OCEANS ON MARS: THE POSSIBILITY OF A NOACHIAN GROUNDWATER-FED OCEAN IN A SUB-FREEZING MARTIAN CLIMATE. Ashley M. Palumbo[1] and James W. Head[1], [1]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence RI 02912, USA (Ashley_Palumbo@Brown.edu).

Introduction: Numerous lines of evidence [e.g. 1–3] suggest that oceans may have existed in the martian northern lowlands (NL) earlier in history, one in the Noachian and one in the Late Hesperian. Although the evidence for oceans is debated [e.g. 4], such a large body of water would have influenced the global hydrologic cycle, climate, and habitability. Thus, determining the required climatic conditions for the formation of oceans increases our knowledge of the plausibility of the oceans and, in turn, improves our understanding of the evolution of Mars. Here, we focus on the required conditions for formation of a Noachian ocean.

Background: On Earth, groundwater-fed bodies of water form where the groundwater table intersects the surface, exposing water that fills a topographic low to the height of the local water table. This same mechanism has been proposed to explain the filling of some martian lakes, such as Columbus crater lake [5]. Formation of the Noachian ocean has also been attributed to this same mechanism of groundwater release [3]. Two criteria are required [3,6]: (1) a large groundwater reservoir, required for the groundwater table to intersect the surface, and (2) global mean annual temperature (MAT) >273 K, required for there to be no cryosphere; a cryosphere would prevent groundwater release, instead trapping it in the subsurface. The first requirement is inferred to be met [3,6] because formation of the Hesperian ocean requires a very large groundwater reservoir [7], implying that such a reservoir existed in the Noachian [3,6]. The second requirement is commonly inferred to be met because of the hypothesized presence of a long-lived "warm and wet", global MAT >273 K, Noachian climate [e.g. 8] (Fig 1A).

The presence of a "warm and wet" climate, however, is a topic of debate: studies have suggested that the climate may have instead been "cold and icy" [9,10], characterized by global MAT ~225 K and a global cryosphere, impeding the formation of an ocean (Fig 1B).

We must consider that global MAT lacks information about seasonal and regional temperature variation. Seasonal variation is driven by solar insolation changes. Regional variation is driven by the adiabatic cooling effect: the higher Noachian atmospheric pressure leads to coupling of the surface and atmosphere, which causes temperature to be dominantly dependent on altitude instead of latitude. In this regime, lower elevation areas have local MAT that is higher than global MAT. This suggests that local MAT can be >273 K even if global MAT is <273 K, and that the temperature requirement for groundwater release can be met in a climate with global MAT <273 K, colder than a "warm and wet" climate. Previous studies of Noachian ocean formation have only considered global MAT [3]; they exclude the regional and seasonal effects.

Here, we explore whether regional and seasonal temperature variations could permit formation of a Noachian ocean in a climate with global MAT <273 K (Fig 1C), or alternatively, whether a "warm and wet" climate is required. We address the following questions:

(1) What is the coldest global MAT at which groundwater release could occur somewhere on Mars?
(2) In what locations would release occur?
(3) If local MAT is slightly below 273 K, are seasonal temperature variations sufficient to remove the cryosphere and permit groundwater release?
(4) How large of a near-surface water inventory is required for groundwater release?
(5) If punctuated heating occurred in an ambient "cold and icy" climate (global MAT ~225 K), how long must these punctuated conditions persist to remove the cryosphere and permit groundwater release?

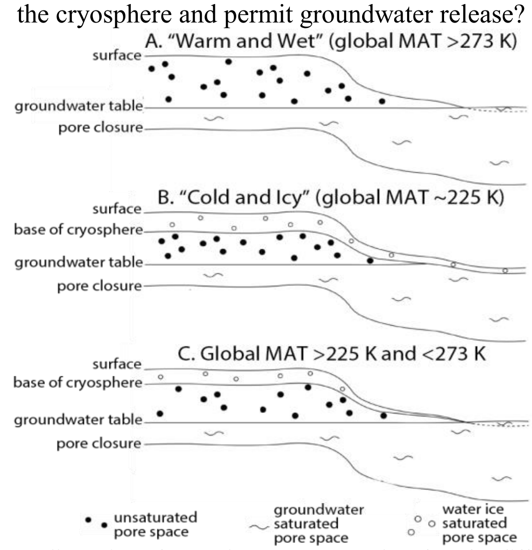

Fig 1. Illustration of groundwater system and surface for different climate cases. Left is highlands, right is lowlands. (A) "Warm and wet": no cryosphere separates groundwater from surface. If enough water is present, the water table will intersect the surface and water will release. (B) "Cold and icy": global cryosphere prevents groundwater release. (C) Global MAT >225 K and <273 K: no cryosphere in lowest elevation areas (e.g. NL), permitting groundwater release.

Methods: We integrate two methods to test the hypothesis that a groundwater-fed Noachian ocean could have formed in a climate with global MAT <273 K. (1) We utilize the 3D LMD GCM for early Mars and implement representative Noachian spin-axis/orbital [13] and atmospheric pressure [14] constraints. We run the model at a resolution of 64x48x25 and collect hourly data; these resolutions are sufficient to capture the regional and seasonal temperature variation. To produce simulations with a range of global MAT from 225 K “cold and icy” to 273 K “warm and wet”, we introduce ‘gray gas’ into the model atmosphere. Gray gas absorbs evenly across the IR spectrum at a defined absorption coefficient to simulate greenhouse warming without incorporating specific greenhouse gases. (2) We model 1D heat conduction in the subsurface to observe the influence of bottom-up geothermal and top-down heating on subsurface temperatures [3,12], using contemporary estimates for martian physical properties, such as geothermal heat flux [15,16], porosity [12] and the decay with depth, and thermal diffusivity and conductivity [3]. GCM-predicted temperatures are fed into the thermal model as input for top-down heating.

Results: The results of our combined models indicate that groundwater release and formation of a Noachian ocean is possible in a climate with global MAT >225 K and <273 K. Below, we address the five questions outlined previously:

(1) Our simulations show that local MAT >273 K exists in specific, low elevation, areas for global MAT >255 K (Fig 2). Thus, the temperature constraint for groundwater release is met if global MAT was >255 K; a “warm and wet” climate is not required.

(2) Due to the adiabatic cooling effect, the highest local MAT occurs within the lowest elevation regions, Hellas basin and Utopia Planitia. The temperature constraint for groundwater release is met at Hellas and Utopia for long-lived global MAT >255 K and >258 K, respectively (Fig 2). The release of large volumes of water at Utopia can lead to flooding of the NL and formation of an ocean.

(3) Our thermal model results suggest that hot summer temperatures are only sufficient to remove the cryosphere temporarily and permit summertime groundwater release in areas where local MAT is ~272 K, very close to the melting point of water.

(4) The minimum required volume of subsurface water for the water table to intersect the surface and permit groundwater release at Hellas is ~63 m global equivalent layer (GEL) and Utopia is ~170 m GEL.

(5) In a long-lived “cold and icy” MAT 225 K climate, a punctuated heating event would have to occur in order for groundwater release to be possible. If the punctuated heating event was characterized by local MAT 273 K and geothermal heat flux was 45 mW m^{-2} (minimum estimate [16]), our 1D thermal model suggests that the heating must persist for ~5960 consecutive years to permit groundwater release at Hellas and ~15000 years to permit release at Utopia. Recall that local MAT >273 K occurs for global MAT >255 K at Hellas and >258 K at Utopia. The required duration of the heating event decreases for increased local MAT or geothermal heat flux. A heating event of this duration could be caused by impact cratering-induced heating following basin formation [17,18], a transient reducing greenhouse atmosphere with modest concentrations of H_2 or CH_4 [19], or other causes.

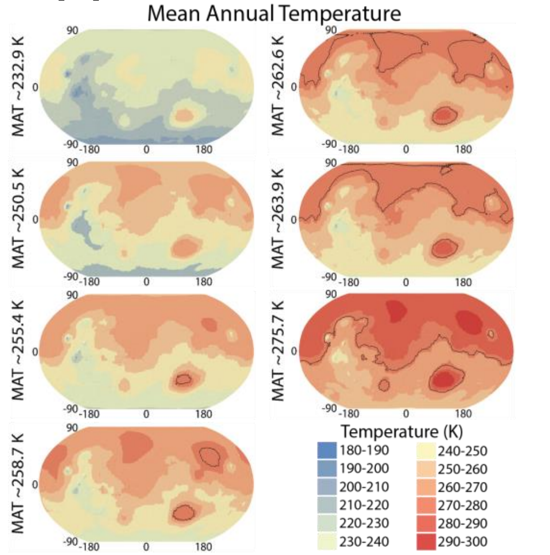

Fig 2. GCM results of 25° obliquity simulations showing variation in regional MAT for different global MATs. Global MAT is labeled to the left of each plot and the black line is the 273 K contour. Simulations with higher obliquity (e.g. 45° [13]) show similar results.

Conclusions: The formation of a groundwater-fed ocean does not require a continuous and long-lived “warm and wet” climate with global MAT >273 K. If long-lived Noachian global MAT was >255 K and the subsurface contained >63 m GEL water, groundwater could release onto the surface at Hellas and pond within the basin; global MAT >258 K and >170 m GEL subsurface water is required for release at Utopia. Groundwater release at Utopia could lead to flooding of the NL and formation of an ocean. Further, in a “cold and icy” MAT 225 K climate, a heating event that raised global MAT to >255 K for a few thousand years could lead to groundwater release and flooding of the lowest points on Mars.

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