INTERNAL BOUNDARY LAYER CONTROL FOR SEDIMENT FLUX IN HERSCHEL CRATER, MARS.

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Introduction: As wind blows over a landscape, increases in surface roughness can act as a sink for the wind's momentum; this retardation diffuses upward creating an internal boundary layer (IBL). Since terrestrial work [1] has shown that IBL formation can easily explain the observed decreasing sand flux profile in a barchan and crescent dune field at White Sand, NM, we are testing the hypothesis that IBL formation can also largely explain measured flux profiles in Martian aeolian settings.

Two distinct modes of sand flux [2] potentially affected by IBLs are saltation and reptation, which together make up the bulk of all sand transport. Saltation is primarily a fluid mechanical phenomenon whereas reptation is largely ballistic. Saltation is the main contributor to the formation and movement of dunes whereas reptation is responsible for the formation and movement of ripples. Tracking dune slip face advancement provides an estimate of total flux (saltation + reptation) whereas tracking ripples (via the semi-automated COSI-Corr method [3]) provides a measure of reptation flux [4].

IBL theory has yet to be tested on Martian sand sheets. These wide-spread sand sheets lack slip faces and have diffuse margins; the only precise means of tracking sand flux via remote sensing is to track ripple migration. Then, assuming a flux partition ratio derived from ripple and slip face studies of dunes, the total flux can be estimated. With such an estimate for total flux, we can compare measured and estimated flux values with those predicted from the formation of an IBL.

Case Study: Herschel Crater is a 300 km diameter Noachian-aged [5] peak-ring impact basin featuring extensive dune and sand sheet fields. The HiRISE camera (High Resolution Imaging Science Experiment) has sufficiently imaged two sites within Herschel (termed Herschel West and Center) in order to produce digital elevation models (DEMs) and to measure changes. Herschel West aeolian morphology grades downwind from barchans, to barchanoids, to barchans together with dome dunes, to sand sheets (Figure 1). Herschel Center only features sand sheets.

Measurements on Herschel West's dunes and sand sheets allows partitioning flux between saltation and reptation; this partition is then used to estimate total flux from the reptation-only measurements in Herschel Center's sand sheets.

Flux Measurements & Partition: *Total Flux:* Co-registered, HiRISE orthoimages reveal advancing slip faces in repeat imaging. Manual mapping of the advancement area and slip face arc length, together with the time between the images, gives an average value for dune advancement rate. Multiplying this rate by the dune height—measured from HiRISE DEMs—yields dune crest volumetric flux.

Reptation Flux: Two co-registered HiRISE orthoimages taken at different times allows measurement of ripple rate and, when multiplied by the average ripple height (taken as the half-height of a representative ripple) yields reptation flux. Ripple heights are below the resolution of the HiRISE-derived DEM and so must be assumed as some fraction of the ripple crest-to-crest wavelength spacing. Using ground-truthed data from the Mars Exploration Rover Spirit [6], the wavelength/ripple height ratio is 0.1-0.15. For Herschel West the mean ripple spacing is 2.6 m and we take the characteristic half-height to be 0.13-0.20 m.

Figure 1. Moving downwind in Herschel West, the dune morphology evolves from discrete barchan to barchanoid, to a mix of barchan and dome dunes, and finally to sand sheets. This change in morphology correlates with a change in flux (Figure 2). Each square frame is 500 m x 500 m. HiRISE/UA PSP_002860_1650.

Fluxes: The mean measured total flux for Herschel West dunes is 1.412 m^3/m/yr; for the same dune population the mean reptation flux is 0.316 m^3/m/yr yielding a total flux/reptation flux ratio of 4.5 (saltation/reptation ratio of 3.5). This ratio is similar to the value of 5 found by [4] in Nili Patera using identical methods. For comparison, dunes in Victoria Valley, Antarctica have volumetric fluxes ~10x higher [4 & references therein].

IBL Comparison with Observed Fluxes: [1] present a relation of predicted flux versus downwind distance assuming the flux is controlled by IBL development:

$$\langle q_s \rangle = 0.055 I \frac{\rho_{\text{air}}}{\rho_{\text{solid}}} \frac{C}{g} \sqrt{\frac{D}{D_0}} U^3 \left(\frac{\nu}{U z_{0L}^{1/5}} \right)^{3/8} x^{-3/10}$$

where the variables are defined in Table 1 alphabetically.

Herschel West Dunes: Figure 2 shows flux predictions (thin colored curves) assuming a range in wind intermittency (Table 1) and is compared against total flux measurements in Herschel West. While the IBL flux predictions envelop most of the measurements, the anomalously high values mid-field can likely be explained from those dunes' positions atop a subdued crater rim, though counterexamples are also apparent. It seems height and downwind distance have competing effects on wind strength and hence sediment flux: increases in elevation compress streamlines within the atmospheric boundary layer (ABL, ~2 km thick) and thus increase wind speed and flux (the "Venturi effect"). However, increasing downwind distance allows the IBL to thicken and hence for wind and flux to decrease. For the anomalous midfield fluxes, we propose that topographically-related wind strengthening dominates over IBL-related weakening, though the reverse may be true for other locations within the aeolian field; future modeling efforts may predict the net effect from this interplay.

Table 1: Variables & values used in IBL flux predictions.

Variable	Value	Description
C	3.88	Friction coefficient for sand at Mars' Reynolds number < 10
D	250 µm	Characteristic grain size
D_0	100 µm	Reference grain size (standard)
g	3.7 m/s^2	Mars gravity
I	0.001, 0.005, 0.01 (varied in model)	Intermittency of above-fluid threshold winds
U	20-37 m/s	Free stream air velocity
x	Varies, m	Distance downwind from the upwind margin
z_{0L}	0.0896 m	Lettau roughness height
ν	6.8831 x 10^{-4} m^2/s	Kinematic viscosity
ρ_{air}	0.0154 kg/m^3	Air density
ρ_{solid}	3000 kg/m^3	Density of (basaltic) sand grains

Herschel Center Sand Sheets: The Herschel Center sand sheets are more complex. Without using *a priori* flux knowledge, IBL estimates agree with the range of estimated total fluxes but not necessarily with the flux profiles. Figure 3 shows two sample profiles out of the seven measured sand sheet profiles for Herschel Center.

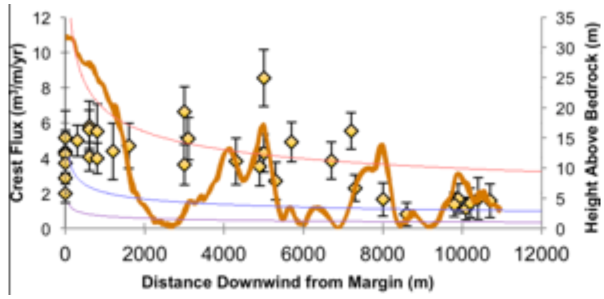

Figure 2. Flux predictions (thin purple, blue, & red curves), actual dune crest measurements (yellow data points), and bedrock topography (thick orange curve). See text for explanation.

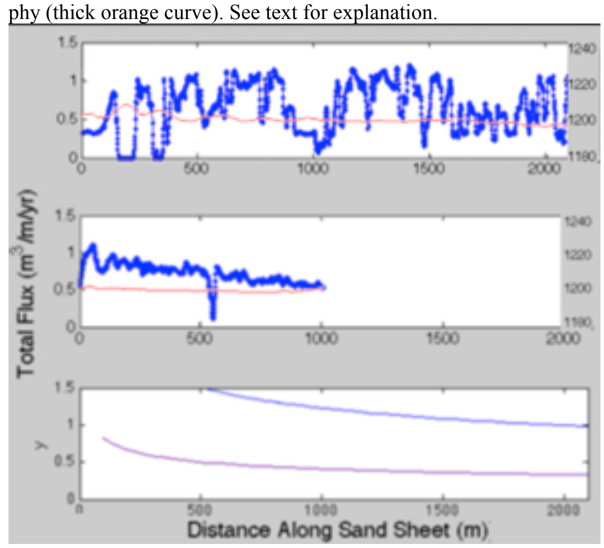

Figure 3. Top two panels show estimated total flux profiles (thick blue squiggles; left-side vertical scale) based on the measured ripple migration rates and a saltation/reptation ratio of 3.5. The thin red squiggles are combined sand sheet/bedrock topography relative to Mars datum (right-side vertical scale). The bottom panel depicts predicted flux profiles from IBL theory, which accurately predicts the overall flux measurements but not necessarily the flux decay profile.

Discussion, Conclusion, & Future Work: Whereas IBL theory seems to dominate the flux decay profile at White Sands, other geophysical factors in Herschel Crater seem to also significantly control aeolian flux profiles, such as the Venturi effect over raised topography. Future work may involve calculating the contribution from the Venturi effect at every point along the transect and comparing with the IBL flux prediction.

References: [1]Jerolmack, D.J. et al., (2012), *Nature Geoscience*, DOI:10.1038/NGEO1381. [2] Anderson, R.S. (1987) *Sedimentology* v. 34, no. *5*, p. *943-956*, doi: 10.1111/j.1365-3091.1987.tb00814.x. [3] Leprince S. et al., (2007) *IEEE Trans. Geosci. and Rem. Sensing, 45, 6.* [4] Bridges N. T. et al. (2012) *Nature 485, 339, doi:10.1038/nature11022.* [5] Tanaka, K.L., et al., (2014), Geologic Map of Mars, *USGS Scientific Investigations Map 3292*. [6] Sullivan R., et al., (2008), *JGR* 13, E06S07, doi:10.1029/2008JE003101.

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