THE MINERALOGY AND SEDIMENTARY HISTORY OF THE GLEN TORRIDON REGION, GALE CRATER, MARS.

M. T. Thorpe[1*], T. F. Bristow[2], E. B. Rampe[1], J. P. Grotzinger[3], V. K. Fox[3], K. A. Bennett[4], A. B. Bryk[5] A. S. Yen[6], A. R. Vasavada[6], D. T Vaniman[7], V. Tu[1], A. H. Treiman[8], S. M. Morrison[9], D. W. Ming[1], R. V. Morris[1], A.C. McAdam[10], C.A. Malespin[11], P. R. Mahaffy[10], R. M. Hazen[9], S. Gupta[11], R. T. Downs[12], G. W. Downs[12], D. J. DesMarais[2], P. I. Craig[7], S. J. Chipera[7], N. Castle[8], D. F. Blake[2], and C. N. Achilles[10], [1]NASA JSC, Houston (michael.t.thorpe@nasa.gov), TX, [2]NASA Ames Research Center, [3]Caltech, [4]USGS, [5]Univ. California, Berkeley, [6]JPL/Caltech, [7]PSI, [8]LPI, [9]Carnegie Institute, [10]NASA GSFC, [11]Imperial College, [12]Univ. Arizona.

Introduction: Gale crater was selected as *Curiosity's* landing site largely because, from orbit, phyllosilicate-rich strata were identified on the slopes of Mt. Sharp [1,2]. This phyllosilicate unit was later dubbed the Glen Torridon (GT) region, and the rover has been traversing this region since early January 2019. On Earth, phyllosilicates in the rock record preserve a history of aqueous conditions, overprinted with paleoclimate and environmental signatures (e.g., ref 3). Thus, the GT is a highly anticipated region of exploration in Gale crater, and the mineralogy of its sedimentary rocks may provide clues to its ancient origin.

The Glen Torridon region is tangent to two prominent features on the slopes of Mt. Sharp: Vera Rubin ridge (VRR) and the Greenheugh pediment (Fig. 1). Sedimentary rocks from VRR to the north are coeval with and sedimentologically very similar to the GT, i.e., finely laminated mudstone, suggesting these sediments were deposited in a lake environment. To the south, there is an unconformable contact (i.e., Siccar Point unconformity) between GT and the Greenheugh pediment, presenting a shift to an eolian sedimentary environment. To best document the sedimentary history in this environment, *Curiosity* has performed an extensive drill campaign in the GT.

Methods: The drill fines of 9 GT targets were analyzed by the CheMin X-ray diffractometer for mineralogy. Glen Torridon has been subdivided into three informal units including the Jura member, the Knockfarril Hill member, and the Fractured Intermediate Unit (FIU). Drilled samples include Aberlady (AL) and Kilmarie (KM) from the Jura member, two different drill samples from both Glen Etive (GE and GE2) and Mary Anning (MA and MA3) localities as well as Groken (GR) from the Knockfarril Hill member, the Glasgow (GG) target from the FIU, and Hutton (HU) from directly below the contact of the FIU and Greenheugh pediment. Drill powder from each sample was delivered to the CheMin X-ray diffractometer (XRD). Rietveld refinement and FULLPAT analysis of CheMin patterns allow for the quantification of crystalline phases and X-ray amorphous materials with a detection limit of ~1 wt.% for minerals [4,5]. Evolved gas analyses by the Sample Analysis at Mars (SAM) instrument allow us to constrain clay mineralogy based on the temperature of H_2O releases [e.g., 6].

Figure 1. Aerial Map of the GT, VRR, and Pediment with the drill targets in the GT marked by stars.

Results: Overall, the Glen Torridon drill targets are mineralogically similar, dominated by plagioclase, Ca-sulfates, phyllosilicates, and X-ray amorphous materials. The GT samples are some of the most phyllosilicate-rich targets explored by *Curiosity*, with abundances ranging from 23 to 35 wt. %. Ferric smectite is the dominant phyllosilicate identified in the suite of GT targets, confirming orbital mineral identifications based on near-infrared spectra [1]. However, while the GT targets appear to be in the same mineralogical family, specific drill samples have distinct differences in the XRD patterns. For example, Fe(II)-bearing carbonate has been identified for the first time by the CheMin instrument in both the Kilmarie and Mary Anning 3 drill fines, also confirmed by SAM [6;7]. In

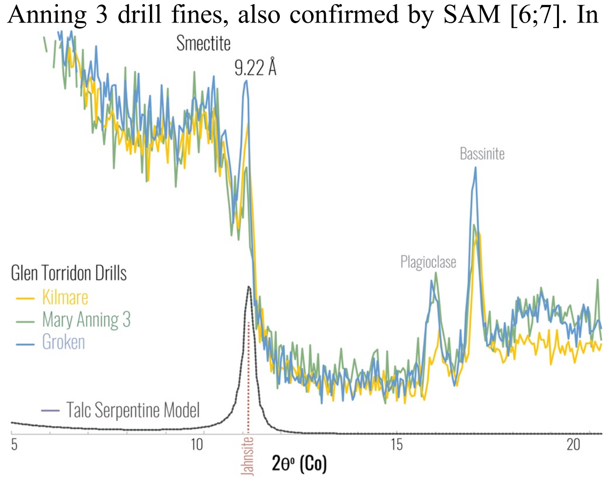

Figure 2. XRD patterns from the GT highlight the new 9.22 Å peak.

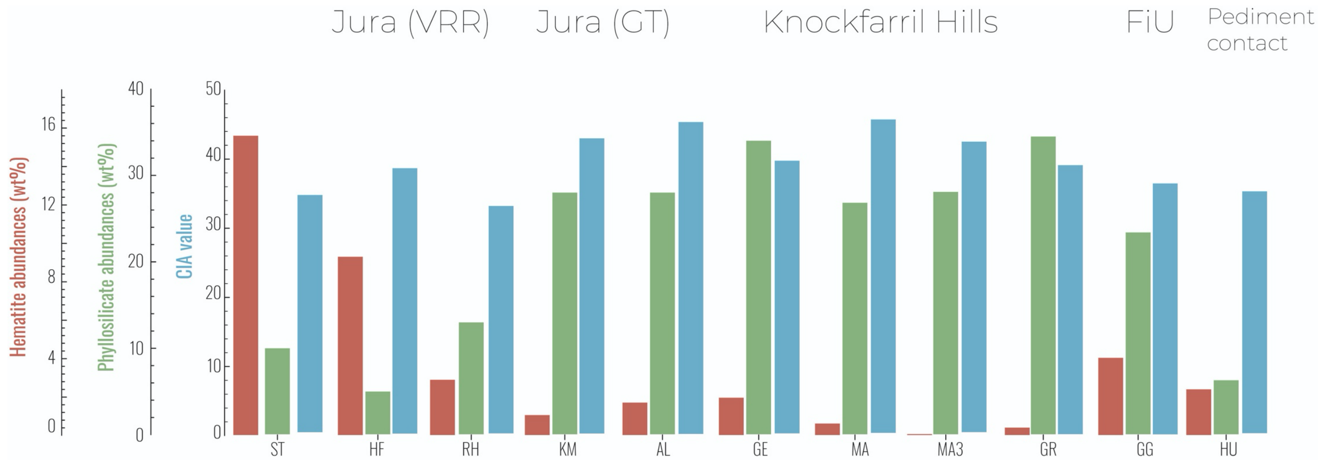

Figure 3. Mineral abundances and the Chemical Index of Alteration (CIA) values for drills in the VRR, GT, and approaching the pediment.

addition to the carbonate, a novel phase is apparent in the XRD patterns of KM, MA, MA3, and GR with the most prominent peak at ~9.22 Å (Fig. 2). The discrete identification of this phase is still being evaluated by the CheMin team, with the two leading candidates being (i) a mixed layer phyllosilicate (e.g., talc-serpentine; T/S) or (ii) a Mn-phosphate (e.g., jahnsite, ref 8).

On a regional scale, the mineral abundances of Glen Torridon drilled samples also display a sharp contrast with adjacent units. This is most notably illustrated in the difference between hematite and phyllosilicate abundances between VRR and GT (Fig. 3). VRR is hematite-rich and phyllosilicate-poor. Additionally, the phyllosilicates in VRR are distinct from the surrounding regions, identified as either ferripyrophyllite or an acid-altered smectite [9]. In contrast, the GT is enriched in a collapsed 10 Å smectite and relatively low abundances of hematite. Finally, the contact between the GT and the pediment mark a decrease in phyllosilicates and elevated hematite (e.g, GG). These mineralogical differences are also accompanied by geochemical variations, as displayed by a change in the Chemical Index of Alteration (CIA) across these units. The GT has some of the higher CIA values in the region, suggesting mobilization of soluble cations. In contrast, the lower CIA values in the VRR and at the contact of the pediment may suggest either less alteration via open system weathering or the recharge of mobilized elements during diagenesis.

Discussion: The identification of the most phyllosilicate-rich samples to date in Glen Torridon confirms orbital observations and provides a ground-truth for remote sensing techniques. This region's enrichment in phyllosilicates suggests that clay minerals play a critical role in shaping the landscape. The resistant VRR and pediment indicate more competent sedimentary rock compared to the GT. This is consistent with clay minerals and the more weathered (e.g., higher CIA) GT samples being more friable and subject to erosion. In contrast, hematite enrichment in VRR and at the pediment contact suggests that iron oxide cements may have played a role in stabilizing the terrains. Previous studies detailed the cannibalization of smectites in the VRR by slightly warm and acidic diagenetic fluids to produce the indurated ridge [9]. Another mechanism for producing these compositional trends from VRR to GT is from subsurface density-driven circulation of mixing groundwater and saline lake waters [10]. This later process is common in saline lakes on Earth [11] and may be responsible for the heterogeneity between the VRR and GT [10]. Additionally, this neutral to alkaline environment is favorable for carbonate precipitation and could be tied to the Fe-carbonate phase identified in the GT.

As for the new phase giving rise to the 9.22 Å peak, the leading candidates invoke vastly different geological interpretations. Jahnsite group minerals are typically associated with the alteration of P-rich progenitors (e.g., pegmatites) on Earth. One hypothesis for forming jahnsite in a basalt-dominated watershed is through the acidic alteration of apatite during diagenesis [9]. In contrast, talc is a common incipient alteration product of pyroxene during the weathering of a mafic provenance and may form during either pedogenesis in the Gale crater source terrains or authigenesis in the Gale basin. Both scenarios may also be consistent with the higher CIA values observed in GT and open system weathering. However, in order to generate an interstratified phyllosilicate, some degree of serpentinization would need to occur, likely in the source terrains of the catchment. Serpentinization of these incipiently altered source rocks with talc would then lend itself to the mixed-layer phyllosilicate (T/S) model for the 9.22 Å phase. Thus, the T/S phase is likely detrital in origin and if positively identified, would provide a new insight to the clay mineral record of Mars.

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