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Lithium Exploration Tools from Source to Sink

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Summary

Due to the mobility and incompatibility of lithium (Li) in the crust and on Earth's surface, the Li mineral system is complex and highly interlinked. In most cases, the development of economic Li brine systems depends upon the concentration, transport, deposition and remobilization of Li from magmatic systems. As such, a complete understanding of where and why Li becomes concentrated in the crust and at Earth's surface, from source to sink, is highly desirable and requires integrated knowledge of the Li mineral system. Development of integrated data and exploration tools for global and regional resource assessment is key for accelerated understanding and targeting of Li resources. CGG are developing a suite of exploration tools to inform global resource assessments and target generation for a wide range of Li brine deposit styles. These tools are underpinned by our integrated approach to the Li mineral system, which informs our understanding of the sources, transport, deposition, enrichment and preservation factors affecting this system.

The Behavior of Lithium in Earth's crust

The behavior of lithium (Li) within Earth's crust is governed by its unique chemical and physical properties. Due to its high electropositivity and small ionic radius, Li has a low affinity to partition from magma into silicate mineral phases, instead remaining in solution until relatively late in the fractionation process. High Li concentrations may be reached within late stage felsic magmas, at which point Li-enriched silicate phases, such as spodumene and lepidolite, may be precipitated within pegmatitic granites (Fig 1; Bowell et al., 2020; Bradley et al., 2017). Significant Li enrichment of magma also occurs through the interaction of evolving magma with felsic crustal material, which itself is typically pre-enriched with respect to Li (Benson et al., 2017).

Lithium readily partitions from magmas into hydrous phases due to its incompatibility and affinity to form complexes with chlorine. At depth, devolatilization of magma may give rise to a Li-enriched magmatic geothermal brine, which may represent a target for both Li extraction and the generation of geothermal energy under favorable geological conditions (Fig. 1). At shallower crustal levels, Li may be lost to the atmosphere through passive or explosive magmatic degassing (Neukampf et al., 2021). Whilst a significant proportion of Li is lost to the atmosphere during the explosive eruptions of highly evolved felsic magmas, sufficient concentrations of Li may also be trapped in volcanic glass which may be deposited in ignimbrites, representing a major source of Li that may be subsequently remobilized through dissolution (Fig. 1; Benson et al., 2017; López Steinmetz & Salvi, 2021).

Lithium is dissolved from rocks through interactions with hydrothermal, meteoric and ground waters, and may either remain in solution or re-precipitate as secondary Li-clay deposits (Von Strandmann et al., 2020). Whilst the dissolution of Li from volcanic glass in ignimbrites and other rock sources often results in only a modest increase in the Li content of the waters themselves, the waters may be further Li enriched through subsequent processes, such as evaporation or mineral precipitation.

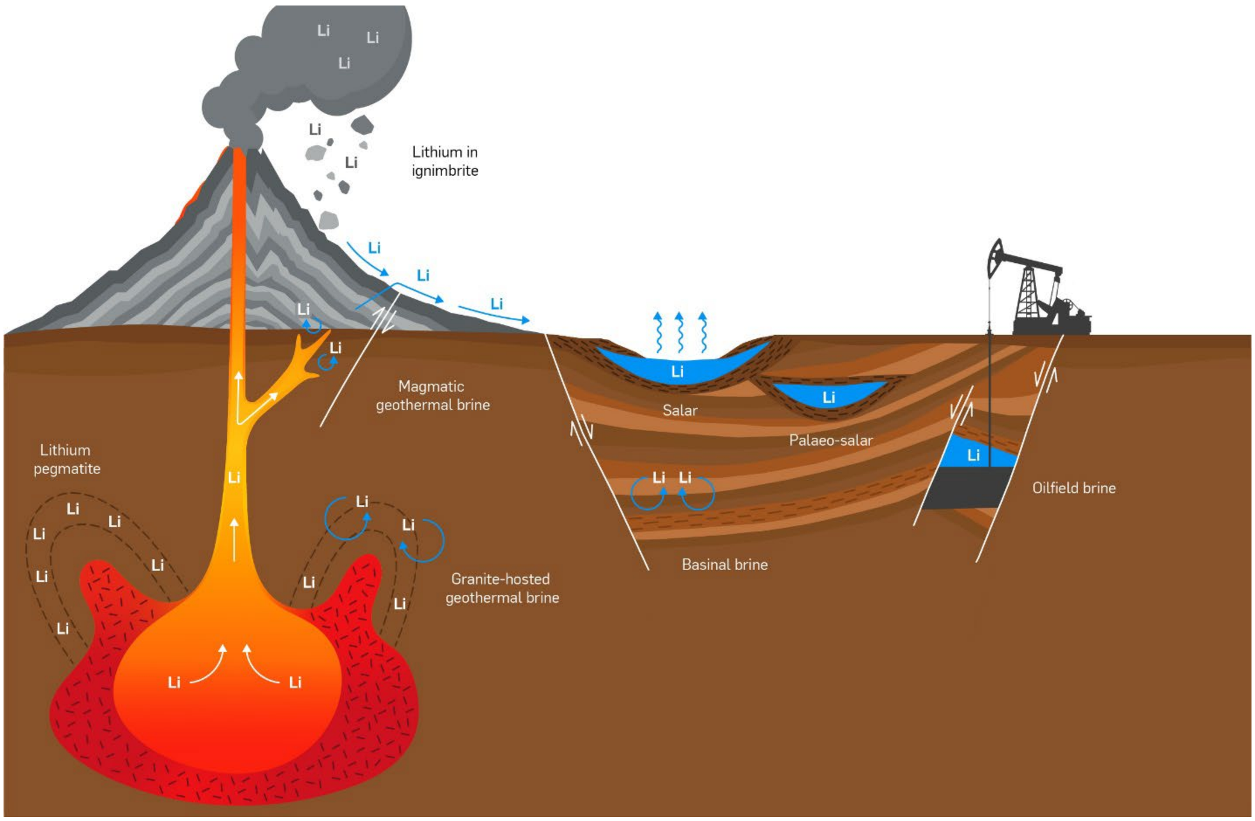

Figure 1 Conceptual illustration of the range of lithium (Li) deposits associated with magmatic and brine systems. These systems are connected by the flux of magma and water, which both transport Li in solution.

Global Screening of Conventional and Non-Conventional Brine Resources

Owing to the increased demand for Li, driven by the green energy transition and the emergence of new direct Li extraction (DLE) technologies that facilitate economic extraction at relatively low Li concentrations, a diverse range of under-explored resources are now being investigated as potential Li sources. These new resources include Li associated with high- to low-enthalpy geothermal brines as well as basinal and oilfield brines (Fig. 1).

The physical and chemical properties of these brines vary drastically, and careful selection of the optimal DLE technology to process a certain brine, or brine to suit a given DLE technology, underpin the technical and economic success of a project. As such, detailed characterization of the chemical and physical properties of global brine resources is crucial in the exploration process, empowering stakeholders to make informed decisions about the characteristics of their “ideal brine” and facilitating predictive exploration targeting.

CGG have compiled, quality controlled and homogenized a global database of water geochemistry from both open and internal sources. This dataset covers a diverse range of water analyses from geothermal, oilfield, salar and ground waters, among others. Alongside Li compositions, the dataset includes accessory water chemistry, physio-chemical properties, temperature, flow rates and other data where available. Additional layers, such as global whole-rock geochemistry, geothermal plant locations and production metrics, are included to enhance the exploration insights that may be drawn from the core dataset. These data are presented in flat table format to maximize accessibility, but include spatial attribution and are optimized for interrogation on GIS platforms, enabling a detailed global assessment of known Li brine resources.

Lithium Enriched Salars Both Present and Past

Roughly 57% of global Li reserves are hosted within shallow surficial basin systems, such as the salars of the Atacama desert (Bradley et al., 2017). These systems form through the accumulation and evaporation of water within endorheic basins in arid to hyper-arid climates (Fig. 1). Because the rate of water recharge is outstripped by the rate of evaporation, waters that accumulate within these basins are gradually enriched with dissolved solids. Evaporation, alongside precipitation of salts such as halite, further concentrates Li within the residual brine, leading to very high salinity brines with Li concentrations of the order of 10^2 to 10^3 mg/L.

It is widely accepted that Li derived from felsic ignimbrites is readily remobilized in solution and represents a common and significant Li source in salar-type deposits (e.g. López Steinmetz & Salvi, 2021). The contribution of dissolved Li from magmatically derived geothermal waters has also been noted in several highly Li-enriched salar systems, such as the Salar de Atacama and Salar de Uyuni, suggesting that the highest grade salars derive their Li from multiple sources (Ide & Kunasz, 1990; Marazuela et al., 2020; Sieland, 2014).

Whilst Li-enriched salars form at the present day in arid regions, the formation and preservation potential of such salars in the geological past is relatively poorly understood. Nevertheless, recent work by Ellis et al. (2022) argues that Li remobilization from ignimbrites occurs at, or very soon after, the time of ignimbrite deposition, suggesting that much of the Li within active salars has resided there for at least several million years. The preservation potential of Li-enriched brines on geologic time scales is further reinforced by the discovery of “paleo-salars”, where the brines occur within permeable evaporite and/or clastic units associated with salar basins that have subsequently been buried beneath younger geological units.

To predict where these concealed paleo-salars could have formed, it is necessary to characterize the local climate, Li sources, drainage catchments, and areas where water may accumulate within a given area. CGG have compiled disparate geological and satellite datasets over a broad region of the western South American margin, and homogenized and augmented these data through CGG’s in house processing techniques. In so doing, CGG have created an accessible prospecting tool that is available through CGG GeoVerse™ and may be used for prospectivity analysis and novel target generation for the exploration of modern and ancient salars.

Oilfield Brine Screening of Canada and the USA

Brines occurring within oilfields have recorded Li values in excess of several 100 mg/L, thus representing a potentially economic Li source (Kumar et al., 2019). Alongside emerging technologies that facilitate DLE from oilfield brines, the economic feasibility of extraction is further enhanced by the pre-existing infrastructure relating to hydrocarbon production that may be leveraged and repurposed for the production of Li from brines. Whilst brines contained within specific geological units within certain basins (e.g., the Smackover Formation in the Gulf of Mexico, and Devonian units in the Alberta basin, Canada) are known to contain elevated Li contents, many other units and basins are relatively barren. CGG are currently compiling data on the chemistry and physical properties of brines associated with oilfields in the USA and Canada. The aim of this work is to offer a comprehensive and easily interrogatable database to aid in exploration decision making, as well as to offer deeper insights into the origins of Li-enriched oilfield brines that may aid in future exploration targeting.

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