CHLORINE AND HYDROGEN CONTENTS FROM THE FIRST 90 SOLS OF MSL DAN ACTIVE MEASUREMENTS.

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Introduction: Soil and rock geochemistry, near-surface layering structure (above ~50cm) and hydrogen abundance influence both the energy distribution and timing of neutron arrival during active measurements made by the Dynamic Albedo of Neutrons (DAN) experiment on-board the Mars Science Laboratory (MSL) rover *Curiosity* [1, 2]. During a typical DAN active measurement, the pulsed neutron generator (PNG) produces many discrete pulses of high energy (14 MeV) neutrons that interact with nuclei in the near-surface through simple scattering or by being absorbed; those that leak back out from the near-surface are detected by the DAN Detector and Electronics (DE). Loss of energy through scattering is primarily controlled by H abundance, while absorption of neutrons is dominated by Cl and Fe due to their relatively high thermal neutron absorption cross section (and variability compared to other geologically relevant elements present in near-surface Martian rocks and soils) [3]. These elements also affect the arrival time of thermal neutrons, as neutrons are absorbed when they interact with Cl or Fe. In a relatively high Cl or Fe rock/soil, thermal neutrons do not travel far into the sub-surface, as there is an increased probability they will be absorbed by a Cl or Fe nucleus. Therefore, for rocks/soils with high Cl or Fe, the total thermal neutron die-away counts will be lower (due to absorption of neutrons) and neutrons will arrive at the DE earlier (due to arrival of neutrons from shallower depths).

Relevance of Cl: The thermal neutron absorption cross section of Cl is ~13 times greater than Fe. This, coupled with the observed variability of Cl on Mars from both GRS and the Mars Exploration Rovers makes it the most significant high absorption cross section element to consider when interpreting DAN data [3, 4]. Spirit and Opportunity both found higher abundances of Cl associated with locales that have experienced aqueous activity in the past [5, 6]. In the first 90 sols near Bradbury Landing, *Curiosity* has observed a variety of geomorphogic features suggestive of alluvial deposition. In this type of depositional environment, there are likely to be increased abundances of incompatible elements and those commonly associated with evaporites, such as Cl. We have previously shown that Cl and Fe can influence the profile of thermal neutron die-away curves [3]. We have also shown that epithermal neutron counts, as well as the timing of thermal neutron arrival at the DE can be used to discriminate the effects of H content versus high absorption cross section elements on time-integrated neutron count rates [3].

DAN Quick-Look (QL) Parameters: The DAN QL parameter #4 is the weighted time-average of thermal neutron arrival, as derived in [3]. This parameter can be used in combination with DAN QL parameter #3 (the thermal/epithermal count ratio) to separte the effects of hydrogen from the effects of high absorption cross-section elements on the die-away curve [3]. QL #3 is derived by dividing the total number of thermal neutron counts (from 100 – 2000 μs) by the total number of epithermal neutron counts (45 – 500 μs). Higher values of QL #3 indicate that there is more H in the near-surface, as increased H abundance will shift the distribution of neutrons from epithermal to thermal energies. The advantage of using QL#3 and QL#4 is that they are not dependent upon the total number of pulses or the total number of neutron counts. Table 1 presents a subset of the QL parameters from Sol 0-90. These were selected to highlight interesting rock/soil targets, as well as to demonstrate the variability in these DAN QL parameters.

Table 1 - Subset of DAN Active QL#3, QL#4 from Sol 0 - 90

Sol	QL #3	QL# 4 [μs]	distance [m]	Notes
14	4.0	562	0	Bradbury Landing
21	3.5	568	5	pre-Goulburn
21	4.8	539	5	Goulburn
22	3.9	557	12	
24	4.2	558	17	*driving with DAN active*
39	5.3	603	131	
39	4.1	584	131	Hottah
40	4.5	575	155	
52	5.0	600	374	*driving with DAN active*
54	5.1	617	376	
72	3.3	587	397	
86	3.3	574	397	Rocknest

*QL #4 was calculated using neutron count rate; distance is from Bradbury Landing

Modeling of DAN measurements: The standard analysis technique for evaluating planetary neutron data is to simulate the geochemistry, hydrogen, layering structure, and detectors within a Monte-Carlo neutron scattering model (MCNPX). Here we use MCNPX to explore the variability in neutron counts seen with DAN [3,7,8]. We perform two sets of initial modeling, a one-layer model and a two-layer model, each with a variety of Cl and H_2O abundances:

1. Single-layer model: Here we model the PNG and DE geometry as they are oriented on *Curiosity* (~80 cm above the ground [1]), with a single homogenous layer of uniform composition (Gusev basaltic soil) [3,9]. We vary the abundances of Cl and H_2O within the homogeneous layer between 0-5 wt% for both Cl and H_2O. QL parameters are then calculated from the simulated data to determine H_2O and Cl content from the observed MSL DAN QL parameters. Results from this modeling are presented in **Figure 1**, which demonstrates a method for comparing the observed DAN QL parameters to models. **Table 2** shows similar fittings of the single layer model to a variety of DAN QL parameters for measurements acquired throughout the first 90 Sols.

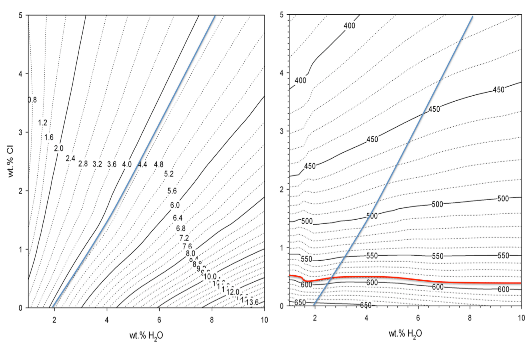

Fig. 1. Contour plots of modeled QL#3 and QL#4 values for single-layer of martian soil with variable Cl and H_2O. *Left:* QL#3 for 0-5 wt.% Cl and H_2O. The blue line represents the modeled values of Cl and H_2O that are consistent with the average value of QL#3 (4.27) from DAN active measurements acquired on Sol 0-90. *Right:* QL#4 for 0-5 wt.% Cl and H_2O. The blue line is the same as in *left* (from QL#3) while the red line defines the possible values of Cl and H_2O from the Sol 0-90 average QL#4 (590 ms). The average abundances of 0.6 wt% Cl and 2 wt.% H_2O are represented by the point of intersection for the two lines.

Table 2 - Fitting of DAN active measurements for Sol 0-90 (single-layer model)					
Sol	**QL #3**	**QL# 4 [μs]**	**wt.% H2O**	**wt.% Cl**	**Notes**
14	4.0	562	**2.8**	**0.8**	Bradbury Landing
21	3.5	568	**2.3**	**0.7**	pre-Goulburn
21	4.8	539	**4.0**	**1.1**	Goulburn
39	5.3	584	**2.8**	**0.5**	Hottah
86	3.3	574	**2.0**	**0.6**	Rocknest
Avg.	4.3	591	**2.4**	**0.5**	Sol 0-90

2. Two-layer model. Here we model the PNG and DE geometry with three different burial depths for the lower layer; 2.5 cm, 5 cm and 10 cm. The upper layer is fixed in Cl, Fe, and H_2O content (0.5 wt.%, 12 wt.%, and 1 wt.%, respectively) while the lower layer varies from 0-5 wt.% in both Cl and H_2O abundance. These values for Cl, Fe, and H_2O in the upper layer are consistent with the intial DAN epithermal results (which are primarily sensitive to H), as well as the results from the single layer model [2].

Sol 0-90 variability in Cl and H_2O: DAN QL parameters 3 and 4 are presented with results from the single-layer model in **Table 2**. There is some deviation from the mean of 0.5 wt.% Cl across the Sol 0-90 DAN active measurements, most notably at Goulburn where Cl is modeled at 1.1 wt.%. H_2O varies between ~1 and ~4 wt.%, with a maximum at Goulburn and a minimum at Rocknest.

The one-layer modeling presented here agrees with the results presented for Hottah by Mitrofanov *et al.* in [2]. Based on the image data and geologic context, several locales listed in **Table 2** may be better represented by a one-layer model, in particular, Hottah and Goulburn. Hottah, a conglomeritic rock target, was raised above the surface by several centimeters. At Goulburn, the descent stage may have removed a top layer of material, making it more likely that Goulburn may also be better represented by a a single layer of material. The H_2O and Cl contents inferred from Goulburn meaurements are amont the highest observed using this analysis.

Interpretations/Conclusions: Although the single-layer model may be more appropriate in some cases, a two-layer model will be necessary to interpret the full suite of DAN data. Future modeling will explore the effects of burial depth, as well as H_2O and Cl content on QL parameters (**Figure 2**) and the shape of the thermal neutron die-away curve.

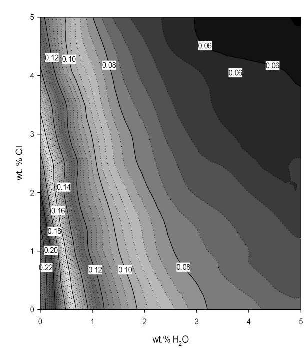

Fig. 2. Contour plot of modeled epithermal neutron ratios (QL#2) for single layer of martian soil with variable Cl and H_2O. The intersection of 3 contour lines (QL#3 and QL#4 in **Fig. 1** *left* and *right*) provides a possible solution for composition (H_2O and Cl) and layering structure (burial depth).

References: [1] Litvak et al., (2008) Astrobio., 8 [2] Mitrofanov I.G. et al. (2012), Space Sci. Rev., 170, 559-582. [3] Hardgrove et al., (2011) Nuc. Instr. Methods A, 659 [4] Boynton, et al., (2004) Space Science Reviews 110 [5] Squyres, et al., (2008) Science 1063 [6] Clark, et al., (1982) JGR 10059. [7] Feldman, et al., (2000) JGR105. [8] Feldman, et al., (2002) Science 297. [9] McSween, et al., (2010) JGR, 115.