THE "TOPOGRAPHIC IMAGE MAP FOSSA DI VULCANO 1: 5,000" – A DIGITAL MAPPING APPROACH BASED ON "HIGH RESOLUTION STEREO CAMERA – AIRBORNE" IMAGERY

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ABSTRACT

As part of the Camera Experiment for the Mars 96 Mission, a digital photogrammetric-cartographic production line has been developed. This contribution outlines the application of this mapping approach for the generation of the "Topographic Image Map Fossa di Vulcano 1: 5,000". The map is based on multi-spectral and stereo imagery of the "High Resolution Stereo Camera - Airborne" (HRSC-A), which provides high resolution orthoimages and digital elevation models at the same time. Efficient acquisition of digital topographic data covering large areas, as frequently required in natural hazard areas, is made possible without need for ground control points through direct sensor orientation. Automated photogrammetric processing based on digital image matching and multiple stereo is used for preparing the image data for map production. Automatic generation of contour lines as well as mosaicking and radiometric adjustment of the orthoimages represent the final step of the photogrammetric processing line.
Aiming at cartographic demands for an easy readable representation, colour processing techniques are applied to prepare the imagery for the subsequent addition of cartographic elements. The map is produced as a topographic image map with the primary cartographic information presented in image format and supplemented by topographical information and all necessary specifications and marginal annotations. The digital production comprises all cartographic processing steps such as compilation and nomenclature of the map content and the reproduction of the whole map frame. Cartographic research activities concentrate on the combination of "carto"-graphical elements with the imagery.

1 INTRODUCTION

1.1 A Problem-Oriented Approach for Topographic Mapping

Topographic maps are a prerequisite for many environmental and geo-scientific investigations. The increasing role of digital information systems for research and planning tasks leads to new demands concerning accuracy and required types of topographic information and affords the accessibility of topographic data in digital form. Knowledge of present day topography and its evolution in time is particularly important in risk areas concerning natural hazards. Topography controls some of the most harmful processes such as gravity driven mass flows and floods. Thus, the mitigation of hazards related to these processes depends significantly on the accuracy and reliability of the topographic base data available, and sufficient surface coverage is required according to the spatial extent and range of the phenomena and for modelling their interaction with topography (e.g. in valley systems). Furthermore, topographic data in the form of maps, map-projected images as well as digital elevation models (DEM) and their follow-up products are essential for campaign planning and data analysis for different ground based and remote sensing techniques applied in hazard monitoring, and frequent updating is required in respective areas.
This paper addresses the use of multi-spectral digital stereo data as a data-source for mapping the topography of an active volcano. The availability of up-to date and accurate topographic data is particularly important for volcano monitoring – not only because of the spatial coincidence of different types of natural hazards, but also due to frequent changes of surface topography through eruptive activity, internal deformation, and highly active erosion processes. The method is based on the simultaneous availability of orthoimages and DEM acquired by a single sensor system. Since data acquisition for large areas is accomplished within short periods, an effective means of representing a topographic situation well defined in time is provided. The approach adopted in this study concentrates on the cartographic representation of terrain morphology, taking into account both the basic data needs and possible time constraints associated with monitoring.

1.2 HRSC-A Sensor and Photogrammetric Processing System

1.2.1 Sensor Technology and Data Acquisition

The »High Resolution Stereo Camera« (HRSC) has originally been designed for the exploration of Planet Mars in the international space mission Mars 96 and will be operated onboard the Mars Express Orbiter to be launched in 2003 to map large parts of the Mars surface at high resolution (Neukum and Tarnopolsky 1990; Albertz et al. 1992a; Neukum et al. 1999). An airborne version of this camera, the HRSC-A, has been successfully applied in Earth observation during numerous aircraft campaigns since 1997 (Neukum 1999). The HRSC instrument is a compact mono-block device featuring nine geometrically calibrated CCD line detectors mounted on a focal plate behind a single optics, operating in pushbroom mode, and taking images simultaneously at specific viewing angles. The along-track stereo and photometry imaging capability is based on five of the nine CCD line arrays, including the nadir line. The remaining four lines are furnished with filters for the acquisition of multi-spectral images. Thus, nine superimposed image swaths are acquired in parallel making use of the forward motion of the aircraft, while stereo and multi-spectral data are provided simultaneously. During flight operation, the camera is mounted on a stabilised platform in order to damp mechanical vibrations and to enforce near-nadir viewing geometry. An integrated GPS/INS navigation system including a GPS receiver and a strap-down INS is used to obtain high accuracy measurements of the exterior sensor orientation (Hutton & Lithopoulos 1998).
The camera system is capable of providing digital elevation models with absolute accuracy of 20-25 cm from a flight altitude of 3,000 m and typical image ground resolutions of 15-100 cm (Wewel et al. 1998). Fast and flexible acquisition of high-resolution data covering large areas, including inaccessible and hazardous areas, is supported without need for ground control points using direct sensor orientation techniques and automated processing. Moreover, the use of 5 stereo channels enhances significantly the visibility conditions for mapping high-relief topography.

Technical Data for HRSC-A

HRSC-A/QM Technical Parameters	
Focal Length:	175 mm
Total Field of View:	37.8° x 11.8°
Number of CCD Lines:	9
Stereo Angles:	±18.9° and ±12.8°
Pixels per CCD Line:	5184 (active)
Pixel Size:	7 µm
Radiometric Resolution:	10 bit reduced to 8 bit
Read-Out Frequency:	450 lines/s
Mass:	12 kg (32 kg including subsystems)

1.2.2 Photogrammetric Processing System

A complete and automated software system for the photogrammetric processing of HRSC-A data has been developed by DLR, which is based on extensive developments in co-operation between DLR and TU Berlin for Mars 96 and other space missions (Uebbing 1996, Scholten 1996, Wewel 1996, Wewel et al. 2000). Photogrammetric processing makes use of a systematically preprocessed set of image, orientation, and calibration data. The exterior orientation of each image line is derived from DGPS/INS data recorded continuously during flight navigation. Using the integrated GPS/INS navigation system for direct sensor orientation, with parallel image tracks no additional ground control point information is needed. However, where possible, a small number of GCP as well as perpendicular image tracks are used to stabilize the results.
Through automatic pyramid-based multiple-image matching sub-pixel coordinates for conjugate image points in each of the five stereo channels are determined (Wewel 1996). Thus, object points can be derived by intersection of up to five rays defined by the set of corresponding image co-ordinates together with the orientation and calibration data. This allows for estimating point accuracy and to use these estimates for the detection and elimination of blunders. The final products of the photogrammetric processing line are DEM derived from the set of object points and orthoimages generated by differential rectification based on the DEM (Scholten 1996).

1.3 Digital Cartographic Production Line

Also as a part of the Camera Experiment for the Mars 96 Mission, a digital photogrammetric-cartographic processing line for the production of the "Topographic Image Map Mars 1: 200,000" (Lehmann 1996) has been developed at the Technical University of Berlin. The system allows to derive multi-spectral orthoimage mosaiks in a chosen map projection and reference system (Scholten 1996). A key element of this process are radiometric adjustments between individual image swaths. Several methods such as weighted average adjustment for image borders and histogram-based techniques for the adjustment of overall image brightness and contrast are implemented. Furthermore, automatic derivation of contour lines has been included and provides vector data that can be modified according to cartographic needs subsequently.

1.4 Target Area

Vulcano is the southernmost of the Aeolian Islands, a volcanic island arc in the Tyrrhenian Sea, and is located about 30 km north of Sicily (Italy). The island covers an area of 21.2 km^2 and consists of three major volcanic edifices. The southern part of the island represents the partially eroded edifice of a complex polygenetic volcano and includes the highest topographic points on the island (up to 500 m). The northern part of this elder volcanic edifice has been destroyed by younger activity, producing a caldera about 3 km in diameter. The steep southern walls of this caldera mark approximately the southern border of the area represented in the image map. In its center the slightly asymmetric active tuff ring "Fossa di Vulcano" has evolved. In local maps, also the name "Gran Cratere" can be found.
The last major explosive events took place in the years 1888-1890, yielding large volumes of pyroclastic material now masking the top of the cone and part of its slopes (Keller 1980). Since the 1888-90 eruption only fumarolic activity was observed from La Fossa cone. Phases of more intense energy output with gas temperatures rising up to about 600° C - 700° C occurred in mid-1920's and between 1988 and 1994. The volcanic risk is very high in the area due to both the violent explosive character of the volcano and the proximity of human settlements to the active crater. Hazards include slope instability and thus land-slides along the dip flanks of the cone and rock-fall of blocks deeply altered by fumaroles.

2 CARTOGRAPHIC CONCEPT AND DESIGN PRINCIPLES

The concept of the "Topographic Image Map Mars 1: 200,000" mentioned above is based on imagery and DEM of the Mars surface to be acquired by an HRSC imaging experiment from orbit. A comprehensive set of design principles for the integration of this data into the map context has been defined for the production of the map series, and have now been adapted for the production of medium and large scale topographic maps of the Earth surface such as the map project described in this work, and which are based on airborne HRSC-A data.

Thus, the Vulcano map is produced as a *Topographic Image Map* with the primary cartographic information presented in image format. The basic information is therefore contained in the colour-orthoimage, supplemented by topographical information and all necessary specifications and marginal annotations. In contrast to the fully automated photogrammetric processing of the image data, the terrain relief information in the form of contour lines has to be adapted to the regional topographic situation. The graphical representation of the contour lines is laid out in such a way that the contours can be easily recognised and that, at the same time, the map content in the form of the image data is disturbed as less as possible.

2.1 Reflections on the Map Scale

The selection of the map scale requires considerations of different aspects. Particularly, the scale has some serious consequences concerning planimetric accuracy, selection of objects and generalisation, and it controls the graphical efficiency of the cartographic representation with regard to the topographic and thematic content.

With respect to the use and properties of a map in general, in particular for the generation of image maps, it is indispensible to provide noticeable patterns and surface features over the entire mapping area. Preliminary tests in the ratio of 1:10,000 and larger were carried out and yielded reasonable results. However, for this project the scale of 1:10,000 would have been less profitable compared to the much more detailed representation of noticable and clearly recognizable topographical features in 1: 5.000. According to the potential of the HRSC-A, the map content and the technical restrictions in the production and printing process, the scale for the project could finally be defined as 1: 5,000. Given the high resolution and geometric accuracy of HRSC-A imagery, cartographic representations in larger map scales can be considered as well.

2.2 Map Projection

The map projection on which this individual map is based has been selected with reference to official national and international map sources for optimal analysis and comparison. In Italy, the GAUSS-BOAGA projection has been the standard for large map scales in the past, but present trends towards the application of the Universal Transversal

Mercator (UTM) projection exist. The decision in favour of the latter projection for the Vulcano map, applied in combination with the World Geodetic System 1984 (WGS84) reference ellipsoid has also been made with respect to the widespread use of this system in many countries worldwide. With regard to versatile handling characteristics and to provide additional information for easy localisation of the map area, geographic coordinates for the sheet corners with the longitudes counting positive to the east were added.

2.3 Map Sheet Definition and Layout

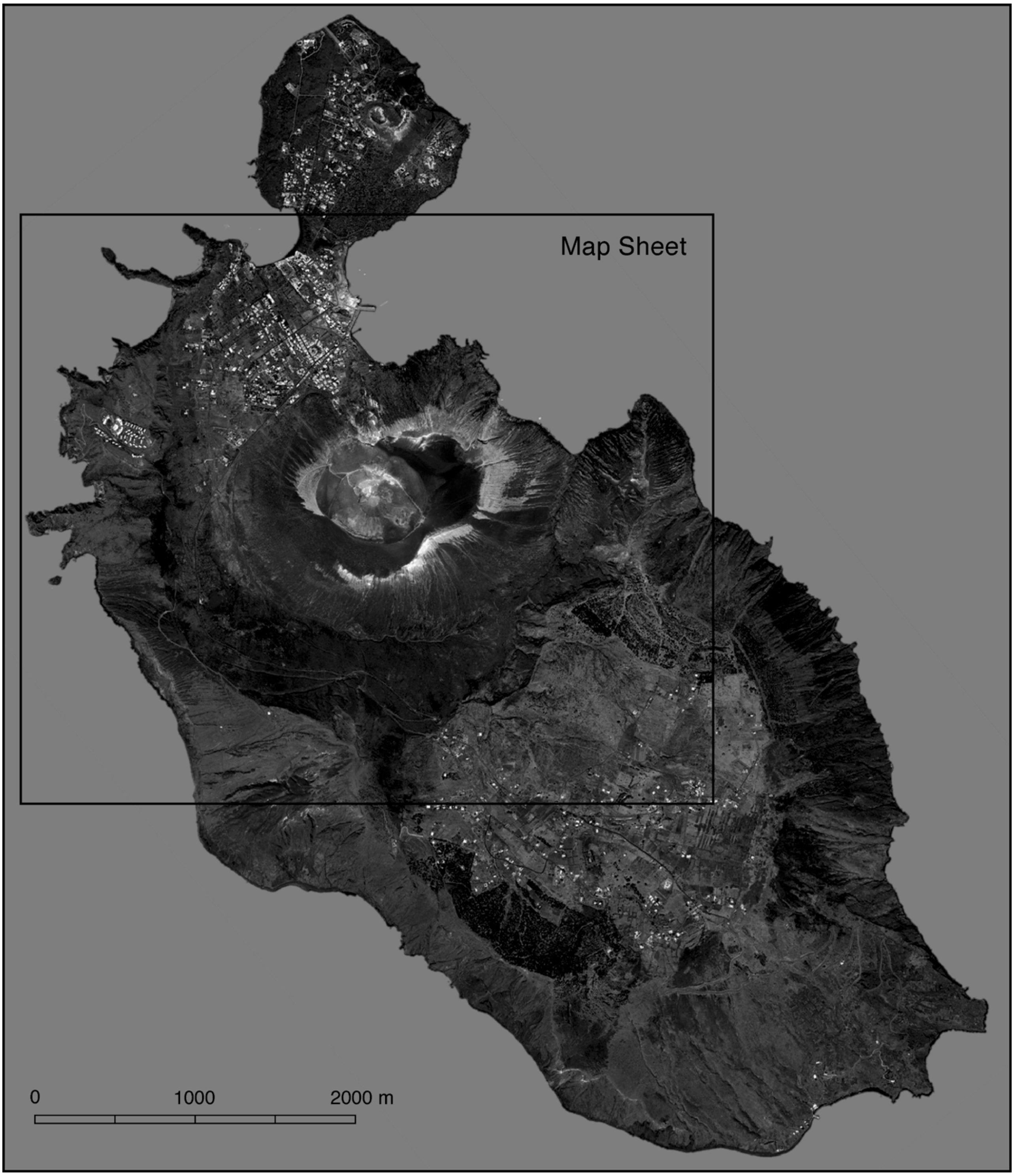

Figure 1: *"Topographic Image Map 1 : 5,000 Fossa di Vulcano"* with topographic reference to the *Island of Vulcano.*

In order to define the technical specifications of the map sheets, a variety of aspects have to be considered. The map format was determined due to ease of handling, costs and technical restrictions in the production process. The borders of the map area were arranged such that the entire caldera structure in wich the active tuff cone resides is represented. From these constraints, a map surface of about 4,350 meters in width and 3,700 meters for height has been defined. This individual map sheet is geodetically determined by indication of values for the Universal Transverse Mercator Grid Zone 33 as reference.

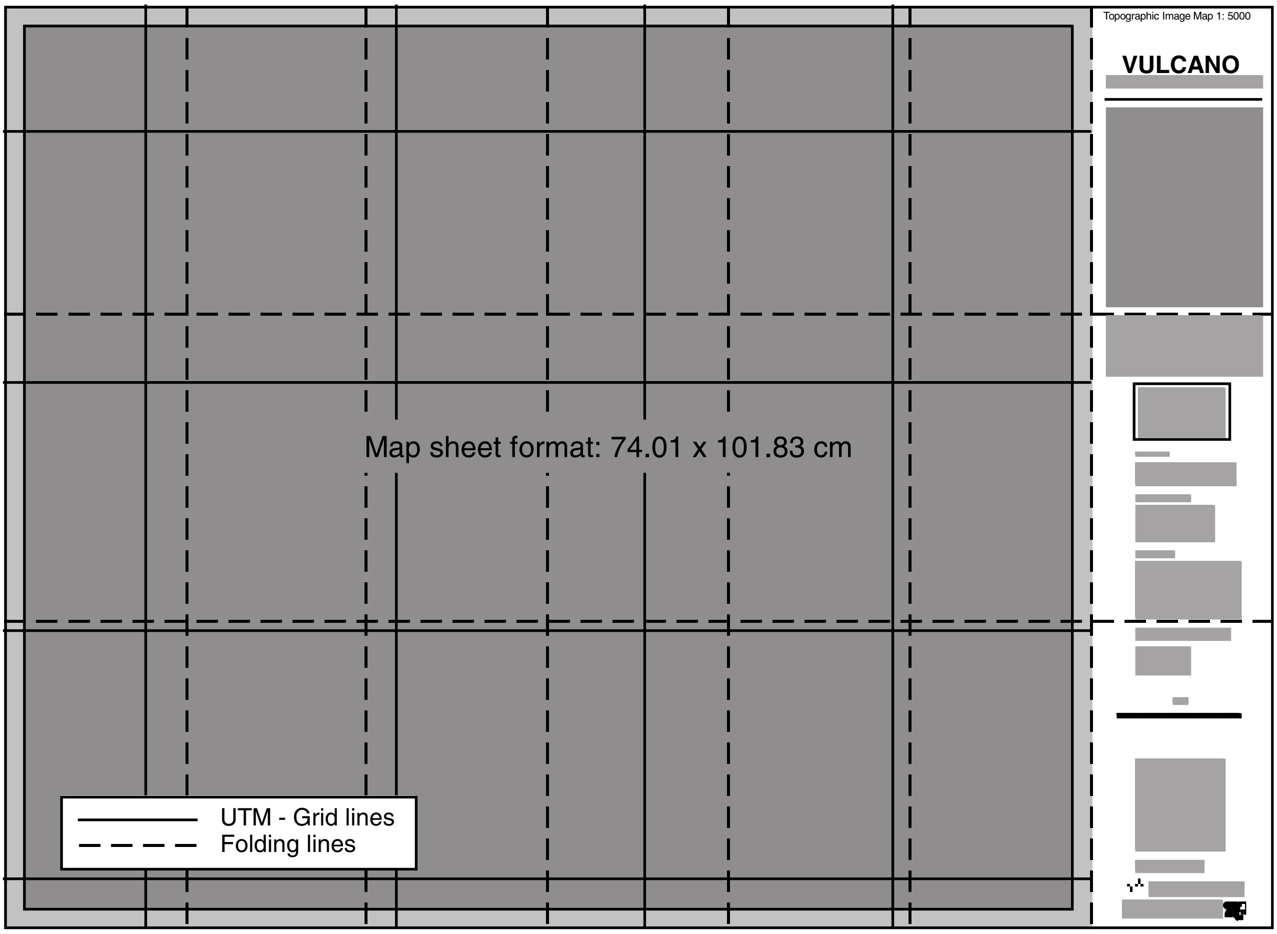

Figure 2: Layout and arrangement for map surface, map frame, marginal elements and paper format for the *"Topographic Image Map 1 : 5,000 Fossa di Vulcano"*.

The generation of topographic image maps requires the integration of graphical elements into the image, which is still a relatively new challenge for cartographic design. It is known from figure-ground experiments that the integration of black graphical elements should generally be preferred to white graphics before a dark background (Albertz 1993). In order to improve the recognisibility of black graphics in dark areas the image can be modified through filter techniques in such a way, that a brightened seam around the graphical element is generated. This method does not interrupt the image information and enhances the recognisibility of the graphics significantly.

A new approach in map design has been followed concerning the spatial relation between mapped area and paper format. In order to represent as much as possible of the island's surface, the mapped area is made exactly identical to the paper format. Making use of the flexibility of digital image processing techniques, the graduation of the image data situated within the "map frame" (containing the UTM grid values) are modified to obtain a brightened frame (15mm in width).

Solely on the right hand side, close to the easternmost margin of the mapped area, all annotations, explanations diagrams and the map title are arranged. As a result of this development, the paper format was determined to be 74.01 cm in height and 101.83 cm in width. A professional folding concept is also part of this map layout. For the folded map sheet this results in a handy size of 14.55 x 24.67 cm.

2.4 Grid

According to optimal usage for orientation and picking up of co-ordinates the integration of the grid lines should be laid out in such a way, that it is easy to recognise and that the map content is disturbed as less as possible by the grid's graphical density. As a result, the integration of the completely drafted grid lines is determined with every 1,000m for the parallels to the centre Meridian (15° East) and latitudes.

With emphasis to optimal and versatile handling characteristics and various practical reasons, the area covered was also provided with degree values for the sheet corners with the longitudes counting positive to the east. The sheet corners are:

NW corner: 14°56'10.00" East longitude / 38° 25'15.00" latitude
NE corner: 14°59'09.97" East longitude / 38° 25'15.06" latitude
SW corner: 14°56'10.11" East longitude / 38° 23'14.92" latitude
SE corner: 14°59'10.00" East longitude / 38° 23'14.99" latitude

3 IMAGE DATA PROCESSING

3.1 Image and DEM Data Basis for the Map

The image data used for the "Topographic Image Map Fossa di Vulcano 1: 5,000" were acquired in 1997 in a pilot study investigating the application of HRSC-A data to volcanology and have been processed using the HRSC-A photogrammetric software system (Gwinner 1999). The flight campaign was performed in co-operation between DLR and the CNR-Istituto Internazionale di Vulcanologia (IIV), Catania, Italy. Vulcano Island was covered by 7 image swaths and mean ground pixel sizes of 25 cm for the nadir channel, 50 cm for the stereo and photometry channels, and 100 cm for the multispectral channels from a flight altitude of 5,000 m. Navigation data have been measured by means of differential GPS (sampling rate: 0.5 s) referenced by three ground receivers as well as an INS system sampling at 400 Hz with the sensor unit mounted on top of the camera head. Object points have been determined by multiple ray intersection using all five stereo and photometry channels. According to the mean relative point accuracy of ±40 cm estimated from intersection accuracy, a raster DEM on a 160 cm grid has been derived for the entire Island based on a total of more than 32 million object points.

3.2 Colour Image Processing

Aiming at cartographic demands for an easy readable representation, colour processing techniques were applied to prepare the imagery for the subsequent addition of cartographic elements. Orthoimages for the HRSC-A multispectral channels and the panchromatic nadir channel were produced based on the DEM derived before from the stereo and photometry channels. All channels then have been mosaicked individually applying weighted averaging to adjust brightness and contrast variations at the border of the individual image swaths. These are mainly related to the directional reflection properties of the ground surface observed at different view angles. View-angle effects due to angular atmospheric transmission and path radiance variations have no visible effect in the imagery due to the small across-track field of view of the sensor (±5.9°). Global adjustment of brightness and contrast between the different spectral image swaths turned out to be unnecessary, according to the short time interval for data acquisition (approximately one hour) at high sun elevation.
To provide a clear and detailed colour image representation also for large map scales, the colour information was combined with the higher resolution of the panchromatic nadir channel by means of IHS transformation, where the nadir channel has been introduced as intensity component in the backward transform to RGB space. Specific image enhancement techniques have been applied for the sea surface, including colour balance adjustment and median filtering, in order to suppress high contrast features due to the strong directional reflection effects associated with water surfaces, particularly sun-glare, and to enhance thus the overall graphical appearance of the land surface.

4 REALIZATION / MAP PRODUCTION

The complete production line for this particular map comprises all cartographic processing steps such as compilation and nomenclature of the map content and the reproduction of the whole map frame.

Terrain relief information in the form of contour lines is adapted to the regional topographic situation. The equidistance of the contour lines for this map project is adapted to the local topography. The general equidistance graduation is determined to be 10 m. Generally, for contour lines (and spot heights), a separate printing ink, respectively the colour black, provides best readability and optimal graphical effect in image maps. In this particular case the graphical representation of the contour lines in a separate black colour, is laid out in such a way, that the contours can be easily recognised.

Following the encouraging results, achieved within the research and development work for the *»Topographic Image Map Series Mars 1:200 000«* it was a reasonable assumption to produce the Vulcano map in "full-color" edition. It is evident, that this new Topographic Image Map is also an ideal data base for many thematic mapping purposes.

5 CONCLUSIONS AND OUTLOOK

In this study, the use of airborne HRSC-A digital orthoimages and DEM for the production of large-scale image maps has been investigated. With the topographic image map "Fossa di Vulcano 1: 5,000" a map sheet covering rugged terrain has been produced, where the good visibility conditions associated with the multiple-stereo principle applied by the sensor allowed for complete coverage with high resolution topographic data. Based on an automated photogrammetric processing line, the mapping approach allows for efficient monitoring of topography, as required specifically in natural hazard areas.
The layout for this map is based on proven cartographic experience combined with new approaches concerning the integration of remote sensing imagery and is closely connected with the potential and the technical standards for digital image processing and digital reproduction. Integrating graphical elements into the image for the production of topographic image maps still requires further research activities that concentrate on the combination of these different graphical elements and on possibilities of automation for this task.

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