ORIGIN OF EXTENSIONAL STRUCTURES IN THE NOACHIS-SABAEA REGION, MARS: ALTERNATIVE HYPOTHESES.

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Introduction: Early dynamic evolution processes of the terrestrial planets are hardly known. In absence of intense surficial weathering and Earth-like tectonic recycling, southern highlands preserve remnants of early Martian tectonic structures. The structural map of the Noachis-Sabaea region [1] suggests the presence of compressional and extensional features throughout. Amongst these, some extensional structures show complex orientations and morphological patterns. The mechanisms for their (especially grabens) formations are not well understood and ideas are mainly linked to the Hellas impact [2]. Here, we have tried to describe the evolution mechanisms of the non-Hellas concentric grabens in the Noachis-Sabaea region.

Background research: We have mapped the tectonic structures (1:5 M scale) in one part of the southern highlands to better visualize the early Martian lithospheric process driven by internal, external or a combination of both processes. The map [1] reveals that compressional structures (both lobate scarps and wrinkle ridges) of an age range around 3.5−3.6, distributed over an extensive region of southern highlands with similar age and orientation trends [3]. There are two types of grabens in the study region: firstly, basin concentric narrow grabens and secondly, wider grabens, tangential to the Hellas basin's outer rim curvature (Fig. 1 shows the second type). Morphologically, Hellas non-concentric grabens resemble Earth's continental rift zone grabens [1, 2]. These grabens are aged around 3.8 Ga (using buffered crater count) (i.e., Late Noachian, Fig. 2) [3] and have orientation and age similarities with the general alignments of the eastern Hellas volcanic province [4]. These resemblances intrigued us to reconstruct alternative hypotheses considering morphological, geochemical and geophysical criteria. This work involves preparing and creating several hypothetical models also to explain the crustal structures of southern highlands.

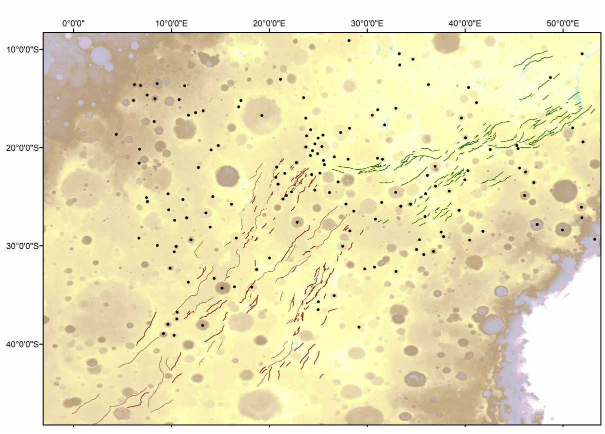

Figure 1. Hellas basin concentric grabens. Western Hellas Grabens (WHGs) marked in red have a trend of NNE-SSW with maximum grabens length of 1200 km and width ranging from 35 to 100 km, North Western Hellas Grabens (NWHGs) are marked in green and have a ENE-WSW trend. Individual grabens of this category range around 500 km in length and around 35 km in width.

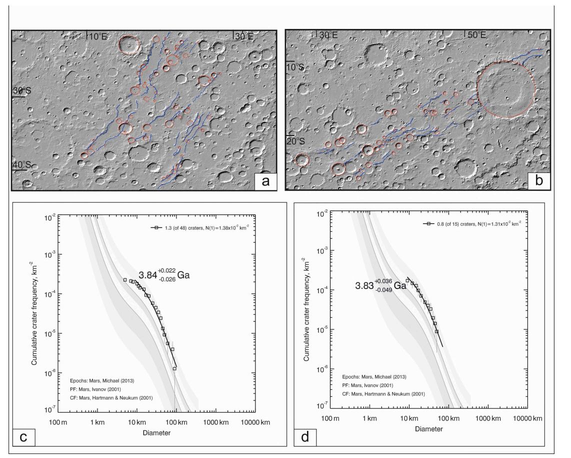

Figure 2. Crater Size Frequency Distribution measurements on grabens [3]. a) Craters interaction with WHGs. b) Crater interaction with NWHGs. c) Model ages of WHGs (a) and NWHGs (b) using CraterStats II [5].

Hypothesis 1: A Hellas size giant impact creates a big vacuum excavating the upper crust and penetrating up to the upper mantle [6]. Impact induced frictional heat causes rising of temperatures of the mantle beneath, creating a density deficit relative to the ambient mantle and thus it induces a visco-elastic flow [7]. This results in doming of the mantle beneath the impact basin. Later, the heated and upraised mantle beneath the impact basin starts to become cooler with conductive cooling. As an effect, a mascon develops, dragging the pressure gradient from the exterior of the basin towards interior of the basin driven by the viscoelastic flow, resulting in an uplift of the basin floor [6]. With time due to conductive cooling and viscoelastic evolution, transient cavity collapses followed by gravitational collapse (overshooting and sloshing of mantle materials) onto the adjacent crust [8]. This gravitation collapse triggers the drag of the upper lithosphere towards the interior of the basin [10]. As a consequence of the lithospheric drag driven stress, fracture opens up in the surroundings of the basin region to accommodate the vacant space.

Hypothesis 2: Conventionally, a thermal plume develops after a pause of planet formation. Mantle heating prevents generation of plumes rapidly at the core-mantle boundary just after the planet formation [10]. However, a transient episode of primary surface recycling [11] could possibly give rise to mantle cooling, even though for a shorter duration [12] inducing transition to the stagnant lid convection [10]. Thereafter, it would shut off mantle heating, resulting in a more distinguished core heat flux and an associated plume activity [13]. Recently scientists [14] have shown that the liquid state of the Martian core (inferred from solar tidal deformation) is consistent with and capable of such a possibility.

We hypothesize that the Hellas impact was responsible for the formation of mantle plumes in its basin-surrounding region. Plumes possibly have been generated due to the Hellas impact. The thermal impulse from such a large impact could alter the underlying mantle dynamics [15]. Reese et al. (2004) has argued that the magmatic evolution of impact-induced thermochemical mantle plumes is related to the mantle's thermal convection. Compositional difference gave rise to buoyancy associated with impact-induced heating, melting and lately magmatic differentiation. These processes could in combination trigger mantle upwellings and a subsequent magmatic activity [10]. However, large-scale melting ceased by the end of the Noachian periods and it is consistent with timing of grabens (both WHGs and NWHGs) and the eastern Hellas volcanics. The thermal erosion at the lower base of the lithosphere generates a higher gravitational potential resulting in the upper crustal material to collapse under gravitational forces and spread, resulting initiation of rifting. The scenario was different for the eastern boundary of the basin where excavation due to a potentially oblique impact making the lithosphere thinner [16].

Doming of the crust is the initial stage of the plume induced rifting followed by the development of steep fractures. These fractures penetrate enough to encompass magma generation and intrusions from the uplifted mantle. Then lithospheric stretching takes place. A horizontal deviatoric stress initiates to break the lithosphere. This is the beginning of continental rifting. Crust becomes thinner vertically with constant thermal erosion from the plume head below. The updomed crust is also laterally extended producing a) thermal buoyancy forces due to upwelling of asthenosphere, b) buoyancy (gravitational forces created by variations in crustal thickness [17]. Here, in the Noachis-Sabaea region, it is supposed that the thermally-induced stress could not exceed the strength of the entire lithosphere [in the thickest Martian lithosphere; 18]. Thereafter, absence of plate boundaries in the Martian crust could not provide space for the newly formed crust to provide stresses due to slab pull or slab push such as a typical Earth-like scenario. That indicates that the accommodation space for the extended crust was absent in the early Martian tectonic scenario.

Hypothesis 3: In absence of a typical Earth-like plume driven plate tectonics scenario, another possible origin of the extensional structures could be lithospheric stretching. Lithospheric stretching is a common phenomenon on Earth and Mars [11, 19], which might lead to extensional stress and formation of grabens in the western part of the Hellas basin. Imposed stress field resulted due to vertical shortening that might have been triggered by gravitational collapse of the Hellas basin during the later phase of the isostatic basin adjustment [20]. This loading related 'mascon' causes changes in the mantle buoyancy giving rise to the convective and thermal stresses. However, it is resulted due to the decrease of Rayleigh number [9]. Ultimately, mantle convection arises in the surrounding region because of the thermal expansion of buoyant mantle. The expansion causes a reduction in density in comparison to the overlying fluid and the resulting buoyant forces cause the material to move upwards.

The basin loading results in a downward deflection of the lithosphere below the interior [21] of the Hellas basin floor region. The basin fill (most probably sediment and ice) and associated lithospheric flexure were not isostatically compensated (hence the sign of positive free-air gravity anomaly beneath the basin).

Conclusion: All the explained hypotheses have their own pros and cons. We also do believe that neither of these hypotheses is single handedly able to demonstrate the formational mechanism of the crustal structures of the Noachis-Sabaea region. We have not been able to come up with one possible origin that itself sufficient to describe all the structures in the studied region.

We are planning to acquire geochemical and geophysical, mineralogical data, in order to put them together and to come up with one most likely hypothesis.

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