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Research paper

The geochemical characteristics and factors controlling the organic matter accumulation of the Late Ordovician-Early Silurian black shale in the Upper Yangtze Basin, South China

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ABSTRACT

Organic-rich black shale of the Upper Yangtze Basin from the Late Ordovician and Early Silurian is considered an excellent source rock in South China. The formation and preservation conditions of this resource are revealed by its geochemical characteristics in this study. Geochemical indices, including redox indices (V/(V + Ni), V/Cr, V/Sc, and Ni/Co) and primary productivity indices (P/Ti and Ba/Al), and paleoclimate, clastic flux and sedimentary rate analyses are presented to investigate the accumulation mechanism of organic matter. Redox indices suggest that a stagnant, anoxic environment predominated in the Upper Yangtze Basin during accumulation of Wufeng and Longmaxi formations. In contrast, ventilated and oxygenated marine conditions pervaded the Upper Yangtze Basin during deposition of Linxiang and Guanyinqiao formations. The concentrations of V and U demonstrate that accumulation of organic matter was mainly controlled by redox conditions. Besides, such factors as clastic fluxes, fresh water inflows or a mixed deposition with a rapid sedimentary rate cannot be ignored due to their influences on organic matter enrichment and preservation. However, weak co-variance relationship of TOC content and productivity proxies, including P/Ti and Ba/Al, demonstrates that the accumulation of organic matter was not controlled by primary productivity. Results of the present study suggest a depositional model that stresses the importance of tectonic movements and glacial events on the accumulation and preservation of organic matter. The model shows that the Upper Yangtze Basin was a semi-restricted basin system influenced by the isolation of Xuefeng, but also it implies that oxygen-depleted bottom water of the basin favored the accumulation and preservation of sedimentary organic matter, resulting in the formation of organic-rich black shale.

1. Introduction

The preservation of organic matter is a complex physical and chemical process, including primary productivity, bottom water oxygen supply, nutrient availability, clastic flux, and post-depositional degradation processes, such as bacterial sulfate reduction (Demaison and Moore, 1980; Pedersen and Calvert, 1990; Arthur and Sageman, 1994; Murphy et al., 2000; Sageman et al., 2003; Wei et al., 2012; Lash and Blood, 2014; Yan et al., 2014; Burdige, 2007; Hedges and Keil, 1995). However, the mechanisms of organic matter accumulation and preservation in black shale continue to be debated (Demaison and Moore, 1980; Murphy et al., 2000). The controversy focuses on whether the enrichment of organic matter is mainly controlled by the primary productivity (the organic carbon flux) (Caplan and Bustin, 1999; Gallego-Torres et al., 2007; Pedersen and Calvert, 1990; Sageman et al., 2003) or by conditions that favor the preservation of organic matter, an anoxic water column (Arthur and Sageman, 1994; Demaison and Moore, 1980; Mort et al., 2007). The preservation model favors the importance of dysoxia or anoxia in the bottom water as the

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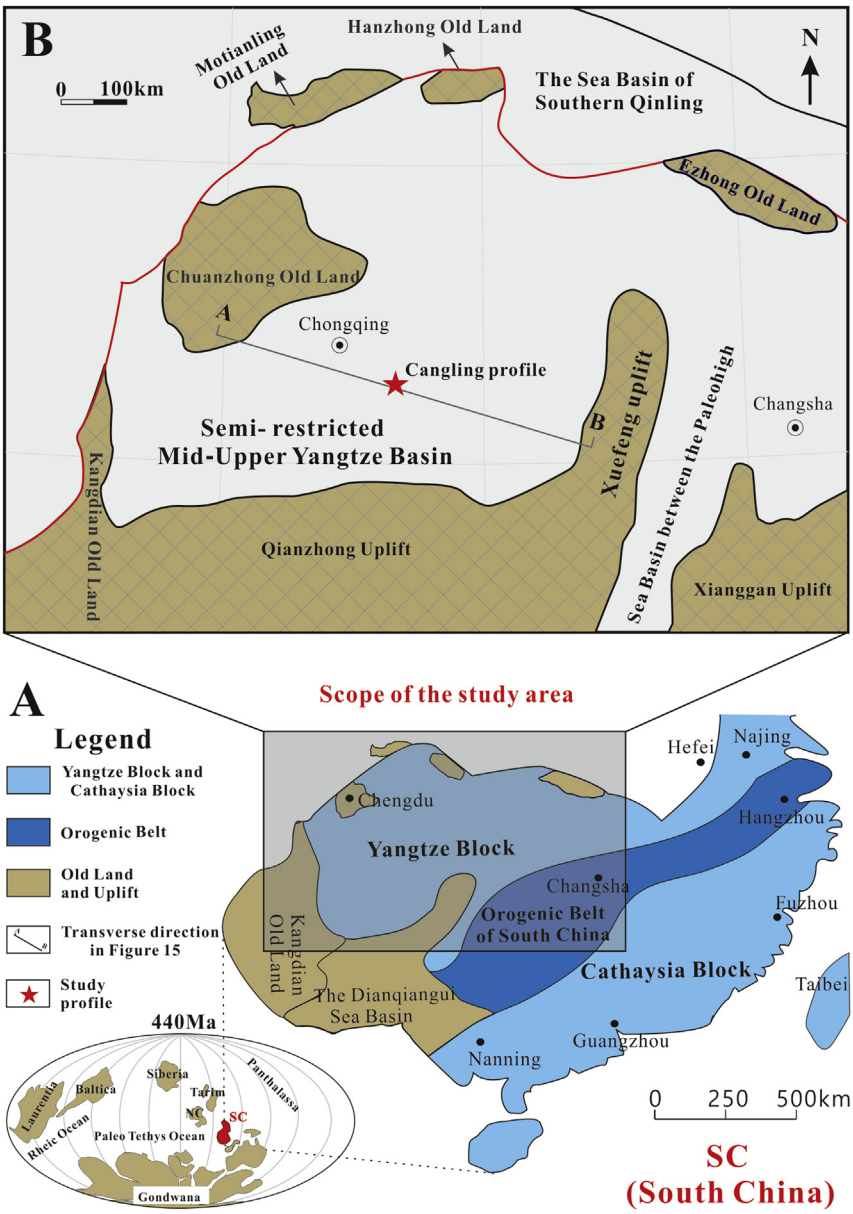

Fig. 1. The Late Ordovician-Early Silurian paleogeography of the South China blocks. (A) The relative locations of the Yangtze Block and the Cathaysia block during the Late Ordovician and Early Silurian (Zhang et al., 2013b). The inset in bottom-left corner is the location of South China on the reconstructed global paleogeographical map (after Ni et al., 2015). (B) The structural framework of the Upper Yangtze Basin during the Late Ordovician and Early Silurian (modified after Zhou et al., 2014; Chen et al., 2014) and the location of the Cangling profile in Youyang, Chongqing province.

cause of enhanced accumulation of organic matter. On the other hand, the productivity paradigm stresses a higher rate of delivery of organic carbon to the sea floor as a result of high primary productivity rate in the surface water (Sageman et al., 2003; H. Wei et al., 2012). However, it is likely that no single control can explain organic accumulation in all sediments, and that each sedimentary setting may reflect the effects of several factors that contribute to the accumulation of organic-rich sediments (Rimmer, 2004).

The Upper Yangtze Basin, several organic-rich black shale and mudstone units, including Late Ordovian Wufeng Formation and Early Silurian Longmaxi Formation, have been assessed as not only good marine source rocks but also as potential shale gas reservoirs (Zou et al., 2010; Mu et al., 2011). Studies of the stratigraphy, paleoecology, lithofacies paleogeography (Mu et al., 1981; Chen et al., 2000, 2004; Mu et al., 2011; Zhou et al., 2014; Chen et al., 2014) and preservation conditions of these units (Li et al., 2008; Zhang et al., 2013a; Yan et al., 2014) have laid the groundwork upon which the present study of factors that controlled accumulation of these organic-rich deposits is based. In this study, the tectonic movement between the Yangtze block and the Cathaysia block as well as melting glaciers on Gondwanaland resulted in a regional increase in the relative sea level in the Upper Yangtze Basin during the Ordovician-Silurian transition period. The relative sea level played a crucial role in the oxygen deficiency on the seafloor and the formation and preservation of the organic-rich black shale in the study area. Therefore, both regional tectonics and glaciation/climate have fundamental effects on the geochemical index by means of sea level changes. The geochemical indices, including the redox indicators (the V/(V + Ni), V/Cr, V/Sc, and Ni/Co) and the