The Habitability of Exoplanets Through Geothermal Heating

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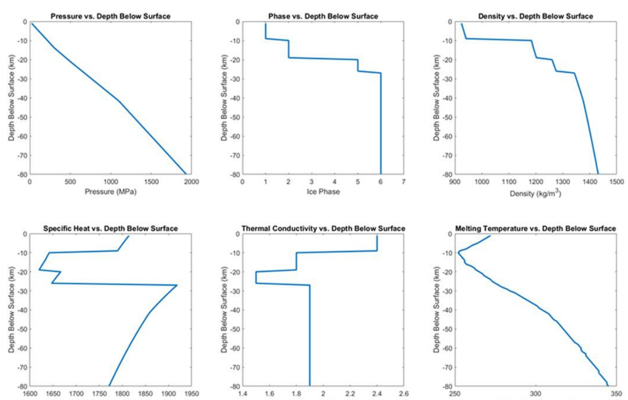
Problem Description

The most important factor for the stability of liquid water is adequate temperature and pressure. As the depth of ice increases on a planetary surface, the pressure and temperature dramatically affect the crystalline structure of ice. Radiogenic heating could provide the extra means of heat for the melting of large H_2O ice glaciers to occur and produce this liquid water. On Earth and Mars, radiogenic heating has been shown to create substantial bodies of liquid water underneath thick ice caps (Ojha 2020). Underneath large ice sheets, heat flow from radiogenic elements can cause basal melting, with the ice acting as a great insulator for the heat flux percolating throughout it. This could potentially provide for great environments for biological development and evolution to take place.

Steady State Temperature Profile

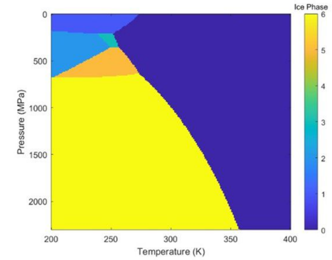
A steady state temperature profile was first made before figuring out how parameters such as ice phase, thermal conductivity, specific heat, density, and specific heat would vary with time and throughout an ice sheet, Once these parameters were found as a function of depth, they could then be plugged in to our thermal evolution profile, with these values changing over time by using the 1-D Heat Diffusion Equation.

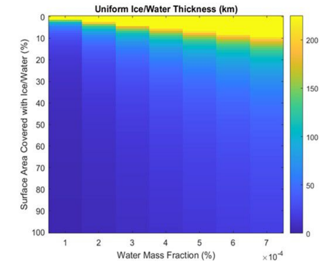


Ice Phase Plots and Distribution

When evaluating the role radiogenic heating has on the stability of water in the subsurface of a planet or moon, varying ice phases as a result extreme pressures and temperature changes must be considered. This subsequently leads to varying densities, thermal conductivities as a function of depth etc. throughout the glacier shelf.

The plot on the bottom left depicts the possible uniform ice/water thicknesses of exoplanet LHS 1140 b. The thickness is a function of possible surface area water/ice coverage and water mass fractions, with the hypothesized maximum being a WMF of ~.0007 (Lillo-Box 2020). On the bottom right is an Ice Phase plot as a function of Pressure and Temperature. In this study, Ice phases up to type 6 were evaluated, with Ice Phase 1 being 1h, or hexagonal crystal structure. Ice Phase zero represents liquid water.

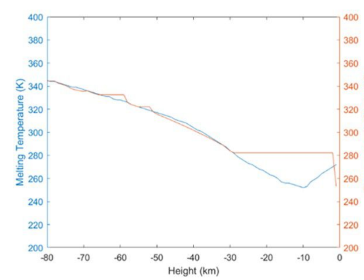


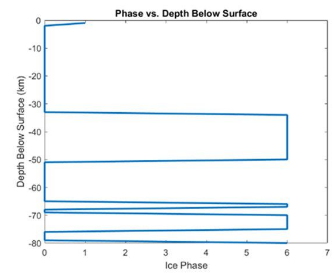


Results

Different Scenarios were modeled through our thermal evolution profile. Resultingly, many scenarios had a possibility of creating liquid water through melt. Depending on heat flux and time, melting can occur at various depths. One of the most promising examples of meltwater being produced by radiogenic heating came by way of a 100 million-year timescale, 60 mW/m² mean surface heat flux scenario. A near 30 km thick near surface ocean, amongst other pockets of water, could be seen to form.

$$\overline{\rho c}\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\bar{k}\frac{\partial T}{\partial z}\right) - \rho_{ice}L\frac{\partial \phi}{\partial t}$$





The 1-D equation describing conservation of energy in the system is above.

Where rho is density, c is specific heat, T is temperature, k is thermal conductivity, L is latent heat of fusion and phi is liquid fraction. Quantities with overbars are volume averaged.

Key Takeaway

Melting is quite feasible on exoplanet LHS 1140 b. The processes modeled here for water production could work in similar manners on other exoplanets and moons such as Enceladus, Europa, and Titan in our very own solar system. The conditions required for melting were not limited to one possibility, and as such, pockets of water have a great chance of existing throughout thick ice glaciers being heated by radiogenic decay due to the conditions on LHS 1140 b and the environment sustained by its central M-Type star LHS 1140.

Works Cited:

1. Ojha, L., Buffo, J., Karunatillake, S., & Siegler, M. (2020). Groundwater production from geothermal heating on early Mars and implication for early martian habitability. Science advances, 6(49), eabb1669.
2. Lillo-Box, J., Figueira, P., Leleu, A., Acuña, L., Faria, J. P., Hara, N., ... & Pepe, F. (2020). Planetary system LHS 1140 revisited with ESPRESSO and TESS. Astronomy & Astrophysics, 642, A121.