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Global model of elastic lithosphere thickness on Mars

K. Kalousová (1), O. Souček (2,1) and O. Čadek (1)
(1) Department of Geophysics, Charles University in Prague, Czech Republic (kalous@karel.troja.mff.cuni.cz)
(2) Geophysics Section, School of Cosmic Physics, Dublin Institute for Advanced Studies, Ireland

Abstract

We present a global model of lateral variations of the elastic lithosphere thickness on Mars derived from a regional analysis of topography and gravity data. In agreement with the concept of frozen-in elastic flexure [1], we interpret the obtained values of the elastic lithosphere thickness in terms of the average thickness of elastic lithosphere at the time of loading. We find that the thickness of the elastic lithosphere has grown in time from a few km in Noachian to more than 150 km at present. The accuracy of our model decreases with the increasing thickness of the elastic lithosphere, so that the estimate of the present-day thickness of the lithosphere on Mars is rather uncertain, ranging from 150 to 200 km.

1. Introduction

Assuming that the dynamic support of the topography is negligible in comparison with the effect of the elastic flexure, the thickness of the elastic lithosphere becomes the key parameter determining the relationship between topography and geoid on Mars. Employing different types of regional analysis of gravitational and topography data, we attempt to estimate the lateral variations of Martian elastic lithosphere thickness (T_e). The resultant map of T_e is then correlated with the age of surface loads and compared with the results of other regional studies.

2. Method

In the first step, we attempt to determine an average value of the elastic lithosphere thickness on Mars by inverting the geoid and topography data degree by degree. We demonstrate that such an inversion cannot provide a reasonably unique solution unless the Tharsis region is excluded. If the topography and geoid signals from Tharsis are filtered out, we obtain the average value of T_e which is close to 15 km. If the same analysis is carried out only for the data coming from the Tharsis region, a significantly higher value ($T_e \sim$ 150 km) is found.

In the next step, we determine the elastic lithosphere thickness as a function of geographic coordinates ϑ and φ by employing a local Gaussian filtration with a dispersion parameter 10, 20 and 30 degrees. We move the Gaussian window with a step of 5 degrees, and for each position of the window, we determine the local value T_e which best predicts the geoid in each region. Besides the moving Gaussian window, we also perform a local inversion based on the wavelet analysis.

The forward problem, i.e. the prediction of the geoid for a given topography, is solved using the thin layer approximation adopted from [9]. Besides this traditional approach we use a fully 3-dimensional spectral code to determine the deformation of an elastic layer of finite thickness. Moreover, we also assess the effects of variations of the elastic lithosphere thickness on the global scale with the aid of the finite-element code Elmer [4].

3. Results

The resultant map of the elastic thickness variations on Mars is shown in Fig. 1. Except the Tharsis region, we find that the thickness of the elastic lithosphere at the time of topography loading was rather small - strikingly smaller than usually expected from global studies. The value of T_e mostly ranges from 1 to 20 km and only locally exceeds 25 km (e.g. Elysium Mons). In contrast, the relatively young Tharsis region is characterized by values of T_e which are several times higher than those obtained for the rest of the planet. In the center of Tharsis, the thickness exceed 150 km and a reasonably good fit to the data can be obtained even for significantly higher values of T_e.

In agreement with previous studies, we find that T_e increases as the age of the surface load decreases, ranging from about 10 km, typical for the Early Noachian, to more than 150 km for the late Amazonian (Fig. 2). The present-day thickness of the elastic lithosphere cannot be, unfortunately, determined with a high accuracy since the sensitivity of the elastic flexure to an intermediate-wavelength loading decreases with the increasing thickness of the elastic layer. The value of 150 km, however, seems to be the lower estimate.

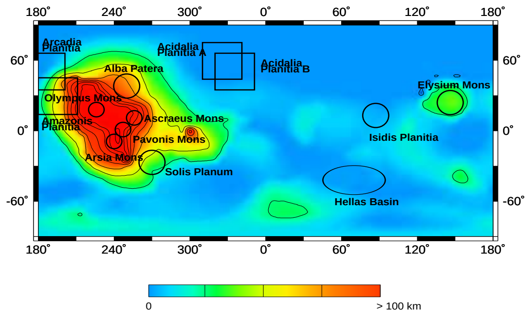

Figure 1: Model of elastic lithosphere thickness on Mars with selected areas used in Fig. 2.

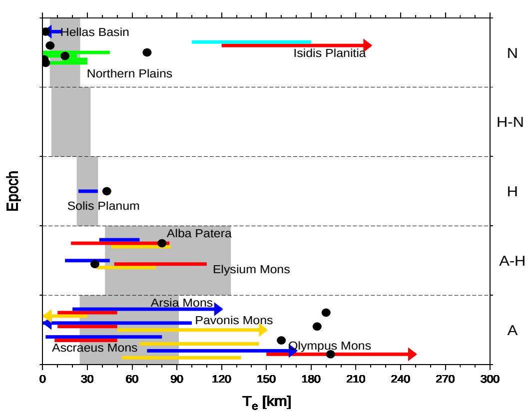

Figure 2: Comparison of our results (black dots) with published values in [2] (yellow), [3] (red), [6] (green), [7] (blue) and [8] (light blue). Mean elastic thickness for each epoch according to [5] (grey).

4. Concluding remarks

Employing a local analysis of the topography and geoid data, we estimated the lateral variations of the elastic lithosphere thickness on Mars corresponding to the thickness of the lithosphere at the time of loading. Our results confirm the exceptional role of Tharsis, already suggested by the degree-by-degree inversion of the data on global scale. For the sake of simplicity, we considered the elastic flexure to be the only mechanism maintaining the Martian topography and we did not take into account the possible effect of mantle flow. As shown by some studies (e.g. [10]), such effect may not be fully negligible and might account for up to 10 per cent of the topography signal.

Acknowledgements

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