# Planetary Maps

**Maps to help you find your way around on the Moon and Mars and on some of Earth's neighboring planets and their satellites—**

U.S. Department of the Interior
U.S. Geological Survey

### Extraterrestrial topography

In 1963, human travel to Earth's Moon—dreamed about since the days of Jules Verne—finally became a realistic prospect as the first trip was scheduled.

To land on the Moon, astronauts needed to know the topography and exact locations of their landing sites.

Until 1963, however, all maps of the Moon had been drawn from Earth-based observations, and most of the Moon's place names dated from the 17th century. Cartographers had to make new lunar maps.

Thus began perhaps the most intensive 5 years of effort in planetary cartographic history. A new era of cartography developed from the tools and techniques used to map the Moon, including telescopes, aerial photogrammetry, computers, and television systems carried by spacecraft.

As a reward for these efforts, on July 20, 1969, the two Apollo 11 astronauts who landed on the Sea of Tranquillity carried maps with them to a place never before reached by humans. Their destination had been selected and accurately mapped before their arrival by cartographers working more than 384,000 kilometers (about 238,000 miles) away (see fig. 1).

In the past 25 years or so, remotely controlled, or robotic, spacecraft have produced images of all the known planets of the solar system and their major satellites except for Pluto and its satellite, Charon.

Within this short time, scientists' knowledge and understanding of Earth's neighboring planets have increased exponentially. Much of this new knowledge is derived from the analysis of images acquired by the Voyager spacecraft, two of the longest lived space missions of the National Aeronautics and Space Administration (NASA).

### Mapping the solar system

Historically, the strategy for planetary exploration has been to progress from telescopic observation, to flyby missions, to orbiters, and then to landers, with or without passengers. With each succeeding stage of exploration, the images that have been sent back have been at higher and higher spatial resolutions, yielding sharper and more detailed information.

Through these images, scientists have learned that all planets and their satellites possess some similarities, but each has its own distinct characteristics. The planets closer to the Sun—Mercury, Venus, Earth, and Mars—are rocky silicate bodies. These four so-called terrestrial planets are smaller and denser than the outer gas giants—Jupiter, Saturn, Uranus, and Neptune—which are composed mainly of hydrogen and helium. We still have much to learn about the size and composition of Pluto, the outermost planet of our solar system.

Of the four inner planets, only two have satellites. Earth has one and Mars has two. All the outer planets have satellites. Jupiter is known to have at least 16, Saturn 17, Uranus 15, Neptune 8, and Pluto 1.

All the gas giants have ring systems composed of small particles that orbit the planets in their equatorial planes. While the major satellites of the gas giants have silicate cores, their mantles are composed largely of water ice.

Astronauts from the United States have taken snapshots on the Moon and have brought back samples of its crust. Scientists have mapped the Moon, Mercury, Venus, and Mars, as well as the major satellites of Jupiter, Saturn, Uranus, and Neptune—20 bodies in all—in great detail. There are remotely sensed images of all the planets except Pluto.

### USGS maps of the Moon and planets

In 1960, on behalf of and working closely with NASA, the U.S. Geological Survey (USGS) established an astrogeology program to support lunar and planetary exploration. Systematic mapping of the Moon's surface began at the U.S. Air Force Aeronautical Chart and Information Center (ACIC), using high-quality photographs of the Moon taken from telescopes on Earth. The ACIC effort was moved from St. Louis, Missouri, to Flagstaff, Arizona, in 1961. The USGS used the ACIC base maps for lunar geologic mapping. The U.S. Army Map Service (AMS) also produced a number of lunar maps, especially of the planned Apollo landing sites. ACIC and AMS together published more than 900 maps of the Moon. The USGS began producing base maps from Mariner 9 images of Mars in 1971.

An important goal of the USGS planetary mapping program is to systematically map the geology of the Moon, Mars, Venus, and Mercury, and the satellites of the outer planets. These geologic maps are published in the USGS Miscellaneous Investigations (I) Series.

Planetary maps on sale at the USGS include shaded-relief maps, topographic maps, geologic maps, and controlled photomosaics. Controlled photomosaics are assembled from two or more photographs or images using a network of points of known latitude and longitude. The images used for most of these planetary maps are electronic images, obtained from orbiting television cameras, various optical-mechanical scanning instruments, or radar imaging systems. Photographic film was used only to map Earth's Moon.

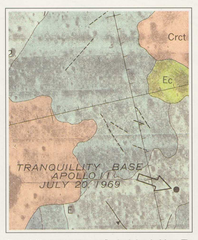


Figure 1. This is where humans first landed on the Moon. The landing site is shown here at a scale of 1:100,000. (Map I-618)

### Map scales

Small-scale maps of entire planets are usually made at the scales of 1:25,000,000 or 1:15,000,000, although the initial mapping of Venus was at the 1:50,000,000 scale. Regional mapping of the planets and satellites is commonly done at the scale of 1:5,000,000 or 1:2,000,000.

Common planetary map scales and the distance equivalents in metric and English units are given in the following table.

| Scale | *1 inch on the map represents this distance on the surface of the planet* Kilometers | Miles |
|---|---|---|
| 1:50,000,000 | 1,270 | 789 |
| 1:25,000,000 | 635 | 394 |
| 1:15,000,000 | 381 | 237 |
| 1:10,000,000 | 254 | 158 |
| 1:5,000,000 | 127 | 79 |
| 1:2,000,000 | 51 | 32 |
| 1:1,000,000 | 25 | 16 |
| 1:500,000 | 13 | 8 |

This publication describes the range of planetary maps available for purchase from the USGS. The descriptions start with Mercury, the closest planet to the Sun, and move outward to Neptune. Except for Earth, Mars is the most extensively mapped planet in the solar system. Map coverage of most of the other bodies is incomplete.

*Acknowledgments:* The technical assistance of Raymond M. Batson, USGS, Flagstaff, Arizona; Jay L. Inge, USGS, Flagstaff, Arizona; and Richard S. Williams, Jr., USGS, Reston, Virginia, is greatly appreciated.

### Where to find maps and colorful images of the planets and satellites in our solar system

For more information about planetary maps, contact any USGS Earth Science Information Center or call 1-800-USA-MAPS.

Planetary maps published or distributed by the U.S. Geological Survey can be purchased from:
USGS Map Sales
Box 25286
Denver, CO 80225
303-236-7477

## Mercury

Mercury is the second smallest planet in our known solar system, and it is the planet closest to the Sun. Its mean distance from the Sun is 58 million kilometers (36 million miles). Its mass is 0.056 that of Earth. Mercury has no known satellites.

USGS maps of Mercury are based on images obtained by Mariner 10. Geologic mapping began in 1975.

A reference mosaic at a scale of 1:10,000,000 was published in 1974. A 1:10,000,000-scale equal-area reference map was published in 1987. Two shaded-relief maps, one with and one without markings, at a scale of 1:15,000,000, were published in 1979.

For mapping at a scale of 1:5,000,000, Mercury was divided into 2 polar maps and 13 quadrangles as shown in figure 2. The polar maps and maps of 7 of the 13 quadrangles were published between 1976 and 1984.

Both polar maps and seven quadrangle maps were published in a shaded-relief edition. Relief shading is a technique for making a map appear three dimensional by adding shadows. In terrestrial maps, the features are shaded to suggest that they are illuminated from the northwest, and shading is based on contour lines. Most planetary maps use western illumination, and feature shading is based on intense scrutiny of image data.

The north polar and six of the seven quadrangle maps of Mercury were also published in a geologic edition (see fig. 3). Some of the published maps have gaps in coverage, and some are partly obscured by darkness. The USGS has also published a shaded-relief map of the Caloris Basin of Mercury at the 1:5,000,000 scale.

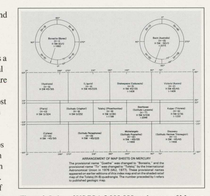


Figure 2. Index of USGS 1:5,000,000-scale maps of Mercury.

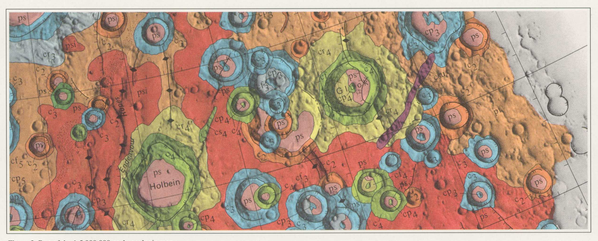


Figure 3. Part of the 1:5,000,000-scale geologic map of the Victoria Quadrangle of Mercury. (Map I-1409)

## Venus

Venus orbits between Earth and Mercury, and its mean distance from the Sun is 108 million kilometers (67 million miles). It is nearly the same diameter and mass as Earth, yet it has evolved quite differently from Earth. Venus is like a giant greenhouse with surface temperatures reaching 482°C (900°F), and it has a dense atmosphere composed of 97 percent carbon dioxide. Venus' surface is completely obscured by thick clouds that can only be penetrated by radar.

The surface of Venus has been studied during the past two decades by Earth-based observations, orbiter spacecraft, and lander spacecraft launched by the Soviet Union and the United States. The data from these missions have shown Venus' surface terrain to be dominated by tectonic activity and volcanism.

The series of maps of Venus produced by scientists from the USGS and the Soviet Union were based on radar image and altimetric data from NASA's Pioneer Venus mission in 1978 and the two Soviet Venera 15 and 16 radar orbiter missions from 1983 to 1985.

In September 1990, NASA's Magellan spacecraft began systematic radar mapping of Venus' surface at resolutions of between 150 and 200 meters. The superb radar images and altimetric data are revealing a high level of surface detail, providing new data on volcanism, tectonism, and the impact cratering process on Venus. New image and topographic maps from the Magellan mission are planned at scales of 1:50,000,00), 1:10,000,000, 1:5,000,000, and 1:1,500,000.

The USGS has published five maps of Venus at a scale of 1:50,000,000. One is an altimetric and shaded-relief map (1981) (see fig. 4). A set of three 1:15,000,000-scale maps was published in 1989 in a historic cooperative mapping effort with the Soviet Union. A geomorphic/geologic map by Soviet authors has also been published by the USGS.

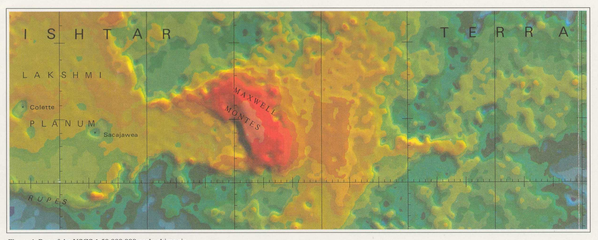


Figure 4. Part of the USGS 1:50,000,000-scale altimetric and shaded-relief map of Venus. (Map I-1324)

## Earth's Moon

The Earth is 150 million kilometers (93 million miles) from the Sun. The mean distance from the center of the Earth to the center of the Moon is 384,321 kilometers (238,663 miles). The Moon's gravity is one-sixth that of the Earth. The Moon's circumference is 10,917 kilometers (6,779 miles), and it has about one-fourth the surface area of the Earth.

Galileo is often regarded as the father of lunar cartography because of telescopic observations he made of the Moon in 1609. But in 1603, the English physician William Gilbert already had drawn a map of the full Moon based on what he could see with the naked eye.

During the 17th century, it was thought that the Moon could serve as a device to measure longitudes for sailors on Earth. This idea inspired a 1645 lunar map by Michel F. Langrenus, an astronomer at the court of King Philip II of Spain. Langrenus' effort did not solve the problem of measuring longitude, but he did identify and name more than 300 lunar features. The Italian, Giovanni Battista Riccioli named the now well-known Sea of Tranquillity on his map of 1651. Astronomer and mathematician Johannes Hevelius was among the most respected lunar cartographers of the 17th century. He built an observatory equipped with the most advanced telescopes of the day. In 1647, he published the *Hevelius Atlas*. Jean Dominique Cassini founded the Paris Observatory and initiated the topographic survey of France. His map of the Moon, published in 1680, is considered one of the most beautiful lunar maps of the 17th century.

In about 1750, Johann Tobias Mayer, a German professor of mathematics, calculated the Moon's axis of rotation. This information was instrumental in determining the Moon's equator and formulating a system of coordinates.

In the 19th century, the German banker William Beer and the astronomer Johann H. Mädler identified a small crater near the lunar equator. Zero degrees longitude was established here, making this crater, Mösting A, the Moon's equivalent of Earth's "Greenwich Meridian." It remains so to this day.

The American rocket scientist, Robert Goddard, effectively launched the space age March 16, 1926, with the flight of his liquid-fueled rocket. His 1919 paper, "A Method of Reaching Extreme Altitudes," suggested a multistage rocket that could travel to the Moon.

### Intensive lunar reconnaissance

*Ranger*. During 1964 and 1965, three Ranger spacecraft succeeded in transmitting television pictures of the Moon's surface before they crashed on the Moon. In 1966, the first soft landing on the Moon by the Soviet unmanned spacecraft, Luna 9, proved that the surface of the Moon was strong enough to support spacecraft and people.

*Lunar Orbiters*. Between May 1966 and January 1968, five Lunar Orbiters acquired 1,474 photographs that showed lunar surface features from various orbital paths and altitudes and provided almost complete image coverage of the surface of the Moon at low to medium resolution. In addition, high-resolution Lunar Orbiter images were used to select landing sites for the subsequent manned missions.

The five Lunar Orbiter missions provided the most valuable data for cartographers. The Lunar Orbiter spacecraft carried complex camera systems in which two separate cameras operated on a single 70-mm strip of film. A clock within the system recorded the time of each exposure. The times were then matched with spacecraft tracking data to determine the exact location on the Moon of each image. The photographs were processed on board the orbiters, scanned electronically, and transmitted as images to Earth. The separate images were assembled into mosaics. Cartographers devised a new Moon-based coordinate system and mapped the lunar far side from the Lunar Orbiter images.

*Surveyors*. Between 1966 and 1968, five U.S. unmanned Surveyor spacecraft made soft landings on the Moon. These landers supplied more than 89,000 closeup pictures and also made chemical analyses of the soil.

*Apollo landings*. The Apollo program culminated in six manned landings between July 1969 and December 1972, all of which returned to Earth with rock and soil samples.

The cameras carried on the Lunar Orbiter and Surveyor missions were not intended for cartographic purposes, and many photographs had only pictorial value. Beginning with the Apollo missions, the spacecraft carried metric cameras needed for photogrammetric mapping. The Apollo missions devoted much effort to acquiring the high-resolution photographs essential for lunar mapping and research on the Moon's geologic history.

*Quality of images*. The spatial resolution of the best telescopic view of the Moon is about 1 kilometer. The best spatial resolutions of the Ranger and Lunar Orbiter images were about 0.5 meter and 1 meter, respectively. The Surveyor and hand-held Apollo astronaut photographs of the Moon's surface had spatial resolutions of less than 1 millimeter.

Figure 5. Shaded-relief map of the lunar far side, 1980. Scale 1:5,000,000. (Map I-1218-B)

*Magnified samples*. Lunar samples brought to Earth by astronauts were examined in laboratories with scanning electron microscopes that can show details as small as a thousandth of a micron. In the 10 years of lunar exploration, scientists' views of the Moon were magnified by a factor of 10 to the 11th power ($10^{11}$).

The U.S. Air Force Aeronautical Chart and Information Center and the U.S. Army Map Service, both now part of the Defense Mapping Agency (DMA), published more than 900 lunar maps prior to 1975.

The USGS has published seven shaded-relief maps of the Moon at a scale of 1:5,000,000. Two maps, a shaded-relief map and a relief map with surface markings, were published for each area of the Moon—the far side (1980) (see fig. 5), the lunar polar regions (1982), and the near side (1991). A seventh map shows the Mare Orientale Basin. In collaboration with DMA, the USGS prepared nine new 1:1,000,000-scale maps, including quadrangles on the lunar far side. These maps were published by DMA.

### Geologic maps of Earth's Moon

Rigorous geologic mapping of extraterrestrial surfaces was first demonstrated, using part of Earth's Moon as an example, by USGS scientists Eugene Shoemaker and Robert Hackman in 1960. Their work led to systematic geologic mapping of the Moon at a scale of 1:1,000,000. The mapping was undertaken in 1961 by the USGS under the auspices of NASA. The first maps were based on telescopic observations from Earth; maps published after 1967 were based on Lunar Orbiter data. The entire near side of the Moon has been mapped at a scale of 1:1,000,000 (see fig. 6).

Most of the Moon's surface has been mapped at a scale of 1:5,000,000 using Apollo photographs and Lunar Orbiter images. Twenty-seven large-scale maps (1:250,000 or greater), including Apollo landing site maps, and a composite 1:5,000,000-scale geologic map of the near side also have been published (see figs. 7 and 8).

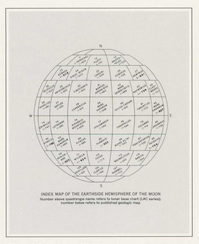


Figure 6. Index of 1:1,000,000-scale base maps of the near side of the Moon.

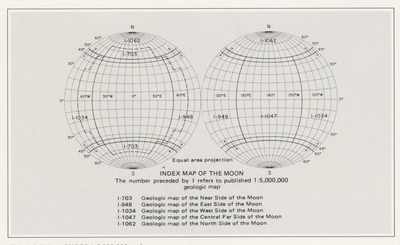


Figure 7 Index of USGS 1:5,000,000-scale geologic maps of the Moon.

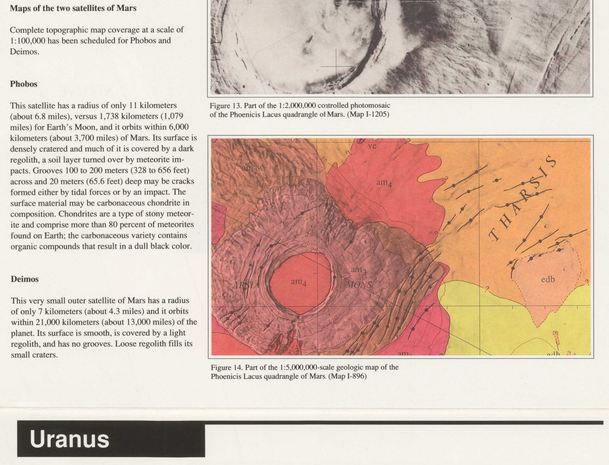


Figure 8. Part of a 1:5,000,000-scale geologic map of the near side of the Moon. (Map I-703)

## Mars

Mars, the fourth planet from the Sun, has two satellites, Phobos and Deimos. Its mean distance from the Sun is 228 million kilometers (142 million miles). Mars is a little more than half the diameter of Earth, but it has no oceans and therefore its surface area is about the same as the land area of Earth. A belt of asteroids orbits the Sun between Mars and Jupiter.

### Early maps of Mars

The first known map of Mars was made in 1840 by lunar cartographers Beer and Mädler. They established a prime meridian on Mars that remains essentially unchanged today.

In 1877, the Italian astronomer Giovanni Virginio Schiaparelli observed Mars and recorded some of its features, including some curious lines he called "canali." When the same phenomena were observed about 10 years later, "canali" had evolved into "canals," and gave rise to tales extolling a superior Martian civilization.

Percival Lowell, an amateur astronomer who was a member of a wealthy and distinguished Boston family, became interested in the Martian "canals." He built an observatory in 1894 at Flagstaff, Arizona, to study Mars. In 1903, he published a map of the canal network and became a leading enthusiast of the theory that the canals were bands of vegetation bordering irrigation ditches dug by intelligent beings. Speculation about intelligent life on Mars climaxed in 1938, when a fictional radio show reported that Martians had landed in New Jersey.

### Full image coverage of Mars

Mariner 4 flew by Mars in July 1965 at a distance of 9,844 kilometers (6,113 miles). It sent back 22 images with a maximum resolution of 3 kilometers (1.86 miles). In February and March 1969, Mariners 6 and 7 flew by Mars at distances of about 3,400 kilometers (about 2,100 miles) and obtained 235 images with a resolution of several hundred meters. These images, for the first time, clearly defined the general nature of the Martian surface.

Mariner 9 began to orbit Mars in November 1971. During nearly a year of operation, it transmitted 6,876 television images covering about 95 percent of the planet. A television image is made up of small units called picture elements (pixels). In spacecraft television images, resolution is expressed as distance per pixel. Thus, each pixel in the image represents a certain distance on the surface of the planet. Mariner 9's cameras achieved resolutions ranging from 1 kilometer (0.621 mile) per pixel to 100 meters (328 feet) per pixel.

Before Mariner 9 ran out of stabilizing fuel to maintain the correct attitude, the little windmill-shaped robot had obtained almost complete image coverage of Mars. Within a month, cartographers had produced a detailed map of the entire planet; it was published in 1972.

The two Viking Orbiters that reached Mars in July and August 1976 returned more than 50,000 images; 1,170 of them, taken from an orbital altitude of about 300 kilometers (186 miles), have a pixel resolution of 6 to 8 meters (19.7 to 26.2 feet). More than 25,000 pictures have a pixel resolution of 100 meters (328 feet) or better.

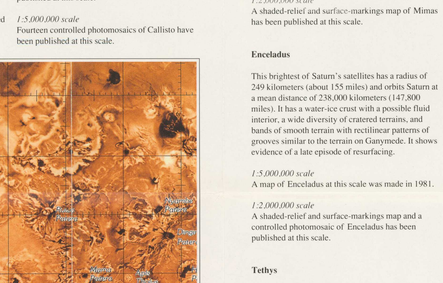


Figure 9. Part of one sheet of Viking Lander 2 rectified photomosaics: Morning scene—camera 1. Rock 1 is 2.4 meters (7.9 feet) from the spacecraft and is 15 centimeters (5.9 inches) wide. Rock 8 is 6.8 meters (22.3 feet) from the spacecraft and is 100 centimeters (39.4 inches) wide. (Map I-1515, sheet 1)

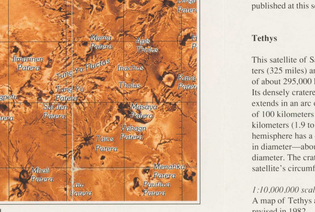


Figure 10. The USGS uses these quadrangles to organize and correlate its 1:5,000,000-scale topographic, shaded-relief, controlled photomosaic, and geologic map coverage of Mars.

### Viking Landers

The Viking Landers returned more than 4,400 images of the Martian surface; maximum pixel resolution was better than 1 millimeter. The Landers also carried out a series of complex experiments that analyzed Martian surface materials for biological, chemical, geological, and physical properties.

*Viking Lander mosaics*. Four sets of mosaics have been published from Viking Lander 1 images, and four sets have also been published from Viking Lander 2 images. Each of the eight sets has five large sheets; part of one sheet is shown in figure 9.

*Martian quadrangles*. The quadrangles used by the USGS to map Mars at the scale of 1:5,000,000 are shown in figure 10.

### Topographic maps of Mars

Topographic data for Mars were developed from various sources. The radius of Mars at certain spots can be determined by radar and tracking data which measure the signal of the spacecraft as it moves behind the planet. These data were combined with photogrammetric plotting from convergent stereoimages to depict contour lines.

Planetwide topographic maps of Mars have been published at the 1:25,000,000 scale and at the 1:15,000,000 scale.

Regional maps of Mars are available at the following scales:

*1:5,000,000 scale*
Topographic maps of 17 of the 30 Martian quadrangles have been compiled with Mariner 9 data and published. They have contour intervals of 1 kilometer. One such quadrangle map is shown in figure 11. New topographic maps based primarily on Viking data are being made, in this format, of at least 70 percent of Mars.

*1:2,000,000 scale*
Forty-three contour maps at this scale are available for parts of Mars.

*1:1,000,000 scale*
Five topographic maps have been published at this scale: the Viking C1 landing site in the Capri Region of Mars, the Chryse Region, the Cydonia Region, the Erythraeum Region, and the Nereidum Montes Region.

### Shaded-relief maps of Mars

*1:25,000,000 scale*
A new planetwide map at this scale based on Viking Lander data has been published.

*1:15,000,000 scale*
In addition to five earlier maps at this scale, a new three-sheet planetwide set of albedo (light and dark patterns) and shaded-relief maps has been published.

*1:5,000,000 scale*
See figure 12.

*1:2,000,000 scale*
Two shaded-relief maps at this scale are of Phoenicis Lacus, NW, and of Coprates, NW.

*1:1,000,000 scale*
Six shaded-relief maps at this scale are of the Erythraeum Region, the Nereidum Montes Region, the Trivonis Lacus Region, (Viking A2 landing site), the Chryse Region, the Cydonia Region, and the Capri Region (Viking C1 landing site).

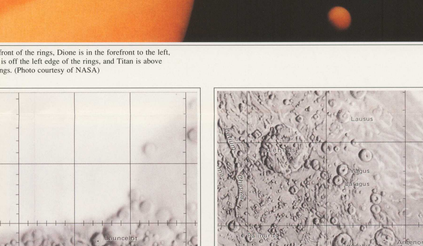


Figure 11. Part of the 1:5,000,000-scale topographic map of the Phoenicis Lacus quadrangle of Mars. (Map I-984)

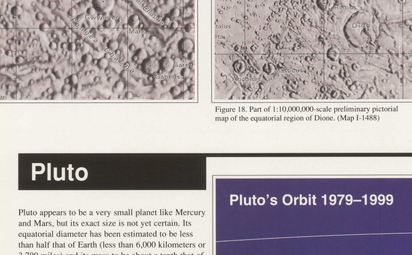


Figure 12. Part of the 1:5,000,000-scale shaded-relief map of the Phoenicis Lacus quadrangle of Mars. (Map I-1252)

### Controlled photomosaics of Mars

*1:2,016,000 scale*
This map of the Olympus Mons Region was published in 1981.

*1:2,000,000 scale*
The controlled photomosaics of Mars are based on subdivisions of the 30-quadrangle scheme used for the 1:5,000,000-scale topographic and geologic maps of Mars. Longitudinal boundaries of the quadrangles for the photomosaics do not always coincide with those of the 1:5,000,000 scheme. A full set of the photomosaics contains 138 sheets (see fig. 13).

*1:500,000 scale*
Nearly 200 controlled photomosaics cover selected areas of Mars at this scale.

*1:250,000 scale*
Three controlled photomosaics at this scale cover the Canberra Region (Viking 2 landing site), the Cydonia Region, and the Yorktown Region (Viking 1 landing site).

### Geologic maps of Mars

A program to map the geology of Mars was begun in 1971 for NASA by geologists at the USGS, NASA field centers, and universities.

*1:25,000,000 scale*
A geologic map of Mars at this scale is synthesized from the 1:5,000,000-scale maps described below.

*1:15,000,000 scale*
The three geologic maps at this scale are titled Polar Regions, Western Equatorial Region, and Eastern Equatorial Region. A new geologic map at this scale has been published.

*1:5,000,000 scale*
Thirty quadrangles have been mapped at this scale using Mariner 9 data (see fig. 14).

*1:2,000,000 scale*
Fifteen large-scale geologic lava-flow maps at this scale show areas of special interest.

### Maps of the two satellites of Mars

Complete topographic map coverage at a scale of 1:100,000 has been scheduled for Phobos and Deimos.

### Phobos

This satellite has a radius of only 11 kilometers (about 6.8 miles), versus 1,738 kilometers (1,079 miles) for Earth's Moon, and it orbits within 6,000 kilometers (about 3,700 miles) of Mars. Its surface is densely cratered and much of it is covered by a dark regolith, a soil layer turned over by meteorite impacts. Grooves 100 to 200 meters (328 to 656 feet) across and 20 meters (65.6 feet) deep may be cracks formed either by tidal forces or by an impact. The surface material may be carbonaceous chondrite in composition. Chondrites are a type of stony meteorite and comprise more than 80 percent of meteorites found on Earth; the carbonaceous variety contains organic compounds that result in a dull black color.

### Deimos

This very small outer satellite of Mars has a radius of only 7 kilometers (about 4.3 miles) and it orbits within 21,000 kilometers (about 13,000 miles) of the planet. Its surface is smooth, is covered by a light regolith, and has no grooves. Loose regolith fills its small craters.

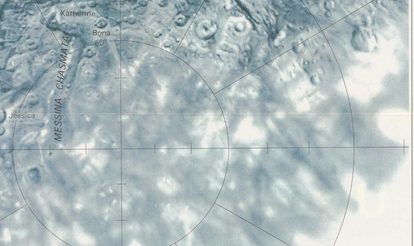

Figure 13. Part of the 1:2,000,000 controlled photomosaic of the Phoenicis Lacus quadrangle of Mars. (Map I-1205)

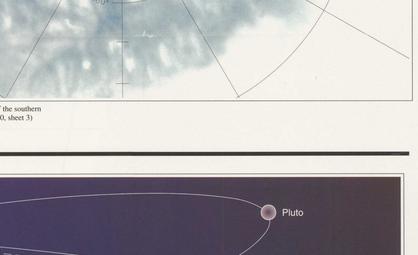


Figure 14. Part of the 1:5,000,000-scale geologic map of the Phoenicis Lacus quadrangle of Mars. (Map I-896)

## Jupiter

### The four gas giants

Jupiter, Saturn, Uranus, and Neptune are composed almost entirely of gas. They may have small silicate cores, but there is no plan to examine, much less to map the cores, if they exist. Features visible to Voyager were cloud patterns that changed hourly. Photomosaics of the atmospheric features have been made on map projections, but these will not be published as map sheets.

### Satellites of Jupiter

Jupiter has 16 known satellites. The four largest, Io, Europa, Ganymede, and Callisto, are called Galilean because they were discovered by Galileo. Jupiter is by far the largest planet in the solar system, with a diameter of 142,900 kilometers (about 88,700 miles). Jupiter orbits between Saturn, the next largest planet, and the asteroid belt. Its mean distance from the Sun is 778 million kilometers (483 million miles).

In 1981, NASA initiated a program, under the management of the USGS, to map the surface features and geology of the satellites of Jupiter using Voyager flyby image data.

### Io

Io, with a radius of 1,821 kilometers (about 1,130 miles), is almost the same size as Earth's Moon. Io orbits within 422,000 kilometers (about 262,100 miles) of Jupiter. Eight active volcanoes were detected by Voyager, and the surface of the satellite is constantly renewed by volcanic activity. Io's yellow-orange color is caused by sulfur compounds.

*1:25,000,000 scale*
A preliminary pictorial shaded-relief map of Io at this scale was made by the USGS in 1980 for the Voyager imaging team.

*1:15,000,000 scale*
A shaded-relief and surface-markings map, a shaded-relief map, and an exaggerated natural color, controlled photomosaic map of Io were completed in 1987 (see fig. 15).

*1:5,000,000 scale*
An airbrush map of the Colchis region, and related airbrush and geologic maps of Ruwa Patera and Lerna have been published at this scale.

*1:2,000,000 scale*
Controlled photomosaics at this scale of Kane Patera and Ra Patera were completed in 1983. A geologic map at this scale of Ra Patera was completed in 1988.

*1:1,000,000 scale*
Two controlled photomosaics of Massaw Patera have been completed, one in 1983 and the other in 1987.

### Europa

This brightest of Jovian satellites has a radius of 1,565 kilometers (about 972 miles) and orbits within 671,000 kilometers (about 416,700 miles) of Jupiter. It has a thin water-ice crust, a mantle of liquid water or softer ice, and a rocky core. A large-scale fracture and ridge system appears in its crust. The scarcity of impact craters on its surface implies a continual resurfacing process with new ice welling up along fractures.

*1:25,000,000 scale*
A preliminary pictorial map of Europa was prepared by the USGS for the Voyager imaging team in 1979.

*1:5,000,000 scale*
A controlled mosaic (1984) and a shaded-relief and surface-markings map (1985) of the Pelorus Linea region have been published. A controlled photomosaic (1985), a shaded-relief (1984), and a topographic map (1985) of the Sidon Flexus region also have been published.

### Ganymede

This largest of planetary satellites has a radius of 2,634 kilometers (about 1,636 miles) and orbits within 1.1 million kilometers (about 683,100 miles) of Jupiter. It has a water-ice crust and a rocky core. Its surface has bright ray craters, light linear stripes, grooved terrain with many faults, and regions of dark, heavily cratered terrain. There is evidence of tectonic movement of the crust and resurfacing.

*1:25,000,000 scale*
A preliminary pictorial map of Ganymede was prepared by the USGS for the Voyager imaging team in 1980.

*1:15,000,000 scale*
A new pictorial map of Ganymede at this scale will be published.

*1:5,000,000 scale*
Shaded-relief and surface-markings maps and airbrush base maps of some of the quadrangles of Ganymede have been published at this scale. Geologic maps of the Philus Sulcus and Uruk Sulcus quadrangles have also been published.

### Callisto

This satellite has a radius of 2,403 kilometers (about 1,492 miles) and orbits within 1.8 million kilometers (about 1.1 million miles) of Jupiter. It has a thick water-ice crust and a rocky core. Its surface is ancient and heavily cratered. Large concentric rings are the remnants of several impact basins. There is no evidence of crustal motion or internal activity.

*1:25,000,000 scale*
A pictorial map of Callisto was prepared for the Voyager imaging team in 1980.

*1:15,000,000 scale*
One controlled photomosaic of Callisto has been published at this scale.

*1:5,000,000 scale*
Fourteen controlled photomosaics of Callisto have been published at this scale.

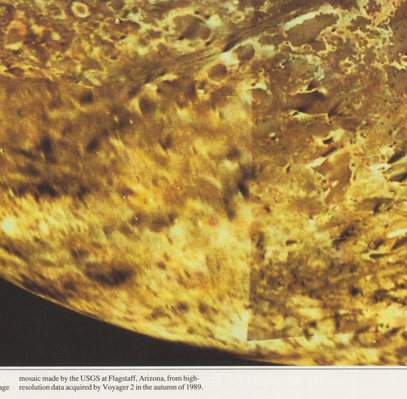


Figure 15. Part of the 1:15,000,000-scale shaded-relief and surface markings map of Io. (Map I-1713)

## Saturn

Saturn has 17 satellites, including Mimas, Enceladus, Tethys, Dione, Rhea, and Iapetus. It is the second largest planet in the solar system and orbits between Jupiter and Uranus. Its mean distance from the Sun is 1.4 billion kilometers (or about 870 million miles).

In 1980, Voyager 1 passed Saturn after a journey of more than 1.5 billion kilometers (930 million miles) and sent back many remarkable images of that planet (see fig. 16).

### Mimas

This satellite has a radius of 199 kilometers (124 miles) and orbits Saturn at a mean distance of 186,000 kilometers (about 116,000 miles). It has a densely cratered surface. A giant impact crater spans about a third of the diameter of the satellite. Grooves up to 90 kilometers (55.9 miles) long, 10 kilometers (6.2 miles) wide and 1 to 2 kilometers (0.6 to 1.2 miles) deep may be fractures resulting from the impact that formed the large crater or from tidal forces.

*1:5,000,000 scale*
A map of Mimas at this scale was made in 1981 and revised in 1982 (see fig. 17).

*1:2,000,000 scale*
A shaded-relief and surface-markings map of Mimas has been published at this scale.

### Enceladus

This brightest of Saturn's satellites has a radius of 249 kilometers (about 155 miles) and orbits Saturn at a mean distance of 238,000 kilometers (147,800 miles). It has a water-ice crust with a possible fluid interior, a wide diversity of cratered terrains, and bands of smooth terrain with rectilinear patterns of grooves similar to the terrain on Ganymede. It shows evidence of a late episode of resurfacing.

*1:5,000,000 scale*
A map of Enceladus at this scale was made in 1981.

*1:2,000,000 scale*
A shaded-relief and surface-markings map and a controlled photomosaic of Enceladus has been published at this scale.

### Tethys

This satellite of Saturn has a radius of 523 kilometers (325 miles) and orbits Saturn at a mean distance of about 295,000 kilometers (about 183,000 miles). Its densely cratered ice surface has a trough that extends in an arc of 140 degrees at an average width of 100 kilometers (62 miles) and a depth of 3 to 5 kilometers (1.9 to 3.1 miles). Its outward-facing hemisphere has a crater 400 kilometers (248 miles) in diameter—about 40 percent of the satellite's diameter. The crater floor has rebounded to the satellite's circumference.

*1:10,000,000 scale*
A map of Tethys at this scale was made in 1981 and revised in 1982.

*1:5,000,000 scale*
A shaded-relief and surface-markings map and a controlled photomosaic of Tethys has been published at this scale.

### Dione

This satellite of Saturn has a radius of 560 kilometers (about 348 miles) and orbits Saturn at a mean distance of 377,000 kilometers (about 234,000 miles). Its densely cratered ice surface has large regional variations in albedo, a complex network of bright wispy linear markings that may be controlled by a regional system of fractures. Differing crater populations of various terrains on the surface of Dione imply one or more resurfacing events in its past.

*1:10,000,000 scale*
A map of Dione at this scale was made in 1981 and revised in 1982 (see fig. 18).

*1:5,000,000 scale*
A shaded-relief and surface-markings map of Dione and a controlled photomosaic have been published at this scale.

### Rhea

This satellite has a radius of 764 kilometers (475 miles) and orbits Saturn at a mean distance of 527,000 kilometers (327,000 miles). Its densely cratered ice surface has large regional variations of light and dark terrains. It has bright wispy streaks similar to those on Dione. Large craters are irregularly shaped. Rhea has no flattened craters.

*1:10,000,000 scale*
A map of Rhea was made at this scale in 1981 and revised in 1982.

*1:5,000,000 scale*
A two-sheet set containing equal-area, Mercator, and stereographic photomosaics of Rhea was made at this scale in 1988.

### Iapetus

Iapetus has a radius of 718 kilometers (about 446 miles) and orbits Saturn at a mean distance of 3.5 million kilometers (about 2.2 million miles). One hemisphere is very dark and the other is very bright. Some craters in the bright hemisphere have dark floors. Dark material of unknown origin may be a coating derived from other bodies or it may have surfaced from the interior. Although the resolution of the Voyager images at the flyby distance is too low to identify craters directly, albedo patterns on the surface suggest their presence.

*1:10,000,000 scale*
A map of Iapetus was made at this scale in 1982. A revised shaded-relief and surface-markings map and a controlled photomosaic have been published at this scale.

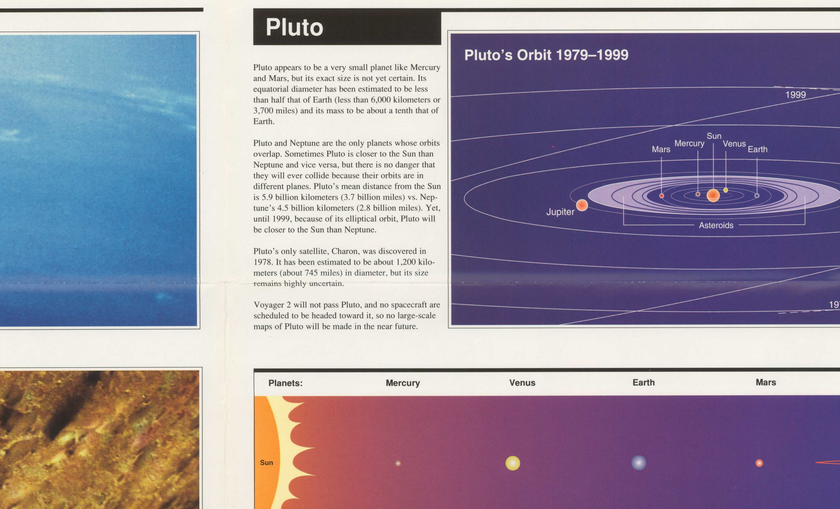

Figure 16. This montage shows Saturn and six of its largest satellites. Moving clockwise from the right, Tethys and cratered Mimas are in front of the planet, Enceladus is in front of the rings, Dione is in the forefront to the left, Rhea is off the left edge of the rings, and Titan is above the rings. (Photo courtesy of NASA)

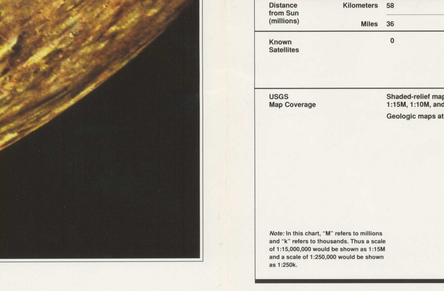


Figure 17. Part of the 1:5,000,000-scale preliminary pictorial map of Mimas. (Map I-1489)

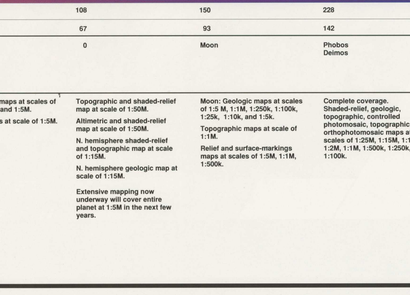


Figure 18. Part of the 1:10,000,000-scale preliminary pictorial map of the equatorial region of Dione. (Map I-1488)

## Uranus

Uranus is the third largest planet and orbits between Saturn and Neptune. It is the seventh planet from the Sun at a mean distance of 2.9 billion kilometers (or 1.8 billion miles), and its mass is about 15 times that of Earth.

Uranus is composed of hydrogen and helium and has a rocky core. Its atmosphere contains more methane than Jupiter's or Saturn's, and it has a complex system of at least five dark rings. It has 15 satellites—10 new ones discovered by Voyager and 5 known previously: Ariel, Umbriel, Titania, Oberon, and Miranda. Miranda has one of the most complex fractured surfaces yet discovered on any satellite.

*1:10,000,000 scale*
A map of Titania, Oberon, anc Umbriel at this scale was published in 1988 (see fig 19).

*1:5,000,000 scale*
Maps of Ariel at this scale were published in 1988.

*1:2,000,000 scale*
Maps of Miranda at this scale were published in 1988.