MICROBIAL SIGNATURES FROM THE ARID ENVIRONMENTS OF WHITE SANDS NATIONAL MONUMENT, NEW MEXICO.

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Introduction: Sulfates have been found as a constitutive part of sedimentary formations exposed to the surface of Mars at different latitudes [e.g. 1, 2, 3, 4]. At the north polar region, gypsum minerals have been identified within dunes at the Olympia Undae [1, 2], and a variety of sulfate minerals have been detected at lower latitudes within the ancient playa-like deposits at the Meridiani Planum [3, 4]. The origin of these deposits is still unknown, however, they were most likely produced by a combination of hydrothermal processes and/or groundwater upwelling which could have brought sulfur compounds into the system, and later on they were weathered by atmospheric and eolian processes [4, 1, 2]. Even though terrestrial geology in many ways resembles Martian geology, the direct terrestrial analog to these types of deposits has not been identified. The White Sands National Monument (WSNM) (New Mexico) with its gypsum dunes and sulfate-rich playa deposits has been proposed as a sedimentologic/hydrogeologic and partially geochemical analog to sulfate deposits from Meridiani Planum and the dunes from Olympia Undae [4, 5, 6]. Since the WSNM represents a terrestrial analog for both Meridiani Planum and Olympia Undae on Mars, we investigated the arid evaporitic systems in the WSNM in order to find different microbial habitats and assess their ecological characteristics through identification of mineral assemblages, pigments, and extractable nitrogen. Additionally we extracted DNA from environmental samples for PCR -based characterizations of the microbial communities.

Materials and Methods: 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 (approximately 0.3m [**7**]). The western part of the WSNM is occupied by Alkali Flats, which are exposed beds of Pleistocene Lake Otero. The southern part of the WSNM holds the modern playa lake Lucero. Collected material consists of: (1) gypsum-rich sand from the dune slopes and partially cemented interdunes; (2) sediments and crusts from the Alkali Flats; (3) crusts and soil from the surfaces of Lake Lucero.

The main minerals were identified by powder diffraction using the InXitu Terra XRD instrument. The nitrogen content from the deposits was assessed through the colorimetric analyses of ammonium (NH_4) and nitrate+nitrite (NO_3+NO_2) concentrations. Both 90% acetone and metanol/ethylacetate (vol. 1:1) were used to extract microbial pigments for anayses of pigments under both visible and UV spectral ranges using a Spectrophotometer (GENESYS 10Bio) in the range of 200 to 800 wavelengths. DNA extractions were carried out on ~ 0.5 g of powdered sample using Power Soil DNA isolation kit (MoBio Laboratories Inc., CA) using a modified protocol allowing for the extractions of gypsum-rich sediments. PCR analysis was performed using a Dyad Peltier Thermal Cycler with puReTaq™ Ready-To-Go™ PCR Beads (Amersham Biosciences, NJ). Universal primers specific to the small subuit rDNAs from all three domains of life were used to determine the microbial diversity of each environmental sample. Functional gene analyses were performed to further determine the metabolic processes represented in the metagenome of the WSNM evaporite environments.

Results and Discussion: *Dune Field:* Sand from the dune field is mainly composed of gypsum and bassanite. The mineral variation largely occurs as a function of gypsum dehydration. The interdune areas show higher mineral diversity. Besides gypsum and bassanite, minor quartz, calcite, and, at some areas, kutnohorite dolomite is present. A green layer composed of microbial mats was found at the interdune areas, close to the surface.

The extractable N content shows a predominance of NO_3+NO_2 over NH_4 (2.8 : 1.4) indicating an oxidative surface environment with more available N in sand from the interdunes than at sand collected from the dune sides. Chlorophyll-a, chlorophyll-b, bacterioruberin, β-carotene, scytonemin, and carotenoids which overlap in the spectra with photo-protective chlorophyll were present in interdune samples. No pigments were found in the dune samples. Based on spectral characteristics, cyanobacteria as well as red/ brown pigmented microbes were found. The presence of carotenoids and scytonemin indicate that the microbes from the dune field have a well-developed protective mechanism against solar radiation [8, 9].

There was a notable absence of DNA from samples collected from the sides of the dunes. The microbial content from the interdune areas varied, with DNA from the older surfaces showing the presence of eubacteria, archaea and eukaryota, whereas the younger surfaces had only eubacteria.

Alkali Flats: The surface sediments and crusts of Alkali Flats are mainly composed of halite, gypsum, clay, quartz, thenardite ($NaSO_4$). At places, approximately 15 to 20 cm large selenite crystals are found. The crystals were partially stuck/cemented in the desert soil, and some of the crystals showed surfaces covered by the green/pink powder coating composed of gypsum, carbonate and phosphate salt minerals.

Generally, samples show higher NO_3+NO_2 than NH_4 content, implying the presence of an oxidizing environment. The large selenite crystals with the green/pink powder contained more N than the selenites without the powder coating, or the desert soil in which the crystals were found. The incrustations from the surface show more N than the ground beneath them. Pigments have been detected only in selenite crystals with the powder coating. Chlorophyll-a, chlorophyll-b, possibly bacteriochlorophyll, bacterioruberin, β-carotene, scytonemin, and carotenoids which overlap in the spectra with photo-protective chlorophyll were present.

PCR analyses showed a eubacterial presence in all of the extracted samples. Additionally, selenites with the powder coating showed an additional presence of archaeal DNA.

Lake Lucero was investigated as a modern analog to the ancient beds of Lake Otero. The lake surface was completely dry and covered by a few cms thick crust composed of mirabalite ($NaSO_4$ x $10H_2O$) and thenardite. The thenardite found on the surface of the Alkali Flats was probably transported by wind from Lake Lucero. Beneath the crust we found a dark compact layer of calcite, clay, quartz, halite, glauberite, dolomite and basssanite. Beneath the dark layer is a reddish layer of bassanite, calcite, halite, and quartz. The reddish layer is followed by the type of soil commonly found in the area. The mineral assemblage is dominated by magnesium calcite, calcite halite, and bassanite. Lake Lucero is the only location where N content clearly showed the presence of a reducing environment associated with dark and reddish layers. The Chlorophyll, Carotenoids, and β-carotene were detected only in the mirabalite/thenardite crust and the dark layer. The spectral characteristics show the change of microbial communities at this site compared to those found at Alkali Flats and at the dune field. Additionally, samples of the crust and the dark layer contained eubacterial, archaeal, and eukaryal DNA.

From the collected sets of data, we can conclude that most of the microbial mat was found within the interdune areas and at the surface of modern playa lake Lucero. These are the surfaces that hold most of the moisture in the investigated area. Additionally, interdunes provide desireable habitats for microbial communities because they are the most stable substrates within the dune field. We observed that zones with microbial mats often have higher mineral diversity, which is frequently associated with the occurrence of different calcite and dolomite minerals. The Lake Lucero environment likely has the most active chemistry in comparison with all the other settings we encountered at the WSNM, which makes the lake a very suitable habitat for the microbial communities by providing a constant source of nutrients.

The pigment analyses revealed that microbial communities found approximately a cm beneath the surface contain spectral signatures of carotenoids and scytonemin pigments which are used as protective mechanisms from UV radiation. Additionally, almost all microbial mats were found below the surface at the interfaces between moist and dry areas which protect them from desiccation.

The desert environments at the WSNM appear to be inhabited by diverse microbial communities well adapted to arid conditions.

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