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Statistic Analysis of Lithium Distribution in Reservoir Rocks across West Canadian Sedimentary Basin (WCSB)

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1. Summary

Lithium, a critical mineral essential for electric vehicle batteries, is predominantly extracted from formation brine. However, the understanding of its concentration in formation rocks, which significantly influences the accumulation in formation brines, remains limited. This study investigates the lithium content within the Alberta Basin, Horn River, and Mackenzie Corridor by analyzing rock element data. Our research highlights the preferential presence of lithium in sandstones over carbonates, with a notable affinity for sandstones of smaller grain sizes for lithium entrapment. Moreover, we discovered that while the majority of lithium-rich rock samples originated from Cretaceous formations, the abundance of lithium-rich brine samples was predominantly found in Devonian formations, suggesting a complex migration and concentration process from reservoir rock to formation brine that warrants further exploration. Additionally, some elements show similar relationships with lithium. For example, Li vs. Al and Li vs. Ti both have linear exponential and cubic relations in East Alberta, Horn River and Machenzie Corridor areas, respectively. Li vs. K and Li vs. Cs both show linear and cubic relations in East Alberta and Machenzie Corridor areas, respectively. Li vs. Mg and Li vs. Mn both show exponential and linear relations in East Alberta and Horn River areas, respectively. This comprehensive analysis lays a foundational framework for quantitatively determining lithium content in reservoir rocks and identifying formations containing lithium-rich brine, thus advancing the understanding of lithium sourcing for sustainable extraction practices.

2. Method

In the comprehensive study undertaken, a vast dataset comprising over 540 core sample analysis data points was meticulously compiled from both publicly available sources and the internal laboratory archives of the Geological Survey of Canada (GSC). These samples underwent a rigorous cleaning and organizational process, categorizing them by specific areas, formations, and lithologies to ensure a structured and coherent dataset for analysis. The geographical scope of the sample collection encompassed three major regions: the Alberta Basin, Horn River, and the Mackenzie Corridor, with the samples from three formations within the Alberta Basin, seven formations in Horn River, and three formations in the Mackenzie Corridor. To delve into the intricate relationship between lithium concentrations and the presence of other elemental constituents across these varied geological settings, both linear and nonlinear regression analyses were employed. This analytical approach enabled the classification of the samples into distinct groups based on the regression outcomes, facilitating a detailed examination of the patterns and similarities in the relationships between lithium and other elements within different areas and formations. This methodology not only enhances our understanding of elemental distributions in these geological contexts but also sets the stage for further investigations into the factors influencing lithium presence in sedimentary environments.

3. Results, Observations, Conclusions

3.1 Lithium Content in Different Basins and Formations

In the comprehensive analysis of 581 geological samples, data were systematically collected across three distinct regions, i.e. Alberta basin, Horn River basin and Machenzie Corridor, yielding insights into the spatial distribution of lithium concentrations within various geological formations. Of the total samples, 137 were sourced from the Alberta Basin, specifically from the Deveney, Montney, and Leduc formations, where the mean lithium concentration was approximately 40 parts per million (ppm), suggesting homogeneity in lithium distribution across these formations. Conversely, the Horn River Basin, from which 383 samples were procured, demonstrated significantly elevated lithium concentrations. Notably, samples from the Golata formation exhibited a mean lithium concentration of 120 ppm, triple that observed in the Alberta Basin samples. This basin was uniquely identified as the exclusive source of samples with lithium concentrations exceeding 100 ppm. Additionally, 61 samples were collected from the Mackenzie Corridor, encompassing the Canol, Hare Indian, and Imperial formations, with an observed mean lithium concentration of 22 ppm, the lowest among the regions assessed. Within this corridor, the Imperial formation exhibited the highest lithium content at 31 ppm, whereas the Canol formation recorded the lowest at 18 ppm, with the Hare Indian formation presenting intermediate values at 24 ppm. This analysis underscores the pronounced variability in lithium concentrations across different geological contexts, with the Horn River Basin emerging as a particularly prolific lithium-bearing region.

3.2 Lithium Content in Different Lithological Rocks

The analysis of core samples, classified into four lithological categories—carbonate, sandstone, siltstone, and shale—reveals distinct patterns in lithium distribution relative to lithology and grain size. Carbonate samples exhibit markedly lower lithium concentrations, with 90% containing less than 10 ppm of lithium, underscoring the elemental scarcity within carbonate lithologies. Conversely, clastic samples (sandstone, siltstone, and shale) display a clear correlation between lithium concentration and grain size. Specifically, shale samples, characterized by the smallest grain sizes, exhibit the highest average lithium concentration at 61 ppm. This contrasts with sandstone samples, which, having the largest grain sizes, show the lowest average lithium concentration at 32 ppm. Siltstone samples, with medium grain sizes, exhibit intermediate lithium concentrations, averaging 49 ppm. These observations underscore the selective affinity of lithium for specific lithologies, with a pronounced tendency for enrichment in shales compared to a notable paucity in carbonates. This differential distribution highlights the influence of lithological characteristics on lithium mobility and concentration, suggesting a fundamental control by grain size and lithology on the elemental accumulation within sedimentary environments.

3.3 Relationships between Lithium and Other Elements

In the investigation of the geochemical relations between lithium (Li) and various major and trace elements—including aluminum (Al), calcium (Ca), potassium (K), magnesium (Mg), titanium (Ti), rubidium (Rb), cesium (Cs), and manganese (Mn), distinct patterns of correlation were elucidated across three geological regions: the Alberta Basin, Horn River Basin, and Mackenzie Corridor. Specifically, the relationships between Li and Al, as well as Li and Ti, demonstrate linear, exponential, and cubic correlations within the Alberta Basin, Horn River Basin, and Mackenzie Corridor, respectively. For the pairs Li vs. Ca and Li vs. Mn, linear relationships were observed in the Alberta Basin. However, in the Horn River Basin, the data for these element pairs fall into two distinct groups based on Li concentration. Above 150 ppm Li, linear correlations persist, while below this threshold, the data exhibit a dispersed pattern, lacking discernible relationships. Similarly, in the Mackenzie Corridor, the data segregate into two groups, with linear relations emerging at higher concentrations of Ca or Mn, while at lower concentrations, the associations become nebulous. Additionally, the correlations between Li and K, Li and Cs, and Li and Rb also vary by location. In the Alberta Basin, linear relationships prevail. In contrast, the Horn River Basin displays exponential relations for Li concentrations below 50 ppm, transitioning to a scattered pattern at higher concentrations, indicating a complex interaction that might be influenced by varying geochemical processes. The Mackenzie Corridor is characterized by cubic relationships for these element pairs.

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