LABORATORY AND REMOTE IDENTIFICATION OF HYDROTHERMAL ALTERATION MATERIALS ASSOCIATED WITH SUBGLACIAL OUTFLOOD SURFACES IN ICELAND

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Introduction: Hydrothermal fluids react with basaltic rocks over a broad range of temperatures to produce diverse alteration mineral assemblages [1]. The discovery of hydrothermal minerals on the surfaces of other planetary bodies can provide important clues for understanding the nature of water-rock interactions and for assessing the potential for past or present habitable environments and life [2,3,4]. The OMEGA and CRISM VIS/NIR spectrometers have recently identified phyllosillicate mineral signatures within layered material on the ancient (>3.5 Ga) southern highlands of Mars [3, 4]. These phylosillicates, which may include a variety of water and hydroxyl bound clay minerals such as smectite, illite, kaolinite, and chlorite are the likely result of chemical reactions of basalt and water [5]. The apparent absence of similar materials on the younger northern lowlands (<3.5 Ga) suggested in data from Mars Express [4] indicates that large-scale water-crust interactions were limited to the first billion years of Martian history. However, small valley networks on the flanks of several Martian volcanoes in the Tharsis and Elysium regions of the northern lowlands and several large catastrophic outflood channels present along the planetary topographic dichotomy indicate localized outflows of water that were likely derived from subsurface reservoirs where geothermal heat maintained the water in liquid form [6, 7].

In this study, we describe hydrothermal alteration mineral assemblages collected from sandur plains of southern Iceland. These sandur plains are dominated by basaltic volcanic material at various states of alteration and are potential terrestrial analogs for the deposits of Martian outflow systems. Sampled sites lie adjacent to several active basaltic volcanic centers that are present beneath the ice sheets of Vatnajokull and Myrdalsjokull in southern Iceland [Fig. 1].

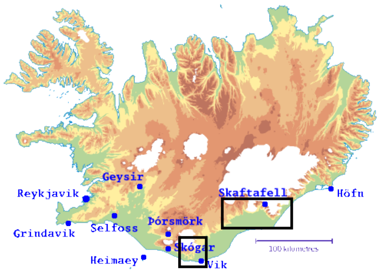

Fig. 1: Field locality sites in southern Iceland including Myrdalsandur (left) and Skeidararsandur (right).

These pro-glacial environments were the sites of several historic catastrophic outfloods described in [8] and [9]. At these locations, geothermal heating associated with subglacial volcanic eruptions has produced several sub-glacial lakes that periodically drain due to lake over-pressure or ice dam breakage, resulting in catastrophic outflooding at glacial margins [10]. At both sample locations, outfloods transported and deposited: 1) juvenile volcanic materials generated during eruptions, 2) volcanic and secondary hydrothermal materials that had accumulated within adjacent subglacial lakes and 3) older volcanic and hydrothermal bedrock materials eroded during outfloods [11].

Methods: Field work was conducted at Myrdalsandur and Skeidararsandur in the summers of 2006 and 2007. Outflood deposited materials from the 1918 Myrdalsandur and 1996 Skeidararsandur events were identified based on stratigraphic relationships previously described by [8, 9]. Sample materials were collected from sandur surfaces, as well as from individual outflood units exposed in stream cuts and gullies.

On sandur surfaces we employed quadrat mapping methods to estimate the percent abundance of different clast lithologies. Fifty random samples were collected from each ~ 50 cm by ~ 50 cm quadrat and returned to the lab for identification. High resolution color digital images were also used to estimate compositional abundances. Point counting of particles < 2 mm gave clast abundances for smaller random (< 2 g) subsamples. Surface samples were also collected for lab analysis to provide ground truth comparison to short wave infrared (SWIR) reflectance data gathered by the orbiting Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). X-ray powder diffraction and VIS/NIR lab spectroscopy from 0.35 μm to 2.5 μm was used to confirm the mineralogy of sandur materials and to assess the accuracy of the remote analysis.

Results: The sandur surfaces contain rounded to sub-angular, boulder to sand-sized, clasts of basaltic glass, dense to moderately vesicular basaltic and intermediate lavas, yellowish-orange palagonitized hyaloclastites, quartz, zeolites, and plagioclase. Point counting of the sand-sized fraction of sediment samples revealed mostly glassy volcanics of varying vesicularity (> 90%), and palagonitized hyaloclastites (~5-10%). Quartz, plagioclase, and zeolite crystals comprised up to 5% of the <250 μm size fraction.

X-ray diffractograms were obtained from mixed surface samples, individual basaltic pumice and palagonite clasts, and palagonitic coatings (Fig. 2). Consistent with an abundance of amorphous glass, the diffractogram for basaltic pumice shows significant noise including a broad hump from 7 – 15 2θ. Minor peaks for plagioclase (albite), quartz (quartz in basaltic pumice samples is present as vesicle and vein fills), and pyroxene are also present in the basaltic pumice samples. The random powder diffractogram of the palagonite clasts shows a dominance of quartz, plagioclase feldspar (albite), saponite, analcime, and pyroxene. Minor peaks for illite and possibly kaolinite are also present.

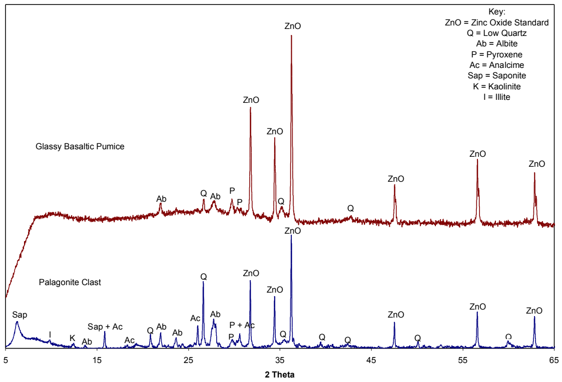

Fig 2: X-ray diffractogram of glassy basaltic and palagonite clasts from Icelandic outwash surfaces. ZnO is a standard.

VIS/NIR lab spectroscopy of mixed sand-size samples show broad absorptions near 1.05 µm representative of pyroxene, water bound absorptions near 1.90 µm, small Si-OH absorptions at 2.23 µm, and a small nontronite clay absorption near 2.30 µm (Fig. 3).

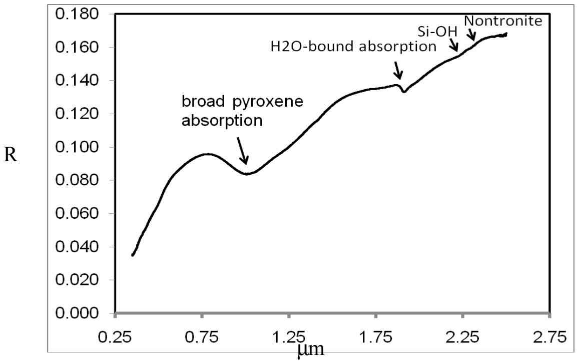

Fig 3: VIS/NIR spectra of a typical sandur surface sample containing ~5% palagonite clasts, ~1% crystallites of quartz, zeolites, and plagioclase, and ~94% basaltic clasts.

ASTER short wave infrared spectra are consistent with clays in sandur materials. Figure 4 displays a series of spectra matched with 90% confidence against the USGS spectral library. Water and hydroxyl bound aluminum silicates with absorptions near 2.2 and 2.3 µm dominate the ASTER spectra for sandur surfaces (Fig 4).

Discussion and Conclusions: Modern subglacial outflood deposits in Iceland are dominated by clasts of unaltered basaltic volcanic glass and lavas. Minor abundances of highly altered palagonitic materials, derived from subglacial hydrothermal alteration of basaltic volcanic glass, are present on sandur surfaces and are detectable by both laboratory and remote techniques. Palagonitized hyaloclastites contain a suite of crystalline and non-crystalline alteration products, including zeolites and quartz in the form of vein fills, vesicle fills, and alteration rinds. Clays and Fe-oxides also occur as alteration rinds on basaltic glass.

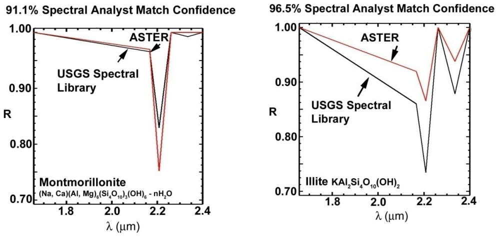

Fig 4: ASTER derived spectra from the proximal region of the Skeidararsandur outwash plain showing strong absorptions near 2.2 and 2.3 µm.

Small absorptions for smectite clay (nontronite) observed in lab VIS/NIR spectra of well-mixed sand samples suggests that the palagonite signature is present but largely masked by the dark, (energy absorbing) unaltered basaltic clasts, challenging the accuracy of detection in remote sensing data. Similar intimate mixing of basaltic sand and bright alteration products may pose a challenge for the remote identification of alteration minerals, like clays at Mars, especially when present at low abundances (~5-10%). However, proximal sandur surfaces have extensive boulder fields containing large meter-scale palagonite and basaltic clasts in similar relative abundance to the sand-sized fraction. Similar boulder-size mixtures in Martian outwash systems may contain limited abundances of alteration material that may be detectable at the current resolutions of CRISM and OMEGA.

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