al. [12] also considered the high-frequency bursts as possible lightning events. They found that while the high-frequency events did show some longitudinal dependence, the data were better ordered by local time, with the peak rates occurring in the dusk local time sector. Consequently, it is now thought that the lightning is not associated with volcanic activity. Rather, it is due to weather processes in an analogous manner to lightning at the Earth, which tends to peak in afternoon local time sector [13].

The evidence for lightning at Venus from the VLF data now falls into two classes. The higher frequency bursts show the local time dependence, and the rate also decreases most quickly as a function of altitude [14]. These bursts are thought be a local response to the lightning discharge, and therefore are best suited for determining planetwide rates. The rates are found to be comparable to terrestrial rates. However, it is still not clear how the high-frequency signals enter the ionosphere. On the other hand, about 50% of the 100-Hz bursts are clearly whistler mode signals, as evidenced by the wave polarization [15]. These signals can propagate some distance in the surface ionosphere waveguide before entering the ionosphere. The 100-Hz bursts are therefore less reliable in determining the lightning rate, or the main source location.

Perhaps the least ambiguous evidence for lightning on Venus has come from the plasma wave data acquired by the Galileo spacecraft during the Venus flyby [16]. Unlike Pioneer Venus, Galileo was able to measure plasma waves at frequencies up to 500 kHz. The plasma wave experiment detected nine impulsive signals that were several standard deviations above the instrument background while the spacecraft was at a distance of about five planetary radii. Although some of the lower-frequency bursts could possibly have been Langmuir wave harmonics, the higher-frequency bursts were probably due to lightning. The bursts were at sufficiently high frequency to pass through the lower-density nightside ionosphere as freely propagating electromagnetic radiation.

While there is a strong body of evidence for the existence of lightning at Venus, there are still many questions that remain. From an ionospheric physics point of view, it is not clear how high-frequency signals can propagate through the ionosphere. The low-frequency signals do appear to be whistler mode waves, although there is still some doubt [17]. Also, although whistler mode propagation may be allowed locally, it is not necessarily certain that the waves can gain access to the ionosphere from below. For example, whistler mode propagation requires that the ambient magnetic field passes through the ionosphere into the atmosphere below. It is possible that the ionosphere completely shields out the magnetic field. With regard to atmospheric science, there are several questions that require further study. First, can charge separation occur in clouds at Venus? Is there sufficient atmospheric circulation to cause a local time dependence as observed in the VLF data? Do Venus clouds discharge to the ionosphere, and so cause strong local electromagnetic or electrostatic signals that could explain the high-frequency VLF bursts? While some of these questions may be answered as low-altitude data are acquired during the final entry phase of the Pioneer Venus Orbiter, many questions will still remain.

Acknowledgments: I wish to thank Christopher T. Russell for invaluable discussions on the evidence for lightning at Venus. This work was supported by NASA grant NAG2-485.

References: [1] Inan U. S. and Carpenter D. C. (1987) *JGR*, *92*, 3293–3303. [2] Russell C. T. et al. (1989) *Adv. Space Res.*, *10(5)*, 37–40. [3] Franz R. C. et al. (1990) *Science*, *249*, 48–51. [4] Ksanfomaliti L. V. et al. (1983) In *Venus*, 565–603, Univ. of Arizona, Tucson. [5] Krasnopol'sky V. A. (1983) In *Venus*, 459–483, Univ. of Arizona, Tucson. [6] Taylor W. W. L. et al. (1979) *Nature*, *279*, 614–616. [7] Scarf F. L. et al. (1980) *JGR*, *85*, 8158–8166. [8] Scarf F. L. and Russell C. T. (1983) *GRL*, *10*, 1192–1195. [9] Taylor H. A. Jr. et al. (1985) *JGR*, *90*, 7415–7426. [10] Taylor H. A. Jr. et al. (1989) *JGR*, *94*, 12087–12091. [11] Ho C.-M. et al. (1991) *JGR*, *96*, 21361–21369. [12] Russell C. T. et al. (1989) *Icarus*, *80*, 390–415. [13] Russell C. T. (1991) *Space Sci. Rev.*, *55*, 317–356. [14] Ho C.-M. et al. (1992) *JGR*, in press. [15] Strangeway R. J. (1991) *JGR*, *96*, 22741–22752. [16] Gurnett D. A. et al. (1991) *Science*, *253*, 1522–1525. [17] Grebowsky J. M. et al. (1991) *JGR*, *96*, 21347–21359.

N93-14487 484392

VOLCANISM BY MELT-DRIVEN RAYLEIGH-TAYLOR INSTABILITIES AND POSSIBLE CONSEQUENCES OF MELTING FOR ADMITTANCE RATIOS ON VENUS.

P. J. Tackley[1], D. J. Stevenson[1], and D. R. Scott[2], [1]Division of Geological and Planetary Sciences, Caltech, Pasadena CA 91125, USA, [2]Department of Geological Sciences, University of Southern California, Los Angeles CA 90089, USA.

A large number of volcanic features exist on Venus, ranging from tens of thousands of small domes to large shields and coronae. It is difficult to reconcile all these with an explanation involving deep mantle plumes, since a number of separate arguments lead to the conclusion that deep mantle plumes reaching the base of the lithosphere must exceed a certain size. In addition, the fraction of basal heating in Venus' mantle may be significantly lower than in Earth's mantle, reducing the number of strong plumes from the core-mantle boundary. In three-dimensional convection simulations with mainly internal heating, weak, distributed upwellings are usually observed.

Description of Instability: We present an alternative mechanism for such volcanism, originally proposed for the Earth [1] and for Venus [2], involving Rayleigh-Taylor instabilities driven by melt buoyancy, occurring spontaneously in partially or incipiently molten regions. An adiabatically upwelling element of rock experiences pressure-release partial melting, hence increased buoyancy and upwelling velocity. This positive feedback situation can lead to an episode of melt buoyancy driven flow and magma production, with the melt percolating through the solid by Darcy flow. The percolation and loss of partial melt diminishes the buoyancy, leading to a maximum upwelling velocity at which melt percolation flux is equal to the rate of melt production by pressure-release melting.

Application to Venus: The instability has been thoroughly investigated and parameterized using finite-element numerical models, and hence its applicability to Venus can be assessed. Numerical convection simulations and theoretical considerations indicate that Venus' interior temperature is likely hotter than Earth's, hence the depth of intersection of the adiabat with the dry solidus may be appreciably deeper. In the regions of distributed broad-scale upwelling commonly observed in internally-heated convection simulations, partial melt may thus be generated by the adiabatically upwelling material, providing the necessary environment for these instabilities to develop. Scaling to realistic material properties and melting depths, the viscosity at shallow depth must be 10^{19} Pa.s or less, leading to a period of self-perpetuating circulation and magma production lasting ~30 Ma, magma production rates of ~1000 km^3/Ma, and lengthscales of ~250 km.

Geoid, Topography, and Viscosity Profiles: Partial melt and buoyant residuum represent density anomalies that are of the same

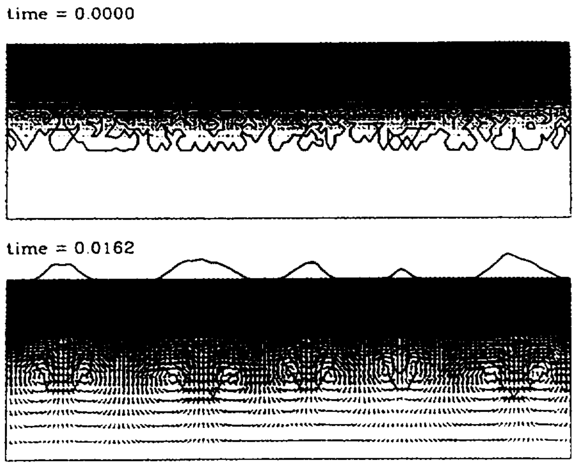

Fig. 1. Finite-element simulation showing the growth of melt-driven instabilities at the top of the mantle (depth of box ~160 km) from initially small (<0.1%) random partial melt perturbations. Temperature (shaded), velocity (arrows), partial melt distribution (contours, at 0 and intervals of 2.5%), melt production rate per unit area (on top). Time nondimensionalized to D^2/κ.

order as thermal anomalies driving mantle flow. Density anomalies equivalent to 100 K are obtained by only 1% partial melt or buoyant residuum, which is 3% depleted. These density effects are expected to have an effect on geoid and topography caused by one of these instabilities, and possibly the geoid and topography caused by thermal plumes.

Comparison of mantle geotherms for Venus (derived both from numerical simulations and from observations combined with theory) with an experimentally determined dry solidus for peridotite [3] indicate that the average geotherm passes close to or even exceeds the dry solidus at a depth of around 90 km. Thus, for any reasonable viscosity law, such as in [4], a region of lower viscosity is expected at shallow depth. This contradicts several geoid/topography studies based on simple mantle models, which require no low-viscosity zone. We investigate the possibility that the presence of buoyant residuum and partial melt at shallow depth may account for this discrepancy.

Global geoid modeling using the technique described in [5] indicates that a possible way to satisfy the long wavelength admittance data is with an Earth-like viscosity structure and a concentration of mass anomalies close to the surface, compatible with a shallow layer of buoyant residuum and/or partial melt. Geoid and topography signatures for local features, specifically Rayleigh-Taylor instabilities and thermal plumes with partial melting, are currently being evaluated and compared to data.

References: [1] Tackley P. J. and Stevenson D. J. (1990) *Eos, 71*, 1582. [2] Tackley P. J. and Stevenson D. J. (1991) *Eos, 72*, 287. [3] Takahashi E. (1986) *JGR, 91*, 9367–9382. [4] Borch R. S. and Green H. W. (1987) *Nature, 330*, 345. [5] Hager B. H. and Clayton R. W. (1989) In *Mantle Convection*. 657–764.

N93-14388 164393

CAN A TIME-STRATIGRAPHIC CLASSIFICATION SYSTEM BE DEVELOPED FOR VENUS?

K. L. Tanaka and G. G. Schaber, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff AZ 86001, USA.

Magellan radar images reveal that Venus' exposed geologic record covers a relatively short and recent time span, as indicated by the low density of impact craters across the planet [1]. Therefore, because impact cratering in itself will not be a useful tool to define geologic ages on Venus, it has been questioned whether a useful stratigraphic scheme can be developed for the planet. We believe that a venusian stratigraphy is possible and that it can be based on (1) an examination of the rationale and methods that have been used to develop such schemes for the other planets, and (2) what can be gleaned from Magellan and other datasets of Venus.

Time-stratigraphic classification systems or schemes have been derived for all other terrestrial planetary bodies (Earth, Moon, Mars, Mercury) [2–5] because the schemes are useful in determining geologic history and in correlating geologic events across the entire surface of a planet. Such schemes consist of a succession of time-stratigraphic units (such as systems and series) that include all geologic units formed during specified intervals of time. Our terrestrial stratigraphy is largely based on successions of fossil assemblages contained in rock units and the relations of such units with others as determined by their lateral continuity and superposition and intersection relations. To define geologic periods on the other planets, where fossil assemblages cannot be used, major geologic events have been employed (such as the formation of large impact basins on the Moon and Mercury [3,5] or the emplacement of widespread geologic terrains on Mars [4,6]). Furthermore, terrestrial schemes have been supplemented by absolute ages determined by radiometric techniques; on the Moon and Mars, relative ages of stratigraphic units have been defined according to impact cratering statistics [3,4].

Stratigraphies are by nature provisional, and they are commonly revised and refined according to new findings. Boundaries of stratigraphic units are difficult to define precisely on a global scale; refinements such as newly discovered marker beds may require changes in nomenclature or minor adjustments in absolute- or relative-age assignments. Although the martian stratigraphy has been revised only once [4], the lunar stratigraphy is in its fifth major version [3] and continues to be refined in detail [7]. Terrestrial stratigraphy has been revised many times in its development over the past century. Although the Galilean satellites of Jupiter are being mapped geologically, there has been insufficient basis or need for the development of formal stratigraphies for them [8].

Given the current state of stratigraphic methods and their application to the planets, what are the prospects for a stratigraphy for Venus? To address this question, we need to examine two related questions: (1) Has the planet experienced widespread geologic events or processes resulting in the broad distribution of coeval materials (which would form the basis for time-stratigraphic units)? (2) Can we unravel the complex stratigraphic-tectonic sequences apparent on Venus? (Or can superposition relations and relative age be reasonably well established from Magellan radar or other datasets?)

Already a variety of potential venusian stratigraphic markers based on widespread geologic events and activities are emerging (Table 1). First, the global distribution of impact craters indicates that Venus had a global resurfacing event or series of events that ended about 500 ± 300 m.y. ago [1]. Presumably, most of the plains material that covers about 80% of the planet formed during that resurfacing and can be included in a stratigraphic system. Underlying much of the plains material are complex ridged or tesselated terrain materials; they must be older than the plains material, but their structures may in part be contemporary with its emplacement [9]. Postdating the plains material are most of the impact craters, many of the largest volcanic shields, and regional fracture belts [1]. Most of the plains are cut by lineations, narrow grabens, and wrinkle ridges. Perhaps such widespread structures may provide a basis for defining regional or even nearly global stratigraphic markers to