PLANETARY SCIENCE

A New Portrait of Venus: Thick-Skinned and Decrepit

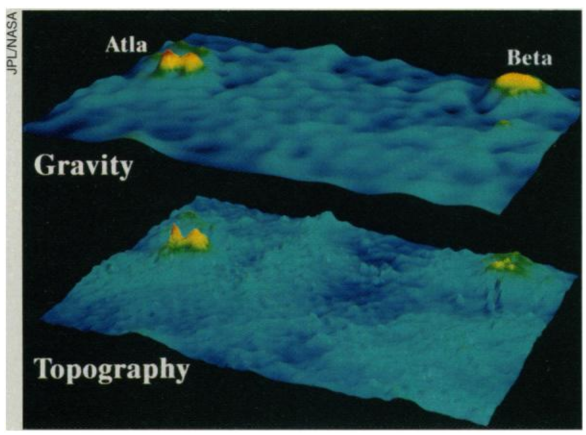
In the imagination of earthlings, Venus has been dying a slow death. When that planet was little more than a gleaming jewel in the sky, science fiction writers imagined a riot of life—steamy jungles and monster-ridden swamps—beneath its thick clouds. Imaginations cooled as satellite-borne radar pierced the cloudy shroud in 1979, revealing the planet's 475°C, parched surface, but if there weren't any steamy tropics, Venus' mountains, volcanoes, and plateaus at least held out the prospect of an active geologic life.

Some planetary scientists, for instance, thought the planet might reshape itself as Earth does by shifting great tectonic plates about its surface. In 1991, more detailed radar images from the Magellan spacecraft ruled out that scenario (*Science*, 12 April 1991, p. 213), but left open the possibility that the planet's topography might be supported by great plumes of hot rock rising from the interior or sculpted by "scum tectonics," in which a thin surface skin is compressed into mountains, ridges, and plateaus by deep interior churnings.

Now even that kind of geologic vitality seems to be flickering out. The latest data from Magellan, together with laboratory studies of rock strength, are leading many researchers to think that some of the forces that shaped the surface of Venus have run out of steam—and others have stopped operating altogether. "Venus has passed its heyday," says planetary geophysicist Roger Phillips of Washington University in St. Louis. "It's starting to look like Mars about 1 billion years ago," when that planet's store of internal heat ran down, shutting off all surface activity, except at a few volcanic centers. On Venus, all but a few of the surface features that were thought to attest to geologic life, says William Kaula of the University of California, Los Angeles, might just be "a relict of past activity."

Planetary scientists had thought that at Venus' rock-softening surface temperatures, its young-looking mountains and other features would collapse if they weren't being pushed up from below or renewed by tectonic activity. But Magellan's measurements of subtle gravity variations are letting researchers probe beneath the surface to find out what is holding up the relief. The answer over most of the planet is that a strong outer rind of rock, perhaps 70 kilometers thick, seems to support most of the planet's topography, needing no help from deep plumes. Laboratory studies emphasize the point by showing how Venusian rocks might retain surprising strength at high temperatures. Meanwhile, earlier evidence of an active Venus, like gravity data that hinted at plumes beneath many uplands, now seems to have been largely an artifact of low-resolution observations.

In fairness, it should be said that the new results don't come as a complete surprise. Last year, Magellan radar images showed that most of the impact craters pocking the Venusian surface look untouched by faulting, folding, or volcanism, hinting that most of Venus' surface had been quiescent for the past 500 million years or so (*Science*, 5 March 1993, p. 1400). But researchers could—and did—dispute the crater studies. The new gravity studies, however, are looking at the inner workings of Venus and coming up with the same diagnosis: geologic senescence, if not near death.



Twin peaks. Atla's gravity anomalies, which mimic its double volcanoes, suggest less support by a rising plume than the broader anomaly at Beta.

A new study by Sean Solomon of the Carnegie Institution of Washington's Department of Terrestrial Magnetism and his colleagues, for example, implies that most Venusian topography may be frozen in place. The researchers used new Magellan gravity data to probe beneath 14 of Venus' great volcanoes and determine what is holding them up. No one had thought that these volcanoes were pushed up by plumes; plumes would affect much broader areas. But if Venus' outer shell were weak, even a volcano would need support in the form of low-density roots, which would act like the hidden bulk of an iceberg and buoy it up.

Rootless mountains. Searching for the roots of volcanoes was beyond the resolution of the earlier gravity survey, done by Pioneer Venus, which went into orbit in 1979. But the job is relatively easy with Magellan, thanks to its less noisy radio signal. That signal, transmitted to Earth, is the clue to gravity. When the spacecraft passes over a volcano, the gravity due to the mountain's mass adds a tiny extra pull to the planet's gravity, tugging the spacecraft ever so slightly downward. That deflection creates a slight Doppler shift in the radio signal; the greater the shift, the greater the gravity anomaly.

To find out what is under the volcanoes, Solomon and his colleagues compare each volcano's gravity anomaly with its volume, as mapped by Magellan's elevation-measuring altimeter. If the gravity anomaly is small for the size of the mountain, it presumably rests on low-density roots, which reduce or cancel its gravitational signal. But if the gravity signal matches the amount of rock visible in the mountain, the peak must sit on strong lithosphere—the planet's rigid surface layer—with little help from buoyant roots below. To their surprise, Solomon and colleagues found that, for many of their volcanoes, the gravity signal nearly equaled what could be attributed to the mountain, implying an absence of buoyant roots. To hold up these volcanoes on its own, Solomon estimates, the lithosphere beneath these volcanoes must be a hefty 30 to 70 kilometers thick.

Besides implying a thicker and stronger lithosphere than had been thought, the finding may also explain how the Pioneer Venus gravity data misled investigators into thinking that broader-scale topography—broad swells extending across thousands of kilometers—was pushed up by plumes. In the low-resolution gravity data produced by Pioneer Venus, the strong, focused gravity anomalies of volcanoes perched on the swells could have smeared out to look like broad anomalies extending across entire swells. No physically reasonable lithosphere could simply hold up the swells to produce the anomalies, so planetary scientists invoked a push from below by plumes of hot rock. Five years ago, recalls Washington University's Phillips, he and many other researchers thought almost all of Venus' highlands had to be pushed up by plumes rising beneath them.

Now, using the new, higher resolution Magellan data, Phillips has trouble finding any evidence of plumes. Once the effects of the volcanoes are confined to their immediate vicinity, the gravitational anomalies across the highlands look smaller. The reduced anomalies imply that, instead of being actively pushed up by plumes, most highlands float on low density material—probably a region of lower lithosphere warmed and made less

Why So Dry, Venus?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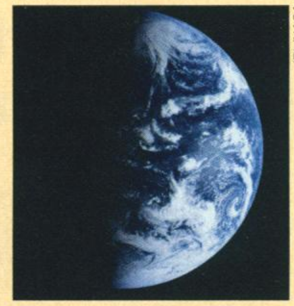
VENUS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EARTH

Venus, Earth's nearest relative, is looking more and more like a distant cousin, geologically speaking. Unlike Earth, whose constantly jostling tectonic plates move in response to deep currents of heat-softened rock, Venus seems to have encased itself in a single thick shell that preserves a frozen record of its last pulses of crustal deformation (see main story). The exceptional strength of this shell—the lithosphere—may be due to the dryness of its rock. But, then, why is Venus so dry?

That's the sort of question planetary scientists tend to shy away from. It immediately drags them into the big questions of origins and first causes, and those are tough to answer. If pressed, planetary physicist David Stevenson of the California Institute of Technology agrees that the answer could be as simple as Venus' location: three-quarters of Earth's distance from the sun.

Extra solar heating, he says, could have evaporated water from the planet's surface early in its history; combined with carbon dioxide, the water vapor would have created a powerful greenhouse effect. In the resulting hot atmosphere, large quantities of water vapor would have reached high altitudes. There, ultraviolet radiation would have broken down water molecules until the planet's atmosphere was parched.

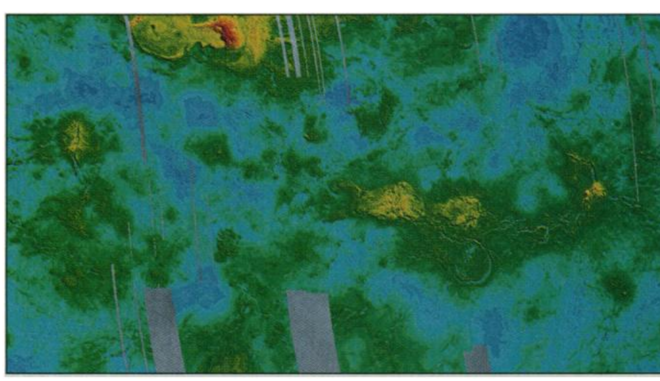
Even then, water would have lingered within the planet. But geologic processes on Venus might have dehydrated at least its crust and upper mantle, researchers note. As on Earth, magmas rising to the surface would have extracted water from below and released it to the atmosphere. But on Earth some of that water is recycled into the interior when ocean plates dive back into the mantle. Not on Venus. Either plate tectonics never got started on Venus or the process eventually shut down, perhaps because the planet's surface rock was too hot and hence too buoyant to sink back into the interior. As a result, water erupting from the interior of Venus could have been lost as well.

Could the difference of a few tens of millions of kilometers in two planets' orbital positions be enough to turn sisters into strangers? Even after 4 years of Magellan data, "I don't understand Venus," says Stevenson. "I find it puzzling still."

–R.A.K.

dense by some heat source in the churning mantle below. The only highland on the planet that Phillips is still willing to certify as plume-supported is Beta Regio, a rifted volcanic bulge. Even Atla Regio, another traditional case of plume support, looks like it gets only part of its lift from a plume, he says.

The presence of a warm, low-density base under many swells not only reduces the number of plumes required; it also provides still more evidence that the Venusian lithosphere as a whole is so strong that most of its features could be frozen in place. Added to the high surface temperatures, a deep heat source would sap the strength from any rocks geologists know on Earth. Even if the lithosphere did not yield, the lower crust—a few tens of kilometers down in the lithosphere and its weakest part—could weaken, and the highlands' volcanoes might lose their underpinnings and collapse. But the Venusian lithosphere doesn't give way. So what is the secret of its strength?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Nearly frozen? Venusian topography may be largely locked in place.

It might be lack of water. Even before the latest Magellan data, hints of exceptional rock strength, such as steep mountain slopes that hadn't oozed back to gentler inclines in spite of Venus' high surface temperatures, had prompted some investigators to suggest that Venusian rocks might contain very little water locked in their crystal structure (see box). On Earth, dry rock is known to be stronger than water-bearing forms, though not strong enough for Venus. But now rock physicist Stephen Mackwell of Pennsylvania State University and his colleagues have thoroughly dried terrestrial rocks that have a composition like those on Venus and found that their strength increased 5- to 10-fold—enough, perhaps, to hold up volcanoes and buoy highlands in spite of the Venusian heat.

All locked up. A strong lithosphere not only would not need the churning of the planet's interior to support most of its features; it should also resist any tectonic processes that did try to deform it. And that's just what is implied by another analysis of Magellan gravity data, designed to catch the planet in the act of tectonic deformation.

Mark Simons and Bradford Hager of the Massachusetts Institute of Technology and Solomon reasoned that ongoing deformation of the crust and lithosphere should appear in the data as a varying relation between gravity and topography around the planet. In scum tectonics, for example, mantle rock sinking beneath the lithosphere first pulls down the surface and then draws crustal rock into the depression, the way the vortex over a drain pulls in surface scum. The downwelling of dense, cold mantle would create a distinct gravity signal as long as it continued, but the topography would switch from negative—the depression—to positive when the crust eventually piled up. If such tectonics were shaping Venus, the relation between gravity and topography should vary from place to place depending on how far things had progressed. But instead of finding both types of gravity-topography relations on Venus, Simons and colleagues found only one, suggesting that the crust took its final form long ago.

To Solomon and others, the new results suggest that tectonic reshaping has largely shut down, leaving little more than the occasional dribble of lava and sporadic heating at the base of the lithosphere to change the face of Venus. Venus, it seems, was condemned perhaps 500 million years ago to a premature tectonic death, when it cooled enough to form a strong outer shell that has locked in all but the most subtle signs of vitality. Whether the planet might someday come back to life when that lithosphere gets so thick and dense that it sinks into the planet's still plastic interior, no one can say. For now, Venus looks not just senescent but close to fossilized.

–Richard A. Kerr