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Climate-Driven Shifts in the Lacustrine Nitrogen Cycle During the Middle Permian Warming in the Junggar Basin, Northwest China

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We examine the biogeochemical nitrogen cycle in Paleolake Junggar, a saline lacustrine system in the Jimsar Sag (Junggar Basin, NW China) through analysis of elemental, isotopic, and biomarker proxies in the Middle Permian Lucaogou Formation, which constitutes a major shale oil-producing unit. The response of nitrogen cycling in lake systems to icehouse-to-greenhouse climate transitions remains essentially uninvestigated, even though similar responses are imminent in modern lakes. Our results document a climatic shift from cold-arid in Interval A (oldest) to warm-humid conditions in Interval C (youngest), promoting terrestrial nutrient influx. A decrease in nitrogen isotopic compositions ($\delta^{15}N$) records a climate-driven reduction in lake water pH, defining three biogeochemical nitrogen cycling stages. Under the initially arid climate conditions of Interval A, anoxic and alkaline conditions were favorable to halotolerant green algae and methanogens, and ammonia volatilization was strong ($\delta^{15}N > +10‰$). Climate warming and increased chemical weathering in Interval B led to cyanobacterial blooms in a nutrient-rich watermass along with incomplete denitrification accompanied by possible biological nitrogen fixation ($+8‰ < \delta^{15}N < +10‰$). Following development of a wetter climate in Interval C, the stratified and neutral-pH lake was marked by increased productivity and bottom-water anoxia, facilitating the enrichment of organic matter and triggering a shift to dominance of denitrification ($+5‰ < \delta^{15}N < +8‰$). This study establishes a link between climate-driven biogeochemical cycling and organic matter accumulation, offering insights for evaluating lacustrine source rock development and paleo-environmental controls on hydrocarbon generation in analogous basin settings.