**FUSION CRUST AND THE MEASUREMENT OF SURFACE AGES OF ANTARCTIC ORDINARY CHONDRITES**. Jannette M.C. Akridge, Paul H. Benoit, and Derek W.G. Sears. Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, Arkansas 72701, USA

**Miono *et al.* generated a reasonable agreement between terrestrial ages calculated using the thermoluminescence (TL) of fusion crust and those calculated from the abundance of cosmogenic nuclides[1]. In a previous paper it was shown that this relationship could be improved if the ages were calculated using an equation that accounted for the decay of natural TL as well as build up[2]. With these corrections Miono *et al.*'s data seem to suggest that the natural TL of the fusion crust would be useful in determining the terrestrial ages of meteorites between 40 and 200 ka. His data were also consistent with meteorite temperatures on the order of 0 $^0$C. The equivalent doses exhibited by a suite of Antarctic meteorites, studied in our laboratory, seem to suggest that the surface of the meteorites reached temperatures on the order of 10 - 15$^0$C. This temperature range limits the use of fusion crust to those meteorites with surface ages < 20 ka.**

## Introduction

Natural thermoluminescence (TL) reflects radiation exposure and storage temperature. Meteorites generally exhibit thermoluminescence acquired during their long exposure to galactic cosmic rays in space. During atmospheric passage, temperatures are high enough to completely drain the TL in the first mm of material under the fusion crust. We therefore refer to this surface layer as "fusion crust" although it does include some unmelted material just below the crust. When the meteorite lands on earth this drained layer will begin to build up natural TL once again due to radiation from cosmic rays and internal radionuclides. Cosmic ray annual dose is estimated[3] to be between 0.04 and 0.06 rad/yr on the earth's surface in Antarctica while the internal radionuclides contribute only about 0.01 rad/yr. Therefore the total annual dose received by the meteorite while it is on the surface is between 0.05 and 0.07 rad/yr. If the meteorite is buried deeply in the ice it is effectively shielded from most cosmic rays and thus only internal radioactivity contributes to the annual dose.

The build up and decay of natural TL can be modeled using the equation:

$$\frac{\mathrm{dn}}{\mathrm{dt}} = \frac{0.693}{R_{\frac{1}{2}}} r\left(N - n\right) - s\, n \exp\left(\frac{-E}{kT}\right)$$

where T = temperature during irradiation, r = annual dose rate, n = number of filled traps, N = number of available traps, s = a frequency factor, E = trap depth, $R_{1/2}$ = the dose required to fill half of the traps, and k = Boltzmann's constant. For ordinary chondrites the values of E, $R_{1/2}$ , s, r, and N are approximately constant[4]. Figure 1 shows the build up of natural TL using the above equation for T= 0 $^0$C, 10 $^0$C, and 15 $^0$C. It can be seen that small changes in temperature have drastic effects on natural TL, such that the meteorites will reach equilibrium at about 400 ka in the first case and 20 ka in the latter. Therefore the temperature of the fusion crust is of great importance in evaluating the use of TL as a chronometer.

## Methods

We acquired nine Antarctic equilibrated ordinary chondrites with fusion crust from the Johnson Space Center and the Smithsonian. Table 1 lists our samples, the lending institution, and the measured equivalent dose. The fusion crust of ALHA 77004, ALHA 81111, and ALHA 76008 was removed in approximately 0.5 mm cuts using a diamond blade saw. The remaining samples had their fusion crust chipped-off with a chisel. The chipped pieces were < 1 mm in diameter. The natural TL measurement and data reduction methods have been described in Benoit *et al*.[5]

## Results and Discussion

Figure 2 shows the natural TL profile of ALHA 76008. The natural TL has been drained for the first 1.2 mm from the surface, the natural TL of the interior of the meteorite being an order of magnitude or more higher than that of the outer layer. Similar results were noted for ALHA 77004 and ALHA 81111. These profiles have two important implications. First, although the TL < 1.2 mm below the surface is low, it is measurable. Second, it is apparent that if the sample of fusion crust was contaminated with material from the interior of the meteorite this would immediately be reflected in the data.

In figure 1 we compare the natural TL measured for our suite of samples with their terrestrial ages estimated from the $^{14}$C and $^{36}$Cl data in the compilation of Nishiizumi *et al*.[6] The equivalent dose reported for ALHA 76008 appears lower than what would be expected possibly due to the heat generated during sampling. The data seem to suggest that the fusion crust experienced temperatures on the order of 10 - 15$^0$C. These results are inconsistent with those of Miono *et. al.* which seemed to follow the 0$^0$C build up curve. The temperature estimation of 10 - 15 $^0$C seems high for Antarctic meteorites. Schultz[7] noted that the temperatures within the interior of the meteorite was generally around -10 $^0$C with a few instances of temperatures above 0 $^0$C. We suspect, however that these higher temperatures are possible immediately below the black fusion crust. Also it is not necessary for the meteorite to be sustained at these high temperatures. The TL exhibited by a meteorite is very sensitive to the highest temperatures reached at any given instance.

**Conclusions**

The equivalent doses collected by our lab are consistent with meteorite surface temperatures between 10 - 15 $^0$C. This comparatively high temperature range limits the use of fusion crust for dating purposes. It seems that fusion crust can only be used to date meteorites with surface ages < 20 ka. $^{14}$C dating can date meteorites in this age range to a greater degree of accuracy than natural TL, and therefore natural TL of fusion crust does not seem to be a useful way of calculating terrestrial age. However our data do suggest that most of the meteorites have spent at least 20,000 years on the ice surface.

**References**

1, S. Miono *et al*. (1995) *Proc. NIPR Symp. Antarctic. Meteorites*, **7**, 225-229.; S. Miono (1990) *Proc. NIPR Symp. Antarctic. Meteorites*, **3**, 240-243. 2, J. M. Cunningham *et. al* (1996) *LPS* ,**27**, 281-282. 3, J.R. Prescott and J.T. Hutton (1994) *Rad. Meas.*, **23**, 497-500. 4, S.W.S. McKeever (1980) *Mod. Geol.*, **7**, 105-114. 5, P.H. Benoit et al. (1992) J. Geophys. Res. **97**, 4629-4648. 6, Nishiizumi *et al.* (1989) *Earth Planet Sci Lett.*, **93**, 299-313. 7, L. Schultz (1990) *In : Workshop on Antarctic Meteorite Stranding Surfaces, LPI Technical Report* **90-03**, 56-59.

| Meteorite | Lending Institution | Equiv. Dose (krad) |
|---|---|---|
| ALHA 83070 | JSC | 0.04 ± 0.01 |
| ALHA 81111 | JSC | 0.49 ± 0.01 |
| ALHA 78114 | Smithsonian | 0.33 ± 0.04 |
| ALHA 78045 | Smithsonian | 0.43 ± 0.08 |
| ALHA 77261 | Smithsonian | 0.34 ± 0.15 |
| ALHA 77231 | JSC | 0.52 ± 0.02 |
| ALHA 77004 | Smithsonian | 0.30 ± 0.02 |
| ALHA 77002 | JSC | 0.50 ± 0.11 |
| ALHA 76008 | JSC | 0.11 ± 0.04 |

Table 1. Meteorites used in this study, lending institution, and equivalent doses for fusion crust measured in krads.

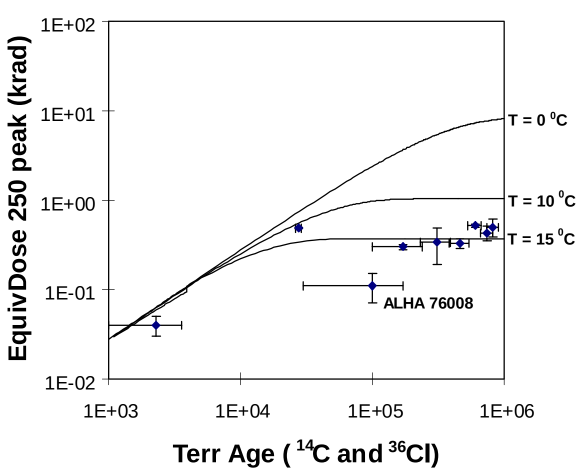


Figure 1. The build up of natural TL as a function of time for the fusion crust of Antarctic ordinary chondrites. The data points are of a suite of Antarctic meteorites for which terrestrial ages have been estimated from radiogenic isotopes.

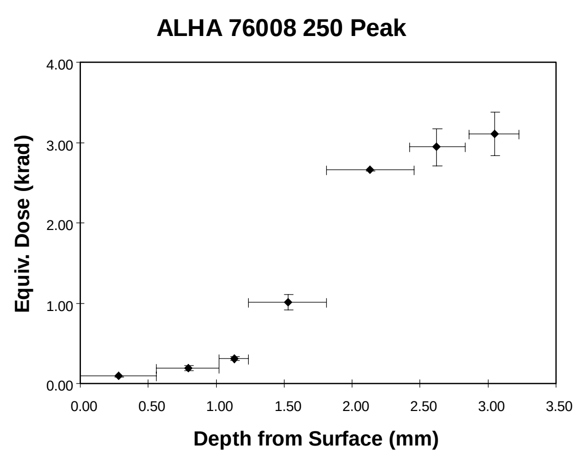


Figure 2. Measured equivalent dose as a function of depth in ALHA 76008.