ERUPTION CONSTRAINTS ON A CHANNELED LAVA FLOW IN MARTE VALLIS, MARS, FROM MARS ORBITER LASER ALTIMETER AND MARS ORBITER CAMERA DATA

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INTRODUCTION

Lava flow emplacement is a fundamental geologic process on Mars and other planetary bodies. By studying the surface morphology of lava flows, we gain insight into eruption parameters and ultimately a region's geothermal history. Images from the Mars Orbiter Camera (MOC) instrument [*Malin et al.*, 1998; *Malin et al.*, 1992] on the Mars Global Surveyor spacecraft show relatively young lava flows in the Marte Vallis region of Mars. These lava flows were recently estimated to be 10 million years old [*Hartmann and Berman*, 2000], suggesting a more recent volcanically active Mars than earlier believed [*Garvin et al.*, 2000].

In this study we attempt to constrain flow rates and velocities for a recent channeled flow in Marte Vallis shown in MOC image SP240703, which was acquired in July 1998 at a resolution of 18.47 m/pixel. Using Mars Orbiter Laser Altimeter (MOLA) [*Smith et al.*, 1998; *Zuber et al.*, 1992] topographic data, channel dimensions we measured included down-flow gradient, channel width, and channel depth. From these, flow rates and velocities were calculated using the rectangular channel flow model of Gregg and Sakimoto [1998, 2000; *Sakimoto and Gregg*, in prep.].

Marte Vallis, located between 170-190°W longitude and 0-20°N latitude, is a region characterized primarily by channels of possible fluvial origin [*Tanaka and Scott*, 1986]. Later volcanic activity, in the form of flood basalts and long lava flows, utilized these channels to transport lava distances as great as five hundred kilometers or more [*Plescia*, 1990] on slopes <0.01° [*Gregg and Sakimoto*, 2000; *Sakimoto and Gregg*, in prep.]. Our study area is the northeasternmost section of Marte Vallis, to the east of Orcus Patera [*Greeley and Guest*, 1987], where these fluvial discharges and lava flows debouched onto Amazonis Planitia [*Plescia*, 1990]. The flow studied is located in the southern half of MOC image SP240703, which is centered at 19.22°N and 174.61°W. In the southernmost portion of the MOC image, a distinct dark lava flow and its terminus are clearly visible within the higher-albedo fluvial channel (Figure 1).

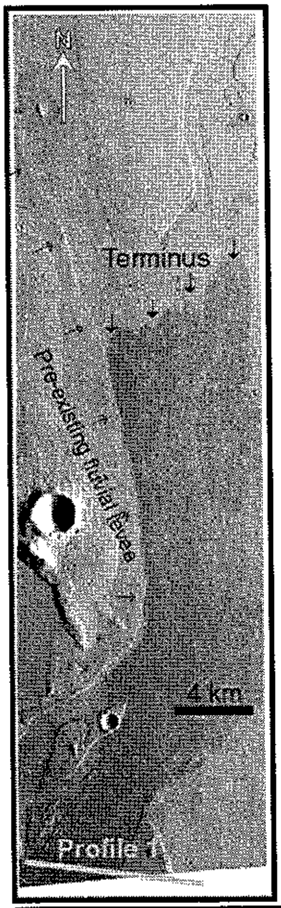

FIGURE 1: MOC Image SP240703 showing a young lava flow in the Marte Vallis region of Mars. The MOC image has a resolution of 18.47 meters per pixel. A distinct dark lava flow and its terminus, the subject of this study, are clearly visible within the higher-albedo fluvial channel. The flow terminus is identified with black arrows. And one of the pre-existing fluvial levees is identified with red arrows. Profile 1 shown in Figure 2.

METHODS

Using the program *Gridview* [*Roark et al.*, 2000], five topographic profiles of the channel were created from MOLA data gridded at 64x256 pixels/degree. At the time of this study, the footprints of our profiles were between 600 and 700 meters apart, and the topography was accurate to within a meter. These profiles reveal the channel levees and are used to determine the dimensions of the channel for input into an analytical model to determine lava flow rates and velocities.

resurfacing a broad area to either side. Subsequent to this flood, repeated episodes of volcanism and water release resulted in the interfingered deposits now evident in the channels.

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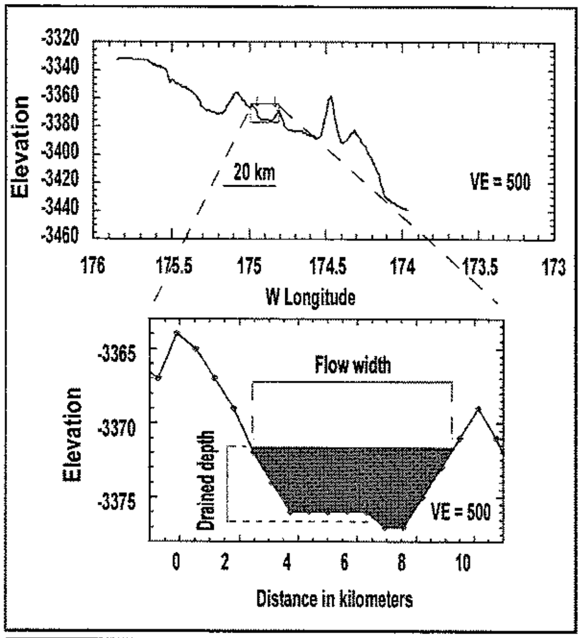

FIGURE 2: MOLA-derived topography from along Profile 1 (location shown in Figure 1). The drained depth is 5 ± 1 m, and the width is 6.5 ± 1.0 km. Individual data points are marked as blue squares. The MOC image provides evidence that the lava flow did not reach the top of the pre-existing fluvial channel levee due to the albedo changes and textural variations; the inferred maximum lava flow thickness is shown in red.

The topographic profiles of the channel reveal the channel levees and can be used to measure channel width; the elevations recorded at the flow's center in each profile help constrain local slope. Another profile collected along the center of the channel places constraints upon the regional slope. A final profile across the terminus of the lava flow was used to determine flow thickness. Lava flow volume was calculated from flow thickness, lobe width, and the surface area of the end-flow. Then, from the total volume and flow rates, we estimated the time required to emplace this terminal portion of the flow.

When calculating volume of the lava flow, we assume a gradual decrease of flow thickness as a function of distance from the toe and complete drainage in the channels. We assume the lava emptied out of the channel, leaving a thin lava veneer seen as an area with low albedo. The precise thickness of the lava veneer is likely a function of lava composition, channel dimensions, cooling rate, and length of flow. Further study might constrain exactly how much material remains in the veneer from lavas of varying viscosities in terrestrial models.

The analytical model [*Gregg and Sakimoto*, 1998; *Gregg and Sakimoto*, 2000; *Sakimoto and Gregg*, in prep.] used in this study was developed to characterize flow rates and velocities of lava flows within pre-established channels based on certain inputs, including the channel's width, depth, and underlying slope. The model assumes a laminar, steady, gravity-driven Newtonian flow in a rectangular channel. Flow rates and velocities can be calculated for a given channel width, depth, gravitational acceleration, flow density, channel slope, and range of viscosities. Previous characterizations using this model were all based on channels that had emptied out [*Gregg and Sakimoto*, 1998; *Gregg and Sakimoto*, 2000; *Sakimoto and Gregg*, in prep.].

RESULTS

Measurements for the flow width and drained depth for the channel profile are illustrated in Figure 2. The drained depth is 5 ± 1 m, and the width is 6.5 ± 1.0 km. When comparing the MOLA topographical profile across the channel with the MOC image, what first appear to be channel levees in the topographic profile are actually knobs and ridges that are cut by the lava flow and visible in the MOC image. The differences in albedo in the MOC image suggest the lava did not reach the top of these features, but rather partway. A regional slope along the channel suggests a very shallowly sloping terrain of 0.04° ± 0.01°.

The measured values for width, depth, and slope were used as model inputs. Values were obtained for flow rates and velocities in the center of the flow by changing viscosity between 100 and 1000 Pa-s and keeping density at either 1200 or 2000 kg/m^3 (Table 1).

Volume and duration were calculated from the measurements found in Table 1. The volume calculation yielded a minimum total volume of 0.65 ± 0.25 km^3. Emplacement duration values based on the minimum total volume can also be found in Table 1. Flow rate calculations based on 100 Pa-s viscosity produced duration values of close to 2 x 10^1 for density of 1200 kg/m^3 and 1.3 x 10^1 for density of 2000 kg/m^3.

Table 1: Lava Velocity and Flow Rate from Channel Dimensions and Emplacement Duration				
width = 6500m	depth = 5m	slope = 0.04°	volume = 0.65km^3	
Density (kg/m^3)	Viscosity (Pa-s)	Velocity (m/s)	Flow rate (m^3/s)	Duration (hr)
1200	100	0.390	8.4×10^3	21
1200	400	0.097	2.1×10^3	84
1200	800	0.049	1.1×10^3	160
1200	1000	0.039	0.8×10^3	210
2000	100	0.650	14×10^3	13
2000	400	0.162	3.5×10^3	51
2000	800	0.081	1.8×10^3	100
2000	1000	0.065	1.4×10^3	130

DISCUSSION

Our calculations of flow rates and velocity assume the channel had emptied out. However, a thin layer of lava must have been left behind to produce the low-albedo area seen in the MOC image. The channel profile in Figure 2, with a vertical exaggeration of 500, shows the eastern side of the channel one meter lower, locally, than the western side. We believe that this depression was either originally a fluvial feature that has been preserved by a very thin draping of lava or a last frozen lava rivulet running along the western side of (and freezing along) the channel bottom. Wind activity is ruled out since no aeolian processes are apparent inside the flow in the MOC image. Velocity, flow rate, volume and duration values are minima because our measurements do not account for this residue. Studies of Hawaiian flows utilizing pre-existing channels, however, suggest that this lava veneer could be as little as a few centimeters [*Hazlett*, 1993].

Viking images of the area show the channel ran northeast and then turned northward. The topographic profile (Fig. 2) seems to show a thalweg that developed at the bend in the channel -- flowing water may have caused erosion on the outside (eastern side) of the bend and deposition on the inside (western side). Given the well-preserved veneer of lava remaining within the fluvial channel and revealed here with the paired MOLA/MOC data, we suggest there may be additional drained lava channels with a thin veneer of lava preserving the original fluvial topography. In-depth study of additional similar sites will need both MOLA and MOC coverage.

Individual MOLA orbit tracks were not used for the profiles in this study because they are oriented north-south, similar to the trend of our flows. With the Gridview program, west-east topographical profiles, from a high-resolution 64x256 grid, were made across the north-south trending flows. Individual MOLA tracks are accurate to within tens of centimeters and have footprints of ~330 meters [*Smith et al.*, 1998]. In Gridview, the footprint distances vary, depending on the angle of the profile. With the current data grid, the footprints of our profiles were between 600 and 700 meters part, and the topography is accurate to within a meter. This implies our large-scale measurements are accurate, but might have missed some not-yet-sampled details between the footprints.

Our results, summarized in Table 1, yield flow rates and velocities for this flow for different viscosities and densities. For viscosities between 100 and 1000 Pa-s, we find the velocity to be between 0.04 and 0.4 m/s for a density of 1200 kg/m^3 and velocities between 0.07 and 0.7 m/s for a density of 2000 kg/m^3. The flow rate was calculated to be between 8.4×10^3 and 1.4×10^4 m^3/s. In comparison, Keszthelyi et al. [2000] have recently calculated the rates for several long, Martian lava flows and propose average eruption rates near 1×10^4 m^3/s. The maximum values for our flow rates are comparable to mean values of Keszthelyi et al. While this flow is somewhat different from that studied by Keszthelyi et al., the most obvious difference is in slopes; the slopes in our region are shallower, a fact that may explain much of the flow-rate variations. For a comparison to a terrestrial basaltic or andesitic-basalt flow, the flow rates for the Umatilla Member of the Columbia River Basalt were found to be between 1×10^3 and 1×10^6 m^3/s [*Reidel*, 1998]. Our flow rates are toward the lower end of these values, again consistent with the shallower slopes in Marte Vallis.

Recent work done by Gregg and Sakimoto [2000] characterized velocities and flow rates of a channeled flow in another part of Marte Vallis. Their velocities ranged from 0.2 - 0.4 m/s for a density of 2000 kg/m^3 and a viscosity of 100 Pa-s. Flow rates spanned 1×10^4 to 7×10^4 m^3/s under the same conditions. The underlying slopes in this area of Marte Vallis studied by Gregg and Sakimoto were shallower than the flow characterized in this study, which may account for the larger velocity and flow rate values calculated in this study.

When calculating volume, we assume a gradual decrease of flow thickness as a function of distance from the toe and complete drainage in the channels. We assume the lava completely emptied out of the channel, which we know isn't exactly true because it left a lava veneer we can see as an area with low albedo. The precise amount of lava veneer is likely a function of lava composition, channel dimensions, cooling rate, and length of flow. Further study of terrestrial models might constrain exactly how much material remains in a veneer for lavas with varying viscosities. This would present a somewhat more accurate measurement of volume, which would provide better insight into flow duration.

Our measurement of duration is dependent on a chain of assumptions. Depending on flow rate, the duration is on the order of tens of hours, possibly as long as 200 hours. This is a relatively short period of eruption; however, it only accounts for one very small part of the larger lava flow system of the Cerberus Plains

CONCLUSIONS

Accurate channel dimensions, including channel depth, width, and regional slope, can be measured and used as model inputs to obtain flow velocities and flow rates. If a flow's terminus is resolvable in MOC images, topographical profiles and high-resolution images can be used to characterize a flows surface area, a total volume for the flow, and duration of eruption. For our flow, we found a velocity between 0.04 and 0.4 m/s and a flow rate near 8.4 x $104 m^3/s$. These results are similar to those found in other recent studies [*Gregg and Sakimoto*, 2000; *Keszthelyi et al.*, 2000; *Reidel*, 1998], which supports the idea that these flows share many of the characteristics of long terrestrial basaltic flows.

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ORCUS PATERA: IMPACT CRATER OR VOLCANIC CALDERA?

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INTRODUCTION

Since the Viking images of the 1970's, various researchers have suggested several possible geologic origins for Orcus Patera, an enigmatic, elongate depression located between the Elysium and Amazonis Plainitias on Mars (11-18°N latitude and 180-183°W longitude). Initially, Orcus Patera was proposed as a possible volcanic landform (Greeley, 1978). Others have since argued that Orcus Patera is a deformed impact crater, a result of a compression zone between the two mega-aureoles of Olympus Mons and Elysium Mons (Jons, 1984). Another argument compares Orcus Patera to Schiller, a 100-km diameter lunar basin of unknown origin, and suggests that the two structures, similar in obliquity, resulted from erosion of "aligned impact craters" (Trego, 1985).

The Mars Global Surveyor (MGS) spacecraft, equipped with the Mars Orbiter Laser Altimeter (MOLA), is providing new high-resolution data. MOLA gridded topography data allows quantitative comparison of morphological parameters to help constrain whether Orcus Patera is an oblique impact crater or a volcanic caldera. These parameters include depth, diameter, flank and cavity slopes, and ellipticity. We offer here a re-evaluation of Orcus Patera using MOLA data and dimensional analyses of other elliptical structures on the Moon, Earth, and Mars.

METHODS

To characterize the elongate geometry of Orcus Patera, we took quantitative measurements from a best-fit ellipse superimposed upon a 256 pixel/degree Viking Mars Digital Image Mosaic (MDIM). From this best-fit ellipse major and minor axes were defined, and the length, width, surface area, eccentricity, and ellipticity values were determined.

The program *Gridview* (Roark, 2000), a software package that creates and manipulates gridded topography data, allowed us to evaluate the topographic character of Orcus Patera through the manipulation of the gridded datasets, from which we extracted MOLA profiles. To determine the actual position of cross-sections relative to the minor axis of Orcus Patera, we compared MOLA profiles to MDIM data. Comparison was necessary, because MOLA data are given in areocentric coordinates, whereas MDIM imagery utilizes a geographic coordinate frame. A corrected MOLA track superimposed upon a processed MDIM served as a reference point for proper alignment of the MOLA profiles (Figure 1). Garvin et al. (2000) found that shifting an MDIM image relative to a MOLA cross-section produces a final horizontal location accuracy of 1-3 MDIM pixels (200-600m or 1-2 MOLA footprints). Depth, diameter, and height measurements (Figure 2) were taken from selected MOLA profiles that provided us with cross-sections of the basin and surrounding flanks. Major and minor axis profiles are shown in Figure 2.

We also calculated cavity-wall and flank slopes. Interior cavity-wall slope values were determined from linear fits. Since the exterior flank slopes of Orcus Patera are poorly fit with a linear function, and for comparison purposes to other elliptical structures, we applied an ejecta thickness function (ETF) (Garvin and Frawley, 1998) to the parabolic flank slopes (Figure 3). In this equation ($t_e = k(r/R)^b$ where k is a constant, r is the horizontal distance from the crater's center, R is the radius of the crater from the rim crest and b is the exponential fit of the curve.