GEOCHEMISTRY AT GALE FROM CHEMCAM: IMPLICATIONS FOR MARTIAN IGNEOUS AND SEDIMENTARY PROCESSES AND FOR HABITABILITY.

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Introduction: Gale crater was selected as the MSL landing site on the basis of multiple fluvial and alteration features (alluvial fan, flow channels, phyllosilicate and hematite spectral signatures), suggesting high potential as a once habitable environment. The sedimentary chemistry observed by Curiosity would be expected to reflect the igneous starting materials which are very different from previous landing sites, as witnessed by float rocks along the traverse. Curiosity's sensitivity to light elements such as H, Li, and F provide important insights into primary source rocks, alteration, and habitability.

Observations: Curiosity is equipped with, among other instruments, the first microprobe for fine-scale analyses (0.35-0.55 mm) in the form of the ChemCam LIBS instrument. Mast mounting facilitates a high volume of analyzed locations (> 3,000, with > 1500 accompanying RMI images by sol 500), while pointing is accurate enough to walk the beam up the inner walls of the 16 mm diameter drill holes and to perform other fine-scale measurements. Depth profiling has played an important role in characterizing surface alteration. Here we describe cross-cutting and significant ChemCam observations.

Igneous Precursors of Gale Sediments: The very first observations, starting immediately at Bradbury Landing, clearly showed coarse-grained igneous rocks unlike any seen before (e.g., Peacock Hill, sol 19; also Fig. 1 and [1]). Trace elements, especially Rb > 100 ppm, corroborated the identification of feldspars [2] Spectra indicated plagioclase grains with a range of compositions, at least some of which are more alkali-rich than Shergottites [3,2]. The primary mafic minerals are pyroxenes; olivine is uncharacteristically low relative to previous landing sites, with no individual olivines clearly observed by ChemCam spectra. More recently the RMI has imaged more impressive feldspar cumulates (Fig. 1), derived either from very thick lava flows or more likely from a magma chamber. Compositional plots of ChemCam data show that the rocks are dominantly basaltic in nature, with mixtures of pyroxene and feldspar dominating the mineral assemblage.

Aside from Gusev, Gale is by far the closest landing site to the southern highlands. While claims have been made in the past of more felsic compositions (Pathfinder, TES), the overall understanding of Mars has been that it had a largely mafic, minimally evolved crust. The Gale findings strongly suggest otherwise, but the extent of evolved magmas is still unknown.

Identification of fluorine-bearing minerals in > 60 ChemCam observations provides additional evidence for evolved magmas [4]. The F-bearing observations come in the absence of accompanying Cl, and overall compositions strongly imply fluorapatite and fluorite in a number of samples, while the chemistry of some observations suggests peraluminous minerals, particularly in several conglomerates at Bradbury Landing.

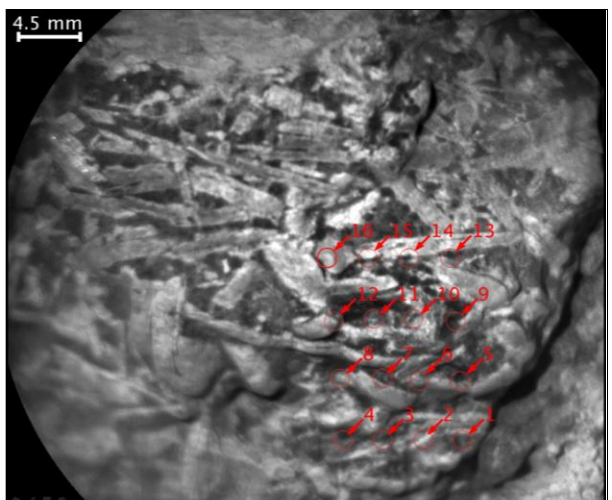

Fig. 1. Harrison (sol 514), a fluorine-bearing feldspar-rich clast embedded in conglomerate typifies ChemCam observations of evolved martian magma (CR0_443119527_CCAM02514).

Sediments in Gale appear to be influenced by two different sources: coarse-grained pebbles and clasts in conglomerates have the same evolved-magma upstream sources as the float rocks, while the finest-grained sedimentary rocks appear strongly influenced by ancient aeolian dust. The elemental composition of the mudstone at Yellowknife Bay (YKB [5]) is more similar to the current global average martian soil without the salt component. CheMin results indicate ~20% phyllosilicate contents of the YKB mudstones, likely authigenic, indicating relatively little alteration [6]. LIBS spectra indicated a low level of hydration for these sediments.

Sandstones, such as encountered at Shaler [3], carry the Sheepbed mudstone signature but with variable addition of alkali, Al, and Si, consistent with comminution of a plagioclase-rich component.

Several outcrops show considerable enrichment in Fe. Bathurst_Inlet had a moderately high Fe content, but the nearby Rocknest rock outcrop had even higher FeO_T, ranging from 19-27 wt. % [7]. Increased Fe did not correlate with other elements, suggesting a hematite-rich cement, also observed in some conglomerates [8]. The rocks of the striated unit near The Kimberley are also characterized by high Fe, similar to Bathurst. These outcrops may bear some relationship to the hematite-rich ridge characterized by CRISM [9] near the base of Mt. Sharp.

Diagenesis: Post-depositional fluids played an important role in nearly all of the Gale floor explored so far. Ca-sulfate veins were observed by ChemCam extensively at YBK [10] but also along the traverse beyond the first waypoint (sol 407) and more again near Dingo Gap (sol 530). At YKB ChemCam also discovered that an erosion-resistant feature was enriched in Mg and Li [11]; APXS also indicated Cl enrichment, together suggesting injection of a Mg-rich clay into pre-existing rock fractures. A strong Mg-Fe anti-correlation was also observed in rocks from the striated unit at The Kimberley, but here it was potentially due to mixing between the hematitic cement and pyroxene. Aside from sulfates, relatively little evaporitic material has been found; NaCl was observed in low abundance by ChemCam in one sulfate vein at YKB [4].

Surface Alteration: ChemCam's retrieval of depth-correlated spectra at every location provides a third dimension with which to probe the rock surfaces. To date only one rock showed a clear compositional gradient characteristic of alteration materials. At three of the five LIBS points on Bathurst (sol 55) the surface was enriched in Li, Rb, K, and Na, suggesting that soluble elements were mobilized towards the surface [2]. Given the active aeolian erosion in this part of Gale [12] such alteration is a surprising find; we are searching the data for additional evidence of surface alteration and its implications for habitability timescales. Manganese-rich observations throughout the traverse indicating up to ~60 wt. % MnO [13], are also an important clue to habitability. Mn-rich minerals are only produced in a highly oxidizing aqueous environment (and on Earth by organisms), though not likely by peroxides, suggesting the likelihood not only of normal-pH water [14] but also of highly oxidized water at some point in the past.

Soils, Hydration, and Habitability: Microbeam analyses of Mars soils at Bradbury has revealed for the first time the presence of three distinct components, one of which is hydrated, and another corresponds to local rock fragments [15-17]. ChemCam's very first laser shot on Mars revealed the hydrated component which was quantified by SAM [18] and corroborated by DAN [19]. The soil's H content is sufficient to explain most of the Mars Odyssey near-equatorial observations of H. Continued monitoring of soil and rock H contents by ChemCam along the rover traverse provides important information not otherwise obtainable between drill locations. Observations of rock and soil hydration directly address habitability, and when observed in rocks it indicates the possibility of phyllosilicates or other clay minerals. An interesting example of this is the Dingo Gap circular feature (Fig. 2).

In Summary, Gale crater exploration with MSL and ChemCam has revealed many new findings on Mars' igneous diversity, on the sources and history of sedimentary rocks, and on Mars soils and weathering.

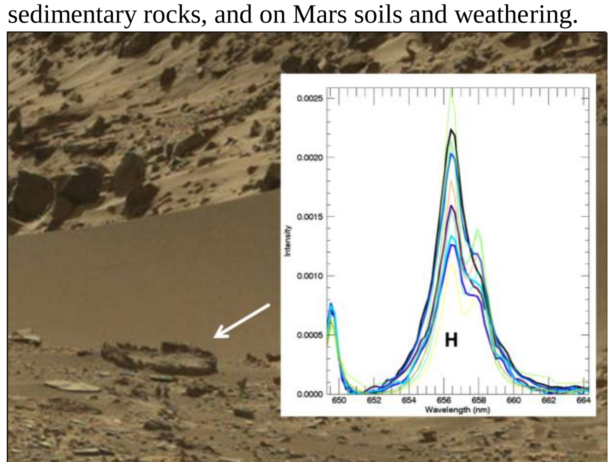

Fig. 2. Circular feature Tappers (sol 530) is Fe- and Mg-rich and shows one of the highest H signals of any rocks observed to date (MCAM0444196262-23989).

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