

THE ULTIMATE GEOLOGIC TRICORDER? HANDHELD SCIENCE INSTRUMENTS AND REQUIREMENTS FOR FUTURE HUMAN EXPLORATION MISSIONS ON OTHER WORLDS. A. Sehlke¹, Z. Mirmalek², B. Cohen³, S.E. Kobs Nawotniak⁴, S.S. Hughes⁴, A. Brown⁵, J.L. Heldmann¹, and D.S.S. Lim⁶
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Introduction: Spectroscopy is a powerful, usually non-destructive method to study elements and minerals on surfaces [1], including to study materials and their distributions on other bodies in our solar system, either on spacecraft flybys, spacecrafts in orbit, rovers deployed onto the surface, or human exploration [2,3,4]. Traditionally, rock samples are collected in the field and analyzed in a laboratory afterwards, yielding high quality data. However, this poses a problem in the realm of human exploration of our solar system and the nature of mission design, as time and resources are very limited, so that these analytical data need to be available immediately. Eliminating the need to return irrelevant samples back to a habitat or Earth for further analyses is therefore crucial for the missions' success.

As more standard laboratory techniques become available as portable instruments, the number of field studies making use of these instruments is increasing. Undeniably, human exploration missions will greatly benefit by incorporating these portable science instruments providing rapid, on-the-spot testing. However, we have yet to fully understand the current strengths and weaknesses of these sophisticated instruments in terms of their data quality, instrument design, and ergonomics [5]. This insight will be critical to the identification of design requirements for future iterations of these instruments, and affect their operational integration into the human exploration of space and the surfaces of other worlds.

With these questions in mind, we deployed three portable science instruments during the 2016 field campaigns of NASA BASALT (Biologic Analog Science Associated with Lava Terrains), including a visible-near infrared (VNIR), a Fourier transform infrared (FTIR), and a x-ray fluorescence (XRF) spectrometer. Our field sites are Craters of the Moon (COTM) National Monument and Preserve, Idaho, and Mauna Ulu, Kilauea volcano, Hawai'i. These basaltic lava flows are terrestrial analogs to planetary surfaces, such as early Mars. These volcanic regions are tectonically and compositionally diverse, therefore spanning a large array of major and trace elements while providing various localized alteration products.

In addition to evaluating the instruments for reliable use and rapid decision-making in the field, we are interested in reproducibility of the field measurements

in a standardized environment, such as a laboratory. For this quality assessment, we developed an array of metrics in which these instruments are tested. Such metrics include evaluation of sensitivity to sample surface roughness (e.g., flat, uneven, porous) and sample heterogeneities in the appearance of small and large-scale chemical zoning (e.g., weathering rinds, filled veins, mineral sizes and distributions). We are also exploring metrics regarding the instrument design and use, such as distance between the instrument and sample or measurement angle, as well as data reproducibility and uncertainty.

Instruments and specifications: We are testing an ASD TerraSpec® Halo portable mineral identifier. The instrument captures continuous single reflectance spectra in the visible near-infrared (VNIR: 350-1000 nm) and near infrared (NIR: 1001-2500 nm) ranges. Samples are illuminated with an internal Quartz Tungsten Halogen bulb with spot size of ~18 mm while the instrument is in contact with the sample. Spectral resolution is 3 nm for wavelengths 350-700 nm, 9.8 nm for 700-1400 nm, and 8.1 nm for 1400-2100 nm. Depending on the setting, the instrument measures 50 to 100 spectra in ~20 seconds and displays an average continuous spectrum. The spectrometer provides a qualitative assessment of identified minerals using a mineral library and fitting routine.

Our second instrument is an Agilent Exoscan 4100 FTIR spectrometer. The instrument has an integrated diffuse reflectance sampling interface measuring continuous reflectance spectra over 500 to ~15,000 nm with a spectral resolution of 4 cm⁻¹. The measurement spot is 2 mm in diameter, allowing very localized measurements. The measurement requires an external PDA over which scanning is controlled and data are stored and displayed.

Our third instrument is a Bruker Tracer-IV SD XRF spectrometer capable of producing an anode current up to 40 kV and a 60 µA beam. An internal filter wheel allows optimization for specialized measurement conditions. We are primarily interested in changes of major elements across outcrops, therefore filters are not used. The instrument can be connected to a vacuum pump, optimizing count rates, especially to detect lighter elements, such as Na and Mg. The spot size is about 3 mm. The instrument is operated via an

external PDA that displays element concentrations as calibrated and requested. Analysis time was set to 30 seconds as default in our field studies, and a maximum of 1 hour out-of-field.

Sample suite and characteristics: We tested our instruments on basalts of varying composition. In particular, we tested how well these instruments identify localized areas of various alteration states, including syn- and post-emplacement alteration products, as well as deposits at active and inactive fumaroles. The mineral assemblages and textures in our rocks vary from phenocrysts of several mm down to microcrystals. Alteration products appear as thin films, thick rinds of clays, and oxides and hydroxides. Our sample catalog ranges from dense to very porous rocks with large (sometimes cm-scale) cavities.

Results: We find that the greatest obstacles in acquiring high quality analyses are the loss of signal due to sample surface geometry and the angle of incidence. As sample surfaces become uneven, instruments lose direct contact with the surface, which results in greater sample-instrument distances and drastic signal losses. For example, raising the instrument up to 5 mm from the surface causes contamination with ambient light (at the low wavelengths) for the VNIR and FTIR instruments. The XRF count rate becomes so low as to make a measurement virtually impossible. As measurements are optimized for shortest travel distance of the detected beam (to minimize interference with the atmosphere), tilting of the instruments is also sensitive to the signal strength. We present a thorough assessment of our instruments metrics, and conclude under what conditions which technique operates with a satisfactory data output.

We find that syn- and post-emplacement alteration products were confidently identified by VNIR spectroscopy, whereas unaltered basalt was most reliably detected by XRF. The FTIR was of very limited use in the field, particularly for unaltered samples, and required expert interpretation.

Conclusions: We identified preferred use conditions based on sampling objective, as well as weaknesses that limited use. Our metrics study enables us to put further requirements on where and how to use these instruments during exploration missions. Using these instruments in conjunction with one another will equip future exploration missions with a powerful on-site identification system for rapid sample assessment.

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Figure 1: Field instruments used in our study, an ASD TerraSpec® Halo VNIR spectrometer (top), Agilent Exoscan 4100 FTIR spectrometer (middle), and a Bruker Tracer-IV SD XRF spectrometer (bottom).

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