# ARE WE VISITING THE COASTLINES OF MARS? LOAD-CORRECTED PALEO-OCEAN LEVELS AT JEZERO, OXIA PLANUM, AND GALE.

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**Summary:** We examine whether hypothetical Martian shorelines follow paleo-equipotentials when correcting for topographic deformation due to the growth of Tharsis and other loads. In contrast to our prior work [1], we analyze the entire Arabia contact dataset and include the effects of impact basin loading. We find the Arabia contact tracks a pre-Tharsis equipotential except for deviations in the region around the Isidis basin and west of Tharsis. We show that misfit in the Isidis region can be partially explained by loading of Isidis as constrained by observed gravity anomalies within these basins. Correcting for plate flexure caused by sediment and volcanic infill of Isidis, Jezero crater (Perseverance rover) would have been at a higher elevation than the expected paleo-ocean level at the time of valley network formation and emplacement of the Arabia contact. An Arabia-level ocean would also cause partial flooding of Gale crater (Curiosity rover). Oxia Planum (Exomars rover) is also located near the proposed Arabia contact, but is in a region of misfit compared to the pre-Tharsis ocean level. The proximity of possible paleo-ocean levels to several current and future Mars missions presents an opportunity to in-situ test the Mars ocean hypothesis.

**Arabia contact:** We examine the full extent of the Arabia contact as mapped in [2]. Because of the Arabia contact's expected age ($>$ 3.7 Ga) and the lack of recent re-mapping, it is unclear whether the contact represents a true shoreline [3]. However, as shown in Fig. 1, the Arabia contact coincides with several other fluvial features, including open deltas [4], valley network (VN) termini [5], and channel knickpoints [6].

**Tharsis deformation:** The Arabia contact (and associated fluvial features) displays large changes in elevation (Fig. 2), which has been used as evidence against interpreting the contact as a coastal feature. However, the long-wavelength topography of the contact may be the result of planetary deformation following the contact's emplacement due to processes such as true polar wander [9] or Tharsis growth [1].

The expected change in topography due to Tharsis ($\Delta T_{\mathrm{Tharsis}}$) was estimated by [8] using a direct fit to the observed Tharsis gravity anomaly. The best-fit pre-Tharsis equipotential for the Arabia contact is $\Delta T_{\mathrm{Tharsis}}$ - 2.2 km (Fig. 2), where -2.2 km is the pre-Tharsis sea-level that minimizes misfit to the contact.

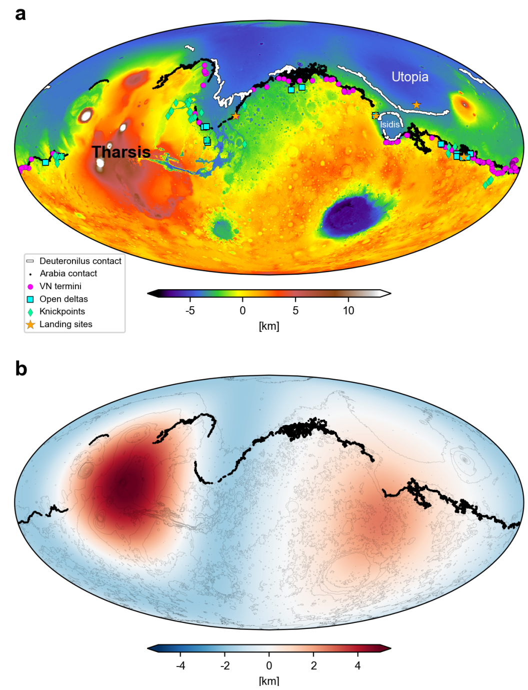


Figure 1: (a) Mars topography, highlighting the Arabia [2] and Deuteronilus [7] contacts, and other fluvial features. (b) Change in topography due to Tharsis (degree-5 model from [8]) with topographic contours in grey and the Arabia contact in black.

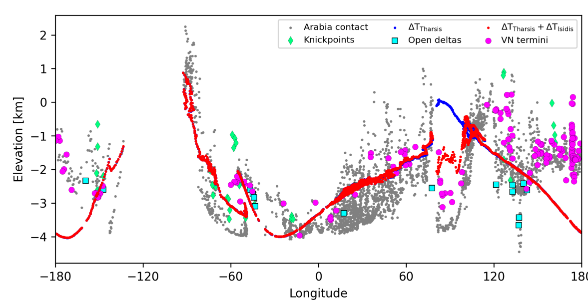


Figure 2: Arabia contact with Tharsis and Isidis loading model. The Arabia contact (grey) follows a long wavelength deformation pattern similar to Tharsis deformation (blue). The lower shoreline elevations in the Isidis basin region (77-100°E) are partially recovered by the inclusion of an Isidis loading model (red).

We analyze the entirety of the Arabia contact from [2], in contrast to [1] which only analyzed the Arabia Terra portion of the contact. The Arabia contact displays long-wavelength trends similar to the expected deformation due to Tharsis (Fig. 2). There are two main areas of misfit: (1) the circum-Tharsis trough (20-50°W and 150-210°E), which may be due to uncertainty in the Tharsis model, and (2) Isidis basin (77-100°E), which may be due to Isidis loading.

**Isidis loading:** Isidis basin contains a positive geoid anomaly (Fig. 3) that indicates the basin was loaded with sediment and volcanic deposits after its formation [10]. Loading of Isidis induces plate flexure that would have depressed the topography of the basin near the load, and also could have resulted in a small flexural bulge further from the load. If the loading occurred after the emplacement of the Arabia contact, it could have modified the topography of the contact.

We model topographic deformation due to Isidis loading using an inverse model [10] and localize the solution over Isidis using Slepian functions. The model change in topography (Fig. 3) partially recovers the lower Arabia contact elevations within Isidis (Fig. 2), although there is still some misfit which might be accounted for with a different basin loading model.

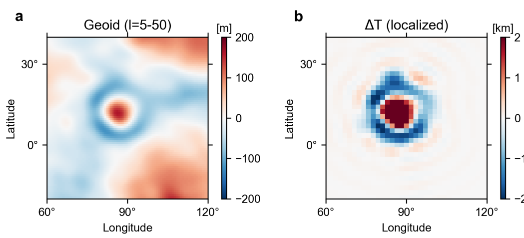


Figure 3: Loading model for Isidis basin. (a) Observed geoid (degrees 5-50). (b) Model change in topography $\Delta T$ localized over Isidis.

**Jezero crater:** As shown in [11], Jezero crater would be approximately 2km below the best fit pre-Tharsis sea-level, which precludes the formation of its fluvial features during the same time period as the Arabia contact. However, when accounting for deformation due to Isidis loading, Jezero crater would be situated above the pre-Tharsis Arabia sea-level (Fig. 4).

**Gale crater:** Gale crater is located on the mapped Arabia contact and near VN termini and open deltas. The best-fit pre-Tharsis sea-level for Arabia would partially fill Gale and breach its northern rim (Fig. 5a).

**Oxia planum:** The Exomars landing site at Oxia Planum is near the mapped Arabia contact (Fig. 5b), but there is misfit between the pre-Tharsis sea-level and the Arabia contact in this region (Fig. 5b). This may be due to an overestimate of the modeled circum-Tharsis depression (Figs. 1 and 2).

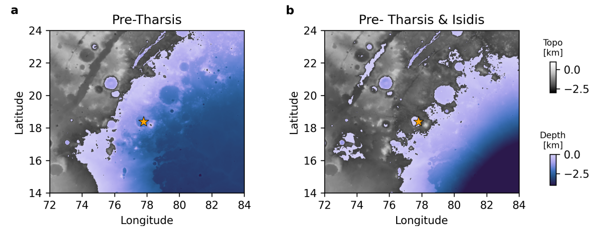


Figure 4: Topography of Jezero crater and the surrounding region (a) prior to Tharsis loading, and (b) prior to both Tharsis and Isidis loading. The depth of the best-fit paleo-ocean level is shown in blue. Jezero (orange star) is located above the expected paleo-ocean level when accounting for loading of the Isidis basin.

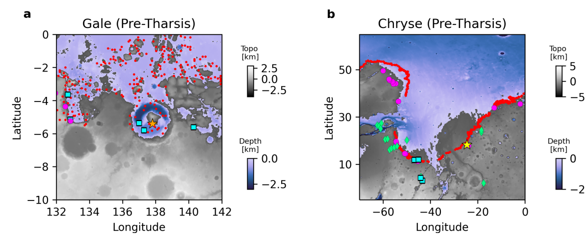


Figure 5: Pre-Tharsis topography of (a) Gale crater, and (b) Chryse region. The depth of the best-fit pre-Tharsis sea-level is shown in blue. Gale crater (orange star) is partially submerged with a breach in the north rim. Oxia planum (yellow star) is near the Arabia contact, but the contact has a poor fit to the model pre-Tharsis ocean level in that region. Also shown are the Arabia contact (red dots), deltas (cyan squares), VN termini (magenta circles), and knickpoints (green diamonds).

**Deuteronilus contact:** The Deuteronilus contact [7] follows a late-Tharsis equipotential [1]. The Tianwen-1 rover is expected to land in SW Utopia interior to the Deuteronilus contact (Fig. 1), and could potentially examine deposits from an ancient ocean.

**References:** [1] Citron R. I. et al. (2018) *Nature*, *555*, 643–646. [2] Clifford S. M. and Parker T. J. (2001) *Icarus*, *154*, 40–79. [3] Sholes S. F. et al. (2019) *Journal of Geophysical Research: Planets*, *124*, 316–336. [4] Di Achille G. and Hynek B. M. (2010) *Nat. Geo.*, *3*, 459–463. [5] Chan N. H. et al. (2018) *JGR: Planets*, *123*, 2138–2150. [6] Duran S. et al. (2019) *Sci. Rpts.*, *9*. [7] Ivanov M. A. et al. (2017) *PSS*, *144*, 49–70. [8] Matsuyama I. and Manga M. (2010) *JGR: Planets*, *115*, 1–14. [9] Perron J. T. et al. (2007) *Nature*, *447*, 840–843. [10] Ritzer J. A. and Hauck S. A. (2009) *Icarus*, *201*, 528–539. [11] Baum M. and Wordsworth R. (2020) *LPSC* 2490.