DETERMINING THE PROVENANCE OF ALTERED BASALTIC CLASTICS BASED ON VNIR AND TIR SPECTROSCOPY: RELEVANCE FOR MARS

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(1) Introduction:
Mars is a planet dominated by basaltic volcanism. It has been suggested that its early volcanic history produced great quantities of clastic materials while later volcanic activity was largely effusive [1]. Flood basalt plains on Mars are riddled with craters and this cratering in turn produced ejecta of comminuted basalt. Superimposed on these primary materials is a history of aqueous alteration- nominally most active in Mars’ early history. Spirit, Opportunity, and Curiosity have all found basaltic sandstones altered to varying extents [e.g., 2-4]. Disentangling the origin of these materials, (e.g., are they of volcanic or impact origin?) and what type of aqueous alteration they have experienced is a non-trivial task. This task is aided by examination of terrestrial analog materials. In our study, we have been examining clastic basaltic materials of hydrovolcanic, glacioclastic, and explosive eruption origin and comparing them with basaltic ejecta from the Lunar Crater impact site [e.g., 5]. We have sought to use analysis techniques analogous to those available to the aforementioned Mars rovers focusing on VNIR and TIR reflectance and emittance spectroscopy with supporting information from thin section petrography and XRD analysis.

(2) Alteration Pathways:
There are several ways in which clastic basaltic materials can undergo alteration. These different alteration pathways can provide information on how the materials were formed and what type of environment was extant at the time. Hydrovolcanic materials can undergo rapid alteration through the process of palagonitization in some tuff rings, tuff cones, and sub-ice eruptions if they are emplaced “wet” with steam adhering to particles [6] (Fig. 1A). Unless subjected to some hydrothermal alteration, explosively generated basaltic ash tends to follow an ambient temperature pedogenic alteration pathway [7] leading to disaggregated tephras (Fig. 1B) in which the glass can also have palagonite alteration rinds.

In [7], Schiffman et al. described differences in tephras altered through “pedogenic” and through “palagonitic” alteration. The former were disaggregated, lacking in smectites, but bearing poorly crystalline minerals such as allophane, imogolite, and ferrilithylite. The latter were well cemented with smectites and zeolites forming in the interstices between palagonitized glass grains.

(3) Field Sites:
Our team has samples from glacioclastic tuyas and tindars and from explosive volcanic ash from Haleakala. We have also been provided with spectra of tephra from the summit of Mauna Kea by R.V. Morris and V.E. Hamilton. We have also conducted field work at multiple hydrovolcanic sites in Idaho, New Mexico, and Utah. One of our team has also conducted extensive field work at Lunar Crater [5].

(4) Analysis Techniques:
0.3 – 2.6 μm bidirectional and 0.83 – 25 μm biconical reflectance of a number of samples were measured at RELAB. MWIR emissivity was measured at Arizona State University and at Stony Brook University. Additionally, thin sections were prepared and examined using standard petrography and with a micro-FTIR reflectance spectrometer at the Stony Brook University Vibrational Spectroscopy Laboratory. XRD analysis of samples at Stony Brook University is on-going.

(5) VNIR Spectra of Altered Tephras:
In the VNIR, palagonite tuffs associated with hydro- and glacioclastic eruptions have deep 1.4 and 1.9 μm water absorption bands and can have a 2.29 μm Fe/Mg-OH overtones band. Ambitently weathered palagonitic soils have shallower water absorption features and lack smectites and associated spectral features (Fig. 2). Even at the multispectral resolution of the MER Pancam, there are distinct spectral differences between the hydro/glacioclastic palagonite tuffs and ambitently weathered palagonitic soils (Fig. 3).

(6) Deconvolution of MWIR Spectra:
The collection of micro-FTIR image cubes of a number of samples allowed for the isolation of pure spectra of basaltic glass and of palagonite rinds. Through application of Kirchoff’s Law these were used as endmembers in a 46 endmember spectral library for application of linear deconvolution [8] to the bulk sample emissivity spectra of hydrovolcanic palagonite tuffs, glacioclastic palagonitized hyaloclastites, ambitently weathered palagonitic soils and hydrothermally altered tephras (the latter two groups of spectra provided by Dr. Morris and Hamilton from work on Mauna Kea tephras detailed in [9]).

Sample measured and modeled deconvolutions are shown in Fig. 4 and bar graphs of deconvolution results of the sample groups are shown in Fig. 5 A - D.

Fig. 1. A. (left) palagonite and cemented tuffs at N. Menan Butte, Idaho. B. (right) Ambitently weathered palagonitic soils on Mauna Kea, Hawaii.

Fig. 2. Reflectance spectra of hydrovolcanic palagonite tuff from Sinker Butte, ID (SB12S-01) and pedogenically altered palagonitic tephras from Haleakala, HI.

Fig. 3. Different spectral trends revealed between palagonitic soils from Mauna Kea and palagonite tuffs from hydrovolcanic sites in Idaho in 754 to 1009 nm slope vs. 904 nm band depth plot.

Fig. 4. Measured (blue) and modeled (red) spectra of A. palagonitized hyaloclastite sample Hf-08 from Helgafell, tindar Iceland. B. Ambitently weathered palagonitic soil from Mauna Kea [9].

Fig. 5. Bar graphs indicating deconvolution results of A. hydrovolcanic palagonite tuffs, B. glacioclastic palagonitized hyaloclastites, C. ambitently weathered Mauna Kea palagonitic soils, D. hydrothermally altered Mauna Kea clay-bearing tephras.

Discussion:
The different sets of altered tephras have distinct spectral differences in both the VNIR and in the MWIR. The different trends in VNIR reflectance indicated by Fig. 3 indicates an ability to distinguish between tephras altered at ambient temperatures through the “pedogenic” alteration process of [7] and those altered at elevated temperatures through a “palagonitic” alteration pathway (again ala [7]) using VNIR multispectral data similar to that returned by Pancam and Mastcam. Differences in mineralogy indicated by the linear deconvolutions of the different sets of tephras spectra indicate additional clues to the type of alteration experienced by these materials. Alteration through elevated temperatures produces higher fractions of zeolites and smectite clays than is observed in materials altered through a more ambient temperature alteration pathway.


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