PRESSURE AND TEMPERATURE EVOLUTION OF MARS' SURFACE. N. Hoffman, WNS GeoScience, 22 Marlow Place, Eltham VIC 3095, Australia (nhoffman@vic.bigpond.net.au).

Introduction: A model is presented for the evolution of the Martian surface and atmosphere based on a cold icy origin interacting with impact cratering. Mars' surface is understood as a thick layered regolith of dirty ice and icy rock with water ice as a solid refractory phase. CO_2-bearing phases dominate the atmospheric pressure equilibrium and greenhouse effect which results in pressure and temperature conditions broadly around the triple point of carbon dioxide.

Pressure and Temperature on Mars: Kasting [1] showed that given the faint early Sun, a thick early CO_2 atmosphere was unstable and would collapse once the early cosmic bombardment ended. I extend that analogy here and look in detail at the collapse process during the final stages of that bombardment. Clearly, if a large number of recent impact craters are present on the surface, they supply heat to the atmosphere and sustain it against collapse, although it will tend to rain out and freeze away from any warm crater or volcanic zone.

After each large impact, or a cluster of lesser ones, the atmosphere will thicken, then it will die away over a relatively short period of time related to the cooling time of each crater, its burial by ejecta from other impacts, and the condensation of CO_2 in colder areas. Given a random expectation of impacts, the atmosphere will fluctuate between thin cold states and thicker warmer ones.

In a separate note I comment on this fluctuation as a prime driver for the thick layering on Mars. Here we concentrate on the atmosphere. The baseline for surface temperature is constrained by the Solar constant, here assumed to be 70% of its present value at 4.55Ga and to increase steadily to the present day. Figures1 and 2 detail the results of a whole-planet model for atmospheric pressure and temperature based on surface occurrence of CO_2 clathrate - the stable cage lattice H_20/CO_2 ice. Extensive surface occurrence of solid CO_2 (which would imply a mass ratio of more than 1 part CO_2 to 2 parts H2O), would lead to somewhat higher but still comparable pressures and temperatures.

You will note from Figure 1 that the temperature cycles decay significantly in magnitude over the first billion years or so as the impact flux is reduced. The exact details of the impact chronology are not relevant providing that atmospheric collapse is rapid compared to the duration of the bombardment. The surface outcome will be essentially identical since we can only date events by the alternation of atmospheric cycles with are coincident with the cratering record.

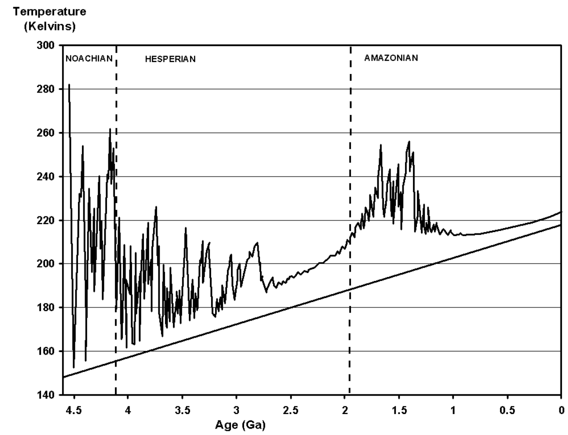

Figure 1: A simulation of Mars' mean surface temperature through geological time based on a steadily warming sun and impact cratering into an icy regolith with repeated cycles of ephemeral atmospheric generation and collapse during the Noachian and early Hesperian. This extends the model of Kasting [1] for early atmospheric collapse post-bombardment to one of repeated cycles of collapse during the closing phase of the bombardment itself.

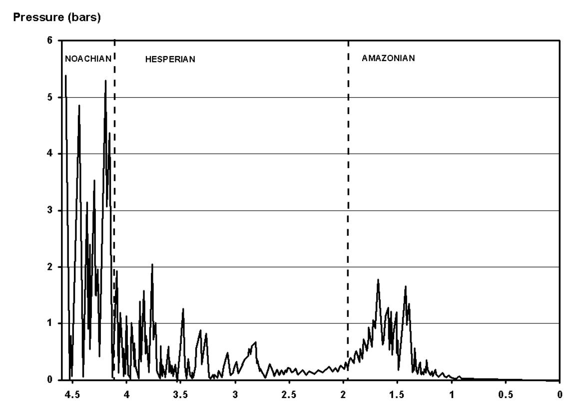

Figure 2: Mean atmospheric pressure within the same simulation. Note that during Noachian times, occasional occurrences of P>5 bars occurs, permitting liquid CO_2 at surface. Liquid CO_2 would be a common occurrence during these times, except in local hot spots where it would be too volatile. CO_2 cycles would consist of rain in the periphery of hotspots, draining through river systems into local warm lakes that evaporated strongly and resupplied the rain.

Noachian Liquids: The highest temperatures do not achieve 273 K, the minimum for pure ice to melt. Therefore liquid water is unlikely at surface in Noachian Mars. Interestingly, the triple point of CO_2 at 220 K, 5 bar is frequently, although ephemerally, exceeded. Therefore, liquid CO_2 would have been a frequent, but short-lived agent on Mars' surface. The Noachian "fluvial" valley systems are ascribed to erosion by ephemeral CO_2 liquid cycles. CO_2.

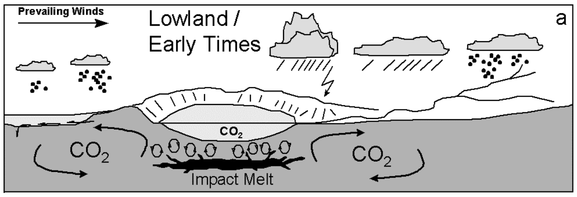

Figure 3: The surface of White Mars in the Noachian. Local CO_2 cycling in the vicinity of warm craters leads to erosion and valley networks. Elsewhere an icy carapace protects the surface from the climate.

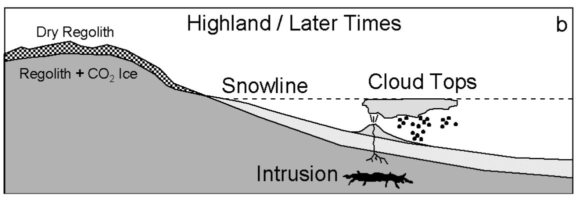

Figure 4: At later times, liquid CO_2 disappears and a cold iceworld sets in. Eventually, atmospheric pressure decreases enough for solid CO_2 to sublimate away entirely at high altitude, explaining why the exposure ages of terrain increase with altitude.

Hesperian: Liquid CO_2 occurrences became very rare events in the Hesperian, due to the drop in cratering rate and magnitude. Peak temperatures and pressures became progressively lower. The lowest temperatures achieved in each cycle are the collapsed state of the atmosphere. Note how this gradually diverges from the baseline as a thin stable atmosphere begins to build and self-reinforce through conventional greenhouse effect. By ~2Ga, mean global temperatures of 210 K and about 0.2 bar of atmosphere are stable.

Amazonian: Under these conditions, large areas of Mars in the equatorial regions would have been close to the CO_2 ice/liquid transition in the subsurface. Other contributions in this series describe how the collapse of unstable layered terrain in a manner first described by Lambert and Chamberlain [3,4], leads to the generation of massive fluid slurry flows and gas-supported density flows. The consequences of these flows are the peaks of atmospheric pressure and temperature during the early Amazonian. Each flow contributes to the atmosphere and to greenhouse warming, but this collapses back as the excess CO_2 condenses in polar regions. After the vulnerable terrain is consumed, the "floods" diminish and Mars evolves to the present thin, dry atmosphere. The late-stage and relatively small collapse events are preserved as the huge landslides and avalanches around the canyons of Mars.

References: [1] Kasting J.F. (1991) *Icarus*, **94**, 1-13. [2] Miller S. L. (1974) In *Natural gases in marine sediments* (I. R. Kaplan, Ed.) 151-177. Plenum Press, N.Y. [3] Lambert R. St J. and Chamberlain V. E. (1978) *Icarus*, **34**, 568-580. [4] Lambert R. St. J. and Chamberlain V. E. (1992) Abstract - NASA *MSATTMA Workshop.*