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Thermochronometry of Lunar Cold Traps via Thermoluminescence: Probing Their Thermal Equilibrium Over Billions of Years

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The lunar regolith displays very strong thermoluminescence (TL). When heated between room temperature and 773 K, the regolith displays eight discrete TL peaks, each with a characteristic activation energy and rate constant (usually referred to as the trap depth, *E*, and frequency factor, *s*). Tentative evidence and theoretical considerations suggest that as many peaks exist below room temperature, and some probably exist around 100 K.

Since temperature and time can be calculated from the TL signal for each peak, the natural thermoluminescence of regolith functions as a thermochronometer and could be used as a tool for prospecting for water ice and other volatiles on the Moon.

In this study, we extend the theory to environmental temperatures relevant for the coldest regions on the Moon, and explore the effect of TL kinetic parameters, namely *E* and *s*, as well as changes in signal strength (*n/N*), environmental dose rate ($\dot{D}$), and characteristic dose (D_0) on the equilibration timescales ('apparent age') and temperatures (T_{eq}).

Extrapolating data from above room temperature to 100 K suggests that the activation energy (*E*) and frequency factor (*s*) for peaks in the 200 K glow curve region are ~ 0.6 eV and 10^{12} s^{-1}, respectively. The characteristic dose is ~5×10^6 Gy, while radiation dose rate on the lunar surface is well established at 0.1 Gy/year.

We find that while frequency factor, signal strength and environmental dose rate have little impact on the calculated equilibrium timescales, *E*and D_0 do (Figure 1). While *E* and *s* determine the equilibrium temperatures (T_{eq}), their measurement uncertainty introduces only a ±10 K error, whereas D_0 has the largest effect (Figure 2). However, this parameter can easily be determined by simple measurements involving artificial irradiation of the sample in a laboratory apparatus at cryogenic temperatures or in-situ on the Moon by a flight-scale TL apparatus (currently at TRL 4).

We conclude that TL can serve as a reliable thermochronometer, covering timescales from tens of millions to several billion years. This capability would enhance our understanding of lunar surface processes involving thermal disturbances in the lunar environment below 100 K.

Figure 1: Thermochronometry via TL

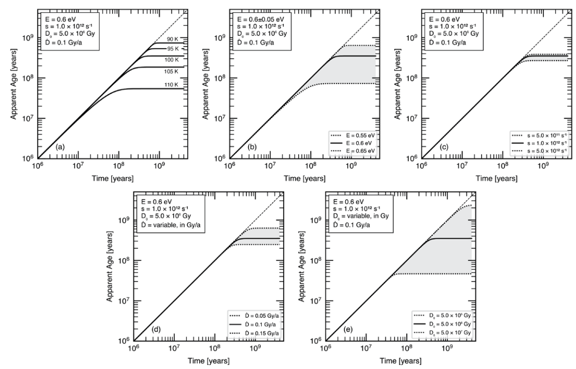

Figure 1: Apparent age evolution (a) at different lunar environmental temperatures, (b) variation of trap depth, (c) frequency factor, (d) environmental radiation dose rate, and (e) characteristic dose for the curve at an environmental temperature of 100 K. Effect of variation of parameters is given by the dotted lines, gray areas represent the range. When functioning as a chronometer, the system's age trajectory follows the 1:1 reference line (dashed); when acting as a thermometer, the apparent age approaches a fixed value.

Figure 2: Equilibrium Temperatures on the Moon

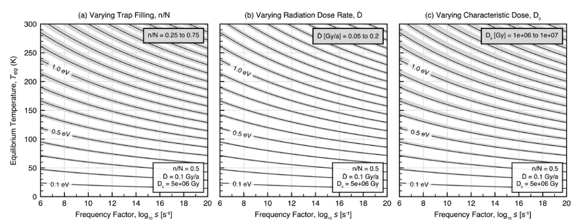

Figure 2: Variation in equilibrium temperature (T_{eq}) depending on *E* and *s* for (a) different levels of trap filling, variations in (b) radiation dose rate and (c) characteristic dose. Gray areas represent the range over which the parameters vary. Black lines are defined by parameters given in lower right box for each plot.