

GENERATION OF DIGITAL TOPOGRAPHIC MAPS OF PLANETARY BODIES

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ABSTRACT:

In recent years, the exploration of the solar system was intensified. Several space missions have been planned, launched, or are in operation yet. Some of them are supplied with modern camera experiments: the *High Resolution Stereo Camera (HRSC)* on *Mars Express* or the *Cassini Imaging Science SubSystem (ISS)*. Especially HRSC data are well suited to derive Digital Terrain Models and color orthoimages, which are of high importance for cartography. Along with these missions, new mapping programs have been started, e.g., the *Topographic Image Map Mars 1:200,000* series.

For supporting such challenges and aiming for automation of the mapping process, the cartographic software package “Planetary Image Mapper” (PIMap) has been developed at *Technische Universität Berlin*. With only few interactive post processing steps, this flexible software enables the generation of high quality topographic maps or map series for various planetary bodies. Results are digital map sheets in PDF, containing all raster and vector data. PIMap is predominantly used for *Mars Express* cartography at *Technische Universität Berlin*. It has been implemented at the *German Aerospace Center (DLR)* in order to map the medium-sized icy satellites of the Saturnian system.

In this paper, the generation of digital topographic maps by utilizing the features of the PIMap software system is described. Different map examples of planetary bodies, such as Mars and Saturnian satellites, are presented. A combined topographic-thematic map of Mars is shown in a companion paper.

KURZFASSUNG:

In den vergangenen Jahren wurde die Erforschung des Sonnensystems intensiviert. Mehrere Raumfahrtmissionen wurden geplant, gestartet oder sind bereits im Einsatz. Einige von ihnen sind mit modernen Kameraexperimenten ausgestattet: die *“High Resolution Stereo Camera (HRSC) auf Mars Express* oder das *Cassini Imaging Science SubSystem (ISS)*. Insbesondere die HRSC-Daten sind dazu geeignet, Digitale Geländemodelle (DGM) und farbige Orthobilder abzuleiten, welche von grundlegender Bedeutung für die Kartographie sind. Einhergehend mit diesen Missionen wurden neue kartographische Programme gestartet, z.B. das großmaßstäbige Kartenwerk *Topographic Image Map Mars 1:200,000*.

Um diese Herausforderungen zu unterstützen und den Prozess der Kartenherstellung zu automatisieren, wurde an der *Technischen Universität Berlin* das kartographische Softwarepaket *Planetary Image Mapper (PIMap)* entwickelt. Bei geringer interaktiver Nachbearbeitung ermöglicht diese flexible Software die Generierung qualitativ hochwertiger topographischer Karten oder Kartenwerke für unterschiedliche Himmelskörper. Ergebnisse sind digitale Kartenblätter in PDF, welche sämtliche Raster- und Vektordaten enthalten. PIMap wird in erster Linie für die *Mars Express* Kartographie an der *Technischen Universität Berlin* eingesetzt. Es wurde am *Deutschen Zentrum für Luft- und Raumfahrt (DLR)* implementiert, um die mittelgroßen Eismonde des Saturnsystems zu kartieren.

In diesem Artikel wird die Herstellung digitaler topographischer Karten unter Anwendung des Softwaresystems PIMap beschrieben. Verschiedene Beispieltkarten von planetaren Körpern wie Mars und Saturnmonden werden vorgestellt. Eine kombinierte topographisch-thematische Karte der Mars-Oberfläche wird in einem Begleitaufsatz gezeigt.

1. INTRODUCTION

At present, systematic exploration of our solar system substantially increases. Several space missions have been planned, launched, or are in operation yet. Some of them carry modern camera experiments, such as, the *High Resolution Stereo Camera (HRSC)* experiment on *Mars Express* orbiter (Neukum et al., 2004) or the *Cassini Imaging Science SubSystem (ISS)*, which operates in the Saturnian System (Porco et al., 2004).

Especially HRSC data are well suited for the derivation of Digital Terrain Models (DTM) and color orthoimage mosaics, which are of high importance for topographic mapping. Consequently, new large-scale mapping programs have been started, e.g. the *Topographic Image Map Mars 1:200,000* series as well as systematic mapping of the icy Saturnian satellites – for some of these bodies the first map series ever generated. For supporting these challenges and also aiming for automation, at least for parts of the mapping process, the cartographic software

package *Planetary Image Mapper* (PIMap) has been developed at *Technische Universität Berlin*.

With PIMap software, digital topographic image maps of planetary surfaces can be generated. Such products are usually based on orthoimages and supplemented with topographic data, in particular consisting of contour lines and named surface features. The topographic content, grids, frame lines, map titles, sheet designations, and further marginal information can be generated using the PIMap software system. All marginal elements, and self-evidently the mapped surface too, can be freely arranged in the digital sheet in order to achieve different layouts. Due to its flexibility regarding reference body definitions, projections, scales, and layout specifications, PIMap is broadly applicable; it enables the generation of different digital topographic maps or map series for various planetary bodies.

At present, PIMap is used for topographic mapping of Mars at *Technische Universität Berlin* and in the *HRSC Co-Investigator Team*. Moreover, the software has been implemented at the *German Aerospace Center (DLR)* for *Cassini* cartography, i.e. to map the medium-sized icy satellites of the Saturnian system, i.e. Mimas, Enceladus, Tethys, Dione, Rhea, Iapetus, and Phoebe. First experiences in Martian thematic cartography, based on topographic maps generated with PIMap, have been made. A

combined topographic-thematic map sheet of the Centauri and Hellas Montes area of Mars is presented in a companion paper by *Lehmann et al.* (2006).

Detailed information on PIMap software features and its usage is given by *Gehrke and Neukum* (2005). In the following, this is presented in brief form including recent updates. The map sheet content – the “layers” that can be generated and combined with PIMap – is illustrated afterwards. This paper concludes with some applications, i.e. map examples of Mars and the Saturnian satellite Mimas.

2. THE CARTOGRAPHIC SOFTWARE PIMAP

Basically, the cartographic software system PIMap has been designed for the operational production of the *Topographic Image Map Mars 1:200,000*, which is the standard map series for *Mars Express*. The software is developed in ANSI C++ and, therefore, executable under both Microsoft Windows and Linux environments. It is controlled by solely one initialization file, which contains all parameters (“keyword equals value”) to define map properties, contents, and layout. Depending on the particular mapping task, further input is required (Fig. 1).

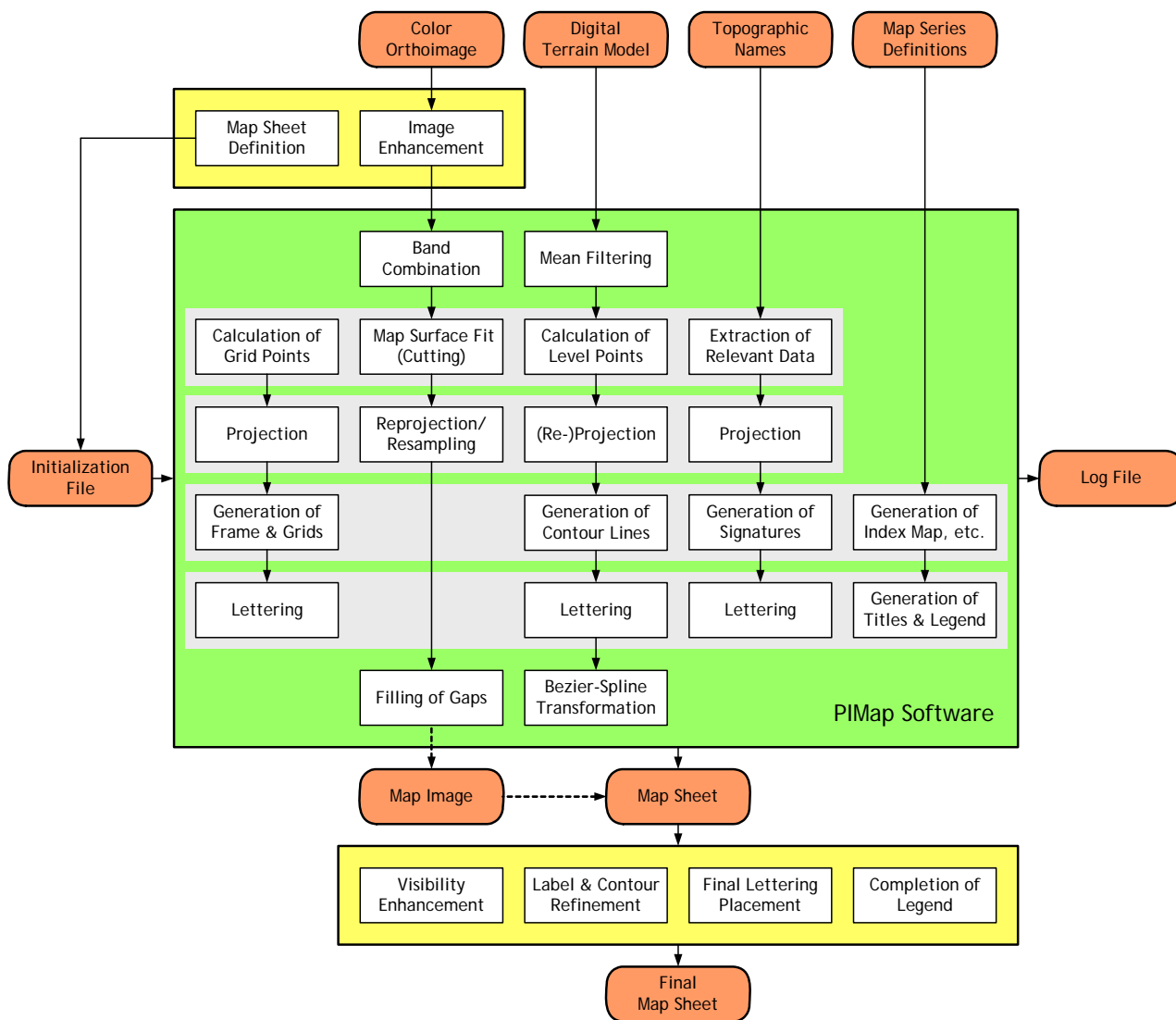


Fig. 1: Map generation using PIMap – from input data to final map sheet including pre and post processing steps.

With PIMap, the following data can be processed:

- Initialization file (mandatory!)
- Orthoimage mosaic
- Digital Terrain Model (DTM)
- Surface features: topographic names and landing sites
- Map series definitions

Based on this input, PIMap automatically generates all raster and vector data of the digital map sheet, which is a PDF file. This common output format ensures the possibility to edit each graphical element if desired. This is of special importance for interactive finishing using commercial standard software (*Corel Draw*, *Freehand*, *Adobe Illustrator*), amongst other things with regard to the final placement of topographic feature lettering (Fig. 1). However, while only few post processing steps are required to yield high quality topographic maps, the integration of thematic data is subject to an interactive follow-up work (*Lehmann et al.*, 2006).

PIMap handles arbitrary spherical and ellipsoidal reference bodies; ellipsoidal input coordinates can consist either of planetocentric or planetographic latitudes in combination with east or west positive longitudes. Azimuthal, conical, cylindrical, *Transverse Mercator*, and sinusoidal standard projections as well as modified forms used in planetary mapping – spherical formulae with ellipsoidal latitudes (the so-called *database projections*, cf. *Albertz et al.*, 2004) – are supported.

3. AUTOMATED GENERATION OF TOPOGRAPHIC MAP CONTENTS

With PIMap any map sheet is producible, which coincides with latitude and longitude lines – this is always the case in planetary cartography (*Greeley and Batson*, 1990; USGS, 2006). Center point, map dimensions, and scales can be freely defined.

The generation of a *Topographic Image Map Mars 1:200 000* standard sheet (“M 200k 0.00N/343.00E OMKT, Iani Chaos Region”) using PIMap is illustrated in Fig. 2 through 6. The map content is grouped into five basic layers (left images); for the north-western subsection, representative for the entire map sheet, the content is generated by accumulating the respective layers (right images). The final map sheet is shown in Fig. 7.

3.1 Map Surface: Neatline and Graticules

For any map sheet that is produced with PIMap, the sheet lines system (neatline) and graticules can be based on arbitrary combinations of ellipsoidal coordinate systems. In the sheets of the *Topographic Image Map Mars 1:200 000* both systems – the Martian standard consisting of planetocentric latitudes and east longitudes as well as planetographic latitudes in combination with west longitudes – are included (cf. Fig. 2). PIMap allows for generating an arbitrary number of graticules in different density and layout; this enables a detailed representation of one and the same grid, e.g. by defining one graticule shown in full lines and a second of the same coordinate system but with denser tick marks. The lettering can be controlled in a similar manner.

3.2 Image Basis

A planetary map is usually based on imagery, in the case of *Mars Express* a color orthoimage mosaic as a result of photo-

grammetric processing (e.g. *Scholten et al.*, 2005). Such images have to be provided either in VICAR (MIPL, 2006) or in common image formats, such as, TIFF, JPEG, etc.; for the latter case necessarily in combination with a separate VICAR label that provides geo-referencing (ASCII file).

Image integration into the mapped surface, which is illustrated in Fig. 3, includes the adaptation of map projection and scale. Thus, without prior transformations, any image data can be directly processed by PIMap – provided the desired region is covered in appropriate resolution.

3.3 Contour Lines

Contour lines are derived within PIMap software from a DTM (*Scholten et al.*, 2005; *Albertz et al.*, 2005b) in VICAR format. Similar to the image, the DTM is spatially adapted to the map sheet. The height reference is implicitly defined through the input data and must be transformed before running PIMap, if required.

For the derivation of contour lines, different equidistance levels can be defined to distinguish index and auxiliary contours. If desired, contour values are placed automatically and, furthermore, short and unlabeled depression contours can be marked with arrow ticks (Fig. 4). Details of the DTM processing and contour line derivation in PIMap are described by *Gehrke and Neukum* (2005).

The appearance of contour lines directly depends on DTM quality. With PIMap a DTM can be low pass (mean) filtered in order to get smoother contours (cp. Fig. 1), especially in comparatively flat regions. However, possible inaccuracies have to be edited after automatic processing; alternatively the contours concerned may be deleted.

3.4 Topographic Names and Landing Sites

Named surface features can be lettered automatically in PIMap, reasonably based on the *Gazetteer of Planetary Nomenclature* (USGS, 2006), which comprises the entire list of names on all planets and satellites. Based on that, topographic features of different kind and diameter can be distinguished by means of font type and size. Therewith also the omission in the map sheet, as it may be desired for tiny features in small-scale maps (or for Albedo features in general), is controllable.

In analogy to topographic names, landing sites can be marked with an appropriate symbol and also lettered automatically with PIMap software.

The output map review should especially consider name placements. Corrections, adaptations (e.g. to valley courses, as shown in Fig. 5) but also cancellations might become necessary in some cases.

3.5 Marginal Information

A planetary map is usually indicated with the title of the map series, a sheet name derived from a topographic surface feature, and its individual *sheet designator terms* following *Greeley and Batson* (1990), which feature encodings of the planet, the map scale, latitude and longitude of the sheet center, the type of map, and the year of publication.

In addition, PIMap can generate several legend entries, such as, the scale bar and explanations of map projection, reference body, and coordinate systems as well as an index map showing the position of a map within the context of its neighboring sheets of the map series – see Fig. 6 and 7.

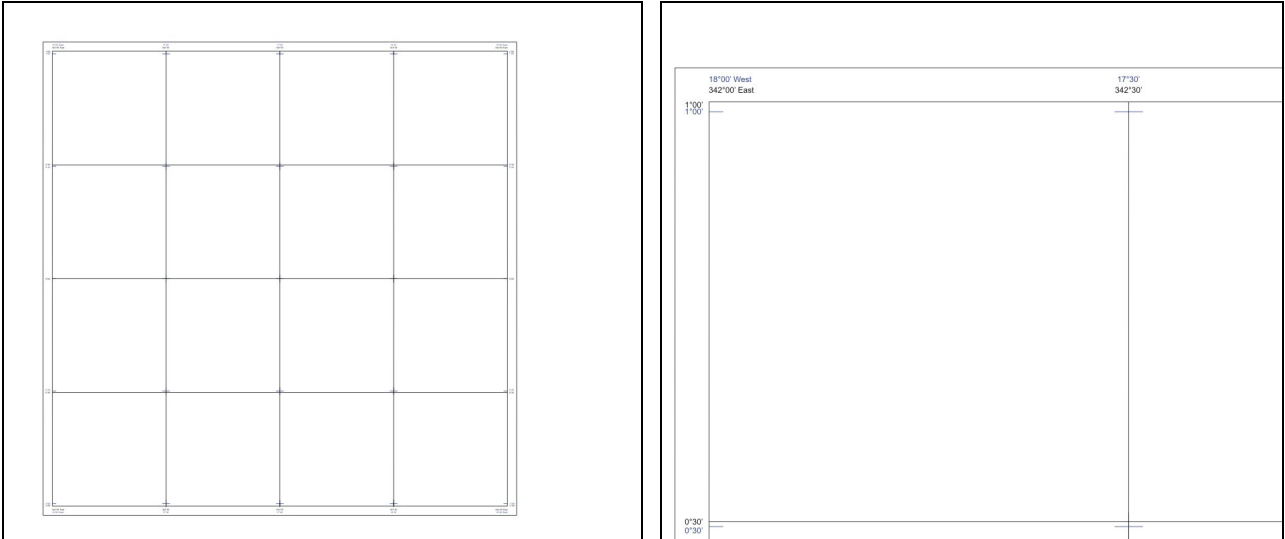


Fig. 2: Neatline, frame, and graticules: planetocentric/east standard (solid lines) and planetographic/west system (tick marks).

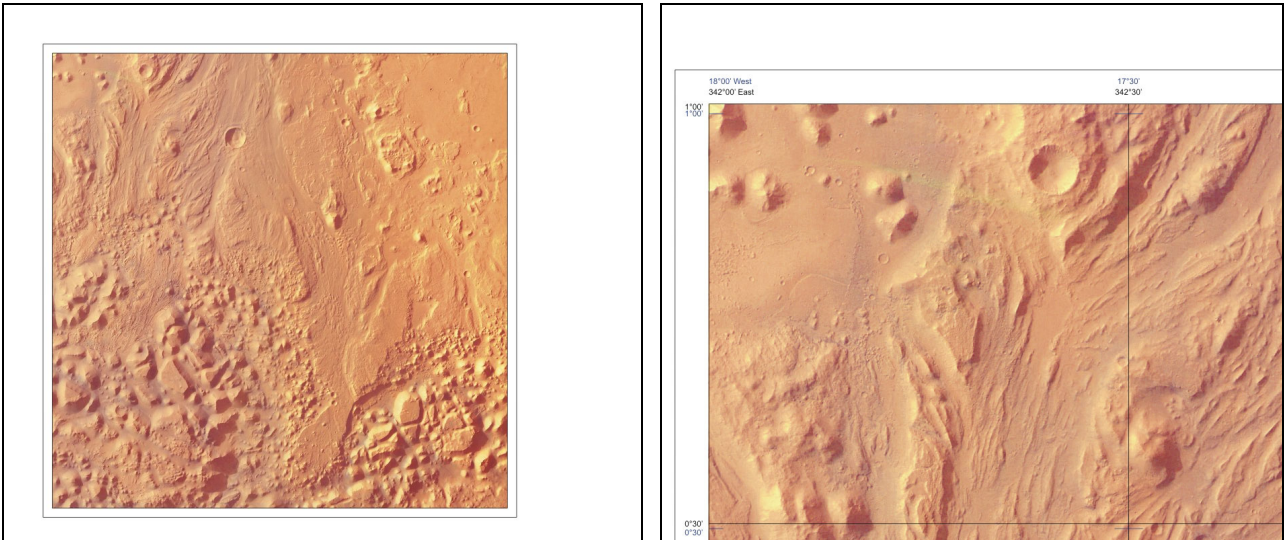


Fig. 3: Orthoimage mosaic.

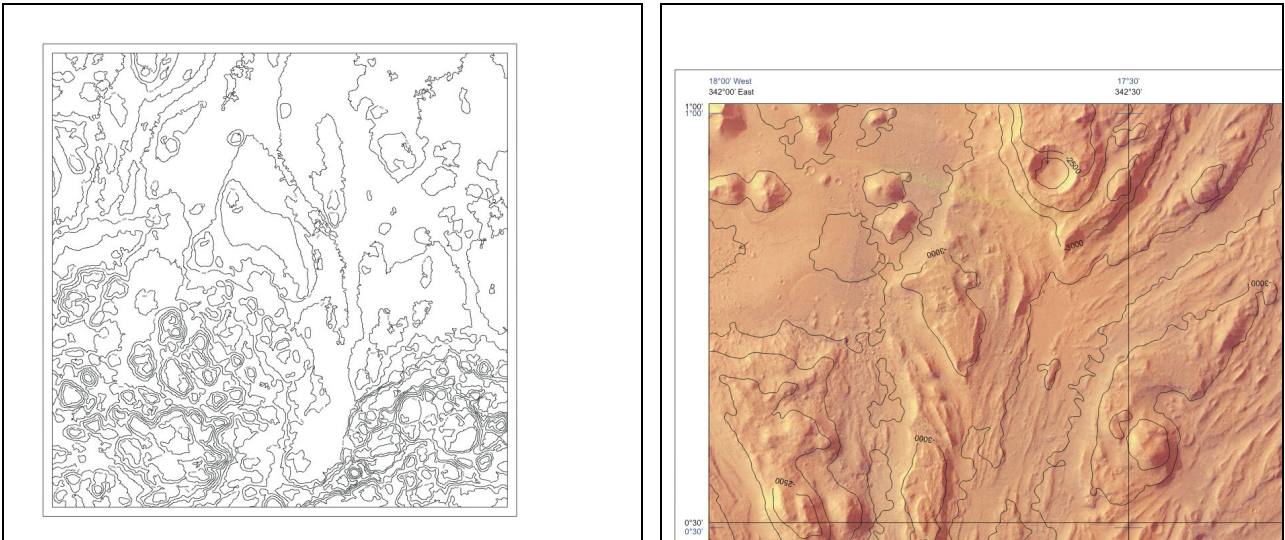


Fig. 4: Contour lines including labels and depression ticks (arrows).

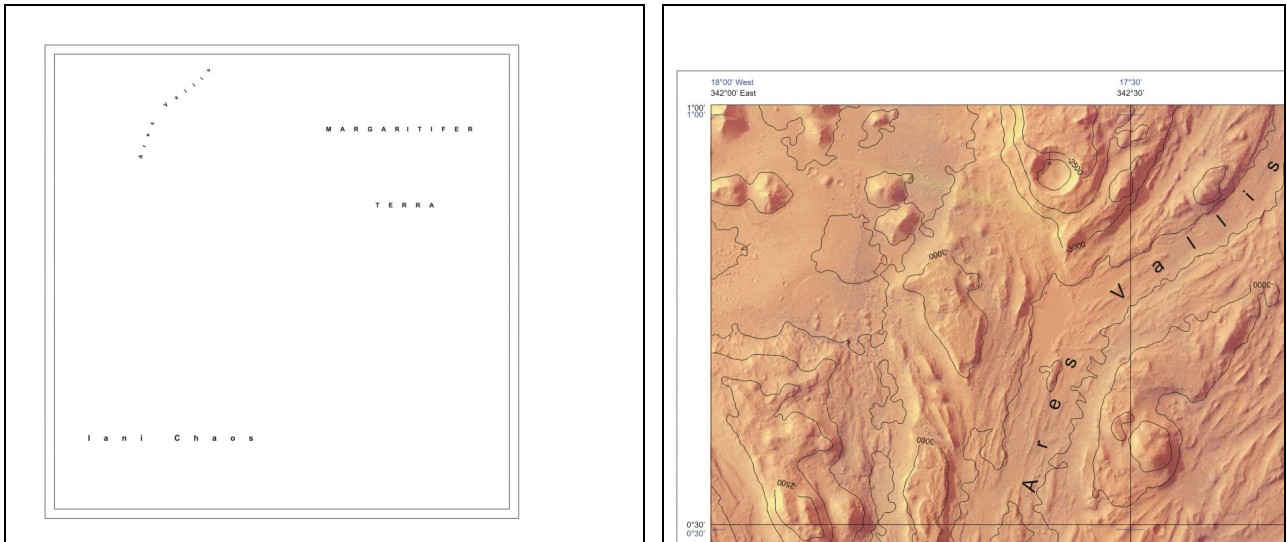


Fig. 5: Topographic names.

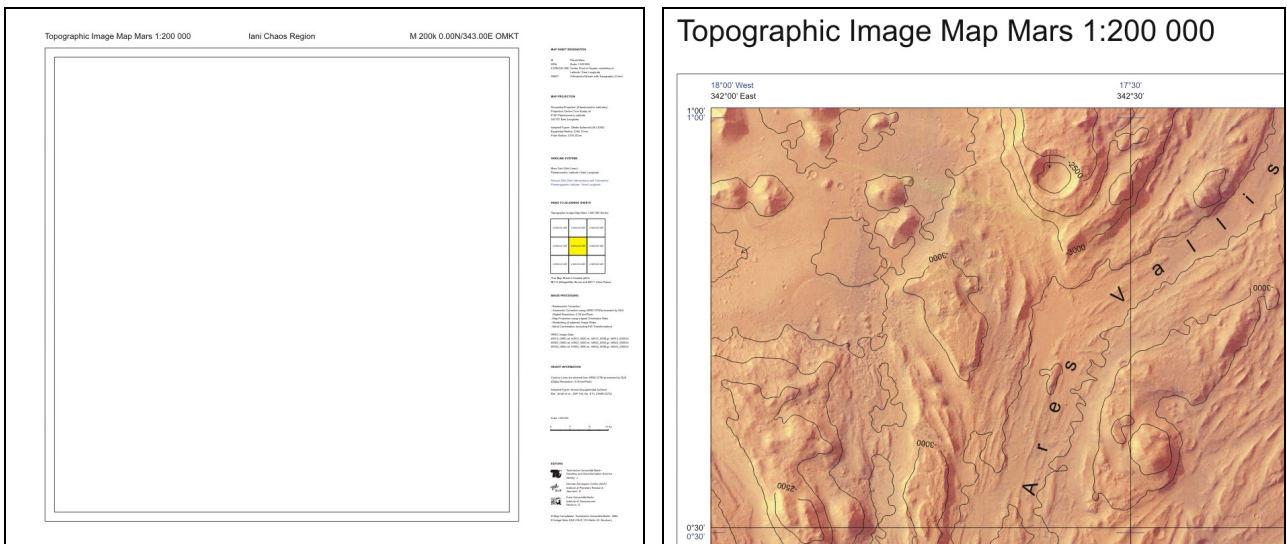


Fig. 6: Map title, sheet name and designation, and further marginal information.

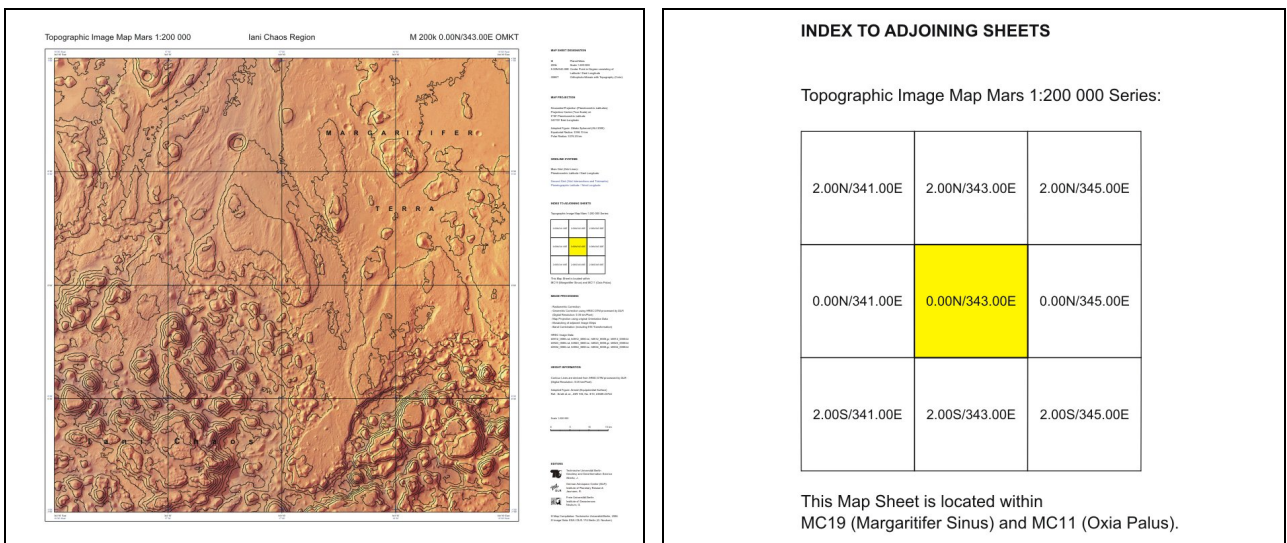


Fig. 7: Final map sheet. Enlarged is the index map including the location within the well-known *Mars Charts* (MC 5M series).

4. LARGE-SCALE CARTOGRAPHY OF MARS

Topographic image maps of the Martian surface have already been produced in preparation of the *Mars Express* mission and presented by Gehrke et al. (2003). Since 2004, along with HRSC image acquisition and processing (Scholten et al., 2005; Alibert et al., 2005b), sheets of the *Topographic Image Map Mars 1:200,000* series and special target maps in different scales are generated for selected regions. The Iani Chaos region, e.g., has been mapped in scales 1:200,000, 1:100,000, and 1:50,000 (Gehrke et al., 2006a, 2006b). Most recently, the first map sheets of the northern polar region have been generated.

4.1 The Cartographic Concept in Brief Form

The standard map series for HRSC on *Mars Express* cartography is the *Topographic Image Map Mars 1:200,000*. This large-scale map series covers Mars in altogether 10,372 individual sheets in equal-area map projections; 10,324 sheets within the $\pm 85^\circ$ latitude zone in *sinusoidal projection* supplemented by 24 around the poles in *Lambert azimuthal equal-area projection*.

Details of this cartographic concept – including reference body

definitions, projection properties, general layout, etc. – have been presented several times, e.g., by Alibert et al. (2004, 2005a, 2005b). The map content and general layout is illustrated in Fig. 2 through 7 as well as in Fig 8.

4.2 A Topographic Image Map of the Planum Boreum/Chasma Boreale Region

While since 2004 several map sheets in sinusoidal map projection have been generated, since recently the first standard sheet of the polar regions – by definition based on *Lambert azimuthal equal-area projection* – is available: “M 200k 86.00N/324.00E OMKN”, a map showing part of the Planum Boreum, and the northernmost part of Chasma Boreale (Fig. 8). The latter surface feature is altogether some 300 km long and almost divides the polar ice cap in two parts (which could not be documented in only one of the large-scale map sheets). The region was covered within HRSC orbit 1154. Photogrammetric data processing has been carried out systematically at DLR (cf. Scholten et al., 2005). The map sheet was generated at *Technische Universität Berlin* using PIMap. In the depicted version, “OMKN”, the map is based on a color orthoimage and provides nomenclature but no contour lines.

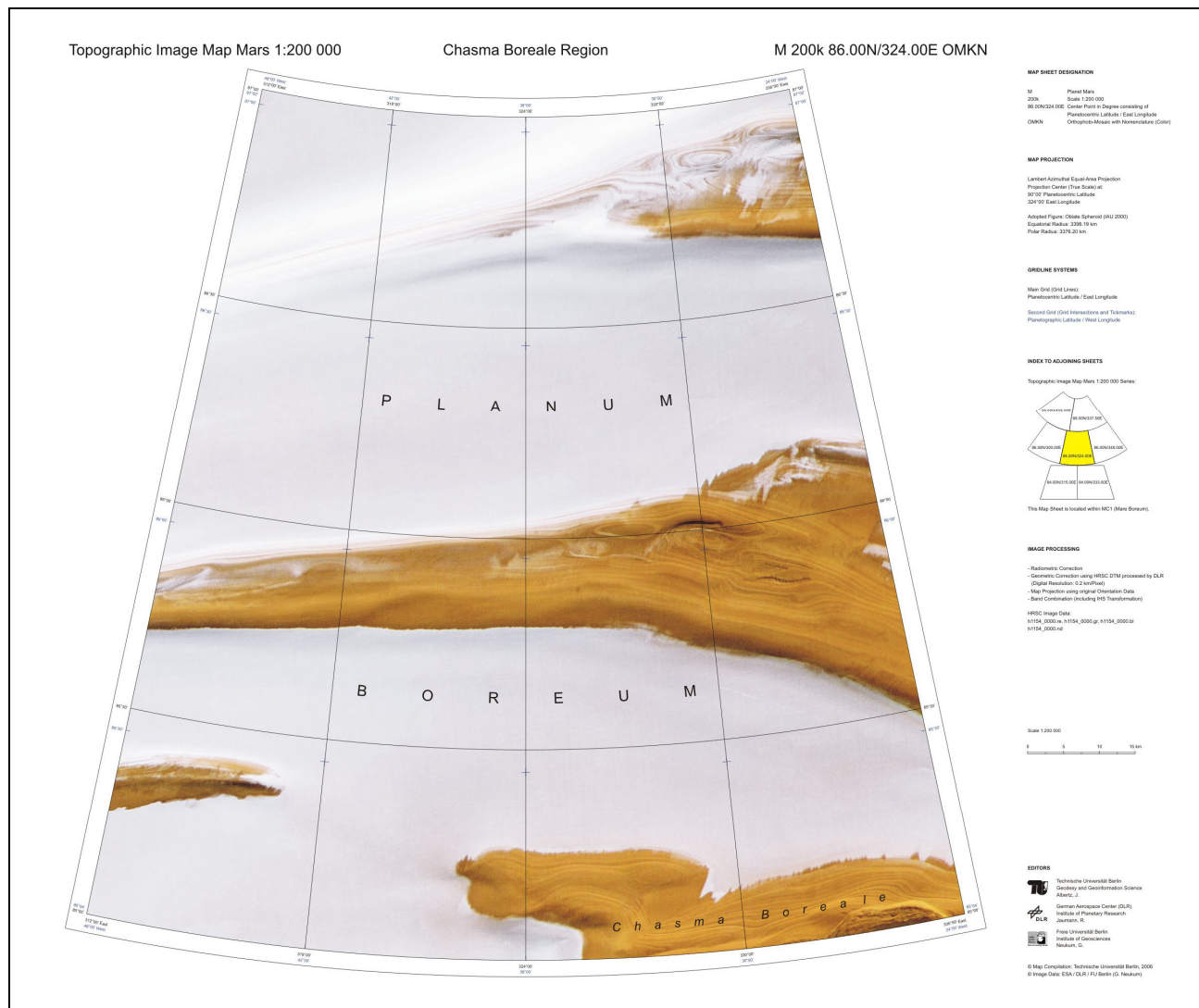


Fig. 8: *Topographic Image Map Mars 1:200,000*, sheet “M 200k 86.00N/324.00E OMKN, Chasma Boreale Region”.

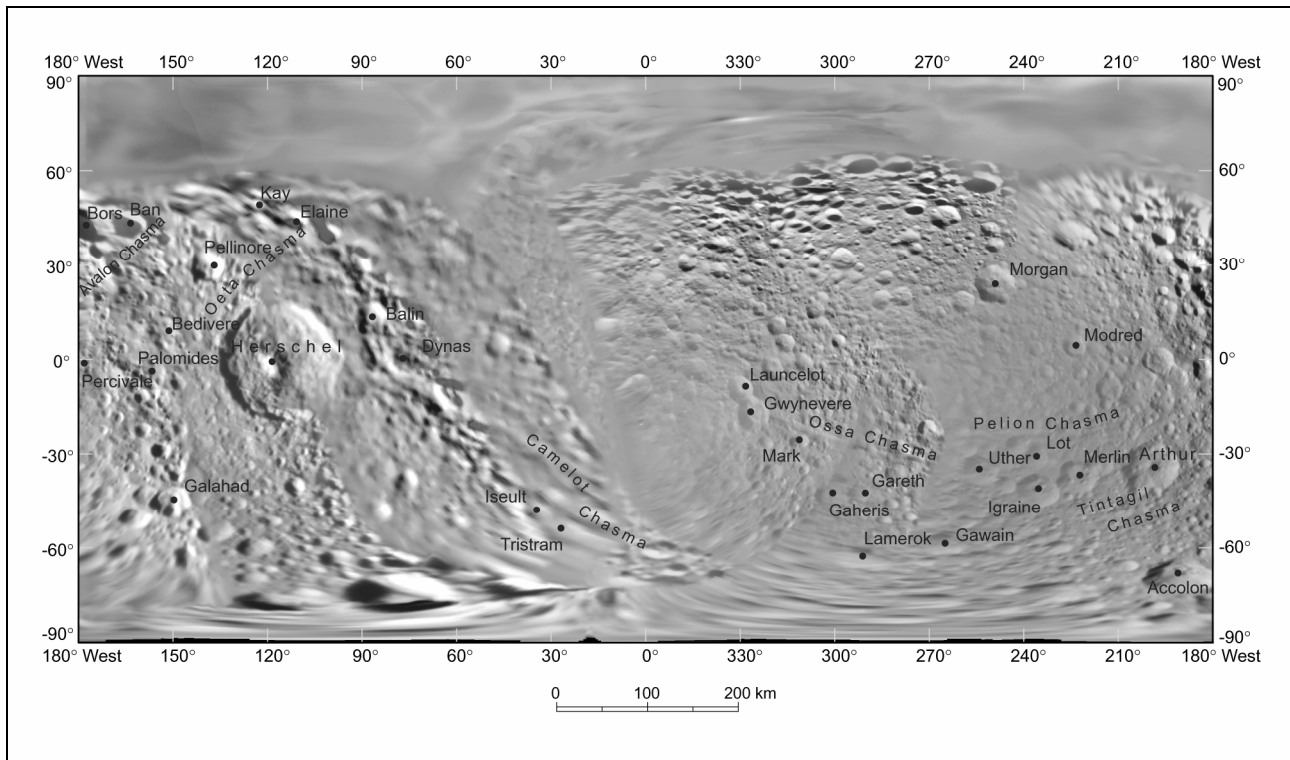


Fig. 9: Mimas base map from *Voyager* and *Cassini* data, after the *Cassini* flyby in August 2005. The mean radius of Mimas is 198.8 km, the digital map resolution is 8 pixel/degree (0.43371 km/pixel).

5. MAPPING OF THE ICY SATURNIAN SATELLITES

Altogether, the Saturnian system contains 47 satellites. The stated objective of the *Cassini* ISS camera experiment is to obtain global coverage for all so-called medium-sized icy satellites with resolutions better than 1 km/pixel (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 until July 2008.

The mapping activities for the satellites Mimas, Enceladus, Tethys, Dione, Rhea, Iapetus, and Phoebe lead to the production of new global mosaics (CICLOPS, 2006; NASA, 2006b; Roatsch et al., 2006a). Map projection and mosaicking are carried out following procedures described for Mars imagery by Scholten et al. (2005). Global 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° to 360° W and latitude range -90° to 90° (Kirk, 1998); the prime meridian is in the center of the map. 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 mosaics can be extended to standard cartographic products. For the preparation of such mosaics for web release or scientific paper, the cartographic group at DLR uses PIMap to add grids and nomenclature (see Fig. 9). Most recently, the production of a high-resolution atlas of Enceladus was started, where PIMap is used to prepare the quadrangles (Roatsch et al, 2006b).

Imaging of the medium-sized icy satellites will continue until the end of the *Cassini* mission, making it possible to improve the image mosaics during the tour.

6. CONCLUSION AND OUTLOOK

The cartographic software package PIMap accomplishes all cartographic processing steps that are required for digital topographic image maps; it is an operational software system. In comparison to common map generation – the preparation of all components on its own followed by cumbersome merging processes – the new comprehensive approach is a substantial step towards future planetary cartography (Albertz et al., 2004, Gehrke and Neukum, 2005). Several map products have been generated using PIMap, such as sheets of the *Topographic Image Map Mars 1:200,000* series, related topographic and thematic maps as well as various products of the mid-sized icy Saturnian satellites. Thus, the software is applied in ongoing planetary missions that involve cartographic projects – like *Mars Express* and *Cassini* – and potentially, in the future exploration of our solar system as well.

Besides processing VICAR images and DTMs, the support of ISIS (USGS, 2006) and PDS (NASA, 2006) formats by PIMap is envisaged.

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