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Geochemistry of mineral dust in the McMurdo Dry Valleys Region, Antarctica

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Abstract

The transport and deposition of windblown materials are major processes in the ice-free areas of polar regions. The deposition of aeolian material provides connectivity within the ecosystems of these regions and is integral in understanding geochemical balances and exchanges between landscape units. We have analyzed materials deposited on glacier and permanent lake-ice surfaces as well as geomorphological features formed by aeolian processes in the largest ice-free area in Antarctica, the McMurdo Dry Valleys (~78 °S) in order to determine the source of this sediment. This presentation will focus on the materials collected from the glacier and lake surfaces. The bulk of sediment movement occurs during foehn events in the austral winter that redistribute material throughout the region. The majority of these samples were sand size (>80 %) by weight. Samples containing the highest silt size were from the glaciers in the eastern portion of the Taylor Valley which is the most downwind position. Major rock-forming elements were analyzed using Standard XRF techniques. The alkali metals were depleted with respect to the Upper Continental Crust (UCC), in both the sand and silt fractions, while the alkaline earths were enriched. The TiO_2, Fe_2O_3 and Al_2O_3 in the sands are similar to UCC values. The major element geochemistry of the aeolian material suggests that it is a mix of the four major rock types in the Valley itself: PreCambrian basement complex, Beacon Sandstone, Ferrar Dolerite and McMurdo Volcanics. Sr isotopic measurements of the fine grained materials from the glacier surfaces indicate the material is similar to the soils from their respective glacier/lake basins. Nd isotope values of this material lie intermediate to the rock values, indicating multiple sources of the aeolian material. The Sr and Nd isotopic data do not plot within the fields of dust from either Vostok or Dome C ice cores which has been interpreted as coming primarily from South America. All of our data suggest a local source of the majority of aeolian material deposited with Taylor Valley.

Keywords: Dust, aeolian deposition, major element chemistry, provenance, McMurdo Dry Valleys.

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1. Introduction

Aeolian transport in the McMurdo Dry Valleys (MDV), and cold regions in general, is dominated by the movement of sand-sized particles derived from parent material and regolith (Lancaster, 2002). As a fluid medium, wind can only readily transport via suspension fine sand and smaller particles. Larger particles are moved shorter distances through saltation. Aeolian sediment flux is greatest where winds maintained at greater speed (Gillies et al., 2013). Low soil moisture and lack of overland flow outside of stream channels (Fountain et al., 1999) allows saltation to readily occur year round when winds are strong enough to allow particle deflation (Gillies et al., 2013).

Aeolian deposition represents a fluctuating source of weatherable material within the MDV environment. Deposition on lake or glacier ice affects the albedo of the ice. On glaciers this leads to the formation of cryoconite holes, which impact glacier melt dynamics and ultimately the composition of streams (Fountain et al., 2004). Aeolian deposition on lakes increased melting and flux of sediment to the lake (Jepsen et al., 2010). Additionally, aeolian material is responsible for the redistribution of solutes, nutrients, and organisms throughout the MDV landscape (Deuerling et al., 2014; Šabacká et al., 2012).

The objectives of this study are to determine the chemical composition of MDV aeolian materials and from this information ascertain their origin. In particular, we are interested in: 1) if the composition of the aeolian material is derived from local materials and 2) if it isotopically resembles dust preserved in ice cores in East Antarctica, which may indicate the MDV is a source of dust inland.

2. Field area description

The MDV are the largest ice-free area of Antarctica covering ~4800 km^2 located at 76.5^o -78.5^{o}S, 160-164^{o}E. The MDV are one of the coldest and driest ecosystems globally: mean annual temperatures in the MDV is -15 ºC to -30 ºC (Doran et al., 2002) and mean annual precipitation is ≤5 cm water equivalent that falls as snow (Fountain et al., 2010).

An east-to-west climatic gradient exists within the MDV, and is most pronounced within the Taylor Valley. Humidity and precipitation both increase with proximity to the coast in the eastern terminus; wind speed and temperature increase toward the ice sheet in the west (Doran et al., 2002). These gradients are largely associated with the interaction of the coastal and foehn wind systems that predominate in the MDV (Fountain et al., 1999).

3. Methods

Sites of aeolian deposition were identified and sampled during the 2008 austral summer. The sites can be subdivided into three general descriptions: ice surface (lake and glacier), "landform", and elevated sediment traps (EST). Samples were collected in new new Whirl-Pak bags with clean, plastic utensils. Nitrile gloves were worn at all times.

About 100 g of the homogenized sample was mechanically shaken for 15 minutes; this process was repeated until the entire sample had been separated. Each size fraction was weighed to obtain percent gravel (≥2 mm), sand (0.063-2 mm), and fines (≤63 μm). The sand and fine size fractions of each sample was then crushed in an alumina ceramic shatterbox for a minimum of 8 minutes until a grain size of less than 2 μm was achieved.

Powdered samples were analyzed for total loss on ignition, prepared, and analyzed for major elemental oxides according to standard x-ray fluorescence techniques (e.g., Deuerling, 2010). Due to mass limitations of the fine size fraction, all of the fines samples from each feature were combined. Samples were analyzed in triplicate and an average concentration calculated. This average was then normalized to the sum of concentrations using LOI data previously determined. Relative standard deviation were calculated for the triplicate runs and determined to be ±5 % and generally less than ±1 %.

A portion of the fine size fraction of from the Canada, Commonwealth, and Howard Glaciers, as well as a bulk sample from the Taylor Glacier were analyzed for $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ at the Thermal Ionization Mass Spectrometry facility at Boston University (e.g., Harvey and Baxter, 2009).

4. Results

4.1 Particle size distribution

Fig. 1 presents a comparison of particle sizes in the bulk aeolian sediment samples. All but five samples have a composition of greater than 80 % sand by weight. Silt composition ranges from 0 to 15.8 % by weight. Samples containing the greatest amount of silt were collected from glacial surfaces in the eastern Fryxell and Hoare basins of Taylor Valley. Gravel composition ranges from 0 to 60.0 % by weight. The samples with the highest composition of gravel are lake and glacial surfaces of the Bonney basin of Taylor Valley, in addition to Bull Pass located between Wright and Victoria Valleys.

4.2 Major elements

A series of major elemental oxide variation diagrams for individual sites with published values for the Beacon Sandstone (BS), Ferrar Dolerite (FD), PreCambrian Basement Complex (BC), and McMurdo Volcanics (MV) normalized to the Upper Continental Crust (UCC; Taylor et al., 1981) is presented in Fig. 2. Rock formations of the MDV and the aeolian sediments of this study demonstrate a wide variation in composition. The geochemical signature of the aeolian sediment samples appears to be largely explained by the mixing of the four MDV rock types. The alkali metals (Na_2O+K_2O) are depleted with respect to UCC in both sand and silt particle sizes; MgO, MnO, and CaO are enriched with respect to UCC in both particle sizes. UCC plots within the sand values of TiO_2, Fe_2O_3, and Al_2O_3. The silt values of TiO_2 and Fe_2O_3 are enriched compared to UCC.

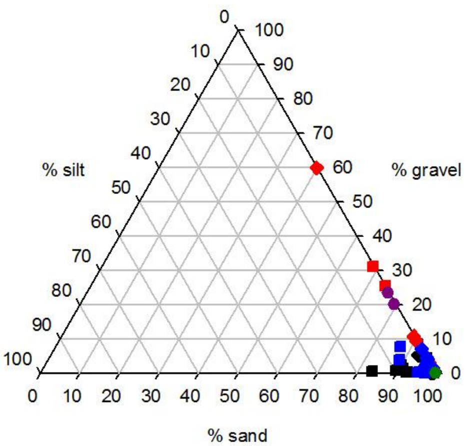

Fig. 1. Grain size distribution of bulk aeolian sediments.

4.3 Isotopic provenance

Sr isotopic values from the glaciers are similar to the soils from their respective basins: Commonwealth is similar to Lake Fryxell soil, Canada is similar to Canada soils, and Taylor is similar both Lake Bonney soil (Fig. 3). $^{87}Sr/^{86}Sr$ versus $\varepsilon_{Nd}(0)$ of the glacial silts do not lie within the field of the East Antarctic ice cores, but do lie within the greater MDV field (Fig. 3). This provides further support for a local source of MDV aeolian sediments.

5. Discussion

5.1 Wind and geomorphology as sorting factors

Wind accounts for the sorting seen in the samples (Fig. 1). The samples with the most silt are from glaciers in the Fryxell basin, while those with the greatest gravel content are lakes from the Bonney basin and Bull Pass. Landscape juxtaposition and sample elevation can explain these trends: Bonney basin lakes and Bull Pass samples were collected at low points in the valley adjacent to steep talus slopes. Fryxell basin glaciers, especially the Commonwealth Glacier with the highest relative percentage of silt, terminate 20+ m above the valley floor and are removed from the direct influence of gravitational settling.

5.2 Aeolian sediment source and composition

There is a difference in chemical composition between the sand and silt size fractions. The distinction is most notable in SiO_2 concentration: silts range from 50.8 to 57.8 % and sands range from 58.7 to 73.7 % SiO_2 by weight (Deuerling et al., 2010). The BS contains >95 % quartz clasts that are more resistant to weathering than softer, less resistant minerals such as calcite/pyroxenes/etc. These minerals are more easily broken down and removed by wind and weathering, causing an enrichment in the fine size fraction of less siliceous, less resistant minerals. Conversely, the sand size fraction of aeolian deposits would be enriched in more resistant, siliceous minerals.

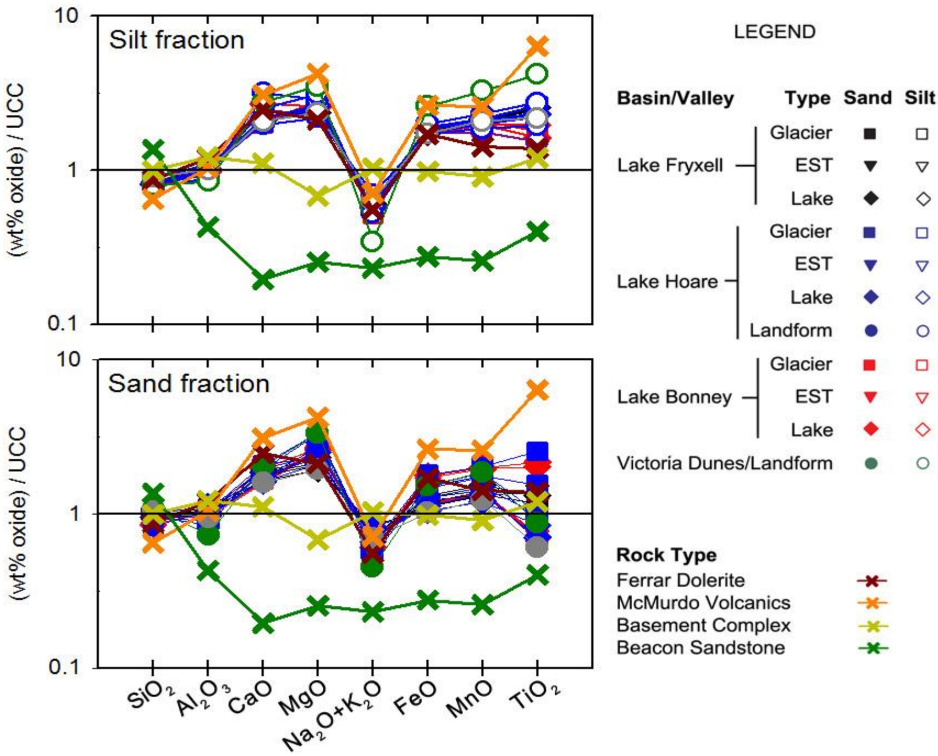

Fig. 2. Major element oxide variation diagrams of aeolian samples at silt and sand sizes. Local MDV rocks are plotted using values from Roser and Payne (1989). All data are normalized to UCC.

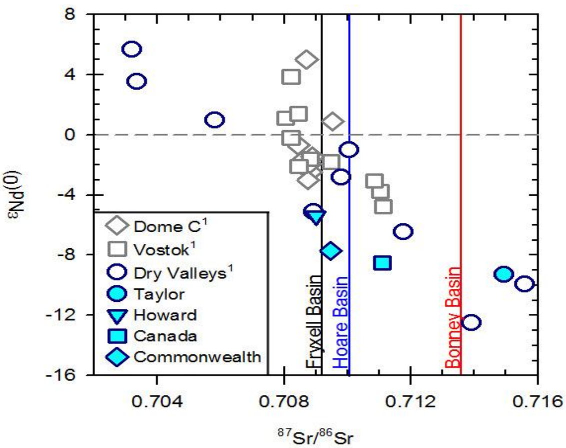

Fig. 3. $^{87}Sr/^{86}Sr$ vs ε_{Nd} fields of ice core dust, local MDV source areas, and silt deposited on glaciers in the MDV from this study. Fryxell/Hoare/Bonney Basin data from Jones and Faure (1978). [1]Data from Delmonte et al. (2004).

Much of the variation in both the silt and sand elemental data can be attributed to the FD (Fig. 2). This is supported by the rare earth element investigations carried out by Baccolo et al. (2014). Relative depletion of Na_2O+K_2O, CaO, and Al_2O_3 compared to these two rock types, however, cannot be explained by the mixing of these two end members. Possible explanations for this depletion are contribution of the BC or the BS to the sample, and the chemical weathering of the silt fraction. Relative depletion of the labile cations from FD and UCC indicates chemical weathering is likely.

The accumulation of salts cannot be discounted as a possible source of variation in the major element data, though based on the high SiO_2 content, their influence would be diminished. The most common salts in the Taylor Valley contain Na and Ca (Keys and Williams, 1981). Many of these salts are readily soluble and are responsible for the flush of solutes seen at the beginning of the melt season (Deuerling et al., 2014; Fountain et al., 1999).

The range of $^{87}Sr/^{86}Sr$ demonstrated by the silt-sized aeolian material from the Taylor Valley glaciers (0.708993–0.714936) are most like the FD (0.71050–0.71270). $^{87}Sr/^{86}Sr$ values indicate that they most resemble the soils of their respective basins (Fig. 2), providing evidence for a local, mixed source of aeolian material.

5.3 Potential inland transfer of aeolian material

Glacial silt $^{87}Sr/^{86}Sr$ and $\varepsilon_{Nd}(0)$ indicate that the MDV do not contribute to the ice core dust record (Fig. 3). Increased dust flux in ice cores correlates to glacial stages; during LGM ice-free areas would be more restricted than at present due to the growth of the Antarctic ice sheets and the development of the lake system in the MDV (Hall and Denton, 2000). Also compelling is the lack of SO_4 and CO_3 salts in the ice core dust record (Delmonte et al., 2004), as gypsum and carbonates are found throughout the MDV in appreciable quantities (Keys and Williams, 1981). Instead, MDV aeolian deposition is local in extent and not well-mixed, suggesting little transport between basins/valleys and that this is a “source limited” system. However, the aeolian material that can be deflated and carried in suspension (<20 µm; Baccolo et al., 2014) must be specifically investigated to fully rule out the possibility of inland transport.

6. Conclusions

The geochemistry presented in this study reveal a complex interaction of wind with major bedrock types and external influence in the formation of salts. Isotopic data indicates a local source of aeolian material, which is explained by the mixing and weathering of the four source rocks. The FD accounts for the majority of variation to the geochemical signatures of MDV aeolian silt and sand. Chemical weathering and the influence of other major rock types must also be considered. The inland transfer to East Antarctica, however, is unlikely based on the evidence presented here. Isotopic data from aeolian silts collected on glacial surfaces indicate that they are not related to the East Antarctic ice core records. Thus, wind interaction is a strong, local force in the MDV.

7. Acknowledgements

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