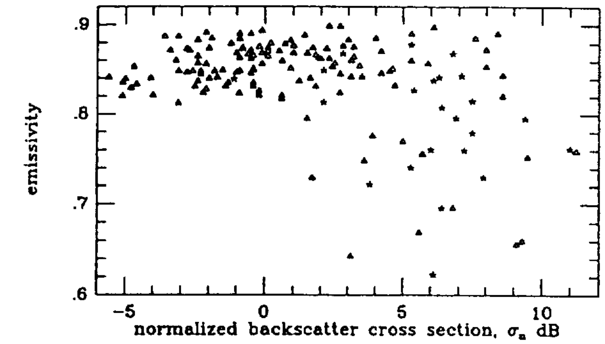

Fig. 1. Microwave emissivity vs. normalized backscatter cross section σ_n of the floors of 158 impact craters with diameters >30 km. Impact craters associated with parabolic-shaped radar-dark halos are shown as ★, craters without an associated parabolic halo are shown as Δ. σ_n values are dB with respect to the normalizing scattering used in the processing of Magellan SAR data [3].

sic reflectivity of the material forming the crater floors. Fifty-three of these (radar) bright floored craters are associated with 93% of the parabolic-shaped radar-dark features found in the Magellan SAR and emissivity data, features that are thought to be among the youngest on the surface of Venus [1]. It was suggested by Campbell et al. [1] that either the bright floors of the parabolic feature parent craters are indicative of a young impact and the floor properties are modified with time to a lower backscatter cross section or that they result from some property of the surface or subsurface material at the point of impact or from the properties of the impacting object. As a continuation of the work in [1] we have examined all craters with diameters greater than 30 km (except 6 that were outside the available data) so both the backscatter cross section and emissivity of the crater floors could be estimated from the Magellan data.

A plot of the emissivity vs. normalized backscatter cross section of the floors of 158 craters with diameters >30 km (Fig. 1) shows little direct correlation between crater floor backscatter brightness and emissivity. One-third of the measured crater floors have normalized backscatter cross sections greater than 3 dB above average and 36% of these have an associated radar-dark parabolic feature. Most of the crater floors have emissivities near 0.85, the typical value for the venusian surface, but many are slightly higher, which may be due to the slight increase in emissivity observed with increased surface roughness [2]. Twenty-five (or 16%) of the craters have floor emissivities <0.81. In an attempt to understand if these low emissivities are the result of elevated Fresnel reflectivities and hence compositional differences in the crater floor material, we plotted the measured emissivities vs. incidence angle along with the theoretical emissivity for a smooth surface with dielectric constant $\varepsilon = 5.0$ (Fig. 2). At the highest incidence angle of the cycle 1 Magellan observations the theoretical emissivity drops to ~0.76, indicating that some of the low emissivities measured at the higher incidence angles may not be the result of compositional differences.

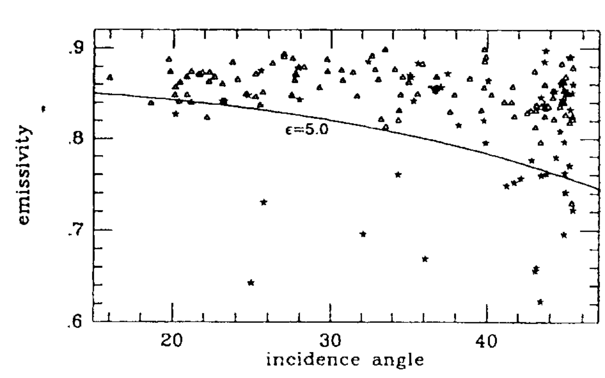

Fig. 2. Microwave emissivity vs. incidence angle of the floors of 158 impact craters with diameters >30 km with the theoretical emissivity for a smooth surface material with dielectric constant $\varepsilon = 5.0$. Impact craters with $\sigma_n \geq 3.0$ dB are shown as ★ and with $\sigma_n < 3.0$ dB as Δ.

References: [1] Campbell D. B. et al. (1992) *JGR,* in press. [2] Ulaby F. T. et al. (1982) In *Microwave Remote Sensing Active and Passive,* 2, 949–966, Addison-Wesley. [3] SDPS-101 (1991) *NASA/JPL Magellan Project SIS F-BIDR,* Appendix F, 31–33.

N93-14385 484390

THE EFFECTS OF VENUSIAN MANTLE CONVECTION WITH MULTIPLE PHASE TRANSITIONS.
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Recently there was a flurry of activities in studying the effects of phase transitions in the Earth's mantle. From petrological and geophysical considerations, phase-transition would also play an important role in venusian dynamics. The basic differences between the two planets are the surface boundary conditions both thermally and mechanically. In this vein we have studied time-dependent mantle convection with multiple phase transitions and depth-dependent thermal expansivity ($\alpha \sim \rho^{-6}$, based on high-pressure and temperature measurements by Chopelas and Boehler [1]). Both the olivine-spinel and spinel-perovskite transitions were simulated by introducing an effective thermal expansivity, as described in [2]. Used together with the extended Boussinesq Approximation [3] this method serves as a powerful tool to examine the effects of phase transitions on convection at relatively low computational costs.

In comparison to models with constant α the decrease of α injects vigor into lower mantle convection and stabilizes long aspect ratio flows. Hence the tendency to layered flows is increased.

Due to its positive Clapeyron slope the olivine-spinel transition increases the effective Rayleigh number in the upper mantle. This effect also stabilizes layered convection. Consequently, layered flows with a third thermal boundary layer at around 700 km depth and very long aspect ratio flows in the upper mantle can be observed (Fig. 1). The amount of exchange of matter between upper and lower mantle depends on the Clapeyron slopes and the "widths" of the

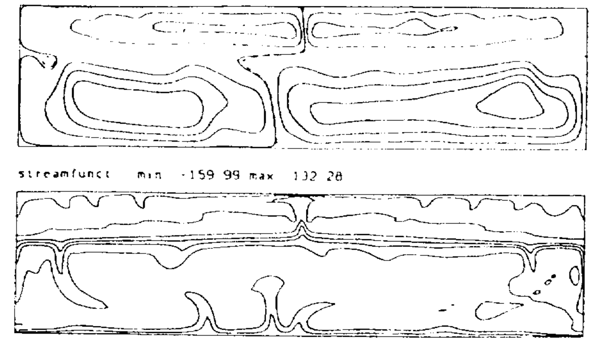

Fig. 1. Streamlines (top) and isotherms (bottom) of a flow with two phase transitions. Rayleigh number (Ra) is 10^7.

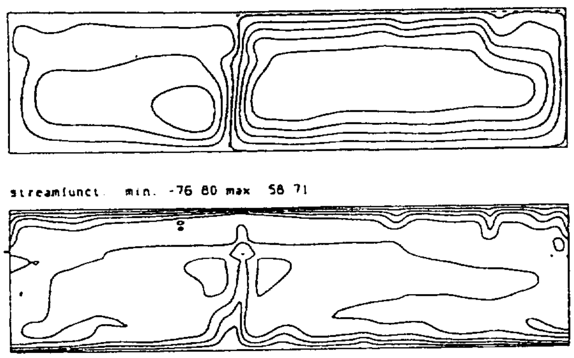

Fig. 2. Same diagram as Fig. 1, but at lower Rayleigh number (Ra = 2×10^6).

phase transitions. The olivine-spinel transition may give rise to secondary instabilities emanating from the thermal boundary layer, as it can be also observed in flows with both temperature- and pressure-dependent viscosity included.

As argued first by Kaula [4], the venusian mantle may contain much less water than the Earth's, resulting in a higher viscosity and therefore lower Rayleigh number. Our calculations confirm that lower Rayleigh number flows show less tendency to be layered (Fig. 2), as observed by Christensen and Yuen [2]. For terrestrial planets like Venus and Earth this means that the form of convection may undergo several changes during the planet's history. In early stages (characterized by high Rayleigh number) phase transitions act as a barrier to convective flows, resulting in low heat flows and cooling rates.

As the Rayleigh number decreases with time, the flow becomes more and more penetrative, the upper mantle heats up, and the lower mantle and core cool down, while heat flow increases despite the lower Rayleigh number. Due to the high cooling rate in this stage the vigor of convection decreases faster and the flow may undergo another transition from time dependent to steady state.

Thus the combined effects of a relatively dry venusian mantle and phase transition would facilitate the cooling of Venus in spite of its having a higher surface temperature. Venus is therefore in a stage of planetary evolution that is characterized by much less tectonic and volcanic activity. On the other hand, convection models with phase transitions [e.g., 5] and global seismic tomography suggest that the present-day Earth is in an earlier state of layered convection.

References: [1] Chopelas A. and Boehler R. (1989) *GRL, 16,* 1347–1350. [2] Christensen U. R. and Yuen D. A. (1985) *JGR, 90,* 10291–10300. [3] Steinbach V. et al. (1989) *GRL, 16,* 633–636. [4] Kaula W. M. (1990) *Science, 247,* 1191–1196. [5] Machetel P. and Weber P. (1991) *Nature, 350,* 55–57.

N93-14486

EVIDENCE FOR LIGHTNING ON VENUS. R. J. Strangeway, Institute of Geophysics and Planetary Physics, University of California, Los Angeles CA 90024, USA.

Lightning is an interesting phenomenon both for atmospheric and ionospheric science. At the Earth lightning is generated in regions where there is strong convection. Lightning also requires the generation of large charge-separation electric fields. The energy dissipated in a lightning discharge can, for example, result in chemical reactions that would not normally occur. From an ionospheric point of view, lightning generates a broad spectrum of electromagnetic radiation. This radiation can propagate through the ionosphere as whistler mode waves, and at the Earth the waves propagate to high altitudes in the plasmasphere where they can cause energetic particle precipitation [1]. The atmosphere and ionosphere of Venus are quite different from at the Earth, and the presence of lightning at Venus has important consequences for our knowledge of why lightning occurs and how the energy is dissipated in the atmosphere and ionosphere.

As discussed here, it now appears that lightning occurs in the dusk local time sector at Venus. Since the clouds are at much higher altitudes at Venus than at the Earth, we expect lightning to be primarily an intracloud phenomenon [2]. It is possible, however, that lightning could also propagate upward into the ionosphere, as has been observed recently at the Earth [3]. This may explain the high-frequency VLF bursts detected at low altitudes in the nightside ionosphere by the Pioneer Venus Orbiter, as described below.

Some of the early evidence for lightning on Venus came from the Venera landers, which carried loop antennas to detect electromagnetic radiation in the VLF range [4]. These sensors detected sporadic impulsive signals. Since the detectors were sensitive to magnetic rather than electric field fluctuations, it is highly unlikely that these impulses were generated locally by the interaction of the lander and the atmosphere. An optical sensor was flown on Venera 9, and this instrument also detected occasional impulsive bursts [5].

The largest body of data used as evidence for lightning on Venus comes from the Pioneer Venus Orbiter electric field detector. This is a small plasma wave experiment that measures wave electric fields in the ELF and VLF range. Because of restrictions on power, weight, and telemetry, the instrument has only four frequency channels (100 Hz, 730 Hz, 5.4 kHz, and 30 kHz). Highly impulsive signals were detected at low altitudes in the nightside ionosphere in all four channels [6]. However, the ambient magnetic field at Venus is small, only a few tens of nanoteslas, and the electron gyrofrequency is usually less than 1 kHz, and often less than 500 Hz. Since there is a stop band for electromagnetic wave propagation between the electron gyrofrequency and plasma frequency, bursts detected in the higher channels do not correspond to freely propagating modes. In subsequent studies [7] F. L. Scarf and colleagues adopted a convention that bursts must be detected at only 100 Hz (i.e., below the gyrofrequency) for the bursts to be considered as lightning-generated whistlers. With this definition it was found that the signals tended to cluster over the highland regions [8], and Scarf and Russell speculated that the VLF bursts were whistler mode waves generated by lightning associated with volcanic activity. This was a highly controversial interpretation, which was subsequently criticized by H. A. Taylor and colleagues [9,10]. Among other criticisms, they pointed out that the studies of Scarf and colleagues were not normalized by the spacecraft dwell time, which tended to exaggerate the altitude dependence of the 100-Hz bursts. However, other studies [11] have shown that the burst rate does maximize at lowest altitudes. Nevertheless, it is important to note that the apparent geographic correlation may in fact be a consequence of the restricted longitudinal coverage of the Pioneer Venus Orbiter for each season of nightside periapsis. Periapsis in the early seasons was maintained at low altitudes, but was allowed to rise in later seasons. The periapsis longitude only covered the lowlands in these later seasons, and since the data were acquired at higher altitude, the event rate decreased. However, this decrease was mainly a consequence of the change in altitude, rather than a change in planetary longitude.

Although Scarf et al. only considered 100-Hz bursts as evidence for lightning, since these waves could be whistler mode, Russell et