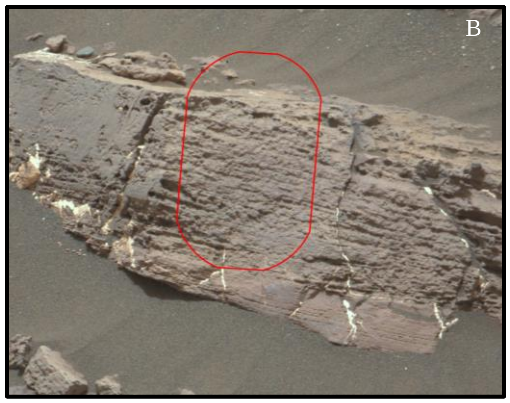
DISTRIBUTION AND ANALYSIS OF CALCIUM SULFATE-CEMENTED SANDSTONES ALONG THE MSL TRAVERSE, GALE CRATER, MARS M.A. Nellessen[1], A.M. Baker[1], H.E. Newsom[1], R.S. Jackson[1], J. Williams[1] M. Nachon[2], F. Rivera-Hernandez[3], R.C. Wiens[4], P. Gasda[4], N. Lanza[4], A. Ollila[4], S. Clegg[4], J. Frydenvang[5], O. Gasnault[6], S. Maurice[6], P.-Y. Meslin[6], A. Cousin[6], W. Rapin[6], J. Lasue[6], O. Forni[6], J. L'Haridon[6], D. Blaney[7], V. Payré[8], N. Mangold[9], L. LeDeit[9], R. Anderson[10], [1]U. New Mexico, Albuquerque, NM 87131, USA (Newsom@unm.edu); [2]UC Davis, CA; [3]Dartmouth College, NH; [4]Los Alamos Nat. Lab, NM; [5]Univsersity of Copenhagen, DK; [6]IRAP/CNRS, FR; [7]Caltech/Jet Prop. Lab, CA; [8]U. Lorraine de Nancy, FR; [9]Lab. de Planet. et Geodynam. de Nantes, FR; [10]USGS, Flagstaff, AZ.



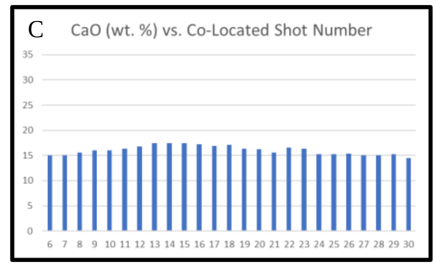


Fig. 1 **A**. ChemCam RMI image mosaic merged with Mastcam color of a portion of the Murray formation (Bobonong target, Sol 1477), with light-toned materials consistent with the presence of pore-filling calcium sulfate cement. **B**. Location of the RMI and ChemCam LIBS obsessrvations **C**. Shot to shot data from one point showing the relative homogeneity with depth. The 25 shots do not include the first 5 shots to ensure there is not surface dust contamination.

Introduction: The Mars Science Laboratory Rover Curiosity has observed abundant calcium sulfate veins in all of the bedrock examined to date in Gale Crater, with the exception of the Bradbury Rise or Rocknest Outcrop areas. The veins are also ubiquitous in the Murray formation, which is mudstone-dominated. But around the time (e.g. **Fig. 1**) the rover reached the Sutton Island member of the Murray Formation on the lower slopes of Mount Sharp, the presence of light-toned outcrops with moderate Ca and S have been observed, suggesting the presence of a cemented porous sandstone. The substantial increase in these elements consistent with Ca-sulfate cemented sandstone (instead of mudstone) (**Fig. 2**), along with changes in other sedimentary structures and chemistry [1-3] may signal changes in the depositional environment, sediment flux, or depositional rate of the lake deposits.

Detection of calcium sulfate cement: We have frequently targeted calcium sulfate veins with ChemCam using Laser Induced Breakdown Spectroscopy (LIBS) [4]. In sandstone, typical porosities vary between 5% by volume up to ~ 30% by volume, with poorly sorted materials having less pore space. Therefore the relative maximum for pore-filling cement is around 30 wt% for Ca-sulfate [5]. Pure Ca-sulfate veins tend to contain Ca in abundance of around 35-45 wt%.Thus CaO abundances around 20 wt% would be consistent with a cemented sandstone.

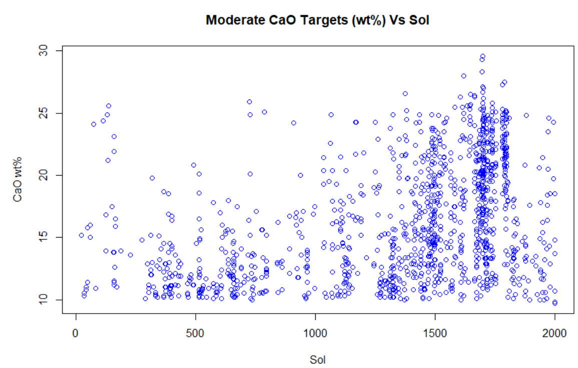


Fig. 2 ChemCam observation points likely to be porous sandstone (rather than mudstone) cemented with calcium sulfate.

We have begun looking at the shot-to-shot patterns to determine different classifications for types of targets we are hitting. The ChemCam spot size is ~400 µm, and Ca-sulfate veins could be mistaken for cement if only a part of the beam hit the vein, resulting in 10-25 wt. % CaO, as in **Fig. 3B**. But there is only a small chance that the laser beam can partly hit a vein plus matrix material. Furthermore, cemented sandstones have very homogeneous shot-to-shot trends with a low standard deviation (<2.0 wt. %; **Fig 3A**). We examined all the ChemCam shot-to-shot data from the beginning of the mission to Sol 2003 for the signature of substantial cement (CaO between 10 and 25 wt. %). We omitted the first 5 shots to ensure lack of contamination from Martian dust [6], which will give inaccurate data on the target rock. We then compiled all of the moderate CaO targets into two lists: one for the homogeneous, cemented targets and one for those displaying heterogeneous targets. We found over 1200 candidate points for Ca-sulfate cement. Shot-to-shot patterns (**Fig. 3**) include the flat-trending (likely cements), continuous increasing/decreasing (may represent hitting edge of vein at transverse angle or changing cement abundance), concave increasing/decreasing (may be similar to to continuous, but additionally have curving veins), and several irregular and complex patterns which may represent small, individual calcium-sulfate grains or potentially a combination of some of the above mentoned features. Understanding and theorizing the potential causes of different shot-to-shot patterns may allow us to determine possibilities for what type of targets each pattern represents and use this information to learn about the environment the feature was deposited in. It was noted that most targets (~80%) with moderate CaO exhibited a homogeneous trend. This indicates that almost all locations with intermediate CaO represent cemented rocks and not the edge of a vein. This has been verified by examination of the RMI and Mastcam context imagery.

Distribution and Origin of Calcium Sulfate Cement: The Murray formation contains abundant calcium sulfate veins, usually ~1 mm to a few mm thick, that commonly cross cut the depositional layers at sub-vertical angles [7]. The Murray formation from the Pahrump Hills through the Karasburg member contains many occurrences of interbedded sandstone. At elevations below the Murray Buttes, the Murray formation apparently consisted largely of mudstones that had very limited porosity when calcium sulfate bearing fluids were present.

The Murray formation from Pahrump, through Marias Pass to the Murray Buttes has little evidence for cement. However, as noted above the character of the bedrock changed in the Sutton Island member around Old Soaker (around Sol 1550 [8], elevation: ~-4335 m), with a variety of sedimentary structures including laminated, wavy/irregular/cross-laminated or cross-bedded layers with clear geometric truncations based on preliminary analysis [9]. This area is where the Ca sulfate cemented sandstones are much more common (**Fig. 2**). The increased abundance of sandstone [3] and the other changes indicate a change in the original depositional environment, sediment flux, or depositional rate.

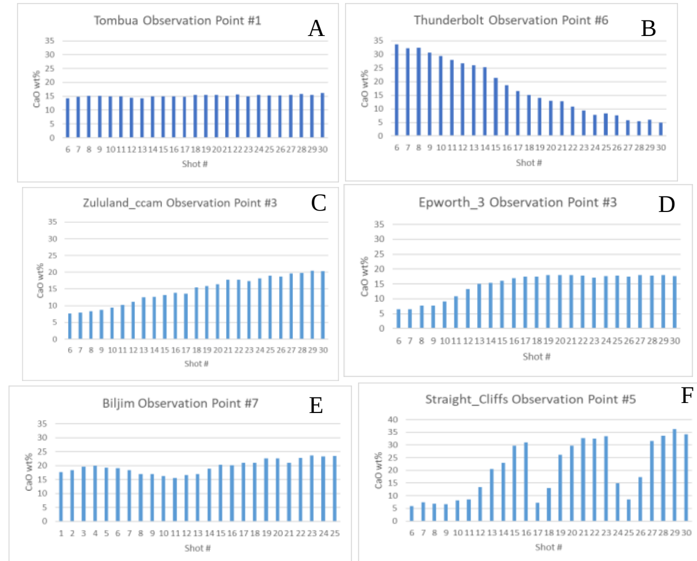


Fig. 3 Different shot-to-shot patterns that have been encountered by ChemCam. **A**. Flat-trending (Tombua Sol 1378). **B**. Steeply decreasing/increasing (Thunderbolt Sol 1033). **C**. Gradual linear increasing/decreasing (Zululand_ccam Sol 1879). **D**. Concave increasing/decreasing (Epworth 3 Sol 84). **E**. Complex (Biljim Sol 1794). **F**. Jagged (Straight Cliffs #5 Sol 766). These different patterns likely represent different types of targets being shot by ChemCam.

Sulfur Analysis: Recent work by Clegg et al. [10] on sulfur calibration for ChemCam has allowed us to make direct calcium-to-sulfur comparisons. Initial analysis between the comparison of Ca and S has revealed a strong correlation between the two. The correlation between CaO and the sulfur supports the interpretation that most of these analyses are sandstones cemented by calcium sulfate.

Conclusions: In contrast to the ubiquitous calcium sulfate veins, since entering the Sutton Island member of the Murray formation and into the Blunts Point member, the presence of calcium sulfate cemented porous sandstone was common, both in images and in ChemCam LIBS analyses. The presence of the cemented sandstone and changes in sedimentary structures suggest a change in depositional environment, including sediment flux or depositional rate of the lake deposits.

References: [1] W. Rapin et al., this meeting. [2] P. Gasda et al., this meeting; [3] F. Rivera-Hernandez et al., this meeting. [4] W. Rapin et al. EPSL, 452:197-205, 2016. [5] Newsom et al. 2016 LPSC, and 2017 LPSC, and in preparation. [6] Lasue, J. et al., (2018) *Geology*, 10.1130/G40005.1. Martian eolian dust probed by ChemCam. *Geophysical Research Letters*. [7] Nachon M. et al. (2017) AGU, #230348. [8] Stein et al. (2017) [9] Grotzinger et al., 2016, AGU. [10] Clegg et al., 2018 LPSC, this volume.