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THE NATURAL THERMOLUMINESCENCE OF METEORITES: A POINTER TO METEORITE ORBITS?

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The apparent existence of two groups of meteorites as determined by their TL properties (Sears and Mills, 1974a,b) has been re-examined. The earlier interpretation of these data is incorrect. Evidence is presented here which suggests that there is a relationship between TL properties and orbits, such that TL may be used to recognise meteorites whose orbits took them particularly close to the Sun. About 17 percent of the meteorites examined have suffered draining of their low temperature TL which we interpret as the effect of small perihelia. The effect upon the TL of shielding, terrestrial age, shock, reheating and albedo, and a number of other factors, are also discussed.

INTRODUCTION

In an attempt to relate the decay of thermoluminescence (TL) from a meteorite to the meteorite's terrestrial age, Sears and Mills (1974a,b) reported upon the apparent existence of "two groups" of chondrites in which the TL appeared to decay at different rates. Normally one expects that when a meteorite falls to Earth it is shielded from further cosmic irradiation and the level of TL ("natural" TL) within the sample is thus free to decay at a rate which is dependent upon the ambient temperature and the particular region of the TL glow-curve under study. By plotting the ratio of the low temperature (LT; ~200°C) TL intensity to the high temperature (HT; ~400°C) TL intensity against terrestrial age (plotted as ln(LT/HT) against Earth residence time in years) Sears and Mills observed the apparent existence of two different decay rates among the meteorites studied. The data of Sears and Mills is re-plotted here in Figure 1. Typical glow curves—plots of TL against temperature—are shown in Figure 2.

More recently, however, Melcher and Sears (1979) have re-examined the question of different decay rates for the TL of ordinary chondrites and have established that members of both the previously defined "Low Retentivity" and "High Retentivity" groups all have similar decay rates. In addition, anomalous fading, i.e., fading of the TL by non-thermal means (Wintle, 1973), does not appear to have been a contributing factor to the apparent grouping observed by Sears and Mills (McKeever and Durrani, 1979).

In this paper we update Figure 1, adding data for a further 21 meteorites (see Figure 3) and we discuss more fully its possible interpretations. We also present data obtained by applying the "plateau test." In the discussion section we compare the results obtained by these methods and then discuss the effect on TL of meteorite class, shielding, orbit, manual and atmospheric reheating, terrestrial age, albedo, shock and cosmic ray exposure. It is concluded that some meteorites with low TL have most probably experienced orbits with low perihelia.

EXPERIMENTAL DETAILS

The apparatus used for the TL measurements is similar in all essential details to that described in earlier publications (e.g. Mills *et al.*, 1977) and it is only necessary here to report that all heatings were performed in an inert-gas atmosphere at a linear heating rate (usually between 2 and 5°C s^{-1}, but the precise value is unimportant for our present purposes). Powdered samples ($<50\,\mu m$) were used in all cases. Other than the measurements described in Sears and Mills (1974a), all experiments were performed in red or yellow light. Effects due to "spurious" thermoluminescence were considered to be negligible.

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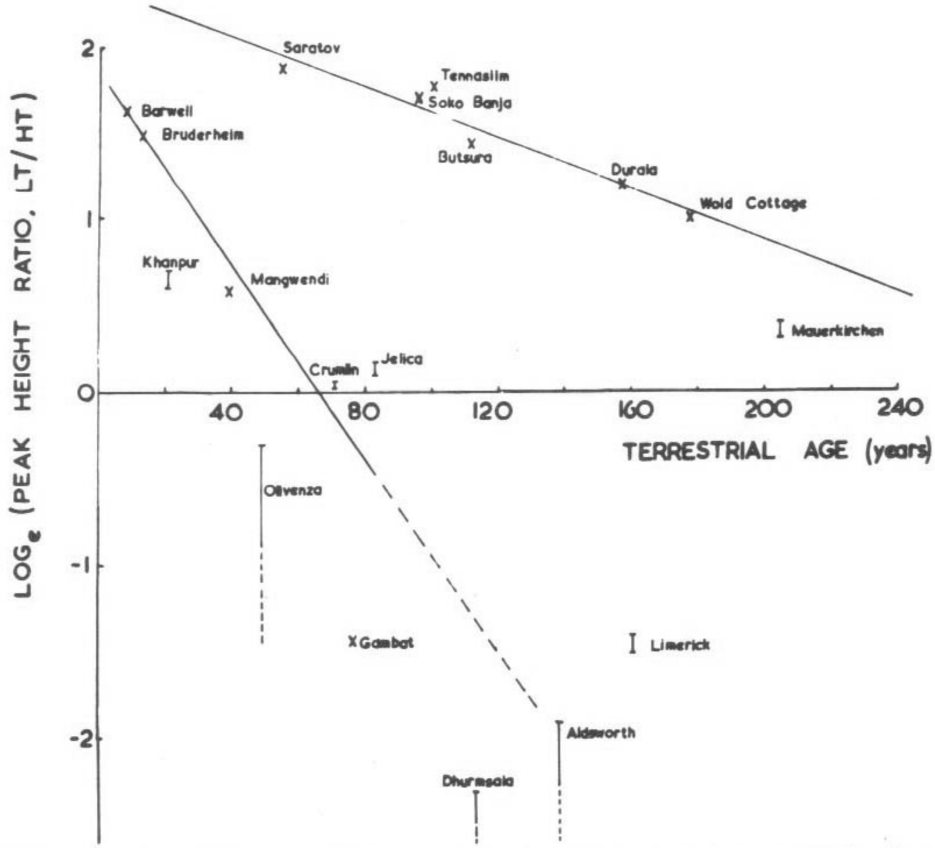

FIGURE 1 A plot of ln(LT/HT) against terrestrial age, from Sears and Mills (1974a). The observation of very low ln(LT/HT) values for several meteorites prompted the suggestion of the existence of two groups of meteorites, characterised by different rates of thermal fading of the LT component.

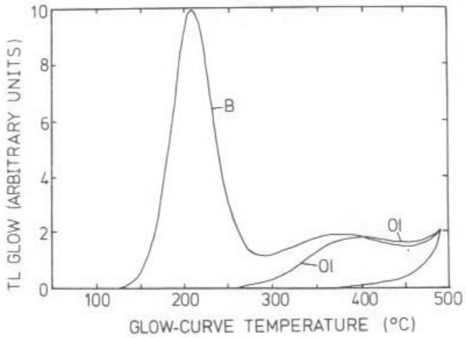

FIGURE 2 Typical TL glow-curves for a member of each group. For Barwell (B; type A) a large TL signal appears below ≃ 300°C. For Olivenza (Ol; type B) little TL is seen below ≃ 300°C. The contribution from black-body radiation has not been subtracted from these curves. Heating rate ≃ 3°/sec.

RESULTS

Peak Height Ratios

By taking the peak height ratio, we are effectively looking at changes in the shape of the glow curve. In this way we allow for those differences in the TL of separate specimens which may be caused by differing amounts of TL phosphor and differing TL sensitivities to radiation.

In addition to the 19 meteorites studied by Sears and Mills 21 extra specimens (all observed falls) have been examined and their peak height ratio (i.e. LT/HT) measured. The results for all 40 meteorites are plotted (as ln(LT/HT)) against terrestrial age in Figure 3. It is evident from this figure that the previously noted "two groups" are no longer clearly defined. Instead, there exists a

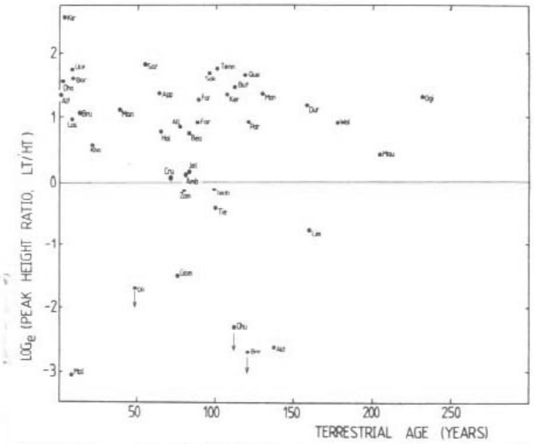

FIGURE 3 New ln(LT/HT) versus terrestrial age data. The groups as defined by Sears and Mills (cf. Figure 1) no longer seem apparent. Instead most meteorites (type A) occupy a band between ln(LT/HT) values of 0 and +2, whilst about 20 percent of them (type B) have values below 0.

well-populated, but diffuse, band of meteorites for which the TL appears to be decaying slowly (with a half-life of possibly 200 years) and for which ln(LT/HT) lies between 0 and +2, and below this e are a number of meteorites with ln(LT/HT) less than zero. To aid future description we call meteorites with ln(LT/HT) greater than, type A, and meteorites with ln(LT/HT) less than 0, type B.† In Table I we list the meteorite samples used in this study (and their sources) together with data relevant to our discussion. The meteorites are listed in order of decreasing ln(LT/HT) to aid comparison with these data.

Plateau Tests

The pleateau test has become a useful criterion in TL studies for determining which traps associated with a given temperature interval in a TL glow-curve are stable enough for retention of the charge-carriers during irradiation. In principle, the glow-curve of the natural TL (TLN) is compared either with that produced from artificial irradiation of the sample (TLA), or with that produced from superimposing an artificial dose on top of the natural dose (TL(N + A)). A plot is then made of TLN/TLA (or of TLN/TL(N + A)) against glow-curve temperature. Those traps which do not have long-term stability at the particular temperature at which the natural radiation is applied, are indicated by a non-constant value for the TL ratio with glow-curve temperature. The region of stable traps is indicated by a constant ratio—or "plateau" (see, for example, Aitken, 1973).

For two samples whose physical make-up and radiation histories are identical in all respects, but which have been irradiated at different temperatures, the plateau tests will produce similar curves, except that the plateau level will be reached at a higher glow-curve temperature for the one which has been irradiated at the higher temperature. A similar effect will be attained if the irradiation temperatures are the same, but one has been recently partially reheated. Thus, Melcher and Zimmerman (1977) have used the plateau test to search for evidence of heat treatments of chert artifacts. Of more interest to the present discussion, however, is the interpretation offered by Melcher and Walker (1977) that meteorites which exhibit certain plateau shapes have suffered reheating by close solar passage within the last 10^6y, or by man.

In Figure 4 we present plateaux for several meteorites. They were obtained by plotting TLN/TL(N + A), with A = 35 krad ^{90}Sr β-particles. The two meteorite TL types produce very different plateaux. The absence of low temperature TL in type B meteorites, such as Olivenza and Malakal, results in an onset of the plateau at higher temperature than the four type A meteorites.

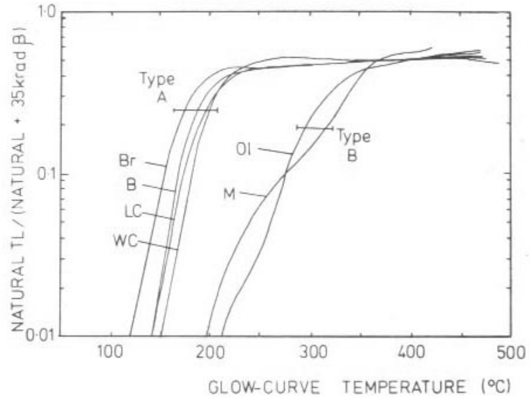

FIGURE 4 Plateau tests for a selection of meteorites of both types (A and B). The plateau test is obtained by plotting TLN/TL (N + 35 krad β) against glow-curve temperature. Code: Br, Bruderheim; B, Barwell; LC, Lost City; WC, Wold Cottage; Ol, Olivenza; M, Malakal.

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† We prefer the term "type" as opposed to "group" because we do not wish to infer discrete populations, but merely wish to use a descriptive label.

TABLE I

Meteorites and the data used in this study

Meteorite (and abbreviation)	Source and catalogue number†	Class	Recovered mass (kg)	Terrestrial age (yr)	ln(LT/HT)	^{3}He[a]	^{21}Ne[a]	^{3}He/^{21}Ne	Albedo[b]	Description
						10^{-8} cc STP/g				
Kirin (Kir)	CAS	H5	2,700.0	3	2.58	—	—	—	—	Veined
Saratov (Sar)	BM1956,169	L4	328.0	55	1.83	32.00	5.02	6.37	0.20	
Tennasilm (Ten)	BM1913,218	H4	28.5	101	1.77	39.77	6.97	5.71	0.22	Veined[c]
Ucera (Uce)	JEV	H5	4.95	7	1.75	10.50	5.47	1.84	—	
Soko Banja (Sok)	BM51857	LL4	80.0	96	1.69	109.67	25.23	4.35	—	Polymict brecciated[c]
Quenggouk (Que)	BM33764	H4	6.04	119	1.66	25.60	7.81	3.28	—	
Barwell (Bar)	BM1966,57	L5	21.4	7.5	1.60	5.65	1.02	5.54	—	
Dhajala (Dha)	PRL	H3	60.0	2	1.56	—	3.17	—	—	
Butsura (But)	BM34795	H6	29.0	112	1.46	58.50	10.39	5.63	—	
Appley Bridge (App)	—	LL6	15.0	64	1.37	1.80	0.29	6.19	0.24	
Monroe (Mon)	BM25462	H4	8.6	130	1.37	18.50	4.12	4.50	—	Polymict brecciated veined
Kernouvé (Ker)	BM43400	H6	80.0	107	1.35	4.88	1.34	3.64	—	Veined[c]
Alta'ameem (Alt)	AR	LL6	6.0	0.5	1.34	—	—	—	—	
Ogi (Ogi)	BM55256	H6	14.2	232	1.31	—	—	—	—	
Forest City (For)	AML H283.61	H5	122.0	89	1.27	9.10	2.25	4.04	—	
Durala (Dur)	BM32097	L6	13.2	158	1.18	—	—	—	—	
Mangwendi (Man)	BM1934,839	LL6	27.3	39	1.10	26.00	4.50	5.78	—	Polymict brecciated[c]
Bruderheim (Bru)	AML H7.45	L6	303.0	13	1.05	47.86	9.76	4.90	0.25	Moderately shocked[d]; veined[c]; heavy to moderate shock[e]
Lost City (Los)	NMNH4848	H5	17.0	7	0.97	10.40	2.09	4.98	—	
Farmington (Far)	BM67016	L5	89.5	88	0.91	0.047	0.035	1.33	0.15	Polymict brecciated black[c]; very heavily shocked[d]
Wold Cottage (Wol)	BM1073	L6	25.5	178	0.91	20.63	7.29	2.83	—	
Parnallee (Par)	BM34792	LL3	77.7	121	0.91	7.60	3.11	2.44	—	Polymict brecciated veined[c]
Allegan (All)	BM1920,281	H5	32.0	77	0.84	9.00	1.72	5.23	0.275	
Holbrook (Hol)	AML 57	L6	219.0	65	0.77	27.98	6.95	4.03	—	Light to moderate shock[e]
Beaver Creek (Bea)	BM73646	H4	14.1	83	0.74	54.00	13.30	4.06	—	
Khanpur (Kha)	BM1933,158	LL5	3.7	21	0.57	—	—	—	—	Brecciated[c]
Mauerkirchen (Mau)	BM19967	L6	19.0	205	0.40	59.30	9.20	6.45	—	
Jelica (Jel)	BM65605	LL6	34.0	83	0.14	46.00	9.95	4.62	0.275	Brecciated[c]
Ambapur Nagla (Amb)	BM81117	H5	6.4	81	0.08	6.85	3.19	2.15	—	
Crumlin (Cru)	BM86115	L5	4.25	71	0.06	—	—	—	—	
Tenham (Ten)	BM1935, 792	L6	159.0	99	−0.11	—	—	—	—	Veined[c]
Zomba (Zom)	BM84357	L6	7.5	80	−0.16	26.70	6.62	4.04	—	
Tieschitz (Tie)	BM1975,411	H3	28.0	100	−0.43	46.80	7.57	6.18	0.13	
Limerick (Lim)	—	H	75.2	160	−0.80	9.45	2.81	3.36	—	Veined[c]
Gambat (Gam)	BM83864	L6	6.36	76	−1.49	—	—	—	—	Veined[c]
Olivenza (Oli)	BM1925,430	LL5	150.0	49	−1.70	12.25	3.20	3.83	0.26	
Dhurmsala (Dhu)	BM33762	LL6	150.0	113	<−2.31	14.00	3.74	3.74	0.225	
Aldsworth (Ald)	BM61308	LL5	1.18	138	−2.62	—	—	—	—	Veined[c]
Bremevörde (Bre)	BM33910	H3	7.25	121	<−2.70	26.97	4.28	6.30	0.125	Polymict brecciated[c]
Malakal (Mal)	BM1971,97	L5	2.0	8	−3.06	—	—	—	—	

[a] Schultz and Kruse (1978).

[b] 15° bi-refl. at 0.5 μm: Chapman and Salisbury (1973).

[c] Hey (1966).

[d] Heymann (1967).

[e] Carter *et al.* (1968).

† BM—Dr. R. Hutchison, British Museum, Natural History.

PRL—Professor D. Lal, Physical Research Laboratory, Ahmadabad, India.
CAS—Dr. O. Ziyan and Dr. L. Shunsheng, Chinese Academy of Sciences, Peking, China.
NMNH—Dr. R. S. Clarke, National Museum of Natural History, Washington.
AML [illegible] G. Huss, American Meteorite Laboratory, Denver, Colorado.
AR— [illegible]. Al-Rawi, College of Science, Baghdad, Iraq.
JEV—[illegible] J. E. Vaz, Instituto Venezolana Cientificas, Caracas, Venezuela.

DISCUSSION

In some respects, a plateau and a peak height ratio present the same information in that meteorites with low peak height ratios produce plateaux which start at high temperature; however there are differences in detail which may make the information from one measurement more reliable than the other. Disadvantages with the peak height ratio method are

i) we assume that HT is a reliable measure of TL sensitivity, against which to normalise LT. If the phosphors responsible for HT were different from those producing LT this would not be true, although there are no data at present which suggests that this is so.

ii) At low peak height ratio, LT is poorly defined, being no more than an inflexion on the side of HT. In some cases, only an upper limit can be determined.

Difficulties with determining the plateau are

i) the temperature axes for the natural and artificial glow curves must be perfectly aligned, since all errors—due, for example, to thermal lag across the specimen—will translate as very large errors in the ratio TLN/TL(N + A), especially in the region below ~350°C.

ii) With N/A plateaux, the specimen used to measure TLA will have been heated. This causes a 30–50 percent decrease in TL sensitivity, and the decrease may differ from meteorite to meteorite (Sears and McKeever, 1980). This, in turn, would affect the height of the plateaux by an equivalent amount.

iii) Meteorites containing considerable rust—this is even true of some observed falls, especially H chondrites—occasionally have anomously shaped glow curves because the rust responds to the artificial radiation.

iv) The shape of the plateau curve in meteorites is dependent on the size of the test dose used (McKeever, 1979).

Both methods also have advantages. Peak height ratios are easily measured from a single glow curve taken on virgin material, whilst the plateau method can be applied to meteorites of any class, not just the ordinary chondrites. The values of ln(LT/HT) have been included in Table I.

We wish now to examine possible causes of the variations in natural TL levels in the hope of shedding light on the cause of the spread in ln(LT/HT) values and, especially, on the cause of the particularly low values for some of the specimens. We will discuss each possibility in turn.

Meteorite Class

The H, L and LL chondrites are qualitatively similar and are sometimes collectively termed the ordinary chondrites; all the specimens discussed here belong to one of these classes. They differ primarily in the proportion of oxidised iron that they contain. TL type B meteorites contain a greater proportion of LL chondrites (43 percent, compared with 21 percent of the type A meteorites), but we are unclear whether this is significant in view of the small number of specimens, especially of type B.

Laboratory experiments have demonstrated that static loading can change the level of natural TL in geological materials (e.g. Douglas *et al.*, 1970). There are no data for laboratory static loading of meteorites, although one might expect an effect (D. J. McDougall, per. comm.). The petrologic type of a meteorite—the numerical part of the class designation in Table I—is assigned on the extent to which the specimen has been metamorphosed. Metamorphism is usually associated with an encumbent load, so the petrologic type should reflect the extent of static loading naturally experienced by the meteorite. No correlation exists between petrologic type and TL type A or B, and we do not believe static loading has seriously affected LT/HT.

Shielding

By taking random samples from each meteorite, at unknown or imprecisely monitored distances from the pre-atmospheric surface, we are failing to account for differences in the level of shielding experienced by the samples. Measurements on isotopes (Wright *et al.*, 1973) and theoretical calculations (Reedy and Arnold, 1972) indicate that there is a variation in absorbed cosmic-ray dose-rate throughout the meteorite. The variations in natural TL throughout a meteorite slice illustrate the way this dose-rate variation is reflected in TL levels (McKeever and Sears, 1979). Secondary radiation makes an important contribution to the dose which produces TL. As a consequence, natural TL builds up with depth, so that large shielding is associated with high TL levels. The same situation applies to low energy cosmogenic isotopes. Sears (1975b) observed a 30 percent increase in the natural TL from the edges to the centre of a 70 cm-sized slice of the Estacado meteorite. We have no depth data for the meteorites in the present study, but have made some assessment of any shielding effects by comparing their TL with the recovered mass (Figure 5). Our assumption is that if the recovered mass is large, it is more likely that the fragment we examined had more shielding from cosmic-rays in space. In fact, there does not appear to be any correlation between ln(LT/HT) and the logarithm of the recovered mass. It would seem that shielding effects are not the cause of the particularly low TL values exhibited by type B meteorites.

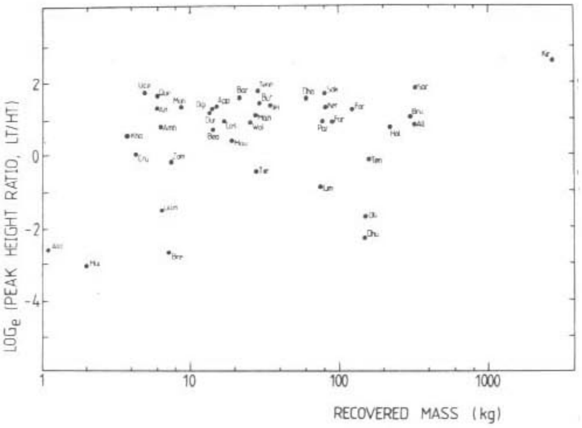

FIGURE 5 Plot of 1n(LT/HT) against the recovered mass. There does not appear to be a correlation between the two parameters.

Heating by Man

Manual heating of a specimen is occasionally reported in the literature, for example there is a report that Ensisheim has been reheated by man in recent times. To account for the present results, the maximum temperature reached during this heating must have been between 250 and 300°C. It seems unlikely that such a narrow, and rather arbitrary, temperature range would result from manual reheating but it is clearly a possibility that we cannot rule out altogether. It seems safe to assume, however, that it will be the exception rather than the rule.

Heating by Atmospheric Passage

This has been thoroughly examined using observational techniques (mainly TL) and theoretical methods (Houtermans and Liener, 1964; Sears, 1975a). The major result to emerge from these studies is that temperatures in excess of 200°C penetrate a remarkably small distance into the meteorite, normally less than five mm. This finding is a result of the high rate of ablation suffered by the meteorites during atmospheric passage. By ensuring that samples for TL measurement are taken at least two cm clear of fusion crust, we are confident that this presents no problem.

Terrestrial Age

A differing plateau shape which results from fading of the TL during the meteorite's life on Earth, can be a serious problem with meteorites of great terrestrial age. However, by limiting the study to relatively recent falls, this factor is not relevant to the present study. Our present conclusions, however, are relevant to the application of TL to determination of terrestrial age, because it is impossible to identify type B meteorites which are not observed falls. It is implicit in the TL terrestrial age method that the specimens are not of type B. The present data suggest that this will be true four times out of five.

Albedo

Butler (1966) observed that albedo can have a significant affect upon a meteorite's temperature in space. This, in turn, might affect its TL. Such a dependence is clear from Eq. (1), see below, because the parameter γ relates strongly to a meteoroid's albedo. This raises the possibility that those meteorites with low (LT/HT) ratios are merely those meteorites with reduced albedos. A comprehensive attempt to measure albedos for several chrondrites has been undertaken by Chapman and Salisbury (1973). Wherever possible we have included their albedo data in Table I. No simple correlation exists between albedo and the LT/HT ratio. Although a possible contributing factor to the spread in ln(LT/HT) values, the variations in albedo cannot be invoked as a cause for the differences in TL between type A and type B samples.

Shock

The relationship between shock and TL has been investigated for a wide variety of materials (see Stöffler, 1974, for an extensive review). The effect of dynamic shock loading on meteorite TL has been examined by Liener (1966) and by ourselves (unpublished). Shock loading using pressures comparable with those experienced by naturally shocked meteorites causes considerable reductions in natural TL and TL sensitivity. We have therefore indicated in Table I those meteorites for which evidence of shock has been described in the literature. The shock symptoms we rely on are various; usually blackening (500–800 kbar) or veining (150–300 kbar, Fredricksson *et al.*, 1963), diffuse X-ray diffraction patterns for olivine (Carter *et al.*, 1968), metallographic structures and inert gas content (Heymann, 1967). As with albedo, there is no simple relationship between shock and TL type. Several meteorites of type A (e.g. Wold Cottage, Mauerkirchen) and several meteorites of type B (e.g. Aldsworth and Limerick) appear to have been shocked.

It is commonly believed that the event which shocked these chondrites occurred 5×10^8 y ago d was associated with the break up of their parent body (Sears, 1978). The TL in meteorites establishes thermal equilibrium in $10^5 - 10^6$ y so the TL equilibrium will have recovered after the shock event. Heavily shocked meteorites are known to have lower TL sensitivity than unshocked meteorites, but there is no evidence to show that the shock affected LT and HT to a different extent.

Cosmic-Ray Exposure

In the dosimetry and pottery dating applications of TL, the level of natural TL is directly related to the total dose received by the specimen. If such a relationship existed in meteorites, the natural TL level would be dependent upon the duration of the meteorite's exposure to cosmic rays. McKeever and Sears (1979) argued that, whilst this might be true of a few meteorites with very short exposure ages, it was not true of most meteorites whose TL was predicted to be in thermal equilibrium. (This does not necessarily apply to the high temperature regions of the glow curve, where the TL might be saturated.) Helium-3 and neon-21 are cosmic ray exposure products with production rates of about 2.0 and 0.377 ($\times 10^{-8}$ cc STP g^{-1} 10^{-6}y), respectively (Sears, 1978). The correlation coefficient, r, between ln(LT/HT) and ^{3}He is -0.28 ($n = 38$) and between ln(LT/HT) and ^{21}Ne is -0.23 ($n = 39$), neither of which are significant at any level of confidence. This is consistent with our belief that the natural TL in meteorites is in thermal equilibrium, and that differences in cosmic ray exposure are not the cause of the spread in ln(LT/HT) values.

Meteorite Orbit

The temperature of a meteoroid in space will be continually varying as it sweeps out its ellipitical orbit around the Sun. The Temperature of a small object is related to its distance (R) from the Sun by:

$$T^4 = \frac{C}{R^2} \cdot \frac{B}{S\delta} \cdot \gamma \tag{1}$$

where C is the solar constant, S is the total area of the object, B is its cross-sectional area (effective in intercepting solar radiation), δ is the Stefan-Boltzmann constant, and γ is the ratio of solar absorptivity to low-temperature emissivity for the object. For a spherical object with $C = 1.35 \times 10^6$ erg cm^{-2} sec^{-1} (Abetti, 1957):

$$T = 278 \left(\frac{\gamma}{R^2}\right)^{1/4} \tag{2}$$

The value of the parameter γ is the most uncertain quantity. Rather than pursue a discussion concerning possible values of γ, we shall use for the purposes of this paper a value of $\gamma = 0.502$, adopted by Goles *et al.* (1960) (Peebles and Dicke (1962) use $\gamma = 0.9$). Although the numerical values for the various temperatures used from this point onwards in our discussion would have to be modified for different values of γ, the principle of the argument remains unchanged.

For a meteoroid with a perihelion of 1 A.U. and an aphelion of 3.0 A.U. the temperatures at perihelion and at aphelion would be 234K and 135K respectively. The loss of TL from the meteoroid is extremely sensitive to temperature, with the TL from the higher glow-curve temperatures being the most stable. Very little loss of TL takes place until the meteorite approaches perihelion. Assuming that the orbits of various meteorites and "meteorite-like" meteors (McCrosky *et al.*, 1971) are typical and by integrating over the entire orbit, it can be shown that the total loss of

TL in one orbit is approximately the same as that which occurs at perihelion in 0.025 to 0.105 of an orbital period (with the smaller values of this fraction being obtained for those meteorites with the smaller perihelion distances). Similar calculations have been performed by Goles *et al.* (1960) for gas diffusion loss. They calculate that the gas loss over the entire orbit is merely that incurred at perihelion in only 0.025 of an orbital period (see also Anders (1962)).

McCrosky *et al.* (1971) tabulate orbital data for the Pribram and Lost City meteorites, plus data for six meteors "believed to be characteristic of meteorites in flight." The perihelia values from McCrosky *et al.* (1971), plus that for Innisfree (Halliday *et al.,* 1978), are tabulated in Table II. The perihelia of the orbits range from 0.772 to 0.986 A.U. Using Eq. (2), with $\gamma = 0.502$, we find that $T_{0.986} = 236\text{K}$ and $T_{0.722} = 275\text{K}$. For TL termal stabilities at a glow-curve temperature of ~250°C (McKeever, 1980), we find that the TL level in a meteorite at 0.986 A.U. will be two orders of magnitude higher than it will be in a specimen with $q = 0.722$ A.U. From Figure 4, at a glow-curve temperature of ~250°C, we can see that the extremes of perihelia quoted in Table II are more than enough to account for the difference observed in TL levels between members of type A and type B. We do not believe that passage within 0.4 A.U. of the Sun, as proposed by Melcher (1978), is required. A relatively small spread of perihelia values will also be a factor contributing to the spread of ln(LT/HT) values.

A particularly low ^{3}He/^{21}Ne ratio can provide independent evidence of close solar passage. The ratio is normally near 5.5—although it shows some variation due to shielding—but passage within 0.4 A.U. of the Sun causes diffusional loss of the lighter helium isotope and a lowering of the ratio. If this loss occurred in the last, say, 10^5 y—so that there was insufficient time for the meteorite TL to return to thermal equilibrium—then we would predict that meteorites with low ^{3}He/^{21}Ne should have low ln(LT/HT) (J. C. Lorin, quoted in Melcher and Walker, 1977). In fact, from Table I, no such correlation seems to exist. An upper limit for the time of degassing can be made from the amount of ^{3}He present. For example, Ucera—with a ^{3}He/^{21}Ne ratio of 1.84—has 10.5×10^{-8} cc STP g^{-1} of ^{3}He corresponding to an exposure age of 5.25 m.y. (for a production rate of 2.0×10^{-8} cc STP g^{-1} 10^{-6} y). This would be the time since the close solar passage, assuming complete loss of ^{3}He. An explanation for the lack of any correlation between ln(LT/HT) and ^{3}He/^{21}Ne, would be that degassing occurred long enough ago for the TL to have returned to thermal equilibrium after the event. Furthermore, meteorites with low LT/HT ratios will not necessarily have low ^{3}He/^{21}Ne ratios because of the different sensitivity of each phenomenon (i.e. TL loss and gas loss) to temperature changes.

TABLE II

Orbital data on meteorites and "meteorite-like" objects (McCrosky *et al.,* 1971; Halliday *et al.,* 1978)

Meteorite/meteor	Perihelion (q; A.U.)
Pribam	0.790
Lost City	0.967
Innisfree	0.986
"Iron Meteor"	0.928
Meteor 1242	0.984
Meteor 19816	0.756
Meteor 7946	0.945
Meteor 40503	0.722
Meteor 40617	0.976

CONCLUSIONS

It seems that shielding, orbital factors, albedo and shock may be contributing to the scatter in ln(LT/HT) but that the orbital considerations seem to offer the best interpretation for the existence of the 20 percent, or so, of our meteorites which have extremely low values of ln(LT/HT). These considerations suggest that members of type B—which have less low temperature TL than the other meteorites—were on orbits which took them nearer the Sun than meteorites of type A. The amount of TL drainage is very sensitive to perihelion distance and data on the orbits of meteorites and meteorite-like meteors suggests that the spread in typical perihelion distances is enough to account for the difference in TL levels.

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