USE OF PORTABLE XRF AND RAMAN FOR *IN SITU* ANALYSES IN MANNED PLANETARY INVESTIGATIONS: LESSONS LEARNED FROM THE KAMESTASTIN LUNAR ANALOGUE MISSION

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Introduction: The Apollo missions were essential in improving our understanding of the types of instrumentation needed for human-led planetary surface investigations [1]. Forty years later, much of this instrumentation is still relevant for conducting basic field geology; however, new technology has been developed to enable more detailed *in situ* investigations. An example of this can be seen in the development of portable geochemical instruments. During the Kamestastin (Mistastin) Research Analogue Site for Human exploration (KRASH) mission in 2011 (see [2] for overview), we tested the feasibility and relative importance of astronauts using a handheld Raman and XRF (X-ray Fluorescence) spectrometer in the field, allowing for real-time analysis of rock geochemistry and mineralogy. We focused in particular on the effects that this instrumentation had on short-term versus long-term decision making with respect to EVAs, next-day traverse plans and sample return. In addition we also investigated the practicality of use of these instruments by humans – especially given the limited dexterity and mobility afforded an astronaut while on an extravehicular activity (EVA). This abstract presents observations from Mission Control as well as astronaut and support crew over the two weeks of field testing during the mission.

Field Site: The field site was the ~36 Ma, 28 km diameter Mistastin Lake impact structure located in Labrador, Canada at N 55°53' W 63°18'. The crater is located in a primarily crystalline target, largely comprised of anorthosite. This composition makes it an excellent lunar analogue site, providing a testing ground for astronaut mission design [2].

Instrumentation: The instruments used were the Bruker AXS Tracer IV-GEO handheld XRF spectrometer and the DeltaNu RockHound handheld Raman spectrometer with attached computer. The instruments were carried by the astronauts in back-packs, and required the presence of both astronauts for initial set up.

The XRF was used to convey real-time elemental chemistry (wt.%) of the substrate in question and was capable of analysing both major oxide and trace element composition, down to elements no lighter than Mg. As mentioned above, initial set-up of the instrument required the presence of another astronaut, in this case, simply to lift the device out of the carrying case of the other astronaut so as to maximize efficiency. Once this step was completed, the XRF could be used by a single astronaut (Figure 1).

Figure 1. "Astronaut" Raymond Francis using the XRF in the field.

The Raman spectrometer was used in conjunction with the XRF and allowed for *in situ* analysis of mineralogy. Raman spectroscopy is a common technique that utilises the vibrational mode of the molecules of a given sample to elucidate the specific chemical bonds [3]. This allows for various compounds, ranging from minerals to organic molecules, to be identified. Raman spectrometers can utilise lasers of different bandwidths, depending on the job at hand. For field analysis, the Raman comes with either a solid/liquid vial holder to allow for the analysis of powdered samples or a Point-and-Shoot attachment for direct contact with a consolidated sample *in situ*, such as a boulder. Both attachments require that a dark sheet be used to shield the sample and detector from ambient light. To use this instrument, one astronaut must hold the spectrometer steady against the rock sample, holding the sheet tight around the sample and instrument, while a second astronaut begins and monitors the analysis via the computer, and may change parameters such as sampling time, averaging of signal, and removal of background interference.

In-Field Use: There are two main methods for use of the handheld XRF and handheld Raman instruments on a planetary mission where astronauts are concerned: during an EVA while the astronaut is face to face with the rock or substance, or on returned samples in a habitat or lander-based laboratory. Both methods were utilised during this mission. Due to issues with the RockHound (see Lessons Learned), the XRF was the instrument primarily used during EVA and the Raman was used primarily in-hab. The samples that were chosen for analysis via XRF were left up to the discretion of the astronaut. Data was sent back to MC in the daily upload packets and analysed the next day.

Mission Control: The instrument lead for the Raman and XRF was responsible for analysis of new data downloaded each day. This data was analysed and interpretations on rock type were reached based solely on these analyses. At this point, high-resolution images of the sample as well as astronaut notes were consulted, to compliment or correct the formed hypothesis. Due to the lack of usable Raman data (see below), this was done solely based on XRF spectra; however, good correlations were frequently achieved. This data helped to inform MC of any changes or additional sampling that needed to occur on the next-day's EVA, and also provided a clearer map of the distribution of various lithologies within the impact structure for both MC and the astronaut team.

Lessons Learned: *XRF:* This unit is user-friendly and proved to be a valuable field tool. Once the unit was set-up, it would take approximately 60 sec per sample to get a reading. The data product generated had a very small file size (between 3-21 kb), and so was easy to include as part of the total data package sent daily from the field to MC, where we were limited on data budget. There were, however, a few drawbacks. In this capacity, the XRF is only taking point-spectra, and as such, is not an accurate representation of the bulk composition of the object in question. What is required then is a trade-off between the number of spectra necessary to properly identify any given sample, versus the amount of time allotted for the EVA. In lab, samples are powdered (and therefore, homogenized) and dissolved into a fused bead or pressed pellet before analysis. This results in data that is of a higher quality in terms of signal-to-noise, as well as data that is representative of bulk composition, reducing the influence of factors such as grain size and crystallinity. Powdering of the samples could be done in the habitat, but would be far too time consuming during the EVA. Finally it was noted that an important aspect for any astronaut using the XRF is a sufficient background in geology to be able to comprehend the meaning of the spectra that they were collecting. If the astronaut is not capable of inferring rock type based on element concentrations, the effectiveness of the instrument in-field is reduced.

Raman: The Raman spectrometer was found to be a difficult instrument to use in-field. As the quality of the spectra acquired is dependent on the distance of the unit from the target, sampling from uneven rock surfaces proved to be a challenging exercise as well as frustrating for the astronauts. The distance-to-target factor was further compounded by the fact that slight hand movements on the part of the astronaut, simply as a function of motor control and even as a result of breathing, also served to throw off measurements. When the instrument could be placed in a proper mount, in dark conditions, these factors could be eliminated – but that could only be achieved back at the habitat post-EVA. This alternative was attempted during the mission, as the more stable environment provided less of a time constraint, however, a proper mount was not available and the instrument was still hand held resulting in poor data quality.

Conclusions: For human use, the Raman was not an appropriate EVA instrument, regardless of its ability to detect mineral phases and organic compounds. Current research for the use of Raman spectroscopy in space-missions is mainly limited to usage as part of a rover – i.e. MARTE [4, 5]. In these cases, the device is designed for use within a borehole, where lighting and substrate conditions can be controlled, and error introduced through astronaut usage is eliminated. One research group, using a human-operated hand-held Raman, has shown that the instrument can operate at high-latitudes and low temperatures. However, the researchers had similar problems with light levels and also did not attempt to collect measurements of *in situ* samples, opting instead for pre-fabricated powdered samples in vials that were then brought to the field location [5]. The XRF, alternatively, proved to be quite useful for both the astronauts and MC. The importance of having in-field geochemical analysis capabilities has been noted by the Desert RATS team [1], and they have stated that it is one of the major goals to be developed on future missions. We found that our use of the XRF in-field further supports this assertion. The XRF allowed for a real-time evolution in the understanding of the regional geology, making planning for further traverses more effective. Furthermore, the astronauts gained a more concrete sense of what they were looking at, and could make more detailed intuitive observations that could then be forwarded to MC.

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