Magellan unveils the mysterious planet Venus

Is Venus geologically alive? The answer to this question was one of the priorities of scientists when the Magellan radar mapping spacecraft was launched in 1989. Carl Osgood reports.

Besides Earth, only two other bodies in the Solar System are known to be geologically active. One of those is Io, a moon of Jupiter, and the other is Triton, a moon of Neptune. These two moons, however, are at opposite ends of the spectrum. Io's volcanoes produce very hot sulfur materials, and are probably influenced by the massive gravitational effects of Jupiter. Triton, on the other hand, has a surface temperature only 30° above absolute zero, and its volcanoes likely produce liquid nitrogen.

The wealth of data about Venus returned by the Magellan spacecraft is allowing scientists to more adequately compare geological processes that occur on Venus with those that occur on Earth. This process, which comes under the new discipline known as comparative planetology, allows scientists to gain a greater understanding of how the Earth was formed and how it has developed, by comparing both the similarities and differences between planets and other heavenly bodies.

Unlike the outer planets, about which little was known when they were visited by the Voyager missions in the 1970s and '80s, Venus had been previously explored by space probes (21 of them, in fact), and scientists already had much data on the planet's atmosphere and a more limited amount on its surface prior to the launch of Magellan. However, the surface data that existed did not answer the question of whether Venus had active volcanoes or earthquake-like activity. The data from Magellan's high resolution mapping radar were expected to provide answers to these questions.

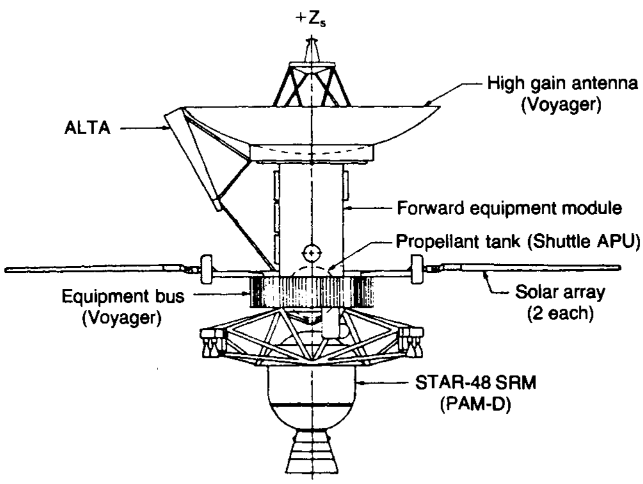
The first radar observations of Venus were attempted in the 1970s by both Soviet and American space probes, and by a ground-based observatory in Puerto Rico. While these radar observations provided the first glimpse of Venus's surface topography, the resolution was very poor, ranging from no better than six-tenths of a mile to several miles, and covering only small portions of the surface. Beginning in 1979, the Pioneer Venus mission provided the first extensive observations of the Venusian atmosphere and also radar mapped 93% of the planet's surface to a resolution of about one-half to one mile.

What became the Magellan radar mapping mission was conceived in the late 1970s as the Venus Orbiting Imaging Radar (VOIR) mission. It was to incorporate a Synthetic Aperture Radar (SAR), which uses computer processing to get the resolution equivalent to an antenna that is 200 feet across, using an antenna that is only 12 feet in diameter. In addition, the mission was to make measurements of Venus's atmosphere. The VOIR didn't make it through President Reagan's first budget, however, and in order to save the program, the National Aeronautics and Space Administration redesigned the mission and the spacecraft to cut costs.

Ultimately Magellan retained only the SAR of VOIR, and that was built using much hardware from previous missions. The antenna, for example, was originally built as a flight spare for the Voyager missions and does double duty as a radar antenna and as the transmitting antenna for sending data to Earth and receiving commands from Earth (see **Figure 1**). The synthetic aperture technology allows Magellan to produce radar images of the surface to a resolution of about 400 feet.

Magellan was launched by a Space Shuttle crew on May

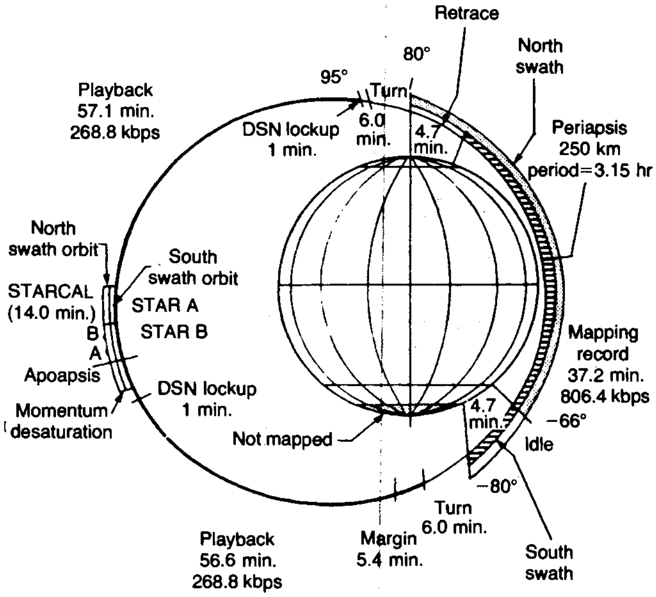
FIGURE 1
Magellan key spacecraft characteristics



Source: NASA

The Magellan Venus Radar mapping spacecraft, shown in cruise cruise configuration. Its 12-foot high-gain antenna is its primary data acquisition instrument.

FIGURE 2
The elliptical orbit of Magellan



Source: NASA

4, 1989 and entered orbit around Venus on Aug. 10, 1990. It was placed into a highly elliptical polar orbit (**Figure 2**) that brings the spacecraft to within 150 (periapsis) miles of the surface at its closest approach and out to 5,000 miles (apoapsis) at its greatest distance from the surface. During the near side of the orbit, Magellan's radar is pointed at the surface for mapping. On the far side of the orbit, Magellan turns itself toward Earth to transmit its data. During its first mapping cycle, it mapped a swath 16 miles wide by 9,600 miles long from the North pole to 70° South latitude during each orbital pass. It takes 1,789 passes to cover the entire planet. The images from each mapping pass are then put together to create mosaics of the whole planet. In this manner, more accurate maps of Venus have been created than exist for much of Earth—the ocean floors have never been mapped as accurately or as completely as Venus has been by Magellan.

Engineers had to overcome problems with Magellan's attitude control system, however, before mapping could begin. The system uses a star sensor to detect the stars Sirius and Rigel so it can turn itself in the right direction for either mapping or transmitting data back to Earth. The sensor had difficulty detecting the stars, and as a result the spacecraft put itself into a "safe" mode several times, pointing its solar panels directly at the Sun and, consequently, its antenna pointed away from Earth and contact was lost. When contact with Earth was lost, Magellan went into a cone-shaped sweeping motion until it regained contact. Engineers got around the problem by reprogramming the computer to bypass a failed memory, which, they speculated, was damaged by a hit from a cosmic ray. These problems delayed the start of mapping for about one month after Magellan entered Venus orbit.

On Jan. 4, one of Magellan's two transmitters failed, again interrupting mapping. The backup transmitter had been shut down in March 1991, because it was overheating, which introduced noise into the transmitted data. Engineers are confident that they can restart normal mapping with the backup transmitter on Jan. 24 by reducing the data transmission rate to 115,000 bits per second, or 43% of the normal rate.

Earth's sister planet?

For centuries, Venus had been called Earth's sister planet, because of the similarities between the two planets in size, density, and distance from the Sun. However, the thick cloud layer covering Venus made it impossible to view the surface. It wasn't until the 1960s that scientists were able to get any data on what surface conditions were like. What they found was nothing even approaching the most extreme conditions found anywhere on Earth. The surface temperature is about 850° Fahrenheit, and the atmospheric pressure at the surface is 90 times that of Earth. It was also discovered that Venus rotates in a retrograde direction, opposite that of

NASA

This crater, called Golubkina, has many of the typical features of an impact crater such as we find on the Moon. It was originally discovered by a Soviet radar survey in the early 1980s.

Earth, and that a day on Venus is longer than a year—it takes the planet 225 days to orbit around the Sun, compared to 243 days to rotate on its axis.

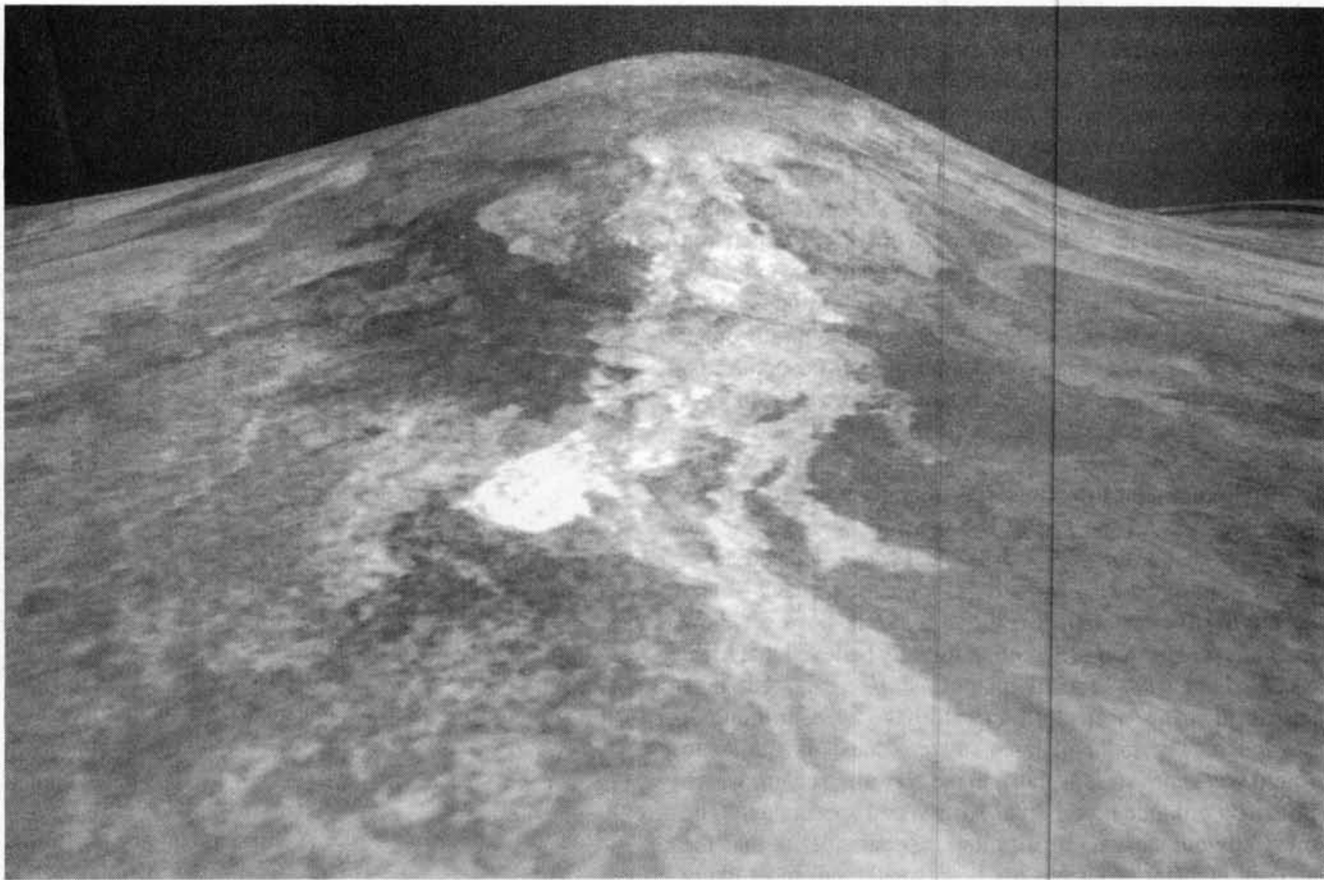
The surface of Venus appears to be relatively young and shows signs of constant renewal. Venus is cratered, but the average crater density is 1,000 times less than on Earth's Moon and there are plains of lava flows with no craters at all. None of the craters is smaller than about four to six miles in diameter, as anything smaller burns up in the thick atmosphere. Some of the smaller craters also have multiple impact points indicating that some of the meteors broke up into pieces and struck simultaneously.

The 20-mile-wide crater Golubkina, which was originally discovered by a Soviet radar survey in the early 1980s, was one of the first craters surveyed by Magellan. It has many of the same characteristics as craters on the Moon. The inner walls are terraced, a central peak rises from the center, and boulders and other debris extend in all directions from the rim. Dr. Steven Saunders, the Magellan project scientist, said that this indicates that cratering on Venus is not all that different from cratering on Earth, the Moon, or Mars.

Widespread volcanism

The relatively young age of the impact craters suggests that widespread volcanism occurs from time to time, which destroys all the craters. Ocean-sized floods of lava once inundated the surface. Most of the lowland areas were created by vast lava flows either from one catastrophic phase of volcanism 400 million years ago, or from a series of different eruptions over that period of time. One image from Magellan showed a volcano measuring 600 miles wide, with some lava flows 300 to 400 miles from the lip of the crater. A comparable feature on Earth is the Columbia Plateau in the northwestern United States. A layer of basalt underlies an area of about 77,000 square miles, up to 1 mile in thickness. The lava welled up through thousands of fissures over a time span of about 10 million years. It is possible that this same process occurred on Venus to produce the vast lava plains. The higher surface temperature of Venus would allow lava to stay liquid longer than it would on Earth, thereby allowing it to flow farther and cover larger areas than it would on Earth.

One of the most unusual features found on Venus is volcanic pancake-shaped domes. These domes are about half a mile high and are 15 to 20 miles across. In one region of the planet, seven of these domes stretch out in a remarkably straight line. Scientists speculate that they were formed by extremely viscous lava pouring out of volcanic vents. Dr. Saunders reports that the pattern "is telling us something about the eruption mechanism, the viscosity and the eruption rate." Similar lava domes are seen on Earth, but only inside



This image of the volcano, Sif Mons, was produced by combining radar data with altimetry data. The volcano, 1.2 miles high, is located in an area called the Western Eistla Regio that may have been formed by the upwelling of hot material from the interior of the planet. The bright areas at the center of the image are considered to be recent lava flows.

the caldera of active volcanoes.

The wide variety of volcanic formations suggests variations in the thickness of molten rock flowing on Venus. Their consistencies range from that of toothpaste, as seen in the pancake domes, to water-like liquid that forms channels hundreds of miles long. This indicates differences in the chemical composition of the hot rock flowing from inside the planet. On Earth, the composition of lavas is generally determined by the presence of iron or of silicon compounds, and also the amounts and types of gases dissolved in the lavas. These gases include carbon dioxide, nitrogen and even a considerable amount of water vapor.

Volcanic gases in the atmosphere

On Earth, sulfur compounds are also an important product of volcanic eruptions. The upper atmosphere of Venus is known, from earlier Pioneer Venus data, to contain sulfur compounds, including sulfur dioxide and sulfuric acids. On Earth, such compounds are produced by what are called pyroclastic eruptions, which primarily produce ash, dust, and hot, explosive gases. These volcanoes result from the buildup of gases coming out of solution in the hot magma and building up pressure inside the cone when the volcanic vent is plugged. When the internal pressure exceeds the capacity of the plug to hold it, an explosion occurs. Examples of this type include the eruption of Mount St. Helens in 1980, and more recently, Mount Pinatubo in the Philippines. So far, no volcanoes of this type have been observed on Venus, but, if they do exist, they could account for the presence of the sulfur compounds in the atmosphere. Before there could be volcanic explosions, however, the hot lava must have concentrations of volatile gases great enough to overcome the high atmospheric pressure that is the equivalent of 2,500 to 3,000 feet underwater on Earth.

That such volcanic activity has a major effect on the atmosphere is a well-understood process on Earth. In 1984, the explosion of the El Chichón volcano in Mexico, which dumped huge quantities of sulfur dioxide into the atmosphere, was followed by an average drop in global temperatures of about 1° Celsius. In the 1950s, one geochemist even came to the astonishing conclusion that all of the water in Earth's oceans and atmosphere could be accounted for by volcanic activity throughout the history of the Earth.

Unusual materials have been observed on Venus, associated with these volcanic mountains, the source of which is causing some speculation among scientists. The tops of the mountain range containing the tallest mountain on Venus, the 38,000 foot Maxwell Montes, are covered with a material that is highly reflective, like ice. Dr. Saunders and other scientists speculate that the material consists of either iron sulfides, magnetite, or hematite. These electrical conductors are not found at the much hotter, lower altitudes. John Wood, a member of the science team from the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, theorized that these compounds are converted from lava deposits by the chemical action of the sulfuric acid in the atmosphere.

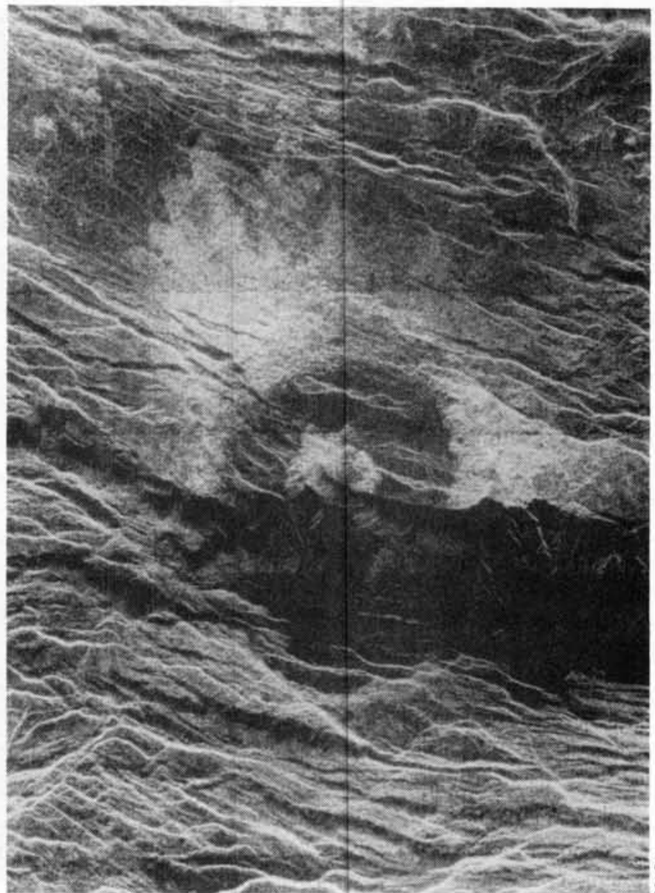
The presence of this material, therefore, seems to be a good indicator of the age of the volcano. Venus's second highest volcano, the 28,000-foot Maat Mons, located on an equatorial highland, is radar dark, indicating a lack of any such reflective material. It is difficult to tell, however, how long this process takes. Scientists initially believed that Maat Mons could have erupted in the last 10 years, but now suspect that the last eruption could have been millions of years ago. The radar pictures suggest that it is similar to shield volcanoes such as those in the Hawaiian chain, which primarily produce liquid lava. John Wood speculates, "The most obvious answer [for its dark appearance] is that the summit of Maat Mons has not been weathered, most likely because it has not had time to be weathered. We consider this the best candidate for a currently active volcano on Venus." The science team hopes to locate evidence of new lava flows from Maat Mons during next year's mapping cycle.

The evidence, however, suggests that surface renewal due to volcanic activity is a slower process than on Earth. Roger Philips, a geologist from Southern Methodist University, speculates that Venus produces about one-tenth of a cubic mile of lava per year, compared to an annual average on Earth of 7.7 cubic miles of lava. Therefore, it is believed that plate tectonics plays a longer-term role in renewing the surface of Venus.

Do 'Venus-quakes' occur?

Other parts of the surface are plains that show much evidence of tortuous tectonic activity. On Earth, earthquake activity usually occurs along the areas where two tectonic plates meet, such as the San Andreas fault in California. "Venus-quake" activity appears to occur over wide regions, instead. There are linear mountain ranges, such as are common on Earth, rift zones, fractured plains and wrinkled plateaus. Scientists speculate Maxwell Montes was formed by the same type of compression forces that created the Himalayas.

However, the radar data did not confirm previous theories of Earth-like plate tectonics. One theory, developed from Pioneer Venus radar data, suggested that one region of Venus, known as Ovda Regio, was the product of the same type of forces that produced Earth's Mid-Atlantic Ridge. In the Pioneer pictures, Ovda Regio resembled Iceland, which is a plateau built on the ridge by an upwelling plume of mantle material that feeds volcanic outpourings on the surface. When scientists examined the higher resolution Magellan images of Ovda Regio, however, they found none of the features of crustal spreading such as that characterized by the Mid-Atlantic ridge.



This "half-crater," located in a region known as Beta Regio, has been cut by many fractures since it was formed by the impact of a large asteroid.

Two theories have since come to the fore to explain features like Ovda Regio. One, suggested by Sean Solomon of Massachusetts Institute of Technology, is that churning mantle rock, just beneath the surface crust, can grab the crust above it and drag it around, causing ridges, plateaus, and mountains where the crust piles up on itself, or great rifts where it gets pulled apart. The second model is the "blob tectonics" model suggested by Robert Herrick and Roger Philips of Southern Methodist University. In this model a blob of hot mantle rises towards the surface, pushing the crust upward, and as the blob flattens out in the subsequent dome, the magma punches through the crust forming volcanic hot spots. Herrick and Philips have identified four areas, including Ovda Regio, which they believe are the products of such "blob" activity.

No erosion on Venus

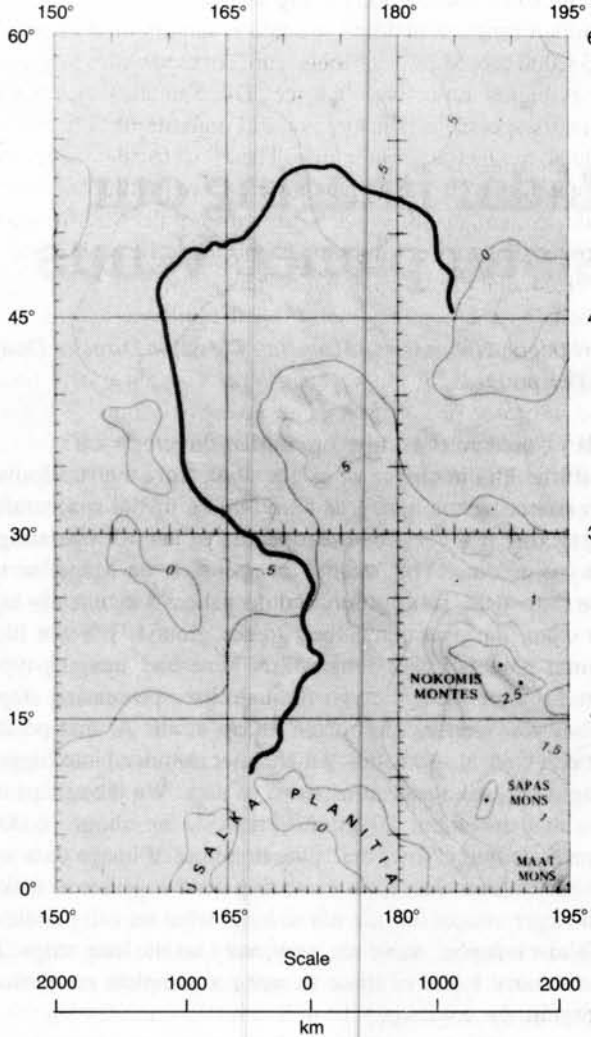
One of the striking characteristics of all the surface features found on Venus is the lack of erosion. On Earth, geological formations begin being eroded by water and wind as soon as they form, and growth of vegetation causes further distortion. The presence of life on Earth also greatly affects atmospheric processes, making any direct linear extrapolation of conditions on Venus to those on Earth to be, at best, incompetent. On Venus, there is no water, no life, and the wind, at the surface, is very slow, about two to four miles per hour (at the lower elevations), which causes some dust movement, but little else. This results in newer formations being superimposed over older ones, such as fault lines running through impact craters. For scientists, this means there is a record of everything that has occurred. The processes of volcanic activity or cratering or tectonic movement are there, unlike on Earth where many features eventually get erased by the flow of water.

The Magellan spacecraft completed its first mapping cycle of Venus last April, and because the quality and quantity of data that it returned exceeded expectations, project scientists immediately got approval to begin a second mapping cycle. One of the goals of the second mapping cycle is to determine whether Venus is still geologically active by comparing images from the first cycle with images of the same areas from the second cycle, taken nine months later. At one point during the second mapping cycle, scientists found what they thought to be a landslide, in a region known as Aphrodite Terra, that had not been seen in the first cycle. However, upon further examination, they concluded that the "landslide" was actually the result of ambiguities in the radar data, because of differences in the radar angle from the first cycle.

Also on the second cycle, Magellan discovered a channel that is the longest known in the Solar System, longer than the Nile River, at 4,200 miles (see **Figure 3**). Dr. Saunders said that the very existence of this channel is a puzzle. "If the channel were carved by something flowing," he said, "the liquid would have to have very unusual properties. There are no likely candidates for a liquid. Lava, even very high temperature types, would need to have a very high extrusion rate to flow so far. This is not consistent with uniform narrow channel morphoplogy." The challenge that this channel provides is in the understanding of planetary geological process and related fields such as material properties and fluid dynamics, particularly under extreme temperatures and pressures, since geologic materials undoubtedly act different under the surface temperatures and pressures of Venus, compared with those of Earth.

FIGURE 3

Hildr channel on Venus



Source: NASA.

Hildr Channel is the longest known channel in the Solar System. Segments of it were first seen in the Soviet Venera 15 and 16 radar images. Both ends of it appear to be buried by younger materials, making its source difficult to identify.

All of this raises interesting questions about the origins of the Solar System. How did Earth and Venus, which initially seemed so similar, end up so different? Some scientists speculate that Venus today is what Earth was in its very early evolution. The crust of Venus could be representative of what Earth's was in the first 100 million years or so, of its existence. Then, by some still-unknown process, the mantle underlying the crust crystallized into the plate tectonic system that we know, today.