CONSIDERATION OF HYDROMAGMATIC ORIGINS FOR HADRIACA PATERA AND TYRRHENA PATERA; *David A. Crown, Ronald Greeley, and Michael F. Sheridan, Department of Geology, Arizona State University, Tempe, Arizona 85287*

While geomorphic studies of martian volcanoes, Viking Lander analyses, earth-based spectroscopic data, and geophysical and petrologic models all suggest the existence of effusive basaltic volcanism on Mars [e.g. 1], the presence of large-scale explosive volcanic deposits has not been confirmed. Various eruption mechanisms on Mars have been considered theoretically [2,3] and applied to potential ash deposits associated with Hecates Tholus [3] and Alba Patera [4,5]. The origins of the basal scarp [6] and aureole deposits [7] of Olympus Mons, extensive deposits in the Amazonis, Memnonia, and Aeolis regions [8], and the martian highland paterae [1] have also been attributed to large-scale explosive volcanism.

The martian highland paterae are a morphologically distinct class of volcano which formed in Upper Noachian to Lower Hesperian time [1]. They are areally extensive, low-relief volcanoes with central caldera complexes and radial channels separating plateau-like erosional remnants [1,9]. Morphologic analyses have thus far not provided a comprehensive model for their formation, perhaps due to their eroded appearances and a lack of definitive criteria for the remote identification of ash deposits. The highland paterae were initially suggested to be the result of eruptions of extremely fluid lavas [10]; however, Pike [11] noted the morphometric correlation of the highland paterae with large terrestrial ash sheets. Greeley and Spudis [1], on the basis of the morphologies and stratigraphic relationships of units composing Tyrrhena Patera, proposed an evolutionary sequence for the paterae beginning with (1) extensive pyroclastic eruptions due to the contact of rising magma with the ice-saturated megaregolith, followed by (2) collapse of the structure and (3) erosion of the pyroclastic materials, and ending with (4) eruptions of lava which filled the caldera and formed a smooth upper shield.

This investigation evaluates hydromagmatic origins for Hadriaca Patera and Tyrrhena Patera, which are located in the cratered highlands on proposed rings of the Hellas Basin [12]. The asymmetry displayed by both structures reflects the presence of the basin and suggests a topographic influence on the deposition of the volcanic materials. Hadriaca Patera has a large caldera containing smooth plains with wrinkle ridges [13]. Broad, radial channels extend from the caldera and cut the flanks of the volcano. Hadriaca Patera is ~288 x 570 km across and stands ~3 km above the surrounding plains. Slopes from the caldera to the base range from ~0.05° - 0.60°. Tyrrhena Patera consists of a lower shield unit of dissected material and a smooth, upper, undissected unit containing wrinkle ridges [1]. Several sinuous rille-like features are associated with the summit caldera region. Tyrrhena Patera is ~426 x 660 km across and has a relief > 2 km with slopes between 0.16° and 0.28°.

Hydrovolcanic eruptions occur due to the interaction of magma with near-surface groundwater [14,15]. Large amounts of water and magma can interact, causing vaporization of the water and fragmentation of the magma, before the confining pressure is overcome and the resulting explosions form a crater and eject tephra. Experimental evidence indicates that water/melt mass ratios between ~0.25 and 0.4 provide the optimum efficiency for the conversion of a basaltic magma's thermal energy into the mechanical energy of an eruption [15,16]. Some hydromagmatic activity is thought to be associated with all terrestrial explosive eruptions. On Mars, contact between groundwater and a rising magma body is probable, especially under early climatic conditions on Mars. Large amounts of water driven by hydrostatic forces could flow into fault zones which provide access to the surface for dikes or into magma chambers in which the pressure has been released by eruption at the surface.

The volumes of Hadriaca Patera (2.4×10^{14} m^3) and Tyrrhena Patera (1.2×10^{14} m^3) have been estimated from the mapped boundaries of the volcanoes and topographic data from the *1:15M Topographic Map of Mars Eastern Region*. Assuming an original magma density of 2700 kg/m^3 and a void space of 45% in the resulting deposits (comparable to that of pyroclastic surge deposits [17]), masses for Hadriaca Patera (3.5×10^{17} kg) and Tyrrhena Patera (1.8×10^{17} kg) can be calculated. From these masses the initial thermal energy can be determined from the following expression [16]: TE = m C_p (T_m - T_{ref}), where TE = thermal energy, m = mass, C_p = specific heat, T_m = magma temperature, and T_{ref} = reference temperature. For $C_p = 1 \times 10^3$ m^2/sec^2 K, T_m = 1473° K, and T_{ref} = 273° K, and the calculated masses, energies of $\sim 10^{23}$ kg m^2/sec^2 are indicated. For the most efficient hydromagmatic eruptions only ~50% of this energy is converted into mechanical energy and only a portion of this mechanical energy is transferred into the kinetic energy ($1/2mv^2$, where v = velocity) of the ejecta [16]. If 10% of the mechanical energy (5% of the initial TE) is transferred, a pyroclastic surge produced by an eruption will have an initial velocity of 345 m/sec. For a 30% energy transfer, an initial velocity of 600 m/sec is indicated.

The energy line concept [18] has been used to represent the movement of a gravity driven flow over a surface resisted by a frictional force and to determine the lengths of pyroclastic flows for a given pre-flow topography [19]. The very large dimensions of Hadriaca Patera and Tyrrhena Patera require extremely large flow lengths assuming eruptions occurred at the central caldera. Half-widths of these features range from ~125-450 km. Assuming a 0.2° slope as measured for the present surfaces of the volcanoes and a value of the coefficient of friction, μ, = 0.1, an initial velocity of 345 m/sec produces a ~167 km long flow and an initial velocity of 600 m/sec produces a ~543 km long flow. Large volume terrestrial pyroclastic flows have values of μ = 0.06-0.20 [20]. On Mars, comparable coefficients of friction should be less due to the lower gravity and less dense atmosphere. For μ = 0.05 and an initial velocity of 345 m/sec a flow length of 347 km is produced. From this analysis it can be demonstrated that conversion of ~5% (i.e. v = 345 m/sec) of the initial thermal energy into kinetic energy is necessary for production of the majority of the flows associated with Hadriaca Patera and Tyrrhena Patera. To produce the longest lengths observed either more energy must be converted into kinetic energy or extremely low frictional coefficients are required.

If a 0.3 water/melt ratio is assumed, estimates of the amounts of water associated with eruptions at Hadriaca Patera ($\sim 1.1 \times 10^{17}$ kg) and Tyrrhena Patera ($\sim 5.3 \times 10^{16}$ kg) can be made. In a study of martian outflow channels, a volumetric flow rate of $\sim 10^5$ m^3/sec was calculated for a 1 km thick aquifer flowing into a chaos region with a 30 km radius [21]. Using this rate and assuming that the average volume of an eruption is 1000 km^3 (2.7×10^{15} kg), the necessary volume of water for each eruption would take ~0.26 years to accumulate. In this scenario, with eruptive volumes comparable to the largest terrestrial ash deposits [22], Hadriaca Patera would require ~130 eruptions and Tyrrhena Patera ~65 eruptions to produce the estimated masses implying minimum lifetimes of $\sim 10^1$ years.

From an energy perspective hydromagmatic origins for Hadriaca Patera and Tyrrhena Patera are realistic. If these volcanoes are composed totally of hydromagmatic deposits, large volumes of water are required. Future work will consider the mechanism of water supply in more detail and the role of magmatic volatiles.

References
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