PLUME-INDUCED FLOOD BASALTS ON HESPERIAN MARS: AN INVESTIGATION OF HESPERIA PLANUM.
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Introduction: The Martian southern highlands harbor several large (>500 km) volcanic provinces of Hesperian age (3.5–3.2 Ga) that have recorded the early volcano-tectonic history of the planet [1]. Little is known about the context of formation of these Hesperian plains. They resemble terrestrial continental flood basalts in several respects, and thus a similar formation mechanism is possible [2,3].

This study investigates Hesperia Planum, a 1000 km wide Hesperian volcanic plain located north-east of the Hellas impact basin (Figure 1). We use thin-shell loading models [4,5] constrained by gravity and topography data and the tectonic record [6] to probe the structure and evolution of this province. Based on our results, we suggest that Hesperia Planum formed as a plume-induced flood basalt province, following an evolutionary path similar to that of continental flood basalts on Earth [3].

Flood basalt provinces on Earth are typically attributed to the effects of mantle plume heads following 5 stages of evolution [3,7]. 1) The plume rises through the mantle and causes a thermal uplift and extension of the surface. 2) The plume head impinges the base of the crust or lithosphere, flattens, and crustal materials are replaced by plume materials causing a local crustal thinning. 3) Extensive flood basalts extrude through the thinned crust at large eruption rates [8]. 4) The plume head dissipates, leading to a phase of thermal subsidence, flexural loading, and compression. Compression is potentially recorded on the cooling thin layer of basalts in form of tectonic features [9]. 5) Flood basalts end, plume tail materials continue to flow upward from the conduit and form a volcanic complex on a thinned lithosphere. We here show that the geophysical and tectonic expression of Hesperia Planum is consistent with a similar sequence of events.

Observations: As seen from orbit, Hesperia Planum is a smooth volcanic plain that surprisingly sits in a 1 km-deep depression compared to the surrounding heavily cratered highlands (Figure 1). Such a depression cannot be explained by the flexural response to volcanic loading only, as this would not push the volcanic surface below the pre-existing surface. Hesperia Planum is characterized by a weak free-air gravity anomaly, which is suggestive of both crustal thinning and a lack of long-wavelength lithospheric flexural support.

A closer look at Hesperia Planum reveals a high density of wrinkle ridges, greater than is found in similarly aged but smaller Hesperian plains scattered throughout the southern highlands (1.2 vs 0.4 $\times 10^{-5}$ km^{-1}). A shield volcano, Tyrrhena Mons, sits at the center of the planum and formed on a thin lithosphere, with an elastic thickness of only 10±10 km [5]. Crater counting statistics suggest that the volcano formed prior or concomitant to the volcanic plains of Hesperia Planum [10]. Gamma-ray measurements [11] indicate that the volcanic surface is richer in SiO_2 and strongly depleted in both Th and K, compared to Amazonian shields in the Tharsis and Elysium regions. This implies that Hesperia Planum formed from a high degree of partial melting, while the later Amazonian magmas were directly derived from a depleted mantle source.

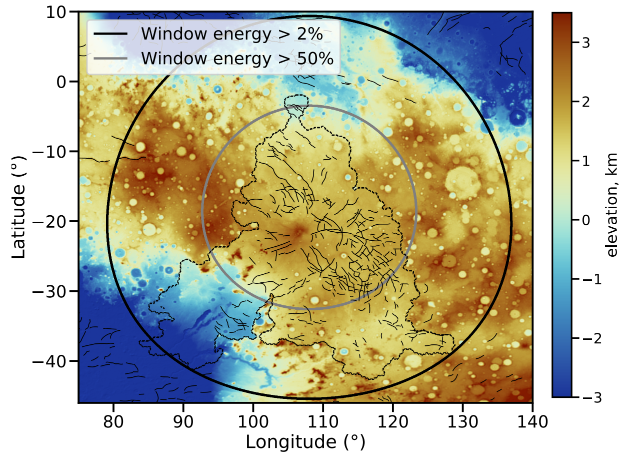

Figure 1. Surface elevation at Hesperia Planum overlaid by compressional tectonic features (thin solid lines) from [6], the localization window (thick solid circles, 3000 km diameter), and a geologic contour of the Planum (dashed line).

Methods: The observed topography and gravity field at Hesperia Planum reflect its time-integrated volcano-tectonic history. In order to understand the geophysical history of the region, two models are here used. First, we analyze localized gravity and topography data by matching their localized spectral ratio (i.e., the admittance) and their correlation to a theoretical loading model [5]. Both the large gravity and topography signals of Tyrrhena Mons were removed from the data using a best fit model [5]. The localization window used has a bandwidth of 10 and an angular size of 24° (Figure 1).

In the second model, we make use of a thin-shell formalism [4] to invert the gravity and topography data for the associated loading and flexure, and to predict the strain concentration at Hesperia Planum. The model uses current global gravity and topography data as input and accounts for crustal thickness variations. All compensation occurs at the crust-mantle boundary by a combination of vertical displacements and crustal thickness variations. The strain distribution is estimated from the displacement assuming an elastic thickness of 100 km, a constant crustal density of 2900 kg m^{-3}, and an average global crustal thickness of 50 km.

Results and discussion: In Figure 2, we show our model fit to the long-wavelength (degree 13 to 40) observed admittance. The elastic thickness is found to be 89 (+11, -59) km, together with a large internal load (modeled as a mass-sheet). The magnitude of the internal load ratio is 1.9 (+0.4, -1.6), where a value of 1 corresponds to an isostatic case. The elastic thickness is larger than at Tyrrhena Mons and indicates that the volcano formed on a locally thinned lithosphere relative to the later thicker lithosphere supporting Hesperia Planum itself. This sequence is consistent with a plume model in which the later subsidence and transition to flexural support of the flood basalts occurs on a colder lithosphere, after the dissipation of the plume-induced thermal anomaly [7]. The internal load reflects the presence of a dense crustal intrusion beneath Hesperia Planum that could be associated with plume materials having replaced a thinned crust.

The predicted compressional strain, based on the present-day gravity and topography (Fig. 3), correlates remarkably well with compressional structures within Isidis and Hellas. In the eastern part of Hesperia Planum, however, the very low predicted compressional strains are inconsistent with the high density of compressional structures. This indicates that the abundance and pattern of compressional structures in Hesperia Planum cannot be explained by the flexural subsidence inferred from the present-day gravity and topography data. A more complex scenario with an additional source of subsidence is thus required. We propose that a plume-induced flood basalt scenario, in which basalts were emplaced on the plume-uplifted lithosphere followed by thermal subsidence and flexure, would be consistent with observed tectonic patterns.

Conclusions: Based on orbital observations and modeling, we propose that Hesperia Planum formed as a plume-induced flood basalt province, similar to continental flood basalts on Earth. The thinning of the crust and inferred high temperatures of the lavas are consistent with the effects of a mantle plume. A thin lithosphere associated with Tyrrhena Mons early in the evolution of the province, followed by a thicker lithosphere supporting Hesperia Planum is consistent with an early thermal thinning of the lithosphere followed by conductive cooling and subsidence. The high density of compressional structures cannot be explained solely by the loading of Hesperia Planum and requires added subsidence as would occur if the lava flows were emplaced upon plume-uplifted lithosphere.

Future work will continue to explore the plume formation scenario for Hesperia Planum. The dynamic topography associated with a plume uplift will be estimated, and plume parameters will be fitted to match the observed tectonic records. A similar investigation will be undertaken for the geologically similar large Hesperian plains, Malea Planum and Syrtis Major.

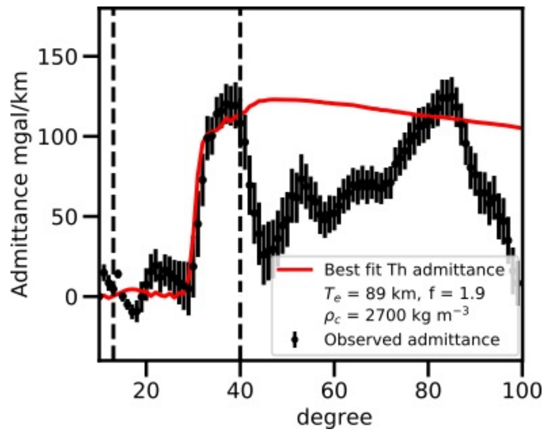

Figure 2. Observed and best-fitting localized admittance.

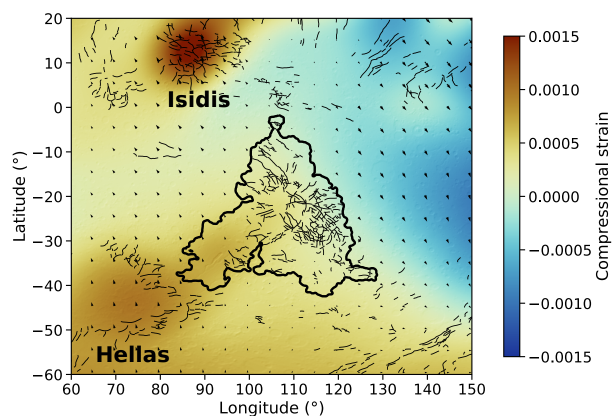

Figure 3. Predicted compressional principal strain magnitude (positive is compression) and direction overlaid by compressional tectonic features [6].

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