IDENTIFICATION AND CHARACTERIZATION OF A SILICIC VOLCANIC LAYER IN GALE CRATER, MARS USING IN SITU ACTIVE NEUTRON SPECTROSCOPY. Sean Czarnecki\textsuperscript{1,2}, Craig Hardgrove\textsuperscript{1}, Patrick Gasda\textsuperscript{2}, William Rapin\textsuperscript{3}, Jens Frydenvang\textsuperscript{4}, Travis S.J. Gabriell\textsuperscript{1}, Mason Starr\textsuperscript{5}, Melissa Rice\textsuperscript{5}, Maxim Litvak\textsuperscript{6}, Suzanne Novicki\textsuperscript{2}, Roger Wiens\textsuperscript{2}, Lucy Thompson\textsuperscript{7}, Horton Newsom\textsuperscript{8}, Fred Calef\textsuperscript{9,10}, Hallie Gengl\textsuperscript{10,11}, \textsuperscript{1}ASU, szczarnel1@asu.edu, \textsuperscript{2}LANL, \textsuperscript{3}CalTech, \textsuperscript{4}Nat. Hist. Mus. of Denmark, Univ. of Copenhagen, \textsuperscript{5}Western Washington Univ., \textsuperscript{6}Space Research Institute, RAS, \textsuperscript{7}Univ. of New Brunswick \textsuperscript{8}Univ. New Mexico, \textsuperscript{9}JPL.

Introduction: The NASA Curiosity rover observed SiO\textsubscript{2} abundances up to 82 wt.%\textsuperscript{1} and tri-dymite (a high-T, low-P SiO\textsubscript{2} polymorph)\textsuperscript{2,3} in a lacustrine mudstone\textsuperscript{4} at Marias Pass in Gale crater. In this area, SiO\textsubscript{2} is anti-correlated with FeO\textsubscript{2} (Fig. 1), a strong thermal neutron absorber. The Dynamic Albedo of Neutrons (DAN) instrument\textsuperscript{5} is sensitive to neutron absorbers, e.g., Fe\textsuperscript{6}, and H (which moderates neutron energy) in the top ~50 cm of the subsurface. Using DAN data, we mapped the distribution of this SiO\textsubscript{2}-rich material in Marias Pass, constraining its hydration, extent, thickness, and orientation.

Figure 1: ChemCam LIBS SiO\textsubscript{2} vs. FeO\textsubscript{2} for Marias Pass mudstone. $\Sigma_{\alpha}$ is bulk neutron absorption cross section.

Methods: In active mode, DAN emits neutrons which return to the DAN detectors with a time and energy distribution dependent on subsurface interactions e.g., 5. To quantify geochemical abundances within the DAN field of view, we forward model DAN time-of-flight spectra using Monte-Carlo N-Particle transport code simulations. Free parameters include Water Equivalent Hydrogen (WEH), elemental geochemistry, and depth for each subsurface layer. Simulated spectra are then compared to DAN data using Markov-Chain Monte-Carlo analyses to produce likelihood distributions as in\textsuperscript{7}. Our models use geochemical abundances measured by the MSL ChemCam instrument\textsuperscript{8} in Marias Pass, with Cl values determined by the MSL APXS instrument\textsuperscript{9}.

Results: We analyzed 13 DAN active measurement sites (Fig. 2) in Marias Pass and found high-SiO\textsubscript{2} material at sites 1-9 and 13. The results for sites 9 and 13 suggested that high-SiO\textsubscript{2} material was exposed at a large bedrock outcrop ($\alpha$ in Fig. 2), and Mastcam multispectral analysis placed this outcrop in family with known high-SiO\textsubscript{2} targets. Rover imagery at sites 10-12, where high-SiO\textsubscript{2} material was not observed, suggests this relatively low-elevation area is filled in with eroded rock and sand. A single, subhorizontal layer can project through all high-SiO\textsubscript{2} material observed in Marias Pass. This layer has a minimum thickness of 104 cm, a maximum dip to the SW of 0.6\textdegree, and WEH ranging from 1.37 \pm 0.40 to 2.77 \pm 0.32 wt.%. Fig. 3 illustrates the geometric relationships that constrain the orientation and thickness of this layer within Marias Pass.

Figure 2: (top) Map of Marias Pass with DAN surface footprints (1-13) and cross section traces. $\alpha$ is a high-SiO\textsubscript{2} outcrop with Mastcam multispectral observations and the blue box is an area of ChemCam high-SiO\textsubscript{2} observations. (bottom) Map of Curiosity traverse showing Marias Pass in green, two high-SiO\textsubscript{2} alteration halos, and CRISM orbital hydrated SiO\textsubscript{2} detections ($\beta$, $\gamma$, and $\delta$).
**Discussion:** The lacustrine Murray formation and overlying aeolian Stimson formation contain abundant light-toned alteration zones surrounding fractures [10]. These “halos” also contain up to 86 wt.% SiO$_2$ and were likely enriched in SiO$_2$ by aqueous mobilization from an underlying source [1,10]. The most likely such source is the layer exposed in Marias Pass [1], suggesting that this layer extends beneath the alteration halos up to ~ 1 km laterally from Marias Pass (Fig. 2). Orbital hyperspectral CRISM observations have detected three exposures of hydrated SiO$_2$ several km from Marias Pass [11,12]. The elevations of these deposits suggest that they are stratigraphically equivalent to the Murray in Marias Pass (Fig. 4), assuming a regional dip ~ 3° NW [13]. We hypothesize that these detections are part of the same layer we have mapped in Marias Pass which indicates that this SiO$_2$-rich layer extends over 17.5 km.

We measured WEH abundances ranging from 1.37 ± 0.40 to 2.77 ± 0.32 wt.% and averaging 1.95 ± 0.12 wt.% with DAN, less than the 4.0 ± 1.2 wt.% average WEH determined by ChemCam for high-SiO$_2$ targets in Marias Pass (Fig. 2). The range of WEH abundances from DAN and ChemCam indicates that the hydration of the high-SiO$_2$ material in Marias Pass is heterogeneous. The tridymite-bearing material contains no hydrous crystalline phases, indicating that H is contained primarily in the amorphous fraction dominated by opal-A and/or rhyolitic glass [2] (cf. high-SiO$_2$ alteration halos, which are primarily opal-A with up to 4.0 ± 1.2 wt.% WEH [14]). Since opal-A has a greater water capacity than volcanic glass; areas with lower WEH likely contain less opal-A than areas with higher WEH.

**Conclusions:** We propose that the silica-rich material exposed at Marias Pass in Gale crater is a regionally extensive tridymite-bearing stratigraphic layer. This is consistent with a silicic volcanic deposit reworked and transported into Gale lake during the formation of the Murray mudstone ~ 3.8-3.6 Ga [15]. This supports previous studies which have identified evolved igneous lithologies on Mars [e.g., 16,17,18], suggesting that evolved magmatism is possible on single-plate planets.


**Figure 3:** Geologic cross sections A-A’ and B-B’ (see Fig. 2 for locations) showing DAN, ChemCam, and Mastcam observations of high-SiO$_2$ material. 4X vertical exaggeration. Constraints on layer thickness and orientation are illustrated.

**Figure 4:** Cross section C-C’ (see Fig. 2 for location) showing topographic relationship of Marias Pass to sites β and γ. 4X vertical exaggeration. Stratigraphic equivalence between Marias Pass and β or γ requires a dip of < 0.5° to the NE or SW.