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J. Frydenvang, K. W. Nikolajsen, E. Dehouck, P. J. Gasda, S. M. Clegg, et al.. Geochemical variations observed by the ChemCam instrument as the Curiosity rover transitioned from clay-mineral to sulfate-mineral rich regions on Aeolis Mons in Gale Crater, Mars. International Conference on Mars, Lunar and Planetary Institute, Jul 2024, Pasadena (CA), United States. pp.3267. hal-04800174

HAL Id: hal-04800174

<https://hal.science/hal-04800174v1>

Submitted on 23 Nov 2024

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Geochemical variations observed by the ChemCam instrument as the Curiosity rover transitioned from clay-mineral to sulfate-mineral rich regions on Aeolis Mons in Gale crater, Mars. J. Frydenvang¹, K.W. Nikolajsen¹, E. Dehouck², P.J. Gasda³, S.M. Clegg³, A.B. Bryk⁴, L.A. Edgar⁵, B.M. Tutolo⁶, W. Rapin⁷, O. Forni⁷, E. Cloutis⁸, A.A. Fraeman⁹, A. Vasavada⁹, S. Maurice⁷, R.C. Wiens¹⁰, O. Gasnault⁷, and N.L. Lanza³.

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Introduction: A key reason for choosing Gale crater as the landing site for the NASA Curiosity rover was orbital observations of mineral spectral signatures showing hydrated clay minerals overlain by hydrated sulfates on the Northwestern slopes of Aeolis Mons, the 5 km high central mound in Gale crater. Notably, the layered sequence of minerals is consistent with the hypothesized mineral fingerprint for a global-scale climate change toward a colder and drier Mars [1-4]. The orbital data, however, provides little information on the nature and location of the transition between the clay-mineral rich regions of Glen Torridon (fig. 1) and the orbitally defined sulfate unit above. This intermediate region is noted the clay-sulfate transition region (CST).

On Martian day (sol) 3072 of the mission, the Curiosity rover initiated its exploration of the CST at the Mont Mercou outcrop overlooking the Glen Torridon region. The exploration more than 500 sols later and approximately 200 m higher on Mount Sharp, in the Marker Band valley (fig. 1) where the first clear hydrated sulfate mineral spectral features are observed from orbit [2-5]. Here, we present the changes observed in the bedrock geochemistry in this transition zone by the ChemCam Laser-Induced Breakdown Spectroscopy (LIBS) instrument [6-7].

Results: Based on rover observations, the CST bedrock was found to record a substantial wet to dry change in depositional environment as rocks above the Pontours member were found to be deposited in a dry aeolian environment, although with lenses in the Contigo member believed to have formed in interdune lakes [8-9] (see fig. 1 for localities and members noted). Similarly, the mineralogy was observed to change substantially already from the base of the CST, most notably reflected by a complete loss of clay-minerals [10]. Compared to the marked shift in mineralogy and depositional environment, a homogeneous geochemistry is observed across the transition from the clay-mineral rich Glen Torridon region and into the CST. The most notable change relative to previous ChemCam bedrock observations in Gale crater was a subtle, but consistent, decrease (approximately 5 wt.%) in the total sum of major oxides quantified by ChemCam noted across the Pontours member.

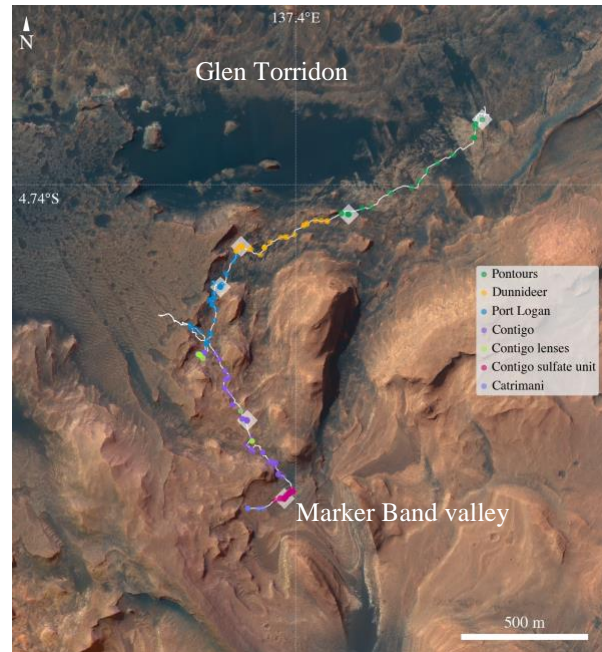


Figure 1: Map showing the clay-sulfate transition region explored by the Curiosity rover. The traverse starts at the Mont Mercou outcrop in the upper right part of the map and extends South (uphill) until it reaches the beginning of the orbitally defined sulfate unit in the Marker Band valley. White line indicated the rover traverse, colored points reflect ChemCam bedrock targets and the geologic member they sample, white diamonds indicate where drill samples were collected.

Above the Pontours member, the decreased level of the total sum of oxides, and in turn the bedrock composition observed by ChemCam, remains overall stable across the Dunnideer, Port Logan and part-way through the Contigo member. Across the upper ~30 m in elevation of the CST region, a substantial divergence relative to anything previously observed in Gale crater is observed. Reflected by a marked decrease in total sum of oxide observed in this range, most oxides quantified by ChemCam show a notable decrease in abundance. The exceptions being that CaO and FeO_T abundances remain approximately stable across the region, and most notably that the MgO abundance increases substantially compared to previous ChemCam bedrock observations from ~5 wt.% at the base of the CST to 15-20 wt.% in

the Marker Band valley. An increase in MgO abundance together with a comparable decrease in the total sum of oxides is the fingerprint we expect to see from the ChemCam quantification model when analyzing rocks with increasing Mg-sulfate content. The notion that we are seeing the geochemical evidence for a substantial increase in the abundance of Mg-sulfate is corroborated by dedicated SO_3 quantification models that are currently under development [e.g., 11] showing an increase in sulfur in correlation with the increase in MgO. When also considering ChemCam observation points hitting ‘raised’ (erosion resistant) features in the CST, a trend emerges where Mg-sulfate is first observed in likely diagenetic features at lower elevation [12-13], then more frequently in the bedrock until it becomes a pervasive component of the bedrock upon reaching the Marker Band valley.

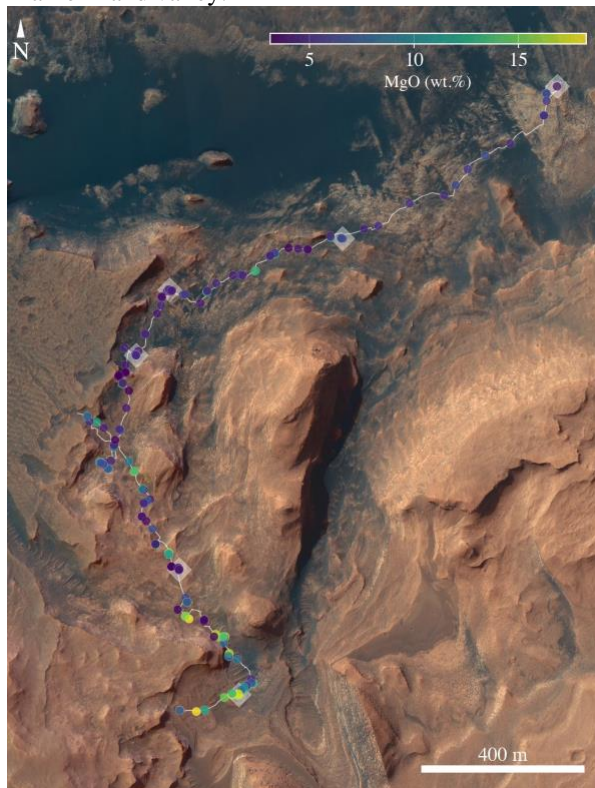


Figure 2: median MgO abundance annotated by color for ChemCam bedrock targets in the CST. A substantial and pervasive increase in quantified MgO abundance is observed in the upper 30 m of the CST (Southern end of the traverse) originating from an increase in Mg-sulfate.

In addition to documenting the appearance of Mg-sulfates across the topmost 30 m of the CST, the ChemCam observations also provides additional constraints to the formation scenario of the heavily altered Hutton section observed just below the Siccar Point unconformity at the Greenheugh pediment in the Glen Torridon region [14]. Upon approaching and

crossing the Siccar Point unconformity in the CST, no comparable alteration was observed. Furthermore, the previously noted correlation between Li abundance and clay minerals [15-16] is observed to break down in the CST – though within the CST, the highest Li is observed in fine grained mud-drapes hypothesized to be rich in clay minerals. Notably, the observed Li abundance across the CST is surprisingly elevated considering the complete loss of clay minerals [17].

Discussion: The ChemCam measurements show that the transition to the sulfate-rich bedrock suggested by orbital observation in the Marker Band valley happened across a relatively narrow 30 m in elevation near the very top of the CST leading in the valley. It is, however, also evident that the pervasive appearance of Mg-sulfates near the top of the section is preceded by observations of Mg-sulfates in diagenetic features at lower elevations. This suggests that the Mg-sulfate could have been a late top-down diagenetic addition to the CST bedrock causing a pervasive addition to the top of the section but a more irregular addition at lower elevations, mostly found in diagenetic features where fractures enabled water to penetrate deeper into the subsurface.

Overall, the enrichment in highly soluble Mg-sulfates, the presence of elevated Li despite the lack of clay-minerals that can effectively bind Li in aqueous conditions, and the lack of diagenetic alteration at the Siccar Point unconformity suggest that the CST bedrock has seen very limited aqueous alteration compared to previous Mount Sharp group bedrock.

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