

**IDENTIFICATION OF A HIGH-SILICA LAYER IN GALE CRATER, MARS USING *IN SITU* ACTIVE NEUTRON SPECTROSCOPY.** Sean Czarnecki<sup>1,2</sup>, Craig Hardgrove<sup>1</sup>, Patrick Gasda<sup>2</sup>, William Rapin<sup>3</sup>, Jens Frydenvang<sup>4</sup>, Travis S.J. Gabriel<sup>1</sup>, Mason Starr<sup>5</sup>, Melissa Rice<sup>5</sup>, Maxim Litvak<sup>6</sup>, Suzanne Nowicki<sup>2</sup>, Roger Wiens<sup>2</sup>, Lucy Thompson<sup>7</sup>, Horton Newsom<sup>8</sup>, Fred Calef<sup>3,9</sup>, Hallie Gengl<sup>3,9</sup>, <sup>1</sup>ASU, sczarne1@asu.edu, <sup>2</sup>LANL, <sup>3</sup>CalTech, <sup>4</sup>Nat. Hist. Mus. of Denmark, Univ. of Copenhagen, <sup>5</sup>Western Washington Univ., <sup>6</sup>Space Research Institute, RAS, <sup>7</sup>Univ. of New Brunswick <sup>8</sup>Univ. New Mexico, <sup>9</sup>JPL

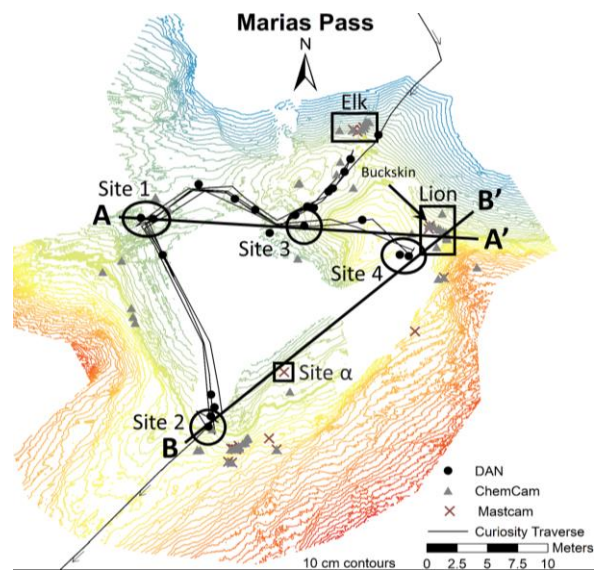
**Introduction:** The NASA Mars Science Laboratory (MSL) *Curiosity* rover investigated a region in Gale crater known as Marias Pass about 1000 days after landing. Both the Murray formation, a primarily lacustrine mudstone [1], and the unconformably overlying Stimson formation, an aeolian sandstone [2] are exposed here. In Marias Pass, the MSL ChemCam instrument observed Murray SiO<sub>2</sub> abundances from 56–82 wt.% and FeO<sub>T</sub> abundances from 2–18 wt.% [3]. Silica and FeO<sub>T</sub> are anti-correlated here, with the highest-silica/lowest-FeO<sub>T</sub> material observed at the “Elk” and “Lion” areas (Fig. 1). This high-silica material has fine-scale parallel laminations characteristic of mudstone [4]. The absence of high-silica Murray material above Lion suggests that it is confined to a stratigraphic layer. High-silica material in the Stimson is also present upsection in vertical “fracture halo” alteration features [3,5,6] containing silica possibly mobilized from an underlying laterally extensive source [3,6].

The MSL CheMin instrument performed an X-ray diffraction experiment on the drilled “Buckskin” sample from the Lion area (Fig. 1) and found ~14 wt.% tridymite and ~2 wt.% cristobalite, high-temperature, low-pressure silica polymorphs [4,7]. This tridymite-bearing material is interpreted to be a product of silicic volcanism [4,7]. The high-silica material in Marias Pass may be a source for silica enrichment in the fracture halos upsection [3]. These lines of evidence suggest that the high-silica material exposed at Lion may be present in the subsurface throughout Marias Pass. Since unaltered volcanic material would be dehydrated relative to aqueously altered material, a volcanically-derived layer could have a composition (low Fe) and hydration (low H) which the Dynamic Albedo of Neutrons (DAN) instrument is sensitive to.

**Methods:** The MSL DAN instrument is a neutron spectrometer sensitive to hydrogen [e.g., 8], neutron absorbing elements (e.g., Fe and Cl) [9], and their depth distribution within the top ~50 cm of the subsurface. Thus, DAN is capable of identifying low-Fe (high-silica) material in Marias Pass, and of quantifying its hydration. We simulated multiple subsurface layers using Monte-Carlo N-Particle (MCNP) transport code and compared these results to those from DAN. Water-Equivalent Hydrogen (WEH), elemental geochemistry, and depth were free parameters for each subsurface layer in our simulations. This created a ‘grid’ of models to be compared to DAN data through-

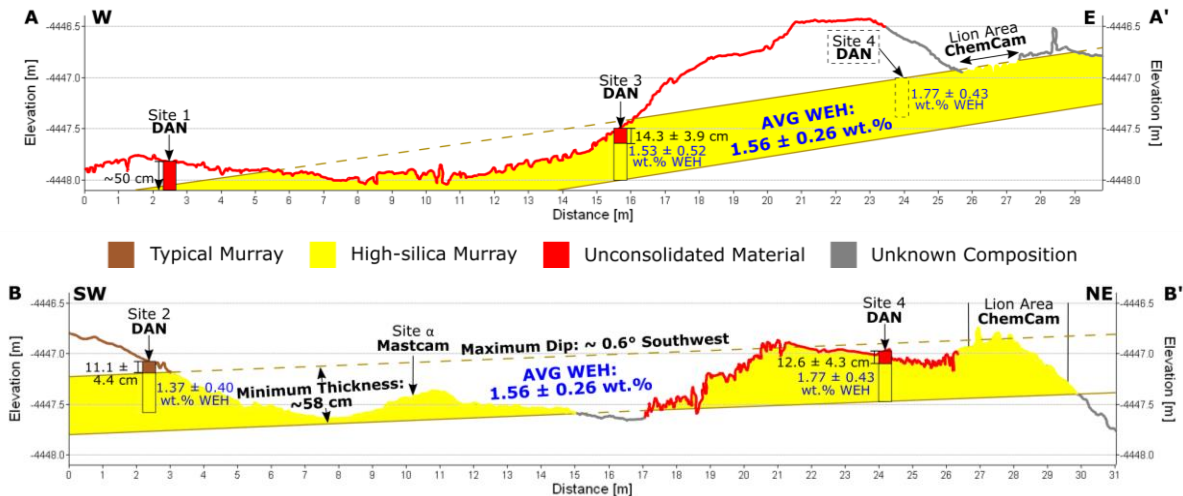
out Marias Pass. We use the Markov-Chain Monte-Carlo (MCMC) analysis routine from [10] to produce a likelihood distribution based on free parameter interpolation. The elemental abundances used were measured by the ChemCam LIBS instrument [11–13], with Cl values determined by the MSL APXS instrument [14].

Figure 1 shows the locations of sites investigated for this study. DAN data from Sites 1–4 were first compared to a grid of one-layer models. Results from Site 2 indicated that surface geochemistry is not homogeneously distributed in the top 50 cm suggesting that high-silica/low-Fe material is present at depth. Follow-up two-layer models included surface geochemistry in the upper layer and variable geochemistry in the lower layer. One-layer results from Sites 3 and 4 also suggested that high-silica/low-Fe material was present at depth. These sites have unconsolidated material of unknown composition at the surface, so follow-up two-layer models included variable upper layer geochemistry and high-silica lower layer geochemistry.



**Figure 1:** Topographic and location map showing cross section traces. Warm contours are topographically higher.

**Results:** Sites 2–4 all contain high-silica/low-Fe material in the subsurface. The high-silica WEH and depth results for each site are shown in Figure 2. The average WEH of high-silica/low-Fe material is  $1.56 \pm 0.26$  wt.%. Analyses of Mastcam multispectral data at Site  $\alpha$  (Fig. 1, 2B) are consistent with a high-silica/low-FeO<sub>T</sub> surface composition similar to material at Elk and Lion.



**Figure 2:** Cross sections with surface/subsurface composition and high-silica/low-Fe WEH. 4X vertical exaggeration. (A) One possible layer dip ( $\sim 2.3^\circ$  SW) is shown, but dip is not constrained in this direction. Site 4 bedrock (dashed, located  $\sim 2$  m south of A-A') is projected from its measured elevation. (B) Sites 2 and 4 constrain the maximum dip and minimum thickness of the layer.

A single sub-horizontal layer can project through all high-silica/low-Fe material in Marias Pass. Our depth results constrain the thickness and orientation of this layer. Relationships shown in Fig. 2B require a thickness of at least  $\sim 58$  cm. The dip from Lion to the top of the high-silica/low-Fe material at Site 2 is  $\sim 0.6^\circ$  SW (Fig. 2B). Lion and Sites 1, 3, and 4 are approximately colinear (Fig. 1, 2A). Since the high-silica/low-Fe layer contacts are not observed at these sites, the E-W dip is unknown. Note that a shallower E-W dip requires a greater high-silica layer thickness. The Murray has a regional dip of  $\sim 3^\circ$  NW [15,16] and the orientation of the high-silica/low-Fe layer in Marias Pass is consistent with a minor local variation of this dip.

Figure 2A shows that the high-silica layer projects into the subsurface at Site 1. The absence of high-silica material in the DAN FOV suggests that such high-silica material has been removed by erosion and that the top  $\sim 50$  cm of Site 1 is composed of material transported from another location. This is supported by rover imagery that shows a heterogeneous mixture of bedrock fragments and sand at Site 1.

**Discussion:** ChemCam measured  $4.0 \pm 1.3$  wt.% WEH at Buckskin [17], significantly higher than our average DAN result of  $1.56 \pm 0.26$  wt.% WEH. DAN measures the average hydration within its FOV ( $\sim 3$  m surface footprint,  $\sim 50$  cm depth), which indicates that the Buckskin location sampled by ChemCam has a higher hydrogen value than the average of the bulk high-silica material in Marias Pass.

The Buckskin drill sample contains  $\sim 60$  wt.% amorphous material. The broad amorphous hump in the CheMin x-ray diffraction pattern can be fit by

either silica glass, opal, or a mixture of these [4]. Since silica glass holds less water than opaline silica [17], the relatively low WEH in our bulk measurements could be due to more abundant silica glass than that observed in Stimson fracture halos, where DAN has measured  $5.1 \pm 1.0$  wt.% WEH and ChemCam has measured  $3.2 \pm 1.0$  to  $4.0 \pm 1.2$  wt.% WEH [17].

**Conclusions:** A stratigraphic layer of silicic volcanic material deposited in a lacustrine environment that preserves significant volcanic glass should be laterally extensive, conformable, and have a low water content. Our results show that subsurface high-silica/low-Fe material in Marias Pass has these characteristics. If this material was a source for Stimson fracture halo silica, then it must extend from Marias Pass to the most distant Stimson fracture halo ( $\sim 900$  m SW of Marias Pass). The Murray was deposited  $\sim 3.8$ - $3.6$  Ga [18], and the identification of a silicic volcanic layer in the Murray indicates that an evolved magma source existed on Mars at or before this time.

**References:** [1] Grotzinger, J.P. et al. (2015) *Science*, 350(6257). [2] Banham, S.G. et al. (2018) *Sedimentology*, 65, 993-1042. [3] Frydenvang, J. et al. (2017) *GRL*, 44, 4716-4724. [4] Morris, R.V. et al. (2016) *PNAS*, 133(26), 7071-7076. [5] Gasda, P.J. et al. (2016) *LPSC*, 1675. [6] Yen, A.S. et al. (2017) *EPSL*, 471, 186-198. [7] Rampe, E.B., et al. (2017) *EPSL*, 471, 172-185. [8] Mitrofanov, I.G. et al. (2012) *Space Sci. Rev.*, 170, 559-582. [9] Hardgrove, C. et al. (2011) *NIMA*, 659, 442-455. [10] Gabriel, T.S.J. et al. (2018) *GRL*, 45. [11] Wiens, R.C. et al. (2012) *SSR*, 170(1-4), 167-227. [12] Maurice, S. et al. (2012) *SSR*, 170(1-4), 95-166. [13] Clegg, S.M. et al. (2017) *Spectrochim. B: A. Spec.*, 129, 64-85. [14] Campbell, J. L. et al. (2014), *NIMB*, 323, 49-58. [15] Kite, et al. (2013) *Geology*, 41(5), 543-546. [16] Lewis, K.W., and Turner, M.L. (2019) *LPSC*. [17] Rapin, W. et al. (2018) *JGR: Planets*, 123. [18] Thomson, B. J. et al. (2011), *Icarus*, 214, 413-432.