DIKE EMPLACEMENT AT ZONES OF NEUTRAL BUOYANCY ON VENUS.

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Overview: On the basis of their structure, plan view geometry and volcanic associations, we have interpreted formation of 118 large, radially lineated structures on Venus to occur in part through subsurface dike injection[1]. On Earth, radiating dike swarms (irrespective of scale) are frequently emplaced laterally about a centralized magma reservoir located near the surface[2]. Theoretically derived neutral buoyancy calculations for Venus[3] predict an altitude-dependent distribution of magma reservoirs which is matched by observations of dike swarms across approximately 90% of the planet's surface; only those highland regions whose elevations exceed 6053 km appear anomalous. Previous analysis of the large volcano population yielded similar results[4], and comparison between the dike swarm (intrusive) and large volcano (extrusive) populations supports the contention that depth to the level of neutral buoyancy increases systematically at altitudes above 6051 km. This suggests that, as observed on Earth, neutral buoyancy plays an important role in governing volcanic processes near the venusian surface, often facilitating radially configured lateral dike emplacement about shallow magma reservoirs.

Theory: Head and Wilson [1992] have proposed that the process of magma reservoir formation on Venus, and thus the development of related volcanic phenomenon such as dike swarms (intrusive) and volcanoes (extrusive), is controlled in part by neutral buoyancy. According to their calculations, high atmospheric pressure at low elevations (planetary radii <6051 km) minimizes volatile exsolution within ascending magma, and thus rock formed when this material erupts and cools will remain dense relative to the density of subsequent magma intrusions, inhibiting the development of neutral buoyancy zones and promoting continued surface eruption. At intermediate elevations (6051-6053 km) the relative decrease in atmospheric pressure permits volatile exsolution and subsequent formation of lower density vesicular rock at the surface. As layers of this material accumulate the resultant low density "cap" makes it increasingly difficult for buoyantly rising magma to reach the surface, and eventually magma will begin to stall within the substrate at a depth of neutral buoyancy. For magma of a given volatile content, the depth to this level of neutral buoyancy increases with elevation. This, in turn, has been shown to facilitate magma reservoir growth and lateral dike emplacement[5]. There should, therefore, be a gradual transition from extrusion- to intrusion-dominated volcanism as one progresses from intermediate to upper (>6053 km) elevations.

Observations: We tested the neutral buoyancy predictions by comparing the distribution of features interpreted to represent dike swarms[1] as a function of elevation with that expected if the population simply reflects the amount of surface area occurring at a given altitude (Figure 1). If swarms are uniformly distributed as a function of surface area, then approximately 12% should lie below a planetary radius of 6051 km, 79% should fall between 6051-6053 km, and the remaining 9% should be located at elevations >6053 km. The observed distribution, however, reveals no swarms located below 6051 km, 92% located between 6051-6053 km, and the remaining 8% at elevations >6053 km. A Chi^2 test indicates a greater than 99% probability that the expected (uniformly distributed) and observed dike swarm populations are statistically different, with the greatest difference occurring from 6052-6053 km.

Discussion: The absence of dike swarms below 6051 km is predicted by the neutral buoyancy model since reservoir formation within the substrate, and thus intrusive volcanism, should be difficult to achieve at these altitudes. Those few reservoirs which do manage to form because of a particularly high magma volatile content, however, should do so very near the surface, a condition favoring the production of volcanoes or other extrusive products (as observed) rather than dike swarms in response to reservoir overpressurization.

At intermediate elevations, the enhanced concentration of dike swarms and large volcanoes[4] suggests that magma frequently stalls to produce reservoirs, again in agreement with

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the neutral buoyancy model predictions. Conditions here should generally favor reservoir development within the upper several kilometers of the crust. Comparison between the distribution of large volcanoes and radiating dike swarms suggests that a transition from extrusive to intrusive reservoir volcanism occurs in this elevation range. At lower intermediate altitudes (~6051-6052 km), extrusive magmatism and volcano production is favored over dike swarm emplacement. At upper intermediate altitudes (~6052-6053 km), however, the formation of radial dike swarms clearly becomes predominant. This suggests that the depth to the magma reservoir, and thus the probability of an intrusive response to overpressurization, increases with elevation as predicted.

At elevations exceeding 6053 km the increased depth to the level of neutral buoyancy should continue to enhance magma reservoir formation and strongly facilitate an intrusive rather than extrusive response to reservoir overpressurization. The distribution of dike swarms observed resembles that expected if their occurrence simply reflects the available surface area, however, and a similar number of large volcanoes occur, suggesting that lateral dike intrusion is not favored over surface eruption. This implies that site-specific factors in addition to altitude-dependent pressure may govern magma behavior in many elevated areas on Venus. One way this could be accomplished is through mantle downwelling[6]: crustal thickening via ductile flow elevates higher density rock, formed through eruption at relatively low altitudes, to heights where low density (highly vesicular) rock would otherwise be expected to occur. The greater than expected density of the surface rock, therefore, would promote shallower magma chamber formation as observed at low and intermediate altitudes. Since elevated regions typically consist of heavily deformed highlands such as Aphrodite and Ishtar Terra, however, void production through spatially inhomogeneous fracturing or other site-specific processes may produce lateral density variations which modify the depth to the level of neutral buoyancy, thus affecting subsequent intrusive versus extrusive responses to reservoir overpressurization. Future consideration of reservoir development and evolution in highland areas across the planet should take into account the local geologic environment, and should provide additional insight into the neutral buoyancy mechanism which appears to satisfactorily account for the observed dike swarm (and large volcano) distribution across the remaining 90% of the venusian surface.

References: 1. Grosfils, E.B. & Head, J.W., *LPSC XXV* (this vol). 2. Halls, H.C., *GACSP v.34*, 483-492 (1987). 3. Head, J.W. & Wilson, L., *JGR v.97*, 3877-3903 (1992). 4. Keddie, S.T. & Head, J.W., *LPSC XXIV* 773-774 (1992). 5. Parfitt, E.A., *et al.*, *JVGR v.55*, 1-14 (1993). 6. Bindschadler, D.L., *et al.*, *JGR v.97*, 13563-13579 (1992).

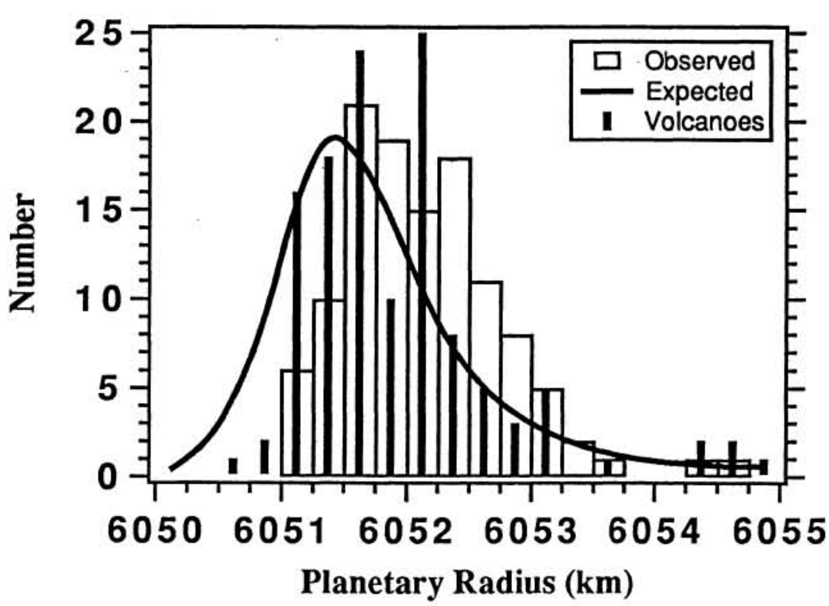

Figure 1: Observed distribution of giant radiating dike swarms as a function of altitude. Expected dike swarm population if distributed uniformly by surface area and distribution of large volcanoes[4] are also shown. Dike swarms are absent below 6051 km, and a transition from extrusive- to intrusive-dominated magmatism occurs between 6051-6053 km.