LINKING ORBITAL, FIELD, AND LABORATORY ANALYSES OF DOLERITES IN THE MCMURDO DRY VALLEYS OF ANTARCTICA: TERRESTRIAL STUDIES AND PLANETARY APPLICATIONS. M. R. Salvatore[1], J. F. Mustard[1], J. W. Head[1], D. R. Marchant[2], M. B. Wyatt[1], and J. Seeley[1,3]. [1]Brown University, Dept. of Geol. Sci., Providence, RI, USA, Mark_Salvatore@brown.edu, [2]Boston University, Dept. of Earth Sci., Boston, MA, USA, [3]University of Southern California, Dept. of Earth Sci., Los Angeles, CA, USA.

Introduction: Low degrees of chemical alteration have been shown to have significant impacts on spectral investigations of rock surfaces [e.g., 1,2]. In cold and dry environments like the surface of Mars and the McMurdo Dry Valleys (MDV) of Antarctica, the products of immature chemical alteration can hold information regarding the environment under which the alteration occurred. In this study, we present the first results from spectrally mapping the MDV using visible/near-infrared (VNIR) and mid-infrared (MIR) orbital datasets and link these data to field and laboratory measurements. In particular, we investigate regions of exposed Ferrar Dolerite where both primary igneous and secondary alteration signatures are readily identifiable. Within different intrusive sills, unique spectral signatures can be linked to variations in primary composition. In the Labyrinth of Wright Valley, strong mafic signatures are significantly weakened on flat, geologically stable plateaus. While the spectral trends of alteration appear to be independent of starting composition, closing the loop between orbital, ground, and laboratory investigations is essential towards putting these alteration signatures into their appropriate compositional and geologic context.

Methods: Advanced Land Imager (ALI; 9 bands, 30 m pix^{-1}) VNIR data were acquired via the USGS Global Visualization tool (Table 1). ALI data were calibrated using the methods of [1]. Atmospheric contributions were removed from each scene using the dark object subtraction technique [2] followed by conversion to top of atmosphere reflectance [1]. The resulting data were compared to in situ and laboratory measurements to ensure accuracy.

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER; 5 bands, 90 m pix^{-1}) MIR data were acquired using the NASA Warehouse Inventory Search Tool (Table 1). Level 2B products were obtained, which are corrected for radiometric and instrumental effects as well as for solar and atmospheric influences. ASTER data were similarly compared to field and laboratory measurements to ensure accuracy.

Data containing clouds, snow, and ice were masked based on their unique spectral signatures. The final mapping product consists of 14 bands spanning both the VNIR and MIR wavelength regions.

Dolerite Alteration Signatures: The Ferrar Dolerite is a shallow intrusive igneous complex that was emplaced in multiple sills that outcrop throughout the MDV. These sills exhibit extensive textural, chemical, and mineralogical variations associated with the emplacement process [3]. The lowermost sills (Basement and Peneplain sills) are more Mg-rich and orthopyroxene-rich than the overlying Asgard and Mt. Fleming sills. These variations are easily observed from orbit in the strength and shape of the 1 μm mafic absorption feature associated with orthopyroxene (Fig. 1).

Hyper-arid and hypo-thermal alteration of the Ferrar Dolerite has also been shown to significantly influence spectral signatures with only minor changes to the overall chemistry and mineralogy of the rock surface [4]. These signatures are the result of oxidation-driven alteration processes via exposure to the oxidizing environment. In the VNIR, the alteration process manifests itself as a weakening of the 1 μm mafic band (associated with orthopyroxene) in addition to a reduction in the spectral slope over the NIR wavelength region. To differentiate between primary compositional variations and alteration signatures, in situ sample collection and subsequent laboratory analyses are necessary to constrain the initial primary signatures. Upon proper characterization of the unaltered doleritic signatures, alteration trends can be interpreted from the data.

Fig. 1 shows the 1 μm band depth and NIR spectral slope calculated using ALI data for several valleys throughout the MDV. The overall spread of data encompass both primary and secondary signatures. For example, the Basement Sill outcrops (green dots), Peneplain Sill outcrops (red dots), and the Asgard and Mt. Fleming Sill deposits (blue dots) occupy unique regions within the scatterplot. However, the spread of data within each group is at least partially the result of alteration processes. Both the primary compositional spread and the variability due to alteration processes can be seen in the laboratory parameters. Fig. 2 shows a plot of only the Peneplain Sill outcrops in the Labyrinth of Upper Wright Valley. The 1 μm mafic band is significantly weaker and the spectral slope significantly shallower on stable plateau surfaces where alteration rinds have had sufficient time to develop and mature. On the other hand, the 1 μm band is much deeper and the spectral slope is much steeper along the fresher slopes throughout the Labyrinth. This relationship confirms that in regions where the primary composition remains fixed, spectral variations can be directly linked to the formation, maturation, and preservation of alteration rinds. This observation is also confirmed by laboratory and ground truth data obtained in the Labyrinth, as shown in Fig. 2.

Relationship to Climatic Variables: The MDV host several microclimate zones that are characterized by variations in average annual temperature and relative humidity [5]. These variations are dictated by topography, elevation, and distance from the McMurdo Sound. Future work is designed to characterize the influence of these climate variables on the dolerite alteration process and resultant alteration products. If these unique products are recognizable using orbital spectroscopy, it may be possible to estimate the exposure age of surfaces throughout the MDV in addition to untangling the climate history of the MDV through spectral observations of the surface. The ability to link surface properties with climate history is a unique and exciting prospect for the study of both terrestrial and planetary surfaces.

Application to Planetary Studies: Alteration rinds have been hypothesized or directly observed on rocks on Mars at the *Pathfinder* [6], *Spirit* [7], and *Opportunity* [8] landing sites. The influence of rinds on spectroscopic observations has also been noted in several studies [e.g., 9] and have been described as a hinderance to direct observations of unaltered primary lithologies. By linking spectral, field, and laboratory observations, however, we are able to identify both primary compositional variations as well as signatures of alteration rind maturity and preservation throughout the MDV. Such a comprehensive examination of martian surface materials may hold similar clues regarding the extent, duration, and nature of alteration processes at various landing sites.

Future Work: Future work will focus around measuring primary dolerite spectral signatures from across the MDV and linking these signatures with orbital datasets. It is possible that the deviation from the unaltered spectral signatures can hold valuable information regarding surface stability, alteration rind preservation, and the current and historic climate regime. The magnitude of spectral offsets will also help to determine the rate of alteration rind formation and how long it takes for alteration rinds to mature to their fullest extent, both of which can be directly related to laboratory investigations of alteration rind development.

References: [1] Chander, G. et al. (2009), *Rem. Sens. Environ.*, *113*, 893-903. [2] Chavez, P. S. (1996), *Photo. Eng. & Rem. Sens.*, *62*, 1025-1036. [3] Marsh, B. (2004), *Eos*, *85*, 497-508. [4] Salvatore, M. R. et al. (2012), *LPSC*, *43*, this issue. [5] Marchant, D. R. & J. W. Head (2007), *Icarus*, *192*, 187-222. [6] McSween, H. Y. et al (1999), *JGR*, *104*, 8679-8716. [7] Haskin, L. A. et al. (2005), *Nature*, *436*, 66-69. [8] Knoll, A. H. et al. (2008), *JGR*, *113*, doi:10.1029/2007JE002949. [9] McSween, H. Y. et al. (2006), *JGR*, *111*, doi:10.1029/2005JE002477.

Table 1. A list of ALI and ASTER images used in the creation of the MDV spectral map. Dates of acquisition are also provided.

Image Name	Acquisition Date
ALI:EO1A0581152008022110KG	Jan. 22, 2008
ALI:EO1A0581152010038110KK	Feb. 7, 2010
ALI:EO1A0581152009339110K0	Dec. 8, 2009
ALI:EO1A0581152010041110K9	Feb. 10, 2010
ASTER:AST_05_00312082002210402	Dec. 8, 2002
ASTER:AST_05_00312112003210330	Dec. 11, 2003
ASTER:AST_05_00312032001211845	Dec. 3, 2001
ASTER:AST_05_00311292000204446	Nov. 29, 2000
ASTER:AST_05_00312032001211854	Dec. 3, 2001

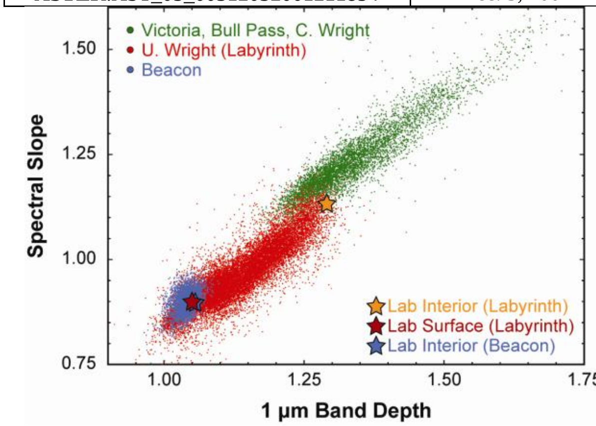

Fig. 1. ALI-derived 1 µm band depth $(((R_{1.25\mu m}+R_{0.79\mu m})/2)/R_{0.8675\mu m})$ vs. NIR spectral slope $(R_{1.25\mu m}/R_{0.79\mu m})$ for doleritic regions of the MDV. $R_{\#\#\mu m}$ indicates the measured reflectance at that particular wavelength. Both primary and secondary compositional influences can be identified. Stars indicate laboratory-derived values from Beacon Valley (blue) and the Labyrinth (red and orange). Increasing alteration rind development draws the primary spectral signatures to the bottom and left in this plot, as shown in the Labyrinth lab data.

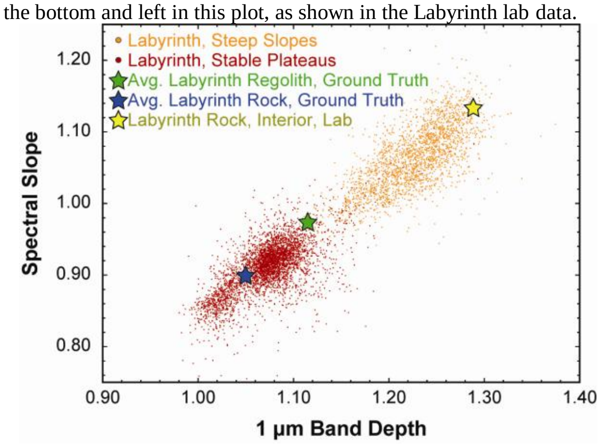

Fig. 2. ALI-derived 1 µm band depth vs. NIR spectral slope for the Labyrinth of Upper Wright Valley. Steep, unstable surfaces are shown in orange, while stable plateau surfaces are shown in red. With increasing maturity and preservation on the plateau surfaces, alteration rinds exhibit weaker 1 µm band depths and shallower spectral slopes (as shown in ground truth data, blue star), while fresher surfaces associated with steep slopes exhibit stronger 1 µm band depths and steeper spectral slopes (as shown in lab data, yellow star). Regolith (green star) represents an intermediate amount of alteration.