Contextualizing CRISM observations of the clay-bearing Glen Torridon region with the Mars Science Laboratory Curiosity rover.

V. K. Fox[1], K. A. Bennett[2], A. B. Bryk[3], C. Fedo[4], R. Arvidson[5], E. Dehouck[6], B. Ehlmann[7] and the MSL Science Team. [1]Carleton College, Northfield, MN (vfox@carleton.edu), [2]USGS Astrogeology Center, Flagstaff, AZ, [3]UC Berkeley, CA. [4]Washington Univ. St. Louis. [5]Université de Lyon [6]Caltech, JPL, Pasadena, CA.

Introduction: In-situ exploration of clay mineral bearing strata within a region called Glen Torridon (GT) in Gale crater has been a major Curiosity rover mission milestone, as these outcrops, which underlie hydrated sulfate layered deposits, are interpreted as potential records of a period of significant environmental and climatic change on ancient Mars [e.g.[1–3]. Indeed, the rover observations of the region has provided important ground context of the orbitally-based observations of the regions[4], inform interpretations of the lithologies and landforms, and uncovered evidence for changing environmental settings within the ancient Gale Crater lake system[5].

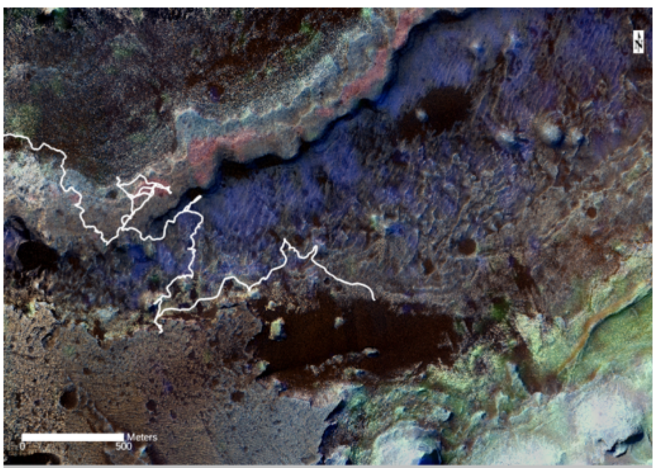

Figure 1. The Glen Torridon region is characterized by recessive and resistant mud and sandstones that exhibit spectral features characteristic of Fe smectite clays (CRISM overlain in blue on HiRISE). Red shading is indicative of hematite on Vera Rubin Ridge to the north, and green shading indicates hydrated sulfates in overlaying layered deposits. Curiosity's traverses are shown in white.

In Situ observations and stratigraphic implications: As anticipated, GT has indeed important insights into the evolution of the strata in Gale crater and changing environments on early Mars.

Geologic Context: Glen Torridon hosts three stratigraphic units that are all members of the Murray formation, which is predominantly finely laminated mudstones intercalated with cross bedded sandstones[6]. The Jura and Knockfarril Hill members, and the orbitally-defined Fractured Intermediate Unit (fIU) are each discernable on the basis of sedimentary characteristics observed by the rover that often correspond to orbital-scale morphological properties. However, unit boundaries cross geomorphological features and orbital-scale patterns; this is particularly apparent in the Jura, which spans both the resistant Vera Rubin ridge (VRR) and the recessed lower GT. Despite the elemental and mineralogical similarities between the GT Jura member and Knockfarril Hill Mbr, their sedimentary textures suggest a change in the primary depositional setting. The finely laminated mudstones of the Jura are consistent with lacustrine deposits in low energy settings[7], but the scale of cross stratification in the Knockfarril Hill member suggest a higher energy depositional environment. The fIU is best distinguished from the Knockfarril Hill member by its lighter tone, a greater diversity of diagenetic features, and lack of cross-stratification.

Diagenesis: The stratigraphic equivalency but significant mineralogical differences between the Jura member on VRR vs. within GT suggest that post depositional alteration significantly influences the geologic record of this area. One possible model is that a diagenetic front preferentially altered and cemented the VRR sediments, and the Jura and Knockfarril Hill members of the GT region have experienced relatively less diagenesis, allowing the preservation of clay minerals. This is supported by mineral assemblages measured in the lower GT compared to VRR[8]. Similar trends are observed within the Fractured Intermediate Unit as evidence for enhanced diagenesis increases with proximity to the Greenheugh pediment. The mineral assemblages in the Hutton drill samples in particular show increased evidence for later diagenetic overprinting and decreased phyllosilicate content compared to other drill samples in the region.

Correlations with Orbital Observations: The GT region is associated with distinct spectral characteristics indicative of smectite clays that are not clearly detected lower in the Murray formation, despite being continuous strata. CRISM data show absorption features at 1.9, 2.24 and 2.8μm consistent with nontronite particularly associated with recessive Jura member mudstones in the lowest regions of GT and cross-bedded Knockfarril Hill sandstones. Mineralogical results from drill samples within GT do indicate elevated abundances of clay minerals[8], although most previous Murray formation drill samples also contained clay minerals[9,10], begging the

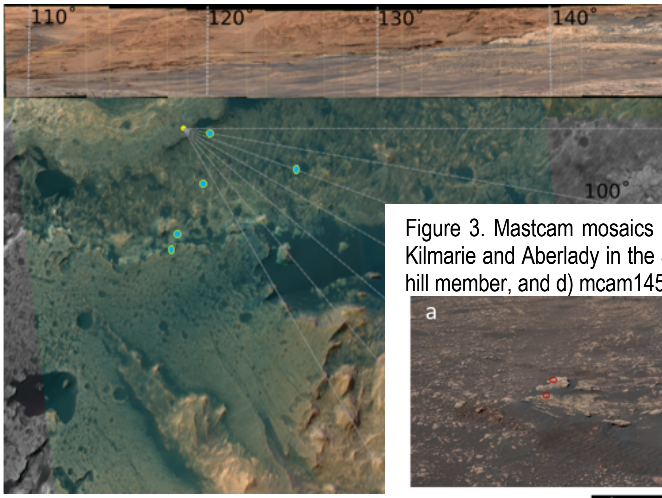

Figure 2. Mastcam 10650 looks south (left) towards the layered sulfate deposits across Glen Torridon and shows (right) the morphological variation associated with different Glen Torridon units and spectral properties. Locations of drill samples collected by Curiosity are indicated by the cyan ovals; the observation origin on top of Vera Rubin Ridge is shown in yellow.

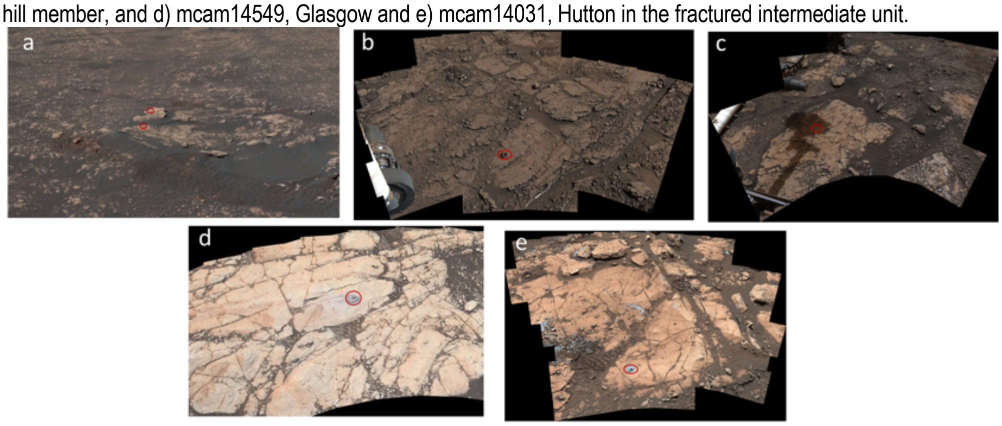

Figure 3. Mastcam mosaics of the drill sites showing the different surface morphologies in GT a) Mcam12780, Kilmarie and Aberlady in the Jura b) Mcam13242, Glen Etive, and c) mcam14883, Mary Anning in the Knockfarril hill member, and d) mcam14549, Glasgow and e) mcam14031, Hutton in the fractured intermediate unit.

question of what makes the GT region favorable for orbital mineral identification.

Curiosity's in-situ exploration has provided key geologic context to better interpret the distribution of orbital mineral detections. Crucially, sand and dust cover obfuscate spectral signatures from bedrock. Clay-bearing units to the north of GT are partially obscured by sand from the Bagnold dune field. Within lower GT, where the strongest CRISM signatures are location, there is very little intact bedrock, but the surface is predominately covered in loose mudstone clasts. Fracturing of surface materials has been observed to enhance the orbital detection of hematite on VRR, as well[4] The effect of dust cover is illustrated again within the Knockfarril Hill member; smectites are still easily detected in the CRISM observations of the blockier sandstones, but visible dust accumulations on the top surfaces of outcrop explain the somewhat weakening spectral signatures.

Enhanced diagenesis also controls the spectral characteristics of facies as seen from orbit; the Glasgow member has a unique spectral pattern in the CRISM data compared to the rest of Glen Torridon and is best characterized as having a steep red slope and variable M-OH features. Further investigation will be undertaken as the rover continues to explore this facies, but physical characteristics of the Glasgow member, including increased cementation, may also play a role in the changing spectral characteristics. Although heavily fractured on the decimeter scale, blocks remain coherent and do not as easily break down into the loose rubble like the Knockfarril Hill and Jura members. Glasgow is also notably lighter toned in the visible than the Knockfarril Hill member (Figure 3), suggesting a more complicated interplay of optical and lithologic properties.

References: [1] Milliken R. E. et al. (2010) *Geophys. Res. Lett.* **37**, L04201. [2] Fraeman A. A. et al. (2016) *J. Geophys. Res. Planets* **121**, 2016JE005095. [3] Anderson R. and Bell J. F. (2010) *The Mars Journal* **5**, 76–128. [4] Fraeman A. A. et al. (2020) *Journal of Geophysical Research. Planets* **In Review**. [5] Rampe E. B. et al. (2020) *Journal of Geophysical Research: Planets* **125**, e2019JE006306. [6] Grotzinger J. P. et al. (2015) *Science* **350**, aac7575. [7] Edgar L. A. et al. (2020) *Journal of Geophysical Research: Planets* **125**, e2019JE006307. [8] Thorpe M. T. (2020) .
[9] Rampe E. B. et al. (2017) *Earth and Planetary Science Letters* **471**, 172–185.
[10] Bristow T. F. et al. (2018) *Science Advances* **4**, eaar3330.