Reports

Magellan: Mission Summary

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The Magellan radar mapping mission is in the process of producing a global, high-resolution image and altimetry data set of Venus. Despite initial communications problems, few data gaps have occurred. Analysis of Magellan data is in the initial stages. The radar system data are of high quality, and the planned performance is being achieved in terms of spatial resolution and geometric and radiometric accuracy. Image performance exceeds expectations, and the image quality and mosaickability are extremely good. Future plans for the mission include obtaining gravity data, filling gaps in the initial map, and conducting special studies with the radar.

EVERY DAY, MAGELLAN ACQUIRES 7.3 orbits of image data. Each orbit covers a strip 20 km wide, extending 17,000 km from the north pole to below 70° south latitude. At the time of this report, Magellan is halfway through its 8-month-long nominal mission. Radar mapping of Venus began on 15 September. Images of almost 15% of the planet have been processed and undergone initial analysis. Individual image strips produced from each mapping orbit (Fig. 1), termed F-BIDRs (full-resolution basic image data records), have been mosaicked to create most of the images in the following reports. Magellan produces about 100 megabytes of image data plus annotation per orbit. For comparison, this volume of data is roughly equal in volume to 75 Viking image frames of Mars. In this report, we summarize the principal features of the Magellan mission (*1*). The detailed science objectives and instrument characteristics are described in (*2*).

The Magellan spacecraft, the first planetary mission launched by the Space Shuttle, was launched from Kennedy Space Center in Florida on 4 May 1989. Magellan spent 15 months in cruise and traveled 580° around the sun before finally arriving at Venus.

On 10 August 1990 Magellan successfully entered orbit around Venus (Table 1). Trajectory correction maneuvers placed the spacecraft on arrival at Venus within 100 km of the aim point, close enough that no correction was required. Initial star scans successfully found the target stars; Venus did not interfere in any unexpected fashion.

After orbit insertion, a thorough checkout of the spacecraft was begun in preparation for the formal start of mapping on 1 September. The checkout plan included an initial turn on and operation of the radar on 15 to 16 August. Special tests were planned to verify proper performance of the navigation, spacecraft, and radar before the start of systematic mapping. The plans for the checkout period changed when the signal from the spacecraft was lost on two separate occasions.

The first radar images were obtained on 16 August 1990, from data produced by the initial checkout radar mapping test. The data from orbits 146 and 147 were received at the Goldstone Deep Space Network (DSN) antennas and shipped to the Jet Propulsion Laboratory (JPL; the first orbit around Venus was designated orbit 100 to allow bookkeeping of test mapping orbits obtained during cruise). After overnight processing of the data, the surface of Venus was visible for the first time at a resolution better than 120 m (Fig. 1). The test mode was expected to produce acceptable images over only a few small regions. Instead, nearly the entire mapping strip could actually be processed; a quantity of image data nearly equal to the total amount received from the Soviet Venera 15 and 16 missions was produced.

The signal from the spacecraft was lost as the radar data from the first orbit was on its way to JPL. Three separate faults had occurred: (i) the spacecraft's attitude control computer stopped performing its normal sequence of operations; (ii) an automatic swap of attitude control computer components restarted the computer, but an incorrect guide star was chosen, and as a result the spacecraft pointed toward an incorrect direction for Earth; and (iii) the reconfigured attitude control computer began to misbehave wildly after 13 hours; as a result, the spacecraft eventually repointed the solar arrays toward the sun and began searching for Earth. The signal was acquired at Goldstone within the first 2 hours.

Before the high-gain antenna could be pointed toward Earth in order to permit a higher data rate, the spacecraft signal was lost again on 21 August. The second incident started with a relatively rapid drop in the expected signal strength over a period of several minutes. The rate at which the signal strength dropped suggested that the spacecraft had changed its pointing direction purposefully, rather than suffering some catastrophic failure. After more than 4 hours had passed without the signal reappearing, the control team decided to transmit commands in the blind. Another 4-hour period passed without the signal reappearing. Finally, the control team sent commands to disable the spacecraft heartbeat-loss monitoring software and successfully took full control from the ground. Despite extensive investigation, the root cause of the two loss-of-signal incidents has never been determined. Several kilograms of hydrazine were used during the incidents. However, 112 kg remained, and only about 3 kg per year are required for normal mapping operations.

On 14 September, the radar instrument

Table 1. Initial orbit parameters.

Parameter	Design orbit	Actual orbit
Periapsis altitude	275.0 km	294 km
Periapsis latitude	10.0°N	9.9°N
Altitude at pole	2145 km	2225 km
Orbit period	3.186 hours	3.26 hours
Inclination	85.30°	85.5°

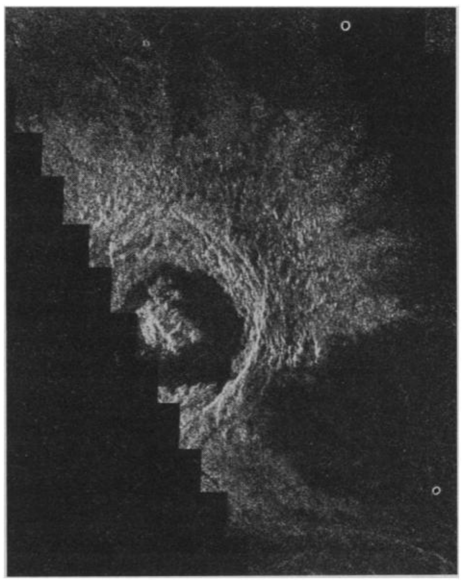

Fig. 1. This image was obtained during the first test of the Magellan radar. The 34-km crater, Golubkina, at 60.5°N, 287.2°, is a typical meteorite impact crater, with terraced inner walls and radar-bright rough ejecta.

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was turned back on for the first time since the first loss of signal. At 9:29 a.m. Pacific daylight time on 15 September, the Magellan spacecraft turned its high-gain antenna away from Earth to start the first radar mapping orbit (orbit 376) using normal operating parameters. The orbit was successfully completed, and mapping operations have proceeded since then, with some data collection gaps (Fig. 2).

In mid-October, three problems were encountered: mechanical vibration occurred during the radar mapping maneuvers, the solar array panels were not pointed in the direction they should have been, and the data replayed from one track of one of the spacecraft's tape recorders was found to show a rapidly increasing error rate. Oscillation in the feedback loop controlling the pointing of the solar panels caused the first two problems. In order to prevent the vibration, the predicted solar position rather than measurements from the sun sensors is now used to control solar-array pointing.

Mapping was suspended for superior conjunction (sun between Venus and Earth) between 26 October 1990 and 10 November (111 orbits). Before superior conjunction Magellan had mapped for 40 days and collected 301 image strips covering 60° of longitude, or almost one-sixth of the planet. The Deep Space Network (DSN) tracking stations had collected 98.8% of the data sent back.

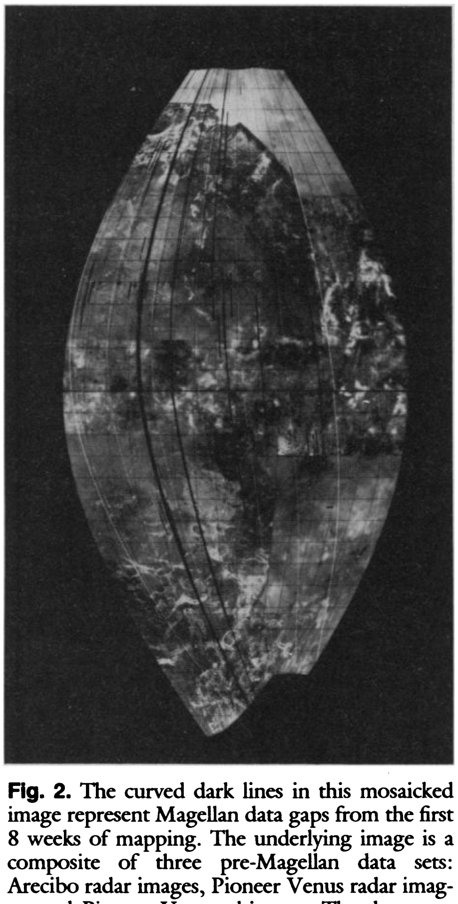

Fig. 2. The curved dark lines in this mosaicked image represent Magellan data gaps from the first 8 weeks of mapping. The underlying image is a composite of three pre-Magellan data sets: Arecibo radar images, Pioneer Venus radar images, and Pioneer Venus altimetry. The data gaps occurred because of DSN outages and pointing errors by the spacecraft.

A third, and considerably shorter, loss-of-signal incident occurred on 15 November when the spacecraft failed to return to Earth pointing. The signal was reacquired 40 minutes later. Automatic sequences reestablished on-board control, but the spacecraft was off-pointed approximately 1.5°, and three orbits were degraded as a result. The quick recovery confirmed the contingency plans established following the earlier loss-of-signal incidents.

By 30 November, it was realized that the remaining two tracks of tape recorder A also were beginning to degrade. Noisy data, seen as an increase in speckle, and an increase in small data gaps were the most common symptoms. Even-numbered orbits, which map southward from the north pole, show the greatest effects between +25° and −16° latitude. In odd-numbered orbits, where the onset of mapping is delayed for approximately 20° of latitude, anomalies linked to the tape recorder are more likely to occur between −8° and −45° latitude. A strategy utilizing a single tape recorder was initiated on 22 December 1990. This single tape recorder strategy results in three small gaps on each orbit. Correction algorithms are being developed to recover most of the data corrupted by the tape recorder problem.

The orbit swaths are now being assembled into mosaics of varying resolution. An initial set of 29 mosaics of full-resolution image data and spanning 5° by 5° (about 530 km on a side) has been produced to provide regional views of the Venusian surface; the locations were chosen to target areas of particular interest such as Maxwell Montes, Alpha Regio, Sif Mons, and Gula Mons.

Ten mosaics were produced as early as possible to test processing capabilities, and as a result may have missing data due to incomplete data processing. This first set was assembled on a test CD-ROM and released to the NASA Space Science Data Center to provide the quickest possible distribution to planetary scientists. All mosaics will be placed on CD-ROMs and distributed in the order that they are produced.

Additional sets of mosaics spanning an increasing area and representing decreasing resolution are planned. Mosaics spanning 15°, 45°, and 120° on a side will have a resolution of 225 m, 675 m, and 2025 m, respectively. These three sets of mosaics are located according to predetermined positioning and thus are processed and completed as a sufficient number of orbits become available.

As of early February 1991, the spacecraft has continued to function nominally and mapping is continuing. Nearly 98% of the data transmitted by the spacecraft are being received. We can expect to map more than 80% of the surface of Venus in the primary mission, which ends 15 May 1991.

Despite the many spacecraft problems, the spacecraft is basically healthy and has a good chance of surviving into the mid-1990s. The lifetime of the single tape recorder may be the limiter for mapping, but the gravity experiment will continue. Like many voyages of discovery, the Magellan story chronicles a succession of problems, and how adversity was overcome to make Magellan's primary mission a success.

The nominal Magellan mission is 243 days, the time it takes the planet to turn once on its axis beneath the plane of the spacecraft orbit. During the second 243-day cycle, the major objective is to fill the gaps in the map. This will include the superior conjunction gap, the Earth occultation gap, as much of the south pole as can be mapped (necessarily right looking), and other major gaps. Toward the end of the second cycle, it will be possible to devote approximately one orbit each day to obtaining high-resolution gravity data. Acquisition of gravity data requires that the high-gain antenna be pointed toward Earth rather than to Venus as is done during mapping. This important objective cannot be met until the spacecraft is on the Earth-facing side of Venus during periapsis (the low point of each orbit).

Several other imaging objectives can be addressed after filling all the major gaps in the map. One important goal is to obtain as much coverage as possible at a constant incidence angle rather than the variable incidence angle obtained in nominal mapping. The incidence angle varies from about 15° near the pole to 45° at periapsis. The variable incidence angle optimizes the coverage for resolution and geologic interpretation of landforms but makes it difficult to compare features between different latitude bands. Another advantage of different incidence angles is the capability to obtain stereo images of many regions.

A promising experiment for the extended mission is radar interferometry. By carefully aligning images obtained from nearly the same vantage point in different cycles, it is possible to obtain interference fringes that can be converted to high-resolution topography (*3*).

Another potentially powerful experiment undergoing analysis is aerobraking the spacecraft into a circular orbit. This would be accomplished by lowering periapsis to allow the atmospheric drag on the spacecraft to lower apoapsis. If this proves feasible, then a valuable set of high-resolution, global gravity data may be obtained. In addition, much higher resolution radar imaging data may be achievable.

REFERENCES AND NOTES

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An Overview of Venus Geology

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The Magellan spacecraft is producing comprehensive image and altimetry data for the planet Venus. Initial geologic mapping of the planet reveals a surface dominated by volcanic plains and characterized by extensive volcanism and tectonic deformation. Geologic and geomorphologic units include plains terrains, tectonic terrains, and surficial material units. Understanding the origin of these units and the relation between them is an ongoing task of the Magellan team.

THE SCIENTIFIC GOALS OF THE MAgellan mission are to improve the knowledge of the geological history of Venus by analysis of the surface morphology and electrical properties and the processes that control them (including tectonic and volcanic histories and evidence for climates different from the present regime) and to improve the knowledge of the geophysics of Venus, principally its density distribution and interior dynamics. In order to accomplish these goals the experimental objectives of the mission are to acquire a global, high spatial resolution radar image of the surface, produce maps of topographic and radar scattering characteristics, and to refine the global gravity field with the use of spacecraft tracking data. With these observations a number of first-order questions on the geologic history and the nature of the geologic processes that have shaped the planet can be addressed (*1*). The data reported in this issue are from the first 6 weeks of Magellan mapping and thus based on coverage of less than 15% of the planet (*2*). Details of the imaging and altimetry data processing are provided elsewhere (*3*).

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In this report, we present an overview of the nature and timing of geological processes in the areas imaged to date. In general, Venus is valuable as a laboratory for testing geologic hypotheses because it lacks a hydrosphere and hence primary features produced by geologic processes have not been extensively eroded (*4*). The dominant processes have been volcanism (*5*) and tectonism (*6*), and it is clear from the relatively low average density of impact craters on the surface that these processes were extremely active during the planet's geologically recent past (*7*).

Soviet and U.S. exploration of Venus began with the U.S. Mariner 2 spacecraft in 1962. In the 1970s, seven Venera landers provided data on the physical and chemical nature of the surface (*8*). Earth-based radar observations of Venus have been made by radiotelescopes at Goldstone, California, and Arecibo, Puerto Rico, and orbiters (Pioneer Venus and Veneras 15 and 16) have provided both radar images and altimetry of the Venus surface. The earliest observations revealed that Venus has fixed features, allowed an estimate of the 243-day retrograde rotation, and provided estimates of surface temperature.

The small-scale morphology of the surface of Venus has been characterized on the basis of lander images provided by Venera 9, 10, 13, and 14 (*8, 9*). Venera 9 showed a steep (~30°) slope of a hill densely covered by decimeter-size plate-like rock fragments and some loose soil in between. Venera 10, 13, and 14 have shown small areas of plains in which the surface is dominated by low-standing, flat-topped outcrops of bedded rocks with variable amounts of loose soil material in local lows.

The chemical composition of surface material has been determined at seven locations (*10, 11*). All of them except the Venera 9 site are in the plains near the equator. Two measurement techniques were used: gamma-ray spectroscopy, which determines the content of K, U, and Th in the surface layer beneath the lander (Venera 8, 9, and 10 and Vega 1 and 2), and x-ray fluorescence, which determines the content of Si, Ti, Al, Fe, Mn, Mg, Ca, K, S, and Cl in a centimeter-size sample taken by drilling beneath the lander (Venera 13 and 14 and Vega 2). At five of the seven landing sites (Venera 9, 10 and 14 and Vega 1 and 2) the surface material is similar in composition to tholeiitic basalt. At the Venera 13 landing site the surface material is similar in composition to terrestrial subalkaline basalt. At the Venera 8 landing site the surface material is similar in composition to alkaline basalts, shoshonites, and syenites. Recently Nikolayeva (*11*) concluded that the material has a quartz monzonite–quartz syenite affinity that resembles parts of Earth's continental crust. The color of the surface material is dark and slightly reddish (*12*). Most of the data (including bedded rocks) indicate that the surface material was friable and porous. Bearing capacity was estimated at 40 to 50 Mg/m^2, and density at 1.4 to 1.5 Mg/m^3. The only exception are data from the gamma-densitometer of Venera 10, which indicated that the density of the rock at the site is as high as 2.8 Mg/m^3 (*9*).

The near-surface temperature (reduced to the topographic datum) measured by Venera and Vega landers was 475 K, the pressure was 90 bar, and the near-surface wind velocity was less than 1 m s^{-1}. The wind was strong enough to gradually decrease the size of a clump of soil thrown onto the supporting ring of the probe during the landing event (*3*).

Goldstone and Arecibo images allowed geologic features on Venus to be studied at a resolution of 1 to 2 km in several areas (*14*). Rift zones were discovered in Beta Regio (*15*), and mountain ranges in Ishtar Terra (*16*) (Fig. 1). Recent Arecibo images of the southern hemisphere of Venus permitted identification of complexly deformed terrain in Alpha Regio (*17*). A major circular feature, Heng-o, identified with Goldstone data (*18*) may be related to hot spot activity (*19*). In general, these data revealed that the Venus surface has a complex and spatially varying tectonic and volcanic history.

In 1978, the Pioneer Venus spacecraft returned radar images from about 40°N to