MARS: VOLCANIC ERUPTION THEORY AND RELATIONSHIPS TO OBSERVED LANDFORMS: Lionel Wilson[1,2] and James W. Head[2], [1]Environmental Science Division, Lancaster Univ., Lancaster LA1 4YQ, UK, [2]Department of Geol. Sci., Brown Univ., Providence, RI USA.

Analysis of the images returned from the Mariner and Viking missions has produced abundant evidence for a variety of volcanic landforms on Mars (1). One approach to understanding the styles of martian volcanic activity represented by these landforms has been to compare the morphologies of martian volcanic structures with those of terrestrial analogs. While useful, this method may overlook potentially dramatic effects of differences between the terrestrial and martian environments on eruptive processes (2). As a result, we have concentrated on a different approach, that of initially considering the processes of ascent and eruption of magma on Mars from first principles and developing predictions of the types of volcanic landforms expected to be produced in the martian lithospheric and atmospheric environment. We then compared these predictions with observed landforms (e.g., 3). We followed the basic approach that we have utilized in analyzing the ascent and emplacement of magma on the Earth and Moon (4) and Venus (5). We first examined modes of magma production in the martian interior, then assessed processes of magma ascent, analyzing the shallow density structure of the crust and lithosphere and its potential influence on the production of zones of neutral buoyancy (Fig. 1). Following this, we examined processes of gas exsolution at shallow depths and how the range of eruption products is manifested in the creation and growth of deposits and landforms (Fig. 2). Finally, we compared theoretical predictions with the range of landforms that have been revealed by Mars exploration, and used these observations as a basis to investigate a number of problems in the thermal and volcanological history of Mars (6).

On the basis of this assessment of the crustal configuration of Mars and the theoretical treatment of the ascent and eruption of magma through this crust in the martian gravity and atmospheric environment, we find that the full range of volcanic eruption styles observed on Earth is to be expected on Mars. It is clear, though, that martian environmental conditions operate to modulate the various eruption styles and the morphology and morphometry of resulting landforms. Using these theoretical predictions as a basis we compared observed deposits and landforms and find general agreement. In several cases we find that theory provides new insight into martian volcanological problems. For example, because of the lower gravity, fluid convective motions and crystal settling processes driven by positive and negative buoyancy forces, and overall diapiric ascent rates, will be slower on Mars than on Earth, permitting larger diapirs to ascend to shallower depths. This factor also favors a systematic increase in dike widths on Mars by a factor of two and consequent higher effusion rates by a factor of five. As a result of the differences in lithospheric bulk density profile, which in turn depend on differences in both gravity and surface atmospheric pressure, magma reservoirs are expected to be deeper on Mars than on Earth, by a factor of about four. The combination of the lower martian gravity and lower atmospheric pressure ensures that both nucleation and disruption of magma occur at systematically greater depths than on Earth.

Although lava flow heat loss processes are such that no major differences between Mars and Earth are to be expected in terms of flow cooling rates and surface textures, the lower gravity causes cooling-limited flows to be longer, and dikes and vents to be wider and characterized by higher effusion rates. Taken together, these factors imply that we might expect compositionally similar cooling-limited lava flows to be about six times longer on Mars than on Earth. For example, a Laki-type flow would have a typical length of 200-350 km on Mars; this would permit the construction of very large volcanoes of the order of 500-700 km in diameter.

For strombolian eruptions on Mars, the main difference is that while the large particles will remain near the vent, the finer material will be more broadly dispersed, and the finest material will be carried up into a convecting cloud over the vent. This means that there would be a tendency for broader deposits of fine tephra surrounding spatter cones on Mars than Earth. On Mars, strombolian eruption deposits should consist of cones that are slightly broader and lower relative to those on Earth, with a surrounding deposit of finer material. Martian hawaiian cones should have diameters that are about a factor of two larger and heights that are correspondingly about a factor of four smaller than on Earth; central craters in these edifices should also be broader on Earth by a factor of up to at least five. Grain sizes in martian hawaiian edifices should be at least an order of magnitude finer than in terrestrial equivalents because of the enhanced magma fragmentation on Mars.

Differences in the atmospheric pressure and temperature structure cause martian plinian eruption clouds to rise about five times higher, for the same eruption rate, than terrestrial clouds. Essentially the same relative shapes of eruption clouds are expected on Mars as on Earth and so the cloud-height/deposit-width relationship should also be similar. This implies that martian fall deposits may be recognized as areas of mantled topography with widths in the range several tens to a few hundred km. A consequence of the lower atmospheric pressure is that martian plinian deposits of any magma composition will be systematically finer-grained than those on Earth by a factor of about 100, almost entirely sub-cm in size. Basaltic plinian eruptions, rare on Earth, should be relatively common on Mars. The production of large-scale plinian deposits may not signal the presence of more silicic compositions, but rather may be linked to the enhanced fragmentation of basaltic magma in the martian environment, or the interaction of basaltic magma with ground water. The occurrence of steep-sided domes potentially formed by viscous, more silicic magma may be largely precluded by enhanced magma fragmentation. Pyroclastic flow formation is clearly inherently more likely to occur on Mars than on Earth, since eruption cloud instability occurs at a lower mass eruption rate for a given magma volatile content. For a given initial magma volatile content, eruption speeds are a factor of at least 1.5 higher on Mars, and so the fountains feeding pyroclastic flows will be more than twice as high as on Earth. Pyroclastic flow travel distances may be a factor of about three greater, leading to values up to at least a few hundred km. Martian environmental conditions thus operate to modulate the various eruption styles and the morphology and morphometry of resulting landforms, providing new insight into several volcanological problems.

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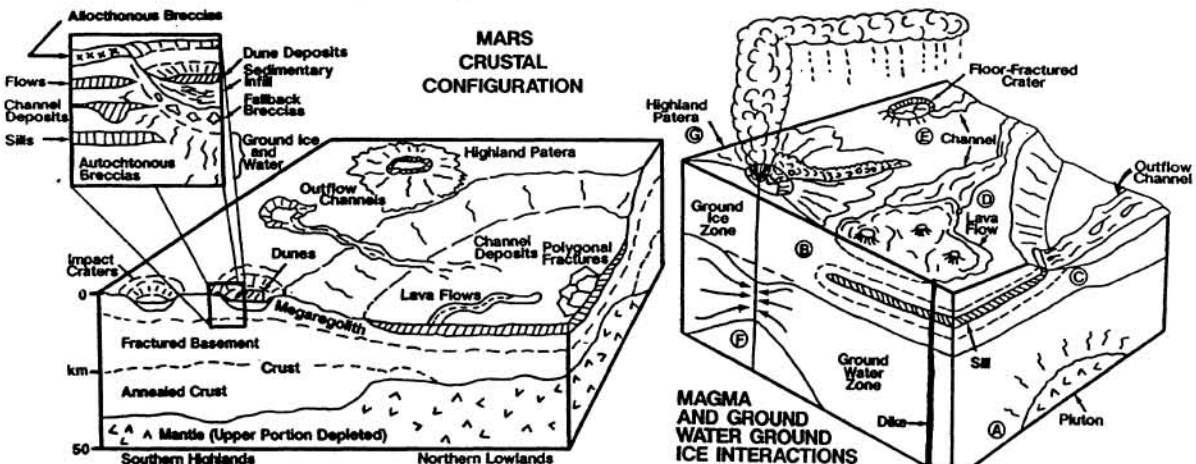
Fig. 1. Diagrams of shallow structure of martian crust.



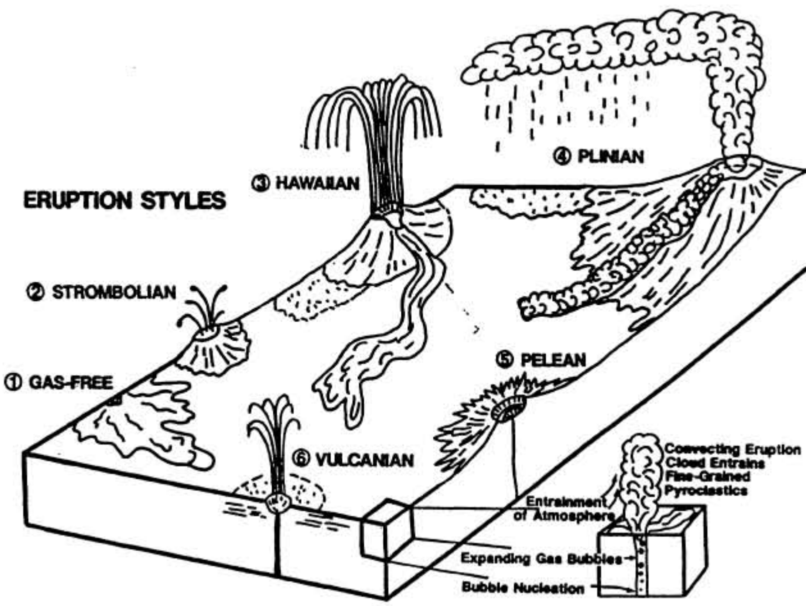


Fig. 2. Typical volcanic eruption styles on Mars.