Meteoritics 26, 157–160 (1991)

Thermoluminescence survey of 12 meteorites collected by the European 1988 Antarctic meteorite expedition to Allan Hills and the importance of acid washing for thermoluminescence sensitivity measurements

P. H. Benoit, H. Sears and D. W. G. Sears
Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701 USA

(*Revised 18 December 1990; accepted in revised form 6 March 1991*)

Abstract—Natural and induced thermoluminescence (TL) data are reported for 12 meteorites recovered from the Allan Hills region of Antarctica by the European field party during the 1988/89 field season. The samples include one with extremely high natural TL, ALH88035, suggestive of exposure to unusually high radiation doses (*i.e.,* low degrees of shielding), and one, ALH88034, whose low natural TL suggests reheating within the last 10^5 years. The remainder have natural TL values suggestive of terrestrial ages similar to those of other meteorites from Allan Hills. ALH88015 (L6) has induced TL data suggestive of intense shock. TL sensitivities of these meteorites are generally lower than observed falls of their petrologic types, as is also observed for Antarctic meteorites in general. Acid-washing experiments indicate that this is solely the result of terrestrial weathering rather than a nonterrestrial Antarctic–non-Antarctic difference. However, other TL parameters, such as natural TL and induced peak temperature-width, are unchanged by acid washing and are sensitive indicators of a meteorite's metamorphic and recent radiation history.

INTRODUCTION

Over the past decade over 10 thousand meteorites have been discovered on the ice sheets of Antarctica (Schutt, 1990). We have measured the natural and induced thermoluminescence (TL) of all the meteorites collected by the United States Antarctic program since the 1985/86 field season which were suitable for the measurements; values for the natural thermoluminescence (NTL) of these meteorites have routinely been reported in the Antarctic Meteorite Newsletter (Score and Lindstrom, 1990; Myers *et al.,* 1990; Benoit *et al.,* 1990). In this paper, we present data on a set of twelve meteorites which were collected by the European expedition at the Allan Hills locality during the 1988/89 field season (Wlotzka, 1990; Wlotzka *et al.,* 1989).

Thermoluminescence measurements provide useful information on relative terrestrial ages, on the thermal and radiation histories of meteorites and on the history of the ice on which they are found. The level of natural TL in a meteorite is the result of a competition between build-up due to exposure to cosmic radiation in space and thermal decay, and is thus primarily a reflection of the terrestrial age of a meteorite (Melcher, 1981a; McKeever, 1982; Sears, 1988). However, other factors, such as close passage to the sun or dose rate variations may also affect natural TL levels resulting in particularly low (<5 krad) or particularly high (>100 krad) values (Melcher, 1981b). Heating during atmospheric passage destroys natural TL, but this heating affects only a thin outer rim (<~5 mm in thickness) of the meteorite and, in principle, its effect can be avoided by careful sampling.

Induced TL (*i.e.,* the TL emitted after the natural TL has been removed by heating and the sample administered a standard radiation dose) is measured by three parameters, namely, the intensity of the TL peak relative to a standard (TL sensitivity), the width of the peak, and the peak temperature. The values of these parameters reflect the abundance and nature of feldspar, the primary phosphor in meteorites (see Sears, 1988, for a recent review). Induced TL thus reflects the degree of metamorphism undergone by the meteorite by indirectly measuring the amount and type of feldspar generated by the devitrifcation of glass (Sears *et al.,* 1980). Induced TL also detects the destruction of feldspar by intense shock events which typically cause TL sensitivity to decrease by 1–2 orders of magnitude and cause qualitative changes in the shape of the TL glow curve (Sears, 1988).

EXPERIMENTAL PROCEDURE

The TL measurements of this study were made on chips taken from the interior of the meteorites using a band saw lubricated with propanol. A portion of each piece was powdered in an agate mortar and the magnetic fraction removed using a hand magnet. The natural TL was determined on three portions of the powdered sample (each 4 mg) by heating in copper pans to 500 °C at 7.5 °C/sec while measuring the amount of light emitted. Each portion was then irradiated with a Sr-90 source and the induced TL measured. A more complete description of the equipment and the data reduction techniques can be found in Sears (1988).

RESULTS

The results of this study are given in Table 1. The classifications were kindly provided by R. Hutchison (*via* L. Schultz). The samples are arranged in order of their numeric designations within class and type. Although TL sensitivity data for unequilibrated chondrites and achondrites are typically reported relative to the Dhajala (H3.8) meteorite, the Kernouve (H6) meteorite is used here as a normalization standard because it is a more appropriate standard for equilibrated ordinary chondrites. Multiplying the given sensitivities by a factor of 25 will convert them to Dhajala normalization (Sears *et al.,* 1980). The quoted uncertainties are the standard deviations shown by triplicate measurements.

Thermoluminescence is one technique used to identify meteorites which are paired fragments of a single larger meteorite. Based on the natural and induced TL properties of the samples in this study (Table 1), and on petrographic and discovery location data (Wlotzka, 1990), there is minimal evidence that any of the samples of this study are paired. The only exception to this is the tentative pairing of ALH88003 and ALH88006 which have very similar induced TL parameters, but differ by more than 10 krad in their natural TL levels. The natural TL of these

TABLE 1. Thermoluminescence data for 12 samples collected in the Allan Hills 1988/89 European Antarctic expedition.† Second row of each sample are data for acid-washed material.

Sample	Class/type	Nat. TL (krad at 250 °C)*	Induced TL: TL sensitivity (Kernouve = 1)	W.F.‡	Peak temp (C)	Peak width (FWHM)
ALH88003	L4	54.9	0.030 ± 0.003		190 ± 2	151 ± 1
		54.2	0.17 ± 0.01	5.7	185 ± 4	145 ± 2
ALH88006	L4	71	0.027 ± 0.003		189 ± 1	155 ± 5
		57.3	0.13 ± 0.01	4.8	185 ± 5	146 ± 3
ALH88005	L6	78.4	0.060 ± 0.007		188 ± 6	147 ± 9
		70	0.46 ± 0.02	7.7	189 ± 2	156 ± 1
ALH88015	L6	18	0.0013 ± 0.0001		195 ± 4	188 ± 2
		14.2	0.006 ± 0.002	4.6	191 ± 2	172 ± 6
ALH88023	L6	8.5	0.100 ± 0.007		175 ± 2	144 ± 3
		9.4	0.36 ± 0.03	3.6	182 ± 3	143 ± 1
ALH88037	H4	46.7	0.18 ± 0.02		188 ± 5	131 ± 4
		38.6	0.43 ± 0.02	2.4	190 ± 2	137 ± 2
ALH88001	H5	61.4	0.050 ± 0.007		200 ± 3	148 ± 2
		57.3	0.71 ± 0.03	14.2	196 ± 2	149 ± 2
ALH88007	H5	22.3	0.031 ± 0.003		181 ± 6	124 ± 4
		19.1	0.32 ± 0.02	10.3	184 ± 1	130 ± 2
ALH88009	H5	26.3	0.077 ± 0.006		180 ± 5	138 ± 3
		24.3	0.44 ± 0.02	5.7	189 ± 2	136 ± 1
ALH88022	H5	14.8	0.34 ± 0.02		184 ± 3	132 ± 1
		13.9	0.6 ± 0.03	1.8	179 ± 2	130 ± 3
ALH88035	H5	123	0.034 ± 0.002		183 ± 2	151 ± 10
		107	0.49 ± 0.03	14.4	177 ± 1	129 ± 1
ALH88034	H6	3.7	0.046 ± 0.005		175 ± 5	136 ± 2
		5.0	0.54 ± 0.03	11.7	177 ± 4	141 ± 6

† Uncertainties are standard deviations of triplicate measurements of a single ~150 mg sample. Uncertainties of natural TL levels is <5%.
* With the exception of ALH88005 and 88034, natural TL level of acid-washed samples is based on a single measurement.
‡ W.F. = Weathering Factor: (acid-washed)/(original) sensitivity.

meteorites after acid washing (as described below) is, however, virtually identical. They are from different icefields (Main and Near-Western icefields, respectively; Wlotzka, 1990), although these icefields are in close proximity.

The natural TL values of these samples range from 3.7 to 123 krad. While most of the samples have fairly typical natural TL values (between 5 and 100 krad) which appear to be primarily related to their terrestrial age (Hasan *et al.,* 1991), ALH88035 has a high level of natural TL which is probably indicative of a history of high radiation doses or, more likely, lesser degrees of shielding in space than is typical for meteorites. Similarly, ALH88034, which has the lowest natural TL of this study, is also likely to have had an unusual history, probably involving a recent (within the last 10^5 years) heating event. Since the induced TL data are not indicative of shock reheating (*e.g.,* Haq *et al.,* 1988), it is possible that this meteorite had an orbit with perihelion <0.85 AU (Benoit and Sears, 1991).

The natural TL results of this study are compared with those of the much larger data set for the 1985/86 collection (ALH 85) in Fig. 1 (Hasan *et al.,* 1991). Although the 1988/89 data set is too small for any statistical testing, it is clear that the range of the 1988/89 data is not radically different from that of the 1985/86 collection for H and L chondrites. This suggests that the two data sets have fairly similar average terrestrial ages which, in the case of the 1985/86 Allan Hills meteorites, has been suggested to be approximately 150,000 ± 100,000 years (Hasan *et al.,* 1991).

The TL sensitivities of these samples vary widely, ranging from 0.0013 for ALH88015 (L6) to 0.34 for ALH88022 (H5). In general, these sensitivities are lower than expected for their respective petrologic types, as is shown in Fig. 2. Weathering is known to lower TL sensitivities of type 3 chondrites by approximately a factor of three (Sears *et al.,* 1982), which would not be sufficient to account for the low sensitivities of the samples of this study. As a test of the effect of weathering on equilibrated chondrites, powders of all the samples of this study were washed in 10 M HCl for approximately 45 seconds with gentle agitation to remove iron-oxide and carbonate weathering products and then rinsed three times in distilled water. The choice of 45 seconds of acid washing was assessed from an experiment in which powders of ALH88034 (H5) were immersed in acid for 15, 30, 60, and 120 seconds. The results were identical within the uncertainties of the induced TL measurement. Forty-five seconds is an arbitrary chosen time within this tested range. After acid washing, the powders (which originally were various shades of grey and reddish-brown) were a fairly uniform light grey and the acid solution had become pale yellow-green. Weight losses as a result of acid washing were <10%. The TL results are listed in Table 1. One sample, a portion of ALH88001, was also washed solely in water to verify to what degree removal of fine dust during washing affects TL sensitivity; as shown in Fig. 2, no change was observed.

Acid washing does not significantly change induced peak temperature-width. In ten out of twelve cases, acid washing also

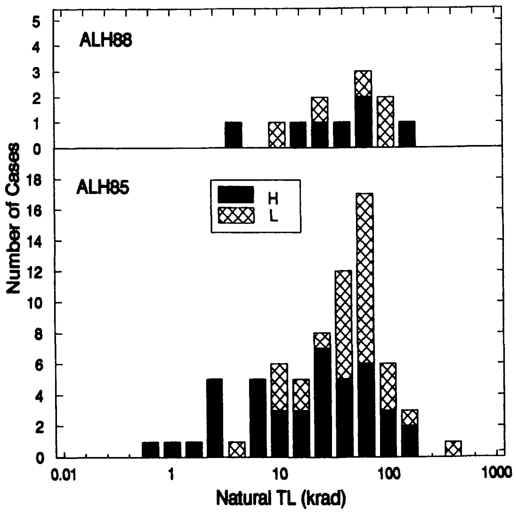

FIG. 1. Histogram of natural TL measurements of 12 samples from the 1988/89 European meteorite expedition (ALH88) and samples from the U.S. Antarctic meteorite program 1985/86 field season (ALH85).

does not appear to affect natural TL, though it is necessary in some cases to apply a correction factor to account for increased dead time in the PMT due to the increased brightness of the samples. The two exceptions, ALH88006 (L4) and ALH88037 (H4), show a drop of about 15% in natural TL after acid washing. It is possible that this apparent loss of natural TL is caused by the preferential dissolution of the fine-grained feldspar phosphor but it is clear from these data that acid washing does not change natural TL enough to change our general interpretation even in these two cases. As shown in Fig. 2, however, almost all the meteorites showed large increases in TL sensitivity after acid washing sufficient to place them in the range of recent falls of their petrologic types. In the case of the H chondrites, sensitivity increased by as much as a factor of 14, while the L chondrites increased slightly less, no more than a factor of 8. Two meteorites, ALH88037 (H4) and ALH88022 (H5), had much higher sensitivities before acid washing than the other samples and showed minimal gains in sensitivity after acid washing. Inspection of the original samples shows that these two meteorites are grey in color, as compared to the typical red brown of the other samples, suggesting that they are much less weathered than the others. The increase in TL sensitivity after acid washing may apparently be used as a guide to the degree of weathering undergone by a meteorite.

One meteorite, ALH88015 (L6), has a sensitivity which is significantly lower than any of the others (Fig. 2). This and the peak temperature-width data for this meteorite, indicates that it has been subjected to an intense shock event. The loss of TL sensitivity as a result of shock, sometimes by two orders of magnitude, has been demonstrated by artificial shock experiments and heavily-shocked meteorites often have unusual glow curve shapes (Sears, 1988). The shock event probably occurred during the last few million years, since the low-temperature natural TL of ALH88015 did not have sufficient time to recover to normal levels.

Sears *et al.* (1991) recently found correlations between position on the induced TL peak temperature-width plot and cosmic-ray exposure age which appear to be the result of distinct differences in thermal histories among Antarctic H chondrites (Haq *et al.,* 1988). Applying these correlations to the data of this study, we infer that ALH88001 and 88037 have cosmic-ray exposure ages of approximately 8 Ma, whereas ALH88007, 88009, 88022, and 88034 have exposure ages greater than 20 Ma.

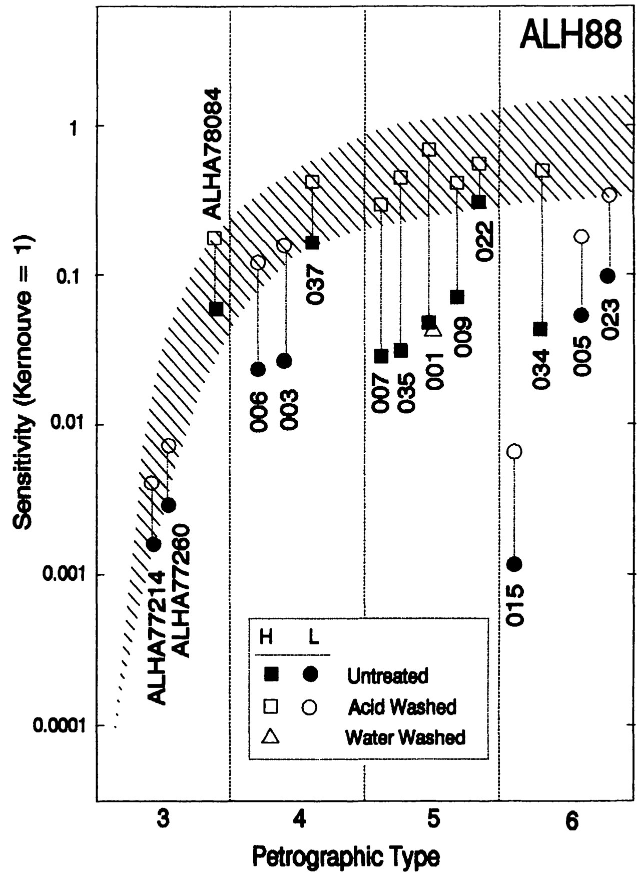

FIG. 2. Plot of TL sensitivity against petrologic type for the meteorites of this study, normalized to the Kernouve meteorite. The sensitivity results both before and after acid washing are shown for each meteorite. Also shown are equivalent data for three type 3 Antarctic meteorites from Sears *et al.* (1982). Region of TL sensitivity displayed by observed falls (as determined by Sears *et al.,* 1980) shown by cross-hatching.

Acknowledgements—We are grateful to H. Palme for suggesting that we make these measurements, L. Schultz for supplying the samples and classifications and Ben Myers (University of Arkansas) for technical assistance. We are also grateful to Jeff Grossman for stimulating exchanges concerning weathering of Antarctic meteorites and excellent reviews from J. Gooding, G. Huss, and K. Nishiizumi. This work is funded by grants from NASA (NAG 9-81) and NSF (DDP-8817569).

Editorial handling: J. T. Wasson.

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