Cartography with HRSC on Mars Express – The New Series "Topographic Image Map Mars 1:200,000"

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Zusammenfassung: *Der Mars ist zurzeit Ziel von vier Raumfahrt-Missionen. Als eine von ihnen bringt Mars Express die hochauflösende Stereokamera HRSC in den Marsorbit. Speziell unter photogrammetrischen und kartographischen Gesichtspunkten konzipiert, wird diese Kamera eine neue Ära der Mars-Kartographie einleiten.*

Während die Bilddaten am Deutschen Zentrum für Luft- und Raumfahrt prozessiert werden, generiert die Technische Universität Berlin darauf aufbauend großmaßstäbige Karten, allen voran die Topographic Image Map Mars 1:200,000. Diese Arbeit beschreibt das Layout des Kartenwerks sowie die zu Grunde liegenden Koordinatensysteme und Projektionen unter Beachtung der jüngsten Neudefinitionen. Bilddaten, deren Prozessierung und daraus abgeleitete Digitale Geländemodelle sowie die Mars-Nomenklatur als Grundlagen topographischer Bildkarten werden erläutert. Abschließend wird das an der TU Berlin entwickelte Softwaresystem zur automatischen Kartenerstellung vorgestellt.

Abstract: *At present Mars is target to four scientific missions. One of them, Mars Express, brings the High Resolution Stereo Camera into a Martian orbit. Since this camera is designed for the special demands of photogrammetry and cartography, it will start a new era of Mars mapping.*

The image data will be photogrammetrically processed at the German Aerospace Center (DLR). Based on the results, the Technical University Berlin generates large-scale map products, mainly the Topographic Image Map Mars 1:200,000. Within this paper, the map series layout as well as the underlying coordinate systems and map projections are described with special regard to the latest definitions in Martian reference frames. Image data and processing, the derived Digital Terrain Models and also Martian nomenclature as basic datasets for topographic image maps are explained. Finally the cartographic software for automatic map production, developed at the TU Berlin, is illustrated.

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1 Introduction

Mars, our neighboring planet, is becoming subject to a new era of scientific research. Not less than four missions are on their way to the Red Planet: the Japanese Nozomi, the American Mars Exploration Rover twins, namely Spirit (MER-A) and Opportunity (MER-B), and *Mars Express*, which is the first European mission to a planet ever. Mars Express was successfully launched on June 2, 2003. As the first of these missions it will enter the Martian Orbit after a seven month journey in late December. Beside the orbiter module the spacecraft brings the lander unit Beagle 2 to Mars.

Amongst other experiments, the Mars Express orbiter carries the *High Resolution Stereo Camera* (HRSC). This research program, which is guided by Prof. Dr. GERHARD NEUKUM (Free University Berlin) as the Principal Investigator, has been particularly designed to meet the demands of stereophotogrammetry and cartography. The camera will provide multi-spectral digital image data of high resolution (up to 10 m) as well as systematic stereo coverage of the Martian surface. Thus, the mission will start a new era of topographic and thematic mapping of planet Mars. Furthermore, the Super Resolution Channel of the camera will acquire image data of extremely high resolution (up to 2 m) from smaller areas of particular interest (NEUKUM et al. 2002).

The HRSC image data will be processed systematically at the German Aerospace Center (DLR) in Berlin to various data levels. Based on these products, the Technical University Berlin can generate large-scale topographic and thematic image maps, special target maps and related products of the Martian Surface. The main goal is the production of the *Topographic Image Map Mars 1:200,000* series. Due to the large number of maps to be generated, this work has to be automated using a cartographic software system.

2 Topographic Image Map Mars 1:200,000

The basic concept of the Topographic Image Map Mars 1:200,000 series originally has been designed for Mars 96 mapping purposes (LEHMANN et al. 1997). For Mars Express and future mapping activities the map series has been updated considering the latest developments with regard to new reference body definitions as well as changes in the common coordinate system. Although the effect to individual map contents is significant in parts, only slight modifications to the principle layout scheme occur.

Despite the loss of the Mars 96 mission some maps in the style of the Topographic Image Map Mars 1:200,000 series have been generated over the past years, such as one showing the Mars Pathfinder landing site (LEHMANN et al. 1999). Recently a specimen sheet of the series according to the new definitions has been presented (GEHRKE et al. 2003).

2.1 Reference System

The common Martian reference body for planimetry is a bi-axial (rotational) ellipsoid. Recently new ellipsoid parameters have been derived through a global adjustment of the most actual and very extensive *Mars Observer Laser Altimeter* (MOLA) dataset. As a result the best-fitting surface has been given by DUXBURY et al. (2002) with a semi-major (equatorial) axis of 3396.19 ± 0.10 km and a semi-minor (polar) axis of 3376.20 ± 0.10 km. These parameters are officially adopted by the International Astronomical Union (IAU) as the Mars IAU 2000 ellipsoid (SEIDELMANN et al. 2002).

An equipotential surface (Areoid = Martian Geoid), which is derived from *Mars Global Surveyor* (MGS) Doppler tracking data, is the reference surface for heights. The average equatorial radius of the Areoid is equal to that of the above-mentioned ellipsoid (SMITH et al. 2001).

According to IAU conventions two different types of planetary coordinate systems are in use. One consists of positive western longitude and planetographic latitude (west/planetographic), the other one of positive eastern longitude and planetocentric latitude (east/planetocentric). While the former system had been the Martian standard for decades, the MOLA team switched to the latter one. Hence, the best global dataset of Mars is in east/planetocentric coordinates (DUXBURY et al. 2002). Since for that reason most mission teams are switching to it, the east/planetocentric coordinate system becomes the standard of Mars Express mapping too. The Topographic Image Map Mars 1:200,000 still contains both the primary east/planetocentric system, which also defines the sheet lines, and the west/planetographic coordinate system.

2.2 Map Projections

As already decided earlier, equal-area map projections are applied for compiling the Topographic Image Map Mars 1:200,000. The Sinusoidal Projection in its authentic ellipsoidal form is applied to all map sheets between 85° north and south. However, the polar regions can not be mapped appropriately by this projection. Therefore the Lambert Azimuthal Projection was selected for mapping the regions beyond 85° and 90° north or respectively south (LEHMANN et al. 1997).

An overview of the map series layout is given by figure 1.

2.3 Map Sheet Layout

Since under the topographic conditions conventional line maps of the Martian surface are not useful, the series is planned as an image map. The orthoimage as the basic information is supplemented by the map frame, two graticules (east/planetocentric and in addition west/planetographic), Martian feature names and marginal annotations. Furthermore, the image map contains relief information in terms of contour lines and spot heights.

The map sheet layout has been designed considering the ease of handling as well as production costs and technical restrictions for printed maps. While all sheets feature the same latitude dimension of 2 degrees, their longitude dimensions are latitude-dependant in such a way that map widths do not vary too much. Considering the scale of 1:200,000 for Mars this results in mapped surfaces of approximately 59 cm in height for the sinusoidal projected sheets, and around 62 cm (with curved parallels) for the azimuthal sheets; the maximum sheet width is approximately 70 cm. Further information regarding the sheet lines as well as the map layout is given by LEHMANN et al. (1997).

Altogether a total number of 10,372 map sheets, 10,324 in Sinusoidal Projection and 48 in Lambert Azimuthal Projection, will provide complete coverage of the planet Mars as illustrated by figure 1.

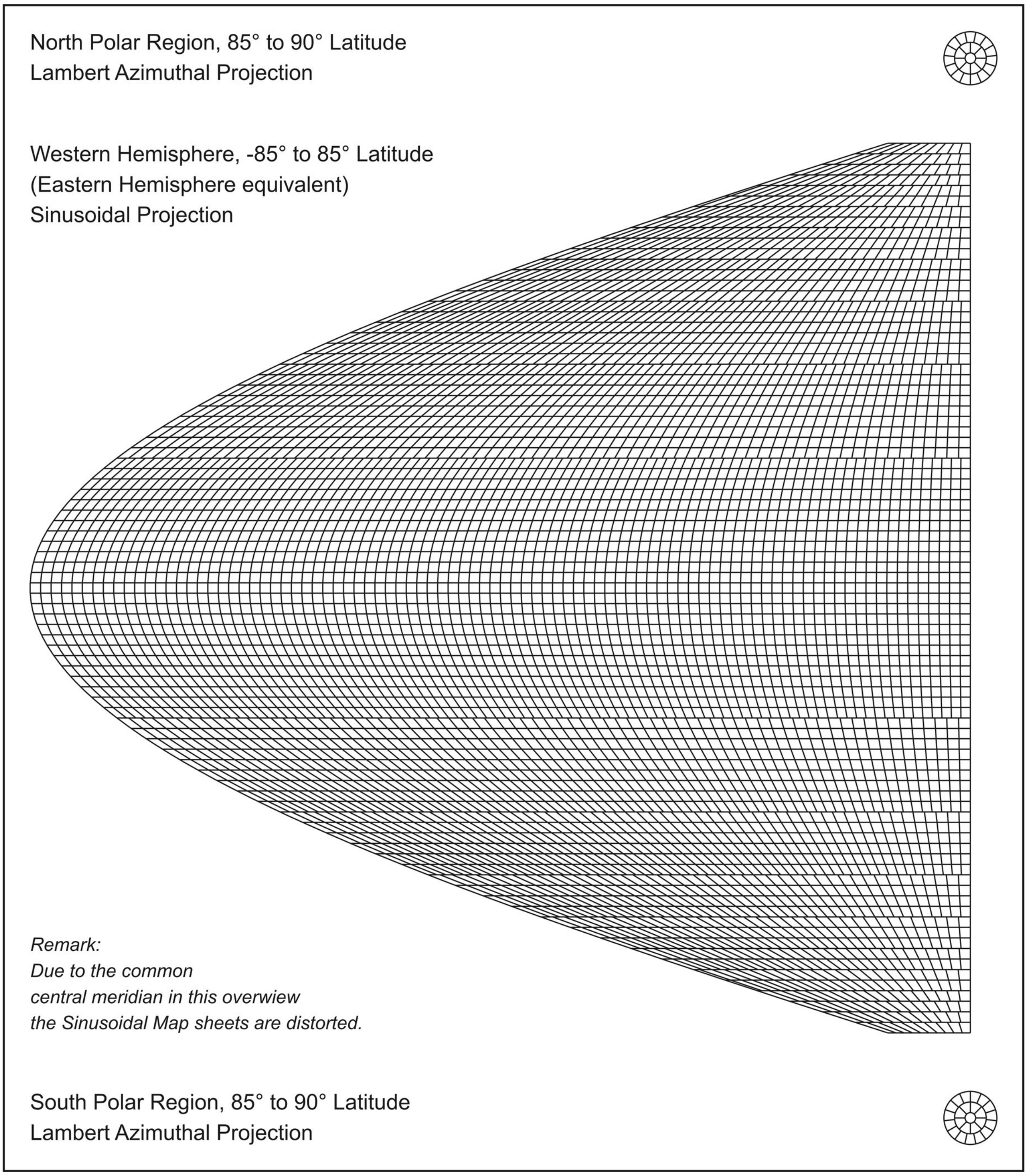

Figure 1: Sheet Lines System of the Topographic Image Map Mars 1:200,000

2.4 Sheet Designation and Name

Each sheet of the Topographic Image Map Mars 1:200,000 series is identified by a specific designation code. According to GREELEY & BATSON (1990) a planetary map is labeled by four designators: planet, scale, location and version. E.g. the code “M 200k 14.0S/176.0E OMT” identifies a map sheet of Mars in scale 1:200,000, centered at 14.0° southern planetocentric latitude and 176.0° eastern longitude, which is based on an orthophotomosaic and supplemented with topographic data, in particular contour lines and nomenclature. Solely the location parameters differ between the sheet designations of the Topographic Image Map Mars 1:200,000 series. It should be remarked, that within this series the year of publication, which is often given as part of the designation, appears in the copyright note.

In addition to the designation the sheets will be named after a mapped surface feature, where this is possible. Since there are less than 1,500 named features on Mars (USGS 2003), obviously only a small share of the 10,372 sheets could be provided with reasonable names – it would not make sense to derive such sheet name from a global feature complemented with a set of complex specifications.

3 Image and DTM Data

The HRSC is designed as a line scanner. Altogether nine lines (four color, including infrared, and five panchromatic) are arranged under five viewing angles (nadir, two backward and forward respecttively). For details see NEUKUM et al. (2002).

At DLR the HRSC data will be processed systematically to various data levels. After basic ground processing, e.g. decompression, calibration and geometric correction, the image data undergo the photogrammetric processing, which is fulfilled by a software system mainly developed at TU Berlin for Mars 96 and now adapted and implemented at DLR. Of special importance for map generation purposes are the resulting orthophoto-mosaics, forming the actual image background, and the Digital Terrain Models (DTM's) as basic dataset for the derivation of contour lines.

Orthophoto-mosaics will be provided as map projected color image data, depending on the available HRSC imagery. Similarly to that DTM files consist of grayscale-coded heights. Although these data can be projected like the map sheet to be generated, it is planned to produce mosaics and DTM's larger than one sheet of the Topographic Image Map Mars 1:200,000. Thus for the practical map production (see also chapter 5) normally image resampling will be necessary, in particular for special target maps.

4 Martian Nomenclature

Martian Nomenclature is regulated by the IAU. Several descriptor terms have been defined to distinguish global land masses (terra, comparable to Earth's continents), regional features like planes, valleys, etc. and local types, e.g. craters (KIEFFER et al. 1992). About 1500 surface features are named until now. Most of them are impact craters. The most actual and all-embracing dataset of these features, amongst other things containing the names and location parameters, is provided within the *Gazetteer of Planetary Nomenclature* by USGS (2003). In particular the feature location is given by the center point, the size (e.g. the diameter of a crater) and in addition the starting and ending latitudes and longitudes (bounding box) as illustrated in figure 2.

By looking at the number of named features, it is clear that the sheets of the Topographic Image Map Mars 1:200,000 will often contain solely one (global) feature. So far Martian names are not assigned if features have been recognized but only when the need of names comes up through scientific investigations, e.g. the analysis of potential landing sites. Although, coming along with the new missions, some further nomenclature will appear, it is subject of discussion to assign new names particularly for the challenge of large-scale mapping of Mars.

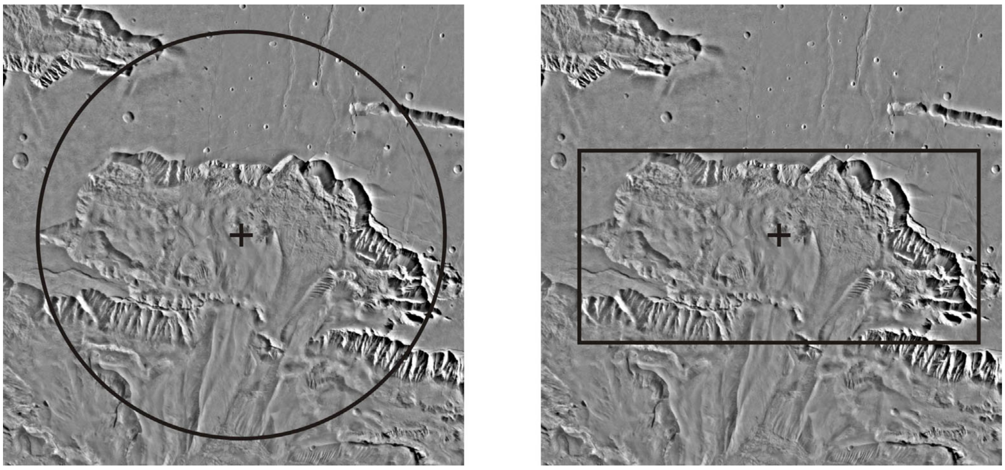

Figure 2: Localization Parameters of Ophir Chasma (Center: 4.0°S/287.5°E)

Especially impact craters are of major scientific interest. On one hand Martian control point networks are based on craters, on the other hand many investigations, e.g. automatic feature detection or ejecta morphology studies, have been made over the past. Recently the *Mars Crater Morphology Consortium* was formed in order to address issues related to impact craters and to integrate inventories into one database. The most complete of the existing data-sets is the *Catalog of Large Martian Impact Craters*, including every crater with a diameter larger than 5 km, altogether more than 40,000. Therefore it is determined by the Consortium being the base of a new Integrated Crater Catalog whose publication through the web is planned (BARLOW et al. 2003).

Amongst other things the Catalog of Large Martian Impact Craters contains feature ID’s (numbers) and their location similar to the above-mentioned Gazetteer of Planetary Nomenclature. When finally revised by the Consortium and transformed into the new east/ planetocentric coordinate system, the catalog will be integrated into the Topographic Image Map Mars 1:200,000. Providing such a large set of information obviously valorizes the map series for its users.

5 Cartographic Data Processing

By looking at the number of 10,372 sheets of the Topographic Image Map Mars 1:200,000 and in addition several other maps to be produced within the Mars Express mission, it is evident that this production has to be fulfilled as automatically as possible, even when only a smaller share of the series is generated. Therefore a sophisticated cartographic software system compiles all map content according to the user’s definitions, which ranges from simply choosing a particular sheet out of the map series up to very individual map specifications. The whole production line becomes completely digitally. Final products are digital versions of maps, which can and will be printed on demand.

The cartographic software system was developed over the past two years at the TU Berlin; it is nearly ready for operation (GEHRKE et al. 2003). Starting from the orthoimages provided by DLR the software adjusts them to the mapped surface by resampling and fitting. This basic data set is automatically completed by frame and grid line systems, all related topographic data and several marginal annotations including the sheet designation.

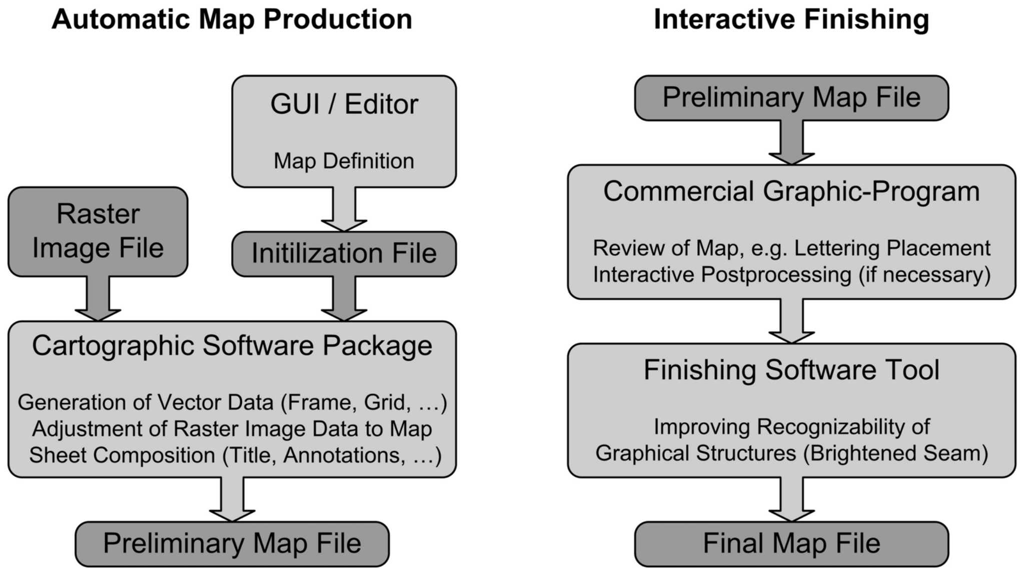

Figure 3: Overlook of the Cartographic Data Processing

An appropriate hybrid format, which is suited to handle both raster and vector data, has been chosen for storing all map content. This is of special importance, since each sheet has to be finished interactively using vector-oriented commercial software. Automatically placed nomenclature could cover important image information and has eventually to be shifted in an appropriate way. Finally the recognizability of graphical structures in dark image regions has to be enhanced by laying a brightened seam around them as proposed by ALBERTZ (1993).

6 Conclusion

The HRSC aboard the Mars Express orbiter will open up a new era of Mars mapping; the Topographic Image Map Mars 1:200,000 series, based on HRSC imagery, will become true as the first large-scale map series of our neighboring planet. Recent changes in Martian reference systems and coordinates as well as results of the latest investigations have been or respectively will be integrated into the map series. Therefore the Topographic Image Map Mars 1:200,000 presents itself as a very modern product, which will be the guideline for future topographic map series in larger scales and for comparable thematic map products as well. Special target maps, e.g. in 1:100,000 and larger scales, could easily be derived by dividing the 1:200,000 maps accordingly.

The cartographic software system, which will handle the automatic map production, has been developed at the TU Berlin. As a first comprehensive test of the software and the whole production line recently a particular sheet of the new Topographic Image Map Mars 1:200,000 has been produced and published by GEHRKE et al. (2003). The generation of this specimen sheet demonstrated, that the software system for the map production works nearly operational.

HRSC image data are expected from early January 2004 on; accordingly the first map products will be published afterwards.

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