Organic compounds in the Forest Vale, H4 ordinary chondrite

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Abstract—We have analyzed the H4 ordinary chondrite Forest Vale for polycyclic aromatic hydrocarbons (PAHs) using two-step laser mass spectrometry (L^2MS) and for amino acids using a standard chromatographic method. Indigenous PAHs were identified in the matrices of freshly cleaved interior faces but could not be detected in pulverized silicates and chondrules. No depth dependence of the PAHs was found in a chipped interior piece. Amino acids, taken from the entire sample, consisted of protein amino acids that were nonracemic, indicating that they are terrestrial contaminants. The presence of indigenous PAHs and absence of indigenous amino acids provides support for the contention that different processes and environments contributed to the synthesis of the organic matter in the solar system.

INTRODUCTION

CARBONACEOUS CHONDRITES contain a large variety of organic materials (see CRONIN et al., 1988, for a recent review). The origin of this organic matter is not well-established but possible synthetic sites include the interstellar medium, the early solar nebula, and the parent bodies of carbonaceous chondrites. Because equilibrium conversion of carbon into organic compounds other than methane is not possible, nonequilibrium processes are required (HAYATSU and ANDERS, 1981). Isotopically enriched carbon and hydrogen in organic components is now generally considered to indicate an interstellar origin (YANG and EPSTEIN, 1983; EPSTEIN et al., 1987).

Carbon in ordinary chondrites has been generally found to consist of components such as graphite and diamond (GRADY et al., 1989), and the abundance of carbon decreases with increasing petrologic type (OTTING and ZAHRINGER, 1967). Organic matter is not thought to be a significant carbon component. Only the L6 ordinary chondrite Holbrook has been previously found to contain trace amounts of organic compounds (HAYES and BIEMANN, 1968). Some achondrites such as the SNC meteorites, which are thought to be of Martian origin, may also contain organic components (WRIGHT et al., 1989).

The H4 ordinary chondrite Forest Vale is of interest because of its old age, its inferred fast cooling rate, and the presence of an anomalous trapped xenon component in its metal phase (MARTI et al., 1989). The substantial trapped Xe component is partially released by combustion in O_2 at low temperatures, an observation that suggests carbonaceous carriers (LAVIELLE and MARTI, 1988). The carbonaceous carriers are much enriched in the fine-grained matrix, in agreement with the bulk carbon determinations (NOONAN

et al., 1972). Because the components of this carbonaceous material have not been characterized, we have analyzed Forest Vale for polycyclic aromatic hydrocarbons (PAHs) and amino acids. These two classes of organic components were selected because they likely have different origins and sources. Polycyclic aromatic hydrocarbons may be ubiquitous interstellar molecules (ALLAMANDOLA et al., 1987), whereas amino acids are likely only synthesized on meteorite parent bodies that experienced aqueous alteration (PELTZER et al., 1984). Organic molecules, in particular PAHs, have been found to be associated with the polymeric kerogen-like material in the matrix of carbonaceous chondrites (ZENOBI et al., 1989). Polymeric organic material is a prime candidate for the unknown carbonaceous carriers of the trapped noble gases in Forest Vale.

Polycyclic aromatic hydrocarbons have been previously detected using two-step laser mass spectrometry (L^2MS) in carbonaceous chondrites, including Allende, but not in ordinary chondrites (HAHN et al., 1988). Recently, the sensitivity of L^2MS has been further improved, and good spatial resolution permits matrix analyses of freshly cleaved surfaces and of silicate grains and chondrules (ZENOBI et al., 1989).

More than seventy amino acids have been positively identified in extracts of Murchison and other carbonaceous chondrites (CRONIN et al., 1988). When free of terrestrial contamination, those amino acids with chiral centers are found to be racemic (BADA et al., 1983). Nonprotein amino acids are present in significant amounts, especially α-aminoisobutyric acid (AIB), the most abundant single amino acid in Murchison, and racemic isovaline (ISOVAL). We concentrated our Forest Vale analyses on these two amino acids because they are extremely rare in organisms and are not known breakdown products of terrestrial amino acids (ZHAO and BADA, 1989).

EXPERIMENTAL

Two interior samples of the Forest Vale chondrite were used. Sample A (NMNH, Smithsonian Inst., Washington, DC) materials were splits of crushed bulk and grain-size separates used in the studies of

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trapped gasses. Sample B (National Museum of Natural History, Paris) was a cube specifically prepared for L²MS analysis.

Two-Step Laser Mass Spectrometry

In the L²MS technique (HAHN et al., 1987, 1988; ZARE et al., 1988; ZENOBI et al., 1989), the pulsed output of a CO_2 laser (10.6 μm; 10 mJ/pulse; 10 μs pulse width) is focused onto the surface of a freshly fractured or ground sample. The infrared (IR) radiation is absorbed by the minerals, and intact neutral molecules are released from their surfaces by rapid laser-induced thermal desorption. Even nonvolatile and thermally labile compounds up to high molecular weight (more than 1000 amu) are readily desorbed (HAHN et al., 1987; ZARE et al., 1988). After a delay of approximately 40 μs, the fourth harmonic of a neodymium:yttrium-aluminum-garnet (Nd: YAG) laser (266 nm wavelength; 0.2 mJ pulse energy; 10 ns pulse width) is used to induce 1 + 1 resonance-enhanced multiphoton ionization (REMPI) of the desorbed molecules 2 mm above the surface. In this ionization scheme, one photon is resonantly absorbed into an electronically excited state, and the second photon ionizes the molecule. Ionization is efficient only if the ionization potential is less than 9.3 eV (two times the energy of a 266-nm photon) and if a strong absorption band is present in the region of the laser wavelength. This requirement holds for most molecules containing an aromatic moiety. For substances that do not resonantly absorb this wavelength, the ionization efficiency is smaller by orders of magnitude. The ions are mass-selected in a reflectron time-of-flight mass spectrometer and detected by a microchannel plate. A complete mass spectrum is obtained for each sequence of laser pulses. Unit mass resolution above 600 amu was achieved at the most sensitive instrument settings. Combining the desorption of intact neutrals with the soft ionization characteristics of REMPI causes parent molecular ion signals to dominate the mass spectra. These features allow interpretation of spectra from complex mixtures and therefore circumvent complicated sample preparation procedures.

The IR laser pulse desorbs material from approximately 1 mm² of the sample surface. This spatial resolution is limited only by the focusing optics and the divergence of the IR laser beam. Mass spectrometric information can be obtained from sample regions much smaller than 1 mm² by partial overlap of consecutive laser shots.

Analysis by L²MS was performed at Stanford University. Great care was taken to avoid sample contamination during sample preparation. The main vacuum chamber was evacuated with turbomolecular pumps, which are essentially oil-free. The chamber was baked every night before measurements were taken. All roughing vacuum lines of the instrument were fitted with molecular sieve traps. Background signals were monitored routinely by exposing clean materials (glass, charcoal, ceramics) for varied times to the atmosphere of different working areas. Brief (30 min or less) exposures of the test materials to the laboratory atmosphere and to a nitrogen-flushed glove box for sample preparation gave rise to a chemical background of about a factor of 2 larger than the electronic noise. However, laboratory air was found to cover surfaces slowly (within many hours) with contaminants, some of which are believed to be PAHs originating from oil vapors or car exhaust entering the laboratory through the ventilation system.

Two different samples were used for analysis by L²MS: (1) pulverized material of different grain size from sample A, and (2) a cube of approximately 5 × 6 × 6 mm dimensions of sample B. The pulverized material was pressed to a thin, 7-mm diameter pellet, using glycerol as a binder. Three different grain-size fractions were analyzed: <38 μm, 38–61 μm, and 61–351 μm. The cube (sample B) was cut in a clean room from a bigger piece such that five of the six exposed faces were interior surfaces. Immediately before analysis, it was cleaved with a rock splitter, and the splits were collected in aluminum foil. Without further treatment, the splits were then mounted onto glass substrates with a thermoplastic polymer[‡] such that the surface of interest was facing the desorption laser. This sample preparation method allowed for some crude depth profiling. The sample probe,

which carried either a pellet or a solid chunk, could be introduced directly into the source region of the laser mass spectrometer through a vacuum interlock.

Because different PAH structures have varied cross-sections for REMPI, quantifying the observed mass signals is not trivial. An estimate for absolute quantitation can be obtained by spiking materials that imitate the meteorite matrix with known quantities of pure substances (ZENOBI et al., 1989). Different PAH skeletons showed large variations in intensity, whereas a minor dependence on the substitution of a given ring structure was found. For example, the sensitivities of phenanthrene (178 amu) and pyrene (202 amu) were enhanced by an order of magnitude over those of their isomers anthracene and fluoranthene.

Amino Acids

The following three samples of Forest Vale were processed at the Scripps Institution of Oceanography, La Jolla, CA, for amino acid analysis: 70.0 mg of bulk sample A; a 54.0 mg split of the 38–61 μm size fraction of sample A; and 121.8 mg of bulk sample B. For comparison, 91.5 mg of the Murchison meteorite were also processed. The samples were pulverized in clean Pyrex test tubes that had been precombusted overnight at 500°C. Blanks consisting of 50 mg ground glass and 50 mg ground glass spiked with AIB and racemic ISOVAL were processed simultaneously. The tubes were sealed with 2 mL of doubly distilled water and heated at 100°C for 24 h. The water extracts were then transferred to a second set of tubes and evaporated. A 2-mL aliquot of doubly distilled 6M HCl was added, and the tubes were sealed and heated again at 100°C for 24 h. The acid hydrolysis was performed to liberate the acid-labile precursors that exist in Murchison and other carbonaceous chondrites (CRONIN et al., 1988). The HCl was evaporated, and the residue dissolved in a small amount of doubly distilled water. The samples were then desalted on 2 mL of fresh Bio-Rad AG 50W-X8 cation exchange resin and eluted with 1.5 M NH_4OH. The ammonia was evaporated, and the desalted samples were redissolved in a small amount of water.

Analysis was performed on an Altex 110A high-performance liquid chromatography (HPLC) system equipped with a C-18 reversed-phase column, a Shimadzu RF-530 fluorescence detection system (excitation wavelength 340 nm; emission wavelength 450 nm), and a Hitachi D-2500 integrator. The analytical procedure was similar to that used by ZHAO and BADA (1989). Ten microliter aliquots of sample were reacted with 5 μL of a reagent containing 4.0 mg o-phthaldialdehyde (OPA), 2.4 mg N-acetyl-L-cysteine (NAC), 0.30 mL methanol, 0.43 mL water, and 0.25 mL of 0.4 M sodium borate buffer at pH 9.4. After 1 or 20 min, the derivatization reaction was stopped with 0.5 mL of 50 mM sodium acetate buffer at pH 5.2. Fifty microliters were injected into the HPLC system. The resulting fluorescent OPA/NAC amino acid derivatives were separated chromatographically on a solvent gradient running from 92% 50 mM sodium acetate buffer at a pH of 5.4 and 8% methanol at 4 min, to 63% buffer and 37% methanol at 14 min, and finally to 58% buffer and 42% methanol at 24 min. The flow rate was 1.0 mL/min. All reagents were Pierce HPLC grade. Good resolution of D/L diastereomers was achieved. Peak identification was by retention time and by response to the duration of derivatization. α-Methyl-substituted amino acids such as AIB and ISOVAL are known to be less responsive than α-proton amino acids to derivatization for 1 min. However, the yield for AIB and ISOVAL is increased roughly five to eight times if derivatization is carried out for 15–20 min at room temperature (ZHAO and BADA, 1989). α-Proton amino acids do not exhibit this behavior. Only if a fluorescent peak had the same retention time as a standard run the same day and if this peak increased in intensity five- to eight-fold after 20 min derivatization was it identified as AIB or ISOVAL.

RESULTS AND DISCUSSION

Initial L²MS experiments were carried out using different size fractions of pulverized material from sample A. Figure 1 shows a representative mass spectrum for the sample A coarse fraction. Intense mass spectra were obtained from all

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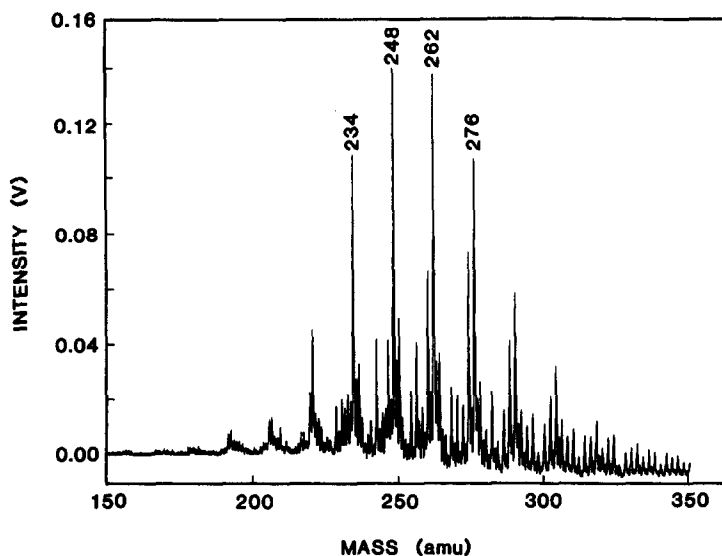[‡] Crystalbond™ 509, Armeco Products, Inc., Ossining, NY.

FIG. 1. L^{2}MS spectrum of the coarse size fraction (61–351 μm) from sample A, obtained from a pressed pellet of pulverized material.

size fractions. Peaks corresponding to masses of 234, 248, 262, 274, 276, and 290 amu were the most prominent in the spectra. The distributions did not vary qualitatively for different size fractions of sample A, but a variation in intensity was found. The dependence of the spectral intensity on grain size was approximately 3:1:5 for the small, medium, and coarse fractions. NOONAN et al. (1972) also found an increased carbon content in smaller size fractions of pulverized Forest Vale material, but the higher concentration of organic material in the coarse fraction was unexpected.

For comparison, an intact cube (sample B) specially prepared for organic analysis from the interior of the Forest Vale meteorite was investigated by L^{2}MS. All mass spectra obtained from this sample were qualitatively different from those

obtained from sample A. The most intense peaks in the mass spectra of sample B were at 178, 192, 206, and 220 amu (Fig. 2). The spectra did not vary qualitatively for different areas analyzed.

The systematic qualitative differences between the L^{2}MS spectra from samples A and B could be caused by inhomogeneities in the Forest Vale meteorite on a centimeter scale, but it also raises the question of contamination. Although the history of sample curation and preparation should be known in order to assess the possibility of contamination from terrestrial sources, such is not the case for sample A. Migration of contaminants from the sample surface into the interior may result in concentration gradients (CRONIN and PIZZARELLO, 1990). No gradient was observed for sample B
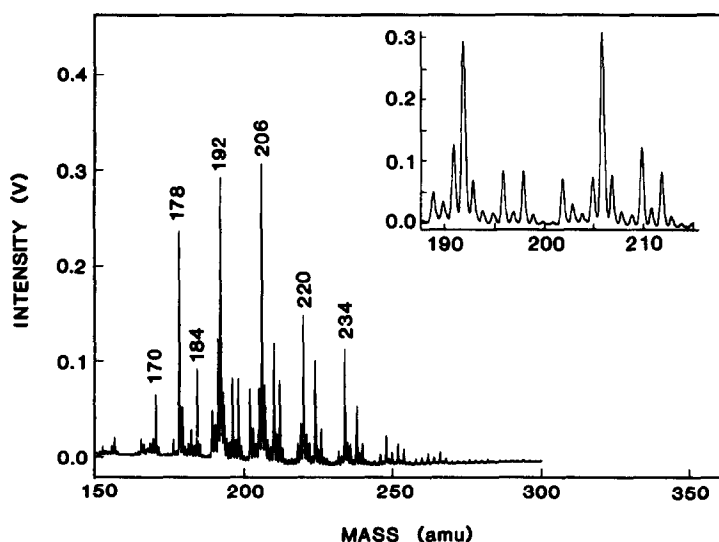

FIG. 2. L^{2}MS spectrum of a freshly cleaved surface from the interior of the Forest Vale meteorite (sample B). See Table 1 for peak assignments. The gain used in Fig. 2 is twice that used to obtain the spectrum shown in Fig. 1. The insert shows high-resolution detail around the base peaks of the same spectrum.

(see Fig. 3). For sample A, only crushed material was available, which rendered impossible the measurement of spatial distributions of organics. Because phenanthrene has an appreciable vapor pressure at room temperature, the peaks at 178, 192, 206, and 220 amu, which are absent in the L^{2}MS spectra of sample A while present in the spectra of sample B, could be caused by the selective loss of certain PAHs from volatilization during processing and storage of the crushed sample A. Several indications, including the amino acid analyses and crushing experiments on sample B presented below, suggest that sample B is probably close to pristine, whereas sample A is contaminated. This contamination probably arose during processing and handling of the sample prior to our obtaining it for analysis. Hence, we will concentrate our discussion and interpretation of the L^{2}MS data on sample B.

Figure 2 shows several series of peaks with characteristic spacings of 14 amu. This spacing indicates that the meteorite contains PAHs with alkylated skeletons. Although the most intense signals were found for PAHs with one or two additional carbon atoms and alkyl substituents, the meteorite contains extensively alkylated PAHs as well. Up to six additional carbon atoms attached to a given PAH skeleton were found. Table 1 lists possible assignments of the observed peaks. Note that different isomers of PAHs cannot be distinguished by L^{2}MS. Using known instrumental sensitivities (in mV/ppm) for pure compounds spiked onto a simulated meteorite matrix, rough estimates for concentrations of various PAHs were obtained (ZENOBI et al., 1989). The ppm values in Table 1 are averages from several spectra of freshly cleaved splits of sample B. For isomers, the concentration listed is for the compound with the higher REMPI cross section.

The peak pattern of sample B (also see insert in Fig. 2) exhibits an obvious even-odd intensity alteration. This could be interpreted that small quantities of nitrogen-containing

aromatic compounds are present. However, most heteroaromatic compounds have excited states in a wavelength region removed from 266 nm (COOPER et al., 1980; LI and LUBMAN, 1988), or possess very short-lived excited states whose decomposition efficiently competes with ionization by a second photon. An alternative possibility is that the odd masses represent the ^{13}C isotopic component of the detected PAHs. Using data from twelve different spectra and mass peaks from 170–238 amu, an average ratio of ^{13}C/^{12}C = 1.23 ($\pm$0.13) $\times$ 10^{-2} (δ^{13}C = +100 $\pm$ 100‰ relative to the PDB standard = 1.11237 $\times$ 10^{-2}) is estimated for the PAHs in sample B, neglecting any possible contribution to the (M + 1)$^+$ ion signals from deuterium enrichment in the PAHs. Our estimated ^{13}C/^{12}C ratio for the Forest Vale PAHs appears slightly greater than the terrestrial organic carbon isotopic ratio of 1.096 $\times$ 10^{-2} (δ^{13}C = 25‰) and is consistent with the findings that at least some extraterrestrial organic molecules are enriched in ^{13}C (YANG and EPSTEIN, 1983; EPSTEIN et al., 1987). Given the uncertainties in our ^{13}C/^{12}C value, however, it would not be prudent to place too much significance in this preliminary carbon isotopic ratio for extraterrestrial PAHs.

By cleaving sample B in different places, an approximate depth profile could be measured. Figure 3 is a plot of the intensities of three different mass peaks as a function of distance from the only unchipped surface of the sample. Although much variation in signal intensity was found, no clear trend with increasing depth was apparent. Samples at 0 and 4.5 mm depth were measured more than once. Whereas the spectral intensities for the two measurements at 4.5 mm depth were almost identical, the data at 0 mm depth showed more variation. We interpret the observed intensity variations in the latter to be a result of sample inhomogeneity.

We also prepared a few samples of finely crushed silicate grains and chondrules for comparison. Compared with spectra obtained from freshly cleaved surfaces, the signal inten-
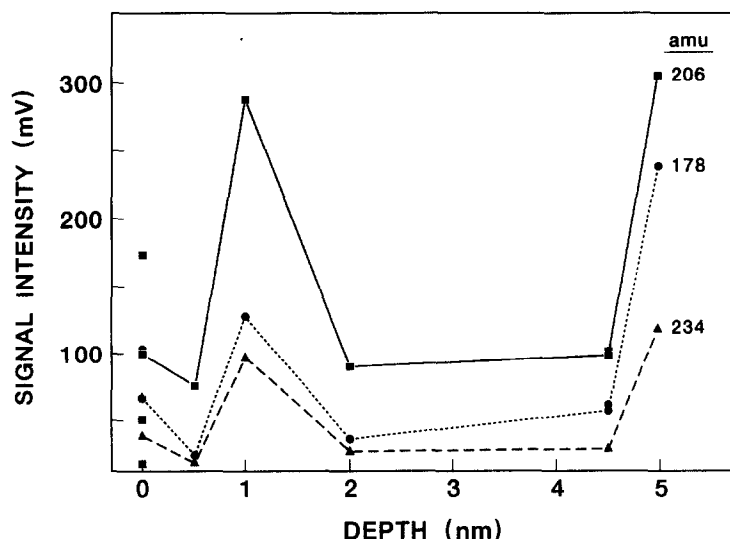

FIG. 3. Depth profile of the peak intensities for three different masses obtained from a small cube of the Forest Vale meteorite by L^{2}MS. The reference surface (zero depth) is the face that has not been chipped. The three points at zero depth indicate the inherent variability of the PAH signals present in the sample.

Table 1: Possible peak assignments for L^2MS mass spectra of sample B. Known instrumental sensitivity factors (ZENOBI *et al.*, 1989) have been used to estimate concentrations.

Mass(amu)	Possible assignments (formula)	Estimated average concentration (ppm)*
166	fluorene ($C_{13}H_{10}$)	trace
170	C_{13}-alkylnaphthalenes ($C_{13}H_{14}$)	0.7
184	C_{14}-alkylnaphthalenes ($C_{14}H_{16}$)	1
198	C_{15}-alkylnaphthalenes ($C_{15}H_{18}$)	1
178	phenanthrene/anthracene ($C_{14}H_{10}$)	2
192	methyl-phenanthrenes/-anthracenes ($C_{15}H_{12}$)	n.d.
206	C_{16}-alkylphenanthrenes/-anthracenes ($C_{16}H_{14}$)	n.d.
220	C_{17}-alkylphenanthrenes/-anthracenes ($C_{17}H_{16}$)	n.d.
234	C_{18}-alkylphenanthrenes/-anthracenes ($C_{18}H_{18}$)	n.d.
182	C_{14}-alkyl-biphenyls/-acenaphthenes ($C_{14}H_{14}$)	n.d.
196	C_{15}-alkyl-biphenyls/-acenaphthenes ($C_{15}H_{16}$)	n.d.
210	C_{16}-alkyl-biphenyls/-acenaphthenes ($C_{16}H_{18}$)	n.d.
224	C_{17}-alkyl-biphenyls/-acenaphthenes ($C_{17}H_{20}$)	n.d.
238	C_{18}-alkyl-biphenyls/-acenaphthenes ($C_{18}H_{22}$)	n.d.
202	pyrene/fluoranthene ($C_{16}H_{10}$)	1

* n.d. = not determined

sities obtained from these crushed samples were approximately two orders of magnitude smaller and in some cases below the detection limit (≈ 0.05 ppm by weight for PAHs containing a naphthalene, phenanthrene, fluorene, or pyrene skeleton). This difference further shows that the carrier phase of the PAHs is in the Forest Vale matrix, in agreement with spatially resolved studies on other meteorites (VAN DER STAP et al., 1986; ZENOBI et al., 1989). When pulverized samples are used, organic matrix constituents will be strongly diluted by crushed silicates and chondrules. This finding is in agreement with earlier L^2MS data obtained from pulverized bulk samples of two noncarbonaceous chondrites, Jilin and Clovis (HAHN et al., 1988).

Amino acids were detected in both Forest Vale samples A and B, especially glycine, L-aspartic acid, and L-alanine. The detected amino acids with chiral centers were very far from racemic, and no detectable amounts of AIB or ISOVAL were observed. The amino acids detected are thus presumed to be terrestrial contaminants. Figure 4 shows the region where AIB and ISOVAL would be expected to elute in the Forest Vale samples, and the complete chromatogram of Murchison. Although a small peak in Forest Vale sample A elutes with the same retention time as AIB, its intensity does not increase with the 20-min. derivatization (ZHAO and BADA, 1989). No peaks corresponding to racemic ISOVAL are observed in the Forest Vale samples. There was no difference in sample A between the bulk Forest Vale and the 38-61 μm grains.

Figure 4 also shows the results for Murchison. Note that AIB is the largest single peak after 20 min derivatization and that peaks corresponding to racemic ISOVAL are prominent. We detected concentrations of 5.5 μg/g AIB and 4.0 μg/g ISOVAL in Murchison, which is consistent with previously reported values (CRONIN and PIZZARELLO, 1983). In Forest Vale, we report limits of <0.08 μg/g AIB and <0.05 μg/g ISOVAL.

The detected levels of amino acids in sample B are close to those of our desalting blanks (i.e., within a factor of 2), which is not the case for sample A for which the amino acid amounts were significantly above the blank. Forest Vale sample B thus seems much cleaner with respect to terrestrial amino acid contamination, which supports our contention based on the PAH analyses that this is the most pristine sample.

Several different processes and chemical environments have been suggested to contribute to the synthesis of meteoritic organic matter (CRONIN et al., 1988). Our findings that Forest Vale contains indigenous PAHs but no detectable indigenous amino acids supports this view. The suite of amino acids found in Murchison is similar to that produced in the Miller-Urey synthesis (WOLMAN et al., 1972). The amino acids in Murchison are thought to have been synthesized from HCN, aldhydes, and ammonia by a Strecker-cyanohydrin pathway in an aqueous environment, perhaps in the pore fluids of the parent body (PELTZER et al., 1984). The
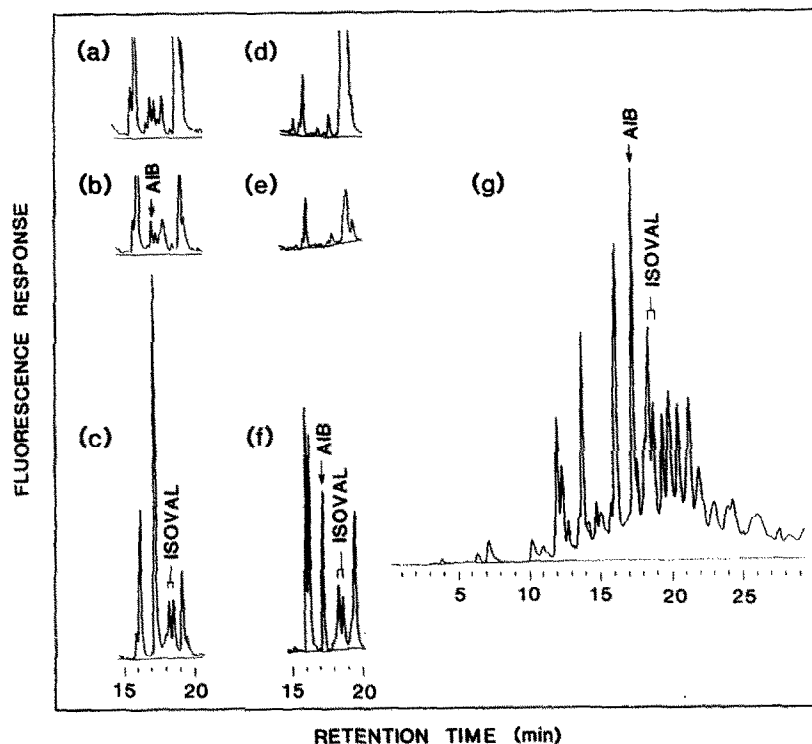
FIG. 4. Results of amino acids analyses. The retention times of AIB and racemic ISOVAL are indicated by the markers. (a) Portion of the HPLC chromatogram of bulk Forest Vale sample A representing the extract of 2.4 mg of sample. Derivatization for 1 min. (b) As (a), derivatized for 20 min. (c) As (b), spiked with a desalted mixture of 2.1 ng of AIB and 0.74 ng of ISOVAL. (d) Portion of the HPLC chromatogram of bulk Forest Vale sample B representing 2.4 mg of sample. Derivatization for 1 min. (e) As (d), derivatized for 20 min. (f) As (e), spiked with an amino acid standard containing 0.5 ng of AIB and 0.6 ng of ISOVAL. The two peaks eluting before AIB are racemic alanine. (g) HPLC chromatogram of Murchison representing the extract of 0.9 mg of sample. Derivatization for 20 min. The scale is twice that of (a)–(f). The nonracemic D/L isovaline ratio (e.g., measured value is 1.4) is caused by the interference from a peak immediately preceding D-isovaline.

suite of aliphatic hydrocarbons found in Murchison and other carbonaceous chondrites has been suggested to resemble that of a Fischer-Tropsch type of product (STUDIER et al., 1972; HAYATSU and ANDERS, 1981), although this view has recently been challenged (CRONIN and PIZZARELLO, 1990). Polycyclic aromatic hydrocarbons may have been synthesized by the thermal aromatization of Fischer-Tropsch products or by photochemical ion-molecule reactions in the envelopes of carbon-rich stars or on interstellar dust grains.

On the bases of the L^2MS data presented here for Forest Vale and previously for several carbonaceous chondrites (HAHN et al., 1988; ZENOBI et al., 1989), it is not possible to arrive at a definitive conclusion regarding the synthetic pathways responsible for the origin of PAHs in meteorites. The L^2MS results, however, do demonstrate that the distribution of PAHs in meteorites is quite diverse and is likely influenced by several processes. In Forest Vale, the diversity of PAHs seems to be greater than that in carbonaceous chondrites, including Murchison, analyzed by the same L^2MS technique (HAHN et al., 1988). WING and BADA (1991) have suggested that the simplicity of the PAH spectra of some carbonaceous chondrites can be attributable to the chromatographic separation of PAHs on meteorite parent bodies by aqueous hydrothermal fluids. Geochromatographic separation of PAHs would not be an important process for H4

chondrites such as Forest Vale because they have never been subjected to the action of aqueous fluids as evidenced by the absence of aqueous alteration products of matrix minerals. ZOLENSKY and MCSWEEN (1988) have reviewed the evidence for aqueous alteration of primitive solar system materials and have concluded that aqueous alteration occurred upon parent bodies of carbonaceous chondrites but not in the solar nebula. The PAHs in Forest Vale may have a presolar system origin, and thus their distribution pattern in this meteorite could be characteristic of presolar organic material.

CONCLUSIONS

We have identified PAHs in the matrix of the H4 chondrite Forest Vale, which has previously been observed to contain carbonaceous carriers of the trapped heavy noble gasses. No depth dependence of the PAHs was observed in a clean, freshly chipped, interior piece. No indigenous amino acids were detected. These results are consistent with the surmise that PAHs and amino acids in meteorites are synthesized by different processes. While amino acids are believed to require the presence of liquid water for their formation, most probably by the Strecker-cyanohydrin synthesis, PAHs apparently do not and may be presolar in origin.

Editorial handling: G. Faure

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