

NASA Contractor Report 3390

Status and Future
of Extraterrestrial
Mapping Programs

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Status and Future of Extraterrestrial Mapping Programs

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STATUS AND FUTURE OF EXTRATERRESTRIAL
MAPPING PROGRAMS

ABSTRACT

Extensive mapping programs have already been completed for the Earth's moon and for the planet Mercury. Mars, Venus, and the Galilean satellites of Jupiter (Io, Europa, Ganymede, and Callisto), are currently being mapped. The two Voyager spacecraft are expected to return data from which maps can be made of as many as six of the satellites of Saturn and two or more of the satellites of Uranus. The standard reconnaissance mapping scales used for the planets are 1:25,000,000 and 1:5,000,000; where resolution of data warrants, maps are compiled at the larger scales of 1:2,000,000, 1:1,000,000 and 1:250,000.

Planimetric maps of a particular planet are usually compiled first. The first spacecraft to visit a planet is usually not designed to return data from which elevations can be determined. As exploration becomes more intensive, however, more sophisticated missions return photogrammetric and other data to permit compilation of contour maps.

INTRODUCTION

This paper presents a brief review of extraterrestrial mapping missions, mapping techniques, and status of mapping programs.

The known mappable area in the solar system is approximately 1.6×10^9 square kilometers of which less than 10% is represented by the land area of the earth (Figure 1). Maps of various scales will have been completed of most of this area by the end of the present decade.

Jupiter, Saturn, Uranus and Neptune are not included in the above figure, nor in current mapping plans, because there may be no solid surface beneath their heavy atmospheres. Pluto and the moons of Neptune also are not included because their sizes are not accurately known and because they would add only a tiny increment to the total area. Tiny, irregular satellites such as Phobos and Deimos (Mars) and Amalthea (Jupiter) and several Saturnian satellites have shapes that defy portrayal in conventional map format. Cartographic treatment of these bodies is planned, but is not yet sufficiently defined to discuss here.

Extraterrestrial mapping began in earnest in the United States in 1960, when the Aeronautical Chart and Information Center (ACIC) of the U.S. Air Force began working with Lowell Observatory, Flagstaff, Arizona, to map the moon by telescopic observation. Since that time 32 American spacecraft have gathered data for mapping fourteen planets*, not including the earth. The Soviet Union has an active program of extraterrestrial mapping, but this paper discusses only the American efforts.

Typically, the first missions to a planet provide data for reconnaissance mapping at low resolution, and data for small, disconnected areas at high resolution. On these missions, the spacecraft flies past the planet, taking pictures and gathering other data as it passes. Planimetric maps are compiled with scales on the order of 1:25,000,000 to 1:5,000,000. Later, more sophisticated programs involve systematic data gathering from orbit. Such data usually permit planimetric, and sometimes topographic, mapping at scales of 1:5,000,000 and larger. When a landing is contemplated, an intensive effort is made to do large-scale (1:1,000,000, 1:250,000, and larger) contour mapping of candidate landing sites. Maps at scales of 1:100, 1:10, and even 1:1 are commonly made with information from landed spacecraft. Except in the case of the moon, maps at scales larger than 1:1,000,000 presently cover only miniscule areas of the planets.

No planet besides the earth has been as intensively mapped as the moon, in large part because its relative accessibility allowed intensive exploration at comparatively low cost. Much lunar mapping was done at larger scales and by more traditional methods (including the use of wide angle mapping cameras, with film returned to the earth) than was the mapping of other planets. The details of these large scale lunar mapping programs are not discussed in this paper.

*In this paper, the word "planet" will be used to refer to all bodies being mapped, whether they are true planets or are satellites of planets.

Mapping has usually been a secondary goal of planetary spaceflights. Instrumentation and data gathering sequences are designed for gathering geophysical, geochemical, meteorological, astronomical, and other data. The planetary cartographer must adapt to this condition. Imaging systems on the spacecraft usually have very narrow fields of view, and can be used for photogrammetry only by carefully planning (or fortuitously obtaining) convergent imaging sequences. The problems and techniques of planetary mapping are therefore rather different than those of terrestrial, or even lunar mapping.

EARTH-BASED EXTRATERRESTRIAL MAPPING PROGRAMS

Telescopic observations: Maps of the moon and planets have been made ever since the telescope was invented, early in the seventeenth century. In the case of the planets, the best resolution attainable even with modern telescopes is of the order of tens or hundreds of kilometers. For example, the best telescopes, under the best viewing conditions, produce an image of Mars comparable to that obtained by viewing an American ten-cent piece with the naked eye from a distance of two meters. Mapping broad surface-coloration patterns on Mercury, Mars, and the four largest satellites of Jupiter is possible under such conditions, but most surface relief is not identifiable until features with dimensions of twenty kilometers or less can be resolved.

Features with dimensions of only a few hundred meters can be identified on the moon under ideal conditions with modern telescopes. During the 1960s, ACIC, in cooperation with Lowell Observatory, made a series of shaded relief maps of the near side of the moon at a scale of 1:1,000,000, based on telescopic observation (Kopal and Carder, 1974). Few of these maps have been revised, even though much more detailed information is now available from spacecraft.

In general, relief on the moon is difficult to measure with a telescope. Some slopes and heights on the limb of the moon have been measured. Relative heights of mountains and depths of craters have been determined by shadow measurements. These measurements at best are accurate only to $\pm 1/4$ to $1/2$ km. A limited stereoscopic effect is present in telescopic pictures of the moon taken at different librations. The results obtained by using this effect for topographic mapping are questionable.

Earth-based radar: Radar antennas on the earth have been engaged in mapping the moon, Mars, and Venus for nearly two decades. Earth-based radar mapping of the moon has resulted in low resolution images and an unpublished array of elevations that may be useful to future mapping programs. Hundreds of east-west profiles have been made in the equatorial regions of Mars. Relative accuracies of these profiles are on the order of tens of meters, but since it is not possible to close the profiles, their absolute accuracy is not known.

Radar mapping of Venus consists of images with resolutions of 5 to 20 km showing radar brightness. Surface roughness can be inferred from these images but interpretation of landforms is difficult. Since Venus always presents the same face to earth during favorable radar apparitions, only that face has been mapped from earth.

EXTRATERRESTRIAL MAPPING SPACECRAFT

Planets that have been or are in the process of being mapped are shown in figure 2, along with names of those spacecraft with mapping capability, that have or will visit the planet. A brief description of each of these missions follows.

Ranger: Three Ranger spacecraft returned nearly 16,000 pictures of small areas on the moon during 1964 and 1965. The spacecraft were programmed to crash into the moon at specified locations, taking pictures until impact. The pictures ranged in resolution from several hundred meters to smaller than one meter. Although stereophotogrammetry is feasible with these pictures, few contour maps were made because of the difficulty in accommodating a near-vertical baseline in the stereoplotters of that time. Thirteen planimetric shaded relief maps (some showing photogrammetrically derived spot elevations) were made with Ranger pictures at scales varying between 1:1,000 and 1:250,000. These maps covered nearly 30,000 km², less than 0.1% of the lunar surface.

Surveyor: Five Surveyor spacecraft landed on the moon during 1966 and 1967, returning nearly 90,000 high resolution pictures from a height of 1.5 m above the lunar surface. Sketch maps were made with Surveyor pictures at scale of 1:1 to 1:100 to illustrate scientific reports, but none were published as individual maps. Techniques used included analytical stereoscopic photogrammetry with pairs of pictures consisting of one view directly with the spacecraft television camera and a second view reflected in mirrors placed on the spacecraft. Contour maps were also made by locating areas of good focus in pictures taken with different focus settings. Since the image geometry and focus setting were known, the location of objects in good focus could be computed. Spot elevations were measured on distant features through determination of vertical angles with Surveyor pictures and horizontal distances with Lunar Orbiter pictures.

Lunar Orbiter: The most comprehensive mapping data set for the moon consists of just under 1,500 pictures taken by five Lunar Orbiter spacecraft. These missions were flown during 1966 and 1967. Seventy millimeter film was exposed by the Lunar Orbiter cameras and developed automatically on board the spacecraft. Strips of each frame 2.5 mm wide were then scanned with a microdensitometer and transmitted like television signals to earth receiving stations. They were then reconstituted on strips of 35 mm film, which were mosaicked to reconstruct the original frame at much enlarged scale. Although a strong stereoscopic effect is present in many Lunar Orbiter picture pairs, the internal geometry of the imaging system is inconsistent, and stereophotogrammetry with the images is marginally satisfactory at best. Image resolution is outstanding, however. Many selected areas have been photographed by Lunar Orbiters 1, 2, 3, and 5 with coverage at one to five meter resolutions. Lunar Orbiter 4 photographed nearly all of the nearside of the moon at resolutions of 60-80 m.

Apollo: The Apollo manned orbital missions carried a variety of sophisticated mapping equipment, including three-inch focal length mapping cameras (resolution about 25 m), optical-bar panoramic cameras (resolution about 1 m) and a variety of hand-held cameras using 35 and 70 mm film. Apollo 17 carried a radar sounding instrument for precise profiling. Retroreflectors were

installed at several landing sites, allowing precise geodetic data to be gathered by laser ranging from earth. The astronaut crews on the surface took more than 6,300 70 mm pictures that were used to make sample-site maps and to locate traverses and sample sites on orbital pictures by resection.

Systematic mapping of nearly 10% of the Lunar surface at 1:250,000 was made possible by the orbiting Apollo mapping cameras. These maps are ortho-photo mosaics with contour lines.

Mariners 4, 6, 7, and 9: These spacecraft provided the first views of martian topography. In 1965, Mariner 4 returned 22 pictures showing that craters exist on the surface of Mars. Mariner 9, the first spacecraft to orbit a planet other than the earth and the moon, revealed spectacular martian volcanos and canyons. This mission returned more than 7,000 pictures and permitted the compilation of a planetwide planimetric control net (Davies and Arthur, 1973) and the systematic mapping of all of Mars at 1:5,000,000 (Batson and others, 1979). Special mapping of selected areas was done at 1:1,000,000 and 1:250,000. Mariner 9 pictures have resolutions of 1 to 3 km over 98% of the planet. High-resolution Mariner 9 pictures (100-500 m) cover about 1% of the planet.

The gravitational figure of Mars was determined by measurement of deviations in the orbit of Mariner 9. Topographic elevations were derived from planetary radii determined by occultations of signals from the spacecraft as it passed behind Mars. Spectroscopic measurements of atmospheric pressures at the surface were made with spacecraft instruments. These, together with earth-based radar measurements were tied to the occultation measurements and used to make a 1 km contour map of all of Mars (Wu, 1978).

Mariner 10: Launched in 1973, and active until March of 1976, Mariner 10 returned digital television pictures of four planets: the earth, the moon, Venus and Mercury. Although the pictures of the earth and moon were taken by the departing spacecraft primarily to test the spacecraft and camera systems, many of the pictures of the north polar regions of the moon cover areas that were inadequately photographed by Lunar Orbiter 4. These pictures aided in the compilation of the recent 1:5,000,000 map of the north polar region of the moon, and could be used to expand the lunar control net.

Mariner 10 returned many pictures of Venus, but these show only clouds and are more interesting to atmosphericists than to cartographers.

The spacecraft's orbit around the sun took it past the planet Mercury three times, providing the only data set yet available for mapping that body. Unfortunately, the illumination of Mercury was identical on all three passes, so that somewhat less than 50% of its surface was scrutinized by Mariner 10 cameras. Resolution of the Mariner 10 pictures of Mercury ranges from several kilometers for most of the illuminated face to about 100 m for small, scattered areas.

Viking 1 and 2: In 1976 two Viking spacecraft landed on Mars. Their imaging systems permitted compilation of detailed maps of about 400 m² at scales ranging from 1:10 to 1:100. These maps have been used as illustrations in scientific reports, but have not yet been published as individual maps.

The Viking orbiters have returned over 50,000 pictures of Mars. Large areas in the equatorial region have coverage with resolution on the order of 7 to 30 m and 90% or more of the planet has now been covered with pictures having resolutions of 100 to 150 m. The equatorial zone and parts of the polar regions have stereoscopic coverage adequate for mapping 500 to 1,000 m contour intervals. A few very small areas have stereoscopic coverage permitting mapping at contour intervals of 20 to 100 m.

The Viking Orbiter cameras were capable of returning reasonably accurate multispectral information in the form of pictures taken through calibrated color filters. In addition to providing valuable geochemical information, these pictures are being composited and used to make controlled photomosaics in color.

Voyager 1 and 2: In 1979, these spacecraft passed through the Jovian system, transmitting thousands of pictures of Jupiter's clouds, and more than 2,500 pictures of its four largest satellites and the tiny satellite Amalthea. In 1980 and 1981 the Voyagers will pass through the Saturnian system and are scheduled to return pictures of six satellites of Saturn. In 1986, Voyager 1 may be programmed to pass through the Uranian system, and to return pictures of two or more satellites of Uranus.

Voyager pictures of the five Jovian satellites have resolutions of 500 m to 20 km. They also have multispectral capability, permitting color mapping. Batson and others (1980) have described plans for mapping the Galilean satellites of Jupiter.

Pioneer Venus: During 1979 and 1980, the Pioneer Venus spacecraft returned radar sounds and low resolution radar images of the surface of Venus. The radar soundings have permitted compilation of a contour map with an interval of 500 m for about 80% of the Venusian surface (Pettengill and others, 1979; Pettengill and others, 1980). The spot size of the soundings is about 50 km, however, so only continental-scale landforms are delineated.

A low resolution radar imaging system was used between about 40° N and 20° S latitudes. These images have roughly the character and resolution of earth-based radar images, and are used to supplement the earth-based images and to extend the coverage to areas inaccessible to earth-based radar (Masursky and others, 1980).

Galileo: Planned for launch from the earth-orbiting Shuttle spacecraft in 1985, Galileo will orbit Jupiter and return high resolution pictures of Jupiter's clouds and of its four largest satellites. If acquired, these pictures will augment and improve on the quality of the Voyager pictures, and will permit more complete mapping of those satellites at 1:5,000,000 as well as mapping of selected areas at scales of 1:1,000,000 and perhaps larger.

Data gathering sequences are not yet complete for the Galileo mission, so mapping coverage cannot yet be determined.

Venus Orbiting Imaging Radar (VOIR): Planned for 1986, this is the second mission (after Lunar Orbiter) devised specifically for mapping the surface of another planet. Since Venus is covered by a layer of thick clouds, the mapping will be done with L-band synthetic aperture radar (SAR) images.

The orbit will be circular and so inclined as to pass within about five degrees of the poles. Systematic mapping images will have resolutions of approximately 600 m. They will cover bands on the surface approximately 50 km wide and hundreds of kilometers long. A high resolution mode will permit taking images in selected areas with 150 m resolution, in bands about 12 km wide. Stereoscopic images will be taken of selected areas, permitting contour mapping with intervals on the order of 150 m. As many as 300,000 images may be returned.

The use of star cameras on the spacecraft and techniques of very long based interferometry (VLBI) may permit accurate location of surface features with an accuracy of less than 1 km.

The VOIR mission has not yet been approved by Congress, and many details relating to the mapping have yet to be decided. If this mission takes place, it will be the most comprehensive and sophisticated mission yet undertaken to map another planet.

MAPPING TECHNIQUES

Map design: Maps of extraterrestrial bodies fall into three main classifications according to scale. Synoptic maps show the whole planet in one or three sheets. Where the three sheet format is used, the polar regions are shown on stereographic projections on one sheet and the equatorial zone on mercator projections on two separate sheets. Scales of the synoptic maps are 1:50,000,000, 1:25,000,000, 1:15,000,000 and 1:5,000,000, depending on the size of the planets (Table 1).

When resolution of data warrants, planets are further divided into quadrangles for systematic mapping at scales of 1:5,000,000, 1:2,000,000 or 1:1,000,000. Polar stereographic, lambert conformal conic, and mercator projections are used (Table 2). The part of the moon that was photographed by Apollo was further sub-divided into 1:250,000 scale quadrangles, which were mapped on transverse mercator projections.

Map quadrangles are named for distinctive features that lie wholly or partially within map boundaries. In the case of Mars, the 30 1:5,000,000 quadrangles were named for telescopically observed albedo features prior to the identification and naming of any topographic features. Mercury maps carry two designations: the primary name is that of a distinctive topographic feature. A secondary name identifying the telescopically observed albedo province is shown in parentheses under the primary name.

Image processing: One of the most fundamental problems in utilizing spacecraft images for mapping is the correction of geometric distortions. The only low distortion mapping camera used on planetary spacecraft to date was the three-inch focal length Apollo mapping camera. Pictures taken by this camera can be used directly in conventional stereoplotting equipment, without special preprocessing. Although the image resolution on Lunar Orbiter pictures is exceptional, their geometry was seriously degraded by segmenting them into strips for transmission. After Lunar Orbiter 1, a reseau was pre-exposed on the flight film, allowing some measure of control, but the Lunar Orbiter pictures in general remain a photogrammetrist's nightmare.

Digital television imaging systems are used for planetary exploration beyond the moon. Although their very narrow fields of view cause severe photogrammetric problems, digital images lend themselves to rigidly controllable computer processing. This processing includes noise removal, correction of internal image geometry, contrast enhancement, spatial frequency filtration, and geometric transformation to any desired map projection. Digital image processing has thus become a fundamental part of planetary mapping programs.

As image signals are received from planetary spacecraft, they are decoded and reconstituted as images by the Mission Test and Imaging System (MTIS) at the California Institute of Technology's Jet Propulsion Laboratory (JPL). Preliminary processing includes removal of transmission noise, correction for known camera shading, spatial filtration, and contrast enhanced, shading corrected version. The others are high-frequency filtered and contrast enhanced so that small topographic details in several frequency ranges will be emphasized. When adequate camera orientation data are available, a second stage of processing transforms the images into specified map projections. This processing stage must commonly await the computation of precise camera orientation matrices by analytical photogrammetry.

Data cataloging: Sorting and locating the tens of thousands of images, and other data required for mapping the planets must be accomplished prior to mapping, and is a major undertaking. Geometric parameters such as spacecraft orientation and camera aiming direction are telemetered to earth along with other parameters such as shutter speed and filter setting. Doppler tracking of spacecraft signals gives the spacecraft location at any given time. Telescopic tracking of planetary bodies over a period of many years gives their position at any given time. All of these data are used to calculate geographic coordinates of picture centers and boundaries and to generate the "Supplementary Engineering Data Record," or SEDR.

The final stage of data cataloging is the compilation of uncontrolled or semicontrolled photomosaics. Although the SEDR is vital for preliminary cartography, a great deal of manual checking and adjustment are required for

cartographic management of the data set. For example, the SEDR gives no indication of the quality of an image. SEDR entries are sometimes generated for pictures that were lost in transmission. The most significant error in the SEDR is the picture location on the planet. This is because the camera orientation is only accurate to 0.1 or 0.2 deg. When pictures have a field-of-view of less than a degree, and when the spacecraft is tens of thousands of kilometers from its target, the errors can be very large. If the pictures are taken nearly vertically, if the field-of-view is not too narrow, and if the spacecraft is fairly close to the planet, the SEDR may be accurate enough to control automatic rectification and scaling of the pictures. In no case has it been sufficiently accurate for map control.

Map control: Final map controls are generated by photogrammetric triangulation. Topographic controls for the moon were computed by block adjustments of Apollo mapping camera pictures of the moon. For most other planetary mapping, the stereoscopic geometry in the survey pictures is too weak to derive elevation data; planetary radii were assumed and held constant for derivation of horizontal control (Davies and Arthur, 1973; Davies and Batson, 1975; Davies and others, 1979).

Final map products: Planetary maps produced to date consist of controlled photomosaics or shaded relief maps. Either type may have a contour overprint, where data are sufficient to justify the compilation. Many controlled photomosaics of the moon consist of optically rectified Lunar Orbiter or Apollo pictures. A series of orthophoto mosaics of Apollo pictures also has been compiled.

Digital television pictures of the other planets are transformed in computers for making most of the controlled photomosaics. Most of these mosaics are made by hand, but many are now assembled in the computer and output as a single image. Although this method is initially quite expensive, it has the advantage that a variety of image processing programs can be applied to an entire map, rather than to each individual picture. Digital terrain models, when available, are used to correct relief distortions in monoscopic pictures for creation of orthophoto mosaics in the computer.

A variety of types of controlled photomosaics are compiled. Many users prefer mosaics with high-frequency detail enhanced. This has the disadvantage that all relief receives equal emphasis. Other versions are therefore made with no spatial filtering and with photometric corrections applied to the pictures. Figure 3 is a hand laid, controlled photomosaic of Viking pictures of a part of the Valles Marineris of Mars. When multispectral information is available, full color mosaics are made (Figure 5). These are usually in natural color, but color ratio versions are being contemplated where such presentation might aid geochemical interpretations.

Airbrushed shaded relief maps (Figure 4) are made in synoptic and systematic map series, and in some special purpose series as well. Whereas only one version of one picture can be used in a photomosaic, skilled airbrush cartographers can incorporate information from many sources into a single, uncluttered portrayal with the airbrush (Inge and Bridges, 1976). The airbrush has also been used to make albedo overprints for shaded relief base maps (Batson and Inge, 1976).

Radar: The surface of Venus is cloud-covered and thus cannot be mapped by conventional imaging systems. Radar, both earth-based and spacecraft-borne, is therefore being used.

Since the early 1970's radar images of Venus have been made with earth-based instruments. Late in 1978, the Pioneer Venus spacecraft began returning images and altimetry data from Venusian orbit (Pettengill and others, 1979). These data are resulting in maps that are quite different than other planetary maps. The radar images show bright and dark areas that probably delineate areas of differing surface roughness. A preliminary map (Figure 6) combines earth-based and Pioneer Venus images and Pioneer Venus altimetry. The altimetry was used to produce a contour map (Masursky and others, 1980) of most of the planet at a 500 m contour interval. Horizontal resolutions of most earth-based and all Pioneer Venus data are on the order of 50 km, however, so mapping at scales larger than 1:50,000,000 will not be attempted.

The VOIR mission, currently planned for 1986, will return planetwide high-resolution SAR images and will permit more conventional cartographic representations at 1:5,000,000 and larger scales.

STATUS OF PROGRAMS

The total number of map sheets, published and planned, are shown in Table 4. Plans are constantly revised as new needs develop and as data are re-evaluated, so the number of "planned" maps fluctuates frequently. In addition to these maps, two bound Atlases (Davies and others, 1978; Batson and others, 1979) have been printed and others are planned. These atlases contain many of the published planetary maps reduced to page size for convenient reference.

Table 4. Numbers of map sheets in current extraterrestrial mapping program

			Mercury	Venus	Moon	Mars	Jovian System	Saturnian System	Uranian System
Total planned for current programs	1:15M	planim	2	6	-	5	16	TBD	TBD
		contour	-	5	-	3	-	-	-
		color	-	-	-	2	4	TBD	TBD
	1:15M to 1:2M	planim	19	62	25	46	96	TBD	TBD
		contour	-	62	5	30	-	-	-
		color	-	-	1	-	TBD	TBD	TBD
1:2M	planim	-	TBD	213	160	5	TBD	TBD	
	contour	-	TBD	394	68	-	-	-	
	color	-	-	-	64	-	-	-	
Published or in Press	1:15M	planim	2	2	-	2	4	-	-
		contour	-	1	-	1	-	-	-
		color	-	-	-	-	1	-	-
	1:15M to 1:2M	planim	10	-	22	46	-	-	-
		contour	-	-	3	30	-	-	-
		color	-	-	-	6	-	-	-
	1:2M	planim	-	-	213	45	-	-	-
		contour	-	-	394	2	-	-	-
		color	-	-	-	6	-	-	-
Total planned			21	135+	638	378	121+	TBD	TBD
Total published			12	3	632	138	5	0	0

Total numbers of planetary maps published or in press as of July, 1980 =790

TBD = To be determined after further evaluation of existing data or pending acquisition of new data.

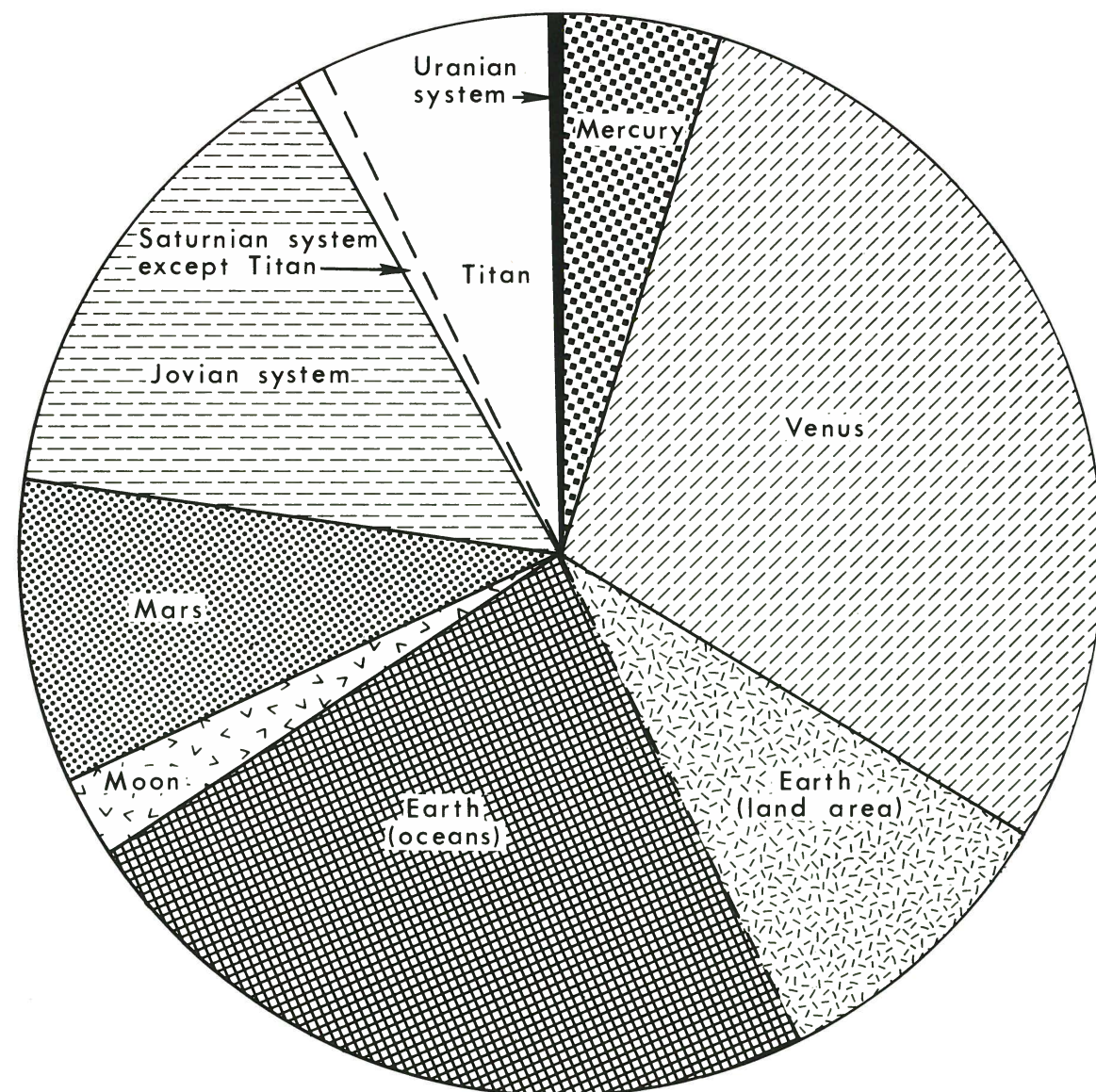
Table includes each version of each map, but does not include superceded or obsolete maps.

Table includes maps published by the U.S. Geological Survey, the Defense Mapping Agencies, and the National Geographic Society.

Figures 6 and 7 show the approximate coverage and resolution of data now available for mapping eight planets. Outlines and number designations of map sheets in the planetwide mapping plans also are shown. Figures 8 through 10 show the land area of each planet that is planned for mapping. Maps for the Uranian satellites are not yet defined.

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Known mappable area in the solar system
 $(\approx 1.6 \times 10^9 \text{ km}^2)$

Figure 1. Known mappable area in the solar system.



Figure 2. Planets that have been, or are being mapped. Images of the planets are at their correct relative scale. Names of spacecraft missions that return data that can be used for mapping are shown next to the appropriate planet. (The Galileo and VOIR missions are shown in blue, because they have not yet flown.) Although terrestrial mapping is not discussed in this paper, the earth is shown for reference.



Figure 3. Controlled photomosaic of the Coprates NW quadrangle of Mars.
Original compilation was at 1:2,000,000; scale of this illustration
is approximately 1:5,400,000.

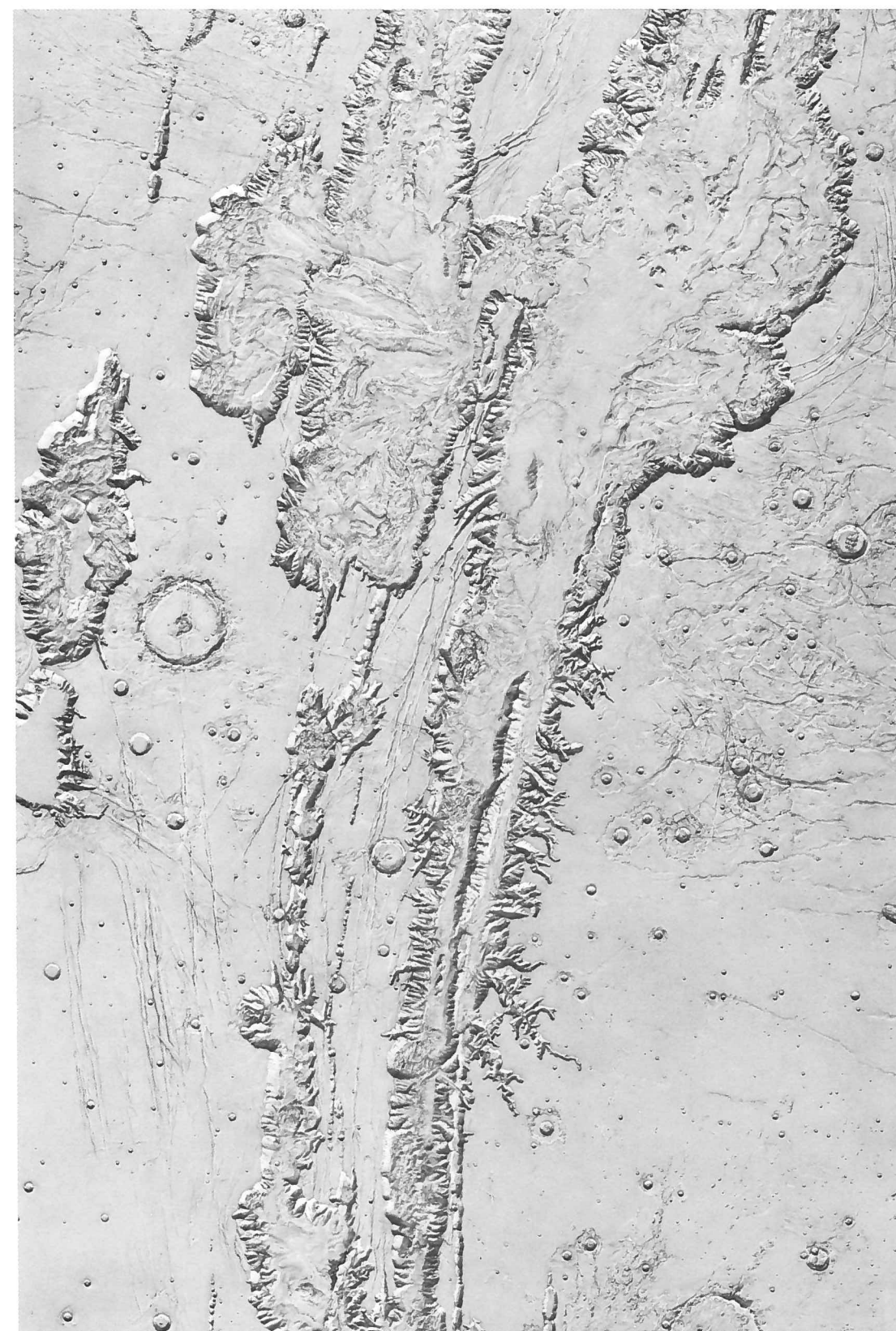


Figure 4. Airbrush shaded relief map of the Coprates NW quadrangle of Mars.
Original compilation was at 1:2,000,000; scale of this illustration
is approximately 1:5,400,000.



Figure 5. Natural color photomosaic of the Coprates NW quadrangle of Mars. Planned publication scale is 1:2,000,000. Scale of this illustration is 1:5,400,000.

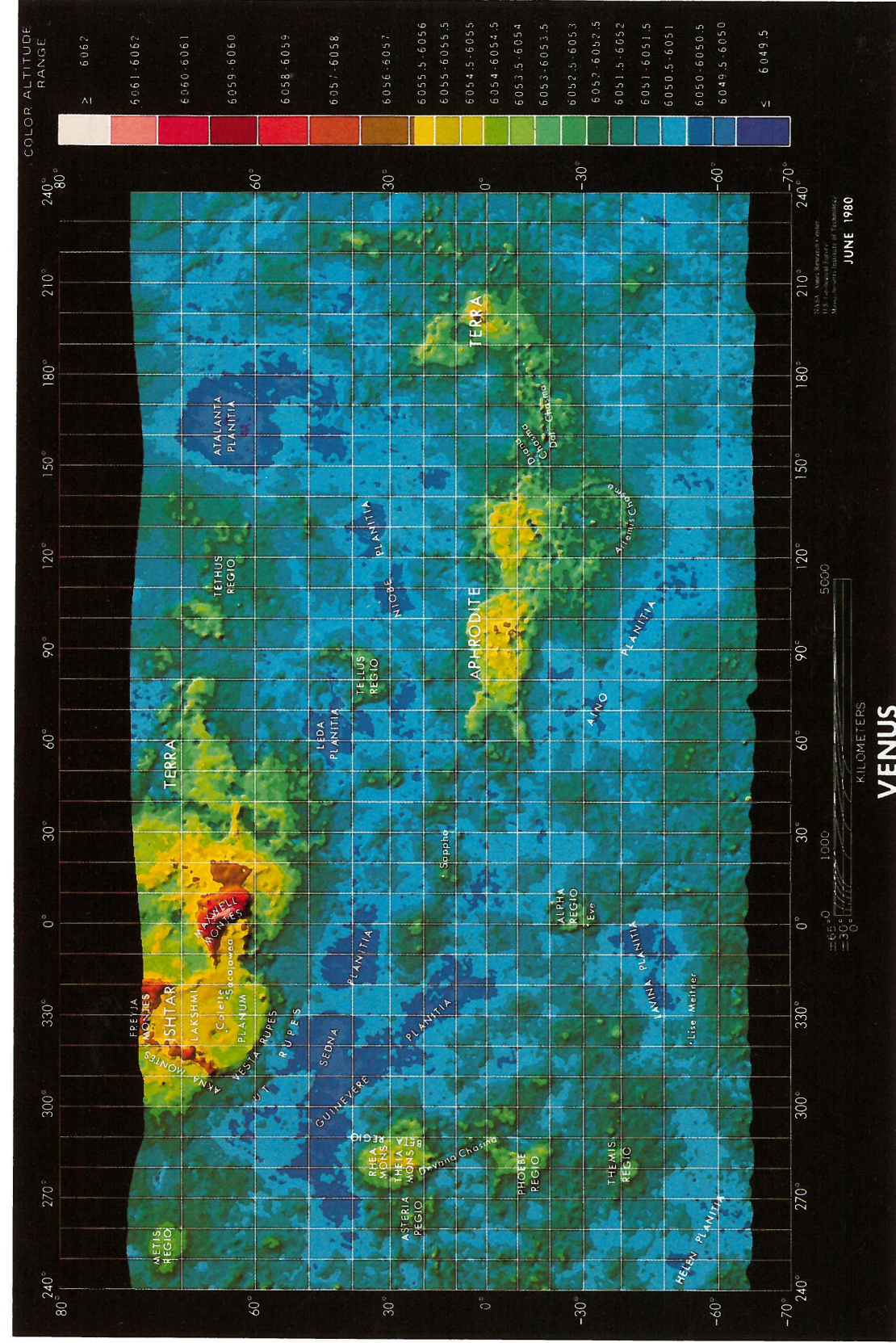


Figure 6. Map of Venus compiled with Venus Pioneer radar altimetry data. A similar, but somewhat more complete version is planned for publication at 1:50,000,000 in 1981. Colored elevation levels are superposed on computer generated shaded relief in this version.

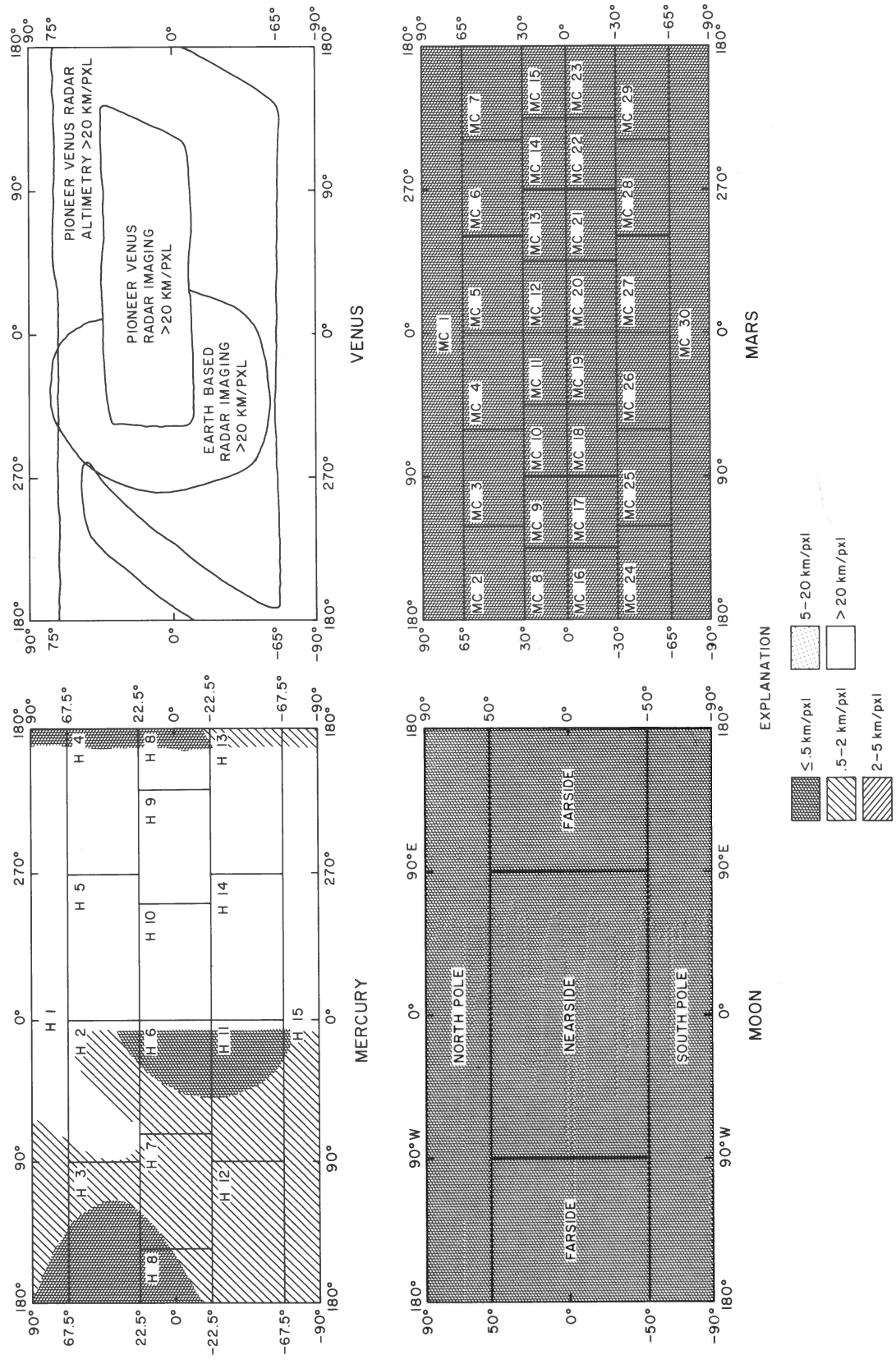


Figure 7. Resolution of images available for mapping Mercury, Venus, the moon, and Mars. As the term is used here, resolution is the size of a picture element on the surface of the planet.

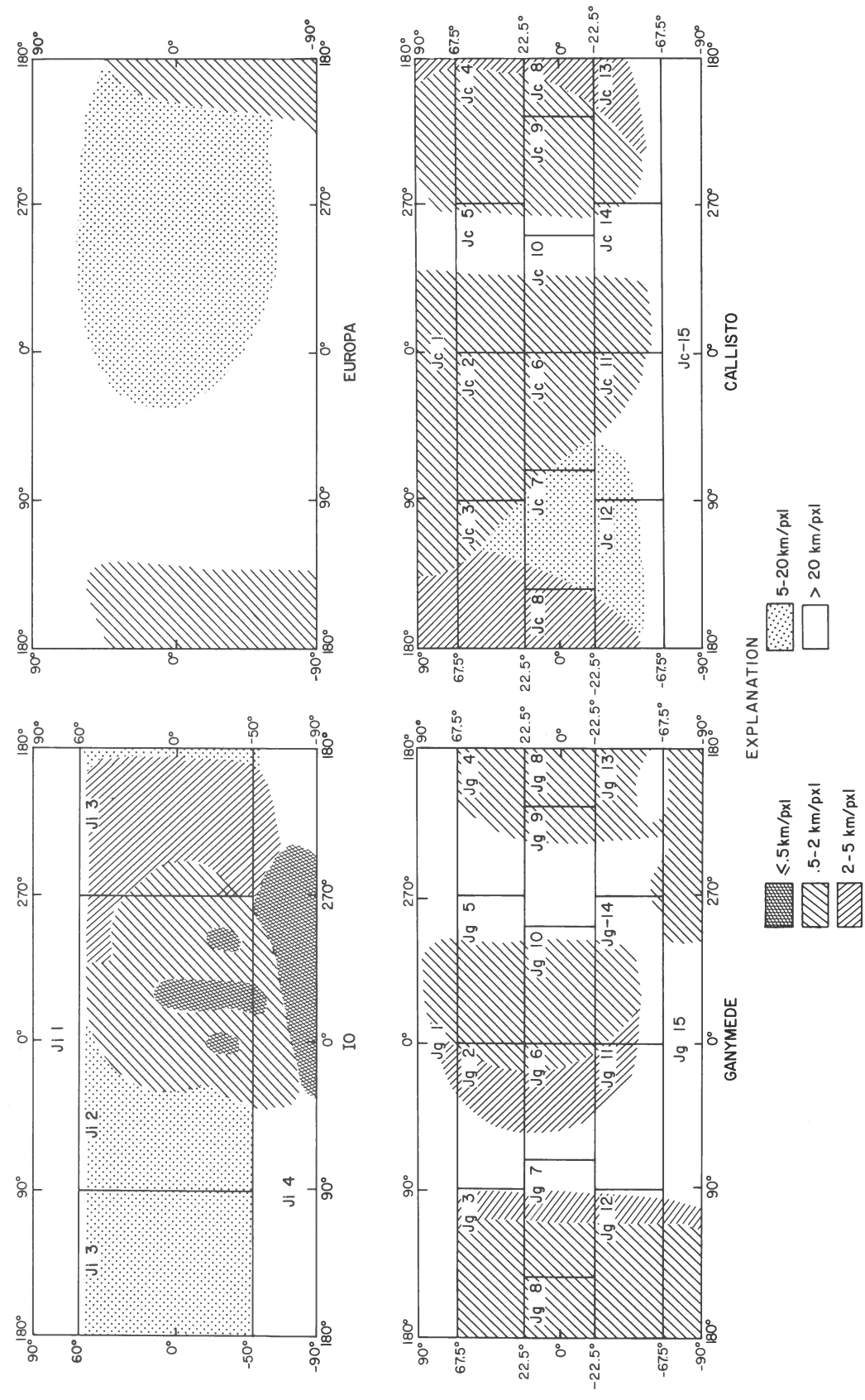


Figure 8. Resolution of images available for mapping Io, Europa, Ganymede, and Callisto.

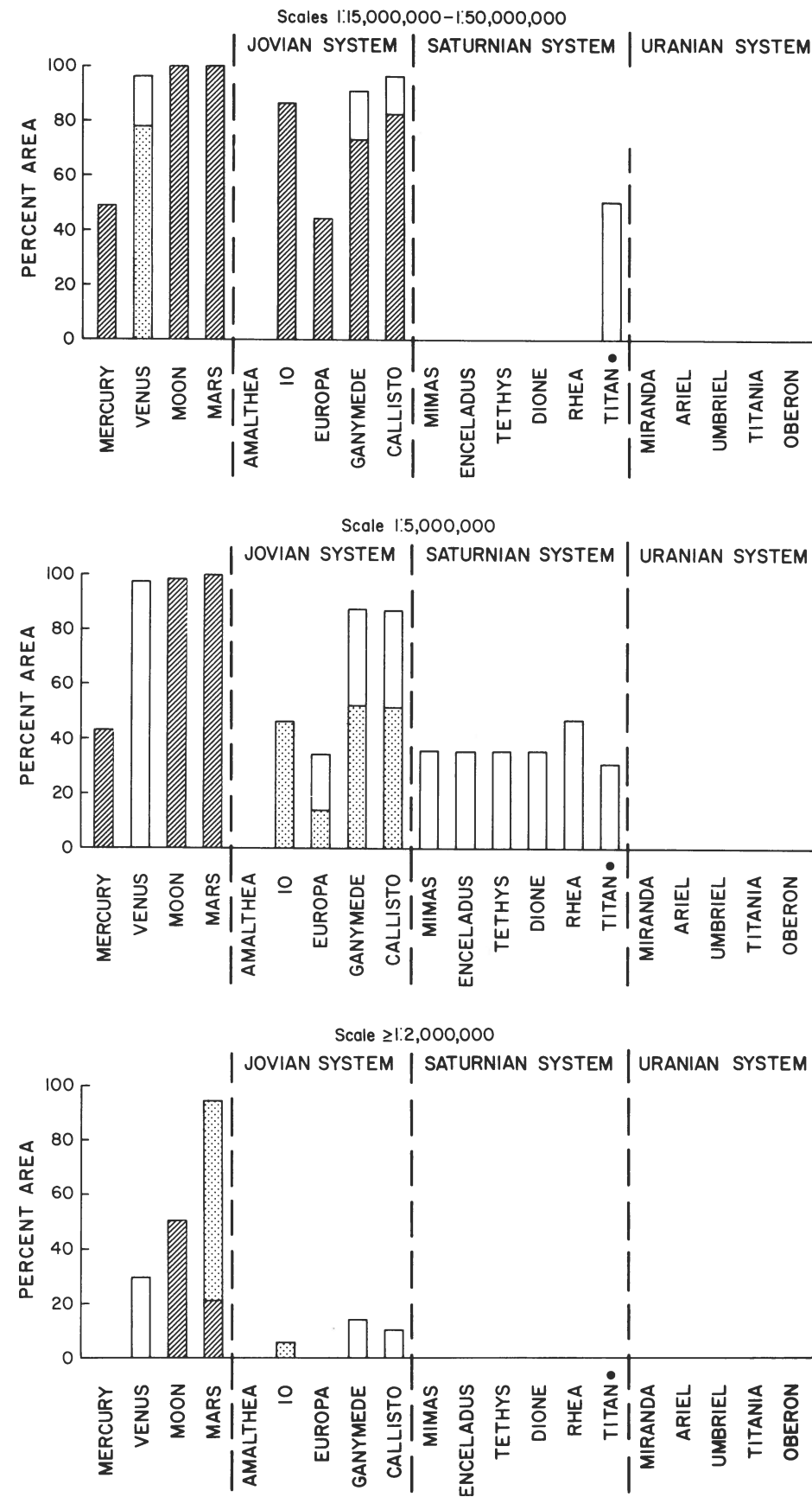


Figure 9. Status of planimetric extraterrestrial mapping. Hatched areas represent completed mapping. Dotted areas show mapping in progress. Open areas show plans for data yet to be acquired.

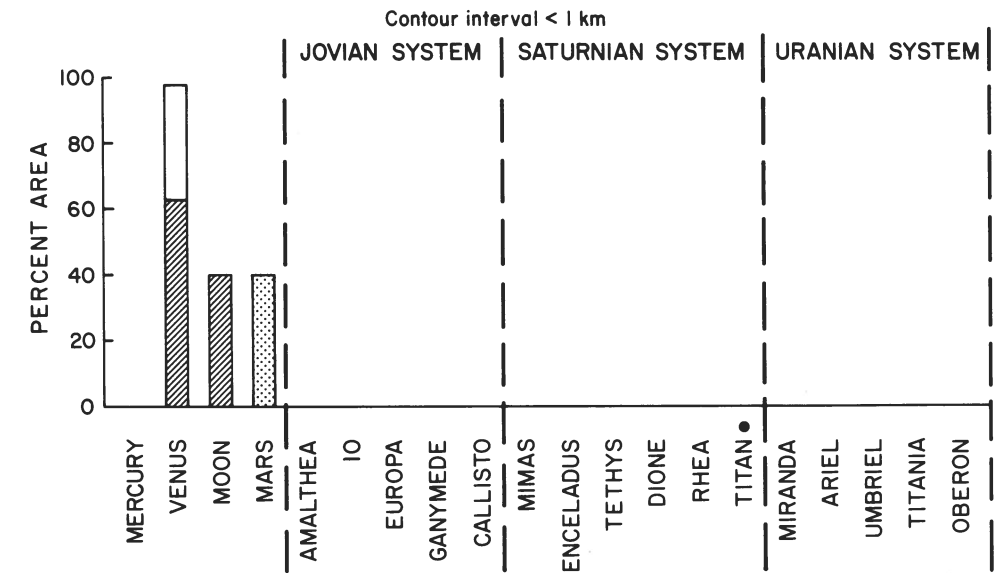


Figure 10 Status of estraterrestrial contour mapping. Hatched areas represent completed mapping. Dotted areas show mapping in progress. Open areas show plans for data yet to be acquired.

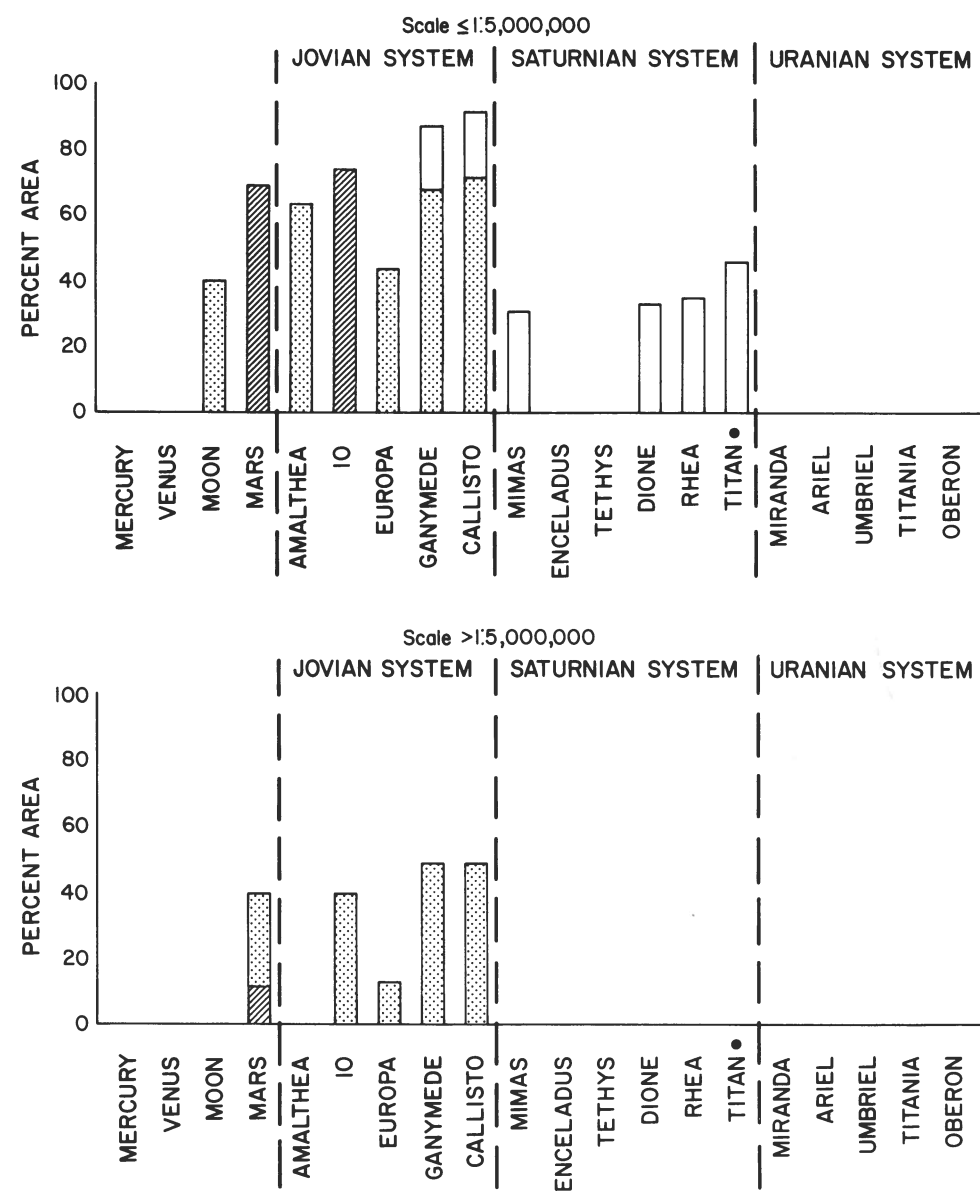
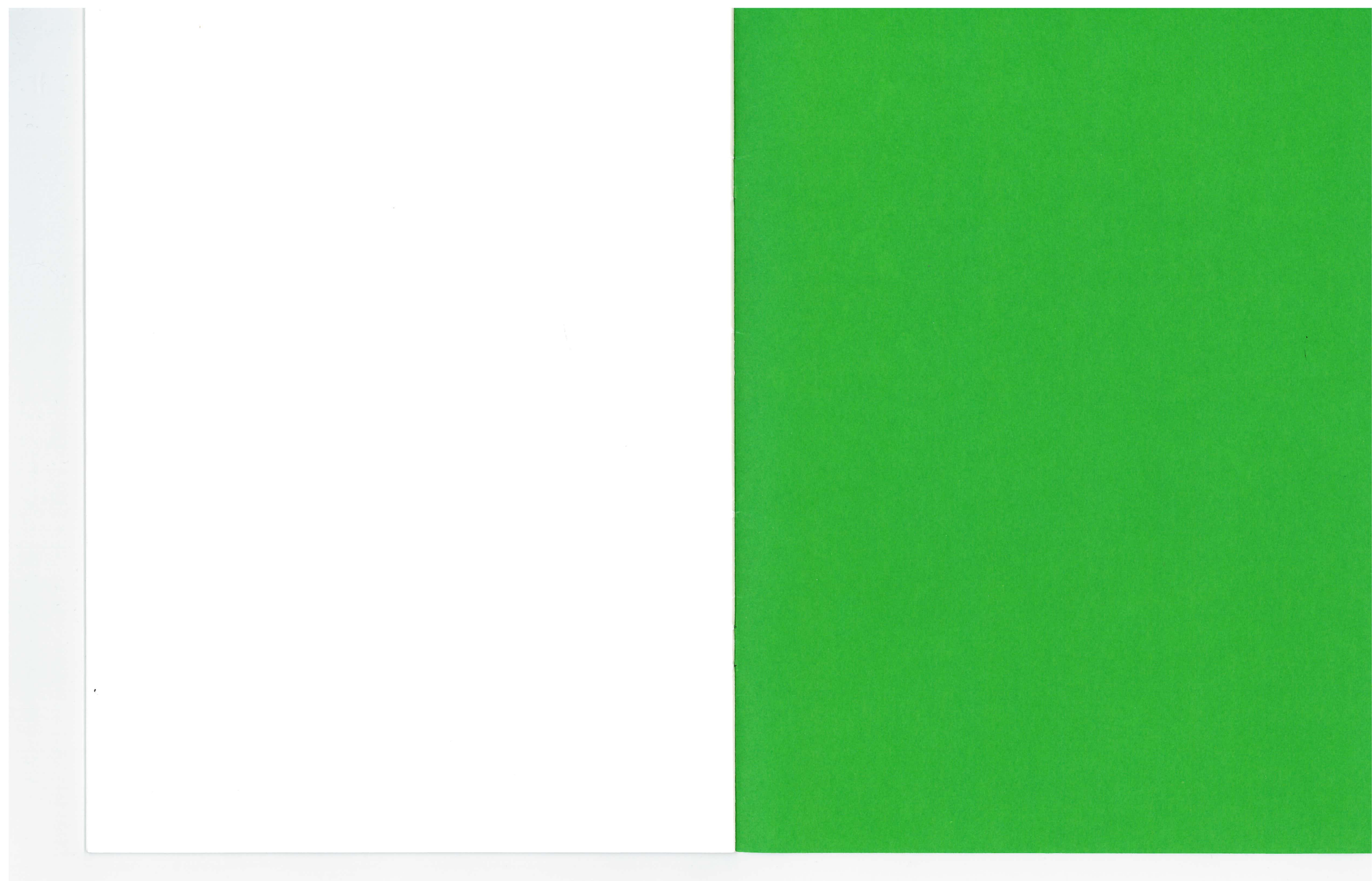


Figure 11. Status of extraterrestrial color mapping. Hatched areas represent completed mapping. Dotted areas show mapping in progress.

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