JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 97, NO. B4, PAGES 4629–4647, APRIL 10, 1992

The Natural Thermoluminescence of Meteorites
4. Ordinary Chondrites at the Lewis Cliff Ice Field

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Natural thermoluminescence (TL) measurements have been made on 302 meteorites from the vicinity of the Lewis Cliff in the Beardmore region of Antarctica. The data provide information on terrestrial age and unusual radiation and thermal histories, which, in turn, are helpful in identifying fragments of a single fall and in understanding ice sheet movements and the mechanisms by which meteorite concentration occurs at this site. The present data with data for induced TL, class, find location, hand-specimen descriptions and mineral composition have enabled 70 of the present samples to be assigned to 27 groups of "paired" meteorites, with between 5 and 2 meteorites in each group. The distribution of meteorites on the ice, the shape of the fields of "paired" meteorites, and trends in the natural TL data indicate that there is a western component to the movement of the ice at this location, as well as the previously supposed movement to the north. This western vector probably explains the concentration of meteorites along the western edge of the ice tongue. Meteorites at the northern end of the tongue (the Lower Ice Tongue), and Meteorite Moraine to the east, have relatively high natural TL, and therefore young terrestrial ages, while those on the upper tongue show a broad range of ages including a great many large ages. Details of the meteorite concentration are different on the Upper and Lower Tongue and it might be that these two parts of the ice sheet are unrelated. These new natural TL data identify several recent falls and several meteorites which probably had unusually small perihelia immediately prior to capture by the earth.

INTRODUCTION

Nearly 10,000 meteorite fragments have been collected on the Antarctic continent, almost entirely on blue ice fields adjacent to mountain ranges [*Yanai, 1981; Yanai and Kojima*, 1987; *Score and Lindstrom*, 1990]. About one-half of these were found by Japanese teams in the Queen Fabiola (Yamato) Mountain; most of the others were found by U.S. teams along the length of the Transantarctic Mountains. The two largest concentrations of meteorites returned by the U.S. teams are the nearly 1800 meteorites found at the Lewis Cliff region (84°17'S, 161°05'E [*Cassidy*, 1990]) and approximately 1550 obtained from the Allan Hills region (76°43'S, 159°40'E [*Schutt et al.*, 1989]). Exploiting the scientific potential of these meteorites has been a challenge to the scientific community [*Sears*, 1987], and it has been necessary to establish a protocol of preliminary measurements in order to describe the chief characteristics of as many of the returned samples as possible and identify those with special attributes that render them more interesting for immediate research. Among these measurements is natural thermoluminescence (TL) [*Sears and Hasan*, 1986], and TL data for over 1000 meteorites are now available. In this paper, we review the natural thermoluminescence data (and, to a lesser extent, the induced thermoluminescence data) for about 302 meteorites collected at the Lewis Cliff region. In a companion paper (*P. H. Benoit et al.*, The natural thermoluminescence of meteorites, 5, Ordinary chondrites at the Allan Hills vicinity, submitted to *Journal of Geophysical Research*, 1991), we will review similar data for samples from the Allan Hills.

Natural thermoluminescence is widely used for radiation dosimetry, both for routine health safety monitoring and for research applications ranging from space shuttle radiation exposure measurements to dating archaeological pottery [*McKeever*, 1985; *Fleming*, 1979; *Aitken*, 1985]. Its application to meteorites (and most geological samples) is complicated by the long time spans involved, which means that thermoluminescence levels reflect saturation or equilibrium between build-up and thermal decay, rather than the simple secular build-up utilized by dosimetry applications. Once on Earth, a new radiation dose rate and temperature regime applies, and the level of stored thermoluminescence adjusts to a new, much lower, equilibrium value. The process has been studied theoretically by *McKeever* [1982], and a variety of empirical studies have also been reported [*Lalou et al.*, 1970; *McKeever and Sears*, 1980; *Sears and Durrani*, 1980; *Melcher*, 1979, 1981*a,b*; *McKeever*, 1982; *Hasan et al.*, 1987; *Benoit et al.*, 1991a]. It is clear that for about 80% of all meteorites, natural TL intensity is related primarily to terrestrial age, while the remaining meteorites have unusually low natural TL levels due to a heating event within the recent past, so that the TL was drained and did not have time to return to its equilibrium level; sometimes, low natural TL values (nominally <5 krad at 250°C in the glow curve) are associated with high ^{26}Al activities [*Hasan et al.*, 1987]. Theoretical studies and measurements on meteorites of known orbit [*Benoit et al.*, 1991*a*] suggest that the source of the heating was probably small perihelia orbits, and the proportion of meteorites with low TL is approximately equal to that expected from meteorite orbits and natural TL models [*McKeever and Sears*, 1980; *Benoit et al.*, 1991*a*]. However, other recent heating events, such as shock reheating,

Paper number 91JB02982.
0148-0227/92/91JB-02982$05.00

Fig. 1. Aerial photograph of the Lewis Cliff Ice Tongue and immediate area looking east. (Right) The northern tip of the tongue showing the structure of the ice core moraine into which it is pushing. (Left) The southern part of the ice field including Meteorite Moraine which is at the center of the image. (Image identification CA0999000033R, frames 42 and 44, from NCIC, U.S. Geological Survey, Reston.)

may also be a strong possibility in individual cases, especially where there is petrographic evidence for such events. Unlike the igneous classes of meteorites, which exhibit "anomalous fading", there is ample experimental evidence that the decay of natural TL in the chondrite classes follows classical thermally controlled kinetics [e.g. *Sears et al.*, 1991*b*].

It is perhaps worth stressing the differences between the present applications of natural TL and those used for pottery dating for which much has been published [e.g.,*Fleming*, 1979; *Aitken*, 1985; *McKeever*, 1985]. In the latter applications, TL signals are very weak and great care is required to avoid spurious TL effects and effects due to non-linearity in the natural TL versus administered dose curves. Independent dosimetry of the environmental and internal dose are also necessary, and a variety of methods have been developed, for example, the separation of coarse grains, which have largely escaped the alpha dose, from the fine-grained material. In the present instance, TL levels are extremely high because of the great age of the samples (10^7 years compared with 10^4 years) and the higher dose rates associated with cosmic ray exposure (10 rad/year compared with a few mrad/year). The present applications involve monitoring the fall of natural TL from their extraordinary high cosmic levels to much lower terrestrial levels, which are still high by pottery-dating standards. Differences due to local dose will be small in view of the high initial levels, but, in any event, the chondrite classes are remarkably isochemical and dose-rates from the ice on which the samples are lying will be uniform and negligible. The main cause of scatter in the present data are the effects of cosmic-ray dose rate variations in the meteorites and their terrestrial storage temperatures.

The Lewis Cliff Ice Tongue is a 10 km long, 2.5 km wide ice field lying north-south on the perimeter of the Walcott Neve in the Transantarctic Mountains (Figure 1). About halfway along the Tongue is a step in the ice, which may be due to obstacles under the ice or to the field consisting of two separate ice sheets. Meteorites have been found primarily on the western half of the tongue (Figure 2). There are field data to suggest that very small meteorites are carried along the ice by wind transport, whose net effect would be to move them northwards. On the eastern end of the base of the tongue, at the bottom of an ice slope, is an area known as Meteorite Moraine in which a large number of H5 chondrites have been found, and it was suspected while they were being collected that many of them were "paired", that is, they may be pieces of a single meteorite which fragmented in the atmosphere or on the surface of the Earth. At the northern tip of the tongue is a series of ice-core moraines, for which there are structural indications for periodic

Fig. 1. (continued)

growth (Figure 1). The process for the formation of such ice-core moraines is unclear [*Boulton*, 1967], and meteorite data may help to clarify this by placing limitations on the time scales for moraine formation and providing evidence for or against periodic flow.

In obtaining large amounts of natural thermoluminescence data for meteorites from the Lewis Cliff, we tried to derive information on several points. (1) We tried to locate meteorites that have experienced unusual orbits. Information on orbit distributions might have major implications for the mechanism by which meteorites were ejected from the asteroid belt and found their way to earth [*Wetherill*, 1985; *Wetherill and Chapman*, 1988]. (2) We tried to locate meteorites with particularly small or particularly large terrestrial ages. Such information is of value in studies of short-lived nuclides and in studies of possible secular variation in the properties of meteorites falling on earth [e.g., *Evans et al.*, 1991]. (3) We tried to see if there was any relationship between natural TL and location on the ice that would provide new insights into meteorite concentration mechanisms at this site, which, in turn, may help identify other sites for productive searching [*Whillans and Cassidy*, 1983; *Cassidy*, 1983; *Nishio et al.*, 1982]. Such data might also help to constrain ice sheet movements and mechanisms for ice core moraine formation [*Boulton*, 1967]. (4) We tried to explore the extent to which these data can be used to identify paired meteorites [*Scott*, 1984, 1989]. We also hoped that the data would form a basis for comparison with other sites, which may provide information on the relative ages of different sites and meteorite concentration mechanisms [*Cassidy and Whillans*, 1990; *Cassidy*, 1983; *Drewry*, 1986].

EXPERIMENTAL

Our experimental procedures and methods of data reduction have been described elsewhere [*Sears et al.*, 1991*b*; *Hasan et al.*, 1989; *Sears et al.* 1991*c*] and are summarized below. The data were gathered over a 4-year period during which our methods improved considerably, so that there is considerable variability in the quality of both the natural and the induced TL data. The major improvement has concerned sampling criteria. Early in our work, many small (<20g) meteorites were accidentally sampled, and such samples may have suffered heating during atmospheric passage [*Sears*, 1975]. Figure 3 compares the data for samples with mass <20g with that of the others. Although there is a large measure of agreement between data for the small and large samples, there is also a tendency for the smaller masses to be displaced towards smaller natural TL values. Natural TL data for samples with original masses <20g listed in our earlier publications [*Hasan et al.*, 1992; *Score and Lindstrom*, 1990], should be regarded with some caution, and our subsequent discussion is restricted to >20g samples. A second reason for ignoring the small samples is that they will have suffered most from wind-blown transport on the ice.

Natural TL data. Samples of $\geq$250mg were obtained >0.6cm from any potential fusion crust to avoid heat-alteration [*Sears*, 1975], as part of their initial processing at the Johnson Space

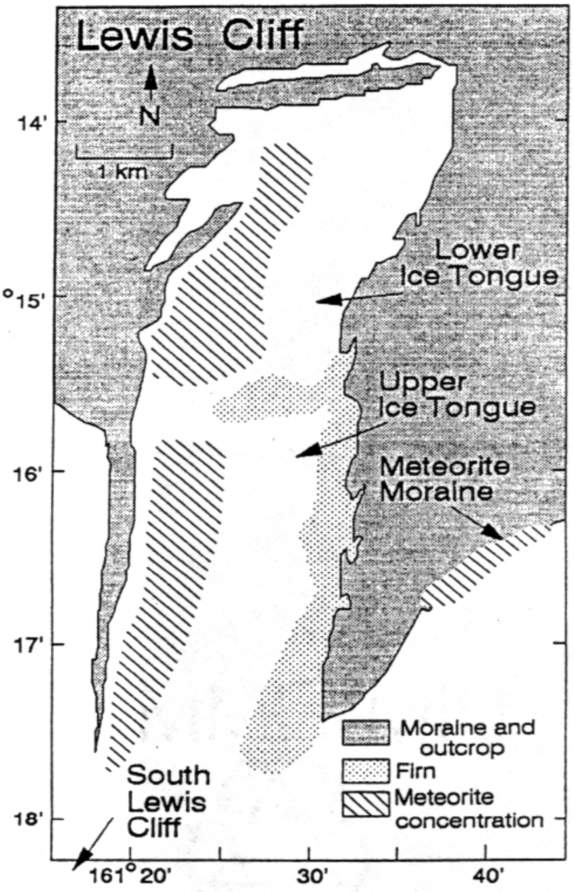

Fig. 2. Sketch map of the Lewis Cliff Ice Tongue and vicinity showing the locations of meteorites collected in the region. Meteorites are concentrated on the west of a northeast-southwest diagonal on the main ice tongue, and along a gully to the east of the tongue called Meteorite Moraine.

Center. The samples were then hand carried to Arkansas, to avoid inadvertent heating or exposure to radiation, and then handled only in red light to avoid optical bleaching of the TL [*Hasan et al.*, 1987; *Hoyt et al.*, 1972]. First, 50-100mg of interior material was taken, then gently ground, the magnetic material removed with a hand magnet, and the powder gently ground again until it just passed through a 100 mesh sieve. Three to five 4-mg aliquants of powder were then placed in shallow Cu pans and their TL measured in Daybreak Nuclear and Medical TL apparatus, modified by (1) placing metering valves in the gas and vacuum lines, (2) placing silica gel capsules in the photomultiplier tube (PMT) housing, (3) putting a shutter on the PMT housing (so that the high-voltage supply to the PMT is left on over 3-6 month periods), (4) gathering the data on a Texas Instruments personal computer using a custom-made interface and software, and (5) placing a 4mm Cu aperture between the sample and PMT window. Homogenizing a 50-100mg mass minimizes problems from sample heterogeneity in these polymineralic samples, and the 3-5 replicates provide an indication of any particular difficulties in this respect. We use EMI 9635 PMTs with Corning 7-59 and 4-69 filters to suppress blackbody radiation. Disposable cellulose sheets, with flat absorption throughout the visible range and with a transmittance of 0.90+-0.01, were placed between the aperture and the PMT to prevent weathering and other products degrading the PMT window. After measuring the natural TL for the 3-5 aliquants, the samples were exposed to a 250mCi Sr-90 source for 2-5 minutes and the induced TL measured. At the beginning and end of each day, samples of the Dhajala meteorite are run as a check on the day-to-day and long-term stability of the apparatus.

Natural TL data reduction. Natural TL data have to be normalized to remove the effects of meteorite-to-meteorite variation in the TL sensitivity: these variations can be very large and are the result of fluctuations in the amount and type of material responsible for the TL, albedo and weathering effects. Metamorphism, shock and sample heterogeneity can affect the amount of TL phosphor in a given sample, while the weathering and albedo affect the amount of light detected by the PMT since light must undergo multiple scattering in the powder. Early studies used two methods of normalization, the peak height ratio (in which the natural TL at 250°C in the glow curve is normalized to that at 350°C) and the "equivalent dose" (in which the natural TL at 250°C is normalized to the induced TL also at 250°C in the glow curve, and the ratio multiplied by the absorbed dose - the parameter therefore has the units of dose absorbed). We continue to use krad, instead of the SI-approved gray, because its use is established in the meteorite literature (of course, 1 Gy = 0.1 krad). A number of studies have shown that 250°C is the optimum temperature at which to monitor thermal and radiation effects using natural thermoluminescence. When peak height ratios are >0.5, their

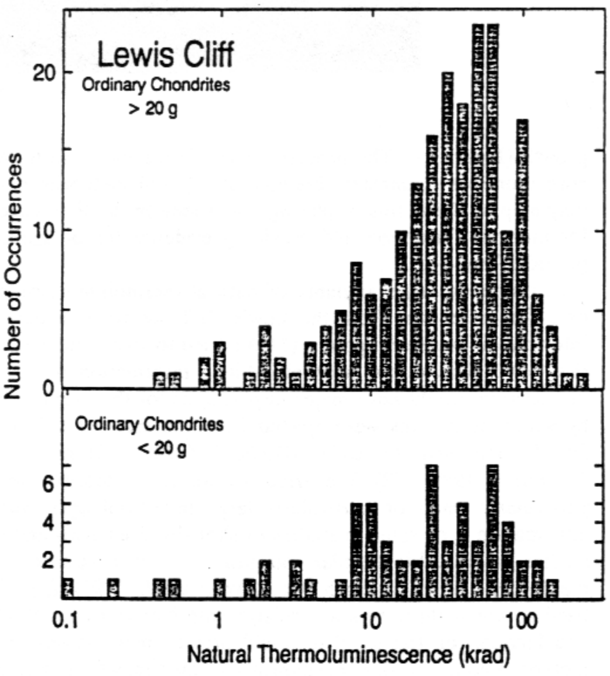

Fig. 3. Histograms of the natural thermoluminescence of meteorites from the Lewis Cliff region. Above, meteorites with masses >20 g; below, meteorites with masses <20 g. Small meteorites may have had their natural TL drained by the heating associated with passage through the atmosphere, which probably accounts for the different distribution in natural TL data, and they will have suffered wind-blown transport on the ice. Small meteorites are not considered further in this paper.

measurement is intrinsically more accurate than that of equivalent doses, typical 1 sigma uncertainties are 4-5% versus 15-20%. For samples with ratios ≥ 0.5, we therefore measure peak height ratios which we then convert to doses using the empirical calibration log (ratio) = 0.775 log (equivalent dose) - 0.844, while for samples with ratios <0.5 we use the equivalent dose directly. The quantity reported is termed the "natural TL" to distinguish it from the other direct measurements. We routinely check this empirical relationship with each independent data set (i.e., every 6 month operating period), and we have checked that weathering, class or petrologic type do not affect the relationship [*Hasan et al.*, 1989].

Induced TL data. The induced TL glow curves for the 3-5 aliquants used for normalization of the natural TL data were used to obtain the induced TL data reported here. Three parameters were measured from each curve, the data for an individual meteorite were averaged and the standard deviation of the measurements determined. The three parameters were (1) the induced TL divided by the induced TL of the Dhajala standard meteorite, referred to as the TL sensitivity, (2) the temperature at which the TL produced is at a maximum, referred to as the TL peak temperature, and (3) the full-width of the TL peak at half its maximum intensity, referred to as the TL peak width or FWHM. Subsequent to most of the present data being obtained, we have found that weathering causes much greater changes in TL sensitivity than the factor of three previously supposed, but peak temperatures and widths are not significantly affected by weathering [*Benoit et al.*, 1991c]. Our TL sensitivity data have not therefore been corrected for weathering, but this should not affect our present conclusions because they are based on peaks in histograms of data and weathering will destroy rather than create such peaks.

RESULTS

Table 1 lists the natural TL data for samples >20g that we have obtained for meteorites from the Lewis Cliff region. Figure 4 shows the data in histogram form, compared with data for non-Antarctic meteorites [*Benoit et al.*, 1991*a*]. At first sight, the distribution of data for the three primary Lewis Cliff sites (Upper Ice Tongue, Lower Ice Tongue and Meteorite Moraine) and for the non-Antarctic meteorites are fairly similar, although the data base for non-Antarctic meteorites is still rather small. Values range over three orders of magnitude, with most being between 5-80 krad. In the Lewis Cliff data, there is a long sparsely populated low-TL tail, and there are very few with natural TL >100 krad. Upon closer scrutiny, however, some site-to-site differences are apparent, and these will become more important when we consider the distribution of meteorites on the ice. For instance, the meteorites from Meteorite Moraine do not include as high a proportion with low natural TL (say, <10 krad) as do those from other sites, and the proportion of samples with fairly low natural TL (in the range 5-30 krad) is higher in the samples from the Upper Lewis Cliff Ice Tongue than from the Lower Tongue or Meteorite Moraine.

Table 2 and Figures 5 and 6 show the induced TL data for the present samples. The TL sensitivities we observe are much lower than expected for equilibrated chondrites [*Sears et al.*, 1980]. As discussed below, this is due to weathering. The histograms for the Upper and Lower Ice Tongue and for Meteorite Moraine (Figure 5) are very different. The strength of the peak in the data for samples from Meteorite Moraine suggests that there is considerable pairing among the samples from that site, a suggestion that was made on the basis of field observations by W. A. Cassidy (personal communication, 1991.). The Upper Tongue has an approximately normal distribution, while samples from the Lower Tongue have a flat distribution with a "spike" superimposed. We suspect that these data are indicative of the possibility of pairing some of the samples from the Lower Tongue with samples from the major concentration at Meteorite Moraine. The remaining two induced TL parameters, peak temperature and width, are plotted in Figure 6. The data for the Lower Ice Tongue and the data for Meteorite Moraine look very similar, again suggesting a link between the two regions. Most notably, the data plot on the lower end of the non-Antarctic H chondrite regression line. The distribution of data for meteorites from the Upper Tongue is very different from the other sites, showing a narrow range in peak width but extending to much higher peak temperatures, with a more or less uniform distribution of data to 205°C and

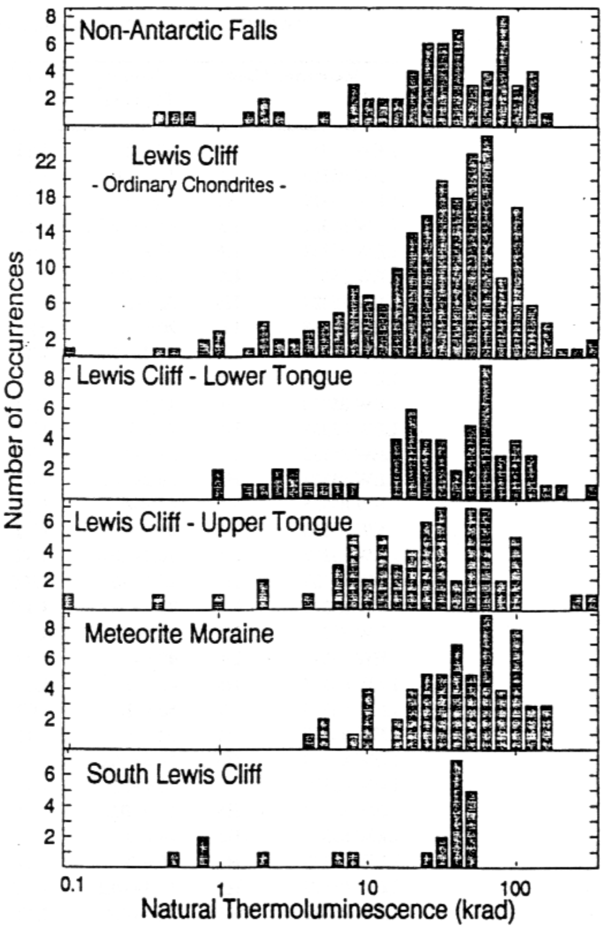

Fig. 4. Distributions of natural thermoluminescence data for meteorites collected from the Lewis Cliff vicinity of Antarctica, divided according to the regions indicated in Figure 2, and of non-Antarctic meteorites [*Benoit et al.* 1991*a*]. The distributions of data at the various sites are fairly similar, but the Lewis Cliff meteorites as a whole may be displaced to slightly lower values relative to non-Antarctic meteorites. The data for the Upper Tongue are noteworthy for the relative abundance of values in the 5-30 krad range and relative lack of values >100 krad. 53% of the data at the Upper Ice Tongue fall in the 5-30 krad range, compared with 33% and 32% at the Lower Ice Tongue and Meteorite Moraine and adjacent sites.

TABLE 1. Natural Thermoluminescence Data for Lewis Cliff Meteorites With Weights >20 g

Meteorite/Class		Natural TL, krad*	Loc+	Meteorite/Class		Natural TL, krad*	Loc+
LEW 85316	H5	52+-2	UIT	LEW 85450	H5	3.2+-0.1	UIT
LEW 85318	H5	12.2+-0.1	UIT	LEW 85457	L6	0.63+-0.03	UIT
LEW 85319	H5	7.3+-0.1	UIT	LEW 85459	H5	1.7+-0.1	UIT
LEW 85321	L6	41.8+-0.8	UIT	LEW 85461	L6	77+-2	UIT
LEW 85322	H6	41+- 1	UIT	LEW 85464	H5	12.5+-0.1	UIT
LEW 85323	L6	6.6+-0.1	MET	LEW 85465	L6	5.3+-0.2	UIT
LEW 85324	H5	32+-3	UIT	LEW 85472	L6	24.2+-0.7	UIT
LEW 85325	L6	20+-1	MET	LEW 85528	L6	27+- 2	LIT
LEW 85327	H5	0.37+-0.05	UIT	LEW 86011	L6	157+-1	MET
LEW 85329	H6	26+-1	UIT	LEW 86012	L6	50.8+-0.9	MET
LEW 85330	H6	12.4+-0.3	UIT	LEW 86013	L6	93+-2	MET
LEW 85331	H6	47+-2	UIT	LEW 86014	L4	93+-2	LIT
LEW 85333	L4	52+-2	UIT	LEW 86015	H6	122+-6	LIT
LEW 85334	H5	26.2+-0.5	UIT	LEW 86016	L6	8.2+-0.3	MET
LEW 85335	H6	6.9+-0.1	UIT	LEW 86017	H6	17+-1	LIT
LEW 85336	H5	82+-4	UIT	LEW 86018	L3	<1	MET
LEW 85337	H6	10.2+-0.4	UIT	LEW 86019	L6	114.8+-0.7	MET
LEW 85338	H5	25.6+-0.6	UIT	LEW 86020	H5	37+-0.2	MET
LEW 85340	L5	27.1+-0.8	UIT	LEW 86021	L3	36+-2	LIT
LEW 85341	H5	14+-1	UIT	LEW 86022	L3	<1	LIT
LEW 85343	L4	40+-1	UIT	LEW 86023	L6	32+-3	SLC
LEW 85345	H5	43+-3	UIT	LEW 86024	L4	21.9+-0.1	MET
LEW 85346	L6	50+-2	UIT	LEW 86025	L6	0.9+-0.1	LIT
LEW 85347	H5	52+-5	UIT	LEW 86026	H5	64+-2	LIT
LEW 85348	H6	19.5+-0.6	UIT	LEW 86028	H6	38+-2	MET
LEW 85350	L4	10+-0.2	UIT	LEW 86031	H5	127+-2	MET
LEW 85357	H5	6.4+-0.2	UIT	LEW 86033	H4	62+-2	LIT
LEW 85371	H5	24+-3	UIT	LEW 86035	H5	96+-0.2	MET
LEW 85373	H6	20+-3	UIT	LEW 86039	H5	5+-2	LIT
LEW 85379	H5	14.4+-0.2	UIT	LEW 86040	L4	139+-5	LIT
LEW 85381	H6	7.8+-0.3	UIT	LEW 86041	H5	2.34+-0.08	LIT
LEW 85398	H4	14+-0.2	UIT	LEW 86047	H5	32.2+-0.8	MET
LEW 85402	H6	31+-0.9	UIT	LEW 86055	H5	37.1+-0.9	LIT
LEW 85404	H5	35+-1	UIT	LEW 86057	LL6	77+-6	LIT
LEW 85405	H5	5.9+-0.2	UIT	LEW 86060	H5	1.4+-0.1	LIT
LEW 85418	H6	10.1+-0.1	UIT	LEW 86073	L6	47+-4	LIT
LEW 85428	L6	13.6+-0.4	LIT	LEW 86076	H5	42.7+-1	LIT
LEW 85433	H5	93+-1	UIT	LEW 86078	H5	107+-5	MET
LEW 85446	H6	48+-1	UIT	LEW 86081	H5	93+-4	MET
LEW 85448	H5	206+-10	UIT	LEW 86083	H5	36+-1	MET
LEW 86084	L6	29+-1	MET	LEW 86273	L6	31+-2	LIT
LEW 86085	L6	19+-1	MET	LEW 86282	L6	89+-0.2	LIT
LEW 86086	H5	93+-2	MET	LEW 86286	H5	327+-10	UIT
LEW 86088	H5	54.9+-2	MET	LEW 86295	H6	5.7+-0.3	UIT
LEW 86089	H6	4.7+-0.3	MET	LEW 86302	H5	1.7+-0.1	UIT
LEW 86090	L6	6.9+-0.1	LIT	LEW 86305	H5	33+-1	MET
LEW 86091	H5	12.7+-0.1	MET	LEW 86311	L6	53+-1	UIT
LEW 86096	H5	76+-1	MET	LEW 86312	H5	19.5+-0.1	UIT
LEW 86098	L4	2.9+-0.1	LIT	LEW 86314	H5	74+-1	MET
LEW 86099	H5	9.7+-0.3	MET	LEW 86317	L6	68+-2	UIT
LEW 86101	LL6	6+-1	LIT	LEW 86327	H5	19.6+-0.5	MET
LEW 86104	H5	22.7+-0.5	MET	LEW 86337	H5	53+-2	MET
LEW 86107	H5	40+-1	LIT	LEW 86340	H6	96+-8	UIT
LEW 86110	L6	53.2+-0.5	LIT	LEW 86349	L6	84+-1	UIT
LEW 86111	H5	59+-2	LIT	LEW 86352	L5	20.4+-0.1	UIT
LEW 86115	L6	52.5+-0.7	LIT	LEW 86354	H5	25+-1	UIT
LEW 86118	H5	3.6+-0.1	LIT	LEW 86360	L4	57+-1	MET
LEW 86120	H6	22.9+-0.9	LIT	LEW 86366	H4	44+-1	MET
LEW 86134	L3	<1	LIT	LEW 86368	H5	96+-3	MET
LEW 86138	L4	196+-22	LIT	LEW 86371	H5	28.4+-0.8	MET
LEW 86161	LL6	69+-2	LIT	LEW 86376	H5	9.9+-0.1	MET

TABLE 1 (continued)

Meteorite/Class		Natural TL, krad*	Loc+	Meteorite/Class		Natural TL, krad*	Loc+
LEW 86164	H5	13.1+-0.4	LIT	LEW 86380	H4	45+-9	LIT
LEW 86166	L6	2.3+-0.2	LIT	LEW 86382	H6	3.8+-0.1	MET
LEW 86174	H5	93+-2	LIT	LEW 86385	H5	50+-1	MET
LEW 86181	H6	16+-1	LIT	LEW 86388	H5	67+-3	MET
LEW 86183	H6	22.3+-0.6	LIT	LEW 86393	H5	21.7+-0.4	MET
LEW 86186	L6	17.9+-0.3	LIT	LEW 86407	H5	16.5+-0.1	MET
LEW 86195	L6	16+-0.5	UIT	LEW 86418	H5	0.85+-0.07	LIT
LEW 86199	H5	27.6+-0.4	LIT	LEW 86438	H5	88+-3	MET
LEW 86203	L6	16+-3	LIT	LEW 86442	H5	28.7+-0.6	MET
LEW 86204	H6	9.7+-0.1	UIT	LEW 86451	H5	52+-1	MET
LEW 86206	H5	96+-3	LIT	LEW 86463	H5	30+-4	MET
LEW 86213	L3	13+-2	LIT	LEW 86465	H5	40+-2	MET
LEW 86215	H5	9+-0.9	MET	LEW 86466	H6	47+-1	MET
LEW 86225	H5	42.5+-0.7	MET	LEW 86471	H6	5+-0.6	MET
LEW 86226	H5	64+-2	MET	LEW 86472	H5	43+-1	MET
LEW 86228	H5	56+-2	MET	LEW 86473	H5	87+-2	UIT
LEW 86238	L6	59+-9	LIT	LEW 86479	H5	80+-10	MET
LEW 86241	H6	20+-0.6	LIT	LEW 86485	H5	28+-0.9	MET
LEW 86249	H6	17+-0.4	LIT	LEW 86489	H5	30+-1	UIT
LEW 86250	H5	45+-2	LIT	LEW 86490	L6	58.5+-0.2	LIT
LEW 86251	L4	56+-1	MET	LEW 86500	H5	38+-2	MET
LEW 86252	H6	155+-19	MET	LEW 86503	H5	28+-1	UIT
LEW 86255	H5	61+-2	MET	LEW 86514	H5	63+-0.8	UIT
LEW 86266	H5	24+-1	UIT	LEW 86515	H5	54+-2	LIT
LEW 86268	L6	16+-1	LIT	LEW 86522	H6	0.9+-0.2	UIT
LEW 86525	H5	7.3+-0.5	UIT	LEW87047	H6	6.9+-0.1	SLC
LEW 86534	H5	14.4+-0.4	LIT	LEW87048	H6	1.7+-0.3	SLC
LEW 86544	H6	18.9+-0.3	UIT	LEW87049	L4	40+-2	SLC
LEW 86546	L6	57+-2	LIT	LEW87055	H6	25.5+-0.7	UWN
LEW 86549	L3	52+-4	LIT	LEW87095	H5	5.5+-0.1	SLC
LEW 87029	H5	20.4+-0.3	SLC	LEW87123	LL6	107+-2	LIT
LEW 87030	H5	11.5+-0.1	UWN	LEW87143	L6	0.42+-0.03	SLC
LEW 87031	H5	37.4+-0.8	SLC	LEW87169	L6	0.7+–.1	SLC
LEW 87033	H5	5+-0.1	UWN	LEW87230	H6	50+-2	SLC
LEW 87034	H5	29.7+-0.2	UWN	LEW87267	H5	107+-1	MET
LEW 87035	L6	35+-1	SLC	LEW87277	H5	86.1+-0.8	MET
LEW 87036	L6	37+-1	SLC	LEW87279	LL6	41.7+-0.5	SLC
LEW 87037	H5	43.6+-0.1	UWN	LEW88013	H5	14.8+-0.2	
LEW 87038	L6	39.6+-0.6	SLC	LEW88014	H5	39.4+-0.2	
LEW 87039	H6	42.7+-0.2	SLC	LEW88015	L6	12+-0.1	
LEW 87040	L6	44+-0.5	SLC	LEW88016	L6	110.7+-0.4	
LEW 87041	H5	117+-2	MET	LEW88017	L6	23+-0.1	
LEW 87042	L6	37+-0.3	SLC	LEW88018	L6	14.6+-0.1	
LEW 87043	H5	0.65+-0.04	SLC	LEW88019	H4	55.7+-0.3	
LEW 87044	H6	34.7+-0.6	SLC	LEW88020	H4	56.5+-0.1	
LEW 87045	L6	29.8+-0.3	SLC	LEW88058	L6	69.7+-0.8	
LEW 87046	L6	26.8+-0.3	SLC				

*Uncertainties are 1 sigma estimates based on measurements of single aliquants.

+Locations based on geographic data provided by W.A. Cassidy. LIT, Lower Ice Tongue; MET, Meteorite Moraine; SLC, South Lewis Cliff; UIT, Upper Ice Tongue; UWN, Upper Walcott Neve.

maybe higher. There is no indication that the data plot along the non-Antarctic regression line; rather the data resemble rather closely the data for H chondrites from the Allan Hills [*Sears et al.*, 1991*a*].

DISCUSSION

We will discuss the data in terms of the effects of weathering, of possible pairing, the variations in natural TL with location on the ice, terrestrial age and orbital implications, and finally the unusual meteorites among the present Lewis Cliff samples.

Weathering

The darkening of the meteorite surface as a result of weathering decreases the scattering of light and therefore the amount of light reaching the detector during TL measurement [*Benoit et al.*, 1991*c*]. Weathering does not affect natural TL

Table 2. Induced thermoluminescence data (TL sensitivity, TL peak temperature and peak width) for Lewis Cliff (LEW) samples

LEW	Sensit.*	Temp.	Width	LEW	Sensit.*	Temp.	Width
85301	1.8+-0.09	192+-3	153+-1	85379	0.47+-0.06	192+-4	141+-8
85314	0.36+-0.05	191+-2	140+-7	85380	4.8+-0.3	185+-3	142+-2
85315	2.8+-0.2	187+-8	139+-3	85381	0.49+-0.06	185+-5	138+-3
85316	0.22+-0.04	202+-7	159+-3	85383	0.1+-0.02	160+-25	151+-9
85317	0.63+-0.06	203+-2	174+-3	85384	2.4+-0.3	195+-2	136+-4
85318	0.98+-0.07	183+-3	145+-2	85385	0.34+-0.04	187+-5	155+-15
85319	0.7+-0.06	191+-7	147+-11	85386	4.1+-0.5	192+-6	128+-29
85321	1.5+-0.12	185+-6	141+-1	85398	0.6+-0.06	199+-6	161+-9
85322	3.3+-0.2	182+-3	140+-3	85402	0.71+-0.09	214+-9	143+-1
85323	1.4+-0.13	181+-3	153+-2	85403	1.2+-0.06	188+-4	151+-5
85324	1.5+-0.1	191+-7	143+-5	85404	0.6+-0. 1	209+-16	141+-3
85325	2.3+-0.15	199+-6	142+-2	85405	0.64+-0.08	203+-7	143+-2
85327	0.8+-0.12	190+-7	141+-1	85406	0.29+-0.04	191+-5	140+-2
85329	1.4+-0.09	180+-3	143+-1	85413	1.3+-0.2	180+-2	138+-4
85330	0.6+-0.08	175+-3	147+-23	85418	0.73+-0.1	174+-5	132+-3
85331	2.3+-0.1	182+-3	144+-2	85423	1.5+-0.1	194+-1	130+-12
85333	0.23+-0.02	194+-9	183+-15	85426	0.35+-0.05	192+-4	137+-4
85334	0.55+-0.03	197+-1	139+-8	85427	1.1+-0.07	209+-3	148+-6
85335	0.38+-0.04	187+-6	134+-3	85428	0.49+-0.02	187+-3	148+-6
85336	0.5+-0.04	196+-7	145+-7	85433	0.18+-0.02	227+-10	165+-1
85337	0.95+-0.08	193+-3	142+-3	85443	0.21+-0.03	197+-7	156+-6
85338	1.1+-0.06	202+-5	146+-12	85445	0.63+-0.08	189+-2	139+-6
85340	0.63+-0.13	199+-7	150+-1	85446	1.8+-0.3	183+-5	137+-4
85341	0.65+-0.06	189+-8	141+-4	85448	0.98+-0.06	203+-4	144+-2
85343	0.68+-0.06	192+-7	155+-14	85449	0.78+-0.05	197+-7	87+-50
85345	0.43+-0.04	173+-5	152+-5	85450	0.35+-0.04	196+-2	67+-13
85346	0.52+-0.08	201+-3	144+-2	85451	0.19+-0.03	196+-7	166+-5
85347	0.4+-0.04	198+-2	140+-2	85454	1.97+-0.22	192+-5	144+-2
85348	0.21+-0.03	189+-5	145+-2	85455	1.2+-0.06	190+-5	142+-7
85350	0.19+-0.02	188+-5	149+-7	85456	0.23+-0.02	217+-4	157+-13
85351	0.57+-0.09	196+-7	161+-1	85457	2.3+-0.4	191+-1	140+-7
85352	0.63+-0.07	200+-4	149+-2	85458	0.33+-0.05	193+-1	141+-1
85354	.017+-.001	199+-6	175+-13	85459	0.32+-0.04	218+-3	159+-1
85356	0.13+-0.01	203+-7	183+-13	85460	0.36+-0.07	188+-3	139+-3
85357	0.5+-0.06	195+-4	139+-6	85461	0.36+-0.06	193+-3	145+-5
85359	0.77+-0.13	196+-8	145+-5	85464	0.33+-0.04	198+-8	137+-3
85360	2.6+-0.3	192+-6	156+-4	85465	0.13+-0.03	182+-9	—
85362	0.75+-0.12	193+-10	151+-7	85472	1.4+-0.2	194+-5	156+-5
85368	0.66+-0.09	185+-2	137+-6	86011	5.88+-0.2	187+-1	135+-1
85371	0.2+-0.03	201+-8	138+-3	86012	3.7+-0.6	181+-1	147+-9
85373	1.3+-0.2	181+-3	135+-6	86013	1.3+-0.2	184+-6	142+-4
86014	0.56+-0.09	181+-1	156+-1	86118	0.5+-0.07	180+-4	145+-7
86015	0.32+-0.04	169+-7	150+-12	86120	1.8+-0.2	179+-9	132+-6
86016	0.97+-0.12	173+-1	152+-17	86135	0.7+-0.2	181+-3	144+-6
86017	3.8+-0.6	185+-14	140+-5	86138	0.23+-0.01	185+-1	192+-3
86019	3.7+-0.6	177+-1	141+-4	86152	2.1+-0.3	187+-8	138+-3
86020	0.5+-0.09	179+-4	138+-4	86160	2.9+-0.4	174+-3	133+-5
86021	0.21+-0.03	167+-5	150+-9	86161	1.4+-0.2	183+-9	151+-8
86023	1.2+-0.2	187+-4	147+-1	86164	1.4+-0.2	181+-6	135+-2
86024	1.6+-0.1	174+-1	145+-3	86165	0.3+-0.04	178+-6	143+-8
86025	0.42+-0.06	181+-5	166+-1	86166	2.7+-0.5	187+-6	134+-4
86026	0.47+-0.06	172+-1	151+-9	86168	0.44+-0.07	174+-3	137+-10
86028	0.47+-0.06	181+-3	143+-3	86174	0.66+-0.1	185+-6	164+-15
86031	0.43+-0.05	189+-1	152+-16	86181	1.1+-0.2	179+-7	138+-5
86033	0.37+-0.06	183+-4	163+-18	86183	0.9+-0.2	175+-14	137+-3
86035	0.47+-0.08	187+-5	147+-8	86186	0.28+-0.01	172+-6	149+-10

Table 2 (continued)

LEW	Sensit.*	Temp.	Width
86040	0.33+-0.06	174+-6	166+-6
86041	0.43+-0.06	177+-5	140+-1
86043	0.5+-0.07	191+-3	159+-11
86044	0.33+-0.14	179+-3	148+-5
86047	0.43+-0.06	185+-4	143+-4
86050	0.44+-0.06	176+-4	148+-15
86053	0.46+-0.05	176+-1	144+-12
86056	0.51+-0.07	182+-6	137+-2
86057	0.2+-0.03	176+-8	174+-15
86060	0.89+-0.2	180+-10	143+-1
86070	2.3+-0.4	174+-1	143+-5
86072	0.57+-0.1	178+-4	155+-4
86073	0.48+-0.09	210+-6	153+-19
86077	0.45+-0.07	181+-1	155+-10
86078	0.5+-0.06	178+-5	151+-10
86079	0.27+-0.04	210+-42	163+-9
86081	0.54+-0.06	185+-2	157+-5
86083	0.5+-0.09	188+-4	138+-6
86084	0.53+-0.06	182+-3	157+-7
86085	0.41+-0.1	186+-3	152+-4
86086	0.58+-0.08	204+-19	152+-4
86089	0.38+-0.05	180+-1	130+-4
86090	0.18+-0.03	182+-13	171+-1
86091	0.42+-0.06	185+-2	141+-2
86096	0.46+-0.05	184+-6	143+-12
86098	0.24+-0.03	173+-4	189+-4
86099	1.4+-0.3	171+-7	145+-1
86101	0.13+-0.1	182+-12	183+-10
86110	1.3+-0.3	184+-6	138+-5
86111	0.46+-0.08	185+-8	145+-6
86115	2.4+-0.4	170+-3	141+-2
86118	0.5+-0.07	180+-4	145+-7
86120	1.8+-0.2	179+-9	132+-6
86135	0.7+-0.2	181+-3	144+-6
86138	0.23+-0.01	185+-1	192+-3
86152	2.1+-0.3	187+-8	138+-3
86160	2.9+-0.4	174+-3	133+-5
86161	1.4+-0.2	183+-9	151+-8
86164	1.4+-0.2	181+-6	135+-2
86165	0.3+-0.04	178+-6	143+-8
86166	2.7+-0.5	187+-6	134+-4
86168	0.44+-0.07	174+-3	137+-10
86174	0.66+-0.1	185+-6	164+-15
86181	1.1+-0.2	179+-7	138+-5
86183	0.9+-0.2	175+-14	137+-3
86186	0.28+-0.01	172+-6	149+-10
86195	0.55+-0.07	167+-1	147+-2
86199	0.68+-0.02	172+-3	141+-17
86204	0.5+-0.07	191+-19	143+-1
86206	0.42+-0.06	187+-5	167+-12
86207	0.27+-0.01	130+-1	122+-15
86213	0.02+-0.00	130+-6	120+-1
86215	0.63+-0.12	175+-4	156+-7
86225	0.44+-0.07	183+-10	154+-2
86228	0.44+-0.01	184+-1	154+-15
86232	1.4+-0.4	182+-6	149+-6
86249	1.2+-0.2	174+-3	139+-6
86250	0.4+-0.1	188+-10	150+-1
86251	0.31+-0.07	173+-2	180+-1
86252	0.71+-0.11	191+-9	154+-1
86255	0.54+-0.09	184+-4	143+-2
86266	0.34+-0.05	180+-3	150+-3
86268	0.9+-0.1	178+-2	153+-10
86273	1.2+-0.2	178+-2	151+-5
86282	0.22+-0.04	185+-3	153+-8
86286	0.52+-0.08	208+-4	158+-3
86295	1.9+-0.1	154+-7	122+-4
86302	0.41+-0.02	175+-11	132+-5
86305	0.63+-0.04	170+-1	135+-4
86311	1.5+-0.2	168+-4	140+-5
86312	1.1+-0.1	170+-7	136+-5
86314	0.54+-0.03	177+-5	135+-4
86317	0.98+-0.05	176+-4	149+-4
86327	0.62+-0.02	170+-2	137+-6
86337	0.35+-0.04	176+-3	145+-5
86340	0.41+-0.03	178+-7	134+-3
86344	0.54+-0.04	171+-2	136+-5
86349	3.2+-0.05	180+-4	134+-4
86352	0.9+-0.03	169+-5	146+-9
86354	1.73+-0.08	163+-4	132+-3
86360	0.36+-0.03	177+-16	162+-6
86366	0.47+-0.07	183+-12	126+-17
86367	0.05+-0.01	110+-6	77+-2
86368	0.51+-0.02	172+-7	143+-3
86380	0.66+-0.03	176+-5	140+-8
86382	1.04+-0.06	158+-11	122+-2
86385	0.84+-0.12	165+-5	143+-9
86395	0.55+-0.02	165+-8	131+-2
86396	0.54+-0.07	180+-1	153+-1
86397	0.33+-0.03	191+-7	142+-12
86438	0.5+-0.04	171+-4	143+-7
86442	0.47+-0.07	180+-5	139+-6
86451	0.47+-0.07	193+-4	140+-4
86470	0.39+-0.02	185+-7	142+-6
86471	0.7+-0.1	150+-5	125+-6
86472	0.46+-0.08	168+-1	140+-1
86473	0.37+-0.02	177+-4	147+-7
86479	0.78+-0.05	169+-6	132+-9
86490	0.28+-0.01	173+-5	159+-4
86499	0.4+-0.03	177+-3	140+-6
86503	0.51+-0.03	171+-11	146+-3
86514	0.45+-0.07	166+-6	139+-10
86515	1.2+-0.2	159+-6	132+-3
86518	0.52+-0.07	189+-7	139+-7
86522	0.91+-0.13	153+-6	129+-4
86525	0.62+-0.08	155+-2	130+-5
86534	1.4+-0.2	169+-10	135+-4
86544	0.31+-0.02	177+-18	134+-7
86546	0.4+-0.02	171+-8	148+-8
86549	0.31+-0.02	168+-6	152+-3
87049	0.78+-0.05	181+-3	135+-4
88013	0.95+-0.14	175+-7	125+-2
88014	1.33+-0.09	183+-6	123+-6
88015	2.25+-0.18	177+-2	124+-1
88016	1.5+-0.19	182+-7	130+-4
88017	0.53+-0.02	186+-4	145+-9
88018	1.36+-0.09	173+-12	130+-5
88019	1+-0.08	177+-2	126+-3
88020	0.93+-0.13	184+-4	124+-1
88058	1.3+-0.1	163+-11	124+-2

* TL sensitivities relative to Dhajala (H3.8).

Uncertainties are 1 sigma based on 3-5 measurements.

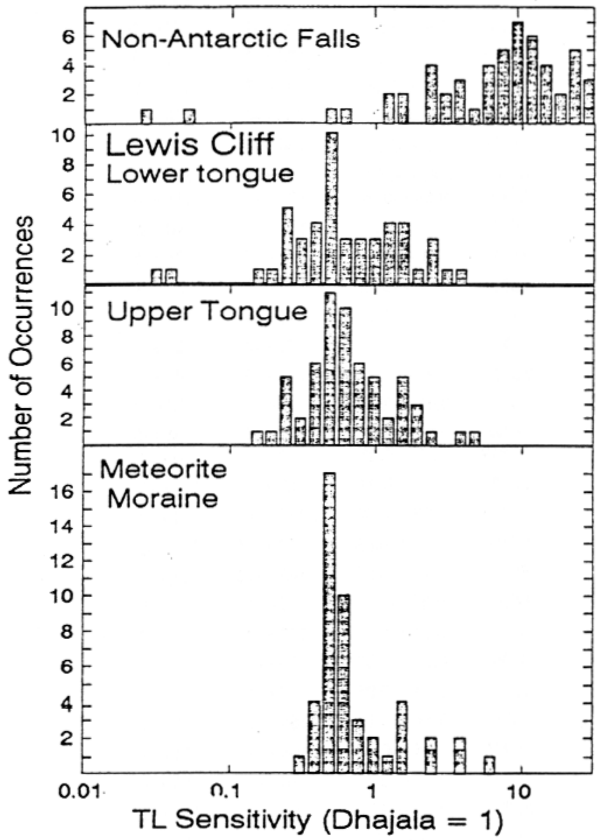

Fig. 5. Histograms of TL sensitivity values for meteorites from several regions in the vicinity of the Lewis Cliff Ice Tongue and for non-Antarctic falls (data from *Haq et al.* [1988]). The strength of the peak for samples at the Meteorite Moraine site suggests the presence of a large pairing group at this site, which is confirmed by natural TL, find location and other data (see Table 4). The narrow peak in the data for the Lower Ice Tongue may indicate some pairing with the meteorites at Meteorite Moraine.

data, because the measurement is essentially "internally standardized." Neither does it affect peak temperature or width, since the effect is independent of sample temperature. However, *Benoit et al.* [1991*b*] found that the TL sensitivities of 12 Antarctic equilibrated chondrites increased by a factors of 2.4-14.4 after the weathering products had been removed by acid-washing. *Haq et al.* [1988] found that the TL sensitivity of about 45 Antarctic H chondrites was skewed to lower values by a factor of about 3, compared to non-Antarctic chondrites, which they presumed was due to weathering. For meteorites with lower TL sensitivity the effect seems to be less, and *D. W. G. Sears et al.* [1991*b*] found that petrological types assigned to type 3 chondrites on the basis of olivine heterogeneity and carbon content were usually within 0.1-0.2 of the type assigned by TL sensitivity. Acid-washing is also consistent with weathering affecting the type 3 chondrites less than the higher TL sensitivity samples. The present TL sensitivity data have not been corrected for weathering. However, weathering should not create peaks in the histograms but smear out any peaks originally present as samples weather at different rates. Weathering might cause pairings to be missed, if different fragments weathered to different extents.

Pairing

One of the major difficulties in using Antarctic meteorites for statistical studies is the abundance of paired meteorites. Meteorites normally fragment during fall. Of the first 100 observed falls in the British Museum *Catalogue of Meteorites* [*Graham et al.*, 1985], 55 produced more than one fragment, 10 producing "showers" on the order of 60 (Beardsley) or more than 100 (Bur-Gheluai) individual fragments. These numbers are almost certainly underestimates because the fragmentation of single "stones" is not always thought noteworthy and because collection is seldom complete. For instance, *Clarke et al.* [1970] suggest that only half of the Allende material was recovered from the fields. For Antarctic meteorites, weathering processes will cause further fragmentation. Mechanical processes in the ice might also contribute to fragmentation, although this is far from certain. *Scott* [1984, 1989] suggests that 50-80% of the samples collected in the 1977/1978 season are paired, and that pairing is probably equally extensive in more recent collections. Many pairings are currently being missed because previous efforts have relied heavily on petrographic methods that are not well-suited to ordinary chondrites. If we use the nonchondrites as a guide, it also seems that more than half the meteorites being found are paired. The 196 nonchondrites listed in the latest index issue of the *Antarctric Meteorite Newsletter* are thought to represent only 87 separate meteorites (statistics in *Score and Lindstrom* [1990]).

Huss [1990, 1991] and *Cassidy and Harvey* [1991] have shown that it is sometimes possible to use mass-frequency curves to deduce the presence of extensive amounts of pairing in Antarctic meteorites. For instance, *Huss* [1990] suggests that there is a major unrecognized H5 shower among the samples collected at the Main and Nearwestern icefields at Allan Hills, and that there is a major unrecognized L6 shower among the Elephant Moraine samples. We prepared mass distribution plots for meteorites from the Lewis Cliff sites, but all classes show a slope of about -0.8 for the large mass part of the curve (Figure 7). These slopes are comparable to that expected for the incoming meteorites and does not indicate the presence of

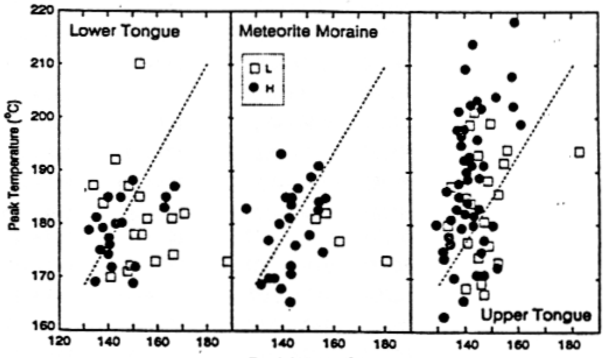

Fig. 6. Plots of the induced TL peak shape parameters, peak temperature and peak width. Meteorites at Meteorite Moraine and the Lower Ice Tongue produce very similar plots, again suggesting a link, while meteorites at the Upper Tongue plot over a narrow range of widths but a broad range of peak temperatures. The distribution of data for the Upper Tongue resembles that shown by samples from the Allan Hills, and is very unlike the data for non-Antarctic H chondrites. The regression line for non-Antarctic chondrites is shown as a broken line. There is an indication that L chondrites plot to the right of the H chondrites in each plot.

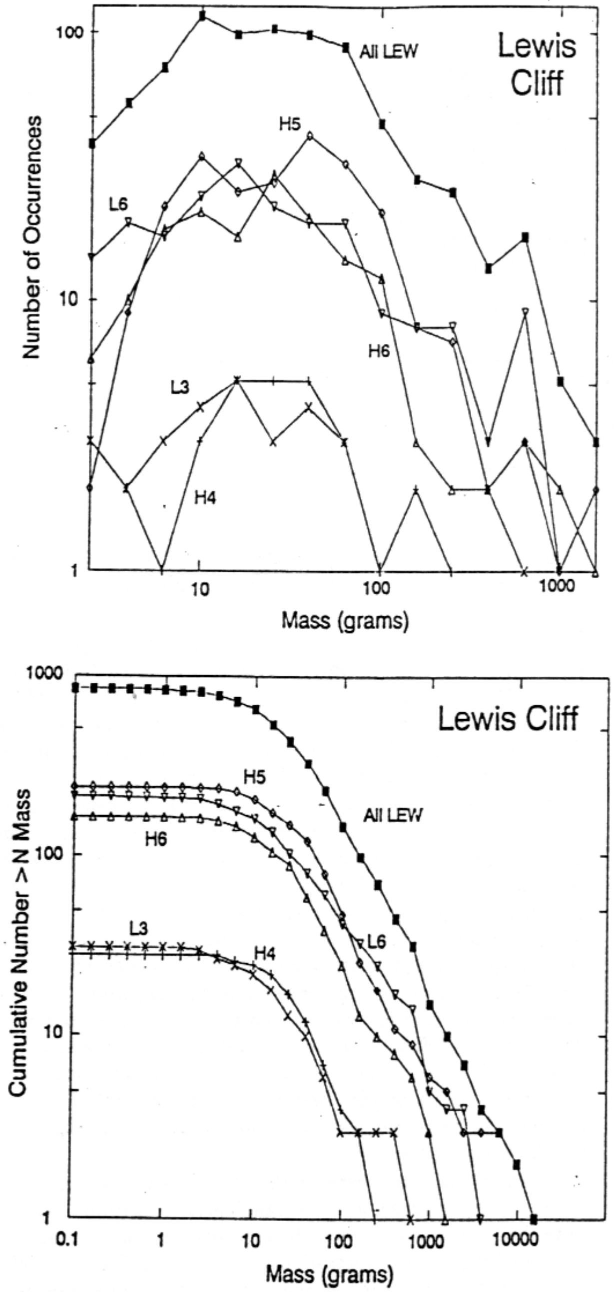

Fig. 7. Mass distribution plots for meteorites from the Lewis Cliff vicinity (data from *Score and Lindstrom* [1990]). *Huss* [1990] has shown that such plots can be used to indicate the presence of particularly large pairing groups. In the present instance, the distributions are very similar to each other and to the distributions for observed falls (i.e. the slope shown by the large masses is about -0.88). There is no evidence for a single major pairing group.

a major shower dominating the statistics, though it should be noted that only a recent large fall will significantly change the mass distribution curve [*Huss*, 1991]. By any reasonable argument, however, it seems that pairing in the Antarctic collections is extensive, and only a small fraction of the pairings actually present are being detected. We have attempted to establish a procedure for identifying paired meteorites among the present samples using the following, largely objective, set of criteria.

1. *Chemical-petrologic class*. For pairing, we will require that meteorites be of the same chemical-petrologic class. Instances of breccias consisting of different classes are known - St. Mesmin is an LL chondrite with a 4 cm H chondrite clast, Fayetteville is an H chondrite with L chondrite clasts, and many regolith breccias contain very small CM-like clasts. However, such breccias are rare, and the requirement that potentially paired meteorites are of the same chemical-petrologic class is probably one of the safest, though there is always a small possibility of some being misclassified.

2. *Proximity of find location*. For pairing we will also require that fragments are found within 1.5 km of each other. Dispersion of fragments over 10-20 km occurs during fall [e.g., *Shima et al.*, 1978]; however, this provides little guidance to the expected dispersion of Antarctic shower fragments because dispersal also may occur during encasement in the ice, as it moves in and around obstacles, and by wind transport on the surface of the ice. Furthermore, fragments will be concentrated as the ice is compressed and ablates [e.g., *Whillans and Cassidy*, 1983]. Both dispersion during fall and wind-transport cause mass-dependent dispersion [*Nininger*, 1952; *Scott*, 1984]. We have been guided by the size of fields over which previously paired Antarctic meteorites have been recovered. As evident from Table 3, paired meteorites are typically found within fields of about 3 km in size. Interestingly, the Lewis Cliff Ice Tongue has yielded a disproportionately large number of L3 chondrites, and many must be paired. The largest group identified to date [*Mason*, 1988*a,b*] are those paired with LEW86127 which, excluding LEW86505, were found along an east-west line 1.3 km long on the lower Ice Tongue (Figure 8).

3. *Natural thermoluminescence*. We make the requirement that natural TL values for two potentially paired meteorites should fall within 10% of each other. The variation of natural TL within meteorites has been determined in several studies, the most recent concerning an Antarctic meteorite [*Sears et al.*, 1990*b*]. The standard deviation of the natural TL of nine samples from two cores from LEW85320 was 6%. Ten percent is approximately the two sigma value, and it is also typical of the observed range in several paired chondrites and splits from single chondrites [*Hasan et al.*, 1987]. One core from the St. Severin LL5 chondrite showed a larger range in natural TL, a factor of approximately two in one direction, so our 10% value will result in a conservative pairing list.

4. *Induced thermoluminescence parameters*. We also require that induced TL data fall within prescribed limits; i.e., that induced TL peak temperature and width are within 10% and 20%, respectively, and that TL sensitivities are within a factor of two. In contrast to natural TL values, which are determined by absorbed dose and mean temperature during exposure, induced TL data are governed by mineralogical factors, i.e., the amount and nature of the feldspar (or other phosphors) in the meteorites. Thus, TL sensitivity shows a metamorphism-related 10^5-fold range over the chondrites as a whole, with type 3 meteorites showing a 1000-fold range. The range within the individual equilibrated petrologic types (types 4-6) is a factor of about 10. Our values for induced TL pairing criteria are based primarily on the LEW85320 core samples, but they are consistent with other data. Two sigma uncertainties for the H6 chondrite, Kernouve, are 20% of the mean for TL sensitivity,

TABLE 3. Dispersion of Paired Meteorite Fragments in the Antarctic

Meteorite[*]	Class	No. of Fragments	Max. extent of field, km[+]	Comments[$]
ALHA76002	IA	5	4.0	PG 5.1, ALH(M)
ALHA76005	Euc	15	4.0	PG 2.1, ALH(M)
ALHA77004	H4	12	1.9	PG 8.1, ALH(NW)
ALHA77011	L3	76	5.6	PG 11.1, ALH(M)
ALHA77021	H5	10	2.2	PG 9.2, ALH(M)
ALHA77219	Meso	3	2.2	PG 4.1, ALH(NW)
ALHA78019	Ure	2	5.5	PG 3.4, +2 nearby ureilites, ALH(M)
ALHA80101	L6	19	0.5	PG 14.8, including 83063, ALH(M)
ALHA81041	H4	11	2.1	PG 8.5, ALH(NW)
LEW86022	L3	2	5.7	
LEW86127	L3	10	4.4	1.3 km without one outlier (86505)
LEW86307	L3	2	0.05	

[*] First member of the pairing group. See *Scott* [1989] or *Score and Lindstrom* [1990] for members of the group.

[+] Maximum extent of the area over which fragments were found, as determined from LPI maps (see *Schutt et al.*[1989], and personal communication [1990]).

[$] PG, pairing group of *Scott* [1984, 1989]. ALH(M) and ALH(NW) refer to Allan Hills Main ice field and Nearwestern ice field, respectively.

10% for peak temperature and 20% for peak width [*Haq et al.*, 1988]. We suspect that the unweathered nature of Kernouve results in better reproducibility in its TL sensitivity data, but its unusual peak shape caused greater uncertainty in the peak temperature and width values and that the LEW85320 data are a more reliable guide, as well as leading to more conservative pairing predictions.

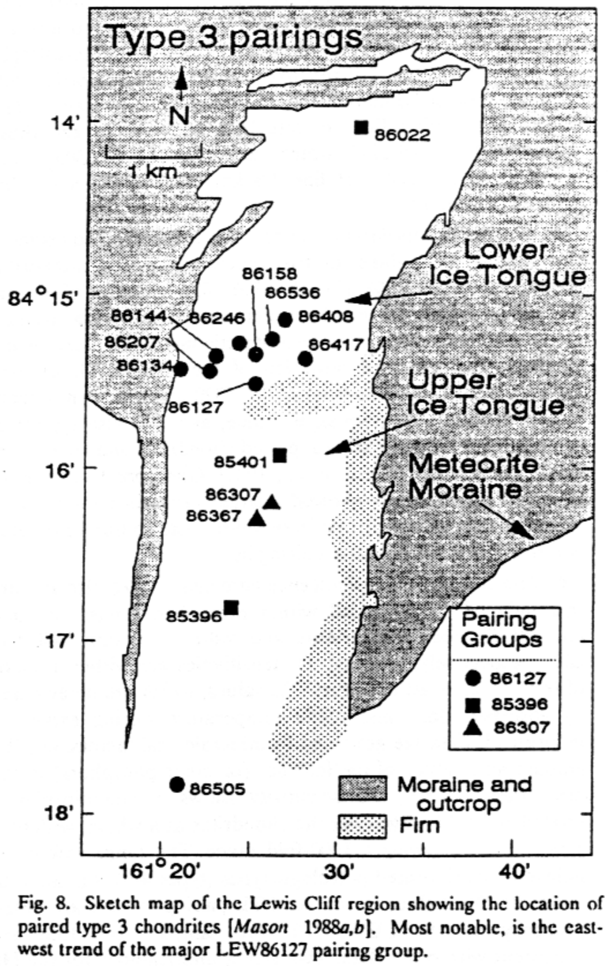

Fig. 8. Sketch map of the Lewis Cliff region showing the location of paired type 3 chondrites [*Mason* 1988*a,b*]. Most notable, is the east-west trend of the major LEW86127 pairing group.

5. *Cosmogenic isotopes*. Stable noble gas isotopes or, more precisely, cosmic ray exposure ages and the ^{3}He/^{21}Ne and ^{22}Ne/^{21}Ne ratios can be used for pairing [*Schultz et al.*, 1991], as can terrestrial ages determined from radioactive isotopes like ^{26}Al, ^{14}C and ^{36}Cl. Unfortunately, these data are largely undetermined for the Lewis Cliff meteorites at this time.

6. *Other petrographic data*. While the petrography of equilibrated chondrites is generally rather similar, occasional use of secondary alteration features such as shock veins, unusual inclusions and brecciation is possible. Olivine and pyroxene compositions are available for most of the present samples, but since equilibrated meteorites are highly uniform in these respects also, the data are of little value in pairing.

7. *Hand-specimen descriptions and field descriptions*. Usually additional information will be available from hand-specimen descriptions (including weathering category, color and other aspects of physical appearance, abundance of inclusions, appearance of TL powder before and after heating). The best evidence for pairing is when the samples actually fit together, but this is extremely rare.

We passed all the present meteorites through the first four filters, thus generating a list of candidates for pairing. These were then examined individually, applying the criteria 6 and 7. The resulting pairing suggestions are listed in Table 4. We suspect that 71 of our 165 samples are paired in some way, and that less than 121 separate falls are represented in our data set. These figures are almost certainly underestimates, since our pairing criteria are conservative.

Figure 9 shows the location of all but three of the 27 pairing groups we have identified (the other three are off the lower edge of the map in the South Lewis Cliff region). The distribution of pairing groups at Meteorite Moraine is not very informative, reflecting only the concentration of meteorites along a very narrow band. The LEW85325 group is the most widespread that we have located, and involves a meteorite 1 km to the south of Meteorite Moraine (LEW85325) and another on the Upper Ice Tongue (LEW85472), as well as two within the moraine (LEW86019 and LEW86085). We suggest that the

TABLE 4. Potential Pairings Among Lewis Cliff Meteorites Based on Natural TL, Induced TL, Location, Chemical-Petrologic Class and Other Data

Name	Nat. TL, krad @ 250°C	Class/ Dist.*	Disp.+
UPPER ICE TONGUE			
85330	12.4	H6	1.3 km
85337	10.2	770 m	1.3 km
85381	7.8	600 m	1.3 km
85418	10.1	560 m	1.3 km
86204	9.7	80 m	1.3 km
85321	41.8	L6	200 m
86311	53	200 m	200 m
85331	47	H6	240 m
85446	48	240 m	240 m
85334	26.2	H5	1.1 km
85338	25.6	450 m	1.1 km
85371	24	620 m	1.1 km
85341	14	H5	1.2 km
85379	14.4	1.0 km	1.2 km
86312	19.5	1.2 km	1.2 km
85405	5.9	H5	900 m
86525	7.3	900m	900 m
85450	3.2	H5	1.4 km
85459	1.7	1.4 km	1.4 km
LOWER ICE TONGUE			
85428	13.6	L6	800 m
86186	17.9	200 m	800 m
86203	16	550 m	800 m
86286	16	800 m	800 m
86041	2.34	H5	450 m
86118	3.6	450 m	450 m
86055	37	H5	900 m
86076	42.7	350 m	900 m
86107	40	850 m	900 m
86250	45	450 m	900 m
86060	1.4	H5	400 m
86418	0.85	400 m	400 m
86073	47	L6	600 m
86110	53.2	600 m	600 m
86115	52	450 m	600 m
86090	6.9	L6	200 m
86166	2.3	200 m	200 m
86120	22.3	H6	400 km
86183	22.3	150 m	150 m
86238	59	L6	1.0 km
86490	58.5	500 m	1.0 km
86546	57	870 m	1.0 km
METEORITE MORAINE			
85325	$20^{\#}$	1.9 km	1.9 km
85427	$24.2^{\$}$	1.3 km	1.9 km
86019	14.8	1.3 km	1.9 km
86085	19	950 m	1.0 km
86011	157	L6	600 m
86013	93	600 m	600 m
86020	37	H5	1.6 km
86083	36	1.1 km	1.6 km
86500	38	1.6 km	1.6 km
86035	96	H5	<20 m
86078	107	<20 m	<20 m
86081	93	<20 m	<20 m
86438	88	<20 m	<20 m
86047	32.2	H5	30 m
86371	28.4	30 m	30 m
86442	28.7	30 m	30 m
86104	12.7	H5	400 m
86099	9.7	400 m	400 m
86104	22.7	H5	200 m
86393	21.7	200 m	200 m
86385	50	H5	240 m
86451	52	240 m	240 m
86463	30	H5	20 m
86485	28	20 m	20 m
SOUTH LEWIS CLIFF			
87035	35	L6	2 km
87042	37	2 km	2 km
87036	37	L6	2 km
87042	35	2 km	2 km
87045	29.8	L6	1 km
87046	26.8	1 km	1 km

* Distance of the fragment from the primary member, whose class is given.
\+ Total dispersion of the group, i.e. maximum distance between individuals in the group.
\# Found on the ice field to the south of Meteorite Moraine.
\$ Found on the eastern side of the Upper Lewis Cliff Ice Tongue.

flow of ice either side of the moraine has separated these members of a single shower.

The distribution of paired meteorites in the main Ice Tongue is very informative. Paired meteorites in the Upper Ice Tongue tend to be found lying in a north-south relationship (Figure 9). This is true of simple pairs of meteorites and of the LEW85330 H6 pairing group where five individual samples are involved. This is in contrast to the eight pairing groups we have identified among samples from the Lower Ice Tongue, and the LEW86127 pairing group identified by *Mason* [1988*a,b*]. On the Lower Ice Tongue the distribution of meteorites is random (LEW85428 group), boomerang-shaped (the LEW86055, LEW86073 and LEW86238 groups), or east-west (the LEW86014 and LEW86120 groups in Figure 9 and LEW86127 group in Figure 8). We suggest that the details by which meteorite concentration occurred on the Upper Ice Tongue were different from those applying on the Lower Ice Tongue. The north-south alignment of paired meteorites on the Upper

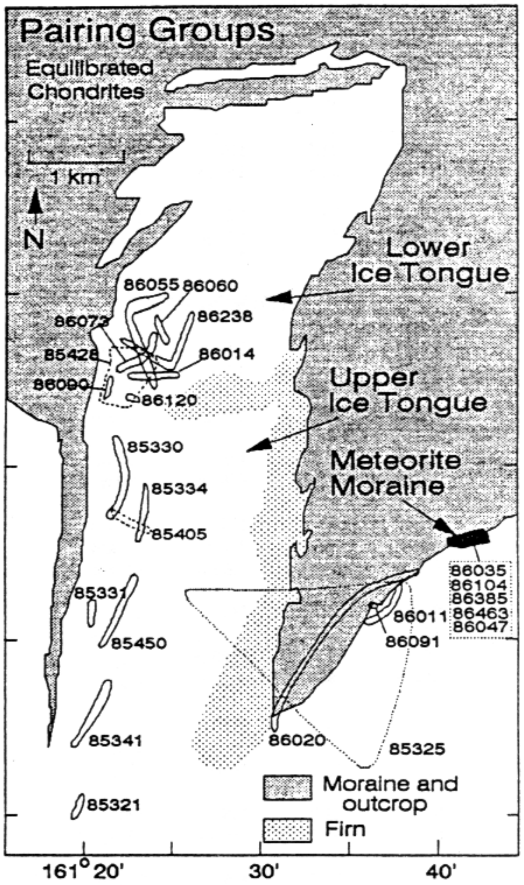

Fig. 9. Sketch map of the Lewis Cliff region showing the location of the pairing groups suggested in Table 4. The present pairing suggestions are based on natural TL, induced TL, find location, class, hand-specimen appearance and olivine/pyroxene compositions. On the upper part of the tongue, the pairing groups run north-south, while on the lower part of the tongue the find patterns are essentially random.

Tongue might suggest that the ice has a component of east-west movement. Such ice movement might also explain why meteorites are concentrated on the western edge of the Ice Tongue, especially on the Upper Ice Tongue.

Spatial Variations in the Natural TL of Meteorites in the Lewis Cliff Region

Early data indicated the possibility of systematic variations in the natural TL of meteorites with find location on the ice, not only between different ice fields [*Hasan and Sears,* 1988], but within the Lewis Cliff ice field [*Hasan et al*., 1989, 1991; *Sears et al*., 1989; *Benoit et al*., 1991c]. However, it was not clear whether some or all of these reflect pairing, incomplete sampling (the most northerly parts of the region of the field were not visited until 1987), or other effects (e.g. smaller samples appear to have been transported by wind). However, all parts of the ice field have now been visited, and the samples fully classified and masses published, so a complete evaluation of spatial variation in natural TL at the Lewis Cliff ice field is possible.

Figure 10 is a map of the Ice Tongue with the natural TL values coded. The intervals of coding have been chosen with the results of several earlier studies in mind, notably the plot of natural TL against ^{26}Al [*Hasan et al*., 1987]. Values of <5 krad are thought to be meteorites with small perihelia orbits (<0.85 A.U., see below); values of 5-30 krad are thought to be indicative of great terrestrial age (say, 400+-150 ka, based on 4 terrestrial ages calculated by *Nishiizumi* [1984]); similarly, values 30-80 krad are thought to be indicative of more "normal" terrestrial ages, 150+-50 ka based on six of Nishiizumi's terrestrial ages. The tail to higher natural TL values seems to run from 80 to 100 krad, and the occasional value >100 krad is truly worthy of note. We suggest that such high values, greater than observed for all but a few observed falls, are indicative of high dose rates associated with especially large falls. Among the few observed falls with such high values is Jilin, which is not only large but has experienced a multi-stage irradiation history.

Samples with natural TL <5 krad are present at all sites, but are best represented on the Lower Tongue. This is consistent

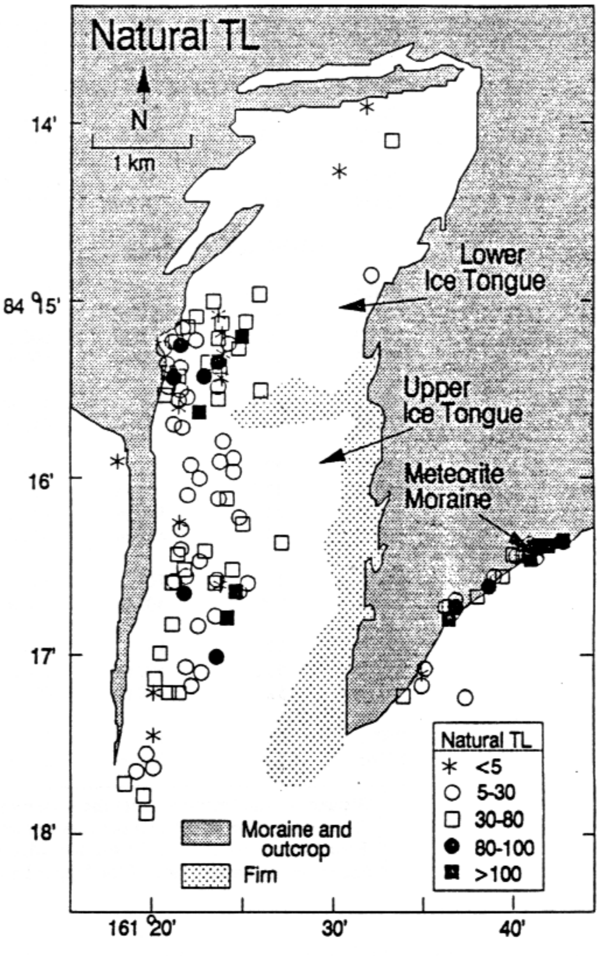

Fig. 10. Sketch map of the Lewis Cliff region showing the location of samples measured in the present study, coded according to natural TL value. Samples with natural TL <5 krad are thought to have been on small perihelion orbits, while samples with natural TL >80 krad appear to have suffered an unusual radiation history. Between 5 and 80 krad, natural TL levels are determined predominantly by terrestrial age, the study of *Hasan et al.* [1987] suggesting that samples with 5-30 krad have terrestrial ages 400+-200 ka while samples with natural TL 30-80 krad have ages 150+-100 ka.

with considerable pairing among these samples. Aside from this there is no particular geographical distribution for <5 krad samples. Samples with extremely high natural TL (say, >80 krad) are rather rare on the Lower and Upper parts of the ice tongue, but are fairly common at the northern end of Meteorite Moraine. In fact, most of the high TL samples at the northern Meteorite Moraine are probably paired (Figure 9). There is some indication that, except for the <5 krad samples, the distribution of samples on the ice is related to natural TL. Samples closest to the Lewis Cliff (i.e., on the westward edge of the ice tongue) tend to have lower natural TL values (5-30 krad) than samples further away from the hills. There is also a trend to lower natural values as one proceeds west along the narrow field of Meteorite Moraine samples, with the very high TL pairing group at the northeastern edge.

To better evaluate these possible trends in the natural TL data, and evaluate the role of pairing in producing these trends, we prepared two dimensional plots on which we could indicate meteorite classification. Figure 11 shows the north-south trend at the main tongue and includes a moving 5 point average line. The step in the ice is also indicated, but it should be stressed that because of the irregular shape of the step its placing here is only an approximate guide. Samples on the Upper Ice Tongue show a wide spread at lower latitudes which decreases and goes to lower values as the step is approached. The Upper Tongue differs from the Lower Tongue in the high proportion of samples with natural TL values of 5-10 krad. While some of these 5-10 krad samples are H6 and H5 chondrites which are thought to be paired, other unpaired H6, H5, L6 and LL6 samples also fall in this natural TL range. The abundance of samples with natural TL in the 5-10 krad range seems therefore to be a characteristic feature of this part of the ice field. North of the step, in the Lower Ice Tongue, samples show a much more restricted range of natural TL, which again cannot be attributed solely to pairing although a large proportion of paired meteorites are present. L3, L4, L6, H4, and H5 chondrites are all present and all have high natural TL levels. Natural TL values of 30-80 krad seem to be a feature of the Lower Ice Tongue.

Figure 12 shows the east-west trend for the meteorites on the upper and lower portions of the ice tongue and Figure 13 shows the trend at Meteorite Moraine. On the Lower Ice Tongue, there is a strong tendency for meteorites with low natural TL (say, <20 krad) to be found near the western edge of the field, while those in the central/eastern part of the tongue have fairly uniform high value of natural TL of approximately 50-80 krad. This trend is much more poorly developed, or absent, among meteorites in the Upper Tongue. For these data, it seems safe to conclude that there are significant differences between the meteorite populations at the upper and lower portions of the

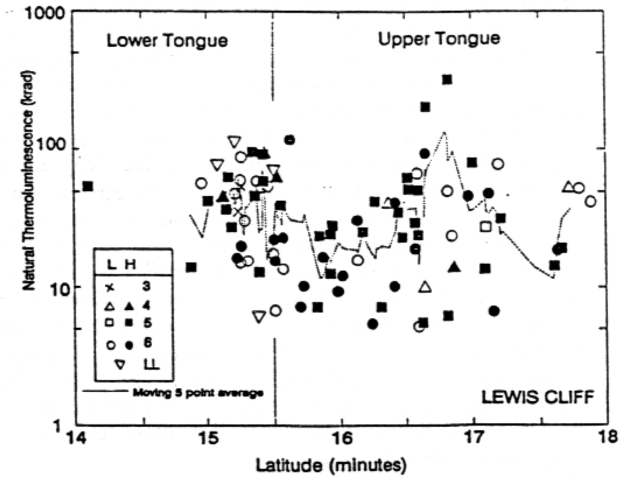

Fig. 11. Natural TL as a function of latitude on the main ice tongue, coded according to class. The step in the tongue is indicated by a vertical line, but because of the irregular shape of the step (Figure 2) it is highly approximate. Samples below the step (Lower Tongue) have higher natural TL than samples on the Upper Tongue, while meteorites on the Upper Tongue show a wide range of natural TL including many values in the range 5-30 krad indicative of large terrestrial ages. These trends cannot be attributed entirely to the presence of multiple fragments of a large unusual meteorite because several classes are involved. The data reflect real differences between the nature of the sites and meteorite concentration mechanisms.

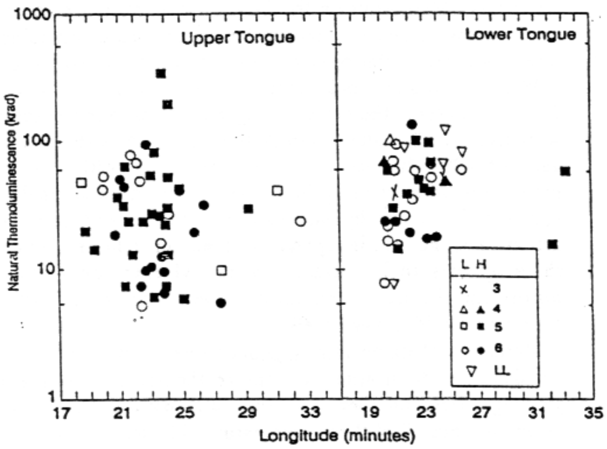

Fig. 12. Natural TL as a function of longitude at the Lewis Cliff Ice Tongue.

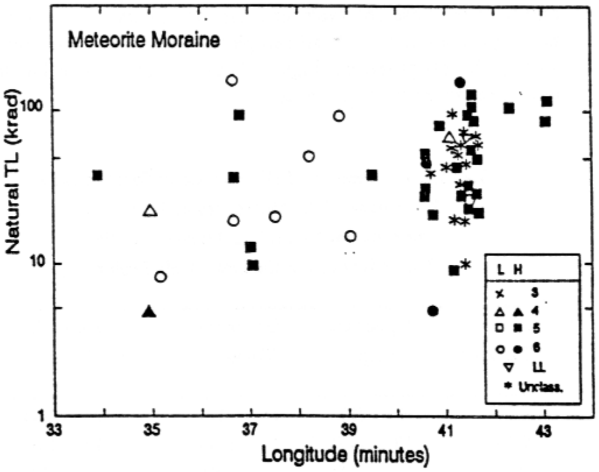

Fig. 13. Natural TL as a function of longitude at the Meteorite Moraine. The northeastern end of the field includes a great many paired samples with unusually high natural TL, while the southwest end has samples with a wide range of natural TL but generally lower than the northeastern end (<80 krad). The high natural TL and abundant pairing indicate that the major H5 fall at the northeast part of the Meteorite Moraine is a very young fall.

ice tongue. Meteorites on the Lower Ice Tongue are generally much younger, and the natural TL values are comparable to those with terrestrial ages of 150+-50 ka in the *Hasan et al.* [1987] study and with older meteorites being closer to the Lewis Cliff. In contrast, the Upper Tongue contains many meteorites with natural TL values comparable to those with terrestrial ages of 400+-200 ka in the earlier study, with the older meteorites closer the step in the ice. These differences do not appear to be caused by movement of small meteorites by wind action since they are independent of meteorite mass. Similarly, there appears to be oxygen isotope evidence for a complex history for the ice at this location, involving more than one source region [*Grootes*, 1990].

Meteorite Moraine also appears to be showing natural TL trends related to location, with the northeastern end of the field yielding a large number of samples with natural TL >80 krad. Many, but not all of these high natural TL samples are paired. The southwestern portion of the moraine yields samples with a wide range of natural TL, but generally in the 5-50 krad range. An east-west trend in natural TL along the gulley would also suggest a westward movement for the ice, with the older meteorites at the western end of the field. The existence of considerable pairing at the eastern end, as well as the high natural TL values of these samples, is consistent with young terrestrial ages, as weathering destroys the smaller fragments. The natural TL trends suggest that in addition to the northerly flow of the ice in the region of the Lewis Cliff Ice Tongue, there is a significant westerly component. This might also be the explanation for the concentration of meteorites on the western edge of the tongue, which is especially true of the Upper part of the Tongue and which cannot be accounted for by subglacial topography.

We have summarized some of our data in Table 5 particularly noteworthy is the fraction of samples in the 5-30 krad range which is much higher at the Upper Ice Tongue (53%) than the Lower Ice Tongue (33%) and Meteorite Moraine (32%), the last two being very similar. We are grateful to W. A. Cassidy for pointing out these data in his review. The fraction of meteorites in the <5 krad and >80 krad is not significantly different at the three sites, especially bearing in mind small numbers in these intervals and the possibility of overlooking pairing among the <5 krad samples at the Lower Ice Tongue. Taking the proposed pairings in Table 4 into account has little influence on these conclusions.

TABLE 5. Summary of Distribution of Samples (as a Percentage of the Meteorites at That Site) Over Several Natural TL Intervals for the Major Regions of the Lewis Cliff Region

Natural TL, krad	Upper Ice Tongue		Lower Ice Tongue		Meteorite Moraine*	
<5	8	(8)	18	(17)	9	(12)
5-30	53	(47)	33	(34)	32	(23)
30-80	30	(37)	35	(29)	42	(50)
>80	10	(12)	15	(20)	16	(14)

Values in parentheses have been corrected for the pairings proposed in Table 4.

*Statistics for samples found at South Lewis Cliff and Upper Walcott Neve are included in those of Meteorite Moraine.

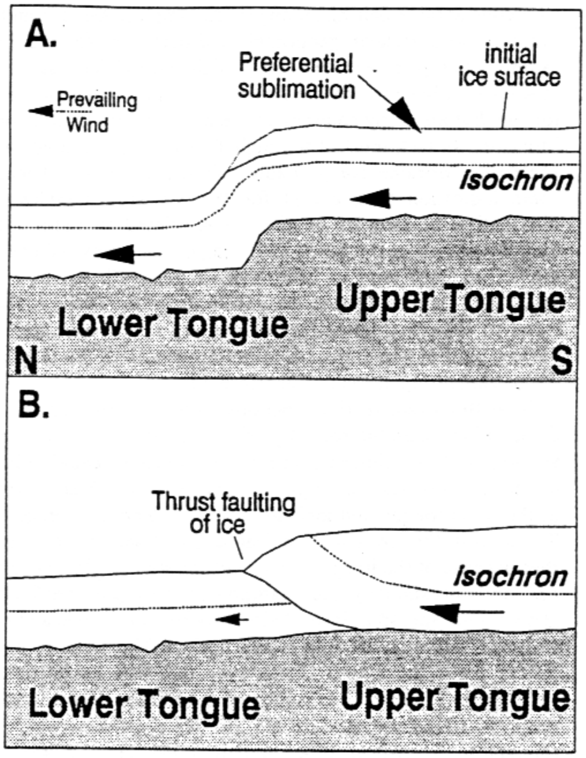

Fig. 14. Two mechanisms of ice movement that might account for the thermoluminescence data for meteorites at the Lewis Cliff ice field. See the text for a detailed discussion.

The present data also indicate that the Lower portion of the Tongue may be unrelated to the Upper Tongue. There are at least two processes that might create natural TL differences between meteorites in the Upper and Lower Ice Tongue. One possibility (Figure 14*a*) is that the ice is crossing a cliff and, because of its slightly greater elevation and exposure, the Upper Tongue loses surface ice by sublimation and ablation at a greater rate than the Lower Tongue. Another possibility (Figure 14*b*) is that the two parts of the Ice Tongue are physically decoupled by faulting in a manner analogous to thin-skinned tectonics. The faulting forces older ice horizons up and over the relatively slow-moving ice of the Lower Tongue. It is possible that Meteorite Moraine represents the eastern equivalent of the Lower Ice Tongue. The ice tectonic model in Figure 14*b* would enable a microscale equivalent of the *Whillans and Cassidy* [1983] mechanism for meteorite concentration to be established, and this would explain the apparent decrease in terrestrial age approaching the ice step on the Upper Ice Tongue (Figure 12), with older ice horizons being found nearest the step.

In either model, it would be expected that the meteorites of the Upper Ice Tongue would be similar to those of the South Lewis Cliff, though the simple ice tectonic model would also suggest that the meteorites in the southern portion of the Upper Tongue should be higher in terrestrial age than those of the northern portion. There are insufficient samples from the South Lewis Cliff region to allow adequate comparison, but the natural TL data hint that they are more similar to the Upper Tongue than to the Lower Tongue, having lower natural TL and thus, in general, greater terrestrial ages. The low natural

TL "tail" observed in the Upper Tongue is poorly developed in the South Lewis Cliff. This which would suggest that the meteorites of the South Lewis Cliff are somewhat younger, in general, than the average value for the Upper Tongue, consistent with the ice tectonic model. The South Lewis Cliff samples are all fairly large (>75 g) so that it is unlikely that they are rock fragments blown off the Upper Ice Tongue. In fact, prevailing winds at the Lewis Cliff Ice Tongue are from south to north.

It should be stressed that the models in Figure 14 are gross simplifications and, again analogous to tectonics, the internal structure of the ice is certainly more complicated than the depicted "isochrons" would suggest. For example, dust bands under the Lower Tongue dip toward the south, as do similar dust bands in the Upper Tongue [*Cassidy*, 1990]. Natural TL data cannot distinguish between the two models presented here. Additional data, including field observations, detailed mapping of ice bands, and geophysical profiles are needed, but the TL data do seem to indicate that meteorite concentration mechanisms are more complicated than originally thought.

Terrestrial Age

Terrestrial ages for Antarctic meteorites from the Allan Hills range from 2000 to 1 Ma, while Yamato meteorites are <210 ka [*Nishiizumi et al.*, 1989]. There is also an indication of a trend in terrestrial age with location on the ice for the main Allan Hills field [*Harvey*, 1990]. Unfortunately, there appears to be only one terrestrial age determination for Lewis Cliff meteorites, a single radiocarbon estimate of >30ka for LEW85320 [*Jull et al.*, 1988]. *Fireman* [1990] has found that tephra in the ice at the Lower Ice Tongue has an age of 20 ka, making the Lewis Cliff Ice Tongue an extremely young ice field.

Early work on meteorite natural TL was prompted by the possibility of a new terrestrial age method, but it soon became apparent that while natural TL levels generally decrease with increasing terrestrial age, a proportion have unusually low levels due to other factors (below we argue that the main factor is orbit). *Nishiizumi et al.* [1989] point this out, but do not discuss the considerable amount of literature on the subject [*Sears et al.*, 1990*a*]. To remove individuals whose TL is low due to small perihelia, we can eliminate meteorites with natural TL levels <5 krad, stressing that this is just a first approximation. It should also be stressed, though, that a natural TL level of, say, >80 krad (at 250°C) cannot be reconciled with a large terrestrial age without invoking large radiation doses in the Antarctic. Thus, while there may be ambiguity over a small natural TL value, the interpretation of large values is open to less uncertainty.

On the basis of natural TL, we suspect that meteorites from the Lower Ice Tongue and, especially, the northeastern part of the Meteorite Moraine, generally have low terrestrial ages, say 150+-50 ka. They might be as young as the 20,000 years obtained for the tephra [*Fireman*, 1990]. Samples from the Upper Lewis Cliff have a wide range of terrestrial ages, including some very large values, say in the order of 500 ka.

Natural TL and Meteorite Orbits

Theoretical treatments show that perihelion distance has a strong influence on natural TL levels. *Benoit et al.* [1991*a*] found that perihelia <0.85 A.U. caused the equilibrium natural TL levels to drop from values of 50-80 krad, typical of meteorites in orbits with perihelia of 0.9-1.0, to values of <5 krad. There is also a correlation between natural TL and perihelion calculated from eye-witness observations by *Simonenko* [1975] which is consistent with the theoretical predictions. *Sears et al.* [1991*b*] also pointed out that the proportion of basaltic meteorites, and ordinary chondrites, with natural TL <0.5 krad is very similar to the proportion of observed falls and Prairie Network fireballs with perihelia <0.85 A.U. If orbit is the main cause of natural TL values <5 krad, then the fraction with low values among the present data, corrected for pairing, should be independent of find site. We find that the fraction of <5 krad samples is 15, 40, 13 and 25% for the Upper Ice Tongue, Lower Ice Tongue, Meteorite Moraine and South Lewis Cliff, respectively. These values seem to be very similar to those expected on the small perihelion orbits. The exceptions are the Lower Ice Tongue, where we have detected much pairing among <5 krad samples but have probably missed more, and the South Lewis Cliff where the statistics are poor due to the small number of samples. Table 6 lists meteorites with natural TL values below 5 krad and which we suspect have been on small perihelion orbits, or otherwise heated. These samples may have low ^{3}He/^{21}Ne due to diffusive loss, or metallographic evidence of heating if the heating was shock induced.

TABLE 6. Antarctic Meteorites With Natural TL Values <5 krad

Meteorite*	Class	Natural TL krad*	Loc+
LEW85327	H5	0.37+-0.05	UIT
LEW85450	H5	3.2+-0.1	UIT
LEW85457	L6	1.63+-0.03	LIT
LEW85459	H5	1.7+-0.1	UIT
LEW86025	L6	0.9+-0.1	LIT
LEW86041	H5	2.34+-0.08	LIT
LEW86060	H5	4+-0.1	LIT
LEW86089	H6	4.7+-0.3	MET
LEW86098	L4	2.9+-0.1	LIT
LEW86118	H5	3.6+-0.1	LIT
LEW86166	L6	2.3+-0.2	LIT
LEW86302	H5	1.7+-0.1	UIT
LEW86382	H6	3.8+-0.1	MET
LEW86418	H5	0.85+-0.07	LIT
LEW86522	H6	0.9+-0.2	UIT
LEW87043	H5	0.65+-0.04	SLC
LEW87048	H6	1.7+-0.3	SLC
LEW87143	L6	0.42+-0.03	SLC
LEW87169	L6	0.7+-0.1	SLC

* Uncertainties are for triplicate measurements of a single aliquant.

+ Find localities: LIT, Lower Ice Tongue; UIT, Upper Ice Tongue; MET, Meteorite Moraine; SCL, South Lewis Cliff.

CONCLUSIONS

Studies of the natural TL of meteorites collected at the Lewis Cliff Ice Tongue and the adjacent Meteorite Moraine have identified many pairings, as expected from statistics for observed falls and other studies of Antarctic meteorites. Two of these pairing groups are especially recent falls (LEW86011, LEW86035) and others have unusually low natural TL suggestive of a meteorite with small perihelion at the time of earth encounter (<0.85 AU; LEW86041, LEW86060, LEW85450). The orientation of pairings on the ice fields, and the levels of natural TL as a function of location on the ice, indicate that in addition to the northern movement of the ice there is a significant component of westerly movement. This western vector probably explains the concentration of meteorites along the western half of the tongue which cannot be explained in terms of sub-ice topography. The distribution of pairings on the ice, and the natural TL values, also indicate that the Lower Ice Tongue and Meteorite Moraine are much younger accumulation sites than the Upper Ice Tongue and that the ice movements and meteorite concentration mechanisms might well be different. Two possible scenarios are suggested. The present data enable the identification of 22 meteorites which have been reheated, most probably by small perihelion passage, and 12 meteorites that have high natural TL consistent with unusual radiation history.

Acknowledgments. We are grateful to W. Cassidy (University of Pittsburgh) for his interest, for frequent and very helpful discussions, and for his constructive review of this paper; to Steve McKeever (Oklahoma State University), Brian Mason (Smithsonian Institution), Ludolf Schultz (Max Planck Institut für Chemie), Ed Scott (University Hawaii), and Steve Sutton (Brookhaven National Lab) for discussions; and to Robert Walker (Washington University) and Lou Rancitelli (Batelle, Columbus, Ohio) for encouraging our interest in these measurements. Brian Fessler (Lunar and Planetary Institute) and John Schutt (University of Pittsburgh) are also thanked for providing maps and related information, and Jim Gooding, Robbie Score, Marilyn Lindstrom, Rene Martinez, Carol Schwarz, and Robbie Marlow (Johnson Space Center) are thanked for their cooperation in the very difficult task of sampling the meteorites for this project. The technical assistance of Ben Myers, Fouad Hasan, Don Hutchings, and Joyce Roth at the University of Arkansas is also appreciated. We also acknowledge the help and cooperation of the Meteorite Working Group of NASA/NSF. This work is funded by NASA (NAG 9-81) and the NSF (DPP 86-13998) in a cost-sharing arrangement.

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(Received June 10, 1991;
revised October 1, 1991;
accepted December 3, 1991.)