Interstellar grains in meteorites?

from R. Hutchison

TODAY, the most favoured theory of the origin of the Solar System entails the collapse of a gas-dust cloud, perhaps initiated by a shock-wave from a nearby supernova. Heating during the collapse phase would have vaporised much, if not all, of the pre-existing dust. The question then arises: did any of the presolar dust-grains survive? And if so, how might they be recognised? Answers to these questions may be found in carbonaceous chondrite meteorites.

Evidence that some materials are enriched in the products of a supernova (or supernovae) was found in inclusions in the Allende meteorite. The scientific community was extremely lucky to receive two tonnes of specimens from the Allende meteorite shower that fell in northern Mexico in February, 1969, making available for study kilograms of samples of a type which had previously been doled out in gram-sized amounts. The Allende material was found to contain whitish inclusions consisting of minerals rich in calcium, aluminium and titanium. Such mineral assemblages were soon recognised as those predicted by Lord in 1965 (*Icarus* **4**, 279) as the first material to condense from a cooling gas of solar composition. And in 1973, R.N. Clayton *et al.* (*Science* **182**, 485) established that the oxygen of the high temperature inclusions and chondrules of Allende and related carbonaceous chondrites is enriched in pure ^{16}O. It was argued that the pure ^{16}O was produced by nuclear processes in an expanding outer shell of a supernova. Soon after the pure ^{16}O was introduced into the Solar System, condensation of refractory minerals trapped a portion of the pure isotope, the remainder having been mixed in with average Solar System oxygen, so losing its identity.

Further studies revealed that the white, calcium, aluminium, titanium-rich inclusions of Allende have anomalous isotopic abundances of various elements. Potentially, the most important of these anomalies is in ^{26}Mg because this is the daughter isotope of ^{26}Al, of which the half-life is only 740,000 years. The ^{26}Mg anomaly was discovered by Gray and Compston (*Nature* **251**, 495; 1974) and by Lee and Papanastassiou (*Geophys. Res. Lett.* **1**, 227; 1974). Wasserburg's group soon showed that in several Allende inclusions there is an internal isochron relationship between ^{26}Mg/^{24}Mg and ^{27}Al/^{24}Mg (*Geophys. Res. Lett.* **3**, 109; 1976). The isotope ^{27}Al is the only stable isotope of the element, and ^{24}Mg is the most abundant common isotope of magnesium. Thus, in each mineral of some inclusions there is a positive correlation between ^{26}Mg and the aluminium to magnesium ratio. We can therefore conclude that these inclusions crystallised when ^{26}Al was still extant. But, as D.D. Clayton has pointed out, there is no positive proof that the white inclusions crystallised within the Solar System (see for example *Nature* **257**, 36; 1975). Because isotopic anomalies of different elements, but especially light and heavy elements, do not generally correlate with each other, it is argued that crystallisation of the white inclusions must predate the Solar System. Injection of newly synthesised nuclides from a supernova into a presolar gas-dust cloud should have caused complete mixing of the injected elements. Thus, any isotopic anomalies should be correlated within each white inclusion. Lack of such correlation may be interpreted as indicating that the white inclusions represent condensates from the outer shells of the expanding supernova itself, assuming that the shells are blown concentrically outwards with a minimum of mixing between them.

Last year, a presolar age for two Allende inclusions was given a boost. Jessberger and Dominik (*Nature* **277**, 554; 1979) found that two inclusions have ^{39}Ar–^{40}Ar ages of about 5.0 Ga. The technique uses the ^{40}K–^{40}Ar decay scheme, but ^{40}K is estimated from the amount of ^{39}Ar produced by neutron irradiation of ^{39}K. If the ^{40}K/^{39}K ratio throughout the inclusion had been uniformly high, it could have accounted for the apparently old age. However, Stegmann and Begemann (*Nature* **282**, 290; 1979) found the potassium isotopic ratios to be normal. Thus the inclusions seem to have crystallised 400 Ma before the birth of the Solar System. But because other age determination techniques give a 'normal' age of about 4.55 Ga for Allende and its inclusions (see for example Tatsumoto *et al. Geochim. cosmochim. Acta* **40**, 617; 1976 and Chen and Tilton, *ibid.*), the ^{39}Ar–^{40}Ar age is still treated with suspicion. Even so, there seems to be a good chance that in some of the Allende inclusions we have presolar aggregates of refractory minerals up to about 1 cm in diameter.

Other approaches in the search for presolar, interstellar grains have been taken by Anders' group at Chicago and Eberhardt's at Bern. In 1969, Black and Pepin argued by a process of elimination than an anomalous neon component in some meteorites is of presolar origin (*Earth planet. Sci. Lett.*, **6**, 395; 1969). This type of neon, 'Ne-E', is characterised by low ^{20}Ne/^{22}Ne and ^{21}Ne/^{22}Ne ratios; Ne-E is, therefore, highly enriched in ^{22}Ne. Because noble gases are released from mineral grains at moderate temperatures, any carrier of Ne-E could not have had a high temperature history like that of the Allende inclusions. So, if the carrier minerals of Ne-E could be separated and identified, this might provide a sample of interstellar grains. To this end the Chicago group used chemical separation techniques and the Bern group physical methods.

Lewis *et al.* of Chicago (*Astrophys. J. Lett.* **234**, 165; 1979) used a sample of the water-bearing, CM2, carbonaceous chondrite which fell at Murchison, Victoria, Australia in September, 1969. As with Allende, scientists were fortunate to have been provided with about 500 kg of a type of meteorite which had previously been in short supply. The Chicago group dissolved away over 99.7% of their sample, using various reagents including HF, HNO_3, NaOH and H_2O_2. The residue was split into three size-fractions and from aliquots of each the rare gases were extracted by stepwise heating. Isotopic ratios were measured in the gas released at each heating step. Ne-E was released from the coarse (>3μm) fraction in two steps at 800 °C and 1,200 °C. Low-temperature (800 °C) release was not observed in an aliquot of material which had been treated with $HClO_4$. The low temperature carrier destroyed by $HClO_4$ was thought to be an oxidisable, carbon-rich material. From previous work and from its resistance to attack, the high temperature carrier of Ne-E was tentatively identified as spinel ($MgAlO_4$). In addition to carriers of Ne-E, a carrier of *s*-process xenon was identified as a carbon-rich phase stable at 1,400 °C. Lewis *et al.* concluded that the two carbonaceous phases and spinel are 'extrasolar'. However, stability of spinel requires a more oxidising environment than phases rich in elemental carbon. The authors, therefore, speculated that the extrasolar minerals may be condensates from red giants "at different stages of evolution".

The Bern group prepared nine density fractions of the Orgueil, water-bearing, carbonaceous chondrite, and stepwise heating was used on all but one, which was too small (*Astrophys. J. Lett.* **834**, 169; 1979). Ne-E was most highly concentrated in the least dense fraction (<2.3 g cm^{-3}), from which it was released below 900 °C. From three high density fractions (total range, 2.9–3.6 g cm^{-3}) Ne-E was mostly released at about 1,200 °C. Because potential contaminants are of lower density, it was argued that the Ne-E carrier probably has a density of about 3.5 and is probably spinel. Eberhardt *et al.* point out that the low density fraction has a low content of cosmic ray-produced ^{21}Ne, which indicates a low abundance of the target elements Mg, Al and Si, and is consistent with a carbon-rich composition. Furthermore, the composition argues against the possibility of the *in situ* production of pure ^{22}Ne by particle bombardment within the Solar System. A presolar origin of one Ne-E carrier therefore seems assured. □

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