Interior channels in Martian valleys: Constraints on fluvial erosion by measurements of the Mars Express High Resolution Stereo Camera

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[1] In High Resolution Stereo Camera (HRSC) images of the Mars Express Mission a 130 km long interior channel is identified within a 400 km long valley network system located in the Lybia Montes. Ages of the valley floor and the surroundings as derived from crater counts define a period of ~350 Myrs during which the valley might have been formed. Based on HRSC stereo measurements the discharge of the interior channel is estimated at ~4800 m³/s, corresponding to a runoff production rate of ~1 cm/day. Mass balances indicate erosion rates of a few cm/year implying the erosion activity in the valley to a few thousand years for continuous flow, or one or more orders of magnitude longer time spans for more intermittent flows. Therefore, during the Hesperian, relatively brief but recurring episodes of erosion intervals are more likely than sustained flow. Citation: Jaumann, R., et al. (2005), Interior channels in Martian valleys: Constraints on fluvial erosion by measurements of the Mars Express High Resolution Stereo Camera, Geophys. Res. Lett., 32, L16203, doi:10.1029/2005GL023415.

1. Introduction

[2] Martian valley networks [Pieri, 1980b] or “runoff channels” [Sharp and Malin, 1975] have been cited as the best evidence that Mars maintained flow of liquid water across the surface. A valley cut by a river usually shows internal structures such as interior channels, terraces and benches. Although those features are extremely rare in Martian valleys [Malin and Edgett, 2000; Carr and Malin, 2000], short segments of interior channels have been identified in Mars Orbiter Camera (MOC) images [Malin and Edgett, 2000; Irwin et al., 2004] and Mars Odyssey Thermal Emission Imaging System (THEMIS) images [Mangold et al., 2004; Irwin et al., 2005]. Interior channels indicate surface flow and constrain the amount of water (discharge) involved in surface runoff. As valley networks are thought to be formed by runoff in immature drainage basins, as well as by paleolake overflows and possible subsurface outflows, the timescales of the erosion are important to constrain the valley formation process [Moore et al., 2003].

[3] A 130 km long and about 500 m wide interior channel has been discovered in Mars Express high-resolution imagery. The Mars Express High Resolution Stereo Camera (HRSC) is a multiple line scanner capable of resolving, at 250 km periapsis height, features as small as 10 m/pixel in stereo and color and by simultaneously covering large surface areas [Neukum et al., 2004].

2. Observations and Geologic Settings

[4] The observed valley network and the interior channel are located between 1.4°N to 3.5°N and 81.6°E to 82.5°E in the western part of Libya Montes (Figure 1). The Libya Montes are thought to be eroded remnants of the Isidis basin rim that consist of Noachian highland materials [Greeley and Guest, 1987]. The oldest unit (Nm) forms rugged mountainous surfaces of massive materials, which are partly remnants of former impact crater rims, heavily modified and locally dissected by drainage patterns [Crumpler and Tanaka, 2003]. Within the Noachian terrain, younger Hesperian plain units (Hd1) are exposed. These plains are characterized by valley systems and their poorly dissected interFluves [Crumpler and Tanaka, 2003]. Within Hd1 a 400 km long valley network extends from south to north and includes major western and eastern branches that converge downstream. The valley floor is covered by smooth material (Hd2). Within these smooth materials an interior channel (Figure 2) winds northward, showing a sinuous pattern. The interior channel incised the unit Hd2 and developed terraces. Further downstream the channel cuts into the floor of a narrow valley and can be identified as an interior channel. Although at some places the valley rims are obscured by subsequent modifications due to mass wasting, the interior channel can be traced for about 130 km. Further north the interior channel crosses the ejecta of an impact crater of about 3 km diameter. The channel winds very closely around the crater rim and is not buried indicating its younger age compared to the crater.

2.1. Morphometry

[5] The HRSC high resolution stereo data allow the determination of the depth and width of the interior channel. Height measurements were carried out based on a high resolution DTM (horizontal resolution 50 m) in three different reaches (upstream, midstream and downstream) of the interior channel (Figures 2 and 3). DTM heights are stored with a resolution of 1 m. The expected mean point accuracy from analysis of a number of high resolution...
HRSC DTM s is about 90% of the nadir image resolution [Gwinner et al., 2005]. Thus we assume a mean height accuracy of 10 m in the case of orbit 47. In order to increase the accuracy of the depth measurements, we combine cross sections and point measurements along the floor and the terraces of the interior channel (Figure 3 and Table 1). The measured channel depths are minimum values because mass wasting and aeolian processes may have filled the channel after formation and for sampling reasons. The depth of the channel (Figure 4) is in the upper reach \(27 \pm 10\) m, in the middle reach \(35 \pm 10\) m and in the lower reach \(55 \pm 10\) m, indicating an increasing incision of the channel bed downstream. The interior channel widths in all areas are \(450 \pm 50\) m, independently of whether they are measured in the image data or in the profiles. The interior channel lays within a \(280 \pm 10\) m deep and \(3500 \pm 50\) m wide valley (Figure 5).

### 2.2. Discharge

[6] The derived morphometric parameters were used to calculate the hydraulic parameters of the interior channel. From these parameters we estimated maximum discharges at different locations as shown in Figure 3 by using a modified Manning’s equation for steady, uniform flow taking into account the lower gravitational acceleration on Mars [Manning, 1891; Komar, 1979; Wilson et al., 2004]:

\[
Q = AU = A \left( s R^{1/3} \right)^{1/2} n_{mars}
\]

where \(A\) is the flow cross-sectional area, \(U\) is the flow velocity, \(S\) is the local slope, \(R\) is the hydraulic radius and \(n_{mars}\) is the Manning roughness coefficient for Mars. For the slope \(S\) we used the measured gradient of 0.01 of the interior channel as derived from the topographic data. The Manning roughness coefficient for Mars is constrained by a dimensionless constant \(K\), the bed roughness scale \(r\) and the acceleration due to gravity. With \(n_{mars} = r^{1/6} g^{-1/2} K^{-1}\) and using \(K = 6.01, g = 3.74 \text{ m/s}^2\) for Mars and \(r = 0.064 \text{ m}\) Wilson et al. [2004] derived an optimum value for \(n_{mars}\) equal to 0.0545 s m\(^{-1/3}\). The peak rates for a bankfull discharge of the interior channel range from \((22 \pm 14) \times 10^4 \text{ m}^3/\text{s}\) upstream to \((68 \pm 27) \times 10^4 \text{ m}^3/\text{s}\) downstream. The channel could not have contained more water than at bankfull and so this is an limiting condition for the total amount of water running through the valley system.

### Table 1. Measured Morphometric Parameters

<table>
<thead>
<tr>
<th>Cross Section(^a)</th>
<th>Height (^1) m</th>
<th>Height (^2) m</th>
<th>Height (^3) m</th>
<th>Depth (m)</th>
<th>Width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-583</td>
<td>-616</td>
<td>-597</td>
<td>26±10</td>
<td>425±50</td>
</tr>
<tr>
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<td>-610</td>
<td>-592</td>
<td>21±10</td>
<td>425±50</td>
</tr>
<tr>
<td>3</td>
<td>-579</td>
<td>-617</td>
<td>-589</td>
<td>33±10</td>
<td>425±50</td>
</tr>
<tr>
<td>P 1 – 3</td>
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<td>-619</td>
<td>-589</td>
<td>29±10</td>
<td>440±50</td>
</tr>
<tr>
<td>4</td>
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<td>-1555</td>
<td>-1538</td>
<td>31±10</td>
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</tr>
<tr>
<td>5</td>
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<td>-1575</td>
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<td>43±10</td>
<td>440±50</td>
</tr>
<tr>
<td>6</td>
<td>-1531</td>
<td>-1562</td>
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<td>28±10</td>
<td>440±50</td>
</tr>
<tr>
<td>P 4 – 6</td>
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<td>-1575</td>
<td>-1541</td>
<td>34±10</td>
<td>615±50</td>
</tr>
<tr>
<td>7</td>
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<td>-1837</td>
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<td>420±50</td>
</tr>
<tr>
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<td>59±10</td>
<td>420±50</td>
</tr>
<tr>
<td>P 7 – 9</td>
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<td>-1890</td>
<td>-1832</td>
<td>52±10</td>
<td>450±50</td>
</tr>
</tbody>
</table>

\(^a\)Cross section numberings correspond to point and profile (P) measurements shown in Figures 3 and 4.

\(^b\)Height 1, 2 and 3 correspond to measurements of the left terraces, the interior channel floors and the right terraces, respectively.
2.3. Ages and Chronology

The age of the valley system was determined by crater counts on the valley floor containing the interior channel and the surrounding terrains, in which the valley eroded. The crater retention ages for the surrounding area (Hd1) are

\[ N(1 \text{ km}) = 5.6 \times 10^{-3} \] and for the valley floor (Hd2) are

\[ N(1 \text{ km}) = 2 \times 10^{-3}. \] To derive the absolute model ages from the crater frequency distributions, we utilized the Martian impact cratering model of Hartmann and Neukum [2001] and polynomial coefficients of Ivanov [2001]. The valley was formed in Hesperian times with absolute model ages for the valley floor including the channel of \(~3.35 \pm 0.05\ \text{Gyr}\) and for the surrounding terrains of \(~3.7 \pm 0.05\ \text{Gyr}\) (Figure 6). Therefore, the maximum valley formation time amounts to \(~350 \pm 100\ \text{Myr}\).

3. Discussion

[8] The erosion of unit Hd1 down to Hd2 is most prominently exposed in the northern part of the valley system, where Hd1 is cut by a narrow and deep segment of the valley (Figure 5). Taking into account the \(~350 \pm 100\ \text{Myr}\) time difference between Hd1 and Hd2 and the valley depth of \(~280 \pm 10\ \text{m}\), the average erosion rate for this valley segment is \(0.8 \pm 0.3\ \text{mm/a}\), which is very low. However, it is unlikely that such low erosion rates would result from fluvial processes in a long-lived Earthlike climate and the valley might have been eroded during a shorter period. In order to investigate this question we need to know how much material was eroded and transported in the valley. The erosion rates of the valley can be constrained by using the erosion power of the interior channel. Within a distance of about 100 km (Figures 3a–3c) the depth of the interior channel increases by a factor of 2 while the width remains almost constant. However, a 10% bankfull discharge of the interior channel sufficient to erode and transport enough material to explain the dimensions of the valley? The frictional shear velocity \(u = (\tau/\rho)^{1/2}\) of the interior channel where \(\tau\) is the stress between the flowing water and the bottom and \(\rho\) is the water density constrains the flow conditions: For near uniform flow \(\tau\) can be determined from the flow depth \(h\) and the channel slope \(S\) through the relationship \(\tau = \rho gh S\) where \(g\) is the acceleration of gravity (3.74 m/s² for Mars). For a 10% bankfull discharge the frictional shear velocity is 33.5 cm/s. According to the relationship between frictional shear velocity and transport load on Mars as developed by Komar [1980] the threshold grain diameter in the interior channel is \(~40\ \text{cm}\), the cutoff diameter between bed load and suspension is

![Figure 4. Cross section profiles of the interior channels (see Figure 3). Arrows show the terraces of the interior channel.](image)

![Figure 5. Cross section profile of the northern valley segment.](image)

![Figure 6. Crater count results of the valley floor (Hd2) (triangles) and surrounding areas (Hd1) (circles).](image)
and and constructive review and an anonymous reviewer. This work was supported by a grant from the German Research Foundation (DFG, SPP 1115). This work was also supported by the Programme National de Planétologie and by the European Community’s Improving Human Potential Program under contract RTN2-2001-00414, MAGE. The authors appreciate the work of the HRSC Co-Investigator Team.

References


Komar, P. D. (1979), Comparisons of the hydraulics of water flows in Martian outflow channels with flows of similar scale on Earth, Icarus, 37, 156–181.


Leopold, L. B., M. G. Wolman, and J. P. Miller (1964), Fluvial Processes in Geomorphology, 522 pp., Dover, Mineola, N. Y.


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