CLASSIFICATION OF THE ALLAN HILLS A77307 METEORITE

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The Allan Hills A77307 meteorite has variously been described as a CO, CV, and a unique CO-CM related chondrite. We have found that its thermoluminescence properties are very different from the established members of the CO chondrite class; it has a TL peak at 170 and a suggestion of a peak at 250°C, while CO chondrites have peaks at 91 ± 7 and 203 ± 11°C. Either the meteorite has suffered some form of alteration or it is not a normal CO chondrite. The latter is consistent with petrologic and compositional data which we interpret to indicate that although Allan Hills A77307 is related to CO chondrites it is not a normal member of that group.

INTRODUCTION

Allan Hills A77307 is one of six carbonaceous chondrites which have been recovered from Antarctica. Unlike the others, there is some question concerning its classification. Mason (1978) originally identified it as a C3 chondrite, Biswas *et al.* (1982) identified it as a CV chondrite, Scott *et al.* (1981) as a CO chondrite and Kallemeyn and Wasson (1982a) as a unique chondrite intermediate between the CO and CM classes. We recently began a study of the thermoluminescence (TL) properties of CO chondrites (Ross and Sears, 1982) and it readily became apparent that Allan Hills A77307 differed considerably from the established members of this class. In view of the importance of the carbonaceous chondrites, we discuss here our TL data and its relevance to the question of the classification of this meteorite.

EXPERIMENTAL

Our TL data were gathered using the apparatus at Washington University, St. Louis, and at the University of Arkansas. The sample was heated at a rate of 7.3°C/s in an atmosphere of high purity nitrogen and the emitted TL measured with an EMI 9635QB photomultiplier tube fitted with thermal and blue filters. Chromel-alumel thermocouples were used to monitor the heating strip temperature and no departures from linearity in the heating rate have ever been observed. Current measuring electronics were used because the relatively high light levels of these samples produced prohibitive dead-times for photon-counting.

Our samples include seven of the eight known CO chondrites, the unexamined CO meteorite being the 1.4 g Allan Hills A77209. These are listed, with their sources, in Table 1. Where possible, two chips of approximately 250 mg were removed from different lithologies on each meteorite so as to make our sampling as representative as possible. They were then ground, the magnetic material removed with a hand magnet and ground again until the powder could pass through a 100 µm sieve. Aliquots weighing 4 mg were used for the TL measurements. All of our discussions will concern TL

Table 1
Thermoluminescence sensitivies of CO chondrites

Meteorite	Source and Catalog number*	TL sensitivity (Dhajala = 1) 90-110°C	mean	190-210°C	mean
Allan Hills A77003	MWG (55)	0.49	0.39	0.20	0.16
	MWG (12)	0.29		0.12	
Felix	SI 235	0.08	0.08	0.09	0.10
		0.09		0.12	
Isna	CGM	1.01	0.78	0.24	0.20
		0.52		0.16	
Kainsaz	Me 2654	0.27	0.22	0.31	0.26
	Me 2755	0.16		0.22	
Lancé	MHN 624	0.22	0.22	0.21	0.20
		0.21		0.18	
Ornans	MHN A581	0.11	0.11	0.10	0.10
		0.11		0.10	
Warrenton	P18d	0.27		0.037	
		160-180°C	**mean**	**240-250°C**	**mean**
Allan Hills A77307	MWG (27)	0.70	0.52	0.34	0.24
		0.33		0.14	

*MWG, Meteorite Working Group of the NSF (D. Bogard), sample number in parenthesis. SI, Smithsonian Institution (R.S. Clarke). CGM, Cairo Geological Museum (R.A. Eissa). Me, Field Museum of Natural History, Chicago (E. Olsen). MHN, Museum National D'Histoire Naturelle Mineralogic, Paris (P. Pellas). P, Peabody Museum, Yale University (K. Turekian).

sensitivity. This is measured TL after the sample has been heated to 500°C to remove its natural TL and then given a standard radiation dose of 25 krad using a ^{90}Sr beta source.

RESULTS AND DISCUSSION

Representative glow curves are shown in Figure 1 and the data are presented in Table 1. With the exception of Allan Hills A77307, the samples are similar in that they have two major TL peaks at approximately 100 and approximately 200°C. Two of them, Ornans and Kainsaz, show evidence for an additional peak at approximately 270°C. The relative intensities of the two major peaks differ from meteorite to meteorite, suggesing that possibly the two peaks may be associated with different minerals. However, this point needs to be checked with mineral separation and cathodoluminescence measurements. On the other hand, the glow curve for Allan Hills A77307 consists of a peak at 170°C with an inflexion suggesting a second peak at approximately 250°C.

The reproducibility of the TL data for a given meteorite appears to be reasonably good, whether one considers peak positions, absolute TL intensities, or glow curve shapes (i.e., the relative heights of the two peaks). The temperatures of the TL peaks are

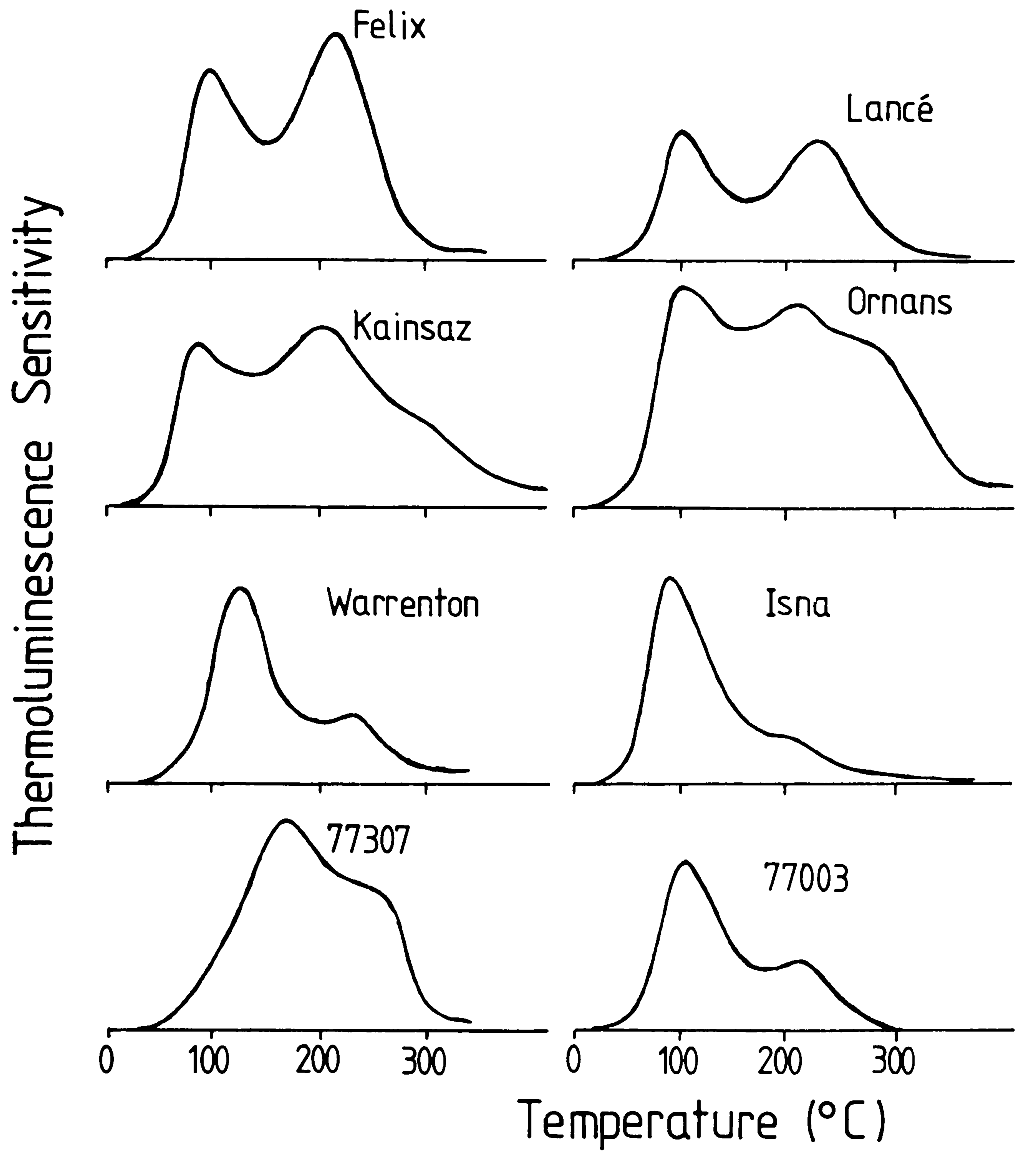

Fig. 1 **Glow curves (TL against temperature) for seven of the eight known CO chondrites and Allan Hills A77307. The curves have been drawn to approximately the same height to facilitate comparison; intensities are given in Table 1. 77307 and 77003 refer to the Allan Hills A meteorites with these numbers.**

compared in Figure 2. The root-mean-squared (RMS) deviation in the peak positions ($\frac{1}{n}$ [Σ (Δ x_i^2)/x_i]$^{1/2}$, where Δx_i is the difference in peak positions for duplicate samples, x_i is the mean peak position and n is the number of meteorites) is only 5% for the 90°C peak and 4% for the 200°C peak for all but Allan Hills A77307, while for the latter the deviation in the position of the 170°C peak between the duplicate samples is 20°C (i.e., 6% from the mean). Similarly, the glow curve shape for the two curves for a given meteorite appears to be highly reproducible. We can approximately quantify the reproducibility in glow curve shape by considering the RMS deviation of the ratio of the heights of the 100 and 200°C peaks. The value of this quantity is 8%. Finally, the RMS deviation, as a fraction of the mean, for the absolute intensity of the two major peaks is 16% for the 90°C peak and 21% for the 200°C. In view of the factor of approximately 10

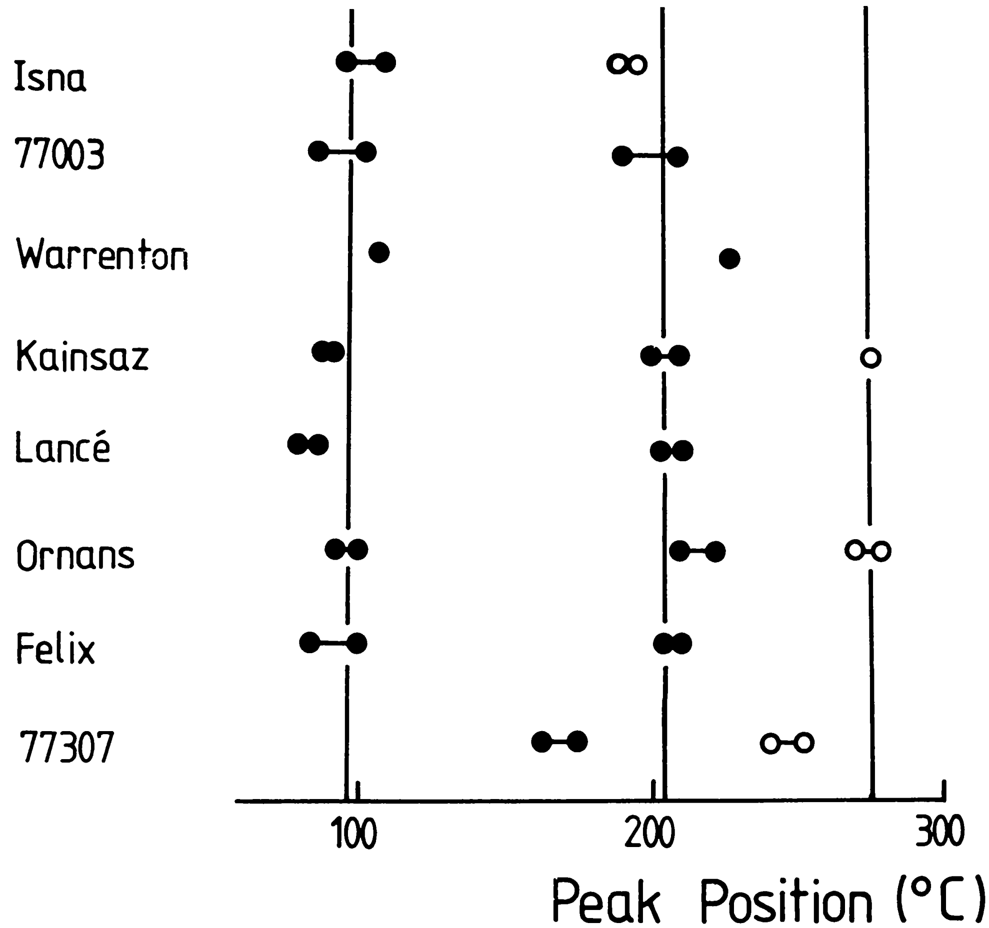

Fig. 2 **Peak positions for the eight meteorites in the present study. For all but Warrenton, duplicate samples were measured. Filled circles represent discrete peaks, open circles indicate peaks inferred from inflexions in the glow curve.**

spread in the TL sensitivities of the seven CO chondrites, deviations on the order of 20% in absolute intensity present no problem.

Figure 2 also demonstrates that the variability in the temperature of the peak from meteorite to meteorite is very minor. If one averages the two data for a single meteorite and then calculates the mean ± one standard deviation for the two major peaks the results are 91 ± 7 and 203 ± 11°C, excluding Allan Hills A77307. This compares with 170 ± 17°C for the major peak of the latter, assuming a conservative uncertainty of 10%. We therefore believe that the differences in TL peak positions as well as in glow curve shape between Allan Hills A77307 and the CO chondrites is significant and not the result of random fluctuations or of sampling atypical material.

Factors governing the peak positions and glow curve shape are numbers, depths and extent of population of electron traps in the TL phosphor(s). Essentially, these are determined by the amount, identity and nature of the phosphor(s). It is feasible that if one of the phosphors was water-soluble or capable of reacting with ground waters, weathering would change the glow curve shape. Similarly, weathering could deposit phosphors. The Antarctic CO chondrite Allan Hills A77003, which has normal CO chondrite properties, has a TL glow curve which is qualitatively the same as the other CO chondrites. Like A77307, it has been assigned to the least weathered category (A) of Score *et al.* (1981). Antarctic ordinary chondrites of weathering category C (highly weathered) have TL characteristics similar to those displayed by their non-Antarctic and unweathered counterparts (Sears *et al.*, 1982). However, it is possible that ordinary chondrites contain fewer minerals capable of ready response to weathering. In short, the TL properties of Allan Hills A77307 are different from the CO chondrites including the Antarctic CO chondrite Allan Hills A77003. Although it is possible that these unusual TL properties are associated with weathering, the details would have to be different from those associated with A77003 which is otherwise similarly weathered.

Pre-terrestrial alteration is another possible explanation for the unusual TL properties of Allan Hills A77307. Any shock or thermal process which is capable of changing the physical or chemical properties of the phosphor is theoretically capable of changing the glow curve shape. However, there are no experimental data for CO chondrites bearing on these possibilities. Both metamorphism and shock produce changes in the TL properties of ordinary chondrites, although changes in glow curve shape are much more subtle than the differences observed here between A77307 and the CO chondrites.

In view of the compositional data for Allan Hills A77307 which are discussed below, it is probably helpful to compare the TL properties of this meteorite with those of a CV chondrite. The thermoluminescence properties of the Allende CV chondrite were studied very thoroughly by Sears and Mills (1974). Most of the samples they studied had TL comparable to the CO chondrites studied here (≈ 0.1 compared with Dhajala) but their glow curves had peaks at 140 or 200°C with varying relative intensities. This is very different from the curve for Allan Hills A77307. A few of the Allende samples (less than five out of 106), which were associated with a calcium-aluminum-rich inclusion, had a TL some 100 times the intensity of "normal" powder and consisted of a broad hump between approximately 150 and approximately 350°C; again quite unlike Allan Hills A77307.

Its TL properties are not the only unusual feature of this meteorite. Scott *et al.* (1981) mention that it is unusual in containing iron carbides and in not containing pentlandite. It also contains kamacite with higher Cr, Si and P contents than any CO chondrite, in fact as Kallemeyn and Wasson (1982b) point out, the metal composition resembles that of CM meteorite. However its matrix and mineral compositions and the abundance, size (< 0.5 mm) and composition of its chondrules are apparently all typical of CO chondrites.

Like mineralogic and petrologic data, compositional data present a confused picture for the classification of Allan Hills A77307. Biswas *et al.* (1982) determined the abundance of 16 trace elements, mainly volatiles, and concluded that the meteorite was a CV chondrite. This conclusion was based primarily on the abundance of Cd (249 ng/g; Kallemeyn and Wasson (1982a) find 393 ng/g for mean CV and 11 ng/g for mean CO), since the concentrations of the other elements considered by Biswas *et al.* (1982) are similar in CO and CV chondrites. Volatile elements demonstrate satisfactorily that A77307 is not a CM or a CI chondrite, both of which have much higher volatile element contents. The major compositional difference between the CO and CV classes concerns their abundance of refractory lithophile elements; CO and CM chondrites have Mg-normalized abundances which are approximately $1.1 \times$ CI whereas CV contain approximately $1.3 \times$ CI (Van Schmus and Hayes, 1974; Kallemeyn and Wasson, 1982a). In its abundance of Al, Sc and REE, Allan Hills A77307 resembles the CM and CO meteorites not CV (Kallemeyn and Wasson, 1982b). The paradox therefore is that the high Cd suggests Allan Hills A77307 is a CV chondrite, while the refractory lithophile/Mg abundance ratio suggests that it is a CO chondrite.

Other compositional anomalies were ascribed by Kallemeyn and Wasson (1982b) to weathering, since the elements involved — Ca, Na, Br and perhaps Mg and Ni — may be partially present in water-soluble form or in a form open to attack by water. However, the high Cd seems unlikely to be the result of weathering-related processes, or for that matter laboratory contamination, since it is not observed for other meteorites with a similar history (Kallemeyn and Wasson, 1982b; Lipschutz, 1981 and references therein).

CONCLUSION

Since the TL data for Allan Hills A77307 are unlike those of the seven CO chondrites we have examined, and in the absence of data suggestng an anomalous thermal/shock or weathering history for this meteorite, we are inclined to concur with Kallemeyn and Wasson's (1982b) conclusion that it is a unique chondrite. The meteorite has many compositional and petrologic properties of a CO chondrite, which surely indicates that it is related to this class, but it has enough unique properties to prevent it from being unambiguously assigned to the CO chondrites.

ACKNOWLEDGMENTS

We are grateful to R.M. Walker for hospitality and access to equipment, to S. Sutton for hospitality and technical assistance, and to the meteorite donors listed in Table 1. This work is supported by grants from the Research Corporation and NASA (NAGW-296).

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Manuscript received 6/2/82