VENUS: ITS GREAT TRANSITION. A. Lenardic and W. M. Kaula, Department of Earth & Space Sciences, University of California, Los Angeles, Los Angeles, CA 90095-1567.

The Magellan imagery shows that Venus has a crater abundance equivalent to a surface age of 300-500 Ma and a crater distribution close to random.. Hence the tectonics of Venus must be quiescent compared to Earth's in the last few 100 Ma. The main debate is whether its decline is closer to monotonic or episodic, with enhanced tectonism and volcanism yet to come. The former hypothesis implies most radioactive heat sources have been differentiated upward; the latter, that they have remained at depth. The low level of activity in the last few 100 million years inferred from imagery favors the monotonic hypothesis; the low abundance of radiogenic argon favors the episodic. A problem for both hypotheses is the rapid decline of thermal and tectonic activity some 300 to 500 Ma. The nature of the convective instabilities that caused the decline, and their propagation, are unclear [1].

Perceptions of Venus have changed significantly in the last five years, not only because of results returned by the Magellan spacecraft, but also because of better experiments on the rheology of dry crustal rocks. The 915 craters identified on Magellan imagery have an abundance indicating an average surface age of 300-500 Ma, and a geographic distribution consistent with randomness on a global scale [2]. Furthermore, the lack of clusters of older craters implies a rapid decline in the resurfacing of Venus-- perhaps within a few 10 My. While more detailed examinations infer that Venus is not entirely dead [3], they generally confirm inferences from Pioneer Venus altimetry [4] that tectonic activity on Venus is slight compared to Earth's over the last few 100 Ma.

Important new experimental data are the results on the rheology of dry diabase [5], which showed it to have a viscosity as high as that of dry olivine [6]-- although at strain rates ten orders-of-magnitude greater than inferred for Venus [7]. This finding removed the constraint on crustal thickness from the high crater depth: diameter ratios [8], based on earlier rheology experiments. It also plausibly removes the need for deep convective sources to support the highland regions [9].

The apparent stiffness of the Venerean upper mantle and the slow time scale of its tectonics seem explicable by its lack of water. Problems remaining are: Can the quiescent tectonics of Venus be explained by most of its radioactive heat sources having been differentiated up into the crust, thus reducing temperature gradients? And: What are the mechanisms causing the apparent rapid decline in resurfacing around 300-500 Ma?

The five lander sites of less than 1% K_2O are often dismissed as resembling terrestrial tholeiites. However, they are actually high in K, U, Th content, not only in measured values compared to MORB's [10], but with respect to their formation and circumstances of measurement. Most of Venus appears to be resurfaced by lavas. The area-dominant lavas should be those of the lowest viscosity. Low viscosity basalts have basic compositions, hence low content of the radiogenic elements. The sites were plausibly selected to minimize the chance that the lander would tip over-- that is, smooth areas, as indicated by radar darkness. This introduces a bias in favor of low viscosity basic lavas. As for more radioactive plutonic rocks, Venus lacks erosion to bring them to the surface. The main evidence in favor of a low radiogenic element content of Venus's crust is the low abundance of radiogenic argon, ^{40}Ar, in the Venus atmosphere-- about one-third that of Earth [11].

The crater distribution has sufficient departures from Poissonian to allow time scale of shutdown of tectonic activity in Venus to be several times 10 million years, perhaps 100 million. This is still difficult to reconcile with a decrease in average strain rate by at least a factor of 100 [7]. Clearly, the decline cannot be due solely to the non-linear rheology interacting with a global nearly uniform thermal state; it must entails non-linearities of the flow system-- compositional as well as thermal. The significant tectonic activity probably was widespread but involved only a minor tectonically active part of the globe (analogous to contemporary Earth); however, the lavas produced thereby must be voluminous and fluid enough to resurface most of the planet within the 100 million years. The problems are (a) the nature of the initiating instabilities; and (b) their propagation throughout a spherical shell with a circumference more than twelve times its depth.

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Factors suggested to affect evolution and the rapid decline include: (i) upward concentration of radioactive heat sources in the crust; (ii) a lithosphere hotter than earth's, leading to a top boundary closer to stress-free; (iii) accumulation of high Mg/Fe residuum in the upper mantle; (iv) transition of the lithosphere to positive buoyancy with cooling; (v) increased rigidity of the lithosphere with cooling; (vi) non-linear dependence of viscosity on temperature and strain-rate; (vii) the absence of water. Transition of dominance from factors i-ii, which promote heat escape from the mantle to factors iii-v, which act to shut it off, is characteristic of most scenarios, implicitly if not explicitly. Dominance of factors iii-vi, coupled with retention of heat sources at depth, could have caused a temperature rise leading to massive melting, rupturing the lithosphere. The non-linearity of factor vi enhances instabilities that propagate rupture, while factor vii acts to strengthen the lithosphere, thus increasing the temperature buildup required for rupture. The lack of water may also have acted to prevent plate tectonics, which depends on weak lithospheric margins, throughout Venus's history.

Instabilities require density inhomogeneities, thermal or compositional, which in turn are normally associated with interfaces. The more pronounced the density differential at the interface, the more likely an instability can occur. Likely locations are (i) The surface: development of a thick, dense lithosphere, which breaks and sinks, as in the Earth's subduction (abetted by lateral variations in crustal density and thickness); (ii) Occurrence of the basalt: eclogite transition just below the crust: mantle interface; (iii). A low density, Mg-rich layer residual to crustal differentiation in the mantle. As the convective vigor slowed, such a layer would not be swept aside so quickly (as it is on Earth)

A combination of (i) and (iii) seems most plausible. They both depend on crustal differentiation, but not on the growth of crust to a thickness of 50 km or more. Probably the greater difficulty is the propagation of instability, a problem somewhat analogous to that of earthquake occurrence: relief of an instability in one place enhances instabilities elsewhere. It is particularly a problem if the upper mantle were already stiff. Propagation would be greatly helped by the presence of an asthenosphere, as in the Turcotte's episodic model [12], to which the main objection is that if heat sources remained at depth, their effects should be seen within a time much less than 300 My after the resurfacing event

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