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The heat flow history of Mars from lithospheric strength

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Lithospheric strength can be used to estimate the heat flow at the time when a given region was deformed, allowing us to constrain the thermal evolution of a planetary body [1,2]. Here we report carefully calculated paleo-heat flow for 22 martian regions of different periods and geological context (Fig. 1), derived from effective elastic thicknesses [1-5] or from faulting depth beneath large thrust faults [6,7], by considering regional radioactive element abundances [8], and realistic thermal conductivities for the crust and mantle lithosphere [9,10]. For the calculations from the effective elastic thickness of the lithosphere we also consider the respective contributions of crust and mantle lithosphere to the total lithospheric strength, along with adequate flow laws [see 10].

The obtained surface heat flows (Figure 2) are in general lower than the equivalent radioactive heat production of Mars in each time, suggesting a limited contribution from secular cooling to the heat flow during the majority of the history of Mars. This is contrary to the predictions from the majority of thermal history models [e.g., 11]. Moreover, the interior of Mars could even have been heating up during part of the thermal history of the planet. Our results can also be interpreted in terms of the Urey number *Ur*, the ratio of the internal heat production to the total surface heat loss in a planet. Figure 2 indicates very low heat flows relative to expected heat output, consistent with very little secular cooling, i.e., a bulk-Mars *Ur* for Mars approaching 1.0 or perhaps even exceeding that value. Current estimates of the bulk-Earth *Ur* are in the range 0.35-0.53 [e.g., 12,13], and somewhat higher (but usually < 0.75) values are predicted for most Martian thermal history models.

Our results would be indicative of less efficient mantle convection than commonly thought (perhaps related to stagnant lid convection with inefficient volatile cycling) and/or a reduced contribution from fossil heat to the surface heat flow, which would result in a lower heat flow from the convective mantle, and possibly elevated lower mantle and core temperatures. Also, there is evidence favoring a heterogeneous heat flow depending on the geological province (volcanic versus non-volcanic provinces), although it cannot presently be definitively demonstrated. Moreover, if the interior of Mars is in fact heating up ($Ur > 1$), there is the potential for a future increase in mantle convective vigor and/or melting, and there may ultimately be an increasing of volcanic and tectonic activity.

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Figure 1. MOLA topography map showing the analyzed regions.

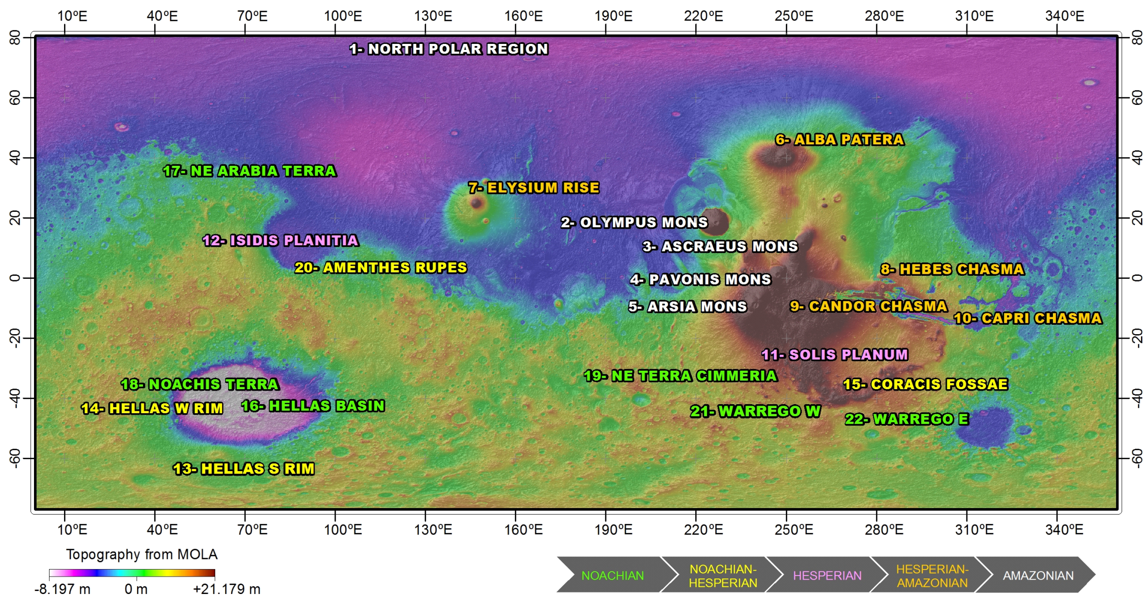

Figure 2. Upper (red) and lower (blue) limits for the surface heat flows for regions of Figure 1. For several regions only upper or lower limit is obtained, since lower or upper limit effective elastic thickness is not available. Curves and horizontal lines indicate uncertainty related to surface age (and hence also to radioactive heating in the lithosphere), not to temporal evolution. The black curves show surface heat flows for three values of the Urey number (the ratio of the internal heat production to the total surface heat loss in a planet), calculated according to the composition model of [14]. The curve labeled "Radioactive (*Ur* = 1)" corresponds to the average surface heat flow which is equivalent to the total radioactive heat production of Mars.