ORIGIN AND WEATHERING OF DUNE SANDS ON MARS FROM THERMAL-INFRARED SPECTRA.

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Introduction: Modern dune sands provide a window into sedimentary processes on Mars, but the source of sand is poorly understood. Composition may provide some constraints on sand origins, as high abundances of primary glass could indicate explosive volcanism or impact processes [1]. Previous landed and orbital studies [2-7] have shown that dune sands are composed of varying abundances of feldspar, pyroxene, glass, and secondary crystalline and amorphous materials, but the abundance and distribution of glass in global dunes is unclear. While some dune fields exhibit glass signatures in orbital visible/near-infrared (VNIR) spectra suggesting high glass abundances [2,3,5], the few global studies where glass has been specifically reported in models of thermal-infrared (TIR) spectra rarely show glass abundances above 10% anywhere on the planet [8,9].

Here we investigate two likely causes of limited TIR glass detections. First, that glass is undermodeled in TIR spectra due to a lack of appropriate endmembers in spectral libraries. Several recent global studies utilizing a variety of altered and unaltered basaltic glass samples with varying compositions and crystallinities have shown abundances of glass > 40% [10,11]; however, no dune TIR study has included mafic glass spectra. Second, we will test the hypothesis that glass is common but is masked by surficial rinds/coatings [6,9,12]. This is supported by the VNIR spectra of some glassy dune fields and the high abundances of high-silica phases in dune fields [3,6]. This would suggest recent aqueous alteration of the dunes. In addition, some studies have shown that high silica-phases may have a strong latitudinal distribution in dunes, perhaps due to additional alteration at high latitudes [3,6,8]. However, the composition of secondary phases in dunes is not well understood, as previous studies grouped primary glass with all secondary amorphous and high-silica phases.

To test these hypotheses, we conduct new models of dune TIR spectra to distinguishing between primary and secondary materials in order to determine the origin of dune sediments and understand global alteration mechanisms. We utilize a revised mineral endmember library [13] to constrain dune composition through deconvolution of Thermal Emission Spectrometer (TES) data.

Methods: TES, onboard Mars Global Surveyor (MGS), utilized a mid-IR (6-50 μm) interferometric spectrometer with a spectral resolution of 5-10 cm^{-1} [14]. We extracted TES data from JMARS, limiting selections to dune fields with at least 3 high-quality observations [15] (e.g., ock<7000; temperature > 260K). Due to a lack of dune fields with high temperature coverage in the north, interpretations are limited to equatorial/southern latitudes. Endmember abundances in vol. % were derived via linear least-squares deconvolution [16]. Atmospheric components are scaled according to modeled concentrations and then removed to produce a surface-only emissivity spectrum [17]. This method produced 59 mineral endmember abundances in 13 groups. Deconvolution model quality is assessed by root-mean-square error and inspection.

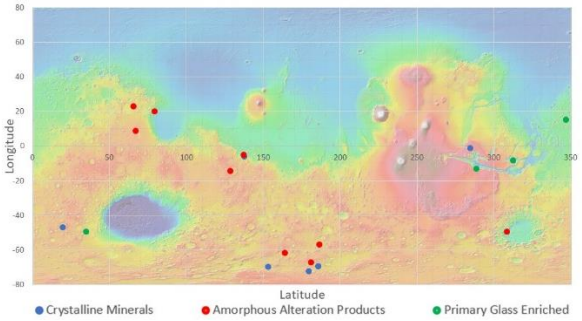

Figure 1: MOLA global topography showing dune locations.

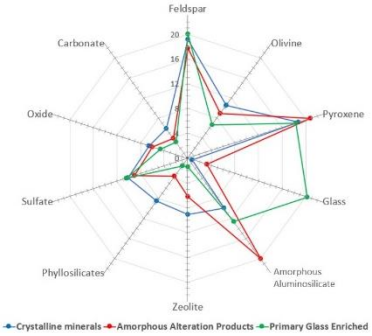

Figure 2: Average bulk mineralogy from TES models of our three dune compositional groups.

Results: A survey of 20 equatorial and southern dune fields (Fig. 1) demonstrates the ability to distinguish primary and secondary high-silica and amorphous phases, while also identifying other dominant minerals. All dunes exhibit high abundances of alteration minerals, ranging from 30-66%, but the composition of both primary and secondary phases varies. We have grouped dune fields of similar composition into 3 categories (Fig. 2).

The first category comprised of 4 dune fields are enriched in primary glass, making up 20-50% of the primary igneous minerals, and exhibits some of the lowest abundances of alteration phases (30-40%). At least two of these dune fields also exhibit glass signatures in VNIR spectra [3]. These new glass detections primarily

correspond to partially devitrified basaltic glass from [10]. Three of the four glassy dunes are equatorial.

The second category, comprised of 9 dune fields, is enriched in amorphous aluminosilicates (15-30%), including alteration products like amorphous silica, allophane, and aluminosilicate gel. These dunes exhibit higher abundances of alteration products overall (43-57%) and are found at both equatorial and mid to high latitudes. Within this category, dune field 1370-050 is located in northern Gale crater and is dominated by pyroxene (30%), amorphous aluminosilicate (20%), olivine (15%), sulfate (18%), and feldspar (9%). These results are generally consistent with in situ dune mineralogy in the Bagnold dune fields by MSL [7,18], which found dune mineralogy dominated by feldspar, olivine, and pyroxene, with high abundances (40%) of unknown X-ray amorphous components. Crystalline sulfates and zeolites were modeled at low to zero abundances from XRD at the MSL site, so if these phases predicted in our TES models are present, they may be poorly crystalline.

The third category, comprised of 7 dune fields, is dominated by crystalline minerals, with limited contribution from amorphous aluminosilicates or glass (typically <15%). Instead, alteration products variably include zeolites (0-25%), sulfates (5-20%), oxides (0-12%), and phyllosilicates (0-20%). These dunes exhibit no clear correlation with latitude.

Across all dunes investigated there is a strong anti-correlation between primary glass and all secondary aluminosilicates. No significant glass detections (>10%) occur in dunes with elevated secondary aluminosilicates (>20%). Other igneous minerals display much weaker or no relationship with secondary phases.

Discussion: In our initial survey of 20 dune fields on Mars, inclusion of additional glass endmembers, in particular partially devitrified glass, does appear to increase glass detections in TES data, consistent with global modeling from [10]. In addition, the strong anti-correlation between glass and overall alteration suggests that glass elsewhere has been removed or obscured by alteration. The observation that glass-bearing dunes tend to occur at low latitudes could suggest that alteration processes are more prevalent at higher latitudes [6], but more coverage will be needed to confirm this trend. However, in our current dataset, there is otherwise only a very weak overall correlation between abundance of alteration phases and latitude, and there is not yet a clear latitudinal trend in their composition.

These results have implications for the nature of "high-silica" phases previously detected on Mars [19,20]. Our results show that a majority of southern and equatorial high-silica phase detections correspond to secondary alteration phases as opposed to primary felsic glass, possibly indicating recent widespread aqueous alteration. We hypothesize that the nearly globally distributed TES Surface Type 2 (ST2) is primarily a result of aqueous alteration. However, comparison to in situ XRD analyses from MSL suggests that many of the alteration phases in the TES models may be poorly crystalline, possibly including not just aluminosilicates but also phases like sulfates and zeolites. Poorly crystalline sulfates have been produced in lab experiments [21], and poorly crystalline zeolites have been tentatively detected via XRD/TIR analysis of palagonites [22]. Poorly crystalline materials tend to form during rapid processes [23], including freeze-thaw cycling [24,25], glass dissolution [26], ice/magma interactions [22], and evaporation [21], all of which are likely under the cold and arid conditions expected throughout the Amazonian. Indeed, VNIR hydrated silica signatures are common in Amazonian aeolian and periglacial sediments on Mars [27].

The strong anti-correlation between glass and alteration could be due to coatings obscuring TIR glass detections. Alteration of glass under acidic conditions produces a silica-enriched rind that obscures the underlying substrate [3,6,28], while acid leaching of partially crystalline basalt causes volumetric alteration [28]. This process has been hypothesized to occur in the northern plains, leading to enhanced high-silica signatures which are correlated with the strongest ST2 detections [3,11].

Conclusions: Our results support the hypothesis that aqueous alteration either removes primary glass or deposits a silica-rich coating/rind that dominates TIR spectra by obscuring the substrate. The least altered dunes in our study contain relatively lightly altered primary glass, while the majority show evidence of significant alteration in the form of crystalline and poorly crystalline secondary phases. This suggests that dune sands across the planet underwent significant alteration, resulting in mixed sediments dominated by secondary phases. Glass-rich sediments in the least altered dunes could be consistent with a contribution from impacts, explosive volcanism, or ice-magma interactions.

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