THE EFFECT OF CO_2 ON MELT DENSITY AND ITS RELEVANCE TO MAGMATISM ON VENUS.

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Introduction: Venus is often referred to as the "twin planet" to Earth because the two planets are the most similar in mass, size, and density of the inner solar system planets [1]. There are some important differences between these two planetary bodies, for example surface conditions on the two planets differ greatly, causing differences in eruption style, weathering, and morphology of igneous bodies. Furthermore, Earth is water-rich and Venus is believed to be very dry [2], which could have a significant effect on melting and eruption processes within the interiors of the two planets. In contrast, both planets are believed to have similar carbon inventories [2], so at least some percent of magmatism on both planets could be similar. One potentially interesting point of similarity is the occurrence of carbonate magmatism, as carbonatites have been discovered on Earth and there is evidence for them having occurred on Venus [3]. Once these magmas reach the surface of their respective planet, their behavior likely differs, but the effect of CO_2 on the physical properties of the magmas at depth in each planet is probably similar, therefore studies of carbonated magmas at pressure are likely relevant to both bodies.

While carbonated magmas have been directly observed on Earth, they have not been found and analyzed on the venusian surface. There are several pieces of evidence to suggest they once existed on Venus. Examples of this evidence are as follows: 1) multiple long, smooth, and uniform channel structures have been observed, and a low viscosity magma, such as a kimberlite or carbonatite, has been proposed to have formed these channels as liquid water is not stable at the surface [4, 2]. 2) The surface of Venus is relatively smooth [1], which would require either a widespread and dense network of vents erupting nearly equal amounts of magma, or a smaller number of vents erupting lower viscosity magma that can spread out more easily and evenly. Some magmas on Earth can have low viscosities because they are melted at very high temperatures (i.e., komatiites). Evidence of a high temperature, komatiite-like lava has not been found on Venus [1], so volatiles are a more likely candidate for reducing magmatic viscosity. 3) The eruption of large volumes of flood basalts on Earth have been correlated with an increase in atmospheric CO_2, indicating the CO_2 was brought to the surface with the basalts. This could be at least partially responsible for Venus's CO_2-rich atmosphere (i.e., 90 bars CO_2 [5, 2]).

Carbonated magmas have been studied on Earth, but examining them in the context of both Earth and Venus could lend insight into the magmatic processes at work for both planets. Because plate tectonics recycles oceanic crust back into the mantle and preserves continental crust, Earth may have lost much of its record of carbonate magmatism in basaltic settings. This preservation bias may provide misleading evidence for associations of carbonate magmas predominantly with continental crust-type settings. With its basaltic crust of relatively uniform thickness and lack of plate tectonics, Venus could provide a wealth of information about carbonate magmatism in basaltic settings that is not readily available on Earth. Carbonated magmas on Venus can also provide valuable information about the influence of volatiles on planetary interiors, evolution, and magmatism. It is believed that water was once present on Venus, but was lost over time to space [1]. As other volatiles have been measured on the surface and in the atmosphere of Venus (Cl, S, and CO_2 [1]), this planet could provide a valuable example of how volatile species other than water can affect the thermal and magmatic evolution of planetary interiors.

Magma Eruptability: While a density contrast can be generated from a magma being hotter than its surrounding mantle alone, volatiles would assist in the ascent of magmas. As CO_2 is probably the most abundant volatile on Venus, it is important to understand how CO_2 effects melt density in the context of the venusian interior.

In the present study we performed high pressure experiments on a water-free, carbon bearing synthetic kimberlite composition, likely similar to a carbonated magma that would occur on Venus. Experiments were designed to determine the density of the melt at various pressures, which, when compared to the density of surrounding mantle material, determines if the melt is buoyant enough to rise to the surface. Because water does not seem to be a major volatile in venusian magmatism and the large amount of CO_2 in the venusian atmosphere suggests CO_2 could be a major magmatic volatile [1], we investigate melt density as a function of pressure and CO_2 content.

Methods: This study was performed using a model terrestrial kimberlite composition after that proposed in [6]. The composition is ultramafic, high in magnesium, calcium, and iron, and has minor elements removed for simplification. Furthermore all experiments were run under nominally anhydrous conditions. Two end member compositions, one with 12 wt% CO_2 and one with no CO_2, were created and then mixed together in varying ratios to create compositions with varying amounts of CO_2 that lie on a mixing line so that the effect of CO_2 on melt density could be examined systematically. CO_2 was added to the starting material using calcium carbonate.

All experiments were conducted using a Walker-style multi-anvil apparatus. Experiments were run in graphite capsules and we qualitatively demonstrated the retention of CO_2 during our experiments by micro-FTIR and inferred it indirectly from low EPMA totals. In situ melt density was determined using the sink/float method of [7]. The primary mineral used as density marker spheres for this study is olivine with differing amounts of fayalite component. Thus far, experiments have been run up to 9 GPa, but experiments at higher pressures are ongoing.

The density data will be used to create a compression curve for the melts over the range of pressures investigated. The density of the carbon free melt will be used with the density of the melts with different amounts of carbon at specific pressures to determine the partial molar volume of CO_2 in the melt, which can be used to create a compression curve for CO_2. The value of VCO_2 can be determined using the

$$\bar{V}_{CO_2}^{P,T} = \left\{ \left(\sum_i M_i X_i / \rho_{CO_2}^{P,T} \right) - \left[\left(\sum_i M_i X_i - M_{CO_2} X_{CO_2} \right) / \rho_N^{P,T} \right] \right\} / X_{CO_2}$$

equation from [8] where $\rho_{CO_2}^{P,T}$ is the density of the carbonated melt, $\rho_N^{P,T}$ is the density of noncarbonated melt, M_i is the molar mass of component *i*, and X_i is the mole fraction of component *i*.

Results: Results for two carbonated compositions are shown in Figure 1. The compositions contain 6 wt% CO_2 (C50), and 12 wt% CO_2 (C100), and show a distinct difference in density at a given pressure. Definite compression curves cannot be fit to the data at this stage, but ongoing experimentation will provide more data, which will allow a curve to be fit and VCO_2 data to be obtained.

Based on the data obtained thus far, ultramafic magmas with 6-12 wt% CO_2 would be able to erupt on Earth and Venus if generated at depths corresponding to approximately 9 GPa. Kimberlites on Earth also contain high amounts of water, which also aid in reducing melt density, but a kimberlite like magma on Venus containing only CO_2 (i.e., venusian interior is dry [1]) would still have a lower density than the surrounding mineralogy and erupt. As shown in [8], water is more compressible than CO_2 when dissolved in melts, which means when considering the mantles of Earth and Venus, there is a pressure range in which a dry, CO_2 bearing melt will have a lower density than a CO_2 free, water bearing melt. The compositions analyzed in this study are somewhat extreme in CO_2 content with respect to terrestrial magmas, but high carbon content magmas may be more common on Venus. Experiments are ongoing, including experiments on the CO_2-free melt composition.

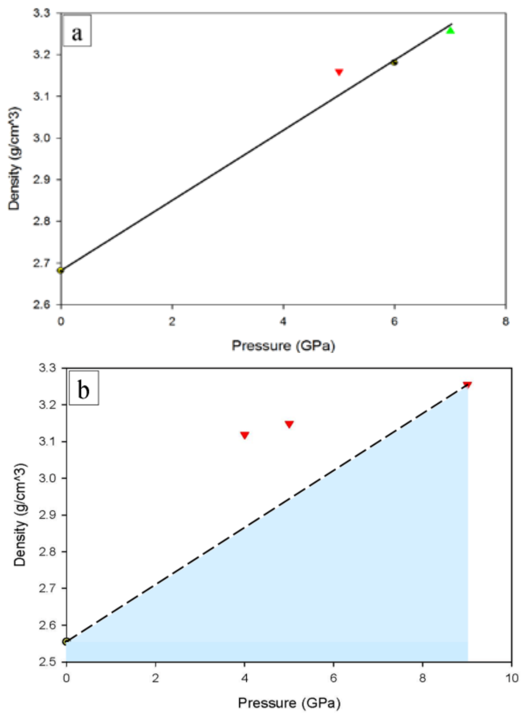

Figure 1. Density data for an ultramafic kimberlite composition with 6 wt% CO_2 (a), and 12 wt% CO_2 (b). Red triangles are sink results, yellow circles are neutral buoyancy results, green triangles are float results, and dashed lines are approximate locations of the compression curve.

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