Anomalous cosmochronology . . .

from Stephen Moorbath and David N. Schramm

FROM the comprehensive sweep of topics at a recent conference on the use of isotopic dating in geology and cosmology*, it is clear that isotopes can shed light on almost every aspect of Earth and Planetary Sciences. Reviews ranging from their use in dating the Universe to their use in deducing the diet of our ancestors indeed provided food for thought.

There has been a revolution in our understanding of the early Solar System as a result of the discoveries of isotopic anomalies in Allende and other carbonaceous chondritic meteorites. The discoveries were led off in 1973 by Clayton and his group at the University of Chicago, who discovered that the oxygen isotopic composition had large variations which could not be explained by simple fractionation and seemed to require an admixture of a different nucleosynthetic component that that of the bulk of the Solar System material. The addition of these non-standard nucleosynthetic components was given a timescale when Typhoon Lee, D. Papanastassiou, and G. J. Wasserburg (Caltech) showed that ^{26}Al was present when objects in the Solar System solidified. Since ^{26}Al was presumably made in a supernova and ^{26}Al has a half-life of only 7×10^5 yr, this seemed to indicate that a supernova explosion had occurred within a few million years of the formation of the Solar System, and had injected freshly synthesised material into the protosolar cloud. With these observations in mind, various astrophysical theorists have developed models for forming the Solar System utilising supernova shocks and grain formation and penetration as a means of getting the anomalies from the supernova into the protosolar cloud.

New isotopic anomalies

At the Snowmass conference, observations of new isotopic anomalies both elucidated and complicated the scenario. Although most of the rocks in Allende have almost normal Solar System isotopic composition, with the exception of oxygen anomalies and excess ^{26}Mg due to the decay of ^{26}Al, it was found about a year ago that two inclusions in Allende, labelled C-1 and EK 1-4-1, were anomalous for almost every element included. In addition, the nature of the isotopic anomalies was different in each inclusion. For example, where one particular set of neutron-rich isotopes might be enriched in EK 1-4-1, the same set is depleted in C-1. The discovery of the anomalies in these samples was made by Clayton's group, Wasserburg's group, and G. Lugmair (University of California, San Diego). New and extremely intriguing isotopic information on these two inclusions was presented. In particular, hopes for a simple explanation tying all the anomalies to one type of nucleosynthetic process were complicated by the discovery that in some mineral separates both proton-rich and neutron-rich anomalies were found, whereas in others only one or the other was present. Also, whereas C-1 seems to show more elements anomalous than normal material, it is depleted in the amount of freshly injected ^{26}Al. Since the anomalies in C-1 for the most part tend to be depletions rather than additions, this may mean that C-1 is a 'truer' sample of the protosolar material, and what we now call normal is really a well-mixed sample, including the ejecta from a supernova. Perhaps EK 1-4-1 is a sample in which the supernova ejecta is enriched relative to normal. The question of the composition of the different components which went to make up the Solar System and eventually became mixed together to yield what we call normalised isotopic composition will continue to be worked on, and there are, no doubt, going to be many new surprises.

Universality

The universal nature of the ^{26}Al chronology, and thus its significance, was strengthened considerably by new results reported by J. C. Lorin and M. C. Michel-Levy (Paris) who showed that ^{26}Al anomalies are also present in the Leoville carbonaceous chondrite, whilst J. D. MacDougall (University of California, San Diego) and D. Phinney (Johnson Space Center) showed that the carbonaceous chondrite Murchison also had ^{26}Al enrichment comparable to that in Allende. They also found that some samples of Murchison showed extremely large mass fractionation of Mg isotopes. This large mass fractionation is intriguing because the only other samples that have shown large isotopic fractionation were EK 1-4-1 and C-1.

One point which received some attention was the relation between the 10^6-yr ^{26}Al time scale and the 10^8-yr time scale relating the last nucleosynthetic event to produce ^{129}I and ^{244}Pu to the time when xenon daughter products of these two radioactive nuclei were retained in meteorites. Typhoon Lee and his collaborators at Chicago showed that it may be quite possible for a supernova simultaneously to make the ^{26}Al and the neutron-rich heavy anomalies observed in EK 1-4-1 and yet not produce ^{129}I and ^{244}Pu. On the subject of ^{129}I, one point brought out by A. Zaikowski (University of California, Berkeley) was that in Allende there seem to be at least two separate periods of condensation separated by about 3.7 Myr. That is, the ^{129}I seemed to be included in some rocks 3.7 Myr before others. This shows that some material in a meteorite may be considerably more primitive than other material in that same meteorite. C. Allègre and a team at Paris are trying to utilise the different nucleochronologies and retention times from Pb, Sr, Ar and Xe to show that the time/temperature history of the early Solar System was probably not monotonic, but went through at least one secondary reheating stage for which he set some parameters, but not all.

Hints of possible new results which have not yet been substantiated, but which if true would be extremely exciting, were presented by O. Manuel (University of Missouri, Rolla) who showed that there may be a correlation of Te isotopic anomalies with the strange Xe anomalies found enhanced in some carbonaceous chondrite material by E. Anders and his group at Chicago. Another intriguing suggestion based on preliminary experimental results was that of J. L. McCrumb and his collaborators at San Diego, who suggested that it may be possible for chemical fractionation to produce non-linear isotopic effects. If true, this would have extremely important implications for interpretations of such things as the oxygen isotopic anomaly.

There was also discussion of cosmological timescales as well as the discussion of timescales in the early Solar System. It was pointed out by K. Hainebach and his collaborators that a consistent age for the Universe can be obtained, utilising not just nucleocosmochronologies, but also the traditional Hubble dynamics and globular cluster ages and big bang nucleosynthesis. The age for the Universe where all methods agree is between 13.5 and 15.5 billion yr.

Stephen Moorbath is in the Department of Geology and Mineralogy, University of Oxford and David N. Schramm is at the Enrico Fermi Institute, University of Chicago.

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