Aeolian transport in Olympia Undae, Mars, based on a field study at White Sands National Monument, New Mexico, USA

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Introduction

Olympia Undae is Mars' largest dune field, made predominantly of iron-bearing glass and high-calcium pyroxene [1], with a minor but significant component of gypsum ($CaSO_4 \cdot 2H_2O$) on dune crests [e.g., 2] in the eastern regions [3]. The occurrence of gypsum is a mystery, given the Amazonian age of the dunes and the prevalence of most other martian sulfates in more ancient deposits [4]. Hypotheses for its origin include alteration from filtered brines [5], erosion from older polar strata [6], and erosion from underlying hydrothermal deposits [7].

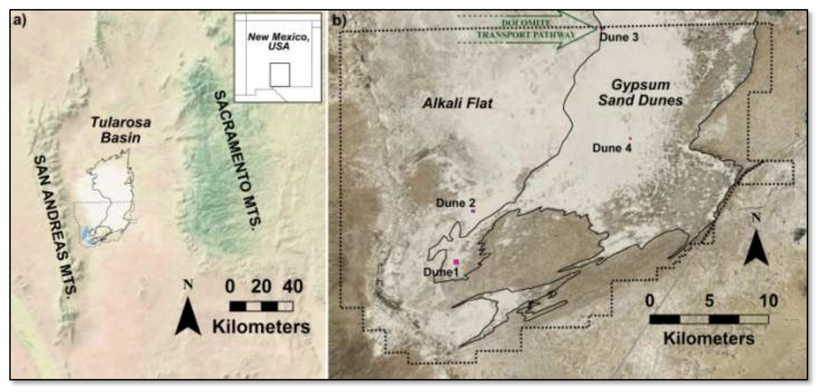

Figure 1. a) Gypsum dune field in the Tularosa Basin, and b) WSNM border. Note the dolomite transport pathway upwind from Dune 3.

To better understand how aeolian processes redistribute gypsum and mafic materials (e.g., soft and hard minerals), we performed a field investigation at White Sands National Monument (WSNM) in New Mexico, USA (**Fig. 1**). The WSNM dune field is the largest known gypsum-rich dune field on Earth. This work focuses on samples taken on and near the stoss slope of a dune ("Dune 3") located at the dune field's upwind (western) margin, along a transport pathway of dolomite ($CaMg(CO_3)_2$) grains that mix with the gypsum grains, potentially interacting in ways analogous to that of the harder and denser mafic grains common to Olympia Undae. **Figure 2** shows the sites of samples on Dune 3, collected along its stoss slope and from two coarse-grained ripples.

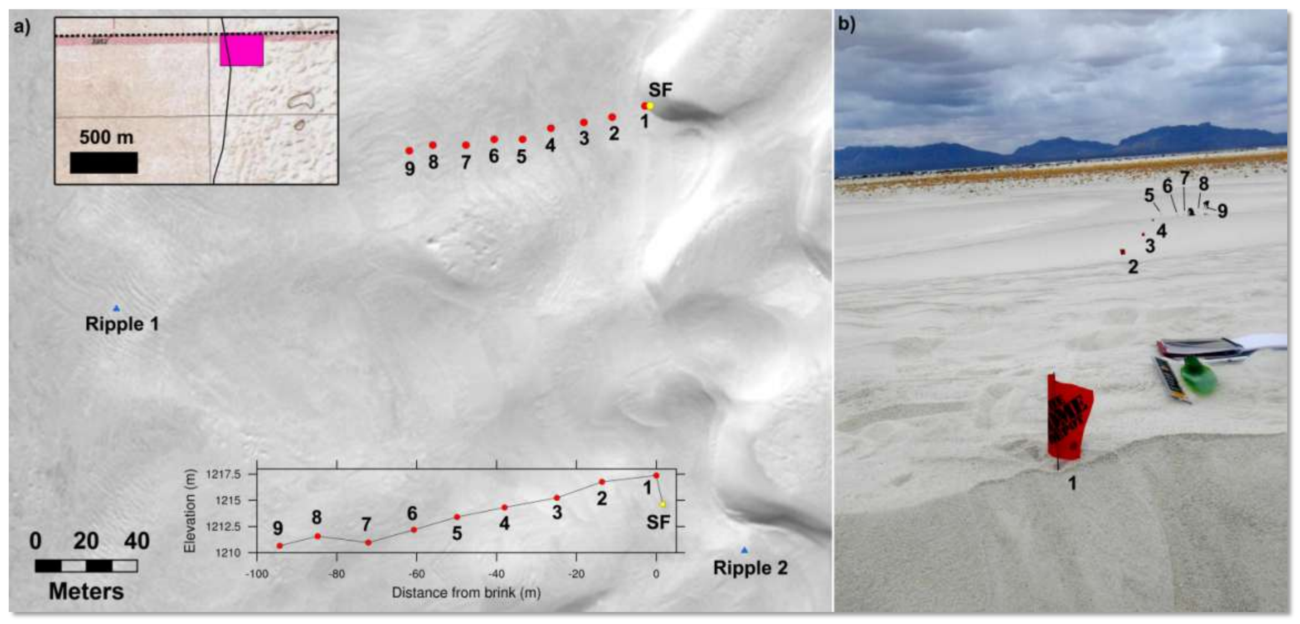

Figure 2. Dune 3, showing a) context, sample locations, and elevation, and b) a westward-looking view from the brink.

VNIR and XRD Mixture Calibration

Figures 3a and **3b** show VNIR spectra of gypsum/quartz and gypsum/dolomite mixtures. Gypsum easily dominates the gypsum/quartz mixtures, so that quartz is only detectable when it consists of >~80% of the mixtures. Dolomite is much more easily detectable, as it can be identified when it is >~20% of the sample.

Figures 3c and **3d** show corresponding XRD spectra of similar mixtures. Gypsum is distinct from both quartz and dolomite, permitting semi-quantitative analyses of mineral abundances using the Reference Intensity Ratio (RIR) method [8].

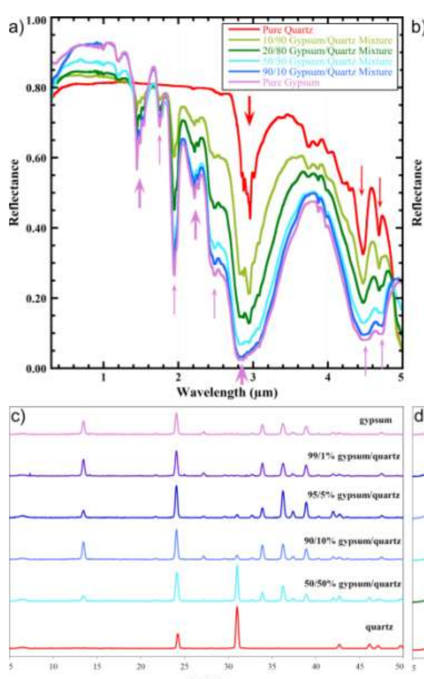

Figure 3. Spectra of gypsum/quartz and gypsum/dolomite in the 45-150 μm size fraction for VNIR (a, b) and XRD (c, d).

VNIR, XRD, and Raman spectra

All VNIR field spectra showed only gypsum, despite the clear presence of darker grains (e.g., the background of this poster shows large grains on the surface of Ripple 1). In the lab, grains from Dune 3 (**Fig. 4**) and Ripples 1 and 2 (**Fig. 5**) were sieved into eight size fractions and spectra were obtained using both VNIR and XRD analysis. The coarsest grains from Ripples 1 and 2 were separated by apparent color and analyzed by these groups. **<u>Mineralogical diversity was broadest 1) in >1 mm grains and 2) upwind of the dune field</u> (Table 1).**

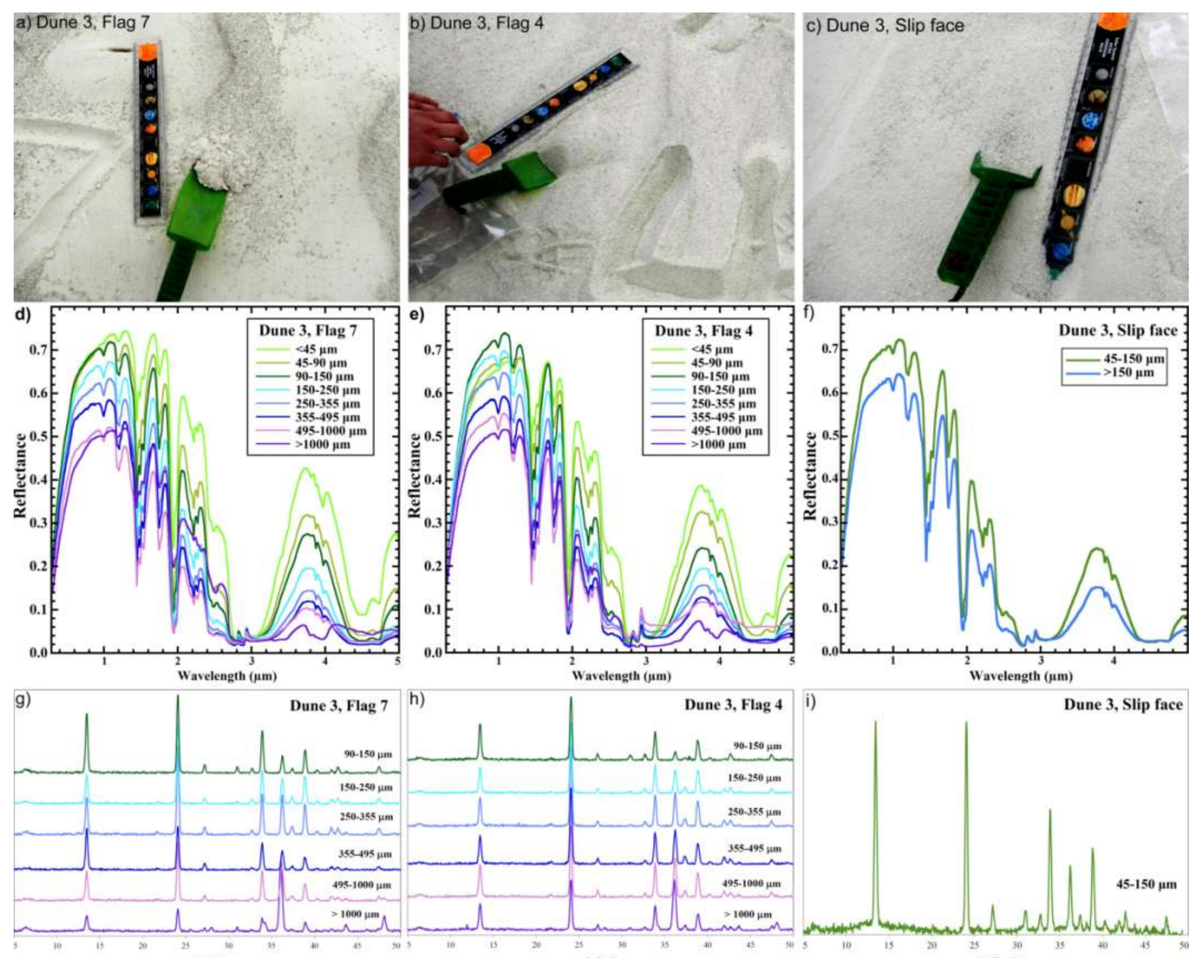

Figure 4. Field collection of samples from Dune 3, from the a) lower stoss, b) upper stoss, and c) slip face. The second row (d-f) shows corresponding VNIR spectra by grain size; the 3rd row (g-i) shows the same with XRD (see also Table 1). Note that (1) gypsum dominates all size fractions except the largest and that (2) mineralogical diversity decreases downwind (to the right).

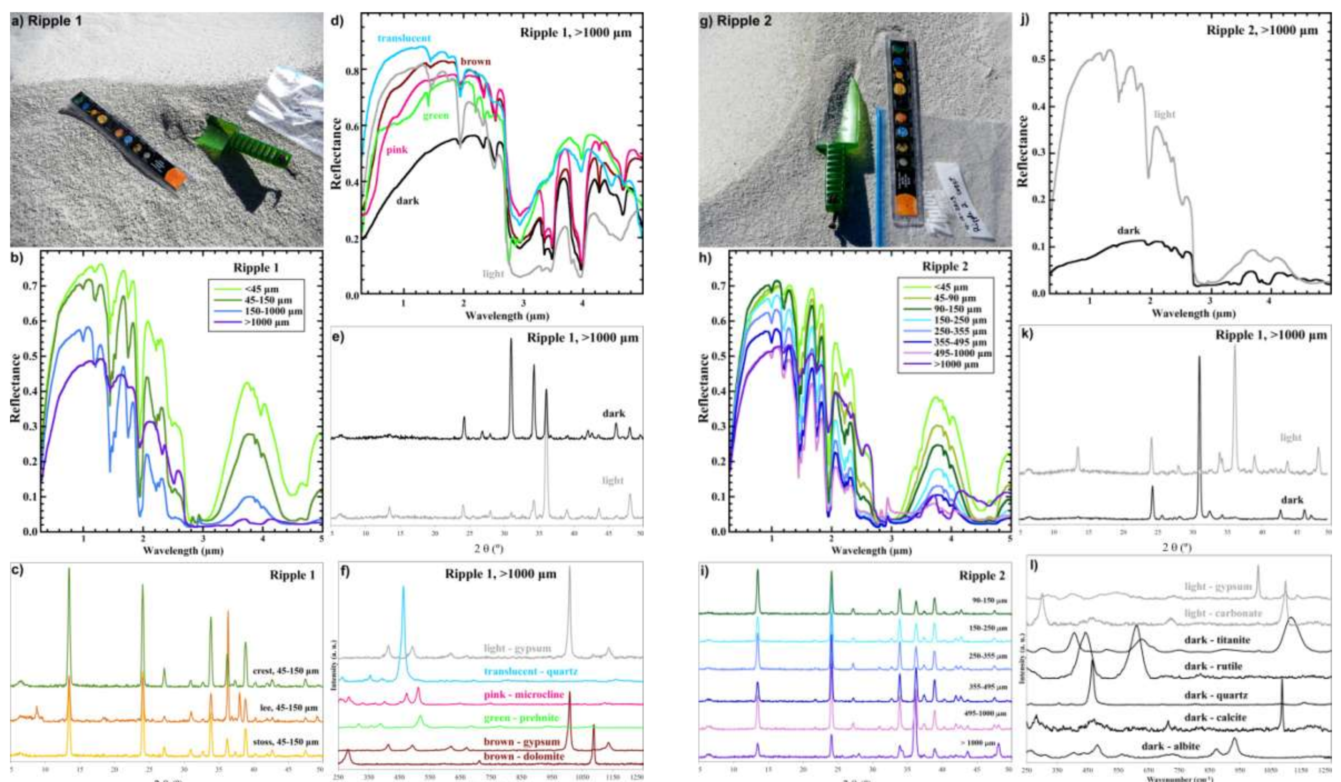

Figure 5. Field collection of samples from a) Ripple 1 (upwind of Dune 3) and g) Ripple 2 (on a neighboring dune stoss). VNIR (b,h) and XRD (c,i) spectra show increasing mineralogical diversity with grain size. Color separates in VNIR (d,j), XRD (e,k), and Raman spectroscopy (f,l) show a loss of mineralogical diversity downwind, similar to that observed on Dune 3 (see Fig. 4 and Table 1).

Table 1. XRD mineral abundances, >1 mm grains	Gypsum	Quartz	Dolomite	Calcite
Dune 3:				
Lower Stoss (Flag 7)	30 wt.%	2 wt.%	60 wt.%	7 wt%
Upper Stoss (Flag 4)	60 wt.%	2 wt.%	39 wt.%	-
Coarse-grained ripples:				
Upwind (Ripple 1)	13 wt.%	5 wt.%	69 wt.%	12 wt.%
Near dune crest (Ripple 2)	30 wt.%	-	63 wt%	7 wt.%

Discussion

The abundance of non-gypsum grains >1 mm drops off sharply at the upwind margin of the dune field, whereas gypsum dominated the finer fractions (<~1 mm) at all sample sites. **Figure 6** shows the estimated saltation mass flux q relative to gypsum grains of the same size (q_{gypsum}) [9,10] for (**Fig. 6a**) the WSNM formative friction velocity [11] and (**Fig. 6b**) the strongest measured winds at WSNM [12]. The ρ_{gypsum}/ρ_g line shows grain differentiation caused by creep [13].

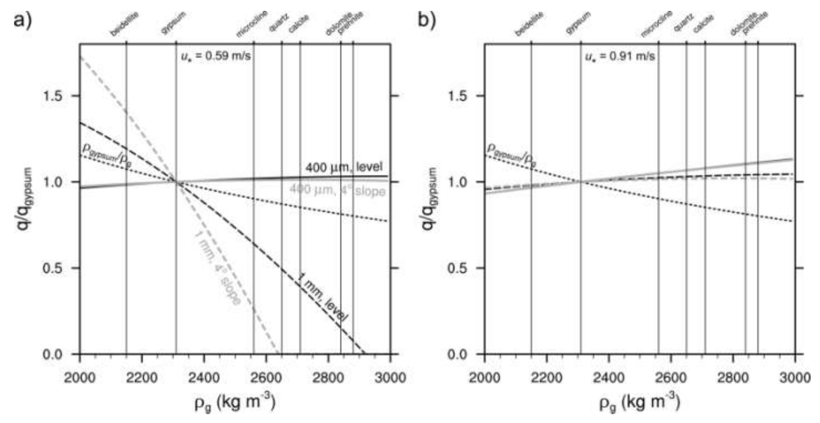

Figure 6. Saltation mass flux q vs. grain density ρ_g for two grain sizes (400 μm, 1 mm), on two slopes (0°, 4°), and at two different wind strengths (a,b). <u>Saltation of >1 mm grains just above the threshold most strongly differentiates grains by density.</u>

A similar analysis for Olympia Undae is shown in **Fig. 7**, using saltation fluxes [14] and (**Fig. 7a**) local friction velocities predicted by the Mars Climate Database (MCD) [15]. **<u>At u_* = 0.5 m/s, all grains would be strongly differentiated by density, consistent with the observed concentration of gypsum on dune crests.</u>** The effect is reduced in stronger winds (**Fig. 7b**), consistent with the MCD output friction velocities.

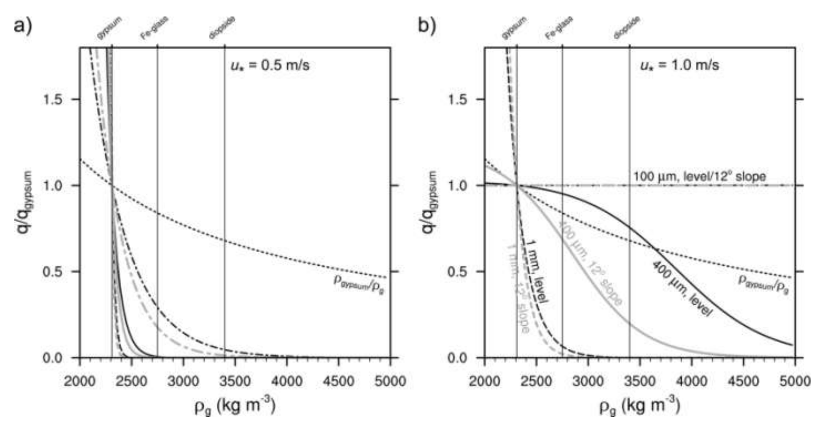

Figure 7. A similar analysis as shown in Fig. 6, done for Olympia Undae.

Conclusions

- Although creep gradually segregates grains by density, the differentiation process is much more effective when winds are just strong enough to saltate >~1 mm grains. Still stronger winds would erase this spatial pattern. <u>As a result, grain differentiation can be used (with care) to remotely estimate typical wind strengths.</u>

- When applied to Olympia Undae, a similar analysis suggests the strongest winds modeled by the MCD would differentiate gypsum from the mafic grains, leading to the observed enhanced abundance on dune crests.

- BEWARE: Mineralogy determined through remote sensing of dune fields and analysis of dune foresets may poorly represent that of source regions. The apparently "pure" gypsum dunes at WSNM do not represent the wide diversity of minerals upwind.

References

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Gypsum on Mars dunes, white crystals blown to the crests. How does wind do that?

1 cm