EPSC Abstracts
Vol. 11, EPSC2017-573, 2017
European Planetary Science Congress 2017

DTM-based automatic mapping and fractal clustering of putative mud volcanoes in Arabia Terra craters

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Abstract

Arabia Terra is a region of Mars where occurrence of past-water manifests at surface and subsurface. To date, several landforms associated with this activity were recognized and mapped, directly influencing the models of fluid circulation. In particular, within several craters such as Firsoff and an unnamed southern crater, putative mud volcanoes were described by several authors [1, 2]. In fact, numerous mounds (from 30 m of diameter in the case of monogenic cones, up to 3-400 m in the case of coalescing mounds) present an apical vent-like depression, resembling subaerial Azerbaijan mud volcanoes and gryphons [3]. To this date, landform analysis through topographic position index and curvatures based on topography was never attempted. We hereby present a landform classification method suitable for mounds automatic mapping. Their resulting spatial distribution is then studied in terms of self-similar clustering.

1. Introduction

Although the putative mud volcanoes were described in detail [2] through high-quality observations from NASA MRO HiRISE (0.25 m/pixel), a sufficient coverage among the entirety of the craters is still not available. However, CTX images at 6 m/px resolution fully cover the studied area, also presenting several overlapping observations suitable for DTM reconstruction and further analyses.

2. Methods

2.1 Stereo DTM generation

CTX stereo-derived DTMs were generated with Ames Stereo Pipeline [4] and co-registered with HRSC DTM and MOLA areoid. Since CTX DTMs have ~18 m post spacing, we developed and tested auto-detection on areas covered also by HiRISE images and DTMs (tipically at 1 m/pixel), that were subsampled at the same resolution of CTX DTM (18 m/pixel) for comparison and validation.

2.2 Mounds automatic extraction

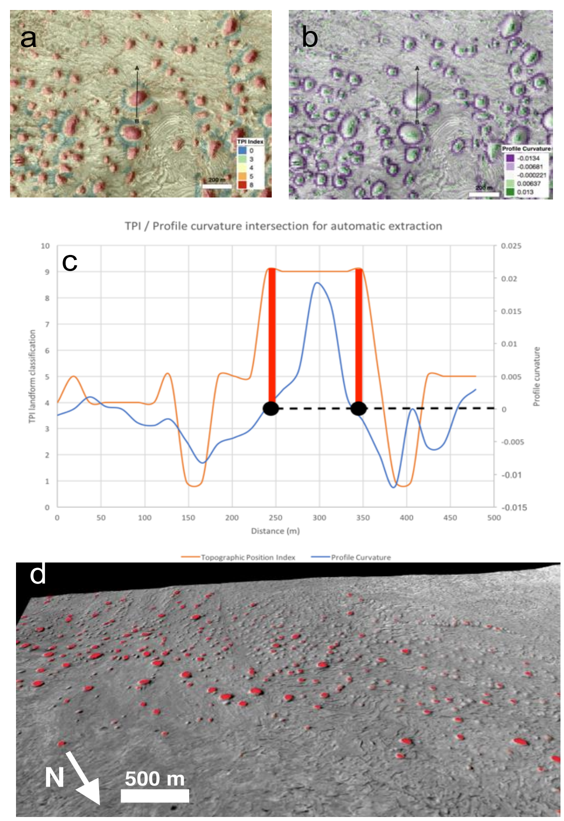

Figure 1: a) TPI index highlighting the mounds in red and their contour base in blue. In b) Profile curvature of the mounds and in c) profile curvature (blue curve) and TPI (orange curve) with the points of intersection used for automatic extraction. In d) a perspective view of mounds extracted on the southern crater

The TPI (Topographic Position Index) [5] is the basis of our morphometric classification and relies on the difference of elevation values between a raster cell and its neighbors. The degree of relief is used to classify the DTM raster cells into slope positions [5]. Since TPI is scale dependent according to the window size, we used a multi-scale approach based on the combination of large and small window sizes to combine small positive topographic expressions with larger ones (100-1000 m)[5]. TPI values <9 were able to identify the mounds (along with ridges and yardangs) both in narrow valleys and broader plains (Figure 1). The intersection of TPI =9 with zero profile curvature was used to automatically extract the mounds' contours (Figure 1c, d). All the outliers with aspect ratio lower than 0.4 [6] (corresponding to ridges and yardangs) and smaller than 60 m (a circular feature to be detected must be at least of 4 pixels in diameter) were then discarded. All the automatically extracted features were then visually checked on HiRISE images resulting in high-precision mounds detection, and then extended on broader areas with CTX coverage.

3. Results of the Cluster analysis and future perspectives

It has been shown that on Mars percolating fractures systems be studied in terms of fractal clustering deriving the depth of fluid reservoirs [7]. In this case, the distribution of the automatically extracted mounds shows a fractal behavior up to a cutoff value that corresponds to 2 and 2.5 km deep fluid reservoir, likely feeding the putative mud volcanoes in the past (Figure 2).

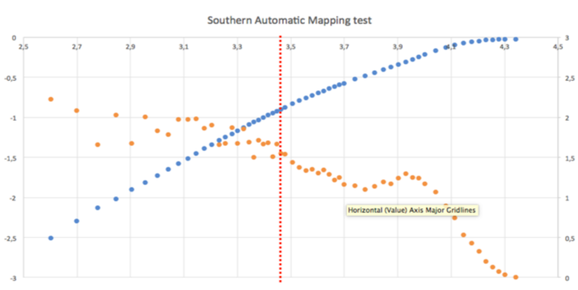

Figure 2: example mounds self-similar clustering in the southern crater based on automatic mapping. The upper cutoff of the fractal distribution is marked with the red dashed line, corresponding to 2-2.5 km of fluid source depth.

New outcomes from ExoMars TGO and CaSSIS will help to better characterize the areas in terms of morphology, composition, to provide broader DTM coverage and, possibly, clues for associated outgassing activity.

4. References

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