BASAL MELTING OF A CO_2-RICH ICECAP ON MARS. Nick Hoffman[1], Jeff Kargel[2], and Ken Tanaka[2]. [1]School of Earth Sciences, University of Melbourne, Parkville; Australia 3010. Email: nhoffman@unimelb.edu.au [2] USGS Astrogeology Team, 2255 N. Gemini Dr., Flagstaff AZ, 86001. Email: jkargel@usgs.gov / ktanaka@usgs.gov

Introduction: A variety of geomorphic features around the polecaps have been interpreted as evidence of episodic basal melting at depths of only a few km in the geologic past [e.g. 1-4]. This has often been invoked as evidence for a thermally active planet, or geothermal activity under the polecap - akin to Icelandic Jokulhlaups.

However, trying to fit such a thermal regime into the remainder of the evidence for modern Mars leads to paradoxical outcomes – the melt depth of a pure H_2O icecap in the presence of strong brines should be 13-20 km, effectively precluding melting without prodigious geothermal or volcanic input, for which we see no modern evidence.

If, instead, we consider a polecap with modest amounts of included CO_2 (either as dry ice, or as CO_2 clathrate), we find a very different scenario. Due to the dramatically lower thermal conductivity of these ices, melting can occur at shallower depths and the evidence for basal release of fluids is best explained by a clathrate-dominated polecap releasing mixtures of liquid CO_2 and liquid water at depth during warming episodes [5].

Therefore, either the model of the permanent polecaps as pure H_2O ice must be incorrect, or the evidence of basal melting must have been misinterpreted.

Heat Flow and Geothermal Gradients on Mars: There are two ways to estimate these parameters for Mars. We may take values from the Earth and scale them to Martian conditions, or we may find another measurement of thermal gradients on Mars. However, these estimates may be in error by as much as a factor of 2 or 3

Earth Analogue. Mars is smaller than Earth and has a larger surface area to volume ratio. It also has a lower mean density and seems to be relatively metal-poor and volatile-rich compared to Earth. Recent estimates of the effect of these variables yields a value for Mars of ~40% that for the Earth [6].

Indirect measurement. Recent estimates of the growth of the lithosphere on Mars have been made by comparing MOLA topography to MGS orbital perturbations due to gravity anomalies [7]. A clear trend with time results [8], and extrapolating to the present day we estimate a lithospheric thickness of 350-400 km. On Earth, continents have lithospheres some 120 km thick. Therefore, geothermal gradients on Mars should be about 1/3 that on Earth's continents.

Geothermal Gradient on Earth and Mars. For the earth, typical continental geothermal gradients are around 35 K/km. For Mars, as calculated above, we expect values of 12-15 K/km. We will be generous for Mars and allow geothermal gradients to locally exceed the mean and reach as high as 20 K/km.

Water Ice. Normal water ice (ice Ih) is unusually conductive. At temperatures typical of the polecaps of Mars (150-200 K) it has a conductivity about 6 times that of other ices such as dry ice (pure CO_2) or CO_2 clathrate (30% CO_2: 70% H_2O). These latter ices have conductivities similar to rocks and minerals [1, 2].

If the permanent polecaps of Mars are composed largely of pure H_2O ice, then they will be highly conductive to heat and will have low geothermal gradients – about 1/6 those calculated above (i.e. 2-3 K/km)

Melting of water ice may occur at temperatures as low as 220K if large amounts of salt are available to depress the freezing point. For annual mean surface temperatures at the poles of ~180 K, some 40 K of temperature increase is required. At the calculated geothermal gradient, this will require burial of 13-20 km and is clearly so deep in the crust of Mars that basal melting of the permanent polecap would require a dramatic input of volcanic heat. Without potent brines, melting will be even deeper.

Earth Analogue. The Greenland and Antarctic ice sheets do not experience basal melting until a depth of 3-4 km is reached. Mars has colder surface temperatures and lower geothermal gradients, so one would expect much deeper melting, as calculated.

CO_2-rich scenarios. Conductivity of a polecap largely composed of dry ice or pure CO_2 would be similar to that of rock, and geothermal gradients would be much greater (12-20 K/km, as calculated above). Buried layers of pure CO_2 would melt to liquid CO_2 at 216 K. This would require only 2-4 km of burial.

For clathrate, melting is pressure-dependent but typically occurs at around 285 K. Burial of 5-8 km would be required before the clathrate dissociated to a two-phase mixture of liquid water and liquid CO_2. Interestingly, brines are ineffectual in reducing the melting point of clathrates [9].

Mixed models: We can extend the calculations above, which apply to pure end-members to a more general case of variable CO_2 to H_2O ratio in the polecaps of Mars. Thermal conductivity is directly related to the proportion of pure water ice present, compared to either clathrate or dry ice components. Assuming equilibrium between the various phases (which may be difficult if the gross observed layering of the icecap is due to compositional differences), we can calculate the expected melt depth for any H_2O:CO_2 ratio (Figure 1). This emphasizes that shallow melt depths of 4 km or less require H_2O:CO_2 to be less than about 3:1 (75% H_2O)

Discussion: The huge melting depth of water ice on Mars clearly precludes a simple aqueous origin of the features described as "floods" near the permanent polecaps on Mars.

The only ways to reconcile the observations of thermal structure of Mars and evidence of melting is to allow significant layers of CO_2-rich ice in the polecaps. Pure CO_2 ice would melt to liquid CO_2 at depths of 1-3 km, and clathrate would decompose to liquid water plus liquid CO_2 at depths of 4-8 km [11].

Either of these latter scenarios is capable of producing flood-like features. The CO_2 component can generate an energetic CO_2 gas-supported density flow [10], while any aqueous component may passively or actively flow in the aftermath of the CO_2 density flow surge, or it may freeze to ice crystals which are advected by the cooling CO_2 density flow. The mechanism of escape of these mixed fluids merits further study.

Rheological studies of the polecap suggest that CO_2 ice is too soft to sustain the observed topography, so a clathrate-based model appears to be the only viable one for basal melting of the polecap.

Of course, if the features near the polecap [1-3] are NOT formed by violent floods, as interpreted by [9] then there is no need to invoke basal melting and the composition of the permanent polecaps remains unconstrained, although this may suggest H_2O-rich polecaps (>75% H_2O)

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Figure 1: Melt depths for a polecap composed of variable amounts of H_2O and CO_2. Z axis is depth in km, X axis is % H_2O. Heat flow of 10 mW/m^2 is assumed. Three possible melt products exist, depending on H_2O: CO_2 ratio. For <70% H_2O, liquid CO_2 can be produced at 216 K from dry ice, and a second melt at ~285 K where clathrate decomposes to 70% H_2O + 30% CO_2 (both liquids at these pressures). Above 70% H_2O, no melt forms at 216 K but instead excess pure ice melts at 273 K, and clathrate at 285 K.