TERRESTRIAL ANALOG ANALYSIS: MINERALOGICAL EVALUATION WITHIN THE VISIBLE AND NEAR-INFRARED. M. L. Meier[1], R. V. Patterson[2], N. C. Pearson[3], R. N. Clark[3], A. C. Martin[4], N. Kumari[5], C. J. Ahrens[6], M.E. Banks[6], E. Bell[6,7,8,], F. Vilas[3], M. Osterloo[8], P. Knightly[9], T. H. Prettyman[3], E. Z. Noe Dobrea[3], A. R. Hendrix[3], [1]University of Idaho, Moscow, ID (meier3789mckayla@gmail.com) [2]University of Houston, Houston, TX [3]Planetary Science Institute, Tucson, AZ, [4]University of Central Florida, Orlando, FL, [5]Stony Brook University, Stony Brook, NY, [6]NASA Goddard Space Flight Center, Greenbelt, MD, [7]University of Maryland, College Park, MD, [8]Space Science Institute, Boulder, CO, [8]CRESST, NASA/GSFC, Greenbelt, MD, [9]Northern Arizona University, Flagstaff, AZ.

Introduction: The Toolbox for Research and Exploration (TREX) Theme 4 field season addresses rover and astronaut operations at a terrestrial analog location (Yellow Cat, Utah). TREX, a NASA SSERVI node, focuses on exploration of airless bodies in correlation to design and preparation of future missions [1]. Our study aims to advance exploration and analytical techniques for robotic and crewed missions used to develop geologic histories of planetary surfaces

To understand the mineralogy of planetary surfaces, orbiter and rover missions have deployed Visible and Near-Infrared (VNIR; 350-2500 nm) spectrometers for identifying clays, iron oxides, water, igneous, and organic materials due to spectrally unique absorption patterns. Additionally, VNIR spectroscopy is ideal for handheld, rover, and orbiter exploration due to the non-destructive and rapid analyses. Here, we present results from our study that focuses on 1) VNIRS on rover missions, 2) impacts of handheld VNIRS, and 3) the coupling of techniques in crewed missions.

Field Operations: The simulation operates in collaboration with Carnegie Mellon University's Field Robotic Center to run a rover, Zoë, within the Yellow Cat field site. The rover traverses the field site autonomously and stops at waypoints for observation. Initial waypoints are set by the science backroom as geologic areas of interests, with the rover autonomously selecting points of uncertainty for sampling in between. A portion of the experiment saw Zoë operating in tandem with astronauts to augment their observations. Alongside the rover, field geologists act as "astronauts" evaluating the analog site geology and effective analysis tools as a model for crewed exploration.

Analytical Instrumentation: The rover is equipped with several instruments, including Analytical Spectral Devices (ASD), that provide spectral sampling of rocks and soils, as well as location profiles. Mounted to the pan–tilt of the rover, along with the science camera, is an ASD Fieldspec Pro that surveys the VNIR (resolution of 3 nm from 350–1000 nm and 10 nm from 1000–2500 nm). Sampling locations are measured differently depending on rover command, such as full panoramas, vertical profiles, or 3x3 grids at differing angles. The objective of the rover ASD is to observe the composition of ground and vertical rock exposures (i.e., outcrops, canyon walls, etc.) from a distance. This approach improves the accessibility of observations by collecting data from places inaccessible to the rover.

In addition to the rover ASD, the field team employs contact ASD to measure the composition of hand samples selected by the science team. This ASD simulates a rover-arm mounted instrument that lowers to the ground and includes its own light source, completing the 0.35-2.5 micron spectrum without gaps due to using the Sun and atmospheric absorption limitations. Using an ASD Fieldspec 3, the field team performs a systematic spectral sampling method at each rover stop to measure soil or rocks of interest. Differing from the rover ASD, the handheld ASD has a narrower view. Samples from the stops are collected and transferred to the rover.

Spectral Processing: The ASD rover and contact measurements are processed in real time by the mineral analysis and identification program, Tetracorder [2] running on the rover. The rover sends the data to a remote server that is analyzed by Tetracorder, in which the results and spectra are available to the science team rapidly. Tetracorder enables the identification of minerals based on VNIR absorption bands. The Tetracorder system compares incoming spectra to a comprehensive, cumulative spectral library of soils and minerals within specific absorption bands. After spectra are processed, the output list of potential minerals is used to decipher geologic history, provenance, and formation processes. The rover uses these analyses to compare the mineral output to a table of likely geologic origins and autonomously populates the hypothesis map. The analytical pipeline provides 1) the rover to select ideal sampling pathways between stops and 2) the ability for crews to have rapid interpretations.

Algorithm Corroboration. Tetracorder uses an expansive spectral library comparison system for the VNIR region, which can lead to potential errors in the results due to overlapping minerals or spectral band gaps. This is significant because several spectral windows ('gaps') exist within the rover-mounted ASD where the atmosphere transmittance is too low. The confidence of a correct mineral identification result is expressed by its fit to library spectral feature and its corresponding absorption depth. To verify the mineral output from Tetracorder, we manually compare rover and handheld ASD results for similar compositions, along with parallel results from other rover and handheld instruments (e.g., FTIR results). Rover and handheld ASD spectra of the same location that show different compositions are further analyzed using Environment for Visualizing Images (ENVI) to evaluate composition using USGS spectral library [3].

Mineralogy Analysis and Applicability: The mineralogy of stops is evaluated through rover and handheld measurements (*Fig. 1*), which can operate simultaneously to address different scientific questions. We compare how rover and astronauts can utilize instrumentation to learn about field site geology.

Rover ASD. The rover ASD is ideal for observing vertical geologic columns. The Yellow Cat field site consists of large mesas with central depositional valleys. The valleys are composed of mixed sediment originating from eroded strata that comprise the cliff faces surrounding the field site. The sediment is a comprehensive mix of the stratigraphy in the region - so broad spectral measurements of these depositional valleys are not suitable when the aim is to decipher geologic origin of individual strata. Collecting spectral measurements of mesas or cliffs in a vertical profile enables the observation of individual strata compositions within a stratigraphic column.

Handheld ASD. Contact measurements are ideal for crewed missions due to the increased site accessibility from on-foot traversing. Contact ASD measurements also boast rapid analysis time associated with mineral identification. The portion of the TREX simulation with analog astronauts capitalized on the availability of near-continuous contact data collection in addition to spectral data harvested by Zoë. The quick nature of the handheld ASD allows for the astronauts to explore less accessible locations, and develop their next tasks in real-time based on new mineralogical results and on-site visual observations. Additionally, astronauts can view the site in its entirety to make interpretations about stratigraphy and geologic processes, which might be missed through the narrow view of rover observations.

Combining rover and crew observations. Coupling rover and astronaut assessments of the field site delivers a more comprehensive geologic understanding of sites than robotic assessment alone. The rover and astronauts worked simultaneously at the Yellow Cat site, in which the rover was able to address mineralogy of the location while the astronauts explored terrain untraversable by the rover. The grouping of these two observation techniques allowed for broader coverage of the site as well as more in-depth geological analysis.

Future work: The TREX theme 4 Yellow Cat field season highlights the use of 1) real-time mineralogical analysis from the VNIR spectrum and 2) blending rover and crews to explore a planetary surface. To improve interpretations of spectroscopic data, the Tetracorder expert system needs more minerals added and greater spectral range cover, which is currently planned. The geologic interpretations from astronauts can be enhanced with handheld instruments, allowing for rapid results. With handheld instrumentation, data viewing during our field season was not optimal for astronauts to have immediate feedback, as it was processed remotely by the science team and then transmitted back. If the rover had a speaker/transmitter, Tetracorder can announce results to the astronauts. The addition of handheld instruments increases complexity of data transfer but provides a great tool to make constructive traverses. Overall, a rover and crew working coherently provides more efficient data collection and advances geologic knowledge considerably compared to operating separately.

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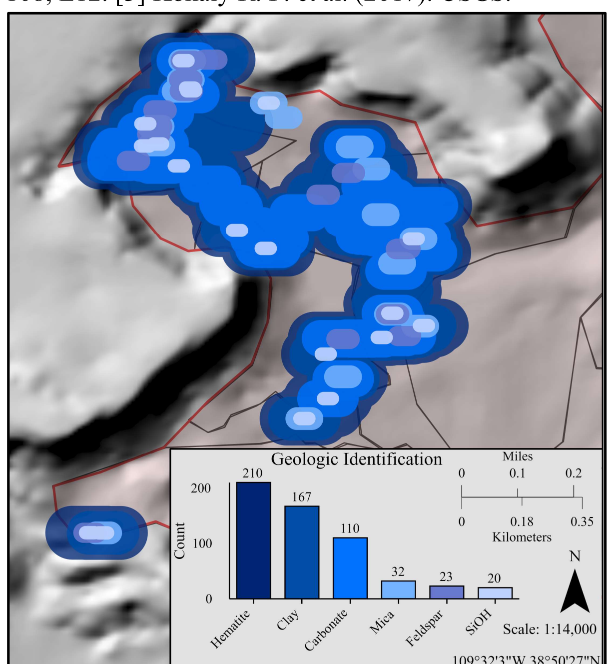

Figure 1. Identified geochemical compositions based on VNIR spectroscopy. Minerals are grouped into major categories, and the larger areas are representative of commonality of the composition class. Rover exploration boundaries in black lines and differentiated geologic origin units in red, overlaying a USGS 10m DEM Hillshade basemap.