CONTROLLED TOPOGRAPHIC IMAGE MOSAICS FROM COMBINATION OF VIKING ORBITER IMAGES AND MARS ORBITER LASER ALTIMETER DATA

**Ernst HAUBER, Jürgen OBERST, Wolfgang ZEITLER, Monika KUSCHEL,
Marita WÄHLISCH, Ralf JAUMANN**
German Aerospace Center (DLR), Institute of Space Sensor Technology and Planetary Exploration
Berlin, Germany
Ernst.Hauber@dlr.de

Working Group IV/5

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ABSTRACT

We compiled topographic image maps for selected regions of Mars. 900-1100 m/pixel Viking Orbiter images were used to initially produce base maps within the global reference frame, to which data from the Mars Orbiter Laser Altimeter (MOLA) were added. The horizontal tie of the map to the Mars-fixed coordinate system is within 1-3 km for most places on the planet. The precision of the elevation data with respect to the Mars center of mass is better than 10m.

1 INTRODUCTION

Geometrically precise maps, i.e. maps in which the Mars-fixed coordinates of features can be extracted with great reliability, are essential planning tools for future missions to Mars. Such maps are typically used for the design of observational sequences from orbit, or for the targeting of spacecraft to safe landing areas. In the past, maps of the "Red Planet" suffered from notorious geometric errors. With data from the Mars Pathfinder, this situation has greatly improved. The coordinates of this lander, i.e. the Mars-fixed coordinates as well as the coordinates in images, were precisely known, thus making this lander an important "anchor point" for maps.

Following the arrival of the Mars Global Surveyor (MGS), Mars cartography has taken another leap forward. A laser altimeter, MOLA (Mars Orbiter Laser Altimeter), on board MGS carries out precision measurements of the slant range between the spacecraft and the surface [Smith et al, 1989; 1999]. By the time of writing, MOLA has gathered > 100 Mio elevation data points which can be assembled to add valuable topographic data to the maps. An additional benefit comes from the fact that the lateral coordinates of the laser return points are precisely known – and that many of these points (estimated > 10,000) can be identified in images. Hence, MOLA gives us an excellent data base for the lateral control of our maps. In this paper, we describe procedures to derive geometrically precise topographic image maps. These are based on Viking Orbiter image mosaics, which are precisely tied to the Mars global geodetic network, as the MOLA data confirms. Finally, MOLA elevation data are added to the map that now shows topography and image information in precise correlation.

2 GEODETIC PARAMETERS FOR MAPPING

Following the landing of the Mars Pathfinder, some of the geodetic parameters for Mars, needed for any cartographic work, were updated. Tracking of the Pathfinder spacecraft resulted in improved rotational parameters for the planet [Folkner et al, 1997], given by:

$$\alpha = 317.681431 - 0.10617\ T$$
$$\delta = 52.886503 - 0.06094\ T$$
$$W = W_0 + 350.891982268\ d,$$

where α and δ are the right ascension and declination of the orientation of the rotational axis, T represents centuries past J2000, and d represents days past J2000. W describes the orientation of the meridian of 0º longitude in space; W_0 generally follows adopted conventions (here: $W_0 = 176.901$ [Davies et al., 1995]).

The Pathfinder landing site marks the most important control point in our geodetic network. Its Mars-fixed coordinates were derived by range and Doppler measurements based on the lander's radio signals. The location of the lander in Viking Orbiter images was determined by correlating features in horizon images with features seen from space. The landing site could be located relative to its surroundings to within +/-40m (Table 1) [Oberst et al., 1998].

Although updated shape models for Mars, based on MOLA data, have recently become available [Smith et al., 1998], we used the established 1994 IAU (International Astronomical Union) ellipsoid [Davies et al., 1995] to define geodetic (areodetic) latitudes of our map. The equatorial and polar axes of this ellipsoid are given by a=b=3397 and 3375 km, respectively, resulting in a flattening of 1/154.4. The rotational parameter W_0 (see above) was recommended by IAU to be $W_0 = 176.901$.

Table 1: Coordinates of the Mars Pathfinder Landing Site
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Image Space:	VO Image #	line (pixel)	sample (pixel)
	004A27	411.0	318.3 *)
	004A44	705.3	386.7 *)

Object Space:	lat (deg)	W. lon (deg)	h (km)
	19.3267	33.5238	-4.91 **)

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*) [Oberst et al., 1998]; coordinates refer to the raw images
**) [Folkner et al. 1997]; (geodetic) latitudes and heights refer to the 1994 IAU ellipsoid [Davies et al., 1995]

3 CONTROL POINT NETWORK

The geodetic basis of our mapping work was a global network of control points, developed over the past years [Zeitler and Oberst, 1999a,b; Zeitler et al., 2000]. This project involved the analysis of 18,976 line/sample measurements in 1138 (900-1100 m/pixel) Viking Orbiter images of 3739 individual prominent landmarks. The measurements were inverted using bundle block adjustment techniques to solve for the Mars-fixed 3-dimensional coordinates of the landmarks and image pointing data. The Pathfinder landing site coordinates and the new Mars rotational parameters were important input data sets for this analysis. Landmark coordinates in the Mars-fixed frame were obtained with a precision of 750m (1 σ).

4 GLOBAL IMAGE BASE MAP

A global map was compiled from the originally 1138 Viking Orbiter control point network images. The images were orthoprojected using a global terrain model as a reference surface (which was originally derived from the control point coordinates, when the MOLA data were not yet available [Zeitler and Oberst, 1999b]) and combined to form a mosaic. As the network images provided multiple coverage of the surface, images were selected, that had appropriate illumination for highest contrast. Histogram adjustment techniques and high-pass filtering techniques were used to mask image boundaries and to enhance image detail. Gaps in the image coverage (less than 5%) were filled by higher-resolution Viking Orbiter images.

5 MOLA DATA

From the known precision of our control points and pointing data, we estimate that the resulting cartographic product is tied to the Mars-fixed coordinate system with an accuracy of approx. 1-3 km for most places on Mars. MOLA data were used to verify this estimate. MOLA measures the slant range between the spacecraft and the surface at a rate of 10 shots per second. The laser beam divergence results in a surface reflection spot of approx. 160m and shot-to-shot spacings of approx. 300m (see Smith et al., [1989; 1999] for the following). Owing to uncertainties in the laser's pointing, the uncertainty of the absolute coordinates of the spot locations ranges between 400 and 2000m. Range measurements can be as accurate as 37.5 cm on smooth surfaces. From uncertainties in the spacecraft altitude and the shape of the Mars Geoid, the errors in absolute elevations with respect to the planet's center of mass are 8m rms.

Some of the MOLA points and portions of laser tracks, such as shot points near crater rims or knobs can clearly be identified in images. One of the above control point images was selected which shows a small – 20 km diameter – crater, intersected by one of the MOLA laser tracks. The image was projected to a map, and latitude/longitude grids were added. Surface coordinates of MOLA shot points were marked on this map and compared with the measured elevation data. The close match between the surface track and the crater's topographic signature shows indeed that the map and MOLA data are tied to within 1 km in this particular example.
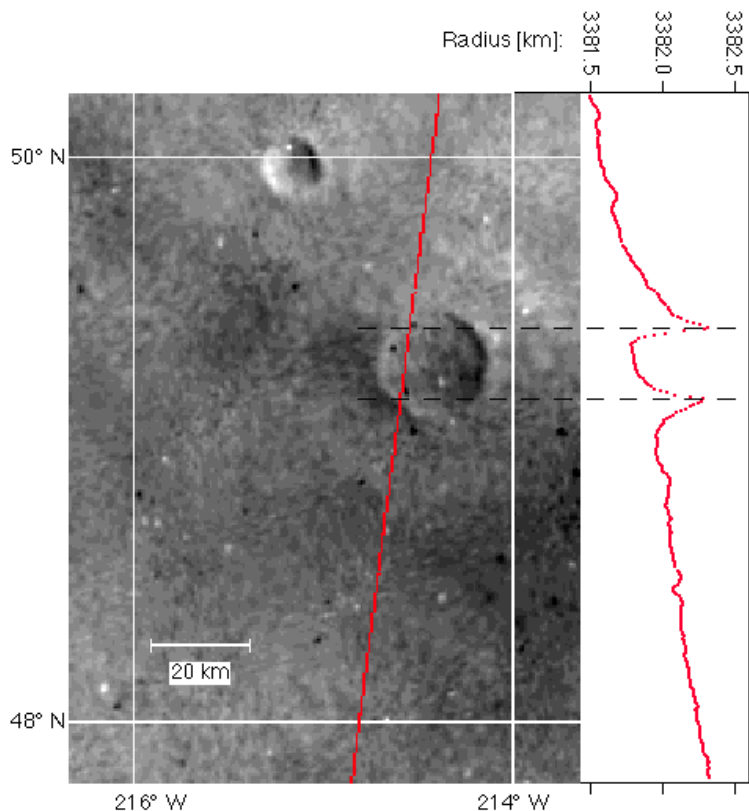
Figure 1. Prototype map for a small area on the northern hemisphere of Mars computed on the basis of the updated Viking control point network. A laser profile obtained by the Mars Orbiter Laser Altimeter (MOLA) onboard the Global Surveyor [Smith et al., 1998] is used to verify the geometric accuracy of this map, which appears to be correctly tied to the Mars-fixed coordinate system to within the map's spatial resolution of 1 km (see text for details).

6 TOPOGRAPHIC MAPS

Geoscientific analyses often require a synoptic view of the morphology and the topography of the terrain. With the global Viking map described above and with the now available MOLA data, it is now possible to produce topographic maps with high positional and topographic accuracy.

All MOLA latitude and longitudes of the surface reflection points (excluding those laser shots reflected by clouds) were then converted to the line/sample space of the projection in which the base map had been produced. Unfortunately, the MOLA surface reflection point coordinates, given in the PDS experiment data records, refer to the the IAU ellipsoid of 1991[1]), rather than the 1994 ellipsoid, used in our study. Hence, the MOLA longitudes are converted by adding a constant value of -0.033° to them to account for the differing rotational parameters W_0. The geodetic (or areodetic) MOLA latitudes were recalculated to match the IAU 1994 ellipsoid of our maps.

From the individual MOLA data point elevations, a contiguous rectangular grid was derived by interpolation, with the greyvalues of this grid being a function of the surface height above the MOLA reference geoid (interim MGM0827e model). Geoid heights are often favored over heights above some reference ellipsoid, as these will show the true upslope and downslope direction in the gravity field, to study possible water flow patterns and mass wasting in the images. MOLA tracks in the area of the map were examined to identify places in which the interpolation had to bridge large data gaps (Fig. 2).

Finally, the two data sets, the global Viking map and the MOLA-based DEM, were merged. Elevations are shown in terms of elevation contours (Fig. 3); alternatively, the MOLA elevations were color-coded and combined with the image data. Figure 4 shows image data, elevation contours and color-codes combined.

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[1] The 1991 IAU ellipsoid on which the MOLA coordinates are based has equatorial and polar radii of 3393.3 and 3375.73 km, respectively, and a corresponding flattening of 1/192.
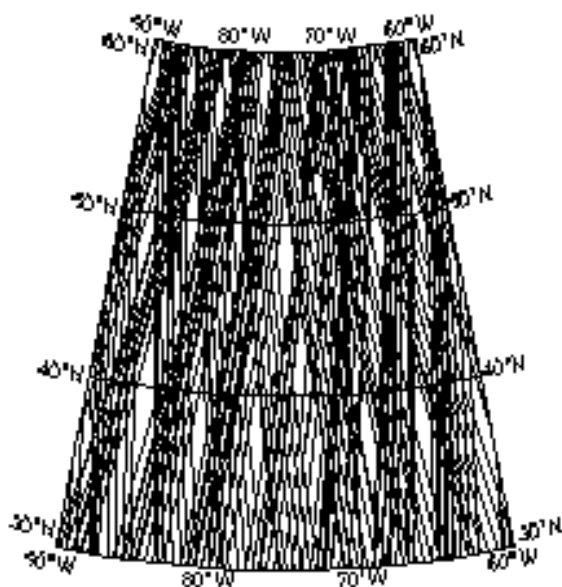
Figure 2: Detail of our global 1km/pixel topographic Viking map in the Tempe Terra region covering the range 60°W-90°W and 30°N-60°N. The image shows all MOLA tracks in the area, released by the time of writing. The tracks combined represent more than 845,000 single shots, all of which were used to calculate the Digital Elevation Model (DEM).
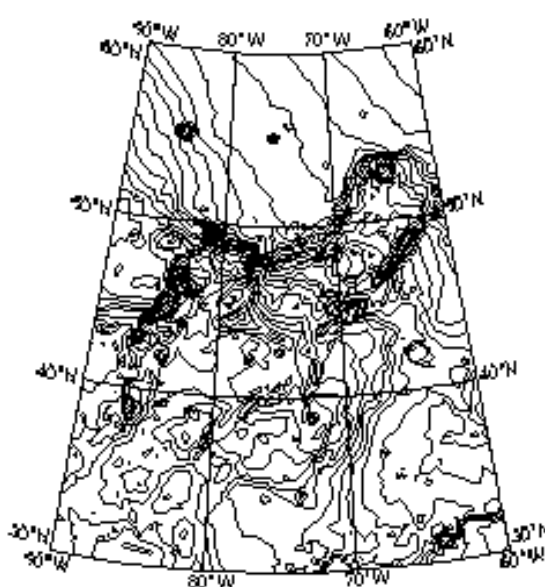
Figure 3: Elevation contour lines (vertical spacing: 250m) derived from the MOLA-based DEM

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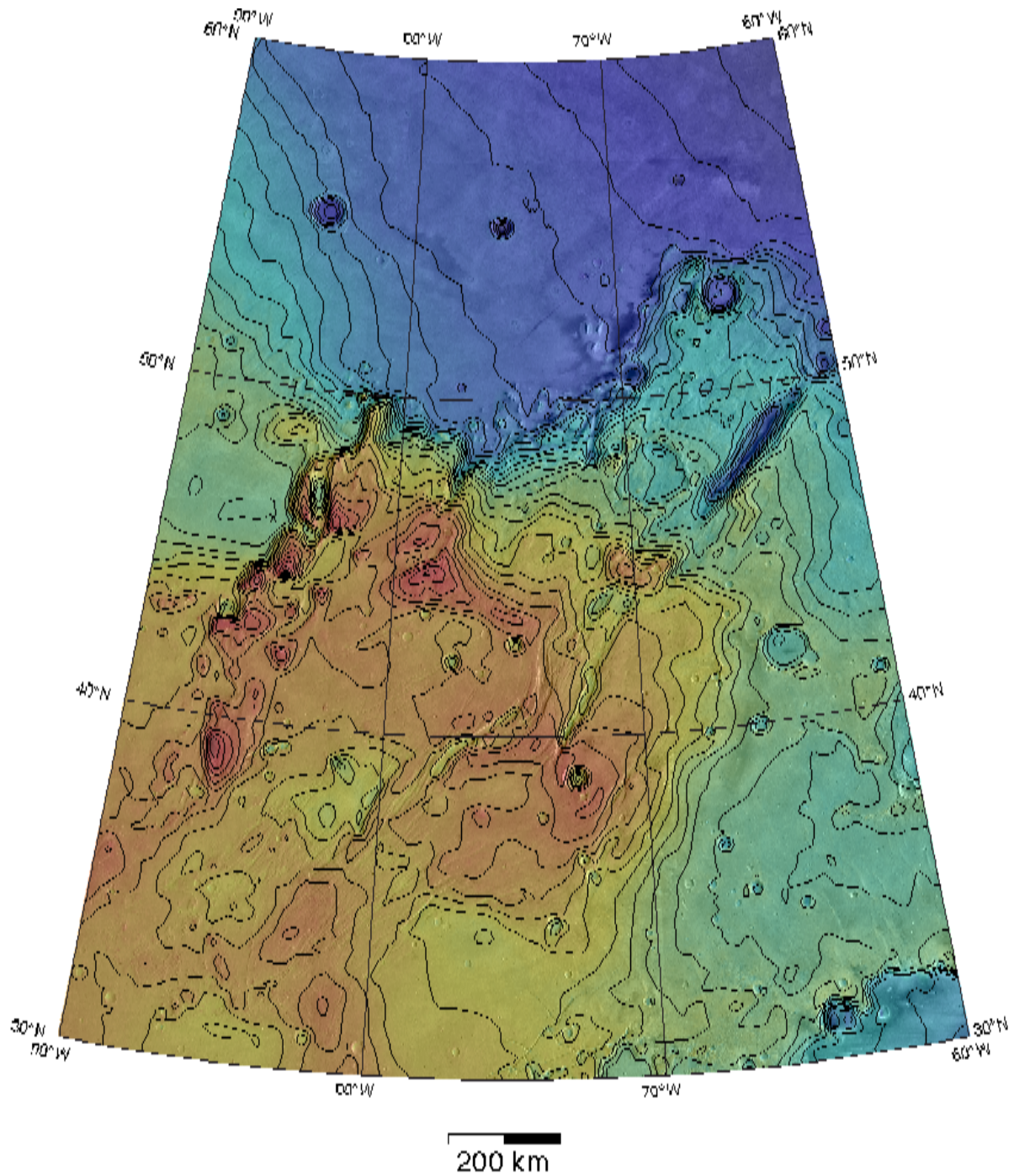
Figure 4: Topographic orthoimage map of Tempe Terra, Mars. The resolution of the Viking image mosaic is 1 km/pixel. The vertical spacing of the contour lines is 250m.