Discovery of Silica-Rich Lacustrine and Eolian Sedimentary Rocks in Gale Crater, Mars.

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Introduction: Between Mars solar days (sols) 991 and 1155 of the Mars Science Laboratory (MSL) mission, the Curiosity rover traversed an area between Marias Pass and Bridger Basin (Fig. 1) with geographically extensive silica enrichment relative to what has been observed elsewhere in Gale Crater. The extensive silica enrichment is observed within the lacustrine mudstones of the Murray formation [1], and also in unconformably overlying cross-bedded sandstones of the Stimson formation, interpreted to be of eolian origin. Here, the nature of the silica enrichment is outlined with emphasis on the insight provided by the large number of ChemCam measurements.

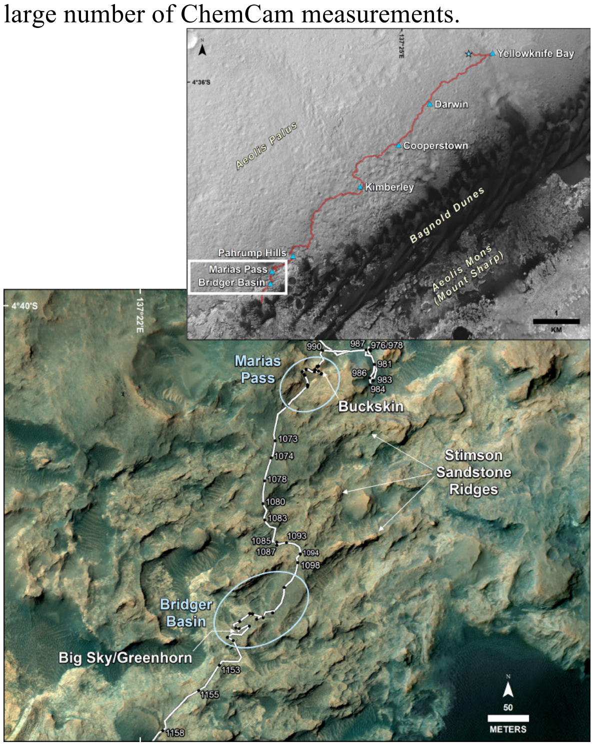

Figure 1: (Top) Traverse of the Curiosity rover to sol 1185, showing the location of the Marias Pass and Bridger Basin waypoints. (Bottom) Elevated silica in Murray and overlying Stimson were observed between the Marias Pass and Bridger Basin locations.

Murray represents the lowest exposed stratigraphic level of of the Mount Sharp group, whereas Stimson is identified as part of an overlying draping strata which postdates deposition of the Mt Sharp Group and subsequent burial and exhumation of Gale Crater [1]. In both Murray and Stimson, bedrock with more than 70 wt.% SiO_2 was observed.

Results: More than 1200 individual ChemCam [2,3] measurement points, 37 Alpha Particle X-ray Spectrometer (APXS) [4] measurements and CheMin [5] analyses of 3 drill hole samples were made to investigate the nature of this silica enrichment, along with a large number of supporting Mastcam [6] and Mars Hand Lens Imager (MAHLI) [7] images.

Murray formation: High silica diagenesis is observed at both the Marias Pass and Bridger Basin locations. At Marias Pass, the enrichment occurs over an extensive horizontal exposure (Fig. 2), whereas the enrichment at Bridger Basin occurs along fractures in the bedrock [8].

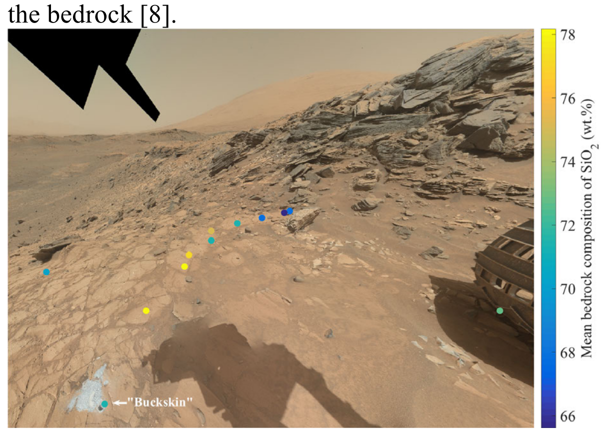

Figure 2: Mahli mosaic showing the 'Lion'-location at Marias Pass. ChemCam performed a transect across the silica rich exposure of Murray to track the silica variation around the Buckskin drill hole. Distance between Buckskin and the closest ChemCam target is ~40cm. Mt. Sharp is seen in the background.

At Marias Pass, CheMin analysis of the Buckskin drill hole showed silica enrichment in the form of both tridymite and amorphous silica (opal-A and/or silica glass) [9]. This drill hole was however not located inside the area with the highest silica concentration as observed by ChemCam.

At both the Marias Pass and Bridger Basin exposures of Murray, ChemCam observes similar chemical variation; ranging from a corresponding low silica

(~60 wt%) and high FeO_T (~20 wt%), to a high silica (>80 wt%) and low FeO_T (<3 wt%). Even the lowest values for SiO_2 are ~10 wt% higher than those observed in the stratigraphically lower exposures of Murray at Pahrump Hills [10] (fig. 1).

Stimson formation: At both Marias Pass [11], Bridger Basin and during the traverse between the two locations, localized high silica diagenesis of Stimson was observed. ChemCam measurements indicate that elevated silica is confined immediately adjacent to fractures that cut through the bedrock, and a transition from low to high silica at the center of fractures is observed (Fig. 3). Throughout the area, Stimson shows a fairly constant composition with ~45wt% SiO_2, ~19wt% FeO_T, ~10wt% Al_2O_3 and ~9wt% MgO outside the diagenesis adjacent to fractures. The high silica Stimson includes the highest silica content measured by ChemCam with one measurement point showing in excess of 90 wt% SiO_2.

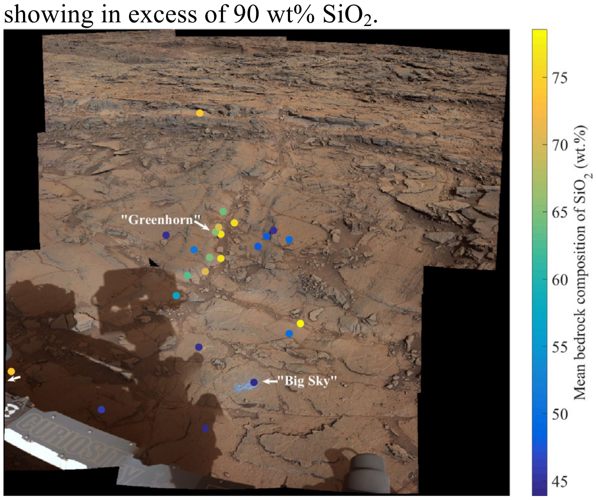

Figure 3: *Mastcam mosaic showing the location of the Big Sky and Greenhorn drill holes and ChemCam targets in the Stimson formation at Bridger Basin. Highest silica observed close to the center of fractures. Distance between Big Sky and Greenhorn is ~2 m.*

Discussion: Based on our data and [1], the geological order of events at Marias Pass and Bridger Basin are – simplistically – understood to be: (1) Deposition of the Mt Sharp group, (2) Termination lake sedimentation and erosion of Mt Sharp group, (3) Eolian burial of Gale crater and formation of upper part of Mt Sharp, (4) Exhumation of Gale crater – exposure of the Murray formation, (5) Deposition, lithification and fracturing of Stimson, (6) Fracture diagenesis, and (7) Exhumation/erosion of Stimson. In addition to this, multiple sulfate fracture filling episodes occurred during steps 3-6. This order of events implies that the the observed silica diagenesis represents one of the youngest episodes of rock-water interaction observed in Gale Crater.

The tridymite detected in the Buckskin drill hole in Murray is considered detrital [9], and is interpreted by us to be part of a primary silica enrichment during deposition of this part of Murray. This interpretation is consistent with the silica content being higher than observed in stratal layers of the Murray formation that occur below and above the silica-rich horizon.

In addition to the initial detrital silica enrichment of the Murray formation, our data indicate that a second enrichment of silica took place at a later stage. This affected both the Murray and Stimson formations. Silica enrichment occurred by fluid flow through fractures and/or more permeable layers in the bedrock. The close association of the silica diagenesis to fractures in Murray and Stimson suggest that this second enrichment episode most likely took place during an additional phase of sediment burial that postdates the exhumation of the Mount Sharp group, including the Murray formation. Constraining the timing of the second silica enrichment to postdate deposition of the Stimson formation, which in turns postdates exhumation of the Mount Sharp group, implies significant rock-water interaction in Gale Crater at a relatively young time.

While still under investigation, the large number of ChemCam targets across both the Murray and Stimson formations suggest that the silica enrichment is caused by silica precipitation from a neutral to alkaline fluid. This is supported by the ratio of other major elements maintaining an approximately constant ratio with increasing silica. Alternatively, the silica enrichment could be caused by acid leaching [9,12].

Only the Murray formation at Bridger Basin appear clearly associated with diagenesis along fractures [8]. However, the similarity in elemental composition between the high and low silica Murray observations at Marias Pass and Bridger Basin suggest they share a common origin of both primary and secondary silica enrichment [8]. In connection with the singular enrichment of amorphous silica in the nearby Greenhorn drill hole (Fig. 3) [12], this indicates that the much later secondary silica enrichment is in amorphous silica across Murray and Stimson at both the Marias Pass and Bridger Basin locations.

References: *[1] Grotzinger J.P. et al. (2015) Science, 350. [2] Wiens R.C. et al. (2012), Space Sci Rev 170, [3] Maurice S. et al. (2012) Space Sci Rev 170, [4] Gellert R. et al. (2015) Elements, 11. [5] Blake D. et al. (2012) Space Sci Rev, 170. [6] Bell J.F. et al. (2012) 43rd LPSC, #2541 [7] Edgett K.S. et al. (2012) Space Sci Rev, 170. [8] Gasda P.J. et al. (2016) This meeting. [9] Morris R.V. et al. (2016) This meeting. [10] Milliken R.E. et al. (2015) 46th LPSC, #2339. [11] Newsom H.E. et al. (2016) This meeting. [12] Yen A.S. et al. (2016) This meeting.*