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Comment on "Update on terrestrial ages of Antarctic meteorites" by K. Nishiizumi, D. Elmore and P.W. Kubik

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Nishiizumi et al. [1] have produced a large quantity of data for ^{36}Cl in Antarctic meteorites, using the AMS technique they described some time ago [2]. In discussing these data, and summarizing the implications for terrestrial age determinations and Antarctic ice movements, Nishiizumi et al. compare natural thermoluminescence data from our laboratory [3], and that of McKeever [4], with terrestrial ages determined by cosmogenic isotopes and point out that there is "no clear correlation". They therefore conclude that natural TL measurements do not yield a "unique" terrestrial age. We wish to point out numerous errors in Nishiizumi et al.'s treatment of the TL data and, most especially, that they have missed the main point made by the many authors who have thought about the natural TL of meteorites, including those whose data they reproduce.

Figure 1 is a reproduction of Nishiizumi et al.'s fig. 7 with additional information included. The curves are McKeever's theoretical predictions based on a detailed analysis of mechanistic and kinetic properties of meteorite TL. The numbers identify meteorites discussed below (these are decoded in the figure caption).

First we discuss the meteorites with natural TL peak height ratio less than 0.8; the "peak height ratio" (LT/HT) refers to the height of the low-temperature peak normalized to the height of the high-temperature peak, this normalization removes the effects of sample heterogeneity, shock, metamorphism and brecciation. It has been known for many years that a few meteorites enter the atmosphere with extremely low levels of natural TL. Melcher [5] and McKeever and Sears [6] studied the effect at some length and concluded that these meteorites came to earth on orbits with relatively small perihelia. Simonenko [7] calculated orbits for 45 meteorites. Most of the perihelia she determined clustered tightly around 0.95 AU, but six had perihelia less than 0.7 AU. A difference in perihelion of 0.7 and 0.95 AU corresponds to a difference in orbital temperature which, in turn, results in a 50–100-fold difference in natural TL. This has been demonstrated by theoretical studies

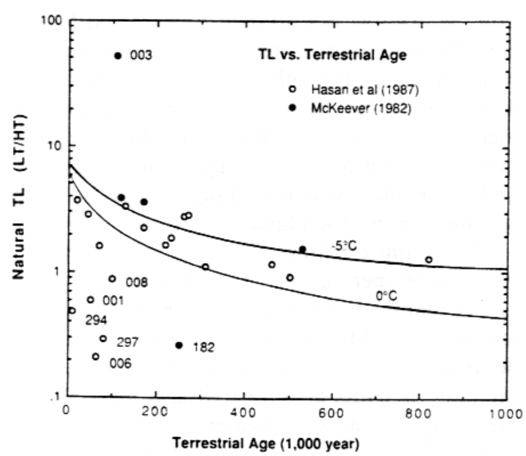

Fig. 1. Plot of natural thermoluminescence (expressed as the ratio of the low-temperature peak to the high-temperature peak) against terrestrial age, calculated, primarily, from Cl-36 measurements. The plot is taken from Nishiizumi et al. [1], but McKeever's [4] theoretical curves for two storage temperatures have been added and labels have been attached to several data points that are discussed in the text. These are as follows: *294*, Allan Hills A77294; *297*, Allan Hills A77297; *006*, Meteorite Hills A78006; *008*, Allan Hills A76008; *182*, Allan Hills A77182; *003*, Allan Hills A77003.

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[5,6] and is borne out by measurements of the natural TL for the meteorites in the Simonenko study [8]. Additionally, Hasan et al. [3] found that while 17 out of 21 meteorites they studied showed a correlation between natural TL and ^{26}Al, six plotted well below the trend line having peak height ratios < 0.8. A bias towards low natural TL may have been factored into the Hasan suite of samples because the samples were chosen by L. Rancitelli to represent a broad range of ^{26}Al contents. This automatically meant that samples with high ^{26}Al were over-represented since they are relatively rare. Interestingly, the cluster of meteorites lying below the trend line not only has very low TL, but includes some of the samples with the highest ^{26}Al, suggesting that the heating event which lowered the TL also involved high radiation doses.

Allan Hills A76008 has a natural TL consistent with the ^{26}Al data, but inconsistent with ^{36}Cl and therefore with the terrestrial age calculated by Nishiizumi et al. An obvious conclusion is that the systematics of build-up and decay for natural TL are more similar to those of ^{26}Al (half-life 750,000 years) than to ^{36}Cl (half-life 300,000 years). Interpretation of the cosmogenic isotope data for Allan Hills A76008 is not straight-forward, Nishiizumi et al. favoring a small terrestrial age and two-stage irradiation [2] while others have argued for a long terrestrial age [9]. In the present instance the argument is mute, clearly the TL (like the isotopes) is providing information on only a part of the story and a detailed understanding of this meteorite requires a multidisciplinary approach.

Nishiizumi et al. are correct in stating that TL decay is temperature-dependent, but incorrect in saying that we have little idea of plausible storage temperatures. McKeever's curve for the predicted decay at $-5°C$ comes close to explaining much of the data in terms of terrestrial age, including the "levelling-off" at ages greater than 300,000 years that Nishiizumi et al. found strange. To a good approximation, as frequently discussed in the literature, natural TL decay in meteorites follows second-order kinetics [4,11]. Nishiizumi et al. do not explain the $\pm 70,000$ year "typical uncertainty" quoted with their terrestrial age data, we are left to assume it is the one sigma value, nor do they factor this uncertainty into their discussions of Fig. 1. In fact, with the uncertainties in the terrestrial age data in mind, the temperature range 0 to $-5°C$ easily encompasses 15 out of 16 meteorites whose TL data we think reflect terrestrial age (Allan Hills A77003 is discussed below). Even if the terrestrial age data are taken at face value, then the data for the same 15 out of 16 meteorites are encompassed by a temperature range of 0 to $-10°C$. Since there seems to be a 1 million year cut-off in terrestrial ages [1], McKeever's curves suggest that peak height ratios less than 0.6 indicate meteorites which have had their natural TL lowered by heating, such as by close solar passage. Hasan et al. suggested a value of 0.8 could be used as the cut-off, based on their natural TL vs. ^{26}Al plot. Nishiizumi et al. seem to think that environmental temperatures much in excess of $0°C$ may have produced the low natural TL values, but the Allan Hills A77294 data would require terrestrial storage conditions similar to those of the US Prairie States for its $10,000 \pm 1000$ year terrestrial age; McKeever finds that his theoretical curve for 17–20°C accounts for the relationship between natural TL and ^{14}C terrestrial age for meteorites found in the Prairie States [4,10]. Of course, no reasonable storage temperature would account for the low natural TL shown by Malakal [11], Limerick and Gambat [4], and several other observed falls [6].

We also criticize Nishiizumi et al. for their uncritical use of the TL data. First, we have stressed (as did McKeever) that the peak height ratio parameter is only applicable to ordinary chondrites [4,6,12,13]. For this reason, we now prefer to publish natural TL data as calculated "equivalent doses" (see Hasan et al. [12] for a discussion). McKeever realized that Allan Hills A77003 was anomalous when he published his paper, and subsequently the meteorite has been reclassified as a CO chondrite [14], a class with distinct TL properties [15]. The meteorite therefore does not belong on the plot. Second, the peak height ratio uses two peaks with different spectral response [16]. McKeever's apparatus used no filters to screen off black-body radiation at high temperature during the experiment, while Hasan et al. [3] use Corning 7–59 and 4–69 filters [3,16,17]. In the present instance, where the range is so large, this effect makes little difference, and the effect is automatically removed with our current methods of data reduction, but lack of attention to potential systematic differences between laboratories is another problem with the Nishiizumi et al. treatment of the TL data.

Finally, probably our major objection to Nishiizumi et al.'s discussion of natural TL data and terrestrial age is a point that underlies much that has been said above. In oversimplifying, to the extent of ignoring major aspects of previous work, Nishiizumi et al. seriously misrepresent previous workers in the field. Melcher [11], McKeever [4], Sutton and Walker [18], McKeever and Sears [6], and Hasan et al. [3] were all well aware of the spread in TL of meteorites whose falls were observed and never claimed a "unique" terrestrial age could be determined by such naive treatments of the data as Nishiizumi et al. present. McKeever states that all his values are upper limits, the other authors tried to separate the reheated meteorites from those for which the simplest history appeared to be the case. Natural TL data are no less complicated than isotopic data, where we may have solar, planetary, cosmogenic and "anomalous" components among the noble gases, and where inconsistencies between cosmogenic isotopes may result from complex irradiation histories, poorly understood shielding effects, partial degassing, etc.

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