FOUR YEARS OF PLANETARY CARTOGRAPHY WITH THE HRSC

J.Albertz[1], S. Gehrke[1,2], H. Lehmann[1], M. Wählisch[3]

[1]Institute for Geodesy and Geoinformation Science, Technical University Berlin, Str. des 17. Juni 135
D-10623 Berlin, Germany - albertz@igg.tu-berlin.de
[2]North West Geomatics, Pixelgrammetry Group, Suite 212, 5438 11 St. NE, Calgary, AB T2E 7E9, Canada - stephan.gehrke@pixelgrammetry.com
[3]Institute for Planetary Research, German Aerospace Center, Rutherfordstr. 2, D-12489 Berlin, Germany - marita.waehlisch@dlr.de

Commission IV, WG IV/7

KEY WORDS: Cartography, Extra-terrestrial, Planetary, Mars, High Resolution, DEM/DTM, Camera, Mapping

ABSTRACT:

The *High Resolution Stereo Camera* (HRSC) on the European *Mars Express* mission began operation in January 2004. With this camera system new standards were set for the acquisition, processing and cartographic application of planetary data, in other words a new era of planetary cartography began. A new cartographic concept for the planet Mars has been designed. The cartographic standard product is the *Topographic Image Map Mars 1:200,000* series. The layout scheme of this map series is flexible also for the generation of maps in other scales, special target maps, thematic maps, and related products.For cartographic processing a new software system has been developed at the *Technical University Berlin*. The main purpose of the software package *Planetary Image Mapper* (PIMap) is to automate the map generation process. The software is controlled by an initialization file, which provides all parameters that are necessary to define map properties, contents, and layout. Until the end of 2007, about 70 map sheets in 15 different regions of the planet Mars have been derived from HRSC data. This comprises sheets of the *Topographic Image Map Mars 1:200,000* series and special target maps in different scales for selected regions. Also maps as subdivision sheets in larger scales, i.e. 1:100,000 and 1:50,000, have been generated. The experiment clearly demonstrated the high quality of the HRSC image data and the flexibility of PIMap as well.

1. INTRODUCTION

The *High Resolution Stereo Camera* (HRSC) on the European *Mars Express* mission is a pushbroom scanning instrument with 9 CCD line detectors mounted in parallel on the focal plane. Its unique feature is the ability to obtain image data of high resolution, with along-track triple stereo, in four colors, and under five different phase angles. The spatial resolution at the nominal periapsis altitudes is up to 12 m/pixel. The data acquired form a unique data set for systematic derivation of Digital Terrain Models (DTM), color orthoimages, and, based on that, high quality cartographic products, which are mainly based on the cartographic concepts of the *Topographic Image Map Mars 1:200,000* series (Albertz et al., 2004; Kirk, 2005; Lehmann et al., 1997). The series' layout scheme is flexible to the generation of special target maps, thematic maps, and related products.

In order to automate the map generation process, the cartographic software package *Planetary Image Mapper* (PIMap) has been developed at *Technische Universität Berlin* (TUB) by Gehrke et al. (2006b). Using this software, map production was carried out at TUB in cooperation with the *German Aerospace Center* (DLR), which is responsible for photogrammetric processing of HRSC data (Gwinner et al., 2005; Scholten et al., 2005). Other HRSC team members are involved, especially with regard to thematic mapping.

A standard sheet of the *Topographic Image Map Mars 1:200,000* displays approximately 120x120 km. Considering an HRSC image width of 60 km in highest resolution of 12 m/pixel, it is evident that mosaics of adjacent orbits are necessary to cover the mapped area. Therefore, especially in the early stage, map sheets needed to be adapted to individual orbits by location and/or scale. The first maps within the regular sheet lines could be generated in summer 2004. Until the end of 2007, a variety of topographic and also thematic maps of different Martian regions has been produced. Furthermore, it has been shown that HRSC data of highest resolution is suitable for mapping even in scales up to 1:50,000.

2. THE TOPOGRAPHIC IMAGE MAP MARS 1:200,000

The large-scale *Topographic Image Map Mars 1:200,000* map series was developed to allow for optimum cartographic representation of HRSC data (Lehmann et al., 1997). It is based on HRSC orthoimages and features contour lines, topographic names as well as map titles, designations, and several legend entries (Albertz et al., 2004; Albertz et al., 2005b; Gehrke et al., 2006b).

Region	HRSC Orbit(s)	Covered Area: Lat/Lon		Scale(s)	Map Type(s)
Alba Patera	68	39.1N - 41.0N	255.0E - 257.5E	200k	OMKT
Albor Tholus	32	18.0N - 20.0N	149.5E - 151.1E	200k	OMKT, OMKN
Candor Chasma	1235	7.9S - 5.9S	282.3E - 284.3E	200k	OMC
Centauri/Hellas	2510	41.0S - 37.0S	95.0E - 97.5E	200k, 300k	OMKT
Chasma Boreale	1154	83.0N - 87.0N	306.0E - 336.0E	200k	OMKT, OMKN
Dokka	1177	77.0N - 79.0N	210.0E - 220.0E	200k	OMKN
Hydraotes Chaos	18	0.7N - 1.7N	322.7E - 324.6E	100k	OMKT
Iani Chaos	912, 923, 934	3.0S - 1.0N	342.0E - 344.0E	200k, 100k, 50k	OMKT
Mangala Valles	286, 299	9.0S - 3.0S	208.0E - 210.0E	200k	OMKT, OMKN
Nanedi Valles	894, 905, 927	3.8N - 5.8N	311.3E - 313.3E	200k	OMC
North Pole	1154, 1167	89.0N - 90.0N	0.0E - 360.0E	200k	OMKN
Sabrina Valles	894, 905, 927	9.8N - 13.3N	310.0E - 314.0E	400k	OMKT
Tithonium Chasma	442	7.0S - 5.0S	268.0E - 270.0E	200k	OMKT
Centauri/Hellas	2510	39.8S - 36.8S	95.0E - 97.5E	300k	G (OMKG)
Gusev	24, 27, 285, 335	18.0S - 10.0S	172.0E - 179.0E	600k	G
Hale/Bond	511, 533	30.5S - 38.0S	320.5E - 327.0E	600k, 750k	G (OMKG)

Table 1. Regions of Mars and related HRSC map products. (Map type designators following Greeley & Batson, 1990: OM = orthoimage mosaic; C = contour lines; N = nomenclature; T = topography, i.e. both contours and nomenclature; G = geology; K = color)

The Martian surface is covered in 10,372 individual sheets in equal-area projections: Sinusoidal projection for latitudes between 85° north and south and Lambert Azimuthal Equal-Area projection around the poles. While all map sheets feature 2° in latitude, the longitude extent increases from 2° in the equatorial zone towards 360° at the poles. Therefore, the mapped area is similar for all sheets (about 120x120 km^2). The series' cartographic concept forms the basis for special target maps in different scales and also for thematic mapping (Albertz et al., 2004).

The common Martian reference body for planimetry is a rotational ellipsoid with an equatorial axis of 3396.19 ± 0.10 km and a polar axis of 3376.20 ± 0.10 km. This parameter set is defined by the International Astronomical Union (IAU) as the *Mars IAU 2000* ellipsoid (Seidelmann et al., 2002). According to IAU conventions two different types of ellipsoidal coordinate systems are in use. One consists of positive western longitudes in combination with planetographic latitudes (west/planetographic), the other one of positive eastern longitudes and planetocentric latitudes (east/planetocentric). The latter is recommended by the Mars Geodesy/Cartography Working Group (MGCWG) to be employed in future map products (Duxbury et al., 2002). Therefore, the east/planetocentric system is defined also as the standard for *Mars Express* mapping (Albertz et al., 2005b).

An Areoid (Martian Geoid) is the topographic reference surface for heights (Seidelmann et al., 2004). It has been derived from *Mars Global Surveyor* data and is defined as the equipotential surface (gravitational plus rotational) whose average value at the equator is equal to the mean radius of 3396.0 km (Smith et al., 2001).

3. MAP PRODUCTS

The first maps have been generated in summer 2004. Until the end 2007, a variety of topographic and also thematic maps of different Martian regions has been produced (Table 1, Figure 1).

3.1 Topographic Standard Sheets

In general, considering HRSC image widths (> 60 km), adjacent orbits have to be mosaicked to cover a sheet of the *Topographic Image Map Mars 1:200,000* series. However, maps within the regular sheet lines have already been accomplished in summer 2004 showing the Mangala Valles complex. Since then, several sheets of different regions of Mars have been produced (Albertz et al., 2005a, 2005b; Gehrke et al., 2006a; Gehrke et al., 2007a). Figure 2 shows two adjacent standard sheets in the north-polar region on either side of the 85° parallel, which is the transition of the two map projections. These topographic maps combine high-resolution HRSC orthoimages with contour lines from *Mars Orbiter Laser Altimeter* (MOLA). The sheets "M 200k 84.00N/315.00E OMKT" (Sinusoidal projection) and "M 200k 86.00N/326.00E OMKT" (Lambert Azimuthal projection) of the Topographic Image Map Mars 1:200,000 cover 2° by 18° and 2° by 24°, respectively. The depicted Chasma Boreale almost divides the ice cap and reveals (in Martian summer) layered structures of water ice and dust. Contour lines nicely fit with these layers and, moreover, give a good impression of the topography of the almost textureless ice cap (Gehrke et al., 2007a). The standard map sheet of the north pole itself has also been produced.

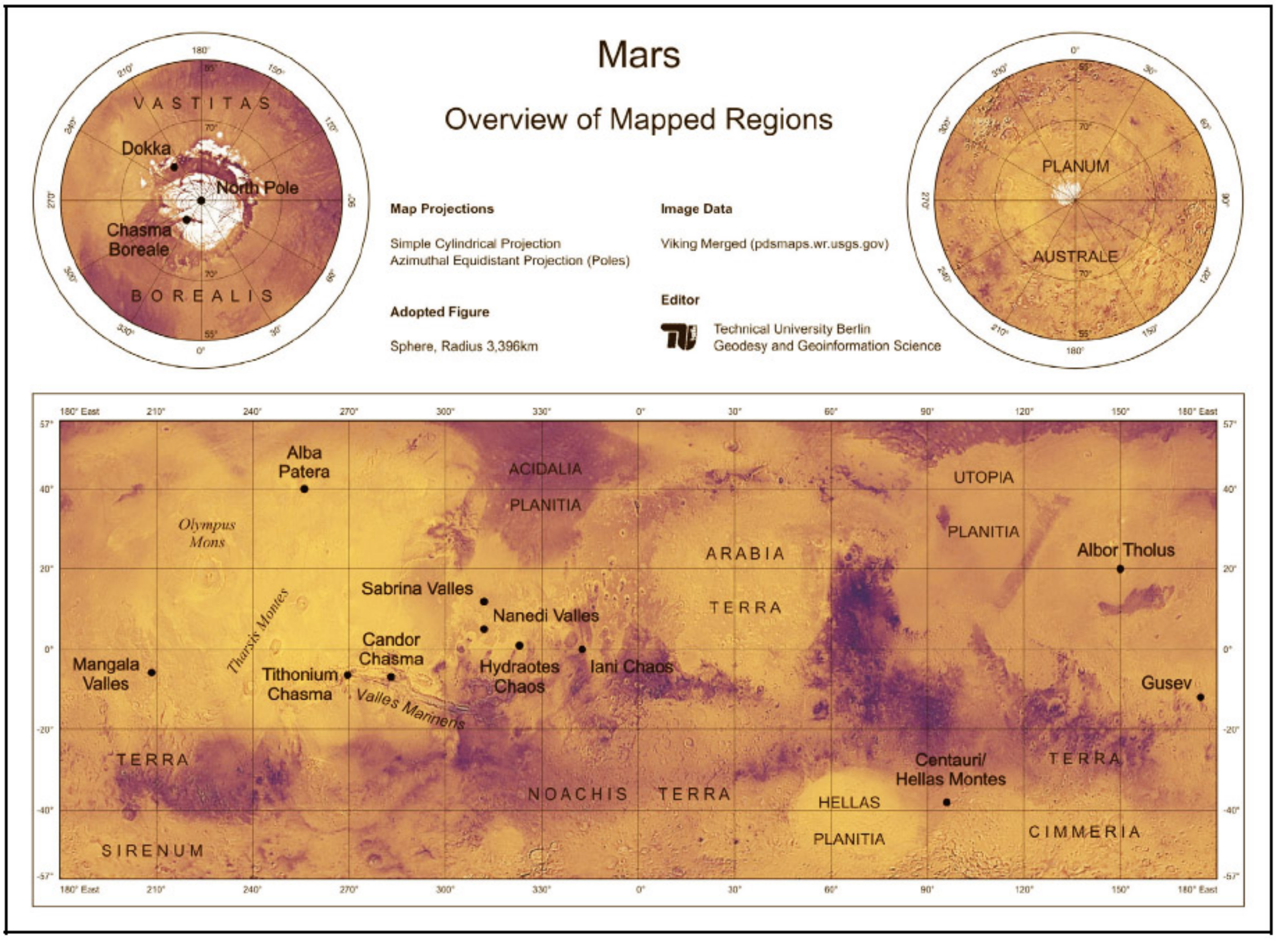

Figure 1. Location of mapped regions on Mars, based on Viking color data (USGS, 2007). Due to the small scale, individual map sheets cannot be shown.

Systematic mapping in larger scales, i.e. 1:100,000 and 1:50,000, can be achieved by dividing standard sheets into quarters and sixteenth, respectively. The suitability of high quality HRSC data, which are both acquired under optimum conditions and adeptly processed, for mapping in those scales has been demonstrated in Iani Chaos: A triplet of topographic image maps, a standard product within the regular sheet lines of the series, “M 200k 2.00S/343.00E OMKT”, and two derived maps, “M 100k 2.50S/343.50E OMKT” and “M 50k 2.25S/343.25E OMKT”, has been generated (Gehrke et al., 2006a).

3.2 Special Target Maps

Especially in the early stage of the *Mars Express* mission map sheets needed to be adapted to individual orbits by location and/or scale. The very first HRSC map, e.g., was a special target map of Hydraotes Chaos in 1:100,000 (Albertz et al., 2004). The “Topographic Image Map Mars 1:400,000, M 400k 11.50N/312.00E OMKT, Sabrina Vallis Region” with additional information from the Catalog of Large Martian Impact Craters has been presented in 2007 by Gehrke et al. (2007b).

3.3 Thematic Maps

Several thematic map products have been generated in cooperation with other HRSC team members. Exemplary products are a geologic map of Gusev area (Albertz et al., 2005b) and a combined topographic- thematic map illustrating the geomorphology of Centauri and Hellas Montes (Lehmann et al., 2006). The most recent thematic product is a special target map of the Hale-Bond region by Hiesinger et al. (2007). In this area, the putative outflow channel Uzboi Vallis is heavily modified by the two impact craters. The valley floor is characterized by relatively smooth terrain between morphologically sharp blocks of eroded ejecta material (Figure 3).

3.4 HRSC DTM Test support

It is evident that DTMs in highest quality are indispensable for the derivation of accurate contour lines. Besides systematic processing of all HRSC data (Scholten et al., 2005), several enhancing and alternative approaches (Albertz et al., 2005b; Gwinner et al., 2005) exist, which have been compared in the *HRSC DTM Test* (Heipke et al., 2007). Part of the evaluation process was the assessment of the contour line quality. For this purpose, topographic map sheets from all delivered DTMs in two different test areas, Nanedi Valles and Candor Chasma, were generated. These sheets follow the layout and scale of the standard map series.

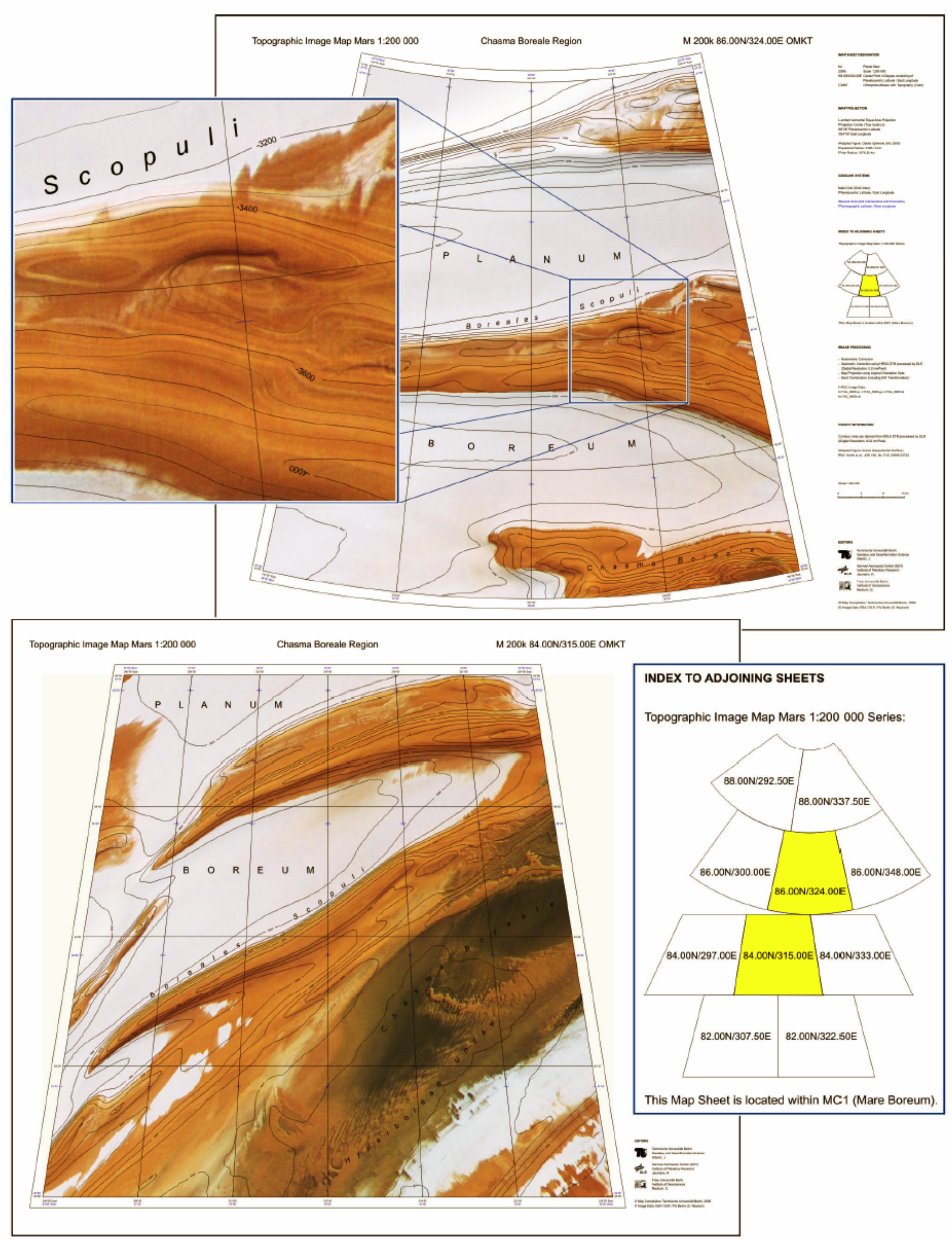

Figure 2. Map sheets “M 200k 84.00N/315.00E OMKT” in Sinusoidal projection and “M 200k 86.00N/326.00E OMKT” in Lambert Azimuthal projection. The index map (lower right image) was combined from both sheets and illustrates their relative location, with map surfaces marked in yellow, and neighboring sheets of the *Topographic Image Map Mars 1:200,000* series in their projections. The subsection of the northern sheet (upper left image) is shown in scale 1:400,000, which is half of the original size.

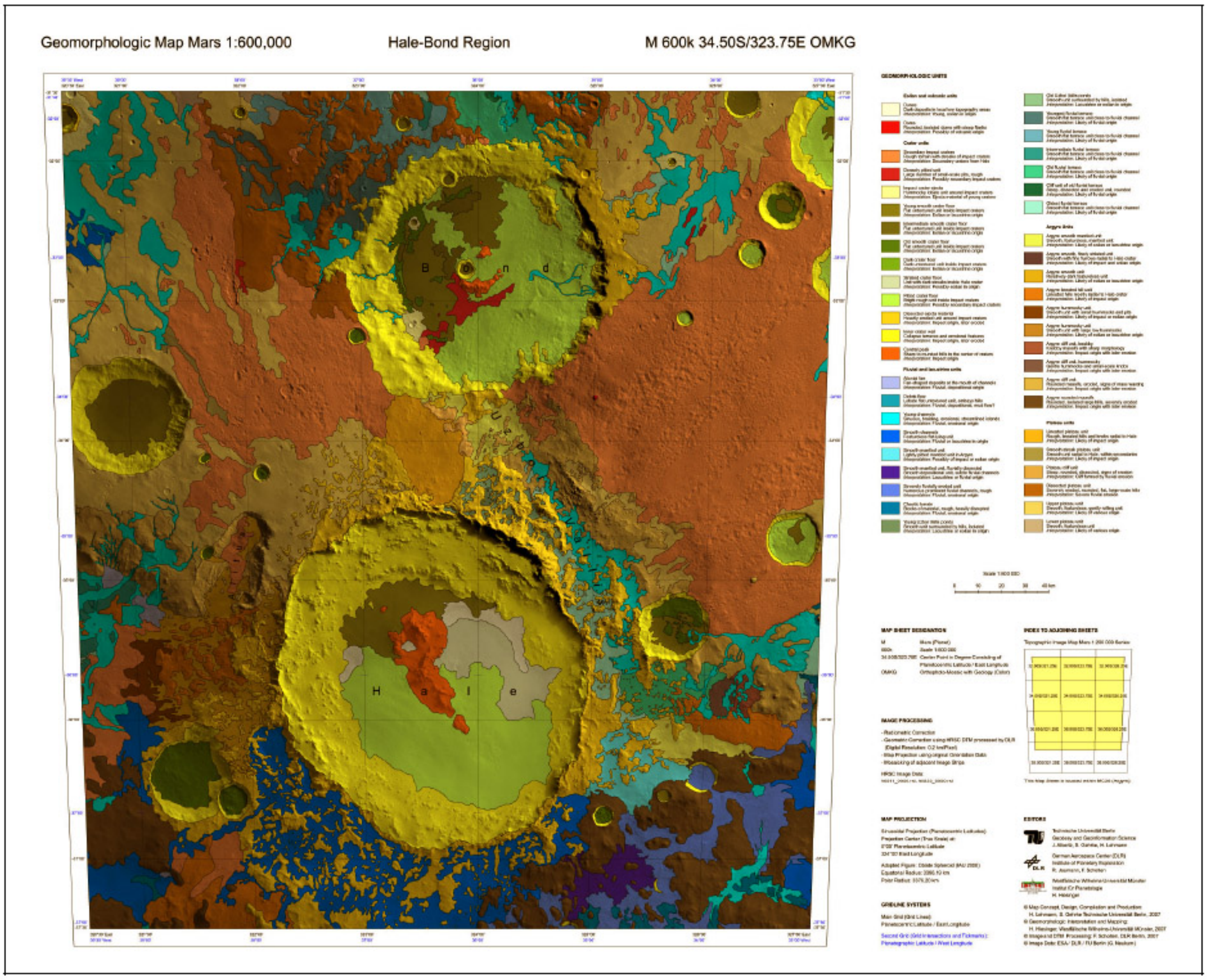

Figure 3. Geomorphologic map "M 600k 34.50S/323.75E OMKG" of the Hale and Bond crater region.

3.5 Map Products of other planets

It is of particular interest that the PIMap software system was also successfully applied to mapping of Saturnian satellites. At DLR global digital mosaics of the medium-sized icy satellites of the Saturnian system have been generated in the framework of the *Cassini* mission. The 15 quadrangles of an atlas of Enceladus and Dione were extracted from global mosaics, reprojected, and coordinate grids were superposed as graphicvectors using the PIMAP software.

4. CONCLUSIONS

From the experience gained during four years HRSC cartography and operational application of the PIMap software, it is evident that a breakthrough for future planetary mapping has been achieved. The cartographic software package PIMap accomplishes all cartographic processing steps that are required for topographic image maps. Furthermore, thematic mapping is substantially supported by the system. Thus, ongoing and future planetary missions that involve cartographic projects will greatly benefit from this development.

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ACKNOWLEDGEMENT

The research project "Software Development and Technical Support for Cartographic Data Processing" at the Technische Universität Berlin was funded by the German Bundesministerium für Bildung und Forschung. This project is part of the research program "High Resolution Stereo Camera (HRSC) on the Mars Express Orbiter" under the guidance of Principal Investigator Prof. Gerhard Neukum, Freie Universität Berlin.