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Constraining the geometry and volume of Tharsis dome, Mars using impact craters central peaks

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1. Introduction

The Tharsis dome is about 5000 km across and represents the largest volcanic province in the solar system. The dome is composed of successive volcanic eruptions spanning the Noachian to Amazonian periods but is thought to have mostly formed at the end of the Noachian epoch [1]. Previous authors [2] determined that the Tharsis dome would have modified the global shape and gravity field of the planet during its formation, producing a major load on the lithosphere and influencing the climate by releasing a large amount of water and carbon dioxide. Using topography and gravimetry models, the volume of the Tharsis dome volume to be $3x10^8$ km^3. However, little is known about the dome 3D geometry. Is the dome symmetrical?, How are its boundaries? Based on an small elastic thickness, of 10 to 40 km [3], estimated for the Noachian period, [4] argued for a late growth (until the Hesperian) of Tharsis. The study of the 3D Tharsis geometry may inform on the elastic properties of the lithosphere such as its elastic thickness, and then on the heat flux of the planet of the time of Tharis formation [5].

A promising study by [6] showed that impact craters located around Valles Marineris, to the east of Tharsis dome, exhibit two different lithologies in their central peaks: Dark, volcanic material to the west, towards the dome center, and light-toned, massive fractured rocks to the east, around the dome possible margin. A simple relation (equation 1) allows us to determine the initial depth of the excavated material in central peaks. [6] have shown that the boundary between the western volcanic material and the eastern light-toned bedrock is sharp and could be followed at depth. This light-toned bedrock is observed in Valles Marineris below the volcanic layers and is interpreted as a mafic lower crust [7].

This study follows the work of [6] in order to study the dome margins, its structure at depth, and to determine its volume.

2. Material and Methods

An initial Tharsis outline was drawn along the Tharsis rise. A buffer zone of 1000 km has been added outwards to define our study area. Imagery and altimetry data from the HiRISE (High Resolution Imaging Science Experiment) [8], and the MOLA (Mars Orbiter Laser Altimeter) [9] instruments were used in this study. All complex craters of at least 30 km of diameter, and with HiRISE coverage, were investigated. Craters were sorted in two categories based on their central peaks lithologies: dark volcanic layers or light-toned massive rocks.

The pre-impact elevation of central peaks materials was found by subtracting the maximum stratigraphic uplift to the central peak elevation. Central peaks of impact craters provide a way to investigate planetary crusts interior as they rise material from depth.

On Earth, [10] established a relation between a crater rim diameter and the amount of uplift undergone by the deepest layers exposed in the centre of the peak. This value represents the maximum possible origin depth of the material which compose the central peak. The Stratigraphic Uplift (SU) is given by the relation:

$$SU(km) = 0.086*D^{1.03} \qquad (1)$$

With D the rim crater diameter in km.

As no comparable relationship exists for Mars, we used the maximum stratigraphic uplift to assess the maximum pre-impact elevation of the central peak material. Elevations of central peaks were measured using MOLA topographic data, and pre-impact elevations were calculated by subtracting the SU from the peak elevation.

The dome's geometry was mapped using lithologies of the central peaks of impact craters. Using depth estimates from cratering equation, we assessed the minimum volume of volcanic material thickness accumulated over time.

In order to perform the volume calculations, all craters exhibiting volcanic layers were projected on an equal area map. A regular grid was used to select each lower points in each grid of equal areas. A surface was drawn using these lower points and this surface was subtracted from the Mola topography.

3. Results

We identify two distinct lithologies exposed in central peaks of impact craters: volcanic layers and massive bright rocks. Some time, both lithologies are exposed in the same central peak. 48 craters expose layers interpreted to be of volcanic origin (ashes or lavas), 11 from [11], 17 from [6] and 20 from this study. 56 craters expose massive, fractured light-toned rocks in the study area. 1 from [12], 12 from [6], which were previously found to be enriched in LCP and 43 craters from this study. Volcanic layers are observed towards the dome center, light-toned rocks all around its periphery, which is consistent with the preliminary observations of [6].

These observations support the hypothesis of [7] and [6] that the light-toned rocks constitute the regional bedrock and possibly represents Mars primitive crust, covered by Noachian to Amazonian volcanic products at the location of Tharsis dome. [6] estimated a thickness of volcanic products of at least 18 km at the location of Oudemans crater confirmed by the absence of bedrock outcrops in the 10 km deep western VM walls [7]. Based on this vertical and horizontal distribution, radial cross-sections were performed at several locations (see example in figure 1). Each cross-section shows a clear transition from massive light-toned rocks to volcanic layers from the outside of the dome toward its center. The boundary between lithologies is sharp and can be followed along the South-East part of the dome where large impact crater central peaks are well-exposed. Craters with both lithologies are located near this boundary.

Volume calculation

A surface was drawn using all the lower points of volcanic material in each box of an equal-area 10 by 10 grid. The sizes of the boxes were define in order to obtain the maximum possible volume. By subtracting this surface to the topography, we estimated a volume of 1.8x10^8 km^3, which is in the same order as found by [2] (3x10^8 km^3). This volume corresponds to a minimum volume as no craters on the dome itself excavated the underlying massive light-toned crust, providing no upper limit for our volume calculations.

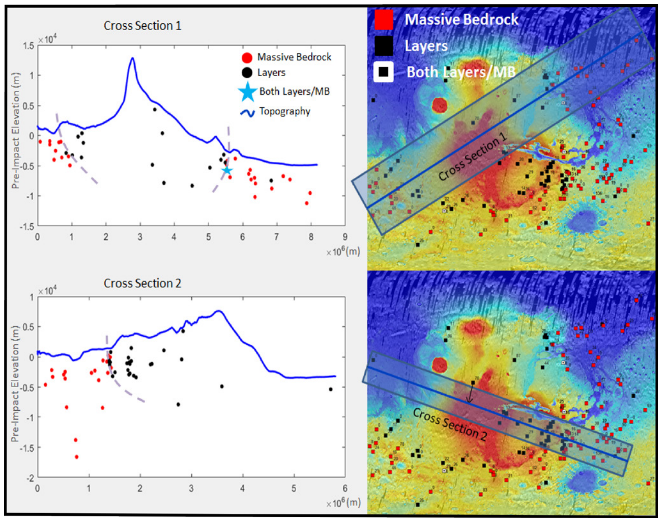

Figure 1: Geologic section of Tharsis dome using stratigraphic uplift of impact craters. Red dots are massive rocks, black dots are volcanic materials. Cf text for more details.

4. Conclusion and Discussion

Geologic sections from this study, based on craters pre-impact elevations, show a sharp boundary between massive rocks and Tharsis volcanic materials along more than half of the dome. This observational bias is explained by the low crater density on younger terrains as the late Hesperian lowlands or Amazonian volcanic units of the dome where few craters with well-exposed central peaks were found. As no craters excavating the underlying massive crust were found on the dome, the volume of 1.8x10^8 km^3 calculated is then a minimum possible volume but is still compatible with previous studies. The edge dip angle still have to be precisely measured and will be used to estimate the resulting lithospheric flexure and a heat flux of the planet at the time the dome was emplaced. These results will be presented at the conference time.

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