THE ICE-COVERED LAKES HYPOTHESIS IN GALE CRATER: IMPLICATIONS FOR THE EARLY HESPERIAN CLIMATE.

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Introduction

Recent geological discoveries from the Mars Science Laboratory (MSL), including stream and lake sedimentary deposits, provide evidence that Gale crater may have intermittently hosted a fluvio-lacustine environment during the Hesperian, with individual lakes lasting for a period of tens to hundreds of thousands of years [1]. Estimates of the CO2 content of the atmosphere at the time the Gale sediments formed are far less than needed by any climate model to warm early Mars [2], given the low solar energy input available at Mars 3.5 Gya. We have therefore explored the possibility that the lakes in Gale during the Hesperian were perennially covered with ice using the Antarctic lakes as analogs.

Environmental requirement for liquid lakes

We estimated the lifespans of individual lakes for different pressures and temperatures of interest, including temperatures which are below the freezing point and for those an icy lake would sublimate. The lakes are assumed to be 100m deep, [1] and the lifespans are derived from the evaporation rates. [3]

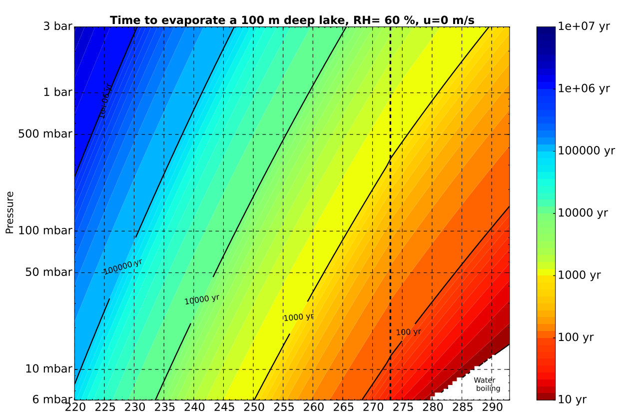

Figure 1: Individual lake's lifetime as a function of pressure and temperature

Figure 1 shows that even for multi-bar atmospheres, a liquid lake ($T > 273K$) will evaporate in less than 10,000 years if not resupplied by precipitation. Similarly, for surface pressure values below 100mbar, which is our preferred environmental context, any temperature $T > 247K$ will also result in the evaporation of the lake in less than 10,000 years. The calculation is conservative as we assumed a high humidity content of the atmosphere (RH=60%) and no convective evaporation.

At 273K, we estimated that Earth-like rainfall rates in the order of 0.1-1 m/yr are required to resupply the lake, depending on the average wind speed (not shown). The absence of geological evidence for the overall weathering that would be associated with such rainfall rates during the Hesperian motivated the investigation of a "cold and wet" scenario for Gale.

The Antarctic lakes analogs

Two different types of Antarctic lakes may be adequate analogs for ancient Gale: the Dry Valleys and the lake Untersee. Both lakes experience annual mean temperature below freezing, respectively -20^o and -10.6^o [4], [5] and still maintain liquid water underneath the ice cover. The area of a perennially covered lake is set by the balance of annual meltwater input and ablation from the surface of the ice cover. The thickness of the ice cover is set by the energy and mass balances of the ice cover, mass being removed by ablation at the surface and added to the bottom by freezing. [4] For the Dry Valleys, the meltwater is provided by seasonal melt of a nearby glacial and driven by the degree days above freezing. For the lake Untersee, the meltwater is provided by subaqueous melting of a glacial dam flowing into the lake and driven by the sunlight which penetrates and warms the bottom of the ice cover *[McKay et al., in prep.]*. We decided to apply the lake Untersee model for Gale as it does not require liquid water to flow at the surface at any time of the year and computed ice thicknesses of perennially-covered lakes at Gale crater as a function of the mean annual temperature and the ice transparency [4], *[McKay et al., in prep.]*

Our best estimate for the annual mean surface temperature at Gale 3.5 Gya is 230K. This value was derived from the surface energy balance assuming present-day obliquity and a simple parametrization for the downward IR radiation was used to mimic a greenhouse warming effect. The downward IR flux was arbitrary chosen as 15% of the peak noon time insulation (present-day value

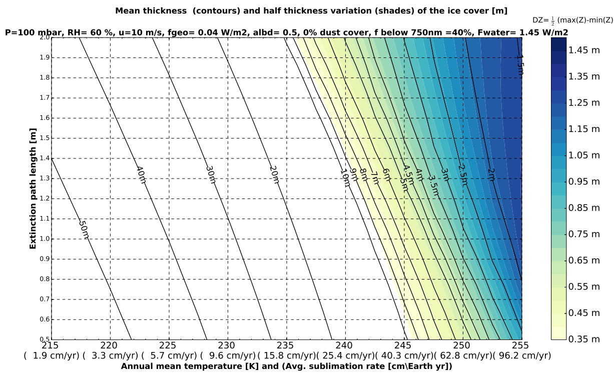

Figure 2: Ice thickness as a function of the extinction path length and mean annual surface temperature (contours). Thickness variation is shown in shades

is close to 4% [6]).

Results

Figure 2 shows that at 230K, the ice thickness ranges from 20-30 meters depending on the ablation rate and the ice transparency and would likely inhibit sediments from entering the lake. Also, for ice covers thicker than 10m, the seasonal variation of the ice thickness is negligible, in the order of +/- a few centimeters to 10's of centimeters. Thus, a first conclusion is that the ice must not be too cold.

We found that for a mean annual temperature of 245K, the ice thickness ranges from 3-10 meters, depending on the ice transparency. These values are comparable to the range of those for the Antarctic lakes (3-6 m), and are not implausible. And they are not so thick that sediments cannot penetrate the ice.

Conclusion and on-going work

Raising the mean annual temperature to 245K is challenging, but not quite as hard as reaching the freezing point. The binary "warm and wet" versus "cold and dry" scenarios for early Mars may have come from the misconception that a liquid lake will freeze solid over time if the surface temperatures are always significantly bellow freezing. This is simply not true as the sublimation of the ice cover and the sunlight penetrating the ice will stabilize the solid/liquid interface at a certain depth. Possibly, if the ice is thin enough to let sediments penetrate the ice, geological features associated with aqueous environments are still possible in a perennially-covered lake on a cold, yet wet planet.

If some geological features at Gale can be interpreted as evidences of a past cold climate environment [7], a major limitation of the ice-covered lake model is the absence of certain glacial features such a glacionenic deposits, boulder conglomerates, or frost wedges, which have not been observed at Gale [1]. On-going work has been done to investigate the sedimentation rates and processes for ice-covered lakes (particles melting through the ice, ice cracks, subglacial flow...) to assess if they could possibly be consistent with the sedimentary deposits observed at Gale *[Rivera-Hernandez et al., in prep]*.

Finally, the main advantage of the ice-covered lake model and the main reason we pursued it, is that it relaxes the requirement for a long-lived active hydrological cycle involving rainfall and runoff, which no climate model is able to produce given known constraints on the early Mars environment.

References

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