# REGIONAL AND GLOBAL CONTEXT OF SOIL AND ROCK CHEMISTRY FROM CHEMCAM AND APXS AT GALE CRATER

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**Introduction:** The rocks and soils analyzed at the MSL landing site "Bradbury Landing" and along the way to the "Rocknest" area represent a diverse population based on preliminary data from the ChemCam [1,2] and APXS [3] instruments. The ChemCam results are being evaluated in ongoing calibration and instrument characterization studies. Data for both rocks and soils from the early studies at Gale Crater can be compared with the accumulated data for martian materials from other landing sites, the Gamma Ray Spectrometer (GRS) experiment on the Mars Odyssey Spacecraft [4,5], and the data for martian meteorites. Variations in the CaO content can reflect local alteration and/or the presence of Ca-rich mineral grains [6,7]. In addition $CaO/Al_2O_3$ in primitive igneous rocks can provide a fundamental signature of crustal formation on Mars [8]. Abundances of other elements like Fe in the surface rocks can reflect later differentiation effects.

**Geochemical components and element ratios:** Comparing the chemistry of Gale samples with other martian data must take into account the different geochemical components in the samples. The most important distinction is between the volatile elements including H, C, Cl, S, and the lithophile elements including Al, Si, Fe, Mn, Ca, Na, Mg, etc. The large enrichments of the volatile elements $SO_3$ and Cl (~ 8 wt% total at Gusev [9]), in the soils may represent contributions from volcanic aerosols [10]. The transport of fluid mobile elements by aqueous or hydrothermal processes could complicate the estimation of the primitive magma composition of elements such as Ca. Other clues to the role of fluids can come from the ChemCam data for the highly fluid mobile element Li [11].

Regional comparisons of chemistry only make sense when considering the absolute abundances and elemental ratios within the different component classes. For GRS data the use of elemental ratios avoids the problem of the correction required to get volatile-free abundance data for comparison of GRS data with meteorites and landing site rocks. In addition to $SO_3$ and Cl, water contents of materials in the Columbia Hills ranged up to 17 wt % [12], and even the water content of NWA 7034 is up to 0.6 wt% [13]. Eventually data from ChemCam, APXS, SAM, and DAN will allow us to improve volatile corrections for GRS observations of Gale Crater and the rest of Mars.

**Initial observations**: The Gale landing site and the nearby Rocknest site include a diversity of materials in terms of compositions (**Fig. 1**). Even the identification of many of the samples as igneous, sedimentary, or impact melt is in doubt, although we assume the sediments were originally derived from essentially basaltic materials.  The large range in ChemCam $CaO/SiO_2$ is due to small sampling size resulting in an inverse correlation between CaO and $SiO_2$ [1], not apparent in the bulk APXS data. The most likely igneous sample, Jake_Matijevic [14], possibly a secondary ejecta fragment, represents an alkalic composition not previously observed on Mars [3, 14].

The GRS compositions reflect the integrated abundances for many elements to a depth of ~ 0.5 m over an area larger than Gale crater. Although it is now premature, the comparison of the available MSL data with the GRS data will eventually provide a link to understanding the nature of the martian crust and the processes by which the planet differentiated.

Determining the GRS composition for the Gale Crater area is complicated by the presence of a geographic and chemical boundary in this area. This area of the crust has high Ca/Si ratios, as seen in the Fig. 1 for Gale, and nearby Elysium Planitia, Cerberus Fossae and Terra Sirenum areas. One surprise, is the difference between the high Ca/Si and Fe/Si for the GRS data from the vicinity of Gale (and the regional lava plains in Elysium), compared with the MSL data. Therefore Gale Crater rocks may be derived from a crust with lower Ca/Si than the regional GRS crust.

Differences in Ca/Al ratios of martian samples are also of interest. The SNC meteorites represent magmas with super chondritic Ca/Al ratios, in contrast to the lower Cal/Al rocks at the Gusev Crater (Adirondack class). Recently, a new meteorite with the same lower Ca/Al signature, NWA 7034 has been described [13], and the rocks from Gale show similar low ratios, especially Jake_Matijevic [3, 14]. Jake_Matijevic also represents a more alkalic composition than previously observed on Mars. This sample was found as a loose rock on the surface between Bradbury Landing and Rocknest. The low Ca/Al ratio rocks from the different landing sites and the NWA 7034 meteorite tend to plot in a similar region of **Fig. 1**.

In contrast to the Jake_Matijevic composition rock, some of the Gale rocks may have closer affinities to the SNC type of compositions, especially in terms of substantially higher iron oxide contents. Some of the Gale crater rocks are substantially more enriched in Fe/Si, up to the ratios observed in the Odyssey GRS data for the martian crust and higher. Models for the formation of SNC meteorites can lead to high FeO contents by high pressure differentiation of a mantle of L type ordinary chondrite composition followed by olivine fractionation [8] (which can explain the high $CaO/Al_2O_3$ ratios of the SNC meteorites).

The Ca/Si ratios also tell an interesting story about the soils at Gale. Note that some of the variations in the soil data may be due to the chemistry of individual grains in the soil due to the small size of the ChemCam spot size (< 0.5 mm) [6,7]. The soils generally have higher Ca/Si ratios than the rocks at Gale. Two possible explanations for the higher ratios include, first, aqueous mobilization of Ca due to alteration of local rocks, which would be consistent with evidence for the presence of water from outcrops of rounded gravel and gravel-bearing conglomerates [15]. On the Earth there is evidence for Ca mobilization in Lonar Crater ejecta, for example [16]. Another possibility is that the soil has been transported from nearby crustal areas with high CaO/FeO ratios as seen in the GRS data (**Fig. 1**).

**Conclusions:** The first geochemical data from the Curiosity rover is providing new insights into the diversity of petrologic and aqueous processes on Mars. The chemical data is already revealing a range of rock and soil compositions that can be compared to data from GRS, other landing sites, and predicted magma compositions [17]. Two different compositions may be present at Gale Crater, which if originally igneous in origin may reflect the dichotomy between the SNC type and Adirondack type magmas. The diversity of compositions may also reflect the different regional compositions seen in the GRS data. Furthermore, the variable calcium contents of the soils may reflect either aqueous transport suggested by the gravels and prominent veins that are present in recent MSL images and/or derivation from nearby regions with higher CaO as seen in the GRS Data.

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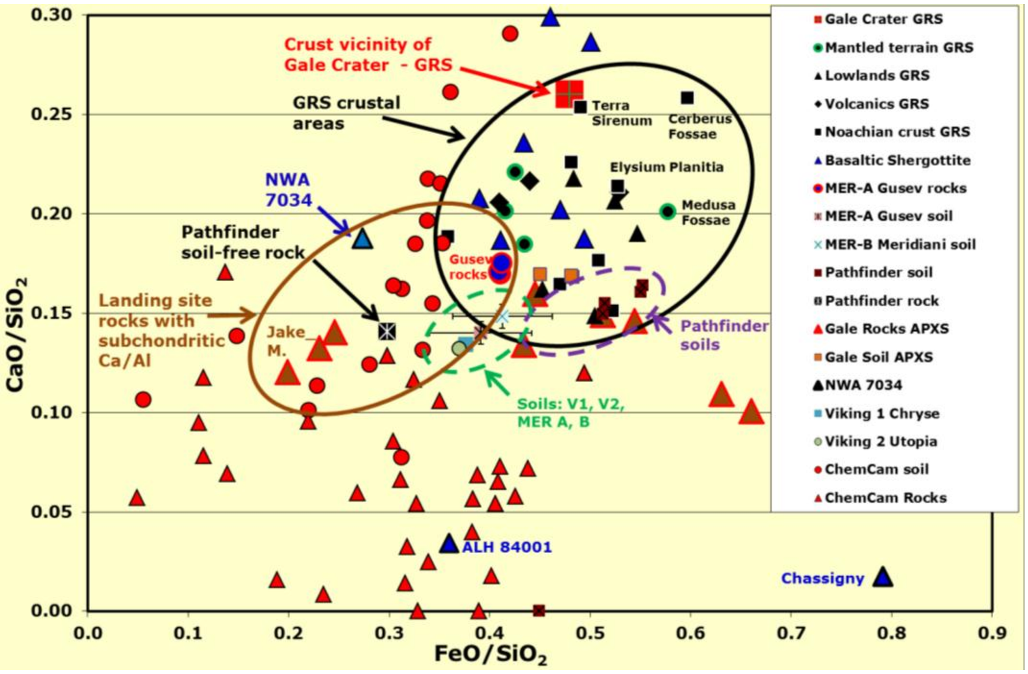

**Fig. 1.** Data: Viking 1 and Viking 2 soils, MER rover soils, and Adirondack basaltic rocks at Gusev. SNC meteorites and new martian meteorite NWA 7034 [13]. Regional Mars Odyssey GRS data. Uncertainties for GRS data are not shown, but the regional variations are statistically different. ChemCam data: median elemental data for each analyzed target (1-9 points). CaO and FeO data are normalized to $SiO_2$ eliminating the need to correct GRS data for volatile element dilution by sulfur, water, and chlorine.