

BULK HYDROGEN CONTENT OF HIGH-SILICA ROCKS IN GALE CRATER WITH THE ACTIVE DYNAMIC ALBEDO OF NEUTRONS EXPERIMENT. T.S.J. Gabriel¹, C. Hardgrove¹, M. Litvak², I. Mitrofanov², W.V. Boynton³, F. Fedosov², D. Golovin², I. Jun⁴, M. Mischna⁴, C.G. Tate⁵, J. Moersch⁵, K. Harshman³, A.S. Kozyrev², A. Malakhov², M. Mokrousov², S. Nikiforov², A.B. Sanin², A. Vostrukhin², P.D. Archer, Jr.⁶, H.B. Franz⁷, L. Thompson⁸, and the MSL Science Team. ¹School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA (Travis.Gabriel@asu.edu), ²Space Research Institute, RAS, Moscow, Russia, ³University of Arizona, Tucson, AZ, USA, ⁴Jet Propulsion Laboratory/California Institute of Technology, Pasadena, CA, USA, ⁵University of Tennessee, Knoxville, TN, USA, ⁶Jacobs, NASA Johnson Space Center, Houston, TX, USA, ⁷NASA Goddard Space Flight Center, Greenbelt, MD, USA, ⁸University of New Brunswick Fredericton, Fredericton, New Brunswick, Canada.

Introduction: The Mars Science Laboratory (MSL) Curiosity rover recently traversed over plateaus of mafic aeolian sandstones (the ‘Stimson’ formation) that overlie mudstones (the ‘Murray’ formation). Within the Stimson formation we observed many lighter-toned, halo-forming features, that are potentially indicative of fluid alteration (see Fig. 1). These halo features extend for tens of meters laterally and are ~1 meter wide. The halo features were characterized by Curiosity’s geochemical instruments:



Figure 1: NavCam image NCAM00354M of a fracture associated halo. Drill samples were acquired from the altered halo rock (Lubango) and the unaltered surrounding rock (Okoruso).

Alpha Proton X-Ray Spectrometer (APXS), Chemin, Chemcam and Sample Analysis at Mars (SAM). With respect to the host (unaltered) Stimson rocks, fracture halos were significantly enriched in silicon and low in iron [1]. Changes in hydrogen abundance (due to its large neutron scattering cross section) greatly influence the magnitude of the thermal neutron response from the Dynamic Albedo of Neutrons (DAN) instrument [2]. There are also some elemental species, e.g. chlorine, iron, and nickel, that have significant microscopic neutron absorption cross sections. These elements can be abundant and variable

in Gale Crater. Changes in their abundances can change both the timing and magnitude of the neutron count rates observed by DAN [2][3]. On Sols 1309-1329, Curiosity performed contact science measurements on unaltered Stimson and halo-forming materials, including a dedicated DAN measurement over the drill target ‘Lubango’. This measurement was made by orienting the rover such that the DAN sensing area was centered directly above the halo. Preliminary geochemical analyses of the halo-forming features showed lower iron and chlorine than unaltered Stimson material by ~7-12wt% and ~0.2-0.8wt%, respectively, which could have a significant affect on the modeling of DAN data (See Fig. 2) [1][4]. We aim to estimate the hydrogen content and depth of alteration features by comparing these measurements to a set of neutron transport models. Here we present the preliminary results for a select high-silica region using refined models that incorporate the observed geochemistries found at the drill sites of the halo-forming, high-silica materials, as well as unaltered Stimson materials.

Modeling: We use the Monte Carlo N-Particle Transport Code (MCNPX) [5] to model a semi-infinite, homogeneous layer below the DAN detectors. We vary water equivalent hydrogen (WEH) between 0-10 wt% in our models. We also allow chlorine to vary slightly from APXS measurements to account for differences in the subsurface abundance of absorbers versus that measured at drill sites. These results are compared to data acquired from active DAN measurements to assess goodness-of-fit (using a χ^2 routine modified from [3]). Chemical abundances from APXS of unaltered Stimson ‘Big Sky’ and ‘Okoruso’, as well as of alteration halos ‘Greenhorn’ and Lubango provide necessary geochemical descriptions for our models. The best-fit WEH values are compared to evolved gas analysis mass spectrometry from the SAM instrument suite. In contrast with the SAM instrument that measures abundances of certain bonded hydrogen species, e.g. H₂O, CH₄, H₂, and H₂S [6], our study provides estimates for bulk hydrogen at depth. Thus, SAM

results provide a useful estimate of the lower bound for bulk hydrogen content (assuming a homogeneous distribution).

Alteration-Depth Model – The Lubango halo material did not encompass the entire DAN field-of-view. Since altered and unaltered material have markedly different abundances of neutron-absorbing elements, this motivates the development of a more representative modeling geometry (See Fig. 3). In contrast with the homogeneous model, the alteration-depth model accounts for a heterogeneity. Depth and WEH of the halo are allowed to vary and will be estimated.

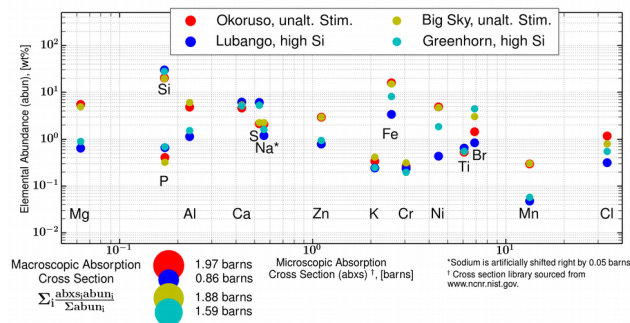


Figure 2: Elemental abundances and associated neutron absorption cross sections. Abundances are computed from APXS drill tailing measurements that represent the bulk composition down to (at most) 6.5 cm in the subsurface. The equivalent macroscopic absorption cross section for each geochemistry is also reported and graphically represented by circles with diameters scaled according to their value (Bottom left). Rocks with sufficiently different macroscopic neutron cross sections can be discerned from one another by DAN.

Preliminary Results: DAN active experiments were performed on nearby unaltered Stimson rock on Sol 1316. We find a best fit of 3.2 wt.% WEH ($\chi^2_{\text{red}}=0.62$, $p=88\%$) when comparing these measurements to homogeneous models using known neutron absorber abundances from the Big Sky unaltered Stimson drill site. In the dedicated DAN active measurements at Lubango on sol 1329 we find a best fit of 2.2 wt % WEH ($\chi^2_{\text{red}}=0.63$, $p=87\%$) when comparing the data to homogeneous models using known absorber abundances from the Greenhorn altered Stimson drill site. Since the Greenhorn geochemistry has an intermediate macroscopic absorption cross section to that of Lubango and Okoruso, we find the homogeneous models of Greenhorn material to fit well on Sol 1329 where the subsurface includes a mixture of Lubango- and Okoruso-type material. These reported WEH values

will be refined using the halo-depth model. Our results are qualitatively consistent with the relatively low H_2O abundance reported by SAM in altered Stimson at the Greenhorn drill site (2.7 ± 0.6 and 1.0 ± 0.4)¹ as compared to the higher abundance in unaltered Stimson at the Big Sky drill site (3.9 ± 1.3 and 1.1 ± 0.4) [7].

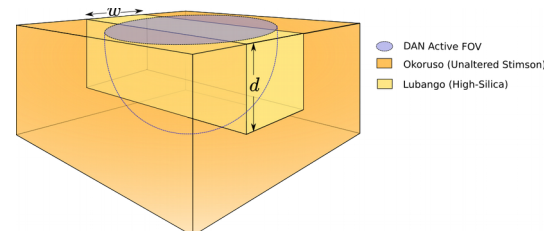


Figure 3: Idealized representation of the DAN field of view and a fracture-associated alteration halo. The DAN field-of-view extends ~ 3 m in diameter on the surface and ~ 60 cm into the subsurface. The width of the halo w is estimated from surface images. With co-located measurements of the geochemistry of altered halo material and the host rock, DAN is capable of estimating the depth d of alteration features, provided a simplified geometric model shown here.

From the preliminary work presented here we find:

- 1) Using refined estimates of neutron absorbers (as informed by geochemical instruments on the Curiosity rover) reduces the free parameters in our modeling. This is especially useful at complicated sites like the Lubango drill area.
- 2) We can better characterize the depth of hydration layers (if any) or geochemical discontinuities (i.e. depth of a fracture halo) by implementing the presented alteration-depth model (Figure 3). The hydrogen abundance and alteration depth results from DAN active data will help constrain the extent of fluid processing in Gale crater. Our preliminary results suggest that the alteration process that generates halo features did not leave behind an appreciable signature in hydrogen, but instead likely produced a depletion in bulk hydrogen. In the future, our refined models may be generalized for other alteration areas along the traverse as well.

References: [1] Frydenvang, J. et al. (2016). LPSC. [2] Hardgrove, C. et al. (2011). *Nuc. Instr. & Meth. In Phys. Res. A*, 659, 442–445. [3] Litvak et al. (2016). JGR:P, 121, 5, 836-845. [4] Lucy Thompson (APXS), Personal communication, Nov. 2016. [5] D.B. Pelowitz (2011). *MCNPX User's Manual*, Version 2.7.0, Los Alamos Nat. Lab. Rep. LA-CP-11-00438, 1–645. [6] Freissenet et al. (2015). JGR:P, 120, 3, 495-514. [7] Heather Franz & Doug Archer (SAM), Personal communication, 2016-2017.

¹ The pair of reported SAM H_2O values are from two different calibration methods. The first and second value in each pair correspond to the same calibration method respectively.