

THE MINERALOGICAL RECORD OF ANCIENT FLUVIO-LACUSTRINE ENVIRONMENTS IN GALE CRATER AS MEASURED BY THE MSL CHEMIN INSTRUMENT. E. B. Rampe¹, T. F. Bristow², D. F. Blake², D. T. Vaniman³, R. V. Morris¹, D. W. Ming¹, C. N. Achilles⁴, S. J. Chipera⁵, S. M. Morrison⁶, A. S. Yen⁷, A. H. Treiman⁸, R. T. Downs⁹, R. M. Hazen⁶, J. P. Grotzinger¹⁰, D. J. Des Marais², P. Sarrazin¹¹, V. M. Tu¹², N. Castle⁸, P. I. Craig³, G. Downs⁹, T. S. Peretyazhko¹², M. T. Thorpe¹³, R. Walroth¹⁴. ¹NASA JSC (elizabeth.b.rampe@nasa.gov), ²NASA ARC, ³PSI, ⁴NPP at NASA GSFC, ⁵Chesapeake Energy, ⁶Carnegie Institution for Science, ⁷JPL, ⁸LPI, ⁹University of Arizona, ¹⁰Caltech, ¹¹SETI, ¹²Jacobs at NASA JSC, ¹³NPP at NASA JSC, ¹⁴NPP at NASA ARC.

Introduction: The Mars Science Laboratory *Curiosity* rover landed in Gale crater in August 2012 to investigate early Hesperian-aged sedimentary rocks on the lower slopes of Aeolis Mons (i.e., Mount Sharp) that show variations in phyllosilicates, hematite, and sulfates from orbital reflectance spectroscopy, suggesting changes in ancient aqueous environments [e.g., 1-2]. During the Eighth International Conference on Mars in July 2014, *Curiosity* was still traversing the Bradbury group on the plains of Gale crater (Aeolis Palus) and had only analyzed four samples in its internal laboratories [e.g., 3-5]. Soon after Mars 8, *Curiosity* began its investigation of Mount Sharp and has since driven through ~350 m of vertical stratigraphy, the majority of which is part of the Murray formation (Fig. 1). The Murray fm is comprised primarily of laminated mudstone with occasional sandstone and heterolithic facies and represents a long-lived fluvio-lacustrine environment [e.g., 6-7]. *Curiosity* has analyzed 13 drilled rock samples from the Murray formation and 4 from the ancient eolian Stimson fm [8] with the Chemistry and Mineralogy (CheMin) instrument. Here, we discuss the mineralogy of all fluvio-lacustrine samples analyzed to date and what these results tell us about sources of the sediments, aqueous environments, and habitability of ancient Gale crater.

The CheMin Instrument: CheMin is an X-ray diffractometer and X-ray fluorescence spectrometer that produces X-ray diffraction (XRD) patterns of drilled rock powder or scooped soil [9]. Samples are delivered to one of 27 reusable sample cells in a wheel configuration. The instrument is in transmission geometry with a collimated Co X-ray beam that passes through the center of the sample cell. Piezoelectric actuators on the cells cause convective flow of sample material during analysis to randomize grain orientations and minimize orientation effects. An X-ray energy-sensitive CCD collects 2D XRD images, which are converted to 1D patterns. Quantitative mineral abundances and unit-cell parameters of major phases are determined through Rietveld refinement [e.g., 10]. The composition of major phases is calculated using refined unit-cell parameters [11-12]. Phyllosilicate and X-ray amorphous abundances are estimated using the FULLPAT program [e.g., 13]. The composition of X-ray amorphous components is estimated from mass balance calculations using the bulk

composition of each sample measured by the Alpha Particle X-ray Spectrometer and calculated composition of the crystalline phases identified by CheMin [e.g., 14].

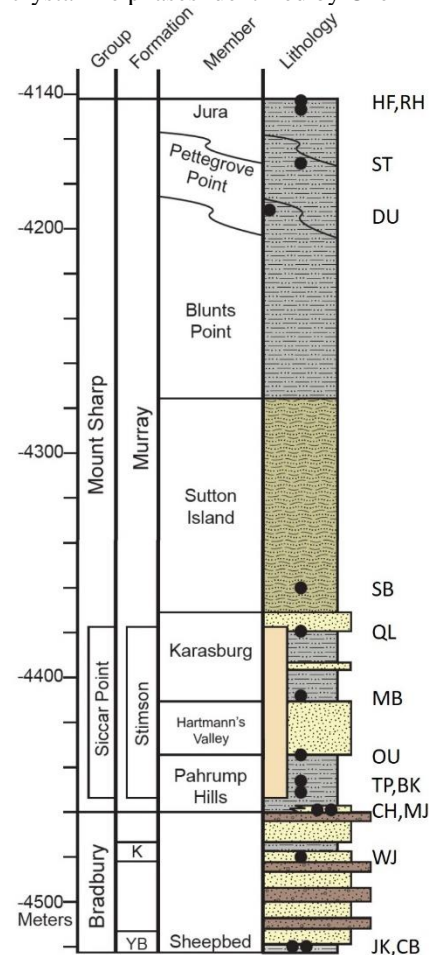


Figure 1. Stratigraphic column showing the units *Curiosity* sampled through January 2019. Black dots represent drill holes. YB = Yellowknife Bay. K = Kimberley. Other abbreviations represent drill sample names. JK = John Klein, CB = Cumberland, WJ = Windjana, CH = Confidence Hills, MJ = Mojave2, MB = Marimba, QL = Quela, SB = Sebina, DU = Duluth, ST = Stoer, HF = Highfield, RH = Rock Hall.

Mineralogical Results: We report on the igneous mineralogy, Fe-oxides, sulfates, phyllosilicates, and X-ray amorphous materials in fluvio-lacustrine samples (Fig. 2).

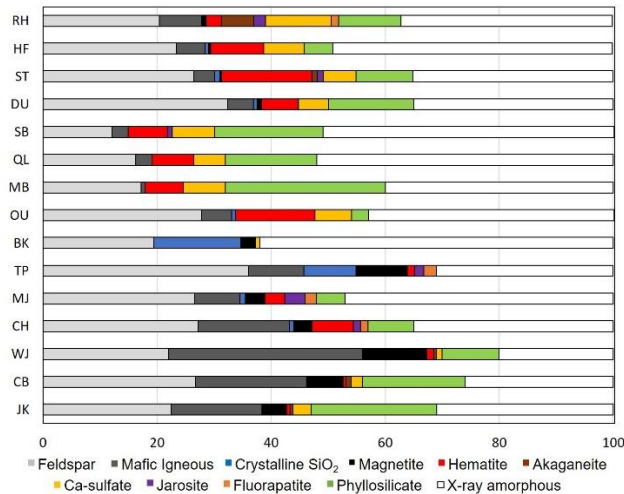


Figure 2. Mineral, phyllosilicate, and X-ray amorphous abundances for all fluvio-lacustrine samples drilled through January 2019.

Igneous mineralogy. In general, plagioclase is the most abundant igneous mineral, with a composition of ~An40 throughout the stratigraphy [e.g., 12]. Sanidine is a minor component of most samples, pyroxene is present in variable amounts, and olivine is only present in the Bradbury gp and lower Murray fm samples [4-5,15]. SiO₂ polymorphs, tridymite and cristobalite, are found in samples from the top of the Pahrump Hills mbr in the Murray fm [16].

Fe-oxides. Hematite and magnetite are the most common Fe-oxide minerals, where magnetite is most common in the Bradbury gp and lower Murray fm samples [4-5,15], and hematite is abundant throughout much of the Murray fm [17]. The Fe-oxyhydroxide mineral akaganeite is present in trace amounts in Bradbury group samples [4-5] and more abundant in two recent samples collected from the Vera Rubin ridge [18].

Sulfates. Ca-sulfates are present in all samples, except those from the lower Murray fm, and are especially abundant above the lower Murray fm [12,17]. All varieties of Ca-sulfate have been detected (anhydrite, bassanite, and gypsum), and all three are sometimes identified in the same sample [e.g., 19]. The Fe(III)-sulfate jarosite is present in trace to minor amounts in most samples from the Murray fm.

Phyllosilicates. XRD patterns are consistent with a collapsed smectite in most samples [4-5,15,17]. For more information about phyllosilicates in Gale crater, see Bristow et al. (this meeting).

X-ray amorphous materials. Amorphous materials make up a significant portion of all samples [3-5,14-18]. Mass balance calculations indicate the amorphous component is principally comprised of SiO₂, FeO_T, and SO₃,

which vary in relative abundance from sample to sample, suggesting that the amorphous materials may have formed from secondary processes [14].

Depositional and Diagenetic Environments in Gale Crater: The variations in mineralogy throughout the stratigraphy point towards dynamic depositional and diagenetic environments ~3.5 Ga in Gale crater. The primary igneous mineralogy and composition of sediments suggests multiple sources for the sediments [e.g., 5, 20-21]. The relative paucity of mafic igneous minerals up section and the change from trioctahedral to dioctahedral smectite suggest more intense alteration over time [e.g., 17,22]. Changes in the relative abundance of magnetite vs. hematite may result from different redox conditions in lake waters [23] or diagenesis in groundwater [15], although in-situ analysis of the Vera Rubin ridge suggests a complex series of diagenetic events was involved in the formation of Fe-oxides on the ridge [e.g., 18,24]. Observations of Ca-sulfate-filled veins and lenticular crystals suggest Ca-sulfate precipitated during early and late diagenesis [25-26], and a surprisingly young K-Ar age of 2.12±0.4 Ga for the jarosite in the Mojave2 sample [27] suggests acid-sulfate groundwater was present ~1.5 Gyr after the rivers and lakes vanished from Gale crater. The mineralogy measured by CheMin indicates Gale crater was the site of a variety of surface and near-surface aqueous environments that may have been habitable to ancient microbial life.

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