

EXAMINING THE EFFECT OF SAND COVER ON THE MARS SCIENCE LABORATORY DYNAMIC ALBEDO OF NEUTRONS INSTRUMENT DATA IN GALE CRATER, MARS. D. L. Sullivan¹, C. Hardgrove¹, T. S. J. Gabriel¹, S. Czarnecki¹ ¹Arizona State University, Tempe, AZ 85287, USA. E-mail address: dan.sullivan@asu.edu

Introduction: The Mars Science Laboratory (MSL) Dynamic Albedo of Neutrons (DAN) instrument measures the hydration of the top ~50 cm of the martian subsurface in Gale crater along the Curiosity rover traverse. The Pahrump Hills region was the first extensively investigated site in the Murray formation, a predominantly lacustrine mudstone [1], from sol 799 to 958. At Pahrump hills the bedrock is relatively uniform and has variable sand cover. In this work we explore how sand cover influences DAN active data in Pahrump Hills. We show that sand covered bedrock reduces the bulk hydration measured by DAN, consistent with findings that sand is dehydrated relative to bedrock in Gale crater [e.g., 2,3]. This work demonstrates the importance of geologic context when comparing DAN data to simulations. We propose that considering local and regional geologic context may help refine previously published results [e.g., 4,5].

Methodology: The DAN instrument is composed of a pulse neutron generator (PNG) and two ³He neutron detectors. The PNG and detectors are on the aft of the rover on the right and left, respectively. The instrument has two modes of operation: (1) passive mode, in which DAN measures the neutron flux generated by galactic cosmic rays and the multi-mission radioisotope thermoelectric generator; (2) active mode, in which the PNG produces 14.1 MeV neutrons at 10 Hz by the fusion reaction $^2\text{H} + ^3\text{H} \rightarrow \text{n} (14.1 \text{ MeV}) + ^4\text{He} (3.5 \text{ MeV})$ with a pulse duration of 1-2 μs . In active mode, the DAN detectors count the moderated neutron flux returning from the subsurface after each pulse. These counts are divided into 64 lognormal time bins. Each bin is co-added across all pulses to produce a neutron response profile (neutron die-away curve, ex., Fig. 1). The relative peak height and slope of the neutron die-away depend on the abundance of subsurface elemental hydrogen and neutron absorbers (primarily Cl and Fe [e.g. 6]), and the bulk density of the material in the DAN field of view (FOV) [2, 7].

To analyze the DAN active data from Pahrump Hills, we compare it to simulation data generated using homogeneous (one-layer) models with variable water content created with the Monte Carlo N-Particle 6 (MCNP6) code [8]. MCNP6 simulates the experiment and generates synthetic die-away curves. Deriving water abundances in this way allows us to understand the bias introduced by variable levels of sand cover. To derive water equivalent hydrogen (WEH) contents for DAN measurements we use the analysis routine of [2]-see Supplementary Material. The bedrock and sand

cover in the DAN FOV at each DAN active site was visually assessed using rear hazard camera (RHAZ) images and classified visually by the fraction of bedrock exposure.

We note that final numerical results will require a Markov Chain Monte-Carlo (MCMC) analysis in order to quantify uncertainties in our results; however, we first perform a chi-squared minimization to select the best-fit model for each DAN measurement, which are the results presented here. In the grid of models, WEH and Cl abundance were varied and the best-fit WEH and Cl values are reported. We note that allowing Cl to vary is a stand in for changes in macroscopic absorption cross section, e.g. changes in Fe content would be modeled as changes in Cl content.

Results: We grouped the DAN measurement sites into two categories: (1) $\geq 80\%$ exposed bedrock, and (2) $\leq 20\%$ exposed bedrock. Examples of DAN die-away curves for 100% bedrock and 100% sand (Fig. 1) show a larger neutron count rate over well-exposed bedrock. Of the 27 DAN active measurements taken at unique sites in Pahrump Hills, seven had $>80\%$ exposed bedrock and 17 had $\leq 20\%$ exposed bedrock. The average best-fit WEH content from chi-squared analysis of sites with $\geq 80\%$ exposed bedrock is 2.5 wt. % (ranging from 1.6 - 3.4 wt. %; see fig. 3). At the 17 sites with $<20\%$ exposed bedrock, the average best-fit water content is 1.5 wt. % WEH (ranging from 0.9-2.6 wt. %).

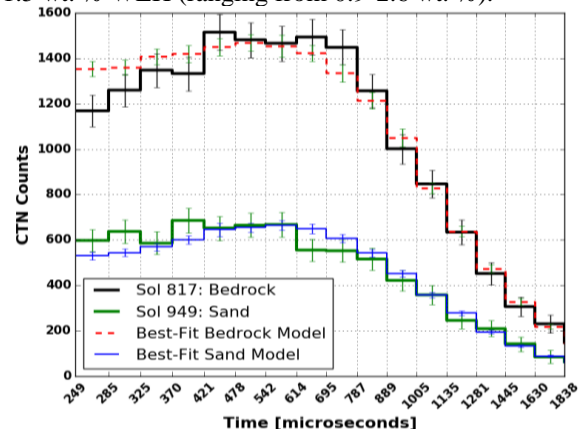


Figure 1. Measured DAN Die-away curves from sols 817 and 949 (pictured in figure 2) and corresponding best-fit models. These sites have the same best-fit model bedrock geochemistry, but the well-exposed bedrock (sol 817) has a larger thermal neutron count rate than the sand covered location (sol 949).



Figure 2. Example RHAZ images of DAN active locations. (Top) Sol 817 showing 100% exposed bedrock in the DAN sensing area. (Bottom) Sol 949 showing 0% exposed bedrock (full sand cover).

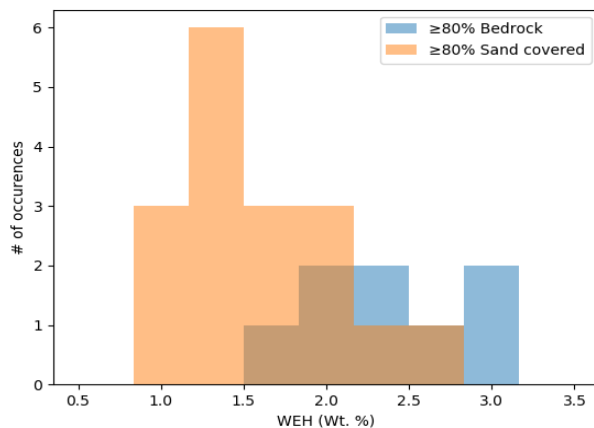


Figure 3. Calculated best-fit WEH values from homogeneous models in the lower Murray formation. These values were generated by minimum chi-squared analysis.

Discussion: We have shown that DAN active measurements acquired over sandy locations will have lower thermal neutron fluxes than what is present in the

bedrock. If a homogenous model is used to derive WEH values from DAN data taken over sandy locations, the results will be biased towards lower water contents, which is consistent with previous analyses of active sands in Gale crater that show the dunes have low levels of hydration [e.g., 2,3]. Our results show that sand cover (~several cm) should be incorporated into MCNP6 models that are used to derive water contents from DAN active experiments. If sand cover is not accounted for, it may lead to artificially low WEH values. However, whether minor amounts (~cm or less) of sand cover substantially bias DAN active interpretations is still unknown, and will be investigated in future work.

We plan to compare results from one-layer models over variable sand cover, to two-layer models that explicitly account for variable sand cover using MCMC analysis [2]. For modeling sand covered sites, the bottom layer bedrock will be fixed at the water value derived from DAN active measurements on well-exposed bedrock within Pahrump Hills. The top layer will be a lower density sand layer with bulk geochemistry from in situ measurements of sand from the same area and variable WEH content in the upper layer. This analysis will allow us to understand the effect of various amounts of sand cover in the active DAN field of view. From this, we can quantitatively derive the threshold of sand cover in the DAN sensing area that warrants careful 2-layer analysis.

Conclusion: DAN is the *Curiosity* rover's only instrument capable of sensing 10s of cm in the subsurface and has acquired hundreds of measurements across the traverse over rocky and sandy locations. DAN active measurements over well-exposed bedrock and sand covered bedrock of similar geochemistry have different average WEH values determined from one-layer modeling, which suggests the sand is less hydrated (lower WEH) and that sand cover has a significant effect on DAN data. We find that the degree of sand cover should be carefully considered in modeling, analysis, and interpretation of DAN data. These results will enable DAN to more accurately investigate and interpret the underlying subsurface bedrock hydration and bulk neutron absorption cross section along *Curiosity*'s traverse.

References:

- [1] Grotzinger et al. (2015) *Science*, 350 [2] Gabriel et al. (2018) *Geophys. Res. Ltrs.*, 45 [3] Ehlmann et al. (2017) *J. Geophys. Res. Planets*, 122, 2510–2543, [4] Mitrofanov et al. (2014) *JGR-Planets*, 119, 1579–1596. [5] Litvak et al. (2016) *JGR-Planets*, 121, 836–845. [6] Hardgrove et al. (2011) *Nuc. Instr. And Mthd. In Phs. Rsch.*, 659, 442-455. [7] Mitrofanov et al. (2016) *Astr. Ltrs.*, 42, 285-293. [8] Pelowitz, et al. (2005) *MNCPX User's Manual, Version 2.5.0*, LANL, LosAlamos, LA-UR-05-0369, 2005.