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Long-term evolution of the Martian cryosphere

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Abstract

We examine the impact of climatic insolation variations of the past 250 millions years on the extent of the Martian cryosphere – with particular regard to the occurrence of thawing in both the deep- and near-subsurface that could promote hydrous alteration.

Introduction

The amount of water necessary to erode the outflow channels suggests that the global inventory of water on Mars may be equivalent to a global ocean 0.5 to 1 km deep [1, 2]. As this inventory post-dates the most efficient water removal processes, the majority of this water is expected to be stored in the planet's subsurface as ground ice and groundwater (e.g. [3, 4]). Recent calculations show that the Martian averaged cryosphere depth could be twice as deep as previously estimated [5].

Here we calculate the influence of long-term climatic variations on the cryosphere thickness at high latitudes over the past 250 million years. We also demonstrate that extensive thawing of the near-subsurface may occur at mid- to high-latitudes at times of high obliquity. Implications for the occurrence of aqueous processes in the subsurface of Mars and on the presence of subpermafrost groundwater are examined.

Model description

The evolution of the Martian cryosphere is calculated with a one-dimensional finite difference thermal model [6]. Recent improvements in the code consider the surface temperature variation due to astronomically induced variations in insolation, the temperature-dependent thermal conductivity, *K*, of rock and ice, the potential effect of the presence of methane hydrate, an exponential decline in porosity with depth [4] and a potentially lower geothermal heat flow (between 15 and 45 $mW.m^{-2}$ [7 – 9]).

The Martian subsurface is assumed to have a layered structure. Within ±40º of latitude a desiccated regolith region is assumed with a maximum equatorial depth of 180 m. The thermal conductivity of the uppermost 5 m is assumed to be 0.05 $W.m^{-1}.K^{-1}$ consistent with measurements by mini-TES [10] and characteristic of a high-porosity granular material at low atmospheric pressure. A second layer of basalt or cemented sedimentary rock is assumed to have K=0.1 $W.m^{-1}.K^{-1}$. Where ice is stable in the subsurface (at latitudes >40º, and at depths below the sublimation front at latitudes <40º) *K* for both ice and rock is given by the temperature-dependent expression $K = \frac{488.19}{T} + 0.4685$ where *T* is the temperature [11].

Fig. 1 shows the structure of the subsurface used for the calculations.

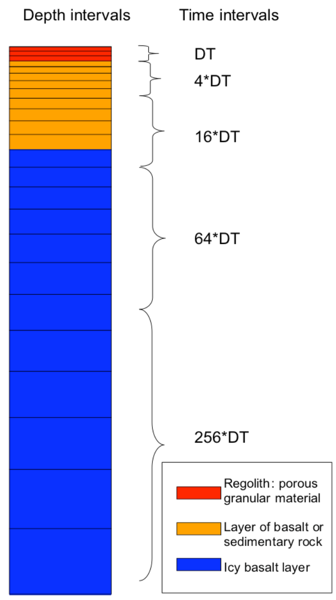

Figure 1: Relative compartment sizes and calculation time intervals. The thickness varies depending on the thermal conductivity considered.

Surface insolation

A mean annual insolation is determined following Hoffert et al., [12]:

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$$S(l) \approx \left[\frac{S_0}{4\sqrt{1-e^2}}\right] \cdot \left[\left(\frac{3}{2} - \frac{2\sin(i)}{\pi}\right) - \left(\frac{3}{2} - \frac{6\sin(i)}{\pi}\right)\sin^2(l)\right]$$

with l the latitude, S_0 the solar constant at the semi-major axis orbital distance, i, Mars' obliquity and e, Mars' orbit eccentricity. The variations of the orbital parameters of Mars have been taken for the nominal case calculated by Laskar et al. [13]. The calculated insolation at the equator over the last 250 million years is shown in Fig. 2.

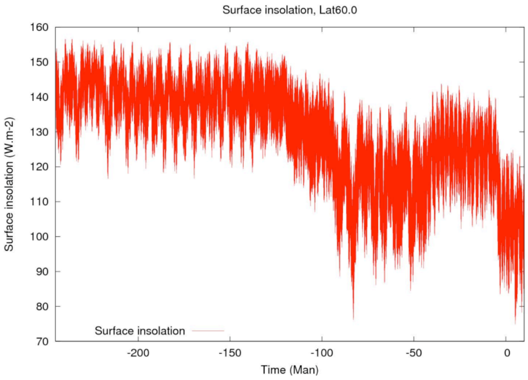

Figure 2: Mean annual insolation of Mars over the past 250 million years at 60° latitude.

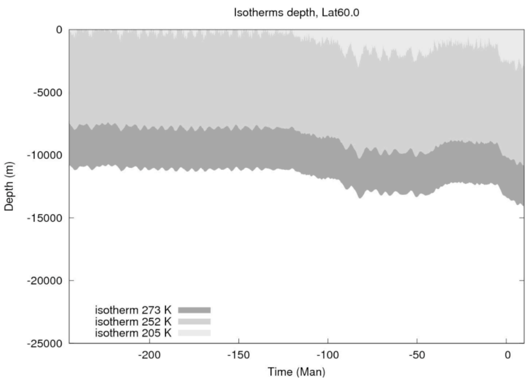

Figure 3: Evolution of the depths for the isotherms of 205 K, 252 K and 273 K over 250 million years for a heat flow of 15 $mW.m^{-2}$ at 60° latitude.

Results

Fig. 3 shows that over millions of years, the astronomically induced variation of insolation can modify the depth of the base of the cryosphere by more than 3 km at 60° latitude. The depths of the isotherms at 205 K, 252 K and 273 K are presented. These values correspond to the freezing-points of the following brines at their eutectics: perchlorates (as detected by Phoenix), NaCl (as inferred from Viking) and pure water ice.

Simulations using gas hydrate instead of water ice as the main volatile component of the cryosphere show that the expected depth of the base of the cryosphere is more than 1 km shallower due to its lower K [14]

Conclusions and implications

Based on these revised estimates of heat flow, thermal conductivity, porosity and freezing-point depression isotherms, we have calculated that the effects of the astronomically induced variations in insolation are significant – resulting in km-scale variations in the depth of the cryosphere at high latitude. The presence of gas hydrates can reduce the thickness of the cryosphere by a similar amount. The most important parameter constraining the depth of the cryosphere is the geothermal heat flow. Variations in the values of crustal heat flow, thermal conductivity and porosity, assumed here, may result in significant departures from the predictions of cryospheric thickness presented here.

Moreover, the large variations in insolation over time can result in extensive thawing of the near-subsurface, e.g. above 60° latitude, promoting hydrous alterations of the near-surface.

Considerations of the evolution of the cryosphere over large periods of time may have important implications for the occurrence of aqueous processes in both the near- and deep-subsurface – a potential that will be discussed in greater details at the meeting.

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