PRECISE TOPOGRAPHIC AND THEMATIC MAPS OF PLANET MARS

JÖRG ALBERTZ 1, STEPHAN GEHRKE 1, HARTMUT LEHMANN 1, MARITA WÄHLISCH 2, GERHARD NEUKUM 3 and the HRSC Co-Investigator Team

1 Technical University of Berlin, Geoinformatics and Cartography, Sekr. H12, Straße des 17. Juni 135, D-10623 Berlin, {albertz | stephan | hartmut}@fpk.tu-berlin.de
2 German Aerospace Center (DLR), Institute of Planetary Research, Rutherfordstraße 2, D-12489 Berlin, marita.waehlisch@dlr.de
3 Freie Universität Berlin, Institut für Geologische Wissenschaften, Malteserstr. 74-100, D-12249 Berlin, gneukum@zedat.fu-berlin.de

ABSTRACT

The High Resolution Stereo Camera (HRSC) on board of the European Mars Express spacecraft provides high resolution color and stereo imagery. Based on orthoimage mosaics and Digital Terrain Models, which are systematically derived from HRSC data, precise topographic and thematic maps of high quality are produced. The main cartographic product is the Topographic Image Map Mars 1:200,000. This newly developed map series has become the standard for large-scale cartography of Mars and, therefore, it is also the guideline for future mapping purposes. Furthermore, the series is the basis for the derivation of thematic data and their cartographic presentation respectively. A sophisticated software system, the Planetary Image Mapper (PIMap), has been developed at the Technical University of Berlin; this software is now in operational use by the HRSC Co-Investigator team members for the automated map generation.

INTRODUCTION

At the present time our neighboring planet Mars is in the focus of various scientific research programs. Mars Express, the first European Space Agency (ESA) mission to a planet ever, carries the High Resolution Stereo Camera (HRSC) that delivers imagery in color and stereo since January 2004. This research program has been particularly designed to meet the special demands of stereophotogrammetry and cartography. The camera provides multispectral digital image data of high resolution (up to 10 m) as well as systematic stereo coverage of the Martian surface. Furthermore, the Super Resolution Channel (SRC) of the camera acquires image data of extremely high resolution from selected areas of particular interest.

HRSC images are processed systematically to various data levels; experiences with the imagery and its processing within the HRSC Co-Investigator team are described by OBERST et al. (2004). Based on the photogrammetric results – i.e. orthoimages and Digital Terrain Models (DTMs) –, large-scale topographic image maps and thematic maps as well as related products of the Martian Surface are generated. The main goal is the production of the Topographic Image Map Mars 1:200,000 series, which stands for both the guideline for topographic mapping as well as the basis for thematic mapping. Special target maps, e.g. in larger scales, can also be derived. The basic principles of this map series have already been defined for the failed Mars96 mission by LEHMANN et al. (1996). Recently, the latest reference system definitions for Mars as well as the change of coordinate systems have been adopted; some contents – e.g. sheet designations – are revised and/or renewed (GEHRKE et al., 2003). Hence, the Topographic Image Map Mars 1:200,000 completes the existing range of Martian small- and mid-scale maps with the appropriate large-scale map series for high-resolution HRSC imagery and future mapping. For the production of such topographic image maps, the cartographic software package Planetary Image Mapper (PIMap) has been developed at the Technical University of Berlin. Based on a detailed set of initialization parameters, this software generates and compiles the entire map content automatically. However, a few interactive finalizations are still necessary.
The generation of different thematic maps, in the first instance mainly geological maps, is currently underway. Recently, the first high quality thematic map based on HRSC imagery has been generated in close cooperation between the Technical University of Berlin and the European Space and Technology Centre (ESTEC) of ESA.

CARTOGRAPHIC CONCEPTS AND MAP COMPILATION

The basic cartographic concepts for the compilation of the new Topographic Image Map Mars 1:200,000 series as the guidelining product for mapping of Mars in larger scales have already been defined in preparation of the Mars Express mission. A summary is given within the following two subsections; for details see LEHMANN et al. (1996), GEHRKE et al. (2003) and ALBERTZ et al. (2004).

Martian Reference Bodies and Coordinate Systems

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.

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 by the mean equatorial radius of 3396.0 km (SMITH et al., 2001).

Map Projections

The Topographic Image Map Mars 1:200,000 series is compiled in equal-area projections. Because of its useful mathematical and graphical properties, the Sinusoidal projection is applied to map sheets between 85° north and 85° south. However, the polar regions can not be mapped appropriately by this projection. Therefore the Lambert Azimuthal projection was selected for mapping those regions between 85° and 90° north or south respectively (Figure 1). The same scheme is applied for the generation of special target maps and thematic maps as well.

Maps and Map Series of Mars

Over the past decades, several topographic and thematic maps have been defined and produced. With regard to the scales, it exists a broad bandwidth from global maps, e.g. derived from early Mars missions like Viking 1 and 2 in the 1970’s, down to the large-scale Topographic Image Map Mars 1:200,000 series for present Mars Express mapping.

![Map of Western part of the quadrangle scheme of the Topographic Image Map Mars 1:200,000 series (left) in comparison to the Mars Charts MC 5M map series (right; GREELEY & BATSON, 1990).](image)
The following scales and/or map series are in use for Mars – cf. GREELEY & BATSON (1990) and ALBERTZ et al. (2004):

- Global maps, mainly 25M and 15M
- Mars Charts series – MC 5M and MC 2M
- Mid-scale maps (1M)
- Mars Transverse Mercator series MTM 500k
- Topographic Image Map Mars 1:200,000 (200k) series and derived products (100k, 50k)

While most of the low- and mid-scale maps and map series of Mars are laid out in conformal map projections, large-scale maps like the Topographic Image Map Mars 1:200,000 series are based on equal-area projections as described above.

Automated Map Generation with PIMap (Planetary Image Mapper)

Due to the large number of maps to be produced, i.e. the sheets of the Topographic Image Map Mars 1:200,000 series, the complete production line is designed as an entirely digital process. A sophisticated cartographic software system, the Planetary Image Mapper (PIMap) has been developed at the Technical University of Berlin. The source code is basically written in ANSI C++; therefore PIMap runs under both Microsoft Windows and Linux environments. It is now in use within the HRSC Co-Investigator team.

The software package accomplishes all cartographic processing steps required for the entire map content. Starting from orthoimages and DTM files (provided in VICAR format – cf. MIPL, 2005), the software adjusts these data to the mapped surface by resampling and fitting. Contour lines are automatically derived and labeled within PIMap. These basic data sets are completed by grid systems and frame, the related Martian nomenclature and several marginal annotations including the sheet designations and legend entries as described in the next chapter. With PDF, which is suited to handle all map contents both raster and vector data, a proven and widely used format is provided by PIMap. This is of special importance, since a map sheet has to be finished interactively – e.g. with regard to the placement and the readability of feature names – using vector-oriented commercial software like Adobe Illustrator, CorelDraw or Macromedia Free-hand respectively. Compared to common map generation procedures including the preparation of all components on its own followed by cumbersome merging processes, this comprehensive approach is a substantial step towards future planetary cartography (ALBERTZ et al., 2004).

THE TOPOGRAPHIC IMAGE MAP MARS 1:200,000 SERIES

A sophisticated cartographic concept was developed and forms the basis for the Topographic Image Map Mars 1:200,000 series for the Red Planet. Altogether, the Martian surface is divided into 10,372 map sheets – 10,324 Sinusoidal and 48 Lambert Azimuthal quadrangles (Figure 1).

For the Sinusoidal sheets, i.e. those between -85° and +85°, the central meridian of the projection (which is shown in true scale) corresponds with the particular center longitudes. Therefore, each sheet features its individual projection parameters. The sheet lines are based on the planetocentric/east system. While the mapped area is always 2° in latitude, it increases in longitude from 2° around the equator up to 360° towards the poles as shown in Figure 1. The general layout of the map sheets – under consideration of recent developments and enhancements (cf. GEHRKE et al, 2003 and ALBERTZ et al., 2004) – is illustrated in Figure 2. All map sheets feature a paper format of 83.0 cm in width and 70.0 cm in height.

Sheets of the Topographic Image Map Mars 1:200,000 series are based on HRSC color imagery, i.e. orthophotomosaics of the Martian surface. Such mosaics as well as Digital Terrain Models (DTM) are generated within the HRSC Co-Investigator team. Hence, the mapped area also contains the terrain representation by contour lines, which are derived from those DTM data. Furthermore, named Martian surface features are lettered taking into account their particular types and sizes. The map sheets contain landing site markings supplemented with the mission name and the date of touch down. Gridlines within the 1:200,000 map sheets follow the planetocentric/east system and, basically, hold a spacing of 0.5°; due to the meridian convergence they are thinned out towards the poles. As a second grid the historical planetographic/west system is plotted in a similar way but represented by colored tick marks (cf. Figure 2).

With regard to the marginal information, each sheet of the Topographic Image Map Mars 1:200,000 is entitled with this series name, an individual sheet name derived from a depicted surface feature, and its designation. The designator terms follow GREELEY & BATSON (1990) and consist of codes for the planet, map scale, center latitude and longitude, and the
Type of map. Several legend entries give information about the map projection, coordinate systems, underlying imagery, DTM and contour properties, etc. The sheet location is given as an index map showing the mapped area within the context of its neighboring sheets. However, having the position in a “more familiar” context – i.e. the large-scale series MC 5M (Figure 1) – seems quite useful. Thus, the concerning quadrangle is referred to in written form additionally.

Basically, all of these map contents can be automatically generated and compiled using the new cartographic software system PIMap.

Figure 2: Principle Layout of the Topographic Image Map Mars 1:200,000 Series, Sheet M 200k 6.00S/269.00E OMKT.

As a general rule, the *Topographic Image Map Mars 1:200,000* series definitions and layout scheme are fundamental for special target maps and thematic products. Series-related sheets in larger scales (1:100,000, 1:50,000, etc.) can be easily derived by appropriate subdivision of the sheet lines (ALBERTZ et al., 2004). The series itself is going to be realized in the HRSC Co-Investigator team.

**THEMATIC MAPPING WITH HRSC IMAGE DATA**

With the increasing amount of suitable HRSC imagery, the data interpretation within the Co-Investigator team leads to beneficial results and data sets that are to be presented adequately in the form of precise thematic maps.

Such thematic map products are necessarily assembled on topographic base maps, e.g. sheets of the *Topographic Image Map Mars 1:200,000* series or special target maps prepared for a particular region of interest. Heterogeneous thematic
information – consisting of linear vector data (boundaries, isolines, and faults), area-related raster or vector data (e.g. geological formations), and signatures – has to be harmoniously merged with the topographic basis. In general, the integration of graphical elements into image data is still a challenge in map design; it has to be realized following well-established cartographic demands. Depending on the thematic structure one must thoroughly consider, in which way the topographic information needs to be represented (e.g. with contour lines integrated and/or underlying image data in color or grayscale featuring transparency, etc.). Taking this into account, it becomes obvious that thematic mapping is a comparatively individual process.

While the necessary topographic basis for a thematic map could be generated using the software system PIMap, the entirely automatic integration of thematic data can be accomplished only to a certain degree. Usually, digital topographic image maps are used by HRSC Co-Investigator team members for their thematic interpretation and mapping purposes. Based on the expert’s specialized knowledge, thematic information is interactively derived and integrated. Aiming at high quality map products, final cartographic processing is necessary taking into account the deliberations as mentioned above.

![Figure 3: Geologic Map of Mars 1:600,000, M 600K 14.00S/175.50E G, Gusev Crater Region](image-url)
Recently, a geologic map of Mars, which shows the Gusev crater and its surroundings, was generated in scale 1:600,000 (Figure 3). Within the crater the landing site of the American *Mars Exploration Rover Spirit* is located. Since the investigated area is not completely covered by HRSC at the present time, geologic features have been derived also from *Themis* visible and infrared as well as *Mars Observer Camera* (MOC) imagery. This interpretation has been carried out at the European Space and Technology Centre (ESTEC) of ESA in The Netherlands and presented by FOING et al. (2004) and ZEEGERS et al. (2005). Concept, design, compilation, and production of the map have been accomplished at the Technical University of Berlin. The cartographic framework has been compiled using the flexible software system PIMap providing the appropriate basis, which enables the professional representation of the geologic theme.

**CONCLUSIONS**

For the production of precise topographic and thematic maps from HRSC on *Mars Express* imagery, the cartographic software package PIMap has been developed at the Technical University of Berlin. Using PIMap, topographic image maps can be generated automatically with an acceptable amount of interactive refinement.

The main product is the new *Topographic Image Map Mars 1:200,000* series, whose basic cartographic concepts, sheet contents, and layout have been presented. This large-scale map series presents itself as a very modern product and, therefore, forms the basis for further topographic and thematic mapping. Several sheets of the *Topographic Image Map Mars 1:200,000* as well as special target maps already have been produced in close cooperation of the German Aerospace Center (DLR), providing the photogrammetric processing of HRSC data, and the Technical University of Berlin, responsible for all cartographic aspects (e.g. Figure 2 and GEHRKE et al., 2003). The generation of thematic maps has just started. First experiences with the presented geologic map sheet of the Gusev crater area (Figure 3) are promising.

In conclusion, the *Mars Express* mission has already opened up a new era of precise topographic and thematic mapping in high resolution. The HRSC Co-Investigator team as well as the scientific community in general and also the public are optimistic to see a wealth of different high-quality cartographic products of Mars to be produced in the near future.

**ACKNOWLEDGEMENT**

The research project *Software Development and Technical Support for Cartographic Data Processing* at the Technical University of Berlin is 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.

**REFERENCES**


BIOGRAPHY

The presenting author, JÖRG ALBERTZ, received his Dr.-Ing. (Doctor of Engineering Sciences) from the Technical University of Berlin in 1965 with a thesis on photogrammetry. He became an Associate Professor at the Institute for Photogrammetry of Karlsruhe University. In 1975 he joined the Technical University of Darmstadt were he was the first Professor for Remote Sensing in Germany. In 1979 he was appointed as a Full Professor for Photogrammetry and Cartography at the Technical University of Berlin. Since 2001 he is a Professor Emeritus, but he continues to work in various research projects.

JÖRG ALBERTZ is an active member of the German Society for Photogrammetry, Remote Sensing and Geoinformation (DGPF) since 1960. He served the Society in many functions, and was the President of DGPF between 1996 and 2000; since 2004, he is the society’s President of Honor. He is a member of the American Society for Photogrammetry and Remote Sensing (ASPRS) since 1973, the German Cartographic Association (DGfK), where he chairs the Commission for Remote Sensing and Cartography, and other associations. In 1980 he was elected as a member of the German Geodetic Commission at the Bavarian Academy of Science.

JÖRG ALBERTZ is the author of more than 150 scientific papers on photogrammetry, remote sensing, and cartography. His research and development activities cover a broad spectrum of subjects, including close-range photogrammetry, geometric restitution of airborne line-scanner data, and extraterrestrial mapping. In remote sensing and cartography the production of satellite image maps was a major field of his activities.

Since 1988 JÖRG ALBERTZ was involved in planetary photogrammetry and cartography in close contact to the German Aerospace Center (DLR) in Berlin. He was a Co-Investigator of the German camera experiment on the Russian Mission Mars96 and acted as the Chairman of the Photogrammetry and Cartography Working Group. Under his guidance software for photogrammetric and cartographic processing of the HRSC data has been developed. This software is also applied to airborne HRSC data with great success, including the generation of digital terrain models, the derivation of orthoimages, and the automated production of large image mosaics.

In the Science Team for the HRSC camera experiment on Mars Express, until recently JÖRG ALBERTZ again acted as Chairman of the Photogrammetry/Cartography Working Group. Under his guidance as a Co-Investigator the development of the software package PIMap for the generation of cartographic products, such as the Topographic Image Map Mars 1:200,000, special maps in larger scales for particular target areas, and thematic maps as well has been accomplished.