DENSITY VARIATIONS AS A FUNCTION OF COMPOSTION IN THE VENUSIAN CRUST: IMPLICATIONS FOR TESSERAE FORMATION. A. R. Baker[1], J. Semprich[1], S.P. Schwenzer[1], J. Filiberto[2], and R.C. Greenwood[1], The Open University (Milton Keynes, MK7 6AA, Aedan.baker@open.ac.uk), [2]ARES Division xI3, NASA Johnson Space Center, Houston, TX 77058, USA.

Introduction: The Venusian surface plains are thought to be predominantly basaltic, while tesserae occupy ~ 7 % and are potentially the oldest units preserved [1]. They consist of layered, folded, and eroded rocks [2], potentially giving an insight into what tectonic regimes were present during Venus' history. Studies of the tesserae have noted lower emissivity measurements compared to the surrounding plains [3]. Several explanations for these lower emissivity values have been proposed, including a more felsic composition for the tesserae [4], that the lower emissivity could be a result of a difference in mineralogy caused by chemical weathering facilitated between the rocks and atmosphere by the lower temperatures at the higher elevations of tesserae [5]. Alternatively, the morphology of some features on tesserae, such as the Ovda Fluctus, are more consistent with a basaltic composition [6].

The presence of significant amounts of felsic igneous compositions could either imply partial melting of hydrous material and hence a higher water content in early Venus [7], or differentiation of basaltic melts [8]. Further, tesserae composition influences the density of the crust with major implications for the stability of crustal roots.

Here, we use thermodynamic modeling to compute phase diagrams and extract rock densities for two end-member compositions: a basalt and a granite. We discuss major phase and density changes for each composition and describe the effect of compositional variations along geothermal gradients with implications for the stability of crustal roots with the aim to provide constraints on the composition of tesserae.

Methods: The bulk composition of the basalt used in our model was taken from [8] which is based on Venusian basalts analyzed by the Venera 14 lander [9]. The granite composition used is a terrestrial granite from the Bad Vermillion Lake greenstone belt collected by [10]. This granite was chosen as greenstone belts are among the oldest remnants preserved on Earth, making for a good comparison to see if Venus could have had a similar tectonic regime to early Earth. Furthermore, Venusian Tesserae resemble Archaean terrain, both featuring high densities of tectonic structures [2]. The composition of the basalt used is (in wt %): 48.7% SiO_2, 1.3% TiO_2, 17.9% Al_2O_3, 8.8% FeO, 8.1% MgO, 10.3% CaO, 2.4% Na_2O and 0.2% K_2O. The granitic composition is 65.5% SiO_2, 0.54% TiO_2, 15% Al_2O_3, 4.32% FeO, 3.41% CaO, 2.42% MgO. 3.89% Na_2O and 4.19% K_2O.

Calculations of the water-free phase diagrams and resulting densities were performed using the Perple_X 6.9.1 Gibbs free energy minimization software [11] and an internally consistent thermodynamic data base [12]. Diagrams presented here were calculated with divalent iron only and the oxides Cr_2O_3, MnO, and P_2O_5 were excluded.

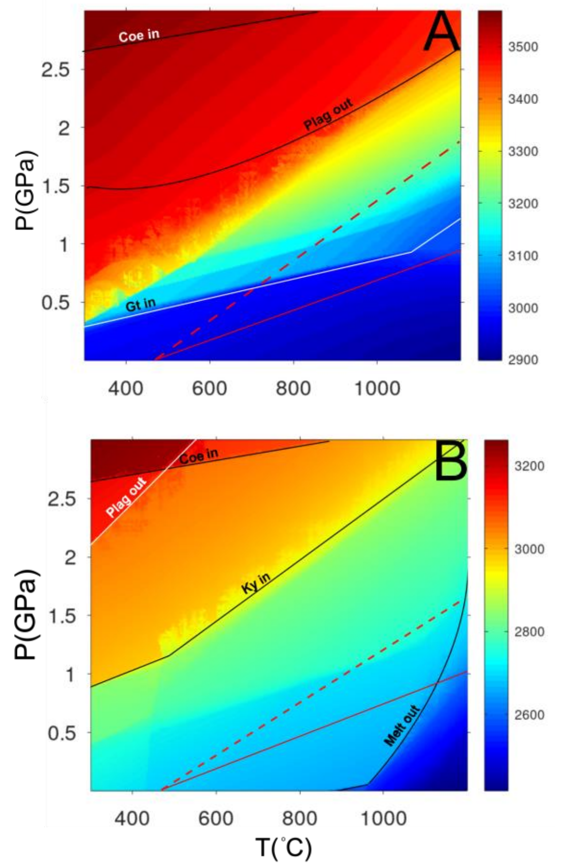

Figure 1: Diagrams showing the density changes for the (a) basalt and (b) granite compositions within a range of Venus-like temperature and pressures. The red dashed lines show a 10°C/km and red solid lines show a 20°C/km geotherm, both starting from the average Venus surface temperature. Abbreviations used in the diagrams are as follows: Gt – garnet, Plag – plagioclase, Coe – coesite and Ky – kyanite.

The solid solution models used in the calculations included those for clinopyroxene, orthopyroxene, garnet, and spinel [13], an ilmenite model from [14], a melt model from [15] and an olivine model from [16].

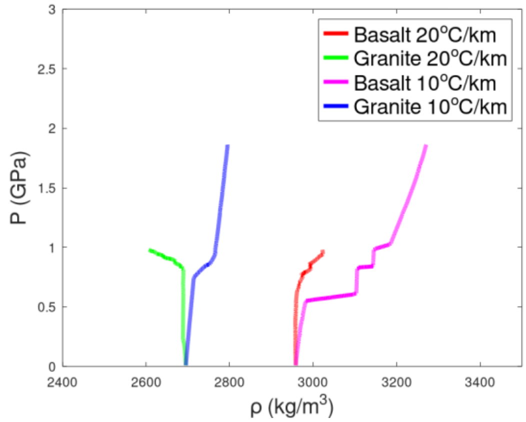

Figure 2: Densities for the basaltic and granitic compositions extracted along a 10 °C/km and 20 °C/km geotherm to a depth of 70km shown in Fig.1.

In the basalt model (Figure 1a), quartz, kyanite, coesite and rutile were assumed to be pure phases. In the granite model sphene and tridymite were also assumed to be pure phases. In the basalt, corundum was excluded as it would not be expected in a metabasic rock.

Densities were extracted along geotherms where we assume a maximum crustal depth of 70 km [17], a surface temperature of ~470 °C, and two geotherms of 10 °C/km and 20 °C/km. Pressures were approximated as ρgh, with $\rho = 3000$ kg/m^3, $g = 8.87$ m/s^2, and h being the crustal depth.

Results: Fig 1a shows the densities extracted for the basaltic composition. Close to the surface at temperatures of ~470°C and pressures of ~9 MPa, the densities are in the range of 2900-3000 kg/m^3, while at high pressure the densities increase significantly to 3500kg/m^3 at higher temperatures around 1200°C or more at lower temperatures. Major changes in density are caused by garnet forming in a granulite transition, plagioclase being replaced during an eclogitic transition (although the transition is more gradual than is visible in the figure), and coesite. The garnet is likely formed from olivine at relatively low pressures. Plagioclase becomes unstable at around 1.5-2.5 GPa and is likely replaced by sodic clinopyroxene and kyanite, while coesite forms as a high-pressure polymorph of quartz.

Fig 1b shows densities extracted from the granite composition. Near the surface the densities range from 2400-2700 kg/m^3 while at high pressures the densities increase to 2900+ kg/m^3. The major density changes are caused by the formation of melt, addition of kyanite, replacement of plagioclase and formation of coesite.

As plagioclase begins to become unstable, sodium-rich plagioclase is first replaced by clinopyroxene and kyanite, K-rich feldspar remains stable towards much higher pressures, resulting in plagioclase being present for much longer compared to the basalt.

Densities extracted along the geotherms shown as dashed and solid red lines in Figure 1 are shown in Figure 2 as a function of pressure. There is little change in the density for both the basalt and granite with increasing temperature and pressure under Venus-like conditions and with a 20 °C/km geotherm (except for a decrease in density of the granite when melt is formed), while the basalt records significant densification on a 10 °C/km geotherm.

Discussion and Outlook: The geothermal gradient on Venus has not been directly measured, but our results show major differences between hotter and colder geotherms for mafic and felsic tesserae compositions.

The 20°C/km geotherm shows no significant density change for either composition other than a slight density decrease at high pressures for granite due to melting and a slight increase for basalt. With the 10°C/km geotherm, basalt shows some densification while granite does not, suggesting that if tesserae were felsic, a thicker crustal root could be sustained.

However, felsic compositions may melt at lower temperatures than basalt, reducing the crustal thickness for hotter geotherms.

The effect of composition will have to be further explored by adding even colder geotherms as proposed by [17] as well as expanding the range of compositions considered by adding alkali-rich compositions, anorthosite and studying the effect of adding fluids.

References:

[1] Ivanov, M. A. and Head J. W. (2011) *Planetary and Space Science*, *59*, 1599–1600. [2] Byrne, P. K. et al. (2020) *Geology*, 49(1), 81-85. [3] Gilmore. M. et al. (2015) *Icarus.*, *254*, 350-361. [4] Hashimoto, G. L. et al. (2005) *JGR:Planets*, 113, E00B24. [5] Brossier, J. F. (2020) *Icarus*, 343, 113693 [6] Wroblewski, F. B. et al. (2019) *JGR:Planets*, *124*, 2233–2245. [7] Way, M. J. et al., (2016) *Geophys. Res. Lett*. 43, 8376-8383. [8] Filiberto, J. (2014) *Icarus*, 231, 131-136. [9] Surkov, Y. A. et al. (1984) *JGR*, B393-B402 [10] Wu, T. et al. (2016) *Precambrian Research*, 282, 21-51. [11] Connolly, J. A. D. (2005) *EPSL*, 236, 524-541. [12] Holland, T .J. B. and Powell, R. (2011) *J. Met. Geol*, 29, 333-383. [13] Holland, T. J. B. et al. (2018) *Journal of Petrology*, 59, 881-900. [14] White, R. W. et al. (2007) *Journal of Metamorphic Geology*, 25, 511-527. [15] Holland, T. J. B. and Powell, R. (2001) *Journal of Petrology*, 42, 673-683. [16] Holland, T. J. B. and R. Powell (1998) *Journal of Metamorphic Geology*, 16, 309-343. [17] James, P. B. et al. (2013) *JGR:Planets*, 118, 859-875.