Chemical weathering of Miocene sediments from the Dry Valleys, Antarctica

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1. Introduction

The chemical index of alternation (CIA) is an effective tool characterize the extent of weathering in sediments (Fedo et al., 1995). The goal of this project is to use the CIA of dated sediments in the Dry Valleys of Antarctica to gain a better understanding of past weathering environments. Today little weathering takes place under the cold and nearly waterless climate conditions. Prior to the start of polar-desert conditions at 13.8 Ma, however, glaciofluvial sedimentary sequences and fossil-rich lacustrine deposits suggest that surface water was much more common and temperatures were above freezing for several months of the year (Lewis et al., 2007; 2008).

Research questions: Prior to the permanent shift to cold-polar conditions in middle Miocene time, was the weathering environment more intense than that of today? Can the CIA of sediments be used to assign sediments to an age range of either pre or post mid Miocene?

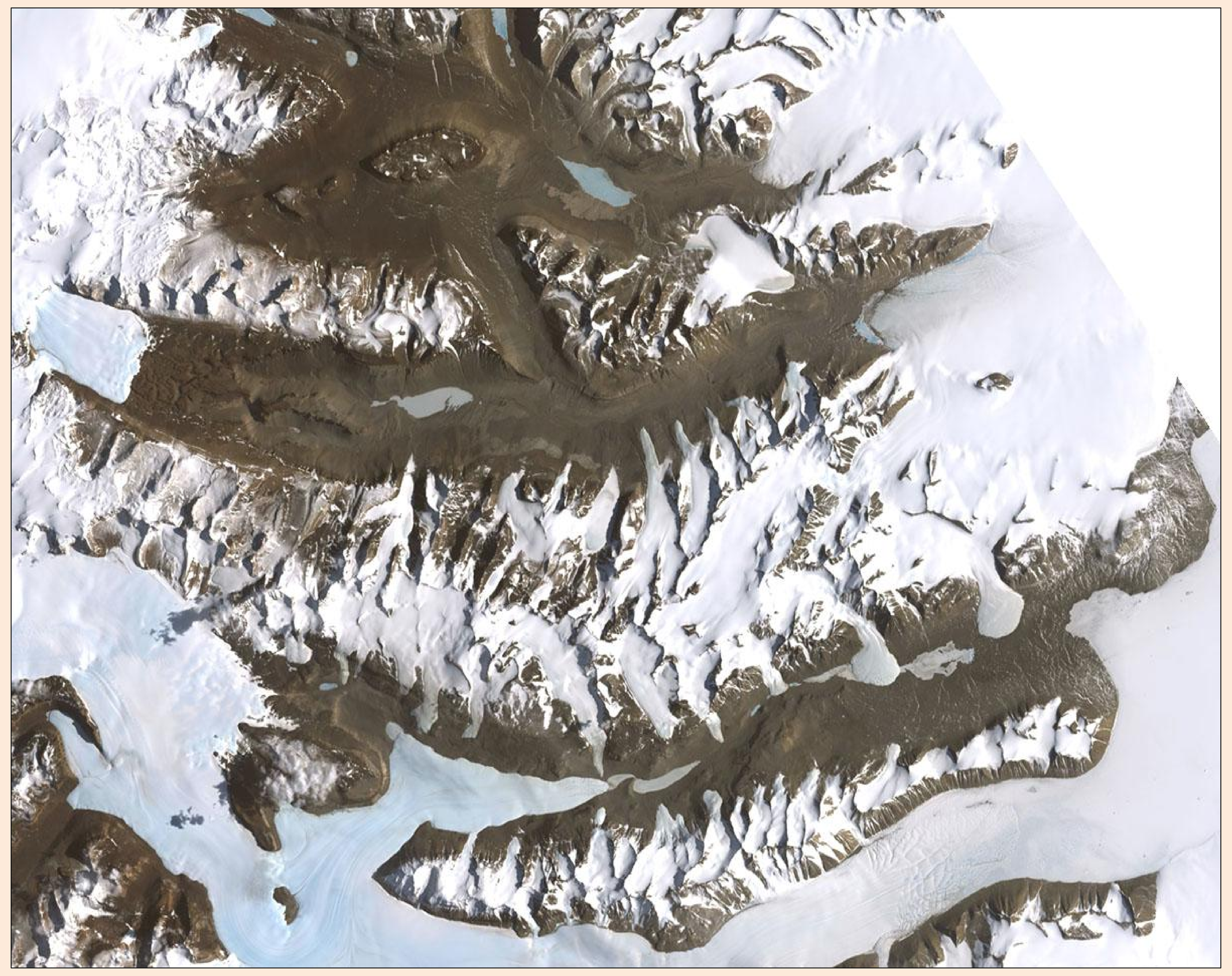

Figure 1. Satellite map of McMurdo Dry Valleys

3. Results

Modern samples:

- Modern streams in Taylor Valley show CIA values ranging from 40 to 44, with an average of 42. Some of these samples might be comparable in age to Holocene debris flows of Mount Jason, Mount Aeolus, and northern Bull Pass.

Holocene-aged samples:

- Mount Aeolus Holocene-age alluvial fan CIA values range from 40 to 44 (avg. = 42).
- Mount Jason Holocene-age alluvial fan CIA values range from 36 to 51 (avg. = 44).
- Holocene-aged undated debris flow near Mount Cerberus in Bull Pass shows CIA values ranging from 37 – 41 (avg. = 39).

Miocene-aged samples:

- Samples taken from Western Olympus Range range in CIA values from 43 to 78, with an average value of 66. These samples, having been dated at >13.85 Ma, near the mid-Miocene climate shift, may still represent wetter climates occurring during the shift.
- CIA values for the 19 Ma group from Friis Hills average 53 , indicating a wetter environment.

Analysis of results

The overall CIA trend for the samples is approximately parallel to the A-CN trend line on an A-CN-K plot, consistent with increased weathering in the older samples. Samples from the Friis Hills show slight variation from the expected trend toward K. Bivariate element comparisons show distinct groupings, potentially allowing sediments to be chemically fingerprinted.

Courtesy Macalester College

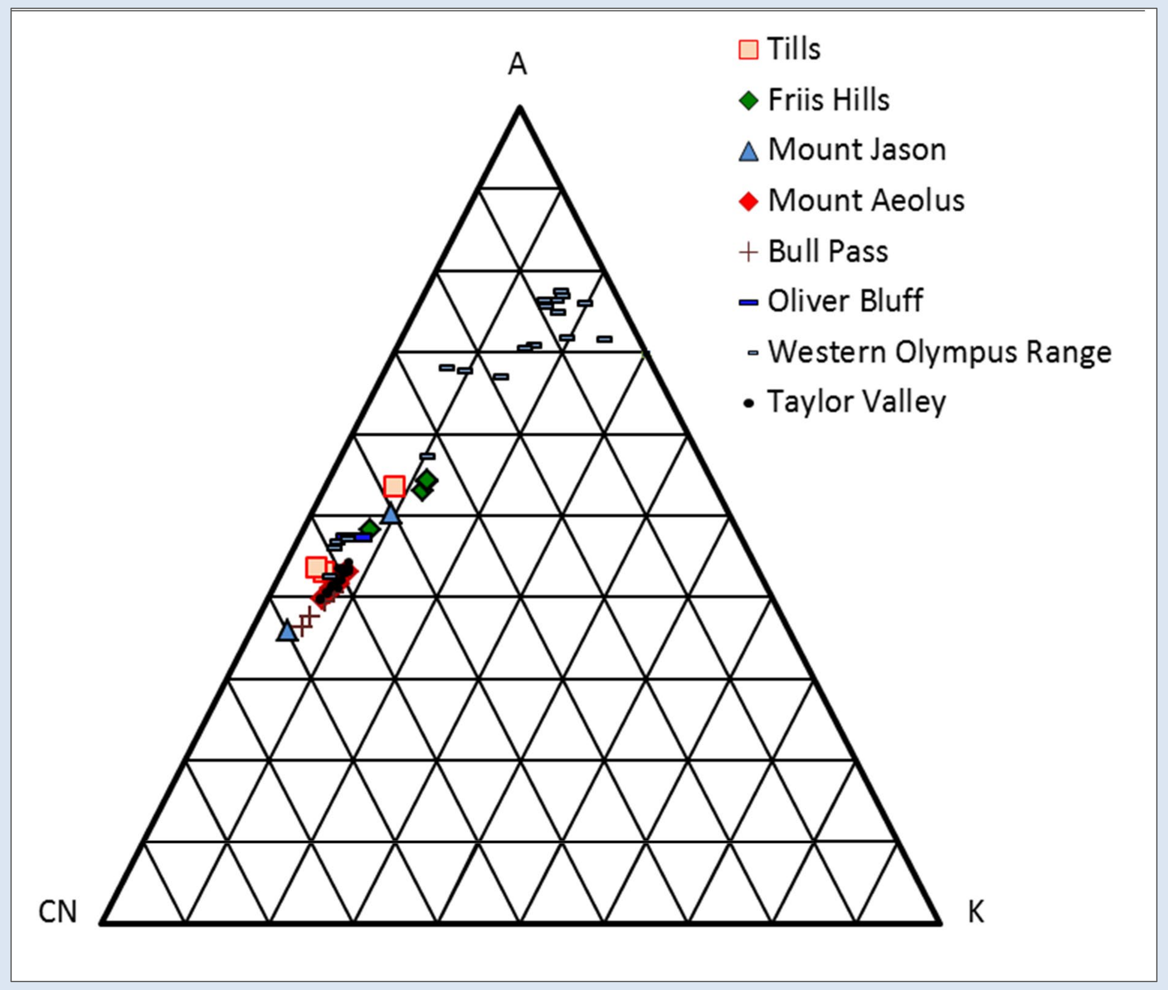

Figure 3. CN-A-K diagram of samples in Table 1.

***Table 1.** Summary of sample descriptions and mean data values.*

Sample Name	Description	Age	Map location	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO*	CaO#	Na_2O	K_2O	P_2O_5	LOI	TC	TIC	CO_2	CIA*	CIA#
Tills (n=3)	Tills taken adjacent to debris flows in McKelvey Valley and Bull Pass	Undated	3 and 7	1.02	0.006	0.13	0.038	0.0015	0.106	0.10	0.095	0.039	0.016	0.00060	4.15	0.25	0.06	0.0049	47	48
Friis Hills (n=3)	Tills	~19 Ma*	2	1.15	0.005	0.11	0.033	0.0011	0.061	0.05	0.045	0.027	0.023	0.00049	3.04	0.12	0.02	0.0017	52	53
Mount Jason (n=2)	Alluvial fan deposits near Mount Jason	Holocene (~1-2 ka)$^{\phi}$	3	1.24	0.004	0.08	0.034	0.0013	0.093	0.08	0.078	0.018	0.012	0.00038	1.17	0.06	0.02	0.0016	43	44
Mount Aeolus (n=8)	Alluvial fan deposits near Mount Aeolus	Holocene (~1-2 ka)$^{\phi}$	4	1.41	0.0038	0.047	0.021	0.0008	0.043	0.046	0.048	0.010	0.0083	0.0004	0.42	0.07	0.015	0.0013	42	42
Bull Pass (n=4)	Alluvial fan deposits in northern Bull Pass	Holocene ? (~1-2 ka)	7	1.32	0.004	0.06	0.027	0.0011	0.079	0.07	0.063	0.016	0.011	0.00036	0.84	0.07	0.02	0.0014	38	39
Oliver Bluff (n=1)	Non-marine glaciogenic sediment	<3.8 Ma - Pliocene**	5	1.03	0.008	0.13	0.031	0.0013	0.075	0.09	0.074	0.035	0.017	0.00079	0.87	2.77	0.256	0.0213	47	50
Western Olympus Range (n=18)	Till, debris flow, fluvial, and lacustrine sediment	>13.85 Ma*	1 and 6	1.30	0.004	0.09	0.018	0.0005	0.024	0.02	0.019	0.012	0.017	0.00041	3.41	0.64	0.02	0.0015	65	66
Taylor Valley (n=16)	Modern stream sediment in Taylor Valley	Modern	Taylor Valley	1.03	0.010	0.13	0.040	0.0016	0.127	0.11	0.110	0.044	0.02	0.00122	-	-	-	-	42	42

CIA*: Balhburg and Dobrzinksi, not considering P2O5, and simply CO2 from TIC, using the formula CaO = CaO - CO2
CIA#: Fedo et al. 1995, using the formula CaO = mol CaO - mol CO2 (cc) - (.5 x mol CO2)(dol) - [(10/3) x mol P2O5] (ap)
*Dated by volcanic ash; $^{\phi}$Dated by OSL
**Ashworth and Kuschel (2003)

$$CIA = \left(\frac{Al_2O_3}{Al_2O_3 + Na_2O + K_2O + CaO}\right) x\,100$$

Calculation using molar values of oxides following Fedo et al., 1995

2. Background

Today, melt water is rare in the McMurdo Dry Valleys. Glaciers are cold-based and produce little to no surface melt water. Above about 500 m elevation, surface melting only occurs at margins of snow banks and glaciers. Soils become wet to depths of a 10 to 20 cm and small pools of surface water collect but channels carrying water are absent. On valley floors melt water collects in channels that lead to streams running along main valley axes (Figure 2A). These streams drain inland into closed basins. They run during most years for 2 to 6 weeks. In this environment weathering is likely restricted to specific sectors of the landscape.

Prior to the climate shift at about 13.8 Ma, the Dry Valleys are believed to have been warmer and more humid, with the presence of wet-based glaciers, melt water streams, and glacially fed lakes. Drifts and soils older than 13.8 Ma are heavily stained by oxidation suggesting in-situ weathering of sediments (Figure 2B).

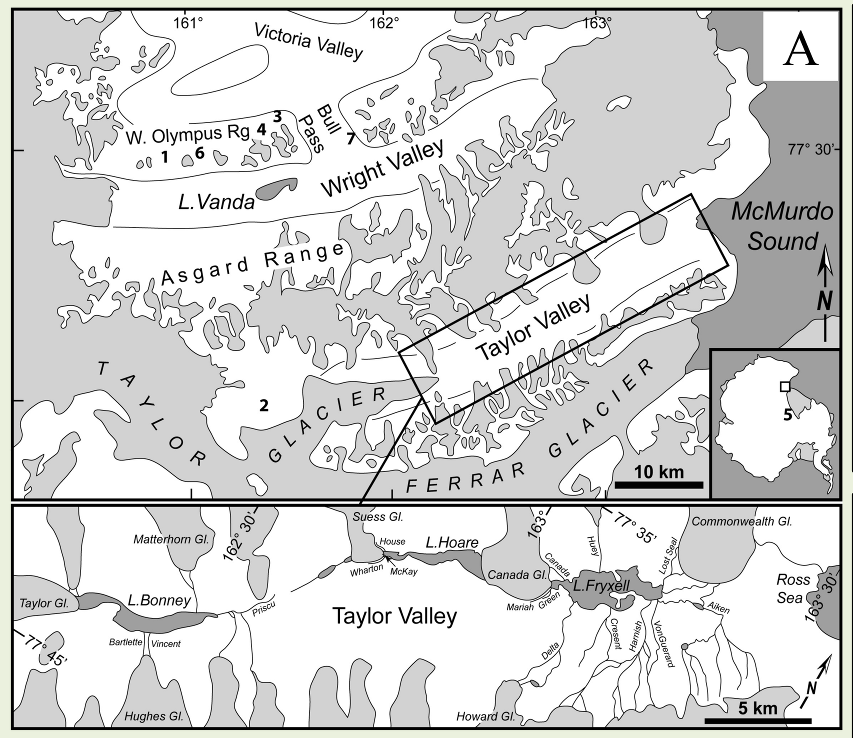

Figure 2A. Map of Taylor Valley stream system

Seventeen samples were collected during the austral summer of 2011, three from the Friis Hills, and one from the Oliver Bluffs in the southern Transantarctic Mountains. These were analyzed by the PANalytical X-ray Fluorescence Spectrometer at Macalester College in St. Paul, MN. Additional data from 18 samples collected from the Western Olympus Range during the 2004 field season and 16 samples from modern stream valleys in Taylor Valley was also used (analyzed by XRF at Ohio State University). Refer to Table 1 and Figure 2A for descriptions and locations of all samples.

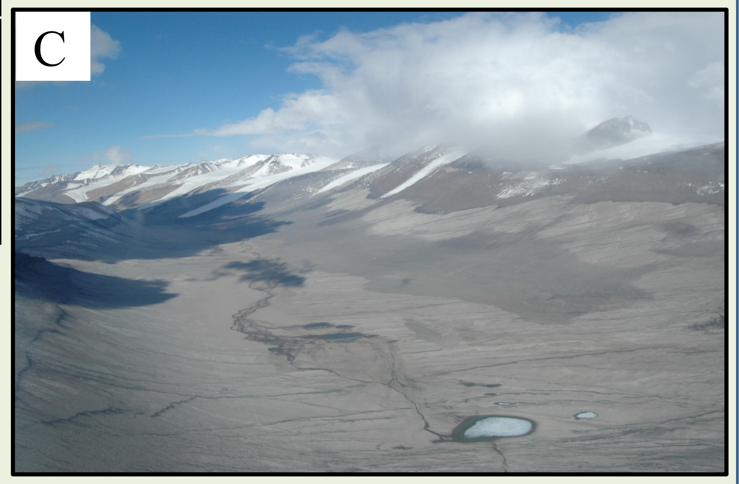

Figure 2B. Devonian-age Beacon Supergroup rocks, **C**. Onyx River in Wright Valley, an example modern stream.

4. Complications

Low CIA results may be influenced by rock sources not previously considered. The Ferrar Dolerite has an average CIA of 40 (Krissek and Kyle, 1998). However, inclusions of orthopyroxene within the websterite and gabbronorite units of the Basement Sill located in Bull Pass have average calculated CIA values as low as 31 (Berdard et al. 2007, supplemental data). This might contribute to low CIA values measured for the 2011 Bull Pass samples.

Salt influx from marine aerosols, having taken place over millions of years, may also play a role in lowering CIA values. Englert et al. (2013) detected SO_4, Cl, and NO_3 anions in sediment samples taken from Wright and Taylor Valleys. In order to determine the magnitude of influence salts may play in chemical abundances, soluble ion analyses will need to be carried out to find out the exact concentrations.

Figure 4. Dike of Jurassic-aged Ferrar Dolerite cross-cutting Beacon Supergroup rocks (Fig. 2B) in the Olympus Range.

References

- Ashworth, A. and Kuschel, G. 2003. Fossil weevils (Coleoptera: Curculionidae) from latitude 85 S Antarctica. *Paleogeography, Palaeoclimatology, Palaeoecology*, vol. 191, p. 191-2002, doi:10.1016/S0031-0182(02)00712-5
- Balburg, H. and Dobrzinksi, N. 2001. A review of the Chemical Index of Alteration (CIA) and its application to the study of Neoproterozoic glacial deposits and climate transitions. *Geological Society of London, Memoirs 2011,* vol. 36, p. 81-92, doi: 10.1144/M36.6
- Bedard, J.H.J., Marsh, B.D., Hersum, T.G., Naslund, H.R., and Mukasa, S.B. 2007. Large-Scale mechanical redistribution of orthopyroxene and plagioclase in the Basement Sill, Ferrar Dolerites, McMurdo Dry Valleys, Antarctica: Petrological, mineral-chemical and field evidence for channelized movement of crystals and melt. *Journal of Petrology*, vol. 48, no. 12, p. 2289-2326, doi:10.1093/petrology/egm060
- Englert, P., Bishop, J.L., Gibson, E.K., Koeberl, C. 2013. Subsurface salts in Antarctic Dry Valley soils. *Lunar and Planetary Science Conference,* abstract.
- Fedo, C.M., Nesbitt, H.W., and Young, G.M. 1995. Unraveling the effects of potassium metasomatism in sedimentary rocks and paleosols, with implications for paleoweathering conditions and provenance. *Geology*, vol. 23, no. 10, p. 921-924, doi: 10.1130/0091-7613(1995)023<0921:UTEOPM>2.3.CO;2
- Krissek, L.A., and Kyle, P.R. 1998. Geochemical indicators of weathering and Cenezoic palaeoclimates in sediments from CRP-1 and CIROS-1, McMurdo Sound, Antarctica. *Terra Antarctica*, vol. 5, no. 3, p. 673-680

5. Acknowledgments

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