COSMIC RAY INDUCED THERMOLUMINESCENCE IN METEORITES

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ABSTRACT

The observed thermoluminescence level in a meteorite is found to be a complex function of the cosmic ray dose rate, the orbital parameters and the size of the parent body, as also of the thermal and shock effects associated with its traversal through the terrestrial atmosphere. In an effort to understand the energy spectrum and the intensity of cosmic rays during the past few m.y., we have carried out study on TL levels on a suite of eight chondrites with effective preatmospheric radius in the range of 6 to 29 cms. A comparative study of the depth profile of TL with those of fossil track density, ^{26}Al and ^{53}Mn allows us to determine the cosmic ray energy spectrum in the ev-MeV range. These studies also enable us to assess the thermal effects associated with meteorite ablation and orientation during its terrestrial trajectory.

1. Introduction

Thermoluminescence (TL) levels in meteorites reflect a dynamic equilibrium between the TL production due to cosmic ray exposure and its thermal decay at ambient space temperatures. Ionization due to galactic cosmic rays provide a dominant contribution to TL induction with nearly insignificant contribution by internal radioactivity. Considerations on GCR attenuation suggests that most of the TL is acquired after the break-up of the meteoroid from the parent body. Qualitatively the factors that determine the TL levels are (i) the size of the meteoroid; (ii) orbital parameters e.g., perihelion distance; (iii) heating and shock suffered during entry into the earth's atmosphere which in turn depends on orientation and fragmentation during its trajectory; and (iv) the terrestrial age of the meteorite.

With the objective of using TL levels of meteorite for estimating the energy spectrum of cosmic ray fluences and the temporal variation of cosmic ray dose rate, a large number of meteorites have been studied. These studies have been further supplemented by extensive fossil track studies (Bhandari et.al., 1980) on samples from the cores drilled through the meteorites and the measurements of radionuclides such as ^{26}Al and ^{53}Mn in these samples (Bhattacharya et.al., 1980).

2. Experimental details

Thermoluminescence as a function of core depth taken from a suite of six chondrites chosen for their preatmospheric size range ($R_E \sim 6-29$ cms) has been measured. Random samples for about 20 other chondrites were also studied. The experimental details have been described earlier (Agrawal et.al., 1981). Briefly, photon counting was used, with EMI 9635 QA photomultiplier tube coupled to Corning 7-59 and 5-58 blue filters. Heating rate was 5^oCs^{-1} and laboratory irradiations were done with a 40mCi ^{90}Sr/^{90}Y beta plaque. The equilibrium doses reported here refer to an equivalent exposure to CaF_2:nat (MBLE Super "S").

3. Results and discussion

The study of the Bansur chondrite which is known to have an oriented entry through the earth's atmosphere, suggests that the low temperature TL, $(TL)_{LT}$, is significantly modified by heating due to ablation, upto considerable depths within the meteorite body (Singhvi et.al., 1982). The least ablated face, as determined by the track density has low $(TL)_{LT}$, whereas the leading face that suffered high ablation has high $(TL)_{LT}$. In comparison, the high temperature TL had a flat profile (Fig. 1), suggesting its relative immunity to thermal processes associated with ablation. This nearly saturated, high temperature TL thus can reflect the depth profile of cosmic ray dose rate in space. Fig. 1 shows the depth profile of equilibrium doses at high temperature for various chondrites alongwith the depth profile of cosmogenic radionuclides (^{53}Mn, ^{26}Al), enabling following inferences:

(i) Most chondrites, with a few exceptions such as Kirin ($\sim$170 k.rads), St. Severin ($\sim$210 k.rads) and Bruderheim ($\sim$240 k.rads), have an equilibrium dose in the range of 125 $\pm$ 25 k.rads. Further no correlation between equilibrium dose and the estimated preatmospheric radius (the sum of the recovered radius and the shielding depth as estimated from fossil track densities) was seen, as is depicted in Fig. 2. It is also evident from the data, that the high temperature TL gradient in all meteorites is nearly flat (within $\pm$ 15%) in chondrites of all sizes.

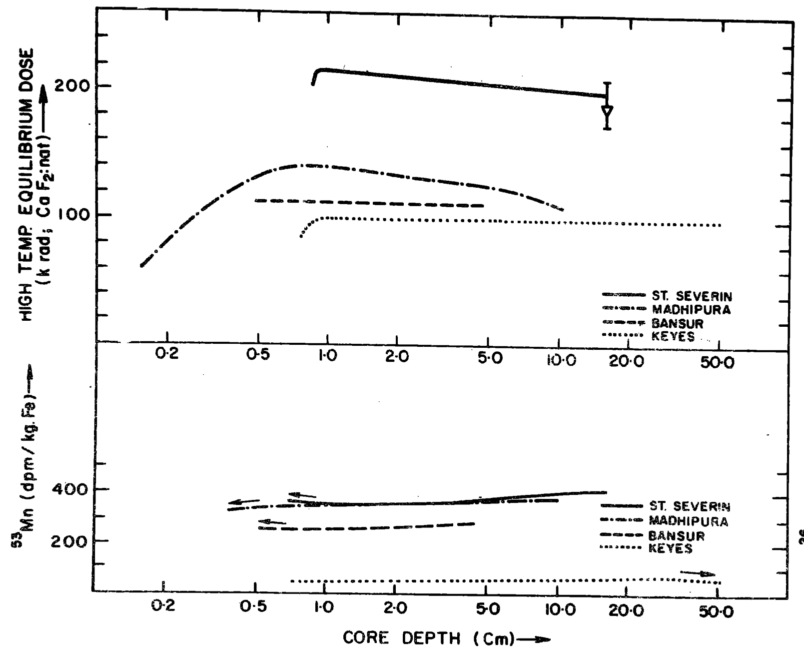

Figure 1: Depth variations of high temperature equilibrium dose (k.rads) and the activity of cosmogenic radionuclides ^{53}Mn and ^{26}Al (dpm/kg) in various chondrites.

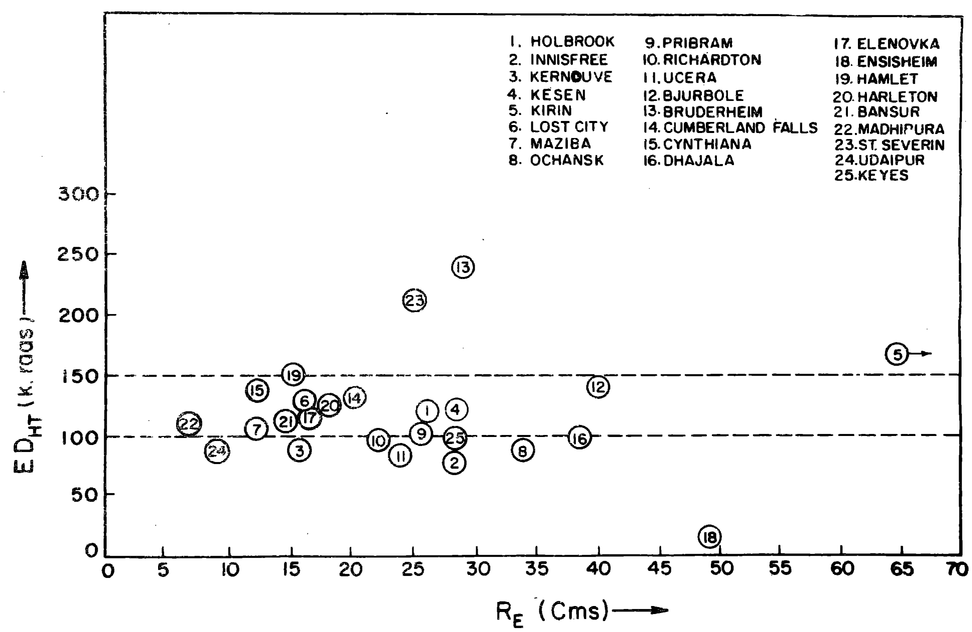

Figure 2: High temperature TL equilibrium dose plotted as a function of preatmospheric radius (estimated as the sum of recovered radius and the shielding depths) inferred by fossil track studies.

(ii) In order to ascertain that the high equilibrium doses in the above mentioned meteorites were genuine, the equilibrium doses were determined by two methods, (a) the normalized growth curve method (i.e. by determining growth curve after the natural (N_{TL}) was erased and estimating as beta dose corresponding to N_{TL}; and (b) the conventional N_{TL}/B_{TL} x dose method (with typical test dose of ~25 k.rads). The similarity of the results by the two methods preclude the possibility of any over-estimation by an extended supra-linear region and a predose effect in other cases, as the cause for this anomaly.

Possible causes for high equilibrium dose in some meteorites include the presence of anomalous orbits with high cosmic ray flux and a possible dose rate effect in some specific mineral phases, and these are now being investigated.

References

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