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# Redox variations and organic matter accumulation on the Yangtze carbonate platform during Late Ediacaran–Early Cambrian: Constraints from petrology and geochemistry

Ping Gao [a,b], Guangdi Liu [a,b,*], Chengzao Jia [a,c], Allison Young [d], Zecheng Wang [c], Tongshan Wang [c], Pengwei Zhang [a,b], Dapeng Wang [a,e]

[a] State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum, Beijing 102249, China
[b] College of Geosciences, China University of Petroleum, Beijing 102249, China
[c] Research Institute of Petroleum Exploration & Development, PetroChina, Beijing 100083, China
[d] Department of Geology, University of Cincinnati, Cincinnati, OH 45221-0013, USA
[e] Petroleum Production and Research Institute of SINOPEC, Beijing 100083, China

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ABSTRACT

In order to understand redox variations and organic matter accumulation on the Yangtze carbonate platform during the Late Ediacaran–Early Cambrian, petrological and geochemical studies of several wells were carried out in this work. Our data suggest that depositional environments were dominated by oxidizing bottom water conditions during the late Ediacaran, and evolved to anoxic conditions, triggered by blooms of microbial organisms in surface waters during the earliest Cambrian. Subsequently, massive release of $H_2S$ derived from both anaerobic recycling of organic matter and, probably, hydrothermal venting promoted a sulfidic ocean. The discovery of a Ni-Mo sulfide ore layer in the basal Cambrian implies that such a sulfidic condition spread onto the Yangtze carbonate platform interior during the late Cambrian Stage 2. Further, transgressive flooding led to widespread black shale deposition and persistently anoxic conditions, as indicated by geochemical proxies. During the late Ediacaran to earliest Cambrian, local and widespread phosphogenesis indicates that organic matter accumulation was intimately associated with microbial (especially cyanobacterial) blooms driven by phosphorus cycling. The organic matter accumulations in early Cambrian black shales, however, were in connection with anoxic bottom water conditions and intermittent replenishment of recycled organic phosphorus to surface waters.



## 1. Introduction

The Ediacaran–Cambrian (E-C) transition is a critical interval in Earth's history characterized by global environmental and biological changes (Kimura and Watanabe, 2001; Steiner et al., 2001; Wang and Li, 2003; Guo et al., 2007a, 2007b). Several lines of evidence suggest that the rise of atmospheric oxygen levels may have facilitated widespread oxygenation of the deep oceans in the late Neoproterozoic and triggered the evolution of the Ediacaran Biota and the subsequent "Cambrian Explosion" (Canfield et al., 2007; Chen et al., 2015). However, numerous geochemical proxies show that intermittent euxinia in continental margin settings and anoxic/ferruginous deeper waters may have occurred during the terminal Ediacaran–Early Cambrian, particularly on the Yangtze Block of South China (Canfield et al., 2008; Pi et al., 2013; Wang et al., 2015). Recent geochemical investigations show that the Ediacaran oceans may have been highly stratified, and mid-depth euxinic waters may have dynamically developed along continental margins, sandwiched by oxic surface waters and ferruginous deep waters (Li et al., 2010). Such a marine redox structure may have extended toward the early Cambrian ocean. Feng et al. (2014) demonstrated that mid-depth euxinia over the margins of the Yangtze platform was expanded during a worldwide marine transgression in the early Cambrian but shrank gradually as a consequence of subsequent regression and widespread shelf oxygenation. Nevertheless, the details of redox conditions of the Late Ediacaran–Early Cambrian Ocean remain unclear at present.

Marine sedimentary rocks of E-C age are developed widely throughout the Yangtze Block. They record the oceanic environmental conditions during their formation and so provide a window to explore oceanic redox changes. Extensive studies on the remarkable biological, oceanic and geochemical changes across the E-C transition have been carried out where E-C successions are well exposed (Steiner et al., 2001; Guo et al., 2007a, 2007b; Goldberg et al., 2007; Och et al., 2013), but little attention has been paid to the Yangtze carbonate platform

* Corresponding author at: State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum, Beijing 102249, China. Tel.: +86 10 89734471.
*E-mail addresses:* lgd@cup.edu.cn (G. Liu), gaoping1212@hotmail.com (P. Gao).

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interior due to greater burial depths of the strata of interest, leading to much uncertainty in understanding oceanic environment changes in the global ocean as a whole.

Although deposition of organic-rich sediments in the Yangtze Block during the E-C transition has been extensively documented, the mechanisms that control organic matter (OM) enrichment remain debatable. Some authors have proposed that the OM enrichment in early Cambrian sediments had a close link to higher primary productivity driven by development of coastal upwelling and/or hydrothermal venting of nutrient-rich waters (Lehmann et al., 2007; Chen et al., 2009; Wang et al., 2015), whereas others have suggested that the anoxic conditions played a key role in OM preservation in black shales (Wu et al., 1999). Thus, organic-rich sediments deposited in the carbonate platform during the E-C transition may provide a useful example for exploring the mechanisms of OM accumulation.

In order to better constrain the oceanic redox variations and OM accumulation on the Yangtze carbonate platform interior during the E-C transition, a comprehensive integrated study based on petrological and geochemical data was carried out in this work.

## 2. Geological setting

During the E-C transition, the Yangtze Block evolved from a rift basin to a passive continental margin basin (Wang and Li, 2003), most of which accommodated the carbonate platform, surrounded by narrow marginal transitional zones to the north (~800 km long) and south-to-southwest (>1600 km long), along which shallow-water carbonates sharply change facies basinwards into black chert-shale successions (Chen et al., 2009). In the deep-water basin, a complete chert succession (Liuchapo Fm.) was deposited. Therefore, the Yangtze Block is usually composed of three main sedimentary facies, including shallow water carbonate facies in the platform interior, transitional facies, and deep water slope and basinal facies from the northwest to southeast (Fig. 1; Steiner et al., 2001; Chen et al., 2009).

The studied wells are located in the Sichuan Basin, a Mesozoic basin superimposed on the Yangtze Craton, situated palaeogeographically in the carbonate platform facies, which host a sedimentary succession of E-C age. The Ediacaran was divided into two series: Lower Ediacaran Doushantuo Formation (Fm.) and Upper Ediacaran Dengying Fm. U–Pb zircon dates from volcanic ash beds within the Doushantuo Fm. indicate that its deposition occurred between 635 and 551 Ma (Condon et al., 2005).

The age of the E-C boundary has been placed at 542 Ma (Shergold and Cooper, 2004). Within the last 9 million years of the Ediacaran Period, massive dolomite sediments of tidal-flat facies were deposited in the Dengying Fm. with thickness up to 800 m. The Dengying Fm. can be subdivided into four members, from bottom to top, based on degree of enrichment in algae and structural characteristics: the first (D1),

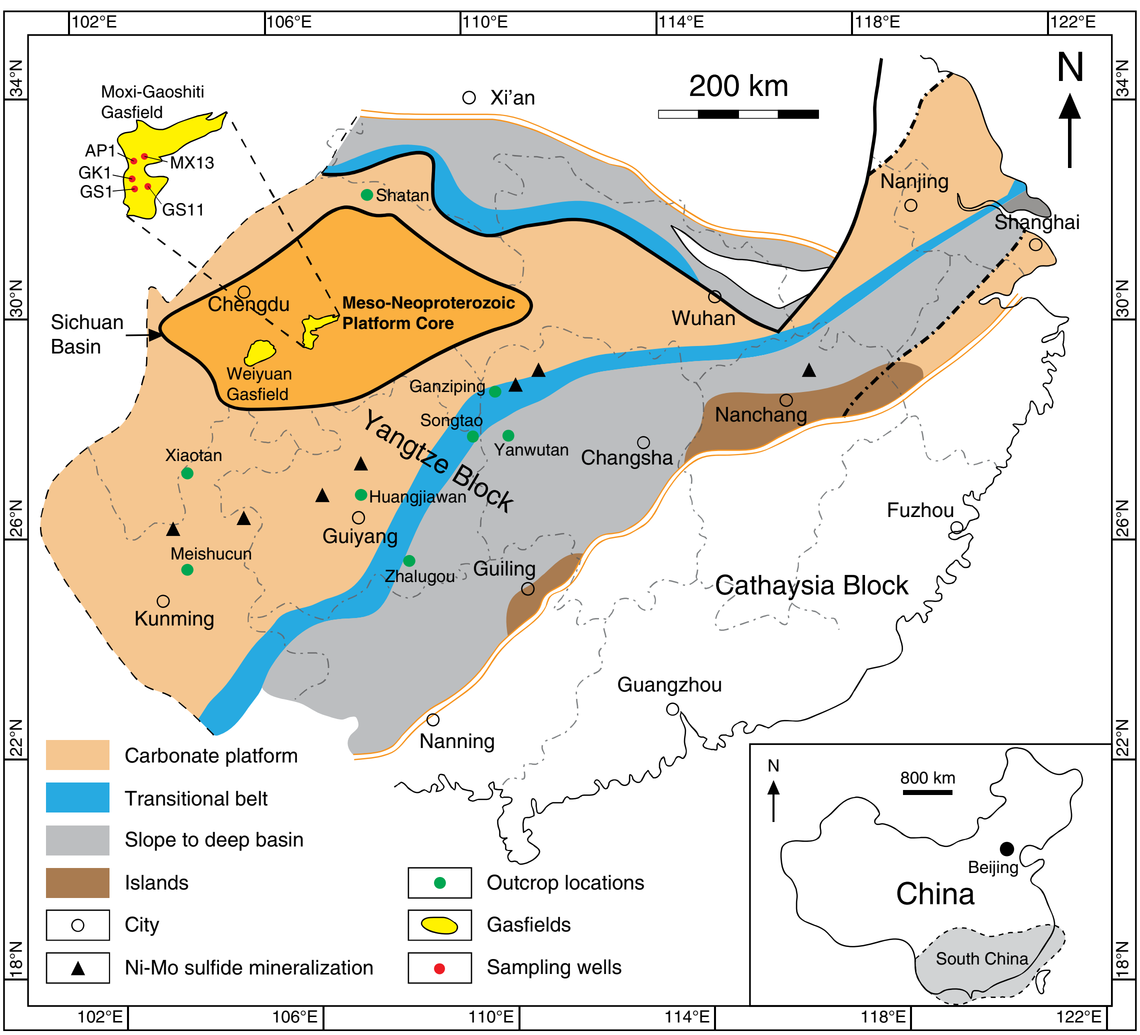


**Fig. 1.** Simplified paleogeographic map of the Yangtze Block during the E-C transition showing geological setting of the study area (modified after Chen et al., 2009; Steiner et al., 2001), distribution of Ni-Mo sulfide ores (Steiner et al., 2001; Křibek et al., 2007; Xu et al., 2013) and outcrops (Steiner et al., 2001; Guo et al., 2007a, 2007b; Goldberg et al., 2007; Och et al., 2013).