^{13}C$ excursion in the cap carbonate at the base of the Ediacaran, the negative $\delta^{13}C$ excursion in the uppermost Doushantuo/Wonoka/Shuram interval represents another, globally correlatable major excursion. The positive $\delta^{13}C$ excursion immediately following the uppermost Doushantuo excursion and ending at 548 Ma is also useful for global correlation.

Current Ediacaran chronostratigraphy and global correlations indicate that the upper Doushantuo/Wonoka/Shuram negative $\delta^{13}C$ excursion ranges from ca. 560 Ma to 551 Ma, and therefore coincides with the evolutionary renovation of life. Feedback between evolutionary innovation and geochemical cycling was the key mechanism for this unique and most strongly negative $\delta^{13}C$ excursion in earth history. Our chronostratigraphic correlations also imply that the earliest known metazoan biotas, namely the Weng'an and characteristic Ediacaran biotas, do not constitute two temporally separate evolutionary lineages, as proposed previously, but represent two parallel evolutionary pathways preceding the Cambrian explosion of animal life.

Keywords: Stratigraphy; Chemostratigraphy; Sequence stratigraphy; Carbon isotopes; Palaeogeography; Neoproterozoic; Ediacaran; Sinian; South China

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doi:10.1016/j.palaeo.2007.03.025

1. Introduction

The newly erected Ediacaran System spans a critical transitional interval in the history of our planet (Knoll et al., 2004, 2006). It follows a global ice age of the Cryogenian Period and ends at the abrupt emergence of Cambrian animals at the beginning of the Phanerozoic Eon. During the Ediacaran Period, Earth's environment was strongly influenced by global tectonic events. Ediacaran rocks record dramatic changes in the composition of seawater and the atmosphere. Geochemical analyses have revealed 1) an increase in oxygen levels (Canfield and Taske, 1996; Catling and Claire, 2005; Kennedy et al., 2006); 2) large excursions in the stable isotopic compositions of carbon (Knoll et al., 1986; Kaufman and Knoll, 1995; Shields, 1999), sulfur (Strauss, 1999; Strauss et al., 2001), and strontium (Jacobsen and Kaufman, 1999) in seawater; and 3) abrupt shifts in the Ca/Mg and other ionic ratios in seawater (e.g. Hardie, 2003; Demicco et al., 2005; Kovalevych et al., 2006; Stanley, 2006). There was even a widespread glaciation event within the Ediacaran, at about 580 Ma (Gaskiers; Eyles and Eyles, 1989; Bowring et al., 2003), and the formation of a possible supercontinent, "Pannotia", at the end of the period (see Meert and Lieberman, 2004). But most importantly, Ediacaran strata contain the first signs of macroscopic life, including Ediacaran-type soft-bodied fossils, which have been found at about 25 localities distributed globally (see, Narbonne, 2005; McCall, 2006 and references therein), megascopic carbonaceous algal compressions (e.g. Xiao et al., 2002), and trace fossils (e.g. Jenkins, 1995; Jensen, 2003). The unique character of this revolutionary period in the history of life has been further magnified by recent discoveries of phosphatized, microscopic multicellular algae and tubular and bilaterian animals in South China (Xiao et al., 1998, 2000; Chen et al., 2000, 2002a,b, 2004; Xiao et al., 2004; Chen et al., 2006), and the poorly mineralized, macroscopic tubular animal, *Cloudina* (Chen and Sun, 2001; Hua et al., 2005). Clearly, the unique history of the Ediacaran Period resulted from interactions between geological and biological processes. However, our understanding of these complex interactions and their influence on organic evolution remains unclear, in large part because fossil-bearing Ediacaran sequences were deposited in widely differing tectonic and environmental settings that have thus far resisted attempts at precise subdivision and time correlation (Knoll et al., 2006). Thus, the critical task of establishing a high resolution Ediacaran time scale has become the primary objective of the International Subcommission on Neoproterozoic Stratigraphy of the ICS. Although recent geochronological investigations have defined some important time levels (Hoffmann et al., 2004; Condon et al., 2005; Zhang et al., 2005), recognizing global criteria for further subdivision and correlation of Ediacaran rocks remains a problem of great urgency.

Unfortunately, biostratigraphy, the principle tool for subdivision and correlation of richly fossiliferous Phanerozoic strata, is of limited usefulness in developing a global time scale for the Ediacaran, owing mainly to low species diversity, taxonomic uncertainty, and the sporadic and endemic palaeogeographic distribution of Ediacaran fossils. Although characteristic Ediacaran-type fossils are reliable biostratigraphic indicators of an Ediacaran age (Jenkins, 1995), the pronounced non-synchroniety of their first and last appearances in different basins makes them useless for GSSP definitions. Only a handful of Ediacaran fossils, for example *Cloudina*, are distributed widely enough and range over a short enough time span to be used as biostratigraphic index fossils. The sporadic occurrences of other Ediacaran animal fossils, macroscopic algae, and trace fossils greatly limit their potential for biostratigraphy. And even if some of these taxa should prove useful in the near future, there is still another problem for Ediacaran biostratigraphy: the Ediacaran Period encompasses a very long interval, from the end of the Nantuo equivalent glaciation (635 Ma, Condon et al., 2005) to the beginning of the Cambrian (542 Ma, Amthor et al., 2003); however, Ediacaran-type fossils are generally limited to strata younger than 580 Ma (Condon et al., 2005). Microfossils, such as the globally distributed acritarchs, which are found throughout the Ediacaran System, may help to define some stratigraphic boundaries. For example, several acritarch assemblage zones have been recognized in Australia (Grey, 2005), but the global applicability of these biostratigraphic zones remains uncertain.

It appears then that chemo-, event, or sequence stratigraphic tools must be applied to subdivide and correlate Ediacaran successions. Zhu et al. (2005), for example, proposed that a mid-Ediacaran glaciation, possibly the third of the Neoproterozoic, divides the Ediacaran into two series. However, it is unclear whether the third Neoproterozoic glaciation is a globally recognizable event or even whether it ended synchronously in different regions. Sequence stratigraphy has proven useful for high resolution intrabasinal correlations (Christie-Blick et al., 1995; Jiang et al., 2002, 2003a,b; Pyle et al., 2004), but it is not a reliable tool for interbasinal chronostratigraphy without radiometric age constraints. Carbon isotope chemostratigraphy may also be a useful