THE ORIGIN OF THE POLYCYCLIC AROMATIC HYDROCARBONS IN METEORITES

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Abstract. Polycyclic aromatic hydrocarbons (PAHs) in C1 and C2 Carbonaceous Chondrites appear to be the product of a high-temperature synthesis. This observation counters a prevailing view that PAHs in meteorites are a thermal alternation product of preexisting aliphatic compounds, which in turn required the presence of low-temperature mineral phases such as magnetite and hydrated phyllosilicates for their formation. Such a process would necessarily lead to a more low-temperature assemblage of PAHs, as many low-temperature minerals and compounds are extant in meteorites.

Ivuna, a C1 carbonaceous chondrite, has been shown to contain abundant amounts of the three-ring PAHs phenanthrene/anthracene, but no detectable levels of the two- and four-ring PAHs naphthalene and pyrene/fluoranthene. Ivuna and other C1 carbonaceous chondrites are known to have been extensively altered by water. The aqueous solubilities of PAHs indicate that some PAHs would have been mobilized during the aqueous alteration phase in meteorite parent bodies. Model geochromatography experiments using crushed serpentine or beach sand as the solid phase and water for elution suggest that the complete separation of two, three, and four-ring PAHs could be expected to occur in the parent body of C1 carbonaceous chondrites. It is proposed that aqueous fluids driven by heat in the parent body of Ivuna migrated from the interior to the surface, in the process transporting, separating and concentrating PAHs at various zones in the parent body.

The presence of indigenous PAHs and absence of indigenous amino acids in the H4 ordinary chondrite Forest Vale provides support for the contention that different processes and environments contributed to the synthesis of the organic matter in the solar system.

Introduction

The analysis of PAHs (see Figure 1 for structures) in carbonaceous chondrites has been severely constrained by sample availability. Typically, several grams of sample are needed in order to obtain meaningful results using a combination of wet chemical isolation methods followed by detection and identification by gas chromatography/mass spectrometry. Most analyses have been performed on the Murchison C2 chondrite (Australia) and the Pueblito de Allende C3 chondrite (Mexico) in the early 1970's, soon after these meteorites fell (Cronin et al., 1988). Meaningful comparisons of PAHs within and between each petrologic class have not been made.

In 1988 Hahn et al. analyzed PAHs in six carbonaceous chondrites and one ordinary chondrite utilizing the new analytical technique of two-step laser desorption/multiphoton ionization mass spectrometry (L²MS). Their results for Murchison were consistent with the earlier studies (e.g. Pering and Ponnamperuma, 1971, Basile et al., 1984). Three major features characterize the data for the various meteorites studies by Hahn and co-workers:
Fig. 1. Structures and molecular weights of some polycyclic aromatic hydrocarbons present in carbonaceous chondrites. The sites of alkylation are arbitrary.

(1) The unalkylated PAHs naphthalene (mass 128), phenanthrene/anthracene (mass 178) and pyrene/fluoranthene (mass 202) generally predominate over their methyl-, dimethyl-, and alkyl- homologs.

(2) Ivuna, the only C1 chondrite in their collection, contained only the three-ring PAHs phenanthrene/anthracene, and smaller amounts of their methyl- and dimethyl- homologs. No detectable amounts of naphthalene or pyrene, which have two and four rings, respectively, were found. In addition, Ivuna contained greater amounts of phenanthrene/anthracene than any of the other carbonaceous meteorites.

(3) The H3 ordinary chondrite Clovis was found to contain no PAHs. A negative result was expected in the case of Clovis, and the analysis provided a valuable control against the possibility of laboratory contamination.

Carbonaceous chondrites contain many other organic species besides PAHs: detected compounds include amino acids, carboxylic acids, heterocyclic compounds, an aromatic polymer, and aliphatic hydrocarbons. Recent comments and reviews on the subject of organics in meteorites (e.g. Wright and Gilmour, 1990; Cronin et al., 1988; Mullie and Reisse, 1987) have focused chiefly on two alternative hypotheses for the formation of organics in meteorites: the Fischer-Tropsch type synthesis (CO and H₂ reacting on low-temperature catalytic surfaces), and the Miller-Urey synthesis (spark discharge in a reducing atmosphere). Three points have been overlooked in these discussions which are the focus of this paper. First, the Fischer-Tropsch type synthesis cannot account for the assemblage of PAHs observed in C1 and C2 carbonaceous chondrites; second, low-molecular weight organics which are not readily soluble in water can be selectively transported and concentrated