WATER CYCLING IN HYDROUS SULFATE SANDS AS A POSSIBLE ANALOG FOR DEHYDRATION OF MERIDIANI PLANUM OUTCROPS. G. V. Chavdarian and D. Y. Sumner, Geology Department, University of California-Davis, Davis, CA 95616, chavdarian@geology.ucdavis.edu, sumner@geology.ucdavis.edu

Introduction: The Mars Exploration Rover Opportunity, on Meridiani Planum, is documenting sulfate-rich sedimentary rocks that formed in eolian environments with some evidence for overland water flow [1], [2]. Contractional cracks on outcrop surfaces define centimeter to decimeter scale polygons that crosscut bedding. The perpendicular-to-outcrop surface orientation of the cracks is inconsistent with synsedimentary contraction, and the cracks are consistent with shrinkage cracks formed from drying of damp sediments or hydrous sedimentary rocks [3], [4]. Rare cracks are associated with fins, which are mm-thick, platy features that protrude a few centimeters above outcrops. Fin geometry is consistent with differential cementation along cracks, followed by differential weathering. We use observations from an analog site at White Sands National Monument, New Mexico, to provide insights into processes forming cracks and fins, in order to understand the effects of water cycling between Meridiani outcrops and the atmosphere.

Geology of White Sands: White Sands contains the largest expanse of sulfate dunes on Earth [5]. White Sands dunes are mostly gypsum with possibly miner calcite and minor siliciclastic sands. Dune grain sizes range from fine to very coarse, with medium sand dominant. The high solubility of gypsum allows most stoss surfaces to be partially cemented. Dunes in the active dune field move an average of 10 m/yr, most of which occurs in March and April.

Dunes and plays at White Sands provide an excellent analog to Meridiani outcrops because of the ubiquitous hydrous sulfate sand, the similarities in depositional environments, and the presence of similar sedimentary structures. For example, cracks and fins at Meridiani and White Sands exhibit similar characteristics in size and morphology.

Cracks: At Meridiani, contractional cracks on outcrop surfaces define centimeter to decimeter scale polygons that crosscut bedding.. The perpendicular-to-outcrop surface orientation of the cracks is inconsistent with synsedimentary contraction, and the cracks are consistent with shrinkage cracks formed from drying of damp sediments or hydrous sedimentary rocks [3, 4].

Cracks at White Sands are ubiquitous in interdune areas, along interdune-dune boundaries, and on dune slopes (Fig. 1A). Cracks define centimeter to decimeter scale polygons that are oblique to bedding. Cracks define five- to six-sided polygons, similar to mudcracks, although clay minerals are absent. Crack polygons range from 5 to >40 cm in diameter, and crack depths extend from 0.1 to >27 cm (6). Crack widths are large compared to polygon sizes. Widths range from less than one to a few millimeters wide. For example, polygons 5-10 cm across have crack widths of 1 mm.

The large crack widths compared to polygon sizes indicates that cracks develop from moisture loss. Evaporation of water and shrinking of sand volume promote crack formation at White Sands. Cementation of sand grains during evaporation may help promote crack formation during volume loss.

Unfilled, sharply defined polygonal cracks were actively forming in the moist sand in January 2005 and February 2007. At other times, cracks on dune slopes were covered and dry. Cracks were actively forming when the sand had abundant moisture after large amounts of rain in the previous months. The one time fresh cracks formed during warmer periods was after one significant rainstorm in June 2005. However, cracks are present throughout the summer, suggesting they may continue forming below the dry sand layer or extend down to large depths as the sand is being eroded away.

Studies are underway to characterize changes in crack morphology on dune slopes as the slopes erode away. These studies will help elucidate whether cracks extend to a certain depth at time of formation which becomes shallower as the dune slope erodes away, or if cracks have a certain depth that is maintained during slope erosion, thus propagating deeper as erosion occurs.

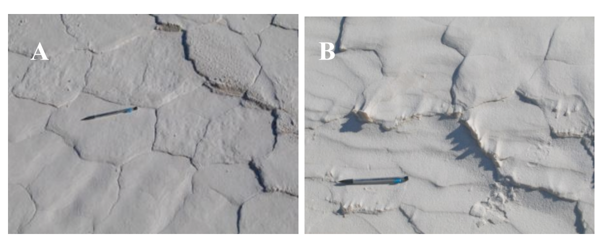


Figure 1: A: Cracks on a dune slope in gypsum sand. B: Damp fins along a crack edge that stand up to a centimeter above the surface.

Fins: Rare cracks are associated with fins at Meridiani; fins are mm-thick, platy features that protrude a few centimeters above outcrops. Fin geometry is consistent with differential cementation along cracks, followed by differential weathering.

Fins at White Sands are thin, platy, preferentially cemented features that protrude out of the dune sand

and are commonly associated with crack edges or laminae edges (Fig. 1B). Fins are either supported on one side by gypsum sand, or protrude out of the ground unsupported. Fins are either damp or dry. Damp fins are tan in color and extend a few centimeters above the dune surface and are less than 3 mm thick. Damp fins dip 50°-90° into the wind. Damp fin surfaces have a finer grain size than the surrounding sediment, consistent with adhesion of wind-blown particles. Damp fins are soft and cohesive rather than firmly cemented, and minor $CaCO_3$ is present on some fin surfaces. Their tan color is due to sufficient water to darken them.

Dry fins are harder than damp fins and deform brittlely. They are white in color, which is due to the absence of moisture in the fin. Damp fins become dry fins as moisture is lost from the fins, but not all dry fins form from this process. Damp and dry fins were present in January 2005 and February 2007 in the abundant moisture. However, only dry fins were present in March and June 2005; fins were absent in other field seasons.

Further studies are underway to characterize damp and dry fins in order to understand the processes by which they form. Cementation is one essential feature that is promoted by both temperature changes and evaporation. Summer temperature changes cause sand grains to cycle back and forth across the gypsum-anhydrite transition at 42-60ºC depending on water activity [7], possibly causing recrystallization or cementation. During dehydration, which is indicated by the cracks, precipitation of sulfate cements is likely, possibly aiding the formation of fins.

Temperature and Humidity Profiles: Temperature and humidity loggers were deployed in January 2006 to monitor subsurface conditions at 10 minute intervals. Temperature varies with depth and time of day; at the surface, daily fluctuations are up to ~30°C, whereas at 53 cm daily fluctuations are ≤1ºC. Atmospheric absolute humidity varies with weather and is almost always less than the absolute humidity between subsurface sand grains. However, the relative humidity measured below the surface of the dunes remains constant at 100% even with daily temperature fluctuations, requiring water to evaporate and condense on a daily cycle,

All conditions show systematic increases in absolute humidity in the subsurface with temperature changes (Table 1B and D). In the subsurface, water is cycling with temperature changes between different depths at all times of the year. At 53 cm depth, the absolute humidity changes by up to about 1 g/m3, demonstrating that water cycling occurs at this and greater depths.

Atmospheric absolute humidity is greater than the absolute humidity between sand grains below the surface for a few hours per day when frost is present (Table 1B), suggesting transport of water from the atmosphere to the subsurface. As atmospheric absolute humidity decreases back below that of the subsurface, water is transported from the surface to the atmosphere. This water loss from the sand may lead to crack formation, as observed during the moist winters of January 2005 and February 2007 with active cracks forming.

Field data show that mineral-atmospheric water cycling occurs at White Sands, and that water cycles between subsurface layers daily. Wind likely plays a role in this cycling process by creating air masses of different humidities above and below the dune surface. The differences in humidity between air in the atmosphere and below the surface causes water to be desorbed from sand grains and either lost to the atmosphere or adsorbed onto grains at different depths. The drying out of the top surface layer due to these humidity differences can cause cementation, contraction, and the formation of cracks (Fig. 2).

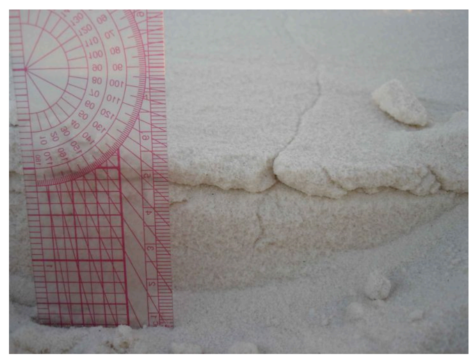


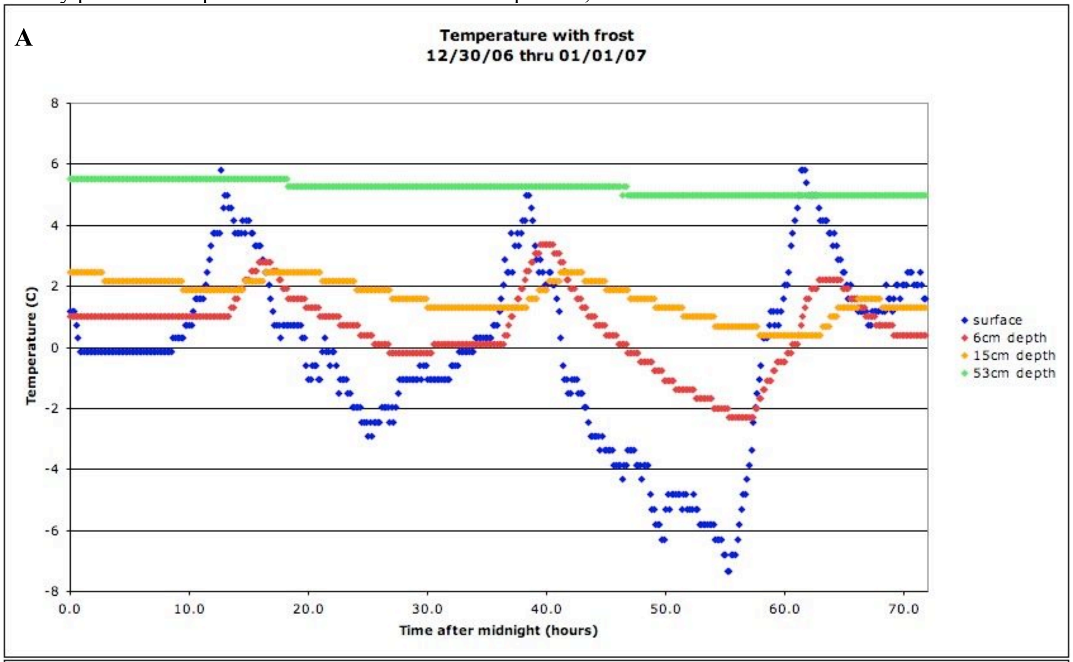
Figure 2: Cracked topmost surface layer

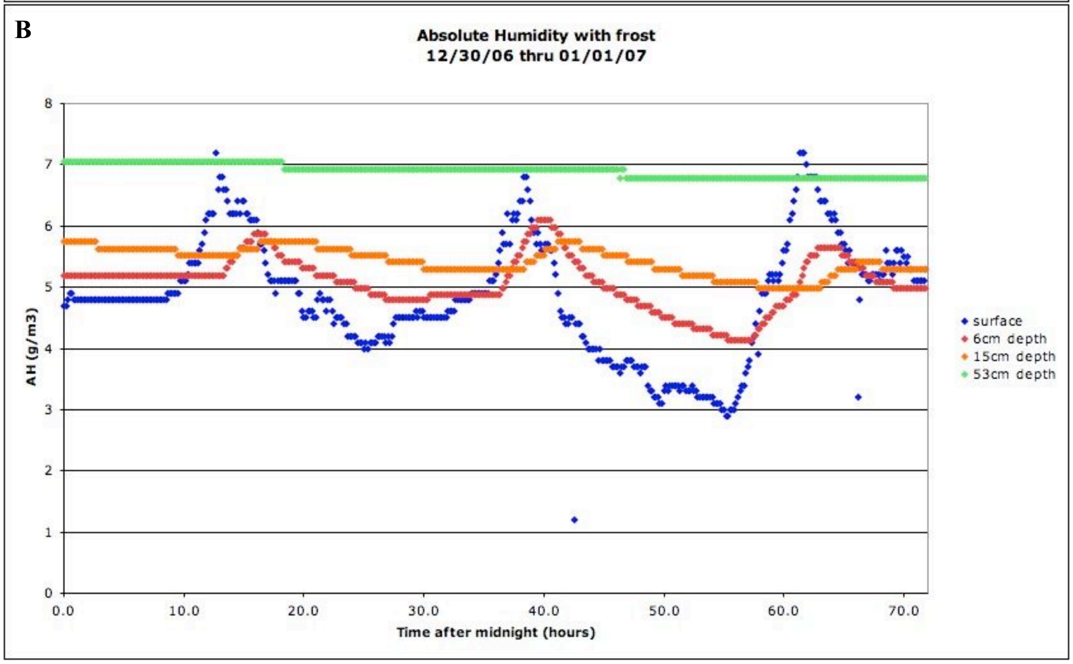
Conclusion: Studies at White Sands show that vapor transport is occurring between the atmosphere and subsurface. Water cycles between subsurface layers daily, and between the subsurface and atmosphere during periods when frost is present. Further work will identify whether water is transported through pore spaces or condenses onto grains by modeling the subsurface temperature. Water cycling probably dissolves and reprecipitates cements. Cementation during dehydration allows sand to crack, and precipitation of sulfate cements may aid in fin formation. Thus, the presence of cracks and fins in hydrous sediments may indicate dehydration.

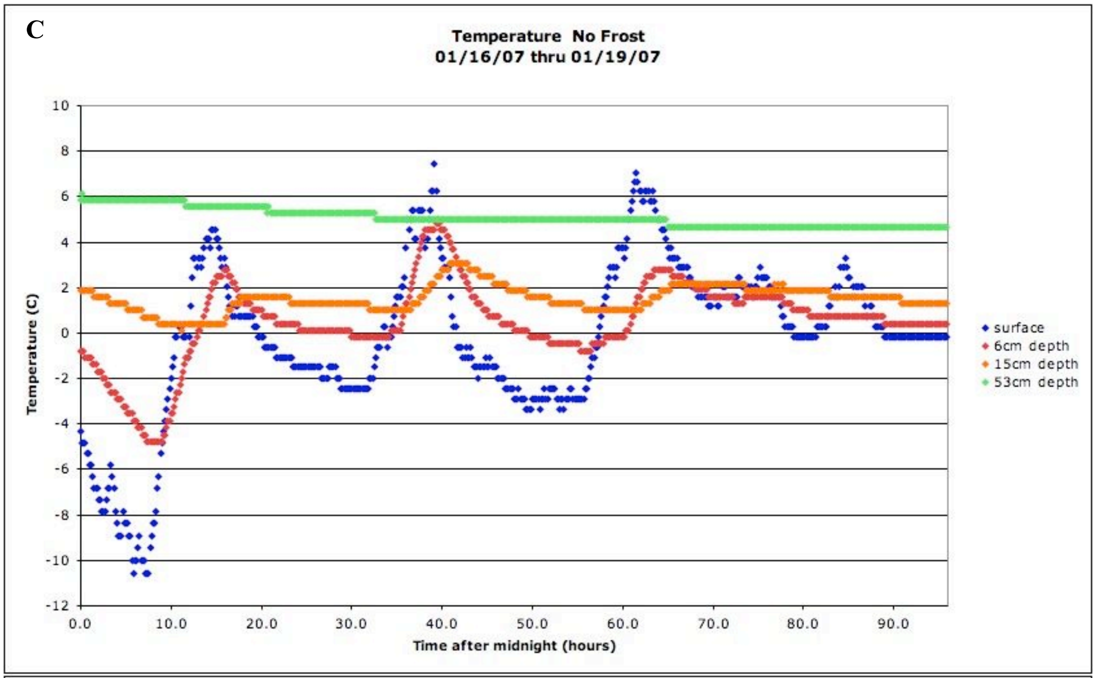
These or similar processes provide a testable model for crack formation in Meridiani Planum outcrops. Hydrous Mg-sulfates break down into water plus less hydrous Mg-sulfates at temperatures near 0ºC [8], and the presence of rare frost on Opportunity demonstrates changes in relative humidity of the local atmosphere. Therefore, a similar water cycling process could cause volume-loss, producing cracks in Meridiani outcrops. This implies an active water vapor cycle on Mars in recent history.

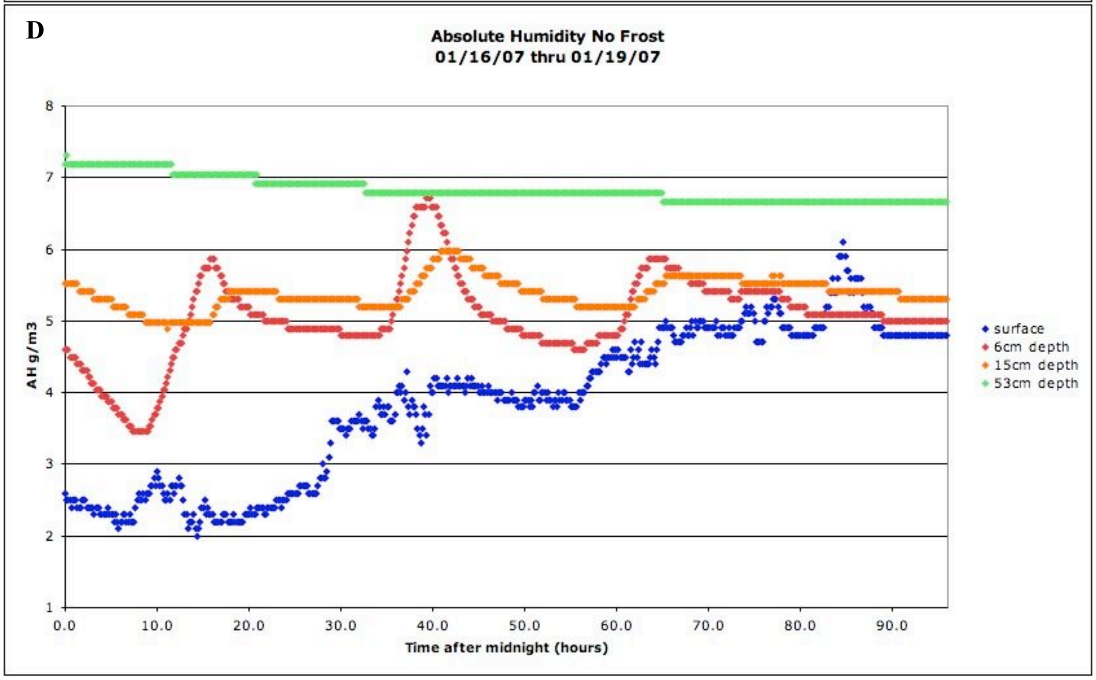
References: [1] Grotzinger J. P. et al (2005) *EPSL, 240,* 11-72. [2] Squyres S. W. and Knoll A. H. (2005) *EPSL, 240,* 1-10. [3] McLennan S. M. et al (2005) *EPSL, 240*, 95-121. [4] Grotzinger J. P. et al (2006) *Geology, 34*, 1085-1088. [5] Langford R. P. (2003) *Quaternary International*, *104*, 31-39. [6] Chavdarian G. V. and Sumner D. Y. (2006) *Geology, 34,* 229-232. [7] Freyer D. and Voigt W. (2003) *Monatshefte für Chemie, 134*, 693-719. [8] Hogenboom D. L. et al (1995) *Icarus, 115*, 258-277.

Table 1: Plots showing changes in temperature and absolute humidity in the atmosphere and at various depths below the surface over 3 and 4 day periods. Graphs A and B show when frost is present; C and D are in the absence of frost.






C
Temperature No Frost
01/16/07 thru 01/19/07
Temperature (C)
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Time after midnight (hours)
surface
6cm depth
15cm depth
53cm depth


D
Absolute Humidity No Frost
01/16/07 thru 01/19/07
AH g/m3
8
7
6
5
4
3
2
1
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Time after midnight (hours)
surface
6cm depth
15cm depth
53cm depth