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Active silicate weathering in Antarctic ice-rich permafrost revealed by Mg isotopes

PROF. RONALD S SLETTEN, PHD[1], NICOLAS CUOZZO[1], YAN HU[2], LU LIU[1], FANGZHEN TENG[1], BIRGIT HAGEDORN[3], DOUGLAS W MING[4] AND VALERIE TU[5]

[1]University of Washington
[2]IPGP CNRS UMR 7154
[3]Sustainable Earth Research LLC
[4]NASA Johnson Space Center
[5]Jacobs, NASA Johnson Space Center

Presenting Author: sletten@uw.edu

Permafrost covers 24% of Earth and all of Mars and is generally considered inert due to the frigid, hyperarid conditions. However, we document that substantial weathering occurs at subzero temperatures in permafrost. A 30-meter ice-rich permafrost core from Beacon Valley, Antarctica (average temperature of -22° C) reveals rock weathering by the concomitant increases in released Mg and pH. Remarkably, alkalinity produced during silicate weathering, as indicated by elevated pH values, is preserved in the ice phase. The Mg isotopic composition in the ice phase reflects mixing between marine aerosols and dolerite. Unfrozen water is the primary control on weathering, and the presence of salts leads to brines. This is most apparent in the upper 7.0 m of the Beacon Valley core, where salts are high, temperatures rise above -21° C, and Pitzer-type modeling indicates that unfrozen water accounts for up to 4% of ice content. In the upper 7.0 m, up to 60% of soluble Mg in the permafrost ice is sourced from Ferrar Dolerite ($d^{26}Mg$ = -0.22 ± 0.07‰) weathering, resulting in $d^{26}Mg$ values ranging from -0.82 to -0.64‰. Deeper than 7.0 m, with temperatures below -21° C, unfrozen water is less than 2% of ice-content and, on average, 5% of soluble Mg is sourced from dolerite weathering with $d^{26}Mg$ values ranging from -1.05 to -0.76‰. Core sections modeled to have no unfrozen water show little or no evidence of chemical weathering with $d^{26}Mg$ values close to Taylor Glacier and Beacon Valley snowfall of -0.93 ± 0.06‰. Further evidence of rock weathering is Mg-rich clay saponite, as predicted by PHREEQ geochemical modeling and confirmed by X-ray diffraction. Mg in unfrozen brines is distributed between the permafrost ice, secondary salts, clay fractions, and exchange sites. This leads to an unprecedented study of equilibrium fractionation of Mg-bearing clay saponite with brine. This ongoing study provides compelling evidence of rock-water interactions in continuously frozen permafrost where the formation of unfrozen brines leads to silicate weathering and clay mineral formation. Similar weathering is expected in frigid deserts, including Mars, where salts accumulate and temperatures exceed the eutectic point.