Interactions of Mechanical Controls on Magma Emplacement with the Petrology of Volcanic Edifice-building Flows on Venus. P. J. McGovern[1] and J. Filiberto[1], [1]Lunar and Planetary Institute, Universities Space Research Association, 3600 Bay Area Blvd., Houston TX 77058, USA (mcgovern@lpi.usra.edu).

Introduction: Large volcanic edifices on Venus constitute a primary expression of the thermal evolution of that planet. Over 150 volcanic edifices with diameters > 100 km are distributed heterogeneously over the surface of Venus [1-4]. They are characterized by extensive radially oriented lava flow aprons and generally shallow flank slopes. The compositions of the lava flows that build such structures potentially record variations in the physical conditions (depths, temperatures of melting, etc.) that govern magma ascent and eruption. In this abstract, we discuss the petrological implications of a recently discovered link between volcanic edifice shape and magma ascent paths that is modulated by lithospheric flexural stresses [5-6]. This link suggests that under certain circumstances, magma may ascend directly from the mantle melt region to the surface, rather than collecting and differentiating in reservoirs at intermediate depths. Furthermore, considerations of buoyancy [7] and enhanced lithospheric stress [8] at the crust-mantle boundary may lead to enhanced magma storage at that horizon. These mechanically based scenarios predict specific trends in major element ratios that may be detectable by instruments on future missions to Venus.

Mechanics of Magma Ascent: The state of stress in the lithosphere can exert a major control on the ascent of magma from mantle melting zones [9]. Two criteria for magma ascent must be satisfied [5-6]: 1) principal stress orientations (least compressive stress horizontal [10]) and 2) gradients of horizontal differential stresses (positive gradients, i.e., horizontal compression decreasing with increasing height [9]). To account for the mitigating effects of buoyancy and overpressurization, small adverse values of horizontal compression and stress gradients are considered to satisfy the ascent criteria.

The "dipole" nature of flexural stress dictates that Criterion 1 will be violated in about half of the lithosphere (in the absence of vertically uniform membrane stress), but for small enough stress magnitudes the mitigating effects will overcome this "half-barrier". In particular, large values of elastic lithosphere thickness T_e (order 40-50 km) create low enough stress magnitudes to allow ascent via Criterion 1 (see Fig. 1). However, as T_e decreases, adverse stress magnitudes and stress gradients tend to shut off magma ascent beneath the centers of large loads; preferred ascent paths migrate toward the outer flanks, favoring formation of more domical-shaped edifices. At the lowest values of T_e (< 15 km or so), adverse compressive stresses and gradients are very high beneath conical and domical edifices. However, annular edifice shapes produce a pair of narrow zones on the inner and outer slopes that satisfy ascent criteria (Fig. 1) at such low Te values. Such a scenario can explain the origin of a number of annular edifices on Venus that have been included in the morphologic/structural category of "corona" [e.g., 2].

The interaction between lithosphere thickness T_e and crustal thickness T_c also plays an important role in magma ascent. If $T_c < T_e$, then the crust-mantle boundary is within the lithosphere. The density contrast between crustal and mantle materials may produce a "density trap" where magmas may stall [e.g., 7] and accrete basaltic materials at the base of the crust, a phenomenon termed "underplating" [e.g., 8]. However, the contrast in stiffness at the crust-mantle boundary may also contribute to underplating, by producing a local maximum in horizontal compressive flexural stress at the top of the mantle [8]. Under either mechanism, magmas may accumulate at the base of the crust and differentiate there; whatever material is not underplated may subsequently erupt at the surface.

Petrologic inferences of Magma Storage and Ascent: The systematics of major element abundances determined from analyses of volcanic samples have been used to infer depths at which magmas have collected and differentiated. For example, K_2O vs. SiO_2 systematics for several terrestrial hotspot-related volcanism locales indicate trends that may be diagnostic of depth of differentiation (Fig. 2). The "base" of the trends outlined in the figure (K_2O < 1% and SiO_2 around 50%) corresponds to tholeiitic magmas that ascend directly from moderate-depth (< 1.8 GPa pressure) mantle melt regions, as at mid-ocean ridges. The Vega 2 and Venera 14 measurements [see 12-13] plot in this area and are thus consistent with directly ascent of these magmas from the mantle. We might expect magmas that take the "direct ascent" paths (e.g., Fig. 1) to exhibit similar chemistry, especially for domical and annular edifices that do not tap central magma chambers but rather follow distal ascent paths.

In Figure 2, the green trend line (data from Alcedo in the Galapagos and Thingmuli in Iceland) indicates differentiation at low pressure (< 0.2 GPa, corresponding to about 7-8 km depth). Evidence from GPS and radar interferometric studies of Galapagos calderas [e.g., 14] suggests that magmas are stored in shallow sills, a finding consistent with the expectation of high levels of compressive stresses in the upper halves of thin lithospheres in settings with young oceanic crust (for Galapagos, T_e ~12 km [15]).

Magmas that differentiate at somewhat higher pressures (0.5-1.6 GPa, corresponding to perhaps 13-60 km depth, depending on planetary gravity and assumptions about densities and crustal structure) follow the black trend line in Fig. 2. These include Hawaiian lavas that differentiate in the mantle before eruption. We might expect lavas from conical edifices on Venus to resemble products from the more or less conical Hawaiian edifices that are supported by substantial lithospheric thickness (T_e ~ 25-40 km [see 8]).

Magmas that differentiate at the highest pressures (1.8-2.7 GPa, perhaps 70-120 km depth) produce the trend marked in yellow in Figure 2. The Venera 13 measurement falls within this trend. Such a suite might be seen at volcanoes on Venus where T_c or T_e is comparable to these depths (assuming trapping at the crust-mantle boundary or lower lithosphere).

Sampling Strategies for Venus:

The best constraints on major element composition (e.g., Fig. 2) for planets like Mars come from rover-based instruments such as the APXS on the Mars Exploration Rovers. Similar point source determinations major element compositions on Venus could determine properties of Venus melts and shed light on the evolution of an individual edifice. To the extent that flows at individual edifices exhibit unique and distinct trends on plots like Fig. 1, a single measurement on a given volcano could in theory provide sufficient information to categorize its differentiation and magma storage history. Thus, an immobile landed probe could provide this information for a specific volcano. However, a more comprehensive test of the proposed link between volcano morphology/shape and magma ascent paths would require measurements from a number of volcanoes. This might be accomplished by a mobile platform, most likely some sort of buoyancy-driven aircraft system (balloon). Such a mission should be targeted for a region which displays a variety of volcano morpholgies, such as Eistla Regio [6]. Ideally, remotely sensed spectroscopic data acquired as spatial maps of element concentrations would allow rigorous tests of the ideas presented here. Unfortunately, whatever advantages Venus presents in this regard (absence of dust and erosion compared to, say, Mars) are more than likely wiped out by atmospheric transmission considerations, even for platforms located within the atmosphere on aircraft. Atmospheric alteration of rock surfaces is also a potential pitfall.

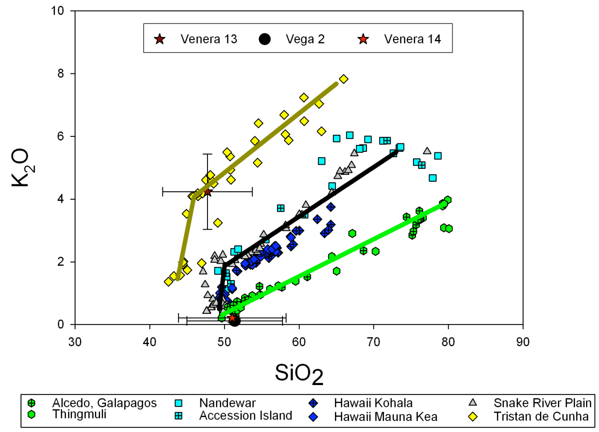

Figure 1 K_2O vs. SiO_2 showing trends found in terrestrial intraplate suites and their conditions of formation (see [11] in this volume for sources of data). All data renormalized to 100 wt% without sodium or phosphorous to be able to directly compare terrestrial rocks with the Venera and Vega data.

References:

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