UNIFORM MT. SHARP BEDROCK COMPOSITION AND MINOR MG-SULFATE IN NODULES: APXS RESULTS FROM THE CLAY-SULFATE TRANSITION IN GALE CRATER, MARS. J.A. Berger[1*], R. Gellert[2], M.A. McCraig[2], C.D. O'Connell-Cooper[3], L.M. Thompson[3], S.J.V. VanBommel[4], A.S. Yen[5]. [1]NPP, NASA Johnson Space Center, Houston, USA; [2]University of Guelph, Guelph, CAN; [3]University of New Brunswick, Fredericton, CAN; [4]Washington University in St. Louis, St. Louis, USA; [5]JPL-Caltech, Pasadena, USA; [*]jeffrey.a.berger@nasa.gov.

Introduction: For the last ~9 Earth months (>265 martian sols), *Curiosity* has been traversing a region of Mt. Sharp where orbital observations predict a vertical stratigraphic transition from a phyllosilicate unit to the overlying layered sulfates of Mt. Sharp [1, 2]. An hypothesis for this Clay-Sulfate Transition (CST) is that the hydrated Mg-sulfates identified from orbit are detectable by the Alpha Particle X-ray Spectrometer (APXS) so that the occurrence of Mg-sulfates can be characterized. This is key to interpreting the transitional paleoenvironment: highly soluble Mg-sulfate in the bedrock matrix has different implications than if it occurs only in diagenetic features (e.g., nodules, veins). The investigation also provides ground-truthing for orbital detections of hydrated Mg-sulfates elsewhere on Mars. Here, we present results from the APXS investigation of the CST, with an emphasis on characterizing the possible occurrence of Mg-sulfate.

Methods and Results: *Bedrock:* The strategy for APXS sampling of the CST bedrock was to acquire at least one measurement at intervals of ≤5±1 m of elevation change, or ≤75 m of traverse distance. The average elemental composition of the CST bedrock is within the same range as the underlying Mt. Sharp units (Fig. 1). Chemostratigraphy is represented by plots of concentrations versus elevation (Fig. 2a), and the mean SO_3 (± 1σ) in the CST (8.7 ± 2.3 wt%) is ~20% higher than the underlying Glen Torridon (GT; 6.7 ± 2.7 wt%). Mean MgO (5.7 ± 1.3 wt%) and CaO (5.6 ± 1.0 wt%) in the CST are respectively ~10% lower and ~20% higher than the underlying GT.

Diagenetic features: Features such as nodules, veins, and rocks with atypical color/morphology were measured when practical to characterize heterogeneity, and most features are interpreted to be diagenetic. Larger nodules (~1-3 cm) with raised topography were measured periodically but could not be brushed and had to be analyzed at higher standoff distances with low X-ray counts resulting in non-ideal statistics. A nodule-crushing experiment used the rover's wheels to crush several larger nodules at one site (sol 3272) and expose fresh interior surfaces. Five measurements of the crushed nodules named "Helmsdale Boulder Beds" (Helmsdale) were acquired, and the nodules have elevated MgO and SO_3 relative to the average CST bedrock (Fig. 3).

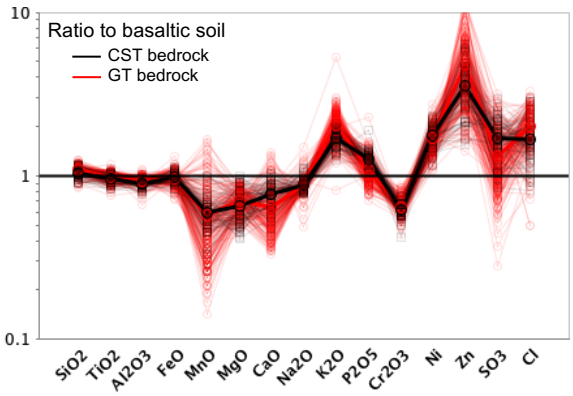

Figure 1: *Clay-sulfate transition bedrock (black; diagenetic features omitted) normalized by basaltic soil. The underlying Glen Torridon bedrock (GT; red) has the same composition, with more variability. The mean values are denoted by the bold lines.*

Discussion: *Clay-Sulfate Transition Bedrock:* The CST bedrock has generally the same chemical composition as the entire Mt. Sharp group explored by *Curiosity*. Compared to basaltic soil (same as average Mars crust; Fig. 1), the characteristic features of the Mt. Sharp group bedrock (which includes the CST) are ~5% higher Si, ~40% lower Mg, ~20% lower Ca, ~half the Mn, and enrichments in Zn (~1000-2000 ppm) and Ge (~100 ppm).

Sulfates: APXS results indicate that there is not a major Mg-sulfate component in the bedrock (Fig. 2b). This is consistent with the results from four drilled CST targets, which were analyzed by CheMin XRD and lacked detectable crystalline Mg-sulfate (LOD ~1 wt%) [3]. SAM EGA has detected Mg-sulfate in bedrock samples, so it is likely X-ray amorphous [3,4]. The lack of stratigraphic changes in Mg+S in the APXS results indicates that differences in amorphous Mg-sulfate abundance are relatively small and/or isochemical.

In the CST bedrock, SO_3 is ~20% higher than in the immediately underlying units of GT (Fig. 2a). The Ca:S correlation found throughout most of the Mt. Sharp bedrock (with Ca-sulfate veins omitted) extends to the CST, with the mean CaO and SO_3 both at higher concentrations in the CST than in the underlying GT (Fig. 2b). The higher SO_3 is thus consistent with a higher abundance of Ca-sulfate in the rock matrix.

Diagenetic features: APXS measurements suggest that some nodules may have minor Mg-sulfate (Fig. 3). The nodules are not pure Mg-sulfate; they appear to be a mix of the bedrock with an addition of ~10-15% Mg-sulfate. Mixed Mg-sulfate/bedrock compositions were also found in Murray formation nodules in the Pahrump Hills member; however, recent CST nodules do not have the same Ni enrichments (up to 4000 ppm).

Other diagenetic features in the CST include: (1) Fe-rich features (FeO 26-41 wt%), two of which have high Cl (up to 3.5 wt%) and a molar Fe/Cl ~6 indicative of akaganeite. (2) Very high Na+Cl features [5]. (3) Ubiquitous cross-cutting white Ca-sulfate veins as found throughout the Mt. Sharp group.

Implications: The CST does not have a significant increase in Mg-sulfate abundance in the bedrock matrix with elevation, and Mg-sulfate is a minor component of some nodular diagenetic features. To reiterate, the bedrock composition continues to be the same as nearly all of the other underlying Mt. Sharp group units. Orbital observations led to the hypothesis that the clay-sulfate transition identified from orbit is a record of a changing paleoenvironment [1,2]. The evidence to date (sol ~3350) support a refinement of this hypothesis: the rover may be observing a record of stratigraphic differences in diagenetic conditions that are broadly isochemical within the GT and CST [cf. 3,4] and may or may not necessarily reflect the primary depositional environment.

Conclusion: No significant changes in elemental compositions have been found in the Clay-Sulfate Transition (CST) bedrock, relative to the underlying Mt. Sharp group sedimentary units, which have a relatively uniform composition. Indications of minor (~10-15%) Mg-sulfate enrichment have been found in diagenetic nodules. We advocate for using the APXS to characterize the diagenetic features in addition to bedrock because they are a record of ancient fluid processes and may be a significant source of the orbital hydrated Mg-sulfate signal. Nodular diagenetic features probably will not be safe for drilling and delivering to CheMin and SAM, therefore the precise quantification of sulfur by the APXS is key to characterizing them.

Acknowledgments: We are grateful for the support of USRA-NPP, the Canadian Space Agency and NASA JPL-Caltech. APXS data are available in the PDS Geosciences node: DOI 10.17189/1518757.

References: [1] Fraeman et al. (2016) JGR *Planets*, *121*(9), 1713–1736. [2] Milliken et al. (2010). *GRL*, *37*, 6. [3] Rampe et al., (2022) this conference. [4] Clark et al. (2022) this conference. [5] Gellert et al. (2022) this conference.

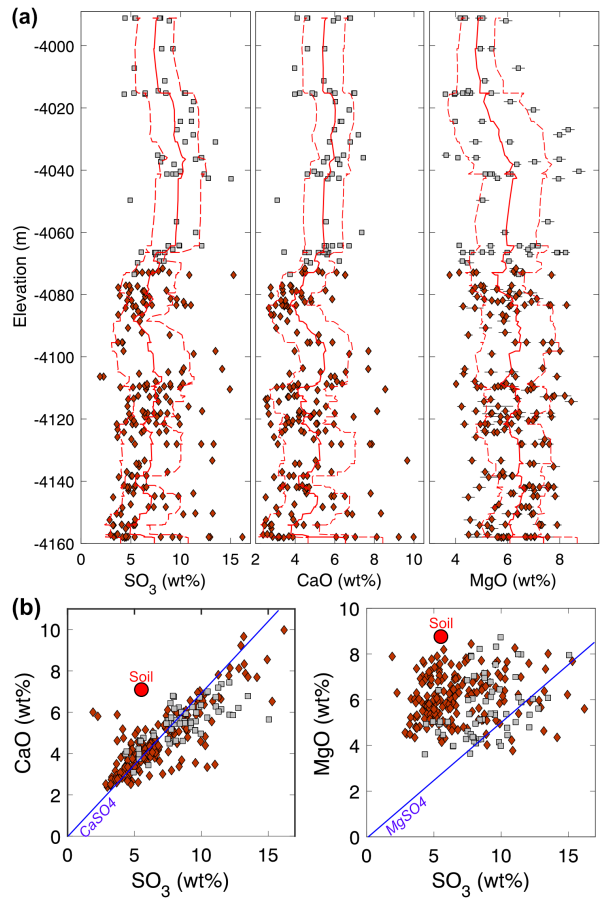

Figure 2: *(a) Chemostratigraphic and (b) bivariate plots of CaO, MgO, and SO_3 (diagenetic features and duplicate measurements omitted). The CST bedrock (gray squares) does not have a significant difference from the underlying Mt. Sharp bedrock in the Glen Torridon region (red diamonds) and S correlates with Ca and not with Mg. The 20-point moving mean (solid line) and ± 1σ (dotted line) are shown.*

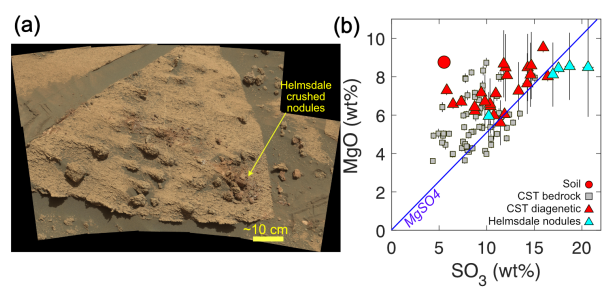

Figure 3: *(a) Mastcam mosaic (Malin Space Science Systems) of crushed Helmsdale Boulder Beds nodules and (b) MgO versus SO_3 plot indicating a possible minor (~10-15%) Mg-sulfate component in Helmsdale and other nodules. Large standoff distance on nodules resulted in greater statistical error (bars) and likely caused atmospheric Mg attenuation and lower MgO for a given SO_3 concentration. Ca-sulfate veins are omitted.*