**CAPPING UNITS OF THE MURRAY FORMATION, GALE CRATER, MARS: SALSBERRY PEAK AS A PRE-STIMSON FORMATION CAPROCK.** R.E. Kronyak[1*], L.C. Kah[1], C.M. Fedo[1], K.M. Stack[2], K.S. Edgett[3], K.L Siebach[4], [1]Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN, *rkronyak@vols.utk.edu, [2]Jet Propulsion Laboratory, Pasadena, CA, [3]Malin Space Sciences Systems, San Diego, CA, [4]Stony Brook University, Stony Brook, NY.

**Introduction:** Since Sol 753, the Mars Science Laboratory Curiosity rover has been examining the Murray formation, which comprises the lowermost strata of the Mt. Sharp group. The Murray formation predominantly consists of fine-grained, thinly laminated mudstone facies that crops out between Hidden Valley and Hematite Ridge [1]. Curiosity investigated the basal Murray formation in detail at Pahrump Hills; here, 13 m of section are capped by a dark-toned, thickly laminated, fine-grained sandstone facies. In higher elevation exposures, Murray formation mudstone is similarly overlain by fine-grained sandstone facies [1].

The Murray formation is also characterized by extensive vein networks. Veins range in thickness from sub-mm to decimeter scale and contain dominantly $CaSO_4$ minerals. Here we examine veins in the Murray formation and capping sandstone units in order to better understand both the timing of vein formation as well as the relationship of veins to caprock lithologies.

**Cap rock lithologies:** At Pahrump Hills, the Murray formation capping lithology is informally called Salsberry Peak. The 0.5 to 2 m-thick Salsberry Peak sandstone overlies Murray formation strata in what appears to be a conformable relationship. The Salsberry Peak sandstone is blue-gray in color and characterized by massive bedding with faint, dominantly parallel lamination (Fig. 1). Salsberry Peak is also heavily jointed. Joints are perpendicular to bedding (average spacing 0.18 m, n=22 measurements), giving Salsberry Peak a blocky appearance.

Beyond Pahrump Hills, the Murray formation is overlain by a thick cross-bedded sandstone unit termed the Stimson formation (Fig. 1B). Analysis of the Murray-Stimson contact has demonstrated an unconformity between the two units [2]. Similar to Salsberry Peak, the Stimson formation is dark-toned and resistant to erosion [2,3]. It is characterized by abundant cross-lamination, and is interpreted to reflect migration of aeolian dunes [2,3].

**Relationship between veins and cap rock:**

*Salsberry Peak caprock.* Veins are abundant features of the Murray formation, particularly at Pahrump Hills [4]. In the lowermost 10 meters of section at Pahrump, veins average ~2 mm in thickness (n=75). In the uppermost 3 meters, which lie directly beneath the Salsberry Peak caprock, veins increase in thickness to an average of ~7 mm (n=59). In addition to an increase in vein thickness, associated dark-toned vein materials (cf. [4]) become increasingly prominent in the 3 meters below the caprock.

White $CaSO_4$ veins can be traced continuously from the underlying Murray mudstone into the Salsberry Peak sandstone (Fig. 2). On the northern side of Salsberry Peak, gray-toned veins also appear to cross the contact. This penetration of veins across the Murray-Salsberry contact indicates that vein filling fluid events post-date deposition, and likely fracturing, of both the Murray formation and Salsberry Peak.

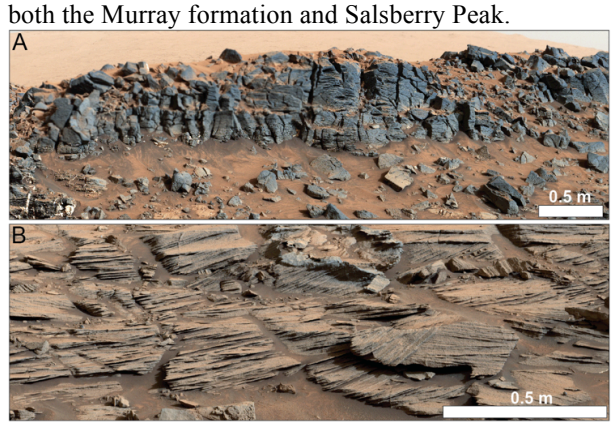


**Figure 1.** Typical expression of (A) Salsberry Peak (Sol 938, mcam 04119) and (B) the Stimson formation (Sol 1003, mcam04483).

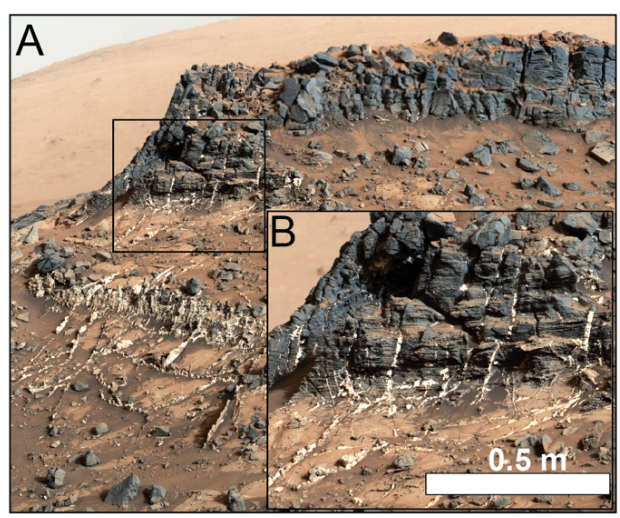


**Figure 2.** Northwest side of Salsberry Peak at Pahrump Hills showing (A) large vein networks just below the

caprock, and (inset B) penetration of $CaSO_4$ veins into the Salsberry Peak sandstone (Sol 938, mcam04119).

*Stimson caprock:* In contrast to the Salsberry Peak sandstone, $CaSO_4$ veins are less common in the Stimson formation [2]. Veins that occur in the underlying Murray formation extend to, but do not typically cross the contact with overlying Stimson. In places (e.g. Missoula), fragments of Murray vein material are also incorporated into the lowermost Stimson [5]. Combined, these observations suggest formation of Murray veins prior to erosion and deposition of the Stimson formation, which is consistent with the notion of a disconformable nature between units.

The Stimson does contain alteration halos that occur as zones of bleaching along joints [2]. These fracture-associated alteration halos likely reflect different fluid events from those that formed the widespread veins in the Murray formation.

**Hypothesis:** Here we hypothesize that Salsberry Peak and the Stimson formation are fundamentally distinct depositional systems, wherein Salsberry Peak represents a facies shift within the broader Murray formation and acts as a caprock seal that affected fluid pressure and vein formation. By contrast, the Stimson formation represents a post-Murray capping lithology.

**Additional investigation of caprock units:**

*Regional Mapping:* From orbit, the Salsberry Peak caprock and adjacent areas to the east of Artist Drive exhibit surface textures that are distinct from surrounding areas that have been mapped as Stimson formation (Fig. 3). These Salsberry Peak regions are generally smoother and lack the rough linear ridges characteristic of the Stimson formation.

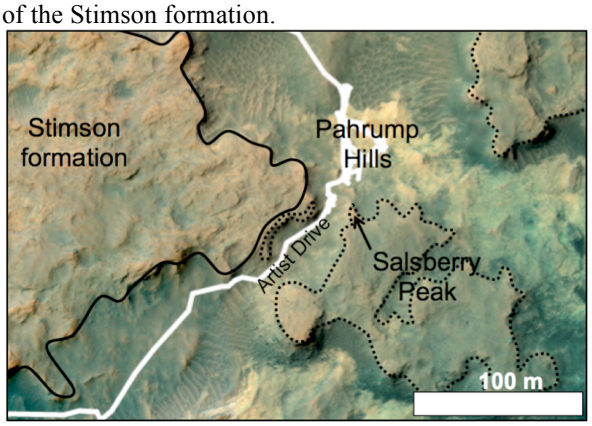


**Figure 3.** Regional HiRISE context map showing surficial texture of the Salsberry Peak unit and surrounding areas (dotted black line), potentially distinguishing them from the Stimson formation (solid black line).

*Chemistry:* Whereas the Stimson formation has been extensively analyzed, the Salsberry Peak sandstone unit was only indirectly sampled with Curiosity's Alpha Particle X-Ray Spectrometer (APXS). APXS analyzed a boulder named Little_Devil (Sol 942) along the traverse that was interpreted to have derived from the Salsberry Peak outcrop (Table 1).

APXS data (Table 1) supports a distinct origin for Salsberry Peak and Stimson cap rock lithologies. Although Salsberry Peak is enriched in $K_2O$, $Na_2O$, and FeO relative to the underlying Murray formation, these units are similar in both MgO and $SiO_2$ content (likely reflecting similarity in provenance) and contain Ni and Zn enrichments (likely reflecting similarity in diagenetic pathway) [6]. By contrast, the Stimson formation shows distinctly higher MgO and lower $SiO_2$, and lacks enrichment in Ni and Zn.

| | Salsberry Peak (Little_Devil) n=1 | Average Murray fm (Pahrump Hills) n=41 | Average Stimson fm (unaltered) n=32 |
|---|---|---|---|
| **$Na_2O$** | 4.03 ± 0.14 | 2.79 ± 0.27 | 2.78 ± 0.14 |
| **MgO** | 3.95 ± 0.08 | 4.98 ± 0.42 | 8.85 ± 0.25 |
| **$Al_2O_3$** | 11.21 ± 0.29 | 10.97 ± 0.67 | 9.75 ± 0.29 |
| **$SiO_2$** | 49.78 ± 0.54 | 51.09 ± 0.96 | 43.1 ± 0.54 |
| **$P_2O_5$** | 0.76 ± 0.05 | 1.23 ± 0.14 | 0.86 ± 0.7 |
| **$SO_3$** | 2.29 ± 0.05 | 5.16 ± 0.38 | 5.65 ± 0.15 |
| **Cl** | 0.7 ± 0.02 | 0.64 ± 0.08 | 1.18 ± 0.03 |
| **$K_2O$** | 2.83 ± 0.10 | 0.79 ± 0.04 | 0.43 ± 0.02 |
| **CaO** | 5.71 ± 0.07 | 4.29 ± 0.08 | 6.50 ± 0.08 |
| **$TiO_2$** | 0.99 ± 0.03 | 1.10 ± 0.07 | 0.92 ± 0.03 |
| **$Cr_2O_3$** | 0.28 ± 0.01 | 0.37 ± 0.08 | 0.406 ± 0.03 |
| **MnO** | 0.29 ± 0.01 | 0.32 ± 0.07 | 0.39 ± 0.02 |
| **FeO** | 16.99 ± 0.20 | 15.88 ± 1.37 | 19.08 ± 0.26 |
| **Ni (ppm)** | 629 | 735 | 462 |
| **Zn (ppm)** | 609 | 1570 | 378 |
| **Br (ppm)** | 77 | 211 | 240 |

**Table 1.** APXS data of Salsberry Peak (sampled at Little_Devil), Murray formation (at Pahrump Hills), and unaltered Stimson formation.

**Conclusions:** Observations suggest that Salsberry Peak is a unique lithology not associated with the aeolian Stimson depositional system. Observations are consistent with a model in which Salsberry Peak represents a coarser-grained facies within the Murray that acted as a pressure seal during vein formation. Later erosion of Murray and Salsberry Peak was followed by Stimson sandstone deposition and ultimate erosion to current topography. Alteration halos within the Stimson suggest that at least one fluid flow event post-dates both the Murray and Stimson formations, indicating numerous fluid events broadly separarated in time.

**References:**

[1] Grotzinger J.P. et al. (2015) *Science, 350,* 6257. [2] Watkins J.A. et al. (2016) *LPS XLVII*, Abstract #2939. [3] Banham S.G. et al. (2016) *LPS XLVII*, Abstract #2346. [4] Kronyak R.E. et al. (2015) *AGU,* Abstract P43B-2122. [5] Newsom, H.E. et al. (2015) *AGU*, Abstract P53F-06. [6] Rampe, E.B. et al. (2016) *EPSL*, in revision.