EPSC Abstracts
Vol. 17, EPSC2024-1095, 2024, updated on 07 Nov 2024
https://doi.org/10.5194/epsc2024-1095
Europlanet Science Congress 2024

Exploring the sulfate-bearing unit: Recent ChemCam results at Gale crater, Mars

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The Curiosity rover of the Mars Science Laboratory mission is exploring Gale crater on Mars since August 2012 [Vasavada2022]. On board, the ChemCam instrument [Wiens2012, Maurice2012] combines Laser-Induced Breakdown Spectroscopy (LIBS), passive spectroscopy and imaging.
ChemCam is a remote sensing instrument, assessing the chemical composition of rocks and soils up to a few meters from the rover, imaging outcrops at longer distances, and surveying the atmospheric variability. The chemistry of primary and secondary phases is obtained using LIBS by performing typically five point rasters on the martian targets. Each point is investigated with 30 laser shots. This technique can therefore highlight some elemental correlations [Rammelkamp2024], or even some depth variations (<1mm) [Maurice2016]. As of Sol 4183 (martian days), ChemCam has acquired thousands (32,776) LIBS observation points (Fig. 1), revealing the chemostratigraphy of the central mound, Aeolis Mons, in Gale crater, as the rover continues its ascent. More than 41,000 passive spectra and 23,700 images were also collected with ChemCam.

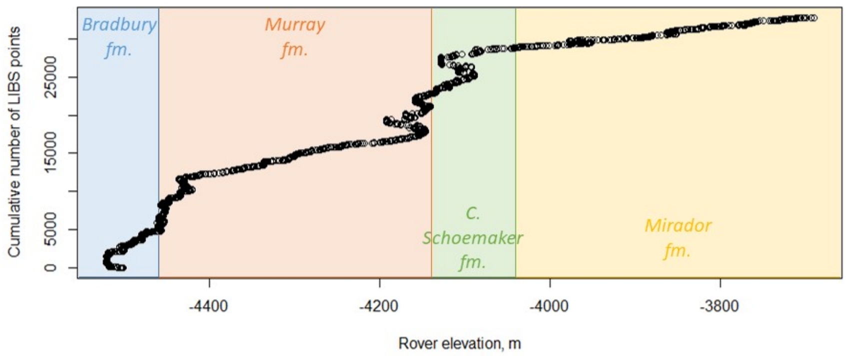

Figure 1: Cumulative number of LIBS points ordered in time, plotted as a function of the rover elevation in the different geologic formations.

One of the main reasons for selecting Gale Crater as the landing site was the orbital observations of hydrated clay minerals on the most basal layers of Aeolis Mons, overlain by hydrated sulfates up-section. This succession of mineral signatures is hypothesized to be a feature of the global-scale climate change that Mars has encountered [Grotzinger2015]. The rover explored the transition between the clay-bearing unit and the sulfate-bearing unit, since Sol 3072 at the Mount Mercou outcrop, and extended up to Sol 3655, in the Marker Band Valley [Edgar2024]. As part of its fourth extended mission, Curiosity's payload is being used to characterize the salt minerals detected in this unit, seek their origins, and test the hypothesis of a link with the global evolution towards an arid climate [Fraeman2021].

The transition zone can be characterized in different ways. From the point of view of sedimentary facies, it is a transition from lacustrine deposits to eolian deposits [Edgar2024]. From a mineralogical point of view, this zone is characterized by the disappearance of clays (evidence of the presence of liquid water on the surface), in favor of sulfates associated with a more arid environment [Rampe2023]. However, before being found in the bedrock, these sulfates were concentrated in abundant secondary phases (nodules, veins) associated with fluid circulations. ChemCam showed that these sulfates were mainly Mg-rich sulfates [Frydenvang2024, Rapin2024]. On the other hand, Ca sulfates are found mainly in the bedrock even though they have also been observed in nodules. This illustrates the complex interactions between primary deposits, their alteration and later diagenetic phenomena when attempting to reconstruct the history of this transitional period. The observations of centimetric polygonal structures in this area, due to their fragility, has led to the suggestion of a relatively rapid repeated succession between wet and arid phases. Multiple climate transitions [Kite2024] or cyclic climatic variations [Rapin2023] would have implications for exobiology research strategies at the boundary between the Noachian and Hesperian epochs, as the rapid and prolonged succession of wet and dry environments could be conducive to the polymerization of organic molecules in a pre-biotic chemistry. In line with these implications, ChemCam has detected much more apparent halite in this transition zone, with unusual facies compared to previous ones [Meslin2024].

Other intriguing zones have been traversed, such as the Amapari Marker Band, which evokes an unexpected coastline interrupting the otherwise arid depositional environment. All in all, water seems to have played a more important role than expected in this unit, with potential implications for its habitability. For example, ChemCam has detected chemical correlations between Mn and Fe contents, and both are enriched compared to average. In some cases, Zn is also elevated, along with Cu [Gasda2024].

In the overlying sulfate-bearing unit, where the rover is now, alternating light- and dark-toned bands are identified from orbit [Sheppard2021]. From its in situ vantage point, rover observations suggest that distinct dark-toned horizons are found predominantly in the orbitally defined dark-toned bands. Geochemical data from ChemCam on these dark-toned horizons (Fig. 2) reveal they are enriched in fluorite [Forni2024], as well as Na-Mg sulfate phase [Hughes2024]. These observations are unique, and along with the observation of siderite [Tutolo2024], suggest complex brine systems possibly at high temperatures [Forni2024].

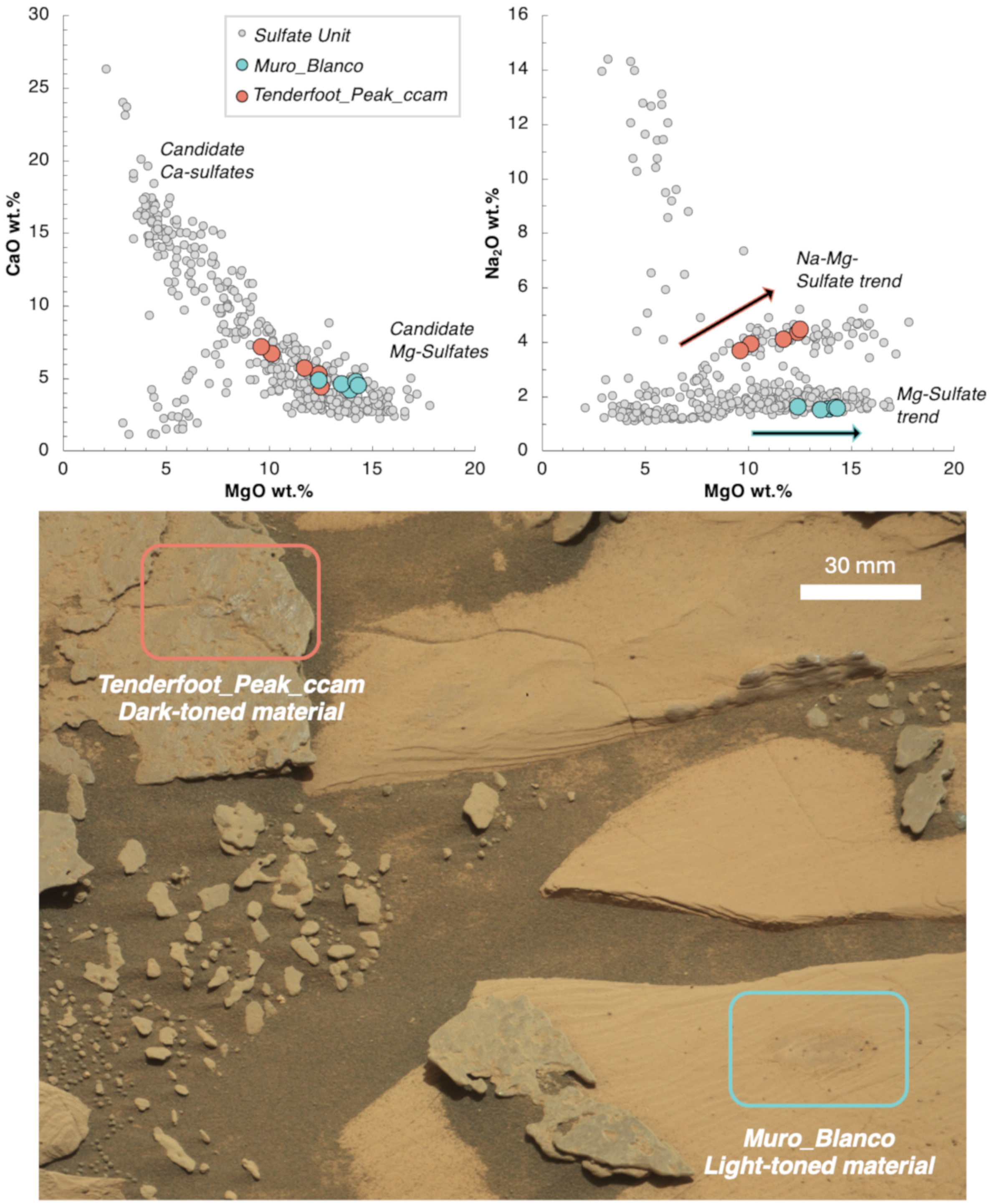

Figure 2: Chemistry from a dark-toned horizon (Tenderfoot_Peak_ccam, red points) and light-toned bedrock (Muro_Blanco, blue points) are highlighted, indicating presence of Na-Mg-sulfates in dark material, Mg-sulfates in light material, and broad contributions from Ca-sulfates and Mg-sulfates to the regional geochemistry. Geochemical data from ChemCam in the Sulfate Unit (sols 3949 – 4107). Background MastCam image credits: NASA/JPL-Caltech/MSSS.

The acquisitions of long-distance ChemCam images of the Gediz Vallis ridge show a clast-supported outcrop consisting of blocks with a wide range of textures, colors (provided by MastCam [Bell2017]), and geomorphological signatures. While still under discussion, this could be interpreted as a rock avalanche [Dietrich2024].

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