H_2O content, (b) low-density overburden, or (c) lesser horizontal length scale of flow.

Relevant to these hypotheses is that differentiation on Venus requires more than adiabatic upwelling and pressure-release melting. In models of this process on Earth [e.g., 5,6] the availability of mantle material to flow into the region is taken as given; the concern is about the rising of magma within a solid matrix, in particular, the mechanism(s) concentrating the melt in a narrow vertical slab. The viscosity of the melt, and hence its ability to separate, is affected by water content. Differentiation from a plume, without pull-apart, under a layer of higher strength or lower density (as is more likely on Venus), requires a surplus of heat, and thus is likely to lead to a lower rate of magmatism for a given heat flow. Also the inhibition of upward flow by a low-density overlying layer may lead to less differentiation of crust. Application of models of a plume under a lithosphere [7] to Venus features such as Atla and Beta indicate that appreciably higher upper mantle viscosities may cause pressure gradients to account for these great peaks in the geoid.

We have applied finite element modeling to problems of the interaction of mantle convection and crust on Venus [8]. The main emphasis has been on the tectonic evolution of Ishtar Terra, as the consequence of convergent mantle flow. The early stage evolution is primarily mechanical, with crust being piled up on the downstream side. Then the downflow migrates away from the center. In the later stages, after more than 100 m.y., thermal effects develop due to the insulating influence of the thickened crust. An important feature of this modeling is the entrainment of some crustal material in downflows.

An important general theme in both convergent and divergent flows is that of mixing vs. stratification. Models of multicomponent solid-state flow obtain that lower-density crustal material can be entrained and recycled, provided that the ratio of low-density to high-density material is small enough (as in subducted slabs on Earth). The same considerations should apply in upflows; a small percent partial melt may be carried along with its matrix and never escape to the surface. Models that assume melt automatically rising to the crust and no entrainment or other mechanism of recycling lower-density material [e.g., 9] obtain oscillatory behavior, because it takes a long time for heat to build up enough to overcome a Mg-rich low-density residuum. However, these models develop much thicker crust than consistent with estimates from crater depth:diameter ratios [1].

References: [1] Sharpton V. L. and Edmunds M.S. (1991) *Eos, 72*, 289. [2] Kaula W. M. (1992a) *Proc. IUGG Symp. Chem. Evol. Planets*, in press. [3] Kaula W. M. (1980) *JGR, 85*, 7031. [4] Kaula W. M. (1992b) *Proc. IAG Symp. Grav. Field Det. Space Air Meas.*, in press. [5] McKenzie D. P. (1985) *EPSL, 74*, 81. [6] Scott D. R. and Stevenson D. J. (1989) *JGR, 94*, 2973. [7] Sleep N. H. (1990) *JGR, 95*, 6715. [8] Lenardic A. et al. (1991) *GRL, 18*, 2209. [9] Parmentier E. M. and Hess P. C. (1992) *LPSC XXIII*, 1037.

N93-14333 488286

LARGE SHELD VOLCANOS ON VENUS: THE EFFECT OF NEUTRAL BUOYANCY ZONE DEVELOPMENT ON EVOLUTION AND ALTITUDE DISTRIBUTION.

S. Keddie and J. Head, Department of Geological Sciences, Brown University, Providence RI 02912, USA.

The Magellan mission to Venus has emphasized the importance of volcanism in shaping the surface of the planet. Volcanic plains make up 80% of the terrain and hundreds of regions of localized eruptions have been identified. Large volcanos, defined as edifices with diameters greater than 100 km, are the sites of some of the most voluminous eruptions. Head et al. [1] have identified 158 of these structures. Their spatial distribution is neither random (see Fig. 1) nor arranged in linear chains as on the Earth; large volcanos on Venus are concentrated in two large, near-equatorial clusters that are also the site of many other forms of volcanic activity [1].

The set of conditions that must be met on Venus that controls the change from widespread, distributed volcanism to focused, shield-building volcanism is not well understood. Future studies of transitional features will help to address this problem. It is likely, however, that the formation and evolution of a neutral buoyancy zone (NBZ) plays an important role in both determining the style of the volcanism and the development of the volcanic feature once it has begun to erupt. Head and Wilson [2] have suggested that the high surface pressure on Venus may inhibit volatile exsolution, which may influence the density distribution of the upper crust and hence control the nature and location of a NBZ. The extreme variations in pressure with elevation may result in significantly different characteristics of such a NBZ at different locations on the planet. In order to test these ideas regarding the importance of NBZ development in the evolution of a large shield and to determine the style of volcanism, three large volcanos that occur at different basal elevations were examined and the distribution of large volcanos as a function of altitude was determined.

The evolution of Sapas Mons, a 600-km-diameter shield volcano, was studied [3]. Six flow units were identified on the basis of radar properties and spatial and temporal relations. The distinctive variation between units was attributed to the evolution of magma in a large chamber at depth. The presence of summit collapse structures and radial fractures, interpreted to be the surface expression of lateral dikes, supports this suggestion. Theory predicts that volcanos located at the altitude of Sapas Mons should have large magma chambers located at zones of neutral buoyancy at relatively shallow depths beneath the substrate [2]. Not only does the evidence from the flow units suggest that such a zone is present, but the size of the summit collapse and the near-surface nature of the radial dikes indicates that the chamber is both large (on the order of 100 km in diameter) and shallow.

In comparison to Sapas Mons, two other volcanos at different elevations were examined. Theory predicts that the volcano at the

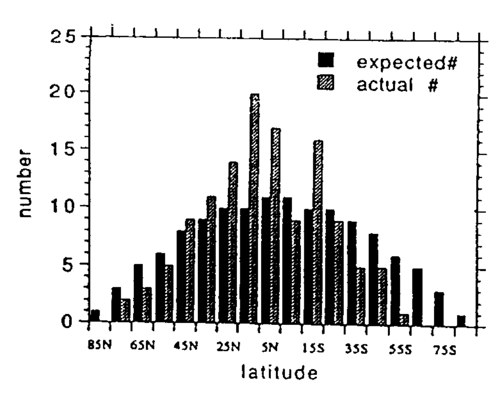

Fig. 1. Location of large volcanos as a function of latitude. The dark-shaded columns indicate where volcanos would be located if they were randomly distributed on the surface as a function of the percentage of area at a given latitude. The striped columns show where the volcanos actually occur. Note the paucity of volcanos at higher latitudes and the concentration in the equatorial region of the planet.

highest basal elevation, Maat Mons, should have a well-developed, large, and relatively deeper NBZ and that the volcano at the lowest altitude, an unnamed volcano located southwest of Beta Regio at 10°, 273°, should have either a poorly developed magma chamber or none at all [2]. Preliminary mapping of Maat Mons [3] identified at least six flow units that exhibit greater variations in morphology and radar properties than the flows of Sapas Mons. These units are also spatially and temporally distinct and suggest the eruption of a continuously evolving magma. Although smaller in diameter, the summit caldera is much better defined than the depression at Sapas. The inferred young age of Maat (Klose et al. [4] suggest that it may even be "active") may mean that the chamber has not yet grown to "full size," explaining the relatively smaller caldera. There is no evidence of radial fractures at Maat Mons, suggesting that if lateral dike propagation occurred, it was sufficiently deep that there was no surface expression. In contrast, the unnamed volcano has no summit features, no radial dikes, and only three flow units that exhibit considerable morphologic variations within units [3]. These observations suggest that either the NBZ is very poorly developed or it does not exist and the magma erupts directly at the surface. Thus the character of three large volcanos on Venus supports the suggestion that basal altitude can play a critical role in the development of a NBZ. Examination of other volcanos at a greater range of altitudes will help to further test this hypothesis.

In addition to studying the detailed evolution of three large volcanos, the altitude and height distribution of all volcanos was determined. Although in general there is a broad distribution of large volcanos as a function of altitude, there is somewhat of a paucity of large volcanos at elevations below 6051 km (Fig. 2). Between 6051 and 6053 km the number of volcanos is slightly greater than expected and above this an absence of volcanos is again observed. This absence at the highest elevations is probably due in large part to the predominance of tessera terrain at these elevations. Those volcanos that do occur in this area are associated with regions of uplift and rifting probably caused by mantle upwelling. Head and Wilson [2] suggested that below an elevation of 6051 km it is unlikely that a NBZ would develop, due largely to the high atmospheric pressure, and thus edifice growth would be inhibited. They also found that the first few kilometers above 6051 km would be most favorable for edifice growth as NBZs develop early at relatively shallow depths beneath the surface. A survey of 110 large volcanos found that this altitude distribution appears to be observed on Venus.

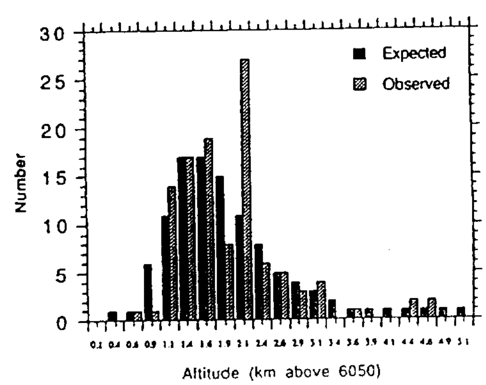

Fig. 2. Location of large volcanos as a function of basal altitude. The dark-shaded columns indicate where volcanos would be located if they were randomly distributed on the surface as a function of the percentage of area at a given altitude. The striped columns show where the volcanos actually occur. See text for a discussion of the implications of this distribution.

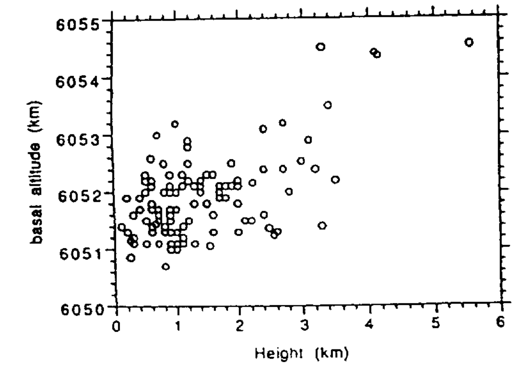

Fig. 3. Graph showing the heights of 110 large volcanos as a function of basal altitude. The majority of volcanos cluster between 6051 and 6053 km and there is a weak positive correlation between height and basal altitude. The majority of volcanos that occur above 6052.8 km and are taller than 2.6 km are located in zones of mantle upwelling and/or rifting.

The height of volcanos is also related to basal altitude and the development of zones of neutral buoyancy. There is a weak correlation of volcano height with basal elevation (Fig. 3). Although many factors need to be considered to explain this correlation, in a general sense NBZ development is responsible. As magma chambers become larger, and thus the "life" of the volcano is lengthened, there is an opportunity for a greater number of repeated, relatively small volume eruptions. This type of eruption enhances edifice growth. Head and Wilson [2] suggested that NBZs will grow to relatively larger sizes at greater altitudes. Therefore this correlation of height with altitude is expected.

Although a good deal more work needs to be done to test the idea that basal altitude plays a significant role in the development and evolution of neutral buoyancy zones on Venus, studies of the altitude distribution and heights of many large volcanos, as well as the evolution of individual volcanos, indicates that NBZ development is occurring, that it is varying, apparently as a function of altitude, and that the morphology and history of large edifices is being strongly influenced.

References: [1] Head J. W. et al. (1992) *JGR*, submitted. [2] Head J. W. and Wilson L. (1992) *JGR, 97*, 3877–3903. [3] Keddie S. T. and Head J. W. (1992) *LPSC XXIII*, 669–670. [4] Klose K. B. et al. (1992) *JGR*, submitted.

N93-14334

MANTLE PLUMES ON VENUS REVISITED.

Walter S. Kiefer, Code 921, Goddard Space Flight Center, Greenbelt MD 20771, USA.

The Equatorial Highlands of Venus consist of a series of quasicircular regions of high topography, rising up to about 5 km above the mean planetary radius [1]. These highlands are strongly correlated with positive geoid anomalies, with a peak amplitude of 120 m at Atla Regio [2,3]. Shield volcanism is observed at Beta, Eistla, Bell, and Atla Regiones and in the Hathor Mons-Innini Mons-Ushas Mons region of the southern hemisphere [4–10].