**CRACKS AS EVIDENCE FOR WATER EVAPORATION AND CONDENSATION ASSOCIATED WITH TEMPERATURE CHANGES IN HYDROUS SULFATE SANDS.** 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 cross-cut 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.

**Cracks and Fins in Gypsum Sand:** Dunes and playas at White Sands National Monument provide excellent analogs for sedimentary structures in Meridiani outcrops because of the ubiquitous hydrous sulfate (gypsum) sand and the similarity of depositional environments. Fieldwork at White Sands has demonstrated that cracks and fins form seasonally in the gypsum sand [5]. Cracks define centimeter to decimeter scale polygons that are oblique to bedding, as do Meridiani cracks. Unfilled polygonal cracks were actively forming in January 2005 in the moist and cohesive sand in the presence of frost (Figure 1A). At all other times observed, cracks on dune slopes were covered and dry. However, cracks did form after one significant rainstorm in June 2005, and they are present throughout the summer, suggesting they may continue forming below the dry sand layer.

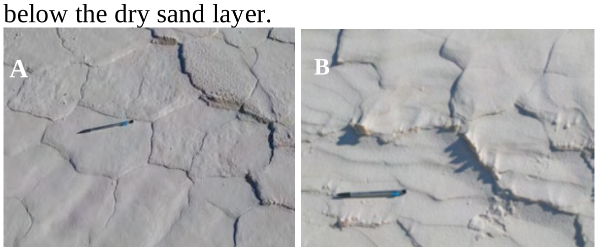


**Figure 1:** A: Cracks on a dune slope in gypsum sand in January 2005 at White Sands National Monument. B: Tan fins along a crack edge that stand up to a centimeter above the surface.

Fins are also present at White Sands [5]. Tan fins are thin, platy, preferentially cemented features that protrude a few centimeters out of the dune sand along crack edges. Tan fin surfaces always face into the wind and are composed of finer grains than the surrounding sediment, indicating adhesion of fine-grained structures to the fin surfaces. Slightly cemented tan colored fins were only present in January 2005 when abundant frost was present (Figure 1B).

**Results:** 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 45 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 significant changes in absolute humidity. These changes require water to evaporate and condense on a daily cycle, which could induce the precipitation of sulfate cements. Summer temperature changes cause sand grains to cycle back and forth across the gypsum-anhydrite transition at 42-60ºC depending on water activity [6]. Cracks may form as the grains contract during dehydration, and precipitation of sulfate cements is also likely.

Wind at White Sands is thought to influence water cycling by promoting temperature and humidity changes in the sand. The relative humidity of the atmosphere is rarely 100%. As wind blows into the dunes, dry air replaces moist air between grains. Water evaporates off of grains, increasing the humidity of the air and drying the sediment. During times when air in near surface sand is warmer than deeper air, flow into a dune causes the warm air of the upper layers to be driven deeper (Figure 2). This transports water vapor out of the surface layers deeper into the dune where it condenses as the air cools. Thus, airflow often lowers the relative humidity of the topmost sand layers. The surface crust layer dries out relative to the subsurface, cementation takes place, and cracks may form due to contraction (Figure 3). Water vapor that is driven down condenses onto deeper grains as the air cools; the relative humidity stays at 100%. At an unknown depth, airflow moves back up toward the surface, driving cold air towards the surface. As it warms, water evaporates off of sand grains, maintaining the air at 100% humidity. As the air exits the dune surface, the surface layer may also dry out, causing additional cementation, contraction, and cracking. Thus, cracks may form as a result of this wind generated water cycling process.

When the air in near surface dune sand is cooler than the air at greater depths, for example at night, wind pushes the cooler air deeper. The colder air replaces warmer, deeper air; as it warms, water evaporates off grains. The displaced warm air transports water vapor upwards, to the surface and into the atmosphere. This water vapor can condense as frost or dew, replenishing near-surface dune moisture. This process dries out deeper layers of the dune, possibly promoting cracking at greater depths. At 30-40 cm depths, the absolute humidity changes by up to about 2 g/m3, demonstrating that water cycling occurs at these and greater depths.

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 transporting air through the dunes. 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.

These or similar processes provide a testable model for crack formation in Meridiani Planum outcrops.

**Figure 2:** Result of airflow through dune when near surface sand layer is warmer than at depth. A: Wind entering the dune dries out the top surface layer due to changes in relative humidity; water escapes to atmosphere or to depth. B: Warmer air driven deeper, water adsorbs onto grains at depth. Water desorbs off grains as airflow removes colder air. C: Airflow leaves dune, drying out top surface layer.

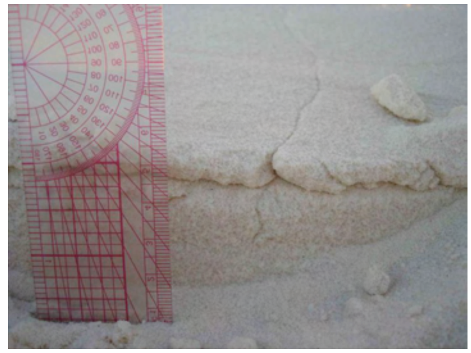

**Figure 3:** Cracked topmost surface layer

Hydrous Mg-sulfates break down into water plus less hydrous Mg-sulfates at temperatures near 0ºC [7], 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 on Meridiani outcrops. Thus, atmospheric water cycling with the evaporation (or sublimation) and condensation of water associated with hydrous sulfates may promote crack formation in sulfate sand both at White Sands and on Mars, implying an active water vapor cycle on Mars in recent history.

**References:**

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