INFLUENCE OF THERMAL GRADIENT AND WATER CONTENT ON THE COMPOSITION OF VENUSIAN BASALTS. J. Semprich[1], [1]AstrobiologyOU, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK (julia.semprich@open.ac.uk).

Introduction: Venusian basalts show compositional differences as recorded by surface measurements of the Venera and Vega landers [e.g., 1] and terrestrial crystallization experiments [2]. This magmatic diversity is a result of variations in melting depth and volatile content in the source rocks [2]. Linking basalt compositions on the surface to melting depth and reservoir is therefore crucial to further constrain Venus' tectonic regime and geological evolution. Constraining the formation conditions of basaltic surface rocks will also contribute to the interpretation of emissivity data from orbit such as FeO content [3], which will be measured by the Venus Emissivity Mapper onboard the upcoming EnVision and VERITAS missions [e.g., 4].

Here, we use petrological modeling to determine the compositions of partial melts originating from the mantle for a range of thermal gradients and varying H_2O contents, compare them to analyzed and derived surface compositions, and predict potential formation conditions.

Methods: Phase equilibria and melting were modeled using the Gibbs free energy minimization software Perple_X 6.9.1 [5] and an internally consistent thermodynamic dataset [6]. As starting composition, we used a terrestrial peridotite [7] since the venusian mantle is likely compositionally similar to Earth's [8]. Phase diagrams were computed for temperatures of 450–2050 °C and pressures of 0.001-8 GPa with H_2O content set to 0, 0.02, and 0.2 wt %, respectively. The oxidation state was assumed to be reducing by adding 0.01 wt % O_2. We used solid solution models for olivine, orthopyroxene, clinopyroxene, garnet, spinel, melt, biotite [9], plagioclase [10], amphibole [11], and chlorite [12]. Melt compositions were extracted on thermal gradients of 5, 10, 15, 20 and 25 °C/km at 5-7 vol % melt proportions.

Results: Fig. 1 shows compositional variations in FeO (Fig 1a) and SiO_2 (Fig. 1b) contents of the computed partial melts, which are generated on the five thermal gradients at varied H_2O content plotted against depth. The analyzed compositions of Venera 13 and 14 [1] and the derived FeO content for Venera 9 [3] based on spectral measurements are also plotted in Fig.1.

Compositional variation with thermal gradient. The dry peridotite composition exposed to a low thermal gradient of 5 °C/km does not melt until a depth of ~270 km. The computed melts at this depth record high FeO (~14 wt %) and relatively low SiO_2 (~42 wt %). With the formation of an increasing amount of melt, the FeO content in the melt decreases (Fig 1a) while SiO_2 increases (Fig, 1b). Peridotite with 0.02 wt % H_2O starts melting at shallower depths of ~100 km due to the presence of low amounts of amphibole (~1 vol %). However, melt volumes of ~6 vol % are only reached at depths comparable to the dry composition. The onset of melting is shifted to even shallower depths for peridotite with 0.2 wt % H_2O resulting in melt volumes of ~6 vol % at ~220 km where the melt composition contains high FeO (~14 wt %) and low SiO_2 (~40 wt %).

On a thermal gradient of 10 °C/km, the dry peridotite composition starts melting at ~105 km with a melt composition of ~11 wt % FeO and ~45 wt % SiO_2. With increasing melt volume, the FeO content of the melt increases before decreasing (Fig, 1a), while SiO_2 first decreases slightly before increasing and decreasing again (Fig. 1b). The composition with 0.02 wt % H_2O shows a similar compositional evolution once melt volumes of ~6 vol % are generated. Peridotite with 0.2 wt % H_2O reaches a melt volume of ~5 % at ~81 km resulting in lower SiO_2 (44 wt %) and FeO (8 wt %) content than for the drier compositions at comparable melt volumes. Melt compositions on thermal gradients of 15-25 °C/km show similar trends as melts generated on the 10 °C/km gradient (Fig 1) but shifted to shallower melting depths with increasing thermal gradient and less compositional variation due to water content.

Comparison to Venera measurements. The derived FeO value for Venera 9 is with 12.2 wt % significantly higher than the range of 8.8-9.3 wt % for Venera 13 and 14. The FeO content derived from Venera 10 surface spectra [3] is with 9.5 wt % comparable to this range (not shown in Fig. 1). The modeled melt compositions only record FeO contents of >12 wt % on the low thermal gradient of 5 °C/km. This would require 35-37 vol % partial melt at melting depths of ~280-290 km with no significant difference between dry and H_2O-bearing compositions. While SiO_2 has not been measured or derived for Venera 9, our models suggest a corresponding value of ~42 vol %.

Melt compositions with FeO contents of 8.8-9.5 wt % as measured by Venera 13 and 14 and derived for Venera 10 can be generated on all thermal gradients and therefore at various depths and melt volumes. On a low thermal gradient of 5 °C/km, high melt proportions of ~80-90 vol % at depths >300 km will result in comparable FeO contents and would therefore require significant mantle melting. A similar FeO content is also recorded in melt compositions forming on the 10 °C/km thermal gradient at high melt proportions of 70-90 vol % equivalent to depths of ~140-150 km for peridotite with no and low H_2O and for partial melts of peridotite with 0.2 wt % H_2O at low melt volumes of 6-8 vol % and 80-90 km depth (Fig 1 a). On higher thermal gradients, melts with FeO content between 8.8-9.5 wt % can be generated by lower volumes of partial melting (9-37 vol %; melt proportion increasing with thermal gradient and H_2O content) or high volumes of partial melting. (70-90 vol %). While FeO content alone will not be sufficient to derive the conditions of melt formation, additional components such as SiO_2 for Venera 13 and 14 (Fig. 1b) can provide further constraints. SiO_2 contents of 45.1 wt % suggests that the Venera 13 basalt formed on a low thermal gradients of 10 °C/km in the deep mantle, while the higher SiO_2 content of the Venera 14 composition (48.7 wt %) indicates shallow mantle melting on higher thermal gradients.

Discussion: Large uncertainties of the geochemical data from the Venera analyses and potential surface alteration make the derivation of a conclusive formation depth and origin challenging. However, our results show that melts with high FeO content comparable to Venera 9 basalts may originate in the deep venusian mantle and could be indicative for mantle plumes. A plume origin is also supported by FeO overlapping with Hawaiian alkali olivine basalt [3]. The models presented here do not include melt fractionation or fractional crystallization processes, which can result in the formation of FeO-rich restitic compositions or cumulates at various depths and thermal conditions. Future models will therefore have to include fractionation to determine how it can influence the composition of surface basalts.

A comparison of Venera analyses to crystallization experiments suggests deep partial melting of a carbonated source region for the Venera 13 composition [2]. Our models corroborate an origin in the deep mantle and low thermal gradients and further models will have to include other volatiles such as CO_2 to further constrain their effect on basalt composition. The Venera 14 composition is similar to those of olivine tholeiites suggesting relatively shallow mantle melting [2] although melting of a metamorphosed basaltic protolith may also result in similar compositions [13].

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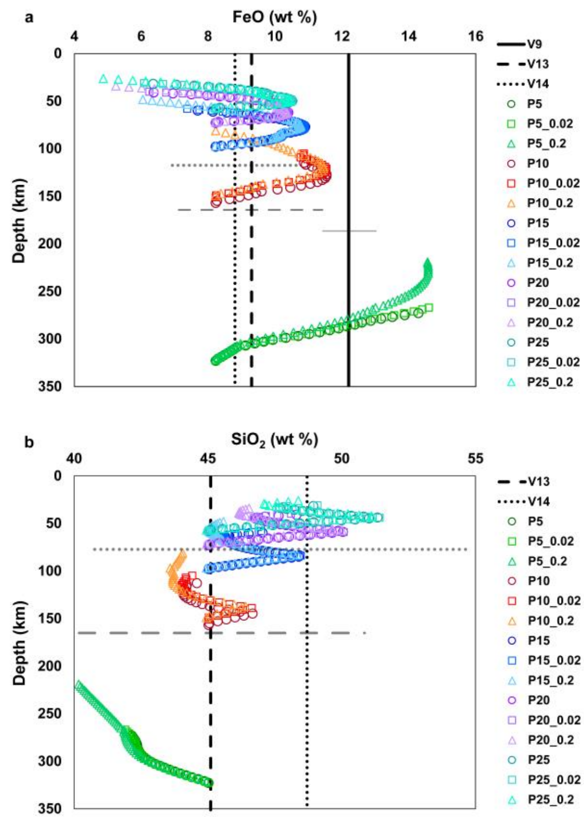

Figure 1:Compositional variation in FeO (a) and SiO2 (b) of the modeled melt compositions generated on a range of thermal gradients plotted against depth. Starting composition is a peridotite (P) with the following composition (in wt %): 44.84 SiO_2, 39.52 MgO, 8.2 FeO, 3.51 Al_2O_3, 3.07 CaO, 0.3 Na_2O, 0.11 TiO_2, 0.02 K_2O, 0.01 O_2. Numbers represent thermal gradients of 5, 10, 15, 20, and 25 °C/km (e.g., P5). Compositions with 0.02 and 0.2 wt % water are indicated by numbers after the underscore (e.g., P5_0.02). Derived FeO content for Venera 9 [3] and analyses for Venera 13 and 14 are shown as vertical black solid, dashed and dotted lines. Errors are 2σ for Venera 13 and 14 analyses and a root mean squared error for Venera 9 [3].