

The source of meteorites in time and space

from Robert Hutchison

VARIOUS false alarms have occurred in the past over alleged discoveries of fossil meteorites. For example, a squarish piece of iron weighing 785g from Tertiary lignite mined at Wolfsegg, Austria, was originally reported as meteoritic (*C.r. hebd. Séanc. Acad. Sci., Paris* **103**, 702; 1886; *Nature* **35**, 36; 1887). More recently, in 1930, a fist-sized piece of iron-nickel metal was said to have been recovered from a borehole at a depth of 1,525 feet in Eocene sediments; this 'Zapata County', Texas, iron has since been lost (Lovering *Nature* **183**, 1664; 1959). Until the discovery of the remains of a chondrite in Ordovician limestone in Sweden by Thorslund and Wickman (see this issue of *Nature*, p. 285), the only probable fossil meteorite material known to the writer was the occurrence of chondrule-like structures in Mesozoic sediment from the Urals (Yudin *Meteoritics* **6**, 99; 1971). The Ordovician chondrite has been reasonably (but not conclusively) identified as a member of the high-iron or H-group of the ordinary chondrites. Its fall to Earth some 460 Myr ago has considerable significance.

There are compelling arguments that most meteorites come from asteroids. But although it now seems probable that there are sufficient numbers of the Earth-crossing Apollo asteroids and the related

Mars-crossing Amor asteroids to account for the observed flux of meteorites, a steady state can only be maintained if these groups are fed from some source beyond Mars (Wetherill *Geochim. cosmochim. Acta* **40**, 1297; 1976). The small Apollo objects have a mean lifetime of only a few tens of millions of years before they are either captured by a planet or ejected from the Solar System by Jupiter. About 30% of observed meteorite falls are H-group chondrites. Most of these meteorites have cosmic-ray exposure ages close to 4 Myr (see, for example, Zähringer *Geochim. cosmochim. Acta* **32**, 209; 1968), which is taken to mean that they were released as metre-sized objects from some larger body some 4 Myr ago. Release was presumably the result of a collision involving the parent body. No stony meteorite has an exposure age greater than 100 Myr. Thorslund and Wickman's discovery indicates that there was H-group chondrite material among Apollo asteroids some 460 Myr ago, and the possibility then arises that the meteorite flux has not changed significantly in composition with time.

If this is so there appears to be a problem. From spectral reflectance data Gaffey and McCord (*Proc. 8th Lunar Sci. Conf.* **1**, 113; 1977) found that belt asteroids rarely have surfaces with the

mineralogy of ordinary chondrites; such surfaces are common among Apollo and Amor objects. Wetherill concludes that to maintain a steady-state population of these bodies, belt asteroids and, dominantly, comets must have orbits which can evolve into Earth- or Mars-crossing orbits. However, belt asteroids appear to have surfaces which are almost exclusively not ordinary chondritic, and Anders (*Icarus* **24**, 363; 1975) has argued, on the basis of the ancient bombardment undergone by meteorites of different types by particles emitted by solar flares, that most stony meteorites cannot have come from the outer Solar System. The problem of the maintenance of the meteoritic flux was recently discussed by Napier and Clube (*Nature* **282**, 455; 1979), who proposed that a proportion of meteorites come from outside the Solar System, but the meteorites themselves have no major chemical or isotopic anomalies consistent with different regimes of nucleosynthesis; so we are left with a Solar System origin. The question of where in the Solar System that might be has, if anything, been aggravated by the new discovery.

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Andreotti (Parma) dealt with crystallographic studies of a whole range of inclusion compounds. It was therefore surprising to learn of the lack of crystallographic studies on Werner inclusion compounds and J. Lipkowski (Warsaw) reported his recent studies which aimed at trying to understand the factors governing host lattice selectivity. A knowledge of the crystal structure is also necessary to understand the energy-transfer processes between host and guest using UV and γ -ray radiation reported by the group from the Institute of Nuclear Chemistry, Rome. Another new term suggested at the meeting was 'excitrate' (A. Guarino, Rome) to denote a clathrate with either the host or guest, or both, in an excited state.

The Hofmann inclusion compound, $\text{Ni}(\text{NH}_3)_2\text{Ni}(\text{CN})_4 \cdot 2\text{C}_6\text{H}_6$, has been known since 1897, but its properties have only been recently studied extensively. The most prominent worker in this field, T. Iwamoto (Tokyo), described his work on modifying these host lattices by replacing the ammonia by bidentate bridging ligands, and by replacing the square planar $\text{Ni}(\text{CN})_4^{2-}$ group by tetrahedral $\text{M}(\text{CN})_4^{2-}$ groups. These modified host lattices show interesting properties such as the ability of

$\text{CdenHg}(\text{CN})_4$ to stabilize the cyclohexadienyl free radical, produced by the γ -ray irradiation of the benzene guest molecule. This free radical is stabilized up to the thermal decomposition temperature of the host lattice, 423K. Vibrational spectroscopic studies of these systems were reported by J.E.D. Davies (Lancaster) and stability studies were reported by A. Sopotová (Košice).

It is true to say that the majority of inclusion compounds known have been discovered by accident, but D.D. MacNicol (Glasgow) gave a fascinating talk outlining his strategy for the synthesis of a variety of compounds which should be expected to act as host lattices. Equally fascinating was the talk by J.L. Atwood (Alabama) describing his work on 'liquid clathrate' systems. These are non-stoichiometric compounds which form in the liquid phase on the interaction of aromatic molecules and $\text{M}[\text{Al}_2\text{R}_6\text{X}]$ moieties. The mole ratio of aromatic to anion can vary enormously, the present record being $[\text{N}(\text{C}_6\text{H}_{13})_4][\text{Al}_2\text{Et}_6\text{I}] \cdot 39.6$ *o*-xylene. A few of these liquid-phase systems have yielded crystalline products, for example $\text{Cs}[\text{Al}_2\text{Me}_6\text{N}_3] \cdot 2p$ -xylene, in which the *p*-xylene molecules sandwich the caesium ion.

A recent interesting application of inclusion compounds is the realization that a chiral host lattice might show enantiomer selectivity, and G. Tsoucaris (Chatenay-Malabry) gave examples of the enantiomeric selectivity of the tri-*o*-thymotide host lattice. Another recent development is the application of solid-state NMR spectroscopy to the study of inclusion compounds. J.A. Ripmeester and D.W. Davidson (Ottawa) illustrated the use of ^{129}Xe NMR in the study of the Structure I xenon clathrate deuterohydrate, where it was possible to observe well separated resonances from the atoms in the two types of cavity.

In conclusion, this was a well timed symposium, as it is apparent that the field of inclusion chemistry has advanced considerably in the 33 years since H.M. Powell first characterized this type of compound, and it is equally apparent that further advances remain to be made. Some of the papers presented at this meeting will be published in a special issue of the *Journal of Molecular Structure*, and it is hoped to hold another symposium in Parma in about two years time. □

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