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Research paper

Widespread coastal upwelling along the Eastern Paleo-Tethys Margin (South China) during the Middle Permian (Guadalupian): Implications for organic matter accumulation

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ABSTRACT

Guadalupian organic-rich depositions within the eastern Paleo-Tethys Margin have been attributed to coastal upwelling, but the idea has not been tested. Here, a suite of geochemical proxies from the Gufeng Formation of the Lower Yangtze region (South China) are used to investigate the formation mechanisms of organic matter accumulation. A high organic carbon content and similar enrichments of bio/redox-sensitive trace metals show strong similarities to the geochemical characteristics of modern upwelling sediments. The use of high Cd/Mo ratios and low Co x Mn values characteristic of modern upwelling settings (Sweere et al., 2016) is replicated in the Gufeng strata implying that Lower Yangtze area was dominated by persistent upwelling that become less intense (seasonal?) later in the Guadalupian. Application of these new geochemical proxies shows that the characteristics of modern upwelling systems, such as the formation of an intense oxygen minimum zone (OMZ), can be confirmed in the ancient. Calculation estimates show that primary productivity was sustained at moderate to high levels and was at comparable levels to those of the modern Peru upwelling system. OMZ-related anoxic conditions (with transient euxinic episodes) dominated permanently during the deposition of the Gufeng Formation and then became more intense conditions (euxinia) later in the Guadalupian. The radiolarian chert/siliceous mudstone rhythms that coincide with fluctuations in major elements, organic carbon, total sulfur and trace metal concentrations may reflect dilution by biogenic silica. Chert Zr/Al ratios are also higher than in mudstone suggesting the cherts may record more winnowed deposition at the margin of an ancient OMZ compared with a location within the OMZ for the mudstone. The organic matter accumulation of the Middle Permian Gufeng Formation may be mainly controlled by the upwelling-driven primary productivity and also influenced by the changes of anoxic/euxinic conditions and the dilution of biogenic silica.

1. Introduction

The Guadalupian interval saw the deposition of some exceptionally organic-rich sediments, which have been associated with vigorous thermohaline circulation and upwelling of nutrient-rich cold waters (Murchey and Jones, 1992; Beauchamp and Baud, 2002). In South China these conditions are manifest as black chert-mudstone rhythms (i.e., Gufeng Formation, e.g., Feng et al., 1993; Kametaka et al., 2005; Yao et al., 2015; Wu et al., 2015), and they have been attributed to multiple, interacting processes of upwelling and river runoff under the control of Milankovitch-scale orbital forcings (Yao et al., 2015). One of the outstanding characteristics of the Gufeng Formation is its extremely high total organic carbon (TOC) content, which is often greater than 20% (e.g., Liang et al., 2009; Saitoh et al., 2013; Du et al., 2015; Shi et al., 2016, Fig. 1b, c) making it one of the most important Palaeozoic petroleum source rocks in China (e.g., Xu, 1990; Liang et al., 2009; Du et al., 2015). However, there is little information available pertinent to the conditions responsible for such organic-rich sediment deposition. An upwelling system has long been considered a likely cause (Lv and Qu, 1989; Wang et al., 1997; Kametaka et al., 2005), but the interpretation of the formation of these organic-rich sediment deposition is still unclear due to a lack of diagnostic data to test such a scenario.

Generally, upwelling zones are not only areas of persistent high productivity in modern oceans (e.g., the Peru Margin, Böning et al., 2004) but they are also considered important depositional settings for ancient source rocks (Demaison and Moore, 1980; Parrish and Curtis,

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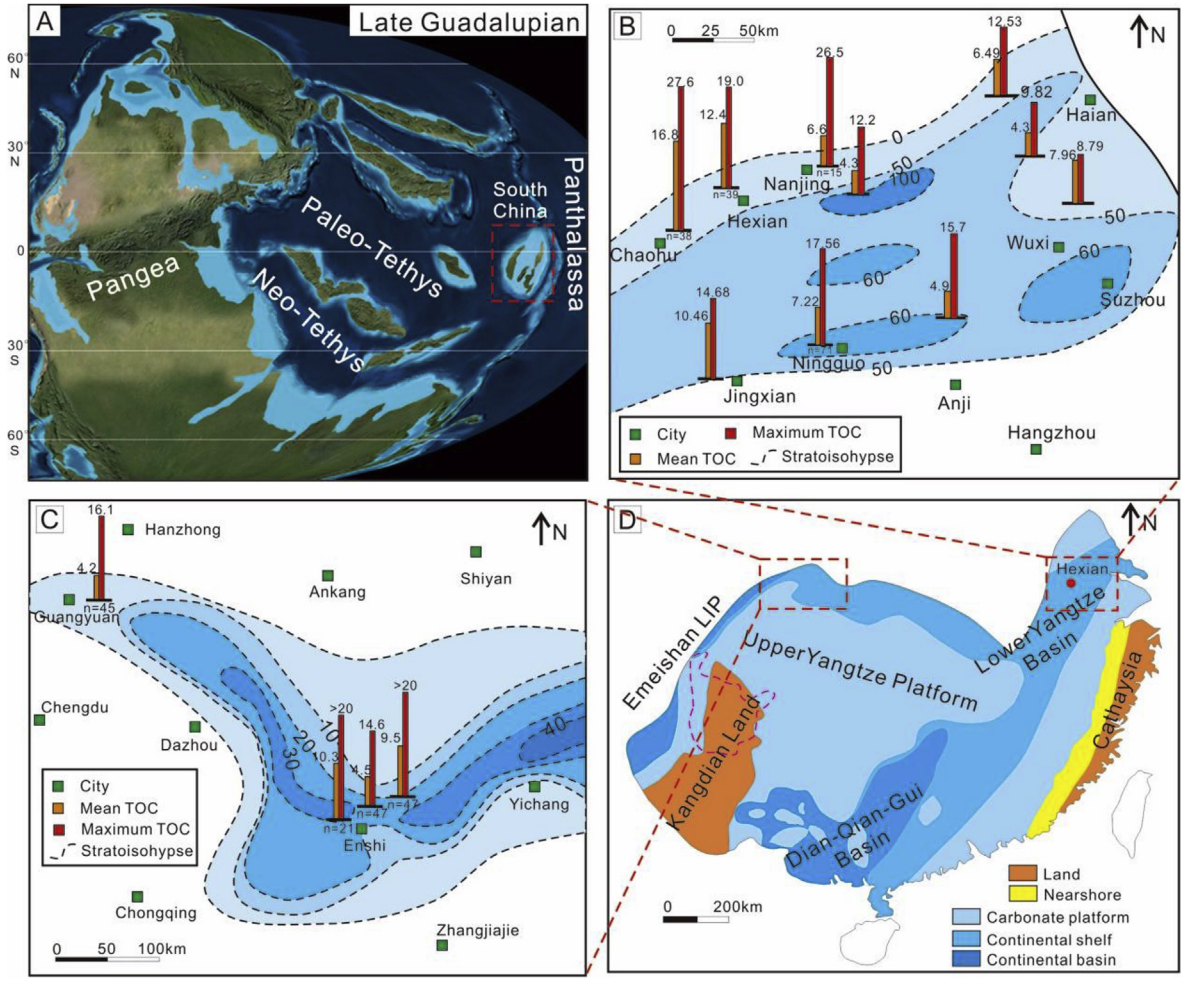

Fig. 1. (a) Late Guadalupian palaeogeography of the world. Base map from Ron Blakey (http://cpgeosystems.com). (b–c) Stratigraphic distribution and TOC characteristic of the Guadalupian organic-rich sediments in the Lower and Upper Yangtze area (modified from Liang et al., 2009; Saitoh et al., 2013; Shi et al., 2016; Wu et al., 2015). (d) Late Guadalupian palaeogeographic reconstruction of South China (modified from Yao et al., 2015).

1982; Parrish, 1982). Although it is easy to predict the location of ancient upwelling zones based on the their palaeogeographic location (i.e., along the west coasts of continents; Parrish and Curtis, 1982; Parrish, 1982) and lithologic characteristics (abundant phosphate, silica, and organic-rich sediments; Lv and Qu, 1989; Wang et al., 1997; Kametaka et al., 2005), it is still difficult to conclusively demonstrate that such sediments formed as upwelling deposits. Diagnostic geochemical evidence is needed demonstrate the development of these ancient upwelling systems.

Different oceanographic and sedimentological factors, such as surface primary productivity (e.g., Caplan and Bustin, 1999; Pedersen and Calvert, 1990; Tyson, 2005), bottom water redox conditions (e.g., Canfield, 1989; Demaison and Moore, 1980) or dilution of terrestrial inputs (e.g., Ibach, 1982; Sageman et al., 2003), are generally considered the primary mechanisms for contributing to the accumulation of organic-rich sediments. In addition, high productivity increases the sinking flux of organic matter, thus favouring reducing conditions at depth, and intensified anoxia results in greater P recycling, enhancing marine productivity in surface waters (Wignall, 1994; Algeo and Ingall, 2007). To better understand the effects of enhanced anoxia and increased productivity on organic matter accumulation in the Gufeng Formation, a comprehensive geochemical study has been carried out.

In this study, we use a series of geochemical proxy data, including total organic carbon (TOC), total sulfur (TS), and major and trace element concentrations of the Middle Permian strata of the Hexian core from the Lower Yangtze area to analyse an ancient upwelling system, reconstruct palaeoenvironments and improve our understanding of the controlling factors of organic matter accumulation. Changes in this sedimentary environment, including upwelling-driven primary productivity, OMZ-related anoxic conditions and controls on organic enrichment are further discussed to evaluate their role in organic matter accumulation.

2. Geologic setting

The South China block was situated in the equatorial eastern margin of the Paleo-Tethys Ocean and likely subject to prevailing northwest trade winds (Enkin et al., 1992; Wang and Jin, 2000, Fig. 1a). Intensive upwelling systems are thought to have stretched for hundreds of kilometres along its margins during the Guadalupian (~272-262 Ma) based on the widespread radiolarian chert and phosphate deposits on the northwest Yangtze Platform (Lv and Qu, 1989; Wang et al., 1997; Kametaka et al., 2005). During this period, Gondwanan glaciation and cool climates could have promoted a vigorous thermohaline circulation and intense upwelling (Beauchamp and Baud, 2002). The widespread Gufeng Formation, a black, radiolarian chert-mudstone succession characterized by extremely high TOC content (typically 4.3–16.8%, with a maximum of 27.6%, Fig. 1b and c) was deposited along the northwest margin of the Yangtze Platform (Fig. 1d). In the late Guadalupian, chert deposition was replaced by siliciclastic sedimentation (Yinping Formation) possibly as a consequence of the cessation of the upwelling and/or global regression (Bureau of Geology and Mineral