75°
70°
60°
50°
300°
310°
320°
330°
340°
350°
0°
10°
20°
30°

Venus: Preliminary Topographic and Surface Imaging Results from the Pioneer Orbiter

Abstract. *Three large Venus surface features, identified previously in images obtained from Earth-based radar observations, are shown by the Pioneer Venus radar mapper to be elevated 5 to 10 kilometers above the surrounding terrain. Two of these features, one bright and the other dark, lie adjacent to each other astride the 65°N parallel between longitudes 310°E and 10°E. The combined region forms a huge tectonically uplifted plateau, surmounted by radar-bright ridges that may have either a volcanic or tectonic origin. The third feature, located at 30°N, 283°E, is radar-bright and may consist of volcanic material extruded along a fault zone. A first radar-scattering image, compiled from data obtained by the mapper in its imaging mode, shows a region north of the equator; several circular depressions seen in this area may result from meteoritic impact.*

The configuration of the radar mapper experiment, installed on the Pioneer Venus orbiter spacecraft, has been described (*1*). Initial data, obtained during the first 13 days after orbital insertion on 4 December 1978, have also been presented (*2*). As noted in (*2*), an instrumental malfunction developed during orbit 14 (18 December 1978) and prevented subsequent normal operation until orbit 47 (20 January 1979). The difficulty was traced to a timing problem resulting from a differential "aging" rate in two interconnected semiconductor devices. Fortunately, the aging was reversible, and the problem was eventually solved by shutting the instrument down for several weeks. Following its recovery on orbit 47, the instrument has been shut off daily for approximately 22 hours and operated in a normal fashion during the remaining 2 hours of each 24-hour orbit when the spacecraft passed through orbital periapsis. Since radar measurements were designed only to be possible below an altitude of 4700 km, corresponding to an observing interval of about 50 minutes each day surrounding periapsis passage, full normal operation of the radar mapper has been restored with negligible operational inconvenience.

In this report we present topographic measurements of three striking features whose unusual radar-scattering properties have been noted previously from Earth-based radar observations (*3*, *4*). These features include a radar-bright area centered at 65°N and 5°E (*5*), which is informally named Maxwell (right-hand part of Fig. 1), a radar-dark area directly west of Maxwell centered at 65°N and 330°E (left side of Fig. 1), and a region informally called Beta (Fig. 2) containing twin radar-bright spots, the upper of which is tentatively called Hertz (33°N, 283°E) and the lower, Gauss (24°N, 282°E) (*6*). In the Earth-based radar observations, all these features lie well back on the planet from the sub-Earth point and thus are observed at relatively large angles of incidence relative to the local surface normal. For this reason, variations in the mean surface slope do not affect the scattered power as strongly as they do when a feature is observed at relatively small angles of incidence. For the features discussed here, therefore, the factor controlling radar brightness is small-scale (2 to 10 cm) surface rough-

Fig. 1 (facing page). Contour map of a region on Venus that includes the Maxwell feature and the great northern plateau. Latitude (vertically at left) and longitude (along the top and bottom) are defined in (*5*). The underlying image was obtained from Earth-based radar observations taken at Arecibo by D. B. Campbell (*3*); contours (in color) are derived from Pioneer Venus radar mapper altimetry data. The contour interval is 1 km; elevations have an absolute accuracy of about 0.5 km and refer to an arbitrary planetary radius of 6045 km. The central axial ridge in Maxwell (right) is aligned parallel to internal streaks seen in computer enhancements of the image (*3*). The ridge may have been formed either by tectonic or volcanic activity, or both. The bright rim of the large plateau (left) probably results from the presence of coarse material lying on the slopes at the edge of the plateau and on the marginal ridges. The plateau appears to be tectonically uplifted; its boundary ridges may be volcanic or tectonic in origin.

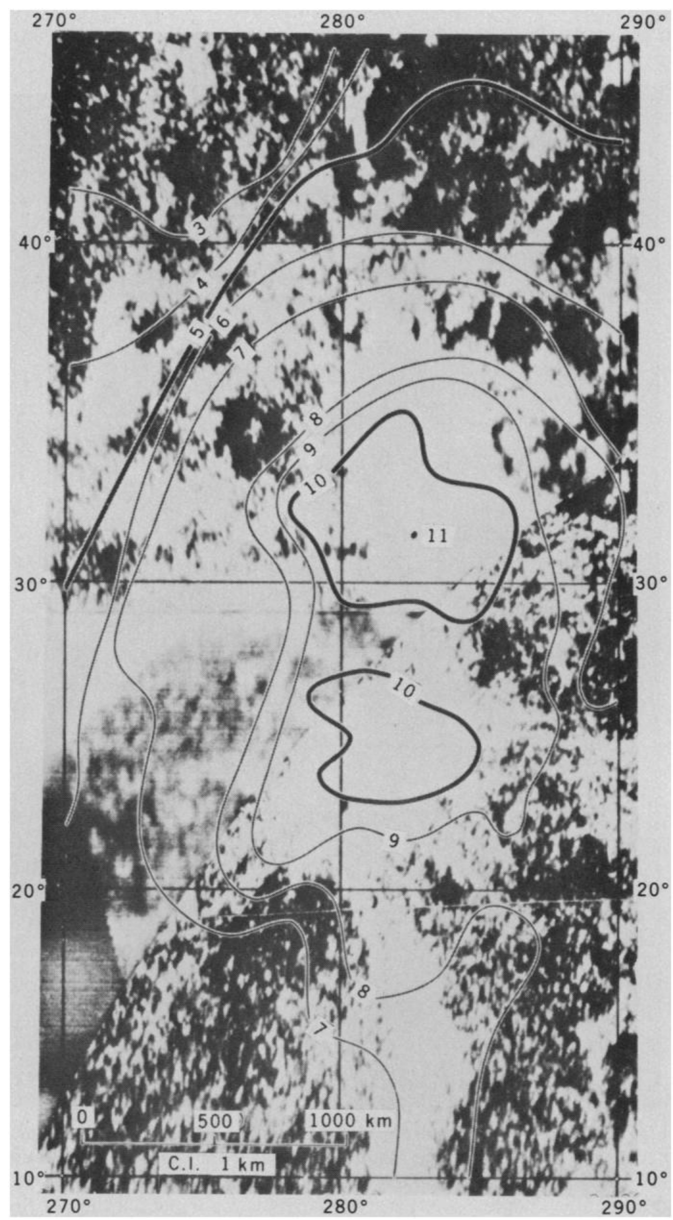

Fig. 2. Contour map of the Beta Complex drawn from Earth-based radar images obtained by Campbell at Arecibo (*8*) and by Goldstein at the Jet Propulsion Laboratory (*4*), with topographic contours (6045-km reference radius) derived from orbital altimetric data. Latitude is given vertically at left and longitude, along the top and bottom. The areas of positive relief may be complex volcanic features that were extruded along a fault zone.

ness, which produces a diffuse radar echo visible at large angles of incidence.

The radar-bright feature Maxwell is a ridge rising about 6 km above a broad plateau that, in turn, stands 3 to 5 km above the surrounding lowlands. An internal "grain," visible in a specially enhanced ground-based reflectivity image (*3, 7*), is parallel to the northwest-southeast elongation of Maxwell. Even at the low resolutions obtained by the Pioneer Venus altimeter, Maxwell is a topographically complex feature. A broad terrace interrupts the steep southwestern margin, a spur ridge extends northeastward from the main ridge crest, and a large, radar-bright, elevated "tail" extends for about 600 km westward from the main body (Fig. 1).

West of Maxwell is a large, radar-dark, pear-shaped feature (Fig. 1) that was tentatively identified as a basin because of its rimmed appearance when first observed in 1975 (*3*). The Pioneer Venus altimetric data now reveal it to be a plateau which stands 3 to 5 km above the lower terrain to its south and west. Surmounting this plateau are two higher regions: a relatively small, curved ridge approximately 2 km high at its western edge and a broad radar-bright fringe along its northern margin that stands at least 3 km above the plateau. The latter feature may be almost as large as Maxwell.

The pear-shaped plateau appears to be continuous with the plateau surrounding Maxwell. Thus the altimetry defines a huge plateau about 3000 km long, at least 1550 km wide, and 3 to 5 km high that is approximately twice the size of the terrestrial Himalayan Plateau. Rising 3 to 6 km above this plateau are three ridges, the largest of which (Maxwell) is about 500 by 1000 km in extent. This plateau probably was formed by tectonic uplift. The high ridges rising above the plateau may be either volcanic or tectonic in origin; if volcanic, their elongate shapes and internal complexities suggest tectonic control.

Using arguments based on analogy with landforms on Mars and Earth, some geologists have interpreted the isolated radar-bright spots on Venus, like those shown in Fig. 2 (*8*), as large volcanic constructs, probably basaltic shields. The most explicit of these interpretations is that of Saunders and Malin (*9*) dealing with the feature Gauss. The general shapes of Gauss and of its northerly neighbor, Hertz (Fig. 2), and the low slopes of their flank areas, are consistent with this interpretation but do not prove it. Our topographic data indicate that the total relief of Gauss is significantly less than the value of 10 km given by Earth-based data (*9*). The horizontal surface resolution (footprint) of the Pioneer Venus altimetry is too coarse to verify the existence of a "summit caldera" as proposed by Saunders and Malin from the Earth-based images. These images also show a bright streak extending southward from Gauss which our data show to have positive relief. Gauss and Hertz may be volcanoes controlled by a major fault which is linear in their vicinity.

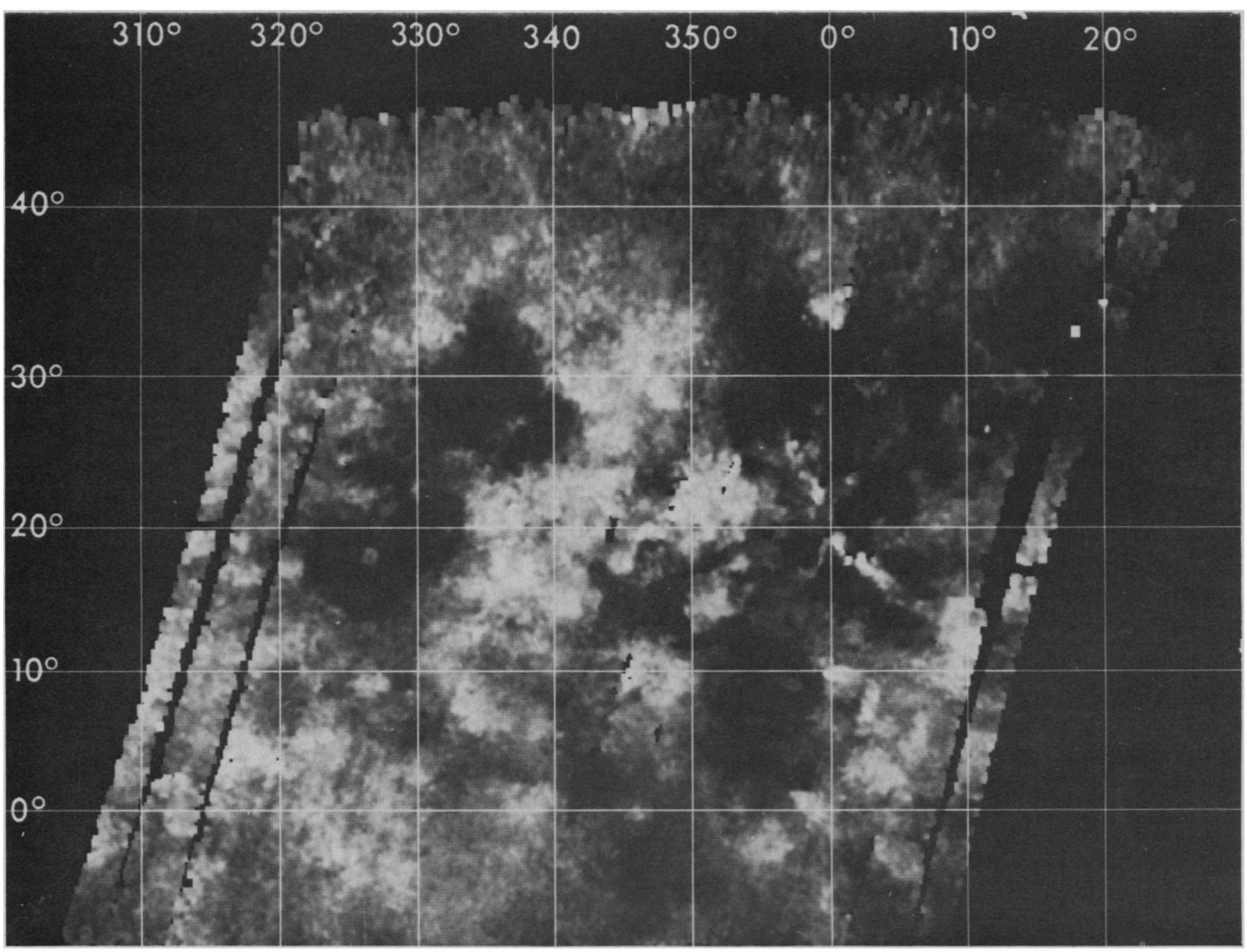

Fig. 3. A Pioneer Venus radar mapper image compiled from data taken on orbits 103 through 141. Latitude is given vertically at left; longitude across the top. The surface resolution varies from 20 to 40 km per image element, being best along 20°N latitude. Several circular features 400 to 800 km in diameter are evident. Associated altimetric measurements indicate that they are depressions; they may be impact basins. However, their depths (500 to 700 m) are very shallow for impact craters of this size.

However, the Beta region becomes more complex to the south where arcuate cusps, convex to the east, break its linear aspect.

Finally, in Fig. 3 we present the first data obtained from the radar mapper operating in the imaging (rather than in the altimetry) mode. These data were obtained on orbits 105 through 141 during periods when the spacecraft altitude was less than 550 km. The image represents a composite of observations taken to the west and to the east of the suborbital surface track on most orbits. The radar image shows dark circular features (for example, 20°N, 331°E; 15°N, 226°E) with bright central spots; these features resemble impact craters 400 to 800 km in diameter. The corresponding altimetry data show shallow depressions 500 to 700 m deep, a shallowness which may result from mobility of the Venus crust. The tentative interpretation of these features as impact craters will be tested in the near future when the spacecraft overflies other similar objects identified as possible impact craters from Earth-based images (*10*).

In summary, the most significant discovery of the Pioneer Venus radar experiment is the strong evidence for tectonic activity. The large plateau is the most spectacular example of this, but the alignment of elevated regions and the elongate shapes of individual ridges also indicate major tectonic control of landforms. Moreover, the Pioneer Venus radar experiment has verified the existence and defined the topography of several large circular depressions that may have an impact origin. And its observations are consistent with a previous interpretation suggesting that at least one radar-bright elevated region may be a large shield volcano.

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11. We thank G. Loriot of Massachusetts Institute of Technology for valuable assistance in preparing many aspects of the digital data-processing programs; we also acknowledge the assistance of R. Apodaca of the Jet Propulsion Laboratory Pioneer Venus navigation team for providing us with timely access to the results of their orbital tracking. F. Schafer of U.S. Geological Survey, Flagstaff, prepared the contour plots. The members of the radar team were supported in part by contracts with the NASA Ames Research Center.

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Gravity Field of Venus: A Preliminary Analysis

Abstract. *The line-of-sight gravity field for Venus has been mapped by tracking the Pioneer Venus spacecraft in the vicinity of periapsis for a 45° swath of longitude eastward of 294°. There are consistent and systematic variations in the gravity signature from orbit to orbit, attesting to the reality of observed anomalies. Orbit 93 passes over a large positive topographic feature, the "northern plateau," for which there is no corresponding gravity signature. If this region has no isostatic compensation, the gravity signal would exceed the noise level by a factor of 7. The results of simulation modeling indicate that the northern plateau must be compensated at depths of about 100 kilometers or less. The long-wavelength anomalies seen in the Venus gravity data have been Fourier-decomposed along the orbital tracks and compared to analogous spectra for Earth. The gross power in the two mean spectra is approximately the same, but systematic variations among the harmonics suggest differences in dynamic processes or lithospheric behavior, or both, for the two planets.*

This report summarizes the gravity field results of the first 30 days of periapsis tracking of the Pioneer Venus orbiter. The spacecraft was placed in near-polar orbit around Venus on 4 December 1978 with the communication link to Earth in the vicinity of the spacecraft periapsis occulted by Venus. During this time and continuing through the present, the spacecraft mean Keplerian orbital elements have been calculated. With a sufficient number of orbits, the time variation of these elements will be used to estimate the low degree and order harmonics of the Venus gravity field; these results will be reported elsewhere (*1*).

In late February the periapsis region became visible from Earth and direct Doppler measurement of spacecraft velocity variations began. This tracking will continue until solar conjunction in August 1979 and will provide information for 210 degrees of longitude. This affords a data type for estimation of the higher-order spherical harmonics of the gravity field as well as for direct mapping (*2*) of the anomalous gravity field when the spacecraft is at altitudes less than 2000 km. Here we report the first results of gravity field mapping and provide preliminary insight on the isostatic compensation of the Venus topography. We also estimate the power in the long-wavelength gravity spectrum of Venus and compare this result to the power spectrum of Earth.

The approach used in reducing the Doppler data to gravity field measurement is precisely that used on the Mars Viking orbiter data (*3*). For each orbit (revolution) of the spacecraft about Venus, 2 hours of Doppler data centered about periapsis were used to estimate the spacecraft position and velocity based on a gravity model with only a central mass term (*4*). All primary planetary perturbations and Earth-spacecraft motions are included in the model; atmospheric parameters were excluded. The velocity residuals from this estimation procedure were spline fit and differentiated to produce line-of-sight (LOS) gravity accelerations, the component of the gravity vector along the direction from Earth to the spacecraft. The individual profiles from each orbit were then aligned geometrically at periapsis to evaluate consistency and obtain a first estimate of the amplitude variations. This is shown in Fig. 1, where the first seven profiles are plotted and show a systematic and consistent variation from orbit to orbit. A single large anomaly with a peak-to-peak variation of 20 to 25 mgal persists throughout

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