Possible subsurface sediment mobilization and release of volatiles in southern Chryse Planitia, Mars

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Abstract: *Here we present the preliminary results of our mapping of a large field of cones and pie-like features in the Chryse Planitia area on Mars, which have been previously described as mud volcanoes [1]. Our aim was to determine the full extent of this field and perform a comprehensive morphological, morphometrical, and spatial analysis of the landforms. We mapped a total of 1280 objects and distinguished four different morphological classes. The spatial distribution of the features is clustered and anticorrelated to the highlands, favouring a sedimentary origin and hence mud volcanism.*

Introduction: Ever since the presence methane in the Martian atmosphere was first reported [2,3], mud volcanism was hypothesized to be a possible release mechanism [4], and various mud volcano fields have been tentatively identified [1]. It is difficult, however, to define diagnostic morphological properties of mud volcanism in remote sensing data, and some of the reported mud volcanos have alternatively been interpreted as igneous volcanoes [5, 6]. Moreover, mud volcanism on Earth has the following characteristics, some of which (e.g., hydrocarbon reservoirs) may not be easily found on Mars: (1) an origin from thick, rapidly deposited sequences; (2) an association to tectonic activity; (3) over- or underpressurization of sediments and accompanying fluid emission (gas, brines, gas hydrate water, or hydrocarbons); and (4) breccias in surrounding rock [7, 8].

In this study, we test the hypothesis by Komatsu and colleagues [1] that small cone- or pie-shaped landforms in Chryse Planitia are mud volcanoes. As the use of the term "mud volcanism" has far-reaching implications (see above), we prefer to follow a more conservative approach and use the more generic term "subsurface sediment mobilization" [9].

Our study area (8°N to 31°N/315°E to 330°E) is located near the southern boundary of Chryse Planitia at the terminations of the large outflow channels such as Ares, Simud, and Tiu Valles. Ancient highlands are eroded into streamlined "islands", and the former floor of the channels has been resurfaced and forms a relatively flat plain formed by flood deposits that slopes very gently towards north. These inter-island plains were mapped as Late Hesperian units HCc_3 and HCc_4 and Early Amazonian unit AB_{Vm} [10].

Methods: Several datasets were used for our morphological interpretations in the Chryse Planitia area: CTX (~5-6 m/pixel, [11]), HiRISE (~0.3 m/pixel, [12]), THEMIS daytime infrared (~100 m/pixel, [13]), and HRSC anaglyph images and Digital Elevation Models (~12.5 m/pixel [14]). Mapping was performed in a GIS (Geographic Information System) environment and units and objects were demarkated as polygons, polylines and shape points. We mapped highlands, craters, ejecta blankets, possibly extrusive features, fractures, and wrinkle ridges. Spatial investigations of mapped objects include nearest neighbor analysis, rectangle analysis, circularity calculations and orientation analysis.

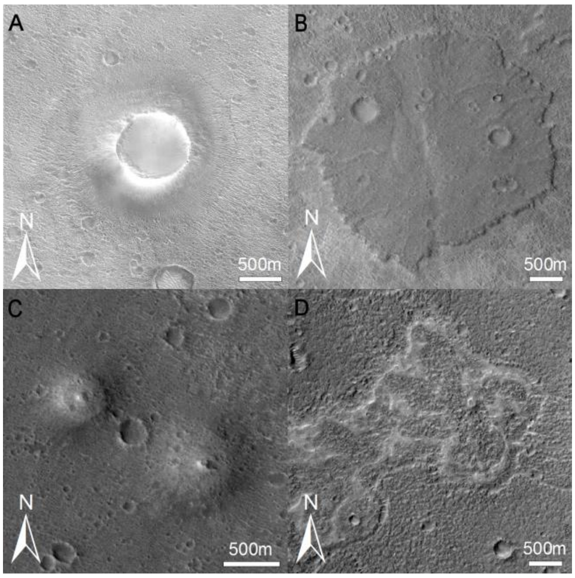

Figure 1: Four types of conical features: A) type 1, cones (HiRISE); B) type 2, pies (CTX); C) type 3, domes (CTX); D) type 4, irregular pies (CTX).Types 1-3 were already described by [1].

Preliminary results: Three types of landforms possibly indicative of extrusive processes in the study area were previously described [1]: type 1 (steep-sided cones; Fig. 1a), type 2 (nearly flat, or pie-like, structures; Fig. 1b), and type 3 (nearly circular, dome-shaped features; Fig. 1c). We include an additional type type 4 (Fig. 1d), which is characterized by a sheet-like appearance with irregular plan shape and lobate margins. Objects of this type are nearly flat (almost no topographical expression) and typically larger than 1 km in diameter, similar to type 2 features. Their surfaces are distinctively different from surrounding material, as they seem to exist of two different morphologies: light, smooth material, and dark, fractured material. In several areas these features can be observed in association with the other types suggesting that there may be a genetic link.

The spatial distribution of the possibly extrusive features appears to be anticorrelated to the highlands (Fig. 2), in other words they only occur on the level plains between the erosional remnants of the ancient highland material. Nearest neighbour analysis shows a less than 1% likelihood that the spatial distribution could be random, i.e. the features are clustered. could be the result of random chance. The different types appear in NEE-SWW oriented bands. Circularity was calculated as a value from 0 to 1, 1 representing a near perfect circle. Type 1 is the most circular of the features described here. Type 2 and 3 are similar in terms of circularity, with most values around 0.8 or higher. Type 4 is the least circular, with most values centered around 0.75. The minimum bounding geometry tool of ArcMap gives the length of the longer side of an enveloping rectangle around the polygons, and is here used as a proxy for the orientation of the extrusive features. We obtain a preferred E-W orientation, ranging from 65° to 115° (clockwise from North), with a mean orientation of 88°. Fractures appear mainly in patterns that are oriented parallel to the flow direction in the outflow channels, and their distribution is also anticorrelated to the highlands. The most densely populated fracture areas are observed in the northern (i.e. distal with respect to the outflow channel terminations) parts of the study area, without a clear correlation to the location of the conical features. Further upstream (proximal), the fractures display more transverse orientations.

Preliminary conclusions: The spatial distribution of the mapped features, which are excusively located in the sedimentary plains between the erosional remnants of the ancient highlands, suggests a formation mechanism that is linked to a relatively shallow source beneath the sediments. Igneous volcanoes fed from deep sources (e.g., distributed in monogenetic volcanic fields), on the other hand, would be expected to be distributed on both the plains and the highlands. Our preliminary observations hence support previous conclusions [1] that an igneous origin is less likely than a sedimentary volcanic origin. In the following steps we would like to (a) constrain the subsurface stratigraphy by determining the crater size-fequency distribution of the sedimentary plains, and (b) develop a simple numerical model with which we test the hypothesis whether subsurface sediment mobilization is a plausible formation mechanism.

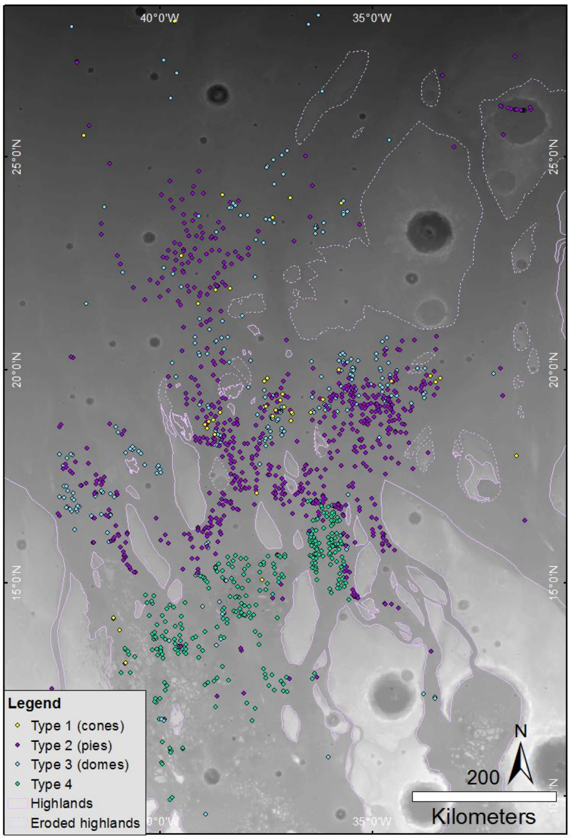

Figure 2: Overview of the mapped landforms on a HRSC DEM basemap. Yellow symbols: type 1 (cones), purple: type 2 (pie-like features); blue: type 3 (domes); green: type 4 (irregular sheet-like features). Highlands (around 200 meters height difference with surroundings) and topographically less distinct erosional remnants are outlined with solid and dotted pale purple lines, respectively.

References: [1] Komatsu et al., 2016, Icarus 268 [2] Formisano et al., 2004, Science 306. [3] Mumma, M. J., et al., 2004, BAAS 36 [4] Oehler and Etiope, 2017, Astrobiology [5] Brož, et al., 2004, EPSL, 406 [6] Brož et al., 2017, EPSL, 473 [7] Kopf, A. J. 2002. Reviews of Geophysics, 40 [8] Mazzini and Etiope, 2017, Earth-Science Reviews [9] Van Rensbergen et al., Subsurface Sediment Mobilization, Geol. Soc. Spec. Publ. 216, 2003. [10] Tanaka et al., 2005, USGS Sci. Inv. Map 2888. [11] Malin et al., 2007, JGR 112, E05S04 [12] McEwen et al., 2007, JGR 112, E05S02 [13] Christensen et al., 2004, SSR, 110 [14] Gwinner et al., 2016, PSS, 126.