

THE MINERALOGY AND THERMOPHYSICAL PROPERTIES OF DUNES ON MARS: IMPLICATIONS FOR THE AGE AND ORIGIN OF MARTIAN SAND. A. R. Khuller¹ and S. Diniega², ¹School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85281 (akhuller@asu.edu), ²Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

Introduction: Sand dunes form on a variety of planetary bodies, provided there is enough atmospheric pressure and wind velocity for saltation and deposition to occur, and there are source materials to erode, be transported and get sorted into dunes. The observance, location and properties of these landforms is hugely informative, with implications on regional, and planetary scale circulation, dust cycling and erosion. Some key questions on Martian sands are: (1) What is the composition of the sand? (2) Is the sand sourced locally, or globally? (3) What is the particle size of the sand? Answering these questions has important implications for the age of sand on Mars in addition to weathering rates and wind patterns. Here we use thermal infrared data from the Thermal Emission Spectrometer (TES) and the Thermal Emission Imaging System (THEMIS) onboard Mars Global Surveyor and Mars Odyssey, respectively, in an attempt to address these questions.

Methods: Eleven dune fields were chosen from the Mars Global Dune Database [1]: six dune fields are intracrater, five are intercrater and three are near regions of ‘known’ mineralogical diversity (e.g. areas where olivine has been detected previously). To explore dune field mineralogy, TES spectra over dune fields and nearby regions were deconvolved using an endmember library based on previous work ([2-4]. THEMIS infrared data was used to calculate thermal inertia from which particle sizes were obtained [5]. Additionally, TES low-albedo Surface Type (ST) [6] and global mineralogy [7] classification data was used to explore patterns with potential source regions globally.

Results:

What is the composition of the sand?

Spectral results over the eleven dune fields are shown in Fig. 1. The dune fields are rich in feldspar, pyroxene and high silica materials, with minor amounts of carbonates, sulfates and olivine. These results are similar to those obtained by [2] over 79 dune fields. When compared to global ST results, the dunes are: (1) lower in feldspar than ST1 & ST2, (2) in between ST1 & ST2 in high silica materials and (3) enriched in olivine.

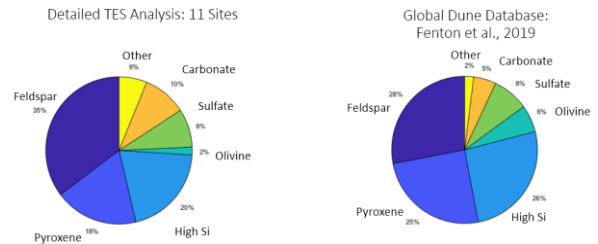


Figure 1. TES results over eleven dune fields compared with TES results from [2].

Is the sand sourced locally, or globally?

Globally, dune fields correspond to local Surface Types (Fig. 2), suggesting that sand is sourced locally from nearby regions. In general, dune Surface Types are anti-correlated, i.e., areas of high ST1 abundance are low in ST2 abundance.

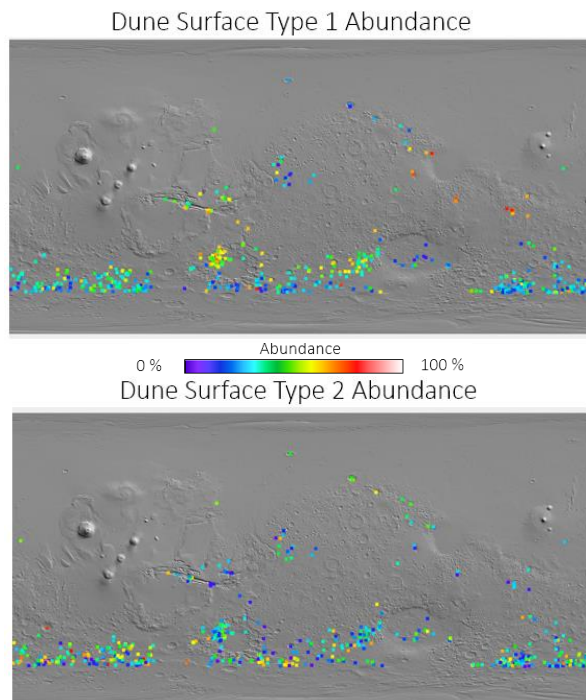


Figure 2. Global dune field Surface Type [2] abundance.

What is the particle size of the sand?

Grain sizes derived from nighttime THEMIS IR data over the eleven sites are shown in comparison with previous work ([9-11]). The Bagnold dune sand was found to range between 50-500 μm [8], with measurements from thermal inertia resulting in a mean grain size of $\sim 175 \mu\text{m}$ [9].

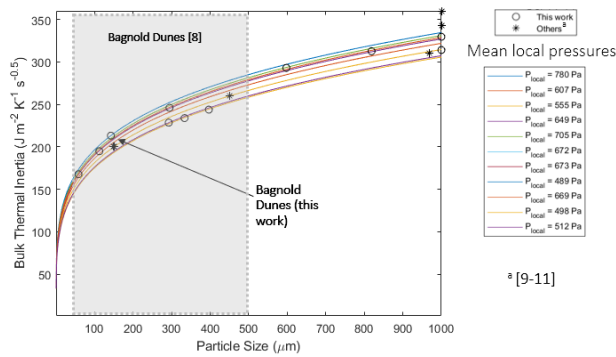


Figure 3. Dune sand particle sizes obtained from THEMIS infrared data in comparison with previous work [9-11].

These results are consistent with a grain size of $\sim 150 \mu\text{m}$ obtained here, which is in between the minimum range of particle sizes caused by aeolian breakdown [12].

Discussion: Basaltic soils on Mars seem to be compositionally similar globally, and unaltered by hydration [13]. Martian dust seems to be globally homogenous, and oxidized [14]. Martian sands also seem to be largely mafic, and therefore unaltered by oxidation and/or hydration. Note that the north polar sand seas have been found to contain hydrated minerals [15], however.

About 0.7% of Mars' surface is covered in sand dunes [16], equivalent to a global equivalent sand layer of $\sim 7 \text{ cm}$ (assuming an average dune/sand sheet height of 10 m). Assuming erosion has taken place since the start of the Noachian (4.25 Ga), this $\sim 7 \text{ cm}$ layer would require an average rate of sand production of $\sim 0.016 \text{ nm/yr}$.

But when did the production of this sand begin?

Three possible timeline hypotheses exist: (A) Sand formation primarily occurring in the Noachian, (B) sand formation primarily occurring in the Hesperian and (C) sand forming continuously throughout Martian history.

In cases A and B, the following stages might have occurred: (1) Sand production from volcanically derived materials. (2) Sands enriched with olivine from local/regional bedrock. (3) Sulfates mixed in with sand. (4) Surficial oxidation can occur; but oxidized layers are removed by wind, and suspended as dust.

If the sands formed primarily in a wet Noachian period, they may have been buried to evade aqueous alteration and then later exhumed. If the sands formed primarily in a dry Hesperian, then no burial/exhumation may be necessary.

In case C, steps (1) and (2) could have been followed by an aqueous weathering stage where some olivine-enriched sand was weathered to clay and removed by wind. Then, stages (3) and (4) could continue.

While it is difficult to discern which hypothesis is most valid, landing site deflation studies indicate an erosional rate of 0.02 nm/yr beginning in the late Hesperian [17]. Perhaps coincidentally, this erosional rate matches the required average rate of sand production ($.07 \text{ m}/3.1 \text{ Ga} \approx .02 \text{ nm/yr}$) if sand production began in the late Hesperian.

References: [1] Hayward R. K. et al. (2007) *JGR*, 112. [2] Fenton, L. K. et al. (2019) *Icarus*, 330, 189-203. [3] Charles, H. et al. (2017) *EPSL*, 458, 152-160. [4] Rogers, A. D., & Aharonson, O. (2008). *JGR*, 113. [5] Presley, M. A., & Christensen, P. R. (1997). *JGR*, 102. [6] Bandfield, J. L. et al. (2000). *Science*, 287(5458). [7] Bandfield, J. L. (2002). *JGR*, 107. [8] Ehlmann, B. L. et al. (2017). *JGR*, 122. [9] Edwards, C. S. et al. (2018). *JGR*, 123. [10] Fenton, L. K. et al. (2003). *JGR*, 108. [11] Fergason, R. L. et al. (2006) *JGR*, 111. [12] Golombek, M. P. et al. (2018) *XLIX LPSC Abstract # 2319*. [13] Yen, A. S. et al. (2005) *Nature*, 436. [14] Yen, A. S. et al. (2013) *XLIV LPSC Abstract # 2495*. [15] Fishbaugh, K. E. et al. (2007) *JGR*, 112. [16] Hayward, R. K. et al. (2014) *Icarus*, 230. [17] Golombek, M. P. et al. (2006) *JGR*, 111.

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