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ESTIMATION OF THE TERRESTRIAL AGE OF ANTARCTIC ORDINARY CHONDRITES USING FUSION CRUST.

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The large number of meteorites found in the Antarctic permits the study of mechanisms that concentrate the meteorites and the possible changes in the meteorite population over the last million years. The terrestrial ages of individual meteorites are important data for these studies. Miono *et al.*[1] have shown that a correlation exists between terrestrial ages calculated using the natural thermoluminescence (TL) of the extreme outer layer of a meteorite (~1mm from the fusion crust) and those determined from the cosmogenic radionuclides ^{14}C and ^{36}Cl. Natural TL within the first mm of the fusion crust is completely drained during atmospheric passage[2] and reaccumulates while on the earth due to exposure to internal and external radiation. Miono *et al.*[1] found that the older meteorites did not seem to correlate as well with cosmogenic radionuclides derived terrestrial ages as the younger ones and he attributed this to an error in the measurement of terrestrial ages using ^{36}Cl. However, Miono *et al.*[1] assumed a linear build up of natural TL. If we account for the nonlinearity of natural TL build up due to thermal decay, there is a better correspondence between natural TL and ^{36}Cl derived ages in excess of ~100 ka. The natural TL of the fusion crust allows the estimation of terrestrial ages even for very small meteorites.

Introduction. The abundances of cosmogenic nuclides, particularly ^{14}C and ^{36}Cl , are commonly used to estimate terrestrial ages of meteorite finds.[3] However, individual cosmogenic radionuclides are limited in the time domain in which they can be used. For meteorites with terrestrial ages not exceeding about 40,000 years ^{14}C is highly accurate whereas ^{36}Cl is best suited for meteorites with ages greater than about 200,000 years. Thus, a large gap exists between 40 and 200 ka in which terrestrial ages of meteorites cannot be determined with any accuracy. Unfortunately a large number of Antarctic meteorites appear to have terrestrial ages in this gap.[3] Bulk natural thermoluminescence (TL) has been used to estimate terrestrial ages.[4] The decay of bulk natural TL is very sensitive to environmental temperatures. Although terrestrial age estimates for bulk natural TL are consistent with ^{14}C estimates for hot desert finds, they are consistently lower than ^{36}Cl terrestrial age estimates of Antarctic finds. This directly reflects the much lower rate of natural TL decay for meteorites buried in the ice, bulk natural TL giving an estimate of the duration of exposure on the relatively warm ice surface. The accuracy of the terrestrial age estimate from bulk natural TL is limited by the assumption of an initial level of natural TL, and about 15% of all meteorites cannot be dated because they were reheated prior to reaching Earth.. The cosmogenic radionuclides are also limited by the assumption of initial saturation levels of the nuclide in question.

Sears *et al.*[2] found that the temperatures experienced within the first mm of the fusion crust as the meteorite passed through the atmosphere was sufficiently high to completely drain the initial natural TL.[3] It should be possible to measure the build up of natural TL in this thermally drained layer, thus eliminating the need to assume initial natural TL values. Miono *et al.*[1] have shown a correlation between the natural TL of the fusion crust and terrestrial ages from cosmogenic nuclides, but noted an apparent discrepancy for ages in excess of about 100 ka. We have re-examined the Miono *et al.*[1] data, incorporating thermal decay as well as build up into the natural TL terrestrial age estimate. We find this improves the correlation between natural TL and cosmogenic nuclide derived terrestrial ages for meteorites with large terrestrial ages.

Results. Miono *et al.*[1] measured the natural TL within the first mm of the fusion crust of 10 Yamato meteorites, 7 Allan Hills meteorites, and 1 meteorite found in Meteorite Hills. The ^{14}C and ^{36}Cl data were taken from the compilation of Nishiizumi *et al.*[3]

Discussion. A major element in the estimation of a terrestrial age from fusion crust is the accuracy of sampling. The internal bulk natural TL is generally much higher than any terrestrial accumulated natural TL. Sears *et al.*[2] measured the natural TL of cross-sections of the Allende and Barwell meteorites. These measurements showed the drastic difference between the natural TL of the first mm of the fusion crust and that of the interior of the meteorite. As the distance from the fusion crust increases the amount of material completely drained begins to decrease. The maximum distance from the fusion crust that is completely drained depends upon the particular area measured. However, at a distance of 1mm from the fusion crust there is no appreciable difference in the drainage of natural TL in relation to the orientation of the area sampled. Any contamination of the fusion crusted sample with interior material should be readily apparent.

Miono *et al.*[1] assumed a linear build up of natural TL as a function of time. A more accurate and realistic approach would account for the nonlinearity of natural TL build up due to thermal decay. The meteorites receive radiation doses from cosmic rays and internal radionuclides. We assume there is no radiation contribution from the ice. The dose received due to cosmic rays[5] has been estimated to be between 0.4 and 0.6 mGy/yr while the dose received due to the internal radionuclides[5] is only about 0.1mGy/yr. For the purposes of this study the terrestrial age calculated at 0.5mGy/yr will represent a lower limit and the age calculated at 0.7 mGy/yr will represent an upper limit.

We calculate the rate of natural TL build up using the equation:

$$\frac{dn}{dt} = \frac{0.693}{R_{1/2}} r(N-n) - snexp(-E/kT)$$

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 = Boltzman's constant. The first half of the equation accounts for the filling of traps (*i.e.* the buildup of natural TL) and the second accounts for the emptying of traps (*i.e.* thermal decay). The values of E and s for various ordinary chondrites have been experimentally measured for various trap populations and are nearly constant for the ordinary chondrites.[6] For the ~250°C region of the glow curve, E = 1.45 eV and $s = 5.3 \times 10^{13} s^{-1}$. For ordinary chondrites the values of N and $R_{1/2}$ are 200 and 1500 Gy, respectively. The temperature of irradiation has been assumed to be 273 K. In figure 1 we show the build up of natural TL as a function of time for dose rates of 0.5mGy/yr and 0.7mGy/yr.

In figure 2 we compare natural TL derived terrestrial ages with those from ^{14}C and ^{36}Cl. In figure 2*a* we use the linear build up suggested by Miono *et al.*[1] and in figure 2*b* we show the natural TL terrestrial ages derived from our calculations including thermal decay (Fig. 1). In general there is a good correlation between the natural TL terrestrial age estimates and those from cosmogenic radionuclide abundances. Regardless of which method is used to reduce the natural TL data, the correlation is significant at the 99% level. Incorporating natural TL decay (Fig. 2*b*) results in meteorites with larger terrestrial ages plotting closer to the 1:1 line.

Conclusions. Miono *et al.*[1] found that there is a good relation between terrestrial ages of Antarctic meteorites from natural TL of the fusion crust and from cosmogenic radionuclides (^{14}C and ^{36}Cl). This relationship is improved for meteorites with terrestrial ages in excess of 100 ka if the effects of terrestrial thermal decay is taken into consideration.

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, D.W. Sears *et al.* (1975) *Mod Geol.* **5**, 155-164. 3, Nishiizumi *et al.* (1989) *Earth Planet Sci Lett.*, **93**, 299-313. 4, Benoit et al. (1993), *Meteoritics*; Benoit (1995) *Quat. Sci. Rev.* 5,. M.J. Aitken (1985) **Thermoluminescence Dating**. 359. 6, S.W.S. McKeever (1980) *Modern Geology* , 7, 105-114.

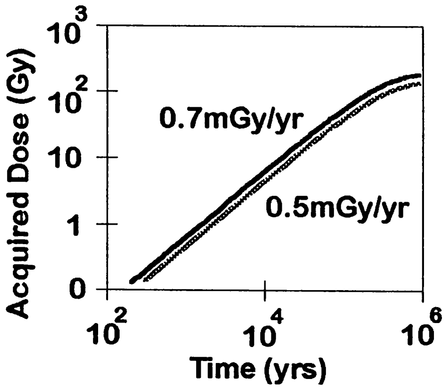

Figure 1. Build up of natural TL as a function of time for the fusion crust for meteorite finds in Antarctica.

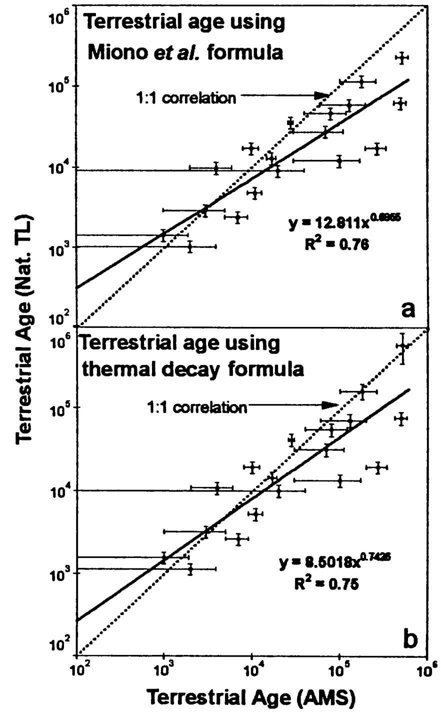

Figure 2. Terrestrial ages derived from natural TL of the fusion crust vs. terrestrial age estimates from cosmogenic radionuclide abundance's (^{14}C and ^{36}Cl) for Antarctic meteorites.