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Current thermal state of Mars from scaled models of surface heat flow

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Abstract

In this work we scale heat flow differences across the martian surface from crustal and topographic differences in the planet, and also taking into account the heat radioactive production provided by the crust and the lithosphere mantle. Our aim is present a preliminary global heat flow model, which will can compared with deductions from InSight in order to gain understanding of the present heat flow pattern of Mars, and their implications for Martian thermal history.

1. Introduction

To understand the current thermal state of the Martian subsurface and interior, must be known values of temperature and heat flow. Until the arrival and InSight mission, which includes the HP^3 heat flow probe, no direct heat flow measurements exist for Mars. A commonly used indirect method is based on the relation between the thermal state of lithospheric rocks and their mechanical strength, which, applied to regions of different ages provides information on the thermal evolution of Mars [1]. In this sense, the finding of a very limited flexure caused by the north polar cap load indicates a very thick (>300 km) present-day effective elastic lithosphere (T_e) on the North Polar Region (NPR) [2], which can be used to obtain very robust estimates of the current heat flow at that region [1]. Here, we perform a global, first-order, scaling of the heat flow deduced for the NPR, in order to present a preliminary global heat flow model, which will can compared with deductions from InSight in order to gain understanding of the present heat flow pattern of Mars, and their implications for Martian thermal history.

2. Lithospheric heat production

The lithosphere is not only heated from below by internal the heat inside the planet, but also by the decay of the radioactive elements it contains. Therefore, we take into account the heat radioactive production provided by both, the crust and the lithosphere mantle. Neglecting lateral heat transfer, the surface heat flow of Mars may be considered the sum of the heat generated in the crust and the heat flow from the mantle. In turn, the heat flow of the mantle is consequence of the heat radioactively produced in the mantle lithosphere (or, more generally, in the stagnant lid), and of the heat coming-up from the deep interior.

The component of the heat flow arising from crustal radioactive heat sources is the sum of the contributions from all the heat-producing radioactive elements (HPE). HPE abundances on the surface of Mars have been estimated from measurements by the GRS instrument aboard 2001 Mars Odyssey spacraft. K and Th abundances were measured directly, whereas a Th/U ratio of 3.8 was assumed [e.g., 3]. The so-obtained average value of the surface heat production of Mars is currently 4.9×10^{-11} W Kg^{-1} [3], or 0.14 mW m^{-2} per each kilometre of crustal column.

On the other hand, HPE abundances in the mantle lithosphere are poorly constrained. Here we use HPE mantle lithosphere abundances 0.1 times the average value for the martian crust [see 1], which translates to ≈0.017 mW m^{-2} per each kilometre of mantle lithosphere column.

3. Scaling of heat flow from variations in crustal thickness

Taking into account average crustal and mantle lithosphere heat production values discussed in the previous section, and assuming a constant heat flow from the deep interior, we can scale heat flow differences across the martian surface from crustal and topographic differences in the planet.

Crustal thickness variations were derived from topography and gravity following the procedure of potential theory [4] by assuming an average thickness of 50 km, This mean crustal thickness is slightly higher than previous models [5], but in line with geophysical and geochemical evidences [6-8], and consistent with average thickness usually used in modeling of lithospheric strength [e.g., 1, 7]. Our crustal thickness model uses densities of 2,900 and 3,500 kg m^{-3}, respectively, for the lithospheric mantle, values widely used for Mars [1, 5, 7].

For anchoring our model, we calculated an upper limit heat flow of 17.0 from T_e = 300 km at the NPR, following the procedure and parameters described in [1] and using a crustal thickness of 35 km in NPR, as derived by our crustal thickness model in this region.

4. Present-day heat flow model

The results are shown in Figure 1. The surface heat flow varies between 14 and 23 mW m^{-2}, with minimum values in regions of crust thinned by giant impact basin, and maximum values corresponding to the thickest crust in the Taumasia, Syria Planum and south Tharsis regions.

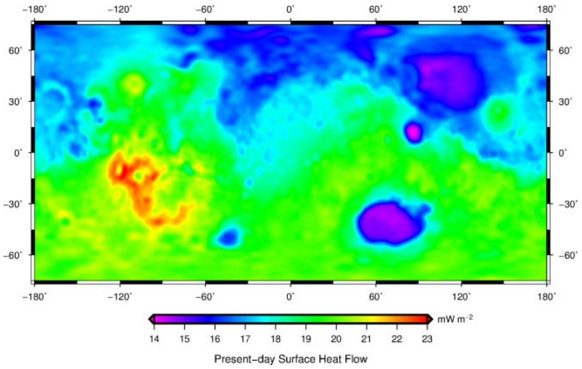

Figure 1: Global model of present-day surface heat flow.

Interestingly, the obtained average surface heat flow is 18.4 mW m^{-2}. If we take into account a present-day radioactive heat production equivalent to a surface heat flow of 14.3, according to the compositional model of [9], then an Urey ratio (defined as the ratio between the total radioactive heat production and the total surface heat loss) of around 0.8 is obtained for the present-day Mars. This value is higher than it (≈0.6) predicted by some thermal evolution models of [10], but consistent with a more limited interior cooling deduced from lithospheric strength analysis [11].

5. Conclusions

Our results of current thermal state of Mars, and the corresponding construction of these models and maps, are preliminary and a first step in our attempt of characterizing the global heat flow, their implications for the thermal history of Mars, and overlooking evaluate specific landing zones upcoming ExoMars missions 2016, 2018 and InSight.

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