THE INTEGRATION OF HANDHELD TECHNOLOGIES INTO PLANETARY SURFACE EXPLORATION.

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Introduction: Future manned planetary surface exploration will be highlighted by a need for effective and efficient surface characterization prior to sample selection for return to Earth. This sample high-grading, while not the only necessary step in exploring a site [1], is crucial in maximizing the science return of a surface mission. Astronauts will have many constraints limiting their surface time devoted to science activities and it is therefore of paramount importance to design sample high-grading technology to be both efficient and unobtrusive to an astronaut's surface activities.

Work is underway to design a suite of instruments to both enhance astronauts' geologic and contextual awareness of a site of interest and to enable them to collect and high-grade samples real-time during surface operations. Initial investigations centered on the effectiveness of the handheld x-ray fluorescence spectrometer (hXRF) [2,3], a commercial off-the-shelf (COTS) technology designed for use in industry and mining applications. Limitations, both in the technology (which focuses only on chemical composition and not structure), the detector hardware (which is unable to accurately detect lighter elements), and the software, have led to the development of the Chromatic Mineral Identification and Surface Texture (CMIST) instrument [4]. CMIST is a contact XRD/XRF instrument currently in development at NASA Goddard Space Flight Center. Instrument testing is taking place in part through SSERVI mission (Solar System Exploration and Research Virtual Institute) activities, specifically with the RIS4E team (Remote, In Situ, and Synchrotron Studies for Science and Exploration).

Primary study goals include evaluating how these developing handheld and field-portable technologies fit into astronaut surface operations. Time available to crews for science data collection is limited, so any implemented technologies can't require extensive time or attention from each astronaut.

Handheld X-Ray Fluorescence Technology: The use of laboratory x-ray fluorescence (XRF) technology in geological applications has been extensive and well-documented [5, 6, etc.]. Recently, companies such as Innov-X, ThermoScientific, and Bruker, for use in industry and mining, have miniaturized this technology. These handheld XRF (hXRF) instruments have potential applications in conducting field geology, both on Earth and in planetary surface exploration. In order to implement this technology into scientific applications, however, we first sought to validate the accuracy of the hXRF. Through a series of analyses conducted over a period of two and a half years at NASA Johnson Space Center, we calibrated an Innov-X hXRF instrument using a suite of terrestrial basaltic sample standards (on loan from the Spectroscopy and Magnetics Lab run by Dr. Richard Morris). Chemical compositional information about these standards was collected using the Franklin and Marshall College's PANalytical 2404 X-ray fluorescence vacuum spectrometer. Calibration curves for nine major elements (Al, Ca, Fe, K, Mg, Mn, P, Si, and Ti; Na is too light to be accurately detected with the hXRF) were developed that are now used to convert raw hXRF counts into major element oxide data (ex. Figure 1).

Additional hXRF investigations have centered on the sample preparation necessary to obtain reasonably accurate hXRF data. Figure 2 shows the comparison between laboratory data and hXRF data taken on both sawed and rough sample surfaces. The data show that, while sawed surfaces give a better approximation to the laboratory standard data, data collected on rough sample surfaces also yield data that can inform astronaut sampling activities.

A small case study was conducted [3] in conjunction with the 2010 NASA Desert RATS (Research and Technology Studies) field test. Four crews (each composed of one astronaut and one field geologist) traversed the San Francisco Volcanic Field in NASA's habitat rover (the MMSEV), with the goal of unraveling the geologic history of the region through exploration and sample collection. [3] evaluated the samples collected by one of these crews with the hXRF to determine how effective the instrument would have been had it been included in the field test. The hXRF was able to differentiate between two lava flows that were indistinguishable during mission operations.

While these preliminary instrument evaluations demonstrated that the hXRF could be a valuable addition to a planetary surface mission and give the user contextual information about their sampling site, there are several limitations with using this COTS technology. Lighter elements (i.e. Na) cannot be detected with current detector technologies. Additionally, as the calibration and software/user interface programming are proprietary, there is no flexibility in data reduction and

integration with other data sets. We now turn to developing new instrumentation to satisfy the need for technology designed to maximize an astronaut's effectiveness in real-time sample high-grading.

Developing CMIST: While traditional X-ray diffraction (XRD) requires crushing and sieving for powder analysis, contact XRD technology requires minimal sample preparation. The CMIST instrument combines this contact XRD capability with XRF technology to allow for a look both at sample chemical composition as well as texture analysis of that sample's surface. In data acquisition times of as low as 10s of seconds, the CMIST instrument can give the user valuable, real-time information about composition, mineral phase identification (including ice), and size and orientation of a variety of mineral phases.

While this instrument is still in the development phase, it shows great potential to be applicable to a variety of exploration scenarios. In order to maximize its utility to an astronaut, software must be developed for this technology that will allow the user access to a) real-time data viewing with no need for data reduction; b) potential integration with other mission data streams; and c) a balance in highlighting available data while not overwhelming the crewmember with overly detailed analyses (but instead helping to inform sample collection and high-grading). This software development will be ongoing over the next several months.

RIS4E Field Activities: The development of the CMIST instrument will take place in part through the field deployments conducted by the Remote, In Situ, and Synchrotron Studies for Science and Exploration (RIS4E) team, one of nine nodes of NASA's SSERVI program (Solar System Exploration and Research Virtual Institute). Team members will travel to the December 1974 flow at Kilauea, HI, in September 2014. Overall mission goals include investigating both the subsurface structure and surface topography of the flow as well as the in situ geochemistry and mineralogy of the site. While CMIST is not yet field portable, samples will be collected in September for future analysis with the laboratory-bound instrument.

Conclusions: Developing a suite of instruments for inclusion in the next generation of planetary surface exploration is of paramount importance in maximizing mission science return. Initial investigations on one such technology, the handheld XRF spectrometer, have shown that in situ geochemical technologies increase the real-time contextual and geologic awareness of an astronaut in the field. More work is needed, however, on streamlining user interface technology to ensure that the crewmember is not overwhelmed with data quantity but instead receives condensed data summaries to assist in sample high-grading decisions.

It should also be noted that sample collection alone is not enough to fully understand a geologic field site. Crewmember observations from the field are also crucial in understanding the context of a site to allow for a complete understanding of where each collected sample fits into the larger regional history [1]. In situ field assessment of geologic context is at least as important as in situ sample analysis for sample high-grading [7], meaning that the former must complement the latter.

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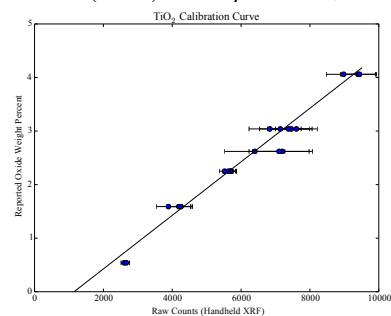

Figure 1: Handheld XRF calibration curve for TiO_2. The equation for the line is $y = 0.0005x - 0.5738$, $R^2 = 0.97411$. These curves formed the basis for the conversion from raw instrument counts to calculated weight percent oxides for the nine major elements discussed in this study. Error bars are all 2σ and errors on the reported oxide weight percent are smaller than the symbols shown.
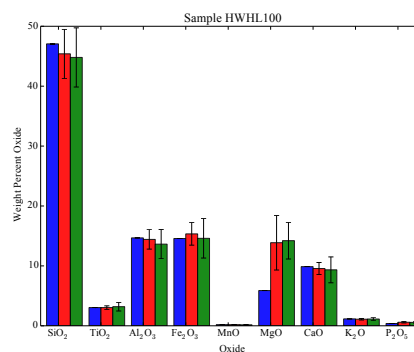

Figure 2: Plot showing comparisons for the nine major elements of interest. Data from the laboratory XRF (blue), hXRF on sawed surfaces (red), and hXRF on rough surfaces (green) are compared. Error bars represent $\pm 2\sigma$. If the error bars are not visible, the errors on that point are too small to be visible.