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Salinity–Temperature Coupling Intensifies Geochemical Processes During Granite–Water Interaction: Experimental Constraints from a Closed-Loop Fixed-Bed Reactor

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Salinity–Temperature Coupling Intensifies Geochemical Processes During Granite–Water Interaction: Experimental Constraints from a Closed-Loop Fixed-Bed Reactor

The combined effects of temperature and salinity on elemental redistribution during granite–water interaction are critical for understanding saline groundwater evolution, lithium enrichment, uranium mobility, and pH-dependent reactions in crystalline systems. We conducted controlled circulation experiments in a Salamander closed-loop fixed-bed reactor, reacting crushed granite with distilled water, 0.5 M NaCl, and 1.0 M NaCl solutions at 50–120 °C for up to five days. Major and trace cations (Li, Na, Mg, Ca, Be, U, Ag) and key anions (Cl^-, carbonate species) were monitored to assess dissolution, ion exchange, secondary mineral precipitation, aqueous complexation, and pH evolution across varying ionic strengths.

In distilled water, increasing temperature elevated total dissolved solids (TDS) and pH, primarily through enhanced Mg and Ca release via kinetically accelerated silicate weathering. Lithium did not follow this trend, indicating its mobility is not solely controlled by congruent mineral dissolution.

In saline solutions, higher ionic strength altered reaction pathways. Sodium concentrations often declined even in NaCl-rich fluids, while lithium exhibited relative enrichment at elevated temperature and salinity, driven by Na–Li exchange and competitive desorption amplified by ionic strength. Magnesium and calcium stabilized or decreased under saline conditions despite rising temperature, consistent with competitive surface complexation and enhanced carbonate precipitation in alkaline environments.

Beryllium was highly sensitive to salinity–temperature effects, enriched under alkaline saline conditions due to pH-dependent hydroxyl complexation. Uranium showed pronounced mobilization at elevated temperatures, reflecting reduced adsorption and stabilization of uranyl–carbonate and uranyl–chloride complexes. Silver decreased with increasing salinity, consistent with AgCl precipitation dominating over chloride complexation. Chloride behaved partially non-conservatively, participating in mineral reactions beyond simple transport.

Overall, the results demonstrate that increasing salinity intensifies and couples geochemical processes by modifying activity coefficients, surface equilibria, and mineral saturation states. Temperature enhances dissolution, but ionic strength governs trace-element redistribution through interconnected exchange, precipitation and complexation feedback in granite–water systems. That has direct implications for lithium exploration, and groundwater quality in saline systems.