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THERMOLUMINESCENCE STUDY OF ORDINARY CHONDRITES BY TL SPATIAL DISTRIBUTION READOUT SYSTEM

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Abstract: The thermoluminescence (TL) image reading technique by the TL spatial distribution readout system is improved 1) to obtain a quantitative glow curve in any part of the TL image, 2) to get fine structure of a TL image and 3) to heat a sample to a higher temperature. This technique is applied to measure the natural and artificial TL glow curves of chondrules in ordinary chondrites, ALH-77294 (H5) and ALH-77216 (L3.8). The fluctuation in the natural LT/HT(region) ratios (LT(region); photons counted in a low temperature region, HT(region); in a high temperature region) of the equilibrated chondrite ALH-77294 is small though that in the unequilibrated chondrite ALH-77216 is large. The equivalent doses of ALH-77294 and ALH-77216 can be estimated from the correlation between natural LT(region) and artificial LT(region) to be about 240 krad and 16 krad respectively, and are consistent with isotopic ages.

1. Introduction

The thermoluminescence (TL) studies of meteorites have concerned with the orbits (MELCHER, 1981a), the heat penetration on atmospheric passage (MELCHER, 1979), the terrestrial age determination (SEARS and DURRANI, 1980; MELCHER, 1981b; NINAGAWA *et al.*, 1983; BHANDARI and SENQUPTA, 1988) and the metamorphic history (SEARS *et al.*, 1980, 1982). These TL studies have been performed by ground samples of meteorites or samples separated from the meteorites using a photomultiplier. An image intensifier has made it possible to measure the TL image of low photon intensity, and the TL spatial distribution readout system was constructed (WALTON and DEBENHAM, 1980; IMAEDA *et al.*, 1985). We measured the TL images of the meteorites and tried to get glow curves of chondrules without separation of chondrules by using the image intensifier (NINAGAWA *et al.*, 1986a). In the case of using the image intensifier, we have gotten qualitative glow curves because the addition of TL images violates the linearity between the output phosphorescence intensity and the input light yield.

YAMAMOTO *et al.* (1987) indicated that the number of photons counted with a two-dimensional photon counting method showed the linearity for the input light yield. This time, a program driving the TL spatial distribution readout system was improved to get quantitative glow curves by the two-dimensional photon counting in any part of TL images. Sample preparation and the equipment are described in Section 2.

The purpose of the present work is to study the characteristics of the TL of ordinary chondrites by this improved technique. The natural and artificial TL images of the ordinary chondrites were measured and the glow curves of chondrules were analyzed. The results are described in Section 3.

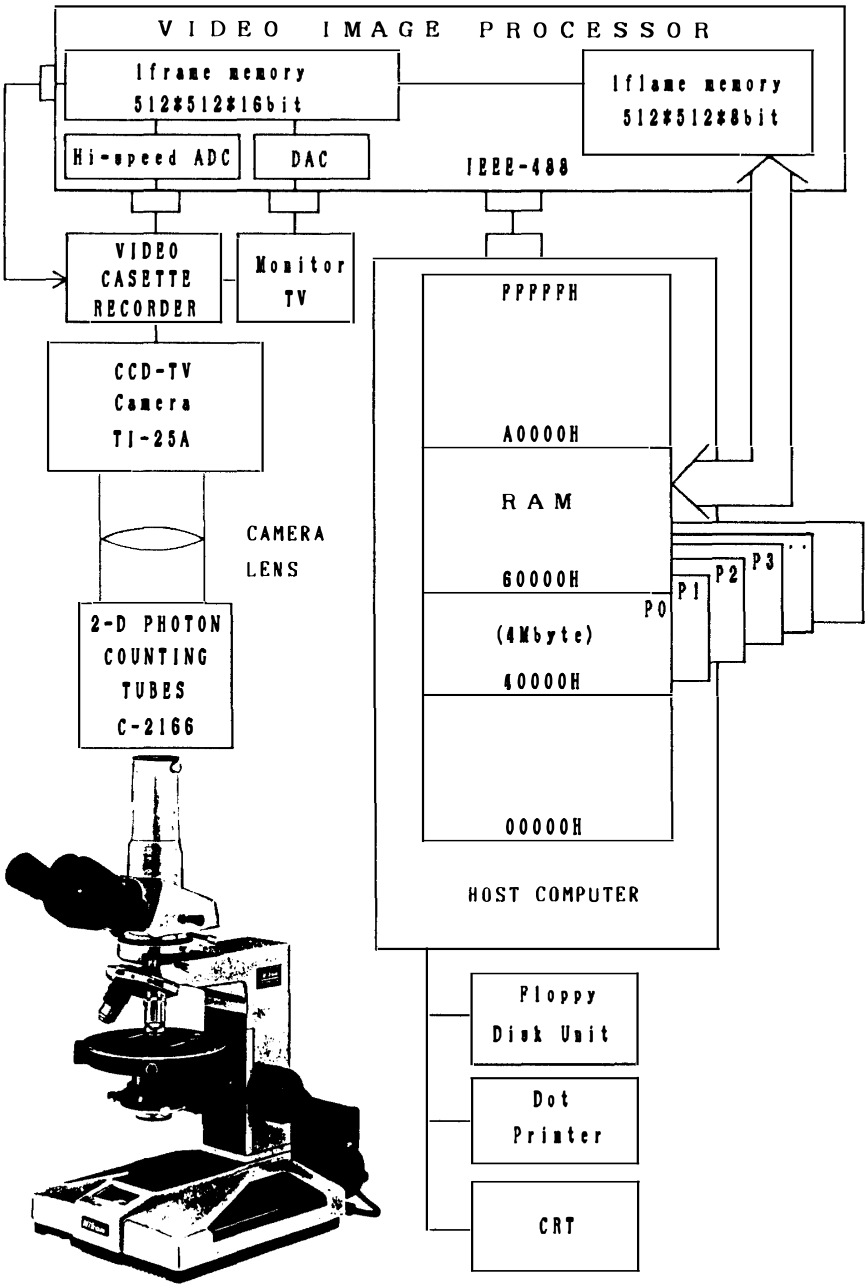


Fig. 1. TL spatial distribution readout system with a microscope.

2. Samples and Experiments

Antarctic ordinary chondrites ALH-77294 and ALH-77216 are used as samples. ALH-77294 is an H5 chondrite and its terrestrial age is $(10\pm1)\times10^3$ years by ^{14}C (JULL *et al.*, 1989), which is a short age for Allan Hills meteorites. ALH-77216 is an L3.8 chondrite (SCOTT, 1984) and its terrestrial age is <630000 years (J. EVANS, unpublished). The samples are prepared in a form of a thick sliced sample, not in a form of a thin section. The meteorites are gently sliced with a wire saw and polished with alumina abrasives to about 1 mm thickness. Then we can heat the samples to a higher temperature about 500°C without the binder's deterioration of the thin section.

The TL spatial distribution readout system was combined with a microscope as shown in Fig. 1, so that we could magnify the TL images of meteorites and observe the fine structure. The magnification of the microscope was set at 4-power. The microscopic heating stage (Leitz 1350) was heated by a heater controller at the rate of

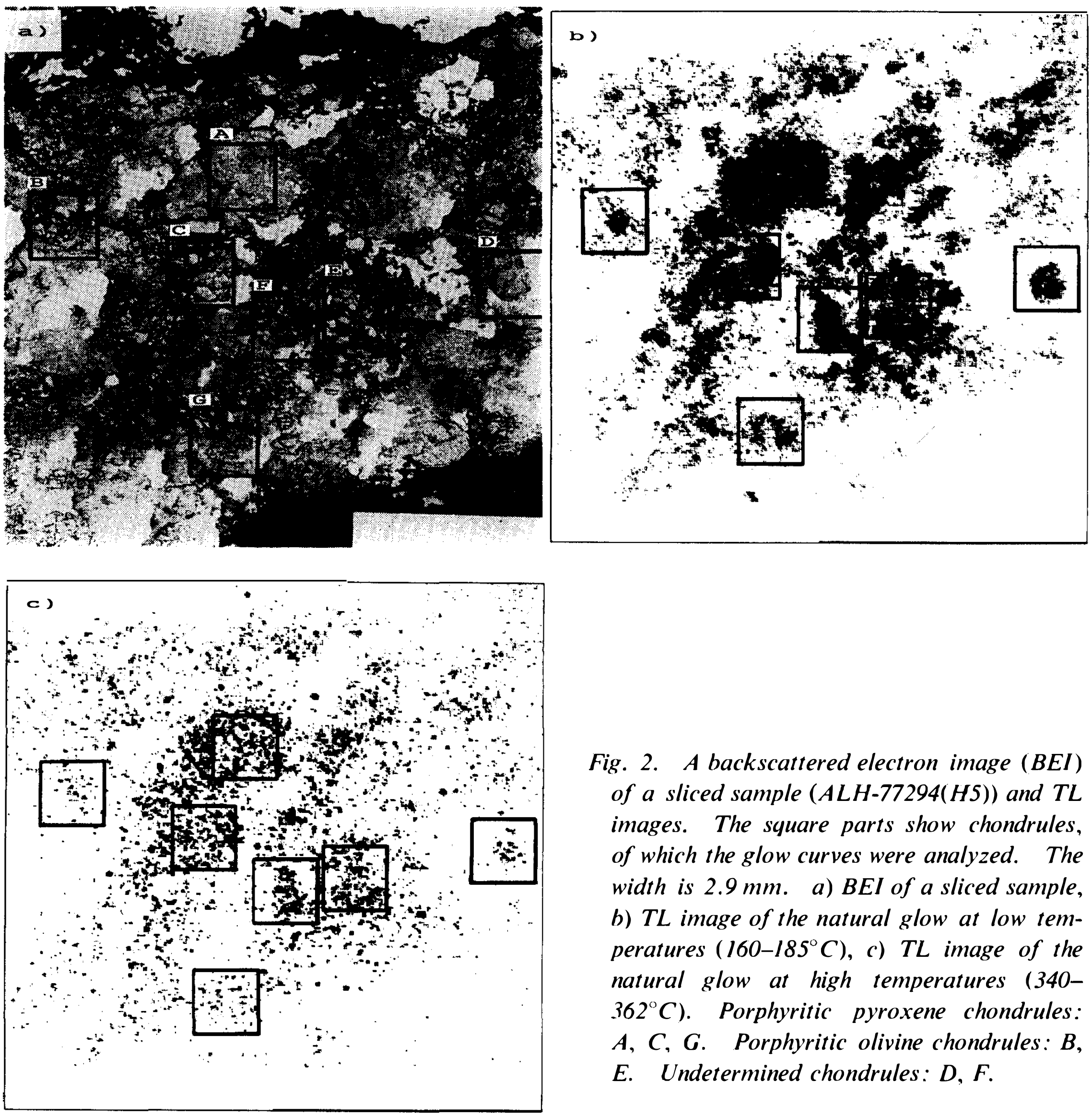
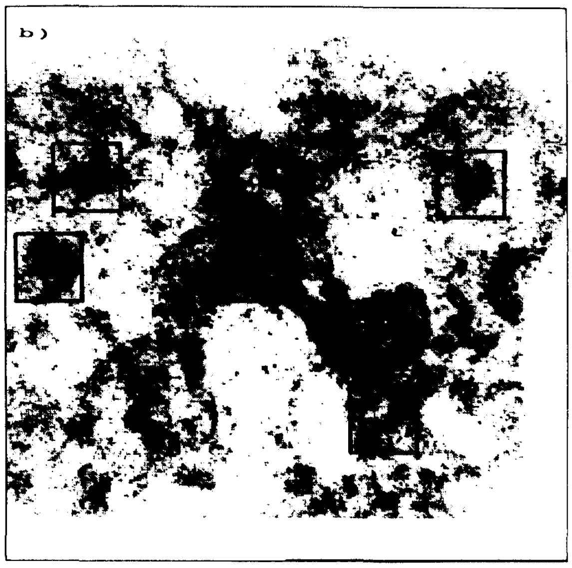


Fig. 2. A backscattered electron image (BEI) of a sliced sample (ALH-77294(H5)) and TL images. The square parts show chondrules, of which the glow curves were analyzed. The width is 2.9 mm. a) BEI of a sliced sample, b) TL image of the natural glow at low temperatures (160–185°C), c) TL image of the natural glow at high temperatures (340–362°C). Porphyritic pyroxene chondrules: A, C, G. Porphyritic olivine chondrules: B, E. Undetermined chondrules: D, F.

temperature rise 0.25°C/s in nitrogen atmosphere. The image intensifier with a bialkali photocathode, which has high sensitivity at short wavelengths (400 nm), has been used. A band pass filter, Corning 4–96 (blue-green) has been used to suppress the blackbody radiation. The program driving the TL spatial distribution readout system was improved to get quantitative glow curves by the two-dimensional photon counting in any part of TL images.

3. Results and Conclusion

Figures 2a, 3a and 4a are backscattered electron images (BEI) of the sliced samples ALH-77294 and ALH-77216. Some chondrules are squared in figures. These sliced samples were heated and TL images were measured by the TL spatial distribution readout system. Figures 2b, 3b and 4b show natural TL images at low temperature and Figs. 2c, 3c and 4c show natural TL images at high temperature. The position of



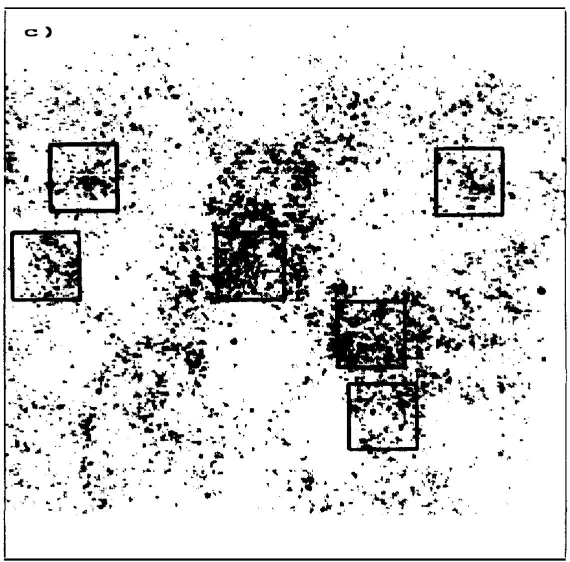
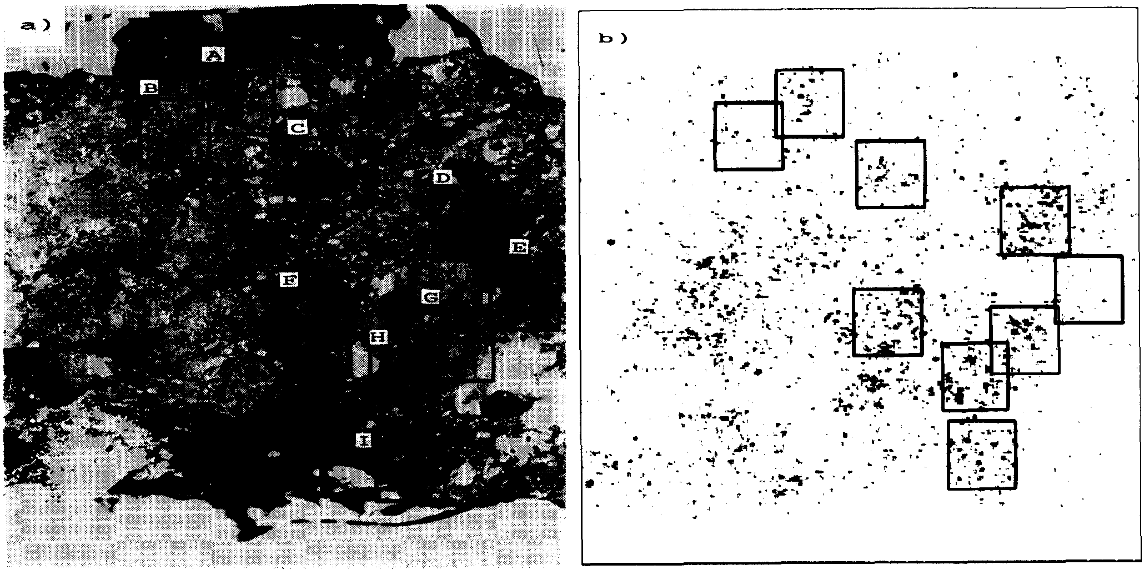


Fig. 3. A backscattered electron image (BEI) of a sliced sample (ALH-77294(H5)) and TL images. The square parts show chondrules, of which the glow curves were analyzed. The width is 2.9 mm. a) BEI of a sliced sample, b) TL image of the natural glow at low temperatures (160–185°C), c) TL image of the natural glow at high temperatures (340–362°C). Porphyritic olivine chondrules: H, I, K, M. Porphyritic olivine and pyroxene chondrule: L. Undetermined chondrule: J.



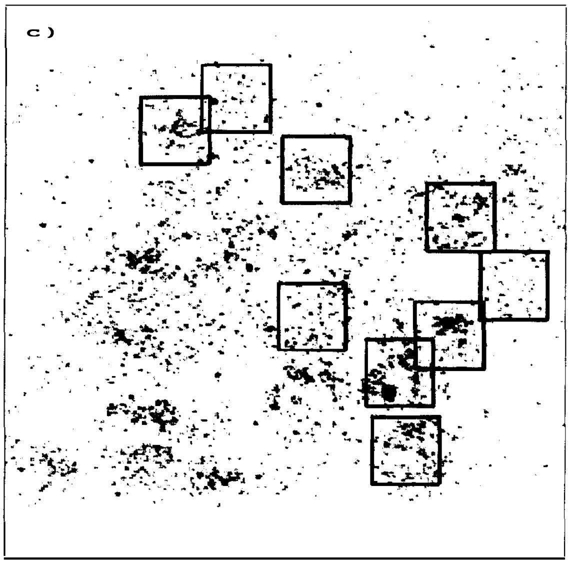


Fig. 4. A backscattered electron image (BEI) of a sliced sample (ALH-77216(L3.8)) and TL images. The square parts show chondrules, of which the glow curves were analyzed. The width is 2.9 mm. a) BEI of a sliced sample, b) TL image of the natural glow at low temperatures (160–185°C), c) TL image of the natural glow at high temperatures (340–362°C). Porphyritic pyroxene chondrule: E. Porphyritic olivine chondrules: B, D, F, H, I. Porphyritic olivine and pyroxene chondrule: G. Barred olivine chondrule: C. Undetermined chondrule: A.

high TL intensity is put with deep black points.

The natural and artificial TL emission spectra of these meteorites were also measured by a time-resolving spectroscopy system (NINAGAWA *et al.*, 1986b). They have a wide peak of about 450 nm at low temperature and a peak of about 400 nm at high temperature and are consistent with those of the ordinary chondrites, Allegan (H5), Barwell (L6), Olivenza (LL5) and Farmington (L5) (STRAIN *et al.*, 1985). The difference between low and high temperature TL spectra implies that the material responsible for the TL at low temperature is different from that at high temperature. But the TL images at low temperature resemble those at high temperature as shown in Figs. 2, 3 and 4. This suggests that there is a correlation between the material responsible for the low temperature TL and those for the high temperature TL in spite of the different emission spectrum.

The natural TL glow curve of each chondrule, squared in Figs. 2, 3 and 4 was quantitatively analyzed. The typical glow curves of chondrules are shown in Fig. 5a,

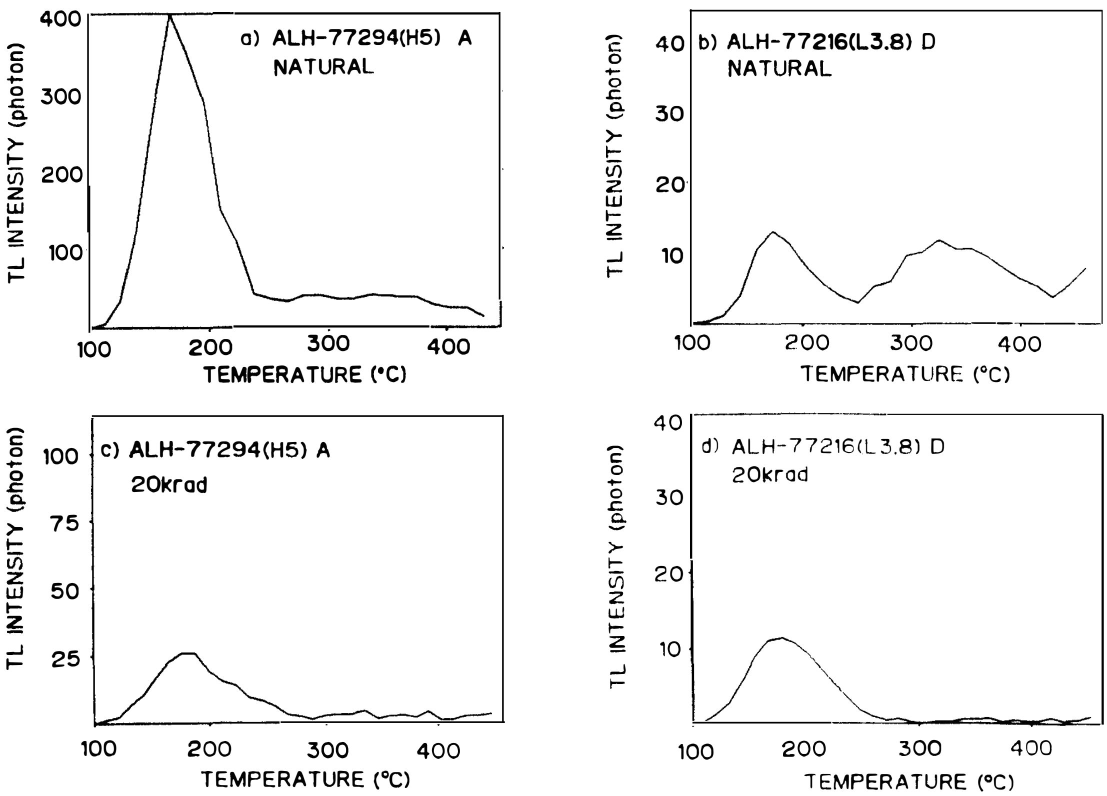


Fig. 5. Glow curves. a) Natural TL glow curve of the square part A (porphyritic pyroxene chondrule) in ALH-77294, indicated in Fig. 2. b) Natural TL glow curve of the square part D (porphyritic olivine chondrule) in ALH-77216, indicated in Fig. 4. c) Artificial (20 krad) TL glow curve of the same square part A in ALH-77294. d) Artificial (20 krad) TL glow curve of the same square part D in ALH-77216.

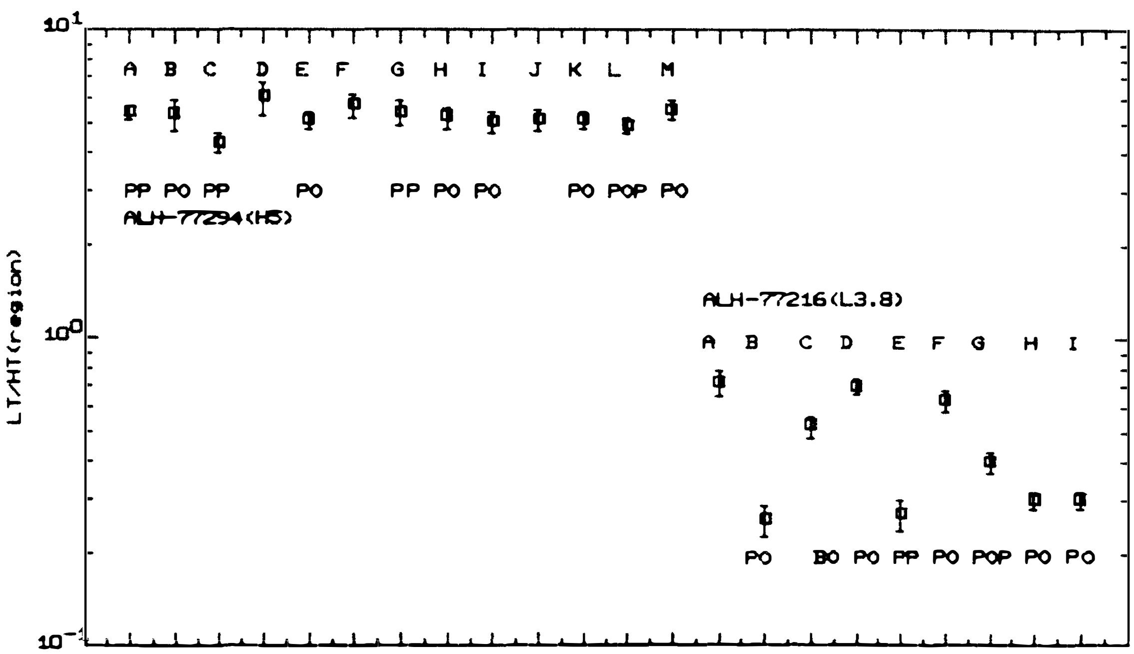


Fig. 6. The natural LT/HT (region) ratios and texture of chondrules. PP: porphyritic pyroxene chondrule, PO: porphyritic olivine chondrule, POP: porphyritic olivine and pyroxene chondrule, BO: barred olivine chondrule.

Table 1. The natural and artificial TL.

Position	texture	Natural *LT* (region) (photons)	Natural *HT* (region) (photons)	Natural *LT/HT* (region)	Artificial *LT* (region) (photons)	Artificial peak (°C)	Artificial *FWHM* (°C)
ALH-77294 (H5)							
A	PP	1946±46	362±20	5.4 ±0.3	149±6	186	81
B	PO	723±30	136±13	5.3 ±0.6	64±4	192	63
C	PP	1319±38	309±18	4.3 ±0.3	143±6	181	75
D	*	562±24	93±10	6.0 ±0.7	65±4	169	58
E	PO	1283±34	251±15	5.1 ±0.3	95±5	169	81
F	*	1017±32	179±13	5.7 ±0.5	64±4	169	81
G	PP	801±28	149±12	5.4 ±0.5	47±4	181	81
H	PO	1355±42	260±18	5.2 ±0.4	120±6	186	86
I	PO	888±30	179±13	5.0 ±0.4	88±5	192	81
J	*	1188±39	231±17	5.1 ±0.4	106±6	181	92
K	PO	1759±42	346±19	5.1 ±0.3	108±5	169	52
L	POP	1548±38	319±17	4.9 ±0.3	117±5	181	81
M	PO	1301±35	238±15	5.5 ±0.4	77±5	192	86
ALH-77216 (L3.8)							
A	*	22±2	30±2	0.72±0.07	28±2	189	77
B	PO	17±2	67±3	0.26±0.03	35±2	183	65
C	BO	26±2	51±3	0.52±0.04	36±2	189	77
D	PO	55±3	79±3	0.70±0.04	73±3	183	83
E	PP	11±1	40±2	0.27±0.03	17±2	159	71
F	PO	35±2	55±3	0.63±0.05	22±2	189	71
G	POP	33±2	82±3	0.40±0.03	34±2	183	65
H	PO	39±2	132±4	0.30±0.02	43±2	177	100
I	PO	38±2	126±4	0.30±0.02	46±3	171	59

PP: porphyritic pyroxene chondrule, PO: porphyritic olivine chondrule, POP: porphyritic olivine and pyroxene chondrule, BO: barred olivine chondrule, *: undetermined chondrule.

b. In these natural glow curves, we found the "normal shape" glow curve and didn't find the "*HHT* deficient shape" one (DURRANI *et al.*, 1979). This time, the *LT* (region) and the *HT* (region) are defined by photons counted in the low temperature region and in the high temperature region, respectively. The natural *LT* (region), *HT* (region) and *LT/HT* (region) ratio are listed in Table 1 and the natural *LT/HT* (region) ratio is plotted in Fig. 6. The *LT/HT* (region) ratio is an indicator of the terrestrial age though it includes ambiguity like the initial value (depending on meteorite orbit, shielding effect and shock heating) and the fading rate (depending on storage temperature). The average *LT/HT* (region) ratios of ALH-77294 and ALH-77216 are 5.2±0.4 and 0.46± 0.19, respectively. These values are consistent with the isotopic ages. On the other hand, the average *LT/HT* (peak) ratio of ALH-77294 is 8.9±0.9, in which the *LT* (peak) and the *HT* (peak) are defined by photons counted at the low temperature peak and at the high temperature peak. But HASAN's *LT/HT* (peak) ratio of ALH-77294 was 2.12±0.06 (HASAN *et al.*, 1987). What is it ascribed to? It would be ascribed to the sampling, the sample preparation or the measuring technique. It needs a calibration to compare these data, using the same samples of ALH-77294 and a standard sample, Dhajala (H3).

The ALH-77294 is an equilibrated chondrite (H5). Then the materials responsible for the low temperature TL and for the high temperature TL would be equilibrated. The fact that the fluctuation in the *LT*/*HT* (region) ratio of ALH-77294 is small (Table 1 and Fig. 6) would be reflected to this equilibrium. On the other hand, that of ALH-77216 is large. The maximum deviation becomes about 60%. This would be ascribed to unequilibrium of the meteorite (petrologic type 3.8). The textures of chondrules are also judged (NAGAHARA, 1983). But as shown in Fig. 6, the *LT*/*HT* (region) ratio is independent of the chondrule texture.

The artificial TL images of the meteorites, which were irradiated with a dose of 20 krad γ-rays after annealing, were also measured. The artificial TL image of each sliced sample resembles the natural one. The artificial TL glow curves of chondrules, squared in Figs. 2, 3 and 4, are also analyzed quantitatively and shown in Fig. 5c, d. The shape of the glow curve also resembles the natural one. Though photons were emitted more than the background level at the high temperature, a clear high temperature peak was not detected. The peak temperature of *LT* (region) and the width of *LT* (region) at half maximum (*FWHM*) were analyzed and are listed in Table 1. The *LT* (region) peak temperatures of the artificial TL glow curves of these chondrules are concentrated around 181°C and the *FWHM*s are around 76°C. The two types of artificial glow curves, which corresponded to the low temperature form and the high temperature form of feldspar, were not found in this analysis (SEARS *et al.*, 1984; GUIMON *et al.*, 1985; KECK *et al.*, 1986). All of the glow curves analyzed this time would be ascribed to the high temperature form of feldspar. Because the feldspar of petrological type 5 (ALH-77294) belongs to the high temperature form and the slow heating rate, 0.25°C/s, shifts the *LT* (region) peak to lower temperature and narrows the *FWHM*. The TL of the low temperature form of feldspar would be faded in the time interval after irradiation, about 3 months, because a lower TL peak of the low temperature form of feldspar is due to a shallower trap depth and the TL fading rate becomes rapid.

The *LT* (region) in the artificial glow curve was also evaluated and is listed in Table 1. Figure 7 shows the correlation between the natural *LT* (region) and the artificial *LT* (region). The variations in the natural TL ranging up to a factor of 3 for ALH-77294 (H5) and a factor of 5 for ALH-77216 (L3.8), are consistent with those by DURRANI *et al.* (1979). The TL sensitivity of ALH-77216 is lower than that of ALH-77294 approximately by a factor of 3. This factor is slightly smaller than that from the correlation between TL sensitivity and petrologic type (GUIMON *et al.*, 1986). The lack of agreement may be related to ALH-77216 being a regolith breccia. The equivalent doses of ALH-77294 and ALH-77216 are estimated to be about 240 and 16 krad, respectively (Fig. 7). These values are also consistent with isotopic ages as mentioned in the natural *LT*/*HT* (region) ratio.

The TL images, which were magnified by 4-power, show that the TL intensity inside of a chondrule is not uniform. The TL sensitivity would be different in the chondrule and the crystallization of feldspar would be inhomogeneous. This TL image reading technique is available to investigate thermal history of meteorites. We plan as a next step to measure the inhomogeneity of TL sensitivity of low-grade metamorphic meteorites as well as these samples irradiated with a large quantity of dose

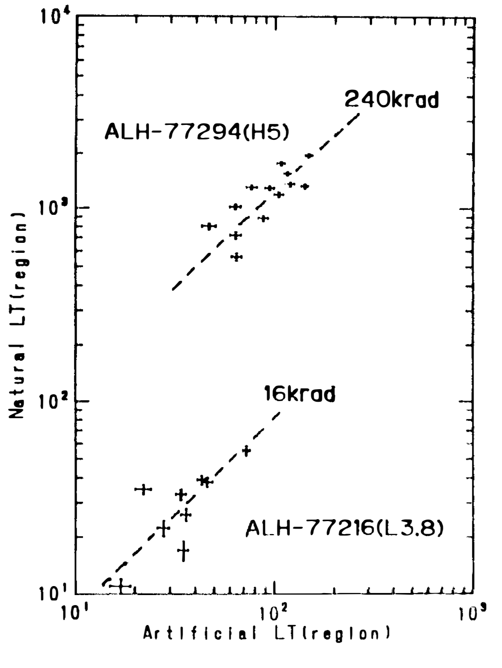


Fig. 7. The correlation between natural LT (region) and artificial LT (region). The dotted lines represent the equivalent doses.

and to investigate the correlation of the TL sensitivity with mineral and chemical compositions.

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