MASS BALANCE OF MARTIAN FAN DEPOSITS: INSIGHTS ON DEPOSITIONAL PROCESSES AND ORIGIN.
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Introduction: Fan-shaped deposits formed at the mouths of Martian valleys, and have been interpreted as indicators of wet conditions during Mars history [1-3]. However, precise details on the types of depositional environments, the required amount of water and the time of formation are sparse. In order to characterize the depositional settings of Martian fan-shaped deposits we present the results of a global mass balance survey [4]. The aim of this study is to better understand the general sedimentary conditions under which previously interpreted fan-deltas [1] might have formed. Namely, by measuring and correlating the volume of eroded materials from the valleys and the volume of materials deposited on the fans. With this approach we test the likelihood of two distinct depositional settings: 1) fan-shaped deposits mainly formed on subaerial settings (Fig. 1b) vs. 2) river deltas formed on stable water bodies (Fig. 1c). The first type of deposits may have formed by limited fluvial activity and mainly by alluvial processes, mass wasting and/or gravity driven flows (e.g. landslides, glacial flows, lahar, etc.); in this case the volume of deposited sediments would be comparable to that eroded within the valley since the material would concentrate within a sediment apron right at the valley's mouth [2]. In contrast, true deltaic deposits would be farther spread within the hosting basins and not confined at the river mouth since a significant portion of the sediment will be transported and dispersed farther from the river mouth (Fig. 1c) [5]. Therefore, a valley/fan volume ratio close to unity would be indicative of a prevalence of subareal conditions while ratios >>1 would be indicative of typical fluvio-deltaic processes and deposition.

Data and methods: Digital terrain models and orthoimages derived from CTX imagery were primarily used to map the extent of the valley networks and associated fan deposits (a total of 60 fans and valleys were surveyed, Fig. 1a). In areas where CTX stereopairs are not available we used HRSC and HiRISE data. The volume of materials removed to form the valleys and the volume of the fans were computed using the DTMs and the mapped outlines (custom algorithms were developed for this purpose, see [4] for details and methods' validation). A comprehensive set of morphometric measurements for the valleys and fans were also compiled.

Mass balance model. The equation $(V_V + V_{TAR}) \times (1-\lambda_V) = (V_F + V_{erod}) \times (1-\lambda_F) \times L$ relates the present day fan and valley volumes (V_F and V_V), their porosities (λ_F and λ_V), the volume of the valleys' aeolian infill (V_{TAR}) and the fan volume that was eroded (V_{erod}) after deposition. A multiplicative coefficient (L) is used to account for the possible sediment loss due to offshore sedimentation of finer sediments. In order to evaluate the fan's post-depositional erosion rates and test the plausibility of syn-sedimentary material dispersion we performed a parametric analysis using the mentioned mass balance equation and our volume measurements (see [4] for details).

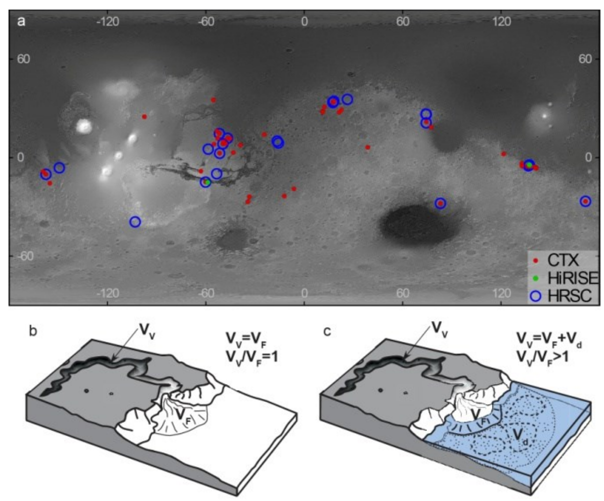

Figure 1 – Location of the mass-balance survey and block diagrams of the tested generic depositional settings. a) Areas surveyed. b) Fan mainly deposited in a subaerial setting resulting on a net ratio of valley volume (V_V) by fan volume (V_F) equal to 1. c) Delta/fan-delta forming in a body of standing water, characterized by a considerable amount of sediment off-shore dispersion (V_d represents the volume of the distal deposits); in this case the V_V/V_F ratio will be higher than 1.

Results: Nearly 70% of the measured valley/fan volume ratios cluster along the 1:1 ratio line (Fig. 2). Using the volume ratios we segmented the studied fans into two main categories: Type I fans with ratios ranging from ½ to 2, and Type II with ratios higher than 2. We then applied the mass balance equation in order to evaluate fan erosion rates and the likelihood of offshore sediment loss during deposition for each subpopulation. For the Type I fans, the optimal solution corresponds to a fan porosity of 0.3, a valley material porosity of 0.25, no offshore loss of sediments (*L*=1) and an eroded equivalent thickness of 16 m. The erosion rates that would explain the removal of this thickness of sediments are within 4-56 nm/yr, a range of values comparable with previous studies [6]. For the Type II fans, the mass balance model solutions for *L*=1 (no offshore sedimentation) requires the post-depositional erosion of more than 1 km of material from the fans. This is an unrealistic high value, corresponding to five times the current average thicknesses of the fans. Therefore, we conclude that a considerable amount of sediment must have been lost during the deposition of Type II fans. The mass balance model for this subpopulation shows that offshore loss coefficients between 3 and 10 are possible.

We have also identified significant morphometric differences between the two proposed subpopulations. Type II set present valleys with larger dimensions, while Type I fans were deposited on steeper surfaces.

Discussion and conclusion: Our results reveal that two different populations of fans might exist on Mars. Type I fans are more abundant and formed by processes that do not produce a relevant offshore loss of sediments during deposition (valley/fan volume ratio ~1). They are associated with smaller and less mature drainage networks and were deposited on steeper gradients. The mass balance modeling suggests that this type of fan/valley association formed mainly under subaerial conditions. We propose that Type I fans were not deposited in prevailing subaqueous deltaic settings, but mainly in subaerial conditions with perhaps sporadic presence of ephemeral bodies of standing water within the basins.

Type II fans present all the characteristic signatures of deltaic processes, with larger and more mature drainage networks, deposition on flatter surfaces and high percentage of sediment bypass. Some of the best studied Martian fans, whose formation was most likely driven by fluvio-lacustrine processes belong to Type II class (e.g. Eberswalde, Jezero, Magong/Sabrina, Nanedi Vallis, Shalbatana), and might be strictly interpreted as river-deltas.

Based on the collected morphometric measurements and mass balance modeling we conclude that only a small percentage of the fans (Type II fans correspond to ~1/3 of the sampled areas) are consistent with the occurrence of long-lived integrated fluvial, deltaic and lacustrine environments, and that the existence of deep syn-depositional paleolakes associated with Type I fans formation is highly questionable. Therefore, our results suggest that the majority of the considered Martian fan-shaped deposits (Type I) do not necessarily imply the occurrence of favorable nor long-lasting habitable conditions.

To complement this work and achieve a better comprehension of the Martian fan-shaped deposits, we plan to update the described fan-valley database (released as supplementary material on [4]), including a larger number of fans, crater counting ages for each fan and the inclusion of basin morphometric attributes.

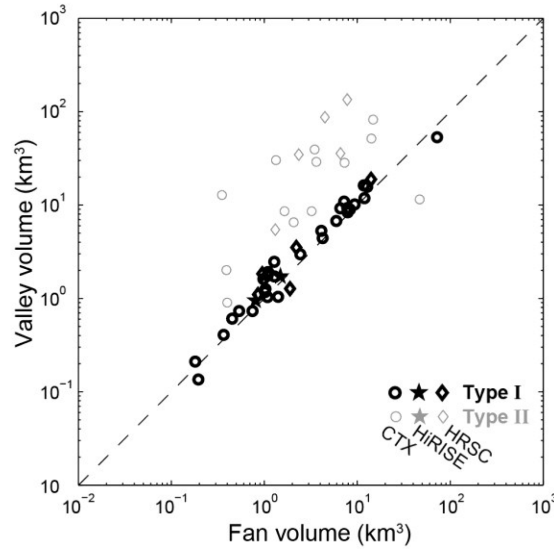

Figure 2 – Based on the V_V/V_F ratio we identify two subpopulations: Type I subpopulation is shown in black (½< ratio < 2), while the Type II subpopulation (gray) corresponds to valley/fan volume ratios >2. These two subpopulations are separately used for a parametric assessment of post-depositional erosion rates and offshore loss of sediments (see [4] for details).

References: [1] Di Achille G. and B. M. Hynek (2010). *Nature Geoscience,* Vol. 3 (7),459-463. [2] Malin M. C. and K. S. Edgett (2003). *Science,* Vol. 302 (5652),1931. [3] Hauber E., et al. (2013). *Journal of Geophysical Research: Planets,* Vol. 118 (7),1529-1544. [4] Vaz D. A., et al. (2020). *Earth Planet. Sci. Lett.,* Vol. In Press. [5] Hoke M. R. T., et al. (2014). *Icarus,* Vol. 228,1-12. [6] Golombek M. P., et al. (2006). *J Geophys Res-Planet,* Vol. 111 (E12).

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