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.

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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

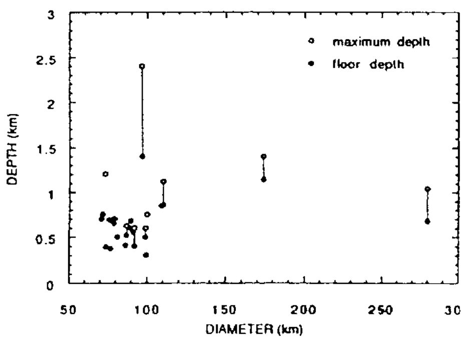

Fig. 1. Depth vs. diameter for LICV.

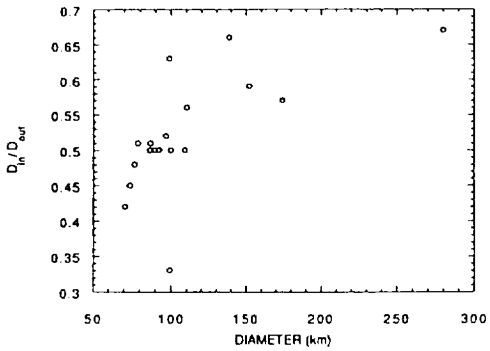

Fig. 2. Ratio of the inner peak ring to the outer ring plotted vs. diameter.

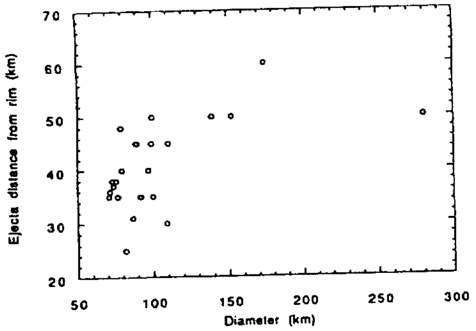

Fig. 3. Ejecta distance from the crater rim vs. diameter.

phenomenon needs additional study to investigate the effect of the atmospheric scale height on ejecta deposition.

The Inner Ring Position: A number of venusian impact craters have asymmetric BED blankets, which may result from the obliqueness of the impact. The general features of this asymmetry have been investigated experimentally for small-scale impacts [9]. At least two venusian craters (Cohran: D = 100 km, RDR = 0.5; Marie Celeste: D = 99 km, RDR = 0.62) have a definite offset of the inner ring in respect to the outer crater ring. If this offset is a consequence of an oblique impact, then we would expect the inner ring to be shifted to the deepest part of the transient cavity, which should be on the uprange side. In fact, Cohran and Marie Celeste have their inner ring offset downrange rather than uprange. Although these two craters suggest that we cannot accurately predict the formation of the multiring structures, we still have a poor understanding of cratering mechanics at this time so we need to investigate this process further. This investigation of the largest craters on Venus is therefore providing new constraints both for cratering mechanics and for the regional geologic study of Venus.

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VENUSIAN EXTENDED EJECTA DEPOSITS AS TIME-STRATIGRAPHIC MARKERS.

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In contrast to the Moon, Mars, and Mercury, where millions of impact craters cover or influence nearly all surface terrains, on Venus there are only about 850 craters. For the Moon, Mars, and Mercury, relative densities of craters on different geologic surfaces provide clues regarding relative age relationships for surface units, both on regional and local scales. For Venus, the population of craters is well dispersed, and based on extensive statistical analysis of the spatial distribution of impact craters, Magellan investigators [1] find that the hypothesis that craters are randomly distributed cannot be rejected. Relative age dating using crater statistics alone is therefore not possible for Venus. However, in the absence of actual rock samples, the venusian crater population is the only tool available for determining a general planetary timescale. An average surface age of approximately 500 Ma is indicated by the total abundance of impact craters, using the assumption that all craters produced over that time have been retained and observed by the Magellan spacecraft [2]. One of the first-order questions regarding Venus presently is whether areas of the planet are clearly older or younger than this statistically determined average age.

On the regional scale, the question of relative age can be approached by examining the crater population and its associations with large-scale geologic terrains. Upon construction and examination of a crater distribution plot, craters appear randomly distributed across the planet. A density plot in which the total crater population has been binned in 20° radius circles every 10° of latitude and longitude to maximize the visibility of regional trends in the concentrations of craters has also been constructed. Some areas show regions with one-third to one-fourth the average planetary crater density, while others represent regions with up to twice the planetary mean. If these low- and high-density areas correlate with the regional geology of the planet, then these regions have ages younger and older than the planetary mean respectively.

The work of [3] and [4] has shown that correlations between crater concentrations and geology do exist. For example, the Beta-Atla-Themis region, shown to have the highest density of volcanic structures on the planet [5], has a low density of impact craters. Likewise, south central Aphrodite Terra, including Artemis Chasma (a large coronae feature on the southern edge of Aphrodite), also has a low crater density. These two areas probably represent broad regions younger than the planetary average age.

On the local scale, both the paucity and distribution of impact craters precludes them as relative age indicators. Relative ages must be established using other means, such as through interpretation of stratigraphic relationships between surface units. Extended ejecta deposits, which cover many times the surface area of their parent craters, are units that provide areally extensive time-stratigraphic markers for their respective localities. Superposition relationships between these deposits, volcanic materials, and tectonic zones would establish relative timing for the deposition of the units involved.

Use of impact crater ejecta as time-stratigraphic markers was established during lunar geologic mapping efforts [6,7]. The basic premise is that the deposition of impact ejecta, either by itself or mixed with impact-excavated material, is superimposed on a surface. The deposit becomes an observable, mappable unit produced in a single instant in geologic time. Up to two-thirds of Venus craters exhibit extended ejecta deposits. Most deposits have low specific radar cross sections, appearing dark on Magellan images relative to surrounding units. Some deposits have specific cross sections higher than the local mean, and some have a number of high and low specific cross-section components. The deposits range in characteristics from extensive parabolic features to halolike zones only a few crater diameters across. Parabolic features are interpreted to be due to interactions of ejecta with strong east-to-west zonal winds [8,9,10]. They extend up to 20 crater radii from the impact site. Ejecta halos, 3 to 10 times the parent crater radius in areal extent, are interpreted to be due to a combination of shock-induced crushing of preexisting material and accumulation of ejecta from the relevant impact crater [1,2,11].

The areal extent of a given extended deposit is significantly greater than that of its parent crater. The largest extended ejecta