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THERMOLUMINESCENCE OF JAPANESE ANTARCTIC ORDINARY CHONDRITE COLLECTION

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Abstract: Thermoluminescence (TL) data for Japanese Antarctic chondrites obtained by laboratories in Arkansas and Okayama were compared and found to be in good agreement. Data for three large Antarctic chondrites were used to develop new TL pairing criteria which were found to be less restrictive than previously used. These new criteria were applied to ten equilibrated and twenty-eight unequilibrated Japanese ordinary chondrites. The petrographic subtype of the forty-three unequilibrated ordinary chondrites were determined from their TL sensitivity and nine were found to have petrographic types under 3.3 and therefore are particularly primitive samples of solar system material.

1. Introduction

Induced TL (thermoluminescence), the response of a luminescent phosphor to a laboratory dose of radiation, reflects the mineralogy and structure of the phosphor, and provides valuable information on the metamorphic and thermal history of meteorites. The TL sensitivity is used to determine petrologic type of type 3 ordinary chondrites (SEARS *et al.*, 1980, 1991a; SEARS, 1988), CO chondrites (SEARS *et al.,* 1991b) and eucrites (BATCHELOR and SEARS, 1991). Differences in thermal histories of Antarctic and non-Antarctic H chondrites were distinguished by the induced TL peak temperature and width (SEARS *et al.*, 1991c; BENOIT and SEARS, 1992).

Natural TL, the luminescence of a sample that has received no irradiation in the laboratory, reflects the thermal history of the meteorite in space and on Earth. Natural TL data thus provide insights into such topics as the orbits of meteoroids, the effects of shock heating, and the terrestrial history of meteorites (BENOIT *et al.*, 1991, 1992). The natural TL of meteorites of the American Antarctic meteorite collection has been routinely measured and these data, along with induced TL data and cosmogenic radionuclide (*e.g.*, ^{26}Al) and noble gas abundance data, have been used to identify potentially paired fragments of Antarctic meteorites. Japanese expeditions have collected about 8700 specimens of Antarctic meteorites since 1969, but systematic TL analysis has not been performed for these members of the Japanese collection.

In this paper we compared TL data obtained at the University of Arkansas and Okayama University of Science as part of a new systematic analysis of the TL properties of the Japanese Antarctic meteorite collection. Furthermore TL criteria for potentially paired fragments were examined analyzing large Antarctic chondrites, and potentially paired fragments were suggested by these criteria. The petrographic subtypes of forty-three unequilibrated Japanese ordinary chondrites were also determined using the TL sensitivity.

2. TL Instruments, Samples and Procedures

Some of the characteristics of TL glow curves depend on instruments and measuring conditions. A comparison of the main features of the University of Arkansas and Okayama University of Science TL systems is listed in Table 1. The main differences in the procedures of the two laboratories involve the photomultipliers used (EMI 9536 and Hamamatsu R762, respectively), test dose (20 Gy from beta radiation and 250 Gy from gamma radiation) and heating rates (7.5 °C/s and 0.5 °C/s). The PMTs and associated optics have different spectral responses which are expected to affect the data in the manner discussed below, while the higher dose used in Japan would cause greater overlapping of adjacent peaks. The difference in heating rate should give the Okayama laboratory poorer detection limits but precise peak resolution and reproducibility. In view of the number and complexity of these differences, direct comparison of data from each laboratory was thought desirable.

We obtained natural and induced TL data for: (1) ten equilibrated ordinary chondrites that had previously been assigned to three pairing groups on the basis of exposure age and cosmogenic nuclide data. (HONDA, 1981); (2) fifteen unequilibrated ordinary chondrites from the Japanese collection, which were assigned to petrographic subtypes using their induced TL; (3) three large Antarctic chondrites, META 78028 (L6), LEW 85319 (H5) and ALHA78084 (L6), which enabled the development of new TL pairing criteria; (4) twenty-eight Japanese unequilibrated ordinary chondrites were measured at the University of Arkansas to explore their petrographic subtype and pairing properties.

Table 1. Differences of TL instruments and measuring conditions between University of Arkansas and Okayama University of Science.

Laboratory	University of Arkansas	Okayama University of Science
TL instrument	Daybreak Co. Ltd.	Handmade
Photomultiplier	EMI 9635	Hamamatsu R762
Filter	Corning 4-96 & 7-56	Corning 4-96 & 7-56
Heating rate	7.5 °C/s	0.5 °C/s
Irradiation source	^{90}Sr-^{90}Y β-rays	^{60}Co γ-rays
Dose	~20 Gy	~250 Gy
Dose rate	~8 Gy/min	~12 Gy/min
Sample weight	4 mg	8 mg
Working standard	Dhajala	none
Air	N_2 gas flow	N_2 gas flow
Counting	Photon counting	Photon counting

3. Results and Discussion

3.1. Comparison of Arkansas and Okayama TL data

Figure 1 compares the natural LT/HT between data for the two laboratories and the data are listed in Table 2. The data correlate very well but do not yield a slope of 1.0, because of the different spectral response of the two systems. The LT spectrum of ordinary chondrites has a peak at 450 nm and the HT spectrum has a peak at 400 nm (STRAIN *et al.*, 1985; NINAGAWA, 1989), thus the Arkansas equipment is more sensitive to shorter wavelengths than the Okayama system.

The TL sensitivity data for the two laboratories agree over 3 orders of magnitude in spite of different artificial dose and heating rates (Fig. 2, Tables 2 and 3). The different sample heating rates produce large differences in induced TL peak temperature and width of induced TL for the two laboratories (Figs. 3 and 4, Tables 2 and 3). However, the differences are systematic and relative agreement is excellent.

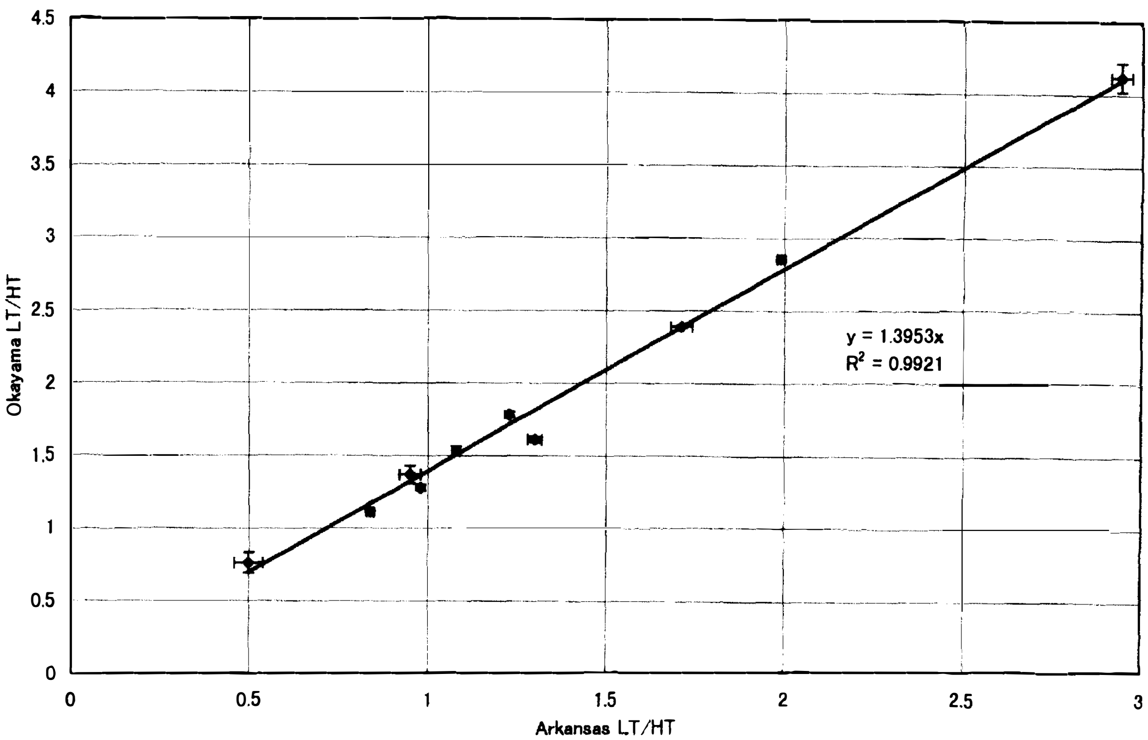

Fig. 1. Plot comparing the natural LT/HT ratio of ten equilibrated ordinary chondrites measured at the University of Arkansas and Okayama University of Science. The LT is intensity of low temperature glow peak and the HT is intensity of high temperature glow peak.

Table 2. Thermoluminescence data of Arkansas and Okayama for ten equilibrated Japanese ordinary chondrites.

Meteorite	Class	Weight (g)	Arkansas: Natural TL: LT/HT	Natural TL: Dose at 250 °C (krad)	Natural TL: LT Intensity ($x10^3$ counts)	Induced TL: TL Sensitivity (Dhajala=1)*	Induced TL: Peak Temp. (°C)	Induced TL: Width (°C)	LT Int./TL Sens. $x10^3$	Pairing**: New Criteria	Pairing**: Usual Criteria
MBR a	H6	1879.70	0.84 ± 0.01	9.8 ± 0.2	0.56 ± 0.00	0.75 ± 0.04	197 ± 1	138 ± 2	0.7 ± 0.0	X	X
MBR b	H6	7265.00	0.98 ± 0.00	12.2 ± 0.0	2.04 ± 0.05	1.65 ± 0.14	206 ± 4	144 ± 2	1.2 ± 0.1	X	X
Y-75271	L6	1797.50	0.50 ± 0.04	4.8 ± 0.5	0.75 ± 0.13	0.93 ± 0.02	201 ± 1	156 ± 2	0.8 ± 0.1	X	X
Y-75102	L6	11000.00	0.95 ± 0.03	11.7 ± 0.5	1.62 ± 0.02	0.51 ± 0.08	196 ± 2	161 ± 2	3.2 ± 0.5	O	X
Y-75108	L6	3966.93	1.08 ± 0.01	13.9 ± 0.2	1.93 ± 0.03	0.58 ± 0.03	199 ± 1	158 ± 2	3.3 ± 0.2	O	X
Y-74190	L6	3235.70	1.23 ± 0.00	16.6 ± 0.0	2.08 ± 0.23	0.36 ± 0.05	194 ± 4	165 ± 5	5.7 ± 1.0	X	X
Y-75097	L6	2570.00	1.30 ± 0.02	17.9 ± 0.4	1.73 ± 0.06	0.42 ± 0.01	214 ± 3	177 ± 3	4.2 ± 0.2	X	X
Y-74115	H6	3235.70	1.71 ± 0.03	26.1 ± 0.6	1.37 ± 0.02	0.93 ± 0.05	200 ± 2	135 ± 1	1.5 ± 0.1	X	X
Y-74418	H6	764.03	1.99 ± 0.01	32.1 ± 0.2	2.13 ± 0.11	0.79 ± 0.04	200 ± 1	135 ± 2	2.7 ± 0.2	X	X
Y-74371	H6	5067.90	2.94 ± 0.03	54.7 ± 0.8	4.87 ± 0.08	2.55 ± 0.06	198 ± 2	135 ± 2	1.9 ± 0.1	X	X

Sample	Class	Weight (g)	Okayama: Natural TL: LT/HT	Natural TL	Natural TL: LT Intensity ($x10^4$ counts)	Induced TL: TL Sensitivity (10^4 counts)*	Induced TL: Peak Temp. (°C)	Induced TL: Width (°C)	LT Int./TL Sens.	Pairing**: New Criteria	Pairing**: Usual Criteria
MBR a	H6	1879.70	1.11 ± 0.01		3.0 ± 0.4	5.3 ± 0.1	153 ± 1	118 ± 2	0.6 ± 0.1	X	
MBR b	H6	7265.00	1.28 ± 0.02		8.9 ± 0.2	9.3 ± 0.1	156 ± 0	127 ± 0	1.0 ± 0.0	X	
Y-75271	L6	1797.50	0.76 ± 0.07		3.2 ± 0.4	4.0 ± 0.1	160 ± 3	143 ± 1	0.8 ± 0.1	X	
Y-75102	L6	11000.00	1.37 ± 0.06		6.5 ± 0.2	2.6 ± 0.0	159 ± 3	146 ± 1	2.5 ± 0.1	O	
Y-75108	L6	3966.93	1.53 ± 0.03		7.1 ± 0.5	2.7 ± 0.2	156 ± 0	141 ± 0	2.6 ± 0.3	O	
Y-74190	L6	3235.70	1.78 ± 0.02		7.9 ± 0.8	1.6 ± 0.1	156 ± 2	146 ± 1	4.8 ± 0.6	X	
Y-75097	L6	2570.00	1.61 ± 0.02		9.6 ± 0.9	1.9 ± 0.1	161 ± 7	160 ± 3	5.0 ± 0.6	X	
Y-74115	H6	3235.70	2.39 ± 0.01		7.1 ± 0.1	6.8 ± 0.3	155 ± 2	121 ± 1	1.0 ± 0.0	X	
Y-74418	H6	764.03	2.86 ± 0.02		9.9 ± 0.2	5.1 ± 0.2	153 ± 0	123 ± 1	2.0 ± 0.1	X	
Y-74371	H6	5067.90	4.12 ± 0.10		24.2 ± 1.0	14.4 ± 0.5	158 ± 2	124 ± 0	1.7 ± 0.1	X	

*; different unit between Arkansas and Okayama.
**; O: paired, X: unpaired.

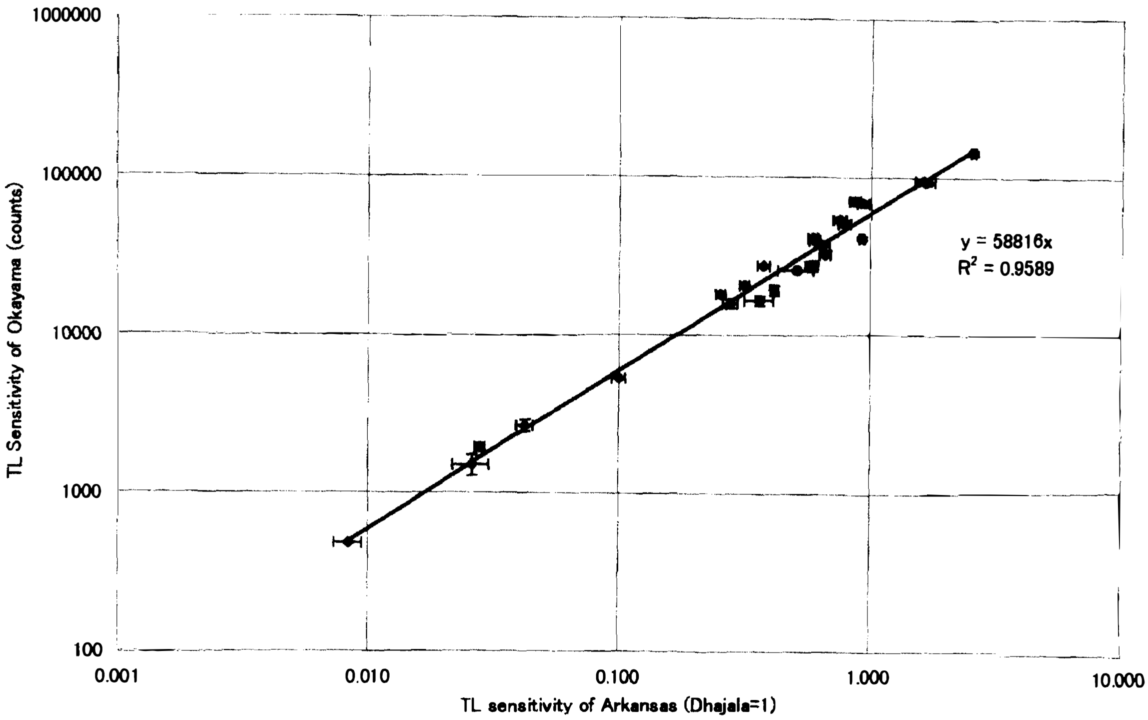

Fig. 2. Plot comparing the TL sensitivities of ten equilibrated and fifteen unequilibrated ordinary chondrites measured at the University of Arkansas and Okayama University of Science. The TL sensitivities of induced TL of Arkansas are normalized by that of Dhajala, while the Okayama data are effectively normalized to applied dose.

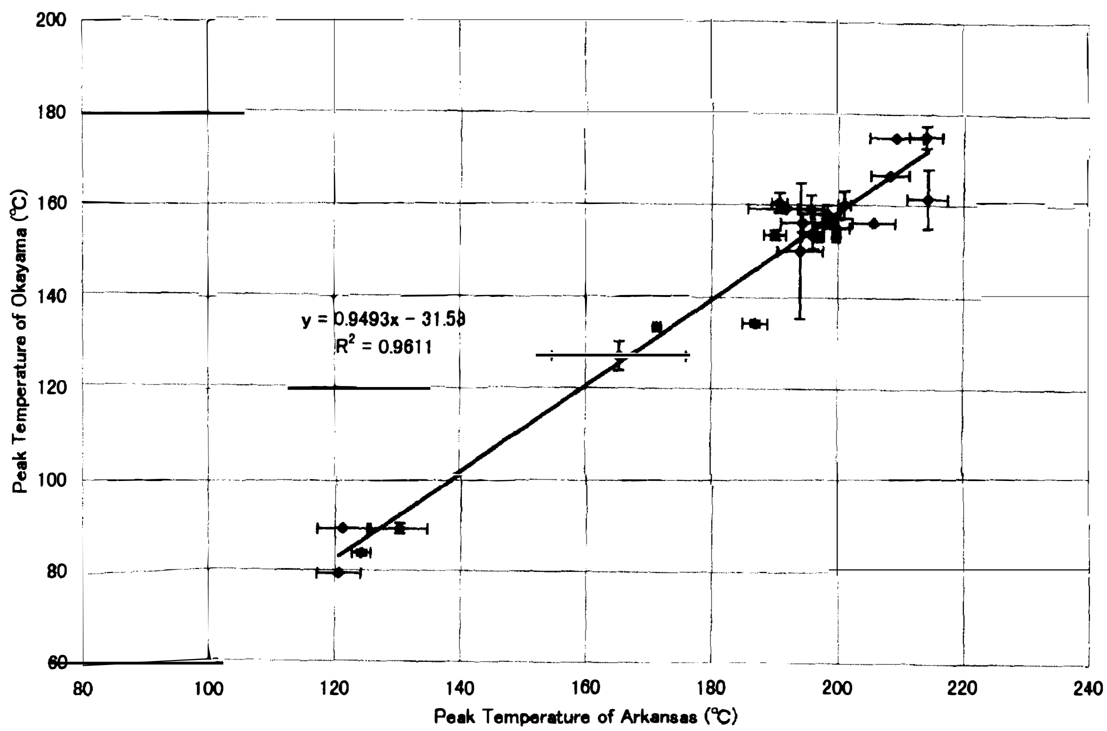

Fig. 3. Plot comparing the TL peak temperatures of ten equilibrated and fifteen unequilibrated ordinary chondrites measured at the University of Arkansas and Okayama University of Science.

Table 3. Thermoluminescence data of Arkansas and Okayama for fifteen unequilibrated Japanese ordinary chondrites.

			Arkansas Induced TL				Okayama Induced TL					
Meteorite	Class	Weight (g)	TL sensitivity (Dhajala=1)*	Peak Temp. (°C)	Width (°C)	TL Subtype	TL sensitivity ($\times 10^3$ counts)*	Peak Temp. (°C)	Width (°C)	Ol. Subtype	Ol. C.V.	L-Ca Py. C.V.
Y-790448	LL3	3480.00	0.008 ± 0.001	121 ± 4	104 ± 13	3.1–3.2	0.48 ± 0.01	89 ± 0	83 ± 2	≦3.4	74	80
Y-791087	H3	579.84	0.66 ± 0.03	196 ± 2	150 ± 3	3.7	32.1 ± 0.3	153 ± 3	134 ± 1		4	23
Y-791340	H3	34.20	0.58 ± 0.03	190 ± 2	146 ± 2	3.7	41.0 ± 1.0	153 ± 1	125 ± 1	3.8	20	17
Y-791428	H3	548.94	0.60 ± 0.03	187 ± 2	151 ± 4	3.7	39.8 ± 0.4	134 ± 1	132 ± 5		3	46
Y-791429	L3	223.53	0.64 ± 0.04	194 ± 4	145 ± 3	3.7	36.8 ± 0.3	150 ± 15	138 ± 1	3.9	10	29
Y-791828	L3	841.00	1.61 ± 0.12	208 ± 3	148 ± 2	3.8	95.2 ± 3.6	167 ± 0	127 ± 2	3.7	23	33
Y-791835	L3	23.80	0.38 ± 0.02	192 ± 6	161 ± 5	3.6	27.3 ± 0.2	159 ± 0	139 ± 0	≦3.4	79	71
Y-791961	L3	1387.00	0.32 ± 0.01	214 ± 3	165 ± 5	3.6	20.6 ± 0.3	175 ± 2	138 ± 0	3.9	9	42
Y-793375	L3	4864.00	0.25 ± 0.01	191 ± 1	162 ± 1	3.6	18.1 ± 0.1	160 ± 2	138 ± 4	3.9	10	46
Y-793396	L3	364.11	0.28 ± 0.02	209 ± 4	169 ± 4	3.6	15.7 ± 1.0	175 ± 0	139 ± 0		2	43
Y-793408	L3	1140.00	0.042 ± 0.003	121 ± 4	92 ± 11	3.3–3.4	2.6 ± 0.2	79 ± 0	71 ± 3	≦3.4	52	80
Y-793567	L3	700.00	0.028 ± 0.001	171 ± 1	158 ± 9	3.3	1.9 ± 0.1	133 ± 0	143 ± 1	3.6	40	53
Y-82038	LL3	199.90	0.026 ± 0.004	130 ± 5	97 ± 10	3.2–3.3	1.5 ± 0.2	89 ± 1	78 ± 0	≦3.4	52	62
ALH-77214	L3	1021.21	0.100 ± 0.006	124 ± 2	67 ± 2	3.4–3.5	5.3 ± 0.1	84 ± 1	52 ± 1	≦3.4	62	88
ALH-77304	L3	334.26	0.86 ± 0.05	165 ± 11	177 ± 8	3.7	70 ± 4	127 ± 3	165 ± 2		2	42

*; different unit between Arkansas and Okayama

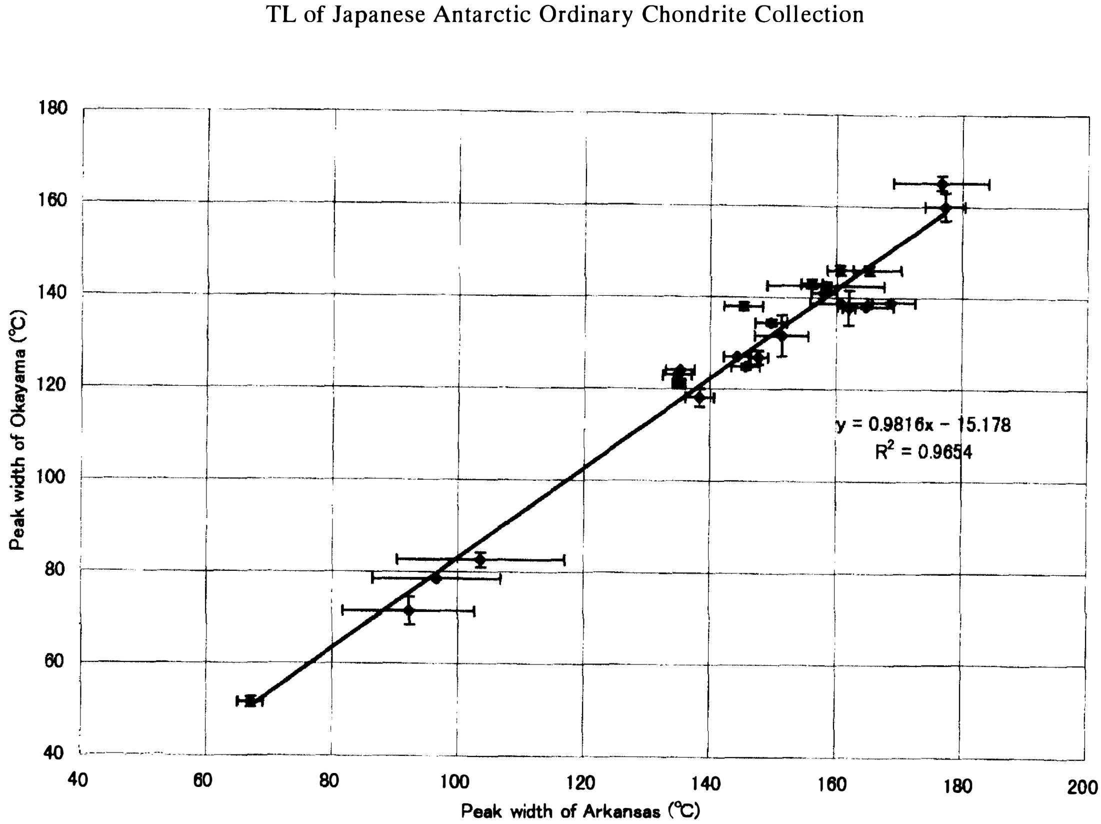

Fig. 4. Plot comparing the TL peak widths of ten equilibrated and fifteen unequilibrated ordinary chondrites measured at the University of Arkansas and Okayama University of Science.

3.2. *TL distribution of large meteorites*

The TL criteria used by Benoit *et al.* (1992) for pairing Antarctic meteorites were that for two meteorites to be paired 1) natural TL dose at 250 °C had to be within 10%, 2) TL sensitivity values had to be within a factor of two, 3) induced TL peak temperatures had to be within 10% and peak widths within 20%. These criteria, based on data for petrographically paired meteorites, were deliberately conservative. A more reliable approach is to examine the variation of TL properties within large chondrites like META78028 (L6), LEW85319 (H5) and ALHA78084 (L6) (20.7, 11.5, and 14.3 kg respectively), taking advantage of the fact that serial samples from these meteorites are known to be paired.

A plot of TL sensitivity versus LT/HT ratio for these meteorites is shown in Fig. 5. LT/HT ratios of META78028 and LEW85319 are within 17% and 6% limits, respectively. On the other hand, the LT/HT ratio of ALHA78084 scatters widely. ALHA78084 has a pronounced natural TL profile that is clearly related to its orientation on the ice (Benoit *et al.*, 1994), *i.e.* the lower potion of the specimen has remained colder than the upper portion. This indicates an unusually stable orientation for a considerable period of time. Thus, pairing criteria are better and more conservatively assessed from the META78028 and LEW85319 data. The LT/HT ratio can be converted to equivalent dose at 250°C by an empirical calibration equation (Benoit *et al.*, 1992). The natural TL doses are listed in Table 4. Rectangles in Fig. 5 show the TL pairing criteria used by Benoit *et al.* (1992). Data for META78028.86 varies from the other values by more

Table 4. Thermoluminescence data for three large chondrites.

Meteorite	Class	Weight (g)	Arkansas: Natural TL: LT/HT	Arkansas: Natural TL: Dose at 250 °C (krad)	Arkansas: Natural TL: LT Intensity ($x10^3$ counts)	Arkansas: Induced TL: TL Sensitivity (Dhajala=1)	Arkansas: Induced TL: Peak Temp. (°C)	Arkansas: Induced TL: Width (°C)	Arkansas: LT Int./TL Sens. ($x10^3$)
META78028.85	L6	20700	1.66 ±0.03	25.0 ± 0.6	3.4 ±0.4	1.67 ±0.22	209 ±4	154 ±2	2.06 ± 0.36
META78028.86	L6	20700	1.52 ±0.02	22.2 ± 0.4	3.0 ±0.4	1.42 ±0.12	207 ±3	155 ±1	2.13 ± 0.32
META78028.87	L6	20700	1.63 ±0.05	24.4 ± 1.0	1.4 ±0.1	0.63 ±0.04	203 ±5	149 ±2	2.23 ± 0.17
META78028.88	L6	20700	1.70 ±0.01	25.8 ± 0.2	3.8 ±0.2	1.63 ±0.16	200 ±2	151 ±1	2.33 ± 0.25
META78028.89	L6	20700	1.78 ±0.05	27.5 ± 1.1	2.0 ±0.2	0.75 ±0.08	204 ±3	153 ±3	2.67 ± 0.34
META78028.90	L6	20700	1.73 ±0.03	26.5 ± 0.6	3.2 ±0.2	1.34 ±0.12	214 ±6	153 ±6	2.39 ± 0.27
META78028.91	L6	20700	1.74 ±0.03	26.7 ± 0.6	2.8 ±0.2	1.25 ±0.06	204 ±2	150 ±1	2.27 ± 0.19
META78028.92	L6	20700	1.75 ±0.01	26.9 ± 0.2	2.8 ±0.2	1.19 ±0.07	203 ±3	151 ±3	2.32 ± 0.23
LEW85319-43	H5	11500	0.67 ±0.01	7.2 ± 0.1	0.41 ±0.01	0.75 ±0.03	209 ±3	136 ±1	0.55 ± 0.02
LEW85319-44	H5	11500	0.65 ±0.00	6.9 ± 0.0	0.29 ±0.00	0.60 ±0.01	202 ±3	134 ±1	0.48 ± 0.01
LEW85319-45	H5	11500	0.66 ±0.01	7.1 ± 0.1	0.27 ±0.01	0.53 ±0.02	200 ±1	134 ±2	0.51 ± 0.02
LEW85319-46	H5	11500	0.64 ±0.00	6.8 ± 0.0	0.33 ±0.02	0.65 ±0.05	199 ±3	135 ±1	0.51 ± 0.05
LEW85319-47	H5	11500	0.68 ±0.01	7.4 ± 0.1	0.22 ±0.02	0.44 ±0.03	210 ±3	136 ±4	0.50 ± 0.05
LEW85319-48	H5	11500	0.65 ±0.01	6.9 ± 0.1	0.24 ±0.00	0.49 ±0.02	201 ±4	135 ±4	0.50 ± 0.02
LEW85319-49	H5	11500	0.64 ±0.03	6.8 ± 0.4	0.23 ±0.01	0.53 ±0.02	203 ±2	138 ±2	0.44 ± 0.03
ALHA78084-104	H4	14300	4.78 ±0.07	106.4 ± 2.1	1.36 ±0.05	0.42 ±0.02	191 ±5	145 ±2	3.27 ± 0.22
ALHA78084-107	H4	14300	4.61 ±0.08	101.2 ± 2.4	1.58 ±0.05	0.41 ±0.04	193 ±2	149 ±2	3.85 ± 0.39
ALHA78084-112	H4	14300	2.65 ±0.08	47.4 ± 2.0	0.76 ±0.02	0.49 ±0.04	194 ±1	148 ±6	1.54 ± 0.12
ALHA78084-129	H4	14300	3.78 ±0.17	77.2 ± 4.7	1.00 ±0.02	0.40 ±0.03	195 ±4	150 ±1	2.49 ± 0.17
ALHA78084-203	H4	14300	3.70 ±0.07	74.9 ± 1.9	1.08 ±0.01	0.45 ±0.05	195 ±4	151 ±4	2.40 ± 0.26
ALHA78084-204	H4	14300	5.27 ±0.09	121.6 ± 2.8	0.93 ±0.05	0.29 ±0.02	192 ±3	149 ±2	3.20 ± 0.25
ALHA78084-206	H4	14300	3.83 ±0.19	78.6 ± 5.3	0.80 ±0.04	0.35 ±0.03	202 ±6	148 ±3	2.31 ± 0.22
ALHA78084-208	H4	14300	4.21 ±0.09	89.4 ± 2.6	0.92 ±0.05	0.36 ±0.03	201 ±7	153 ±2	2.53 ± 0.25
ALHA78084-210	H4	14300	4.68 ±0.06	103.3 ± 1.8	1.57 ±0.06	0.47 ±0.03	200 ±1	148 ±1	3.38 ± 0.23
ALHA78084-211	H4	14300	5.42 ±0.05	126.3 ± 1.6	1.26 ±0.05	0.33 ±0.02	195 ±6	151 ±2	3.78 ± 0.29

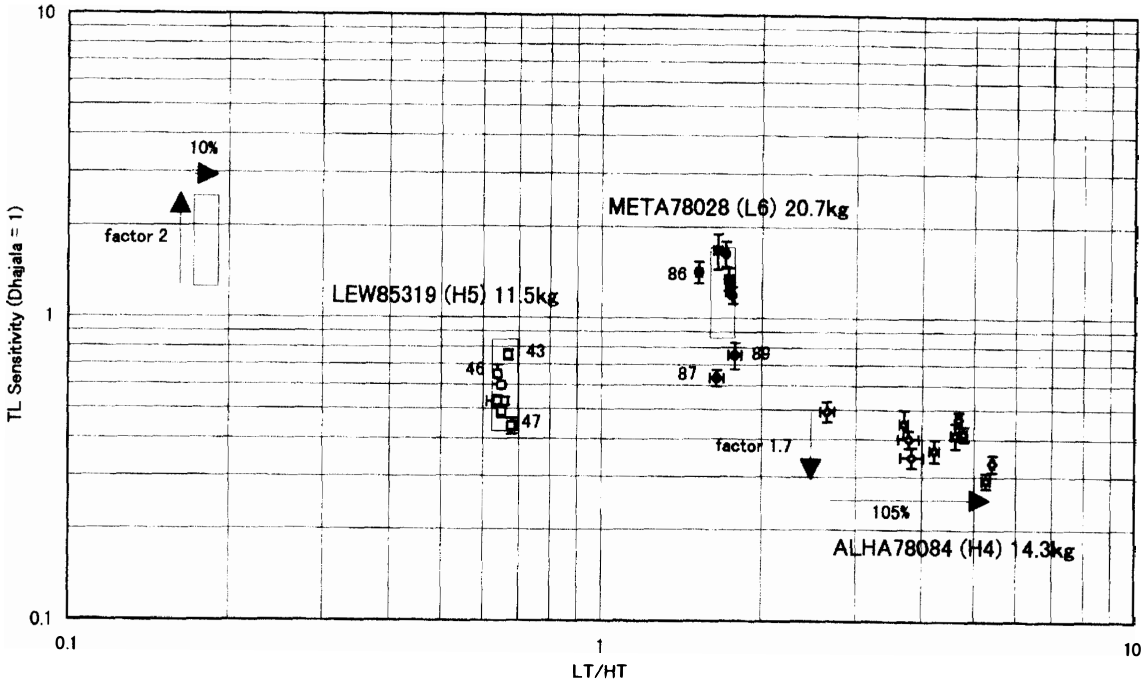

Fig. 5. Induced TL sensitivity vs. natural TL peak height ratio for three large Antarctic ordinary chondrites. The rectangles correspond to a factor of two in TL sensitivity and 10% in dose at 250°C. The number by each datum is the subsample number.

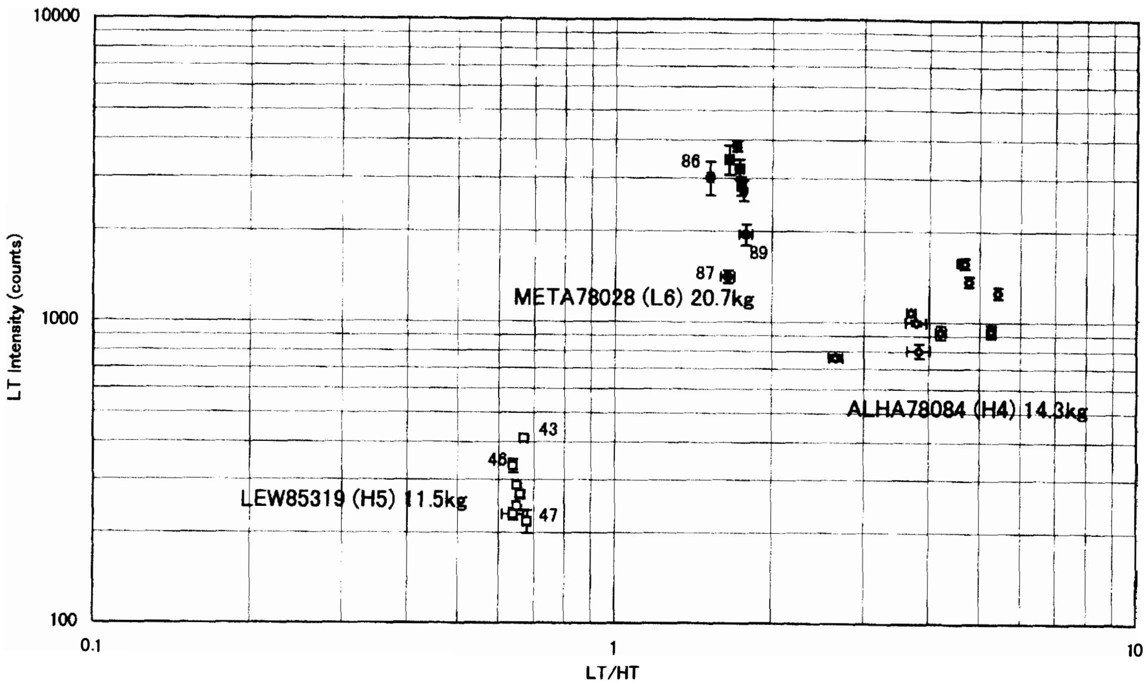

Fig. 6. Natural TL signal (raw data as number of counts) against natural TL peak height ratio for three large Antarctic ordinary chondrites. The number by each datum is the subsample number.

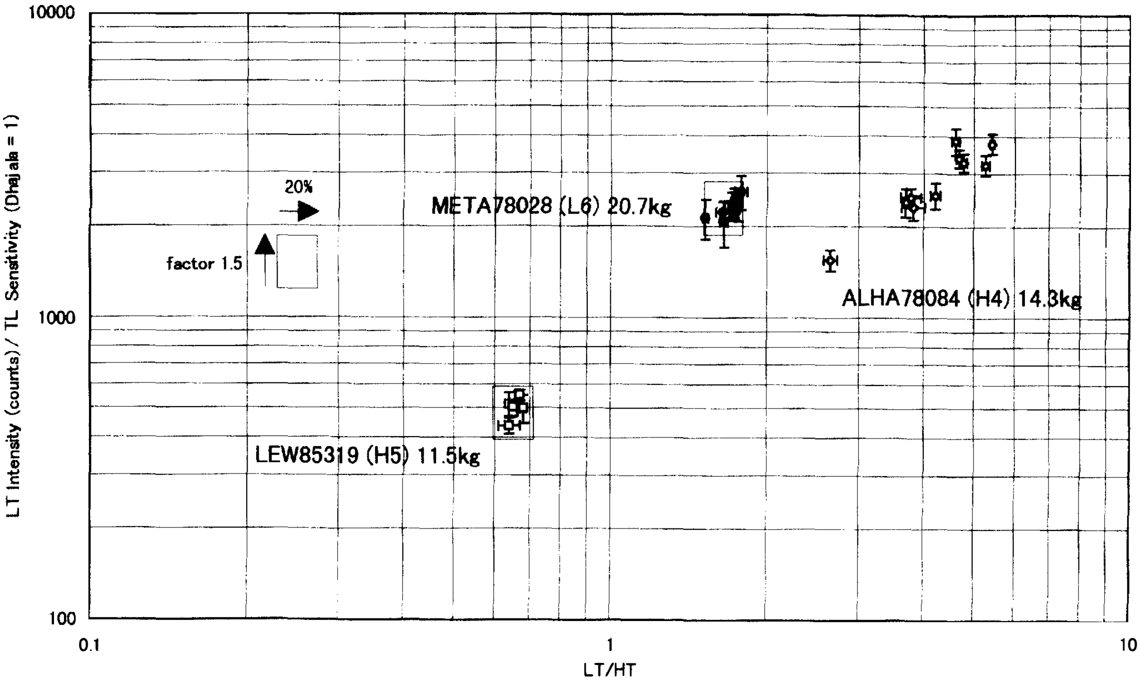

Fig. 7. Ratio of the natural TL signal (raw data as number of counts) to the Dhajala-normalized TL sensitivity vs. natural TL peak height ratio for three large Antarctic chondrites. The rectangles correspond to regions in which LT intensity/TL sensitivity varies by a factor of 1.5 and LT/HT varies by 20%. The number by each datum is the subsample number.

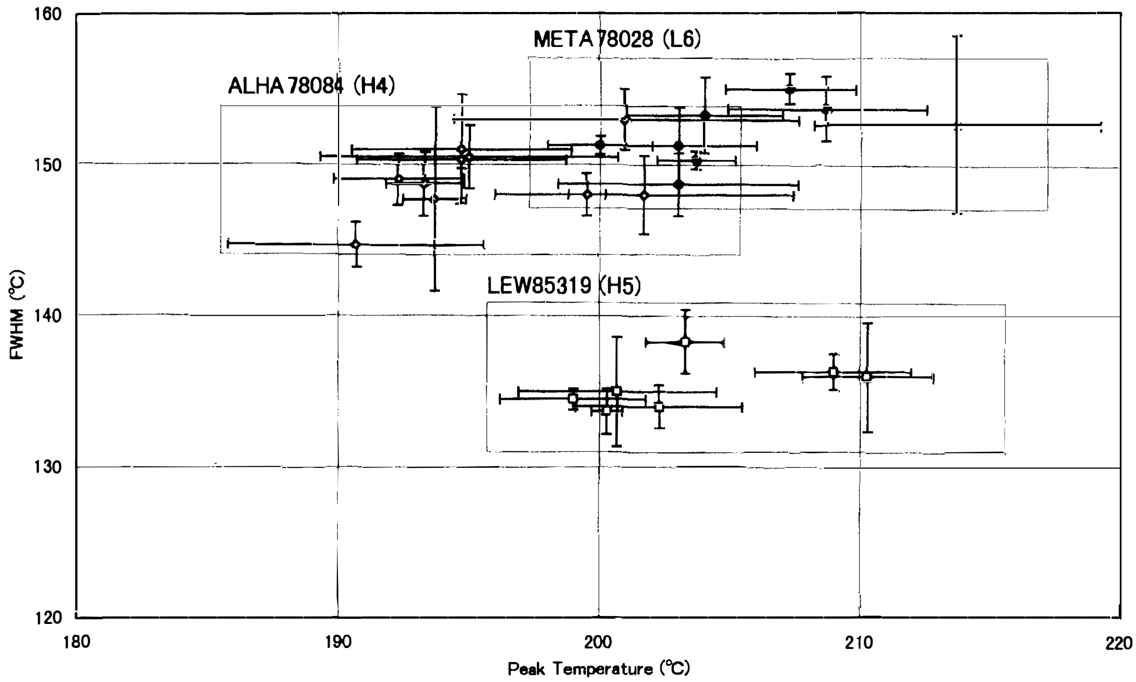

Fig. 8. TL peak width vs. TL peak temperature for three large Antarctic ordinary chondrites. The rectangles correspond to regions in which peak temperature varies by 20°C in peak temperature and peak width by 10°C.

than 10%, suggesting that a criterion by which LT/HT agree within 20% might be more appropriate.

The ranges of TL sensitivity of META78028 and LEW85319 cover factors 2.6 and 1.7, suggesting that a criterion of 2) may also be too conservative. Coefficients of variation (σ as a percentage of the mean) of TL sensitivity of them are also large, 31% and 18%, respectively. A plot of natural TL signal (raw data as number of counts) *versus* LT/HT ratio for the three meteorites is shown in Fig. 6. LT intensity ranges over factors 2.4 and 1.9, and coefficients of variation are also large, 28% and 24%, respectively. But the lower LT intensity portion of META78028 and LEW85319 in Fig. 6 corresponds to lower TL sensitivity portion in Fig. 5, and *vice versa*. It is possible to normalize the raw natural TL signal to the induced TL in order to remove mineralogical effects on the natural TL signal. These LT intensity/TL sensitivity ratios are plotted in Fig. 7 and in this case the spread in our data is less than a factor of 1.5. Coefficients of variation are also reduced to 8% and 7%, respectively. We propose that raw natural TL/induced TL ratio within 1.5 provides another pairing criterion. This procedure assists in correcting the data for sample inhomogeneity and/or weathering.

Relations between peak temperature and peak width are shown in Fig. 8. The peak temperatures are distributed within 7% (14°C) and 6% (11°C), respectively, for META 78028 and LEW 85319. The widths are distributed within 4% (6°C) and 3% (5°C). It thus appears that criteria of about 10% or about 20°C and about 10°C for peak temperature and peak width, respectively, are appropriate for pairing identification. As a result of these studies, new TL pairing criteria are that for TL data to be consistent with pair-

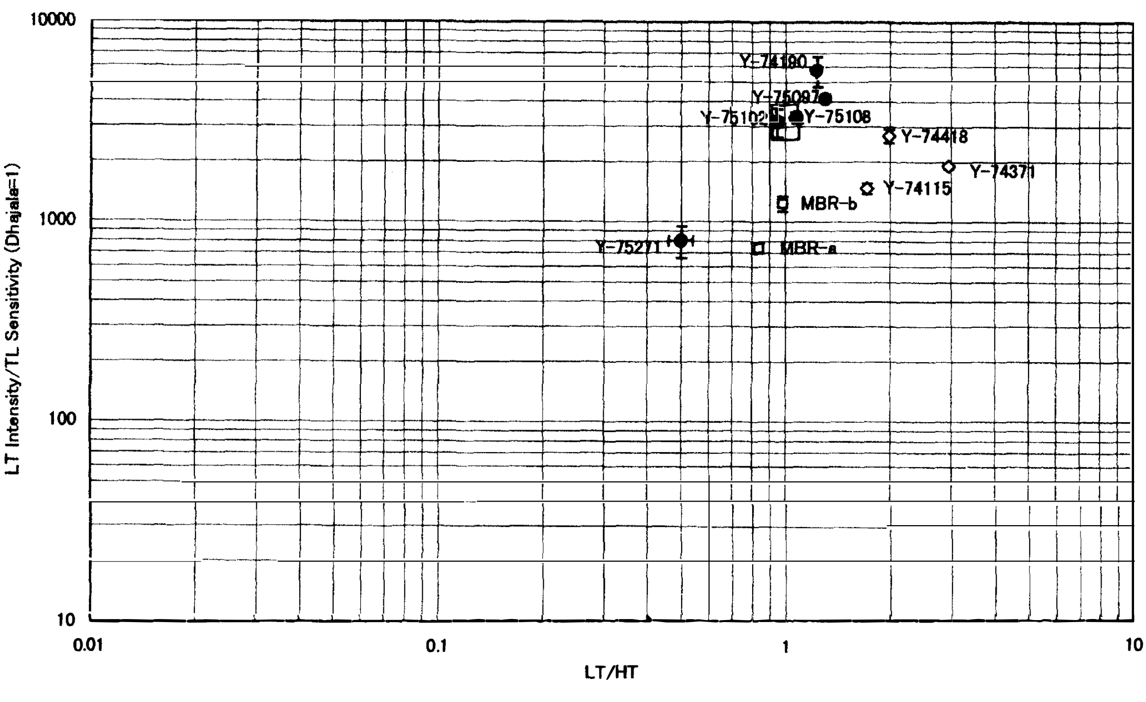

Fig. 9. Same as Fig. 7 but for ten equilibrated ordinary chondrites from the Japanese Antarctic meteorite collection.

ing: 1) LT/HT should agree within 20%; 2) raw natural TL/induced TL ratio within 1.5; 3) the TL peak temperatures should be within 20°C and peak widths within 10°C.

3.3. Pairing of Japanese equilibrated chondrites

HONDA (1981) thought, on the basis of exposure age and cosmogenic nuclide data, that the ten equilibrated chondrites listed in Table 2 represented three discrete falls. Using our present criteria, Y-75102 and Y-75108 are potentially paired as shown in Fig. 9, while the others are not paired. MIONO and NAKANISHI (1994) suggested that while Y-75271, Y-75102, Y-74190 and Y-75097 have the same exposure age, terrestrial ages determined by the TL fusion crust method were different, implying separate falls. The present results also suggest that they are not paired.

3.4. Subtypes of Japanese unequilibrated chondrites

Metamorphism causes the production of feldspar, the major TL phosphor in ordinary chondrites, by the devitrification of feldspathic mesostasis. Induced TL sensitivity increases by a factor of 1000 from petrographic subtype 3.0 to 3.9. Subtypes of the present Japanese unequilibrated ordinary chondrites were determined, using induced TL sensitivity. Nine chondrites [Y-790448(LL3), Y-793408(L3), Y-793567(L3), Y-82038(LL3), Y-793596(LL3), Y-793565(LL3), Y-791324(LL3), Y-791558(LL3) and Y-790787(L3)] were found to have very low TL sensitivity, equivalent to petrologic type

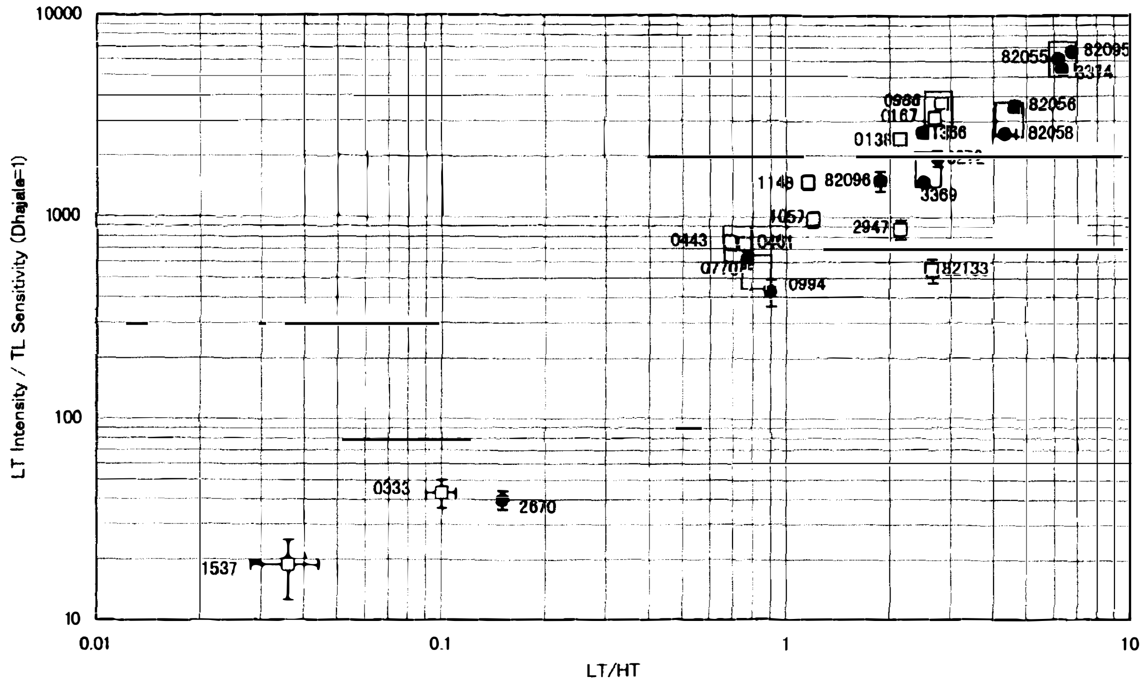

Fig. 10. Ratio of the natural TL signal (raw data as number of counts) to the Dhajala-normalized TL sensitivity vs. natural TL peak height ratio for twenty-eight unequilibrated ordinary chondrites from the Japanese Antarctic meteorite collection. The rectangles correspond to regions in which LT intensity/TL sensitivity varies by a factor of 1.5 and LT/HT varies by 20%. Meteorites may be identified from Table 5, the last 4 or 5 numbers of the meteorites' names have been used. ❑:H3, ●:L3

Table 5. Thermoluminescence data of Arkansas for twenty-eight unequilibrated Japanese ordinary chondrites.

			Arkansas												
			Natural TL			Induced TL				LT Int.	Pairing***				
Meteorite	Class	Weight (g)	LT/HT	Dose at 250 °C (krad)	LT Intensity (10^3 counts)	TL Sensitivity (Dhajala=1)	Peak Temp (°C)	Width (°C)	TL Subtype**	/TL Sens. ($\times10^3$)	New Criteria	Usual Criteria	Ol. Subtype	Ol. C.V.	L-Ca Py. C.V.
Y-793596	LL3	62.93				0.0025 ± 0.0006			3.0				3.5	49	101
Y-793565	LL3	16.24				0.0028 ± 0.0006			3.0				≦3.4	60	96
Y-791324	LL3	20.67				0.0048 ± 0.0025	132 ± 4		3.0–3.1				≦3.4	54	102
Y-791558	LL3	101.64				0.0065 ± 0.0006	132 ± 3	110 ± 7	3.1				≦3.4	53	78
Y-790787	L3	46.08				0.0030 ± 0.0032			3.0–3.1				3.8	15	17
Y-792670	L3	119.36	0.15 ± 0.00	0.9 ± 0.0	0.011 ± 0.001	0.28 ± 0.02	177 ± 7	149 ± 4	3.6	0.040 ± 0.004			3.9	8	49
Y-790770	L3	21.20	0.77 ± 0.02	8.7 ± 0.3	0.37 ± 0.02	0.60 ± 0.05	204 ± 3	158 ± 3	3.7	0.62 ± 0.06	O	X		2	27
Y-790994	L3	49.45	0.90 ± 0.03	10.8 ± 0.5	0.08 ± 0.01	0.18 ± 0.02	199 ± 10	162 ± 8	3.7(3.5–3.6)	0.43 ± 0.07	O	X	3.9	7	31
Y-82096	L3	168.51	1.89 ± 0.06	29.9 ± 1.3	0.36 ± 0.04	0.24 ± 0.01	168 ± 2	152 ± 2	3.6	1.5 ± 0.2			3.9	8	51
Y-791366	L3	23.04	2.51 ± 0.06	44.1 ± 1.4	1.33 ± 0.04	0.51 ± 0.03	196 ± 4	149 ± 3	3.6–3.7	2.6 ± 0.2				1	11
Y-793369	L3	43.63	2.51 ± 0.02	44.1 ± 0.5	0.25 ± 0.00	0.17 ± 0.01	184 ± 8	147 ± 2	3.5	1.5 ± 0.1	O	X	3.9	10	43
Y-793272	L3	95.96	2.75 ± 0.03	49.9 ± 0.7	0.36 ± 0.02	0.18 ± 0.01	175 ± 3	152 ± 3	3.5	2.0 ± 0.2	O	X	3.8	16	37
Y-82058	L3	127.95	4.35 ± 0.34	93.5 ± 10.0	0.38 ± 0.01	0.15 ± 0.01	191 ± 9	154 ± 3	3.6(3.5)	2.6 ± 0.1	O	O	3.8	20	42
Y-82056	L3	913.79	4.63 ± 0.17	101.8 ± 5.1	0.99 ± 0.04	0.28 ± 0.01	189 ± 3	147 ± 5	3.6	3.6 ± 0.2	O	O	3.9	5	46
Y-82055	L3	946.75	6.16 ± 0.11	150.5 ± 3.7	1.59 ± 0.02	0.26 ± 0.01	168 ± 6	157 ± 5	3.6	6.1 ± 0.3	O	*		3	19
Y-793374	L3	206.91	6.35 ± 0.16	156.9 ± 5.4	1.44 ± 0.05	0.27 ± 0.01	170 ± 3	153 ± 3	3.6	5.4 ± 0.2	O	*		3	36
Y-82095	L3	710.18	6.74 ± 0.04	170.3 ± 1.4	1.78 ± 0.02	0.27 ± 0.01	181 ± 6	158 ± 2	3.6	6.6 ± 0.3	O	*	3.9	5	40
Y-791537	H3	66.18	0.04 ± 0.01	0.1 ± 0.0	0.006 ± 0.002	0.32 ± 0.01	182 ± 6	146 ± 4	3.6	0.019 ± 0.006				3	24
Y-790333	H3	17.73	0.10 ± 0.01	0.5 ± 0.1	0.012 ± 0.001	0.28 ± 0.04	177 ± 4	152 ± 1	3.5–3.6	0.043 ± 0.007			3.9	6	32
Y-790443	H3	19.49	0.69 ± 0.03	7.5 ± 0.4	0.25 ± 0.02	0.33 ± 0.02	192 ± 1	147 ± 4	3.7(3.6)	0.8 ± 0.1	O	X		3	36
Y-790461	H3	778.90	0.76 ± 0.03	8.6 ± 0.5	0.41 ± 0.02	0.55 ± 0.02	190 ± 3	138 ± 1	3.7	0.7 ± 0.0	O	X	3.8	13	45
Y-791148	H3	58.36	1.16 ± 0.01	15.3 ± 0.2	0.58 ± 0.04	0.39 ± 0.02	198 ± 6	144 ± 3	3.6	1.5 ± 0.1			3.7	22	18
Y-791057	H3	66.68	1.20 ± 0.04	16.0 ± 0.7	0.46 ± 0.02	0.47 ± 0.04	202 ± 3	158 ± 2	3.6–3.7	1.0 ± 0.1				2	31
Y-792947	H3	233.40	2.14 ± 0.06	35.4 ± 1.4	0.09 ± 0.01	0.10 ± 0.01	141 ± 8	126 ± 6	3.4–3.5	0.9 ± 0.1			3.5	46	69
Y-790138	H3	39.32	2.16 ± 0.01	35.9 ± 0.2	0.82 ± 0.03	0.34 ± 0.02	189 ± 2	146 ± 3	3.6	2.4 ± 0.1				3	23
Y-82133	H3	93.28	2.66 ± 0.08	47.7 ± 2.0	0.059 ± 0.001	0.11 ± 0.01	150 ± 8	127 ± 4	3.4–3.5	0.5 ± 0.1			3.6	40	68
Y-790167	H3	18.75	2.71 ± 0.05	48.9 ± 1.2	1.11 ± 0.08	0.36 ± 0.01	208 ± 2	156 ± 2	3.7(3.6)	3.1 ± 0.2	O	O		2	9
Y-790986	H3	135.79	2.83 ± 0.05	51.9 ± 1.3	2.68 ± 0.02	0.73 ± 0.03	190 ± 4	151 ± 2	3.7	3.7 ± 0.1	O	O		4	36

* Y-82055 could be paired to Y-793374. Y-793374 could be paired to Y-82095. Y-83055 is probably not paired to Y-82095.
** The values in parentheses are TL subtypes before paired.
*** O: paired, X: unpaired.

3.3 or below (Tables 3 and 5). Pairing was also examined by the new criteria for the twenty-eight unequilibrated chondrites. Thirteen chondrites were paired to six falls as shown in Fig. 10 and in Table 5.

Metamorphism causes the homogenization of Fe contents in olivine and low-Ca pyroxene, and volatilizes carbon and inert gas. Figure 11 compares TL sensitivity and olivine heterogeneity for the present samples, while Fig. 12 compares TL sensitivity and low-Ca pyroxene heterogeneity. The trends are very similar to those observed in previous TL studies of type 3 ordinary chondrites (SEARS et al., 1991a). Figure 13 shows a histogram of occurrence for the type 3 chondrites. It is clear that H chondrites tend towards higher petrographic types, while LL chondrites show lower. The distribution of L chondrites in the present study is different from that of SEARS et al. (1991a), but this may reflect the small number of samples examined in the present study.

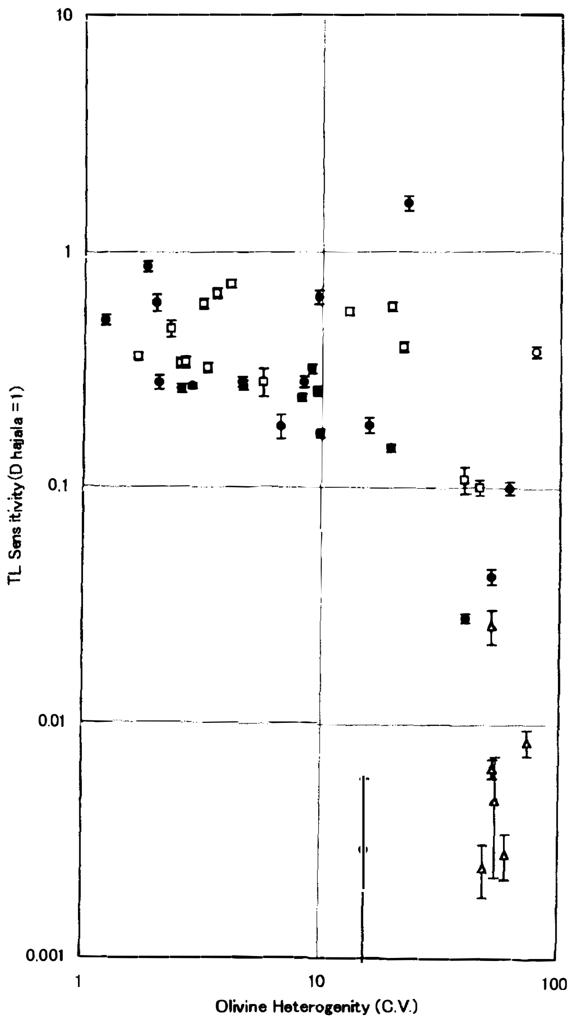

Fig. 11.

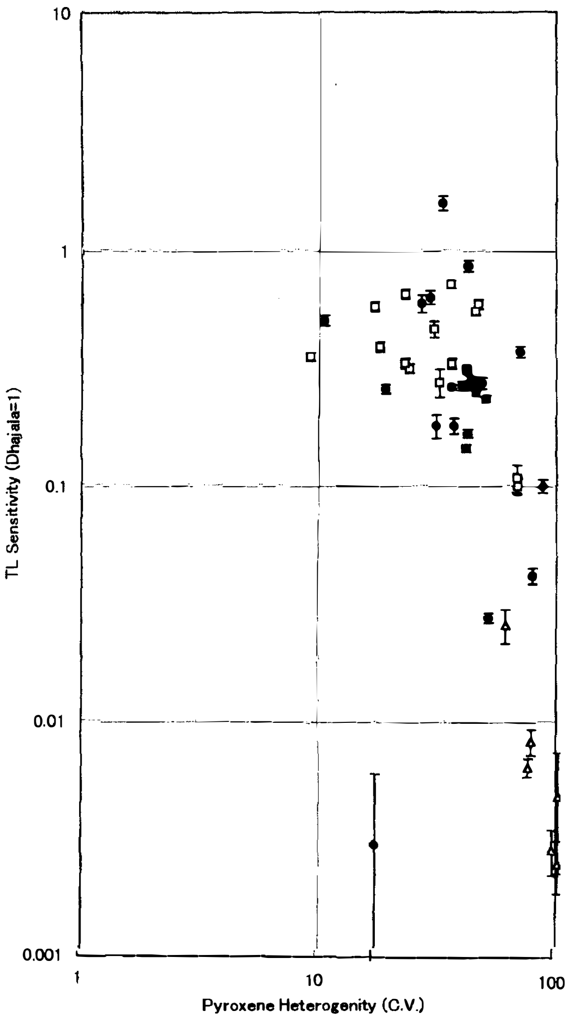

Fig. 12.

Figs. 11, 12. Dhajala-normalized TL sensitivity vs. olivine heterogeneity (Fig. 11) and pyroxene heterogeneity (Fig. 12) of forty-three unequilibrated ordinary chondrites from the Japanese Antarctic meteorite collection. △: LL3, ❑:H3, ●:L3

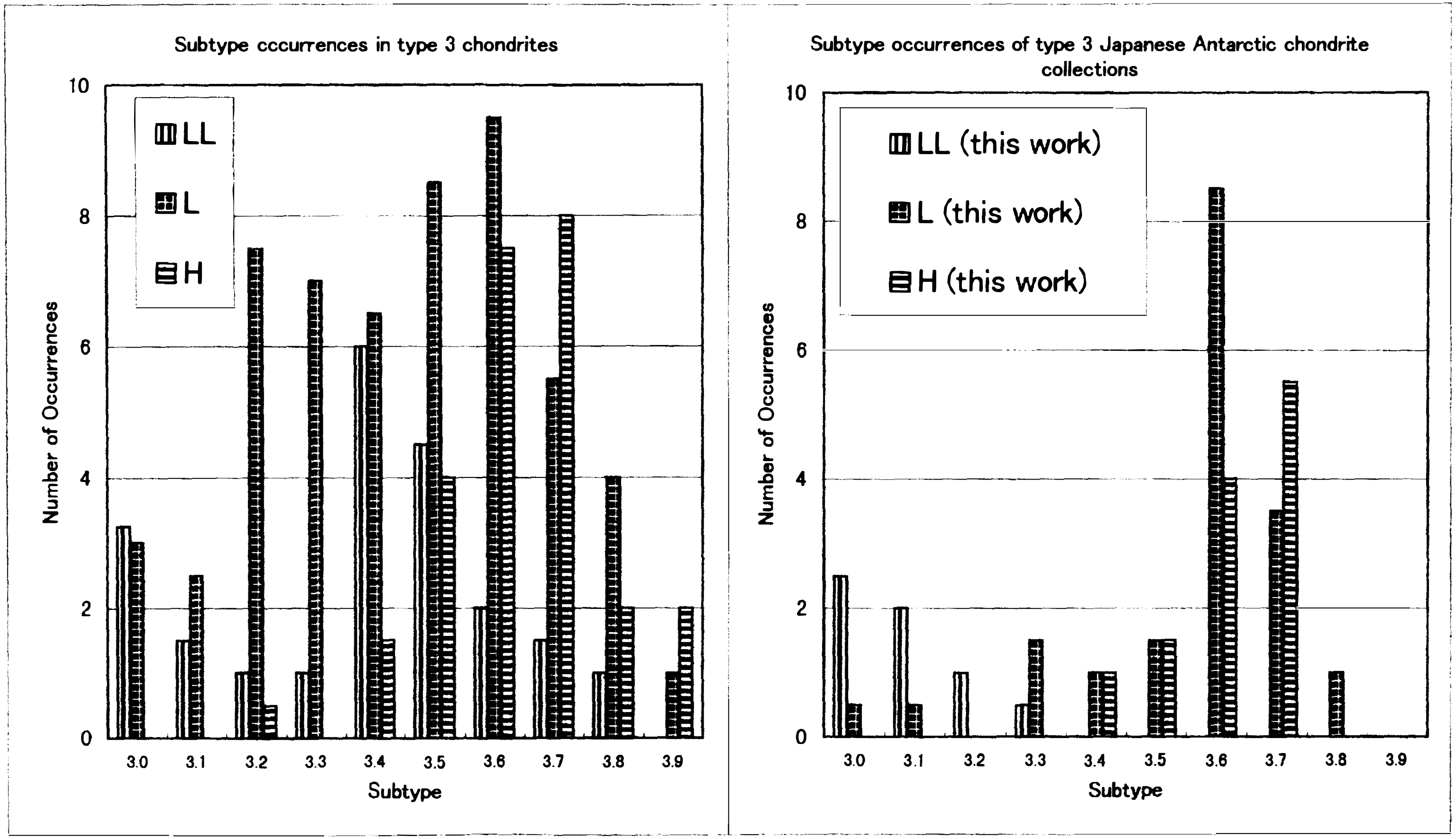

Fig. 13. Histograms of the petrographic types of unequilibrated ordinary chondrites. Left, data from Table 4 of S*EARS et al. (1991a). Right, present work, Tables 3 and 5.*

4. Summary

The thermoluminescence of Antarctic chondrites from the Japanese collection was measured at both the University of Arkansas and Okayama University of Science. We find that:

1) TL data between the two laboratories are consistent with each other. Instrumental differences lead to differences in the data which are either minor or readily allowed for.

2) A new set of TL pairing criteria, based on the TL of three large Antarctic chondrites, are somewhat more permissive than those used previously. The new criteria are that for TL to be consistent with the pairing of ordinary chondrites: 1) the natural TL peak height ratios, LT/HT, should be within 20%; 2) that ratios of raw natural TL signal to induced TL signal should be within 1.5; 3) the TL peak temperatures should be within 20 °C and peak widths within 10 °C.

3) Pairings of ten equilibrated ordinary chondrites were investigated. Y-75102 and Y-75108 are potentially paired according to the new TL criteria. The present data are not consistent with extensive pairing suggested by cosmogenic isotope data.

4) Petrologic subtypes of forty-three Antarctic chondrites from the Japanese collection were determined from induced TL data. Nine were found to be of petrologic type <3.3 and therefore are especially significant little-metamorphosed ordinary chondrites.

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