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Overview of ChemCam Activities and Discoveries during 5 years at Gale Crater, Mars

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Abstract

The first extraterrestrially employed LIBS (laser-induced breakdown spectroscopy) instrument is ChemCam [1,2] on NASA's Mars rover Curiosity, which has been successfully analyzing materials on the martian surface since the rover's landing in August 2012. Since then, the rover drove more than 16 km from the Bradbury landing site southwest, traversing the dark colored Bagnold Dunes, and is now ascending the foothills of Mt. Sharp (formally Aeolis Mons). Here, we are presenting the major findings of ChemCam along the traverse with a focus on the geochemical stratigraphy of the recently explored lower Mt. Sharp.

1. Introduction

ChemCam is composed of two instruments: a LIBS instrument for assessing the chemistry of targets in distances of up to 7 m and a Remote Micro-Imager (RMI) [3] that provides high resolution context images. The LIBS measurements require relatively little time and energy, enabling that ChemCam data is taken almost on a daily basis on Mars. Variations in composition can be uniquely tracked at the submillimeter scale and ChemCam collects ample of data on the geochemical stratigraphy while Curiosity is climbing up Mt. Sharp.

2. Major Findings of ChemCam

Within the first 1700 days of the mission over 450.000 ChemCam LIBS spectra of soils and rocks were recorded in Gale crater, analyzing more than 1800 targets and taking more than 7400 RMI images [4,5,6]. Additionally, many ChemCam passive spectra (i.e. without lasing) have been recorded and analyzed [7,8]. The numerous analyses revealed the compositional diversity of the igneous rocks, the sedimentary rocks, and the diagenetic features.

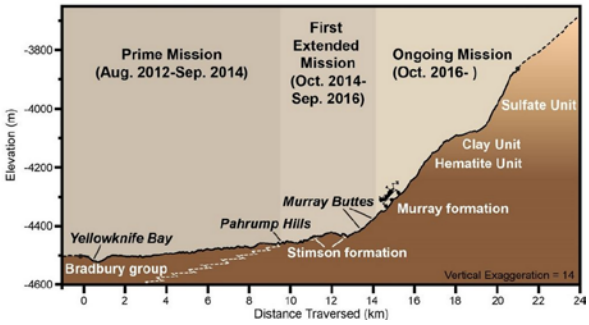

Figure 1: Driving distance, elevation, geological units and time intervals of Curiosity, as of late 2016 (Image Credit: NASA/JPL-Caltech).

2.1 Bradbury Rise

The Bradbury landing site, a plain located at a distal portion of the alluvial fan from Peace Vallis, exposed several float rocks [9,10] presenting igneous compositions ranging from mafic up to a trachytic endmember [11]. These observations provided an important clue concerning the diversity of early Mars magmatism that was not previously recognized. More igneous float rocks have been observed all along the traverse, being more felsic closer to the landing site, and more mafic near the cratered unit, after the Kimberley formation [12].

2.2 Sheepbed and Shaler

The Sheepbed area at Yellowknife Bay is essentially composed of mudstones that show a very homogeneous composition, close to the average Martian crust, providing evidence of aqueous episodes with little alteration in this area. ChemCam showed that the bedrock host experienced other diagenetic events with Mg- and Fe-rich clays in erosion-resistant raised ridges on one hand, and calcium sulfate veins on the other hand. The nearby Shaler fluvial sandstone outcrop [13], the first outcrop of potential deltaic foreset beds, shows K enrichment.

2.3 Conglomerates

Conglomerates have been analyzed in detail all along the traverse as they represent a link between the source rocks and the finer-grained sediments such as the sandstones and mudstones. They have shown an average composition that is enriched in alkalis, Al, and Si compared to the average Martian crust, with a clear enrichment in K_2O in the vicinity of the Kimberley formation [14]. Enrichment in K_2O at Kimberley in conglomerates and in sandstone outcrops reveals the presence of an alkali-rich source rock [15,16].

2.4 Pahrump Hills and Marias Pass

Further along the traverse, the Pahrump outcrop corresponds to the first observed material at Mt. Sharp's base and is part of the Murray Formation, mainly constituted of mudstones. Its facies suggest a stronger alteration, with presence of F-bearing materials such as apatite, fluorite, and phyllosilicates [17]. The Stimson unit, which is unconformably overlying the Murray formation, is composed of eolian cross-bedded sandstones possibly evolved from ancient dunes. Both Murray and Stimson formations are highly enriched in SiO2 (>80 wt. %) locally at Marias Pass and Bridger Basin [18,19,20]. The Murray enrichment may be from a pulse of volcanic ash, as it contains tridymite, with subsequent mobilization to fractures in the Stimson.

2.5 Soils

ChemCam analyzed >200 soil locations along the traverse ("Aeolis Palus soils"). The analyses indicate that fine-grained soils have a mafic composition. Analysis of coarser grains gave the possibility to study the link between local rocks and soils. ChemCam also adds new information on the ubiquitous hydration of these soils [21,22]. Soils investigated close to the active dark-colored Bagnold dunes and the Bagnold dunes themselves are overall similar in composition to the previously encountered Aeolis Palus soils but contain less altered phases with lower volatiles [23]. The Bagnold dunes are composed of grains that are mostly <250 μm. Coarser grains (150-250 μm) show an enrichment in the mafic elements Fe and Mn, suggesting a larger content in olivine compared to smaller grains of the Bagnold Dunes and Aeolis Palus soils.

2.6 Latest chemostratigraphy

Curiosity is now near the top of the Murray formation (200 m vertical thickness). The rover's cameras have observed indications of periodic desiccation in the sediments, including putative mud cracks [24,25]. In terms of chemistry, the upper Murray formation displays increasing chemical index of alteration (CIA) anticorrelated with Ca, suggesting increasing weathering, especially leaching of the latter [26]. Most recently ChemCam, APXS, and Mastcam have together observed locally high Fe abundances (to >35 wt.% FeO_T) associated with gray patches of bedrock yielding the multispectral signature of hematite, likely indicators of what is to come as the rover approaches Vera Rubin Ridge, where hematite signatures are observed from orbit.

Acknowledgements

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All Mars LIBS spectra and derived elemental compositions are available at *http://pds-geosciences.wustl.edu/missions/msl/chemcam.htm* and are described in > 40 peer-reviewed papers.

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