SHOULD PALEOSHORELINES OF ANCIENT MARTIAN OCEANS BE CLOSE TO PRESENT-DAY EQUIPOTENTIAL SURFACES?

Javier Ruiz[1,*], Alberto G. Fairén[2], James M. Dohm[3], Rosa Tejero[1], Gabriel Castilla[1],
Jose A. Álvarez-Gómez[1], Esther R. Uceda[4]

[1] Departamento de Geodinámica, Universidad Complutense de Madrid, 28040 Madrid, Spain
[2] CBM, CSIC-Universidad Autónoma de Madrid, 28049 Cantoblanco, Madrid, Spain
[3] Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona 85721, USA
[4] S.E., Hospital Ramón y Cajal, 28937 Madrid, Spain
* Corresponding author. Fax: +34-91-394-48-45, E-mail: jaruiz@geo.ucm.es.

Abstract

Thermal isostasy provides a link between surface elevation and thermal state of the lithosphere. Variations in martian surface heat flow, similar to those observed in terrestrial continental tectonothermally stable areas, could result in elevation differences of kilometric scale through differential thermal isostasy. This effect is enhanced with the increase of heat sources located within the crust. Local differences in the thermal history of the Mars' lithosphere could have appreciably distorted the original long-wavelength topography of putative martian paleoshorelines. This work shows that a paleoequipotential surface does not necessarily have to fit well a present-day equipotential surface, and that diverse processes, including thermal isostasy and operating throughout the martian history, must be taken into account when evaluating paleoshorelines through assessment of high-resolution topography.

1. Introduction

Several evidences suggest the possible existence of large bodies of water in the northern plains of Mars that range from oceans (1-3) to lakes (4), and several paleoshorelines have been proposed. While Malin and Edgett (5) indicate that there is not sufficient geomorphologic evidence to support the shoreline hypothesis through analysis of high-resolution MOC imagery targeted in specific putative shoreline localities, other investigators present arguments that dispute these findings (4,6,7). The observed present-day martian topography has been used to test the putative paleoshorelines hypothesis (8,9), considering that a good candidate to paleoshoreline must fit well a present-day paleoequipotential surface.

But evaluation of possible paleoshorelines through assessment of high-resolution MOLA topography must be made very cautiously. Indeed, thermal isostasy provides a link between surface elevation and thermal state of the lithosphere, and we have used this concept to show that different thermal isostasy histories among martian regions may have contributed to the deformation of the original paleotopographic signatures of possible martian paleoshorelines.

2. Methodology

Here we use a simple model for the thermal structure of the martian lithosphere to show that heat flow variations may result in significant changes in surface elevation, and to offer an estimation of its scale. So, we used the methodology in (10) to calculate the component of the elevation of the surface relative to the free (uncompressed) height of the asthenosphere due to the thermal buoyancy of the lithosphere (H). We assume that there are heat sources homogeneously distributed in the crust. The concentration of crustal heat sources is described by mean of the fraction of the surface heat flow originated by radioactive heating within the crust. We do not take into account the existence of radioactive heat sources beneath the crust, and so, in the lithospheric mantle the heat flow is linear.

Calculations have been performed using lithospheric constants as in (10). An assumed average surface temperature of 0ºC is maybe appropriate for times in which oceans could have existed. The crustal thickness is taken as constant since that this paper addresses the component of the topography related to differential isostasy (so, isostasy related to the lower compositional density of the crust is not considered here). Crustal thickness is assumed as 40 km, in accordance with a typical mean value for the northern lowlands derived from topography and gravity data (11). Calculations have been made for a range of F values between 10 and 50 mW m^{-2}, which roughly correspond to the surface heat flow range proposed for diverse regions and at varied times from estimates of the elastic thickness of the lithosphere (12). For the purposes of this work, the interesting point is the relative differences of H, and not the absolute values obtained for this parameter (planetary topographies are referred to arbitrary datum).

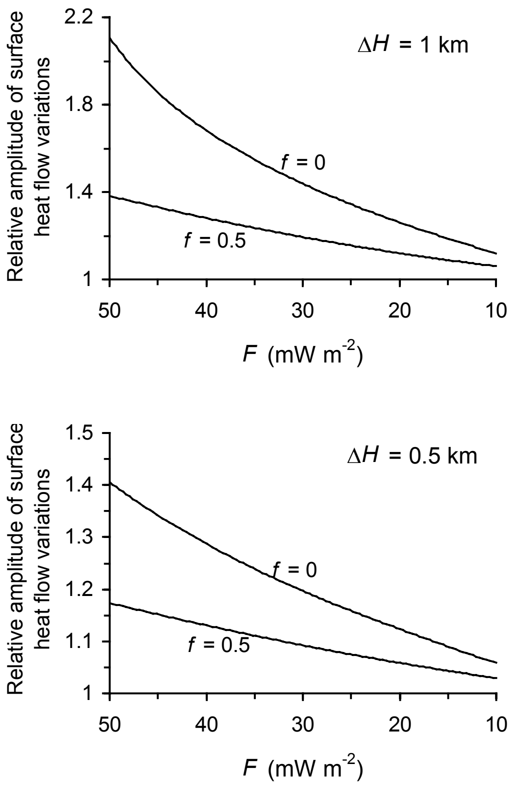

Figure 1. Relative amplitude of surface heat flow variations that can produce elevation ranges of 1 (top) and 0.5 (bottom) km centered on the mean surface elevation (*H*) value corresponding to a reference heat flow in the range from 10 to 50 mW m^{-2}.

3. Results

Figure 1 shows the relative amplitude of surface heat flow variations that can produce elevation ranges of 1 and 0.5 km centered on the *H* value corresponding to a reference heat flow in the range from 10 to 50 mW m^{-2}. The relative amplitude of heat flow variations is obtained as the quotient between the maximum and minimum heat flow that can produce positive and negative elevations, respectively, of 0.5 and 0.25 km with respect to the reference *H* value. In the figure it can be seen that ancient surface heat flow variations lesser of a factor ~2 may account for differences of elevation of 1 km. An elevation range of 0.5 km could be produced by surface heat flow variations less than a factor 1.5. These values would are further lowered if a substantial amount of the martian heat sources are located within the crust.

Variations in surface heat flow in Earth's continental regions observed from contoured maps (13,14) can be higher than a factor of 2 or 3, sufficient for significant paleoshoreline deformation. If local variations of surface heat flow of at least similar amplitude existed in Mars during any moment of its history, then our results indicate that differential thermal isostasy should result in substantial deformation of and deviation from an equipotential surface along putative paleoshorelines, even in a range of elevations of a kilometric scale.

Moreover it is significant that if, as is the case for Earth, half of the surface heat flow originated from crustal heat sources at the time of the putative shoreline formation, then heat flow variations lower than a modest factor of ~1.2-1.4, which is similar to even lower than those observed in terrestrial continental tectonothermally stable areas (10,14), may account for present-day, large wavelength, elevation ranges of 0.5-1 km (if, as it seem reasonable, these heat flow variations are currently greatly attenuated). These elevation ranges are respectively similar to the ±1 standard deviation and the total estimated elevation range of the putative Deuteronilus shoreline (9), but they represent an important amount of deformation along any possible paleoshoreline.

Finally, it is important to remind that thermal isostasy is only one of many influences on paleoshoreline topography (for example, a similar consideration takes into account the lithosphere rebound due to water unloading associated with the disappearance of an ocean with irregularly shaped margins ()), which makes more pressing the main argument of this work: a paleoequipotential surface dating from an earlier Mars does not necessarily must fit well a present-day equipotential surface.

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