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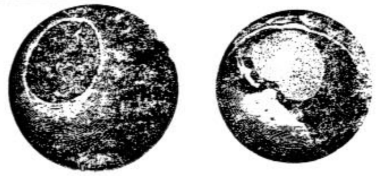
Deep-sea stony spherules and the primordial nebula

from Derek W.G. Sears

An example of how work designed to explore one question sometimes throws light on a seemingly unrelated question is provided by a pair of papers just published in *Nature*[1,2]. The authors of these papers set out to investigate the origin of isolated grains of the mineral, olivine, in the carbonaceous chondrite type of meteorites by making systematic studies of the cathodoluminescence of the grains and their 'minor' element chemistry. The result is both some new thoughts on the origin of the grains and the best evidence yet that some of the stony spherules extracted from deep-sea sediments are extraterrestrial in origin.

Meteorites are relics from the earliest days of the solar system. They are a complicated mixture of components which formed under a variety of physical conditions; some components may even have formed beyond the confines of the solar system. Isolated olivine grains of carbonaceous chondrites have attracted interest because they may be primary crystals formed by condensation in the primordial nebula at relatively high temperatures (above 900 K). Grossman and Olsen[3], who were probably the first to make this suggestion, were led to do so by the abundance of refractory trace elements in the grains, the presence of minerals calculated to condense at high temperatures, the absence of glass inclusions and their surface topography. On the other hand, McSween[4] found that isolated olivine grains have compositional and textural properties which grade into, or are similar to, those of olivine grains found inside another major structural component in chondrites, the chondrules. With a few exceptions, the olivines in chondrules are widely believed to have been formed by crystallization from a liquid. The debate in much that has recently been written on the origin of the isolated olivine grains has therefore centred on whether they are products of high-temperature condensation or the fragments of chondrules—the latter carrying the connotation of crystallization from a liquid.

Steele and his coworkers[1] have examined the cathodoluminescence of isolated olivine grains in two carbonaceous chondrites, Murchison (a type CM carbonaceous chondrite) and Allende (a type CV carbonaceous chondrite). In both cases, the cores of the grains luminesced blue while the rims luminesced red. In general, luminescence colour reflects trace element chemistry, and high quality electron microprobe analyses revealed that the blue regions are low in Fe and enriched in the refractory elements, Ca, Al and Ti, while the red regions are high in Fe and much lower in refractory elements. The red regions also contain inclusions of glass, silicates and metal, an indication that the olivine formed from a liquid. Steele *et al.* suggest that the blue olivine formed by condensation from vapour at high temperatures and then experienced a short-lived melting event which produced the red rim.



Black spherules, each with a metallic nucleus, collected from *Challenger* at 2,375 fathoms in the South Pacific (left) and 3,150 fathoms in the Atlantic (right). Magnified 60 times. From ref. 7.

This suggestion strikes a familiar chord. In the past few years, several authors have suggested that although chondrules are often droplets produced by melting preexisting solids, on occasion a few grains of the precursor solid can survive the melting. They are termed relic grains, and are often olivine[5,6]. Steele *et al.* suggest that all the isolated grains in CM chondrites are relic grains, which were formed by high-temperature condensation and which have subsequently passed through the chondrule-forming process; in essence, both ideas for the origin of isolated olivine grains—vapour condensation and liquid crystallization—are true. The idea merits attention and will suffer intense scrutiny. The immediate problem is that it implies that relic grains in chondrules are commonplace, which is contrary to current observations. Does this reflect our inability unambiguously to recognize all relic grains?

Whatever their origin, the minor element chemistry of isolated olivine grains in carbonaceous chondrites seems to provide them with a unique fingerprint which helps resolve a one-hundred-year-old problem. The circumnavigation of the world by the *Challenger* in the latter part of the nineteenth century marked the beginnings of the modern science of oceanography and yielded many discoveries. One was that the ocean sediment, which was routinely scooped up during the voyages, contains numerous black magnetic spherules, whose discovery was described in 1884 in *Nature*[7]. Their origin remained unclear well into the present century when modern instrumental methods became available. The spherules, which are of the 'iron type', frequently contain an offset iron-nickel core surrounded by magnetite, which is also sometimes nickel-bearing[8]. The prevalence of nickel is widely considered as evidence for an extraterrestrial origin for the iron type spherules, analogues of the nickel-rich core and magnetite shell structure also being found in iron meteorite fusion crusts. However, the origin of the so-called 'stony-type' spherules remained unclear.

Neutron activation analysis[9] and defocussed-beam electron microprobe analysis[10] of deep-sea stony spherules yield bulk compositions that are consistent with an extraterrestrial origin for the spherules, but interpretation is difficult because of the considerable terrestrial alteration they have suffered. Oxygen isotopes have provided a means of distinguishing the various meteorite classes and finding genetic links between them and, last summer, Mayeda *et al.* produced some oxygen isotope data for deep-sea spherules[11]. The problem is that not only are the spherules weathered, but they will have picked up considerable atmospheric oxygen during their atmospheric passage. On the assumption that iron spherules contain only terrestrial oxygen and that the stony spherules contain a mixture of terrestrial and extraterrestrial oxygen, Mayeda *et al.* suggested that the extraterrestrial oxygen in the spherules resembles that in anhydrous components from CM chondrites, such as their isolated olivine grains, or CV chondrites.

Like the chondrules, a few of the deep-sea stony spherules contain tiny mineral grains which survived the melting that produced the spherule and so have also been called 'relic'[10]. The minor element chemistry of isolated olivine grains from CM chondrites resembles that of the relic olivine grains in deep-sea stony spherules, and is quite distinct from that of olivines from other sources[2]. Take, for example, the Mn-Cr systematics. On a plot of MnO agains Cr_2O_3, there is a positive correlation, with a distinctive concave trend, for olivines from the CM chondrites, not found for other classes of chondritic meteorite but rather closely matched by the deep-sea spherule olivines. Unlike the bulk composition and oxygen isotopes of the deep-sea stony spherules, the relic olivines seem to have been impervious to atmospheric or aqueous alteration. This, and the distinctiveness of their composition, provides the best evidence yet that certain deep-sea stony spherules are of extraterrestrial origin. ☐

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