Plate Tectonics Boundaries and Convection on Venus Implied from a Comparison of Gravity Aspects on Earth . K. Karimi[1], G. Kletetschka[1,2], [1]Charles University, Albertov 6, Prague, 12843, Czechia, kurosh.karimi@natur.cuni.cz, [2]University of Alaska-Fairbanks, 903 N Koyukuk Drive, AK, USA, gkletetschka@alaska.edu. for second author (full mailing address and e-mail address).

Introduction: Venus is the most similar extra-terrestrial planet, especially in terms of gravitation, in the solar system to Earth. Some characteristics of the Venusian geology could be deduced by comparing its gravity aspects (Shgi180ua01 gravity model) to those of the Earth (EIGEN 6C4 gravity model). The gravity aspects evaluated here are gravity disturbance (δg), Murussi tensor components ($\mathbf{T}_{ij}$'s) and its invariant (I), Horizontal Gradient Tensor (HGT), and strike lineament. We discovered, based on the mantle behavior of the Earth revealed in δg and I maps, some upwelling and down-welling mantle patterns for the Venus. The Total Horizontal Gradient (THG) and mottled pattern of T_{zz} map on Venus imply that this planet may have had some plate tectonics in the past, and it is inactive now because of its "slowed down" planet rotation. The structural weakness and faulting planes on the crusts are revealed in strike solutions. To examine mantle behavior of the planets and circumvent the truncation error of the spherical harmonic series of the geopotential field, the gravity models are considered at h=200km. Detection of the shallower depths is done by T_{zz}. The grid node distance is 1 degree.

Mathematical tools:

The Marussi tensor is defined as [1]:

$$\Gamma = \nabla(\nabla T)^{transpose} = \begin{bmatrix} \Gamma_{ii} & \Gamma_{ij} & \Gamma_{ik} \\ \Gamma_{ji} & \Gamma_{jj} & \Gamma_{jk} \\ \Gamma_{ki} & \Gamma_{kj} & \Gamma_{kk} \end{bmatrix} \qquad (1)$$

Where T is disturbing potential [2]. The second derivative components of the gravity potential are $\Gamma_{ij} = \frac{\partial}{\partial i}(T_j)$. In a Cartesian coordinate system where **z=k,** T_{zz} notation is alternatively used instead of Γ_{zz}. The spherical approximation of the gravity disturbance reads [3]: $\delta g = -\frac{\partial T}{\partial r}$

Tensor Invariants. The tensor Γ has three invariants I_0, I_1 and I_2 [2]:

$$I_0 = Trace(\Gamma) = \sum_{i=1}^{3} \Gamma_{ii} = 0$$

$$I_1 = \frac{1}{2}((Trace\ (\Gamma))^2 - Trace(\Gamma^2)), \qquad I_2 = det(\Gamma)$$

$$0 \le I = -\frac{(I_2/2)^2}{(I_1/2)^3} \le 1 \qquad (2)$$

zero value of I shows a pure 2-dimensional, and 1 signifies a pure 3-dimensional body.

Strike direction or lineament is a direction along which the gravitational response of a geological construct is constant. Mostly, it is parallel to the weakness in the configurational structure of rocks and masses like faults, micro-faults and schistosity directions [2]. The direction of the strike with reference to ***i*** axis in a right handed coordinate system (i,j,k) is [1]:

$$\theta_s = \frac{1}{2}\left\{tan^{-1}(2\ \frac{\Gamma_{ij}(\Gamma_{ii}+\Gamma_{jj}) + \Gamma_{ik}\Gamma_{jk}}{\Gamma_{ii}^2 - \Gamma_{jj}^2 + \Gamma_{ik}^2 - \Gamma_{jk}^2})\right\} \qquad (3)$$

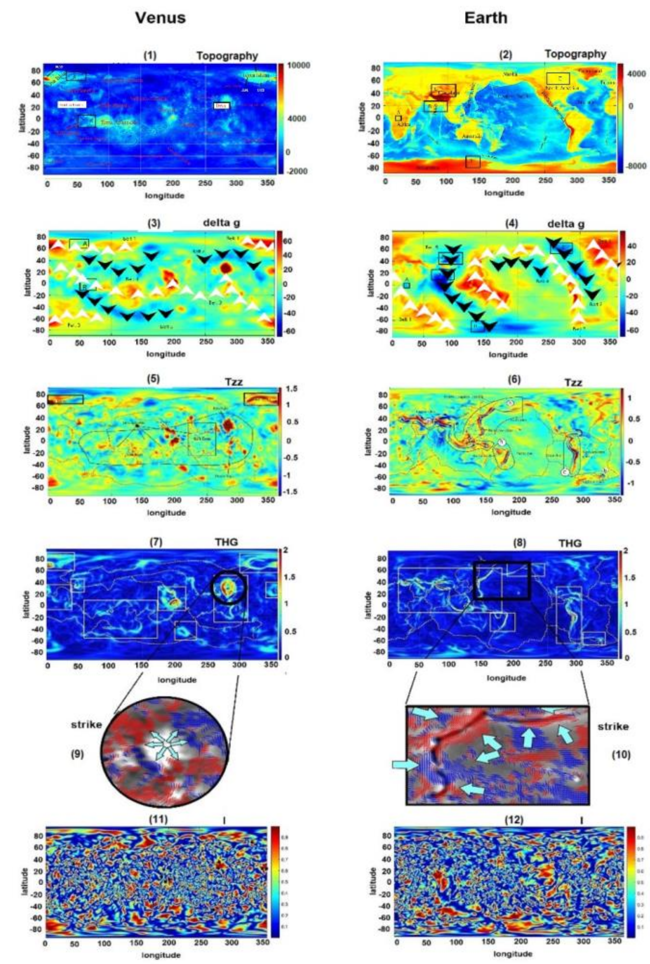
Results and discussion: *Analysis of the gravity aspects.* There are zones, like A, B, C, D and E on the Earth (Figures 2,4), and A and B on Venus (Figure 1,3), where the topography do not correlate with δg anomalies, implying that there is an ongoing geological activity resulting in rheological disequilibrium of the mantle in the respective districts. The highest altitude zones on Venus are Ishtare Terra, the Atla Regio and Beta Regio (AB Regio) (Figure 1). The average elevation of Ishtar Terra is larger than the average height of AB Regio (~ 2000m versus ~ 1400m). However, δg for Ishtar Terra is smaller (~ 30 mgal as opposed to ~ 43 mgal), This implies that either the AB Regio possess higher density or Ishtar Terra is closer to isostatic equilibrium. Similarly, the average height of Ovda Regio and Thetis Regio (OT Regio) is the same as AB Regio, but δg for this zone (~5 mgal) is less than δg of AB Regio (~43 mgal). Since the origin of Ishtar Terra formation differs from OT and AB Regios [40], (1) the likelihood for Ishtar Terra to be less dense than AB Regio, and the likelihood for OT Regio to be more isostatically compensated than AB Regio seem to be higher. Both planets reveal several δg positive and negative wide belts (Figures 3,4). These negative and positive belts likely correspond with the down-welling and up-welling of the mantle, respectively. For the Earth, two of these belts are defined as down-welling (black arrows in Figure 4), and three as upwelling (white arrows). Likewise and in comparison to the Earth, yet more disorganized, δg on Venus reveals two upwelling and three down-welling belts (Figure 3). These upwelling and down-welling are also visible in I maps (Figures 11,12). T_{zz} map of Earth (Figure 6) reveals elongated areas of maxima and minima that coincide with the plate boundaries, the areas with active orogeny, volcanism, and seismicity. These elongated T_{zz} patterns are related to the two plates: the one going beneath the other, with $T_{zz} < 0$ and $T_{zz} > 0$, respectively (zones A, B, C, D and E in Figure 6). In addition, some mottled patterns with weaker gradient field (T_{zz}), with respect to the aforesaid stretched patterns, appear in south of Africa where at least two plate boundaries exist.

The negative T_{zz} anomalous zones on Venus are chiefly associated with regional plains, lowlands of volcanic origin, and the moats around the mountains and volcanoes. Any conspicuous tectonic activity for Venus, like those of the Earth (demonstrated by negative-positive T_{zz} pairs), is not clearly revealed. However, the mottled T_{zz} pattern on Venus may lead us to reach clues about the inactive tectonism on this planet.

Here we set forward the following hypothesis: For global recent convection and tectonics detection we need high amplitude T_{zz}. If not, the elasticity had time to erase the high amplitudes, and therefore, the geologic construct is more ancient. This suggests that plate tectonics may have been on the Venus but is not active now. This would be supported by modelling of the orbital and rotational motions [4], where there is an indication that the prograde rotational motion of Venus has slowed down due to atmospheric tidal friction. With this activity the rotational axis has migrated towards equator and moved to the opposing side, while activating the retrograde motion of the Venus [25]. This change from prograde to retrograde motion may have been the cause of Coriolis force change, slowing down the mantle convection, plate tectonic activity, that subsequently resulted in the mottled T_{zz} pattern shown in Figure 5. Comparing THG maps (Figures 7,8), it is deduced that Venus possesses numerous circular and curved contacting zones, a feature that is found on Earth less. The moat zones surrounding AB and OT Regio, and those encircling Ishtar Terra, are seen in Figure 7. The Earth, however, reflects its piece-wise tectonic, and the collision zones on Earth, where plates intersect, are highlighted (Figure 8).

The strike solution on selected zones of the planets for I < 0.3 is plotted in Figures 9 and 10. The strike solutions in these regions provide information about the stress anisotropy due to the plate tectonics as well as volcanism. The solutions are perpendicular to the existing stress, and discloses the developed configurational weaknesses such as faulting. Unlike the Earth with elongated pattern, the combed zones on Venus are circular. The greenish blue arrows in Figures 9 and 10 illustrate the linear and radial stress directions for the Earth and Venus in two selected districts, respectively.

Conclusion: We applied a new way of truncating errors of gravity aspect solution by solving at h=200km to avoid the truncation error. we discovered reduced number of zones having negative δg despite their positive elevation compared to Earth. Additionally, the Ishtar Terra and OT Regio appear to be, respectively, less dense than AB Regio and closer to isostatic equilibrium than AB Regio. Downwelling and upwelling zones are suggested using δg and I maps where both 3D and 2D construct of the mantle are consistent with this interpretation. From T_{zz} maps, it could be inferred that Venus has had active tectonics in the past, although it has become inactive now. And finally, the strike solution illustrates the developed structural weakness as 2D or semi-2D constructs.



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