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Natural thermoluminescence of meteorites and paleoice movement at the Lewis Cliff blue ice field

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Approximately 6,000 meteorite fragments have been collected on the antarctic continent by U.S. teams (Schutt 1990). Virtually all finds have been on blue ice fields adjacent to mountain ranges (Score and Lindstrom 1990). This large collection, unbiased by regional sampling efficiencies, which strongly affect the nonantarctic collection, provides a unique opportunity to study both the meteorites themselves (Palme 1986) and the large-scale interactions of ice and mountains, interactions that have resulted in their concentration and exposure (Annexstad 1986). Our laboratory has been measuring the natural thermoluminescence levels of many of these meteorites as part of our effort to identify those that have undergone unusual thermal or radiation histories and to identify "pairings" (i.e., fragments that are actually part of a single meteorite). This article reports on our detailed analysis of the largely complete collection from the Lewis Cliff ice field and relates our data to possible paleoice movements at this site.

Natural thermoluminescence levels in meteorites are a function of the number of electrons in metastable traps in a crystal lattice, which, in turn, is determined by the mineralogy of the meteorite, the amount of ionizing radiation to which it has been exposed, and the effective temperature over the recent history of the meteorite (the last few million years in the case of the cold antarctic climate). Natural thermoluminescence levels are very high in space but decrease with time on Earth because of the higher temperatures and lower incidence of cosmic-ray exposure. The decay is a second-order process; the decrease is a factor of about 2.5 in 1 million years for storage temperatures close to 0°C (McKeever 1982; Hasan, Haq, and Sears 1987). Most meteorites have natural thermoluminescence levels of 30,000–100,000 rad, depending on their period on Earth. Samples with extremely long terrestrial histories may decay to levels less than 30,000 rad. Samples with natural thermoluminescence greater than 100,000 rad not only have fallen recently but also must have been exposed to unusually high radiation doses in space. Some meteorites with extremely low natural thermoluminescence levels (less than 5,000 rad) may have been reheated, either by close passage to the Sun or recent (within approximately 100,000 years) shock events in space (see McKeever and Sears 1980; Melcher 1981; Benoit, Sears, and McKeever 1991).

A very small number of samples that exhibit low natural thermoluminescence levels may be the result of sampling too close to the heat-altered surface of the meteorite produced during atmospheric passage, although every effort is made to avoid this during sampling.

To date, we have measured the natural thermoluminescence levels of more than 700 antarctic meteorites, including 302 from the Lewis Cliff site (84°16'S 161°25'E), collected during the 1985–1986, 1986–1987, and 1987–1988 field seasons. The data are summarized in Score and Lindstrom (1990) and Lindstrom (1990). The Lewis Cliff site is a 2.3-kilometer wide, 8-kilometer long, north-south tongue of ice, divided into an upper and lower tongue by a step approximately halfway along its length. Many meteorites were also collected from a gully to the east of the tongue called "Meteorite Moraine."*

Our data, in conjunction with petrographic descriptions and classifications (Score and Lindstrom 1990) and geographic data, indicate that the 302 samples we have measured represent a maximum of 259 distinct meteorites (i.e., our data show that 70 of the samples can be combined as 27 individual meteorites which fragmented after Earth impact, in addition to 232 samples which do not appear to be so "paired"). We stress that our pairing criteria are highly conservative and that there is almost certainly a large amount of unrecognized pairing in our data.

Figure 1 shows our data for the meteorites from the ice tongue as a north-south profile with data for "Meteorite Moraine" included for comparison. The meteorites from the upper tongue show a broad range of natural thermoluminescence but appear to converge on a low thermoluminescence value of approximately 20,000 rad in its northernmost portion. The lower tongue shows a fairly tight cluster at relatively high (approximately 60,000 rad) natural thermoluminescence levels, a finding that is similar to the data from "Meteorite Moraine." These trends are independent of pairing, as shown by the variety of meteorite types and classes. There are also some indications that meteorites on the west side of the lower tongue (nearest the cliff) have lower natural thermoluminescence levels than those to the east. This trend is, however, poorly developed and is not as apparent in the upper tongue data.

We interpret these data in terms of terrestrial age differences in the meteorites from the various portions of the tongue. Our

*"Meteorite Moraine" is not an official name.

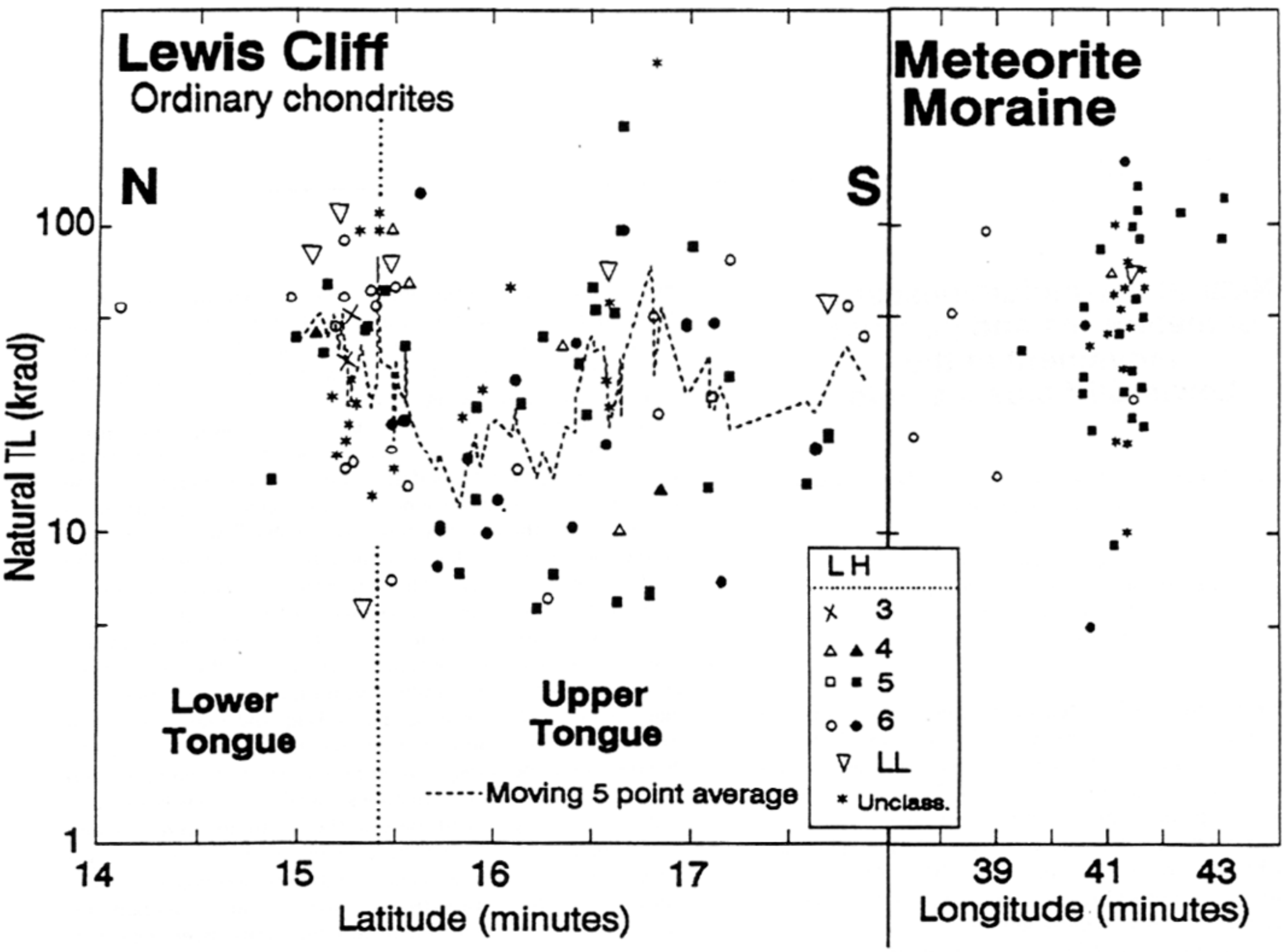

Figure 1. Geographic north-south profile showing location of meteorite finds and their natural thermoluminescence levels and coded according to their class and type. Dashed line between the upper and lower tongue represents the approximate location of the ice step dividing the two areas. An east-west profile of "Meteorite Moraine" is shown for comparison. (TL denotes thermoluminescence.)

data suggest that the meteorites from the upper tongue have, in general, fairly large terrestrial ages and that their ages get progressively older and more homogeneous as the step between the lower and upper tongue is approached. The meteorites from the lower tongue, however, have uniformly low terrestrial ages (i.e., having high natural thermoluminescence levels, 50,000–80,000 rad); their ages are similar to those of the meteorites from "Meteorite Moraine."

We suggest that the meteorites from the lower tongue and "Meteorite Moraine" are fairly young and were accumulated at about the same time. Fireman (1990) has determined a uranium-series age for tephra bands in the lower tongue as approximately 25,000 years. We also suggest that the upper and lower portions of the tongue are "decoupled" (figure 2) and that the upper tongue is composed of older ice overriding the younger lower tongue. This small-scale application of the Whillans-Cassidy model for meteorite accumulation (Whillans and Cassidy 1983) would also explain the trends observed in the upper tongue, where older ice horizons (and meteorites) are exposed as the boundary between the upper and lower tongues is approached. Further integration of field observations and additional laboratory work will be needed to develop these ideas.

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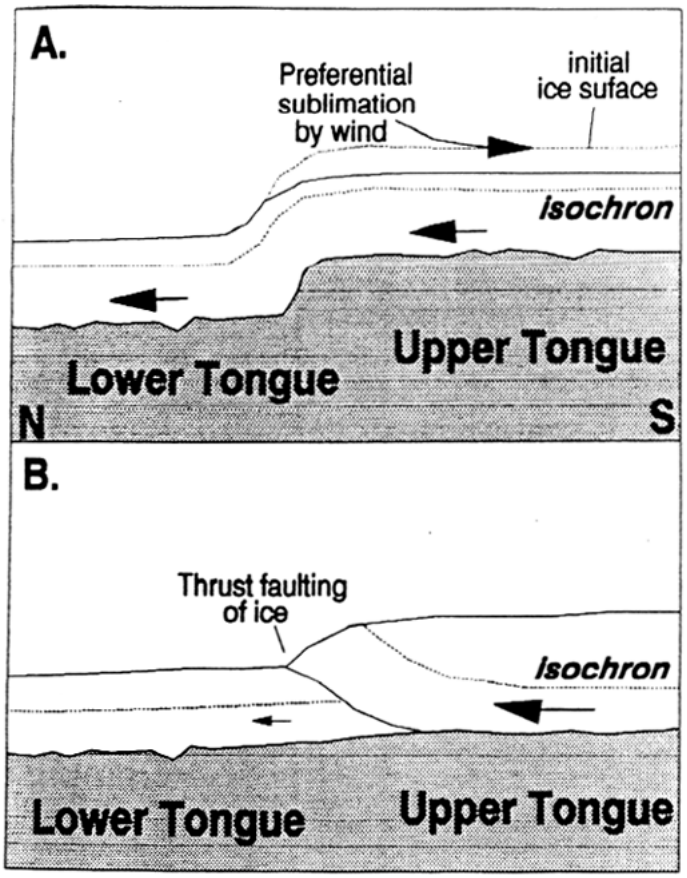

Figure 2. Hypothetical north-south cross-sections of the ice of the Lewis Cliff ice tongue. The thermoluminescence data suggest that either (*A*) older ice is being exposed by preferential ice sublimation on the upper tongue or (*B*) the upper tongues may be "decoupled" with the older upper tongue overriding the younger lower tongue.

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