Introduction: Results from the 2015 CanMars Mars sample return (MSR) rover analogue mission [1] allowed for a geologic characterization of the concealed Mars analogue field site in Utah (southwest US). This was accomplished using a suite of stand-in and integrated instruments on board the CSA Mars Exploration Science Rover (MESR) built by MacDonald, Dettwiler and Associates Ltd. (MDA). The analogue mission was carried out in partnership between the Canadian Space Agency, MDA, and the Centre for Planetary Science and Exploration (CPSX) at the University of Western Ontario, as part of the NSERC CREATE project “Technologies and Techniques for Earth and Space Exploration” (create.uwo.ca). The mission goals were to vet current software and hardware capabilities as well as logistics and workflow of a MSR mission. The X-ray fluorescence spectrometer (XRF) was among the stand-in instruments, the functionality of which was modeled after the MSL instrument LIBS [2]; the XRF was particularly important for geologic characterization of the analogue site through in situ outcrop and regolith geochemical measurements. Here, we report the preliminary XRF data-derived observations and consequent interpretations 1) to constrain the geology of the field site and 2) evaluate the efficacy and limitations of such an instrument in the sample collection and geologic context-assessment phase of a MSR mission (prior to sample retrieval).

Geochemical Observations: Throughout the duration of the analogue mission, 113 XRF-derived geochemical data suites were collected. TEMMI (Three Dimensional Exploration Multispectral Microscope Imager) [3] coupled with high-resolution images gave context to each data point, allowing application of appropriate geochemical classification schemes. These included Ca-Mg-(Na+K) ternary diagram (as used by [4] to assess evaporitic streams), sandstone and sediment classification diagrams [5, 6], sediment chemical maturity plots [7], clay-carbonate-quartz trends [8], A-CN-K feldspar and clay weathering trends [9], regolith parent classifications [10], and mudstone classifications [11] as well as numerous other geochemical X-Y ratio plots.

The first in situ and regolith data suites were acquired on sol 2. The science team predicted a transgressive-regressive aqueous environment from pre-landing imagery and spectral data, though the specific geologic setting for emplacement could not be determined. From these first measurements, we did not find evidence of salinity or concentration of elements by evaporative processes, though it must be noted that the diagnostic elements might be below the XRF limits of detection. (Cl, for example, has detection limits of 80 ppm and lighter elements such as Na cannot be detected by the instrument.) However, Ca/[Σ(Ti+Fe+Al)] ratios indeed indicated aqueous environmental conditions of emplacement [12]. A geochemical match for hornblende, which easily alters to chlorite, was also likely present.

Pre-landing areal imagery showed a coherent unit which capped underlying layered units. Sol 4 – 6 measurements were taken from this unit and matched closely with a USGS geochemical standard for clastic sedimentary rock, with minor clays and possible evaporites. This rock classification was corroborated by imagery of rounded, gravel-sized clasts in the unit. This unit had a differentially eroded dark coating which was also seen on a dark float pebble in sol 7. Mn- and Fe-oxides were increased on these dark surfaces ~80% as compared to the powdered samples (interior), supporting similar surficial processes on both this unit and the pebble.

Following sols investigated white-red-blue layered and semi-consolidated stratigraphy known as the Jotenheitm outcrop. The red and white units were geochemically classified as argillaceous mudstones, with mineralogy between smectite and illite clays. The red layers were more Mg- and Fe-rich and Si-poor; the white layers were more Ca- and Si-rich. One lens of more coherent, blocky material within a white layer was more plagioclase-rich and less clay-rich.

Regolith samples from all sols followed a similar geochemical trend. They are classified as having been transported from clays, siltstone/sandstone, and young alluvium with enrichments in Fe, Mn, Mg, and Ti as compared to the rock outcrops.

As the mission progressed and more data was acquired, unit and regolith comparison graphs showed relative enrichments and depletions of elements. This assisted in interpretation of the changing source material, energy, and redox states throughout the regional stratigraphy. Principal component analysis (PCA) also became increasingly valuable with the acquisition of greater data points, which allowed for identifying geochemical data clusters. Cluster analysis assisted with interpretation of changing environmental conditions and source material for a given rock or regolith sample. Associative trends indicated a generally Si-rich envi-
environment, with Ca enrichments in the basal rock samples north of the field site and more Mg-rich rocks in the capping unit. Measurements of the regolith nearest to Jotenheim are Fe- and P-rich and more deplete in Si and K than those in the north of the field site in proximity to the sandstones. A Fe/Si geochemical cross-plot was used as a standard for identifying likely volcanic compositions [13]; the rocks, sands, silts, and clays in the field area were ubiquitously identified as not being mafic in composition. Similarly, Ca/Mg, Si/Ti, and Ca/Ti ratios indicated that biochemical calcite, carbonate, and dolomitic precipitation in this field area were unlikely [14, 15].

**Discussion:**

*Environmental characterization.* The XRF results support the geologic interpretation of transgressive-regressive very low – zero energy and fluvial environments with a late-present erosional regime. PCA-confirmed Ca/Mg trends and stratigraphic superposition indicate multiple paleochannel generations.

Along with the geochemical observations, TEMMMI and other images, and sediment maturity and sandstone classification plots, the basal unit of the field site was interpreted to be a hematite-cemented arkosic sandstone. The unit was deposited in a medium energy fluvial setting and was not subsequently altered by oxidation-reduction weathering processes.

The Jotenheim layered stratigraphy was the next youngest unit, consisting largely of clay-rich mudstones with possible evaporitic erosional material. The unit was a very low – zero energy depositional setting with alternating changes in redox state shown by variable Fe-oxide precipitation throughout the unit.

The siliciclastic sedimentary cap unit of Jotenheim was deposited in likely the same type of fluvial environment as the basal sandstone units but having higher energy and different source material. Locally, this unit has a dark, Mn-oxide rich, thin weathering product which indicates 1) present-day oxidizing conditions and 2) erosional resistance.

Although the regolith samples followed a similar trend, indicating a present-day erosional setting, two outlier groups emerged through PCA analysis. In high-resolution imagery, measurements acquired from the base of the Jotenheim stratigraphy came from one bright white patch (though TEMMMI imagery and hence textural information could not be acquired). The Mg/Si ratio of this white patch was an order of magnitude larger than any other regolith measurements; this ratio may indicate Mg-salts or another increase in solute concentration whether by carbonate or salt precipitation [16]. Geochemical data acquired on sol 10 was from a modern, transiently wet fluvial channel and was also clustered apart from the other regolith samples. Coupled with geomorphologic mapping, this indicated that the source material for these fresh channels were most likely from north of the field site.

**Preliminary evaluation of XRF instrument capabilities.** Although arguably the most useful instrument on the analogue mission due to the quantitative nature of the data and the remote capability, as modeled after LIBS, reliable geologic interpretation is necessarily accomplished by a suite of instrumentation. Information about grain size and morphology, long-range imagery of regional stratigraphy, and areal multi-spectral data were combined with geochemical analyses to provide contextual interpretations of the field site. Aside from the inability of the XRF instrument to detect light elements, the one constraining issue with the XRF analysis and interpretation was context. It was very difficult to locate the exact target of the cm-scale instrument field of view unless requested from high resolution imagery. (It was necessary in some circumstances to request measurement targets from panoramic images due to time and objective constraints.) Advanced targeting capabilities (e.g., autonomous targeting) or workflow adjustments (e.g., post-measurement high resolution imagery or other target confirmation) is a crucial capability to develop for a MESR-integrated XRF instrument.

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**References:**