**Further Development and Tests of these Scenarios:** No one observation can be shown to uniquely confirm these models and scenarios, but many of the features predicted by the models are consistent with the observed characteristics of Venus geology and geophysics. These models therefore merit further consideration. Some of the things that are required to permit the further analysis and testing of these scenarios include (1) Better definition of the growth, stability, and style of renewal of the crust and depleted layer, and the relation to lithosphere evolution. (2) Analysis of the scale and nature of instability: Is it characterized by catastrophic surface turnover and crustal spreading, or deeper negative diapirs and resurfacing of a relatively stable and intact veneer? (3) Do the heavily deformed tesserae show patterns consistent with the initiation and subsequent deformation during the period of instability? (4) If crustal spreading has taken place as part of the resurfacing process, what geometries and rates are compatible with the cratering record? (5) How fast does resurfacing have to be to be consistent with the crater record? Is this reasonable from turnover and magma generation point of view?

Crustal formation processes have been characterized as primary (resulting from accretional heating), secondary (resulting from partial melting of planetary mantles), and tertiary (resulting from reprocessing of secondary crust [20]. Venus appears to represent a laboratory for the study of vertical accretion of secondary crust, which may have important implications for the earliest history of the Earth.

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**N93-14325**

**DYNAMICS OF THE VENUS ATMOSPHERE.** A. P. Ingersoll, California Institute of Technology, Pasadena CA 91125, USA.

The superrotation of the Venus atmosphere is a major unanswered problem in planetary science [1]. At cloud-top levels (65–70 km altitude) the atmosphere rotates with a five-day period, corresponding to an equatorial wind speed of 90 m/s [2–4]. Angular velocity is roughly constant on spherical shells, and decreases linearly with altitude to zero at the surface. The direction of rotation is the same as that of the solid planet, which is retrograde—opposite to the direction of orbital motion, but the 5-day period is short compared to the 243-day spin period of the solid planet or to the mean solar day, which is 117 Earth-days at the surface.

The problem with the superrotation is that shearing stresses tend to transfer angular momentum downward, and would slow the atmosphere until it is spinning with the solid planet. Some organized circulation pattern is counteracting this tendency, but the pattern has not been identified. A simple Hadley-type circulation cannot do it because such a circulation is zonally symmetric and Hide's theorem [5] states that in an axisymmetric circulation an extremum in angular momentum per unit mass M can exist only at the surface. Venus violates the last condition, having a maximum of retrograde M on the equator at 70–80 km altitude. This leaves waves and eddies to maintain the superrotation, but the length scales and forcing mechanisms for these motions need to be specified.

The wind speed at cloud-top level is proportional to the equator-to-pole temperature difference through a relation known as the thermal wind equation [1]. The magnitude of the temperature difference reflects a balance between radiative forcing, which tends to warm the equator and cool the pole, and poleward heat transport by atmospheric motions—including the same waves and eddies that are maintaining the superrotation. The great mass and large heat-carrying capacity of the lower atmosphere limits the temperature gradient there. The temperature difference at cloud-top level is of order 30 K [1]. If the circulation were more efficient at all altitudes, the temperature difference would be smaller and the superrotation would be weaker. Understanding the superrotation is equivalent to understanding the equator-to-pole temperature distribution, and neither are understood at present.

The mean meridional wind at cloud-top level is poleward in both hemispheres, according to cloud-tracked wind analysis from 1974 to 1990 [2–4]. The zonal wind varied from 80 to 100 m/s during the same period. Both the eddies and the symmetric circulation are tending to remove angular momentum from the equator at cloud-top levels [2,3], thereby adding to the load that other waves and eddies must carry. The most visible global feature is the Y, a dark marking centered on the equator that looks like the letter Y rotated counterclockwise by 90°. Its four-day period is significantly shorter than that of small-scale markings that drift with the flow, so it is probably a Kelvin wave with zonal wavenumber equal to one [6,7]. On Earth, the eastward-propagating Kelvin waves and the westward-propagating Rossby-gravity waves alternate in driving the winds of the equatorial stratosphere to the east and west, respectively, in a cycle known as the quasibiennial oscillation (QBO). The waves are presumably driven by convection in the troposphere, but the exact nature of their excitation is not yet fully understood [5]. The role of these waves on Venus, how they are excited, and why they do not produce larger swings in the equatorial zonal wind are still unanswered questions. Convection occurs in two altitude ranges on Venus: from the surface to about 30 km altitude, and within the clouds from 49 to 55 km altitude [1]. It is possible that small-scale convective motions randomly excite the large-scale Kelvin wave, which carries retrograde momentum upward and maintains the superrotation.

Tides are the other major class of atmospheric motions that could be maintaining the superrotation [8–10]. They are the atmosphere's linear response to daily heating by the Sun. Both the heating and the response are global in scale and are phase-locked to the Sun as the atmosphere rotates beneath it. Tides propagate vertically, away from the altitudes where solar heat is absorbed. On Venus this heating is located near the tops of the clouds. The propagating waves carry energy and momentum away from this layer and could lead to a net retrograde acceleration. Tides are seen in the Venus images [2,3,6] and temperature data [11], and many of the observed features are reproduced in the models. The problems center around the distribution of tidal heating, the dissipation of tidal energy, the relation between tides and convection, which also has a diurnal component, and the role of the deep atmosphere, which is difficult to model because of its long thermal response time and convective temperature distribution.

More observations are needed to sort out the different possibilities. A network of probes or balloons would help define the types of waves that are present. Measuring the correlations between the different components of velocity with each other and with temperature at different points in space and time is the time-honored way of measuring heat and momentum transports. The same methods that have worked for the Earth's atmosphere should work for Venus.

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**LARGEST IMPACT CRATERS ON VENUS.** B. A. Ivanov[1], C. M. Weitz[2], and A. T. Basilevsky[3], [1]Institute for Dynamics of Geospheres, Russian Academy of Sciences, Moscow, Russia, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA, [3]Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow, Russia.

**Introduction:** High-resolution radar images from the Magellan spacecraft have allowed us to perform a detailed study on 25 large impact craters on Venus with diameters from 70 to 280 km. The dimension of these large craters is comparable with the characteristic thickness of the venusian lithosphere and the atmospheric scale height. Some physical parameters for the largest impact craters on Venus (LICV), such as depth, ring/diameter ratio, and range of ballistic ejecta deposits, have been obtained from the SAR images and the altimetry dataset produced by MIT [1].

**Crater Depth Results:** Impact crater depths previously measured using Venera 15/16 images [2,3,4] are in close agreement with the depths measured from the Magellan altimetry for the craters with diameters larger than the altimeter footprint on the surface. Two craters seem to have anomalous depths: Cleopatra (D = 100 km) and Mead (D = 280 km) (Fig. 1). Cleopatra is approximately twice as deep as other craters with the same diameter. Several hypotheses on the origin of Cleopatra have already been discussed [5,6]. Mead is a double-ring structure with an inner-ring flat floor depth of about 700 m and a maximum depth of 1000 m below the surrounding terrain. This maximum depth is approximately 100 m less than the depth for Klenova (D = 140 km). The maximum depth of Isabella (D = 173 km) is about 1400 m, which is about 400 m deeper than for Mead. A comparison of our data with estimates made by Grimm and Solomon [7] suggests that Mead may be one of the first examples of crater relaxation on Venus due to viscous flow of the crust. Because of the large footprint of the altimeter, viscous relaxation in smaller craters cannot be seen, yet we cannot reject this process. Hopefully, parallax measurements made from different viewing geometries will allow us to make better depth measurements, especially for the smaller craters.

**Ring Diameter Ratios:** A majority of venusian impact craters with diameters larger than 70 km have a double-ring structure. All craters with D > 90 km are double ring. Melosh [8] separated the cratering data for all terrestrial planets into peak-ring craters (PRC) and multiring basins (MRB). For PRC, he found that the inner-to-outer ring diameter ratio (RDR) is about 0.5 for all planetary bodies, while the morphology of MRB is specific for each planet depending upon the details of the upper crust structure. Many of the LICV have RDR of 0.5 and smaller and may be classified as PRC (Fig. 2). Three craters with diameters from 90 to 280 km have RDR from 0.6 to 0.67. These three craters may be candidates for venusian MRB, but more morphologic and comparative studies need to be done for proper classification. An interesting finding is the coexistence of craters with RDR ≤ 0.5 (four structures) and RDR > 0.5 (three structures) in the diameter range from 90 to 110 km. By comparing the local geologic setting around each crater, it may be possible to determine if the terrain is influencing the RDR for this diameter range.

**Distance of Ballistic Ejecta Deposits (BED):** The measurement of the outer distance of ballistic ejecta deposits has some uncertainty due to the obliqueness of the impact and ejecta disturbed by radar-bright outflows from some craters. Measurements may be done more accurately in the future when geologic mapping is completed for all the craters under investigation in this study. The data we now have for 25 craters shows that the radial distance of the BED from the crater rim increases for craters with diameters less than 100 km (Fig. 3). For larger craters, the width of the BED seems to stay at approximately 50 km from the crater rim. This observed

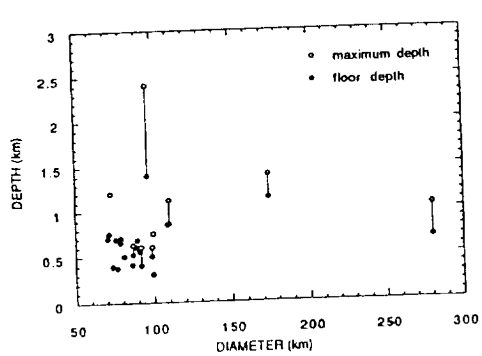


Fig. 1. Depth vs. diameter for LICV.

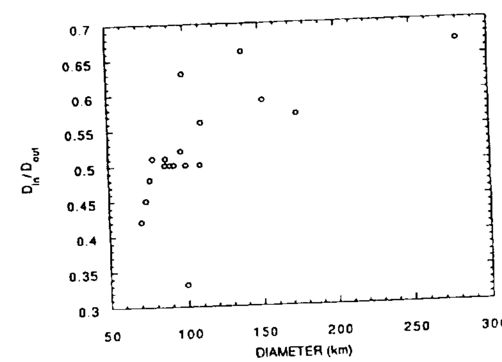


Fig. 2. Ratio of the inner peak ring to the outer ring plotted vs. diameter.