

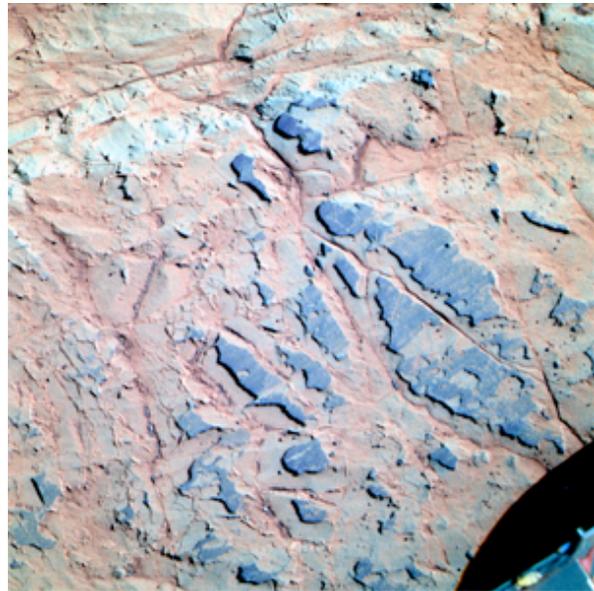
**WEATHERING RINDS ON BASALTS AND BASALTIC SANDSTONES IN THE ANTARTIC CLIMATE: SPECTROSCOPIC IMPLICATIONS FOR MARS.** K. M. Cannon<sup>1</sup>, M. R. Salvatore<sup>1</sup> and J. F. Mustard<sup>1</sup>,  
<sup>1</sup>Brown University, Department of Geological Sciences, Providence, RI, USA, [kevin\\_cannon@brown.edu](mailto:kevin_cannon@brown.edu)

**Introduction:** Alteration during the cold and dry Amazonian period on Mars has likely been limited in extent with extremely low water-to-rock ratios. In these conditions physical weathering is expected to dominate over chemical and mineralogical transformations. However, previous work has shown that weathering in similar hypothermal hyperarid climates of the Antarctic Dry Valleys (ADV) can produce surficial rinds on rocks that dramatically alter their visible near-infrared (VNIR) and especially mid-infrared (MIR) spectral characteristics [1,2]. So far these studies have focused on the Ferrar Dolerite, proposed as a chemically analogous lithology to shallow intrusive martian rocks [3]. Here we build on this work with a suite of diverse igneous and sedimentary samples from the Carapace Nunatak in Antarctica to investigate the expression of these weathering processes in different lithologies.

Carapace Nunatak is located northwest of the ADV at 76°53'S, 159°25'E, with approximately 1.6 km<sup>2</sup> of areal exposure above the surrounding ice. Basal outcrop consists of a 125 m stack of the Carapace Sandstone, an immature basaltic sandstone interbedded with conglomerate layers [4]. This is conformably overlain by 250 m of an extrusive unit (the Kirkpatrick Basalt) with a variable extent of hydrothermal alteration and bright red lenses of hyaloclastite breccia [4].

The Carapace Sandstone and Kirkpatrick Basalt can serve as useful analog materials to show how the two major types of rocks discovered by landed missions to Mars [5,6] are weathered in Amazonian-like conditions. Curiosity has already encountered both basalts and layered sedimentary rocks in Gale crater, including fluvial conglomerates [7]. Previous work has highlighted the possibility of rinds and coatings on martian rocks at the Mars Exploration Rover (MER) landing sites [8] with putative rinds visible in recent PANCAM images (Fig. 1).

**Laboratory Work on Carapace Rocks:** Thin sections were prepared for a representative suite of samples including the Carapace Sandstone and a range of variably altered Kirkpatrick basalts and were examined using standard optical microscopy. Chemical analyses were performed on separated powders from the exterior rinds and fresh interiors of each sample, dry sieved to <125 µm. Powders were fluxed with LiBO<sub>2</sub> and fused at 1050°C then quenched in nitric acid that was then filtered in preparation for ICP-AES analysis. Both powders (<125 µm) and solid chips from the exterior rind and fresh interiors were analyzed



**Figure 1.** False-color L257 raw PANCAM image (seq. 2564) from MER-B (Opportunity) on sol 3074 during ongoing investigations of Matijevic Hill. The rind or surficial coating shows marked contrast in visible wavelengths to the underlying rock.

by VNIR spectroscopy using an Analytical Spectral Devices (ASD) spectrometer. Work is underway to supplement this with MIR and additional VNIR measurements using bidirectional and FTIR instruments.

**Results:** Petrographic analyses of Carapace samples reveal a similar expression of surface alteration to the oxidation-driven rind formation [9] described in the Ferrar Dolerite [1,2]. These rinds are not depositional and appear as an imprinting on existing mineral textures in both basaltic and sedimentary samples. In addition to poorly defined reddish staining at the surface we observe what appear to be well-defined secondary phases having optical properties consistent with palagonite. Some Carapace samples also have a distinctive black rind clearly visible in hand specimens that was not observed in the Ferrar Dolerite. This may represent a secondary oxidation front, but further work is necessary to fully understand its nature.

*Chemical Analyses.* Major oxide chemistry is shown in Fig. 2 for the Carapace samples as a ratio between exterior rind and fresh interior. APXS data from MER are included in the same plot from rocks that were analyzed both post-brush and post-RAT. The ratio of brushed to RATED surfaces is used as a proxy

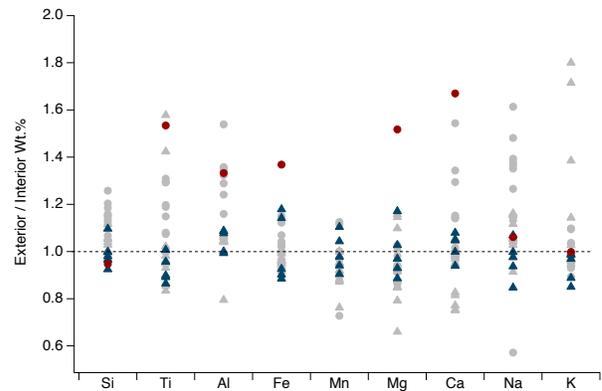
for exterior divided by interior. Carapace basalts track closely with Spirit analyses from Gusev with most divalent cations conserved or slightly depleted in the weathering rinds. The Carapace Sandstone shows similar trends to sedimentary rocks from Meridiani, with surface enrichments in Ti, Al and Ca, and a greater divergence between interior and exterior. Importantly most Carapace samples and MER ratios show no significant changes in chemistry that might be expected from prolonged aqueous alteration and leaching.

**Visible and Infrared Spectroscopy.** VNIR spectra of solid exteriors and interiors of Carapace samples show significant differences that are highlighted for representative samples in Fig. 3 by taking ratios of exterior to interior spectra. Most samples show an enhanced slope from interior to exterior in the 0.5-0.8  $\mu\text{m}$  region caused by a strong Fe charge-transfer absorption, implying a greater extent of oxidation in the surface rind. However no specific iron oxides have been positively identified, leaving open the possibility of poorly crystalline material such as palagonite.

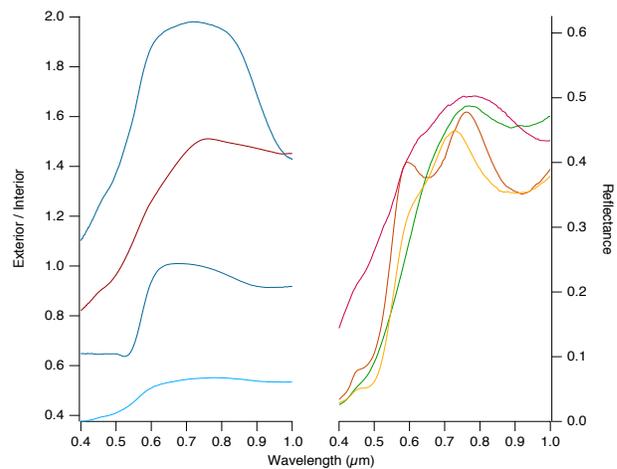
**Implications for Mars:** Previous studies have highlighted the potential for oxidized surface layers on martian rocks and their incorporation into the regolith through aeolian abrasion [10]. Optically thick but physically thin surficial layers may represent limited amounts of alteration that can be misinterpreted through remote sensing techniques as more pervasive weathering, so understanding the nature of these surface rinds is critical to determining the alteration extent of martian rocks. The MER instrument suite is limited in its capabilities to examine this style of alteration, but ChemCam on Curiosity is ideal for analyzing chemistry in the types of thin surficial layers that may be common on martian rocks [11].

Additionally if oxidative weathering in a cold dry climate can produce amorphous silicate phases such as palagonite this may help to explain the significant amount of X-ray amorphous material found in initial soil samples ingested by Curiosity [12].

**Future Work:** Subsequent laboratory analyses of samples from Carapace Nunatak will include Mössbauer spectroscopy, scanning-electron microscopy and proposed in-situ studies of thin sections at the National Synchrotron Light Source at the Brookhaven National Laboratory. Microdiffraction and  $\mu\text{XANES}$  measurements performed at the synchrotron will be used to constrain the crystallinity and oxidation state of secondary products in the weathering rinds. Imaging with a hyperspectral camera and micro-FTIR instrument will provide insight on the gradational spectral evolution of the rock surfaces from unweathered interior to exterior rinds that eventually flake off and are incorporated into nearby soils.



**Figure 2.** ICP-AES results for Carapace samples. Ratios of weight percent oxides between exterior and interior are shown here for basaltic (blue triangles) and sandstone (red circles) samples. APXS data from Spirit (gray triangles) and Opportunity (gray circles) are plotted as a ratio between brushed and RATED surfaces.



**Figure 3.** ASD VNIR spectral ratios of exterior to interior (left) for representative samples of the Carapace Sandstone (red) and Kirkpatrick Basalt (blues), with laboratory spectra (right) of iron oxides akagaenite, goethite and ferrihydrite (yellow, orange and green) and palagonite (magenta) for comparison.

**References:** [1] Salvatore M. R. et al. (2012), *LPSC 43*, abs. 1594. [2] Salvatore M. R. et al, *GCA, in revision*. [3] Harvey R. P. (2001), *Martian Highlands & Mojave Desert Wkshp.*, 25-26. [4] Ballance P. F. and Watters W. A. (1971), *New Zealand J. Geol. Geophys.*, 14:3, 512-527. [5] McSween H. Y. et al. (2006), *JGR*, 111, doi:10.1029/2005JE002477. [6] Grotzinger J. P. et al. (2005), *EPSL*, 240, 11-72. [7] Grotzinger J. P. et al. (2012) *AGU*, abs. 1500061. [8] Knoll, A. H. et al. (2008), *JGR*, 113, E06S16. [9] Cooper, R. F. et al. (1996), *GCA*, 60, 3253-3265. [10] Allen C. C. et al. (1981) *Icarus*, 45, 347-369. [11] Lanza N. L. et al. (2012) *App. Optics*, 51:7, [12] Blake D. F. et al. (2012), *AGU*, abs. 1471307.