COORDINATED IN-SITU HYPERSPECTRAL AND GEOCHEMICAL OBSERVATIONS OF PHREATOMAGMATIC DEPOSITS IN POTRILLO VOLCANIC FIELD, NEW MEXICO.

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Overview: Evaluating the eruptive history of volcanic regions is a fundamental objective of planetary exploration because it provides constraints on the timing and nature of the underlying controls (tectonic, hydrologic, thermal) on magmatic/volcanic activity. Fine-grained volcanic deposits could potentially record individual eruptive events through changes in mineralogy or geochemistry. In this work, we used a suite of handheld and standoff instruments to measure geochemical and mineralogical changes in two well-exposed vertical sections of volcanoclastic deposits in Potrillo Volcanic Field, New Mexico (NM). Our objectives are to: (1) characterize the spectral, mineralogical, and geochemical changes that are present within the stratigraphy, and (2) understand the sensitivities of various in-situ measurements to changing mineral and chemical abundances in a natural setting. A broader goal is to gather insights on effective approaches for conducting coordinated in-situ measurement campaigns during human exploration of the Moon and Mars [1,2].

Field location and imaging sites: Data were collected from Hunts Hole and Kilbourne Hole maar craters during April 2022 as part of the field activities of the Remote, In Situ and Synchrotron Studies for Science and Exploration-2 (RISE2) sub-node of the NASA Solar System Exploration Research Virtual Institute (SSERVI). Both maar craters contain rhyolitic ash fall deposits, base surge deposits, paleosols, basaltic lava flows and abundant mantle/crustal xenoliths [3].

Instruments: Standoff spectral imaging was acquired using a tripod-mounted thermal infrared (TIR) hyperspectral imager (HSI) from Spectrum Photonics, Inc. The HSI measures radiance between ~7-14 µm that yields information about spectral emissivity and surface temperature. Emissivity spectra are sensitive to changes in bulk silica content and to various silicate, sulfate, carbonate, and iron oxide minerals [4]. However, small particle sizes (<~60 µm) and porous/rough surfaces can greatly reduce the spectral contrast of these features [4], complicating quantitative analysis. Spectral sampling was set to ~15 cm^{-1} (41 channels) for this work.

Point analyses of elemental chemistry were carried out with a SciAps handheld X-ray fluorescence (hXRF) spectrometer. The hXRF uses a rugged Rh X-ray source (50 kV, 200 uA, 5 W) and a high-resolution silicon drift detector, and has a ~4 mm spot size. A handheld Analytical Spectral Devices Inc. (ASD) TerraSpec Halo visible-to-shortwave-infrared (VNSWIR) spectrometer (0.35-2.5 µm) was also used to provide additional constraints on mineralogy.

Data Acquisition: hXRF and VNSWIR measurements were acquired from six locations chosen along bedding-perpendicular sections, based on visible differences in color or texture within the outcrop (**Fig. 1**). Reflective pushpins were used to mark measurement locations. At the Kilbourne site, HSI data were acquired at a standoff distance of ~3 m resulting in ~3 mm pixel width. At the Hunts location, HSI data were acquired at a farther distance resulting in pixel sizes of ≥10 mm.
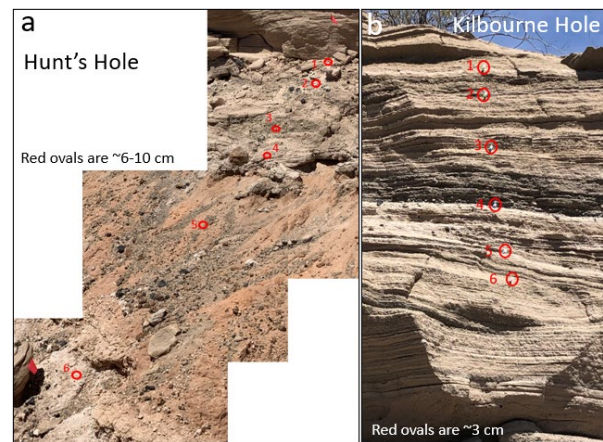

Fig. 1. Photos of the in-situ measurement locations. The Kilbourne section forms vertical faces and consists entirely of pyroclastic surge deposits (1-6). Kilbourne measurement spots sample a finer-scale stratigraphy than the Hunts locations. The sampled Hunts section contained sloping surge deposits (1-4) overlying paleosols (5-6). (Hunts Hole also contains surge deposits with vertical erosional faces, like Kilbourne, but those were not measured.)

Results: hXRF. Calibrated elemental abundances were converted to oxides for each of the 12 measurement locations and then normalized such that all oxides sum to 100%. For easier visualization on a single plot, the normalized oxides were then standardized by subtracting the mean of all 12 locations and dividing by the standard deviation. This permits an easier view of relative chemical differences between each measurement location (**Fig. 2**).

The Kilbourne measurement locations show relatively little chemical variability compared to Hunts locations; this is not surprising given the more obvious visual variability in color and texture at Hunts. Kilbourne units exhibit generally higher SiO_2 (~70-78 wt %) abundances than Hunts units (~60-68 wt%) (**Fig. 2**), suggesting that the younger, "cliff-forming" surge units are slightly enriched in SiO_2. Though the

variations are subtle, significant variability is observed in FeO (0-7 wt %) and MgO (0-4 wt %) at some locations. At Hunts, spot 2 is enriched in CaO (51 wt %) and MnO (1 wt %). Spot 5 exhibits high SiO_2 abundance (81 wt %) and spot 6 contains higher CaO (32 wt %).
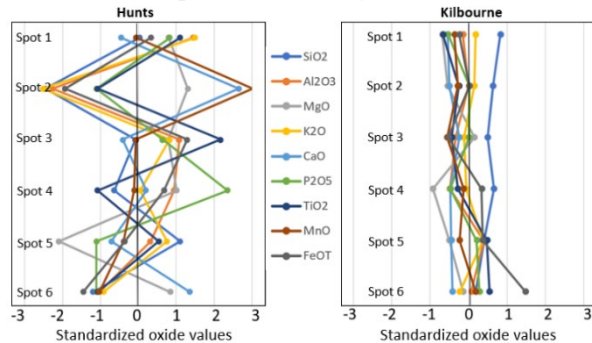

Fig. 2. Standardized hXRF oxide abundances.

VNSWIR. All measurement locations exhibit spectral features at ~1.4, 1.9 µm due to H_2O and/or OH (1.4 µm) (**Fig. 3**). All spots also exhibit a 2.2 µm feature that can arise from metal-OH bonds or Si-OH, as found in phyllosilicates and opaline silica, respectively. For all spots, the 2.2 µm feature is broad and asymmetric, which is more consistent with opaline silica [5]; however, broadening can also occur from overlapping metal-OH bands. At Kilbourne, spots 1, 2, 3 and 6 exhibit weak features at ~2.30 and ~2.31 µm that appear to be absent from all of the Hunts locations. Among library spectra, these features closely match the metal-OH bands of hectorite. At Hunts, two spots (2 and 6) exhibit strong features at ~2.34 and ~2.50 µm and a reflectance peak at 2.39 µm, consistent with carbonate.
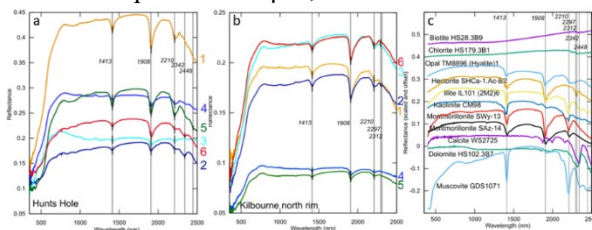

Fig. 3. Reflectance spectra from (a) Hunts and (b) Kilbourne hole, along with (c) USGS library reflectance spectra of selected phases. Vertical lines indicate wavelength position (nm) of observed features; notations are to the left of the line.

TIR HSI. HSI false color images showed little variation within the surge deposits at Kilbourne Hole but suggest spectral differences between the surge deposits and underlying paleosols at Hunts Hole. Spectra (~5-6-pixel averages) (**Fig. 4**) were extracted from the images at the handheld instrument measurement locations and modeled using a least-squares fitting routine with a mineral spectral library. Kilbourne spectra are relatively invariant and are plotted as a single color; the spectra have shallow depth likely due to the fine-grained, porous nature of the material. The best fit model to the

average surge deposit suggests a dominance of phyllo-silicate minerals with minor amounts of carbonate, quartz and sulfate; however, the lack of strong spectral features results in large uncertainty in these models. Slightly elevated carbonate abundance (~10% higher than the average surge deposit) is modeled from Hunts spot 2; significantly elevated quartz abundance is modeled from Hunts paleosol locations (spots 5 and 6).
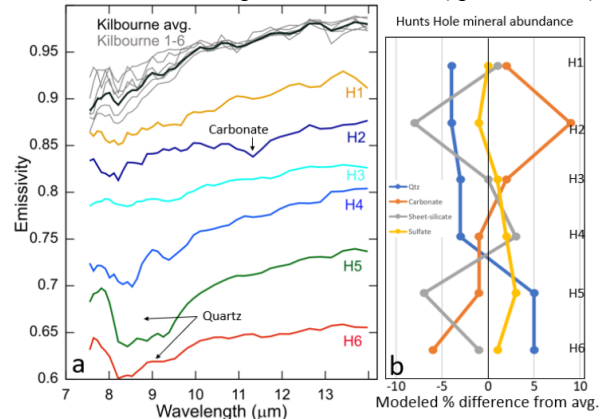

Fig. 4. (a) TIR spectra from the same locations as handheld measurements. (b) Modeled mineral abundances for Hunts TIR spectra, relative to Kilbourne avg.

Discussion. All three data sets suggest that there is little variability in mineral abundance or major elements within the cliff-forming surge deposits at Kilbourne hole, and support the dominance of sheet silicate, poorly crystalline mineraloids, and/or amorphous silica. At Hunts, all data sets suggest elevated carbonate at spot 2. Both the hXRF and TIR HSI data support elevated quartz at Hunts spot 5, and both the hXRF and VNSWIR data support elevated carbonate at Hunts spot 6. Carbonate is modeled at relatively low abundance in Hunts spot 6 TIR HSI data. Differences between data sets could be attributed to varying spot sizes, as well as different sensitivities between data sets. For example, quartz lacks spectral features in VNSWIR data, and porous materials can reduce spectral features in the TIR.

Uncertainty in the expected degree of chemical or mineralogical variability with eruptive event could be addressed by repeating this study using sediment-logical and stratigraphic observations to first identify unconformities and measuring between them. This would further help to understand whether alteration has fully obscured compositional changes within the proto-lith. Additional future work will include X-ray diffract-tion measurements for confirmation of mineralogy.

References: [1] Knudson et al., LPSC 2022, #1725 [2] Knudson et al., this mtg. [3] Hoffer J. M. and R. L. Hoffer (1998), El Paso Geol. Soc. [4] Lane and Bishop (2020), in Rem. Comp. Analysis, ed. by Bishop et al., Cambridge. [5] Milliken et al. (2008), Geology, doi: 10.1130/G24967A.1.