In most hot stars there is no convection zone near the atmosphere, so neither convective cells nor wave mechanisms would seem to work, and yet both coronae and microturbulence are observed. Radiative amplification of acoustic waves is a possible explanation[8] but again the magnetic structure of the star may be important.

The detailed computation of these dynamic and noisy atmospheres is orders of magnitude more time consuming than the usual simple plane-parallel static models. The possible influence of the chromosphere on the lower layers of the atmosphere, effects of sphericity in extended atmospheres, proper accounting for the thermodynamic disturbances exerted by waves[9] and relaxation of the local thermodynamic equilibrium condition can all add to the complication. The setting up of a collaborative computing project seems to be a timely move. □

1. Hunger, K. *et al. Astr. Astrophys.* **95**, 244 (1981).
2. Simon, K.P. *et al. Astr. Astrophys.* **98**, 211 (1981).
3. Winget, D.E. & Cabot, W. *Astrophys. J.* **242**, 1166 (1980).
4. Edmunds, M.G. *Astr. Astrophys.* **64**, 103 (1978).
5. Ulmschneider, P. & Bonn, H.U. *Astr. Astrophys.* **99**, 173 (1981).
6. Vaiana, G.S. *et al. Astrophys. J.* **245**, 163 (1981).
7. Stein, R.F. *Astrophys. J.* **246**, 966 (1981).
8. Martens, P.C.H. *Astr. Astrophys.* **75**, L7 (1979).
9. Cram, L.E. *Astrophys. J.* **247**, 239 (1981).

Terrestrial ages of meteorites

from Derek W.G. Sears

It has taken about 250 years of scanning the popular journals, of writing begging letters, of circulating popularized leaflets and of outright bribery to amass the collection of around 2,000 meteorites that were in the world's museums in 1969. In the last decade or so, while the attention of most of us was focused on the rocks being gathered on the Moon, almost 4,000 meteorites have been discovered in several regions of Antarctica.

The Antarctic discoveries have led to a rekindling of interest in determining how long the meteorites have been on Earth, their so-called terrestrial age. Prosaic reasons for determining terrestrial ages are often offered — for example, it may enable meteorites which are fragments of a single fall to be identified — but when so many meteorites are found over an area of a few thousand km^2 it seems natural to ask how long they have been accumulating.

Terrestrial age determination is made possible because nuclear reactions are induced in meteorites by cosmic rays. The nuclides produced by such reactions are usually radioactive. If one knows their abundance at the time of fall and their rate of radioactive decay, then it is a trivial matter to calculate the meteorite's terrestrial age from the present abundance of such nuclides. However, the abundance at the time of fall is difficult to determine, and consequently terrestrial age determinations are appreciably less accurate than those of the several other important ages in the life of a meteorite, such as their formation age or the duration of their exposure to cosmic radiation. Usually the abundance of a cosmic ray-produced nuclide is measured in a number of meteorites that have fallen recently, and their average value is assumed to apply to all the meteorites being dated. In fact, this quantity is affected by many factors, such as the duration of exposure to cosmic rays and the depth of the sample in the meteorite during this exposure, and varies considerably.

Another complication is that the terrestrial age must be within a factor of about 10 of the half life of the activity being used if it is to be determined. If too many half lives have passed since fall, then too little activity will remain to permit detection. If less than a half life has passed, then there will be too little decay to detect. In such cases only a lower limit or an upper limit, respectively, can be determined. Fortunately, the half lives available seem to cover the appropriate range so that with two activities one can frequently bracket the actual value. For example, Fireman *et al.*[1] observed that the Antarctic meteorites were frequently too newly fallen for ^{26}Al dating ($t_{1/2}$ = 0.72 Myr) and too old for ^{14}C dating ($t_{1/2}$ = 5,720 yr), and this has proved to be a general rule[2,3]. From a judicious combination of ^{36}Cl ($t_{1/2}$ = 0.3 Myr), ^{26}Al, ^{14}C and ^{53}Mn ($t_{1/2}$ = 3.7 Myr) data, Nishiizumi *et al.*[4] were recently able to assign terrestrial ages to nine Antarctic meteorites: three had ages of $<$ 0.2 Myr, one of 10^4 yr and the remainder of 0.13–0.69 Myr, with typical errors of 10–20 per cent.

The thermoluminescence (TL) technique is the latest to be applied to this purpose. The level of TL in a meteorite is dictated by competition between its build up due to exposure to ionizing radiation, and its decay due to thermal draining. In the low-level radiation environment of Earth, TL decays from its high in-space levels to a much lower intensity. Once again, a major uncertainty is the in-space level; freshly fallen meteorites show a wide range in their TL intensity.

In a recent paper[5] Melcher follows the work of Sears and Mills[6] and plots TL against terrestrial age for numerous meteorites with known dates of fall. He departs from the earlier authors in normalizing his data differently but the overall picture is unchanged. There is a hint that after about 250 yr some decay in the TL can be detected, but the 250 yr period with available data is clearly far too short for any really convincing trends to appear. How then is one to calibrate the TL decay in terms of terrestrial age? This has proved to be far more difficult than the optimistic efforts of Sears and Mills in 1974 supposed.

Unlike the decay rate of a radioactive isotope, the rate of TL decay is not a well determined, invariable quantity. Only recently has it become apparent that meteorite TL obeys second-order kinetics; that is, logarithm of the TL intensity does not decrease at constant rate, but at a rate proportioned to its intensity. The decay rate is also highly sensitive to the ambient temperature of the meteorite, being higher for higher storage temperatures. Melcher also reports that at 160°C, TL decay can be observed after only a few hours. Using plausible solid-state models for the TL mechanism, he calculates the decay at lower temperatures which can be compared with further annealing experiments. It seemed to this reader that theory and experiment were already parting company when extrapolated from 160°C down to 121°C; even allowing for the very large uncertainties in the data used in the theory. Melcher's data do not bode well for determining the decay curves for Antarctic meteorites from such procedures.

We are left with the rather unsatisfying procedure of calibrating the TL decay using terrestrial ages obtained isotopically. Melcher finds a 'rough correlation' between TL and the ^{26}Al content of nine meteorites and the ^{36}Cl content of another eight. Using 17 meteorites from the Prairie States of the US, where terrestrial ages seem to be appropriate for ^{14}C dating, Sears and Durrani[7] found statistically significant correlations between TL and ^{14}C terrestrial age. Such exercises serve to demonstrate the predicted relationship between TL and terrestrial age. However, until the TL technique can be put into absolute footing, independent of the isotopic techniques, it will not find widespread application, except perhaps, as Melcher suggests, as a 'quick and dirty' method of rapidly screening large numbers of meteorites in order to select interesting ones for study by other techniques. □

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1. Fireman, E.L., Rancitelli, L.A. and Kirsten, T. *Science* **203**, 453 (1979).
2. Evans, J.C., Rancitelli, L.A. and Reeves, J.H. *Proc. 10th Lunar planet. Sci. Conf.* 1061 (1979).
3. Fireman, E.L. *Proc. 10th Lunar Planet. Sci. Conf.* 1053 (1979).
4. Nishiizumi, K. *et al. Earth planet. Sci. Lett.* (in the press).
5. Melcher, C.L. *Geochim. cosmochim. Acta* **45**, 615 (1981).
6. Sears, D.W. and Mills, A.A. *Meteoritics* **9**, 47 (1974).
7. Sears, D.W. and Durrani, S.A. *Earth planet. Sci. Lett.* **46**, 159 (1980).