CHEMCAM RESULTS FROM THE SHALER OUTCROP IN GALE CRATER, MARS. R.B. Anderson[1], L. Edgar[2], J.C. Bridges[3], A. Williams[4], J. Williams[5],A. Ollila[5], O. Forni[6], N. Mangold[7], N. Lanza[8], V. Sautter[9], S. Gupta[10], D. Blaney[11], B. Clark[12], S. Clegg[8], G. Dromart[13], O. Gasnault[6], J. Lasue[6], S. Le Mouélic[7], R. Leveille[14], E. Lewin[15], K. Lewis[16], S. Maurice[6], M. Nachon[7], H. Newsom[5], D. Vaniman[17], R.C. Wiens[8], [1]USGS, Astrogeology Science Center, Flagstaff, AZ (rbanderson@usgs.gov), [2]ASU, Tempe, AZ, [3]U. Leicester, UK, [4]UC, Davis, CA, [5]UNM, Albuquerque, NM, [6]IRAP, Toulouse, France,[7]U. Nantes, France, [8]LANL, Los Alamos, NM, [9]MNHN, Paris, France, [10] IC London, [11]JPL, Pasadena, CA. UK, [12]SSI, Boulder, CO, [13]ENS, Lyon, France, [14]Canadian Space Agency, Montreal, Canada,[15]U. Joseph Fourier, Grenoble, France,[16]JHU, Baltimore, MD, [17]PSI, Tucson, AZ.

Introduction: The "Shaler" outcrop in Gale crater is approximately 0.7 m thick and >20 m long, and exhibits multiple well-exposed platy and cross-stratified facies [1] interpreted to be primarily fluvial sandstone deposits. The outcrop is a part of the upper Glenelg member in the Yellowknife Bay (YKB) stratigraphic section [2]. Curiosity first encountered the "Shaler" outcrop on sol 121 of the mission, and returned to the outcrop on sols 309-324.

The rugged nature of the outcrop and short time available for analysis limited opportunities for contact science, but ChemCam's ability to remotely collect compositional and textural observations resulted in a large data set from Shaler. ChemCam conducted analyses of 29 non-soil targets at Shaler, 26 of which used laser-induced breakdown spectroscopy (LIBS) for a total of 9,180 spectra. Three observations used only the remote micro-imager (RMI). Each of the 26 LIBS targets were analyzed at between 5 and 25 points, providing a measure of the target homogeneity and in some cases transecting fine strata.

Facies: The "Shaler" outcrop can be subdivided into seven facies on the basis of color, texture, erosional characteristics, and bedding patterns. Facies three through seven were analyzed by ChemCam and are briefly described in Table 1. For more detail on the sedimentology and grain size measurements of the facies, refer to [2] and [3], respectively.

Table 1: Shaler Facies

Facies #	Description
3	Light-toned, cross stratified
4	Recessive, vertically fractured
5	Resistant, cross-stratified
6	Pitted, cross stratified
7	Dark, blocky, cross-stratifed

Facies Compositions: Figure 1 shows the average composition of each facies, normalized to the composition of the Sheepbed mudstone [4] to emphasize relative rather than absolute variations. Most facies are similar in composition, with significant variation within each facies, consistent with coarse-grained sandstone. The most distinct facies are Facies 3 and Facies 7. Facies 3 is characterized by low K_2O, while Facies 7 has high K_2O and elevated Na_2O, Al_2O_3, and SiO_2.

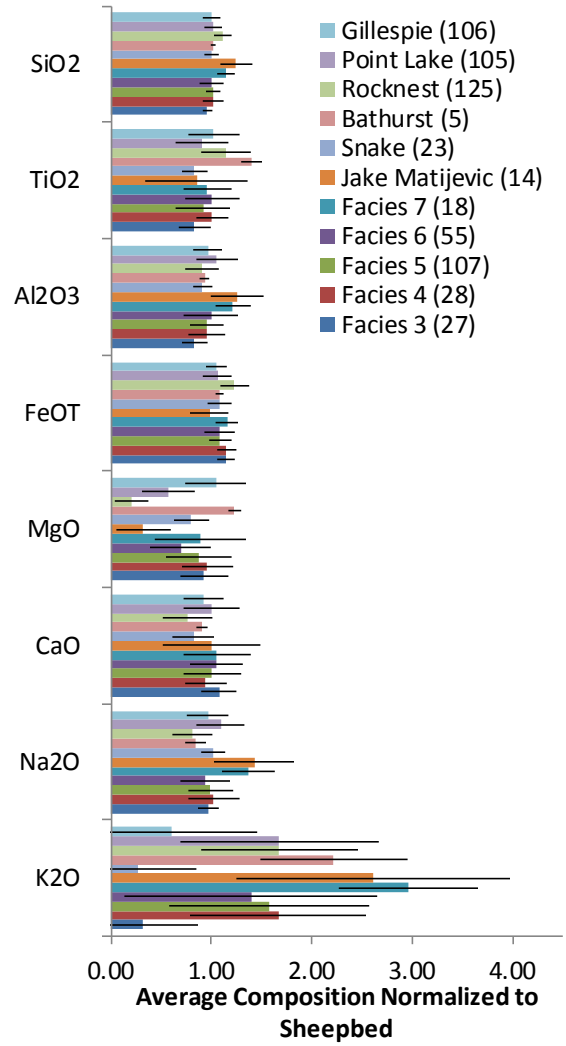

Figure 1: Average composition of Shaler facies and other targets, normalized to Sheepbed. Number of analysis points averaged for each bar are shown in the key, and error bars indicate the standard deviation of compositions from those points. Given the small ChemCam spot size, average compositions for heterogeneous targets with few analysis points are tentative.

Figure 1 also shows compositions for other units in the YKB stratigraphy (e.g., Point Lake, Gillespie Lake, Bathurst, Rocknest rocks), the float rock Jake Matejivic [5], and the "Snake", a clastic dike [2].

The low-K_2O composition of Facies 3 (0.16 wt.% K_2O vs. 0.57 wt.% in Sheepbed) is similar to the Snake

(0.17 wt.% K_2O), despite their stratigraphic separation, suggesting that they may derive from different episodes sampling the same source region. Facies 7 is somewhat similar in composition to the rock Jake Matejevic, but has higher MgO (5.47 wt.% vs. 1.96 wt.% in Jake Matejevic). Jake Matejevic has been interpreted to be an igneous rock [5], while Facies 7 shows clear sedimentary structures [1]. It is possible that Jake Matejevic is ejecta from the same source region that eroded into the sediment that composes Facies 7, and that the MgO difference is the result of diagenesis. It has been noted that Facies 6 and the Point Lake outcrop are also compositionally similar, but with ~0.8 wt.% higher MgO in Facies 6 [6].

Chemical Alteration: Shaler analysis points are plotted on an Al_2O_3-CaO+Na_2O+K_2O-FeO_T+MgO (A-CNK-FM) diagram in Figure 2 (FeO_T is total iron, expressed as FeO). Chemical weathering of terrestrial basalts produces a trend up and to the right on this diagram, such that points above the solid line in Figure 2 indicate alteration [4]. The few Shaler points that plot above this line likely represent locations where the laser hit feldspars, and therefore do not represent the bulk rock. Thus, there is little evidence for chemical alteration of Shaler sediment, consistent with rapid deposition and/or a cold climate. Other work on the rocks of YKB comes to the same conclusion [4].

Mineral Identification: By examining single-shot spectra, pure minerals and mineral mixtures can be identified. To identify feldspars, the spectra were restricted to low MgO (<5 wt.%), high Al_2O_3 (>13 wt.%), and an Al/Si molar ratio between 0.3 and 0.4. Spectra identified in this manner also show elevated Sr, supporting the inferred presence of feldspar grains.

In all of the cases of putative feldspars, there is excess FeO_T that must be normalized out to arrive at a feldspar composition. Explanations for this excess FeO_T include: Fe-oxide cement similar to Rocknest [7], a mixture of feldspar and pyroxene, or an alteration phase that contains both Fe and Al.

By plotting Shaler single shot results on a tetrahedral diagram (Figure 3), a trend between the feldspar field and the pyroxene field can be seen. This trend is consistent with the basaltic composition of Shaler, indicating that the sediment source was likely the physical breakdown of basaltic rocks with little alteration. There is no overlap with nontronite or Fe-rich saponite, suggesting a clay-poor assemblage.

Conclusion: The Shaler outcrop has an overall basaltic composition, with significant overlap in composition between the facies. Facies 3 has low K_2O, and is compositionally similar to the "Snake", a clastic dike lower in the stratigraphic column. Facies 7 has high K_2O, and is somewhat similar in composition to Jake Matejevic, but with higher MgO. There is little evidence for alteration, and the single-shot results are consistent with feldspar and pyroxene grains derived from breakdown of basaltic rock.

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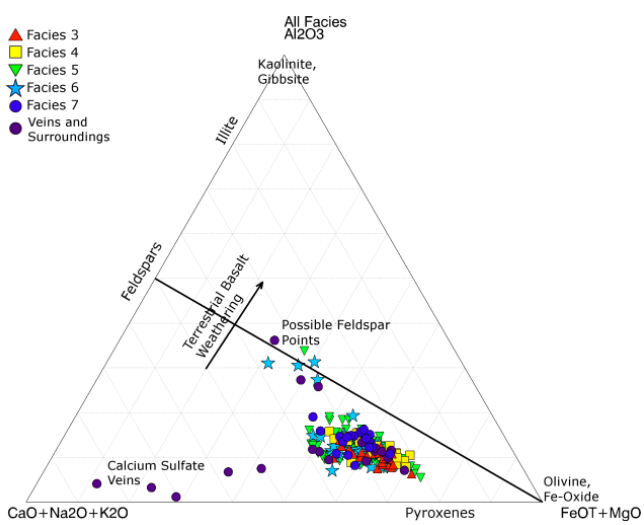
References: [1] L. A. Edgar, et al., LPSC 45, 2014. [2] J. P. Grotzinger, et al., *Science*, 2013. [3] A. J. Williams, et al., LPSC 45, 2014. [4] S. McLennan, et al., Science, 2013. [5] E. M. Stolper, et al., *Science*, vol. 341, no. 6153, 2013. [6] N. Mangold, et al., *J. Geophys. Res.*, Submitted, 2014. [7] D. Blaney, et al. *J. Geophys. Res.*, Submitted, 2014.



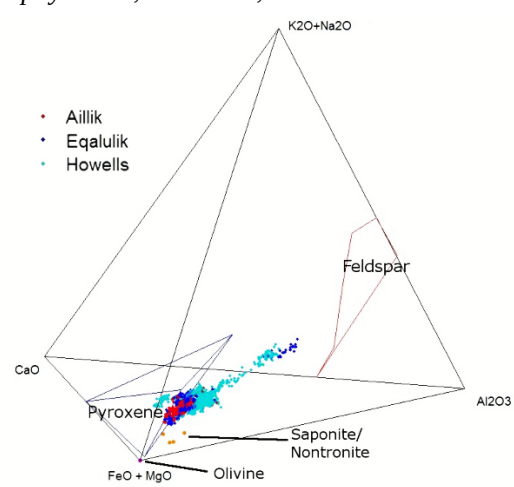


Fig. 2 (left): A-CNK-FM diagram with Shaler analysis points, showing no clear evidence of typical terrestrial alteration. **Fig. 3 (above)**: Tetrahedral diagram of Shaler shots in wt.% oxide, showing the trend between feldspar and pyroxenes.