MICROBIAL INFLUENCES ON AEOLIAN SULFATES; A CASE STUDY OF A DUNE FIELD AT WHITE SANDS NATIONAL MONUMENT, NEW MEXICO. M. Glamoclija[1], A. Steele[1] and M. L. Fogel[1], [1]Geophysical Laboratory, [1]Carnegie Institution of Washington, 5251 Broad Branch Rd, Washington, DC 20015 (e-mail: mglamoclija@ciw.edu).

Introduction: Sulfates have been found as a constitutive part of sedimentary formations exposed to the surface of Mars [e.g. 1, 2, 3, 4]. At the North Polar Region, gypsum minerals have been identified within dunes at the Olympia Undae [1, 2, 5], with a stronger gypsum signature detected along the dune crests than in the interdune areas [6, 7]. As terrestrial gypsum, gypsum at the Olympia Undae may have been re-precipitated by ground- or surface-water activity after the main deflation events [8]. Additionally, preserved sulfate-rich interdune deposits have been found at three outcrops at the Opportunity landing site in Meridiani Planum. These deposits have been interpreted as formed in wet and damp-wet interdune and sand sheet environments [4, 9], evidence that environments or settings similar to those of the White Sands National Monument (WSNM) from New Mexico may have existed on Mars during the past.

The WSNM contains one of the largest known gypsum dune fields on Earth. The dune field is dominated by transverse dunes, which are cemented by a high groundwater table (~ 0.3 m [10]). The dunes are formed from deflated material of the Pleistocene Lake Otero about 7000 yrs ago [8]. Remote sensing of historical aerial images revealed the average rate of dune migration to be about 3.4 m per year and the interdune areas within the dune field may be approximately 50 yrs old [8]. The preserved interdune structures found along west margin of the dune field are estimated to be 600 to 1000 yrs old [8]. Here we report our findings about mineral composition of the dune deposits, where similarly to Martian dunes, dune crests exhibit less mineral diversity and slightly different mineral signature than the interdune areas. This difference at the WSNM is partially caused by early diagenetic processes and partially by biological presence. Biofilm acts as a trap for anions and cations brought by ground water or mineral dissolution or produced by microbes. These trapped compounds will upon biofilm desiccation form mineral precipitates. Additionally, some of mineral precipitates will form in biofilm vicinity as its presence locally changes the chemistry of the environment.

Materials and Methods: The sampling strategy included the collection of samples from the surface and a depth of 10 cm at the same sampling spot. The samples were collected along a dune profile, including dune slopes and interdunes. Further, different types of interdune surfaces were sampled, including 600 - 1000 yr and 50 yr old interdunes, and the vesicular crust formed by microbial respiration processes, most likely after the flooding of the dune field in 2007.

The main minerals were identified by powder diffraction of dried and moist samples using the InXitu Terra XRD instrument, a commercial version of CheMin XRD instrument. Scanning Electron Microscopy (SEM) in conjunction with energy dispersive x-ray analysis (EDS) (JEOL JSM 6500F equipped with EDS) was employed for detailed morphological and specific chemical compositional study of minerals, microbial forms and biofilm. Analytical conditions for SEM observations of platinum coated samples were standard high vacuum mode (1.9×10^{-4} Pa) with 15 and 12 kV beam. Each sample was divided into 3 sub-samples. One set of sub-samples was dried under 50°C, another set was etched with 1N HCl for 2 minutes and the acid was washed out with reagent grade clean water. The last set of sub-samples was fixed by immersion in 2% glutaraldehyde for 30 min and dehydrated through a graded ethanol series (35%, 50%, 75%, 80%, 95%, and 100%). After dehydration samples were mounted onto SEM stubs and coated with platinum. Dried and etched samples were used for mineral analysis and to identify and characterize relationship between biofilm and minerals; whereas fixed samples were used for observations of biological material.

Results and Discussion: *Dune Sides.* Mineral grains from dune sides are well-rounded by the aeolian erosion. Gypsum and bassanite are the main minerals. The mineral variation at the dune sides largely occurs as a function of gypsum dehydration, with surface samples composed mainly of bassanite and the subsurface composed of gypsum. Mineral grains were not covered with fresh biofilm or microbial cells, however irregular mineral surfaces and fractures of larger grains were filled by desiccated biofilm and the associated precipitates. Biofilm precipitates are: gypsum (by EDS we could not discriminate gypsum from bassanite), carbonates (calcite and huntite), celestine and amorphous silicate enriched in magnesium.

Common Interdune Areas. The interdune areas show higher mineral diversity than the dune sides. A common type of interdune area consists of gypsum, bassanite and minor calcite and quartz, while the subsurface consists of gypsum and bassanite. About few mm thick biofilm was found 0.5 cm beneath the sediment surface. Besides the biofilm and microbial cells, SEM analysis revealed the presence of diatoms and spores. Gypsum grains are covered by fresh and partially permineralized biofilm that holds and cements the grains. It is notable that biofilm was the thickest on the grain sides which were already eroded/dissolved and on the sides where gypsum sheets were exposed. In such way the mineral surface provided the larger area for the biofilm attachment and likely was easier to dissolve. The dissolution surfaces caused by biofilm exhibit small pits. Fresh biofilm and cells contained Mg, Cl, Si and Ca compounds. Micron scale precipitates detected on dried biofilm were mostly tabular and lenticular gypsum, silicates, halite, chlorides of Mg and Ca (tachyhydrate-like mineral), huntite, calcite and celestine. Except gypsum, halite and celestine, mineral phases detected in biofilm are irregular grains without any crystallographic characteristics.

Interdune Areas With Vesicular Sand. Some of the interdune surfaces have vesicular crust and sand, which were formed by microbial respiration processes. These sediments are composed of gypsum, hexahydrite, glauberite, halite and minor quartz and bassanite. This type of interdunes shows higher content of salt than common type of interdunes or oldest interdunes. The grains are partially cemented by fresh well-developed biofilm and cells with minor mineral precipitates. Diatoms were present at this site too. Mineral precipitates associated with biofilm are: halite, celestine, hexahydrite and magnesium chloride. Gypsum grains, more than 100 μm in size, without traces of aeolian or biological erosion were observed. These grains were new minerals formed at this site during period of locally high fringe.

Subsurface deposits are mainly composed of lenticular and tabular gypsum/bassanite, minor quartz and carbonate minerals. Micron-scale minerals associated with biofilm are calcite, huntite, dolomite, celestine, and alluminosilicates of Fe and K (mica minerals).

600 to 1000 yrs Old Interdune Areas. Unlike the interdune areas from the dune field, the old interdunes have surface crusts mainly composed of gypsum, dolomite, and quartz minerals, whereas the subsurface sediment is mostly gypsum. This site is characterized by high level of moisture and well-developed ~ 1 cm thick biofilm, numerous microbial cells, diatoms and eukaryotes. Mineral grains are entirely included in biofilm. Mineral precipitates observed on/in biofilm include halite, magnesium chloride, gypsum, huntite, dolomite, celestine, amorphous silicate and magnesium silicate. In some cases dolomite is associated with amorphous silicate from the biofilm. At this site new gypsum minerals (more than 100 μm in size) were observed.

At the interdune areas biofilm will form at the dry-moist sediment interface. As this interface represents the zone of desiccation some of the salt compounds and gypsum will precipitate even without the biofilm presence. These minerals are usually larger in size than precipitates associated with biofilm. The biofilms show significant Mg, Si, Ca, Na, Cl and S components according to EDS analyses. Diatoms may have provided the Si compound, whereas Ca, Na, Cl, and S may have been brought by the groundwater system. Mg compound is always strictly associated with biofilm, so we may assume that this compound is of biologic origin. Some of these elements may have been used by microbes for metabolic activities while others were likely trapped in biofilm as a protective mechanism. Oversaturation of biofilm by these compounds will cause mineral precipitation that was detected by XRD and EDS analyses. Additionally, the presence of desiccated biofilm and precipitates on the grains analyzed from the continuously migrating dune sides will provide supply of carbon and minerals that could be used as nutrients for seasonally newly formed biofilm at the interdune areas.

As observed at the WSNM the difference in mineral signatures between dune crests and interdune areas is common on Earth as well. In terrestrial settings this difference is caused by both early diagenetic processes and by biological influence. Therefore it is possible that similar aeolian gypsiferous dune settings at Meridiani Planum or at Olympia Undae may have offered similar habitable settings as those found at the WSNM.

References: [1] Langevin Y. et al. (2005) *Science, 307,* 1584–1586. [2] Fishbaugh K. E. et al. (2007) *JGR, 112,* doi:10.1029/2006JE002862. [3] Gendrin A. et al. (2005) *Science, 307,* 1587–1591. [4] Grotzinger J. P. et al. (2005) *Earth Planet. Sci. Lett., 240,* 11–72. [5] Tanaka K. et al. (2009) *Icarus, 196,* 318-358. [6] Roach et al. (2007) *LPSC 38th,* Abs. 1970. [7] Lathela H. et al. (2009) *LPSC 40th,* Abs. 254. [8] Szynkiewicz A. et al. (2009) *Geomorphology, (in press)*. [9] Metz J. M. et al. (2009) *J. Sedim. Res., 79,* 247-264. [10] Kocurek G. et al. (2007) *Sediment. Geol., 197,* 313-331.

Acknowledgements: This work was funded by NAI, Carnegie Institution of Washington (PI G. Cody), and ASTEP Program (PI A. Steele). We would like to thank the White Sands National Monument and D. Bustos for his hospitality and help during the fieldwork. We are also thankful to D. Bower for field assistance.