CRACK GEOMETRY AND MORPHOLOGY 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 cracks are consistent with shrinkage cracks formed from drying of damp sediments or loss of water from hydrous sedimentary rocks [3], [4]. We use observations of crack morphology in gypsum sand from an analog site at White Sands National Monument, New Mexico, to understand the processes affecting crack morphology over time. Dunes and playas at White Sands provide excellent analogs for sedimentary structures in Meridiani outcrops because of the ubiquitous hydrous sulfate (gypsum) sand and the similarity of depositional environments between the two sites [5].

Background: Cracks form when stress exceeds the local tensile strength of a material. After a crack forms, it grows perpendicularly to the direction of stress [6-8]. The stress near an existing crack is parallel to the crack face, so growing cracks approach existing cracks at 90º angles. However, non-perpendicular junctions can form by the nucleation of multiple cracks at a single point, from the influence of nearby cracks on the local stress field, or by a crack tip splitting into multiple cracks. Crack polygons increase in maturity when angles at crack triple junctions evolve to 120° from either repeated healing and refracturing or by crack propagation below the surface. Newly formed cracks are considered 'immature' cracks since they have not yet formed into 'mature' polygonal crack patterns with junctions of 120º [8]. In both starch experiments and columnar jointing, fracture patterns at the surface are disordered and irregular, but as depth increases, the fractures become more ordered, reaching an almost stable polygonal configuration at depth [6-8].

Cracks: Cracks form in the gypsum sand at White Sands in interdunes, at interdune-dune boundaries, and on the tops and stoss slopes of dunes (Figure 1). Cracks define four- to six-sided polygons, similar to other contractional cracks. Cracks are oblique to bedding on dune slopes. Crack geometries are straight to wavy, and polygon triple junction angles range from <90º to >120º. Crack polygon diameters vary from 5 to 40+ cm across.

Cracks extend to variable depths at White Sands, and crack geometry changes with depth. Some cracks extend almost vertically straight into dunes, whereas most extend down slanted at an angle or in a wavy profile.

Figure 1: Mostly mature crack polygons.

A group of crack depths were measured with vernier calipers to look for similarities between the depth of crack groups. This method only measures the vertical depth of a crack before it slants away since most cracks are not vertical. Each group consisted of three to six neighboring cracks, with a total of twenty cracks measured, mostly at the interdune-dune boundaries. The depths ranged from 1.0-5.09 cm, with an average of 2.9 cm. Groups of cracks usually had depths within 0.5-1.5 cm of each other. Wider cracks usually had deeper initial veritical depths. Limited trenching has also demonstrated that cracks extend from 0.1 to at least 27 cm into the subsurface.

Crack widths are large compared to polygon diameters. Widths range from less than one to a few millimeters wide. For example, polygons 5-10 cm across can have crack widths of 1 mm. The large width of the cracks suggests that they form due to mass loss rather than thermal contraction of the sand. Water loss is likely based on observations of water cycling and the role water evaporation and condensation plays in dune sand cementation. Water temporarily wets dune surfaces when it rains, snows, and/or frosts. Water also accumulates in the dunes from seasonal rains. This causes ponding of water in interdune areas and water can remain in the dunes for months. Water is lost from the dunes through evaporation. The wetting and drying of the sand is thought to be a major process for crack formation.

Cracks at White Sands are found in both wet and dry sand. The moist cracks are present in the topmost loose surface sand layer when the dune surface is wet. They are sharply defined and cracks are open, lacking loose sand fill. Conversely, dry cracks are present in the cemented sand layer that lies at the surface to a few centimeters below a topmost loose sand layer. The surface and cemented gypsum sand layer containing the cracks is dry. Unlike the sharply defined moist cracks, the dry cracks are filled, and frequently covered, with sand. Wet cracks become dry cracks as the dune surface dries out, and dry cracks can become wet with rain, snow or frost.

Wet cracks were observed in January 2005 and February 2007. Cracks were actively forming when the sand had abundant moisture after recent frost events and large amounts of rain in the previous months. At all other times observed, cracks on dune slopes were covered and dry.

Humidity: Temperature and humidity loggers buried in a dune show 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. The humidity of the top surface layer of dunes from the surface to a max of 10 cm depth is less than 100%. Humidity data require that mineral-atmospheric water cycling occurs between subsurface layers daily. 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 loss of water out of the surface layer due to these humidity differences can cause cementation, contraction, and the formation of cracks.

Crack Maturity: Crack geometry and morphology mature from tripple junctions at 90º angles to 120º as they reform and propagate with depth. We predict that when cracks first form on the surface of the sand, their geometry is immature. But, as the cracks propagate downward, the polygons become more ordered. When the sand erodes, the more ordered and mature polygons below the surface become exposed. Polygons on the surface can also increase in maturity from the repeated healing and fracturing of cracks. As water repeatedly condenses and evaporates, cracks could cycle between opening and closing, and triple junctions may become more ordered to 120° as a result. Field work is planned to test the maturation of cracks with depth and through time.

Both moist and dry cracks have been observed to range in maturity from immature to mature (Figures 1-3). This implies that the only difference between these cracks is the moisture level of the surface sand. Immature moist cracks can become immature dry cracks if they dry out without any erosion (Figure 2).

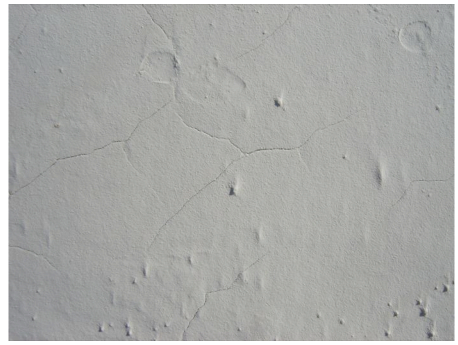

Figure 2: Immature cracks; angles are ~90º, and cracks do not all connect.

They can become semi-mature dry cracks if they dry out and erode, exposing the more ordered polygons, and can become mature dry cracks if they dry out and experience lots of erosion (Figures 1, 3). Immature moist cracks can become semi- to mature moist cracks as they propagate and erode to expose the lower polygons, or as they repeatedly fracture and heal.

Figure 3: Semi-mature cracks

Conclusion: Understanding crack formation over time at White Sands will give insights into the processes in which cracks occur in hydrous sulfates. Studying crack morphology will help constrain the maturity level of cracks and give insights as to the history of cracking processes. Models for crack formation can be used as working hypotheses for cracks on Meridiani Planum outcrops.

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