IS THE CLAY-BEARING UNIT DISTINCT IN GALE CRATER? GEOCHEMICAL DIVERSITY AND OPEN-SYSTEM ALTERATION REVEALED BY MSL AND CHEMCAM AT GLEN TORRIDON, MARS.

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Introduction: Since January 2019, the Mars Science Laboratory (MSL) rover *Curiosity* has been investigating the Glen Torridon (GT) area, a section of Mt Sharp (Aeolis Mons) stratigraphy where spatially extensive spectral signatures of clay minerals were detected from orbit [1-4]. Among other objectives, the ongoing scientific campaign aims at better understanding the origin of these spectral signatures, i.e., determining if they are due to higher abundances of clay minerals compared to previous terrains [5-7], or if other factors play a role [4]. Glen Torridon is also of special interest because it corresponds to the last unit where clay minerals are expected to dominate the mineralogy, before *Curiosity* enters the overlying "sulfate unit" [1-3;8]. In this contribution, we present the observations of the ChemCam instrument during the first year of the GT campaign.

Dataset: The ChemCam instrument measures the chemical composition of targeted rocks and soils within a few meters of the rover using laser-induced breakdown spectroscopy (LIBS). Quantification of major rock-forming oxides is performed routinely [9]. Each ChemCam analysis consists of a raster of several points a few millimeters apart from each other, and each point itself consists of a series of laser shots (typically 30). This approach enables removal of possible contaminations from diagenetic features (e.g., Ca-sulfate veins) and soil cover, by discarding the corresponding points [e.g., 10]. In addition, given the fine-grained nature of Mt Sharp sedimentary rocks [e.g., 11], averaging several ChemCam points provides a reasonable bulk composition for each target (because grains are typically smaller than the laser spot size of ~0.5 mm). As of late December 2019, ChemCam has analyzed 379 targets at Glen Torridon, corresponding to >3170 raster points.

Geochemical diversity: Earlier in the campaign [12], we reported that the lowermost section of GT (previously known as the "smooth clay-bearing unit" due to its appearance in orbital imagery) was composed of two main facies: (1) the "coherent" bedrock, forming relatively large but sparse slabs, and (2) the "rubbly" bedrock, composed of smaller fragments but much more spatially extensive. This lowermost area is now recognized as a lateral continuation of the Jura member previously investigated by *Curiosity* on the Vera Rubin ridge [13]. Compositionally, the coherent bedrock is characterized by an enrichment in MgO (~6 to 10 wt%) compared to the rubbly bedrock. Conversely, the rubbly bedrock is characterized by lower MgO and by enrichments in both K_2O (>1.5 wt%) and SiO_2 (>55 wt%) (Table 1). Compared to the coherent bedrock, the rubbly bedrock is also distinctively enriched in Li and Rb [14], and displays very few Ca-sulfate veins [15].

After the Jura member, *Curiosity* started to explore the overlying and sandstone-dominated Knockfarril Hill member (KfH). There, the compositions measured by ChemCam show variability both at the scale of individual rasters (higher dispersion due to the coarser grain size) and between the different locations visited. Indeed, while the rocks analyzed at Teal Ridge (the first KfH location encountered) show high-Mg and low-K compositions roughly similar to the Jura coherent bedrock, those at Harlaw Rise (located ~30 m to the west) show K_2O abundances spanning the two Jura endmembers, and comparatively low Na_2O (Table 1). Then, near Glen Etive, where the rover acquired its third and fourth GT drill samples, ChemCam measured high K_2O but intermediate MgO abundances (Table 1). Finally, while driving further south towards Central Butte, *Curiosity* encountered a layer remarkably similar to the Jura rubbly bedrock, both in terms of surface expression and composition (KfH rubbly in Table 1).

Aqueous alteration: In order to evaluate the degree of weathering of the GT rocks, we calculated the Chemical Index of Alteration (CIA) [e.g., 16] for the different locations and types of bedrock described above (Fig. 1). The results show that all GT rocks have elevated CIA values (~55-60) indicative of open-system alteration [10]. Nonetheless, these values are in the same range as those measured in some other members of the Murray formation (namely Sutton Island and Blunts Point). Note that the lower dispersion in CIA values for GT rocks compared to previous terrains (Fig. 1) is likely due to a lesser influence of Ca-sulfate materials (veinlets and/or cements) [15], which tend to lower the CIA when not fully corrected [10].

Link with mineralogy and orbital observations: At the time of writing, *Curiosity* has acquired four drill samples in Glen Torridon, named Aberlady, Kilmarie, and Glen Etive 1 and 2. The first two were taken <1 m from each other and are both representative of the Jura coherent bedrock, whereas the Glen Etive samples belong to the Knockfarril Hill member. No drill hole could be made in the Jura rubbly bedrock due to the small size of the rocks encountered along the rover path.

X-ray diffraction analyses performed by the CheMin instrument show that GT samples all contain ~30 wt% of (mostly dioctahedral) smectites [17], and are thus the most clay-rich samples found at Gale to date. However, this abundance is only marginally higher than at Marimba (28 ± 5 wt%), a sample from the Karasburg member of the Murray formation [7]. Together with the CIA values measured by ChemCam, these results suggest that enhanced alteration may not be the primary reason why Glen Torridon shows more spatially extensive spectral signatures of clay minerals from orbit, compared to previous terrains. Other factors such as dust/sand cover or surface expression may also play a significant role, the details of which need to be investigated further [4,18].

Another interesting result from CheMin is that the Glen Etive samples have a mineralogy very similar to Aberlady and Kilmarie [17] despite a distinctive lithofacies and a higher K_2O content. Variations in K_2O could be due to variable amounts of either K-felspar or illite (possibly interstratified with smectites) [14], but this is difficult to confirm with the MSL payload, especially considering that the absolute difference in K_2O between the Jura coherent bedrock and Glen Etive is quite small (~0.9 wt%, Table 1). Alternatively, the variations in K_2O might be tied to the amorphous component, the composition of which has proved to be highly variable along the traverse [e.g., 19]. Absolute variations in MgO at Glen Torridon are larger than those for K_2O (>3 wt% overall, Table 1), but are also difficult to correlate to changes in the mineralogy since no low-Mg rock could be drilled so far due to their rubbly nature.

Conclusion: ChemCam data collected so far at Glen Torridon reveal bedrock compositions that are overall in family with the rest of the Murray formation, but that are also significantly variable laterally, even within the same stratigraphic member. Most remarkably, the Jura coherent and rubbly bedrocks span together the full range of variability observed previously in the Murray formation [12]. All GT rocks show strong geochemical evidence for open-system alteration (CIA >50), which suggests that they all contribute to some degree to the clay-mineral signatures detected from orbit. However, both the CIA values measured by ChemCam and the abundances of clay minerals measured by CheMin [17] remain close to those found in previous members of the Murray formation. This suggests that in addition to the actual mineralogical composition of the bedrock, surface properties likely play an important role in the distinct orbital signature of the clay-bearing unit [18].

References: [1] Milliken R. E. et al. (2010) *GRL, 37.* [2] Grotzinger J. P. et al. (2012) *Space Sci. Rev., 170.* [3] Fraeman A. A. et al. (2016) *JGR-Planets, 121.* [4] Fox V. K. et al. (2020) *this conf.* [5] Vaniman D. T. et al. (2014) *Science, 343.* [6] Rampe E. B. et al. (2017) *EPSL, 471.* [7] Bristow T. F. et al. (2018) *Science Adv., 4.* [8] Rapin W. et al. (2020) *this conf.* [9] Clegg S. M. et al. (2017) *Spectrochim. Acta B, 129.* [10] Mangold N. et al. (2019) *Icarus, 321.* [11] Rivera-Hernandez F. et al. (2020) *this conf.* [12] Dehouck E. et al. (2019) *9th Internat. Conf. on Mars*, abstract #6125. [13] Fedo C. M. et al. (2020) *this conf.* [14] Cousin A. et al. (2020) *this conf.* [15] Gasda P. et al. (2020) *this conf.* [16] McLennan S. M. et al. (2014) *Science, 343.* [17] Thorpe M. T. et al. (2020) *this conf.* [18] Salvatore M. R. et al. (2020) *this conf.* [19] Smith R. J. et al. (2020) *this conf.*

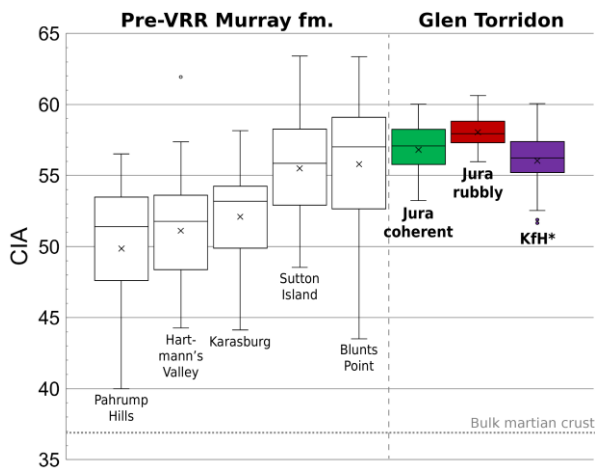

Fig. 1: Chemical Index of Alteration (CIA) measured by ChemCam in Glen Torridon, compared to previous members of the Murray formation [10]. *Value for the Knockfarril Hill member (KfH) combines targets from the Teal Ridge, Harlaw Rise and Glen Etive locations.

	N**	SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Sum
Jura coherent	269	53.47	1.02	11.81	18.03	7.34	2.29	2.63	0.95	97.54
Jura rubbly	343	57.00	0.97	11.90	19.13	4.86	1.30	2.65	1.91	99.70
KfH Teal Ridge	65	51.25	1.00	12.44	18.95	7.50	3.50	2.63	0.84	98.10
KfH Harlaw Rise	124	53.99	1.00	11.29	18.96	6.89	2.24	2.38	1.41	98.16
KfH Glen Etive	242	54.78	0.98	11.30	18.88	6.43	1.95	2.31	1.86	98.50
KfH rubbly	30	57.39	1.02	11.31	20.11	4.08	1.08	2.60	1.94	99.54

Table 1: Average chemical compositions of the bedrock (excluding contaminations from soil and diagenetic features) measured by ChemCam in the Jura and Knockfarril Hill (KfH) members of the Glen Torridon area. **N = number of raster points used for the calculations.