THE MATERIALS AT AN UNCONFORMITY BETWEEN THE MURRAY AND STIMSON FORMATIONS AT MARIAS PASS, GALE CRATER, MARS H.E. Newsom[1], I. Belgacem[1,3], R. Jackson[1], B. Ha[1], Z. Vaci[1], R.C. Wiens[2], J. Frydenvang[2], P. Gasda[2], N. Lanza[2], S. Clegg[2], O. Gasnault[3], S. Maurice[3], A. Cousin[3], W. Rapin[3], O. Forni[3] S. Banham[4], S. Gupta[4], A. Williams[5], J. Grotzinger[6], D. Blaney[6], J. Schroeder[6], F. Calef[6], R. Francis[6], B. Ehlmann[6], A. Yen[6], N. Stein[6], J. Watkins[6], D. Rubin[7], N. Bridges[8], J. Johnson[8], K. Lewis[8], V. Payré[9], N. Mangold[10], K. Edgett[11], D. Fey[11], M. Fisk[12]; R. Gellert[13], L. Thompson[14], M. Schmidt[15], G. Perrett[16], L. Kah[17], R. Kronyak[17], R. Anderson[18], K. Herkenhoff[18], J. Bridges[19], J. Hurowitz[20], J. Schieber[21], E. Heydari[22], [1]U. New Mexico, Albuquerque, NM 87131, USA (Newsom@unm.edu); [2]Los Alamos Nat. Lab, NM; [3]IRAP/CNRS, FR; [4]Imperial College, UK; [5]Towson U., MD; [6]Caltech/Jet Prop. Lab, CA; [7]UC Santa Cruz, CA; [8]App. Phys. Lab, MD; [9]U. Lorraine de Nancy, FR; [10]Lab. de Planet. et Geodynam. de Nantes, FR; [11]Malin Sp. Sci. Sys., San Diego, CA; [12]Oregon State, OR; [13]U. Guelph, Can.; [14]U. New Brunswick, Can.; [15]Brock U., Can., [16]Cornell, NY; [17]U. Tenn., TN; [18]USGS, Flagstaff, AZ; [19]U. Leicester, UK, [20]Stony Brook U. NY; [21]Indiana U., IA; [22]Jackson St. U., MS.

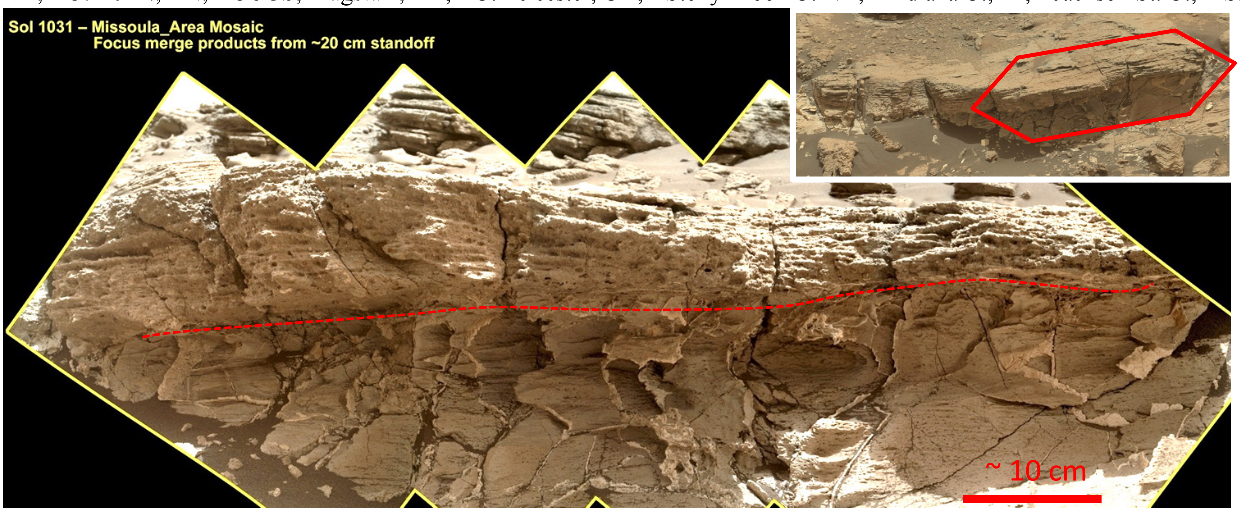

Fig. 1 MAHLI image mosaic of a portion of the Missoula/Ronan outcrop with Murray/Stimson contact (red dashed line). The image perspective from the arm camera is a “dog’s eye” view. Inset Mastcam image of the outcrop, with MAHLI location.

Introduction: The Mars Science Laboratory rover Curiosity began exploring the lacustrine mudstones of the Murray Fm (Formation) on Sol 753 (Sept. 18, 2014) at the Pahrump Hills outcrop. Leaving this area on Sol 949, the rover proceeded toward the contact between the Murray Fm and the unconformably overlying Stimson Fm, whose thick cross bed sets are consistent with aeolian deposition. Reaching the Marias Pass area, on Sol 992 (May 21, 2015) the ChemCam instrument observed the “Elk” target, still in the Murray Fm, that has a very high SiO_2 content of >80 wt% [1]. The rover continued to an area dubbed “Missoula/Ronan”, where the contact is fully exposed (**Fig. 1**). ChemCam, MAHLI and APXS observations were acquired on the rocks and materials in this area of the contact during two visits, which ended with the departure of Curiosity from the Marias Pass area on Sol 1072 (Aug. 12, 2015).

Geology of the outcrop: The Murray Fm was first studied at the Pahrump Hills, located 2-3 meters stratigraphically below the rocks exposed at Marias Pass [2]. At Marias Pass, the Murray also consists of finely laminated (~1 mm) mudstones, suggesting lacustrine deposition in a distal environment. A bimodal population of grains is present in the Murray targets, dominated by very fine-grains (<64 microns), with a low abundance of small rounded grains (<1 mm). The lowermost Stimson just above the contact consists of an erosionally resistant layer, up to 5 cm thick, designated the Missoula Mbr (Member). This layer exhibits discontinuous horizontal layering and contains small rounded mm size lustrous and polished mineral grains. There is strong visual evidence that irregular shaped fine-grain light-toned mudstone clasts, and light-toned clasts that could be pieces of calcium sulfate veins, were derived from the underlying Murray Fm [3]. The lower 2.5 cm of the Missoula Mbr contains a concentration of light-toned areas (**Fig. 1,** missing on the right side). Other enigmatic light-toned areas or surfaces could be sockets left by erosion of mudstone clasts or plucking of grains.

Also found nearby is a resistant piece of Stimson float represented by the Big Arm target. MAHLI and RMI images on a sandstone bedding surface reveal an abundant and diverse population of dark, possibly lithic grains, polymineralic grains, light-toned polished grains, and irregular shaped fine-grain light-toned clasts in the Missoula Mbr, that were probably derived from the underlying Murray Fm. The Missoula Mbr and Big Arm lithologies, with their horizontal flat-lying beds, could be of possible fluvial or aeolian origin.

Calcium sulfate veins and cement: The Murray Fm contains abundant calcium sulfate veins, usually ~1 mm to a few mm thick, that mostly cross cut at sub-vertical angles, which are probably truncated at the contact with the Stimson. The Stimson has far fewer veins, but along the contact itself is a sub-horizontal vein complex (**Fig. 1**, especially right side). At some locations along the contact there appears to be a single vein, less than 1 mm thick, while other areas consist of multiple less defined veins a few mm thick embedded in a fine-grain deposit that may be nearly 10 mm thick.

The Missoula Mbr, above the veins along the contact, appears to be locally cemented with calcium sulfate. ChemCam LIBS on many points, including the enigmatic light-toned areas (**Fig. 2**), commonly have low totals, implying a missing component, probably sulfur, which correlates with CaO abundances, and is consistent with impure calcium sulfate cement.

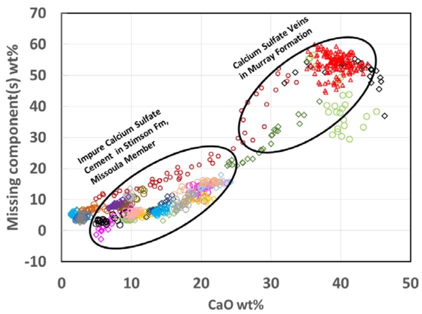

Fig. 2 ChemCam shot to shot evidence for impure calcium sulfate cement in Missoula Mbr points.

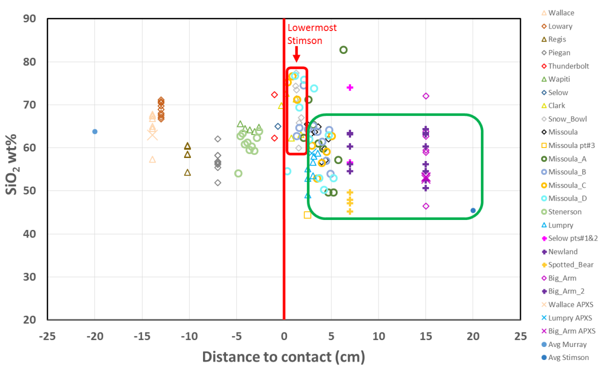

Fig. 3 ChemCam LIBS and APXS SiO_2 analyses of materials above and below the contact.

Major elements above and below the contact: The chemistry of Murray just below the contact (**Figs. 3, 4**), including SiO_2, is consistent with other Murray analyses at Marias Pass with no evidence for paleosol formation associated with the eroded surface, and no evidence of the high SiO_2 Elk type materials found elsewhere in the Murray. However, compared to Stimson above this layer, the lowermost Missoula Mbr is distinctly elevated in SiO_2 (to >75 wt%), up to 2.5 cm above the contact (**Fig. 3**, red box). The other major elements are anti-correlated with SiO_2, e.g. Al_2O_3, (**Fig. 4**), K_2O, MgO, FeO, CaO, Na_2O. The non-SiO_2 elements also have inter-element ratios that are the same as the Stimson higher up. CIA (Chemical Index of Alteration) and TiO_2 abundances are constant in Stimson from both ChemCam and APXS analyses [4].

Origin of SiO_2 diagenesis in the Missoula Mbr: In contrast with the Murray, where detrital high-temperature tridymite, may play a role [1], in the Stimson late fluids as a source of precipitated silica is consistent with the anti-correlation of silica with other major elements, and localization of the silica enrichments near fluid barriers created by calcium sulfate veins. An alternative explanation is acid sulfate alteration [4], but the CIA provides no evidence for an alteration trend with increasing SiO_2. Also, acid sulfate alteration should increase TiO_2, and decrease P, but the Lumpry APXS analysis, closest to the contact is actually higher in both SiO_2 and P than the other Stimson APXS analyses at this outcrop.

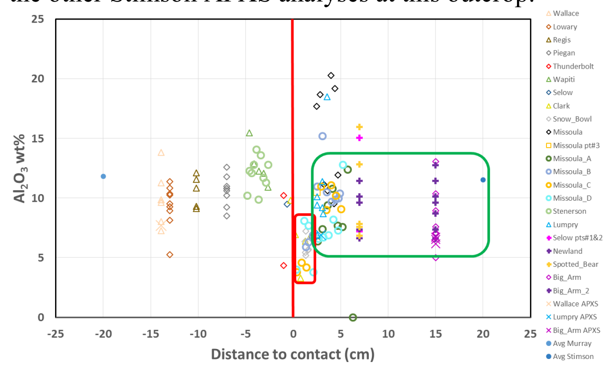

Fig. 4 ChemCam LIBS and APXS Al_2O_3 analyses of materials above and below the contact.

Conclusions: Lacustrine deposition of the Murray Fm and abundant calcium sulfate veins was followed by extensive erosion [5], but with no paleosol alteration at the contact, and no elevated SiO_2. The mainly aeolian Stimson Fm was deposited on the contact, beginning with the Missoula Mbr, which could have involved fluvial or aeolian processes. This layer probably contains light-toned clasts of mudstone and eroded fragments of calcium sulfate veins eroded from the Murray [3]. Although some of the light-toned clasts could represent remnants of calcium sulfate veins eroded from the Murray, other elements do not support derivation of the Missoula member as a whole from the Murray, as K_2O/Al_2O_3 ratios are distinctly Stimson-like.

Following Stimson deposition, diagenesis of the lowermost Missoula Mbr involved emplacement of calcium sulfate and enrichment of SiO_2 up to 75 wt% near the contact. Calcium sulfate was deposited along the contact in veins, and locally intruded the sediment forming an impure cement. Chemical trends in the Missoula Mbr suggest that silica diagenesis involved precipitation, although acid sulfate alteration is possible [4].

References: [1] Frydenvang *et al.* (2016) *LPSC 47* (this volume). [2] Grotzinger et al. (2015) Science, 350, doi:10.1126/science.aac7575. [3] Edgett *et al.* (2016) *LPSC 47* (this volume). [4] Yen *et al.* (2016) *LPSC 47* (this volume). [5] J. Watkins *et al.* (2016) *LPSC 47* (this volume).