PROCEDURE STANDARDIZATION FOR TOOLBOX FOR RESEARCH AND EXPLORATION (TREX) FIELD DATA ANALYSIS.

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Introduction: **T**he NASA Toolbox for Research and Exploration (TREX) SSERVI node carried out field testing of operational scenarios [1], including traditional science team-led operations, rover autonomous operations, and astronaut-led operations at Yellow Cat, Utah during October 2022. This abstract describes approaches to procedure standardization that could be implemented in future field exercises.

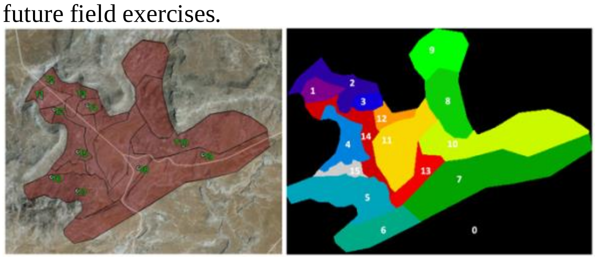

Fig. 1. Geologic units of the Yellow Cat study area assigned by science team consensus based on aerial imagery and mineralogy a) unit shapefiles overlayed on the Google earth imagery with the marked rover-visited units, b) all the defined units including the ones that were not visited

Data Analysis: The data captured by the rover included images from panoramic to micro scales. Along with the images, a series of spectroscopic data were acquired including Gamma Ray (GRS, up to 3.5 MeV) [2], Ultraviolet (UV-Vis, 0.2-1 um), Visible-Near-Infrared (VNIR, 0.35-2.5 um), Mid Infrared (MIR, 2.5-15.4 um) and X-Ray Diffraction (XRD). The VNIR and near-MIR (0.35 – 5 um range only; aka near-FTIR) measurements were processed by Tetracorder software [3] to identify the minerals potentially present in rock and soil samples. Tetracorder analyzes spectral features in many spectral regions simultaneously using multiple algorithms and a reference spectral library for mineral identification. Results include a correlation coefficient to judge the confidence in the identification. Not all spectral features are diagnostic of composition; therefore, some are reported as generic feature types, e.g., Fe^{2+} or OH absorptions. Tetracorder results were generally reported to the science team within seconds of receipt of data on the science team server. In contrast, the MIR spectra were processed through a python routine that used Spectral Angle Mapper (SAM) for comparison with six different spectral libraries to return the top five best fits per library (Fig. 2), which were further manually inspected in the science operations center (SOC) to remove any anomalies. The UV spectra were interpreted by a homegrown IDL routine through a manual comparison to a UV spectral library.

A preliminary geologic origins hypothesis map was created from Tetracorder mineral maps using AVIRIS VNIR spectral data of the area and a geologic origins lookup table for each mineral identified by Tetracorder. Aerial imagery, AVIRIS mineralogy, and the hypothesis map were used to divide the site into 14 distinct geologic units. This unit map was used to guide automated rover operations (Fig. 1).

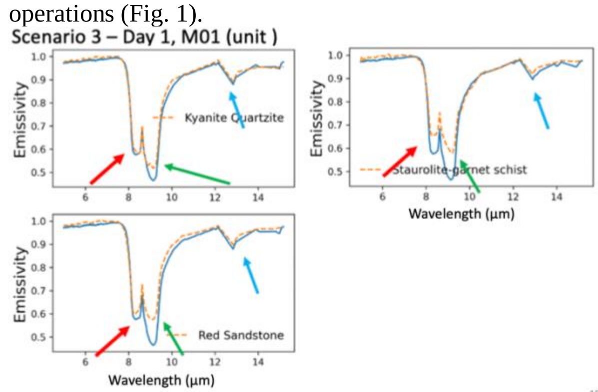

Fig. 2. The three best matches from a MIR spectrum acquired during scenario 3 with the python routine trying to find the best match. The colored (red, blue and green) display the common absorption dips with the library spectra.

Field Scenarios: Exploration of the field site was carried out for three operational scenarios. For science team-led operations (Scenario 1), the rover was directed to waypoints assigned by the science team. Spectroscopic measurements were captured using the data sent from the site at each stop and along the traverse. The spectroscopic measurements were then used by the science team to assess site geology.

For rover autonomous operations (Scenario 2), the preliminary hypothesis origins maps were provided to the rover. The rover updated the map using VNIR measurements acquired along each traverse processed via Tetracorder on the rover. As with the AVIRIS data, a geologic origins lookup table was used to automatically assess origins hypotheses based on observed mineralogy.

For astronaut-led operations (Scenario 3), a team of astronauts and the rover carried out independent investigations, with astronaut objectives set by the SOC. The traverse was automatically determined by the rover given the input hypothesis map and analyzed by the science team in the SOC at the end of each day and further updated for the next run.

Procedure Standardization for Future Field Exercises: The field expedition was successful, informing the team of techniques that were useful and those that require more preparation prior to the next field season. A well-planned field strategy led to a clear work definition for the entire team. Lessons learned from previous field exercises helped reduce our time drastically for MIR spectral analysis while increasing accuracy. The methods used to process the MIR data can potentially be extended to other regimes of spectroscopy that use manual comparison (such as the UV) and can be further improved using the innovation borrowed from Tetracorder. Such an automated approach could help in integration of various spectra and strengthen the automated hypothesis map update carried out by the rover computer.

The next area that can be further updated for improved accuracy is the initial hypothesis map provided to the rover. Currently, we manually divide the areas and prepare the hypothesis map which we found sometimes led to inaccuracies due to the large area binned into each unit and the variable nature of the field. In future operations, the map should be prepared for each pixel from Tetracorder results or other methods (such as Pure Pixel Identification and SAM, etc.). In the absence of pure pixels, which is usually the case, we can also tie rover measurement location using GPS to the pixel in the AVIRIS image, and then use SAM score to identify further similar pixels to update at once. This approach can be further extended to the automated hypothesis map upgrade carried out by the rover upon measurements in the field for Scenarios 2 and 3. This technique will help update the map of the entire area instead of only the manually divided zones (Fig.1).

Another upgrade would be improved and more complete mineral identifications leading to a better understanding of geologic origins. The latest Tetracorder expert system, 5.27b2, analyses 26 spectral groups at 0.35-5 um using 1060 spectral features. Some spectral regions are not fully populated with all the needed reference spectra, so only spectral band positions are reported. With additional entries, some of those spectral regions can be made to detect specific mineralogy. Expanding the expert system spectral range further into the infrared, and into the UV will enable the full spectral range to be analyzed. Determining how to integrate measurements of radioelement concentrations by GRS with mineralogy to update the hypothesis map is the subject of future work. It may be possible to use K concentrations to constrain the mineral assemblages used to assess hypotheses; however, this requires complete and accurate determination of the abundance of K-bearing minerals. In addition, if amorphous K-bearing phases are present, it may not be possible to partition K across observed minerals [4]. In this abstract, we focus on integrating techniques that can identify specific minerals. The analysis results will be analyzed real time as data arrive, both on the rover, and for the science team.

Finally, correcting the hypothesis map prepared by the rover requires the science team to edit the probability values for the zones. Currently, this process is carried out via a qualitative analysis. A standardization of this approach using the occurring minerals weighted by abundance in the region and then using the origins table to calculate the probability seems to be the recommended way going forward. To implement this strategy, we need to work separately on two things: 1) an origins table for minerals in MIR along with UV and XRD and 2) a code for using the mineral name repetition in all the wavelengths and weighing them together. The mineral frequency map of each unit that the rover traversed was prepared manually using the Tetracorder output of best fits. This could be automated using Natural Language Processing (NLP) algorithms for efficiency, fewer mishaps, and increased accuracy and automation.

Overall, this field trip vastly helped in preparing a roadmap for TREX future trips to automate data collection and processing.

Acknowledgment: This research was supported by NASA SSERVI NNH16ZDA001N.

References: [1] Noe Dobrea, E. Z. et al., LPSC LIII, #1674. [2] Prettyman, T. H. et al. (2023), LPSC LIII #1389, [3] Clark R. N. et al., (2003), JGR, Vol. 108, E12. [4] Prettyman et al. (2020), LPSC LI, #2326