# A MATTER OF

For two years, the radar eyes of the Magellan spacecraft have revealed the cloud-bedecked face of Venus in extraordinary detail: massive volcanoes, mountains higher than Mt. Everest, a random assortment of craters, and a broad brushstroke of lowlands.

But how did the planet's tallest mountain form? What holds up the highlands and what shaped the lowlands? Does the pattern of cratering truly indicate that a planet-wide outpouring of lava resurfaced Venus some 500 million years ago? Some of the answers lie deep inside the planet's hellish interior, where high temperatures create a paroxysm of activity that drives heat to the surface and ultimately sculpts the topography.

Planetary scientists expect Magellan to soon reveal new insights into Venus' internal structure and the geologic forces that have shaped its surface.

NASA doesn't have an instrument that can drill into the hot surface of Venus. But Magellan — its radar-imaging mission over — is now doing the next best thing. Since last September, to get under the skin of the planet often referred to as Earth's twin, the craft has recorded variations in the tug of gravity as it flies over different parts of Venus. These highs and lows in the gravity field indicate differences in the density of Venus' lithosphere, or outer shell, as well as in the underlying mantle. For example, the presence of an unusually thick lithosphere — one explanation for how Venus might support its tallest mountains — produces a particular type of gravity signal. Plumes of hot material rising up from the mantle, an alternative explanation for how the highlands keep their shape, exhibit another type of signal.

"Some people say that with the end of its imaging mission, Magellan's geology mission is now over, and that the rest is just geophysics. But the gravity data are crucial to sorting out the nature of surface features," says geologist James W. Head of Brown University in Providence, R.I.

*In this radar view of Venus, generated by Magellan, the bright center shows the mountainous region Ovda Regio.*


Measuring Venus' gravitational field is relatively simple, since the craft speeds up or slows down when it passes over a region of the planet that has a higher or lower density. A transmitter on Earth beams a radio signal continuously to the craft; the signal sent back shifts in frequency if the craft has changed its velocity. This enables planetary scientists to gauge the strength of Venus' gravitational field region by region (SN: 6/12/93, p.332).

So far, the gravity maps generated by Magellan have slightly better resolution than those produced a decade ago by another craft, Pioneer Venus. But at present, Magellan's maps only cover a 60°-wide belt around the equator. That's because the craft's elliptical orbit carries it too far away from Venus' polar regions to accurately record the gravitational pull of polar features, even those as large as Maxwell Montes, at 11 kilometers the planet's tallest mountain.

To map more of the planet, Magellan must have a lower, near-circular path. To achieve that goal, NASA engineers in late May began a risky set of maneuvers never before attempted in interplanetary space. Because Magellan lacks the power to alter its own orbit, NASA scientists are letting the drag of Venus' atmosphere do the work for them. As they dip the craft ever so slightly into the Venusian atmosphere, Magellan experiences a drag force that robs it of energy and thus lowers its orbit.

Magellan could burn up or its detectors could be exposed to dangerously high temperatures if the craft plunges too deeply into the thick atmosphere. Thus, flight controllers must "aerobrake" gradually. All readings so far indicate that detectors aboard Magellan have experienced a smaller rise in temperature than expected; as a result, aerobraking has proceeded more rapidly and will be completed by Aug. 5, eight days ahead of schedule.

The highest point in Magellan's orbit before aerobraking was 8,500 kilometers; after aerobraking, Magellan will stray no farther from the planet than 600 kilometers. The craft will be at its lowest over the equator, where it will have an altitude of about 200 kilometers, the same as in the earlier flight path.

By mid-August, Magellan should begin recording the same high-quality gravity data at the poles that it gathered from the equator, says William L. Sjogren, a member of the Magellan team at NASA's Jet Propulsion Laboratory in Pasadena, Calif.

A sharper global gravity map may help settle one of the most enduring debates to emerge from the earlier phase of the Magellan mission. Radar images taken by the craft reveal that the face of Venus has relatively few pockmarks. Only about 900 craters wider than 2 kilometers mar the planet's surface. In contrast, the crater density on Earth's moon is 1,000 times higher. Moreover, the Venusian craters seem randomly distributed over the surface, and about two-thirds of them appear pristine — untouched by volcanic activity, erosion, faults, or other common processes on the planet (SN: 12/21&28/91, p.424). In particular, only about 4 percent of the craters show evidence that volcanic lava once flooded them.

According to some Magellan researchers, the paucity of craters on Venus, coupled with the pristine condition of those that have made their mark, suggests that the entire surface has the same youthful age, even though the planet itself is as old as the solar system. These researchers believe that Venus' youthful visage stems from a global facelift that happened some 300 to 500 million years ago. That rejuvenation, contend Gerald G. Schaber of the U.S. Geological Survey in Flagstaff, Ariz., and Robert G. Strom of the University of Arizona in Tucson, came during a catastrophic period when volcanoes erupted everywhere on Venus, belching thick lava that covered ancient craters and other old surface scars.

According to their model, the outpouring of lava abruptly ended after about 100 million years, with only a small amount of volcanism remaining. This would account for the pristine appearance of most craters on the planet, which presumably have formed since the resurfacing.

But not everyone agrees with their model. Roger J. Phillips of Washington University in St. Louis bases his long-standing objection on the location and appearance of the craters. In his view, the cratering pattern suggests that the face of Venus divides into at least three broad regions, each with a different age. "If global resurfacing existed, there should be no special place on the planet; all regions should have about the same age," he says.

Although the craters appear randomly distributed, Phillips maintains that about 25 percent of the planet has a larger number of these blemishes, while another 25 percent has fewer than average. He believes that the areas with fewer craters, found most often in highlands, were resurfaced more recently. Those with a larger number of craters, mostly in the lowlands, were resurfaced earlier. Phillips summarized his work at a May meeting of the American Geophysical Union (AGU) in Baltimore.

Several key pieces of data support that assertion, he notes. Areas on Venus with a

# GRAVITY

By RON COWEN

## A new gravity map may explain how Venus' surface keeps its shape

high crater density tend to have a greater number of pristine impacts, untouched by volcanic activity. In addition, these areas appear dark on Magellan's radar images, an indication that volcanism or tectonic activity hasn't broken up the surface for more than 500 million years.

In contrast, the regions with fewer craters also tend to have a higher percentage of craters that are partially erased or degraded, an indication that volcanic eruptions occurred more recently. These regions look brighter on radar images, suggesting that recent upheavals roughened up the surface and increased its radar reflectivity.

Phillips says the data suggest that volcanic activity on different parts of Venus flicks on and off at different times, rather than all at once. In other words, he asserts, resurfacing never happened all at once. Schaber, however, maintains that small amounts of residual volcanism that continue after a planet-wide eruption could account for these differences.

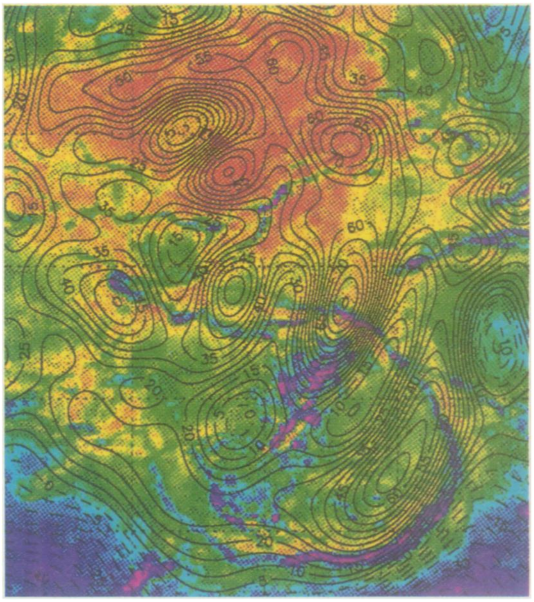
Sean C. Solomon, now at the Carnegie Institution of Washington (D.C.), also favors a less catastrophic form of resurfacing. But in Solomon's model, it's the deformation of crust through faulting, folding, and the movement of various crustal layers that erases craters, rather than burial by a planet-wide outpouring of lava.

He suggests that more than 500 million years ago, the temperature at the base of Venus' crust was as much as 100 kelvins higher than now. This would have made the crust considerably more pliable, or easier to deform. Combined with the transport of heat pushing upward from the mantle beneath, the crust may have been far more prone to buckling, fracturing, and faulting hundreds of millions of years ago, Solomon conjectures.

"My guess is that if we looked at the planet a billion years ago, faulting and folding would have covered nearly 100 percent of the surface," he says. Solomon notes that as the planet cooled, the crust would stiffen, eventually halting extensive fracturing. Thinner parts of the crust would stiffen earlier, and thus halt resurfacing sooner, than thicker regions, such as the highlands. This could explain why some of the highlands have a younger appearance than the lowlands, he adds.

Two years ago, James Head also doubted that the proposed facelift ever happened. Now, he says, a more detailed analysis of Venus' cratering record, combined with new computer simulations, have convinced him that global resurfacing best explains the planet's youthful appearance. "It looks pretty much like people are coming around to believe that [resurfacing] was a real event," he says. "The question now is, what was that event and what's been happening since then?"

To understand how Venus might have gotten a facelift, geologists rely on different proposed properties of the Venusian interior. For example, several researchers suggest that the formation and breakup of a thick lithosphere may explain how a massive outpouring of lava could begin and then abruptly end. The growth of a thick, stable lithosphere would temporarily keep a lid on volcanic



NASA/JPL

*Data from the Artemis corona, the largest of several puzzling circular uplifts on Venus, show that its strongest gravity signals coincide with the corona's tallest parts. It remains unclear whether a thick crust or the upwelling of hot material maintains a corona's shape.*

activity, preventing heat and lava from reaching the surface, says Donald L. Turcotte of Cornell University in Ithaca, N.Y.

Turcotte suggests that some 500 million years ago, a wave of heat from Venus' churning interior expanded the volume of the upper mantle, making it less dense than the lithosphere above it. Unable to support its own weight, the lithosphere sank into the mantle, clearing the way for hot rock to spew out on the surface. This venting action cooled the mantle. Over time, the cooling allowed the formation of a new planetary skin, shutting down volcanic activity.

"The combination of a thick lithosphere and global resurfacing makes eminent sense," Turcotte asserts. In this scenario, resurfacing would happen episodically, each time the lithosphere collapsed. Turcotte also presented his work at the AGU meeting.

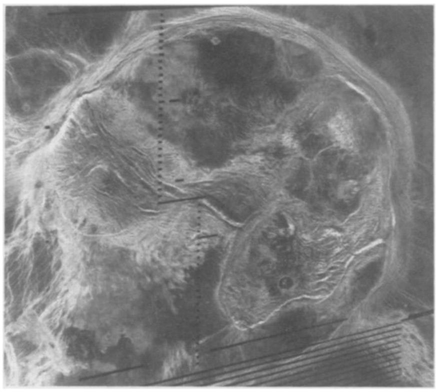
In a separate study, E. Mark Parmentier and Paul C. Hess of Brown University recently calculated that a similar process for the breakup and reformation of lithosphere would take about 500 million years, roughly the time elapsed since Venus last got a facelift.

If all of Venus now has a thick lithosphere, a year's worth of high-resolution gravity data should reveal it, Turcotte says.

Even Magellan's first eight months of gravity mapping, conducted through last May while the craft circled Venus in its higher orbit, have yielded new findings, says geologist Gerald Schubert of the University of California, Los Angeles. Before Magellan, he notes, researchers had known only that the planet's largest mountains and volcanoes are associated with gravity anomalies – highs or lows in the strength of the planet's gravitational field. The craft has now shown that small surface features exhibit similar gravity signals. These structures include volcanoes measuring no more than a few hundred kilometers across and puzzling circular features, known as coronas, so far found only on Venus. Even the smallest coronas – those stretching no more than 300 kilometers in diameter – are linked with a gravity high that comes from a region of the planet directly beneath them.

Other gravity signals support previous findings that isolated parts of Venus undergo a kind of folding and tearing similar to the processes that continually reshape the surface of Earth. For instance, Schubert and David T. Sandwell of the Scripps Institution of Oceanography in La Jolla, Calif., reported last year that Magellan imaging data revealed deep, circular trenches surrounding Venusian coronas (SN: 8/8/92, p.86).

The trenches resemble those found on Earth where one plate, or patch of lithosphere, dives beneath another. This process, called subduction, is a key element of plate tectonics, which governs the majority of Earth's surface changes. On Earth, the plates move in the horizontal plane for large distances before one dives underneath another. On Venus, scientists conjecture, the motion is almost entirely vertical. The gravity signals from trenches on Venus match those measured from subduction trenches on Earth, Schubert told SCIENCE NEWS.



NASA/JPL

*Magellan image reveals the detailed structure of the Artemis corona, which has a diameter of 2,100 kilometers.*

Magellan also found preliminary evidence about the way Venus supports its mountains and volcanoes. On Earth, typical highland features have an underpinning of low-density crust that extends some 10 to 65 kilometers beneath the surface. These massive "crustal roots" float in the higher-density mantle like an iceberg in the ocean. Just as the submerged part of an iceberg displaces seawater, providing a buoyant force that supports the part of the iceberg above water, submerged crust on Earth displaces the denser mantle, keeping afloat highland features that stick out above the surface. Thus, a gravity map of a mountain on Earth shows the combined effects of the mass of the mountain (a gravity high) supported by the crustal root just beneath (a gravity low).

In contrast, crustal roots on Venus seem to penetrate much deeper. Magellan has already confirmed findings from its predecessor, Pioneer Venus, that a typical mountain on Venus is not supported by buoyant crust lurking just a few tens of kilometers below the surface. Instead, some highlands on Venus appear to be supported by crustal roots that burrow 150 to 200 kilometers beneath the skin of the planet. These deep, low-density roots may explain why the highlands on Venus correlate with a strong gravity high. No such correlation exists on Earth.

A thick crustal root implies a thick lithosphere, Schubert notes. This suggests an alternative explanation for the way features on Venus retain their shape over millions of years, he adds. If Venus has a lithosphere as thick as 200 kilometers, it alone might support mountains and volcanoes by flexing like a steel beam in response to the extra weight.

In some areas, Schubert says, an entirely different process may support the topography. Plumes of hot material continually pushing toward the surface may keep certain highlands intact. Turcotte notes that chimney-like plumes, which would originate thousands of kilometers beneath the surface, would likely create broad, rounded highlands such as the large equatorial uprising known as Beta Regio. But he adds that unless a plume is geologically confined to a narrow, pipe-like region as it emerges, it could not form a narrow, sharply defined mountain such as Maxwell Montes near the north pole.

Turcotte notes that Magellan's high-resolution map should allow researchers to distinguish between shallower support structures, such as a crustal root or a thick lithosphere, and a dynamic support, such as a plume, which extends 10 times as deep. Support structures closer to the surface would produce a gravity signal extending over a larger region of the surface, he says.

Several Magellan scientists say they consider a gravity map of the region beneath Maxwell Montes, Venus' tallest mountain, a test case for understanding how other structures on the planet remain intact. "If we know how this mountain is supported, we can understand how many other features on Venus are held up," says Turcotte. □

## A reality beyond gravity

In order to produce a sharp gravity map of Venus, NASA has played out a nail-biting drama for the past two months: aerobraking Magellan into a lower, near-circular orbit without burning up the craft (see main story). But with the suspense in space nearly over – engineers expect to safely settle Magellan into its new orbit by Aug. 5 – another kind of drama continues on the ground. Planetary scientists say it will take a full year for the craft to generate a high-resolution gravity map of the entire planet. But NASA administrators say that at present they only have enough money to fund the gravity mission through the current fiscal year, which ends Sept. 30.

NASA currently finds itself $6.7 million short of the amount needed to continue gravity mapping for another year, says Wesley T. Huntress Jr., associate administrator for space sciences at NASA headquarters in Washington, D.C.

That dollar amount is, of course, tiny compared with the estimated $100 million it would cost to build a new spacecraft to produce the same gravity map of Venus, notes Magellan project manager Douglas Griffith at NASA's Jet Propulsion Laboratory in Pasadena, Calif. But the proposed fiscal 1994 budget for NASA's planetary science projects doesn't keep pace with inflation. Combined with the financial drain of start-up and maintenance costs for other long-term missions, this means belt tightening across the board, including Magellan, adds Huntress.

This isn't the first time Magellan's funding has been threatened. One reason the craft is able to do research through the current fiscal year is that NASA shaved $12 million from last year's operating budget for the craft and applied it to this year's allotment. Magellan's latest funding woes are "a case of penny wise but pound foolish – in spades," asserts geologist Roger J. Phillips of Washington University in St. Louis, a member of the gravity-mapping team.

Huntress remains cautiously hopeful that by this September, when final congressional appropriations for NASA should be completed, the agency will have enough money to fund the full gravity-mapping mission. The House has already proposed an overall funding increase for NASA's space and planetary science research that exceeds the President's 1994 budget request by $22.5 million. If the Senate agrees on a similar increase, that will undoubtedly ease some of the agency's financial constraints. But in the meantime, says Griffith, "we're living month to month."

*– R. Cowen*