61045H

Mars Global Surveyor Data Analysis Program

Origins of Small Volcanic Cones: Eruption Mechanisms and Implications for Water on Mars

NAG5-11199

Summary of Research

08/15/01–08/14/02

Principal Investigator: Sarah A. Fagents*

Department of Geological Sciences
Box 871404
Arizona State University
Tempe, AZ 85287-1404

Collaborators:
Ronald Greeley, Arizona State University
Thorvaldur Thordarson, University of Hawaii

*Now at:
Hawaii Institute of Geophysics and Planetology
School of Ocean and Earth Sciences and Technology
University of Hawaii at Manoa
2525 Correa Road
Honolulu, HI 96822
T: (808) 956 3163
F: (808) 956 6322
fagents@hawaii.edu

NOTE: SPECIAL CIRCUMSTANCES OF THIS REPORT: RELOCATION OF PI TO UNIVERSITY OF HAWAII

The project giving rise to this report was selected for 3 years of funding by the *Mars Global Surveyor Data Analysis Program* in 2001. The work reported on here, is the result of the first year of the grant, which was awarded to Arizona State University, the PI's institution at that time. In summer 2002, the PI relocated to the University of Hawaii, where she now holds a full-time tenure-track faculty position.

Following the advised NASA procedure, the work proposed for years 2 and 3 was resubmitted to the Mars Data Analysis Program in August 2002 to effect a transfer of the grant to the University of Hawaii for the remaining 2-year period of performance. In addition, Arizona State University sent notice to the NASA-Goddard Grants Officer stating that it relinquished any interest in years 2 and 3 of MGSDAP grant NAG5-1119.

Accordingly, this Summary of Research reports on the work completed by the expiration date of the grant at Arizona State University (i.e. after one year, from 08/15/01 to 08/14/02).

INTRODUCTION

The goal of the proposed work was to determine the origins of small volcanic cones observed in *Mars Global Surveyor* (MGS) data, and their implications for regolith ice stores and magma volatile contents.

High resolution images of the northern hemisphere of Mars reveal numerous small conical constructs located within the lowland plains. Application of geologic criteria designed to elucidate their origins suggests that many of these features are volcanic in origin. Two mechanisms of formation require consideration: (i) lava flows explosively vaporizing water/ice within the substrate, repeatedly excavating the lava to construct a rootless volcanic cone (or "pseudocrater"); (ii) low-viscosity volatile-bearing magmas ascending from a magma body at depth in the crust, producing weakly explosive strombolian or lava-fountaining activity, and constructing a "rooted" cone over a primary vent.

For this 1-year study, our approach involved a combination of:

- ❖ Quantitative morphologic analysis and interpretation of *Mars Orbiter Camera* (MOC) and *Mars Orbiter Laser Altimeter* (MOLA) data.
- ❖ Numerical modeling of eruption processes responsible for producing the observed features.
- ❖ Fieldwork on terrestrial analogs in Iceland.

Following this approach, this study succeeded in furthering our understanding of (i) the spatial and temporal distribution of near-surface water ice, as defined by the distribution and sizes of rootless volcanic cones ("pseudocraters"), and (ii) the properties, eruption conditions, and volatile contents of magmas producing primary vent cones.

The work plan for year 1 called for the initiation of MOC data analysis, numerical modeling and fieldwork. Here we report the achievements in all these areas, and summarize the conclusions reached at the end of this 1-year study.

DATA ANALYSIS

The data analysis task focused primarily on extending the search of the MOC data to identify volcanic cones. As of August 2002, all released narrow-angle (NA) MOC images were scrutinized for the following (primarily northern lowland plains) areas: 0-45°N, 90–285°W; 0–15°S, 105–145°W (Tharsis– Amazonis–Elysium–Isidis); 30–60°N, 0–45°W (Acidalia); 30–45°S, 225–240°W (Arrhenius). These areas cover not only the locations of putative rootless volcanic cones identified on the basis of Viking data [*Frey et al.*, 1979; *Frey and Jarosewich*, 1982; *Hodges and Moore*, 1994], but also the flanks of major shield volcanoes, where one might expect, by analogy with terrestrial shield volcanism, rooted parasitic cones to form.

For Amazonis, Acidalia, and Isidis Planitiae (areas having well-preserved or numerous cones), all NA images containing cones were identified and processed in preparation for morphometric analysis. The images were reprojected and mosaicked into the wide-angle context images using the USGS ISIS software [http://wwwflag.wr.usgs.gov/isis-bin/isis.cgi]. Simultaneously-acquired MOLA tracks were also laid over the image data. In some instances, MOLA footprints fall fortuitously on the summits and surroundings of these very small (30 m to <1 km diameter) features, which provide lower limits on their heights.

In addition to cone height, other measurements made on the cones include basal diameter and crater diameter. We then constructed plots of cone size distributions and ratio of crater/cone diameters for the different regions under study [*Greeley and Fagents*, 2001; *Fagents et al.*, 2002a,b].

We find that the cones in Amazonis Planitia are the smallest (30–180 m) and most pristine of the areas studied so far. Having applied criteria designed to assess their origin, we have confidence that these are indeed rootless cones [*Greeley and Fagents*, 2001; *Lanagan et al.*, 2001; *Fagents et al.*, 2002a,b].

Other cones are less pristine and do not lie on obvious lava surfaces. In these cases, the origins are ambiguous. While they could plausibly be pseudocraters, another possibility is that they are "rooted" cones constructed over conduits from magma bodies deeper in the crust, with possible magma–water interactions during conduit ascent. Cones in Isidis Planitia have basal diameters of ~160–1000 m [*Fagents et al.*, 2002a,b].

From our morphologic studies, we note that the martian cones have relatively large ratios of crater diameter to cone diameter [*Greeley and Fagents*, 2001; *Fagents et al.*, 2002a,b]. Based on comparison with terrestrial cones, large crater/cone ratios are interpreted to represent vigorous explosivity.

However, our knowledge of Mars' low-gravity and low-atmospheric pressure environment requires caution in drawing conclusions for the amount of external water involved based on morphologic comparisons alone. In order to assess the influence of these factors on the amount of water required to produce the observed features, requires theoretical modeling of the explosion process (see below).

FIELDWORK

Fieldwork was conducted at five localities hosting rootless volcanic cones in Iceland: Myvatn in north Iceland, Raudholar in southwest Iceland, Thjorsardalur in central Iceland, and Alftaver and Landbrot on the south coast. In each case, lava flows entered environments with abundant water, allowing for the formation of extensive rootless cone fields.

At each locality cone morphology and pyroclast characteristics were noted. Cones range in diameter from just a few meters to >300, with 20–100 m being typical. There was a large degree of variability in cone morphology both between and within each cone field. However, the following general relationship was noted: large, broad-cratered cones tend to be comprised of small (<1 cm), blocky scoriaceous clasts, whereas steeper cones having small crater/cone ratios tended to consist of large (~10 cm), irregularly-shaped, fluidal spatter [*Fagents et al.*, 2002a,b].

Based on these observations, we infer that there is a greater degree of lava–water interaction (and more energetic explosions) forming the former broad-cratered cones, and very little external water involved in barely fragmenting the lava to form the latter, spatter-rich cones.

In order to place some quantitative constraints on these observations, we turn to numerical modeling of the explosion process.

MODELING

During the 1-year duration of the study (at ASU) we focused on modeling the explosion process of rootless volcanic cones. Subsequent years (i.e., continuation of the project at UH) will include modeling of primary vent eruptive processes.

We infer the explosion process leading to the formation of rootless volcanic cones to be the result of a number of stages [*Greeley and Fagents*, 2001; *Fagents et al.*, 2002a,b]:

- Initial emplacement of lava and heating of substrate.
- Vaporization of water/ice in the substrate, and accumulation of pressurized gas.
- A minimum threshold pressure is exceeded (defined as the sum of the pressure due to the weight of overlying lava, the tensile strength of solid lava, the yield strength of liquid lava, and the external atmospheric pressure), and the explosion is initiated.
- The gas expands out of the explosion site, excavating the lava and displacing a mass of atmospheric gas above the explosion site.
- Fragmented lava clasts follow trajectories through the moving gas flow-field and accumulate around the explosion site.

- Continued flow of lava from the molten core fills the cavity, and repeated cycles of vaporization, pressurization, and excavation build the cone.

We model this process by integrating the equation of motion of the slug of expanding gas, excavated lava, and displaced atmosphere for given initial conditions of vapor pressure, vapor amount, and lava overburden. This yields the ejection velocity of lava fragments, and subsequent computation of their trajectories allows their landing positions to be determined [*Greeley and Fagents*, 2001]. Synthesis of trajectories for different clast sizes and ejection angles permits determination of the size of the cone produced.

Comparison of the modeling results with features observed in the field or in MOC data allows us to determine the conditions leading to their formation. Specifically, we are able to determine the amount of water required in explosions producing cones of the sizes observed in the data.

For typical Icelandic rootless cones (~20 m in diameter), repeated explosions involving 14–3000 kg water are required to produce the observed features. This is entirely consistent with the water-rich environments (stream sediments, lake basins, glacial outwash plains) in which the lavas were emplaced.

For the Amazonis cones, 2–1000 kg of water vapor are required to produce the observed features. This is significantly less than is required for the Icelandic cones (despite the *larger* martian cone sizes), which emphasizes the necessity of accounting for the influence of atmospheric pressure and gravity on eruptive processes. The larger Isidis cones require approximately an order of magnitude more, and are probably the result of more vigorous lava–water interactions.

SUMMARY AND CONCLUSIONS

1. Most cones identified in the image data occur in lowland plains, and have characteristics suggestive of a rootless origin (though fields of monogenetic cones cannot always be ruled out for less pristine examples).

2. Rooted (parasitic) cones on the major martian shields appear to be rare. If this is not simply a limitation of the MOC coverage, this might indicate that magmatic eruptions at these edifices are volatile-poor, and significant magma fragmentation does not occur.

3. Martian cones tend to have large crater/cone diameter ratios (in comparison to terrestrial cones). However, the model predicts only modest amounts of water vapor are required to produce the observed features. The influence of atmospheric pressure and gravity are key factors in determining the explosivity of a rootless event, and hence the size and morphology of the resulting cone.

4. We conclude that for the subkilometer materian cones identified in this study, the predicted amounts of water required to produce rootless explosions are consistent with water present as ice within a porous regolith.

5. The very youthful surfaces on which some martian rootless cones are located [e.g., Amazonis; Hartmann et al., 1999; 2000] indicates than conditions were favorable for the retention of shallow ground ice within the last 10 Ma, suggesting the possibility of present-day regolith ice stores at mid to low latitudes.

6. The results of the survey of the MGS data, morphometric analysis, terrestrial analog studies, and modeling of the pseudocrater explosion process for cones in Amazonis and Isidis Planitiae, was presented at the Lunar and Planetary Science Conference in 2002 [*Fagents et al.*, 2000b]. This study forms the basis of a chapter in the forthcoming Geological Society of London Special Publication on *Lava–Ice Interactions on Earth and Mars* [*Fagents et al.*, 2002a]. Finally, a manuscript focusing on comparison of martian and Icelandic features is in preparation for a new book on Mars geology [*Fagents et al.*, in prep.].

7. In the event of a successful transfer of funding to UH, this study will be extended to complete the survey of MOC data and make further morphologic measurements. Further field data will be acquired for rootless cones in Iceland and cinder cones in Hawaii. New numerical models will be developed to investigate the processes of heating and vaporization of ground water/ice by the advancing lava, as well as the controls on and consequences of magmatic eruptions under martian environmental conditions. Thus, we aim to understand the origins of martian volcanic cones, and their implications for Mars' magmatic and climatic evolution.

REFERENCES

Fagents, S.A., P. Lanagan, and R. Greeley. Rootless cones on Mars: A consequence of lava–ground ice interaction. *Lava–Ice Interactions on Earth and Mars, Geol. Soc. Lond. Spec. Pub.*, in press, 2002a.

Fagents, S.A., K. Pace, and R. Greeley. Origins of small volcanic cones on Mars (abstract), *Lunar Planet Sci. Conf. XXXII,* #1594, 2002b.

Fagents, S.A., Th. Thordarson, and H.V. Frey. Rootless cones in Iceland and on Mars. *In prep. for "The Geology of Mars: Evidence from Earth-based Analogues"*, M. Chapman and I. Skilling (eds.), Cambridge University Press.

Frey, H., B.L. Lowry, and S.A. Chase, Pseudocraters on Mars, *J. Geophys. Res.*, *84*, 8075-8068, 1979.

Frey, H., and M. Jarosewich, Subkilometer martian volcanoes: Properties and possible terrestrial analogs, *J. Geophys. Res.*, *87*, 9867-9879, 1982.

Greeley, R., and S.A. Fagents, Icelandic pseudocraters as analogs to some volcanic cones on Mars, *J. Geophys. Res.*, *106,* 20,527-20,546, 2001.

Hartmann, W.K., and D.C. Berman, Elysium Planitia lava flows; crater count chronology and geological implications, *J. Geophys. Res.*, *105*, 15,011-15,025, 2000.

Hartmann, W.K., M.C. Malin, A.S. McEwen, M.H. Carr, L.A. Soderblom, P.C. Thomas, E. Danielson, P.B. James, and J. Veverka, Evidence for recent volcanism on Mars from crater counts, *Nature*, *397*, 586-589, 1999.

Hodges, C.A., and H.J. Moore, *Atlas of Volcanic Landforms on Mars*, 194 pp., 1994.