CLAY SEDIMENTS FROM BASALTIC TERRAINS: IMPLICATIONS FOR SEDIMENTARY PROCESSES ON MARS. M. T. Thorpe[1,2], E. B. Rampe[1], K. L. Siebach[2], C. C. Bedford[1,3], R.C. Ewing[4], R. Christoffersen[5], P. Sinha[6], B. Horgan[6], M. Lapotre[7], M. Nachon[4], K. Mason[4], E. Champion[4], and the SAND-E team, [1]NASA JSC, Houston, TX (michael.t.thorpe@nasa.gov), [2]Rice University, [3]Lunar and Planetary Institute/USRA, [4]Texas A&M University, [5]Jacobs, NASA JSC, [6]Purdue University, and [7]Stanford University.

Introduction: The Mars Science Laboratory (MSL) rover, *Curiosity*, has been traversing across fluvial, lacustrine, and eolian sedimentary rocks since it touched down in 2012. The CheMin X-ray diffractometer (XRD) on board *Curiosity* has revealed smectite clay minerals in most fluvio-lacustrine samples and abundant X-ray amorphous materials in all samples analyzed to date. For example, mudstones from the Sheepbed member at the base of the stratigraphic section and the lower part of the Murray formation contain on average ~7 to 20 wt% smectite and ~30 to 46 wt% X-ray amorphous abundances [1].

On Earth, smectite and secondary X-ray amorphous materials are juvenile weathering products that are generated in sedimentary environments and ultimately record the interaction between primary igneous minerals and the hydrosphere, atmosphere, and biosphere [2,3]. For this study, we investigated glacio-fluvio-eolian sediments generated in basaltic terrains as terrestrial analogs for the mudstones from Gale Crater, Mars. This work focuses on the clay sized sediments (<2 μm) from these deposits as this grain size hosts the most mineralogically and geochemically altered detritus in sedimentary environments [e.g., 3-6]. The goal of investigating basaltic sedimentation is to create a terrestrial reference frame that sheds light on the paleoclimate and paleoaqueous conditions responsible for shaping the ancient sedimentary environments of Mars (e.g., Gale Crater and Jezero Crater).

Study Site: Iceland presents a unique opportunity to explore the composition and mineralogy of sediments almost exclusively from a basaltic source. Additionally, Iceland may have a climate similar to ancient Mars that could have fostered the incipient alteration products observed by *Curiosity* [7]. As part of the SAND-E:Semi-Autonomous Navigation of Detrital Environments project, we traversed terrains in southwest Iceland at Skjaldbreiðauhraun during July of 2019 and collected detritus from both fluvial and eolian environments to serve as a terrestrial analog for sedimentary rocks in similar environments on ancient Mars [7-12].

Methods: The clay sized sediments were first isolated from the rest of the unconsolidated detritus through sonication and centrifugation. XRD patterns of oriented, glycolated, and randomly oriented mounts were collected on a Rigaku MiniFlex with a cobalt Kα source. XRD patterns were analyzed for relative abundances of well-crystalline phases (e.g., plagioclase and pyroxene), clay minerals, and X-ray amorphous materials. However, X-ray amorphous material(s) generally lack long-range atomic order, and phyllosilicates can be poorly crystalline, presenting an analytical challenge for characterizing these materials using traditional laboratory benchtop diffraction instruments. Therefore, we also prepared microtomed sections of the sediments and analyzed them with transmission electron microscopy (TEM) for nano-scale structure and electron dispersive spectroscopy (EDS) for elemental composition.

Results: From XRD patterns, near-source fluvial and eolian sediments display little mineralogical variation when compared to an Icelandic basalt progenitor (Fig. 1). As fluvial sediments are transported further downstream, clay mineral and X-ray amorphous material abundances increase and are variable between sites. High-resolution TEM images of fluvial sediments display an intimate mixture of clay minerals with X-ray amorphous material (Fig. 2). Fluvial sediments sampled

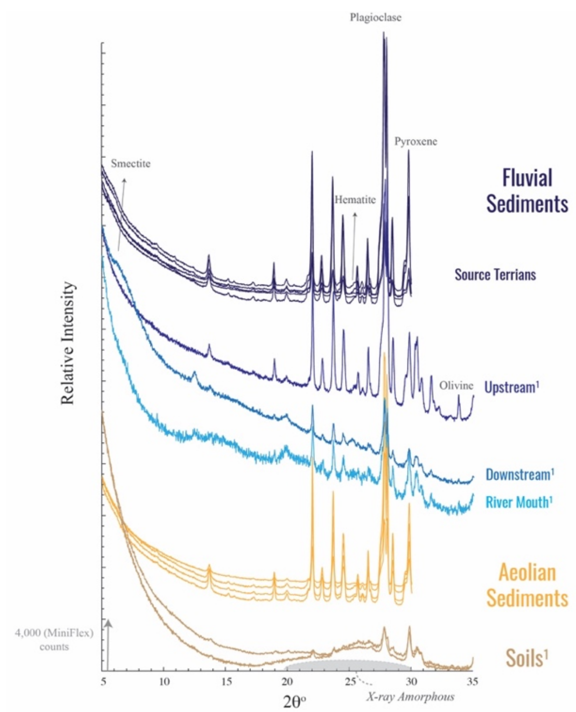

Figure 1. X-ray diffraction patterns for the <2-micron fraction from Icelandic fluvial detritus, eolian sediments, and soil samples from this study as well as *Thorpe et. al*., 2019.

from a river delta in Iceland [3] display morphologies in the TEM images consistent with layered silicates (e.g., clay minerals) and multiple X-ray amorphous materials. An electron dispersive spectroscopy (EDS) map demonstrates that amorphous materials are variably enriched in Si, Al, and Fe. Selective EDS spectra from these areas demonstrate that Mg is associated with clay minerals and may be used to differentiate clay mineral vs. X-ray amorphous material (Fig. 3).

Findings and Future Work: The clay-sized sediment of basaltic detritus records a detailed history of sedimentary processing from source to sink. Overall, fine-grained sediments from Iceland are complex mixtures of well-crystalline phases, smectite clay minerals, and multiple X-ray amorphous materials. Terrestrial analog sediments display a diversity in clay mineral and X-ray amorphous abundances that vary as a function of distance from the source and sedimentary processing (e.g., eolian vs. fluvial). From XRD, the near-source clay-sized sediments display little evidence of chemical weathering, suggesting that mechanical breakdown is the primary process generating <2 µm sediments in the source terrains. Similarly, eolian sediments display no signs of alteration products in the XRD patterns, suggesting that any clay minerals and X-ray amorphous materials transported via wind erosion remain in suspension. In contrast, sediments from downstream [3] are enriched in clay minerals and X-ray amorphous materials. These findings are consistent with chemical weathering being enhanced with distance from the source (i.e., during transport) and/or chemical weathering advanced during sediment storage at temporary depositional sites (e.g., floodplains).

These preliminary findings from Mars-analog basaltic sediments suggest that the phyllosilicate and X-ray amorphous fraction of martian mudstones is also likely

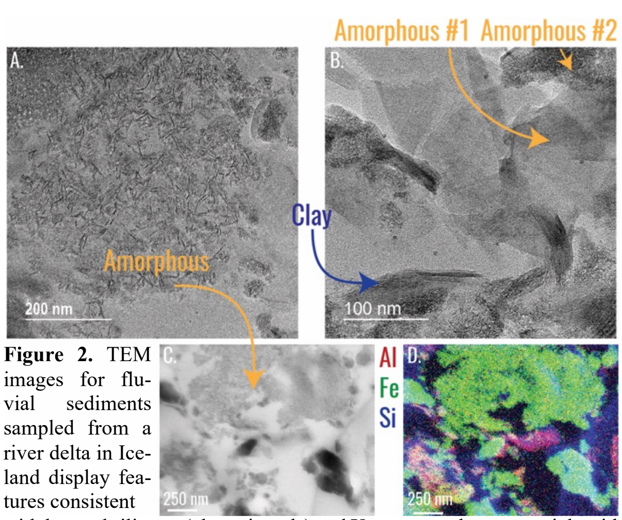

Figure 2. TEM images for fluvial sediments sampled from a river delta in Iceland display features consistent with layered silicates (clay minerals) and X-ray amorphous materials with different morphologies (a and b). EDS map demonstrates that amorphous materials are variably enriched in Si, Al, and Fe (c and d).

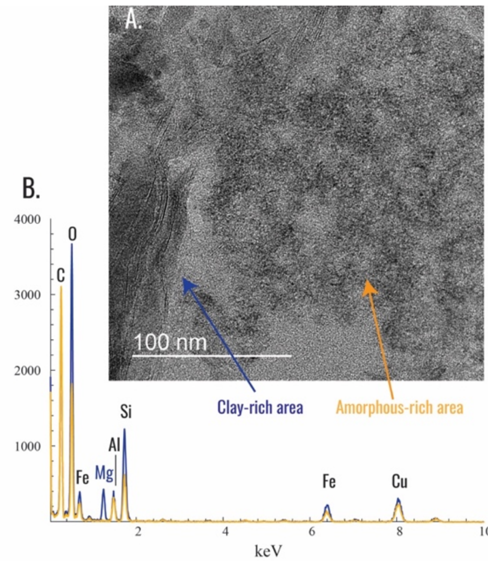

Figure 3. Selective EDS spectra from clay-rich and X-ray amorphous-rich areas in fluvial sediments downstream.

complex. Unraveling the sedimentary processes imprinted on the sediment composition remains a challenge in terrestrial samples, but traditional XRD supplemented with high-resolution analysis presents a novel method for characterizing the structure and composition of incipient alteration products. The preliminary TEM results from our terrestrial analogs suggest that multiple X-ray amorphous materials are likely contributing to the overall X-ray amorphous abundances in mudstones targeted by *Curiosity*. Mass balance calculations of the X-ray amorphous component composition in martian mudstones similarly demonstrate that the composition is variable between samples [13]. Further work is needed to understand the modal abundances of clay minerals vs. amorphous material as well as determine the variability in X-ray amorphous materials in sedimentary environments of basaltic terrains. Developing an understanding of how these nano-scale weathering environments are established in basaltic sediments will be fundamental in determining the sedimentary history of Gale Crater. This terrestrial reference frame will be timely for the Mars 2020 mission, particularly since Jezero Crater displays strong orbital signatures for clay minerals [14].

References: [1] Rampe, E.B., et al., (submitted), *Geochemistry*. [2] Tosca and Knoll, (2009), *EPSL*. [3] Thorpe, M.T., et al., (2019), *GCA*. [4] Rampe, E.B., 2017 GSA. [5] Smith, R.J., et al., (2017), *JGR*. [6] Thorpe, M.T., et, al., (2020), *Geology, in prep*. [7] Rampe, E.B., et, al., (2020), *this meeting*. [8] Bedford, C.C., et, al., (2020), *this conference*. [9] Ewing, R.C., et, al., (2020), *this meeting*. [10] Mason, K., et, al., (2020), *this meeting*. [11] Nachon., M., et, al., (2020), *this meeting*. [12] Champion., E., et, al., (2020), *this meeting*. [13] Achilles, C.N., et, al., (2020), *this meeting*. [14] Goudge, T.A., et al., (2018), *Icarus*. **Acknowledgments:** This work was supported by the NASA Postdoctoral Program (NPP) and NASA PSTAR grant NNH17ZDA001N-0010.