LATERAL DIKE INJECTION AND MAGMA ERUPTION AROUND NOVAE AND CORONAE ON VENUS. L. Wilson[1] and J.W. Head[2], [1]Environmental Science Department, Lancaster University, Lancaster LA1 4YQ, UK., [2]Geological Science Dept., Brown University, Providence RI 02912 (*l.wilson@lancaster.ac.uk*).

Introduction: Patterns of radiating fractures, the distal parts of which are fissure vents for lava flow formation, are a common feature of novae and some coronae on Venus, e.g. Figure 1. The visibility of the fractures in Magellan images implies that they have substantial topography, and the eruption of magma from their distal ends strongly suggests that they are associated with radial dike injection from a central subsurface source. Yet magma systematically avoids being released from the proximal parts of the fractures. We seek an explanation in terms of the lithosphere structure and magma density variations that control the level to which magma can rise.

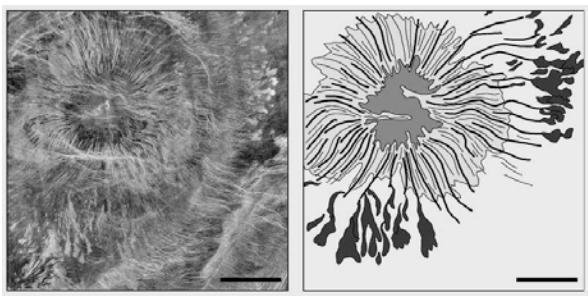

Figure 1. Image and map of nova (mapping by M. Ivanov). Scale bar is 50 km long.

Analysis: Radial dike propagation is associated with major sources of mantle magma on Earth, Mars and Venus [1]. The flow of magma in any dike requires a pressure gradient acting between the magma source and all propagating dike tips. A radial dike quickly establishes a vertical height controlled by the variations with depth of the magma density and the host rock density, and subsequent magma motion is almost entirely horizontal [2], centered on or close to a neutral-buoyancy depth [3]. While magma is moving there must be a lateral pressure gradient acting along the dike, and because the dike is narrowest at its tip the pressure gradient is very large close to the propagating distal end and very small at the end proximal to the central magma source [4]. Thus the vertical distribution of magma in most of the dike proximal to the source, especially the depth below the surface of the top of the magma in the dike, is controlled by static, rather than dynamic, forces, simplifying the analysis.

Table 1 shows a possible density structure for the Venus lithosphere and for magma forming a dike intruded laterally into it. The host rock density profile exemplifies a plausible crust-mantle structure taking account of the fact that large-scale erosion and production of low-density sediments does not seem to be common on Venus, and magmas are not expected to commonly erupt explosively producing loosely packed pyroclastics [5]. The magma density is assumed to decrease toward the surface due to exsolution of volatiles. Exsolution is a function of the pressure to which the magma is subjected. The pressure is lowest at the radially most distant lateral tip of the dike and gas exsolved in a region behind the tip forms bubbles that drift upward through the magma as it is emplaced against the widening dike wall after the tip has passed by. Thus there will be a general tendency for the density of magma to decrease upward through the magma column. This trend will increase toward the distal end of the dike as it grows: magma arriving there will have spent a greater total time in the low pressure region - partly as a result of greater distance it must travel and partly as a result of the reduced speed as the available pressure drop is spread over the greater distance.

Effects of depth of melting: We first explore the effects of the depth at which partial melting begins in the mantle. Mantle melts are positively buoyant in their source region, and this offsets the negative buoyancy of the magma in the shallowest part of the crust, determining how close to the surface a column of magma can rise under the near-hydrostatic conditions in the proximal part of a radial dike system: Figure 2.

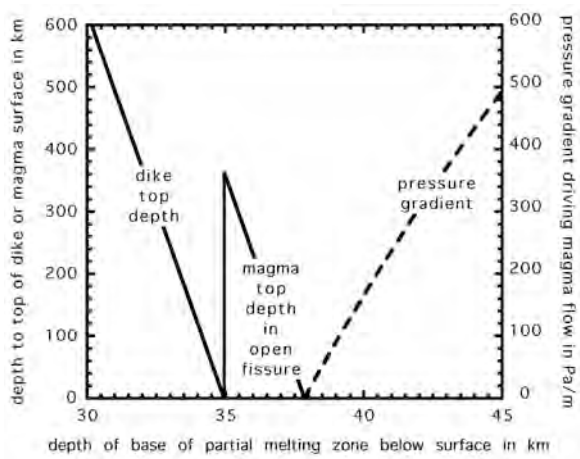

Figure 2. Effect of depth of partial melting on ability of melt to approach the surface or erupt.

If melting begins at relatively shallow depth in the mantle, not much positive magma buoyancy is available in the mantle to offset negative magma buoyancy in the shallow crust, and the upper edge of the dike, defined by the maximum height to which magma can rise, is at

great depth. As the level at which melting begins moves deeper into the mantle, the top of the magma column approaches the surface, reaching it when melting starts at 35 km depth. For all examples here, the stress intensity at the upper dike tip easily exceeds any fracture toughness of crustal rocks and the dike breaks through to the surface. However, when it does so, the pressure at the top of the magma column, previously set at 2-3 MPa by H_2O or SO_2 exsolution from the melt, is suddenly required to equal the atmospheric pressure, ~9 MPa in lowland volcanic plains on Venus. Buoyancy can no longer support the magma to the surface, and a new equilibrium is reached with the top of the magma column at a depth of about 360 m. An open fracture connects the top of the magma to the surface, but no eruption takes place through this open fracture unless the magma is able to vesiculate to the point of fragmentation at atmospheric pressure, which requires it to contain > 3.4 wt.% dissolved CO_2 or > 1.9 wt.% H_2O (or any equivalent combination of volatiles). On Earth the same pattern of conditions applies, but the atmospheric pressure is only ~0.1 MPa, and so the vertical extent of the open crack, given by [atmospheric pressure/(magma density x acceleration due to gravity)], is much smaller, only ~4 m. Furthermore, on being exposed to Earth's atmospheric pressure mafic magma will vesiculate and erupt explosively if it contains > 0.0396 wt% CO_2 or 0.0375 wt% H_2O or equivalent. It is easy to see why on Earth an explosive eruption will virtually always happen under these conditions but an eruption can readily be avoided in these circumstances on Venus.

If the depth of melting extends even deeper into the mantle, the level of magma in the open fracture eventually reaches the surface, and for melting depths > ~37.9 km an eruption takes place. The scale on the right-hand side of Figure 1 shows the pressure gradient then available to drive the eruption, which will be effusive unless the volatile content approaches the above- stated limits of ~3.4 wt% CO_2 or ~1.9 wt% H_2O.

Effects of magma density change: We now consider the conditions discussed above, in which the density of the magma in the shallow part of the dike decreases with increasing distance from the source region as ever increasing numbers of bubbles of exsolved volatiles migrate upward through it. Figure 3 shows how the proximity of the top of the magma column to the surface varies with the density of the magma in the shallow part of the dike. The density structure of the lithosphere is the same as in Figure 2 and Table 1, and the depth of melting is fixed at 37.5 km, corresponding to the presence of an open fracture at the surface.

If the magma density in the shallow part of the dike is similar to that of the shallow crust, 2900 kg m^{-3} (see Table 1), the top of the dike is located ~ 200 m below the surface. As the shallow magma density decreases, the top of the dike approaches the surface, reaching it when the melt density is ~2860 kg m^{-3}. At this point an open fracture forms and the top of the melt recedes down to a depth of ~360 m. As the shallow melt density continues to decrease with distance from the magma source the top of the magma again approaches the surface, reaching it when the magma density has decreased to ~2790 kg m^{-3}. Any continuing decrease in the magma density now produces a positive pressure gradient as shown on the right-hand graph axis to drive an eruption (again effusive unless the volatile content is more than the limits quoted earlier). A density reduction from 2900 to 2650 kg m^{-3}, the entire range spanned by Figure 3, requires the accumulation near the dike top of only ~0.1 wt. % of CO_2.

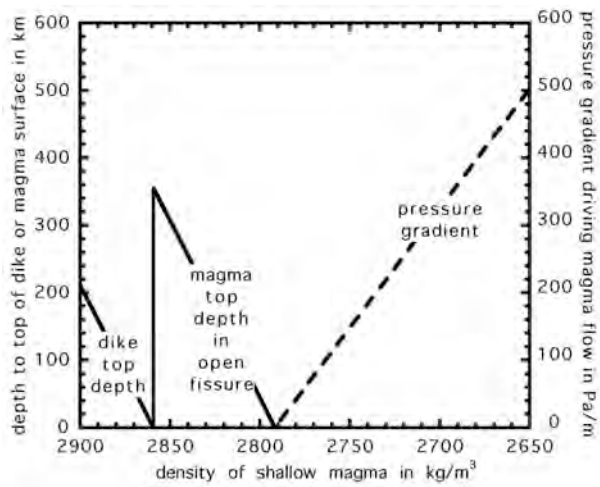

Figure 3. Effect of changing density of magma in shallow part of dike.

Summary: The pattern of radiating fractures leading to distal fissure vents erupting lava, seen in nova and some corona structures on Venus, is a consequence of the high atmospheric pressure influencing conditions in the shallow parts of laterally propagating dikes.

References: [1] Ernst R.E., et al. (1995) *Earth Sci. Rev.* 39, 1. [2] Lister J.R. (1990) *JFM* 217, 213. [3] Ryan M.P. (1987) *Geochem. Soc. Spec. Publ. 1*, 259. [4] Rubin A.M. (1993) *EPSL* 119, 641.[5] Head, J.W. & Wilson, L. (1986) *JGR* 91, 9407.

Table 1. A simple model of the variation with depth of lithosphere and magma densities on Venus.

	depth in km	host density kg/m³	host pressure MPa	magma density kg/m³
surface	0		9.00	
upper crust		2500		2800
intra-crust density step	15		341.00	
lower crust		2900		2900
crust-mantle interface	25		599.00	
mantle		3350		3000
melting begins here	variable		variable	