INCORPORATION OF PORTABLE INFRARED SPECTRAL IMAGING INTO PLANETARY GEOLOGICAL FIELD WORK: ANALOG STUDIES AT KILAUEA VOLCANO, HAWAII AND POTRILLO VOLCANIC FIELD, NEW MEXICO.

G. Ito[1], A. D. Rogers[1], K. E. Young[2], J. E. Bleacher[2], C. S. Edwards[3], P. G. Lucey[4,5,6], C. I. Honniball[4,5], D. Piquero[6], B. Wolfe[6], J. Hinrichs[6], and T. D. Glotch[1], [1]Stony Brook University, Stony Brook, NY 11794-2100 (gen.ito@stonybrook.edu), [2]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [3]Northern Arizona University, Flagstaff, AZ, USA, [4]Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, Honolulu, HI, USA, [5]Department of Geology and Geophysics, University of Hawaii at Manoa, Honolulu, HI, USA, [6]Spectrum Photonics, Inc., Honolulu, HI, USA.

Introduction: Hardware and operations tests conducted in field campaigns that simulate planetary field work scenarios frequently bring valuable knowledge that contributes to preparation for human and robotic missions to planetary bodies (e.g., Desert Research and Technology Studies) [1]. The sample collection workflow during future human missions to planetary bodies will likely benefit from portable/hand-held geochemical and mineralogical instruments [2-3], and strategies to effectively incorporate them are needed.

Ground-based infrared spectral imaging has been used to characterize the mineralogy in geological field work in the past [4-5] with encouraging initial outcomes. To fully assess the potential of infrared spectral imaging for geological field work in future planetary missions, more detailed evaluations and better incorporation strategies are further required.

As part of the Remote, In Situ, and Synchrotron Studies for Science and Exploration (RIS^{4}E) node of Solar System Exploration Research Virtual Institute (SSERVI) effort, we assess the incorporation of infrared spectral imaging into geological field work through expeditions at terrestrial analog sites. We explore the advantages and limitations of infrared spectral imaging operating in geological field work and evaluate its potential impact to future planetary surface missions.

Field Site: We have conducted field analog studies at two locations, Kilauea Volcano, Hawaii, and Potrillo Volcanic Field, New Mexico.

Kilauea Volcano is located on the island of Hawai'i and is considered an analog for the Moon, differentiated asteroids, and Mars (e.g., [6]). The geological setting at Kilauea is dominated by basaltic volcanism, and the mineral and spectral characteristics have already been characterized reasonably well [7]. This makes Kilauea an ideal place to evaluate the incorporation strategies of infrared spectral imaging into geological field work on a planetary surface. In particular, our field site focuses on a basaltic flow known as the December 1974 Flow and its vicinity.

The Potrillo Volcanic Field lies in the region known as the southern Rio Grande rift in south central New Mexico. Active magmatism from Tertiary tectonic extension created many volcanic features comparable to features on planetary surfaces, including our target feature, Kilbourne Hole [8]. Formed by an hydrological explosion of groundwater heated by magmatism, Kilbourne Hole contains mantle xenoliths that have ascended to the surface from deep subsurface due to the explosion. This presents a unique setting, especially compared to basalt dominated Kilauea, for spectral imaging to capture major variabilities within field scenes.

Methodology: Thermal emission spectroscopy is utilized to characterize the mineralogy of the geological materials at the field sites. We use a prototype scanning hyperspectral imager from Spectrum Photonics, Inc. and an in-house assembled multispectral frame imager operating in the 8 – 13 µm wavelength range. This covers the range for major spectral features of silicate minerals and the terrestrial atmospheric window in the thermal infrared wavelengths. Both are portable and operational from the ground.

The instruments measure radiance, which is calibrated and reduced to emissivity. Spectral image cubes are processed with the decorrelation stretch technique to produce false-colored images that present spectral variability. The user may then decide to use these images as a documentation tool, a guiding map during sample collection, or a reference in making traverse plans.

Results: Infrared imaging captured bulk compositional variability within scenes. The false color images enhanced the ease with which geological variability can be recognized. Furthermore, infrared spectral imaging was capable of detecting subtle and concealed variabilities often not easily recongnizable with the naked eye (Fig. 1).

At inaccessible locations, such as near-vertical outcrops, infrared spectral imaging was able to characterize the scene remotely, providing the user with the ability to collect data without risking their safety.

Discussion: We found three major advantages in using infrared spectral imaging for geological field work: documentation of bulk compositional variations, enhancement of visibly subtle or concealed variability in (sub)units, and characterization of inaccessible outcrops. The ability to document bulk compositional variability is important for understanding the geological

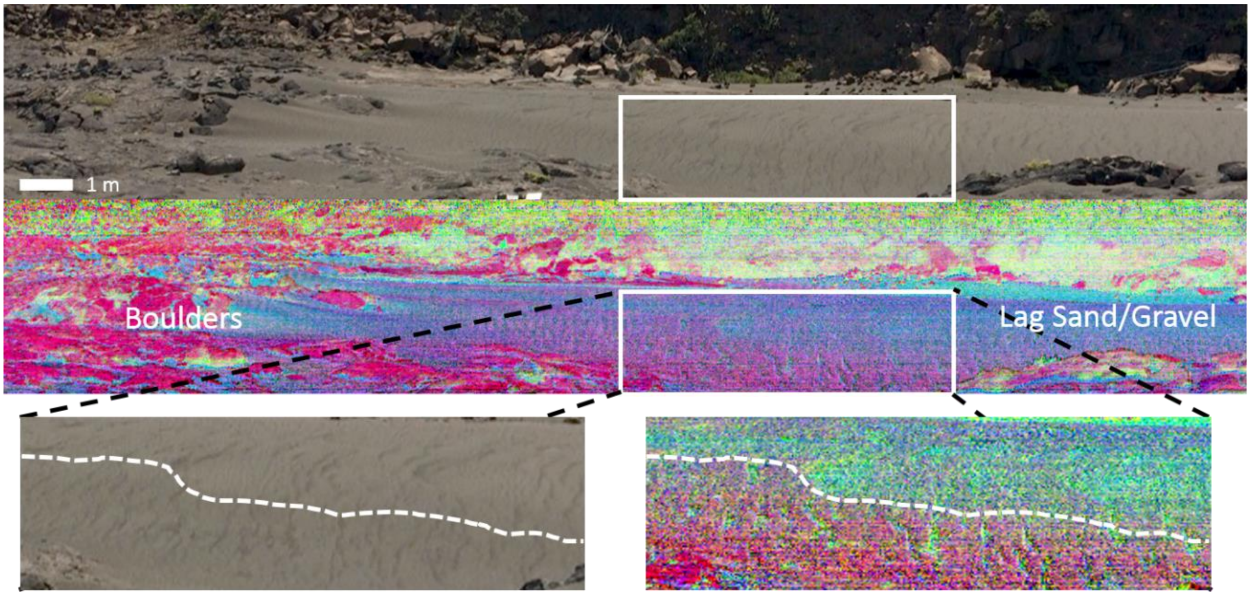

Figure 1. Scene at Kilauea, Hawaii, seen in visible light (top) and in false color infrared (middle) derived from thermal emissivity spectra. The spectral image is from hyperspectral imaging and has been decorrelation stretched where blue, green, and red were assigned to the wavelengths 8.5, 9.1, and 11.3 μm, respectively. Shadows, vertical rock faces and vegetation appear yellow-green. A section of the lag sand/gravel unit that corresponds to the white boxes is zoomed-in (bottom). Dashed line indicates an approximate division that highlights the variability within the lag sand/gravel unit.

context of the field site. The ability to detect visibly subtle or concealed variability enhances the available knowledge about the field site, thus increasing the opportunity for discovery and advancing scientific insight. For inaccessible outcrops, hyperspectral imaging could provide compositional information where in-situ measurements are not possible, and could also be used to relate more accessible samples (such as float rocks) to intact stratigraphy. We envision that field workers will benefit by exploiting these advantages in conducting geological field work.

We also note an another important aspect of ground based spectral imaging, which is that it provides a critical link in scale between orbital infrared imaging and individual samples. Ground-based spectral images act as a connection between orbitally/aerially-measured maps and individual samples, and they provide critical contextual information of the collected samples.

In geological field work strategies that incorporate infrared spectral imaging along with other in situ instruments, infrared spectral imaging could be used in concert with portable in-situ chemical or geophysical instruments and serve as one input in making traverse plans in addition to field reconnaissance. For instance, coupling spectral imaging data with X-ray fluorescence spot data or LIDAR (Light Detection and Ranging) imagery may become valuable in addressing specific science questions [9].

Conclusions: Infrared spectral imaging is capable of detecting important geological information at terrestrial analog sites and has been shown to help field workers simulating extravehicular activities [10], demonstrating that infrared spectral imaging is a potentially useful tool for future planetary geological exploration. This fundamental assessment of infrared spectral imaging will be valuable to the engineering of future instruments specifically designed for missions and the development of planetary surface exploration methodologies.

References: [1] Eppler D. et al. (2013) *Acta Astronaut.*, *90*, 224-241. [2] Hurtado Jr. J. M. et al. (2013) *Acta Astronaut.*, *90*, 344-355. [3] Young K. E. et al (2013) *Acta Astronaut.*, *90*, 332-343. [4] Greenberger R. N. et al. (2015), *GSA Today*, *25*(12), doi:10.1130/GSATG252A.1. [5] Ramsey M. S. and Harris A. J. L. (2012), *J. Volcanol. Geoth. Res.*, *249*, 217–233. [6] Malin et al. (1983), *Geol. Soc. Am. Bull.*, *94*, 1148-1158. [7] Minnitti et al. (2007), *J. Geophys. Res. 112*(E05015), doi:10.1029/2006JE002839. [8] Anthony E. Y. et al. (1992), *Geol. Soc. Am. Bull.*, *104*, 973-979. [9] Young K. E. et al. (2016) *LPS XLVI*, Abstract #1658. [10] Young K. E. et al. (2015) *AGU*, Abstract #P44A-06.