MATTERS ARISING

Superheavy-element fission tracks in iron meteorites

BULL'S careful search[1] for superheavy element (SHE) fission tracks in silicate inclusions within iron meteorites seems to have given a null result. He finds an upper limit of 10^{-12} kg per kg for the original abundance of SHEs in the class 1A Odessa iron meteorite. As this is many orders of magnitude below what we postulated[2] from considerations of early heat sources in the Moon and from a highly speculative interpretation of elemental abundances in iron meteorites[3], Bull's result may be accepted as proof that superheavy elements either did not exist or did not play any part in the early Solar System. His observations therefore merit further study. His result refers to the date at which track retention becomes possible, that is when the temperature has fallen to ~200 °C. Now although the Rb–Sr, K–Ar dates of silicate inclusions in iron meteorites range up to ~4,600 Myr, they are not to be interpreted simply as the 'age' of iron meteorites nor are they the dates of the emplacement of the silicate grains. The process by which silicate inclusions get into iron meteorites is unknown: but they must certainly enter while the temperature of the iron is near to its melting point. Cooling rates of iron meteorites are determined by metallographic study and for the Odessa meteorite it is 1.5 °C Myr^{-1} in the range 700–300 °C. The meteorite might, therefore, only reach track retention temperatures 800 Myr after the emplacement of the silicate crystals. Taking the half life of SHEs determined from the decay of the ancient lunar magnetic field[4] as 100 Myr, the original abundance of SHEs in the iron would have decayed by nearly 3 orders of magnitude. This, of course, assumes that the rate of cooling at higher temperatures and at lower temperatures is the same. In fact if, as we suppose, SHEs have played a dominant part in the early thermal history of the parent bodies of meteorites, the cooling rates at higher temperatures may have been slower and the diminution in the abundance of SHEs at the time when track retention became possible greater than we have estimated here. Another possible explanation of Bull's results is, of course, that SHEs on the condensation of grains in the early Solar System were never fully taken up by the iron. This explanation seems probable in the case of the Odessa meteorite as IA iron meteorites have been interpreted as not originating in the iron core in a sizeable asteroid-like body. Probably only in a completely melted sizeable body would the molten iron, mixing with other crystals, dissolve the SHEs. The IA meteorites have reasonably been interpreted in terms of a model in which iron condenses from the nebula and forms small bodies within a much larger silicate parent body. If this model is correct, then the existence of ^{244}Pu fission tracks would have a simple explanation. Bull's studies ought to be done on the IIAB iron meteorites which are more reasonably assumed to come from the cores of entirely melted parent bodies, but the difficulty is that there are no silicate grains to record fission tracks. *Note added in proof*: We are, of course, aware that if the tracks inside the diopside crystals are due to the decay of Pu^{244}, synthesized with the other elements in stellar nucleogenesis processes just before the condensation of the primeval Solar System nebula, our first argument, that the presumed SHE tracks have disappeared due to annealing processes, collapses. But we wonder whether this identification, which, as Bull so clearly explains, is arrived at by a process of elimination, should be accepted without question. Extrapolation of the Periodic Table[1] does not show that all the SHE are siderophile and perhaps some of them, with longer half life, went into the mineral phase.

We agree that our suggested thermal history are necessarily speculative—as are all others—but the track retention temperatures of minerals, such as the quoted 400 °C for diopside, are based on laboratory annealing experiments.[5] But this extrapolation to 4,000 Myr assumes that the same excitation process can be assumed as in laboratory annealing; but it is characteristic of solid state physics phenomena that processes with different excitation energies are dominant over different ranges of temperature and time.

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BULL REPLIES—Runcorn *et al.* have proposed two explanations for the lack of superheavy element (SHE) fission tracks which I observed in silicates from the Odessa iron meteorite[1].

First, they point out that a thermal history for Odessa can be constructed in which the meteorite reaches track retention temperatures only after a time corresponding to many half lives for the SHEs (taken to be ~100 Myr) has elapsed. This explanation, however, fails to account for the large excess of fission tracks distributed throughout the diopside grains in Odessa. These exceed the number accruing through the decay of ^{238}U in the lifetime of the Solar System by a factor of ~100 and the most plausible source of this excess is the decay of ^{244}Pu which, significantly, has a half life which is very close to that assumed for the SHEs. This means that any cooling which was slow enough to allow most of the SHEs to decay would also result in the loss of most of the Pu and the very large excess of fission tracks in the diopside would be difficult to account for unless this mineral was very much enriched in Pu relative to U (an initial ratio of Pu/U of ~10 would be needed compared to values of ~0.01–0.1, inferred from fission Xe measurements on chondritic whitlockites[2]). As to the thermal history proposed by Runcorn *et al.*, I would point out that the track retention temperature of diopside is higher than 200 °C, probably nearer 400 °C and that there is considerable uncertainty as to the metallographic cooling rates.

The second explanation by Runcorn *et al.* is that the IA irons never took up many SHEs. This point may be valid in that the group IA meteorites are not typical irons and there is evidence that they were never melted. The pallasites, however, are believed to be fragments of a core boundary region and pallasitic metal probably represents core material. In Brenham the superheavy content of the metal was less than 10^{-15} kg per kg at the time of track retention but unfortunately we cannot as yet place firm constraints on when track retention occurred.

Finally, note that silicate inclusions are occasionally found in other iron meteorites groups and a study of these should provide further clues to the abundance of SHEs in the early Solar System.

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