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Geochemical Controls on Lithium Enrichment in the Smackover Formation and Implications for Sustainable Extraction

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Lithium has been designated a critical mineral by the U.S. Department of Energy, and rising demand for energy-storage technologies has intensified interest in lithium-rich brines associated with oil and geothermal systems. This study investigates the mechanisms responsible for lithium enrichment in produced waters from the Smackover Formation (USA) and evaluates the potential for sustainable lithium co-production with geothermal energy. The objectives are to 1)identify geochemical processes controlling lithium enrichment using high-salinity geochemical modeling, and 2) assess the long-term sustainability of lithium and geothermal co-production through reactive transport simulations.

Smackover brines evolve through ion exchange, sediment leaching, mineral precipitation, sulfate reduction, and ultrafiltration across clay–shale membranes, influenced by fluid circulation between permeable reservoir units and low-permeability aquitards. High-TDS systems require Pitzer-type activity models to accurately represent aqueous speciation and reaction kinetics. Because primary lithium minerals are absent, model calibration incorporates a thermodynamic database capturing lithium substitution in clay and feldspathic minerals. Geochemical modeling using TOUGHREACT v4.17 [1] was calibrated with produced-water samples from the Smackover in Louisiana. The calibrated model reproduces mineral–water kinetics and predicts temporal evolution of major and trace aqueous species, including lithium.

Preliminary results show that Smackover brines are low in magnesium relative to evaporite brines, likely due to dolomitization driven by Mg–calcite reactions. Lithium is primarily associated with clays and feldspars such as albite. Key geochemical indicators of lithium enrichment include elevated potassium, calcium, boron, high TDS, and structural features such as major faults, which reflect significant heterogeneity across the basin—for example, contrasting water signatures between northern Louisiana and southern Arkansas. This work establishes a mechanistic framework for lithium enrichment in produced waters from sedimentary basins and provides a predictive basis for evaluating the viability and sustainability of lithium and geothermal extraction from produced waters.

[1] Sonnenthal, E., Spycher, N., Xu, T., & Zheng, L. (2021). TOUGHREACT V4.1-OMP reference manual: a parallel simulation program for non-isothermal multiphase geochemical reactive transport: University of California, Berkeley.