VOLCANISM IN THE CRATERED TERRAIN HEMISPHERE OF MARS

Ronald Greeley and Paul D. Spudis

Department of Geology and Center for Meteorite Studies, Arizona State University
Tempe, Arizona 85281

Abstract. Viking Orbiter photography has revealed the importance of volcanism in the geologic evolution of the cratered terrain hemisphere (generally in the southern hemisphere) of Mars. Volcanic units in this region are classified morphologically into four major units: 1) Patera, comprising 2.37 x 10^5 km^2 (0.3% of the cratered terrain hemisphere), are large, low profile volcanic structures; some appear to be older shield volcanoes, others apparently represent a unique style of volcanism; 2) "Plains" volcanics occupy 2.3 x 10^6 km^2 (2.9% of hemisphere) and represent low volume eruptions that formed cones, low shields and other small scale structures; 3) flood volcanics (3.7 x 10^6 km^2; 4.7% of hemisphere) are produced by high volume eruptions, post-date the older and more degraded plateau plains, and occur mostly as basin-fill materials; and 4) Plateau plains (28.5 x 10^6 km^2; 36% of hemisphere), the martian intercrater plains, contain many wrinkle ridges and floor-fractured craters. The results of this study suggest volcanic processes, as well as erosional processes have been important in the obliteration of small (less than 10km) craters on Mars and that volcanic products may constitute a significant fraction (up to 44%) of the surface rocks in the cratered terrain.

Introduction

Viking Orbiter systematic mapping has given new insight into the geologic evolution of the southern hemisphere of Mars. Although coverage is incomplete and of non-uniform quality, preliminary mapping has been completed for large parts of Mars. Mariner 9 results showed that most of the southern hemisphere of Mars is heavily cratered (termed the *cratered terrain hemisphere,* which makes up 55 percent of the martian surface), whereas much of the northern hemisphere has been extensively modified and resurfaced (*Mutch et al.,* 1976 and references therein); moreover, most large martian craters have been extensively modified and the heavily cratered terrain seen on the Moon has no equivalent on Mars (*Murray et al.,* 1971; *Wilhelms,* 1974). *Wilhelms* (1974) suggested that extensive volcanism modified much of the ancient cratered terrain of Mars, producing smooth intercrater plains. Preliminary mapping of Viking images support this conclusion and provide details on the styles of volcanism that modified the cratered terrain.

Volcanic Units of the Cratered Terrain Hemisphere

The volcanic units of the cratered terrain hemisphere may be classified into four main morphologic types (Table 1).

Patera Volcanic Units

The *patera,* of which Tyrrhena, Hadriaca, and Amphitrites are most prominent, occupy approximately 0.3 percent (237,000 km^2) of the cratered terrain hemisphere. The various patera have been classified by morphology into four groups (*Greeley et al.,* 1978). Class I patera (similar to Tharsis-type shields) are rare in the cratered terrain, represented only by Apollinaris Patera, situated on the margin of the cratered terrain hemisphere. Class II patera, such as Tyrrhena Patera (Fig. 1), are characterized by deeply incised channels that are radial to their central caldera. The radial channels may be either erosional or primary structures. Class III patera are modified impact craters (not volcanic) and have not been identified in the cratered terrain hemisphere. Class IV patera are very low profile distinctive volcanic structures typified by Alba Patera in the northern hemisphere. Amphitrites Patera south of Hellas may fit into this class of structure. These constructs all lie stratigraphically above the martian intercrater plains (cratered plateau of *Scott and Carr,* 1978).

TABLE 1. Volcanic units of the cratered terrain hemisphere of Mars

Unit	Area (km^2)	Area (% hemisphere)	Description
Patera	2.37 x 10^5	0.3%	Large, low profile volcanoes; older shields and other unique types
"Plains" volcanics	2.3 x 10^6	2.9%	Volcanic regions with lava channels, cinder cones, low shields; low volume eruptions
"Flood" volcanics	3.7 x 10^6	4.7%	Basin fill lavas; flow fronts fronts and wrinkle ridges; high volume eruptions; post-date heavy bombardment
Plateau plains	2.85 x 10^7	36.0%	Inter-crater plains; wrinkle ridges, floor-fractured craters; oldest volcanic unit on Mars

"Plains" Volcanic Units

"Plains" volcanics are characterized by the presence of lava tubes, lava channels, cones, domes, low shields, and leveed flows and are thought to represent low volume, "Hawaiian-type" eruptions (*Greeley,* 1976). These volcanics comprise approximately 2.9 percent (2.3 x 10^6 km^2) of the cratered terrain hemisphere, being most prominent around the margins of the Hellas basin. Numerous small cones and low shields occur in the vicinity of Amphitrites Patera and their relatively fresh state of preservation indicates they must have developed much later than the highly degraded patera. Detailed mapping of a "plains" area east of Hellas (Fig. 2) suggests at least some of these cones and low shields may be contemporaneous with smooth plains layered deposits and that the layered plains

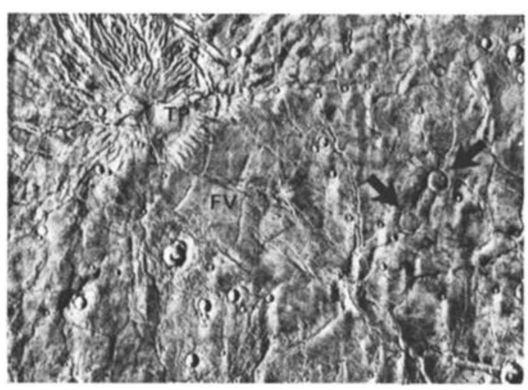

Fig. 1. Hesperia Planum showing location of the type II patera, Tyhenna Patera (TP). The volcano is surrounded and embayed by flood volcanics (FV) which display typical wrinkle ridge morphology in this region. Arrows locate unusual ridge-ring structures, probably produced by the settling of deep, ponded flood lava over buried crater rims. North toward top; mosaic is 500 by 575 km (portion of Viking Orbiter mosaic 211-5213).

Paper number 8L0495.
0094-8276/78/068L-0495$01.00

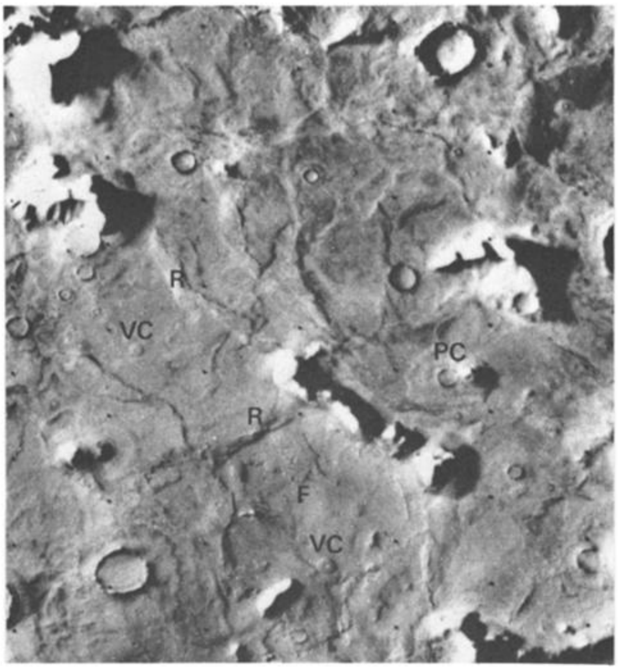

Fig. 2. Area of "plains" volcanism near east margin of Hellas basin. Numerous wrinkle ridges (R), flow scarps (F) and volcanic cones (VC) are visible. Note distinctive morphology of volcanic cones (convex profiles, rimless summit pits) in contrast to that of impact produced pedestal craters (PC; flat, mesa-like profile, raised rim crater). North toward bottom; picture is 190 by 230 km (Viking Orbiter frame 97A59).

are composed of a succession of individual lava flows. The close association of many of these "plains" volcanics with the larger patera attest to a prolonged volcanic evolution for these regions. A small structure interpreted as a possible dissected composite cone (Fig. 3) has recently been found and may be representative of others in regions for which only poor photographic coverage exists.

Flood-type Volcanic Units

Large parts of the plains in the cratered terrain hemisphere are characterized mostly by flow scarps and wrinkle ridges, typical of *flood-type volcanism.* These units are most extensive as basin fill materials that postdate early heavy bombardment and the more extensive intercrater plains, but may also occur in elevated areas (e.g., Hesperia Planum) in association with older volcanic patera (Fig. 1). These flood-lavas comprise about 4.7 percent (3.7×10^6 km^2) of the cratered terrain hemisphere. Although wrinkle ridges and flow fronts are abundant in this unit, aeolian cover

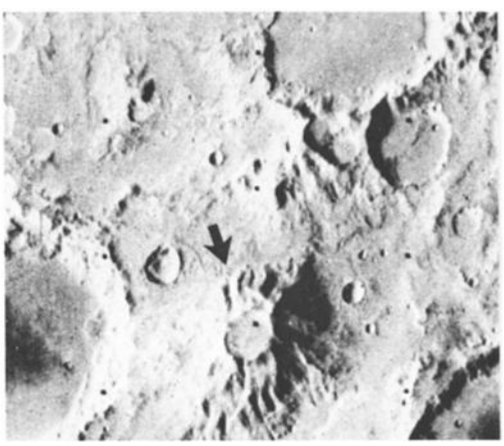

Fig. 3. Isolated possible composite cone (arrow) in Aeolis region. North toward bottom; picture is 73 by 115 km (Viking Orbiter frame 88A65).

Fig. 4. Lava flow scarp (arrows) in plateau plains unit near west rim of Hellas basin. Typical morphology of the plateau plains includes numerous wrinkle ridges (R). North toward bottom; picture is 150 by 170 km (Viking Orbiter frame 95A10).

frequently masks primary volcanic surface morphologies, particularly in active aeolian regimes such as the floor of the Hellas basin. Because of this mantling, the full areal extent of the flood lavas is uncertain and may be gradational with the plateau plains.

Plateau Plains Units

The *plateau plains* (cratered plateau of *Scott and Carr,* 1978) comprise almost 36 percent (28.5×10^6 km^2) of the cratered terrain hemisphere and about 20 percent (28.8×10^6 km^2) of the entire sufrace of Mars. It was observed from Mariner 9 that the densely cratered terrain of the lunar highlands has no equivalent on Mars and it was suggested the smooth intercrater plains that occur over much of the cratered terrain hemisphere were volcanic (*Wilhelms,* 1974). Although the coverage is limited in areal extent, Viking photography available for this unit supports this conclusion.

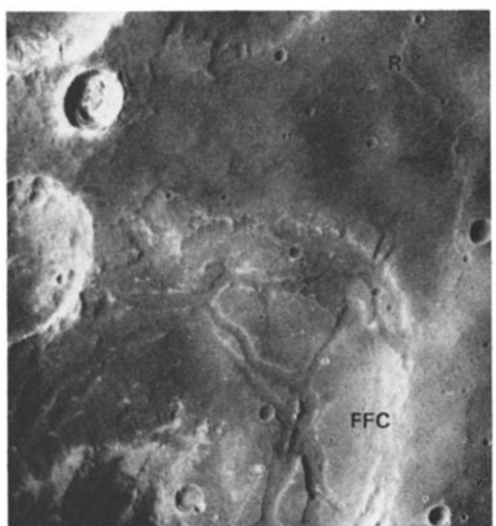

Fig. 5. Martian floor-fractured crater (FFC) within plateau plains unit in the Oxia Palus region. Typical morphology of plateau plains is displayed by wrinkle ridges (R). North toward top; picture is 72 by 72 km (Viking Orbiter frame 206A02).

Wrinkle ridges are common and flow scarps of probable volcanic origin are present but are less abundant (Fig. 4). Many of the plateau plains are closely associated with volcanic centers of the southern hemisphere. In the Amphitrites Patera region the plateau plains appear to comprise the basal stratigraphic unit of the volcanic center. This unit is distinguished morphologically from the cratered terrain (hilly and cratered materials of *Scott and Carr,* 1978) which frequently displays fine-scale channeling usually absent on the plateau plains unit.

Volcanic processes that modify the floors of impact craters on the Moon have been described in detail by *Schultz* (1976). Martian craters of similar morphology were identified and mapped using Mariner 9 images (*Schultz,* 1977); additional craters have been discovered on Viking images (Fig. 5). These craters correspond well with the distribution of the plateau plains unit, which, with surface morphology, argues strongly for a volcanic origin for the plains at least in the areas where adequate photographic coverage exists. However, the plateau plains may have a variety of origins and the volcanic interpretation of this unit is the least certain of those described. The widespread occurrence and stratigraphic relations of the plateau plains suggest extensive volcanism, possibly contemporaneous with the end of the period of early, heavy bombardment (*Soderblom et al.,* 1974). Results from crater studies (summarized in *Chapman and Jones,* 1977) show an episode of extensive crater obliteration and although other photogeologic evidence (e.g., small-scale channeling in cratered terrains) suggests earlier intensive erosion on Mars, the eruption of the plateau plains volcanics may have been important in the obliteration of small (less than 10km) craters in the cratered terrain hemisphere.

Conclusions

Viking mapping shows that the cratered terrain hemisphere of Mars has been extensively modified by volcanic processes. The earliest discernible episodes of volcanic modification involved emplacement of the plateau plains unit, possibly coincident with episodes of planetwide crater obliteration (see *Chapman and Jones,* 1977, and references therein). This early volcanism was pervasive (*Wilhelms,* 1974) and extensively modified the ancient primordial crust. Flood volcanism, possibly accompanied by shield building episodes (e.g., patera) followed, was less extensive than earlier plateau plains volcanism and was important primarily during major basin filling. Flood-type flows are roughly correlative with the "cratered plains" units of Lunae Planum (*Milton,* 1975). Although the patera display a wide range of ages, most appear to be contemporaneous with late state plateau plains and early flood volcanism. "Plains" style volcanism is the youngest recognized episode of volcanism in the cratered terrain hemisphere; "plains" volcanic centers are isolated, low volume units and confined to areas of previous volcanic activity. All volcanic units have been subjected to subsequent aeolian erosion.

Acknowledgements. This work supported by NASA contract 954837 through the Jet Propulsion Laboratory. Thanks are due to R.S. Saunders and an anonymous reviewer for helpful criticisms of an earlier version of this paper. This paper constitutes Contribution No. 14 of the Basaltic Volcanism Study Project, which is organized and administered by the Lunar and Planetary Institute/Universities Space Research Association under Contract NSR 09-051-001 with the National Aeronautics and Space Administration.

References

Chapman, C.R., and K.L. Jones, Cratering and obliteration history of Mars, *Ann. Rev. Earth Planet. Sci., 5,* 515-560, 1977.

Greeley, R., Modes of emplacement of basalt terrains and an analysis of mare volcanism in the Orientale basin, Proc. 7th Lunar Sci. Conf., *Geochim. Cosmochim. Acta, Suppl. 7, 3,* 2747-2759, 1976.

Greeley, R., P.D. Spudis, and M.B. Womer, The patera of Mars – a unique style of planetary volcanism, *EOS Trans. Amer. Geophys. Union, 59,* 310 p., 1978.

Milton, D.J., Geologic map of the Lunae Planum Quadrangle of Mars, *U.S. Geol. Surv. Misc. Geol. Inv.,* Map I-894, 1975.

Murray, B.C., L.A. Soderblom, R.P. Sharp, and J.A. Cutts, The surface of Mars, 1, Cratered terrains, *J. Geophys. Res., 76,* 313-330, 1971.

Mutch, T.A., R.A. Arvidson, K.L. Jones, J.W. Head, and R.S. Saunders, *The Geology of Mars,* Princeton Press, 1976.

Schultz, P.H., Floor-fractured lunar craters, *The Moon, 15,* 241-273, 1976.

Schultz, P.H., Lunar and martian floor-fractured craters (abstract), *Basaltic Volcanism Study Project, Contr. 7,* The Lunar Science Institute, Houston, Texas, 53-55, 1977.

Scott, D.H., and M.H. Carr, Geologic map of Mars, *U.S. Geol. Survey Misc. Geol. Inv. Map,* (in press), 1978.

Soderblom, L.A., C.D. Condit, R.A. West, B.M. Herman, and T.J. Kreidler, Martian planetwide crater distributions: Implications for geologic history and surface processes, *Icarus, 22,* 239-263, 1974.

Wilhelms, D.E. Comparison of martian and lunar geologic provinces, *J. Geophys. Res., 79,* 3933-3941, 1974.

(Received February 22, 1978;
revised April 12, 1978;
accepted April 21, 1978.)