THE COMPOSITION OF THE BASAL MURRAY FORMATION AT PAHRUMP HILLS, GALE CRATER, MARS

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Introduction: The MSL Curiosity rover, has arrived at the base of Mount Sharp after driving ~9 km since landing within Gale crater in August 2012 (Fig 1). As Curiosity traversed the crater floor deposits en-route to Mount Sharp, a number of key locations of interest identified from orbit, as well as other rock and soil targets, were investigated utilizing the rover instrument payload. Specifically, Curiosity's APXS instrument has acquired 138 analyses along the traverse, recording a diversity of rock compositions.

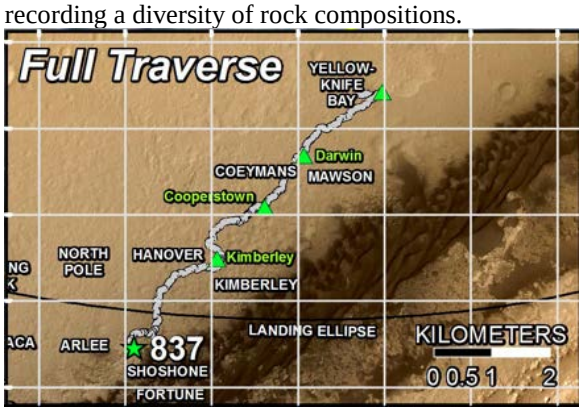

Fig. 1. HiRise map with rover traverse superimposed.

The rover is now investigating the lowermost sedimentary strata at the base of Mount Sharp, the Murray Formation , at the Pahrump Hills location (Figs. 1 and 2). This work describes the results from 19 distinct APXS targets in this section. The compositions of these rocks are compared to targets encountered along our transit route and placed in a regional context within

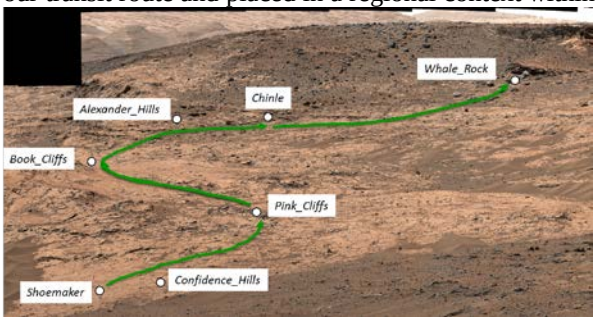

Fig. 2. MCAM mosaic of Pahrump Hills with rover traverse and points of interest (from Joy Crisp).

Gale Crater. Compositional variations within the Pahrump section are highlighted. Specifically, differences between isolated, raised features and the surrounding bedrock and what this may reveal about the diagenetic history of these rocks is explored.

Murray Formation at Pahrump Hills: From orbital HiRise imagery, the Murray Formation, located at the base of Mount Sharp, is light-toned and appears to be softer than many of the previously encountered units, which retain craters more effectively. MCAM, MAHLI [1] and CCAM RMI images reveal the rocks to comprise interbedded recessive and resistant, fine to medium grained sedimentary strata that can be laminated or more massive, and can exhibit cross stratification. Brushing of the dusty surfaces has revealed interesting textures on many of the bedrock surfaces; from light-toned, lozenge shape crystals (Mojave) to more irregular shaped, light and dark toned inclusions (Afton Canyon) (Fig. 3).

Fig. 3. MAHLI images showing the variable texures of the brushed rock surfaces. Left to right: Mojave recessive bedrock, Afton Canyon resistant bedrock and Morrison raised, nodular feature

Distinctive features of these rocks are raised, resistant, irregularly shaped nodular concretions. They can be isolated (Fig. 3) or form part of a more extensive cluster [2]. Linear raised ridges and white vein fracture fills are also present.

Composition as Determined by APXS:

Pahrump Bedrock. APXS analyses of the various Pahrump bedrock targets reveal a new and distinct compositional class at Gale crater (Fig. 4), characterized by relatively high Si, Ni and Zn and low Mg, Ca

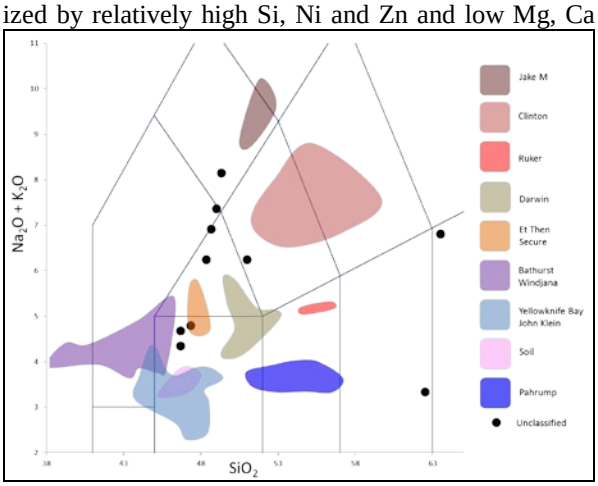

Fig. 4. Total alkalis v's SiO2 for all rocks and soils analyzed by APXS at Gale. Pahrump rocks are royal blue.

Table 1. Average composition of bedrock from APXS analyses

	wt%	std
SiO_2	52.40	1.48
TiO_2	1.05	0.05
Al_2O_3	11.38	1.00
FeO_T	14.87	1.76
MnO	0.30	0.07
MgO	5.04	0.39
CaO	4.09	0.37
Na_2O	2.76	0.12
K_2O	0.78	0.09
P_2O_5	1.16	0.16
Cr_2O_3	0.36	0.03
SO_3	4.82	1.42
Cl	0.63	0.22
ppm		
Ni	716	214
Zn	1506	221
Br	288	320
CIA	48.97	2.49

and Cl, as well as a relatively high CIA index (high Al/Al+Ca+Na+K) (Table 1). No compositional trends or elemental correlations are observed for resistant versus recessive bedding planes. However, plots of elemental variation with stratigraphic height reveal horizons (Pink Cliffs and Book Cliffs) enriched in Al and depleted in Fe compared to other bedrock and other isolated targets that are relatively depleted or enriched in certain elements. Book Cliffs is also enriched in Br, and exhibits relatively high Mg compared to other Pahrump bedrock analyses.

Diagenetic Features. The isolated, raised, resistant nodular concretions ubiquitous throughout the Pahrump section (e.g., Fig. 3, [2]), are compositionally distinct from the bedrock. They exhibit characteristically high Mg, S and Ni contents, as well as elevated Cl and Br relative to nearby bedrock (Table 2). The Ni contents are the highest so far recorded on Mars, with the exception of meteorite samples. The Zn contents are higher than for most rocks at Gale, but similar to the bedrock. APXS analyses of nearby bedrock and a raster analysis of the raised features (APXS field of views encompass different proportions of the raised feature versus bedrock [3]) reveal strong positive correlations of Mg, S, Ni and Cl from bedrock to raised feature. Specifically, the Mg and S is consistent with an increase of up to 12 wt% $MgSO_4$ within the raised features relative to the bedrock (Fig. 5).

Table 2. Average composition of raised features from APXS

	wt%	std
SiO_2	44.51	1.06
TiO_2	1.10	0.10
Al_2O_3	9.29	0.28
FeO_T	14.49	2.44
MnO	0.31	0.02
MgO	7.76	0.57
CaO	4.39	0.74
Na_2O	2.52	0.16
K_2O	0.66	0.09
P_2O_5	1.04	0.05
Cr_2O_3	0.34	0.01
SO_3	11.76	1.56
Cl	0.80	0.26
ppm		
Ni	3747	401
Zn	1917	259
Br	102	42

Conclusions: APXS analyses of the basal, Murray Formation bedrock at Pahrump Hills indicate that the sedimentary strata have a characteristic and distinct composition compared to other rocks analyzed by APXS at Gale. They are broadly basaltic andesite in composition. The relatively high CIA index indicates that the sediments could have been derived from a broadly basaltic source area, then undergone alteration and weathering to produce the bulk composition observed. The bedrock also tends to exhibit low Mg/Fe ratios and very low Ca, further supporting this interpretation.

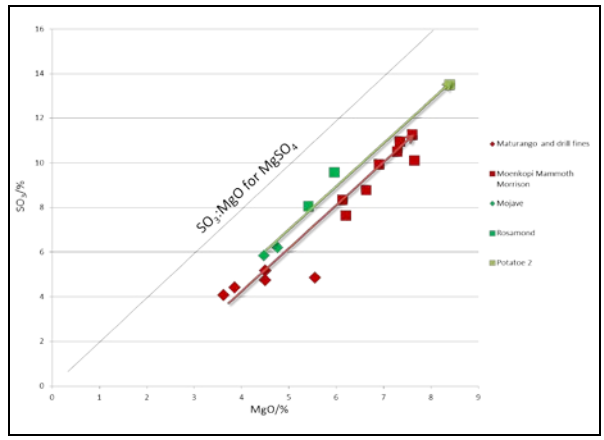

Fig. 5. SO_3 v's MgO of raised, nodular concretions (squares)and associated bedrock (diamonds).

The composition of the isolated, raised nodular concretions is consistent with the presence of a concentration of a $MgSO_4$ phase (likely hydrated). The association and correlation with elevated Ni, Cl and Br suggest that briney fluids could have leached Mg, Ni and S (or the S could have come from the fluid) from the surrounding bedrock and precipitated $MgSO_4$-rich cement around some pre-existing nucleas to form the concretion. Alternatively, the $MgSO_4$ may not be a primary diagenetic phase, but could instead be a replacement after some other mineral phase. However, the fact that the concretions are not a pure mineral phase, and are instead compositionally a mixture of the bedrock and other phases, does not support this. The positive, linear correlation of the Ni with Mg and S within the concretions indicates that the Ni may be in the same mineral species as the $MgSO_4$ phase. The very high Ni content of the concretions and the high Ni content of the bedrock in general, may indicate meteoritic material within the source area of these sedimentary rocks.

References: [1] Mc Bride M. et al. (2015) *LPS XLVI*. [2] Kah L. C. et al. (2015) *LPS XLVI*. [3] Van Bommel S. et al. (2015) *LPS XLVI*.

Acknowledgements: MSL APXS is managed and financed by the Canadian Space Agency (CSA). We acknowledge the important role of engineers at JPL during operations.