RARE EARTH ELEMENT ABUNDANCES & CHEMICAL ALTERATION IN MICROENVIRONMENTS OF THE MCMURDO DRY VALLEYS

A. Foerder[1], P. Englert[1], J. L. Bishop[2,3], C. Koeberl[4,5], E.K. Gibson[6],

[1]University of Hawaiʻi at Mānoa (Honolulu, HI; afoerder@hawaii.edu, penglert@hawaii.edu), [2]SETI Institute (Mountain View, CA), [3]NASA Ames Research Center (Moffet Field, CA), [4]Natural History Museum (Vienna, Austria), [5]Department of Lithospheric Research, University of Vienna (Vienna, Austria), [6]NASA Johnson Space Center (Houston, TX).

Abstract/Summary

The McMurdo Dry Valleys (MDV) region is the Earth's coldest and driest desert; mean annual air temperatures range from -25 to -20°C, with a mean annual precipitation of 15 g/cm^2/yr [2,5]. Investigations of alteration in MDV soils have found physical alteration to dominate, however, this is not to say that chemical alteration is not occurring, and possibly more so than previously thought. The aim of this study is to investigate soil provenance and the extent of chemical alteration by examining Rare Earth Element (REE) abundance in soils and their corresponding source rocks in the MDV. Because MDV conditions are not conducive to chemical alteration, special focus is given to microenvironments exhibiting data different from expected abundances and patterns. Similarities in climate, surface geology, and chemical properties of the MDV to Mars suggest similar processes to be taking place throughout the Martian landscape. Coordinating REE analyses with geochemical and mineralogical analyses of MDV microenvironments could aid in understanding alteration in the Dry Valleys and help constrain and reconstruct Mars' geochemical history.

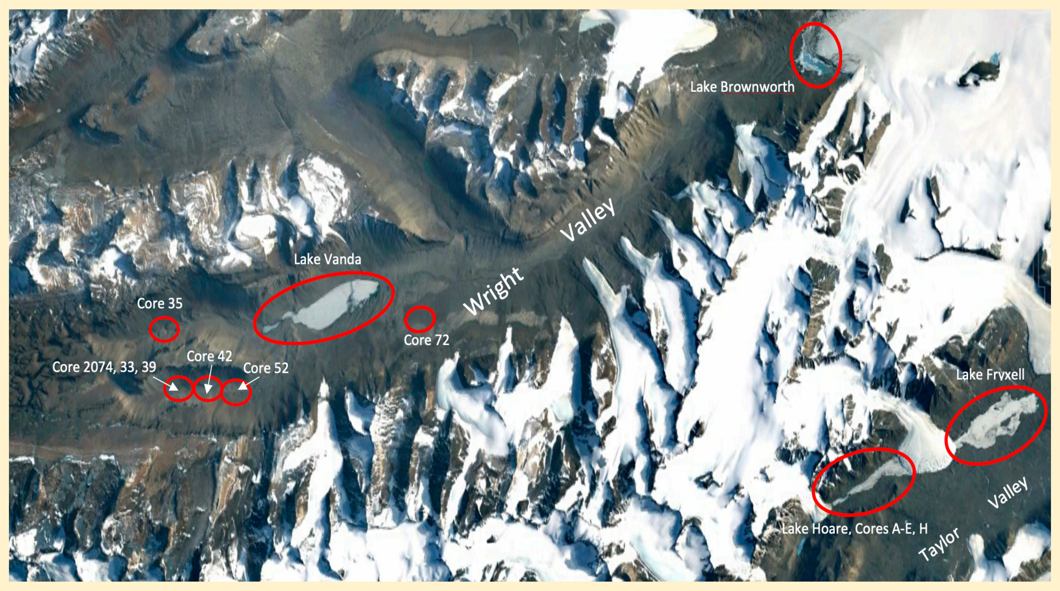

Figure 1: McMurdo Dry Valley sampling sites

Rare Earth Elements

A rare-earth element is one of 17 elements, 15 of which are known as lanthanides, the other two being scandium and yttrium, on the periodic table. They are of interest to geologists because of their immobility during chemical alteration processes, largely attributed to the small relative size of their ionic radii. Elements with larger ionic radii, such as potassium, are more mobile and soluble whereas elements with smaller ionic radii, such as REEs, tend to be more immobile and less soluble. These characteristics permit REEs to be effective tools for tracing soil provenance. Our work focuses on the abundance of ten REEs (La, Ce, Nd, Sm, Eu, Gd, Tb, Tm, Yb, and Lu), accessible through INAA.

Methods

Surface samples were collected on or near lakes Vanda (V), Brownworth (B), and Fryxell (F) [8], and cores from ponds in Upper Wright Valley (UWV) [9] and Lake Hoare (H) [13] (Figure 1). Samples were analyzed using standard Instrumental Neutron Activation Analysis (INAA) [7] and compared to potential source rocks in the MDV, based on available REE data. Source rock data include REEs from Granitoids [1], Beacon Sandstone [4], Ferrar Dolerite [3], Bonney Pluton, Valhalla Pluton, and Brownworth Pluton [1]. Of the source rocks, Granitoids exhibit the highest REE abundances, followed by Brownworth Pluton, Bonney Pluton, Valhalla Pluton, Ferrar Dolerite, and Beacon Sandstone. REE abundances were normalized to Solar System averages as in [6,12]. In Figure 1, Cores 2074, 33, and 39 from Don Juan Basin are grouped as one due to local proximity.

Results: Chemical alteration

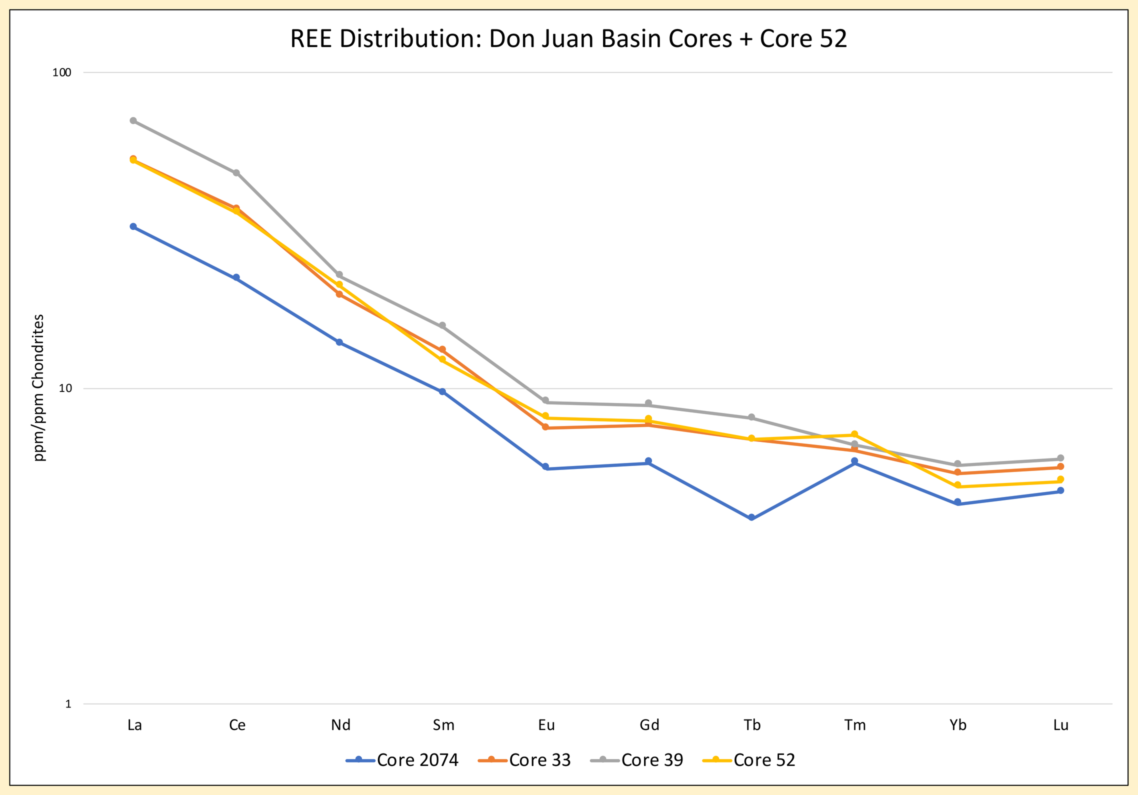

Figure 2: Rare Earth Element distribution, normalized to Solar System average, in Don Juan Basin cores (2074, 33, 39) and Core 52.

- All samples exhibit a slight negative Eu anomaly
- Core 2074 exhibits the lowest REE abundances of all the cores, and a significant negative Tb anomaly
- Core 52 exhibits a positive Tm anomaly
- Core 33 exhibits the highest REE abundances

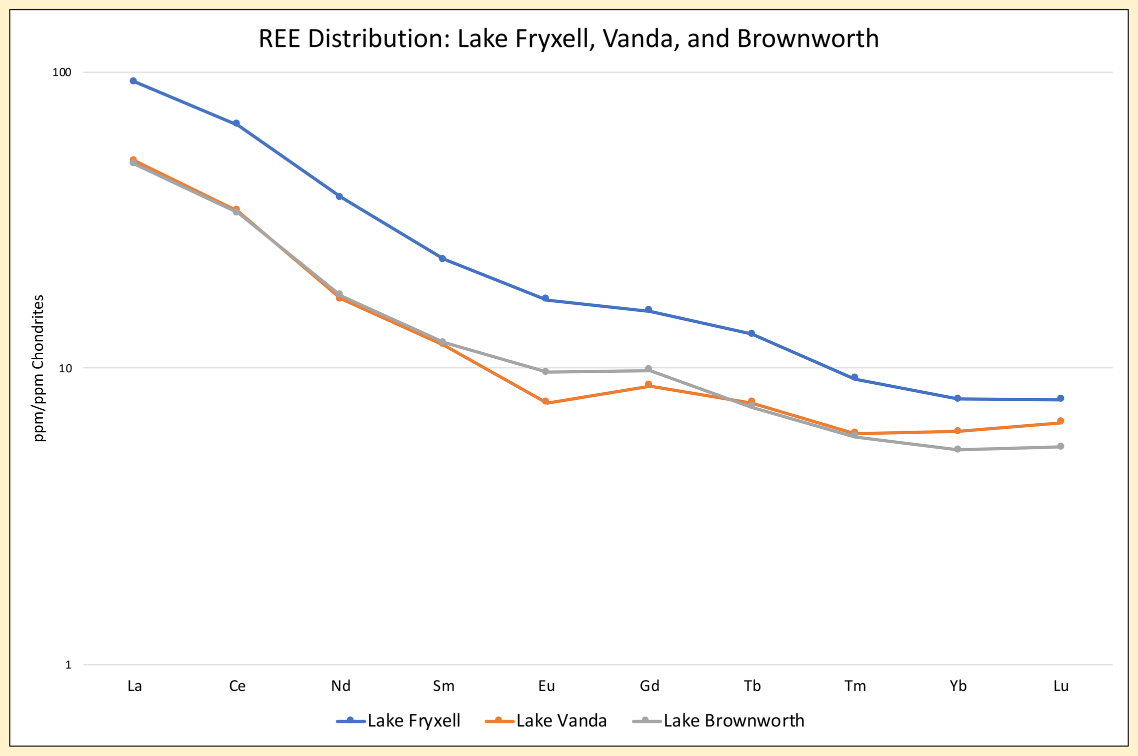

Figure 3: Rare Earth Element distribution, normalized to Solar System average, for Lakes Fryxell, Vanda, and Brownworth.

- All lakes exhibit relatively similar REE *trends*
- Lake Vanda and Brownworth exhibit very similar abundances. However, Lake Vanda displays a negative Eu anomaly and positive Yb and Lu anomaly.
- Lake Fryxell exhibits the highest REE abundances of the lakes.

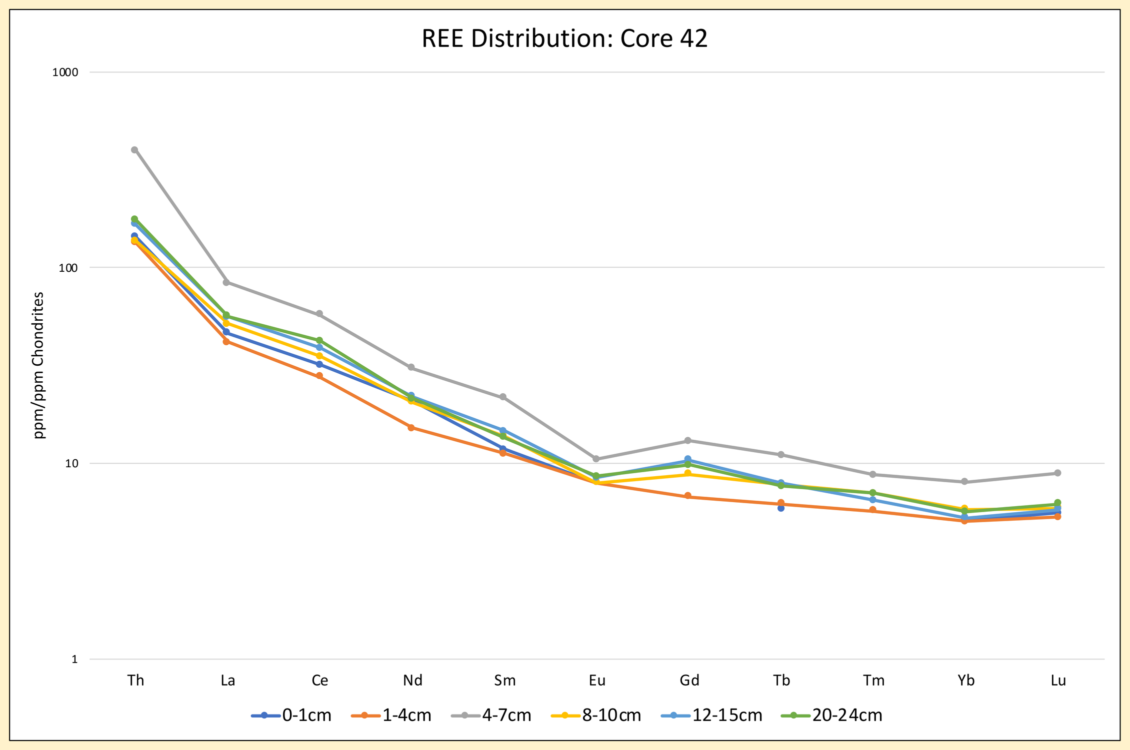

Figure 4: Rare Earth Element distribution, normalized to Solar System average, for Core 42 at VXE-6 Pond.

- Core 42 exhibits similar REE trends and abundances in nearly all samples.
- The sample from the 1-4 cm depth range exhibits the lowest REE abundance.
- The sample from the 4-7 cm depth range exhibits the highest REE abundance.
- Nearly all samples exhibit a negative Eu anomaly, with the most prominent in the 4-7 cm depth range.

Results: Sediment provenance

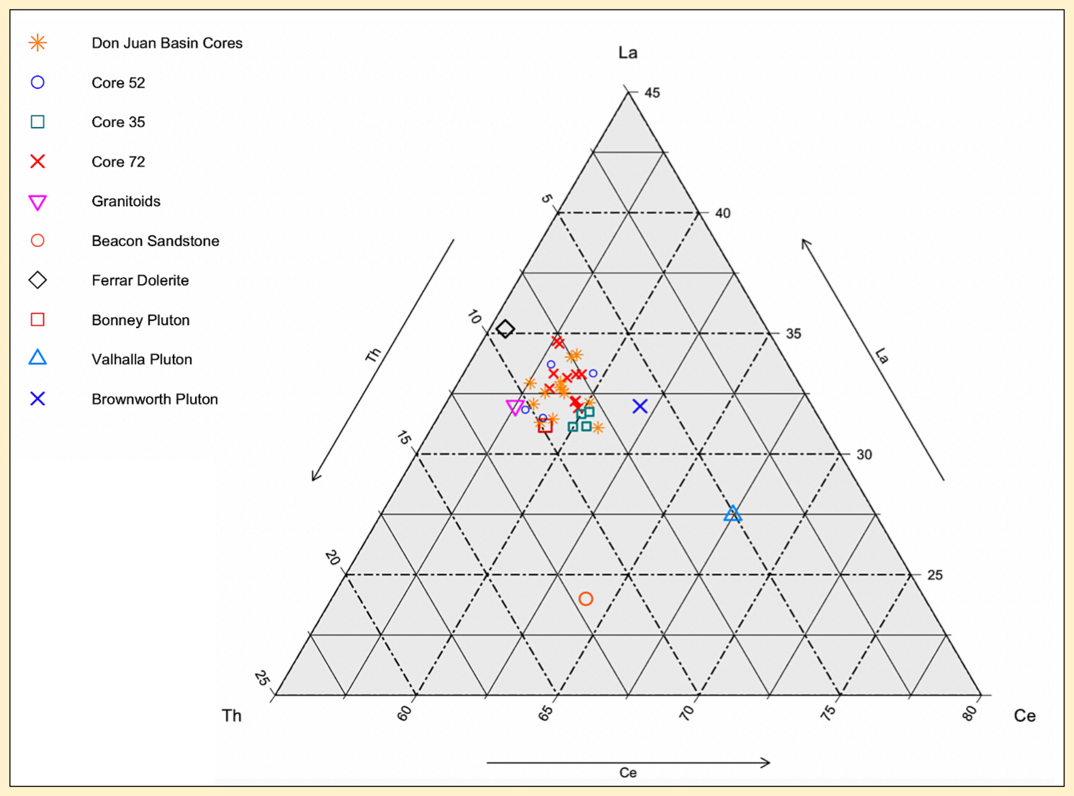

Figure 5: Ternary diagram of Th, La, and Ce abundances of Don Juan Basin Cores, Core 52, 35, and 72; Source rocks: Granitoids, Beacon Sandstone, Ferrar Dolerite, and plutons Bonney, Valhalla, Brownworth.

- All samples plot in the similar region suggesting similar origin; most likely Granitoids and Ferrar Dolerite.

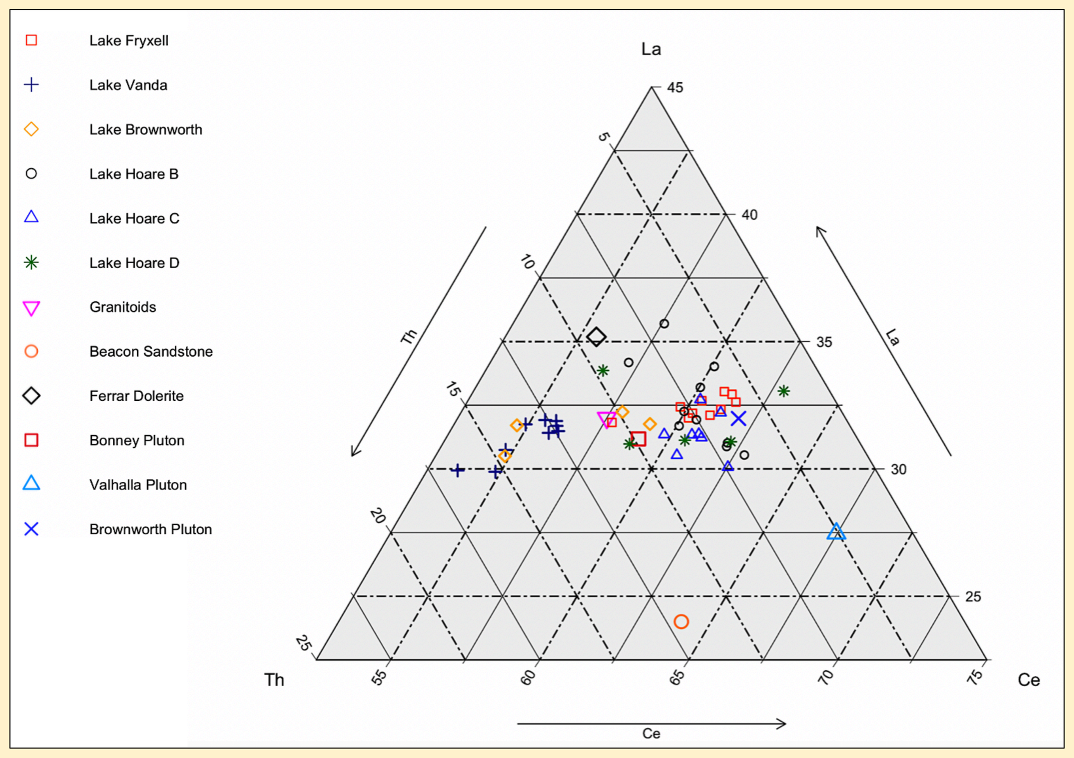

Figure 6: Ternary diagram of Th, La, and Ce abundances at Lakes Vanda, Fryxell, Brownworth, and Hoare; Source rocks: Granitoids, Beacon Sandstone, Ferrar Dolerite, and plutons Bonney, Valhalla, Brownworth; Lakes Fryxell, Vanda, and Brownworth are all surface samples; Lake Hoare samples are all cores.

- Lakes V and B exhibit relatively similar abundances, sediment origin is likely Granitoids and Ferrar Dolerite. Possibly Bonney Pluton.
- Lake F exhibits relatively high abundances of La and Ce, sediment origin is likely Granitoids, Ferrar Dolerite, and Bonney Pluton.
- Lake H cores show relative variation but plot in a similar region of the diagram. Sediment origin is likely Granitoids, Ferrar Dolerite, and Bonney Pluton.

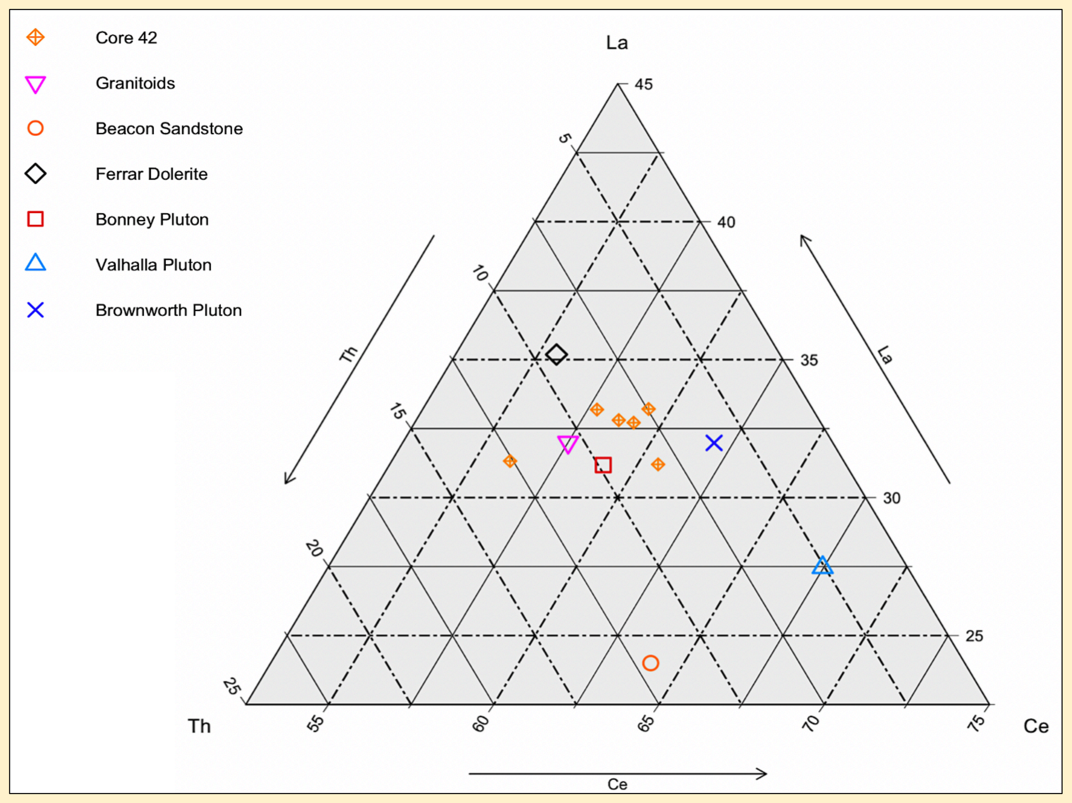

Figure 7: Ternary diagram of Th, La, and Ce abundances of Core 42; Source rocks: Granitoids, Beacon Sandstone, Ferrar Dolerite, and plutons Bonney, Valhalla, Brownworth.

- All Core 42 samples, except for that in the 4-7 cm depth range exhibit similarity in La, Ce, Th abundance.
- Based on the diagram, the most likely origin for Core 42 sediments is Granitoids and Ferrar Dolerite.

Results cont…

Figure 4 shows REE distribution as a function of depth for Core 42. Samples at 1 cm, 10 cm, 15 cm, and 24 cm depths exhibit similar REE abundance trends, while samples at 4cm and 7 cm depths experience comparatively low (4 cm) and high (7 cm) REE abundances, with the sample at 4 cm not experiencing a negative Eu anomaly, which is likely due to Na_2O enrichment. Generally, a negative Eu anomaly is attributed to CaO and Na_2O depletion [10]. A horizon of elevated elemental abundance in the 4-7 cm depth range suggests a clay layer undergoing active alteration [11]. Elevated REE abundance in the 4-7 cm depth range corroborates these findings.

Interpretation

Surface sediments collected near Lakes Fryxell, Vanda, and Brownworth all group in a similar region of Figure 6, as do core samples from DJB in Figure 5. These consistent trends across the surface sediments indicate that similar geologic histories governed processes at these disparate sites in both Wright and Taylor Valley.

Variations of REE abundances between different core samples are attributed to the local geologic setting of cores. Examples include Core 39, which is located at the base of an alluvial fan, Core 33 sits in the path of a wet encrustation, and Core 2074 sits in the center of Don Juan Pond where the highest salinity and lowest REE abundance is reported. REE abundances in Figure 2 exhibit comparable trends, with variations in total abundance. Core 2074 from Don Juan Pond has the lowest Tb abundance of all cores presented in this study which could be due to dilution from high salt content. It also suggests that REEs are relatively immobile and insusceptible to chemical alteration.

Implications

Due to the extreme cold and aridity of both the MDV and Martian landscape, terrestrial analysis of REE rock and soil data could be compared to Martian rover REE rock and soil analysis to test the efficacy of micro-environments in the MDV as analogs for Martian microenvironments. Additionally, due to their immobility, REEs could be well-suited for tracing soil provenance in terrestrial and Martian landscapes. Coordinating REE analyses with geochemical and mineralogical analyses of MDV microenvironments could aid in understanding alteration in the Dry Valleys and help constrain and reconstruct Mars' geochemical history. From this, the scientific community could move closer to answering questions regarding the potential of life and habitability outside of Earth.

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