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Meteorites

Calcium- and aluminium-rich inclusions

from Derek W.G. Sears

IN recent months there have been new developments in our understanding of calcium–aluminium-rich inclusions (CAI) and the meteorites in which they are found. Meeker, Wasserburg and Armstrong[1] argue that some CAI have suffered considerable alteration by processes which occur on small parent bodies. This adds a new episode to the history of the objects and their parent meteorites. And in this issue of *Nature* (p.588), Bischoff and Keil[2] discuss several CAI they have found in the largest meteorite class, the ordinary chondrites. Although there are many earlier studies of occasional CAI (see, for example, ref.3), it is the fact that Bischoff and Keil found CAI in every one of the 11 ordinary chondrites they examined which is significant.

CAI are light-coloured inclusions varying in size from millimetres to centimetres[4,5], and which were first found in quantity in the Allende meteorite. The inclusions were found to have had extremely low initial $^{87}Sr/^{86}Sr$ ratios, indicating that they were one of the earliest substances to form in the Solar System[6]. They were also found to be rich in all the refractory elements[7] and to consist of a number of calcium- and aluminium-rich minerals which had previously been considered either absent or rare in meteorites. In 1973 they were found to have anomalous oxygen isotope abundances[8] and soon a whole plethora of isotopic anomalies were reported; elements such as Ca, Ti, Sr, Ba, Sm and Nd were all found to have relative isotopic abundances that were not explicable in terms of well-defined chemical processes or nuclear processes such as radioactive decay or cosmic-ray-induced nuclear reactions[9]. Moreover, excess ^{26}Mg and ^{129}Xe, the products of radioactive decay of ^{26}Al ($t_{1/2} = 0.75$ Myr) and ^{129}I ($t_{1/2} = 18$ Myr) respectively, were found[10,11]. The presence, at some time, of ^{26}Al in the inclusions is considered particularly significant as it may provide the long-sought heat source in the early Solar System.

What Meeker and co-workers[1] recently observed is that in those inclusions which are fairly coarse-grained and consist predominantly of the minerals pyroxene, melilite, spinel and plagioclase, much of the melilite appears to have grown out of the pyroxene. They interpret this as evidence for a solid-state reaction at elevated temperatures and pressures (metamorphism), since crystallization from a liquid or direct condensation from the nebula would produce the opposite relationship, that is melilite from which pyroxene would grow.

They observe a whole spectrum in the extent of metamorphic alteration, ranging from little or none, where the textures suggest that virtually all the inclusions crystallized from a melt, to two instances where most of the inclusion appears to be alteration product. Two inclusions are also described where the core is crystallization product and alteration has occurred from the outside inwards and consumed roughly half the inclusion. Other properties of the inclusions also support the concept of metamorphism, such as reaction textures between melilite and spinel, lobate-sutured grain boundaries and 120° interceptions between grain boundaries.

Meeker *et al.* face certain mass-balance problems — they need to invoke *ad hoc* means to introduce Ca and remove Ti — but their idea provides an attractive means of explaining some oxygen isotope data. Clayton *et al.*[12] found that different minerals from a single inclusion had different oxygen isotope ratios, suggesting that different minerals had received different amounts of exotic oxygen. Metamorphism would be expected to produce such a distribution because different minerals have different equilibration temperatures and reaction rates for oxygen exchange. The fact that different inclusions from the same meteorite have been metamorphosed to differing degrees indicates a rather complex sequence of events: metamorphism on a parent body, disaggregation and finally re-assembly, presumably on a new parent body. Thus some CAI are as much the product of planetary processing as anything else, and the Allende meteorite has a considerably more complicated early history than most workers previously supposed.

Although it is probably the best known and studied meteorite, the Allende meteorite is actually a member of a very small meteorite class, the CV chondrites. In this issue of *Nature*[2], Bischoff and Keil show that there are many similarities between ordinary-chondrite CAI and Allende CAI. They have the same mineralogy and bulk compositions, and both meteorite classes have high levels of Na and K in CAI. Na and K are fairly volatile elements, whose presence is difficult to reconcile with high-temperature condensation or evaporation.

A major implication Bischoff and Keil see in their observation is that it again brings out the similarities between diverse meteorite classes. It is certainly true that the majority of meteorites have many similarities: the composition of all the classes is basically solar — except for the most volatile elements, the compositional differences on which the classification of meteorites is based are in a quantitative sense very minor; they consist of essentially the same components; and they are all extremely old. But it is also true, as many authors have pointed out[13,14], that there are important compositional and isotopic differences between the classes, and in stressing the similarities it is important not to lose sight of the differences. □

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