D/19-90 38 9157

N86-28830

THERMOLUMINESCENCE OF ANTARCTIC METEORITES: A RAPID SCREENING TECHNIQUE FOR TERRESTRIAL AGE ESTIMATION, PAIRING STUDIES, AND IDENTIFICATION OF SPECIMENS WITH UNUSUAL PRE-FALL HISTORIES.

S. R. Sutton and R. M. Walker, McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130.

ABSTRACT: Thermoluminescence (TL) is a promising technique for rapid screening of the large numbers of Antarctic meteorites, permitting identification of interesting specimens that can then be studied in detail by other, more definitive techniques. Specifically, TL permits determination of rough terrestrial age, identification of potential paired groups and location of specimens with unusual pre-fall histories. Meteorites with long terrestrial ages are particularly valuable for studying transport and weathering mechanisms. Pairing studies are possible because TL variations among meteorites are large compared to variations within individual objects, especially for natural TL. Available TL data for several L3 fragments, three of which have been paired by other techniques, are presented as an example of the use of TL parameters in pairing studies. Additional TL measurements, specifically a blind test, are recommended to satisfactorily establish the reliability of this pairing property. TL measurements also identify fragments with unusual pre-fall histories, such as near-sun orbits.

INTRODUCTION: Thermoluminescence is a relatively rapid analytical technique. Although the results may sometimes be ambiguous, permitting several interpretations, it is potentially useful as a method for rapidly identifying interesting specimens that can then be examined by other methods in a timely fashion. This paper discusses the use of TL in determination of terrestrial ages, pairing properties, and unusual pre-fall histories. Field observations raise immediate questions concerning certain specimens and it would be useful to have a rapid technique for giving first order answers to these questions. For example, in the 1984-85 field season, fragments of a distinctive meteorite were found scattered over a large area. The fact that some fragments were found on white ice, not blue ice (as is usually the case), suggests that the fragments were part of a shower that arrived on Earth quite recently. Corroboration of this hypothesis (or not) could influence plans for the study of these fragments as well as affect thinking about concentration mechanisms.

TL MEASUREMENT: The thermoluminescence measurement consists of heating the sample (typically 5 mg of powder) from room temperature to about 500 °C and plotting the TL intensity versus sample temperature, the so-called "glow curve." Two types of glow curves, natural and artificial, are registered for each fragment. The natural glow curve is that measured for the "as-received" material while the artificial glow curve is that measured after draining the natural TL and irradiating the sample to some known dose (e.g., 10^5 rads with beta particles). In general, natural TL provides information on the thermal and irradiation history of the object while information on the phosphors and their abundance is derived from artificial TL. Two characteristics of the glow curves lend themselves to these analyses, shape and intensity.

TERRESTRIAL AGE: Upon arrival on Earth, meteorites are shielded from cosmic irradiation by the Earth's atmosphere and their natural TL decays. Attempts to use the extent of TL decay for accurate terrestrial age determination [1,2] have been hindered by a lack of accurate knowledge of (1) the TL levels present in individual fragments immediately after fall and (2) the Antarctic storage temperature. It has been shown, however, by comparison with radiometrically-determined terrestrial ages that TL measurements are capable of providing approximate terrestrial ages. That is, specimens with high natural TL *must* have short terrestrial ages while those with low natural TL are likely to have long terrestrial ages (a caveat in the latter case, however, is that rare near-sun orbits can also reduce natural TL; see below). Melcher [1] used the intensity of natural TL expressed as equivalent dose (ED) as a measure of terrestrial age. The ED at a given glow curve temperature, the laboratory dose required to match the natural

TL intensity, is given by

$$ED = \frac{Natural\ TL}{Artificial\ TL} x\ Lab\ Dose$$

Eleven L and H chondrites from Antarctica gave ED values at 200 ° C in the glow curve ranging from 0.13 to 22.7 krads. Estimated terrestrial ages ranged from <100,000 to >400,000 years and were consistent with ^{36}Cl ages. An order of magnitude difference in ED corresponds to roughly an order of magnitude difference in age. In another terrestrial age study of Antarctic meteorites, McKeever [2] examined the shape of the natural glow curve expressed as the ratio of the low temperature intensity (LT) to the high temperature intensity (HT) for eight L and H chondrites. TL terrestrial ages again were consistent with radiometric estimates.

PAIRING STUDIES: The TL emitted by a meteorite is a complex combination of many factors including phosphor TL characteristics and abundance, thermal history, irradiation history and terrestrial age. Because these factors are likely to be unique for each meteorite, unpaired meteorites are expected to have significantly different TL properties. Pairing studies using TL are possible because observed meteorite-to-meteorite TL variations are generally large compared to variations within single objects. The similarity of TL response from two objects would be consistent with pairing while discrepancy would be evidence for non-pairing.

INTER-METEORITE TL VARIATIONS: (1) Natural TL - In Melcher's terrestrial age study [1], the eleven L and H chondrites from Antarctica gave ED (200 ° C) covering a dynamic range of about a factor of 200. A variation of about 200 was also found in LT/HT values in McKeever's work [2]. (2) Artificial TL - The shape of the artificial glow curve in equilibrated chondrites has been found to be very similar although significant variations are found for unequilibrated chondrites [1,3]. This characteristic is not expected to be a very sensitive indicator of pairing. The variation in intensity of artificial glow curves, TL sensitivity, depends on petrologic type. Sears et al. [3] have found a variation of >1,000 in TL sensitivity for type 3's while types 4-6 vary by only a factor of about 10.

INTRA-METEORITE TL VARIATIONS: (1) Natural TL - Two effects are expected to be most important in producing natural TL gradients within individual meteorites, attenuation of cosmic radiation and thermal gradients during atmospheric entry. Simulation experiments suggest that cosmic ray attenuation effects should be less than a factor of two over dimensions of several tens of centimeters [4]. Natural TL gradients observed in 3 meteorites are consistent with this value (Ucera- 30%/10cm [5]; Plainview- 60%/10cm [6]; St. Severin- 50%/30cm [4]. In most cases, thermal decay of natural TL produced during atmospheric entry is significant only within a few millimeters of the fusion crust [7,8] so that careful selection of samples for TL analysis can avoid this effect. An exception, however, is Farmville (H4) which shows a factor of 10 variation in ED (200 ° C) across a 20 cm slab possibly resulting from an oriented entry [9]. (2) Artificial TL - Artificial TL variations result principally from phosphor abundance heteorogeniety but variations in phosphor TL characteristics can also be significant for unequilibrated specimens. The range of TL sensitivity measurements on different fragments from the same meteorite is typically better than a factor of two [10]. For both artificial TL and natural TL measurements, the reproducibility of 5 mg aliquots from powdered small chips (~100 mg) is typically better than ± 20%, i.e., small compared to the effects described above [1].

TL PAIRING DATA FOR SELECT ANTARCTIC L3 CHONDRITES: Although the current TL data set for Antarctic meteorites is limited, data does exist for three L3 chondrites, ALHA-77015, 77140 and 77214, paired by other techniques (petrography, noble gases and radionuclides [11]). Table 1 summarizes the TL data on these fragments and other unpaired L3's. The small ED and TL sensitivity differences between 77140 and 77214 are consistent with the paired identification for these two fragments. However, the TL sensitivity for 77015 is a factor of 2 greater, a greater difference than the measured reproducibility of replicate measurements. TL sensitivity differences on this order led Sears et al. [12] to suggest that two separate falls are represented, one containing three members including 77015 and another containing 5 members including 77140 and 77214. The LT/HT values (natural TL glow curve shape parameter), different by a factor of 3 for 77015 and 77214, are consistent with this interpretation. Table 1 also shows the clearly distinct TL data for two unpaired fragments, 77003 and 77278.

TABLE 1: TL Pairing Data for Several Antarctic L3 Chondrites

Specimen	ED (200° C)[a] (krads)	LT/HT[b]	TL Sensitivity[d]
Paired:			
ALHA-77015	nd	1.35	0.15[c]
ALHA-77140	4.95	nd	0.08[e]
ALHA-77214	6.5	3.90	0.078[c]
Unpaired:			
ALHA-77003	22.7	52.5	0.48[e]
ALHA-77278	3.2	nd	0.25[c]

[a]Melcher [1]; [b]McKeever [2]; [c]Sears, et al. [12]; [d]relative to Djahala; [e]Melcher [9]; nd=not determined

UNUSUAL PRE-FALL HISTORIES: An important asset of meteorite TL measurements is the ability to quickly identify meteorites with atypical thermal and/or irradiation histories. The classic example is Malakal (L5) which has extremely reduced low temperature ED although its high temperature ED is "normal" [1]. The extent of reduction suggests that the object suffered solar heating in an orbit with a perihelion of 0.5-0.6 AU, consistent with its unusually high ^{26}Al (79 ± 2 dpm/kg [13]). In another such example, the abnormally reduced low temperature ED's of two lunar meteorites, ALHA-81005 and Yamato-791197, were interpreted as resulting from heating during impact ejection and a subsequent space exposure which was sufficiently short to prohibited significant TL reaccumulation. A maximum Earth transit time of only ~2,000 years was indicated for both objects [14,15].

CONCLUSIONS: Natural and artificial thermoluminescence measurements on Antarctic meteorite fragments provide valuable information on the histories of these objects. Meteorites with short terrestrial ages can be easily identified as well as those likely to have very long terrestrial ages. Pairing studies are also feasible. Natural TL, probably the more sensitive pairing property, is observed to vary by a factor of 200 among individual Antarctic chondrite fragments while variations within fragments are expected to be less than a factor of 2. Inter-meteorite variation of artificial TL is less, only a factor of 10, but can be greater for particular meteorite classes (e.g., the >1,000-fold variation observed in type 3 unequilibrated chondrites). A systematic test program including a blind test is recommended to establish the reliability of TL pairing more definitively than is currently possible with the limited available data. TL can also pinpoint meteorites with unusual pre-fall histories, such as those with near-sun orbits or those such as lunar meteorites which have been exposed in space for only a short time. Such information would be useful in planning studies of particular meteorites by complementary (and more time consuming) techniques.

REFERENCES: [1] Melcher, C. L. (1981) *Geochim. Cosmochim. Acta, 45*, 615-626. [2] McKeever, S. W. S. (1982) *Earth Planet. Sci. Lett. 58*, 419-429. [3] Sears, D. W., J. N. Grossman, C. L. Melcher, L. M. Ross and A. A. Mills (1980) *Nature 287*, 791-795. [4] Lalou, C., D. Nordemann and J. Labeyrie (1970) *C. R. Acad. Sci. Paris, Ser. D, 270*, 2401-2404. [5] Vaz, J. E. (1972) *Meteoritics, 7*, 77-86. [6] Vaz, J. E. and D. W. Sears (1977) *Meteoritics 12*, 47-60. [7] Melcher, C. L. (1979) *Meteoritics, 14*, 309-316. [8] Sears, D. W. (1975) *Modern Geology, 5*, 155-164. [9] Melcher, C. L. (1985) private communication. [10] Sears, D. W. G. and K. S. Weeks (1983) *Lunar Planet. Sci. XIV*, 682-683. [11] Scott, E. R. D. (1984) *Proc. Ninth Symposium on Antarctic Meteorites*, in press. [12] Sears, D. W., J. N. Grossman and C. L. Melcher (1982) *Geochim. Cosmochim. Acta 46*, 2471-2481. [13] Cressy, P. J., Jr. and L. A. Rancitelli (1974) *Earth Planet. Sci. Lett. 22*, 275-283. [14] Sutton, S. R. and G. C. Crozaz (1983) *GRL 10*, 809-812. [15] Sutton, S. R. (1985) abstract- 10th Symposium on Antarctic Meteorites, Tokyo.