A COORDINATED LUNAR RESOURCE CAMPAIGN FOR SUBTERRANEAN LUNAR WATER

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Introduction: The Moon has a hot interior and a relatively cold surface, with a cooler crust on top of a warmer mantle. The near-surface thermal conductivity measured by the Apollo ALSEP experiments [1] was very low, with k of order 10^{-3} W K^{-1} m^{-1} in the top 2-cm of the regolith, and order 10^{-2} W K^{-1} m^{-1} at a depth of 1 meter [2]. Below a regolith layer of order 10 - 20 meters depth, the lunar crust must approach the much larger thermal conductivity of its constituent rocks, thought to be plagioclase feldspars in the lunar highlands; we estimate a bulk crustal thermal gradient beneath the Apollo 17 site of 11.2 K km^{-1} with a bulk crustal thermal conductivity of 0.94 W K^{-1} m^{-1}, in reasonable agreement with the measured thermal conductivity of plagioclase feldspar labradorites [3].

Lunar Water at Depth: Even if the lunar interior is totally dry, water has been delivered to the Moon by the impacts of comets and meteorites [4], possibly during periods of a transient lunar atmosphere [5]. This water, although initially distributed on the lunar surface, could be subsequently buried by later meteorite impacts or even lunar volcanism.

While surface ice is thought to be geologically stable only in regions with surface temperatures $\lesssim$ 110 K, i.e., in the Permanently Shadowed Regions (PSRs) close to the poles, sublimation of underground ice is slowed by the overhead rock and regolith between it and the surface. Buried ice can be stable underground at higher temperatures [6], and can thus survive at depth in a wider latitude range. **Any** region with underground ice is likely to have underground liquid water in the warmer rock layers beneath; with the subsurface ice cap protecting the water and preventing it from escaping to space.

Figure 1 shows the depth of a temperature of 0° C for the two 1-D thermal equation models. As the subsurface temperature increases monotonically with depth, water ice can exist above the indicated curves, and liquid water below each curve. Near the poles water ice could form very thick subterranean layers, potentially many km thick [7], whereas at midlatitudes this resource would be closer to the surface, and below about 40° latitude the subsurface is too warm for unprotected water to survive at any depth.

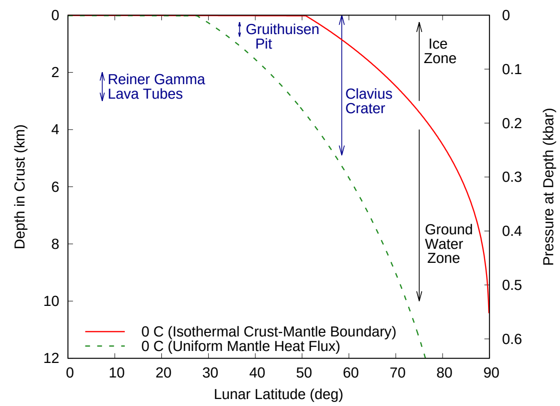

Figure 1: The depth at which pure liquid water would freeze assuming a 1-D heat equation and two types of boundary conditions: Dirichlet boundary conditions (with an isothermal crust-mantle boundary) and mixed Dirichlet-Neumann boundary conditions (with a uniform crust-mantle boundary heat-flux). Liquid water may be found under a cap of ice even at mid-latitudes, and it is even possible that buried features, such as the hypothesized Reiner Gamma lava tubes, could be protected by solid lava layers, instead of by ice, and thus might maintain some liquid water.

Searching for Liquid Water with MHz Radar: Subsurface water lakes are clearly a potential economic resource. Extracting surface water from lunar PSRs will be difficult and expensive, requiring the development of mining technologies capable of operating at 110 K in constant darkness. Extracting subsurface liquid water, by contrast, could be done by drilling in sunlight with direct communications with Earth.

Experience with Ground-Penetrating Radar (GPR) on Mars [8] shows that 1 MHz radar can penenetrate deep into dry regolith crustal material, receiving radar echos from liquid water at depth. Both surface and orbital radars should be deployed in the lunar environment to search for water; in addition, some areas (such as Clasius Crater) may be still releasing subsurface water into space; the electrical properties of these regions should be explored to characterize these emissions.

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