MEASUREMENT OF TERRESTRIAL AGE OF ANTARCTIC METEORITES BY THERMOLUMINESCENCE TECHNIQUE

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Abstract: The thermoluminescence (TL) of Antarctic meteorites, ALH-77256, 90(Di), ALH-77294,81,82(H5), ALH-765,75,85(Eu), ALH-768,83(H6) and ALH-77272,83,84(L6) is measured. The depth dependence of the TL for ALH-77294, 81, ALH-765,75 and ALH-768,83, which have fusion crusts, is also measured. The heating of the surface material (0-1.5 mm depth) during atmospheric passage is estimated from the fading of the high temperature TL. It is revealed that this atmospheric heating entirely removes the low temperature TL from the surface of a meteorite and the present low temperautre TL glow of the surface material is produced by subsequent terrestrial radiation in Antarctica. The terrestrial ages of these meteorites are estimated from the TL of the surface material with an assumption about the Antarctic storage conditions (stored on the surface or buried under the ice sheet).

1. Introduction

The thermoluminescence (TL) technique, previously used for dating the terrestrial ages of the meteorites (SEARS and DURRANI, 1980; MELCHER, 1981a) was based on the TL fading of interior samples. In space, the TL is maintained at high level by cosmic ray bombardment. Once a meteorite has fallen on the Earth, where the cosmic ray level is low and the environmental temperature is about 25°C, its TL fades. Their terrestrial age was estimated from the magnitude of the fading.

In Antarctica where the environmental temperatures are between −15 and −45°C, the fading rate of the TL is very slow and since the TL of the surface had been removed by heating, the terrestrial age can be estimated from TL growth by the terrestrial radiation in surface material.

2. Sample Preparation and Experimental Apparatus

The pertinent properties of the studied samples are listed in Table 1. The small chip samples without fusion crusts were gently powdered in a mortar. The samples with fusion crusts, ALH-77294,81, ALH-765,75 and ALH-768,83 were cut parallel to the crust at depth intervals of 1.5 mm and gently powdered in a mortar. Sample of

Table 1. List of meteorites.

Meteorite	Classification	Constituent minerals	Cosmogenic terrestrial age (10^3 yr)		Fusion crust
ALH-77256,90	Diogenite	Orthopyroxene	^{14}C 11.1±1.0	*	×
ALH-77294,81	H5	Olivine	^{14}C 30±2	*	○
		Orthopyroxene			
82		Plagioclase			×
ALH-765,75	Eucrite	Pigeonite	^{14}C >34	*	○
85		Plagioclase	^{36}Cl 60±30	**	×
ALH-768,83	H6	Olivine	^{14}C >32	*	○
		Orthopyroxene	^{36}Cl 70±30	**	
		Plagioclase			
ALH-77272,83	L6	Olivine	^{14}C >38	*	×
		Orthopyroxene	^{36}Cl 560±60	**	
84		Plagioclase			○

* FIREMAN and NORRIS, 1981. ** HONDA, 1981.

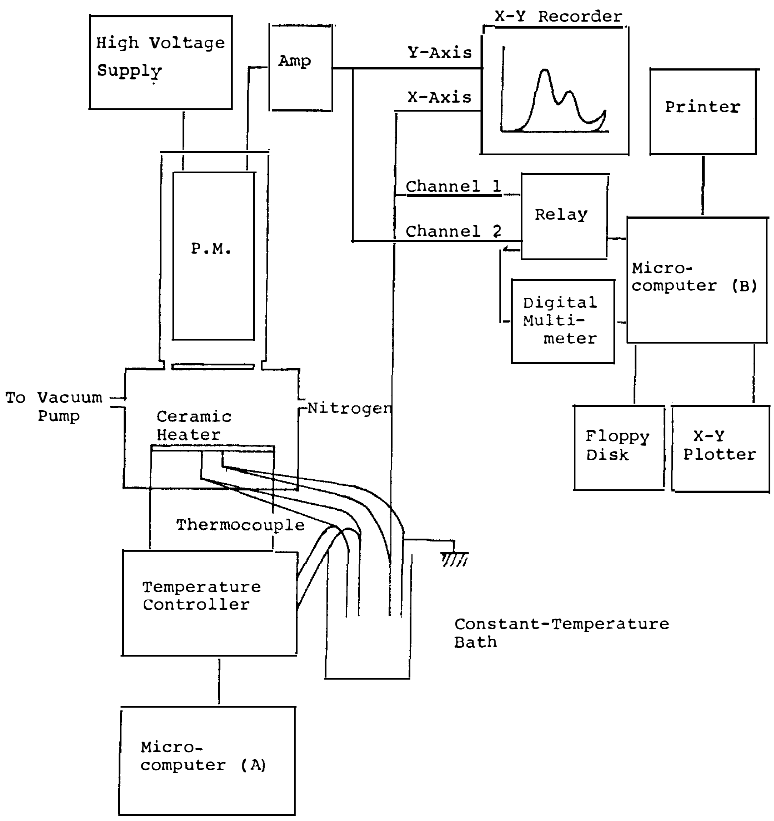

Fig. 1. Block diagram of the apparatus for the thermoluminescence measurement

5 mg was used for each TL measurement.

A block diagram of the apparatus for the TL measurement is shown in Fig. 1. The powdered samples are placed on a ceramic heater in a chamber which is filled with nitrogen. Two chromel-alumel thermocouples are used to control the heater voltage and to measure the heater temperature, respectively. One is connected to a temperature controller which compares thermocouple output with output of a microcomputer (A) and controls the heater voltage to produce a rate of temperature rise of 1.3°C/s. The other is connected to an X-Y recorder and channel 1 of a relay. The TL is detected by a Hamamatsu R208 photomultiplier (P.M.). A blue 5–60 Corning filter is used to suppress the blackbody radiation. The amplified P. M. output is connected to the X-Y recorder and to channel 2 of the relay. The relay controlled by a microcomputer (B) connects channel 1 and channel 2 to a digital multimeter mutually. Output from the digital multimeter is fed to the microcomputer (B) and the data of the TL are stored in a floppy disk.

3. Results and Discussion

3.1. TL of interior samples

The TL glow curves for the samples without fusion crusts and the innermost portion of the sample with fusion crusts are shown in Fig. 2. The low temperature TL glow for ALH-77294,82(H5) is higher than the other ordinary chondrites. This implies that the fading of the low temperature TL glow for ALH-77294,82 is slight and

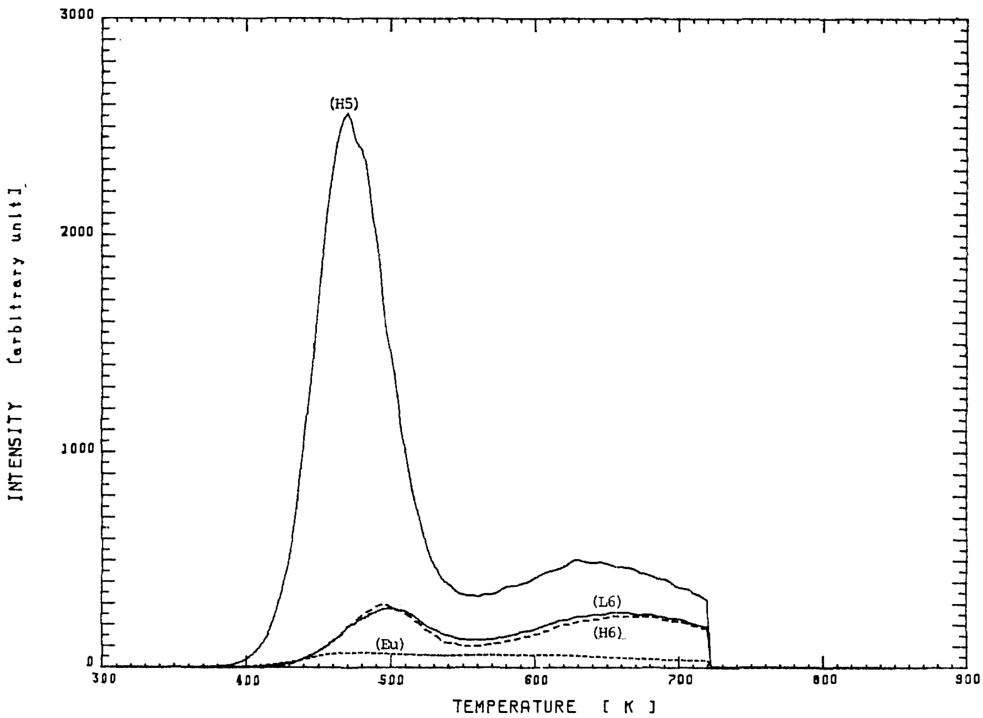

Fig. 2. Thermoluminescence glow curves for ALH-77294,82(H5), ALH-765,85 (eucrite), ALH-768,83 (H6) and ALH-77272,83 (L6). The blackbody radiation is subtracted. ALH-77256,90 (diogenite) does not show any TL.

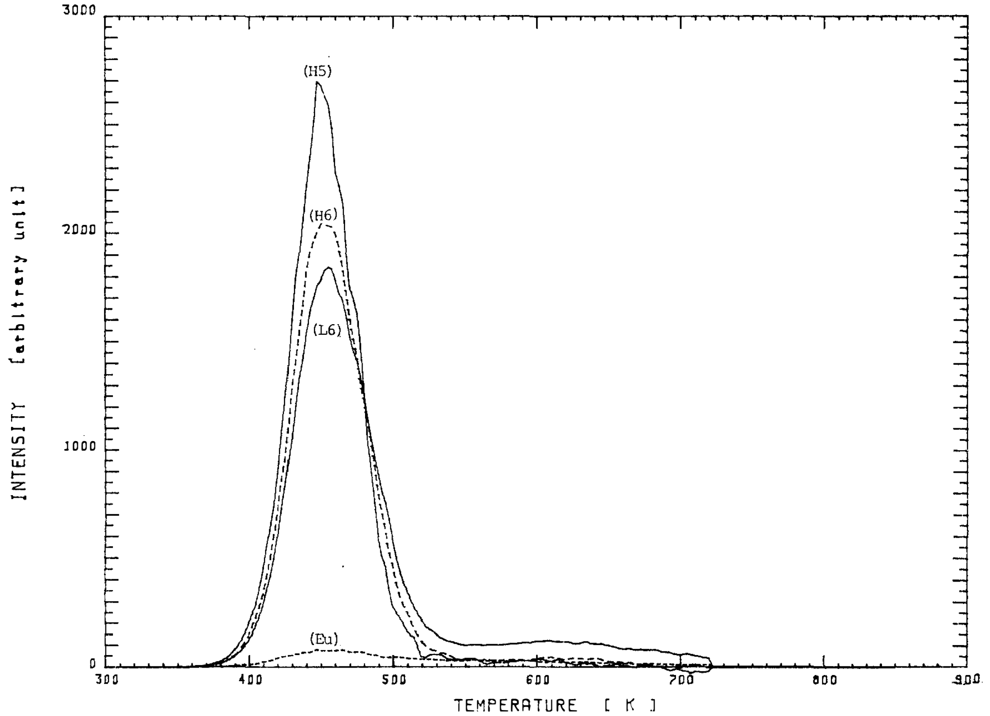

Fig. 3. Thermoluminescence sensitivity to radiation. These glow curves are derived by subtracting natural glows from artificial glows of the samples which have received a dose of 46 krad: ALH-77294,82 (H5), ALH-765,85 (eucrite), ALH-768,83 (H6), ALH-77272, 83 (L6).

the terrestrial age of this sample is younger than those of the other ordinary chondrites. The diogenite, ALH-77256,90 does not show any TL.

To measure the TL sensitivity to radiation (TL intensity/absorbed dose), an aliquot of sample was artificially exposed to γ ray from ^{60}Co and received a dose of 46 krad. Figure 3 shows the TL glow curves which are derived by subtracting natural glows from artificial glows for the samples (TL intensity/46 krad). The H5, H6 and L6 chondrites have higher TL sensitivities than the eucrite.

3.2. *TL depth dependence and calculated surface temperature*

The depth dependences of the TL for ALH-77294,81, ALH-765,75 and ALH-768, 83 are shown in Fig. 4. The surface samples have lower TL intensity than the interior samples. These results suggest that during atmospheric passage the surface temperature rose and the TL near the surface was drained.

The surface temperature during atmospheric passage is estimated as follows. A second-order kinetics for the TL fading process is assumed. Then the heating temperature T is calculated from the equation,

$$T=\frac{E}{k}\frac{1}{\log\left(\dfrac{stI_0'/I_0}{I_0'/I-1}\right)}, \qquad (1)$$

I : TL intensity of the surface,

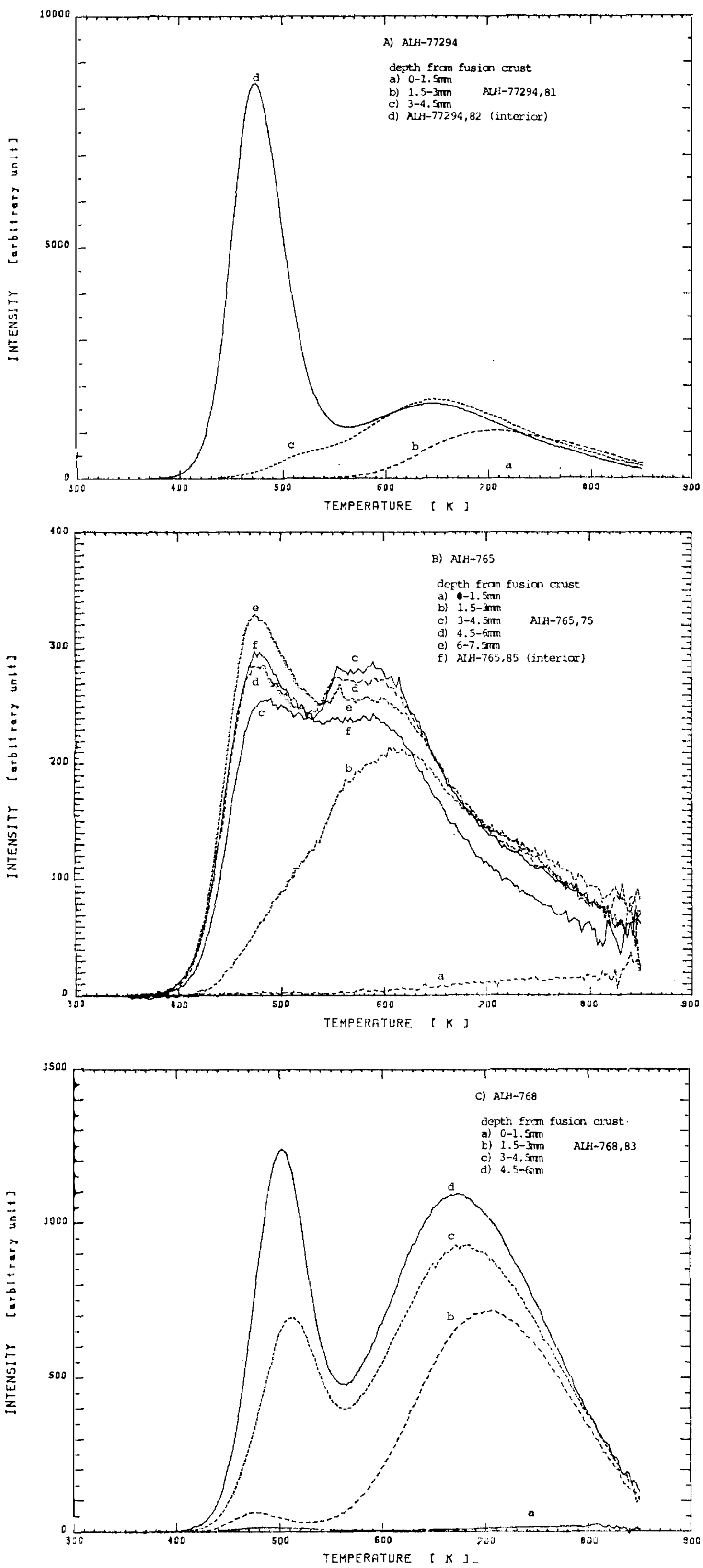

Fig. 4. Depth dependence of the thermoluminescence glow curve. A) ALH-77294, B) ALH-765, C) ALH-768.

I_0' : TL intensity of interior,
I_0 : saturated TL intensity of interior,
t : heating time,
s : frequency factor,
E : trap depth,
k : Boltzmann constant.

A trap depth can be calculated from the experimental formula (MELCHER, 1981a),

$$E = T^*/375 - 0.03 \text{ eV}, \tag{2}$$

where T^* is the peak temperature of the TL glow curve. Assuming a frequency factor $s = 3 \times 10^{12}$/s, heating time of 1 s and $I_0'/I_0 = 10^{-3}$, the heating temperature at 0–1.5 mm portion is estimated to be 1300, 1000 and 1200 K for ALH-77294,81, ALH-765,75 and ALH-768,83, respectively, from the TL ratio (I_0'/I) of the innermost portion to 0–1.5 mm portion at the high temperature glow peak.

The magnitude of fading of the low temperature TL glow near 480 K can be also estimated by transposing eq. (1) and using eq. (2). It is revealed that the low temperature TL glow for these portions must have faded into nearly zero when 0–1.5 mm portions were heated to 1300, 1000 and 1200 K, respectively. This suggests that the low temperature glow observed at present in the 0–1.5 mm portion must be the TL grown after the fall of the meteorite on Antarctica.

3.3. *Terrestrial dose*

An aliquot of the 0–1.5 mm sample was artificially exposed to γ ray from ^{60}Co and received a dose of 1.8 krad. Figure 5 shows the natural TL glow curve, the artificial TL glow curve for the 0–1.5 mm portion of ALH-768,83 and the ratio of natural TL to artificial TL at each temperature. There is a plateau region from 490 to 600 K in the ratio curve. The ratio of integrated natural TL to integrated artificial TL from 600 K to each temperature is calculated to determine the ratio value and shown also in Fig. 5. From the ratio value of 17.5$\pm$2.1%, the terrestrial dose for ALH-768,83 is estimated to be 370$\pm$60 rad (1σ).

For ALH-77294,81 and ALH-765,75, there is no clear plateau region. Then the glow curve area ratios near 480 K are calculated to be 3–10 and 22–33%, respectively, and the terrestrial doses are estimated to be about 50–200 rad and 500–900 rad respectively.

3.4. *Terrestrial age estimation*

On Antarctica, to cause TL in a meteorite there are such sources as the cosmic ray, the environmental radiation and the radiation from meteorite itself. Since the elevation of the Allan Hills is 2000 m, the dose rate by cosmic ray is estimated to be about 61 mrad/yr on the surface (UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECT OF ATOMIC RADIATION, 1977) and nearly zero at 1000 m under an ice sheet. The environmental radiation would be zero because meteorites were on or in the ice sheet. Assuming the relative trapping effeciency of 0.2 for α ray, the radiation from meteorite itself is estimated to be about 9 mrad/yr for the ordinary chondrite and 21 mrad/yr for the eucrite because typical contents of uranium, thorium and potassium in ordinary

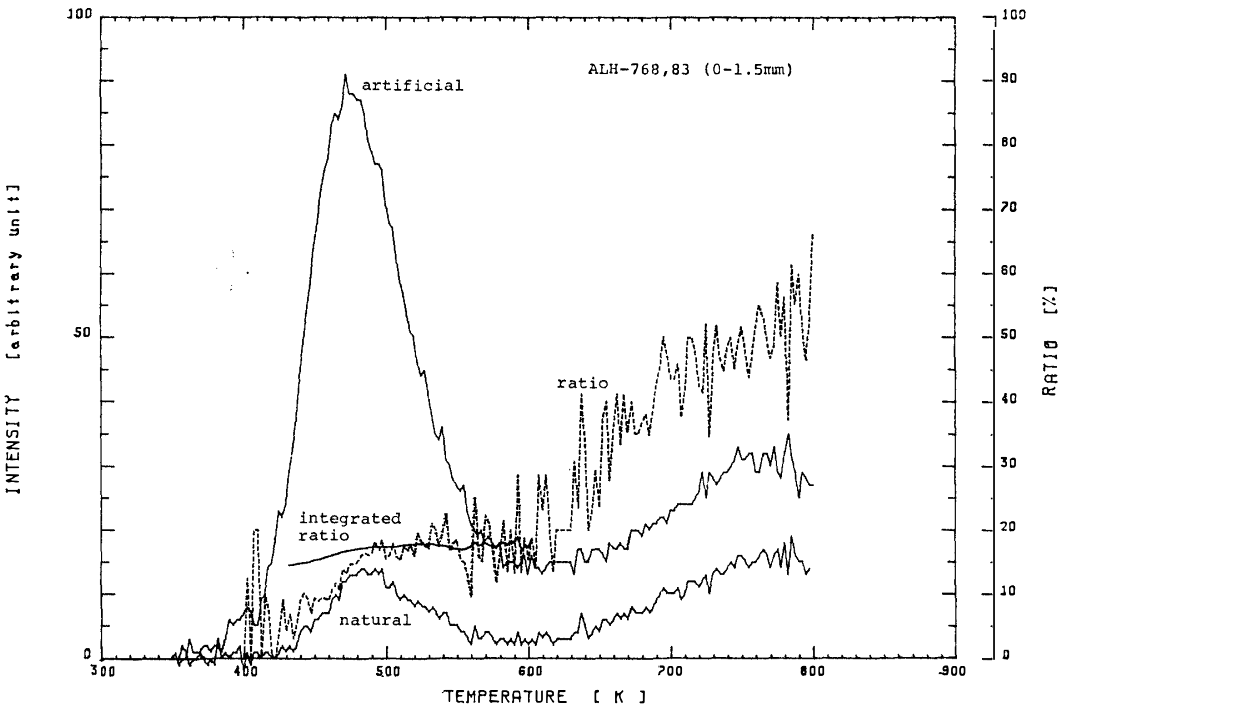

Fig. 5. Thermoluminescence (TL) glow curve for 0–1.5 mm portion of ALH-768,83 and ratio curves: natural TL glow curve, artificial TL glow curve for the sample which has received a does of 1.8 krad, the ratio of natural TL to artificial TL at each temperature (ratio curve), the ratio of integrated natural TL to integrated artificial TL from 600 k to each temperature (integrated ratio curve).

chondrite are 13 ppb, 40 ppb and 0.084% (MELCHER, 1981b) and mean contents of those elements in brecciated eucrite are 130 ppb, 430 ppb (MORGAN, 1971) and 0.05% (OLSEN *et al.*, 1978), respectively.

Two extreme cases are assumed for the terrestrial history of Antarctic meteorites. One is that the meteorite has stayed on the surface for a long time and the dose rate would be as high as 70 mrad/yr for the ordinary chondrite and 82 mrad/yr for the eucrite. The other is that the meteorite has been buried deeply in the ice sheet during the greater part of its terrestrial history and the dose rate would be as low as 9 mrad/yr for the ordinary chondrite and 21 mrad/yr for the eucrite.

The terrestrial ages of meteorites estimated by TL for those cases are listed in

Table 2. Terrestrial ages of meteorites.

Meteorite	Terrestrial dose (rad)	TL terrestrial age (surface) (10^3 yr)	TL terrestrial age (buried) (10^3 yr)	Cosmogenic terrestrial age (10^3 yr)		
ALH-77294,81	50–200	0.8– 3	6–22	^{14}C	30± 2	*
ALH-765,75	500–900	6–11	24–41	^{14}C	>34	*
				^{36}Cl	60±30	**
ALH-768,83	370±60	5.3±0.9	41±7	^{14}C	>32	*
				^{36}Cl	70±30	**

* FIREMAN and NORRIS, 1981. ** HONDA, 1981.

Table 2. Comparing the results with the terrestrial ages estimated from cosmogenic nuclides, ^{14}C and ^{36}Cl (FIREMAN and NORRIS, 1981; HONDA, 1981), the latter situation might be closer to the case. The measurement of the TL for the meteorite would contribute not only to the determination of the terrestrial age but also to the determination of the storage condition in Antarctica in comparison with the terrestrial ages by cosmogenic nuclides.

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