

The C-S-Fe System Evolution of Lacustrine Shale Influenced by Volcanic Activity and Evidenced by Iron Isotopes: A Case Study of the Late Triassic Ordos Basin, China

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The C-S-Fe system is a crucial component of the Earth's biogeochemical cycles. Given the continuing exploration and development of oil and gas in lacustrine shale, investigating the mechanisms of organic matter (OM) enrichment in ancient lacustrine shale through the lens of C-S-Fe system evolution becomes imperative. In contrast to marine shale, studies on the C-S-Fe system in lacustrine shale are still in early stages. Systematic studies have yet to be conducted on the C-S-Fe system fluctuations during lacustrine deposition, which encompass external dynamics, internal biogeochemical processes, and the associated fractionation characteristics of typical elements. In this study, we conducted geochemical experimental analyses on the Late-Triassic Chang 7 Member of the Ordos Basin in China, which has the largest scale of lacustrine shale oil and gas resources and is significantly influenced by volcanic activity. Subsequently, we utilized modeling and data-driven clustering analysis methods to further investigate this section. The findings are as follows: (1) The sedimentary environment of the Chang 7 Member is characterized by anoxic and ferruginous conditions. Furthermore, the section experienced an anomalous input of sulfur, iron, and other elements attributable to volcanic activity. This resulted in pronounced bacterial sulfate reduction (BSR) and the formation of an anoxic environment that is more suitable for OM preservation, and promoted phosphorus cycling. (2) Although this freshwater lake basin ($0.01 < Fe_{py}/Fe_{HR} < 0.77$) did not attain a euxinic environment ($Fe_{py}/Fe_{HR} > 0.8$), the abnormal input of sulfur significantly impacted biogeochemical cycling. This is primarily reflected in the reduced intensity of dissimilatory iron reduction (DIR) and the increased intensity of BSR. (3) The variations in DIR and BSR intensities influence the redox conditions, which constitute the main reason for iron isotope fractionation. $\delta^{56}Fe$ values of Chang 7 shales exhibit a restricted range (-0.16‰~0.23‰, n=42), with lower values observed under predominant BSR conditions compared to predominant DIR conditions. This study systematically elucidates the evolution of the C-S-Fe system in the Chang 7 Member, employing typical lacustrine shale as an exemplar and concentrating on the iron cycle. It offers a reference for further research into the dynamic evolution of the lacustrine C-S-Fe system and its implications for