

DEUTERIUM ENRICHMENTS AND SYNTHESIS OF METEORITIC ORGANIC MATTER

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Several features of the distribution of different organic molecules in C-chondrites suggest a major contribution from Fischer-Tropsch-like catalytic reactions [1]. Furthermore, pronounced D enrichment now seems to be a general feature of the organic population in those meteorites. Are such extreme D enrichments consistent with FT-type synthesis of the organic matter?

Under equilibrium conditions, the stability field of organic matter in a nebula of solar composition lies well below the temperature at which CO would have reacted to form CH_4 [1]. However, the latter reaction would have been kinetically inhibited [1,2], permitting CO to survive as a metastable phase down to the temperature, about 400 K at putative nebular pressures, at which organic matter would have become stable and where its formation could plausibly be catalysed. But before a cooling nebula reached that temperature, the activity of the dominant available catalyst, metallic FeNi, would have been poisoned by FeS formation on grain surfaces at 680 K. In the FT hypothesis, therefore, the catalyst responsible for hydrogenation of CO to organic molecules in the solar nebula is generally identified [1] as the clay minerals that are abundant in organic-rich meteorites. Such clays would have become stable below about 350 K in the nebula [3], but recent reaction-rate calculations [4] indicate that formation of such minerals by hydration of anhydrous silicates would have been kinetically inhibited at plausible nebular temperatures and pressures. Furthermore, the petrology and mineral chemistry of C-chondrites show clearly [5] that their clay minerals were formed on their parent asteroids by aqueous alteration of an earlier, possibly nebular, lithology. Thus, the suggestion that clays acted as FT catalysts during organic synthesis in the solar nebula lacks theoretical and observational support.

Most of the meteoritic organic matter consists of an insoluble, macro-molecular complex resembling terrestrial kerogen [1]. The large D enrichment observed in this material [6,7], relative to galactic H, is generally attributed to isotopic fractionation during ion-molecule reactions in interstellar clouds [6-9]. However, it has not been known whether that D enrichment is carried by a small fraction of highly enriched interstellar kerogen-like material, or whether the insoluble fraction as a whole was made from D-enriched gas. Also, the isotopic relationship between the kerogen-like fraction and the population of characterisable organic molecules is not well understood [10]. Thus, the significance of the D data for constraining models of organic synthesis has been problematical. This issue has recently been brought into sharper focus by the observation [11] in a meteoritic amino-acid fraction of D enrichment comparable to that in the kerogen-like material. Assuming that these D enrichments reflect fractionation in a molecular cloud, how did such interstellar H become incorporated into a meteoritic amino acid?

It seems plausible that amino acids are synthesised by ion-molecule reactions in interstellar clouds though none have yet been observed astronomically [12]. However, even assuming that interstellar amino acids exist, would they have survived in measurable quantities to be incorporated into meteorites in the early solar system? This seems unlikely: the relatively labile bonds in amino-acid structures would have made them vulnerable to destruction by cosmic rays, supernova shock waves and heating during collapse to form the solar nebula. It seems more likely that, by the time they arrived in the nebula, interstellar molecules, presumably incorporated into initially volatile mantles on oxide and/or silicate grains [13], would have been broken down into a relatively refractory form of carbonaceous matter. Such carbon-

aceous residues would probably resemble the polycyclic aromatic hydrocarbons (PAHs) believed to cause the interstellar IR emission features [14].

I suggest, therefore, that the solar nebula, consisting predominantly of low-D H₂ [9], also contained relatively refractory D-rich carbonaceous entities, tentatively identifiable with PAHs, and that the C-chondrite parent asteroid accreted from a mixture of such PAHs, anhydrous mineral grains, plus water ice moderately enriched in D relative to the nebular D/H ratio (by isotopic fractionation at the quench temperature for H₂-H₂O exchange [4]). Subsequent heating of that asteroid, by either electromagnetic induction [15] or decay of ²⁶Al [16], would have melted the ice, mobilising water. That water would have diffused to the surface, probably forming a relatively durable "permafrost" layer [17], beneath which chemically active liquid water would have been trapped for long enough to produce the observed secondary lithology of the C chondrites.

Further heating in the asteroid interior would have broken down the PAHs, generating CO, CO₂, CH₄, H₂ and H₂O, of which the last three would have been highly D enriched. Those gases could then have reacted to form a further generation of organic matter, catalysed by the secondary clay minerals in the asteroid surface regions. Some low-D hydrogen, inorganically combined in the catalysts, would probably have entered the organic products, lowering their final D contents relative to that of the interstellar PAHs, but isotopic exchange would have been inadequate to eliminate the disequilibrium distribution of the H isotopes. Some interstellar PAHs may well survive in the meteoritic kerogen-like fraction [14,18].

Synthesis of meteoritic organics in an asteroidal setting decoupled from the predominant nebular H reservoir, D-poor H₂ gas, can explain the D enrichment of the organic matter, but whether it can explain the isotopic composition of the organic C, N and O is not yet clear. A successful model must also account, for example, for the systematic decrease in ¹³C content with increasing C number in homologous series of alkanes and carboxylic acids [19], the difference in ¹³C content between aliphatic and aromatic moieties in the kerogen-like fraction [18], and the enrichment in ¹³C of oxidised relative to reduced C [20]. Synthesis of organic matter on meteorite parent asteroids has previously been proposed, on other grounds, by Bunch and Chang [21].

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