

NATURAL THERMOLUMINESCENCE PROFILES IN METEORITES: COSMOGENIC AND TERRESTRIAL PROFILES IN FALLS AND FINDS. P.H. Benoit¹, Y. Chen^{1,2}, and D.W.G. Sears¹. ¹Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701, USA. ²Institute of Geological New Technology, Chinese Academy of Sciences, Wushan, Guangzhou 510640, PRC.

The recent history of meteoroid bodies in space has been explored through their long-term radiation exposure as determined by cosmic-ray tracks or abundances of cosmogenic nuclides. Natural thermoluminescence (TL) levels of meteorites and lunar samples also reflect radiation exposure, although unlike cosmogenic noble gases natural TL cannot be used to determine exposure times for most meteorites due to the relatively rapid attainment of equilibrium. Unlike cosmogenic nuclides, however, TL is sensitive to recent thermal history; hence, natural TL levels are generally controlled by solar heating which, in turn, is determined by orbital history. In this paper we present new data on natural TL profiles of a number of meteorite falls and finds. We find that, as expected from our previous lunar core data, cosmogenic natural TL profiles in meteorite falls are generally very shallow. Much larger profiles, however, can be produced in meteorite finds, especially those with large terrestrial ages, as a result of terrestrial thermal profiles. These data indicate that (a) cosmogenic TL profiles are generally not significant compared to thermal effects in typical meteoroid bodies and (b) the terrestrial history of larger meteorite finds can be studied through terrestrial TL profiles.

Introduction. We have previously reported natural TL results for lunar cores [1] and discussed the implications of these data for meteoroid bodies irradiated in space [2]. In the present paper we discuss some recently acquired data on several modern falls which generally support the previous work. In addition, however, we extend the theory of TL decay to discuss the effect of temperature gradients in large meteorite finds.

Cosmogenic TL Profiles. The natural TL profiles observed for lunar cores (up to 300 cm below the surface) are fairly flat, compared to the more steep profile calculated from only the primary and secondary proton flux [3]. The discrepancy probably reflects the fact that TL is produced by a variety of energetic events, including cosmogenic nuclear reactions, *i.e.*, as a result of interaction of secondary neutrons with the target material. If we use the lunar core profile instead of the calculated proton-induced profile and correct for 4π irradiation (*e.g.*, thick target accelerator experiments [4]) we find that the expected TL profile in typical meteoroid sized bodies is also very modest. In fact, for a fairly large meteoroid-sized body (100 cm radius) of H chondrite composition our calculations indicate a total variation in TL levels of no more than 25% from surface to center.

Previous work on Lost City and Ucera (approximately 50 cm and 6 cm terrestrial radii, respectively) shows a total variation in natural TL levels of about 22% and essentially 0%, respectively [5]. Compared to our calculated profiles, these data indicate that Ucera was no larger than 20 cm prior to atmospheric entry whereas Lost City was at least 100 cm in radius during irradiation in space. The larger size for Lost City is also supported by the asymmetrical shape of the TL profile, which decreases linearly from one side of the meteorite to the opposite side. These data are independent of atmospheric entry heating; we observe steep decreases in TL levels only within 0.3 cm of fusion crust and these decreases are quite distinct from the more gentle slopes observed in interior profiles.

We have also recently acquired data for samples from St. Severin and Jilin. We find that the TL profile for St. Severin is essentially flat and this TL profile suggests that St. Severin was no larger than about 20 to 25 cm during irradiation. In comparison, cosmogenic nuclide profiles [6] suggest a radius of about 30 cm for St. Severin.

Six samples of Jilin show a very large variation in natural TL (45% total variation). A large degree of variation in natural TL is expected from the large size of the terrestrial body but its magnitude is greater than that predicted in our current calculated profiles using the radius of about 85 cm derived from cosmogenic nuclide abundances [7]. We find, however, that the variation is accentuated by a single sample with a very high TL level; this sample is from the surface of the meteorite. The remainder of the samples, from various depths in the meteorite, show a total variation of only 25% with TL decreasing with depth as expected from the calculated profiles. This degree of variation is about that expected for a meteoroid body with a radius of about 100 cm during irradiation. The source of the very high TL in the surface sample is unknown, but could be related to solar flare irradiation effects.

Terrestrial Profiles. As has been noted elsewhere [*e.g.*, 1,2,8], aside from the fairly shallow cosmogenic profiles natural TL levels are largely governed by temperature, either temperature in space (in the case of modern falls) or on Earth (in the case of older finds). Due to the relatively rapid attainment of thermal equilibrium from solar heating compared to the typical orbital times of meteoroid bodies it is not expected that pre-terrestrial thermal profiles would be observed in most modern falls. In larger terrestrial finds, however, it is possible that temperature gradients are established, *i.e.*, that one face of the meteorite may be consistently warmer due to solar heating than other faces which are protected by soil, ice, etc. If such

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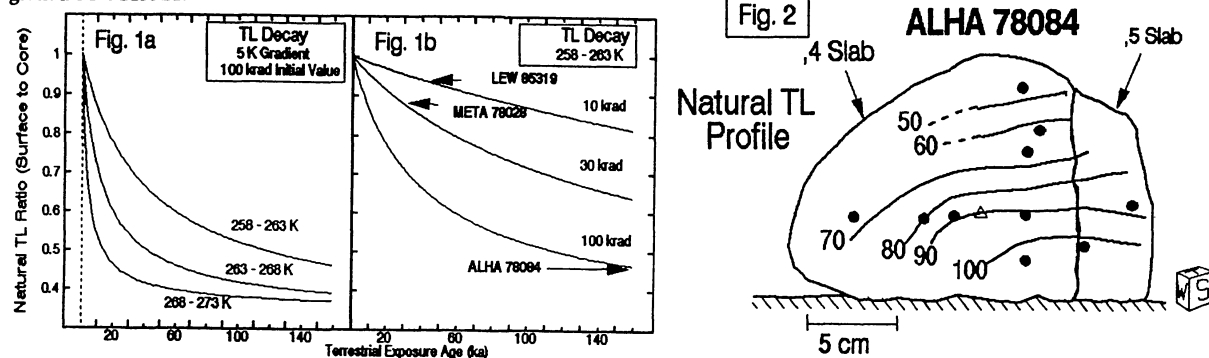
temperature gradients are maintained over extended periods of time the rate of TL decay will be different for different portions of the meteorite due to this thermal gradient. In an example calculation, we assume a five °C difference between two samples of the same meteorite which began with the exact same initial TL level. As expected, the difference in TL between the two samples increases as a function of time (Fig. 1). Two variables determine the rate of TL decay and thus can modify this calculation, namely, the absolute temperatures (Fig. 1a) and the level of initial TL (Fig. 1b). For Antarctic meteorites (with relatively low TL decay rates due to the low absolute temperatures averaged over long periods of time) one can use the highest level of TL observed in a meteorite as an indicator of the initial TL level. It is more difficult to make assumptions about which absolute temperatures are appropriate (Fig. 1a) but Schultz [9] has observed a difference of about 5 - 10 °C between air temperatures and the relatively warm interior of a meteorite on the ice surface with typical interior temperatures being about -10 °C. Thus the 258 - 263 K curve in Fig. 1a is probably a fairly good model of the TL response of samples from the surface and the interior portions of an Antarctic meteorite find, although, as mentioned below, not all Antarctic meteorites have necessarily experienced significant thermal gradients over much of their terrestrial history.

We have measured TL profiles in three large Antarctic ordinary chondrite finds. In two of these meteorites, namely, META 78028 (L6, 20.7 kg) and LEW 85319 (H5, 11.5 kg) the TL profiles are essentially flat, indicating that (a) these meteorites were small bodies (< 20 - 25 cm radii) during irradiation in space, as discussed above and (b) there is no evidence for a long-term terrestrial thermal profile in these meteorites. The lack of a terrestrial thermal profile might be due to long-term homogenization of their terrestrial thermal history, by continuous "tumbling" by ice movement for instance. Perhaps more likely, however, is that their flat profiles reflect small terrestrial surface exposure ages. Meteorites completely surrounded by ice will not have any differential thermal profiles; hence their long-term TL profiles will be governed solely by pre-terrestrial cosmogenic effects. One can obtain an upper limit for terrestrial surface exposure age from Fig. 1b, with the assumptions mentioned above. We find that META 78028 and LEW 85319 could not have been exposed on the ice surface for more than 40 ka. In comparison, the ^{36}Cl -derived terrestrial age of these meteorites is 70 ± 40 and 70 ± 70 ka, respectively [10].

In contrast, ALHA 78084 (H4, 14.3 kg) has a very strong natural TL profile which is clearly related to its orientation on the ice, with the lowest TL levels being nearest to the upper, solar-heated face of the meteorite (Fig. 2). Using the same assumptions used above (Fig. 1b) we find that this it would require more than 140 ka to produce this profile. This meteorite has a ^{36}Cl -derived terrestrial age of 140 ± 70 ka [10]. If we assume that the temperature gradient across the meteorite was greater than the 5 °C used in Fig. 1 the TL-determined surface exposure age would be < 140 ka. However, it is apparent that, within the error limits and assumptions of both ^{36}Cl and TL, this meteorite has spent a significant fraction of its terrestrial history on the surface of the ice in the orientation in which it was found. This, in turn, suggests that the Allan Hills Mid-western icefield, the find locality of this meteorite, has been a stable "platform" over at least this period of time.

Summary. As expected from our previous work on lunar core samples, we find that cosmogenic TL profiles of meteorites tend to be fairly shallow. Meteoroid bodies with radii < 25 cm should have essentially flat TL profiles and TL measurements on samples from various small meteorite falls confirms this. We find, however, that very steep TL profiles can be produced in meteorite finds with long terrestrial ages due to thermal profiles caused by differential solar heating. In the case of Antarctic meteorites these profiles can be used as indicators of surface exposure ages up to about 160 ka under certain conditions.

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