POLAR BASAL MELTING AT LOW OBLIQUITY ON A COLD EARLY MARS AND ITS POTENTIAL IMPLICATIONS FOR THE RECHARGE OF A NORTHERN OCEAN. S. M. Clifford[1], R. D. Wordsworth[2] and R. Greve[3], [1]Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ 85719 USA (sclifford@psi.edu); [2]Dept. of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138, USA; [3]Institute of Low Temperature Science, Hokkaido University, Sapporo 060-0819 Japan.

Introduction: The MARSIS orbital radar sounder has identified at least one location at the base of the present-day Martian south polar layered deposits (SPLD) where the combination of mean annual temperature, polar deposit thickness, thermal conductivity, local geothermal heat flow, and salt-induced freezing point depression, are sufficient to raise the basal temperature to the melting point [1, 2]. However, during the Late Noachian/Early Hesperian (LN/EH), the conditions for basal melting are thought to have been significantly more favorable, including a denser atmosphere, warmer climate, thicker and more extensive polar deposits, and a ~2-3x higher geothermal heat flow. Such melting is believed to have been the primary mechanism for the recharge of an early subpermafrost groundwater system and the potential replenishment of an ice-covered northern ocean [3, 4] – the two most probable habitable environments for sustaining Martian life.

To investigate this potential, we have integrated a Mars GCM [5, 6] with a dynamical model of the evolution of large ice sheets [7, 8], which is used to predict ice sheet extent and thickness (Fig 1a), flow velocity, basal temperature (Fig. 1b) and melt rate, based on a polar water inventories of 150-250 m GEL, atmospheric surface pressures (0.1 - 1 bar CO_2), obliquities (5° - 35°), geothermal heat flow (45 - 65 mW m^{-2}) and Martian crustal properties. We find that for a 1-bar atmosphere, 25° obliquity, and 200 m GEL polar inventory of water, up to ∼1.4 km^3 of H_2O may have been introduced into the subsurface each year by basal melting (Table 1) – resulting in the growth of a groundwater mound >1 km high in ~10^4 yrs and the cycling of up to ∼960 m GEL of water through the atmosphere and subsurface every 10^8 yrs.

Table 1. Influence of obliquity and geothermal heat flow on the basal melting of the LN/EH SPLD, for a 1-bar CO_2 atmosphere and 200 m GEL polar inventory of H_2O.

	Basal Melting Rate (km^3 yr^{-1})		
Obliquity	45 mW m^{-2}	55 mW m^{-2}	65 mW m^{-2}
5°	0.0017	0.17	1.07
15°	0.0045	0.25	1.34
25°	0.019	0.32	1.39
35°	0.023	0.26	0.94

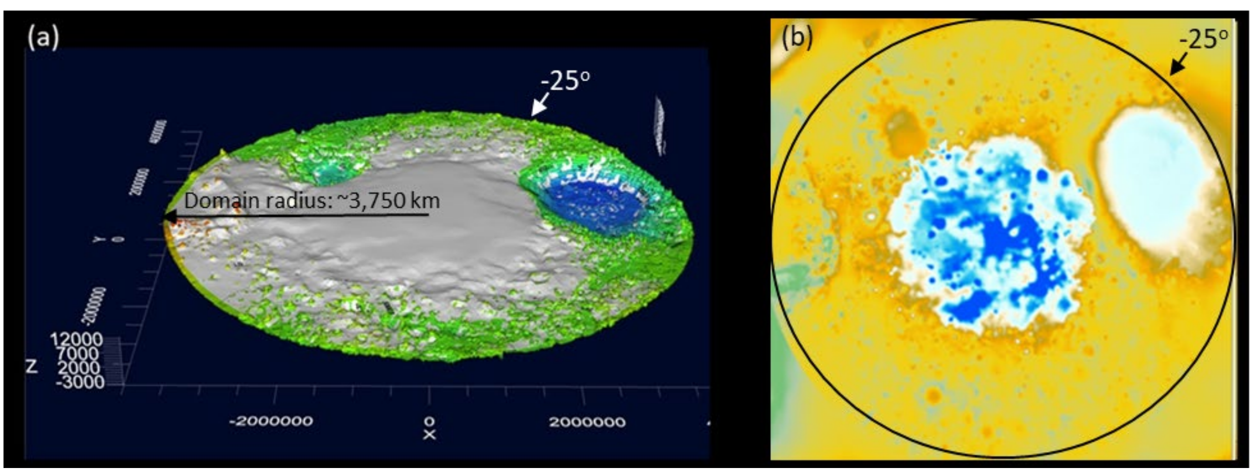

Fig. 1. (a) Predicted ice sheet extent and thickness for 1-bar, 25° obliquity, 55 mW m^{-2} heat flow and polar water inventory of 200 m GEL. (b) Ice sheet basal temperature distribution for (a), where dark blue indicates regions of active basal melting. Visible model domain extends to -25°, while the groundwater simulation domain extends 2,500 km further.

The response of a subpermafrost groundwater system to polar recharge is calculated using an unstructured grid implementation of the USGS groundwater modeling software MODFLOW. The model domain consists of a south polar stereographic projection of Mars extending down to -25º – a radial distance of ~3750 km (Fig. 1a). For the groundwater head boundary condition, the same crustal properties are assumed to extend another 2,500 km beyond the domain periphery. This is the distance to Contact 2, which has been identified as the possible paleoshoreline of a LN/EH northern ocean [9]. Our nominal crustal model consists of an impermeable cryosphere followed by 6 progressively thicker, less permeable layers extending to a maximum depth of -27 km. The initial water table depth is assumed to lie at the same elevation as Contact 2 (i.e., -3792 m, Fig. 2) [9].

Polar basal melting is modulated by the planet's $1.2x10^5$-yr obliquity cycle and Fig. 2 illustrates how an early subpermafrost groundwater system would have responded to multiple episodes of obliquity-driven basal melting. At T0, the groundwater table is assumed to lie at the same elevation as the ocean 'sea level'. In reality, previous episodes of rainfall, during a warmer early climate, should have charged the highland's crust with groundwater – resulting in an elevated water table before a global cryosphere developed.

As the SPLD grew in response to the precipitation of water sublimed from an ice-covered ocean, basal melting of the SPLD would have resulted in the formation of a transient groundwater mound that propagated away from the pole as each obliquity-induced phase of basal melting subsided. As it did so, the amplitude of this pulse would have declined and its width broadened until it reached the northern ocean, some ~10^7 – 10^8 yrs later (T1). Repeated episodes of basal melting would have caused the elevation of the highland's water table to rise over time (T2) due to the relatively low permeability of the crust. This also increased the south-to-north hydraulic gradient, thereby increasing the flux of groundwater into a northern ocean.

Our preliminary results indicate that, given reasonable values of crustal permeability, sufficient basal melting may have occurred at low obliquity to sustain an ice-covered ocean for up to several hundred million years. Factors that may have influenced whether a northern ocean would have frozen throughout or sublimed away faster than it was replenished, include: (i) the rate and duration of basal melting, (ii) the permeability of the southern highland crust, (iii) how quickly the early climate cooled, and (iv) the thickness of any sedimentary deposits that may have inhibited the thermal exposure and sublimation of the ocean ice cover.

At obliquities >40º, atmospheric precipitation and ice sheet development would have preferentially occurred at lower latitudes – primarily in Tharsis and Elysium – where basal melting has the potential to replenish a northern ocean on a much faster timescale (~10^3 yrs), scenarios we plan to investigate in the coming year.

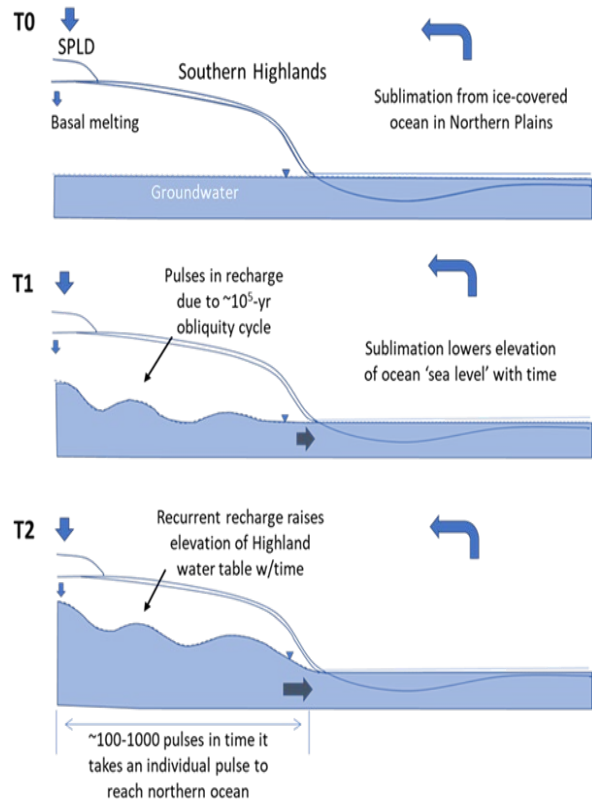

Fig. 2. Pole-to-pole cross-section of the crust illustrating the temporal evolution of a subpermafrost groundwater system after the onset of basal melting.

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