A NEW MECHANISM FOR CALDERA FORMATION RESULTING FROM INTERACTIONS BETWEEN MAGMATIC HEAT AND CRYOSPHERIC ICE.

S. Tyson, L. Wilson, J. S. Gilbert and S. J. Lane, Division of Environmental Science, Lancaster University, Lancaster, LA1 4YQ, UK, (s.tyson@lancaster.ac.uk).

Introduction: It is generally accepted that volcanic caldera formation takes place when supporting material is removed from below. There is much field and laboratory evidence to suggest that this material is removed via magma loss from a shallow reservoir to feed an eruption or intrusion (e.g. [1, 2 and 3]). There is nothing to suggest however that the supporting material *must* be magma.

Calculations show that if the ice held within a cryosphere were melted, by a hot magmatic intrusion, compaction of the remaining rock could take place and cause collapse of a coherent overlying block, analogous to conventional caldera collapse. Furthermore this process is likely to occur at a variety of smaller scales in a similar fashion to kettle-hole formation on Earth.

Hecates Tholus, Mars (31.73° N 150° E) has many pits, channels and depressions of ambiguous origin in addition to well-studied fluvial channels (Fig 1). We explore the hypothesis that many of these features were formed by this ice-melting mechanism and that such melting could have influenced the formation of one or more of the calderas themselves.

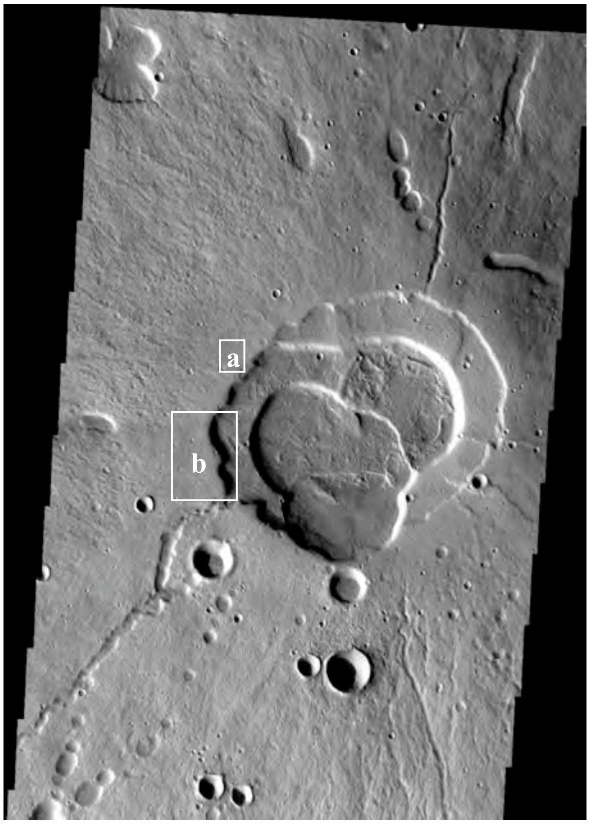

Figure 1. THEMIS image V17606020 showing the many and varied collapse features around the summit region of Hecates Tholus. North is up and the caldera is ~12 km in diameter at its widest point. Boxes are locations of MOC images in Fig. 2.

Analysis: It is reasonable to assume that a Martian volcano will be made up of vesicular basaltic lava flows and pyroclastic deposits [4]. This would provide a permeable environment for water (or water vapour) to travel through and reside within pores in the rock. For much of Mars' history any water in the top few km of lithosphere (at the latitude of Hecates Tholus) would be frozen into the pores, forming a cryosphere [5]. Whilst this ice is present within the pores compaction by the overburden will be resisted. However, if this ice were melted, by heat energy provided by a hot magmatic intrusion, the remaining porous rock may not retain sufficient strength to resist compaction as the liquid water percolates away. Compaction may also occur as a result of the reduction in volume which would occur due to the phase change from ice to water.

A reasonable estimate for porosity of Martian basaltic lithosphere is 15 vol.% [6]. If this 15% were compacted by half, a maximum reduction in thickness of ~225 m would be attained in a 3 km thick cryosphere. This compaction could result in a piston-like caldera collapse over the region heated by the intrusion much like conventional magmatic caldera collapse (but without volcanic deposits), where steeply outward-dipping ring or arcuate faults are initiated and the central block (or plate) subsides [1]. On smaller scales, perhaps above a dike tip which approaches the surface, the amount of subsidence at the surface could be indicative of the thickness of cryosphere affected by melting.

Discussion: The caldera complex at the summit of Hecates Tholus is made up of at least five overlapping piston-type calderas. They are all less than 150 m deep with variable floor morphologies (Fig 1). If their origin is due to ice melting then variable starting porosity, amount of compaction and extent of melting of the cryospheric ice could all contribute to changes in volume beneath a fault block. Incomplete melting of cryospheric ice could clearly be caused by a deep or small intrusion which would not provide sufficient heat to melt the ice right up to the surface.

An intriguing set of deposits, concentrated within 500 – 1000 m of the top of the scarp walls on some sections of the outer calderas, may provide support for this new hypothesis. The deposits are distinctly smoother than the surrounding terrain and infill some small impact craters. In some areas the deposits are lobate but they all appear to be very thin; their patchiness in some areas may be due to wind erosion (Fig 2).

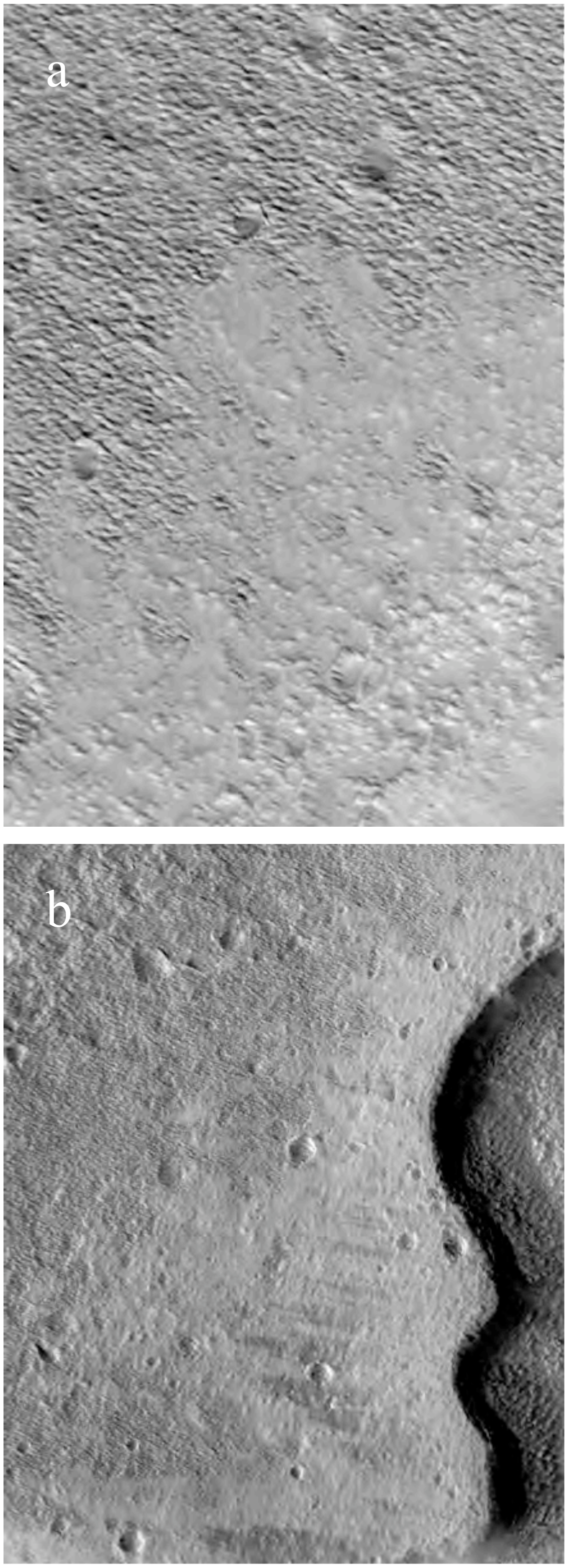

Figure 2. MOC images of thin lobate deposits on caldera rims. The exact positions are shown on Figure 1. 2a is MOC image e1200879d with a resolution of 1.53 m/px, 2b is MOC image m1801860b with a resolution of 3.59 m/px; the darker 'stripes' are wind streaks.

We suggest that these deposits may represent small mud flows produced by a water-sediment mixture 'erupted' along the fault as the caldera floor block subsided. This mixture could have been made up of either water melted from the cryosphere by the intrusion, which travelled up the fault from below entraining rock particles or water melted from cryospheric ice by friction at the fault plane, which was then squeezed up to the surface along the fault plane again entraining rock particles. The rock particles are likely to be fine grained 'fault-gouge' produced during faulting. The water within this mixture would rapidly evaporate, freeze or flow away once 'erupted' depositing the sediment near the caldera rim.

We acknowledge as an alternative that this deposit could represent remaining small patches of an air-fall deposit as proposed elsewhere on Hecates Tholus [7]. However, as the deposit appears to be mostly restricted to the immediate vicinity of some of the caldera rims this seems less likely.

Conclusion: We propose a previously unrecognised mechanism of Martian caldera formation which, if proved valid, is likely also to have occurred on Earth during past ice ages when a cryosphere would have been widespread.

References: [1] Lipman P.W. (2000) *In: Sigurdsson, H. (Ed.), Encyclopedia of Volcanoes. Academic Press, San Francisco*, 643-662. [2] Geyer A. et al. (2006) *J.V.G.R.*, *157*, 375-386. [3] Cole J. W. et al. (2005) *Earth-Science Reviews, 69*, 1-26. [4] Head J.W. and Wilson L. (1998) *LPSC XXIX*, #1127. [5] Baker V.R. (2001) *Nature, 412*, 228-236. [6] Head III J.W. and Wilson L. (2002) *Geol. Soc., London, Spec. Publ.*, 202, 27-57. [7] Mouginis-Mark P.J. *et al.* (1982) *JGR 87*, 9890.