INSIGHT INTO TERRESTRIAL PLANETARY EVOLUTION VIA MANTLE POTENTIAL TEMPERATURES. M. B. Weller[1] and M. S. Duncan[1], [1]Department of Earth Science, Rice University, Houston, TX 77005, USA (matt.b.weller@rice.edu, megan.s.duncan@rice.edu).

Introduction and Motivation: Of all the solar system bodies (except for perhaps the Earth), the current and past tectonic states of Venus are the most hotly debated. It is currently unclear if Venus operates within a stagnant- to highly sluggish-lid [e.g., 1,2], within an episodic regime [e.g., 3-5], or within a (perhaps localized) mobile-lid regime in its past [6]. Recently, several studies found that increasing surface temperatures over geologic time scales may cause a transition from mobile-lid convection into and through a long lived episodic-lid regime, before eventually settling into stagnant-lid behavior [7-10].

A large amplitude increase in the surface temperature over geologic time scales (e.g. ~ 100 °C operating over ~0.1 – 1 By time scales) should lead to an increase in temperature within the interior of the planet, shown by scaling theory and numerical models [7-10]. All things being held equal, this implies that high surface temperatures should translate into a higher internal temperature for the system. It has also been shown that internal temperatures of long-lived stagnant-lids should be measurably higher than a respective mobile-lid system [e.g. 11], with episodic-lids perhaps falling in between. Therefore in this simplified system, internal temperatures (approximated by the mantle potential temperature - T_P) may be used to infer lid-states and help to constrain the thermal-tectonic evolution of the system.

The key questions this study seeks to address are: (1) Can mantle potential temperatures for remote planets be recovered using current data? (2) Does this data reliably compare to data from the Earth? (3) Can this data reliably be used to infer the thermal-tectonic evolution of planets?

Methods: In order to glean the most information out of the limited Venus (and planetary) geochemical data, we have applied our knowledge of mantle melting and basalt generation on Earth to Venus and the other inner solar system bodies. Because there are only three measured surface compositions from the Venera and Vega lander missions (and with large error), and no Na information, we calculated the composition of the primary melts using the original, Na-free data and with the Na included in the calculation based on [12], assuming the measured surface basalts are primitive (MgO > 8 wt.%). Primary melts were calculated assuming that the source mantle is in equilibrium with olivine of a set composition (here represented as Fo#) and that the initial melt was also in equilibrium with this olivine. This fixes the amount of Fe and Mg in the melt, due to well-known partitioning behavior of Fe and Mg between this olivine and melt typically represented as $K_D^{ol/melt}$. The value of K_D has been determined for the Earth from many studies and typically has a value of 0.32 [e.g. 13].

However, the primary melt is not that which erupts, and the erupted melt's composition has deviated from the primary melt. To go from the surface composition back to the primary melt composition, we incrementally added olivine to the erupted composition until the equilibrium olivine reached the desired value. We assumed this value to be Fo_{90} for Venus, similar for Earth based on the initial equilibrium olivine values and that Venus is likely similar to the Earth in composition, when compared to the other inner solar system bodies. After calculating the primary melt compositions, we calculated the *T* and *P* of primary melt generation by applying the thermometers of [14] and [13], and the barometer of [14] (Fig. 1).

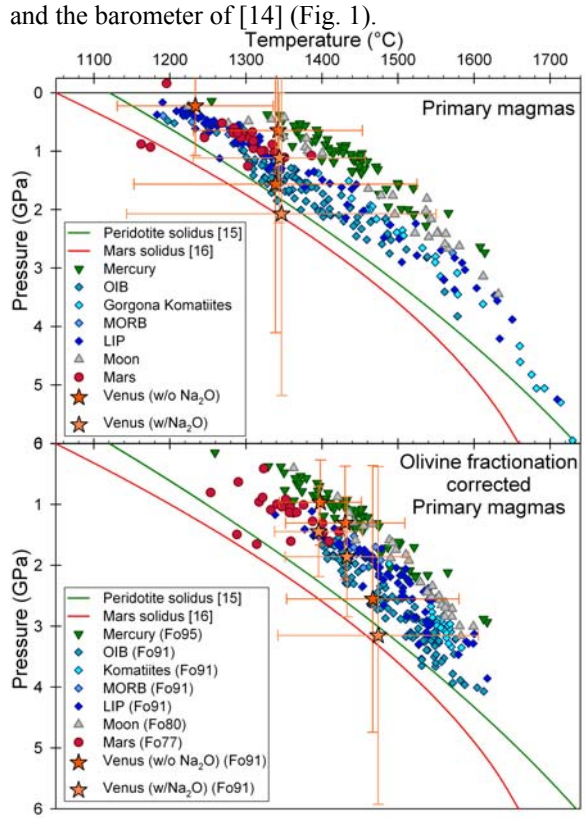

Figure 1: Top: Calculated *T* and *P* of melt generation [14] based on raw data of 'primary' melt compositions. Bottom: Calculated *T* and *P* of olivine corrected 'primitive' melt compositions, mantle equilibrium olivine values in parentheses.

In order to calculate T_P, the melt *T* and *P* calculated previously must be "corrected" to an adiabat. This

correction was accomplished following the method used by [16] for Mars by taking into account the latent heat associated with melting and calculating melt fraction based on the partitioning of Ti between the melt and the residual solid. We made assumptions about mantle composition to calculate the mantle potential temperature and then compared to the formulation of [17], which is simply a function of primary melt MgO content. Due to the lack of data for Venus, we assumed that the mantle is similar to that of Earth, i.e., in equilibrium with $Fo_{90\text{-}91}$ and bulk composition of that calculated as Bulk Silicate Earth [18] (Fig. 2). We followed a similar routine for Mars and the Earth to compare to previous studies [16,17], and extended the comparison to Mercury and the Moon.

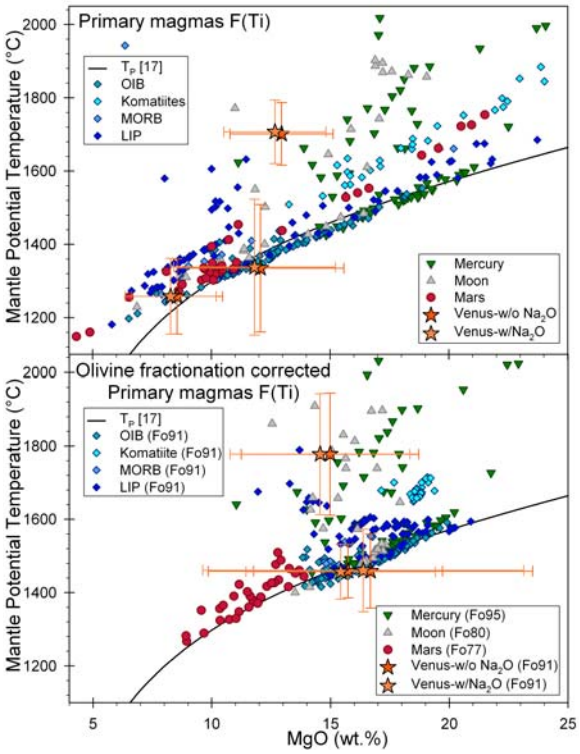

Figure 2: Top: Calculated T_P of mantle based on raw data of 'primary' melt compositions. Bottom: Calculated T_P of mantle based on olivine corrected 'primitive' melt compositions, mantle 'equilibrium' olivine Fo values in parentheses. Calculated potential temperatures based on Ti partitioning between bulk silicate mantle and melt, compared to [17].

Results and Discussion: Calculated T_Ps for the Venus olivine corrected compositions (Na-free calculation) are 1459±73 °C, 1459±101 °C, and 1778±167 °C, for Venera 13, Venera 14, and Vega 2, respectively. Adding Na_2O increases T_P values by a maximum of 2 °C. Initial melting depths of 2.6±2.2, 1.3±0.9, and 1.0±0.7 GPa (90±77, 46±33, 34±25 km), respectively. All errors are determined based on the 1σ variation in the initial composition values.

Overall, the calculated T_Ps for Venus are higher than those calculated for Earth today ~1350 °C calculated from MORBs, but closer to the T_P of ~1550 °C at Hawai'i and that of Archean basalts 1500-1600 °C [19] and that calculated based on the Vega 2 data is similar to that for Archean komatiites ≥1700 °C [20].

T_Ps estimates appear robust for the Earth and inner terrestrial planets. Corrected data indicates that Mars generally has the lowest overall pressure and temperatures recorded. Venusian results are elevated in temperature as compared to the modern Earth (in line with Archean results). Mercury and the Moon diverge from these trends. Our next steps are to test the mantle potential temperature calculations against well established internal heating scaling laws [e.g. 11, 21, 22] that take into account different lid states [11]. From the scaling laws derived for both mobile and stagnant-lids, estimates of mantle potential temperatures from data for Venus, Earth, and Mars, may be used to infer the thermal-tectonic evolution of these systems.

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