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Mapping of the icy Saturnian satellites: First results from Cassini-ISS

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Abstract

Images of the icy Saturnian satellites Mimas, Enceladus, Tethys, Dione, Rhea, Iapetus, and Phoebe, derived by the Voyager and Cassini cameras are used to produce new local high-resolution image mosaics as well as global mosaics [http://ciclops.org, http://photojournal.jpl.nasa.gov]. These global mosaics are valuable both for scientific interpretation and for the planning of future flybys later in the ongoing Cassini orbital tour. Furthermore, these global mosaics can be extended to standard cartographic products.

Keywords: Cassini; Icy satellites; Planetary mapping; Saturnian system

1. Introduction

The Saturnian system contains 56 satellites of different sizes. This paper deals with the mapping of the so-called medium-sized icy satellites Mimas, Enceladus, Tethys, Dione, Rhea, Iapetus, and Phoebe.

Voyager-1 and Voyager-2 obtained a large number of images from the icy Saturnian satellites during their journeys through the Saturnian system in 1980 and 1981 (Smith et al., 1982; http://www.jpl.nasa.gov/voyager). These images constitute the basis for the planning of the Cassini mission [http://saturn.jpl.nasa.gov].

The Cassini Imaging Science Subsystem (ISS) consists of two framing cameras. The narrow angle camera is a reflecting telescope with a focal length of 2000 mm and a field of view of 0.35°. The wide-angle camera is a refractor with a focal length of 200 mm and a field of view of 3.5°. Each camera is outfitted with a large number of spectral filters which, taken together, span the electromagnetic spectrum from 0.2 to 1.1 μm. At the heart of each camera is a charged coupled device (CCD) detector consisting of a 1024 square array of pixels, each 12 μm on a side. The data system allows many options for data collection, including choices for on-chip summing and data compression. The stated objective of the ISS is to obtain global coverage for all medium-sized icy satellites with a resolution better than 1 km/pixel and high-resolution images (Porco et al., 2004). This goal is being achieved with image sequences obtained during close flybys supplemented by images from greater distances to complete the coverage. Close flybys of all medium sized satellites except Mimas are planned during the nominal mission of the Cassini spacecraft. The first flybys during the mission were those of Phoebe in June 2004 and Iapetus in December 2004 followed by three flybys of Enceladus in February, March, and July 2005 (see Table 1) (Porco et al., 2005, 2006).

Details of the image processing will be described in chapter 2, Voyager maps will be shown in chapter 3, followed by Cassini image mosaics and maps in chapter 4.

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Table 1
Cassini flybys in 2004/2005

Satellite	Flyby date	Flyby altitude (km)
Phoebe	11 June 2004	2070
Iapetus	31 December 2004	123,400
Enceladus	17 February 2005	1260
Enceladus	09 March 2005	500
Enceladus	14 July 2005	170
Mimas	02 August 2005	61,150
Tethys	24 September 2005	1500
Hyperion	26 September 2005	500
Dione	11 October 2005	500
Rhea	26 November 2005	500

2. Data processing

2.1. Voyager

All images taken by the Imaging Science Subsystems (ISS) aboard Voyager-1 and Voyager-2 are available online from the Planetary Data System (PDS) Imaging Node [http://pds-imaging.jpl.nasa.gov]. Though many images have been acquired with narrow band filters only clear filter images were used during the processing reported here. The first steps of the data processing chain are the conversion from PDS format to VICAR (Video Image Communication and Retrieval) format, followed by the radiometric and geometric calibrations using standard VICAR programs [http://rushmore.jpl.nasa.gov/vicar.html]. The next step is to convert the images to digital maps, which requires precise orbit and pointing data for each image. We used the position and pointing data by Davies and Katayama (1983a–c, 1984) which were derived by block adjustment techniques, and delivered electronically in 1989 (Davies et al., personal communication). For other images improved pointing data were calculated using limb-fitting techniques and nominal pointing data as input. The inner Saturnian satellites are best described by tri-axial ellipsoids as recommended in the report of the International Astronomical Union (IAU) (Seidelmann et al., 2002). However, to facilitate comparison and interpretation of the maps, ellipsoids were only used for the calculation of the ray intersection points, while the map projection was done onto a sphere with the mean IAU radius. All projection parameters are described in Section 3. The final step of the image processing is the combination of all map-projected images to a homogeneous mosaic. Special care must be taken to handle the different ground resolutions within overlapping regions and the variable illumination conditions in the different images in order to minimize the loss of high-resolution image information and contrast. Both map projection and mosaicking are carried out following procedures described in Scholten (1996) and Scholten et al. (2005) for Mars imagery.

2.2. Cassini

Though the Cassini-ISS camera takes images using many different filters (Porco et al., 2004), we used only images taken with the filters CL1, CL2 or GRN, as these images show similar contrast. The processing of the Cassini images follows basically the same processing sequence as for the Voyager images. For the Cassini mission, spacecraft position and camera pointing data are available in the form of SPICE kernels [http://naif.jpl.nasa.gov]. While the orbit information is sufficiently accurate to be used directly for mapping purposes, the pointing information must be corrected using limb fits (see Fig. 1 for an example). High-resolution images that do not contain the limb were registered to limb images to improve the pointing. For the Cassini maps, newly derived tri-axial ellipsoid models (Thomas et al., 2006) were used to calculate the surface intersection points (for new mean radii see Table 3). The coordinate system adopted by the Cassini mission for satellite mapping is the IAU "planetographic" system, consisting of planetographic latitude and positive west longitude, but because a spherical reference surface is used for map projections of the satellites, planetographic and planetocentric latitudes are numerically equal. Digital maps are prepared in simple cylindrical projection, a special case of equirectangular projection. The mapping cylinder is tangent to the equator of the sphere, the longitude range is 0–360°W and latitude range -90° to 90° (Kirk et al., 1998). The prime meridian is in the center of the map [http://ciclops.org, http://photojournal.jpl.nasa.gov]. Additionally to the Voyager data processing steps, a photometric correction using the Henyey–Greenstein function (Hapke, 1993) was applied to the image data before mosaicking with function parameters adopted from Verbiscer and Veverka (1989, 1992, 1994) and Simonelli et al. (1999).

3. Voyager mosaics and maps

The map resolutions (in pixel/deg) chosen were depending on mosaic resolution rounded to nearest integer and turn out to be similar or identical to those of the "Standard Cartographic Products" established by the United States Geological Survey (USGS) [http://astrogeology.usgs.gov/Projects/SaturnSatellites/]. Map sheets were produced to conform with the design and standards of the USGS airbrush maps and photomosaics, established by Greeley and Batson (1990), widely used in planetary cartography. The map sheets combine a Mercator map within the latitude range of -57° to 57° and two polar maps in stereographic projection polewards beyond $\pm 55^\circ$ latitude. All maps include current nomenclature [http://planetarynames.wr.usgs.gov] (see Fig. 2 for an example). Table 2 shows the resolution of all mosaics and the scale of all produced maps (Roatsch et al., 2004).

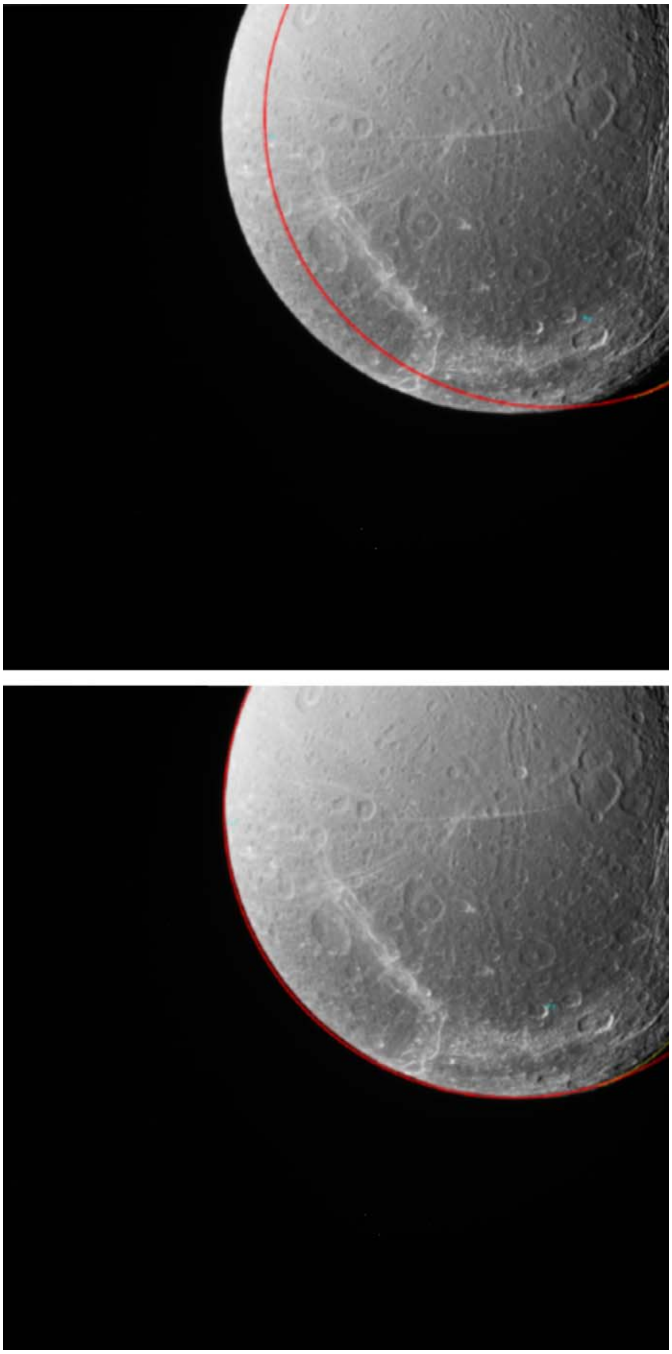

Fig. 1. Limb position for satellite Dione, predicted from the SPICE kernel (top) and after interactive limb fitting (bottom).

4. Cassini mosaics and maps

Imaging of the medium-sized icy satellites is ongoing and will continue until the end of the Cassini mission, making it possible to improve the image mosaics during the tour. The starting points of global mosaics for any satellite are the Voyager mosaics in which areas can be replaced gradually by higher-resolution Cassini images as data become available. At some point in time new mosaics can be generated on the basis of Cassini image data, where Voyager data fill the gaps between the Cassini images. In these maps, the satellite coverage, as expected by the end of the nominal Cassini mission in July 2008, can be visualized (see Fig. 3 for an example).

The global mosaics are usually produced using images of a similar resolution. However, some areas of the satellites are imaged at very high resolution. These higher resolution images were processed to separate mosaics (see Fig. 4 for an example).

The data set of Phoebe is the only one that is complete, as no more high-resolution images are expected during the mission. Also, we will not obtain new high-resolution Enceladus images until 2008. Therefore standard maps were generated for these two satellites. Table 3 shows the resolution and scale of these maps.

A global mosaic and a standard map sheet of Phoebe were produced in a scale of 1:1,000,000 (see Fig. 5). We produced the Phoebe mosaic from 42 narrow-angle (NA) images of the Cassini ISS camera. We used the Mercator projection within the latitude range -57° to $+57^\circ$ and the stereographic projections polewards beyond $\pm 55^\circ$, respectively. As proposed by Greeley and Batson (1990) the projections are conformal, the quadrangles overlap, and the scale of the poles was chosen such that the circumference of the stereographic projection at the center of the overlap is identical to the width of the Mercator projection. The nomenclature was proposed by the Cassini imaging team and has yet to be validated by the IAU. The resolution of the mosaics is 0.233 km/pixel, although the highest resolution images have resolutions of 0.07 km/pixel. A dedicated regional orthoimage mosaic for Phoebe using true topography as reference surface was derived and is being reported in a separate paper (Giese et al., 2006).

We used 47 images of the narrow-angle and two images of the wide-angle (WA) camera to produce a 40 pixel/deg global mosaic and a standard map for Enceladus. The map is produced in a scale of 1:500,000 consisting of a quadrangle scheme with 15 tiles, as proposed by Greeley and Batson (1990) and Kirk (1997, 2002, 2003) for large satellites (see Fig. 6). A map scale of 1:500,000 guarantees a mapping in the highest possible resolution. The equatorial part of the map (-21° to 21° latitude) is in Mercator projection onto a secant cylinder using standard parallels at -13° and 13° latitude. The regions between the equator region and the poles (-66° to -21° and 21° to 66° latitude) are projected in Lambert conic projection with two standard parallels at -30° and -62° (or 30° and 62°, respectively). The poles are projected in stereographic projection (-90° to -65° latitude and 65° to 90° latitude).

5. Outlook

The Cassini spacecraft will continue its imaging campaign through the Saturnian system. Satellite close flybys are scheduled for Tethys, Dione, Rhea, Iapetus, and

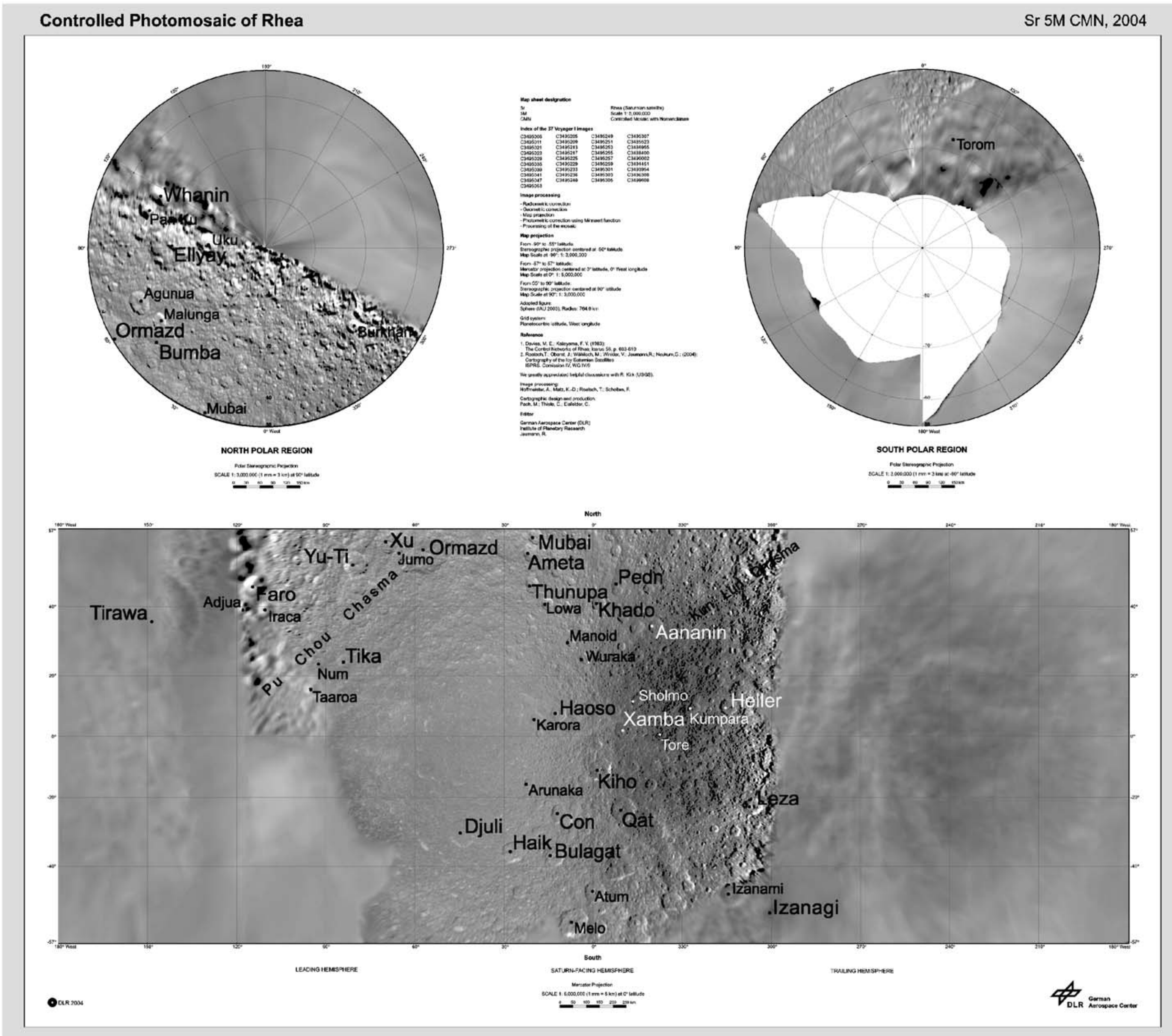

Fig. 2. Voyager map of Rhea at scale 1:5,000,000. The nominal scale is that of the Mercator map at the Equator; the scales of the polar maps are somewhat larger.

Table 2
Resolution and scale of the Voyager maps

	Mean radius used for map projection (km)	Resolution of digital map (pixel/ degree)	Scale of digital global map (km/pixel)	Map scale	Printing scale of the hardcopy map (pixel/mm)
Dione	560.0	10	0.97738	1:5,000,000	5.1
Enceladus	249.4	10	0.43529	1:2,000,000	4.6
Iapetus	718.0	2.5	5.01250	NA	NA
Mimas	198.6	5	0.69325	1:2,000,000	2.9
Rhea	764.0	20	0.66672	1:5,000,000	7.5
Tethys	529.8	5	1.84936	1:5,000,000	2.7

Note: There is no map of Iapetus due to the low image resolution.

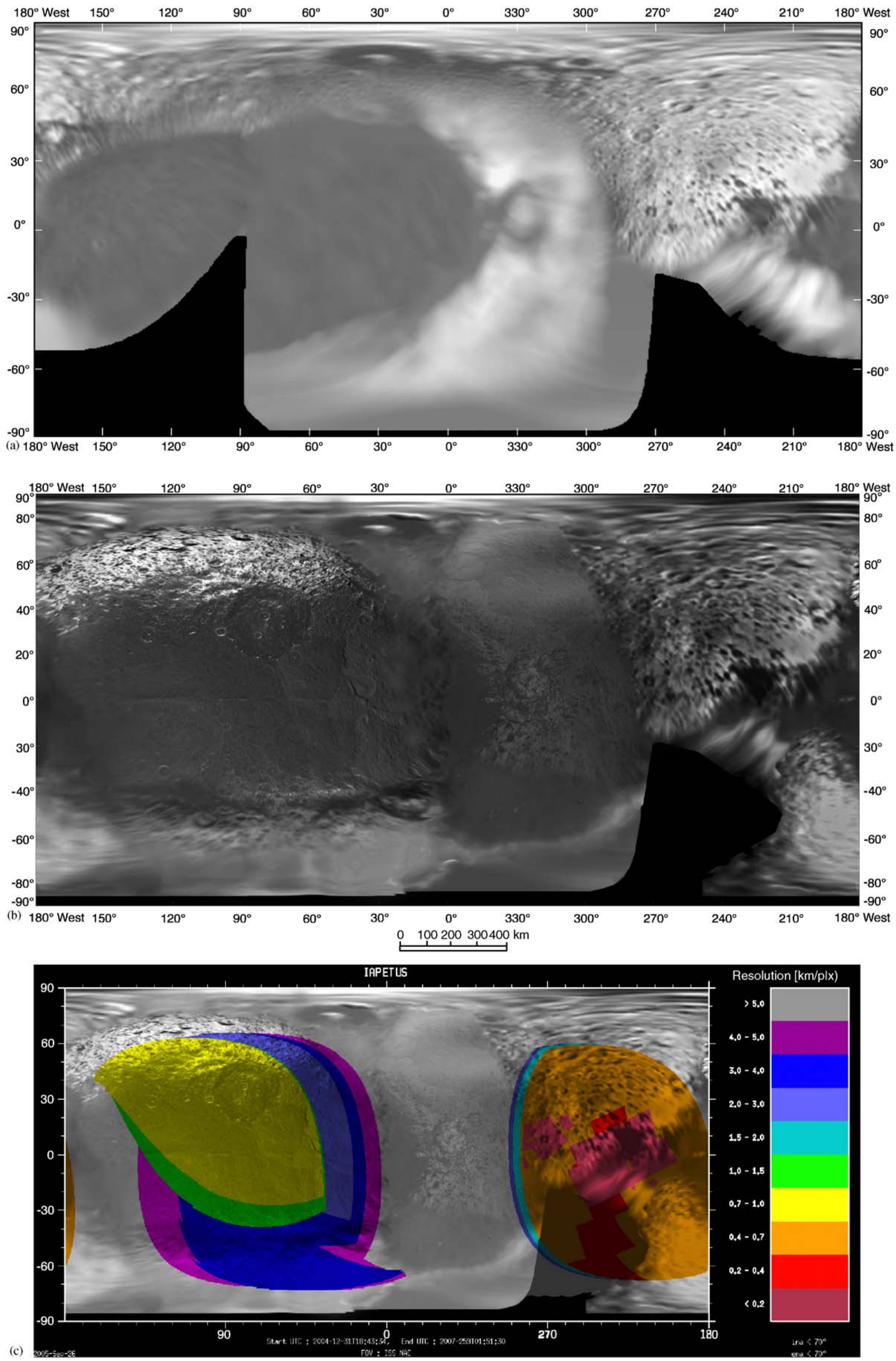

Fig. 3. Iapetus base map generated from: (a) Voyager data and (b) Cassini and Voyager data, produced following the Iapetus flyby in December 2004 (see next page). (c) Total Iapetus coverage planned through the end of Cassini's nominal mission.

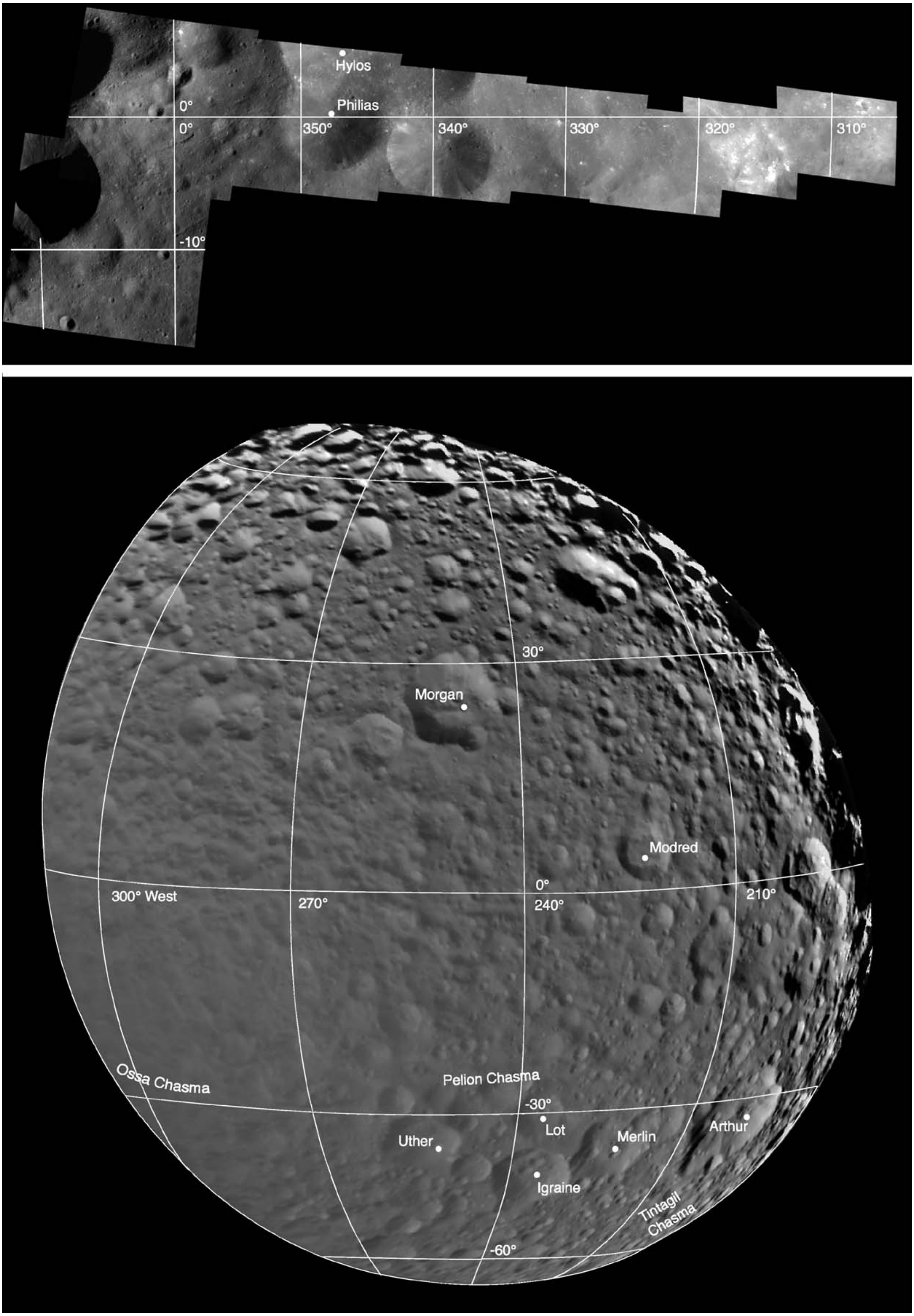

Fig. 4. High-resolution mosaics of Phoebe (top) with a map scale of 10 m/pixel, in sinusoidal projection and in a latitude/longitude range of 8.2°N–17.5°S and 13.4–305.4°W. Mimas (bottom) with a map scale of 370 m/pixel, in orthographic projection and in a latitude/longitude range of 71°N–69.8°S and 313–180°W.

Table 3
Resolution and scale of the Cassini maps

	Mean radius used for map projection (km)	Resolution of digital map (pixel/ degree)	Scale of digital global map (km/pixel)	Map scale	Printing scale of the hardcopy map (pixel/mm)
Dione	562.3	10	0.98140		
Enceladus	252.31	40	0.11009	1:500,000	4.5 (in process)
Iapetus	734.5	20	0.64097		
Mimas	198.6	5	0.69324		
Phoebe	106.8	8	0.23300	1:1,000,000	4.3
Rhea	764.5	20	0.66715		
Tethys	536.3	5	1.87204		

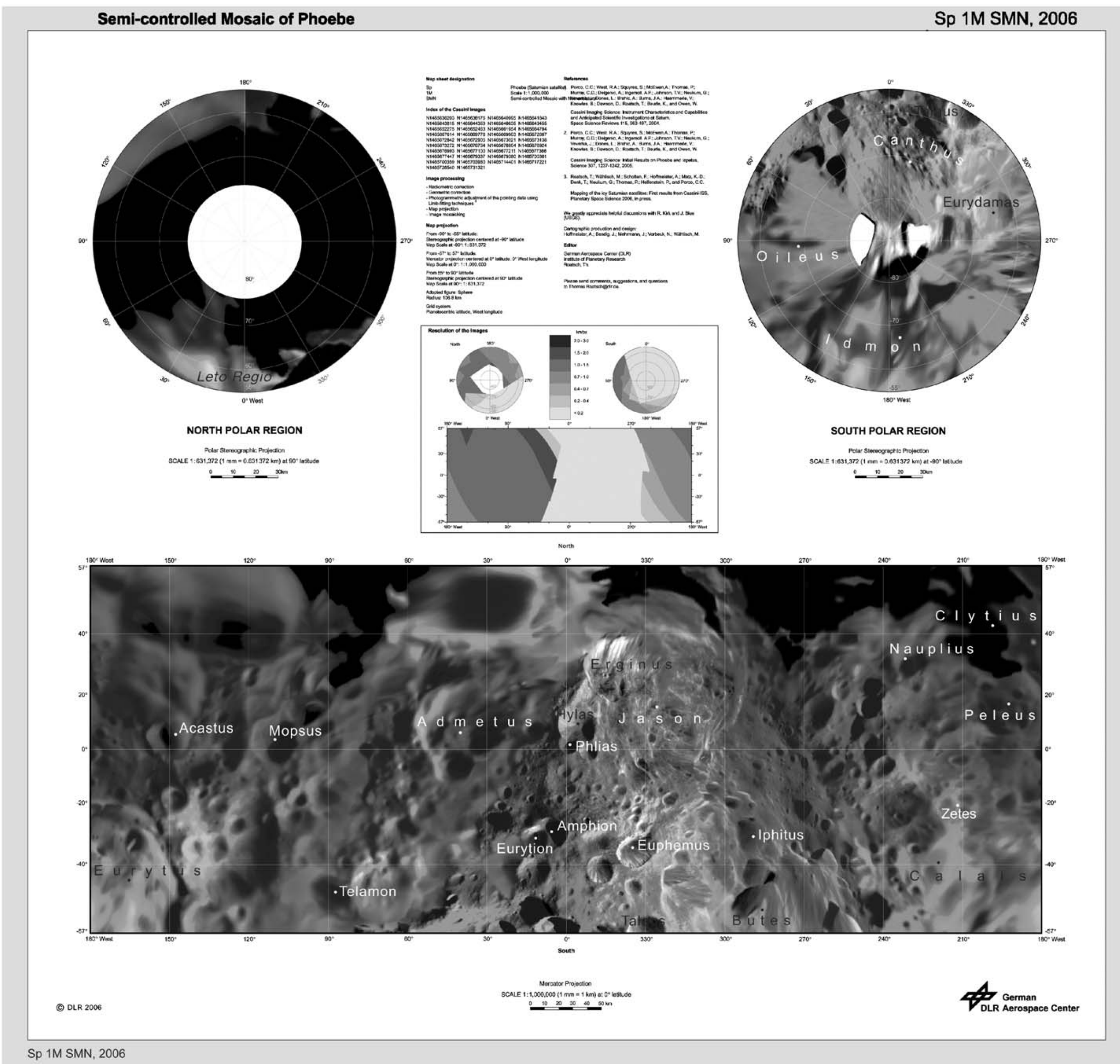

Fig. 5. Phoebe map at 1:1,000,000 scale.

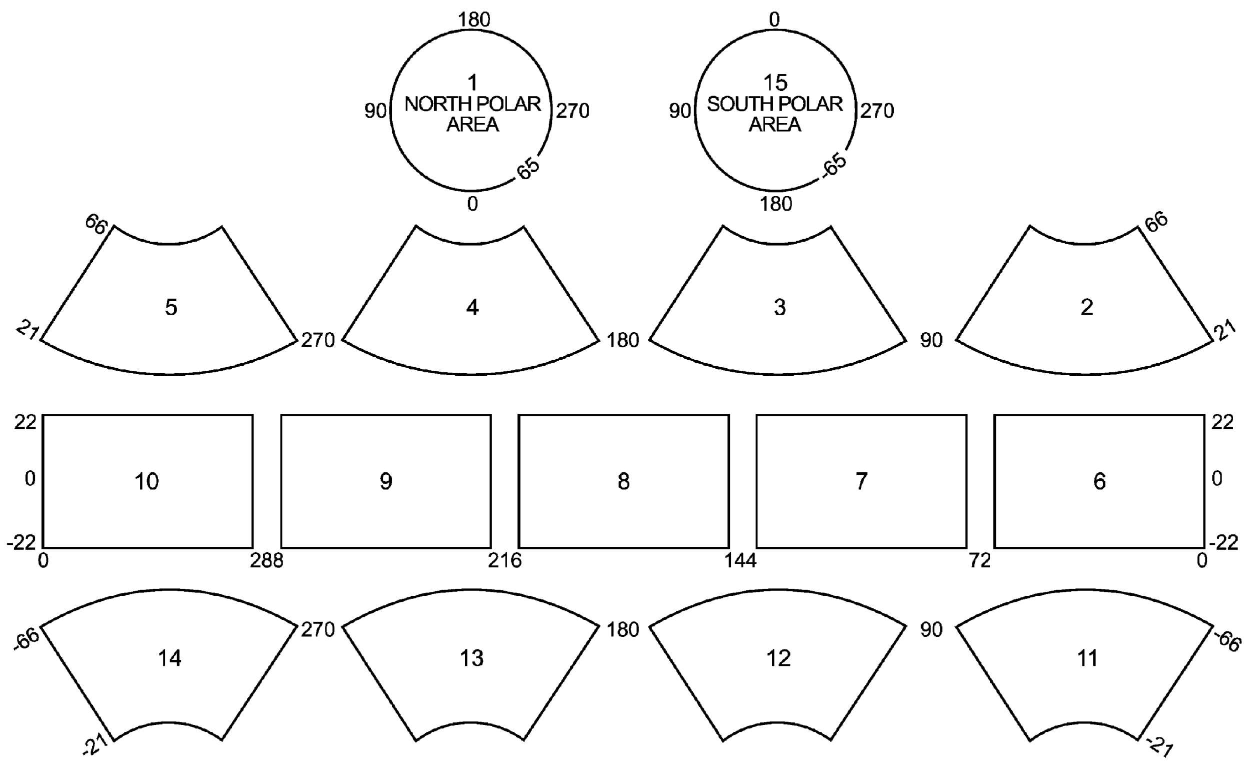

Fig. 6. Quadrangle scheme adopted for regional mapping, beginning with high-resolution maps of Enceladus.

Enceladus within the nominal mission ending in 2008. These data will be used to further improve the existing semi-controlled mosaics and maps and also to update or calculate initial global geodetic control networks of the Saturnian satellites for controlled orthophoto mosaics.

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