COSMIC RAY RADIATION HISTORY EXAMINED USING HIGH TEMPERATURE THERMOLUMINESCENCE

Jannette M.C. Akridge, Paul H. Benoit, and Derek W.G. Sears. Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, Arkansas 72701, USA

Abstract

Because of the stability of a high temperature peak found at about 310 ^{0}C in the glow curve, natural thermoluminescence can be used to detect variations in the relative cosmic ray dose rates of meteorites. Approximate dose rates for Lost City, Pribram, Innisfree, Paragould, Tilden, and Chicora ranging from 0.39 to 1.15 rads/yr. The variations in the calculated results may indicate a decrease in the cosmic ray dose rate with aphelion, or large differences in shielding.

Introduction

Natural thermoluminescence (TL) in meteorites reflects thermal and radiation history. The TL glow curve can be roughly divided into two portions. The low temperature TL is in a state of dynamic equilibrium which is dependent upon storage temperature and dose rate. The high temperature TL level is less thermally sensitive,[1] and primarily reflects radiation history. The natural TL glow curve is actually composed of many peaks.[2,3] In our study we used peak 4 in the high temperature region of the glow curve (Fig. 1) to evaluate the cosmic ray dose rate of a group of observed falls.

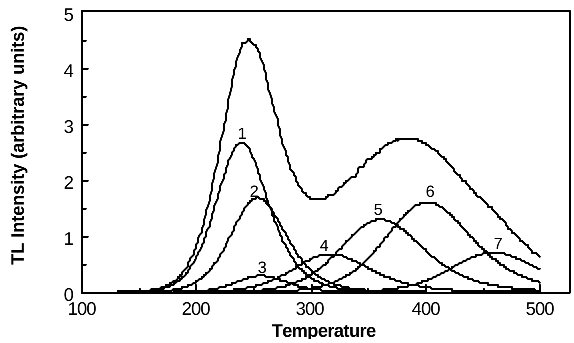

Figure 1. The natural TL glow curve of Pribram. Under the glow curve are the individual peaks that sum together to form the whole curve.

Theory

If a phosphor is stored at a temperature, T,with an absorbed radiation dose rate, r, the rate of filling of a TL trap per unit volume can be described by[4]

$$\frac{\mathrm{dn}}{\mathrm{dt}} = \frac{1}{R_0} r(N - n) - sn\exp\left(\frac{-E}{kT}\right) \qquad \text{eq. 1}$$

where n = number of filled traps, approximately equal to peak height, N = total number of traps, approximately equal to saturation peak height, *s* = a frequency factor, E = trap depth, R_0 = dose required to reach saturation, and *k* = Boltzmann's constant. The first term is the rate at which traps are filled while the second term is the rate at which the traps are emptied by thermal excitation. When the rate of filling equals the rate of emptying, the peak is in a state of dynamic equilibrium. Equation 1 can then be solved for the dose rate:

$$r = s\ \exp\left(\frac{-E}{kT}\right) * \frac{R_0}{\frac{N}{n_m} - 1} \qquad \text{eq. 2}$$

where n from equation 1 is now represented by n_m, the equilibrium peak height. The decay parameters E and *s* can be determined using a computerized curve-fitting procedure.[5] The build up parameters N and R_0 can be determined by successive irridiations of the meteorite in the laboratory with known doses, and n_m is measured directly from the natural TL glow curve.

Methods

We measured the natural TL levels of three meteorites with known orbits (Lost City, Innisfree, Pribram) and three for which orbits have been estimated using visual observations (Chicora, Paragould, Tilden)[6,7,8,9]. We determined TL decay parameters (E and s) using a curve fitting program (Fig 1). The values of E and *s* were tested by heating the samples for varying lengths of time and comparing calculated decay with experimental decay. The values of N and R_0 were experimentally determined by subjecting samples to known doses of radiation at very high dose rates, relative to natural dose rates, so that thermal decay was negligible. The value of n_m was measured directly from the natural TL glow curves.

Results and Discussion

The E and *s* values of Pribram's of peak 4, 1.227 ± 0.007 and 3.53 ± 0.03 x 10^9 respectively, are similar for each of the meteorites. Figure 2 shows the experimental and theoretical heating curves used to verify and refine E and *s*. The trap-filling values of N and R_0 were determined using dose response curves. The curves of the six meteorites were very similar. Each sample took about 380 krads, R_0, to reach saturation. The saturation level, N, for each meteorite is dependent on the amounts of trace minerals responsible for the production of TL Therefore the saturation value of each meteorite will vary.

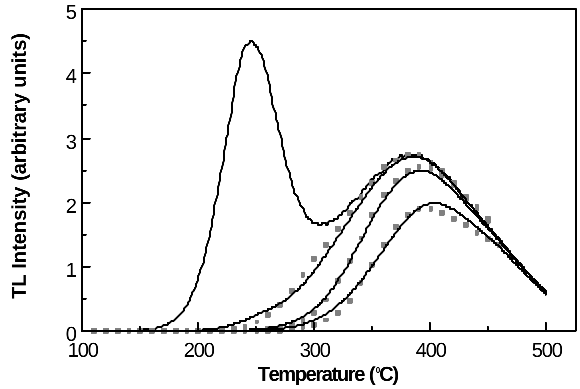

Figure 2. The natural TL glow curve of Pribram. The gray squares represent the natural TL glow curve after successive heatings. The solid lines represent calculated decay curves for the experimental conditions.

Calculated dose rates (rad/yr) for the meteorites are as follows: Tilden = 0.88±0.04, Chicora = 0.97±0.05, Paragould = 0.39±0.02, Lost City = 1.15±0.06, Pribram = 0.58±0.03, and Innisfree = 0.80±0.04. We stress that these dose rates are only approximations since they have not been corrected for shielding, and because of this the uncertainties represent the relative errors rather than absolute errors. Both shielding and the dose rate affect the equilibrium value, n_m, reached. If the degree of shielding for each sample is comparable then the variation seen represents actual differences in the cosmic ray flux. Figure 3 is a plot of the calculated dose rates against aphelion data taken from [6,7,8,9]. If shielding varies from sample to sample, the trend in figure 3 would probably still be present since an order of magnitude or more difference in shielding would be needed eliminate the apparent relationship.

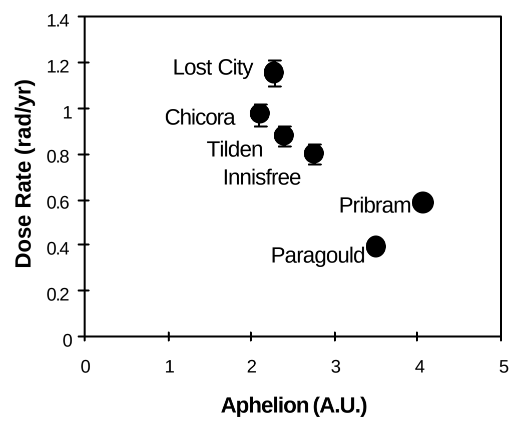

Figure 3. Calculated Dose Rates vs. aphelion. The aphelion of Innisfree, Lost City, and Pribram was calculated from photographs and video. The others were estimated from visual observations.

Conclusions

Peak 4 in the natural TL glow curve is at equilibrium and is not affected by the temperatures experienced during close passage to the sun. This peak can therefore be used to calculate relative cosmic ray dose rates for our suite of meteorites. Based on our experiments and calculations, the dose rates of meteorites with large aphelion appear to be lower than those with smaller aphelion.

References

1, D.W.G.Sears (1988) *Nucl. Tracts Radiat. Meas.* **14**, 5-17.; 2, S.W.S. McKeever (1980) *Mod. Geol.*, **7**, 105-114.; 3, P.H. Benoit *et al.* (1991) *Icarus* **94**, 311-325.; 4, C. Christodoulides *et al.* (1971) *Mod Geol*, **2**, 275-280.; 5, S.W.S. McKeever (1985) **Thermoluminescence of Solids**.; 6, Z. Ceplecha. (1961) *Bull. Astron. Czech.*, **12**, 21-47.; 7, I. Halliday *et al* (1978) *J. R. Astron. Soc. Can.*, **7**, 15-39.; 8, R.E. McCrosky *et al* (1971) *J. Geophys. Res.*, **76**, 4090-4108.; 9, A.N. Simonenko (1975) **The Orbital Elements of 45 Meteorites.**