LIMITS ON THE CO_2 CONTENT OF THE MARTIAN POLAR DEPOSITS.

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It has recently been suggested that large quantities of CO_2 could be sequestered within the martian polar deposits as CO_2 ice or CO_2 clathrate hydrate, stabilized against sublimation by a non-porous overburden of water ice. I investigate the phase stability of CO_2-bearing polar ices and place limits on the quantity of CO_2 that can be sequestered. The magnitude of this limitation follows from CO_2-bearing ices having thermal conductivities on the order of 5 to 6 times smaller than that of water ice, producing a higher geothermal gradient. By calculating the effective thermal conductivity of a mixture of ices and the resulting temperature-pressure profile of the polar deposits and comparing these profiles with the phase diagrams of water ice, CO_2 ice, and CO_2 clathrate hydrate, I set limits on the quantity of CO_2 in the polar deposits.

The abundance of past fluvial activity on Mars has led many investigators to conclude that Mars once had a warmer and wetter climate than it has today, maintained by a dense atmosphere containing greenhouse gases. Owing to the current atmospheric composition, CO_2 has been included as the primary greenhouse gas in the early martian atmosphere and as much as several bars would have been required to bring the global temperature above the freezing point of water. Today the climate is colder and only 5-6 mbar of CO_2 is present in the atmosphere. Therefore, if Mars once had a warm, wet climate caused by a thick CO_2 atmosphere, nearly all that CO_2 would need to have been subsequently lost to space and/or be currently sequestered in some non-atmospheric reservoir. Recent attention has been brought to possible polar deposits of CO_2 ice and CO_2 clathrate hydrate, where sublimation of the polar cap as a whole, during times of extremely high obliquity, could provide a mechanism for periodic climate change.

Upper limits on the CO_2 content of the polar deposits can be obtained from calculating the temperature-pressure profile within the deposits. Mixtures of water ice and CO_2-bearing ice will affect the thermal conductivity of the deposit. Water ice alone will have a high thermal conductivity and result in a low geothermal gradient. Adding low thermal conductivity CO_2-bearing ice (CO_2 ice and CO_2 clathrate hydrate) will lower the conductivity, raising the geothermal gradient, and raising the polar basal temperature. By requiring that the polar deposits consist of a solid phase of the volatiles, an upper limit on the CO_2 content is obtained.

Assuming a nominal surface heat flow of 30 mW/m^2 and a long-term mean surface temperature of 155 K, I find that in a 4 km thick north polar deposit 112 mbar (equivalent atmospheric pressure) of CO_2 can be sequestered in the form of clathrate (Figure 1) or 254 mbar in the form of CO_2 ice. Less CO_2 is also allowed. To obtain these values required optimum (and probably unrealistic) conditions; I assumed a lower limit on the maximum thickness of the deposit, low values of heat flow (ignored frictional heating) and low surface temperature (ignored insulating polar firn deposits), excluded salts and dust, and assumed perfectly random and isotropic CO_2-bearing ice inclusions with no layering or contact resistance. Any one or combination of these effects are probable and will reduce the allowed CO_2 content of the polar deposits. With more realistic conditions it is unlikely that the north polar deposit can contain more than a few 10's of mbar of CO_2, with less also being allowed. No CO_2 is required by existing observations.

A similar quantity might be expected in the south polar deposit due to similar climate conditions accounting for its formation and similarities in its present state and structure, however, the smaller thickness of the deposit does not allow for direct constraints as in the north.

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The most important implication of these results is that the polar deposits of Mars do not contain large quantities of CO_2 that could be periodically available for climate change during periods of high obliquity, or as a relic of an early warm, wet climate. Models of the climate evolution of CO_2 are correct to reject results predicting a thick CO_2-ice polar cap at present and should be cautious of past thick CO_2-bearing deposits. Nevertheless, periodic release of even a few 10's of mbar of CO_2 during high obliquity would have a notable effect on the martian climate and surface-atmosphere interactions.

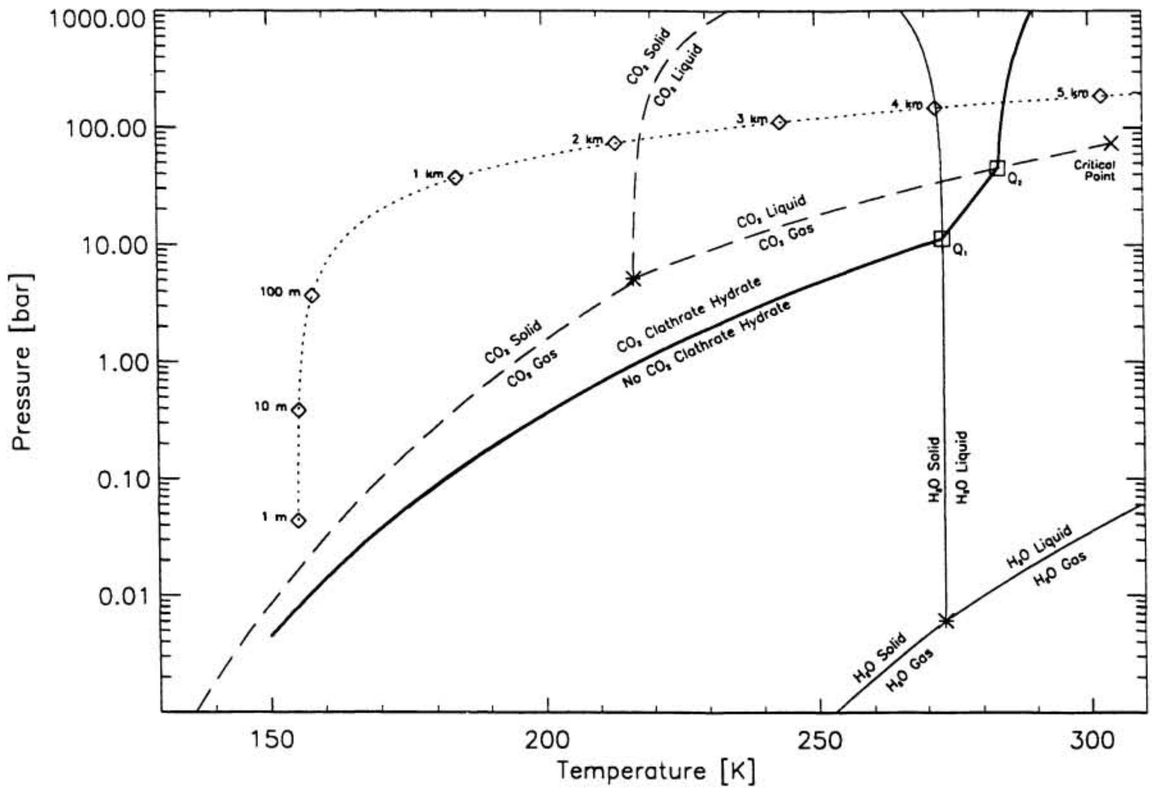

Figure 1. Polar subsurface temperature-pressure profile (dotted) superimposed on the phase boundaries of water ice, CO_2 ice, and CO_2 clathrate hydrate. This profile is chosen such that a water-ice and clathrate mixture will remain in a solid phase at all depths in a 4 km thick cap deposit. For the nominal heat flow and surface temperature stated, the resulting thermal conductivity is 1.02 W/m K. A higher conductivity will also meet the solid-ice criteria. From this conductivity and an understanding of the bulk conductivity of composite materials, an upper limit on CO_2 content is obtained. Similar arguments apply to water and CO_2 ice mixtures.