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TERRESTRIAL AGE CLUSTERING OF METEORITE FINDS FROM SITES IN ANTARCTICA AND HOT DESERTS.

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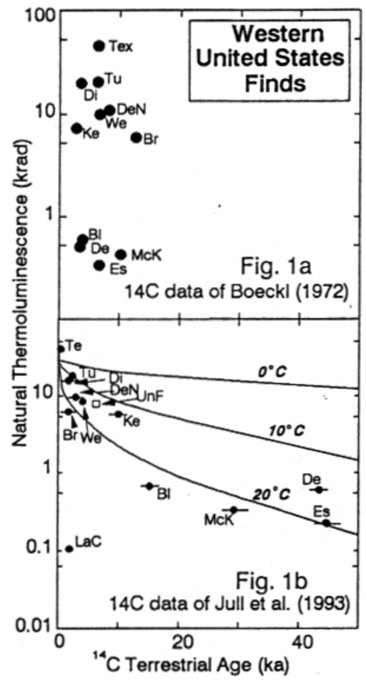
Many concentrations of meteorite finds have been found in hot and cold desert regions of the world. The sites include the deserts of northern Africa, the western United States, and Australia, in addition to the ice fields of Antarctica [1,2,3]. These large groups of meteorite finds allow detailed study of the nature of the meteorite flux in the pre-historical past [*e.g.*, 4,5]. In this paper we discuss terrestrial age data, derived from cosmogenic radionuclide abundances (such as ^{14}C and ^{36}Cl) and natural thermoluminescence data for meteorite finds from sites in both hot and cold desert sites. We find that at all the sites we have examined to date there is distinct clustering of either terrestrial ages or surface exposure ages of the meteorite finds; we suggest that meteorite concentration in hot and cold deserts is generally episodic, reflecting changes in regional climate or changes in local conditions such as directions of ice or stream flow over time.

The natural thermoluminescence (TL) level of a meteorite find is determined by radiation dose, temperature, and time. At a given temperature, the equilibrium natural TL level of a meteorite is directly proportional to the dose rate. Since the radiation dose rate for meteorite finds is inevitably far less than during irradiation in space, the natural TL level of a meteorite on Earth will decrease over time until a new, much lower equilibrium level is reached, this level being determined by terrestrial temperature and radiation dose. At equilibrium, higher temperatures result in lower natural TL levels. Under non-equilibrium conditions, the rate of TL decay is determined by temperature. The systematics of natural TL decay in ordinary chondrites have been detailed by theoretical calculations and laboratory heating experiments [6] and comparisons have been made with terrestrial age estimates obtained using cosmogenic radionuclide abundances [7,8]. However, the latter comparison makes the assumption that meteorite finds have one-stage terrestrial thermal histories which is not necessarily the case for Antarctic meteorites. In fact, TL results can be particularly interesting in cases where the meteorites have experienced discrete multi-stage terrestrial thermal histories.



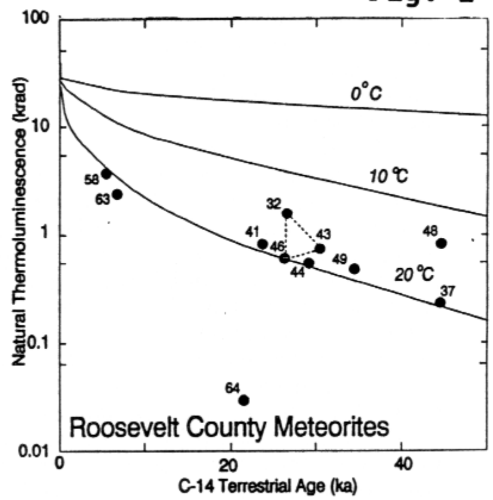
The TL methodology and data reduction techniques have been discussed elsewhere [*e.g.*, 8,9]. Depth effects, which are common problems in cosmogenic nuclide studies, are not a significant factor in governing natural TL levels except for the largest meteorites [10]. In the present study we limit our database to ordinary chondrites of type 3.7 and higher which are thought to have the same major TL phosphor. It is possible to compared TL data for achondrites with those of ordinary chondrites but corrections must be made for "anomalous fading" [9].

Roosevelt County/western United States. In Fig. 1 we compare our TL data with the ^{14}C-derived terrestrial ages for meteorite finds from the western United States. We show in Fig. 1*a* the 1980 version of this plot, where ^{14}C terrestrial ages were obtained by Boeckl by β counting [11] and in Fig. 1*b* the current version where ^{14}C terrestrial ages are from Jull's AMS data [12]. Apparently between 1980 and 1990 TL data was providing more reliable information on meteorite terrestrial ages than ^{14}C data and there was a misplaced confidence in ^{14}C-derived terrestrial ages. Natural TL decay curves for various "storage temperatures" are also shown on Fig. 1*b*. In general, the meteorites plot close to the 20°C TL decay line. From data for finds from the western United States (Fig. 1*b*) it is apparent that most of these meteorites have fairly short terrestrial ages, with most having terrestrial ages <5 ka. There are few meteorites with terrestrial ages between about 5 and 30 ka, and even fewer with ages >30 ka. This distribution is very different from that of the Roosevelt County meteorite finds (Fig. 2, ^{14}C data from [13]) in which only a very few meteorites have terrestrial ages <5 ka and all other meteorites have terrestrial ages >20 ka. In both databases there are a few meteorites (Ladder Creek and RC-064) with TL levels far lower than that expected in consideration of their ^{14}C-derived terrestrial ages; these meteorites were probably reheated in space prior to Earth impact [14].

The difference in age distributions between these two collections almost certainly reflects differences in collection and recovery history. The Roosevelt County samples are from highly localized blow-outs which were systematically searched, while the western United States finds are chance discoveries over an ≈ 800 km region. However, it is interesting that in both databases there is a fairly distinct gap between about 10 - 20 ka in which few meteorites are found. Jull et al. [12] suggested that the Roosevelt County distribution was produced by the loss of meteorites in the intermediate age range during the blow-out events. This interpretation seems reasonable because of the small size of these meteorites (generally <100 grams). However, the western U.S. finds are generally >2 kg and occasionally >100 kg. The only meteorite which has an age in the 10-20 ka range is the L6 chondrite Bluff which is especially large (142 kg). One possible conclusion from this is that between about 10 to 20 ka ago conditions were unsuitable for meteorite accumulation/preservation over most of the western United States and that a regional variable, such as an unfavorable climate, was responsible for loss of most meteorites in the gap.

North Africa. A plot of ^{14}C-derived terrestrial ages [2] vs. natural TL data for a fairly small group of finds from Daraj, Libya looks similar to the equivalent plot for finds from the western United States (Fig. 1*b*), although the meteorites tend to plot along a TL decay curve for a storage temperature of 30°C instead of 20°C (see [8]). If we plot our TL data for meteorite finds from the Acfer, Hammadah al Hamra, Ilafegh, Reggane, and Tanezrouft sites along this curve (^{14}C data are not available for these meteorites) we find that there are four distinct groups (Fig. 3). Three of the groups appear to reflect the terrestrial age distribution, whereas the fourth probably consists of reheated meteorites, which most likely have had their TL drained in small perihelia orbits. North Africa has had a complex climate history over the last 15 ka, but it appears that the area was much wetter in the past and fluvial processes were especially active at about 10,000 and 5100 BP, at least in some portions of the current Sahara desert [15]. It thus appears that, as suggested by Jull *et al.* [2], meteorite accumulation/preservation in this region is episodic and controlled by climate variations.

Fig. 2



Antarctica. Meteorites in Antarctica can be in one of two thermal states, (1) buried in the ice or (2) exposed on the ice surface. When on the surface of the ice meteorites can have temperatures higher than the air as a result of solar heating [16]. Calculations indicate that the rates of TL decay at temperatures experienced while encased in the ice are insignificant compared to those at surface temperatures. Thus, the natural TL level of an Antarctic meteorite find is largely determined by the "surface exposure age" rather than the total terrestrial age.

We have calculated surface exposure ages for a group of meteorites for which terrestrial ages, largely determined from ^{36}Cl abundances [17] are available (Fig. 4). To make this calculation we assume an average surface exposure temperature of -15°C [16] and an initial TL level of 100 krad [18]. Ignoring the group of meteorites with apparently small terrestrial ages but very large surface exposure ages because these are "reheated meteorites" which are also observed in every other database (*i.e.*, Figs 1*b* and 2), there is a large range of exposure ages. Most meteorites spent ≤50% of their terrestrial histories exposed on the ice surface. There appears to be a hiatus in exposure ages between about 0.18 and 0.2 Ma, and a "ceiling" at about 0.25 Ma with even meteorites with terrestrial ages ≈ 1 Ma having surface exposure ages of ≈ 0.2 Ma. Either 0.2 Ma is the length of time required to move a meteorite across a blue ice field and back onto active ice or an event cleared the icefield of meteorites with surface exposure ages >0.25 Ma. One could also interpret the meteorites with small surface exposure ages and small terrestrial ages as locally derived, while those with greater surface exposure ages and terrestrial ages could represent meteorites derived from some distance away and transported to the field by the ice. In this case, our data agree with the suggestions of Huss [19] in that it appears that locally derived meteorites dominate the dataset.

The data shown in Fig. 4 are dominated by meteorites from the Allan Hills Main and Near Western fields. We have previously suggested on the basis of natural TL data that there are differences in surface exposure ages between fields and, in a few cases, in regions within fields. Among our observations, we have noted that there are apparent differences in surface exposure ages between the

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Elephant Moraine icefields and the Allan Hills Main icefield, with the Elephant Moraine meteorites generally have fairly small surface exposure ages [18]. We have also noted that there are differences between the Lower and Upper Ice Tongues at the Lewis Cliff site, with meteorites from the Lower Ice Tongue having apparently lower surface exposure ages than those with the Upper Ice Tongue [20]. The cosmogenic radionuclide database for Lewis Cliff meteorites is still very small, but two meteorites from the Lower Ice Tongue plot with the group with small terrestrial ages and small surface exposure ages whereas a single Upper Ice Tongue meteorite plots with the meteorites with high surface exposure age.

Conclusions. We have used natural TL data to determine terrestrial ages and, in the case of Antarctic meteorites, surface exposure ages. We find that there is evidence that meteorite accumulation/preservation has been episodic in the western United States and the Sahara desert. This presents difficulties in estimating meteorite flux from numbers of meteorites on accumulation surfaces (*e.g.*, [12]). We also find that Antarctic meteorite accumulation surfaces may also be episodic in activity and that some fields are more "stable" than others.

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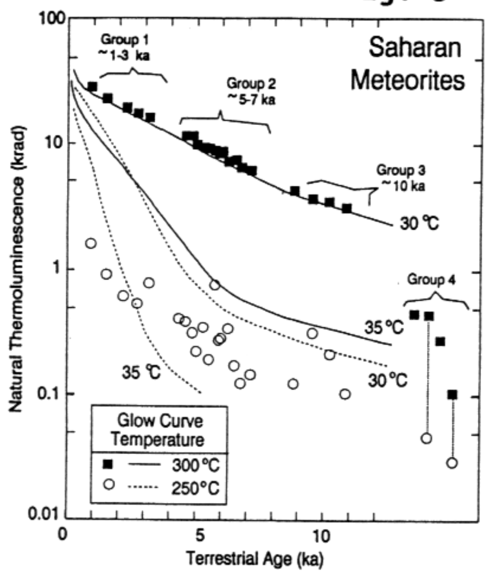
Fig. 3



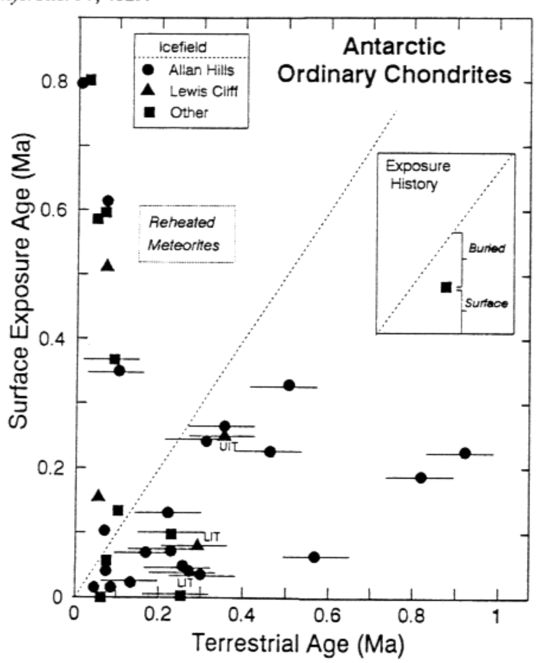


Fig. 4