DIGITAL CARTOGRAPHY WITH HRSC ON MARS EXPRESS

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ABSTRACT:

The *High Resolution Stereo Camera* (HRSC) on board of the European space mission Mars Express provides multispectral digital image data in high resolution as well as the systematic stereo coverage of our neighbouring planet. Thus, these data particularly meet the requirements of stereophotogrammetric processing and cartographic applications.
Based on HRSC imagery, large-scale topographic and thematic map products of the Martian surface are generated by the Technical University of Berlin and other HRSC Co-Investigator team members. The main task is the production of the map series *Topographic Image Map Mars 1:200,000*. While the basics of this series have been defined earlier, it was updated e.g. by adopting the latest changes in Martian reference systems. These concepts as well as map sheet contents and layout are described and illustrated. The *Topographic Image Map Mars 1:200,000* series is expected to be the guideline not only for Mars Express mapping purposes but also for large-scale planetary cartography in the future.
As an innovation in extraterrestrial mapping, the production line is designed as an entirely digital process using the cartographic software system *Planetary Image Mapper* (PIMap) which is developed at the Technical University of Berlin.

KURZFASSUNG:

Die *High Resolution Stereo Camera* (HRSC) an Bord der europäischen Raumsonde Mars Express liefert multispektrale, hochauflösende Bilddaten sowie die systematische Stereo-Abdeckung unseres Nachbarplaneten. Daher erfüllen diese Daten die besonderen Anforderungen der stereophotogrammetrischen Prozessierung sowie kartographischer Anwendungen.
Auf der Grundlage von HRSC-Bilddaten erstellen die Technische Universität Berlin und andere Mitglieder des HRSC Co-Investigator Teams großmaßstäbige topographische und thematische Karten der Mars-Oberfläche. Hauptaufgabe ist die Produktion des Kartenwerks *Topographic Image Map Mars 1:200,000*. Während die Grundkonzepte dieses Kartenwerks bereits definiert waren, wurde es aufgrund aktueller Erkenntnisse – z.B. Neudefinitionen der Referenzsysteme – angepasst. Diese Konzepte sowie Karteninhalte und -layout werden anschaulich dargelegt. Die *Topographic Image Map Mars 1:200,000* wird nicht nur als Kartenwerk für die Mars Express Mission, sondern darüber hinaus auch als Richtlinie für zukünftige großmaßstäbige planetare Karten dienen.
Eine Innovation innerhalb der Planetenkartographie ist es, dass die gesamte Produktionslinie als digitaler Prozess unter Nutzung des an der Technischen Universität Berlin entwickelten kartographischen Software-Systems *Planetary Image Mapper* (PIMap) ausgelegt wurde.

1. INTRODUCTION

At present, Mars is the subject of special scientific interest; not less than three space missions are currently operating at the Red Planet. One of them is ESA's Mars Express orbiter which carries the *High Resolution Stereo Camera* (HRSC) experiment – an image acquisition system designed for the special requirements of photogrammetry and cartography. Since January 2004, HRSC delivers multispectral and stereo imagery with a resolution of 10 - 20 m/pixel (Neukum et al., 2004).

Image processing – i.e. systematic geometric and radiometric correction of HRSC data as well as stereophotogrammetric evaluation and derivation of Digital Terrain Models (DTMs), orthoimage generation and image mosaicking –, which leads to input data for map products as presented within this paper is carried out at the German Aerospace Center (DLR). First experiences with HRSC imagery and data processing are described by Oberst et al. (2004).

The main cartographic product is the *Topographic Image Map Mars 1:200,000* series, which stands for both the guideline for topographic 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. (1997). Recently, the latest reference body definitions for Mars as well as the change of coordinate systems have been adopted (Gehrke et al., 2003b). Furthermore, some contents – e.g. sheet designations – are revised and/or renewed. Hence, this map series completes the existing range of Martian small- and mid-scale series (cf. Greeley & Batson, 1990) with a large-scale frame, as it is appropriate for high-resolution HRSC imagery and future mapping purposes.

A sophisticated cartographic software system, the *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, some interactive finalization is still necessary. Compared to common map generation procedures – including the preparation of all components on its own followed by intricate merging processes –, this comprehensive approach is a substantial step towards future planetary cartography.

Recently, the first map sheets based on HRSC image data have been generated.

2. CARTOGRAPHIC CONCEPTS

2.1 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 in principle two different types of planetary 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). 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 (Gehrke et al., 2003). The prime meridian – i.e. zero longitude going through the Airy-0 crater – is determined by an angle W_0 of 176.630° with respect to the inertial coordinate system (Seidelmann et al., 2002).

An areoid (Martian geoid) is defined as the topographic reference surface for heights (Seidelmann et al., 2004).

2.2 Map Projections

Equal-area map projections are used for compiling the *Topographic Image Map Mars 1:200,000*. Because of its useful mathematical and graphical properties, the *Sinusoidal* projection (cf. equations 30-8 and 3-27a/30-9 in Snyder, 1987) 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 (cf. equations 21-17 and 24-18 in Snyder, 1987) was selected for mapping those regions between 85° and 90° north or respectively south (Lehmann et al., 1997). The same scheme is applied for the generation of special target maps.

It should be pointed out, that in this context, i.e. for Mars Express mapping purposes, the Sinusoidal map projection yields truly equal-area results, even though it is carried out with an ellipsoidal reference body as defined for Mars. In planetary sciences approximations based on the spherical formulae (cf. equations 30-1 and 30-2 in Snyder, 1987) – using both either planetocentric or planetographic latitudes – have been widely used, mainly for data storing purposes but less for mapping. The occurring differences between those projections and the true ellipsoidal form have been further investigated by the authors; see also Deuchler et al. (2004).

2.3 The Topographic Image Map Mars 1:200 000 Series

Fundamentally the *Topographic Image Map Mars 1:200,000* series was introduced by Lehmann et al. (1997) for HRSC mapping purposes during the preparations for the failed Mars96 mission.

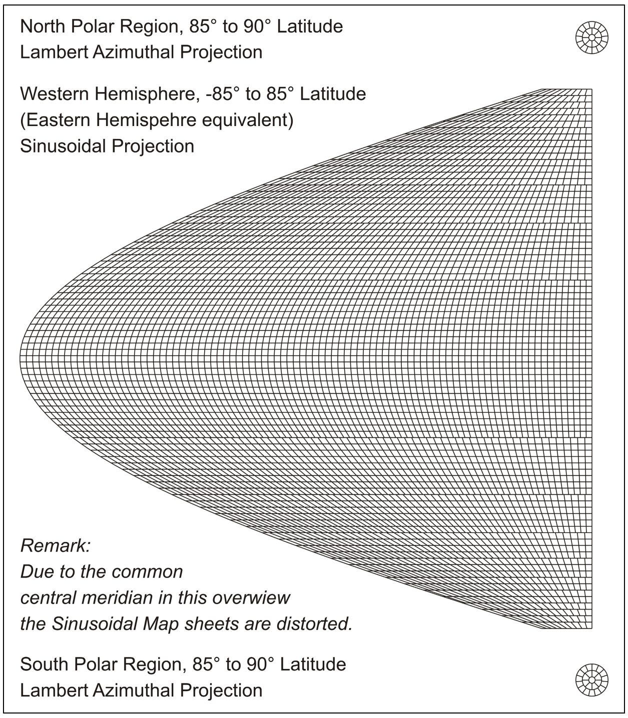

Figure 1. Sheet Lines System of the *Topographic Image Map Mars 1:200,000*

The map series completes the existing bandwidth with the required large-scale frame. Hence, the following scales and/or series are in use for Mars:

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

While most of these listed maps are conformal (i.e. Mercator, Lambert Conic and Polar Stereographic projection), the *Topographic Image Map Mars 1:200,000* is based on equal-area projections (Figure 1). For the Sinusoidal sheets, i.e. those between -85° and +85°, the central meridian (which is shown in true scale) corresponds with the particular center longitudes. Therefore, each sheet features its individual projection parameters. The latest IAU reference body definitions and coordinate systems have been adopted. Hence, the sheet lines are based on the planetocentric/east system. Each quadrangle covers two degrees of latitude. Longitude dimensions increase from the equator towards the poles. Altogether the Martian surface is divided into 10,372 individual map sheets (10,324 Sinusoidal and 48 Lambert Azimuthal quadrangles) as illustrated by Figure 1.

As a general rule the series definitions and layout scheme (Figure 2) are also the guideline for special target maps. Series-related sheets in larger scales (100k, 50k, etc.) can be easily derived by appropriate subdivision of the particular sheets. Moreover, the generation of thematic maps, showing the scientific findings of other research disciplines, is planned. Therefore, the *Topographic Image Map Mars 1:200,000* series is expected to be the general guideline for future large-scale planetary mapping purposes.

3. MAP CONTENT AND SHEET LAYOUT

Important properties of the components of the *Topographic Image Map Mars 1:200,000* or similar products are explained below. All of these elements can be automatically generated and compiled to the map sheet using the newly developed cartographic software PIMap, which is described in chapter 4.

3.1 Image Data

The *Topographic Image Map Mars 1:200,000* sheets as well as derived or similar products are based on HRSC color imagery, i.e. orthophotomosaics featuring a well defined map projection. Such mosaics are generated in cooperation within the HRSC Co-Investigator team.

For the integration into the particular map, an image has to be trimmed to the sheet lines. Previous resampling will be necessary, if the projection or even one of its defining parameters – e.g. the central meridian of a Sinusoidal projection – differs between image and desired map sheet. (In case of the mentioned Sinusoidal projection this resampling causes only a negligible loss of quality, since solely a shift of image lines is implied – cf. Snyder, 1987.)

3.2 Contour Lines

A Digital Terrain Model (DTM), representing the topographic surface information, is calculated by the HRSC team from the camera's stereo information. With geometric properties similar to the described orthoimages, such DTM files consist of grayscale-coded heights.

Within a map sheet the Martian surface – in particular its height above the areoid – is portrayed by contour lines, which are derived from the given DTM. Depending on the terrain that is mapped (plains or scarps respectively) and scale factors on the other hand contours follow reasonable equidistances. According to several official map specifications, index lines are always labeled in such a way, that their altitude is readable while looking uphill. To distinguish from domes, short and unlabeled depression contours – regardless, if index or intermediate lines – are marked each with a tick or respectively an arrow pointing into it. An example is given by Figure 4.

Smoothing of the DTM and/or the contour lines themselves can lead to better cartographic results, i.e. good-looking as well as scientifically useful representations of the surface topography with fewer artifacts. However, this approach has to be further investigated as a consequence of gaining more experiences with HRSC DTM's and their processing.

3.3 Grids

From the beginning the *Topographic Image Map Mars 1:200,000* series was foreseen to show both the planetographic/west as well as the planetocentric/east coordinate system (Lehmann et al., 1997). Following latest definitions, the latter forms the main grid within the map sheets. Basically, the gridlines hold a spacing of 0.5° but are thinned out towards the poles due to the meridian convergence. As a second grid the planetographic/west system is plotted in a similar way but represented by colored tick marks. This has become the common procedure for other cartographic products of Mars too (e.g., Rosiek et al., 2003).

As a consequence of described regulations the neat line of a mapped surface shows the planetocentric/east coordinate system.

3.4 Martian Nomenclature

Martian Nomenclature is regulated by the IAU. Several descriptor terms have been defined to distinguish global land masses (Terrae, comparable to Earth's continents), regional features like planes, valleys, etc. and local types, e.g. impact craters. Over 1500 surface features are named until now. The most actual and all-embracing dataset of these features, amongst other things containing the names, location parameters and feature dimensions, is provided through the *Gazetteer of Planetary Nomenclature* by USGS (2004). Based on this information, Martian features are lettered within a map sheet taking into account their particular types and sizes.

Map sheets contain landing site markings supplemented with the mission name as well as the date of touch down.

It is the future plan, to provide map users the information of the *Catalog of Large Martian Impact Craters*, which contains several data of about 40,000 mostly unnamed craters larger than 5 km in diameter. It is chosen by the *Mars Crater Morphology Consortium* being the base of a new *Integrated Crater Catalog* (Barlow et al., 2003). However, the revision of that catalog is not yet finished.

3.5 Map Title and Sheet Designations

Basically, a map is given a title indicating its type. All sheets of the *Topographic Image Map Mars 1:200,000* are naturally termed with the series name.

Following Greeley & Batson (1990), individual map sheet designators consist of several codes including the planetary body, the scale factor, the center of map and the map version. Thus, "M 200k 40.00N/256.25E OMKT" designates a map of Mars (M) in scale 1:200 000 (200k), which is centered at 40° northern planetocentric latitude and 256°15' eastern longitude. The sheet is based on an orthophotomosaic (OM) and supplemented with topographic data (T), i.e. nomenclature and contour lines. It contains color information (K), in this case denoting the image basis. Sheets of the *Topographic Image Map Mars 1:200,000* series solely differ in their center point coordinates. Different from previous regulations and as a consequence of larger scales – particularly with regard to special target maps having dimensions of less than one degree – the map center is no longer rounded to full degrees (see Figure 4). Hence, unclear or even wrong identical designators of neighboring sheets are avoided.

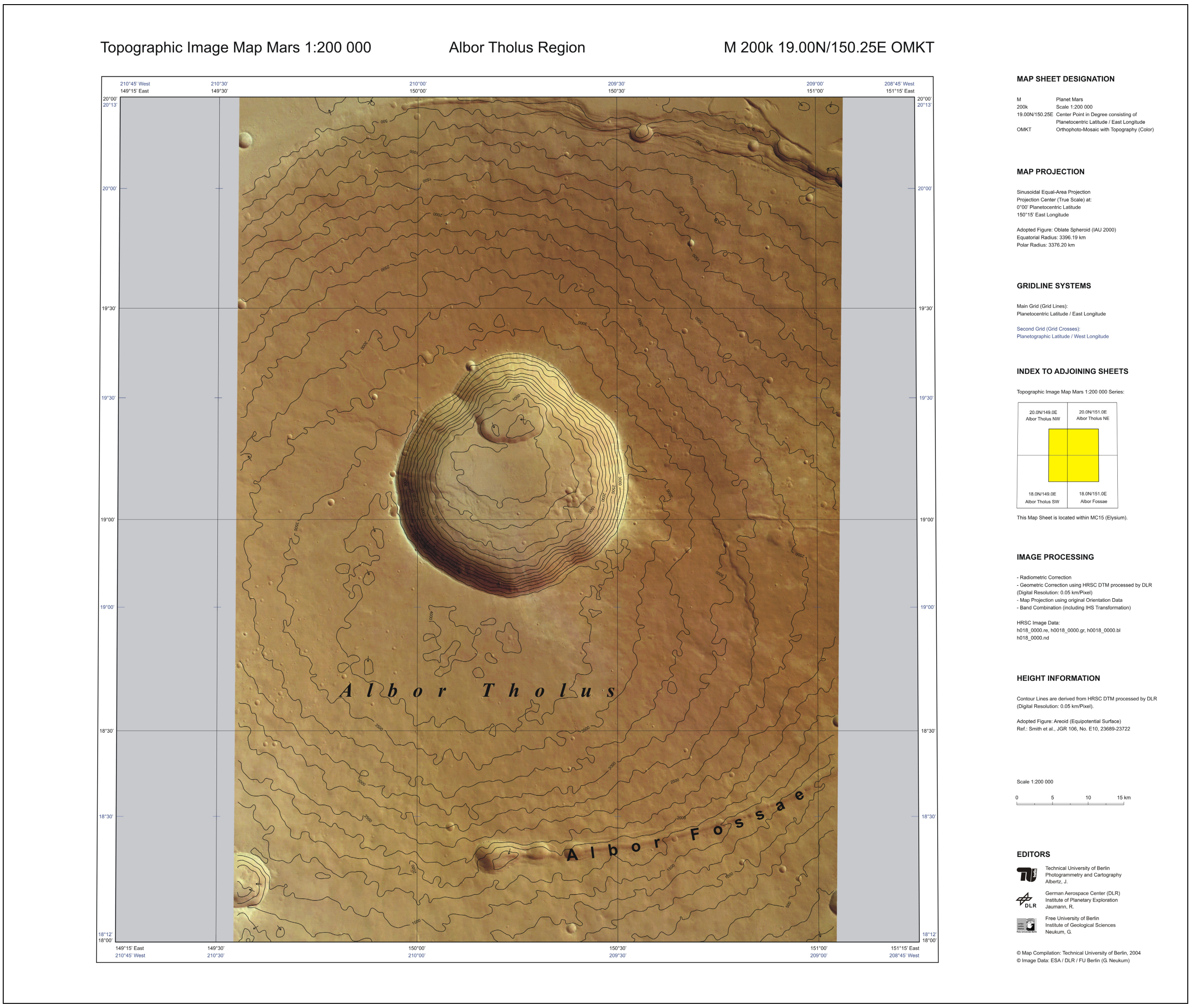

Figure 2. Layout of the *Topographic Image Map Mars 1:200,000* series (special sheet M 200k 19.0N/150.3E OMKT, Albor Tholus Region – areas without HRSC image information are shown in grey)

In addition to these designations a sheet is named after a mapped feature, where this is possible. Since there are about 1,500 named surface features on Mars, obviously only a small share of the 10,372 quadrangles could be provided with reasonable names.

3.6 Marginal Information

Symbols and conventions, on which a map sheet is based, are explained within the legend. In particular, this contains parameters of the projection and the lateral and vertical references as well as coordinate (or more appositely grid system) classifications. Furthermore some information on the used HRSC imagery and its processing is provided.

The position of a map sheet is given within an index map showing the neighboring sheets of the *Topographic Image Map Mars 1:200,000*. Special target maps are localized in an analogous manner with regard to this series. However, having the sheet location in a "more familiar" context – i.e. the large-scale series MC 5M and MC 2M respectively – seems quite useful. Therefore, the concerning quadrangle is referred to in written form additionally.

4. AUTOMATTED MAP GENERATION WITH PIMap

It is evident that the map generation has to be fulfilled automatically as far as possible. Therefore, the whole production line is laid out as an entirely digital process with the cartographic software system PIMap being in the center as illustrated in Figure 3. PIMap compiles all map components according to the user's definitions, which range from simply choosing a particular sheet out of the series up to very individual and comprehensive map specifications. Final products are digital versions of the maps, which can be printed on demand or provided in digital formats (Gehrke et al., 2003b).

The cartographic software PIMap was developed in C++ since late 2001 at the Technical University of Berlin and runs under both Microsoft Windows as well as Linux environments. It is now in use for Mars Express mapping. Starting from the orthoimages and DTM files (provided in VICAR format), the software adjusts these data to the mapped surface by resampling and fitting. Contour lines are automatically derived and labeled within PIMap. Furthermore, this basic data set is completed by grid systems and frame, the related Martian nomenclature and several marginal annotations including the sheet designations and legend entries as described in chapter 3.

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 (Adobe Illustrator, CorelDraw or Macromedia FreeHand respectively).

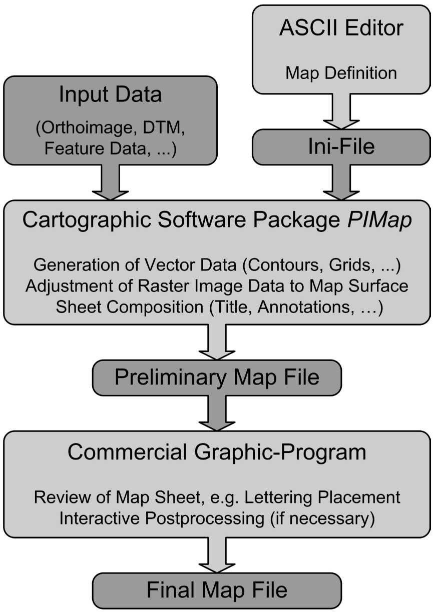

Figure 3. Overview of map production line

Since PIMap enables not only the Sinusoidal and Lambert Azimuthal projection – as it is a requirement for the *Topographic Image Map Mars 1:200,000* – but all common projections, the software is applicable for the generation of any Martian maps including the common series as listed in chapter 2.3. Moreover, topographic mapping of other planetary bodies (with spherical or ellipsoidal reference surfaces) is supported. Nevertheless, as a consequence of new developments – in particular with regard to thematic mapping purposes – the software system will be upgraded accordingly.

5. FIRST RESULTS

5.1 Specimen Sheets

With the original development of the *Topographic Image Map Mars 1:200,000* series the basic concepts and layout have been presented by means of several examples. Based on the series definitions, amongst other projects the Mars Pathfinder landing site has been mapped by Lehmann et al. (1999).

In preparation of the Mars Express mission, specimen sheets have been generated that already feature most of the changes and/or updates as described in this paper (cf. Gehrke et al., 2003b). Such examples are based on *Mars Orbiter Camera* (MOC) wide angle imagery and *Mars Orbiter Laser Altimeter* (MOLA) topography; results have been presented by Gehrke et al. (2003a).

Furthermore, a few tests with bodies different from Mars, i.e. the Saturnian satellites, confirmed the flexibility of the software PIMap prior to the HRSC mapping phase.

5.2 First HRSC Maps

Based on the first HRSC data, orthoimages and DTMs have been generated at DLR for cartographic utilization. Several *Topographic Image Map Mars 1:200,000* sheets as well as special target maps following this concept have been generated at the Technical University of Berlin using PIMap. Thus, e.g. the Albor Tholus volcano (Figure 2) or the Hydraotes Chaos region (Figure 4), which is part of the Martian valley complex Valles Marineris, are mapped in very impressive sheets of high quality.

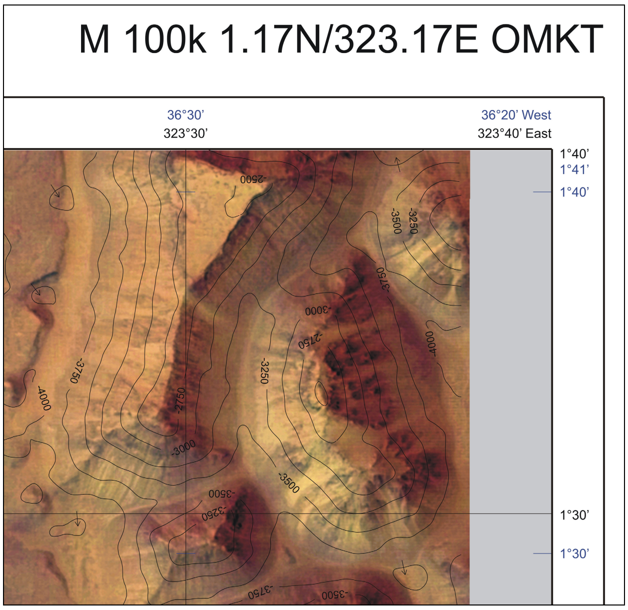

Figure 4. Section of M 100k 1.17N/323.13E OMKT, a special target map of the Hydraotes Chaos region (again, areas without HRSC image information are shown in grey)

6. CONCLUSION

The HRSC camera system aboard the Mars Express orbiter opened up a new era of Mars mapping; obtained images still inspire both the public as well as the scientific community. As one high-level result, the *Topographic Image Map Mars 1:200,000* series, based on HRSC imagery, now becomes true as the first large-scale map series of our neighboring planet. Hence, it enlarges and completes the existing band widths of Martian map series. With regard to several updates that have been made, 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, for special target maps and for comparable thematic map products as well.

The cartographic software system PIMap, which handles the automatic map production, has been developed at the Technical University of Berlin. Throughout several tests in preparation of the Mars Express mission and most important by generating the first map sheets from HRSC image data, PIMap did indicate and eventually prove its operational status. Software upgrades –

in particular with regard to the generation of thematic maps derived from the image map basis – are envisaged. Nevertheless, PIMap started a new era in digital planetary image map generation towards an entirely automatic process with very little interactive post-processing.

In conclusion, very promising results – both the cartographic software PIMap as well as first HRSC map products with the *Topographic Image Map Mars 1:200,000* series at the head – haven been obtained until now, although the Mars Express mission is just in the beginning.

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