

## Compositions of sedimentary strata, nodular features and veins at the base of Mount Sharp, Gale crater, Mars: an APXS perspective

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### Abstract

Since the MSL Curiosity rover arrived at the lower most slopes of Mount Sharp, the APXS instrument has encountered four distinct bedrock compositions, two of which have not previously been encountered on the mission, indicating different source regions and/or post-depositional alteration/diagenetic histories. Raised, resistant nodular features are interpreted as diagenetic and exhibit elevated, and positively correlated Mg, S and Ni. Late vein networks and associated resistant fins reveal a complex texture and chemistry, recording multiple fluid flow events.

### 1. 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. Curiosity's APXS instrument has acquired 138 analyses en route to Mount Sharp, recording a diversity of rock chemistries, facilitating the development of an APXS compositional classification scheme [1] [2].

Since arriving at the base of Mount Sharp, the rover has completed a detailed investigation of the Pahrump Hills stratigraphic section. This work describes the results from 26 distinct APXS targets in this section, as well as several target locations examined along the traverse route since commencing the ascent of Mount Sharp. The compositions determined by APXS are compared to targets encountered along the transit route and are placed in a regional context within Gale Crater. Compositional variations within the Pahrump section are highlighted. Specifically, differences in chemistry between raised, resistant features and the surrounding bedrock, and what this reveals about the diagenetic history of these rocks are explored. The extensive vein network encountered at Garden City is also examined in detail.

### 2. Pahrump Hills to Kanosh

The strata at Pahrump Hills is light-toned and appears softer than many previously encountered units, which retain craters more effectively. The rocks comprise interbedded recessive and resistant, fine to medium grained sedimentary strata that can be laminated or more massive, and which can exhibit cross stratification. Brushing has revealed interesting textures on many of the bedrock surfaces; from light-toned, lozenge shape crystals to more irregular shaped, light- and dark-toned inclusions.

The uppermost section is characterized by more resistant, massive, sandstone (Whale Rock). Distinctive features of the Pahrump rocks are raised, resistant, irregularly shaped nodular concretions. They can be isolated or form part of a more extensive cluster [3].

Bedrock encountered since driving away from Pahrump is similar to the uppermost recessive units at Pahrump. However, the boulder Kanosh is interpreted to represent a fragment of a more resistant, crater-retaining cap rock unit exposed in the Salsberry Peak area. Vein networks and associated resistant "fins" at Garden City reveal complex textures of light- and dark-toned materials that cross-cut the bedrock.

### 3. APXS Results

**Pahrump Bedrock:** APXS analyses of the various Pahrump bedrock targets reveal three different compositions: 1) The majority define a new and distinct compositional class at Gale crater (Fig. 1), characterized by relatively high Si, Ni and Zn, and low Mg, Ca and Cl, as well as a relatively high CIA index (i.e., high Al/Al+Ca+Na+K).

2) The recessive bedrock encountered at the top of the Pahrump section, and since leaving Pahrump (Santa Ana and Telegraph Peak), is characterized by elevated Na, Si, Fe and K, and lower Mg, Al, S, Ca, Mn, Ni, Zn and Se compared to the majority of Pahrump bedrock (Fig. 1). 3) In contrast, the resistant, cross laminated sandstone ledge exposed at Whale

Rock is characterized by low Ni, Zn, Si, Al, Cr, K, P and Ti, and high Mn, Fe, S, Br, Mg, Ca and Cl compared to the majority of Pahrump bedrock (Fig. 1).

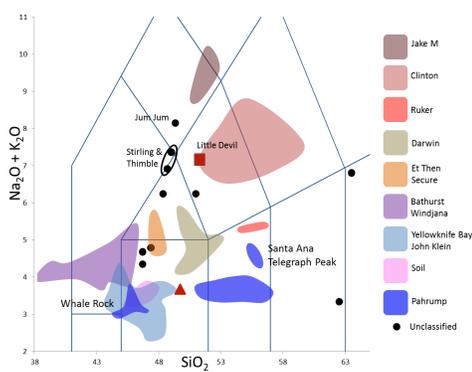


Fig. 1: Total alkalis versus  $\text{SiO}_2$  for all rocks and soils analyzed by APXS at Gale. Pahrump rocks are royal blue.

**Pahrump Raised, Nodular Features:** The isolated, raised, resistant nodular concretions ubiquitous throughout the basal Pahrump section [3], 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. 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. The strong positive correlations of Mg, S, Ni and Cl from bedrock to raised feature are consistent with an increase of up to 12 wt%  $\text{MgSO}_4$  (Fig. 2).

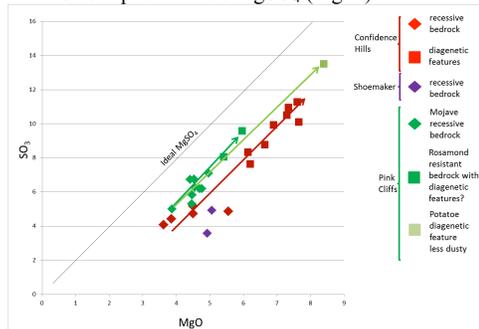


Fig. 2:  $\text{SO}_3$  versus  $\text{MgO}$  of raised, nodular concretions (squares) and associated bedrock (diamonds).

**Garden City Veins:** At least four distinct compositional phases are identified associated with

the vein system at Garden City: 1) white,  $\text{CaSO}_4$ -bearing veins, 2) dark, Ca-enriched (little to no associated S) material (high Mn, Zn and Ni), which is intimately associated with the white vein material, 3) dark, Mg-rich material (high Ge), also associated with the white veins, and 4) resistant dark “fins”/plates with characteristically high Na, K, Fe and P, as well as elevated Ga, Sr, Ge and Pb.

**Kanosh – Little Devil Cap Rock:** APXS analysis reveals a similar composition to other targets thought to represent cap rock (Stirling and Thimble) (Fig. 1). These rocks are characterized by relatively high Na, and K, and moderate Si and Fe.

## 4. Discussion

The APXS instrument has encountered four distinct bedrock compositions at the base of Mount Sharp, two of which have not previously been encountered on the mission, indicating different source regions and/or post-depositional alteration/diagenetic histories.

Raised, resistant nodular features within the Pahrump section are interpreted as diagenetic and exhibit elevated, and positively correlated Mg, S and Ni consistent with ~12% of a  $\text{MgSO}_4$  phase.

Late vein networks and associated resistant “fins” reveal a complex texture and chemistry, apparently recording multiple fluid flow events.

The cap rock exposed in the area has a similar composition to other cap rock targets previously analyzed by APXS along the route to Mount Sharp, possibly indicating the presence of a once continuous layer of cap rock.

## Acknowledgements

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## References

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