APXS geochemistry of the fractured Intermediate Unit (fIU) - its relationship to underlying Glen Torridon units and overlying pediment rocks at the Greenheugh unconformity

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Introduction: For over two years, the *Curiosity* (MSL) rover (Gale crater, Mars) has investigated the "Glen Torridon" area (GT) within the fluvio-lacustrine Murray formation (Mount Sharp group) [***1-2***]. Two clay-rich units [***3-4***], displaying strong Fe/mg smectite signals, have been divided, via orbital mapping, into smooth- and fractured-clay-bearing units (sCBU and fCBU). In situ lithostratigraphic mapping identifies two corresponding members: the mudstone dominated Jura (herein *Jura_Gt*) (~sCBU) and the cross stratified sandstone dominated Knockfarril Hill (KH) (~fCBU).

Between the lower GT clay-rich units and the overlying sulfate units, a transitional unit (fractured intermediate unit or "*fIU*") [***3***] was identified, via orbital mapping, with a spectral signature suggesting a mix of smectites and hydrated sulfates [e.g., ***5-6***]. Rover operations over the past year have focused on in situ mapping and geochemical analysis of the *fIU* (including a local contact with the Greenheugh Pediment). The Canadian built Alpha Particle X-ray Spectrometer (APXS) has been used to systemically determine bulk geochemical compositions, through the combination of PIXE and XRF analytical techniques [***7***].

APXS analysis - lower GT (i.e., Jura_Gt and KH): APXS analysis of the lower GT identifies four key elements – K_2O, MgO, MnO, and Zn. Correlation relationships are identified, via both univariate and multivariate correlation analysis (**Fig. 1**): (1) Positive correlations between Mg, Mn and Zn and (2) negative correlations between K and Mg, Mn, and Zn [***8***]. An inverse relationship is identified, whereby finer grained mudstones & pebbles have higher K concentrations than the sandstones [***8***]. Trends are strongest in Jura_Gt, decreasing with elevation, but, importantly, are not identified in the stratigraphically equivalent (and likely syn-depositional) [***2, 9***] Jura mbr on the Vera Rubin ridge (VRR) (Jura_VRR). The correlation of strong geochemical trends (K-Mg-Zn-Mn) with grainsize in the lower GT targets are probably indicative of sorting processes [***8***].

*Variance analysis***:** Variance analysis shows that Jura_Gt and KH are compositionally similar, with P showing a statistically significant difference between the two. However, there are several differences between the lower GT members, and mean_Murray (Zn, Ti, Br for both; Jura_Gt only: Fe, P, S, Ca; KH only: Cr, Mg, Na, Si) (in order of decreasing significance). Additionally, differences are identified between Jura_GT and Jura_VRR, indicating a substantive change in bulk chemistry: Fe, Ti, Br, Cr are significantly higher in Jura_Gt; S, Al, Na, Ca, Ni lower in Jura_Gt.

APXS analysis - fIU: APXS has analyzed fIU targets at the "buttes" [Central (CB), Western (WB), Tower (TB)], the upland plateau between the buttes, and along the traverse to the sulfate unit. The majority of these are classified as "*fIU_typical"*. A geochemically distinct subunit (herein "*fIU_HT")* was identified in the Hutton drill zone at Tower Butte, just below the Greenheugh unconformity.

fIU_typical: Relative to lower GT (mean Jura_Gt+KH), the fIU_typical is depleted in Zn, Mn, Br, Cl, K, Mg, Fe, Cr, Ti, and enriched in S, Ca, P, Ni (in order of decreasing differences) **(Fig. 2)**. Highest concentrations of K, Mg, Mn, Zn are typically identified at lower elevations, in particular just above the contact with KH along the base of CB.

fIU_HT: Similar to the fIU_typical, the fIU_HT is depleted (relative to mean lower_GT) in Zn, Br, Cl, Ti, Cr, K, Fe, and enriched in P, Ca, with highest average P for the GT locale in the fIU_HT. However, unlike the fIU_typical, Mn, Mg, Na, are also enriched in fIU_HT whilst Ni, S are depleted (Fig. 2). This enrichment in Mn, Mg, Na is also seen in the overlying Stimson and Edinburgh drill locale, above the Greenheugh unconformity [***10***].

Correlation analysis: The strong correlation trends identified in lower GT are weak (if present) in the fIU_typical and absent from the fIU_HT. The paired increase in both Mn and Mg with increases in Zn is notably absent in the fIU.

Diagenesis in fIU: The fIU is typically lighter toned than lower GT, with abundant nodules and CaSO4-rich veining (rare or absent in lower GT). Evidence for diagenesis increases with elevation in the fIU, and with proximity to the Greenheugh unconformity, in the fIU_HT.

CaO, SO_3: Ca and S are strongly correlated (Pearson correlation coefficient, r, >0.90) in lower GT, with concentrations increasing with elevation into KH and the lowermost fIU at CB. However, with increasing elevation in the fIU, *r* falls to ~0.60, indicating a decoupling of Ca and S. Excess S (relative to the $CaSO_4$ addition trend line) is common in WB and plateau fIU bedrock targets, whilst excess Ca is common in bedrock in the fIU_HT and the top of WB (**Fig. 3A**).

Na_2O: Na concentrations are stable throughout the lower Gt and fIU_typical but jump dramatically at the Hutton zone, with highest values in fIU_HT (& EB locale) (**Fig. 3B**). Variance analysis shows that the high (fIU_HT) Na values result in the greatest degree of statistical significance for any element within GT.

Veining and nodules: In addition to $CaSO_4$ rich veins, complex Mg-K (Mg 11-17 wt. %, K 2 w%) and Fe-Mn (Fe 40 wt. %, Mn 5-6%) vein networks are also identified in the fIU_HT, and on top of WB. Raised "nodular" features, typically spherical or rounded, found throughout the fIU, are typically compositionally similar to underlying bedrock but some exceptions have been identified e.g., "An_Dun", in the geomorphic unit "fIU_rubbly" [***11***] is enriched in Mg+ S.

Discussion: The *fIU* may mark the transition from the underlying clay-rich units (lower GT) to overlying sulfate-rich unit. As the rover approaches the sulfate unit, tracking and interpreting fIU compositional changes (especially in Ca, S, Mg etc.) and any increased diagenesis (resulting from increased proximity to the sulfate unit) with APXS will be vital to our understanding of the evolution of the fIU. The fIU may also be key to interpreting environmental and depositional changes (from fluviolacustrine to sulfate rich), within Gale crater, with potential global implications for the evolution of Mars.

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References:

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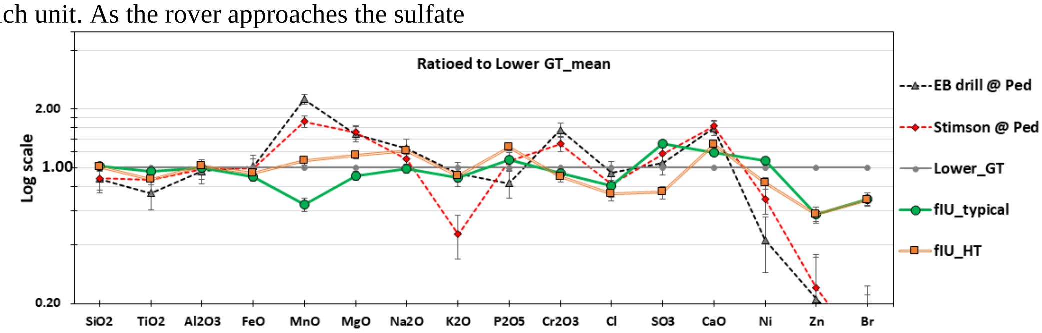

Figure 1. Averages for fIU_typical, fIU_HT, Stimson on Greenheugh Pediment, Edinburgh drill locale. Ratioed to mean_lower GT (Jura_Gt, KH, excludes obvious diagenetic features)

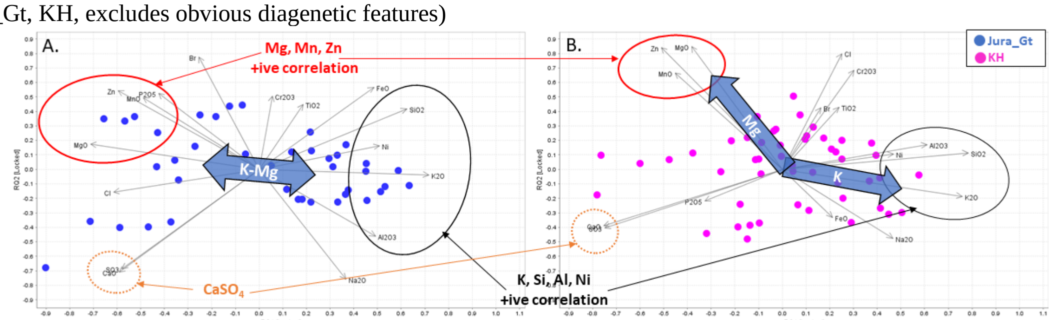

Figure 2. Principal Component Analysis (PCA). **A.** Jura_Gt. **B.** Knockfarril Hill (KH). Excludes obvious diagenetic features.

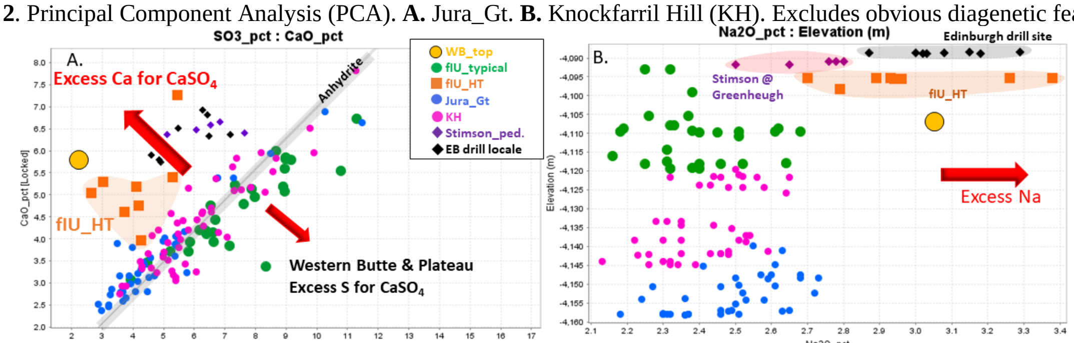

Figure 3. A. SO_3 Vs CaO. **B.** Na_2O Vs P_2O_5. All oxides wt. %