BASALTIC FLUVIAL AND LACUSTRINE SEDIMENTS FROM ICELAND AS AN ANALOG FOR MARS. C. R. Cousins[1], P. Mann[2], E. Cloutis[2], J. Cherry[1], E. Allender[1], M. Fox-Powell[1], M. Gunn[3]. [1]School of Earth and Environmental Sciences, University of St Andrews, Irvine Building, North Street, St Andrews, UK (crc9@st-andrews.ac.uk), [2]Department of Geography, University of Winnipeg, Winnipeg, Manitoba, Canada, [3]Department of Physics, Penglais Campus, Aberystwyth University, Aberystwyth, UK.

Introduction: Martian sediments are geochemically immature in comparison to their terrestrial counterparts, due to largely mafic sediment protoliths and lack of crustal recycling via plate tectonics [1,2]. Little is known about the alteration pathways recorded within such sediments and their spectral signatures, which are used to characterise much of the martian surface. We present a spectroscopic and mineralogical study of Mars-analogue basaltic sediments in Iceland.

Field areas: The volcanic island of Iceland offers a unique opportunity to investigate comparable sedimentary lithologies to those on Mars. Here, deposition of immature sediments sourced from the largely basaltic crust occurs within a variety of minimally-vegetated fluvial, lacustrine, and glacial systems, including those that are currently active, and those that existed during the Pleistocene. These provide access to sediments dominated by detrital basalt, neoformed phyllosilicates, and low-temperature alteration phases [2]. Moreover, due to the near-arctic location of Iceland, many sedimentary deposits exist within a cold and dry climate, limiting subsequent pedogenic alteration, erosion, and biogenic weathering. 29 sediment samples were collected in August 2014 and 2015. Sediments comprise (i) modern glaciofluvial sandur deposits (Kverkjökull), (ii) Holocene glaciolacustrine sediments (Emstrulón, Gígjökulslón, Hagavatn, Laugarvatn), (iii) modern lacustrine surface sediment (Đorisvatn) and (iv) glacial till (Hagavatn, Karahnjukar).

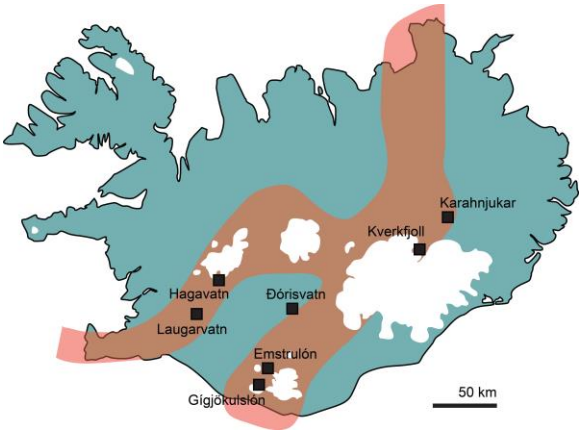

Figure 1. Map of Icelandic sampling sites along the volcanic rift zone (orange). Glaciers in white.

Methods: Spectroscopic analysis was carried out at the Planetary Spectroscopy Facility, University of Winnipeg. All samples were air-dried, then ground to produce <45 µm and 45 – 1000 µm powders in addition to the "whole" sample. Visible - SWIR spectra were acquired with an ASD FieldSpec Pro HR spectrometer over the range of 350 to 2500 nm in 1.4 nm steps, with a spectral resolution of 2 to 7 nm. Incident lighting was provided by an in-house 150W quartz–tungsten–halogen collimated light source. Sample spectra were measured relative to a 100% Labsphere Spectralon® standard. Sample mineralogy was determined by quantitative XRD (qXRD). Samples were crushed to <5µm in acetone and dried at 38°C overnight. Prepared samples were analysed with a Philips PW1050 / Hiltonbrooks DG2 instrument. Mineral identification was done using DiffracPlus, using ICDD PDF4, and quantification achieved using the Reitveld method in SiroQuant ver3. Particle size analysis (40 nm – 2 mm) of unconsolidated sediments was performed using a Laser Granulometer. Prior to analysis, sediments were digested with 30 % hydrogen peroxide to remove any organic material and 10 % HCl to remove any carbonate. Digested sediments were then suspended in 20 ml of DI water plus 2 ml of 5% sodium hexametaphosphate. Pore water pH was measured from a 1:1 slurry of sediment and DI water using litmus paper.

Results: Grainsize measurements reveal the jokulhaulp sandur sediments are dominated by sand-sized particles within their <2mm sized fraction, while lacustrine sediments are dominated by clay and silt particle sizes. Laugarvatn subglacial lake siltstone has a bimodal grainsize distribution, consistent with the laminated clay and silt structure of this deposit. All samples have a Chemical Alteration Index [3] of 0.49 – 0.58. consistent with immature, Mars-analogue sediments from the Antarctic Dry Valleys [1,4]. Pore-water pH for all samples ranged between a circum-neutral pH of 6.5 – 7.5. All sediments, regardless of their depositional environment, comprise detrital basaltic minerals and a significant amorphous component (6 – 50 %). XRD peaks were identified for plagioclase, pyroxene, olivine, and low temperature phases include smectite phyllosilicates, chlorite, analcime, and chabazite. There is a total absence of sulfate minerals in all sediments. Petrographic analysis (Figure 2) shows different altera-

tion and transport histories for the sediments. The young (2011) Gígjökulslón lake sediment comprises unconcolidated sub-angular, minimally reworked basaltic tephra with no hydrous alteration phases. Sandur fluvial sediment has cemented well-rounded basaltic glass and lithic grains, many with alteration rims, and secondary zeolite in pore spaces. The intact nature of these grains and infilling with secondary phases indicates the zeolite and smectite clay are syn- or post-depositional. Conversely, basaltic glass and lithic grains in Emstrulón mud-siltstone are angular and lack alteration rims, indicating minimal transport and a detrital origin for alteration phases prior to deposition.

Vis-SWIR spectroscopy. Vis-SWIR reflectance spectra of the samples reveal a distinction between sediments deposited within lacustrine and fluvial settings. Lacustrine sediments typically have a deeper Fe^{2+} absorption at 1 micron, and shallow hydration bands at 1.4 and 1.91 µm. The opposite is true for the fluvial sediments, which have considerably deeper 1.4 and 1.91 µm hydration bands, and an increasing positive Visible - SWIR slope up to the albedo maximum at ~1850 µm. While smectite clays were identified in all but the youngest (2011) sediments, only a subset of these exhibited 2.2 and 2.3 µm absorption bands associated with Al-OH and Fe/Mg-OH bonds respectively.

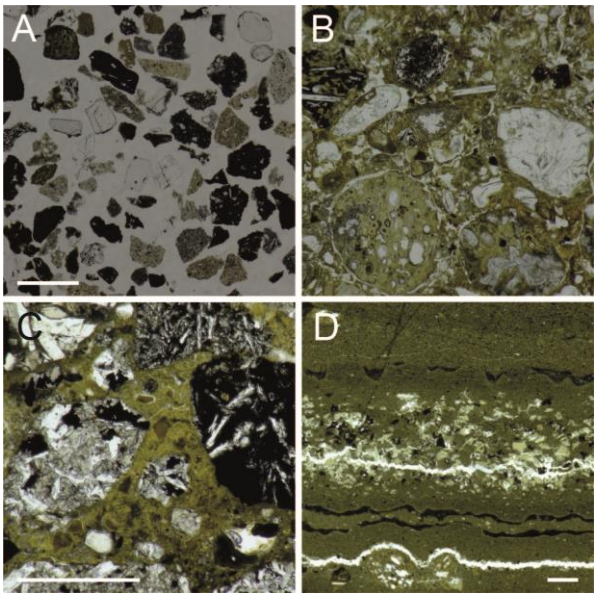

Figure 2. Petrographic light microscope images of (A) Gígjökulslón 2011 lake sediment, (B) Sandur fluvial sediment, (C) Karahnjukar glacial till, and (D) Emstrulón paleolake mud/siltstone. Scale bar = 500 µm.

Discussion: Basaltic sediments from low temperature aqueous environments record distinctive alteration histories with associated spectral properties. Overall, fluvial sediments exhibit a stronger 1.91 µm H_2O absorption, have a higher Chemical Alteration Index, and major element geochemistry indicative of open-system high water-rock ratio alteration. Lacustrine and glacial sediments conversely have spectral profiles dominated by detrital basalt mineral phases, minimal hydration bands, and major element geochemistry indicative of closed, relatively low water-rock ratios. Young basaltic tephra rapidly deposited in Gígjökulslón has the least alteration, and represents a 'Time 0' for charting future alteration. Emstrulón conversely has significant chlorite and smectite clay component.

The dominant alteration pathway in the majority of sediments is that of basaltic glass becoming altered to amorphous - nanocrystalline phases, zeolites, and smectite clays, with alteration of primary olivine and pyroxene to chlorite only likely for the Emstrulón palaeolake mud-siltstone.

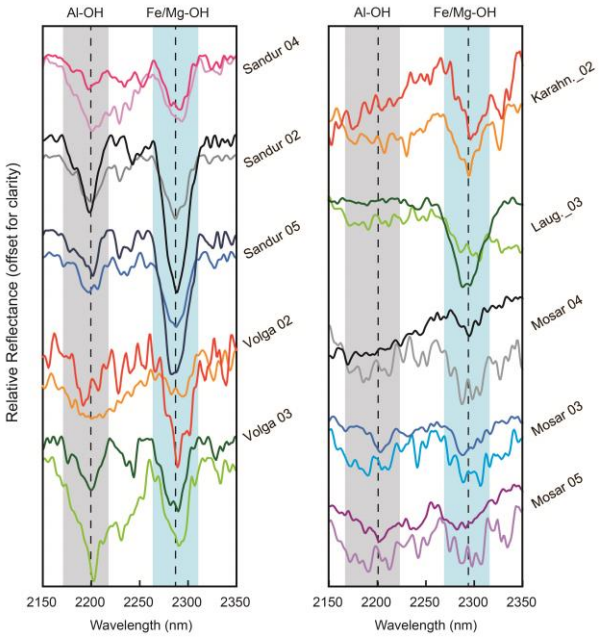

Figure 3. SWIR continuum-removed spectra for samples with 2.2 and/or 2.3 µm absorption bands. Dark colours represent whole rock measurements, and corresponding light colours represent the same sample homogenized to a <45µm grainsize.

References: [1] Cannon A. B. et al. (2015) *EPSL, 417*,78-86. [2] Cousins C. R. (2015) *Life, 5*. [3] Nesbitt and Young (1982) *Nature 199*, 715–717. [4] Bishop et al. (2014) *Philos. Trans. R. Soc. A 372*.

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