

Spatial and seasonal controls on phosphate accumulation at an origin-of-life analog environment

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Alkaline lakes represent a relatively clement form of extreme environment. They can be immensely bioproductive and have been touted for being rare sites with high dissolved phosphate¹, a sought-after attribute in origin-of-life research. Yet dissolved phosphate accumulation is a delicate process that depends on (at least) evaporation rate versus the flux and chemistry of inflow waters, as well as the solubilities of key minerals such as apatite and natron. Here we examine Last Chance Lake (British Columbia, Canada), the site of the highest recorded lacustrine alkalinity (3.7 Eq/L) and phosphate (38.3 mmol/l) on Earth², with a focus on spatial and temporal geochemical trends and their implications for prebiotic research.

Sediment cores were collected across two field seasons (June 2021 and April 2024) at basin margin and interior locations. Porewater concentrations of phosphate and alkalinity notably increase moving toward the basin interior. For instance, there is a more than five-fold increase in average phosphate concentrations when comparing marginal (0.6 mmol/kg, n = 16) versus interior (3.4 mmol/kg, n = 21) porewaters. Additionally, key anions (sulfate, phosphate, and Cl⁻) within interior porewaters become more concentrated with depth relative to their margin counterparts, while certain cations either stay constant (Ca²⁺ and Mg²⁺) or increase less than Na⁺ (e.g., K⁺). We hypothesize “sink-switching” for cations on seasonal timescales, from non-carbonate (during freezing conditions) to carbonate (during spring thaw) anions. This modulates Ca²⁺ and thus limits apatite precipitation, facilitating high phosphate concentrations.

These data stress the importance of groundwater recharge chemistry and seasonality on alkaline lakes as origin-of-life environments. The shorelines of aqueous environments may be considered preferable for prebiotic chemistry, as life may have originated in part through the development of organic polymers via repeated wet-dry cycles³. However, Last Chance Lake shows that calcium-bearing input waters will tend around the margins and act as a localized sink for phosphate. Additionally, freeze-thaw conditions may facilitate phosphate buildup, implying periodically cold temperatures and dynamic seasons are desirable for *de novo* origin scenarios in alkaline lakes. [1]Toner & Catling (2020) *PNAS* 117, 883. [2]Hirst (1995) University of Saskatchewan. [3]Damer & Deamer (2020) *Astrobiology* 20(4), 429.