MARS PATHFINDER: CARTOGRAPHIC ANALYSIS OF THE LANDING SITE FROM ORBIT

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ABSTRACT

Viking Orbiter stereo images were used to derive a geometrially precise orthoimage mosaic at 40m scale for the Mars Pathfinder landing site. Camera pointing for each images was obtained by a formal bundle block adjustment, using 1,219 tiepoint measurements and taking into account updated Viking Orbiter trajectory data as well as updated rotational parameters for Mars. Pathfinder, for which planet-fixed coordinates as well as coordinates in images are precisely known, was used as a fixed control point in the adjustment. The block adjustment also resulted in a catalog of 484 object point coordinates which were interpolated to form a DTM of the area. The DTM was used to rectify the images and to provide elevation contours for the mosaic.

1 INTRODUCTION

The Mars Pathfinder spacecraft landed near the mouth of Ares Vallis, an ancient outflow channel in a complex regional morphologic setting (e.g. Tanaka, 1997; Rice and Edgett, 1997). The various types of data collected by the lander and its rover "Sojourner" provide important ground truth for remote sensing studies from orbit (Golombek *et al.*, 1997). However, to study the geological context of the site, it is mandatory to establish precise cartographic products for the area. Unfortunately, control point networks available before the Pathfinder mission (Davies *et al.*, 1992) suffered from large random and systematic errors; early maps that were based on these networks (Batson and Eliason, 1995) therefore had significant geometric errors.

This paper describes our effort to derive a new topographic image map of the Pathfinder landing site using Viking Orbiter images. In the past years, chances to derive precise cartographic products for Mars have greatly improved. With data from the Pathfinder mission, updated rotational parameters and coordinate systems for Mars are available. Also, recently, the orbit data for the Viking Orbiter spacecraft has been thoroughly restored. Finally, the fact that the Pathfinder landing site is precisely known in terms of Mars-fixed coordinates as well as in images makes the landing site a unique "landmark" on the

planet. This control point thus constitutes a unique tie between the Mars-fixed coordinate system and any cartographic products.

2 VIKING ORBITER IMAGE DATA

The Viking Mission to Mars consisted of two identical spacecraft, each consisting of an orbiter and a lander (Snyder, 1977). They were launched in 1975 and operated through 1982, when Viking lander 1 stopped its data transmission. While the main goal of the Vikings was the search for life on Mars, the wealth of science data returned during the mission is still the background of most of our knowledge about the Red Planet. Among the various science products, the most important single source of information came from the images taken from orbit. The two Viking Orbiters were each equipped with twin Vidicon framing cameras which had Schmidt-Cassegrain telescopes with a focal length of 475mm (Wellman et al., 1976). The central region of the 37-mmdiameter vidicon was scanned with a raster format of 1056 lines by 1182 samples (Soffen, 1977). More than 50,000 images were obtained during the nominal and extended missions. As Ares Vallis was one of the candidate sites for the Viking landers, the area was extensively studied in the early mission phase. A total of 16 high-resolution (40m/pixel) images were identified to cover the general Pathfinder area. This included in particular a set of four images looking forward from nadir



Fig. 1: Twin Peaks North (right) and South (left) as seen by the IMP camera. These are estimated to be 780m and 910m from the Pathfinder landing site.

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about 16° and four additional overlapping images of the same site looking backward taken during orbit (REV) 4 (Table 1). The attitude of VO-1 was held fixed during the sequences and accurate to within 0.5° (1 σ) (Duxbury, 1995)

F004A25	F004A39	F004A40
F004A27	F004A41	F004A42
F004A29	F004A43	F004A44
F004A30	F004A45	
F006A64	F006A89	
F006A66	F006A21	
F006A68		

Table 1: Viking Orbiter images used for mapping of the Pathfinder area. Images from Viking Orbiter I, orbit #4 and orbit #6, used in our mapping effort. While the block adjustment was carried out using the 16 images, only 11 images were used in the mosaic. The remaining images (in *italic*) were images overlapping with the primary set of 11 and were therefore not needed.

3 MARS-FIXED COORDINATES OF LANDING SITES AND ROTATION OF MARS

Folkner *et al.* (1997) carried out a combined analysis of radio experiment data from the Pathfinder and Viking Landers and derived improved rotational elements for Mars (Table 2) as well as estimates of planet-fixed coordinates for the landers (Table 3). As the Pathfinder X band radio system operated at higher frequency than the Viking S band, Doppler and ranging measurements were less affected by charged particles in the Earth's ionosphere and therefore more accurate. Owing to the long operational period of the Viking Landers of 6 years the rotation rate of Mars was refined by one order of magnitude over results from initial analyses of these data shortly after the landing. The errors for all lander coordinates were estimated to be 30m in radius and latitude and about 100m in longitude.

Before this analysis was carried out, there was a concern of combining the analysis of Viking image data, gathered 25 years ago, with coordinate estimates from today's tracking data of Pathfinder, as uncertainties in the rotational rate of Mars may propagate into uncertainties in the tie between images and Mars-fixed coordinates. However, over the years that have passed since the Viking missions, the current error in the rotation rate of Mars adds up to only 0.0073° or 400m at the Pathfinder latitude, when the new parameter of W for the rotational rate by Folkner *et al.*, 1997, Table 2) is adopted.

α	317.681431 - 0.10617 T
δ	52.886503 - 0.06094 T
W	W ₀ + 350.891982268 d

Table 2: Updated Rotational Elements for Mars. 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 origin of longitudes in space; $W_0 = 176.901$ was adopted from IAU recommendations (Davies *et al.*, 1995).







Fig. 2: Northeast Knob (top), South Knob (center), and Far Knob (bottom), as seen in Pathfinder horizon images.

4 LANDING SITE COORDINATES IN IMAGES

The Mars-fixed coordinates of Pathfinder were used to find the approximate landing site area in Viking images. The precise location was determined by correlating topographic features seen at Pathfinder's horizon with features seen in the images from orbit. Five features were selected, Twin Peak North and South (Fig. 1) as well as North Knob, Southeast Knob, and Far Knob (Fig. 2) (Golombek *et al.*, 1997; Oberst *et al.*, 1998a).

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	Pathfinder:	Viking Lander1:
Longitude	33.5238°W	48.2217°W
Latitude 1)	19.0949°N	22.2692°N
Radius ¹⁾	3389.71 km	3389.32 km
Latitude ²⁾	19.4724°N	22.6969°N
Elevation ²⁾	-3.61 km	-2.69 km
Latitude 3)	19.3267°N	22.5319°
Elevation 3)	-4.907 km	-4.496 km

Table 3: Mars-Fixed Coordinates of Landing Sites. ¹⁾ planetocentric latitude and distance from center of

- mass ²⁾ planetographic latitude and heights with respect to reference ellipsoid of a=b= 3397.2 km and c= 3361.5 km, as given by Folkner *et al.* (1997); heights are measured along the surface normal
- ³⁾ planetographic latitude and heights with respect to IAU reference ellipsoid of a=b= 3397 km and c= 3375 km (Davies *et al.*, 1995); heights are measured along the surface normal

Azimuth angles for these features were measured in horizon images for which the pointing had been calibrated with respect to the North direction (see companion paper by Oberst *et al.*, 1998b; Oberst *et al.*, 1998a). The landing site in image coordinates were then determined to be where azimuth angles measured in the image agreed best with the azimuth angles in the panorama (Tables 4 and 5). The resulting errors were approx. 1 pixel, or 40m.

Feature	distance [m]	azimuth [°]
North Knob	1,840	3.60
Southeast Knob	21,200	133.55
Far Knob	31,520	177.47
Twin Peak		
South	910	241.53
North	780	258.46

Table 4: Horizon Features: Distances from Landing Site and Azimuths

Image	line	sample
004A27	411.0	318.3 +/- 1.0
004A44	705.3	386.7 +/- 1.0

Table 5: Coordinates of the Pathfinder Landing Site in Viking Orbiter images.

5 BLOCK ADJUSTMENT

A block adjustment was carried out to determine precise pointing data for the 16 selected Viking Orbiter images. We adopted a set of 1,219 image coordinate measurements for 484 control points that were made by T. Duxbury (Jet Propulsion Laboratory), with additional measurements added by the authors. This effort was part of a more general project in which Zeitler and Oberst (1998) recomputed the global USGS control point network. This global model included 16,711 coordinate measurements in 1,140 images, representing a total of 3,739 control points.



Fig. 3: Portion of Viking Orbiter I image 004A44 showing the Pathfinder area. North Knob (left horizontal arrow) and Twin Peaks (bottom left arrow) as seen by the Viking Orbiter camera. Southeast Knob and Far Knob are off the image. The Pathfinder landing site is marked by the dark cross. Note the large crater (bottom right arrow), approx. 1.8 km in diameter, south of the landing site.

The adjustment greatly benefits from the revised rotational parameters for Mars mentioned above (Table 2) as well as from new spacecraft trajectory information. The Viking Orbiter tracking data were recently restored (Konopliv and Sjogren, 1995). The processing of very long arcs of radio tracking Doppler data significantly improved the Mars gravitational field and motion models for the two orbiters, resulting in orbit precisions of 100m along-track and cross-track and 50m in radius. This represents an order of magnitude or more improvement over previous orbit information (Duxbury, 1995). Spacecraft position and camera pointing data for each image were transformed into a Mars-centered Mars-fixed cartesian coordinate system using the planet's given rotational parameters (Table 2). Mars Pathfinder and Viking Lander 1 for both of which planet-fixed coordinates as well as coordinates in image space were known (Tables 2 and 4; Oberst et al., 1998a; Morris et al., 1978; Morris, 1980), were introduced as fixed control points.

The procedure resulted in precise 3-dimensional surface coordinates of the 484 control points with errors relative to Pathfinder of less than 50m, as well as in adjusted camera position and pointing data for all images involved. As the control points are part of a global network, the area is firmly tied to the global reference system. Positional $(1\sigma/3\sigma)$ errors of these 3,739 globally distributed control points are estimated to be 740/2220m.



Fig. 4: Distribution of control points in the Pathfinder area. Pathfinder is marked by a cross.

6 DTM

From the 484 control points, we formed a gridded DTM. Object points were converted to (planetographic) latitude, longitude, and height, where latitudes and elevations were computed with respect to the IAU reference ellipsoid (equatorial radius of 3397 km; polar radius of 3375 km; Davies *et al.*, 1975). The DTM was finally formed by sector-based weighted average interpolation. 80% of the control points and of the area covered by the DTM have elevations ranging from -5000m to -4200m (Fig. 5). Areoid undulation, i.e the height difference between the geoid and the reference ellipsoid, are approximately constant at 630 m below the ellipsoid in the rather small area, i.e. 630m should be added to the heights in the DTM to obtain the elevation above the 6.1 mbar reference Areoid surface.



Fig. 5 Histogram of height values in the area covered by the terrain model. Elevations are above the IAU ellipsoid.

7 ORTHOIMAGE MOSAIC

11 out of the 16 images were used to produce an image mosaic map of the landing site. The images were geometriclly corrected for Vidicon distortion inherent to the Viking Orbiter cameras and rectified. The rectification was carried out using the DTM as well as spacecraft position and adjusted camera pointing, obtained from the block adjustment. A sinusoidal map format with scale of 40 m/pixel, a center longitude of 34° W and a center latitude of 0° was chosen. The individual orthoimages were combined to form a mosaic, extending from 18.2° to 20.8° latitude and from 32.4° to 35.4° West.

Histogram (grey level) adjustments and general image processing techniques were used to even out differences in the apparent brightness of individual images, to improve image contrast and to remove image artifacts, such as blemishes, wrinkles, single pixel errors (spikes), reseau marks, and dust rings. Latitude/longitude grids and height contours were finally added (Fig. 6). The mosaic contains remaining wave-like artifacts (see raw image in Fig. 3) owing to the stretch of the Viking 7bit image to 8 bit images, however, no effort was made to remove these, as this would have deteriorated the image quality to unacceptable degree.

8 DISCUSSION AND OUTLOOK

The mosaic we derived represents a geometrically precise image map of the Mars Pathfinder landing site taking into account recent advances in the studies of the planet's rotation, as well as the precisely known tie between image data and Mars-fixed coordinates in the Pathfinder area. In addition, the image map is firmly tied to a global network of control points. Hence, geometric relationships between control points in the Pathfinder area and other landmarks on the planet are precisely known.

Results from our current study will make it possible to improve the accuarcy of maps even beyond the Pathfinder area. In particular, we estimate that the tie between Mars-fixed coordinates and latitude/longitude grids of maps can be reduced to the nominal $(1\sigma/3\sigma)$ error of our control point coordinates of 740m/2220m. This will greatly help in the targetting of future lander mission to Mars and in the planning of imaging sequences from orbit. Unfortunately, the cartographic precision of these maps is probably not going to improve significantly beyond this point anytime soon. Currently, the Mars Global Surveyor is orbiting the planet and has begun obtaining high resolution image data (Malin et al., 1992; 1998). However, the major science goal of the MOC (Mars Orbiting Camera) instrument is in the high-resolution (<1m/pixel) photogeological reconnaissance and (<100m/pixel) global monitoring of the planet, not in precision cartography. The camera is a single-line scanner operated in the pushbroom mode; these images generally lack the geometric stability of framing camera images. The geometric precision of data products from this mission therefore remains to be seen. In addition, MOLA (Mars Orbiter Laser Altimeter: Zuber et al., 1992: Smith et al., 1998) is expected to return several million range measurements with along-track and across-track spacings of 300 m and 3 km near the equator, respectively. Vertical precisions will be up to 30 cm on smooth surfaces. Operation will result in a precise topographic model with a grid size of 0.2° x 0.2° of the entire planet. However, owing to the differing natures of the data sets, it will be a challenging task to combine images and elevation for topographic maps. Mars Global Surveyor will have reached its nominal mapping orbit in March 1999 and run its nominal mission for 2 years.

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Fig. 6: Precision orthoimage mosaic of the Mars Pathfinder landing area, compiled from the Viking Orbiter images. Note that (areodetic) latitudes and elevations refer to the IAU ellipsoid (equatorial radius: 3397 km; polar radius: 3375 km). The Pathfinder landing site is marked by a small cross at 19.3267°N, 33.5238°W.

In 2003, the Mars Express mission will be launched. An orbiter will carry the HRSC (High-Resolution Stereo Camera), a multiple-line multispectral stereo scanner instrument. This camera is believed to be superior to MOC in its prospects for cartographic mapping of the planet (Neukum *et al.*, 1995). For one, forward- and backward looking imagery yield effective stereo pairs from which high-resolution surface topography can be derived. In addition, the combined analysis of the two stereo with the nadir sensors, makes it possible to recover

the spacecraft orbit and camera pointing history in with respect to surface coordinates. Thus, data from this instrument will be the basis for improved control point networks of Mars, high-resolution DTMs, and detailed color maps.

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