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INSIDE

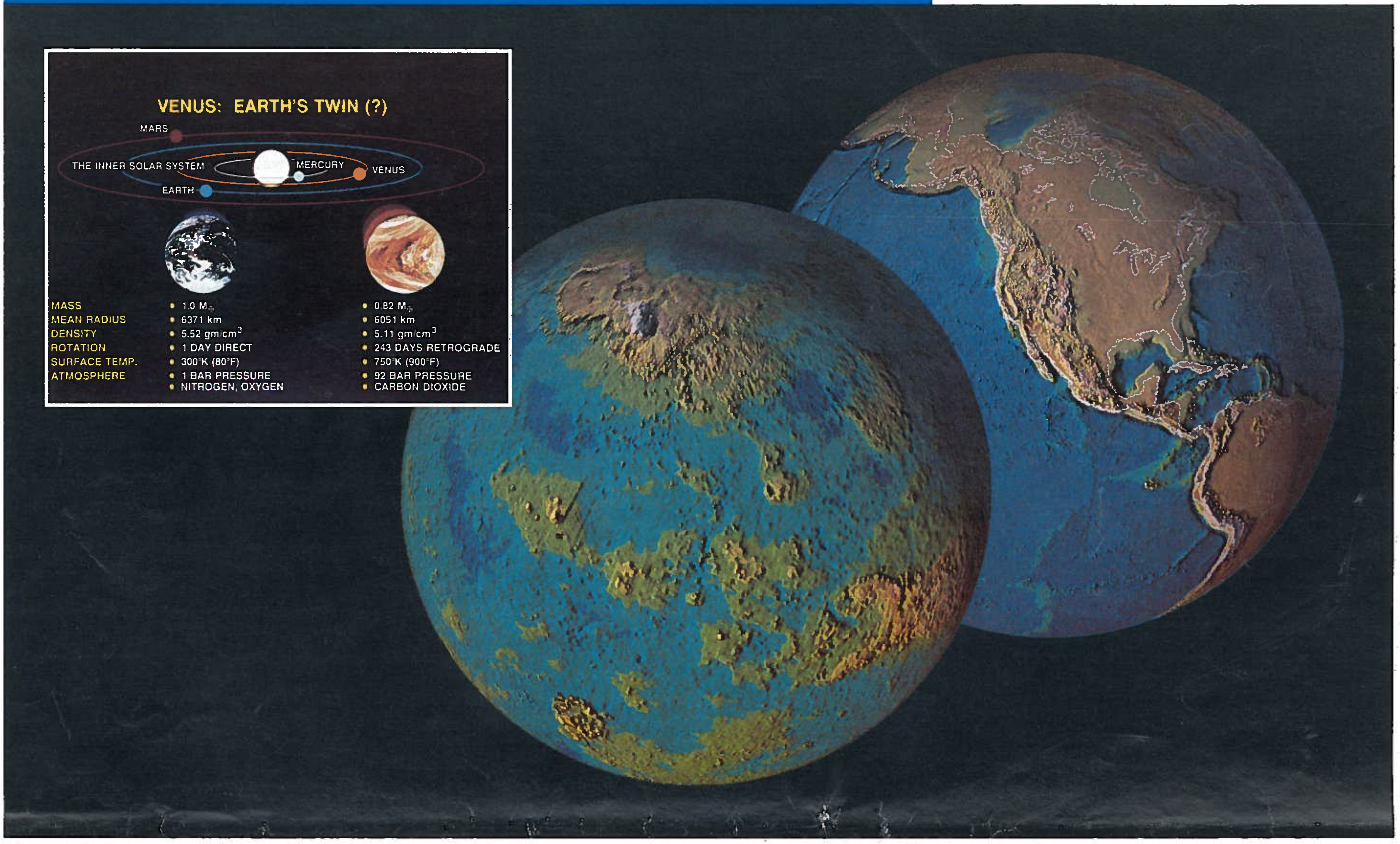

Figure 1. (Upper left) Comparison of major characteristics of Venus and Earth. **Figure 2.** (Right) Computer-generated globes of Venus and Earth. Venus topography is derived from combination of Pioneer-Venus Orbiter altimetry data and Soviet Venera 15/16 altimetry data for northern high latitudes. Darker blue shades are lowest elevations; pink represents highest elevations.

Geology of Venus: A Perspective From Early Magellan Mission Results

James W. Head
Department of Geological Sciences
Brown University, Providence, RI 02912

R. Stephen Saunders
Magellan Project Scientist
Jet Propulsion Laboratory, Pasadena CA 91109

ABSTRACT

The Magellan mission will provide global high-resolution image and altimetry data sets for comparison of geologic processes and history of Venus, Earth, and the smaller terrestrial planets. Images of the first 10%–20% of the surface observed by Magellan show the surfaces to be dominated by volcanic plains, abundant small shield volcanoes similar to seamounts, large local rises capped with volcanic edifices, linear rift zones from which lava flows hundreds of kilometres long emerge, and local steep-sided domes similar in morphology to rhyolite and dacite domes on Earth. Tectonic structures include orogenic belts up to 11 km high, suggestive of extensive crustal shortening and thickening, and a variety of other linear deformation zones showing evidence for shear, shortening, and extension. Circular to elliptical structures 200–1000 km in diameter display concentric zones of deformation and central volcanism, suggesting localized mantle upwelling. The abundance of impact craters is more Earth-like than Moon-like, and the crater ejecta patterns show evidence of fluidized flow. Erosion appears to be of minimal importance relative to Earth because of the lack of water, and the abundance of soils is very low. Where soils exist, there is evidence for eolian activity in the form of streaks and possible dunes. Assessment of global tectonic styles and modes of crustal formation await additional coverage and the acquisition of gravity data.

Introduction

In the past 30 years, exploration of the terrestrial planets has provided us with a perspective on our own planet Earth (Head and Solomon, 1981). Those planetary bodies one-half the diameter of the Earth and smaller (Moon, Mercury, and Mars) are known to be characterized by unsegmented globally continuous lithospheres (one-plate planets), and they have remained largely unmodified since the first third of Solar System history, losing their internal heat by conduction (Solomon and Head, 1982). In contrast to these ancient, relatively unmodified surfaces, Earth presents a dynamic picture of a segmented lithosphere with laterally moving plates and tectonic and volcanic activity linked largely to their creation and destruction. The abundance of water, the significance of aqueous erosion, and the formation of continents also distinguish Earth from these smaller planets. Venus, on the other hand, is very close to Earth in terms of size, density, and position in the Solar System, but it differs in other characteristics, most particularly its atmosphere and surface temperatures and pressures (Fig. 1). What geologic and geophysical processes have formed and modified the surface and interior of Venus, and how do they compare to those of Earth and smaller terrestrial planets? Is Venus Earth's twin, a distant family member, or could it perhaps be similar to Earth as it was sometime in its early history? These are the kind of questions that have motivated the Soviet Union and

Venus *continued on p. 50*

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Venus *continued from p. 49*

the United States to send spacecraft to penetrate the thick continuous cloud cover of Venus to explore and map the surface by means of orbiting radar experiments and landers. The U.S. Pioneer-Venus and Soviet Venera 15/16 missions provided data on the topography of Venus and revealed that it was unimodal in character, in contrast to the bimodal nature of Earth's global topography (Fig. 2). The Soviet spacecraft also provided images of the northern 25% of the planet (Barsukov et al., 1986), and these data, together with images from Earth-based radio telescopes (e.g., Campbell et al., 1989), showed abundant evidence for volcanic and tectonic activity and surfaces with ages that were more Earth-like (less than about 1 b.y. old; Ivanov et al., 1986) than like the smaller planets. These data resulted in numerous local and regional analyses that set the stage for global questions about Venus and its affinities to Earth (Basilevsky, 1990; Basilevsky et al., 1990; Grimm, 1990; S. C. Solomon and J. W. Head, in preparation).

In response to the obvious need for global coverage with high-resolution images, NASA launched the Magellan spacecraft, which was inserted into orbit around Venus in August 1990, and began systematic global mapping on September 15, 1990. The major instrument on board the spacecraft is a synthetic aperture radar (Saunders et al., 1990; G. H. Pettengill et al., in preparation) that provides images at 120–300 m, considerably better than those obtained previously (Fig. 3). Analysis of the data is being carried out by an international team of scientists from many different institutions.[1] Data returned in the early part of the mission have provided an unprecedented view of the surface. In this article, we describe some of the features and processes that have been revealed.

Volcanic Features

That volcanism is a dominant process in the formation and modification of the surface of Venus is being confirmed by Magellan (Head et al., in preparation). Volcanic plains with a wide variety of surface characteristics make up over 80% of the planet observed thus far. Radar-bright (rough) units with associated flow lobes are seen superposed on dark (smoother) flow units (Fig. 4A; *Note: Figures 4–15 are on p. 58–59*), indicating stratigraphic relations and local sequences of buildup of the volcanic plains. Elsewhere, dark flow units emerge from fractures in the plains, flow downslope, and pond locally in adjacent lows (Fig. 4B). Thousands of small shield volcanoes, generally 2 to 8 km in diameter, with associated summit pits are observed in the plains; local concentrations are quite high (Fig. 4C). These features are similar to terrestrial seamounts and small shields on Hawaii and Iceland. Here too, the sources of the small shields are often linked to structure in the plains, being both superposed on and cut by regional fractures and grabens. Other centers of volcanism are marked by 2–10-km-diameter caldera-like structures with varieties of shapes (Fig. 4D) and evidence for several stages of subsidence and filling (Fig. 4E).

Narrow, sinuous channels about 0.5–1.5 km wide and extremely constant in width have been discovered by Magellan in the volcanic plains of Venus. These sinuous channels commonly do not show evidence for associated flow lobes or lava-flow deposits, and some of them appear to empty into low-lying areas to form widespread plains deposits. In one example (Fig. 4F), a sinuous radar-dark band about 0.75–1.5 km wide extends for hundreds of kilometres and is linked to a fan-shaped area of dark volcanic plains at one end. Details of the rille show what appear to be radar-bright levees and local "breakouts," where the dark material flowing in the interior of the rille has broken through the levees and spilled out to form a new channel. These characteristics are very similar to sinuous rilles on the Moon which are interpreted to have formed when very low viscosity lava or lava emerging at very high effusion rates becomes turbulent and thermally erodes and incises a channel into the preexisting plains deposits. If these structures are of similar origin, the higher surface temperatures on Venus may enhance thermal erosion processes.

In some places volcanism is locally concentrated and edifices have been constructed (Fig. 5A). Sif Mons, a volcano some 225 km in diameter is located on Western Eistla Regio, a broad rise in the Venus equatorial region more than 2000 km across. The volcano itself is characterized by hundreds of radial flow units, which build up an edifice about 1.7 km above the top of the rise. Some of the flows emanating from the vicinity of the summit extend downslope for more than 300–600 km, veneering large parts of the rise and locally flooding radial graben-like fractures (Fig. 5B). This collection of features may indicate the presence of a broad mantle upwelling or hot spot beneath Western Eistla Regio.

In contrast to the Sif Mons shield, an extremely large and deep caldera is observed in the highlands of Ishtar Terra in the northern high latitudes. Located in Lakshmi Planum, a broad volcanic plateau surrounded by orogenic belts, Sacajawea Patera is 200 by 300 km in diameter and 1–2 km deep (Fig. 5C). No shield edifice comparable to Sif Mons is observed in either image or altimetry data, and very few flow features are observed on the rim of Sacajawea. The volume of the depression is between 2.4 and 6.3×10^4 km^3, considerably greater than volumes of typical terrestrial calderas. No distinctive single ridge or scarp sharply defines the rim of Sacajawea, and the outer walls are characterized by a wide belt of circumferential, curvilinear grabens, rather than the crests of rotated blocks commonly associated with listric faults on collapsed caldera margins. A rift-zone–like feature extends from the southeast boundary of Sacajawea. Apparently, magma rising from depth reached neutral buoyancy in the upper part of the crust, creating a large magma reservoir. Instead of effusive eruptions contributing to a surrounding edifice as at Sif Mons, magma was predominantly intruded laterally along dikes into the preexisting crust. Continued lateral intrusion caused subsidence of the rim, characterized by broad downwarping which resulted in an annulus of graben structures.

The very high surface atmospheric pressure on Venus will serve to inhibit the exsolution of volatiles as magma rises in the crust. Theoretical calculations (Head and Wilson, 1986) suggest that unless the volatile content exceeds about 2–4 wt%, explosive disruption of the rising magma in the vent will not be favored, and Hawaiian-style pyroclastic activity will probably not occur. In spite of this, there is some evidence for pyroclastic deposits. Dark fragmental materials appear to mantle heavily fractured volcanic plains (Fig. 6) in a few areas. Bright wedge-shaped exposures of underlying plains appear to extend away from small vent-like features within the mantling deposits. These generally are oriented in the same direction and are interpreted to be places where regional Venus winds have encountered areas of local surface roughness (the vent-like areas) causing local turbulence and the sweeping clean of fragmental pyroclastic deposits downrange.

Most volcanic landforms and deposits seen in pre-Magellan image data were interpreted to be related to

Venus *continued on p. 57*

Figure 3. Comparison of resolution of Magellan radar images with previous Venus imaging systems. Magellan resolution is 120–300 m, Venera 15/16 resolution is 1–2 km, and Pioneer-Venus Radar image resolution is 20–70 km. Resolution is simulated using Seasat image of Mount St. Helens.

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[1] Raymond E. Arvidson, Washington University; Victor R. Baker, University of Arizona; Alexander Basilevsky, USSR Vernadsky Institute of Geochemistry; Joseph H. Binsack, Massachusetts Institute of Technology; Joseph M. Boyce (Magellan Program Scientist), National Aeronautics and Space Administration; Donald B. Campbell, Cornell University; Merton E. Davies, RAND Corporation; Charles Elachi, Jet Propulsion Laboratory; John E. Guest, University of London; James W. Head III, Brown University; William M. Kaula, University of California, Los Angeles; Kurt L. Lambeck, Australian National University; Franz W. Leberl, Vexcel Corporation; Dan P. McKenzie, Cambridge University; Barry E. Parsons, Oxford University; Gordon H. Pettengill (RADIG Principal Investigator), Massachusetts Institute of Technology; Roger J. Phillips, Southern Methodist University; R. Keith Raney, Canada Centre for Remote Sensing; R. Stephen Saunders (Magellan Project Scientist), Jet Propulsion Laboratory; Gerald G. Schaber, U.S. Geological Survey, Flagstaff; Gerald S. Schubert, University of California, Los Angeles; Laurence A. Soderblom, U.S. Geological Survey, Flagstaff; Sean C. Solomon, Massachusetts Institute of Technology; Manik Talwani, Houston Area Research Center; G. Leonard Tyler, Stanford University; John A. Wood, Smithsonian Astrophysical Observatory; Alexander Zakharov, USSR Institute of Radio Engineering and Electronics.

SAGE REMARKS

Allison R. (Pete) Palmer

Opportunities for Partnering—Check Your ZIP Code

We are beginning to receive some Partners for Excellence application forms in the mail from teachers interested in partners. Until we get our partnering database set up, I will use this column to attempt to find partners for these teachers. Teachers in the following ZIP code areas would like to find partners. If your ZIP code matches the first 3 digits and you want to partner, let me know and I'll put you in touch with the teachers.

Northeastern Section	
Delaware	19810
North-Central Section	
Wisconsin	53220
Illinois	60137
Illinois	60634
Missouri	63010

Southeastern Section	
Virginia	24038
Alabama	35405
Cordilleran Section	
Nevada	89015
California	90056

More on Creationism

The following thoughtful opinion was sent in by E-An Zen as an extension to my remarks in my column last June. (I also received some comments from some of my geological old-Earth creationist colleagues, to whom I've responded individually.)

> "If scientists construct a wall that cuts off meaningful communication with the creationists, we can expect a wall constructed against scientists in return. Polarization does not promote understanding. As scientists, we assume that the origin and working of the physical universe can be comprehended only with inferences ultimately based on observations of nature; we do not accept or tolerate the idea of possible intercession in the workings of the universe by supernatural causes. I believe this is a good and valuable working assumption, but I must not forget that it is only an assumption. While we can corroborate its usefulness in individual cases, we have no way to independently verify its general validity and thereby to exclude other views of how the universe works.
>
> "Creationists, both the "young Earth" type who insists on a literal reading of the Bible, and the "old Earth" type who accepts the antiquity of the Earth and the universe but thinks Divine or Intelligent Guidance gave rise to life as we know it, challenge the exclusivity of the scientists' basic assumption. Obviously, we cannot refute their viewpoint logically by our assumption. The "young Earth" creationists damage their own credibility when they selectively reject or accept facts (e.g., accept the Second Law of Thermodynamics but reject the constant rate of decay of radioisotopes), or torture the data to fit preconceptions (e.g., misinterpret the rock records to conform to the Noachian flood story). While we rightly deplore these affronts, we would be committing comparable affronts if we extrapolate scientific inferences to areas of human knowledge where they are invalid (e.g., to claim that our observations prove that there is no God). Realization that our work is founded on an unprovable assumption, that is, on faith, should make us humble, and make us listen as well as propound.
>
> "As scientists, we might prefer everybody to see the world the way we do, but the goal of education should not be philosophical conformity. Rather, it should initiate interactive discourse, however bizarre we think the other viewpoints are. Aside from practical, functional literacy, a main goal of science education should be to understand what the scientific method is all about. The splendor of science lies in our method. Scientists are generous to a fault: we deliberately invite the world to examine our hypotheses and find fault with them (i.e., falsify them). Creationists are exercising that prerogative at a very basic level; if we keep our minds open, we stand to benefit from this debate because the creationists can provide us with a different, challenging if jarring, mirror with which to view ourselves."
>
> *E-an Zen*

Mind Boggles

Many topics related to the Earth and some of the issues that we talk about can be developed from a base of mind boggles. Deep time is one of the most important and was dealt with in our video "The Earth *Has* a History." Here are a few more that have come to mind. If you have any good ones, let me know.

- Do you realize that a global population growth rate of only 0.2%/year (not quite ZPG) will result in an octupling of the world population in about 1050 years? A similar span of time the other way gets us not quite back to the time of Mohammed. Who wants eight times the present garbage or traffic?
- How many students realize that the K/T bolide, when scaled to the size of your 16" office globe, would approximate a grain of silt? It's amazing what that little silt grain may have accomplished.
- How many students realize that the roughness of the paper on that same 16" globe is comparable to the relief on Earth's surface scaled to this size. In a cosmic sense, getting to the top of Mt. Everest isn't getting very far.
- How many students realize that the 10 km K/T bolide would have gone only half-way under water in most of the world's oceans before striking bottom? Not unlike a pebble in a puddle.
- How many students realize that the "cataclysmic" collisions of plates take place at rates similar to fingernail growth rates, and those are fast geologic rates. Remarkably, though, tectonics is far from boring. ■

Venus *continued from p. 50*

basaltic volcanism. Magellan data have revealed some structures and edifices with characteristics that suggest the presence of magmas with higher effective viscosities and/or more acidic compositions. A group of seven steep-sided volcanic domes located east of Alpha Regio (30°S, 11°–13°) show these characteristics (Fig. 7). Each of the domes is about 25 km in diameter and hundreds of metres high, and relatively flat-topped. The steep slopes are very rough and have radial fractures, and the summit is characterized by a polygonal network of concentric and radial fractures and small grabens and by central craters. The general morphology of these domes is very similar to extrusive domes of viscous magmas (rhyolitic, dacitic, andesitic) seen on Earth in association with continental volcanism and large calderas (e.g., Mono Lake, California; Valles, New Mexico). Terrestrial domes are characterized by both endogenous activity (magma intruded internally, causing expansion and growth of the dome) and exogenous activity (breakthrough of flows or small extrusions, and explosive activity due to gas buildup), and both types of activity are seen on the Venus domes. The relatively large diameters of these domes may be due to the high surface temperatures on Venus, which would retard cooling of extruded magma and enhance radial flow distance. At present, it is not known if these represent more acidic compositions and, if so, whether such compositions represent a major component of the crust of Venus.

Tectonic Features

A wide variety of tectonic activity disrupts the abundant volcanic deposits and edifices on Venus (S. C. Solomon et al., in preparation). Some areas of volcanic plains are completely laced by polygonal faults and fractures (Fig. 6), and in some places they are extremely regular and essentially orthogonal in orientation (Fig. 8), almost resembling a perthitic texture. In this example, the fainter lineations are spaced about 1 km apart and are less than a few hundred metres wide. The orthogonal set is brighter, wider, more irregular, and slightly more widely spaced, and appears more dominant. Several members of this set appear to be flat-floored grabens. The origin of such widespread regular deformation is not known.

In other places, deformation is concentrated in linear belts rather than distributed throughout the plains. One type of linear deformation belt is characterized by ridges and broad arches. In the example shown in Figure 9, the smooth volcanic plains are disrupted by north-northwest–trending narrow ridges and a broad arch about 5 km wide. These features are very similar to ridges and arches formed in the lunar maria during loading and subsidence, and they represent small amounts of crustal shortening and buckling. Other linear deformation belts are characterized by narrow parallel and anastomosing fractures and grooves that appear to be of extensional origin. One example (Fig. 10) shows three such belts of features, each separated by about 25 km. The two scales of deformation may be linked to brittle deformation of the upper part of the crust (small features), and broader scale deformation of deeper crustal materials (the belts themselves).

The presence of large circular features on Venus known as corona was revealed by Venera 15/16 and Arecibo images (Pronin and Stofan, 1990). These features, 200 to 1000 km in diameter, are characterized by an annulus of ridges, an exterior moat sometimes filled with lava flows, and interior deformation and volcanism. They are thought to represent the surface manifestation of mantle upwelling (perhaps hot spots). Such a feature may be more readily distinctive and visible on Venus because of the higher surface temperatures and a relatively thinner outer rigid layer there. Magellan data revealed significant details of Quetzalpetlatl, an 800–1000-km-diameter corona in northern Lada Terra seen first in Arecibo data (Fig. 11A). The central part of the corona is seen to be a distinctive volcanic caldera, 150 km wide, 200 km long, and 400 m deep, with a family of associated domes, small shields, and cones (Fig. 11B).

Perhaps the most spectacular tectonic features known on Venus are the orogenic belts of Western Ishtar Terra. These are known from pre-Magellan data to be as much as 1000 km long, several hundred kilometres wide, and more than several kilometres in elevation, and were interpreted to be characterized by folds, low-angle thrusts, and strike-slip faults (Crumpler et al., 1986). The high-resolution Magellan data reveal complex structure within the mountains, particularly showing evidence for extensional deformation superposed on the structure of the mountain belts. One prominent example is seen along the eastern margin of Freyja Montes, a mountain belt at the northern edge of Western Ishtar Terra (Fig. 12). Here, the higher parts of the mountains (a region about 70 × 125 km) are laced with 1–5-km-wide graben. Some graben are parallel to the crest of the mountain, while others are parallel or subparallel to the surrounding slopes. Along the lower flanks of the high region, large- and small-scale folds and thrusts dominate. This collection of features is consistent with gravitational collapse of the mountains.

One of these belts, Maxwell Montes, rises up to 7 km above the adjacent plains and 11 km above mean planetary radius. In Figure 13, the westernmost edge of the radar-bright Maxwell and the distinctive ridges that make up much of the mountainous terrain are visible. The ridges are thought to be of compressional origin, and adjacent to the western edge of Maxwell, the dark volcanic plains of Lakshmi Planum are seen to be deformed in parallel ridge–like fashion. Maxwell Montes is asymmetric in cross section. This side of the mountain is one of the steepest slopes yet known on the planet, with elevations rising several kilometres over a distance of less than 100 km. The presence of these mountains and the implied crustal thickening suggests significant crustal shortening localized along these zones, although the mechanisms of formation and the amount of shortening are not known. The fact that they maintain such high elevations strongly suggests that the forces that formed them have been active in the recent past and perhaps are still active today.

Impact Features

On the eastern slope of Maxwell Montes near the crest is a 100-km-diameter circular feature, known as Cleopatra, that is 2.5 km deep (Fig. 14). Previous data could not resolve conclusively whether Cleopatra was of impact (Basilevsky and Ivanov, 1990) or volcanic (Schaber et al., 1987) origin.

Venus *continued on p. 60*
Figs. 4–15 on p. 58–59

Views of Venus

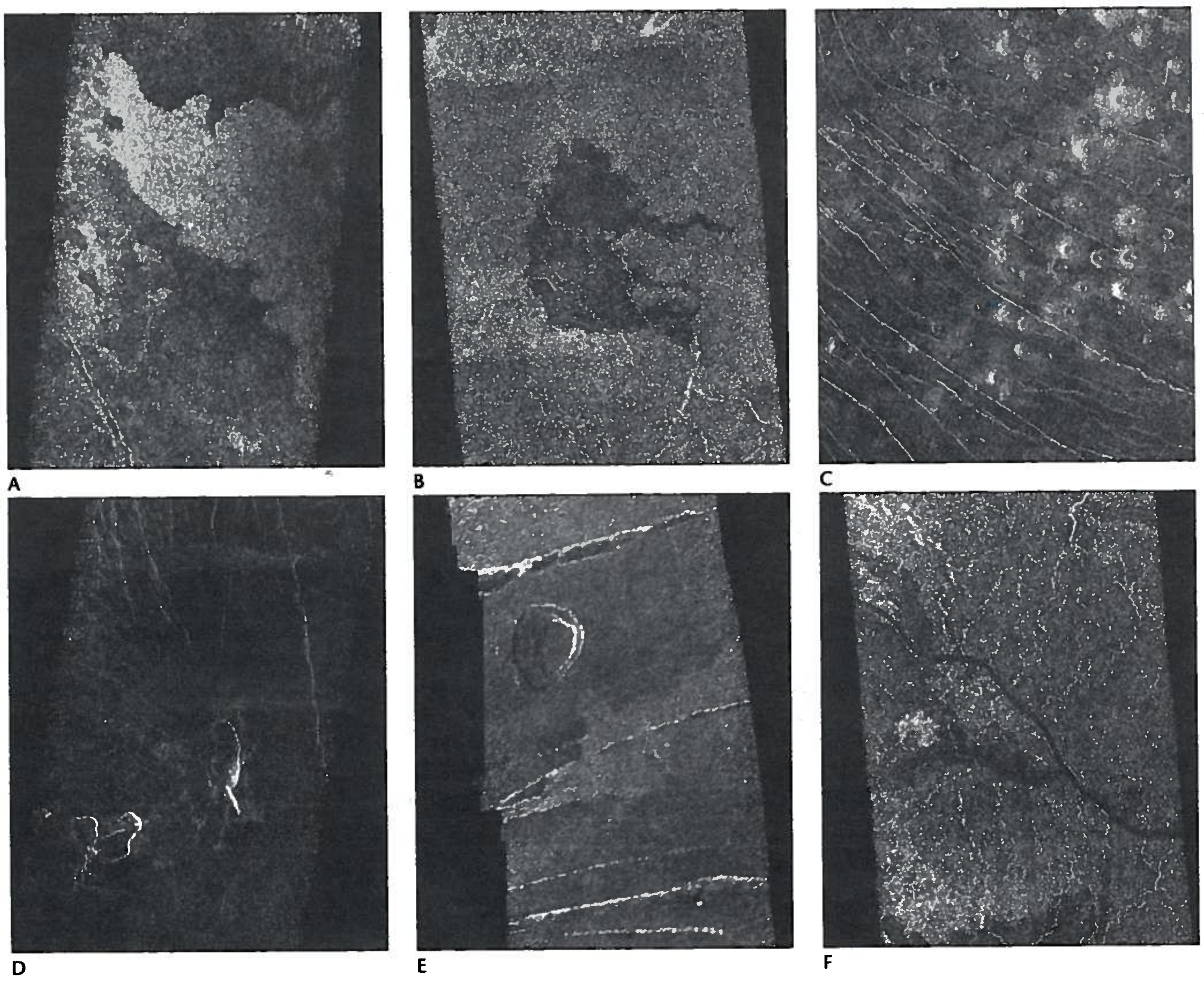

Figure 4. A: Radar-bright (relatively rough) lava flow superposed on radar-dark plains near Phoebe Regio (291°, 20°S). Width of image is 30 km. B: Radar-dark (relatively smooth) lava flows emerging from several sources along a fracture (bright, discontinuous line) and coalescing and ponding in adjacent low part of plains in southern Guinevere Planitia (331.8°, 4.6°N). Width of image is 45 km. C: Field of small shield volcanoes in Guinevere Planitia (330°, 35°N). Most of the shields are 3–8 km in diameter and have distinctive summit pits. D: Irregular-shaped caldera-like feature in Phoebe Regio (292°, 24°S) 8 km long and 3.6 km wide. Kidney-shaped depression is surrounded by volcanic plains. E: Irregular depression located in northern Lada Terra and interpreted to be caldera (356°, 68.7°S). Structure is 8 km by 10 km in dimension and contains an inner steep-sided depression, suggesting several phases of magma filling and withdrawal. F: Radar-dark sinuous channel extending across parts of Navka Planitia (335°, 14.5°S). Channel is 1–2 km wide and has narrow bright margins in some places, suggesting levees. In central part of image, dark material appears to have broken out of channel and flowed to west. Irregular radar-bright lines in plains are parts of patterns of fracturing and deformation.

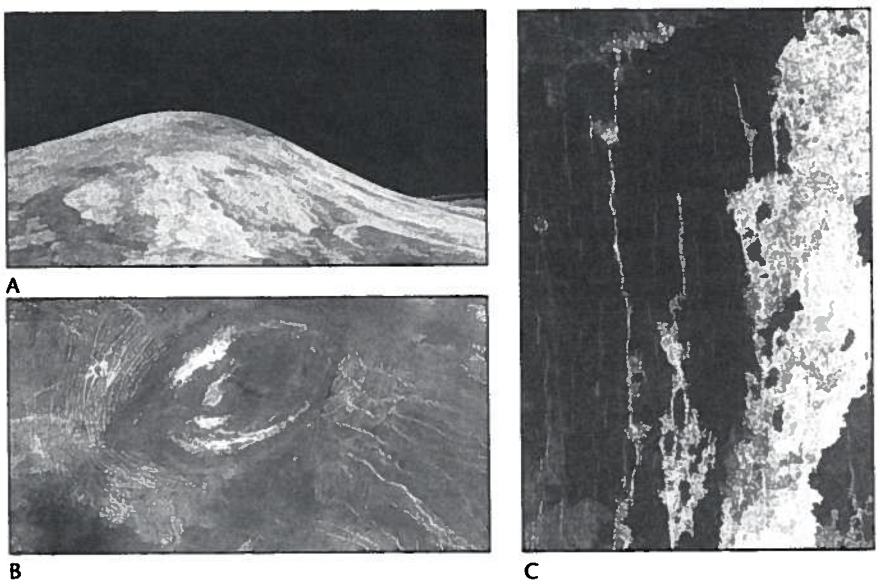

Figure 5. A: Perspective view of summit of the 225-km-wide and 1.7-km-high volcano Sif Mons (352°, 23°N), viewed from northeast. Radar-bright flows stream from summit region and veneer surrounding flanks of Western Eistla rise.
B: Details of lava-flow units trending north, down northern slope of Western Eistla Regio. Radar-bright (relatively rough) flows emerge from vicinity of summit region of Sif Mons and extend hundreds of kilometres downslope across variety of volcanic plains units. Locally, flows have been captured by narrow grabens for distances in excess of several hundred kilometres. Width of image is 55 km.
C: Sacajawea Patera, large elongate caldera located in Western Ishtar Terra on smooth plateau of Lakshmi Planum (337°, 65.5°N). Sacajawea is 200 by 300 km in dimension and 1–2 km deep and is surrounded by concentric grabens and rift-like zone to southeast. Width of image is about 420 km.

Figure 6. Intensely fractured plains northeast of Ushas Mons (near 330°, 20°S) and superposed dark mantle of fragmental material. Small bright spots are probable source vents, and bright patches near them are believed to represent fragmental material being removed by wind erosion. Width of image is 40 km.

Figure 7. Seven steep-sided, flat-top
edge of Alpha Regio (11.8°, 30°S). Ea
are very similar to terrestrial rhyolitic
ture and morphology suggest that th
relatively high effective viscosity and/

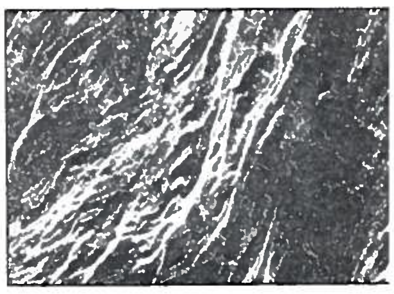

Figure 10. Three parallel belts of na
Planitia (340.4°, 41.4°S). Belts are al
troughs from 200 m to 3 km wide,

Figures 4–15 from "Geology of Venus:
A Perspective From Early Magellan Mission Results"
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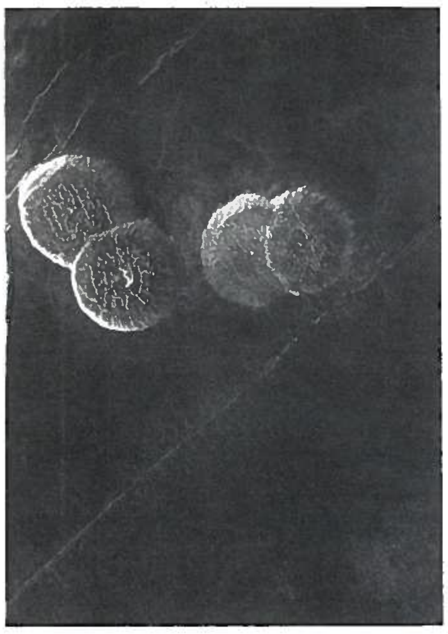

d domes located in plains near eastern dome is about 25 km in diameter. They d dacitic domes, and their surface struc- are formed by extrusion of magma with more acidic composition.

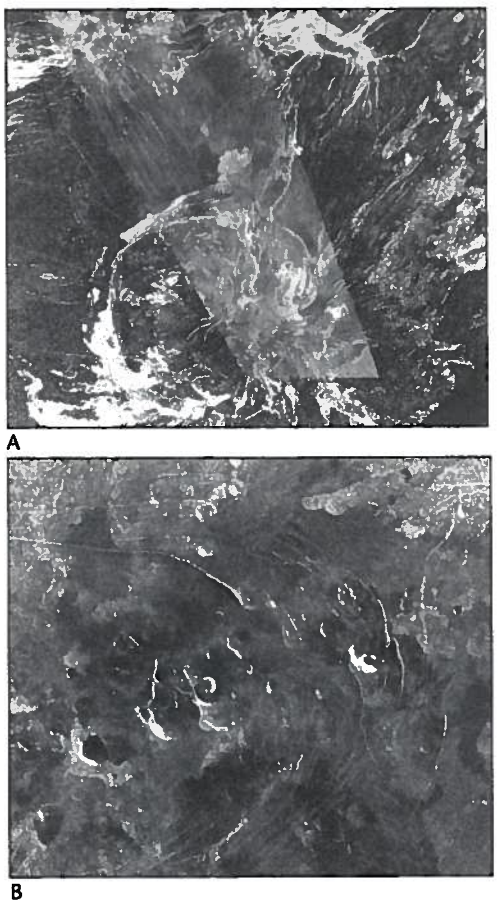

Figure 11. A: Quetzalpetlatl corona (355°, 68°S) in northern Lada Terra. This composite image was created by inserting new Magellan data into an Earth-based image obtained at Arecibo Observatory in Puerto Rico in 1988. Outer deformed annulus is developed in northern part of corona, and lava flows flood adjacent parallel depression in northwest. Width of corona is more than 800 km. B: Caldera-like region in southeast part of Quetzalpetlatl corona (355°, 68°S) in northern Lada Terra. Numerous domes, volcanic shields, and associated flows are visible within and adjacent to caldera fractures. Width of image is about 200 km.

Figure 12. Faulted and folded mountains of Eastern Freyja Montes in Western Ishtar Terra (342°, 72°N). Width of image is about 125 km.

Figure 8. Gridded volcanic plains in Guinevere-Sedna region (333.3°, 30°N). Two sets of fractures have different characteristics and are oriented nearly orthogonally. Width of image is 37 km.

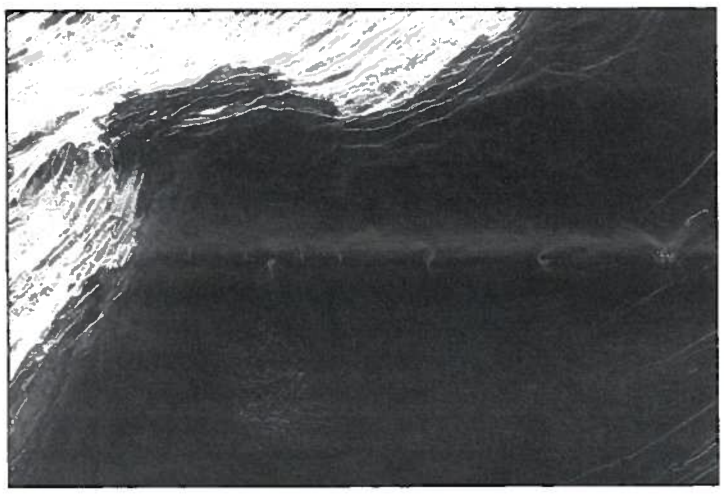

Figure 13. Western edge of Maxwell Montes (bright area in eastern part of image) showing parallel ridges and troughs interpreted to represent compressional deformation in this orogenic belt (358°, 65°N). Adjacent dark volcanic plains of eastern Lakshmi Planum are also deformed. Maxwell Montes rises more than 7 km from base to summit less than 200 km to the east. Series of arcuate troughs 10–40 km wide are seen along southwest part of image. Width of image is 300 km. North is right.

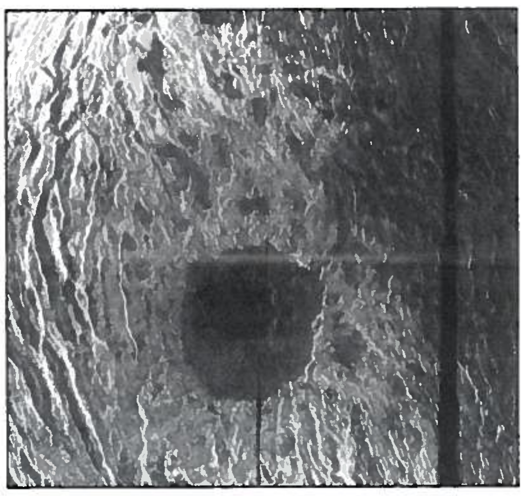

Figure 14. Cleopatra, 100-km-diameter double-ringed crater located near summit of Maxwell Montes, highest mountain belt on Venus (10°, 66°N).

Figure 9. Belt of narrow ridges and broad arches in Lavinia Planitia (337.9°, 36.4°S). These features are similar to mare ridges on Moon and represent modest levels of crustal shortening. Width of image is 37 km.

w fractures and troughs located in Lavinia t 25 km apart and composed of narrow gesting extensional deformation.

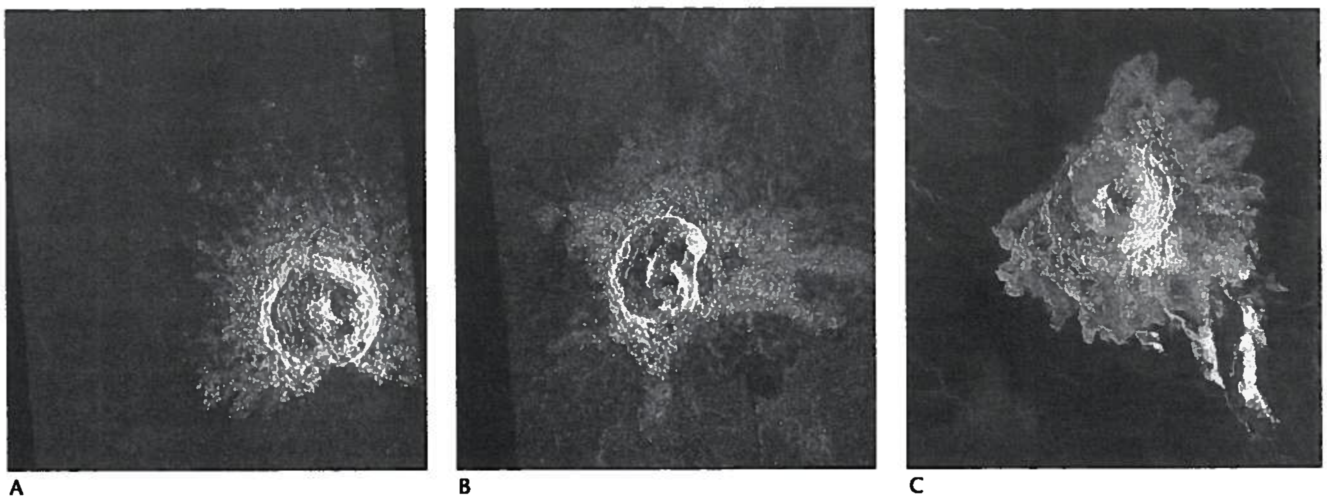

Figure 15. A: Impact crater 12.5 km in diameter located in Guinevere Planitia (335°, 6°N). Asymmetric ejecta pattern suggests oblique impact of crater-forming projectile. B: Irregular impact crater about 9 by 12 km, located in Navka Planitia (334.5°, 21.4°S). Multiple depressions in interior suggest that projectile broke up in dense Venus atmosphere and created simultaneous cluster of small impacts. C: Crater Aurelia (331.8°, 20.3°N), about 31 km in diameter. Note asymmetrical radial lobate ejecta pattern, and bright flows that extend from the southeast part of continuous ejecta deposit.

Venus *continued from p. 57*

Magellan data show details of ejecta deposits on the rim of the double-ringed structure and burying surrounding terrain, supporting the interpretation that the double-ringed crater is of impact origin. However, dark deposits within the inner ring appear to have exited the crater through a breach in the northeastern part of the rim and flowed through a channel, flooding the adjacent ridges along the low parts of the mountain flanks. Such dark material could be impact melt or volcanic material linked to the formation of the impact itself. It is perhaps an odd coincidence that such a large impact is situated near the highest point on the planet on what must be one of the youngest mountains on Venus.

Impact craters are also seen elsewhere on Venus; they have a range of surface morphologies in both their interiors and exteriors (R. J. Phillips et al., in preparation). Craters larger than about 10 km in diameter (Fig. 15A) show features (central peaks, wall terraces, hummocky rims, and radial ejecta) that are similar to those associated with fresh impact craters on the Moon, Mercury, and Mars. In many cases, there are distinctive asymmetries of ejecta (Fig. 15A) which suggest that the projectiles hit the surface at oblique angles. Many of the craters smaller than about 10 km are characterized by a complex interior that appears to represent the impact of several projectiles simultaneously (Fig. 15B). These clusters are interpreted to represent the impact of a family of smaller projectiles derived from a larger bolide that broke up as it encountered the very dense atmosphere of Venus.

Larger craters show evidence for distinctive, bright flow-like features extending tens to hundreds of kilometres from the distal parts of their ejecta deposits. The crater Aurelia, about 31 km in diameter (Fig. 15C), shows an asymmetrical ejecta deposit and distinctly lobate ejecta. Two large flow-like features extend for 45–75 km beyond the continuous deposit and are diverted by local structure. The origin of these flows is controversial, but they may be due to flows of impact melt, nuée ardente–like flows of very fine grained ejecta and incorporated atmosphere, or to other factors.

The number of impact craters can be used to estimate the age of the surface, and the size and frequency distribution of craters revealed so far by Venera 15/16, Arecibo Earth-based, and Magellan data are consistent with the surface ages being variable and less than about 800 Ga.

Erosional Features

Erosional and depositional processes do not seem to be significant on Venus (R. A. Arvidson et al., in preparation). Eolian and mass-wasting transport processes appear not to be significant, particularly because of the lack of sediment supply. In a few regions, distinct wind streaks, resembling those seen in some desert regions of Earth, are seen in the lee of topographic obstacles. Mapping of wind streaks may reveal regional patterns of surface winds on Venus. Evidence for erosion and local transport is seen near local sources of sediment, such as adjacent to fault scarps and impact crater ejecta deposits. On Earth's Moon, the lack of an atmosphere emphasizes the role of micrometeorite bombardment in comminuting rocks and producing a soil layer or regolith. On Earth, the atmosphere screens out micrometeorites, and aqueous physical and chemical processes dominate. On Venus, the dense atmosphere screens out micrometeorites, and the constant high temperatures and lack of water on the surface mean that rocks are not subject to freeze-thaw cycles and aqueous physical and chemical erosion processes as on Earth. Tectonic and volcanic structures and sequences of events are thus remarkably well preserved on Venus, and this will allow study of important processes and relations that are commonly eroded and obscured on Earth.

Discussion

At this point, we have just begun to see the new world of Venus as revealed by Magellan. It is as if we have been studying and classifying hand samples of rocks for several years, and then suddenly we are introduced to the microscope and thin sections. In the coming months, as we build up a global view of the planet at high resolution, we will be working to understand the implications of the details of the images for the nature of geologic processes such as volcanism, tectonism, and impact cratering. At the same time, we will be completing regional geologic maps of the surface (R. S. Saunders et al., in preparation), which will be combined to develop a global view of the distribution of volcanoes, linear deformation zones, orogenic belts, and terrains of different ages. At this point we will be in a position to begin the assessment of global tectonic and volcanic styles and to view the ways in which these link to mantle processes and patterns of mantle flow. In the coming months and years, the global geology of Venus will finally emerge from beneath the clouds, and we will begin the fundamental global comparison of the two largest terrestrial planets.

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References Cited

Barsukov, V.L., and 29 others, 1986, The geology and geomorphology of the Venus surface as revealed by the radar images obtained by Veneras 15 and 16: Journal of Geophysical Research, v. 91, p. D378–D398.

Basilevsky, A.T., 1990, Vital problems of Venus geology: Outlook for their resolution by Magellan and post-Magellan missions: Earth, Moon and Planets, v. 50/51, p. 1.

Basilevsky, A.T., and Ivanov, B.A., 1990, Cleopatra Crater on Venus: Venera 15/16 data and impact/volcanic origin controversy: Geophysical Research Letters, v. 17, p. 175.

Basilevsky, A.T., Head, J.W., Pettengill, G.H., and Saunders, R.S., eds., 1990, Geology and tectonics of Venus: Earth, Moon and Planets, v. 50/51.

Campbell, D.B., Head, J.W., Hine, A.A., Harmon, J.K., Senske, D.A., and Fisher, P.C., 1989, Styles of volcanism on Venus: New Arecibo high resolution data: Science, v. 246, p. 373–377.

Crumpler, L.S., Head, J.W., and Campbell, D.B., 1986, Orogenic belts on Venus: Geology, v. 14, p. 1031.

Grimm, R.E., ed., 1990, Magellan arrives at Venus: Geophysical Research Letters, v. 17, p. 1335.

Head, J.W., and Solomon, S.C., 1981, Tectonic evolution of the terrestrial planets: Science, v. 213, p. 262.

Head, J.W., and Wilson, L., 1986, Volcanic processes and landforms on Venus: Theory, predictions, and observations: Journal of Geophysical Research, v. 91, p. 9407.

Ivanov, B.A., Basilevsky, A.T., Kryuchkov, V.P., and Chernaya, I.M., 1986, Impact craters of Venus: Analysis of Venera 15 and 16 data: Journal of Geophysical Research, v. 91, p. D413.

Pronin, A.A., and Stofan, E.R., 1990, Coronae on Venus: Morphology, classification, and distribution: Icarus, v. 87, p. 452.

Saunders, R.S., et al. 1990, The Magellan Venus radar mapping mission, Journal of Geophysical Research, v. 95, p. 8339.

Schaber, G.G., Kozak, R.C., and Masursky, H., 1987, Cleopatra Patera on Venus: Venera 15/16 evidence for a volcanic origin: Geophysical Research Letters, v. 14, p. 41.

Solomon, S.C., and Head, J.W., 1982, Mechanisms for lithospheric heat transport on Venus: Implications for tectonic style and volcanism: Journal of Geophysical Research, v. 87, p. 9236. ■

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