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Open System Alteration At Gale Crater, Using Chemcam, Onboard The Curiosity Rover

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Abstract

We provide a summary of the chemical composition along the >300 m-thick pile of sedimentary rocks, encountered by Curiosity at Gale crater. The continuity in sedimentary deposition and chemical trends such as the high Chemical Index of Alteration indicate an environment of deposition that requires aqueous alteration in open system at the surface, over geologically long durations.

1. Introduction and Dataset

The Curiosity rover has crossed >20 km from its landing to the layered rocks of Mt. Sharp (also named Aeolis Mons), spending >2400 sols (Martian days) at the surface of Mars. The >300 m-thick pile of sedimentary rocks, names Murray formation, are dominated by mudstones and sandstones, interpreted as predominantly due of fluvial and lacustrine processes [1]. Chemcam is a Laser Induced Breakdown Spectroscopy (LIBS) instrument, with an associated Remote Micro-Imager (RMI) [2]. Chemical quantifications are obtained using a multivariate analysis technique, which compares Mars spectra to a laboratory database [3]. As volatiles (H, S, Cl) are not quantified, the sum of major oxides is often <100% suggesting a contribution from these volatiles. Thus, we normalize the wt.% obtained for each element to 100% to compare the same volatile-free fraction of rocks. Figure 1 presents the stratigraphic column with three chemical parameters plotted as a function of elevation. The Chemical Index of Alteration (CIA) is: $\mathrm{CIA}=100^{*}\mathrm{Al_2O_3}/(\mathrm{Al_2O_3}+\mathrm{CaO}^{*}+\mathrm{Na_2O}+\mathrm{K_2O})$ (molar). The CIA starts to reflect the influence of surface weathering when >50 for felsic rocks, and >40-45 for mafic rocks [4]. The average crust composition [5] is indicated in green as a useful reference to define the sediments encountered (e.g., alkali-rich, sodic, etc.) [6].

2. Results

Analysed early in the mission, the Yellowknife Bay (YKB, blue dots) rocks have a low CIA interpreted as alteration in a closed diagenetic system [7], and a relatively high $\mathrm{MgO/SiO_2}$ ratio typical of mafic rocks. The Cooperstown (gray dots) and Kimberley rocks (black dots) are characterized by an increasing potassic component. The high $\mathrm{K_2O/Na_2O}$ ratio indicates a change in feldspar type from plagioclase-dominant at YKB to alkali-feldspar dominant at Kimberley, resulting likely from a change in sedimentary provenance [8]. Starting at Pahrump Hills (yellow dots), the sedimentary rocks display a continuous series of sedimentary layers named the Murray formation. ChemCam data show a change in the chemistry at Murray compared to previous sedimentary rocks, as highlighted by a lower $\mathrm{MgO/SiO_2}$ ratio and a higher CIA. From Hartmann Valley (orange) to Blunts Point (light pink), the CIA displays an overall increase up section (up to 65), with very few points <50 in Karasburg and Sutton Island members (red dots) [9]. CIA values ranging from 50 to 65 are an evidence for substantial weathering in open system [7]. The bulk chemistry of these members also presents a low abundance of CaO of 1-2wt.%, well below Mars crust average (8wt.%), consistent with a leaching of Ca. Some of the highest CIA values are observed at Sutton Island in the vicinity of mud cracks due to desiccation [10]. The only exception to this trend corresponds to targets at the top of Sutton Island and bottom of Blunts Point with a high $\mathrm{MgO/SiO_2}$ ratio, that are interpreted as local Mg-sulphate deposits, potentially signing periods of increasing salt activity in relation with periods of lake dry-out [11].

3. Conclusions

While initially taken as the reference for lacustrine mudstones are Gale crater, the Yellowknife Bay area is not representative of Gale crater sedimentary rocks. The overall chemistry of the >300 m thick Murray formation does not follow the basaltic “average crust-like” chemistry observed at YKB on a <10 m thick outcrop. In addition, the difference in CIA highlights a change in condition of alteration (from close to open system), which is also observed by CheMin X-Ray Diffraction data. Indeed, CheMin data show that the phyllosilicates observed change from ferrous, Mg-rich tri-octahedral smectites at YKB to ferric, Al-rich di-octahedral smectites in the Murray formation [12]. Along the whole Murray formation, there is a consistency in the chemistry with only slight variations related to specific layers, and to varying weathering intensity tracked by the CIA. The continuity in sedimentary deposition and chemical trends highlights an environment of deposition that requires aqueous alteration, deposition and burial with prolonged groundwater circulation over geological long durations and a climate favorable to the presence of persistent liquid water at the surface.

Figure 1: Chemostratigraphy using ChemCam average composition for each target with mudstones and sandstones from sol 110 to 2070. Colors are relative to each members with clear in place outcrops.

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