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Major Oxide Chemistry of Mineral Dust, McMurdo Dry Valleys, Antarctica: Revisited

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Abstract

At the 2014 DUST meeting some of the first geochemical data of aeolian materials from the McMurdo Dry Valleys (MDV), Antarctica were presented. The MDV is the largest ice-free area in Antarctica, and the transport and deposition of windblown materials are thought to play an important role in landscape connectivity, which in turn has important ecological consequences. The previous work was on samples collected only 30cm off the ground and probably represents material transported primarily by saltation. In this study, we have collected samples at multiple heights, including at 100cm above the ground surface. Samples were collected during two different periods during 2013–2015. Bulk samples were analyzed by XRF techniques for major oxides. The CIAs of the aeolian material indicate little chemical weathering, and the values varied little with respect to height above the surface. The least weathered material comes from the highest elevation valleys, where liquid water is thought to be less available for chemical weathering to occur. These data are similar to those reported for the original, 30cm height samples, and are most similar to the local Ferrar Dolerite. Additionally, Al_2O_3:TiO_3 values indicate differences in the weathering of available materials spatially, particularly with height above the surface. These data indicate multiple terrestrial sources contributing to the geochemistry of aeolian material, even in cold and arid environments.

Keywords: Antarctica, McMurdo Dry Valleys, Bulk geochemistry, Chemical weathering

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1. Introduction

The major dust producing regions are located in the Northern Hemisphere, such as the Saharan and Gobi Deserts (Tanaka & Chiba, 2006). Atmospheric winds transport material from these deserts globally, but mixing between the North and Southern Hemispheres does not typically occur until the Intertropical Convergence Zone (ITCZ) shifts southward. This atmospheric boundary generally isolates polluted NH air from cleaner SH air (Prospero & Carlson, 1972). Further, ocean and atmospheric circulation boundaries within the hemispheres can isolate environments on smaller scales. One such occurrence is around Antarctica.

Antarctica is generally isolated from other continents and dust producing regions by the circumpolar current, which passesthrough the Drake Passage and beneath Australia and Africa. The circumpolar current plays animportant role in maintaining cold and arid conditions across the continent. Antarctica is primarily overlain by the East and West Antarctic Ice Sheets, which limits chemical weathering to areas beneath the ice and the relatively small ice-free areas around the continent (Siegert et al., 2001). These ice-free areas, specifically the McMurdo Dry Valleys (MDV) which are the largest ice-free area, are believed to be primary sources of dust to local areas (Deuerling et al., 2014). Interpretation of the geochemistry of Antarctic aeolian material will aid in our understanding of weathering and landscape evolution in cold desert environments.

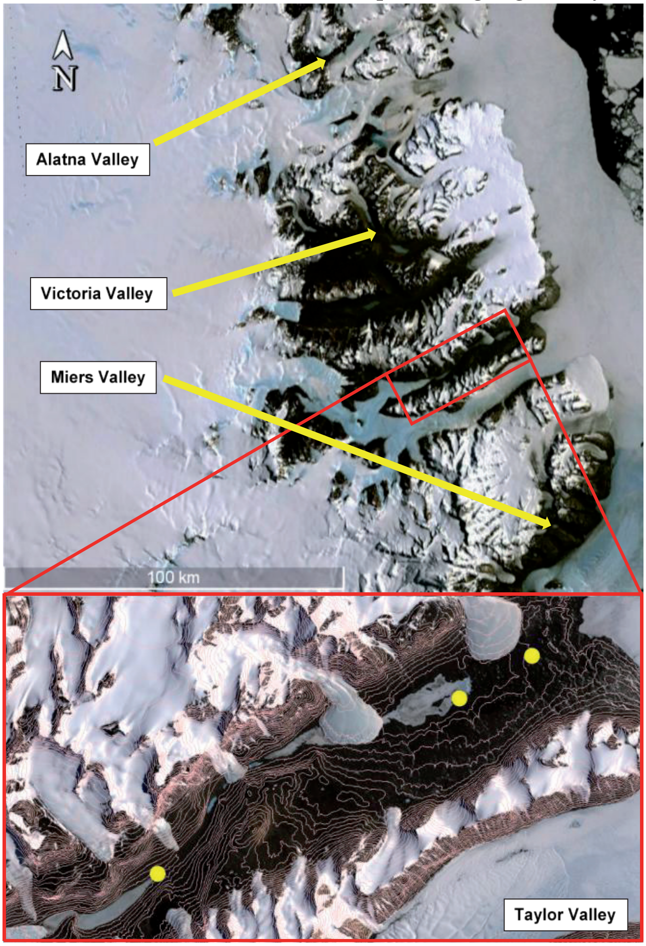

Fig. 1. The McMurdo Dry Valleys, located in Southern Victoria Land, Antarctica. Samples were collected from Alatna, Victoria, Taylor, and Miers Valleys. An insert of Taylor Valley is shown indicating additional sampling at Explorer's Cove, Lake Fryxell, and East Lake Bonney (from right to left)

2. Methods

Wind-blown materials were collected at approximately 5, 10, 20, 50, and 100 cm above the surface from four valleys in the McMurdo Dry Valleys Antarctica (Fig. 1) from 2013 through 2015. The sampling scheme includes coastal, inland, low elevation, and high elevation sites and encompasses an array of paleoenvironments. Un-sieved material was ground using a mortar and pestle for bulk geochemical analysis. Major oxide percentages were determined for 35 samples on sample beads made through ore grade borate fusion at SGS Canada Inc. and analyzed via X-ray fluorescence (XRF).

An indicator of the degree of chemical weathering sediment has experienced is the Chemical Index of Alteration (CIA) (Equation 1). CIA values were calculated for aeolian samples in each valley and elevational profiles were developed between the bottom (~5 cm) and top (~100 cm) samples (Fig. 2). The CIA was developed to measure the extent of alteration of primary igneous minerals, such as feldspars, to clays, such as kaolinite (Nesbitt and Young, 1982), but has been used more broadly to quantify silicate weathering (Price and Velbel, 2003; Shao and Yang, 2012; Deuerling et al., 2014). As chemical weathering occurs, alkaline earth and alkali metals are preferentially solubilized from the minerals present relative to Al, thereby increasing the CIA value. As weathering continues, the denominator approaches the numerator, further increasing the CIA value towards 100%.

$$\text{CIA} = \frac{Al_2O_3}{Al_2O_3 + CaO + Na_2O + K_2O} * 100 \quad (1)$$

3. Results

CIA values show that wind-blown material from all valleys is poorly weathered and varies little with respect to height above surface and between valleys (Fig. 2). Values ranged from 51.2% to 53.4% in Taylor Valley and 43.6% to 54.7% in the other valleys (Figure 2), with Victoria Valley being the least weathered at 43.6%. For reference, unweathered rocks, such as basalts, have low CIAs (< 50%), while highly weathered rocks, such as sandstone, have higher CIAs (> 60%) (Nesbitt and Young, 1982). Deuerling et al. (2014) found CIA values ranging from 44% to 57%, which were similar to the values reported here, and strongly indicates limited chemical weathering of the total material.

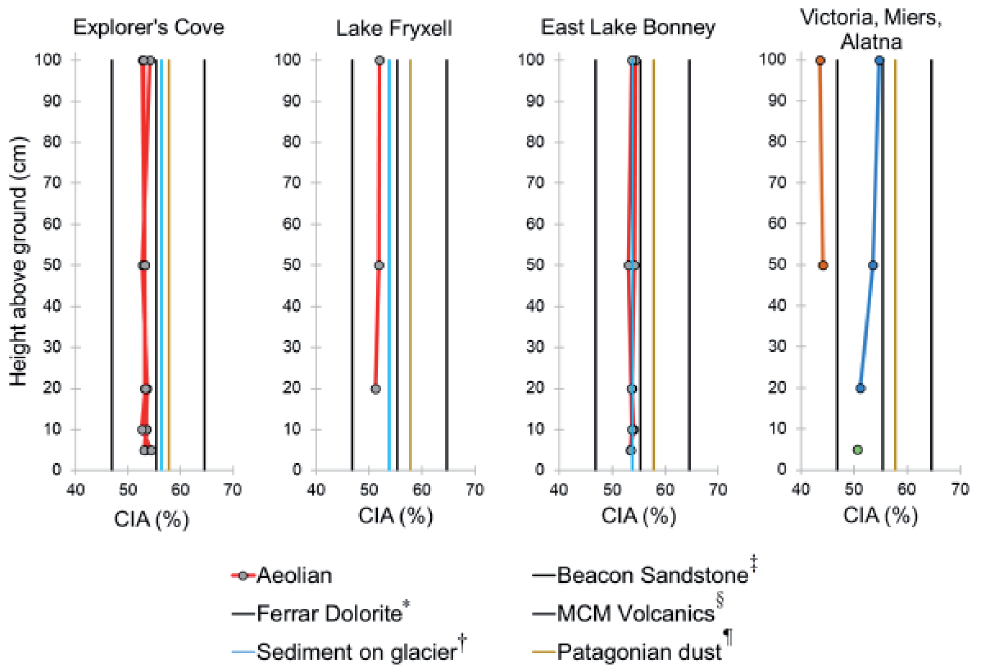

Fig. 2. CIA values for aeolian sediment (red line with points), average McMurdo Dry Valley source rocks (black lines), Patagonian dust (beige line), and average nearby sediment on glaciers and lakes (blue lines). Values are plotted against collection height and compared to potential local sources. In the fourth CIA diagram, orange is Victoria Valley, green is Alatna Valley, and blue is Miers Valley.[*Antonini et al. (1999), †Deuerling et al.(2014) ‡Roser and Pyne (1981), §Cooper et al. (2007), ¶Gaiero et al. (2003)]

4. Discussion

The CIA profiles are compared to average CIA values of local MDV rock types that are potential sources of this aeolian material, specifically McMurdo Volcanics -46.9% (Cooper et al., 2007), Ferrar Dolerite -55.4% (Antonini et al., 1999) and Beacon Sandstone -64.5% (Roser and Pyne, 1981). The CIAs for the average sediments on ice covered surfaces (Deuerling et al., 2014) and dust from Patagonia (Gaiero et al., 2003), of which has previously been identified in East Antarctic ice cores (Basile et al., 1997), were also included.

Compared to these potential material sources, the CIAs of aeolian sediment were an intermediate between the poorly weathered end-member McMurdo Volcanics and the Beacon Sandstone, and were most similar to Ferrar Dolerite (Figure 2). Patagonian dust had higher CIA values than MDV aeolian material, and even sediment on lake ice (Deuerling et al., 2014) which can experience chemical weathering during seasonal ice cover melting in the austral summer. Based on the placement of elevational CIA profiles in relation to other sediments and rocks types found in Antarctica, MDV aeolian CIA values suggest minor silicate chemical weathering of material, and a mixture of local source rocks.

To supplement our understanding of the types of material contributing to Antarctic dust, Al to Ti oxide ratios were calculated and compared between all locations (Fig. 3).

Al_2O_3/TiO_2values less than 7 indicate a basalt source, while values greater than 15 indicate a granite source.

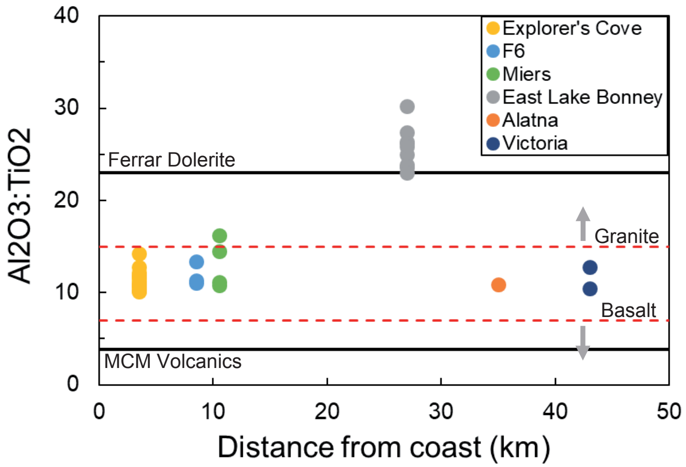

Fig. 3. Al and Ti oxide ratios with distance from the coast. Values below 7 indicate a basalt source (lower red line), while values above 15 indicate a granite source (upper red line). Average McMurdo Volcanic Group and Ferrar Dolerite compositions are shown for comparison

All locations, with the strong exception of East Lake Bonney, indicate a mixture of sources between granite, basalt, and perhaps dolerite. The samples plotting below the granite line are greatly influenced by a basalt component. East Lake Bonney has an overwhelming granite source and plots closer to Ferrar Dolerite, which was already observed in the CIA profiles. Interestingly, even locations such as Victoria Valley and Alatna Valley, which have not been as heavily modified by the McMurdo Volcanic Group from Ross Island as locations close to the coast, have Al to Ti ratios suggesting a basalt source.

Unlike the CIA values, Al_2O_3/TiO_2 values do vary with distance above the surface. Generally, the aeolian materials are relatively more enriched in Al at ~100 cm compared to lower heights (Fig. 2). While the implications of these variations with respect to weathering are unclear, these data do indicate minor, but significant differences in the material near and further away from the surface.

5. Conclusions

Chemical weathering is most extensive in temperate and tropical areas with high amounts of rainfall. Weathering of rocks creates clays and soluble salts and nutrients which support aquatic and terrestrial ecosystems. In polar desert environments, such as the McMurdo Dry Valleys, chemical weathering is generally limited to fixed proglacial stream channels and their extensive hypothetic zones (Gooseff et al., 2002). Winds have been shown to transport soluble salts and nutrients which can modify the surface chemistry of depositional regions. Chemical Index of Alteration values for MDV aeolian material suggest little chemical weathering of local lithology, even at 100cm above the surface. The material appears to be primarily a mixture of the McMurdo Volcanic Group and Ferrar Dolerite, with little contributions of Beacon Sandstone, though high Al_2O_3/TiO_2 ratios at East Lake Bonney may suggest an additional sandstone source.

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