MARTIAN VOLCANISM: A REVIEW.

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Volcanic activity was widespread on Mars when the geologic record emerged around 3.8 Ga ago but became progressively more restricted with time such that the most recent activity has been largely confined to the large Tharsis shields (Scott and Carr, 1978). Two man types of activity are recognized: formation of lava plains, presumably as result of fissure eruptions, and accumulation around central vents to form roughly circular volcanoes. Both types appear to have been dominated by effusion of low viscosity lava that has formed a variety of landforms such as lobate flow fronts, leveed channels and sinuous rilles, that are familiar from terrestrial, and lunar basaltic terranes.

Lava plains probably constitute the bulk of the volcanic products. Three main types can be recognized (Carr, 1981; Greeley and Spudis, 1981). (1) On flow plains individual flows can be readily identified, and ridges like those on the lunar maria are generally absent. Flow plains are common in central Tharsis, central Elysium, around Alba Patera, in Solis Planum and Syria Planum and on the south of Hellas. The size of the flows suggests that effusion rates were extremely high compared with typical terrestrial rates. (2) On ridged plains flows are rarely observed but ridges similar to those on the lunar maria are common. Ridged plains are found mainly in Chryse Planitia, Lunar Planum, eastern Syria Planum, and Hesperia Planum, and small areas occur locally throughout the cratered uplands. The plains are presumed to be volcanic largely on the basis of their resemblance to lunar maria. Most ridged plains are older than the flow plains. (3) Pitted plains are present in some areas, particularly in Isidis Planitia. These are characterized by lines of small <1 km diam.) cones, that may merge to form ridges with slotted central vents (Frey and Jarosewich, 1982). The ridges resemble spatter ramparts, such as occur along the Hawaiian rift zones. Not all plains fall into these three types. Extensive areas of plains have a variety of characteristics that are difficult to reconcile with a simple volcanic origin. Many of their features have been attributed presence of ground ice or the result of interaction of volcanics with ground ice (Carr and Schaber, 1977; Lucchitta, 1981; Allen, 1979). These plains, in which the volcanic component is unclear, include Amazonis Planitia, the peripheral regions of Elysium Planitia, and most of the plains in the high northern latitudes.

The central-type volcanoes provide the most obvious manifestations of martian volcanism. Several types are recognized (Greeley and Spudis, 1981). (1) Shield volcanoes typically have large summit calderas and gently sloping flanks on which are numerous long linear flows. The three large shields of central Tharsis appear to have gone through a similar growth cycle - the building of a radially symmetric shield to a height of about 25 km above the Mars datum was followed by eruptions from the NE and SW flanks which caused embayments in the shields, buried their lower flanks, and covered extensive areas of the surrounding plains. Growth of Olympus Mons was more symmetric. The lithosphere appears to have deformed under the weight of the large shields. Estimates of the thickness of the elastic lithosphere from its flexure range from 20 km under Arsia and Ascreaus Mons to 150 km under Olympus Mons (Comer et al., 1985). All the large Tharsis shields have terraced flanks, possibly the result of thrusting caused by compression of the edifice.

as the lithosphere flexes under the volcano load (Morris, personal comm.). Large central calderas suggest the volcanoes incorporate or overlie magma chambers that are large compared with those under terrestrial shield volcanoes (Wood, 1984). Several small shield volcanoes in Tharsis and Elysium are partly buried by lavas that form the surrounding plains. (2) Domes or Tholi generally have smaller diameters and steeper slopes than the shield volcanoes. The group also includes some small shields, but includes some volcanoes that are distinctively different from shields. Hecates Tholus and Ceraunius Tholus have densely pitted flanks with numerous roughly radial channels. The summit of Hecates Tholus is muted as though blanketed with debris. All these features have been ascribed to pyroclastic activity (Reimers and Komar, 1979; Mouginis-Mark et al., 1979; Greeley and Spudis, 1981). Whether the explosive activity is the result of a distinctive composition of the lavas or interaction of basaltic lava with groundwater is unclear. (3) Patera is a term applied to volcanoes with very little vertical relief, but the various paterae have little in common other than low relief. The largest patera, Alba Patera, is over 1500 km across and has flanks that slope less than 1°. From the features on its flanks it appears to have been built almost entirely of low viscosity lava. In contrast, Tyrrhenna Patera appears to be surrounded by deeply eroded horizontal sheets of debris, as though formed mainly by ash flows.

Comparison of the martian volcanic features with those of the Earth and the Moon suggests that the volcanism has been dominantly basaltic. Such a composition is consistent with the available spectroscopic data (Singer et al., 1979;), and interpretation of analyses of debris from the Viking landing sites (Toulmin et al., 1977). The SNC meteorites suggest that the martian mantle is more iron rich than the Earth's and richer in moderately volatile elements such as Na, K, and Rb (Dreibus and Wanke, 1983). Modeling of planetary accretion also suggests that the Mars mantle is more iron-rich than the Earth's (Lewis, 1972, 1974; Ringwood and Clark, 1971). These models of composition of the Mars mantle are consistent with a mantle density of 3.44 gm cm^{-2} estimated from the planet's mean density and moment of inertia factor (Goettel, 1983). The intercumulus melts from Shergotty liquid yield liquids with viscosities around 200 poise as compared with values of 400-1000 poise typical of terrestrial basalts (McSween, 1985). Thus the properties of the lavas inferred from surface morphology, surface reflectivity, SNC meteorites and the bulk planet properties are all consistent.

REFERENCES

Allen, C. C., J. Geophys. Res., 84,, 8048-8059, 1979; Carr, M. H., The Surface of Mars, Yale University Press, 1981; Carr, M. H., and Schaber, G. G., J. Geophys. Res., 82, 4039-4065, 1977; Comer, R. P., Solomon, S. P., and Head, J. W., Rev. Geophys., 28, 61-92, 1980; Dreibus, G., and Wanke, H., Proc. 27th Int. Geol. Congr., Moscow, 11, 1-11, 1984; Frey, H., and Jarosewich, M., J. Geophys. Res., 87, 9867-9879, 1882; Goettel, K. A., Carnegie Inst. Year Book, 82, 363-366, 1983; Greeley, R., and Spudis, P., Rev. Geophys. Space Phys., 19, 13-41, 1981; Lewis, J. S., Earth and Planet. Sci. Lett., 15, 286-290, 1972; Lucchitta, B. K., Icarus, 45, 264-303, 1981; McSween, H. Y., Lunar and Planet. Sci. XVI, 546-547, 1985; Mouginis-Mark, P. J., Wilson, L., and Head, J. W., J. Geophys. Res., 87, 9890-9904, 1982; Reimers, C. E., and Komar, P. D., Icarus, 39, 88-110, 1979; Ringwood, A. E., and Clark, S. P., Nature, 234, 89-92, 1971; Scott, D. H., and Carr, M. H., U. S. Geological Survey, Misc. Inv. Map I-1083, 1978; Singer, R. B., McCord, T. B., Clark, R. N., Adams, J. B., and Huguenin, R. L., J. Geophys. Res., 84, 1979; Toulmin, P., Baird, A. K., Clark, B. C., Keil, K., Rose, H. J., Christian, R. P., Evens, P. H., and Kelliher, W. C., J. Geophys. Res., 82, 4625-4634, 1977; Wood, C. A., J. Geophys. Res., 89, 8391-8406, 1984.