SOURCE-TO-SINK MINERALOGY OF BASALTIC SEDIMENT GENERATED IN AN ICELANDIC WATERSHED.

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Introduction: The sedimentary rock record of Mars documents a paleoclimate that was significantly wetter during the Noachian than the hyper-arid conditions that persist today [1]. The geochemistry, mineralogy, and stratigraphy from certain sedimentary deposits on the Martian surface suggest the presence of ancient conditions that are analogous to aqueous driven terrestrial weathering environments [e.g., 1-3]. In particular, stratigraphic relationships at Gale Crater provide evidence for a long-lived, fluvio-deltaic environment [1]. Additionally, Curiosity has identified basaltic mudstones along its traverse that contain clay minerals and amorphous phases [4]. The smectite clay minerals discovered at Yellowknife Bay suggest the formation from aqueous alteration of an olivine precursor, with the kinetics of this reaction implying that aqueous conditions were favorable for thousands of years [5]. Even with such evidence for the sustained activity of liquid water, an outstanding question remains about whether the ancient Martian climate conditions were "warm and wet" [6], or "cold and icy" [7]?

The first scenario of a "warm and wet" paleoclimate is evidenced by widespread hydrous clay deposits on the surface of Mars [8]. The stratigraphy of these deposits are similar to terrestrial settings where liquid water, overland flow, and subaerial weathering dominates [8]. In contrast to mineralogical and stratigraphic relations, climate models find it difficult to produce enough green house warming to sustain a climate conducive to presence of liquid water for extended periods of time. This paradoxical relationship has led to the suggestion of a colder Noachian paleoclimate [9].

Here, we investigate the mineralogical changes that occur in basaltic sediment as it evolves along a fluvial network in Iceland. This terrestrial analog serves as a reasonable candidate for a "cold and icy" Noachian climate. The focus of the work will be centered on understanding the basic process of generating sediment in a basaltic watershed. The mineralogical variations that accompany this process will serve as a fingerprint for climatic influences on basaltic sedimentation and provide greater insight into the ancient Martian environments.

Methods: *Fieldwork*: A ten-day excursion to southern-central Iceland was conducted in the fall of 2015, targeting sediment deposits along the Ölfusá River and the Hvítá River, shown on Fig. 1. Both rivers are fed by seasonal melts from the Langjokull Glacier, generating the glacial lakes Sandvatn and Hvítárvatn. The upper reaches of the watershed were sampled, along with sediment depositional sites following the river's pathway.

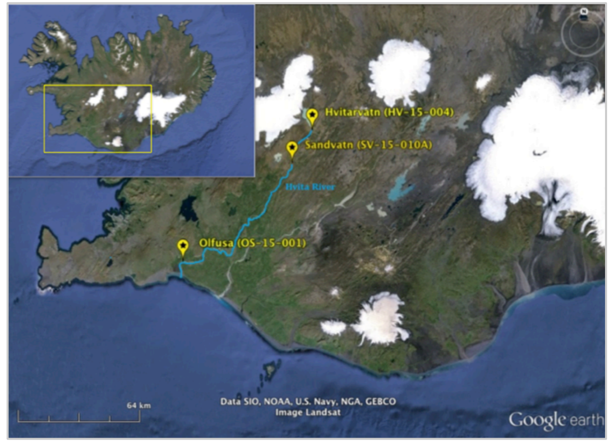

Figure 1. A map of Iceland with an insert displaying sample sites (yellow markers) around the Hvítá River (blue line). Hvítárvatn will be considered our source rock and both Sandvatn and Ölfusá are sediment deposits. *Map Credit: Google Earth*

Mineralogical Analysis: Bulk mineralogy measurements were completed on powdered samples (<20μm) using a Rigaku Ultima IV diffractometer with Cu Kα radiation, from a 2θ range of 5-70°. Unconsolidated samples were sieved into various grain size separates, and standard clay separation techniques were employed to create an orientated clay mount [10]. Orientated clay mounts were used to enhance any potential clay mineral 001 reflections and were measured from 5-35° two-theta. Randomly orientated clay size fractions were also scanned from a two-theta range of 5-70° in order to distinguish any potential 06l reflections commonly present from 58-62° two-theta, which can be diagnostic of the clay mineral's octahedral site occupancy [10].

Results: The mineralogy of a cobble from our source terrain (Hvítárvatn), along with the two randomly orientated clay size fractions from depositional sites are displayed in Fig. 2. Source terrain mineralogy consists of plagioclase (~65%), pyroxene (~30%), olivine (~4%), and ilmenite (<1%). The Sandvatn clay size fraction mineralogy closely resembles that of our source basalt, with well crystalline phases present. However, the Ölfusá sample displays a significant loss in primary mineral reflections. Orientated mounts of both the clay size fractions display no obvious 001 clay mineral phase peaks in low two-theta degrees (Fig. 3). Furthermore, the Ölfusá orientated clay mount displays broad and shallow peaks, suggestive of poorly crystalline or amorphous phases.

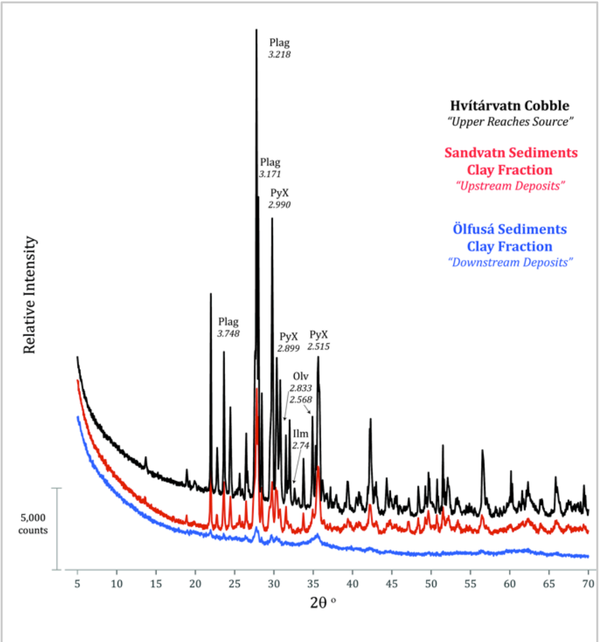

Figure 2. Powdered Bulk XRD patterns for our source rock (black) and randomly orientated clay size fractions of sediment along the sour-to-sink path. *Plag=plagioclase, PyX=pyroxene, Olv=Olivine, Ilm=Ilmenite. D-spacing listed in italics*

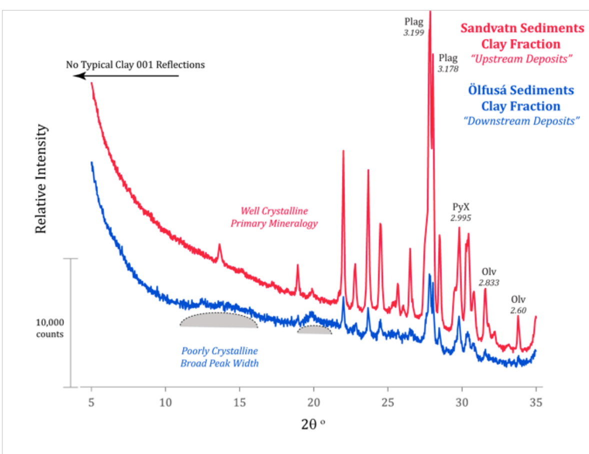

Figure 3. Orientated clay mount XRD patterns of two clay size fraction Sandvatn sediments appear to preserve bulk mineralogy, suggesting only mechanical breakdown of the source material. Ölfusá sediments display a broadening of peak width, suggesting poorly crystalline material. *Plag=plagioclase, PyX=pyroxene, Olv=Olivine. D-spacing listed in italics*

Discussion: Our preliminary results indicate that the mineralogy of Icelandic basalts is preserved in the clay size fraction of a sedimentary deposit in the upper reaches of the watershed (Sandvatn). However, further downstream (Ölfusá), the igneous mineralogy of the clay fraction is replaced by a residual poorly crystalline phase(s). This suggests that mechanical weathering and physical erosion are the principal mechanisms for the breakdown of the source terrain early in the sedimentation process. Further away from the source, continued water-rock interaction results in the dissolution of primary minerals, coinciding with the replacement by secondary weathering products. However, the absence of clay mineral phases in the < 2μm fraction indicates that the kinetics of these chemical weathering reactions are slow in comparison to physical erosion. The broad peak widths in the Ölfusá sample may indicate a poorly crystalline precursor to smectite clay and/or other oxy-hydroxide phases on the basis of commonly observed terrestrial weathering sequences [11].

Summary: The mineralogy of Icelandic sediments demonstrate that in a cold, fluvial catchment, mechanical weathering and physical erosion can break sediment down into a clay size fraction while still preserving its primary basaltic mineralogy. However, increased distance from the source rock leads to the chemical breakdown of igneous minerals (olivine, plagioclase, and pyroxene) and the formation of secondary amorphous phases.

In contrast to Iceland, we previously investigated a source-to-sink system in Idaho, where conditions are much more temperate, forming a good analogue to a "warm and wet' paleoclimate of Noachian Mars [12]. The mineralogy of sediments generated in more clement conditions is significantly different than the results determined for Icelandic sediments. A warmer climate resulted in a more rapid breakdown of the primary mafic mineralogy and the formation of multiple clay mineral phases (i.e., smectites and kaolinite) [12]. However, for both climate scenarios, the degree of weathering and the specific minerals present are also related to the distance from the source. These results are critical for assessing the effect of climate conditions on the generation of secondary mineral assemblages; particularly because both clay minerals and amorphous phases have been discovered as weathering products on the surface of Mars.

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