NEW ANALYSIS OF HYDROGEN ABUNDANCE IN THE SHEEPBED MEMBER OF YELLOWKNIFE BAY USING *IN SITU* GEOCHEMICAL DATA.

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Introduction: The Mars Science Laboratory (MSL) rover, Curiosity, entered a fluvio-lacustrine depression named Yellowknife Bay (YKB) in December 2012. Curiosity completed a detailed observational campaign as it traversed across several geologic units of the YKB formation, including the basal Sheepbed (SB) member [1,2]. Along the traverse, measurements were acquired with the Dynamic Albedo of Neutrons (DAN) instrument, a neutron spectrometer capable of measuring the hydrogen (H) abundance of the top ~ 50 cm of the subsurface. To determine H content, we compare DAN data to models which simulate the martian subsurface with user-supplied geochemistry. This geochemical data can be a variation of a standard base geochemistry [1,2,3] or can be from *in situ* measurements [4,5].

For this study, we first simulated the previously-published, best-fit DAN active model result for H abundance and depth [1] of the lower SB subunit using updated *in situ* geochemical data. This updated model used a similar analysis routine as described in [6] and the H content and depth distributions reported in [1], but produced poor fits for all DAN active measurements in the SB, suggesting the previously-reported H abundance could be refined.

Reported SB WEH values from the MSL Chemistry and Camera (ChemCam) [7] and Sample Analysis at Mars (SAM) [8] instruments suggest that H is gradational in the near surface, which could be a result of surface desiccation [9]. We ran simulations to test for surface desiccation, and our initial results are consistent with centimeter-scale desiccation in the SB. We then provide a preliminary H abundance range for the SB, which will be further refined in future work. These results demonstrate that *in situ* geochemistry can be used to improve interpretations of DAN active data when determining the subsurface H abundance along Curiosity's traverse, as well as the ability of the DAN instrument to test for surface desiccation in conjunction with other MSL instruments.

Previous Work: The SB member contains a variety of diagenetic features which indicate the presence of a long-term post-depositional aqueous environment [10], and is composed of mudstones with ~ 20% smectite clays [11]. Previous studies [1,2,10] have identified two SB subunits which will be referred to here as lower Sheepbed (LSB) and upper Sheepbed (USB).

Previous studies have reported H abundances as wt. % Water-Equivalent-Hydrogen (WEH), assuming all H is bound in water, a convention we follow here. Litvak et al. (2014) reported WEH based on 2-layer DAN active modeling using variable Cl and top layer depth. Table 1 lists their results for the SB subunits. Moersch et al. (2013) used the previously modeled WEH values along topographic contours to infer a possible dessication layer in the LSB and USB. Tate et al. (2015) reported a WEH range of 2.1 ± 0.5 to 3.7 ± 0.2 within the SB member based on DAN passive measurements in a homogeneous model. Each of these previous studies varied Cl abundance (an important neutron absorber) as a proxy for geochemical composition. In this study, however, we use *in situ* geochemistry measured by MSL's Alpha Particle X-ray Spectrometer (APXS).

Unit	Top WEH	Depth [cm]	Bottom WEH	Cl [wt. %]
USB	1.50 ± 0.12	20 ± 3	2.9 ± 0.3	1.05 ± 0.17
LSB	1.40 ± 0.14	30 ± 5	2.8 ± 0.3	0.80 ± 0.05

Table 1: *Previously published results from [1] for the LSB and USB subunits, using bulk Mars geochemistry.*

ChemCam measured an average WEH of 1.3 from the top 1 cm of two SB drill sites, John Klein (JK) and Cumberland (CB) [9]. SAM measured an elevated WEH of 1.7 ± 1.3 to 2.5 ± 1.6 in drill tailings from ~ 2 - 6 cm depth from these targets [8]. The difference in these H values suggests the presence of a desiccated surface layer. To test for desiccation in this study, we have compared homogeneous models to 2-layer models which simulate desiccation with a shallow top layer using ChemCam *in situ* WEH and a bottom layer of variable WEH.

Methods: In active mode, DAN has an ~ 1.5 m radius field of view and produces time-binned spectra of thermal and epithermal neutrons, known as die-away curves, which are used to reconstruct the abundance and depth distribution of H in the subsurface [4]. Details about DAN instrument operation can be found in previous publications [e.g., 12]. While epithermal neutron count rates are dependent primarily on H abundance, thermal neutron count rates vary significantly on Mars due to the abundance and variability of neutron absorbing elements like Cl and Fe [13]. APXS determined elemental abundances of tailings from the JK and CB drill sites, which are ~ 3 m apart. The difference between the bulk neutron absorption cross-section for JK and CB is small relative to the difference between some other closely spaced targets along Curiosity's traverse, such as Lubango and Okoruso [14]. This study uses models with either CB or average JK/CB geochemistry.

Several models were compared to SB DAN die-away curves from sols 125 - 299. Our first model uses the WEH results reported in [1] with APXS-derived SB geochemistry. We also ran models intended to test for evidence of surface desiccation. First we ran homogeneous models with *in situ* geochemistry and variable WEH. Then we ran 2-layer desiccation models with *in situ* geochemistry, the average ChemCam-derived SB WEH of 1.3 [9] and a depth of 6 cm (approximate drill depth [11]) for the desiccation layer, and variable bottom layer WEH. All models with *in situ* geochemistry also use natural isotopic abundances. The goodness of fit for each model-to-data comparison was determined using the χ^2 fit analysis described in [5].

Results and Discussion: Models using the 2-layer WEH from [1] with updated *in situ* geochemistry produced a poor fit for every DAN active measurement in the SB, which suggests that the previous best-fit SB WEH values can be refined in order to get a better fit with *in situ* geochemical models.

Desiccation models were run with two different APXS-derived *in situ* geochemistries. For all SB DAN measurements, one or more desiccation models fit better than the best-fit homogeneous model. An example is shown in Figure 1, which is the neutron die-away curve from the DAN measurement taken over the CB drill site plotted with the best-fit homogeneous and desiccation models. This result is consistent with the hypothesis that the SB has experienced desiccation on the order of several centimeters.

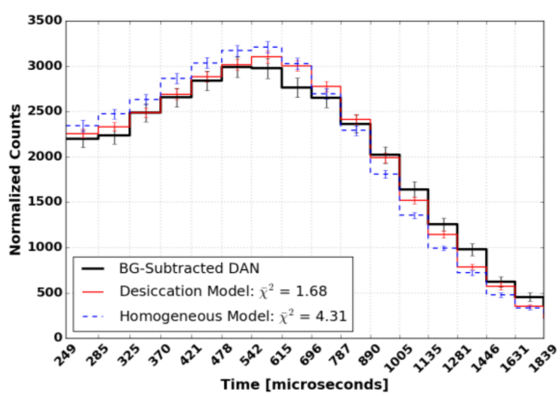

Figure 1: *Neutron die-away plot for the DAN measurement taken over the CB drill site on sol 295. The best-fit homogeneous and desiccation models are plotted for comparison. The time bin range is that used in our χ^2 analysis, and counts are normalized across this range.*

Figure 2 is a plot of p-values for the CB drill site DAN data shown in Figure 1. For this measurement, the best-fit bottom layer WEH value is 4.07 ± 0.44 (2σ). The same desiccation analysis was conducted for all DAN measurements in the SB. The best-fit bottom layer WEH values for these SB DAN measurements (sols 125 – 299) ranged from a minimum of 3.10 ± 0.54 to a maximum of 4.67 ± 0.39 (both 2σ).

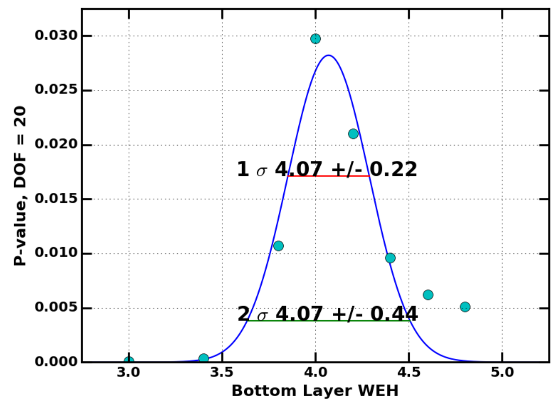

Figure 2: *Plot of desiccation model p-values for the DAN active measurement taken over the CB drill site on sol 295. The horizontal position of the Gaussian peak corresponds to the best-fit bottom layer WEH.*

Conclusions: Our results show that using *in situ* geochemistry improves model-to-data fits for DAN data in the SB member. Although near-surface geochemical data sets from APXS and ChemCam represent smaller sensing areas and shallower depths, these *in situ* data can be used to improve DAN modeling, particularly in H-rich units (which can include clay-rich units or opaline silica-rich fracture halos). In addition, our desiccation models fit better with SB DAN data than do homogeneous models, which is consistent with cm-scale surface desiccation in the SB. It should be noted, however, that these results are preliminary. Additional modeling is needed to refine these WEH abundances and confirm the presence of surface desiccation in the SB. Future work will include comparing similar models to DAN data acquired in the Gillespie Lake member of the YKB formation, which overlies and is geochemically similar to the SB member [10]. The results of these comparisons will constrain WEH and test for surface desiccation in Gillespie Lake.

References: [1] Litvak, M.L. et al. (2014) *JGR Planets, 119*, 1259-1275. [2] Moersch, J. et al. (2013) *AGUFM*, P14B-08. [3] Tate, C.G. et al. (2015) *Icarus, 262*, 102-123. [4] Litvak, M.L. et al. (2016) *JGR Planets, 121*, 836-845. [5] Gabriel, T.S.J. et al. (2018) *in prep*. [6] Sanin, A.B. et al. (2015) *NIMA, 789*, 114-127. [7] Rapin, W. et al. (2017) *Spectrochim Acta B, 130*, 82-100. [8] Ming, D.W. et al. (2014) *Science, 343(6169)*. [9] Rapin, W. (2017) pers. comm. [10] McLennan, S.M. et al. (2014) *Science, 343(6169)*. [11] Grotzinger, J.P. et al. (2014) *Science, 343(6169)*. [12] Litvak, M.L. et al. (2008) *Astrobiology, 8(3)*, 605-612. [13] Hardgrove, C. et al. (2011) *NIMA, 659*, 442-455. [14] Gabriel, T.S.J. et al. (2017), *LPSC*, #2875.