RECONSTRUCTING THE FORMATIVE WINDS OF A DUNE FIELD IN GANGES CHASMA, MARS, BY BOOTSTRAPPING WITH THE RULE OF MAXIMUM GROSS BEDFORM-NORMAL TRANSPORT.

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Introduction: The widespread presence of bedforms on the surface of Mars holds a largely untapped potential for reconstructing their formative wind regimes, which are critical for understanding patterns of sediment transport and climate change. We quantitatively apply the concept of maximum gross bedform-normal transport (MGBNT) in a dune field in Ganges Chasma on Mars, showing that dune morphology reveals winds not easily distinguishable without use of this approach.

Bootstrapping with the Rule of Maximum Gross Bedform-Normal Transport: Experimental studies have shown that the orientation of a bedform is aligned as transverse as possible to all incident, sediment-bearing flows [1, 2]. Mathematically, the gross bedform-normal transport T across any potential bedform trend can be represented as the sum of N transport vectors Q_i (e.g., measured sand fluxes) projected onto the gross bedform-normal transport:

$$T = \sum_{i=1}^{N} Q_i \left|\sin\alpha_i\right|$$

where α_i is the angle between each transport vector Q_i and the bedform trend. The bedform will develop so that it is aligned orthogonal to the maximum gross bedform-normal transport T_m (see Fig. 1).

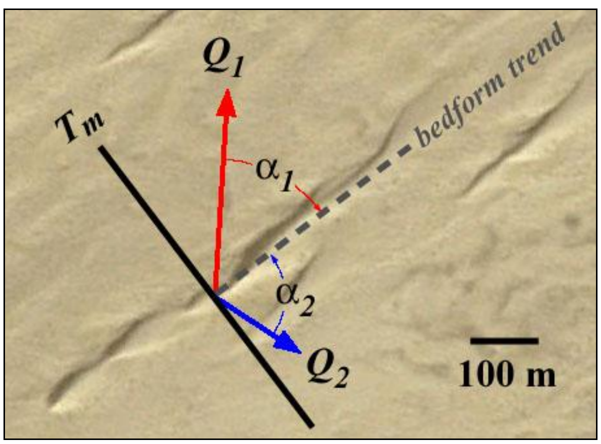

Figure 1. Bedforms are aligned orthogonal to the maximum gross bedform-normal transport, T_m.

The bedform trend is distinct from the resultant transport direction (i.e., the vector sum of all transport vectors Q_i), which may be orthogonal, parallel, or oblique to the bedform trend (resulting in transverse, longitudinal, and oblique dunes, respectively). In conditions in which the direction and relative strengths of incident sand-bearing winds are known, the rule of MGBNT allows prediction of bedform type and orientation.

However, there are few locations on Mars where the wind regime is known with enough accuracy to determine the local bedform morphology. On Mars, local winds may occasionally be inferred from unidirectional wind markers, such as yardangs and wind streaks. Using MGBNT, the relative sand transport capacity of such winds can be determined by comparison with dune crestline orientation (i.e., the relative magnitude of the transport vectors Q_i can be determined by calculating the set of angles α_i that produce the maximum gross bedform-normal transport T_m).

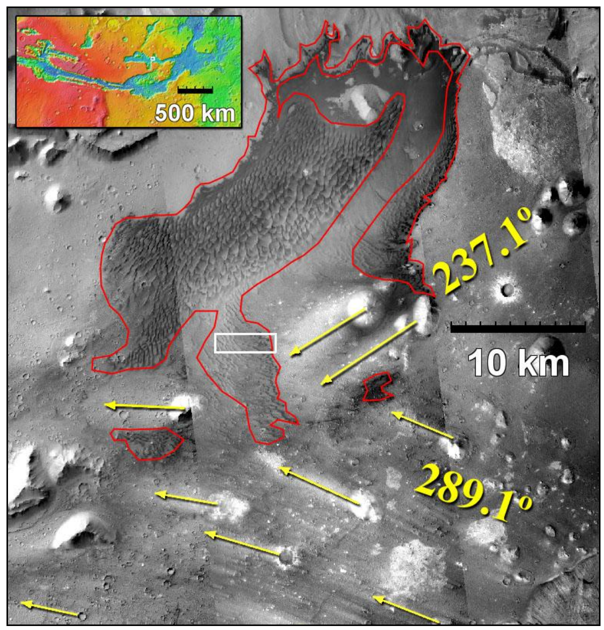

Figure 2. A dune field in Ganges Chasma, showing with two sets of wind streaks formed from sand-transporting winds. The white box shows the location of Fig. 3.

If nearby dunes appear to be shaped by a more complex wind regime than that implied by unidirectional wind markers, then it is possible to constrain the formative wind regime using a process here termed “reverse-MGBNT”. In this case, the concept of MGBNT is used to determine the possible range of incident winds that would combine with known winds to produce the observed dune crestlines (i.e., possible transport vectors Q_i are identified by their capacity to produce the observed bedform trend). The solution is nonunique, but the wind regime can often be constrained by dune morphology. By assuming that such identified winds are now "known", one can reapply them elsewhere in the same dune field with the rule of MGBNT in a bootstrapping process.

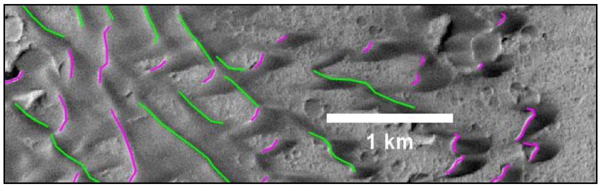

Figure 3. A portion of the dune field from Fig. 2, showing two sets of crestlines: barchanoid dunes in magenta and oblique or linear dunes in green.

Example in Ganges Chasma: Figure 2 shows the largest dune field on the floor of Ganges Chasma, which is one of several large canyons in Valles Marineris (see inset). The dune field spans 305 km^2, with its main body extending NE-SW, parallel to the local chasma wall. Hundreds of wind streaks, yardangs, wind scours, and barchans in the chasma indicate that the net sand transport is towards the west, parallel to the walls [3]. In the region of the dune field, there are two sets of wind streaks: a prominent set flowing WNW (289.1º) and a less distinct set flowing SW (237.1º). Figure 3 shows a small portion of the south-east edge of the dune field, with two sets of dune crestlines outlined (a total of eight different sets, not shown, were identified in the dune field). Each set of dune crestlines was produced by a different combination of transport winds (Q_i).

Magenta crestlines. Magenta crestlines outline a population of barchans, barchanoid, and transverse dunes in the southeastern portion of the dune field. Because of their morphology, it is likely that they were formed by winds with strong easterly components, so we use MGBNT to determine if the two wind-streak-forming winds could have produced these dunes, and in what proportion.

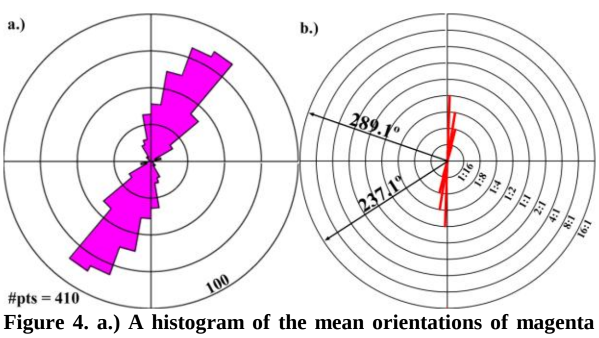

Figure 4. a.) A histogram of the mean orientations of magenta crestlines and b.) matching MGBNT crestlines produced by the two wind-streak-forming winds. Circles indicate varying relative strengths of the two winds (ratios are shown as 237.1º:289.1º).

Figure 4a shows a histogram of the magenta crestlines, which have a strong mode oriented NE-SW. The two wind-streak-forming winds, Q_1 and Q_2 in this example, combine to produce transverse dunes that best align with the magenta crestlines when the WNW-flowing wind (289.1º) dominates by at least a factor of two (with ratios of 1:2, 1:4, 1:8, and 1:16 in Fig. 4b).

Green crestlines: Green crestlines correspond to dunes that appear to be either oblique or longitudinal, with net transport towards the northwest. This is a case where reverse-GBNT can be used to constrain formative wind directions. It is possible that either or both of the two wind-streak-forming winds created these dunes, but at least one more sand-transporting wind must have contributed to produce the observed morphology. Building on the results from MGBNT analysis of the barchanoid dunes, we solve for all possible winds that could combine with the 289.1º winds to produce the green crestlines.

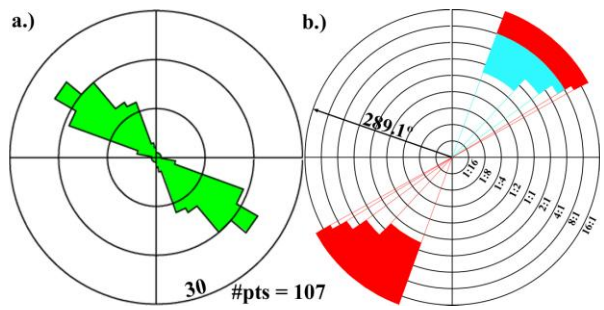

Figure 5. a.) A histogram of the mean orientations of green crestlines and b.) possible formative winds that produce the crestlines (red = transverse, blue = oblique).

Figure 5a shows a histogram of the green crestlines. Figure 5b shows possible combinations of winds that, together with the WNW-flowing wind, produce crestlines that align with those of Fig. 5a. Winds blowing to the SW (lower left quadrant) may be ruled out because dune morphology indicates a net transport towards the NW, which would not be the case if SW-flowing winds dominated dune formation. Assuming that only two winds form these dunes (likely an oversimplification), and that they are oblique, reverse-MGBNT indicates that they were formed by winds blowing toward the NE, with a transport magnitude 2-8 times that of the WNW-flowing wind streak winds.

Conclusions: In the absence of meteorological data, the principle of gross bedform-normal transport can be used to analyze dune fields remotely to determine the primary dune-building winds. Two sets of dune crests in a dune field in Ganges Chasma indicate formative winds blowing towards the WNW and NE, producing both barchanoid and oblique dunes.

References: [1] Rubin D. M. and Hunter R. E. (1987) *Science, 237,* 276-278. [2] Rubin, D. M. and Ikeda H. (1990) *Sedimentology, 37,* 673-684. [3] Fenton L. K. et al. (2012) *LPS XLIII,* Abstract #2441.