VOLCANISM AND VOLATILE RECYCLING ON VENUS FROM LITHOSPHERIC DELAMINATION.

L. T. Elkins-Tanton[1], P.C. Hess[1], S.E. Smrekar[2], and E.M. Parmentier[1]. [1]Brown University (Lindy@brown.edu), [2]Jet Propulsion Laboratory.

Introduction: Venus has an unmoving lithosphere, a young surface indicative of volcanic resurfacing, and a wide variety of volcanic and tectonic features. The planet’s ubiquitous magmatic features include 100,000 small shield volcanoes as well as the descriptively named pancakes, ticks, and arachnoids [1]. Coronae, volcanic and tectonic features up to 2,600 km in diameter, have been attributed to lithospheric interactions with upwelling plumes [e.g., 2], but more recently to delamination of the lower lithosphere with [3] or without [4] a central upwelling.

Lavas issuing from different volcanic features appear to have a range of compositions, as evidenced by their apparent viscosities and by data from Soviet landers. Steep-sided or “pancake” domes [e.g., 5] appear to consist of more viscous magma [6], perhaps silicic compositions created by remelting basaltic crust [7]. These steep-sided domes are associated with coronae and with shield volcanoes effusing basaltic magmas [7,8] with apparently low viscosities (low enough to allow fluid flow for hundreds of km, creating channels reminiscent of water rivers on Earth). Pancake domes, in contrast, can be up to 3 km in height and have volumes from 30 to ~3,000 km^3 [calculated from data in 8], and hundreds dot the planet [6-8].

Data from Soviet landers also indicates compositional variability in Venusian magmas. Rocks analyzed by the *Venera 9* and *10* and *Vega 1* and *2* landers have K less than 1 wt% and U less than 1 ppm, while rocks at the *Venera 8* landing site have K contents as high as 4 ± 1.2 wt% and U as high as 2.2 ± 0.7 ppm [9]. Nikolaeva and Ariskin [9] suggest that the *Venera 8* composition may be the result of melting an eclogite, while the other magmas may be mantle melts.

Parmentier and Hess [10] suggest that Venus has undergone cyclic catastrophic crustal recycling through gravitational instability. Both Dupeyrat and Sotin [1] and Hoogenboom and Houseman [4] suggest that eclogitization of the lower lithosphere can be a driving force for delamination, a process that has been invoked on Earth to create distinctive surface topography and magmatism [11-13].

Here we present models showing that lithospheric delamination can produce both dry and hydrous magmas. Hydrous melting of delaminating lithosphere is a candidate process to create high-viscosity silicic melts such as those forming the steep-sided pancake domes, and dry or wet melting of Venusian mantle can produce low-viscosity basaltic melts.

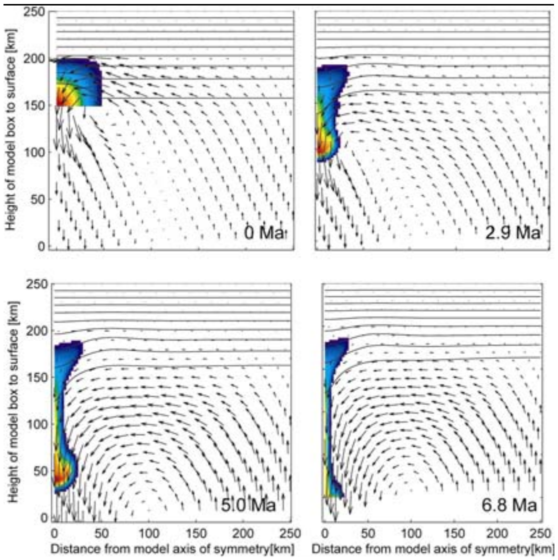

Fig. 1. Numerical model (d4): cross-sections through the crust into the mantle. The left boundary is an axis of symmetry, passing through the center of the Rayleigh-Taylor instability. Temperature is in solid contours of 10%, vectors show velocity, and dense composition $\Delta\rho$ is shown in color with red = 5% and white = 0%. 4,000 km^3 of dry mantle melt is produced by 2.9 My.

Models: Numerical experiments have been run using a spherical axisymmetric version of the two-dimensional finite-element code ConMan [14] called SSAXC. This code solves conservation equations for heat, mass, and momentum (equations given in [15]). Both temperature and composition contribute to buoyancy. Thermal buoyancy is determined by the Raleigh number, here 2×10^5. Viscosity is calculated using a Newtonian temperature- and pressure-dependent law.

In each model a lithosphere is created by cooling and a region of material with a negative density contrast is added to the lower lithosphere to mimic eclogitization. A starting condition is shown in the first panel of figure 1. The transition of basalt to eclogite in the lower lithosphere can occur simply as a result of higher pressures during lithospheric thickening [11]. Models were run with lithospheres of 50 and 100 km thickness, in the presence of and without upwellings, and with density contrasts in the lower lithosphere from 1 to 5%.

Dry adiabatic melt volumes are calculated from the numerical model output using a post-processor routine in which vertical velocity and temperature difference between the material and its solidus is translated into melt volume. Wet melting volumes are not estimated.

Results: Almost all models exhibited delamination. During delamination there are two opportunities to create melt: first, the mantle may melt through adiabatic decompression if it flows upward to replace the delaminating material; and second, if the delaminating material is volatile-rich, it will lose its volatiles under the effects of pressure and temperature as it sinks (as a subducting slab does on Earth). Volatiles (H_2O and CO_2) can trigger melting.

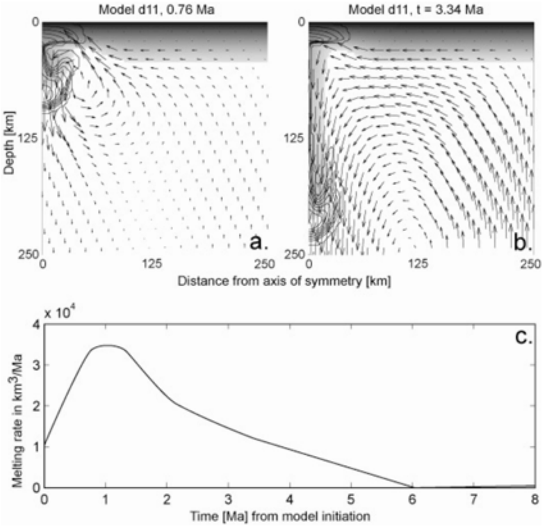

Fig. 2. Numerical model of delamination. As fig. 1, but temperature is shown as shades of gray and dense composition is shown with contours. 80,000 km^3 of dry mantle melt is produced by 6 My.

Dry melting: During delamination with an extant upwelling dry adiabatic melting can produce 1,000,000 km^3 of magma in less than 1 My. In the absence of an upwelling the mantle only melts when it is forced to flow upward by the delaminating material. Dry melting can total 80,000 km^3 for a 50-km thick lithosphere with an underlying mantle at 1,300°C (fig. 2), and 15,000 km^3 for a 100-km thick lithosphere. This dry adiabatic melting may produce Venus' low-viscosity melts.

"Wet" melting: Delaminating material will eventually lose its volatiles as it sinks. The addition of volatiles can trigger melting in silicate materials below their dry solidii. Wet melting, particularly of lithospheric materials, can produce more silicic magmas than does dry melting, and may be responsible for the apparently high-viscosity pancake domes on Venus.

Fig. 3 shows the paths for heating and dewatering delaminating material. Wet melting can be induced over a pressure range from 2 to 7 GPa, with compositions and volumes highly dependent upon the concentration of volatiles and the source mineralogy. The melt may be produced from the delaminating lithosphere itself, or from surrounding mantle material.

Discussion and conclusions: Delamination of a volatile-rich lithosphere on Venus is a mechanism that can produce volcanism as well as the shapes and patterns of coronae. Some delamination events do not produce melt, while others produce either or both dry adiabatic mantle melts and volatile-rich melts from lithospheric and mantle sources.

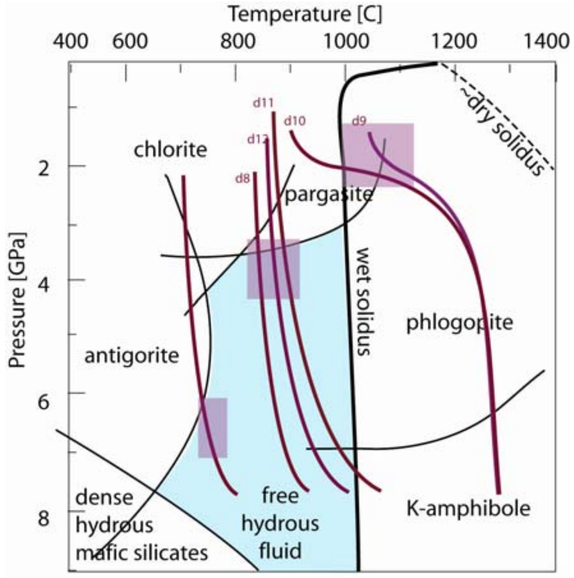

Fig. 3. P-T paths of delaminating material are shown in red, along with the hydrous mineral stability fields and wet solidus of a fertile peridotite [16,17]. Red squares indicate where material will melt or devolatilize.

High atmospheric pressure acts to hold water in the crust and mantle: degassing of lavas is inefficient first because high heat transfer to the dense atmosphere quickly quenches lava, and second because Venus' atmospheric pressure allows basalt liquid to be saturated with on the order of 1 wt% water.

Venus's crust is therefore likely to be volatile rich if the planetary interior is volatile rich. Delaminating crustal material will therefore carry volatiles into the mantle. Some of the resulting melt may erupt, but as pressure rises while the instability sinks liquids will be trapped by refreezing. Delamination therefore refertilizes the mantle with volatiles and eclogite and makes possible a boninite-producing mantle in the absence of plate tectonics. Through time the mantle's bulk melting temperature therefore decreases, encouraging catastrophic melting and resurfacing events.

References: [1] Dupeyrat (1995) *Pl. Sp. Sci*., *43*, 909. [2] Stofan (1991) *JGR, 94,* 20933. [3] Smrekar (1997) *Science., 277,* 1289. [4] Hoogenboom (2005) *sub. to Icarus*. [5] Head (1991) *Science*, *252*, 276. [6] Pavri (1992) *JGR*, *97*, 13445. [7] Ivanov (1999) *JGR*, *104*, 18907. [8] Smith (1996) *JVGR*, *73*, 47. [9] Nikalaeva (1999) *JGR*, *104*, 18889. [10] Parmentier (1992) *GRL*, *19*, 2015. [11] Kay (1993) *Tectonoph.*, *219*, 17. [12] Schott (1998) *Tectonoph.*, *296*, 225. [13] Elkins-Tanton (2000) *GRL*, *27*, 3937. [14] King (1990) *PEPI*, *59*, 195. [15] van Keken (1997) *JGR*, *102*, 22,477. [16] Kawamoto (2004) *PEPI*, *143*, 387. [17] Litasov (2003) *GRL*, *30*.