GEOCHEMISTRY OF THE STIMSON SANDSTONE, GALE CRATER, MARS. K. L. Siebach[1], S. M. McLennan[1], and C. M. Fedo[2] [1]Department of Geosciences, Stony Brook University, Stony Brook, NY, 11794, USA (kirsten.siebach@stonybrook.edu). [2]Department of Earth & Planetary Sciences, University of Tennessee, Knoxville, TN, 37996, USA.

Introduction: The Stimson sandstone is a lithified basaltic eolian sandstone [1], with a composition very similar to average Mars crust [2], that is unconformably draped above the mound-forming units in Gale crater [3, 4]. The Curiosity rover observed the sandstone in multiple locations beween sol ~970 (4/29/2015) and sol ~1360 (5/3/2016), obtaining x-ray-diffraction-based mineralogy for four drilled powder samples and bulk geochemical data from the Alpha Particle X-ray Spectrometer (APXS) for 64 1.5-cm diameter spots on 35 unique targets. Approximately half of these observations focused on light-toned diagenetically altered surfaces found adjacent to fractures within the Stimson [5-8], however, here we focus on the observations of dark-toned, "unaltered", typical Stimson sandstone (2 drilled samples, 33 APXS observations of 18 unique targets).

The elemental geochemistry of sedimentary rocks provides information about the provenance and chemical weathering of the detrital grains, sorting processes that occur during grain transport, and cementation or alteration processes that occur during rock lithification [9, 10]. The presence of unaltered primary basaltic minerals and the very consistent geochemistry of the Stimson sandstone, along with the striking similarity between the sandstone composition and average Mars crust composition (although the Stimson has more FeO_T and less SiO_2) [11] indicate that the source of the eolian sand was either average martian basalt or a well-mixed variety of sources. Furthermore, the chemistry was not significantly affected by transport sorting processes, and the cementation of this unit was most likely nearly isochemical, except for potential addition of Fe.

	STIMSON SURFACE SAMPLES* (N=18)	DRILLED STIMSON SAMPLES (N=4)	AVG MARS SOIL [11]	DUST (SOL 571) [12]
Na_2O	2.71 ± 0.12	↑3.13 ± 0.06	2.73	2.75
MgO	8.84 ± 0.67	↓7.99 ± 0.97	8.35	8.31
Al_2O_3	9.61 ± 1.26	↑10.99 ± 1.10	9.71	8.91
SiO_2	43.32 ± 1.52	↑45.14 ± 1.78	45.41	39.3
P_2O_5	0.88 ± 0.07	↓0.76 ± 0.06	0.83	0
SO_3	5.59 ± 1.10	↓2.49 ± 1.80	6.16	8.34
Cl	1.33 ± 0.29	↓0.67 ± 0.15	0.68	1.08
K_2O	0.42 ± 0.08	0.44 ± 0.05	0.44	0.47
CaO	6.29 ± 0.53	6.47 ± 0.29	6.37	7.04
TiO_2	0.92 ± 0.05	0.95 ± 0.03	0.9	1.06
Cr_2O_3	0.42 ± 0.09	0.41 ± 0.07	0.36	0
MnO	0.40 ± 0.05	0.38 ± 0.03	0.33	0.42
FeO_T	19.12 ± 2.16	↑20.05 ± 2.36	16.73	21
Ni	473 ± 66	460 ± 72	490	nd
Zn	396 ± 159	338 ± 32	286	nd
Br	216 ± 145	225 ± 136	61	nd

Table 1. Averages and standard deviations for APXS-derived compositions for Stimson surface samples (i.e., one of each unique* in-situ unaltered Stimson rock target, 7 of 18 are brushed), Stimson drilled samples (the pre-sieve dump pile and the post-sieve dump piles for drilled samples Big Sky and Okoruso; arrows show differences relative to average surface compositions), average Mars soil [11], and the composition of Martian dust on sol 571 as reported by Berger et al. [12].
*Five Stimson surface targets were analyzed with a raster of two or three offset, overlapping spots. The average chemistry of the raster spots was used as the composition for these targets.

APXS Geochemistry: The geochemistry of the Stimson sandstone is very uniform compared to other units observed in Gale crater, and it is very similar to average Mars soil, although there are a few minor differences (Table 1). Surface analyses of the Stimson sandstone have an average of ~2.2 wt% more FeO_T and ~2.3 wt% less SiO_2 than average soil (we use average Mars soil here as a proxy for average Mars crust because SO_3 and Cl are included). Stimson surfaces are also slightly enriched (~0.5 wt%) in Cl and MgO. Subsurface samples, or APXS analyses on drilled powders, have less dust and may represent the rock composition better, but we also have fewer samples of the subsurface (two drill spots), so these are more likely to be affected by sampling bias or minor heterogeneities. When only subsurface (drilled powder) Stimson samples are considered, SiO_2 is much closer to average Mars soil, but FeO_T is higher by 3.3 wt% and SO_3 is lower by 3.7 wt% in the drilled Stimson relative to average soil or surface Stimson. Al_2O_3 and Na_2O are also slightly higher in subsurface Stimson samples, whereas MgO, P_2O_5, and Cl are lower in the subsurface relative to the surface. FeO_T, SO_3, SiO_2, Al_2O_3, and then MgO and CaO, respectively, are the most variable components between different Stimson targets, both in the surface and subsurface.

Stimson Provenance: Sedimentologically, the provenance for the Stimson sandstone is not well constrained; it is present in thin patches that unconformabley overly the Mount Sharp group [3], so it has been interpreted as representing preserved sand dunes that climbed up a proto-mound some time after the deposition, lithification, and erosion of the Mount Sharp group [1, 3]. The sandstone is primarily composed of well-rounded sand-sized grains, including some dark grey grains that appear to be lithic fragments [5]. Based on cross-bedding geometries, Banham et al. concluded that the Stimson-forming sand dunes were migrating to the north-east [1] along the north-west dipping paleoslope of the proto-Mount Sharp [1, 3], but the sand sources could be widespread; any sand trapped in Gale crater could have become part of the dunes.

Geochemically, there is a lack of evidence for input of chemically distinctive units that contributed to the Bradbury group and Mt Sharp group, e.g., potassium-rich trachytes [13] or evolved silica-rich volcanics [14]; Stimson sandstones show minimal K_2O and SiO_2 at or below crustal average. Instead, the Stimson source rocks are likely to be sourced from well-averaged or typical Mars basalts based on the close similarity with average Mars soil. There is no evidence for chemical weathering of the source region; minimum (uncorrected) Chemical Index of Alteration (CIA) values range from 32 to 46, which is within the range for unaltered terrestrial basalts (CIA is a molar ratio of mobile elements CaO, MgO, and Na_2O to Al_2O_3 and is a proxy for open-system chemical weathering of feldspars or Ca-bearing pyroxenes).

Mineralogically, the Stimson sandstones are composed of plagioclase, pyroxenes, magnetite, hematite, basanite, anhydrite, minor quartz (1-2 wt%), and amorphous material. This mineral assemblage is reasonable for a typical martian basalt except for a notable lack of olivine, which must be explained by consideration of the provenance, transport processes (which may segregate olivine, e.g., [15]), and in-place alteration or diagenetic processes.

Lithification of the Stimson Sandstone: The Stimson sandstone is well-lithified and must have been well-cemented prior to fracture formation and diagenetic fluid alteration along fractures, because that stage of diagenetic alteration is limited to fracture-associated halos (e.g., Figure 1). This lack of significant porosity and permeability implies that the pore spaces have mostly been filled with cement. Based on cubic closest packing of equal-sized sand grains, this could require a maximum of 25 vol% cement, although realistically the cement could be ~10-20 vol%. The most variable elements in the Stimson composition include FeO_T and CaO or MgO and SO_3, which indicates that the rock could be partially cemented by diagenetic iron oxides or sulfates. The amorphous component could also contribute to the volume of cement necessary to preclude porosity; analyses of the amorphous components in the Bradbury group showed that the rocks have a significant fraction of amorphous material that is not basaltic glass but may include ferrihydrates and/or amorphous sulfates [16], which could form during in-situ mineralization during diagenesis.

Figure 1. MAHLI image of broken piece of Stimson sandstone called Impalila (sol 1345, image 1345MH0006150000501780R00). Lower portion is unaltered Stimson, light-toned upper portion has been affected by diagenetic fluids. Sand-size clasts in the sandstone range from light-toned to dark-toned, and the rock is well-cemented; there is a lack of visible porosity and these late diagenetic fluids did not permeate through all of the rock.

References:

[1] Banham, S.G., et al. (2016) *LPSC XLVII*, Abs. #2346.
[2] Thompson, L.M., et al. (2016) *LPSC XLVII*, Abs. #2709.
[3] Watkins, J., et al. (2016) *LPSC XLVII*, Abs. #2939.
[4] Grotzinger, J.P., et al. (2015) *Science, 350,* aac7575.
[5] Edgett, K.S., et al. (2016) *LPSC XLVII*, Abs. #1382.
[6] Frydenvang, J., et al. (2016) *LPSC XLVII*, Abs. #2349.
[7] Gasda, P.J., et al. (2016) *LPSC XLVII*, Abs. #1675.
[8] Yen, A.S., et al. (2016) *LPSC XLVII*, Abs. #1649.
[9] Siebach, K.L., et al. (2017) *JGR, accepted.*
[10] McLennan, S.M., et al. (2014) *Science, 343.*
[11] Taylor, S.M. and S.M. McLennan 2009 *Planetary Crusts: Their Composition, Origin, and Evolution,* 378 pp.
[12] Berger, J.A., et al. (2016) *GRL, 43,* 67-75.
[13] Treiman, A.H., et al. (2016) *JGR, 121.*
[14] Morris, R.V., et al. (2016) *PNAS, 113,* 7071-6.
[15] Mangold, N., et al. (2011) *EPSL, 310,* 233-243.
[16] Dehouck, E., et al. (2014) *JGR, 119,* 2640-2657.