VOLUME, GEOMETRY, AND DEPTH OF MAGMA CHAMBERS ASSOCIATED WITH LARGE VOLCANOES ON VENUS.

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Overview: Previous studies [1,2], together with predictions based on neutral buoyancy theory, indicate that the formation of large volcanoes on Venus and their subsequent characteristics are altitude dependent. The findings presented here suggest they may not be. Using the Magellan data, we examine 15 of 18 known large volcanoes with calderas to determine if a relationship exists between altitude and magma chamber volume and geometry, and if a uniform geometry exists between magma chambers or if several shapes are needed to explain the observed surface features. These 15 volcanoes represent a range of altitudes that is common for large volcanoes on Venus. The presence of a magma chamber may be inferred from features such as volcanic edifices, lava flows, and calderas [2]. The parameters of the latter two features can be used to constrain a model for describing the magma chamber volume, geometry, and depth [3,4]. Therefore, three volcanoes (Shiwanokia Corona, Hatshepsut Patera, and an unnamed volcano located at 9N029) and their associated lava flows are mapped to estimate lava flow volumes. Lava flow volumes are estimated by determining lava flow areas, based on radar brightness and morphology, and by assuming a uniform lava flow thickness of 15 m--a value derived from terrestrial analogs and Keddie and Head [5]. Lava flow volumes are then used to approximate the total volume of the magma chamber for each of these three volcanoes [3]. Finally, the basal altitude, height, and caldera parameters of all 15 volcanoes are measured.

Relationship of caldera diameter to basal altitude: Of these 15 large volcanoes with calderas, nine lie below the mean planetary radius (MPR), two occur at the MPR, and four lie above the MPR. Earlier work predicts that neither a neutral buoyancy zone (NBZ), the point where magma chambers are thought to form, nor a magma chamber is likely to form below the MPR; however, if a magma chamber is present, it will likely be small and poorly developed [2]. However, the presence of 11 calderas, each >10 km in diameter, at or below the MPR, indicates that magma chamber formation has occurred at these elevations, and that they are well developed (lateral diameter >10 km). This suggests that the formation of magma chambers may not be as strongly dependent on basal altitude as previously predicted.

Relationship of caldera diameter to magma chamber volume: The caldera diameter of a shield volcano is approximately equal to the plan view diameter of the associated magma chamber [4]. Therefore, the caldera diameter can be used as an indicator of the relative size of the magma chamber. The magma chamber volume calculations of the three mapped volcanoes were based on lava flow volume in relation to eruptive percentage of the magma chamber [3]; they did not consider the caldera diameter. Hatshepsut Patera, which has the largest caldera, also has the largest magma chamber volume (2525 km^3). Shiwanokia Corona, which has the smallest caldera, has the smallest magma chamber volume (108 km^3). The unnamed volcano has a caldera diameter and magma chamber volume (1400 km^3) intermediate between the other two. These two independent approximations confirm that a larger caldera corresponds to a greater magma chamber volume. Hence, caldera diameter appears to be a useful tool for estimating magma chamber volume. Additionally, the magma chamber volumes of these three volcanoes decrease with basal altitude. The basal altitude of Hatshepsut Patera, the unnamed volcano, and Shiwanokia Corona are 6051.1 km, 6051.5 km, and 6051.9 km respectively. Thus, for these three volcanoes, magma chamber volume does not appear to be dependent on basal altitude.

Relationship of caldera diameter to volcano height: On Venus, large magma chambers tend to respond to the influx of new magma by growing laterally, through the emplacement of radial dikes, instead of through vertical eruptions [2]. Therefore, large magma chambers may be more likely to be associated with short edifices rather than tall ones. A plot of caldera diameter as a function of volcano height reveals that no correlation exits between these two parameters (R^2=.088). For example, one of the 15 volcanoes has a height of 400 m and a caldera diameter of 150 m. Another also has a caldera diameter of 150 m, yet its height is 1.7 km. Because the caldera diameter is approximately equal to the magma chamber diameter [4], we conclude that there is no relationship between the size of the magma chamber and the height of the edifice and that large magma chambers on Venus may be as likely to respond to the influx of new magma through extrusive activity as they are to respond through intrusive activity; therefore, large magma chambers on Venus may or may not favor lateral growth. This may serve as a source of variation in the geometry of the magma chamber.

Magma chamber vertical dimensions: Vertical dimensions are calculated using the volume for an ellipsoid. The results for the three mapped volcanoes show that the magma chambers are all oblate ellipsoids rather than prolate. Shiwanokia Corona and the unnamed volcano each have similar magma chamber diameter to vertical axis ratios ($\approx$4.5: 1). Hatshepsut Patera has a ratio of 56.7:1. Hatshepsut Patera has numerous lineaments extending radially from the caldera, some for hundreds of kilometers. We suggest that these lineaments are the surface expression of intrusive dikes. The presence of these dikes indicates that Hatshepsut Patera has undergone extensive intrusive episodes, which could explain its flattened magma chamber geometry. Although there appears to be a basic three-dimensional geometry among the magma chambers, the variation in ratios indicates that more than one shape exists.

Depth to the magma chamber: The calderas associated with the three mapped volcanoes have aspect ratios that range from 0.833 to 1.0. This suggests that the magma chambers are circular in plan view, and they are located deep within the substrate [6]. The caldera diameter, which is approximately equal to the depth to the magma chamber [4] of each mapped volcano, also supports magma chamber locations at depths within the substrate. Shiwanokia Corona has a height of $\approx$100 m and a caldera diameter of 10 km; the unnamed volcano has a height of $\approx$2.3 km and a caldera diameter of 24 km; Hatshepsut Patera has a height of <100 m and a caldera diameter of 68 km. Clearly the magma chambers of these three volcanoes cannot be located within the edifice with their corresponding depths. These observations agree with the prediction that magma chambers on Venus linger in the substrate, and they do not migrate rapidly upwards into the rising edifice [2].

Depth to the NBZ: The depth to the NBZ of the three mapped volcanoes, as predicted by our data, is greater than the depth based on predictions made by Head and Wilson [2]. According to our model, the depth to the NBZ, for Shiwanokia Corona, the unnamed volcano, and Hatshepsut Patera are 10 km, 24 km and 68 km respectively. The depths to the NBZs for these same volcanoes, based on the model used by Head and Wilson [2], are 7.1 km, 7.0 km, and 6.8 km respectively. Our model has two important implications: magma chambers may be forming at depths that do not coincide with a NBZ and may be forming in response to other mechanisms, or NBZs may occur at depths greater than previously predicted.

References: [1] Keddie S. T. and Head J. W. (1994) *Planetary and Space Science, 42,* 455-462; [2] Head J. W. and Wilson L. (1992) *JGR, 97,* 3877-3903; [3] Blake S. (1981) *Nature, 289,* 783-785; [4] Wood C. A. (1984) *JGR, 89,* 8391-8406; [5] Keddie S. T. and Head J. W. (1994) *Earth, Moon and Planets, 65,* 129-190; [6] Ryan M. P. et al. (1983) *JGR, 88,* 4147-4181.

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