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Sulfur isotope constraints on marine transgression in the lacustrine Upper Cretaceous Songliao Basin, northeastern China

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ABSTRACT

Organic-rich Cretaceous source rocks of the petroliferous Songliao Basin in northeast China are considered to be lacustrine in origin, but paleontological and organic geochemical evidence suggest episodic marine incursions. As a test of this hypothesis, we applied time-series measurements of elemental and isotopic abundances on core and cutting samples to evaluate fluctuations in the sulfur and carbon cycles across the Santonian–Campanian transition preserved in the upper Yaojia and lower Nenjiang formations. The data reveal a spike in pyrite sulfur abundance and a marked negative excursion in $\delta^{34}S$ at the base of the Nenjiang Formation when the basin expanded to its maximal extent. The elemental and isotopic data suggest that flooding was associated with rapid marine transgression that enhanced sulfate concentrations, which promoted microbial sulfate reduction in anoxic bottom waters that were episodically euxinic. Subsequent restriction of the basin and a decline in marine influence is supported by progressive upsection ^{34}S enrichment (up to 30‰) in Nenjiang Member I, which are interpreted to reflect the distillation of sulfate through enhanced pyrite burial, followed by a gradual return to lacustrine conditions that prevailed in overlying strata.

1. Introduction

The Cretaceous Period is generally characterized by hothouse climates and repeated oceanic anoxic events (OAEs) resulting in the deposition of organic-rich source rocks in marine environments and associated positive carbon and sulfur isotope anomalies (Tarduno et al., 1998; Skelton et al., 2003; Owens et al., 2013). The OAEs may be linked to the reorganization of ocean circulation patterns and enhanced greenhouse gas concentrations in the atmosphere, which were potentially enhanced by widespread rifting and volcanism (Arthur et al., 1990; Poulsen et al., 2001). At present, however, it is unclear whether the globally distributed marine events may have teleconnections to the terrestrial realm through either atmospheric processes or oceanic transgression onto continental margins.

To evaluate whether the continental Upper Cretaceous Songliao Basin of northeast China was influenced by ocean water and evaluate redox conditions during the deposition of important source rocks, we conducted a high-resolution time-series carbon and sulfur isotope study of the Santonian to Campanian Yaojia and Nenjiang formations. The sedimentary rocks of the Songliao Basin contain the most productive oil and gas reserves of the country, and are widely believed to be lacustrine in origin due to the preservation of terrestrial and freshwater plant and animals fossils (Wu et al., 2007; Sha, 2007; Feng et al., 2010; Wan et al., 2013). On the other hand, a marine affinity for source rocks of both the Qingshankou and lower Nenjiang formations is supported by the discovery of foraminifera (Xi et al., 2011), euryhaline dinoflagellates (Hou et al., 2000), and fish adapted to saline environments, as well as the preservation of specific organic biomarkers, including certain methyl- and desmethylsteranes, gammacerane, and β-carotene (Song et al., 2013). If correct, OAE expression in the lacustrine Songliao Basin is likely related to episodic marine transgression (Arthur and Sageman, 2005) conceivably linked to enhanced seafloor spreading and global warming.

The third and last of the Cretaceous OAEs (Wagreich, 2012) around the Coniacian–Santonian boundary (which is restricted to equatorial to mid-latitude Atlantic and adjacent basins, but not including the north or south Atlantic nor the Tethys or Pacific oceans) coincides with a nadir of $^{87}Sr/^{86}Sr$ values recorded in marine proxies. This observation suggests that enhanced hydrothermal circulation associated with greater ridge activity (Jones and Jenkyns, 2001) could explain marine transgression, as well as increasing temperature through volcanic release of CO_2 (Royer, 2006). Insofar as ridge volume provides a first-order control on eustatic sea level, it is plausible that the lacustrine Songliao Basin was episodically flooded in response to global tectonic activity during the Cretaceous Period. Marine flooding (in particular

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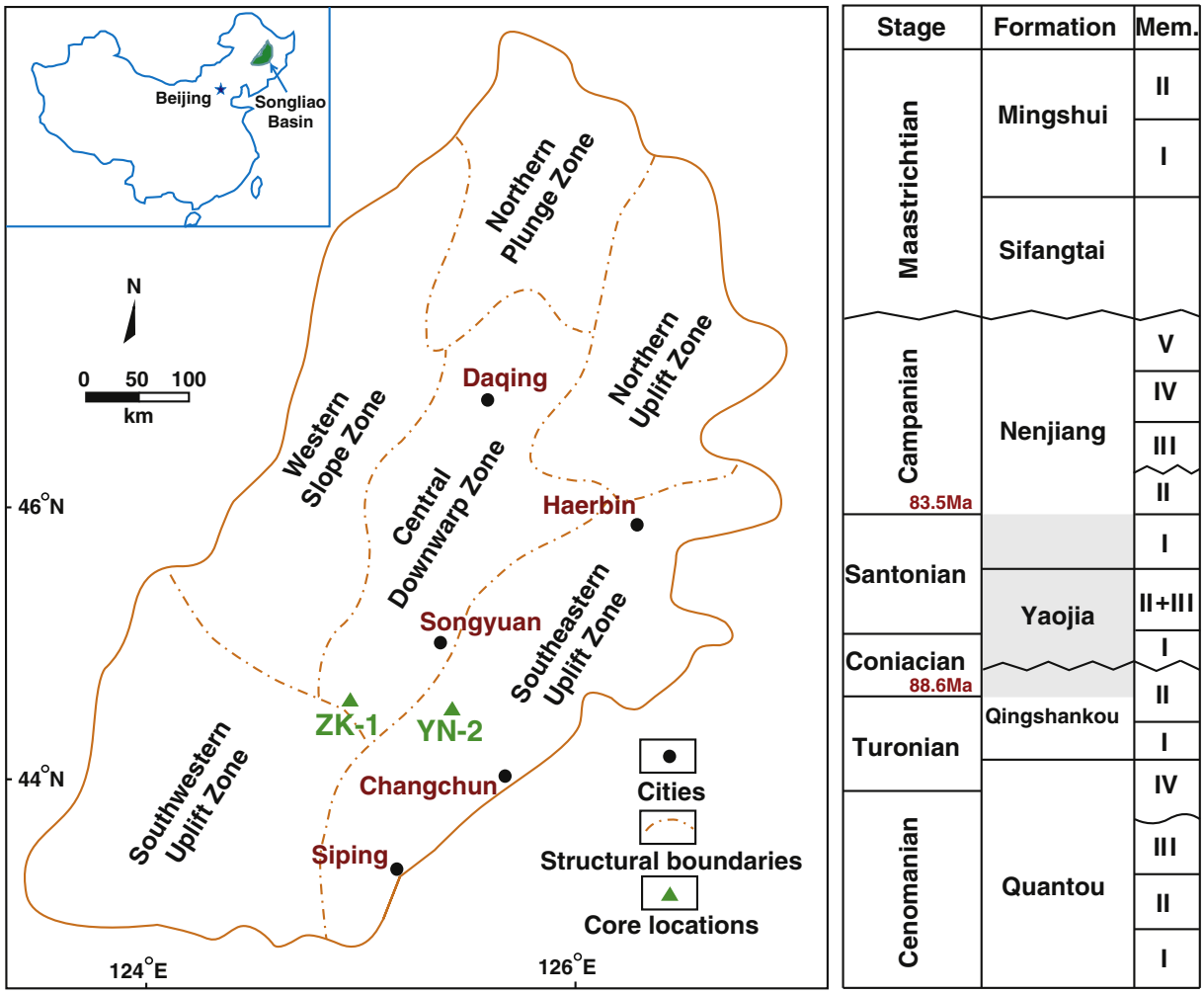

Fig. 1. Map of structural units with locations of cores used in this study (YN-2 and ZK-1) along with Late Cretaceous stage assignments for units in the Songliao Basin of Northeast China (modified from Feng et al., 2010). Grey interval spanning from the upper Qingshankou to the lower Nenjiang formations broadly corresponds to OAE 3 (ca. 88.6–83.5 Ma) in the marine realm (Wagreich, 2012).

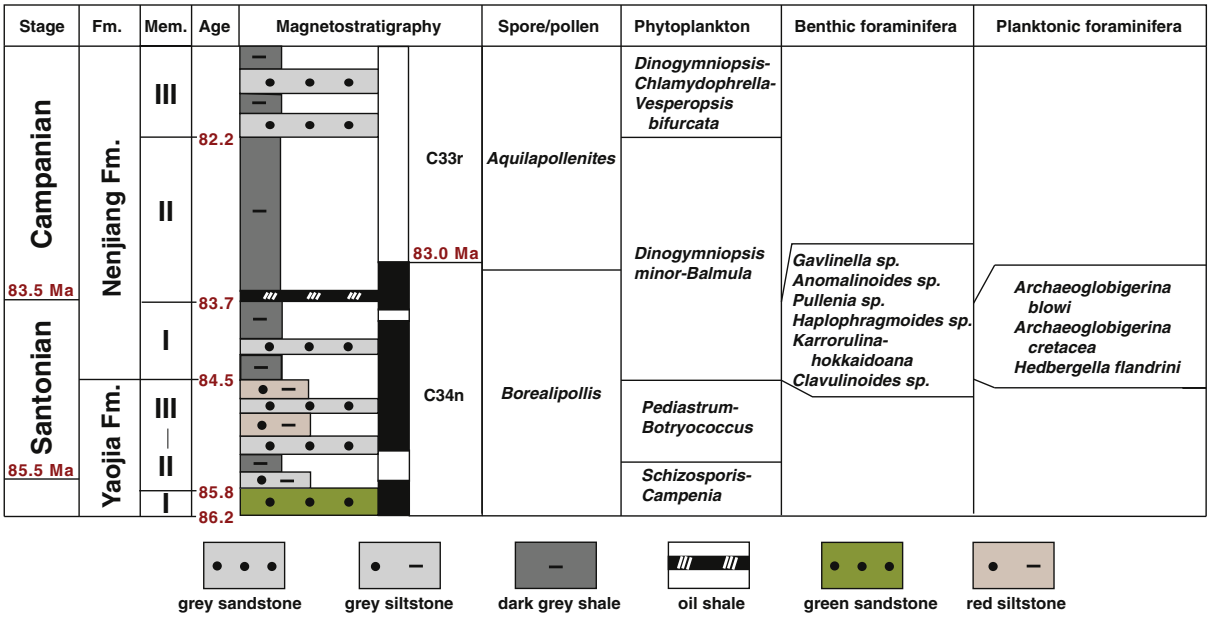

Fig. 2. Lithostratigraphy, magnetostratigraphy, and biostratigraphy of the Yaojia and lower Nenjiang formations (modified from Wan et al., 2013; Xi et al., 2011).