THERMAL ISOSTASY ON MARS. Javier Ruiz[1], Alberto G. Fairén[2,3], and Miguel A. De Pablo[3,4]. [1]Departamento de Geodinámica, Facultad de Ciencias Geológicas, Universidad Complutense de Madrid, 28040 Madrid, Spain, jaruiz@geo.ucm.es. [2]Centro de Biología Molecular, Universidad Autónoma de Madrid, 28049 Cantoblanco, Madrid, Spain. [3]Seminar on Planetary Sciences, Universidad Complutense de Madrid, 28040 Madrid, Spain. [4]Escuela Superior de Ciencias Experimentales y Tecnología, Universidad Rey Juan Carlos, 28933 Móstoles, Madrid, Spain.

Introduction: A relation exists between Earth's surface elevation and the thermal state of the lithosphere [1]. The warmer the lithosphere, the lower its mean density, and the higher its buoyancy with respect to the fluid material underneath. This relation allows us to use topography and superficial thermal flux data to constrain Earth's continental lithospheric thermal structure [2]. This same relation may be valid for Mars.

Here we use a simple model of thermal structure of the martian lithosphere to show that local and/or temporal changes in the thermal state may drive to significant local and/or temporal changes in the martian topography. In addition, we use our results to suggest these processes as capable to affect the topography of a putative early coastline.

Thermal state and buoyancy of the lithosphere: The contribution to the elevation of the lithospheric surface above the free (uncompressed) height of the fluid material below (the "astenosphere") due to the thermal buoyancy of the lithosphere is given by

$$e = \alpha\,(\overline{T} - T_l)\,b\,, \qquad (1)$$

where α is the thermal expansion coefficient, $\overline{T}$ is the mean temperature of the lithosphere, T_l is the temperature in the base of the lithosphere, and b is the thickness of the lithosphere.

Here we calculate $\overline{T}$ and b in terms of the surface heat flow using a simplified model. In this model we consider that there are heat sources homogeneously distributed in radioactively productive layer. So, within this layer the temperature at a depth z is

$$T_z = T_s + \frac{Fz}{k} - \frac{Az^2}{2k}\,, \qquad (2)$$

where T_s is the surface temperature, F is the surface heat flow, k is the crustal thermal conductivity, and A is the volumetric (radiogenic) heating rate. In turn, A can be written as

$$A = fF / b_r\,, \qquad (3)$$

where f is the fraction of the surface heat flow originated by heating within the radioactively productive layer. Thus, for $z = b_r$ it is obtained

$$T_r = T_s + \frac{Fb_r}{k}\left(1 - f/2\right)\,\cdot \qquad (4)$$

We do not take into account the existence of heat sources below the radioactively productive layer (on Earth, radiogenic sources are sparse within the lithospheric mantle and they do not greatly deviate the temperature profile from a strictly linear one), and so b and $\overline{T}$ are calculated as

$$b = b_r + \frac{k(T_l - T_r)}{F(1-f)}\,, \qquad (5)$$

$$\overline{T} = \frac{1}{b}\int_0^b T(z)\,\mathrm{d}z\,\cdot \qquad (6)$$

Results: The equations have been solved using standard values for lithosphere properties: $\alpha = 3 \times 10^{-5}$ ºC^{-1}, $k = 3$ W m^{-1} ºC^{-1}, and $T_l = 1200$ºC. We use a the radioactively productive layer thickness of 50 km, according to a mean crustal thickness proposed from topography and gravity data [3]; and a surface temperature of –50ºC, a value close to the current average for Mars. The calculation have been performed for $f = 0$ (corresponding to a linear thermal gradient) and for $f = 0.5$, although we note that the value of f could change with time.

Figure 1 shows e as a function of F for a range of F values between 60 and 15 mW m^{-2}, which roughly correspond to the whole range of surface heat flows deduced from the estimations of elastic thickness (for different regions and time) of the lithosphere [3,4].

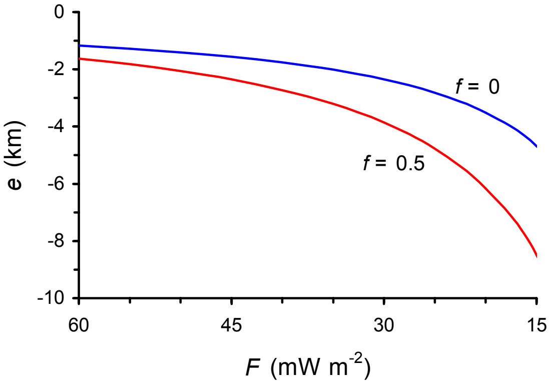

Figure 1

Moreover, in Earth's regions as Europe [5] local variations in surface heat flow can be higher than a factor 3, and so the range in Figure 1 could also account for local variations of F in a single epoch.

Our results show that differences conceivable to exist (both local and temporally) in the thermal state of the martian lithosphere can produce elevation differences of a kilometric scale (the free height of the "astenosphere" is not dependent on the thermal state of the lithosphere).

So, different thermal evolution in distinct areas on Mars must have an expression in the evolution of the martian topography.

A possible Noachian coastline: Two mapping contacts (named Contacts 1 and 2), have been proposed to be coastlines of ancient Martian oceans [6,7]. The youngest, Hesperian-aged, topographically lowest proposed coastline (Contact 2) exists on Martian lowlands and has probed not to differ greatly from an equipotential surface [8]. The oldest, Noachian-aged, proposed coastline (Contact 1) roughly follows the lowland/highland dichotomy boundary, and appreciably differs from an equipotential surface [8], which indicates it is not a real coastline.

Also, the existence of a pre-Contac 1 coastline has been proposed in northern Sinus Meridiani and western Arabia Terra [9,10]. Among arguments used to propose this coastline is the existence of valley channels that abruptly terminate in it. An alternative explanation for the implied features is extensive erosive denudation [11]. This possible coastline is phisiographically set in the southern highlands, south and west from the dichotomy boundary in Arabia Terra region, well above (2-3 km) Contact 1 at northwest Arabia Terra; here, precisely, is where the dichotomy boundary is topographically lowest than the average elevation of the boundary [8,12].

Basing on MOLA topographic mapping [12], we point out that the general elevation of the possible coastline in western Arabia Terra is similar to the one in Contact 1 through northeast Arabia Terra, Utopia (no taken into account the Isidis impact basin), Elysium and Amazonis Planitiae. If there really was a Noachian ocean, a coastline in western Arabia, and northeast Arabia, Elysium and Amazonis approximate much better an equipotential surface than Contact 1: total elevation differences are ~2 km, greatly lower than ~11 km noted for Contact 1.

As we have shown here, topography changes (e.g. deviations of equipotentiallity) of kilometric scale can be related by local differences in the evolution of the thermal state of the martian lithosphere.

Conclusions: We have shown that variations in the thermal history between martian regions can drive to relative topography changes, of a kilometric scale. If there was a Noachian ocean, this differential thermal evolution could have importantly contributed to the distortion of the original coastline topography. If martian thermal anomalies had majority dissipated when Contact 2 established (which has a better reputation as acceptable coastline), it has remained nearly equipotential to date.

So, thermal isostasy is a process that must be taken into account as an important factor in the evolution of the Martian surface.

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