HECATES THOLUS: DEFROSTING A VOLCANO. S. Tyson, L. Wilson, S. J. Lane and J. S. Gilbert, Environmental Science Div., Lancaster University, Lancaster, LA1 4YQ, UK (S.Tyson@lancaster.ac.uk).

Introduction: Hecates Tholus lies within the Elysium volcanic region, Mars, centred at 31.73°N 150.08°E. It is generally accepted that most of the distinctive radial channels on the flanks of the volcano were eroded by fluvial activity; the source of the eroding water, however, is still very much under discussion. Existing hypotheses and models concerning the generation of water on the flanks of the volcano were investigated: two current hypotheses suggest either meltwater from a summit snowpack/glacier or seepage of groundwater from a hydrothermal system. Both of these hypotheses require an increased geothermal heat flux from an active magma intrusion. A new energy balance model presented here investigates quantitatively the effect of the cryosphere on the heat flux reaching the surface.

Background: Hecates Tholus rises >7.5 km above the surrounding plains and has a complex summit caldera ~12 km in diameter (Fig. 1); much of the edifice is thought to be Hesperian in age (>2.5 Ga).

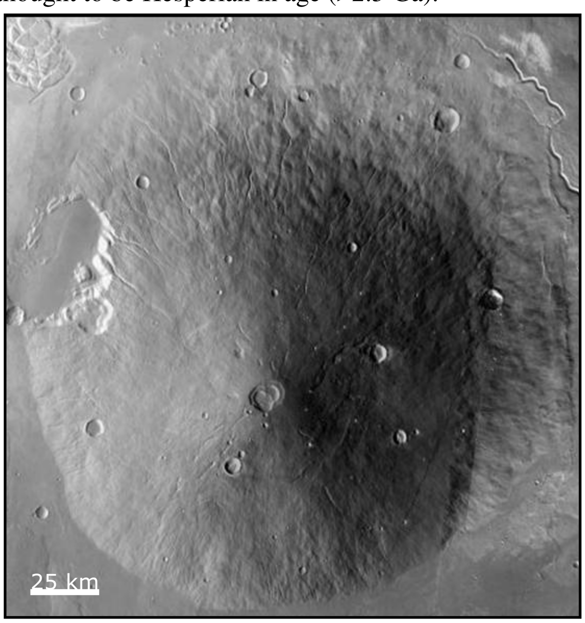

Figure 1. A composite of infra-red images from Mars Odyssey's THEMIS instrument. The overlapping craters just below centre make up the summit caldera. Maximum resolution of images is 100 m/px. (image credit NASA/JPL/ASU).

Previous studies have focused on 1) the extensive radial channels on Hecates' flanks [e.g. 1, 2, 3 & 4], 2) a young, dark deposit on the NW flank [5] and 3) very young glacial activity apparent at the termini of some channels [6 & 7]. These studies have lead to the hypothesis that Hecates may be an explosive volcano with readily erodable slopes. Fassett & Head [1] use an energy balance calculation to show that a moderately sized magmatic intrusion could melt sufficient water to erode the radial channels. They propose that this water could be melted from the base of a summit snowpack. However any heat flux to the surface would have to pass through, and heat, the rock and ice within the cryosphere to ≥273 K. It is reasonable to assume the presence of a cryosphere as it is thought that Mars has maintained a global cryosphere of varying thickness for >3.5 Ga [8]. Therefore we have developed an extended energy balance model.

Energy Balance Model: Fassett and Head [1] determined the total heat energy (Qm) available from a body of magma as the product of its mass (Mm), its specific heat capacity (C), and the change in its temperature (ΔT):

$$Q\text{m} = M\text{m}\ (C\ \Delta T) \qquad (1)$$

The minimum amount of energy needed to melt snow from a snowpack (Qs) is the product of the mass of snow (Ms) and the latent heat of fusion of ice (L) (335 kJ/kg):

$$Q\text{s} = \text{Ms}\ L \qquad (2)$$

Fassett and Head [1] conclude that it is possible to produce sufficient meltwater to support a variety of sediment load ratios in the water, providing there was a large enough snowpack present initially. Our extended model investigates how much of the available heat-energy would be required to heat and melt the cryospheric ice (Qc), and if there would be sufficient heat left to melt a summit snowpack, so:

$$Q\text{c} = (M\text{i}\ L) + ((\Phi\text{i}\ \rho\text{i} <\Delta T\text{i}\ C\text{i}>)\ \text{Vc}) + (((1 - \Phi\text{i})\ \rho\text{r} <\Delta T\text{r}\ C\text{r}>)\ V\text{c}) \qquad (3)$$

where Mi is the mass of ice within the cryosphere, Φi is the volume fraction of ice within the cryosphere (0.15) (after [9]), ρi is the density of ice (917 kg/m^3), $<\Delta T\text{i}\ C\text{i}>$ is the average product of temperature changes and specific heats of ice within layers through the cryosphere. It is necessary to divide the cryosphere into layers as the rock and ice in each layer would have different initial temperatures, thus requiring different amounts of heat to reach 273 K; in addition the specific heat of any substance varies appreciably with its temperature [10]. <Δ*T*r *C*r> is the analogue of <Δ*T*i *C*i> but for cryospheric rock, *ρ*r is the density of basaltic rock (2900 kg/m^3) and Vc is the volume of the cryosphere. The cryosphere is likely to be made up of basaltic rock with ~15 vol.% of ice held within pores. The depth of the cryosphere within the edifice is unknown but Clifford [11] suggests a thickness of >3 km at the latitude of Hecates Tholus. Thus our initial model is based on these assumptions.

Results and Discussion:. Fassett & Head [1] state that with a sediment to water ratio of 1:100, up to 6000 km^3 of water would be required to erode the channels on Hecates' flanks. To produce this volume of melt-water a snowpack of at least 6000 km^2 and 1 km thick would be required. This is considerably larger than quoted in [1]. Our model predicts that, at 60% efficiency, an intrusion would need to have a volume of 2000 km^3 or more. This would produce sufficient heat to first melt the ice within the cryosphere underlying the snowpack, and then the snowpack itself (Fig. 2).

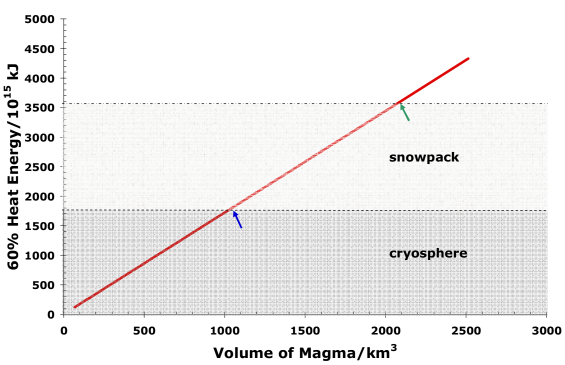

Figure 2. The heat energy transferred at 60% efficiency from increasing volumes of magma. Once the line crosses the first critical point (lower arrow) there is enough energy to melt the cryospheric ice. Once the line crosses the second critical point (upper arrow) there is enough energy to melt both the cryospheric ice and the snowpack.

The presence of the summit caldera complex (Fig. 1) places some constraints on the possible shape of the intrusion. From studying terrestrial analogues it is thought that the diameter of a piston caldera approximately represents the diameter of the magma reservoir beneath it [e.g. 12 & 13]. Also the depth of the caldera represents the drop in the level of magma within the reservoir, removed by an eruption or intrusion (e.g. dike or sill) elsewhere. For a cylindrical intrusion this holds true; however, if the intrusion was more nearly spherical the diameter evacuated by an ongoing eruption would increase until the mid-depth point of the intrusion was reached. Thus the caldera may not represent the full diameter of the intrusion. In addition, the presence of multiple calderas represents several phases of episodic activity [14]. At this stage, our initial model is based on a cylindrical intrusion. Using the diameter of the summit caldera (12 km) as the diameter of the intrusion, a vertical extent of 18.5 km would be required to hold a volume of 2000 km^3. This is larger than would be expected on the grounds of gravity scaling which would imply a vertical extent closer to 8 km, requiring a cylindrical diameter of ~18 km [15].

Conclusion: The quantitative constraints provided by the energy balance model present many interesting questions. Is a magma reservoir of the size required feasible? Could such a substantial snowpack be sustained at any point in Mars' history? If so how was the snowpack re-supplied? With further development of our model we aim to consider a wider range of scenarios, including an investigation into an alternative hypothesis involving the water melted from the cryosphere. It is likely that this water would contribute to an active hydrothermal system; fumerolic activity and seepage from such a system could provide another source of water to the surface. Our aim is that these detailed quantitative analyses will enhance our understanding of the physical processes which shaped Hecates Tholus, and ultimately other volcanoes on Mars.

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