APXS ANALYSIS OF THE JURA AND KNOCKFARRIL HILL MEMBERS OF THE MURRAY FORMATION WITHIN THE GLEN TORRIDON LOCALE, GALE CRATER, MARS.

Introduction: Since leaving Vera Rubin ridge (VRR) in January 2018, the Curiosity (MSL) rover (Gale crater, Mars) has been exploring the phyllosilicate unit or trough [1, 2], now informally called “Glen Torridon” (Fig. 1). Glen Torridon lies within the Murray formation (Mount Sharp group), a series of fluvio-lacustrine mudstones to sandstones [3-4]. The Glen Torridon bedrock comprises a series of units identified from orbit as Fe/Mg smectite clay rich [e.g., 2, 5], in a geographic trough skirting along the edge of VRR and located below layered sulfate units. The change from clay- to sulfate-rich indicates a significant change in environmental and depositional conditions [5-6]. The Canadian built Alpha Particle X-ray Spectrometer (APXS) has been used to determine bulk geochemical compositions, through the combination of PIXE and XRF analytical techniques [7].

Figure 1. (A) Gale crater, rover traverse shown in grey. (B) Glen Torridon, showing waypoints or major locales (orange), 4 drill holes (red) and traverse (yellow). Four drill holes: Aberlady + Kilmarie (GT_Jura mbr); Glen Etive_1 + Glen Etive_2 (KH mbr).

Context: On the basis of orbital data, bedrock within Glen Torridon was subdivided into two, potentially interbedded, units [8-9] (Fig. 1): (i) a smooth, ridged sub-unit (smooth clay-bearing unit or “sCBU”), with a strong smectite spectral signal; and (ii) a rough, polygonally fractured unit (fractured unit or “fCBU”), with a weaker smectite signature. Between these units and the overlying sulfate units, a transitional or intermediate fractured unit (intermediate unit or “fIU”) [8] is identified, with a spectral signature suggesting a mix of smectites and hydrated sulfates [e.g., 10-11].

Sedimentological units: Two members - Jura (GT_Jura) and Knockfarril Hill (KH) are identified within GT [12-13], with a transition identified between GT_Jura & KH e.g., at Knockfarril Hill (Fig. 1). The GT_Jura mbr (stratigraphically equivalent to the Jura mbr previously identified on VRR [4, 12]) roughly correlates with the sCBU, and comprises finer grained material (mudstone), with pebbles, cobbles and rare patches of more coherent bedrock. The Knockfarril Hill mbr (KH) [12] roughly correlates with the fCBU, and comprises primarily coarser grained, coherent cross laminated sandstones, and, less commonly coherent mudstone layers and rubbly fragments.

APXS analyses: Two geochemical end-members are identified in GT bedrock, based primarily on K2O concentrations, and strong negative (e.g., K2O-MgO, Fig. 2A) or positive (e.g., MnO-Zinc, Fig. 2B) correlation relationships. Most of the targets analyzed to date can be classified as either a low K-high Mg or a high K-low Mg endmember; however a small number of “intermediate” targets lie between the two endmembers. Both geochemical end-members are present in both the GT_Jura and KH mbrs.

Grain size relationship: There is a clear relationship between grain size/morphology and composition. Finer grained material (rubbly to more coherent mudstones within GT_Jura and KH) tends to high-K, low-Mg. More coherent, coarser bedrock (sandstone) (dominant morphology in KH, less commonly in GT_Jura) tends to low-K, high-Mg. This is also identified using Gini Index analysis of ChemCam LIBS shots [14].

Relationship to VRR_Jura: GT samples fall within family of median Murray (Fig. 3). However, although GT_Jura is stratigraphically equivalent to VRR_Jura and therefore likely syn-depositional, APXS has identified changes in geochemistry between the two (Fig. 3). Most notably, GT_Jura tends to lower Si, Al, Na and higher Ti, Fe, Zn, Br than VRR_Jura. Mn and Cr abundances are similar for GT and VRR but GT samples exhibit local enrichments, at the AL+KM locale, and throughout KH mbr. Ni is lower in GT, with bulk values similar to those in “typical” VRR_Jura, but lower than “blue-grey” VRR_Jura (Fig. 3). A slight trend of increasing Ni with elevation is identified in KH, but does not appear to continue into the Buttes. Br concentrations include the highest identified in Murray to date, esp. at AL+KM, and throughout KH.
K₂O+MgO: K₂O and MgO have a broader range in GT than identified in VRR_Jura. GT_Jura has higher K and lower Mg than median Murray (Figs. 2A, 3). Highest Mg, lowest K values in GT_Jura are identified in more coherent bedrock, such as the AL+KM locale. Within KH, Mg typically trends high, and K low, in line with the observation that most bedrock is coherent and coarser grained. Highest K, lowest Mg values are identified in finer-grained mudstone layers, e.g., the Glen Etive drill locale.

Zinc: Although bulk Zn is similar to, or lower than median Murray (Figs. 2B, 3), some very high abundances (highest in Murray) are identified locally, at the AL+KM and Teal Ridge + Harlaw Rise locales (Fig. 1). This finding is also highlighted by [15]. High values at AL+KM are positively correlated with high Mn (highest in Murray). A strong anti-correlation (r=-0.75) is identified between Zn and K; highest Zinc levels are found in coherent bedrock (both GT_Jura and KH), rather than in the K₂O-rich rubby material.

The Buttes: Preliminary results from the Central and Western Buttes, within the intermediate unit (IU) (Figs. 2, 3), whilst showing increased evidence for diagenesis (bleaching of high-K targets, abundant nodular type features in specific intervals), fall within family with other GT bedrock, with both high-K & low-K end-members. The exception to this are the “Blackwater-foot”-type float rocks, speculated to be part of the Western Butte capping unit, which are more similar to Bradbury group targets.

Drill holes: Initial CheMin results indicate that the four GT drill targets are the most clay-mineral rich samples to date in Gale crater (≥30% wt.) [16-17], with slightly higher clay abundances (≥2-3%) in KH targets [GE1+GE2] [17]. APXS analyses indicates drill locale samples lie on the extreme end of the range for most elements - highest Ti, Fe, Mn, Cr, Zn, Br; lowest Al, Na, broad range Mg, K, Ni.

Discussion: The transition from finer-grained mudstones (GT_Jura) to coarser-grained, cross-laminated sandstones (KH) indicates a change from a low energy depositional environment to a higher energy setting. Despite this, APXS analyses shows similarity and geochemical compositional overlap between GT_Jura and KH, with high-K and low-K end-members identified in both, suggesting a common source. Changing K-Mg-Zn levels correlate strongly with grain size, suggesting that sorting processes may be an important element in the evolution of Glen Torridon.

Differences in both mineralogy [16] and geochemistry are identified between GT_Jura and VRR_Jura. These changes may be due to later post-depositional alteration, concentrated in a front along VRR, altering the ridge mineralogy to be more hematite-rich, clay-poor [18]. Higher-K abundances seen throughout GT_Jura may result from some (limited?) degree of diagenesis, not identified in KH.

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