Did Venus Hiccup or Just Run Down?

Researchers are debating how Venus evolved: Did it gush lava 500 million years ago and then go nearly dormant, or is it slowly dying like the rest of the rocky planets?

The geological lifeblood of every rocky planet—its deep store of heat—has been seeping away since birth. As it escapes, it drives the planet's geology—the drifting continents of Earth, the mammoth volcanoes of Mars, and the pervasive lava flows of Venus. But the history of that leakage can be a bit obscure. The heat engine that drives plate tectonics on Earth seems to have run pretty smoothly for at least several billion years, though it may have slowed over the eons as Earth's internal heat supplies dwindled. Geophysicists have presumed that the heat engines of other rocky planets run at a fairly steady clip as well.

But if one controversial analysis of the radar images coming from the Magellan spacecraft is correct, Venus may be a dramatic exception to the rule of a smoothly running, steadily slowing planetary heat engine. According to an interpretation of Magellan data being advanced by planetary geologists Gerald Schaber of the U.S. Geological Survey in Flagstaff and Robert Strom of the University of Arizona, a paroxysm of volcanic outpourings kept the face of the planet wiped clean of landmarks until some 500 million years ago. Then, in less than 100 million years—abruptly, in geological terms—the planetary heat engine was throttled back, leaving a barely detectable trickle of lava.

That picture would explain the fresh appearance of the Venusian surface as the Magellan radar mapping satellite has unveiled it (*Science*, 21 December 1990, p. 1660). And many researchers are intrigued by the possibility that they have found an oddball among the terrestrial planets. "I'm really excited" by the Magellan data, says geophysicist Robert Grimm of Arizona State University. "Venus is such a cornerstone planet to understand how terrestrial planets work. It ought to be Earth's twin [given their nearly identical sizes]. Whether it's a modest cousin or a really flamboyant one is the issue now."

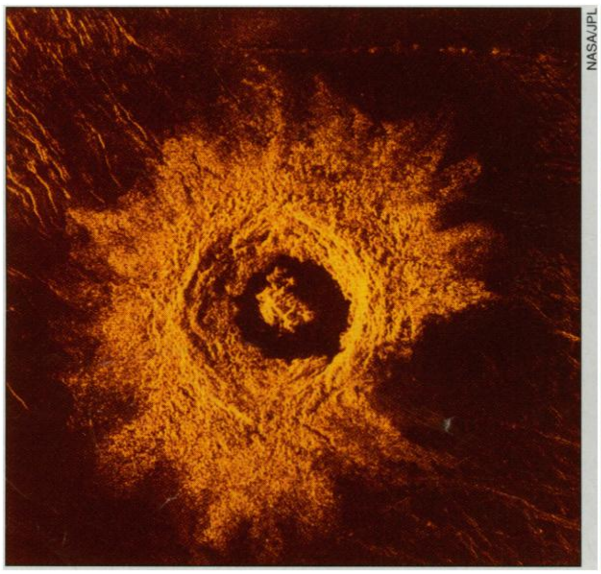
Being intrigued by Schaber's proposal is not the same as accepting it, however. Though some geophysicists who model how heat flows out of planetary interiors can envision how a planet might sustain such flamboyant behavior, to most "the geophysical implications are tortuous," says Grimm. "What's most natural for geophysicists is [to think] that the internal engine operates smoothly." And geophysicist Roger Phillips of Washington University in St. Louis, who like Schaber is a Magellan team member, thinks it's far too early to set aside that notion for Venus. When he looks at the Magellan data, he doesn't see evidence of one global episode of resurfacing. Instead, he sees a patchwork, in which smaller regions were renewed at different times over Venusian history—a story far more like that of the other terrestrial planets.

At the heart of the debate is the clock that planetary geologists use to measure the passage of time. Like grains of sand falling from some celestial hourglass, a steady rain of meteorites has pitted the Venusian surface. By combining estimates of how fast that rain has fallen with counts of the impact craters revealed by Magellan, planetary scientists have arrived at an average age of the planet's surface—the time since it was last wiped clean of craters—of about 500 million years. That's only one-ninth the age of the planet, marking Venus as geologically active enough to keep itself looking relatively young.

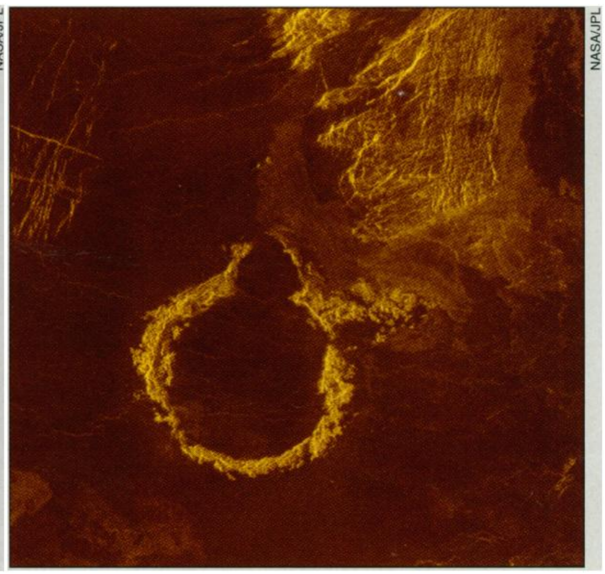
A clean slate

As an average figure, this age is not in dispute. Schaber, however, believes that the age is roughly constant across most of the Venusian surface, while researchers such as Phillips believe that there are large variations in the ages of different regions. Schaber's interpretation implies that the planet underwent a geologically abrupt drop from rapid to negligible resurfacing a half-billion years ago. In effect, the Venusian slate was wiped clean, then left mostly alone. As evidence, he points to the spacing of the planet's large impact craters: Any patch of surface that had been resurfaced more recently than others would have fewer, more widely scattered craters—but in fact the spacing of large craters is fairly even. True, Schaber admits, the spacing of craters is marred by occasional crater-free regions, but he attributes those gaps to the chance scattering of impacters. And he points out that only about 4% of all the craters show signs of encroaching volcanic activity.

"The evidence is clear to us as geologists," says Schaber. "The only thing that works is 100% of the surface being flooded [with lava] 500 million years ago." Since then, he says, "the planet has not only decreased its



Untouched for half a billion years? The preponderance of pristine impact craters on Venus (such as this 34-kilometer example) suggests massive volcanism ended abruptly.



Drowning in a rocky sea. Impact craters embayed by lava flows, such as double crater Heloise (diameters of 16 and 40 kilometers), are rare, but they show Venus is not dead.

resurfacing rate, but that decline was rapid." All told, he and his colleagues say, their analysis of the Magellan images implies that only 6% to 8% of the planet has been resurfaced in the past half-billion years.

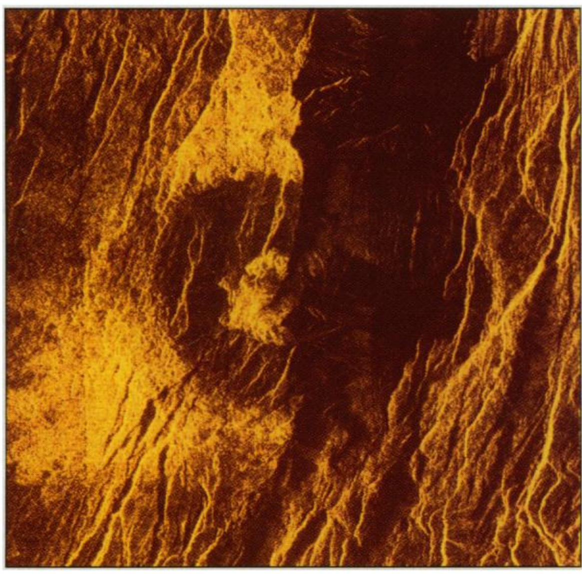
To Phillips, though, the portion of the planet resurfaced over that period "can't be as small as 10%. We can certainly reject the catastrophic [extreme]." For Phillips, the crater-free regions Schaber dismisses are key evidence against the catastrophic scenario. His modeling of processes that might have created these gaps leaves open the possibility that they were formed recently by patches of volcanism. Ongoing volcanism would also explain why, to Phillips' eye, the planet's surface seems to be roughly divided into regions having three different ages, rather than the pervasive single age predicted by the catastrophic resurfacing model. The areas that look oldest—constituting perhaps 25% of the planet—have unusually high numbers of craters and appear dark in radar images, implying little disruption by later geological activity. But another 25% of the planet seems to be younger than average, Phillips says, having relatively low crater densities and higher radar reflectivity, as expected if the crustal faulting that often accompanies volcanism had roughened the surface. And though craters half-drowned by lava flows are rare on the planet as a whole, they're concentrated in these younger areas, Phillips says, hinting that the young-looking surface was created at least in part by recent volcanism. "That tells me something is eating craters," he says.

Even if there's still a viable case for a steady heat engine, however, a few geophysicists have gone on to look for ways to make Schaber's catastrophic concept of Venus work. In one kind of mechanism, suggested independently by Donald Turcotte of Cornell University and Mark Parmentier and Paul Hess of Brown University, the planet's rigid surface layer, or lithosphere, episodically sinks into its mantle, clearing the way for an eruption pulse. In Turcotte's mechanism, the volcanic pulse would be choked off as the uppermost mantle cooled and a new lithosphere formed, like a thick skin on a pudding. Parmentier and Hess, in contrast, re-form the lithosphere with added mantle rock that has become buoyant because of the loss of magma. Either way, the global resurfacing that ended 500 million years ago would have been only the most recent of many episodes, and more are on the way.

Other modelers, though, call for a one-time change in Venus' internal workings about 500 million years ago. Jafar Arkani-Hamed of McGill University in Montreal has proposed that volcanism was widespread until then, as the deep heat reserves that slowly churned Venus' viscous mantle dwindled. But when the mantle passed a key temperature threshold, he argues, it would have all but frozen up, abruptly ending the rapid resurfacing of the planet. To Volker Steinbach of the University of Cologne and David Yuen of the University of Minnesota, mantle cooling could have had a different effect: Instead of stabilizing the mantle and shutting down volcanism, it could have broken down the layers into which the mantle had been divided. That would have churned up the mantle, bringing up rock from the hot bottom layer and triggering a one-time volcanic outburst.

Too soon to tell?

All this haste to explain a still contentious geological hypothesis disturbs Magellan project scientist Stephen Saunders of the Jet Propulsion Laboratory, a geologist. "A lot of geophysicists and petrology modelers have accepted catastrophic volcanism as what needs to be explained. That may be because it gives you something concrete to model. But that worries me. If it isn't true, a lot of people have wasted a lot of time."


NASA/JPL

High and dry but fading fast. Rifting of the crust has destroyed half of this 37-kilometer impact crater. Such tectonism may have been the primary agent of resurfacing.

Before the modelers get too enthusiastic, says Saunders, "some rather detailed geological analysis" of the Magellan images is needed. The simple crater counts Schaber and Phillips are arguing about have not yielded a definitive answer, he notes, because Venus' heavy atmosphere has screened out many of the smaller, more numerous meteorites, weakening the crater statistics. As one example of the more detailed analysis he's calling for, Saunders points to work by Noam Isenberg and Raymond Arvidson of Washington University, who are looking beyond the craters themselves to the large debris sheets around them for signs of recent disruption. Isenberg and Arvidson's preliminary analysis seems to support Schaber: "For the most part, the craters formed after volcanic and tectonic events," says Arvidson. "That suggests that the rate of volcanism and tectonism has been on the decline."

But even if the geological evidence eventually stacks up in favor of Schaber, geophysicists may not have to accept "tortuous implications" for the planet's interior, says Sean Solomon of the Carnegie Institution of Washington's Department of Terrestrial Magnetism. Solomon was a latecomer to Schaber's interpretation of the Magellan images. "Until a few months ago, I had favored Phillips' [noncatastrophic] model," he says. Solomon had been uncomfortable with the drowning lithospheres and overturning mantles postulated to explain the young surface. His change of heart came only after he realized that planet-wide resurfacing might not have to be driven by pulses of rock from the planet's interior. "I convinced myself there was a 'catastrophic' explanation that had nothing more catastrophic about it than planetary cooling."

While other geophysicists have speculated about Venus' interior, Solomon realized that what sets Venus apart might be something less exotic—the blistering Venusian surface temperature of 475° C created by the thick atmosphere's powerful greenhouse effect. As he will argue later this month at the Lunar and Planetary Science Conference in Houston, the surface heat, combined with the additional heat flowing from a hotter interior in the distant past, could have kept near-surface rock soft well into Venus' history. The weakened crust would have faulted and deformed so easily that any impact crater would have been wiped out in quick order without any need for volcanism.

But this tectonic resurfacing would eventually have ended as the planet's interior cooled. Eventually—perhaps 500 million years ago—it would have come to an abrupt, "catastrophic" end as the crust passed through a temperature threshold below which the rock stiffened, resisting stresses and preserving craters. Resurfacing would have plummeted with nary a cough from the planetary heat engine. If that's the way it really happened, Venus could keep its flamboyant reputation—and still be pretty conventional at heart.

–Richard A. Kerr

Additional Reading

Abstracts of the sessions "Recent Results on Venus, I and II," *Eos Trans. AGU* **73**, 328 (1992).

S. C. Solomon, "Keeping That Youthful Look," *Nature* **361**, 114 (1993).