EFFECTS OF WATER ON THE DENSITY AND ELEVATION OF TESSERAE ON VENUS.

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Introduction: While the current conditions on Venus are inhospitable, with surface temperatures of ~ 470 °C, pressures of 92 bars, and a CO_2 dominated atmosphere, early Venus may have had a more temperate climate with water on the surface [1-4]. Water is not only crucial to understanding the habitability potential of Venus, but also has major implications for the tectonic regime and thermal evolution of a planet.

Tesserae are believed to be the oldest exposed features on the surface of Venus [5] and may have formed during a period with higher water content. Some of this water might have been preserved as hydrous minerals in the Venusian subsurface. The presence of these minerals has an effect on the density profiles and isostatic behaviour of the tesserae and therefore requires a more detailed investigation.

Here we will present results of phase equilibria and isostasy modelling on a range of Tesserae-analogue rock compositions with varying water content and along a range of potential thermal gradients. We compare our results to anhydrous models performed previously under similar thermal regime [6] to constrain the conditions (rock composition, thermal gradient, and water content) needed for tesserae stability.

Methods: The range of rock types which we used and their bulk compositions are given in Table 1. The basalt is the only composition of Venusian origin, being based on surface rock analysis performed by the Venera 14 lander [7]. Terrestrial samples are used here as analogues for potential tesserae compositions. A composition of alkali basalt from the Sverrefjell volcano on Svalbard was chosen as it has been used to model a Venusian mantle plume setting [8]. A granite from the Bad Vermillion Lake greenstone belt [9] was chosen due to the similarities between greenstone belts on Earth and tesserae on Venus, the granodiorite from the Kuhmo greenstone belt [10] was chosen for the same reason as the granite. Finally, an anorthosite composition from the Duluth Complex, Minnesota [11] was used as previous studies have suggested such a composition for tesserae due to their presence on other terrestrial bodies such as the Moon and Mars [12].

These compositions were modelled under Venusian pressure and temperature (P-T) conditions using the Perple_X 6.9.1 Gibbs free energy minimization software [13], with an internally consistent thermodynamic database [14]. The calculations were performed with three distinct water contents: 0.2 wt%, 1.2 wt% and 2 wt%. Several simplifications have been made, including using only divalent iron as an input, converting any amount of trivalent iron in the compositions to an equivalent divalent iron abundance, and excluding Cr_2O_3 and P_2O_5. These were made as the components were found to have little effect on the key calculation outputs for this study.

A set of solid solution models were used to represent the compositional variation of some minerals, including those from [6], in addition to models for amphibole from [15], biotite from [16] and mica and staurolite from [17]. Additionally, quartz, kyanite and rutile were assumed to be pure and corundum was excluded from some calculations, as it would not be expected.

We extracted densities along thermal gradients of 20, 15, 10 and 5 °C/km. These were used to calculate the maximum possible crustal thickness along each gradient for every composition at the chosen water contents. The change in density along the thermal gradients, as well as the calculated maximum crustal thickness values, were then used as inputs for isostasy calculations to determine the maximum possible elevation and required crustal root thickness that each composition could support under the different gradients and water contents.

Results: For the basalt (Fig. 1), the addition of 0.2 wt% water causes a decrease in average melting temperature of around 500 °C and alters the behaviour of the curve with pressure.

While the melting temperature increases with pressure in the anhydrous calculation (solid white lines in Fig. 1A), the addition of water causes the opposite behaviour past 0.5 GPa, with the melting temperature decreasing with higher pressures (Fig. 1B). The density is notably different from the anhydrous case, showing an increase of up to almost 90 kg/m^3 at low pressures, but at higher pressures a decrease of up to 100 kg/m^3 is observed under some conditions. On average, the density decreases by 20 kg/m^3 compared with the dry composition model. These changes are due to the formation of hydrous minerals such as amphibole and micas, which have a lower density than the anhydrous minerals in the dry composition, which causes the slight density decrease. Furthermore, dehydration reactions and the release of water at higher pressures would serve to enhance melting, allowing it to occur at much lower temperatures. As a result, the maximum crustal thickness for most thermal gradients is up to 34 km less, and there is a corresponding loss in elevation and root thickness. The 5 °C/km gradient however, where delamination occurs before melting, has an increased crustal thickness compared to its anhydrous counterpart. Delamination is a process where the density of the base of the crust exceeds that of the mantle and ‘drips’ off into it. The lower average density allows hydrated basalt to form a slightly thicker crust than dry compositions.

The tallest elevation which can be supported with a 0.2 wt% water content is 1.3 km which is stable under a 10 °C/km thermal gradient. This is significantly less than the dry model which can support up to 3.2 km under the same gradient. A similar trend would be expected when adding water to the other compositions listed in Table 1.

Discussion and outlook: Our results suggest that, in general, hydrated compositions on Venus will be less stable and that the current crust of Venus, including the subsurface, has very little water present. This is, however, under the assumption that the entire crustal column is hydrated, which on Venus is unlikely to be the case. Ongoing analyses will investigate whether any hydrated compositions are capable of supporting significant elevations.

Table 1: Bulk rock compositions of all rock types used in our models. FeO_T represents the total FeO content including converted Fe_2O_3. The oxide abundances are in wt%. Abbreviations used: B – Basalt, AB – alkali basalt, Gd – granodiorite, An – anorthosite, G – granite

	B	**AB**	**Gd**	**An**	**G**
SiO_2	48.7	47.9	66.1	54.3	73.5
TiO_2	1.30	2.80	0.656	0.25	0.140
Al_2O_3	17.9	18.0	15.8	27.9	14.7
FeO_T	8.80	9.60	4.68	1.02	1.44
CaO	10.3	7.70	2.78	11.5	1.45
MgO	8.10	3.30	2.01	0.19	0.33
K_2O	0.20	2.70	2.12	0.45	3.74
Na_2O	2.40	6.00	4.83	4.3	4.46

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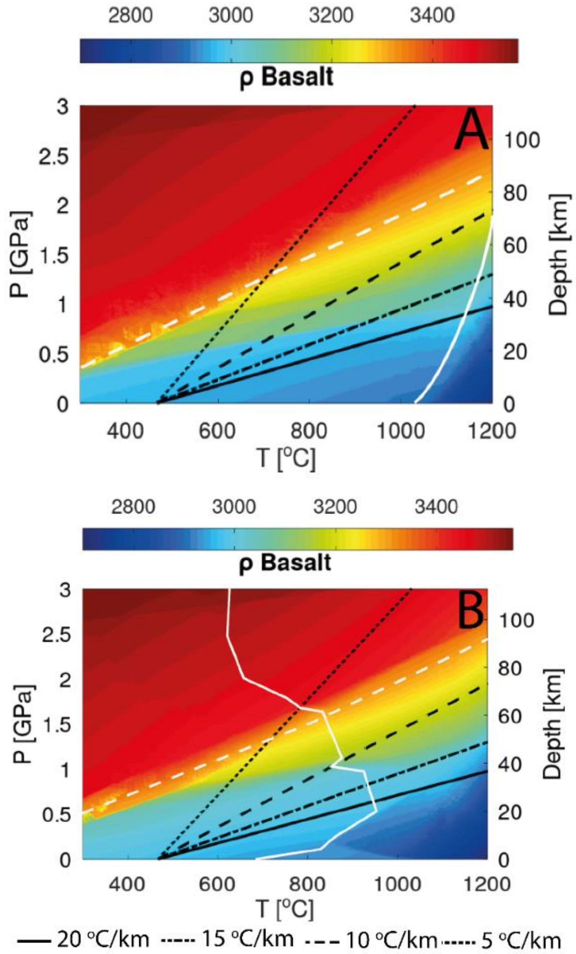

Figure 1: Diagrams showing the density changes across the modelled space for basalt (A) under anhydrous conditions and (B) with low water content. The white lines indicate the two limiting factors on crustal thickness used in this study, the solid white line indicates the solidus while the dashed white line indicates the point where the density exceeds 3300 kg/m^3, where the crustal root would begin to delaminate. The black lines indicate different thermal gradients