ORCUS PATERA: IMPACT CRATER OR VOLCANIC CALDERA?

KRYSTAL TRIBBETT
Department of Geology, Vassar College
Faculty Sponsor: Brian McAdoo

DOLORES VAN DER KOLK
Department of Geology, California State University, Fullerton
Faculty Sponsor: Phillip Armstrong

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.

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.

REFERENCES

Garvin, J.B., S.E.H. Sakimoto, J.J. Frawley, C.C. Schnetzler, and H.M. Wright, Topographic evidence for geologically recent near-polar volcanism on Mars, *Icarus*, *145*, 648-652, 2000.

Greeley, R., and J.E. Guest, Geologic map of the eastern equatorial region of Mars, U.S. Geological Survey, 1987.

Gregg, T.K.P., and S.E.H. Sakimoto, Inside the "black box": Velocity distributions and flow rates in lava channels from laboratory, analytic, and computational fluid dynamics methods, in *Lunar and Planetary Science Conference*, Abstract # 1499, Houston, TX, 1998.

Gregg, T.K.P., and S.E.H. Sakimoto, Marte Valles lava channel flow rates and rheology from MOC and MOLA data, in *Lunar and Planetary Science Conference*, Abstract # 1758, Houston, TX, 2000.

Hartmann, W.K., and D.C. Berman, Elysium Planitia lava flows and geological implications, *Journal of Geophysical Research*, *105*, 15,011-15,025, 2000.

Keszthelyi, L., A.S. McEwen, and T. Thordarson, Terrestrial analogs and thermal models for Martian flood lavas, *Journal of Geophysical Research*, *105*, 15,027-15,049, 2000.

Malin, M.C., M.H. Carr, G.E. Danielson, M.E. Davies, W.K. Hartmann, A.P. Ingersoll, P.B. James, H. Masursky, A.S. McEwen, L.A. Soderblom, P. Thomas, J.L. Veverka, M.A. Caplinger, M.A. Ravine, T.A. Soulanille, and J.L. Warren, Early views of the Martian surface from the Mars Orbiter Camera of Mars Global Surveyor, *Science*, *279*, 1681-1685, 1998.

Malin, M.C., G.E. Danielson, A.P. Ingersoll, H. Masursky, J. Veverka, M.A. Ravine, and T.A. Soulanille, Mars Observer Camera, *Journal of Geophysical Research*, *97*, 7699-7718, 1992.

Plescia, J.B., Recent flood lavas in the Elysium Region of Mars, *Icarus*, *88*, 465-490, 1990.

Reidel, S.P., Emplacement of Columbia River flood basalt, *Journal of Geophysical Research*, *103*, 27,393-27,410, 1998.

Roark, J., H. Frey, and S. Sakimoto, Interactive graphics tools for analysis of MOLA and other data, in *Lunar and Planetary Science Conference*, Abstract # 2026, Houston, TX, 2000.

Sakimoto, S.E.H., and T.K.P. Gregg, Channeled flow: Analytic solutions, laboratory experiments, and applications to lava flows, *submitted to the Journal of Geophysical Research*, in prep.

Smith, D.E., M.T. Zuber, H.V. Frey, J.B. Garvin, J.W. Head, D.O. Muhleman, G.H. Pettengill, R.J. Phillips, S.C. Solomon, H.J. Zwally, W.B. Banerdt, and T.C. Duxbury, Topography of the northern hemisphere of Mars from the Mars Orbiter Laser Altimeter, *Science*, *279*, 1682-1692, 1998.

Tanaka, K.L., and D.H. Scott, The youngest channel system on Mars, in *LPSC*, Houston, TX, 1986.

Zuber, M.T., D.E. Smith, S.C. Solomon, D.O. Muhleman, J.W. Head, J.B. Garvin, J.B. Abshire, and J.L. Bufton, The Mars Observer Laser Altimeter investigation, *Journal of Geophysical Research*, *97*, 7781-7797, 1992.

RESULTS

Orcus Patera's shape is well fit by an ellipse with minor and major axes of 107 and 367 km, respectively. The area of the best-fit ellipse is 38,900 km^2, while the plan view area of the best-fit free-form polygon is 33,900 km^2. Depths (d) measured from the rim height to the depression floor range from 1.4 to 2.4 km. Floor topography varies on the order of 100 m and the rim heights vary in elevation by a kilometer. Rim heights (h) extend from 1.0 to 1.8 km above the plains surrounding Orcus Patera, whereas the floor depth is typically 0.4 to 0.6 km below surrounding plains. The cavity floor has complex interior deposits, poorly resolved in Viking images, which are well characterized in new MOLA data. For instance, an S-shaped ridge system with 150 m of relief runs approximately 300 km from the deep northern area of Orcus Patera to the shallower southern area.

The average best-fit curvature (b in the ETF equation) for the slopes of Orcus Patera's truncated asymmetric flanks is –0.30, with an average R^2 fit value of 0.72. The average inner cavity-wall slope (ß) of Orcus Patera is 6.45°. The steepest cavity-wall slope of 9.65° is located on the southern wall of the major axis, while the west wall on the minor axis has the most gradual slope of 4.33°.

Orcus Patera's eccentricity of 0.94 is very similar to the 0.93 eccentricity characteristic of Schiller (Bottke, 2000), but it is different from the eccentricity of 0.87 which characterizes Long Valley caldera in California. Similarly, Orcus Patera has an ellipticity value of 2.97 whereas Schiller's is 2.76 and Long Valley's is 2.0.

DISCUSSION

The difference between the two area values of the best-fit ellipse and best-fit polygon is ~13%, suggesting that the ellipse is a good first order way to evaluate the plan view dimensions of this feature, and thus mathematically describe the shape of Orcus Patera as somewhat elongate. It is important to note that Orcus Patera and Schiller are very similar in shape, but the origin of Schiller is also poorly understood at present. The average flank slope ETF value of –0.30 found for Orcus Patera is only barely within the –0.30 to –2.33 range for ETF exponents that were found for other Martian impact craters. Cavity-wall slopes range from 4.33 to 9.65° and are more gradual than expected for degraded Martian impact craters. The floor of Orcus Patera is relatively flat, though this appears to be the result of post-formation lava flooding; the feature's cross sectional geometry is thus not typical of an impact crater of this size. MOLA color-stretched topographic grids around the depression reveal a shape that *could* be interpreted as the remnants of a butterfly ejecta pattern commonly emplaced by elliptical impact craters. However, taken together, these data provide insufficient grounds for interpreting Orcus Patera as an impact basin.

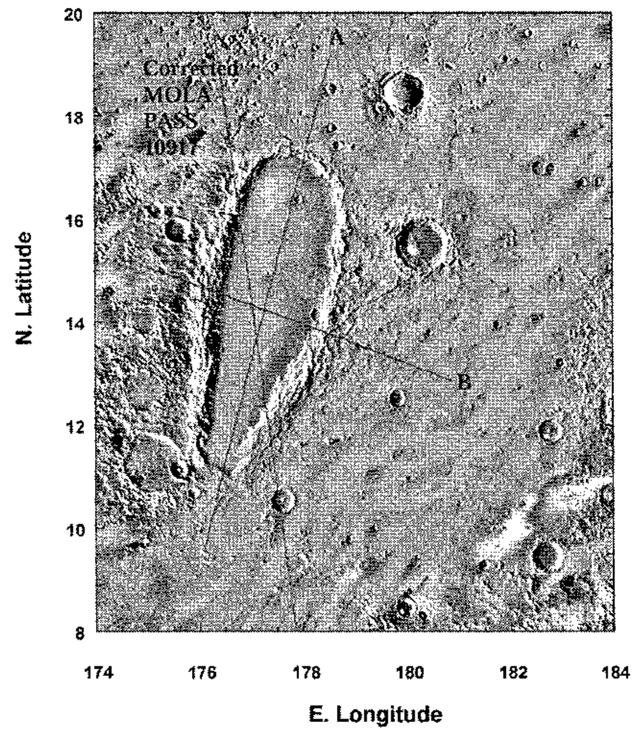

Figure 1. Viking MDIM of Orcus Patera showing a corrected MOLA pass ground track 10917 and the location of major (A) and minor (B) axes.

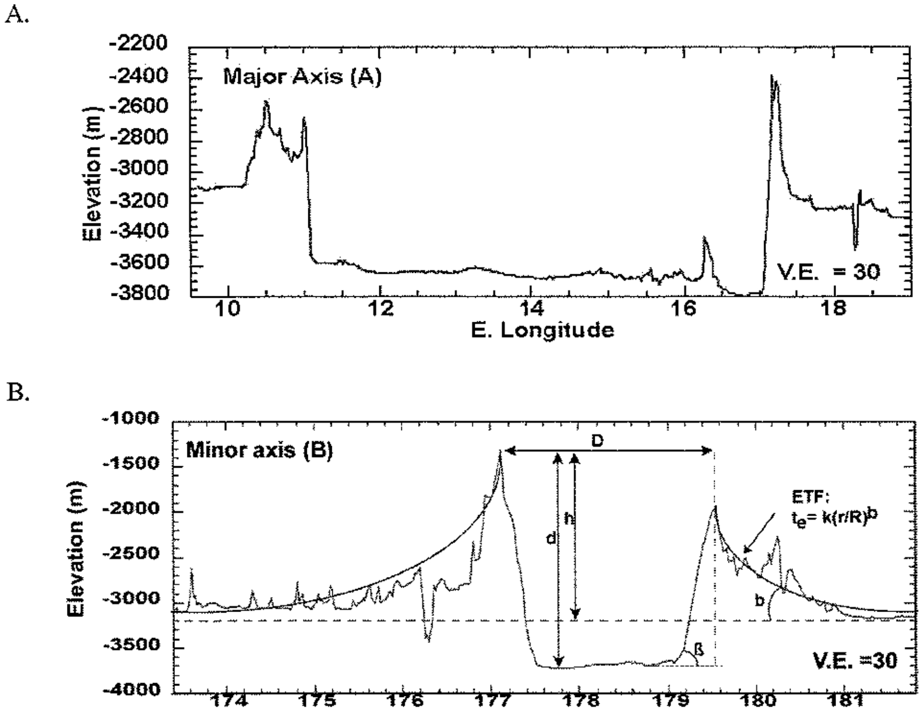

Figure 2. Gridview profiles taken across Orcus Patera along the major and minor axes. Symbols incorporated in B show how floor depth (d), rim height above plains (h), diameter (D), cavity-wall slope (ß), and the curvature slope (b) were determined for all profiles.

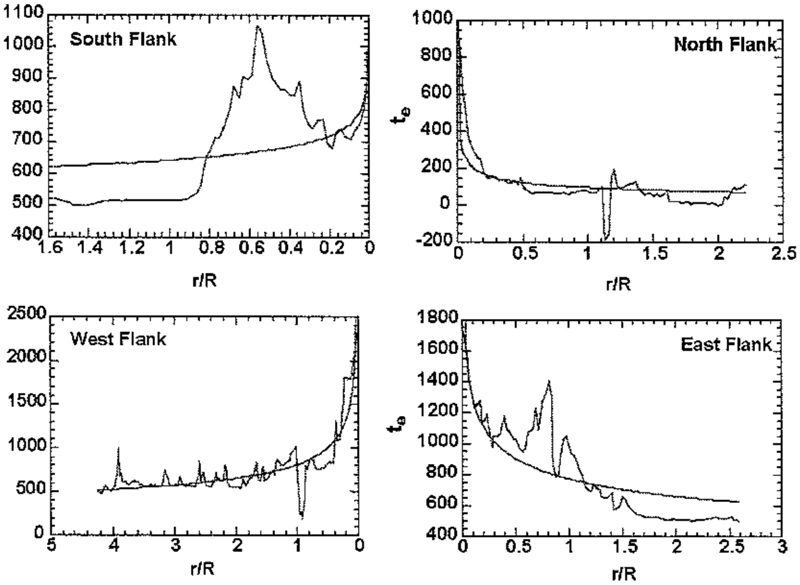

Figure 3. Flank topographic profiles with t_e vs. r/R form the ejecta thickness function (ETF) (Garvin and Frawley, 1998). The t_e values for all graphs are relative to 500 m.

Unfortunately, Orcus Patera's elliptical shape, interior resurfacing, and floor topography also fail to provide enough strong support for a solely volcanic origin. For instance, the plan view shape of the basin is similar to that of Long Valley caldera, one of the largest elongate calderas on Earth. Also, Orcus Patera's S-shaped ridge system resembles a similar feature within the Kilauea Iki Crater in Hawaii, which was produced by a fire fountain or rift spatter eruption. Orcus Patera's depth below the surrounding plains and truncated asymmetric flanks, however, are similar to what is observed for small volcanic edifices in the Tharsis region on Mars, where subsequent deposits have flooded onto the flanks. Finally, if Orcus Patera is volcanic in origin, the difference in absolute age for Orcus Patera's interior and exterior deposits (volcanic infilling in the interior is younger than the surrounding flanks) suggests that the feature had a prolonged volcanic history and multiple episodes of flooding (Yoburn and Yazzie, 2001). Further investigation of relative and absolute ages for smaller distinct units within this region is necessary to identify whether volcanism played a key role in the origin of Orcus Patera or simply modified it subsequent to formation.

CONCLUSION

In summary, new data from MGS allow us to characterize the geometry of Orcus Patera more fully, but even so the observed geometric and stratigraphic relationships and parameters do not clearly support either volcanism or impact as a sole mode of origin. In truth, its geometry is not a good fit to classical forms of either landform type. Clearly, volcanism has occurred within the central depression more recently than the flanks were emplaced, and recent MOLA topography showing the spatter-rampart like central ridge in the depression adds evidence for this. However, it remains to be seen whether Orcus Patera was initially of predominantly volcanic origin, predominantly impact origin, or if it originated through a complex interplay of both that was then altered by the later volcanism.

ACKNOWLEDGEMENTS

We would like to thank KECK Geology Consortium for providing this research opportunity. Thank you to the Keck Foundation, NSF and the MOLA Science team for additional funding support, and Herb Frey and Code 921 of the Geodynamics Branch at NASA Goddard Space Flight Center for hosting the project. We benefited greatly from discussions with Eric Grosfils, Susan Sakimoto, and Carl Mendelson. A special thank you to Jacob Bleacher whom provided technical support. Special thanks to

Martin Wong, Greg Neumann, and Jim Roark for data processing and visualization assistance. Also, this abstract benefited greatly from discussion with our advisors, Brian McAdoo and Phil Armstrong.

REFERENCES

Bottke, B., "Strange Craters Formed by Oblique Impact." 7 July 2000. http://astrosum.tn.cornell.edu/staff/bottke/Oblique_craters/oblique.html

Garvin, J.B., and J.J. Frawley, 1998, Geometric properties of Martian impact craters: preliminary results from the Mars Orbiter Laser Altimeter: Geophysical Research Letters, v.25 , p.4005-4408.

Garvin, J.B., Sakimoto, S.E.H., Fraley, J.J., Schnetzler, C.C., and Wright, H.M., 2000, North polar region craterforms on Mars: Geometric characteristics from the Mars Orbiter Laser Altimeter: Icarus, v. 144, p. 329-352.

Greeley, R., Spudis, P.D., and Womer, M.B., 1978, The patera of Mars; a unique style of volcanism: Trans. American Geophysical Union, v. 59, p. 310.

Jöns, H.P., 1984, Orcus Patera and its surrounding; a squeezed zone between two mega-aureoles? Lunar Planetary and Science Conference XV, p. 415-416.

Roark, J., Frey, H., and Sakimoto, S.E.H., 2000, Interactive graphics tools for analysis of MOLA and other data, Lunar Planetary and Science Conference XXXI, abstr. 2026.

Trego, K.D., 1985, Implied origin for the craters Orcus Patera and Schiller from the lunar channel Bouvard: *Earth, Moon, Planets*, v.33, p. 99-102.

Yoburn, J., 2001 and R. Yazzie, 2001, Age relationships and chronology for the Orcus Patera region of Mars. Keck Geology Consortium, this volume.