Heat flow and thermal structure of the Martian lithosphere

Laura M. Parro[1], Alberto Jiménez-Díaz[1], Federico Mansilla[1], Isabel Egea-González[2], Javier Ruiz[1]
[1]Departamento de Geodinámica, Universidad Complutense de Madrid
[2]Departamento de Física Aplicada. Escuela Superior de Ingeniería. Universidad de Cádiz.

Introduction: The heat flow is the movement of heat (or energy) from the interior of a planet to its surface. On Earth, for example, the global surface heat flow maps show clear variations of its distribution between the oceanic crust and the continental crust, but also, high values of thermal flow are registered in active continental zones and regions [1]. Clearly, the heat flow is a good indicator of the geodynamics of a planet, and is an important parameter for understanding the thermal, and in general, the interior evolution of a planetary body.

On Mars, the heat flow should vary across its surface (as well as in time), depending on the abundances and distribution of the crust and mantle heat-producing elements, and on the thermal state of the planet's interior and ability to dissipate heat. Because variations of heat flow can probably affect, among many other things, the internal geodynamics of the planet, the distribution of groundwater, ice and clathrates, and processes such as subsurface melting and fluid circulation; it is essential obtain global heatflow models to predict those variations throughout the planet geographically.

Thermal state and mechanical structure of the lithosphere: Until the arrival of InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport), NASA Discovery Program mission, which includes the HP^3 (Heat Flow and Physical Properties Probe) instrument, there are no exists direct measurements of heat flow on Mars.

The study of the mechanical properties of the lithosphere of Mars has allowed us to deduce the thermal state of it; besides expanding our knowledge about the characteristics and structure of the Martian crust [2]. This is due to the relationship between the mechanical behavior of the rocks and the temperature, which allows us to calculate the heat flows corresponding to the epoch in which the geological structures used as indicators were formed [3,4]. The most commonly used heat flow indicator is the effective elastic thickness (T_e) of the lithosphere and the depth to the brittle-ductile transition (BDT) beneath large faults [2-4].

Although numerous paleo-heat flow estimates have been derived using this approach, information on the present-day heat flow of this planet is limited by the difficulty in finding young structures on the surface of Mars [2,3]. Thus, one of our main motivations has been to study and describe the present-day pattern of heat flow of the planet, from obtaining the heat flow in the polar regions that are some of the few young structures on Mars [5].

Present-day thermal state of Mars: We have modelled the present-day surface heat flow across the Martian geography (**Fig. 1**) from (i) the radiogenic heat production of the crust and the lithosphere mantle, (ii) scaling heat flow variations arising from crustal thickness and topography crustal thickness variations, and (iii) the heat flow derived from the effective elastic thickness of the lithosphere beneath the North Polar Region (as a control, we have checked our results deriving the equivalent model the heat flow computed from the effective elastic thickness of the lithosphere in the South Polar Region, obtained very similar results) [5].

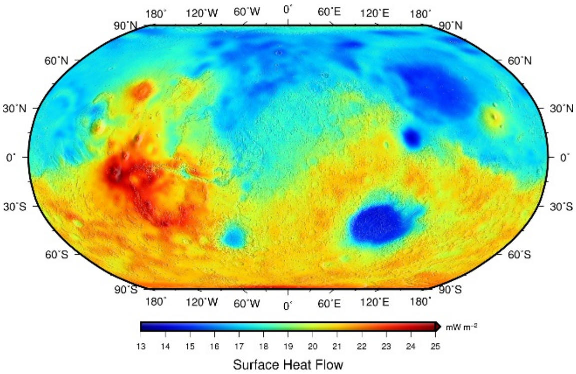

Figure 1: Present-day surface heat flow on Mars (sampled on a 2º × 2º grid), shown over a shaded relief map of Mars Orbiter Laser Altimeter (MOLA) topography for context [5].

The present-day surface heat flow is 19 mW m^{-2} in average, and varies between 14 and 25 mW m^{-2} across the Martian surface. The lowest values are found in the northern lowlands (Utopia Planitia or Acidalia Planitia), where the surface heat flow is below than the global average, and in regions of crust thinned by giant impact basin, for example Hellas, Argyre or Isidis-Planitiae. Conversely, the southern highlands have a higher than average surface heat flow. The highest peaks of surface heat flow correspond to the volcanic regions such as Tharsis-Montes, Syria Planum, Alba Patera, Solis Planum, Terra Sirenum, or Thaumasia Montes [5].

Furthermore, we calculated the Urey ratio (defined as the ratio between the total radioactive heat production and the total heat loss through the surface of a planetary body) predicted by our model. The Urey ratio is a means to visualize the internal heat budget of a planetary body. We obtain a value of around 0.75 for the present-day Mars [5], which is consistent with a relatively limited interior cooling deduced from lithospheric strength analysis [3] or with sub-chondritic heat-producing elements abundances [6]

Evolutionary frame of heat flow: Our next step in the study of the thermal evolution of the Martian lithosphere was elaborate crustal and total heat flow models for Mars calculated for 1.5, 3 and 3.5 Ga, by taking into account the temporal evolution of radioactive heat production, assuming a total heat flow consistent with a Urey ratio = 1 (**Fig. 2**), and following procedure to that used for elaborating the present-day heat flow model.

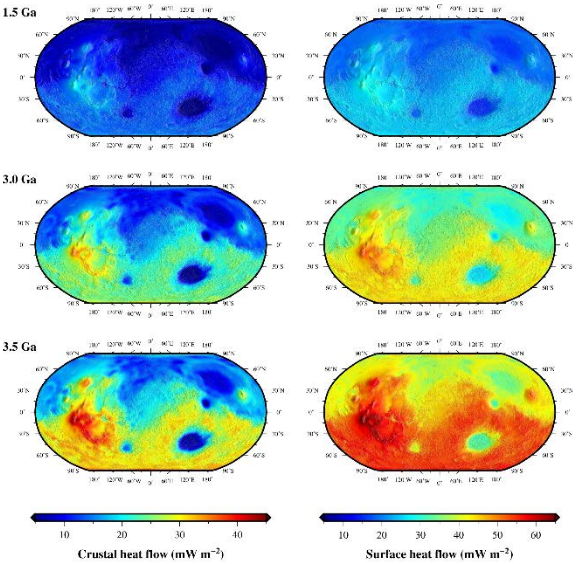

Figure 2: Global crustal and surface heat flow models for sev-eral times of Mars. Figure format is the same as Fig. 1.

The selected ages roughly represent mid-Amazonian period, Hesperian-Amazonian boundary time, and Early Hesperian period. We cannot reliably perform heat flow models for times much older than 3.5 Ga because the uncertainty in crustal thickness evolution [e.g., 7] and heat flow and Urey number [2,4]. As expected, the heat flows increase towards the past as the amount of radioactive heat production increases too. Also, the regional variations of crustal heat flow are strongly dependent on crustal thickness, which produces higher (lower) heat flow in zones with thickened (thinned) crust (see Fig. 2).

Heat flow data distribution: The result show in Figure 2 correspond to the crustal thickness model at 1 degree resolution, and crustal and surface heat flow models, at 2 degree resolution, for 1.5, 3.0 and 3.5 Ga times.

Finally, we are developing a web map to help us on the dissemination process. This tool runs with ArcGIS Online®, which allows us to display our results, being at the same time easy to use (https://www.ucm.es/upwards).

Local heat flow models: At the moment we are studying the InSight and ExoMars landing sites from the point of view of the heat flow and subsurface thermal state. We will use a finite element method to solve the three dimensional heat conduction equation by including local properties that could have influence in the local heat flow, such as topography, crustal thickness, crustal composition and abundance of heat-producing elements. Our results will help to interpret data returned from these missions and will increase our knowledge about the spatial heat flow variability and the thermal state of the planet.

References:

[1] Davies, J. H. and Davies, D. R.**Solid Earth**, 1, 5–24, 2010.; [2] Ruiz, J., **Sci. Rep.**, 4, 4338, 2014; [3] Ruiz, J. et al., **Icarus** 215, 508- 517, 2011; [4] Egea-González, I. et al., **Icarus**, 288,53–68, 2017; [5] Parro, L. M. et al., **Sci. Rep**. 7, 45629, 2017. [6] Phillips, R.J. et al.,**Science** 320, 1182-1185, 2008. [7] Grott, M., **Geophys. Res. Lett.**32, L23201, 2005.

Acknowledgements: This work has received fundingfrom the European Union’s Horizon 2020 Programme (H2020-Compet-08-2014) under grant agreement UPWARDS-633127, and from the Spanish Ministry of Economy and Competitiveness Project CGL2014-59363-P(AMARTE). The work by L.M.P. was supported by a FPU2014 grant from the Ministerio de Educación, Cultura y Deporte of Spain.