REDOX CONDITIONS AND THE SURFACE ROUGHNESS OF LAVA FLOWS. G. D. Tolometti[1], R. L. Flemming[1], C. D. Neish[1], G. R. Osinski[1,2]. [1]Department of Earth Sciences, Centre for Planetary Science Exploration, University of Western Ontario, London, ON (gtolomet@uwo.ca); [2]Department of Physics and Astronomy, University of Western Ontario, London, ON.

Introduction: Craters of the Moon (COTM) lava field hosts a suite of lava flows with diverse geochemical assemblages and surface roughness properties [1]. The geochemical diversity originates from the complex magmatic history of the Snake River Plain region, which comprises numerous lava fields including COTM. The surface roughness can be related to lava flow melt properties and emplacement conditions [2], which are related to the mineralogy, crystallization and cooling histories, and temperature [3]. Geochemical analyses of two lava flows in COTM (Devil's Orchard and Highway Flow) show similar compositions, yet they exhibit different surface roughness (Figure 1). Highway Flow is described as a rough frothy lava flow with a vesicular, glassy surface. Devil's Orchard has a blocky surface comprising decimetre size lava blocks forming piles up to 6 m high. In this study, we compare the mineralogy of Devil's Orchard and Highway flows to understand why they exhibit different surface roughness despite being geochemically similar. The mineralogy is analysed using powder X-ray Diffraction (XRD) and optical microscopy. The mineralogy of the lava flows provides us context for crystallization and cooling histories, which can help us to estimate the temperature of lava flows on Earth and other terrestrial bodies.

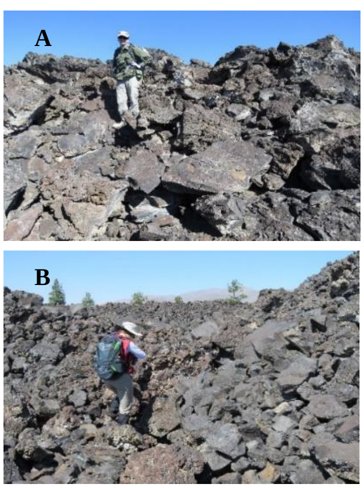

Figure 1: Field images of rough frothy Highway Flow (A) and blocky Devil's Orchard (B). Human (~1.5 m) for scale.

Methodology: Samples from Devil's Orchard and Highway Flow were powdered using a rock crusher and agate mill. Further crushing was required by hand using a mortar to ensure the grains were <5 µm. Hand crushing the powder was necessary to mitigate exaggerated peak intensities and preferred orientations of the crystal structures during XRD analysis. Using a Rigaku powder diffractometer, diffraction patterns were collected using Co Kα1 radiation (λ = 1.7889 Å), step size 0.02° /step, 5 s per step counting time, at 40 kV accelerating voltage and 35 mA beam current. Mineral phases in the samples were identified using DIFFRAC.EVA, which is a crystallography analysis program designed to identify and match mineral phases in XRD diffraction patterns by interfacing with the International Centre for Diffraction Data (ICDD) database. Petrographic textures, mineralogy, glass content, and vesicularity of the powdered XRD samples were analysed using optical microscopy.

Petrographic Analysis: Devil's Orchard and Highway Flow (Figure 2) both comprise fayalite, augite, and plagioclase. Titanian magnetite and/or ulvospinel are present in Devil's Orchard, while opaque minerals are very fine grained in Highway Flow making them difficult to distinguish from the translucent glass. Trachylitic textures in Devil's Orchard have aligned elongate plagioclase laths parallel to the flow direction. Highway Flow textures show a transition from holocrystalline to hypocrystalline moving a few centimetres beneath the surface, corresponding to rapid crystallization close to the surface. The Highway Flow sample has a glass content of 65–80%, ~20% greater than Devil's Orchard. Highway Flow has a vesicularity of 90% at the surface and decreases moving down into the lava flow body to as low as 32%. Devil's Orchard vesicularity is 40%

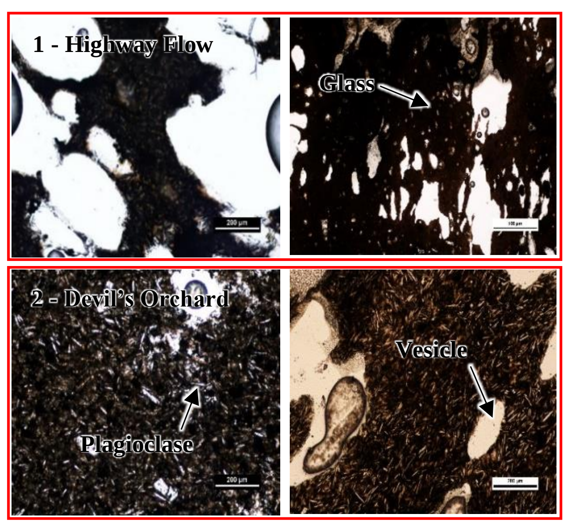

Figure 2. Thin section images of Highway Flow and Devil's Orchard show holocrystalline - hypocrystalline (1) and trachylitic (2) textures.

throughout the flow and the vesicles are deformed, trending the same orientation as the plagioclase crystals.

XRD Analysis: Diffraction patterns (Figure 3) confirmed mineral phases observed in petrographic analysis as well as identifying minerals that were too fine to identify via optical microscopy. Mineral phases identified in both samples are fayalite, augite, and plagioclase. DIFFRAC.EVA had difficulty selecting a suitable plagioclase phase as anorthite and albite peaks both fit reasonably well. Titanian magnetite and/or ulvospinel were detected in Devil's Orchard but not in Highway Flow. Instead, ilmenite crystals were identified. Traces of hematite were also found in petrographic analyses.

Discussion: The main mineralogical differences are the absence of titanian magnetite and/or ulvospinel in Devil's Orchard, and the presence of ilmenite and hematite in Highway Flow. Petrographic results for the two lava flows suggests they exhibited different cooling histories. Ilmenite crystals can form through magmatic processes, by the oxidation of ulvospinel, or through solid solution of hematite [4]. This suggests Highway Flow formed under oxidizing conditions, and Devil's Orchard was more reducing. Oxidation conditions on Earth affect ulvospinel-ilmenite crystallization as experiments by [5] have shown ilmenite in terrestrial igneous rocks form in absolute oxygen fugacity conditions (log fO_2 – mineral stability at different oxygen fugacity's) close to -8. Oxygen fugacity conditions are different on the Moon and Mars; lava flows and even impact melt flows would exhibit different crystallization histories, which would influence their surface roughness.

The Moon has a more reducing environment according to Apollo and LAP (LaPaz) meteorites as their fO_2 is below the iron-wustite buffer (-12 to -25) [6]. Martian conditions (collected from the Dar al Gani 476 martian basalt [7]) are slightly more oxidizing than the Moon but is considered more reducing than Earth (-17.2 to -11.4). With the Moon and Mars hosting reducing conditions, crystallization within lava flows and impact melts would be different than on Earth. Ulvospinel and other iron-bearing minerals would crystallize and remain stable during and after solidification. If the breakdown of ulvospinel to ilmenite and hematite is linked to the rough frothy surface of Highway Flow, then this would imply that Martian lava flows and lunar lava and impact melt flows would exhibit surfaces closely related to the blocky surface roughness of Devil's Orchard, which corresponds to interpretations made by [8].

Conclusion: Petrographic and powder XRD analysis identified the mineral phases in blocky Devil's Orchard and rough frothy Highway Flow. Analysis revealed both lava flows contain fayalite, augite, and plagioclase. Titanian magnetite and/or ulvospinel are only found in Devil's Orchard, while instead ilmenite and hematite are present in Highway Flow. Ilmenite is interpreted to have formed from the oxidation of titanian magnetite and/or ulvospinel, contributing to the formation of the frothy surface in Highway Flow. The reducing conditions on the Moon and Mars would favour the production of a Devil's Orchard-style blocky surface, while oxidising conditions favour the rough frothy surface at COTM.

References: [1] Kuntz M. A., et al. (1982) *IBM and GB, 26,* 423-437. [2] Neish et al. (2017) *Icarus, 281, 73-89.* [3] Gregg and Fink (2000) *Journal of Volcanology and Geothermal Research, 96, 145*-159. [4] Brown et al. (1993) *American Mineralogist, 78, 941-951.* [5] Lattard (1995) *American Mineralogist, 80, 968-981.* [6] Collins et al. (2005) *LPSC XXXVI, Abstract #114.* [7] Herd et al. (2002) *Geochim. et Cosmo. Acta, 66, 11, 2025-2036.* [8] Harmon et al. (2012) *Icarus, 220, 990-1030.*

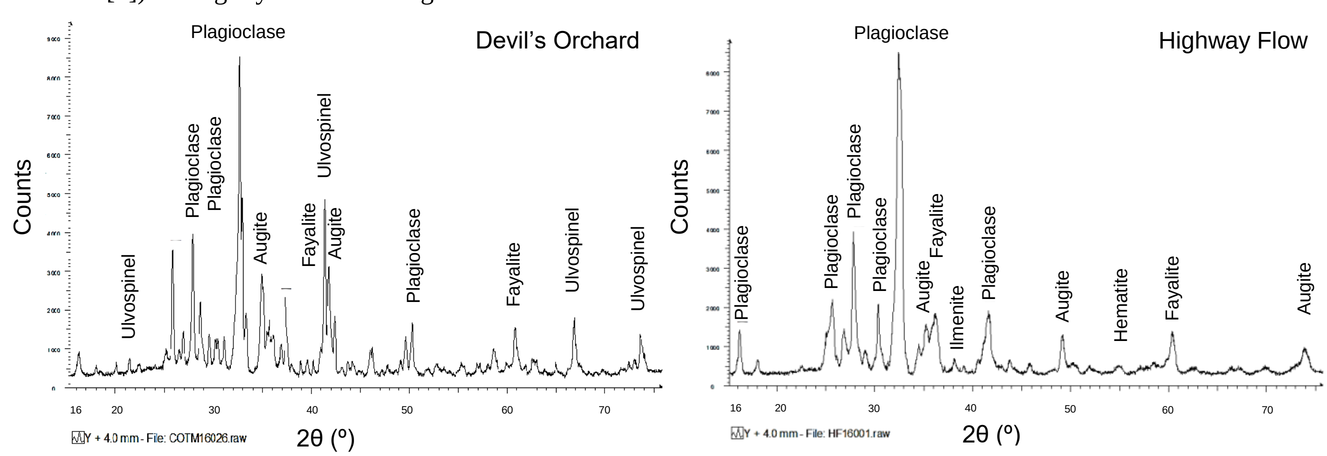

Figure 3. X-ray Diffraction patterns with background data from DIFFRAC.EVA. Both patterns show the same major minerals fayalite, augite, and plagioclase. Minor mineral ulvospinel (or Ti-magnetite) is identified in Devil's Orchard, but only ilmenite is identified in Highway Flow. The glass in the samples is represented by the curvature of the base of the main peaks.