WHITE SANDS GYPSUM DUNES: A TERRESTRIAL ANALOG TO NORTH POLAR DUNES ON MARS?

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Introduction: Many dunes on Earth are indicators of an arid climate where strong aeolian processes cause deposition of well-sorted, fine, sandy material. Although dune *deposition* is primarily associated with arid conditions, the deposition of the source sediments is usually related to water-associated processes.

The White Sands gypsum dunes (WSgd) are the largest known aeolian sulfate-rich deposits on Earth and are an excellent natural laboratory for studying the origins of sulfate dunes. In particular, this communication focuses on the interaction between hydrology and climate that lead to the deposition of the source sediment for the dunes and controls the current dune field morphology.

The WSgd may be a terrestrial analog to the gypsum-rich dunes of Olimpia Undae (OUgd) detected in the north polar region of Mars. The OUgd appear to have undergone complex chemical and physical evolution, possibly involving hydrothermal heating and mobilization of sulfides by fluids, followed by aeolian weathering [1,2,3,4].

The source area for gypsum in the OUgd has not yet been determined but the OUgd are near the north polar cap, a plausible Martian water-source. Also, the proximity of the OUgd to the outwash channels of the Chasma Boreal [2,4] suggests that the gypsum supply might have been controlled by water-involved processes similar to those on Earth.

We have used stable isotope methods at WSgd to determine the source of the original dune sediments, document the involvement of water in their deposition, and to trace the connection of these sediments to the current dune field. We also present examples of aeolian sedimentary features, recognizable on aerial photographs, that show the influence of geochemical processes on the character of the surface morphology as seen “from the air”. This study of the WSgd region, at multiple scales, may help in the understanding and recognition of similar processes operating in the OUgd and possibly elsewhere on the surface of Mars.

Geological setting: The WSgd are located in south central New Mexico, in the closed-drainage Tularosa Basin, a graben formed by extensional tectonics in the Rio Grande Rift. The basin is bordered on the east and west by mountain ranges containing Precambrian and Paleozoic rocks. Both the ranges and Tularosa Basin show evidence of tectonic processes within the last 20 ka. The pluvial Lake Otero existed in the northern part of the basin during the late-Pleistocene/Holocene and left gypsiferous evaporative deposits [5]. Regional deflation events have been dated at 7 ka and 4 ka BP [5].

Methods: We sampled a 7 m thick sequence of Holocene age lakebeds from a fault scarp in the southern part of the White Sands National Monument in order to determine the sulfur isotope composition of this probable sediment source for the dunes. Also, gypsum sand was sampled and the sulfur isotope composition determined for samples from 8 transects across the northern, central and southern part of the dune field inside the Monument.

Results and discussion: The current groundwater system at White Sands is dominated by SO_4 ions originated from the dissolution, by meteoric water, of Middle Permian strata with $\delta^{34}S$ values from 10.8 to 12.3 ‰ (all values reported vs. VCDT). However, the range of $\delta^{34}S$ values, from the bottom (11.3 ‰) to the top (13.8 ‰), of the lakebed sequence indicates that an SO_4 ion source with higher $\delta^{34}S$ must have been involved. This source is the Lower Permian strata that has higher $\delta^{34}S$ values (12.5 to 14.4 ‰). Because, in the basin center, the Lower Permian strata are overlain by the Middle Permian approximately 1000 m beneath the surface, the positive excursion of $\delta^{34}S$ values suggests the influx, in the past, of water from deeper parts of the basin into the playa. The change in sulfate source can be tied to climate evolution toward more arid conditions and possibly to tectonic activity that might have increased the release of deeper-seated groundwater through faults extending into the playa surface.

After that time, gypsiferous sediments underwent extensive deflation that led to the formation of the White Sands dune field with parabolic and traverse dunes prevailing on the eastern and western sides, respectively. To explain the evolution of the dune field, we used $\delta^{34}S$ values as a tracer of the gypsum source and compared them to the studied lakebed sequence. The increase of $\delta^{34}S$ values in gypsum sand from the SW towards the NE of the dune field follows the prevailing wind direction (Fig. 1) and suggests that the eastern parabolic dunes were formed from deflation of sediments from the top of the lakebed sequence, and the western traverse dunes were sourced by gypsum coming from older lakebeds that were deflated during a later episode(s). Based on our data, we propose that an approximately 4 m thick sequence of playa sediments was removed from the source region to form the White

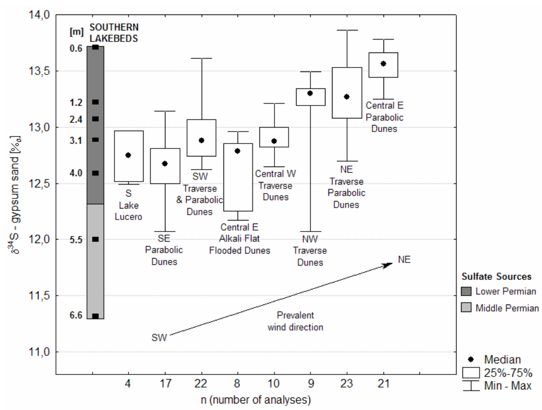

Fig. 1. A box diagram showing the statistical distribution of δ^{34}S values of gypsum sand in a dune field inside the White Sands National Monument. The left side shows variation of δ^{34}S values along the sequence of lakebed sediments from the southern part of the Monument. Lighter and darker gray colors indicate the influx of sulfate from dissolution of Middle and Lower Permian strata, respectively.

Sands dunes and that the process was essentially unidirectional.

Today, in the White Sands area, aeolian processes are limited by a relatively high groundwater table [5], advanced dune cementation [6], and re-exposure of an old lacustrine, sulfate-poorer, clay sequence on the playa surface. This indicates that, if the sediment sequence in the playa includes less or non-gypsiferous sediments, the source region may be subject to exhaustion of gypsum. Similarly, the lack of an observed (currently) source area for gypsum at the OUgd, suggests that there were limited amounts of gypsiferous sediments in the north polar region of Mars in the past, or that such gypsiferous sediments have been buried by younger rocks.

Remote sensing is the dominant technique for investigating the Martian surface. Studies of comparable terrestrial geological systems, as analogs, should increase our understanding of geological processes and related morphological features and so help in our interpretation of the geological history of Mars. Aerial photographs of the White Sands area reveal well-developed cross-bedding features related to aeolian transport of sand particles and reveal a long-term record of migration because of advanced cementation (Fig. 2). Large horizontal cross-bedding features are best exposed in the interdune areas and less so in the downwind slopes of dunes. These are stoss slopes of migrating dunes that have been cemented by gypsum and are erosion resistant. In the central parts of interdune areas stoss slopes are progressively buried by

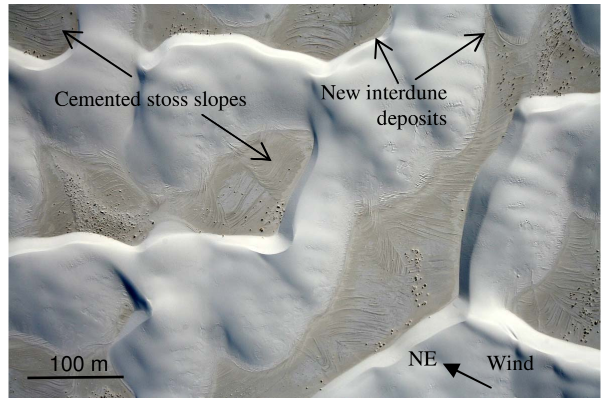

Fig. 2. An aerial photo, taken from an altitude of about 450 m in October of 2007 over the heart of the White Sands dunes and revealing a longer-term record of migration because of advanced cementation of stoss slopes.

wet/damp interdune deposits [7]. After groundwater discharge into interdune areas during the 2006/2007 winter, new interdune gypsum-rich deposits partly covered large cross-bedding features. This process is best visible around interdune areas at the bottom of downwind and slip slopes (Fig. 2).

Conclusions: The δ^{34}S values in gypsum sand from the WSgd indicate that the dune field was mainly sourced by gypsum precipitated from an old deep groundwater system that discharged into the White Sands area. WSgd formation appears to be linked to a specific time period characterized by a distinct climatic and/or tectonic regime during the Holocene.

The geographical position of OUgd on Mars indicates that a similar sulfate-rich aeolian system might have formed under Martian polar conditions. The spatial distribution of gypsum within OUgd may be connected to melting events in the Martian north polar cap and the OUgd may be indicators of water-involved processes on Mars similar to those observed at WSgd.

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