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Tyrrhena Patera, Mars: Evidence for a solidified magma chamber?

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Abstract

The noachian-aged martian highland volcano Tyrrhena Patera is associated with a well pronounced gravity anomaly and admittance modeling suggests that the observed signal can be explained by a high density surface load. Alternatively, a solidified magma chamber could be present at depth, and subsurface loading could correspond to up to 10 % of the surface load.

1. Introduction

Tyrrhena Patera is a low-relief martian highland volcano and its morphology is attributed to explosive volcanism related to phreatomagmatic processes. The volcano was emplaced in the Noachian period, but subsequently modified during the Hesperian and Amazonian periods [6].

A well localized positive free-air gravity anomaly is associated with the construct (cp. Fig. 1) and a good correlation exists with the features topography. Gravity modeling suggests that the elastic lithosphere thickness T_e at the time of load emplacement was relatively small, with $5 < T_e < 27$ km [1]. This is consistent with other T_e estimates for the Noachian period, indicating surface heat flows between 26 and 82 mW m^{-2} [1].

It has been argued that the large gravity anomaly associated with Tyrrhena Patera indicates the presence of a dense magma chamber at depth [3], and similar arguments have been put forward for other highland volcanoes such as Hadriaca Patera [3] and Syrtis Major [2]. On the other hand, the admittance spectrum at Tyrrhena Patera can be modeled assuming surface loading only if load densities are assumed to be large enough [1].

Here we use the latest gravity field model for Mars expanded up to degree and order 110 to model the admittance spectrum at Tyrrhena Patera. We consider surface as well as subsurface loading and quantify the range of admissible surface load densities as well as the admissible magnitude of the subsurface load.

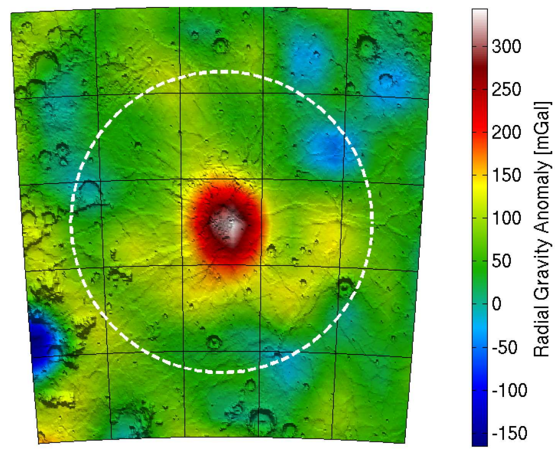

Figure 1: Radial gravity anomaly at Tyrrhena Patera referenced to a sphere of radius $R = 3395.5$ km and truncated at spherical harmonic degree 95. The circle indicates the location of the localization window.

2. Modeling

Tyrrhena Patera is located at 106.53^{o}E and 21.36^{o}S and we use a spherical cap localization window centered around this location to perform a localized admittance study. The localization window has a cap diameter of 7^o and a spherical harmonic bandwidth of 37. Ignoring the lowest degree terms that may be influenced by the Tharsis signal, we thus analyze the localized admittance in the degree range 42 to 57.

The observed admittance is then compared to a forward model which is localized in the same manner as the data. The model is an extension of an admittance model for surface loading by [5] and includes loading in the subsurface, which is assumed to be in phase with the surface load. For a locked phase relation between surface and subsurface loads the correlation function γ is expected to be unity, and we will treat deviations from this value as being caused by either measurement noise in the gravity field or gravity signals that are uncorrelated with the surface topography. In this way formal error bounds can be defined [5], and we will consider models to be valid if they fall within the error bounds for $\gamma > 0.775$, corresponding to a signal to noise ratio of 1.5.

The modeled admittance depends (amongst other parameters) on elastic thickness T_e, load density ρ_l, and the loading parameter L, which describes the fraction of the total load that is coming from the subsurface. We invert for these parameters using a grid-search approach.

3. Results

We have varied load densities between 2900 and 3500 kg m^{-3}, T_e between 0 and 40 km, and L between -1 and 1, and results of the calculations are shown in Fig. 2. Only models with $-0.2 \leq L \leq 0.1$ fall strictly within the errorbounds and elastic thicknesses are between 0 and 27 km, consistent with the results by [1]. If no subsurface loading is assumed ($L = 0$), load densities need to be between 3290 and 3450 kg m^{-3}, but subsurface loading up to $L = 0.1$ is admissible. In this case, smaller load densities between 3070 and 3380 kg m^{-3} are consistent with the data.

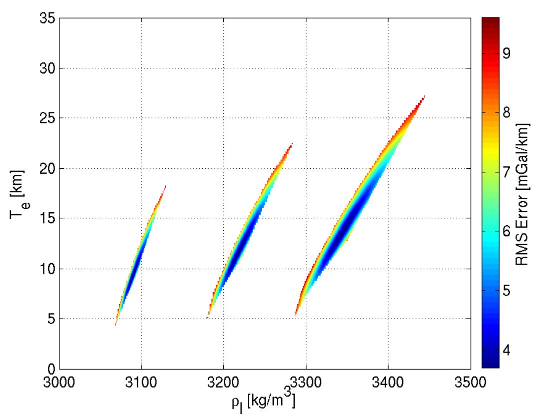

Figure 2: Color coded contour plot of the root mean square misfit between the modeled and observed admittance at degrees between 47 and 57. Only models strictly within the errorbars are shown. From left to right, error ellipses correspond to models with L = 0.1, 0.05 and 0, respectively. Crustal density is 2900 kg m^{-3}.

4. Summary and Conclusions

Admittance modeling of the Tyrrhena Patera highland volcano indicates that models considering loading of an initially flat surface only are consistent with the data if the load densities are large enough. Required densities fall within the range estimated for pore-free rocks from martian meteorites, which are 3250 and 3450 kg m^{-3} [4].

Therefore, although the gravity signature at Tyrrhena Patera could indicate the presence of a high density subsurface load, this does not necessarily have to be the case. However, given that Tyrrhena Patera is likely partially composed of pyroclastic rocks [6], low load densities appear plausible. In this case, a dense solidified magma chamber at depth would be required to explain the observed gravity signal.

Acknowledgements

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