N90-27565

Carbon-rich Particles in Comet Halley*

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INTRODUCTION

The majority of particles detected in the coma of Comet Halley contain carbon atoms; many of these grains appear to consist preponderately or only of light elements. These light-element particles may be composed of organic compounds. Of the possible combinations of the elements hydrogen, carbon, nitrogen, and oxygen, numerous examples are found of particles containing the combinations (H,C,O,N), (H,C,N), (H,C,O), and (H,C). These results may bear on the recent detection of polyoxymethylene fragments, the observation of cyanojets (CN patterns consistent with release from solid particles), the possible presence of cyanopolyacetylenes or HCN polymer, and the make-up of the CHON particles. If cometary matter could reach the surface of the earth without complete disruption, these diverse organic and mixed particles could create unique microenvironments, possibly with significant or even pivotal prebiotic chemical activity.

This report provides a speculative insight into possible relationships between carbon in comets and carbon in life, as well as providing a brief overview of on-going analysis of data from the highly successful Particle Impact Analyzer (PIA) experiment flown on the Giotto spacecraft for the flyby of Comet Halley (development and implementation of PIA was under the direction of J. Kissel of the Max Planck Institute for Kernphysik, Heidelberg). PIA is a time-of-flight analyzer which obtains mass spectra of ions from individual particles impacting on a Pt-Ag foil target within the instrument. It is a pleasure to acknowledge the collaboration of L. W. Mason, who has accomplished invaluable work on data manipulation and scanning algorithms for implementing automatic classification of the empirically-deduced particle types.

RESULTS

Particle Types

At the relative speed of 70 km/s, particle kinetic energy is much higher than the average molecular binding energies of the constituents, resulting in a spectrum which to first order is of the singly-charged ions of these atoms. Several thousand instrument triggers occurred, due to impacts and trigger noise, with at least 2,000 spectra which appear to contain interpretable information on particle composition. The spectral lines occurring most consistently and pervasively are those of carbon and hydrogen.

Particles of differing composition are present. A plurality of particles appear to be of cosmic composition (major C, O, Mg, and Si; often with S and Fe, minor N, and sometimes Ca). These are termed "mixed" particles because they almost certainly contain more than a single chemical phase. Another group of particles consist of O, Mg, Si, and often Fe and Ca. These particles may well be silicate minerals. A final major group, with several possible subgroups, consists of particles predominantly of light elements. Such particles may be mostly or solely organic. The current analysis of this latter group will be emphasized in this communication.

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* PIA data analysis is supported in part by NASA, under contract JPL-956214.

CHON Particles

The CHON particles contain the elements attributed in the name, with N sometimes higher and other times lower than O. The discovery spectra for CHON and mixed particles are shown in Figures 1 and 2, respectively. These are so-called mode-zero spectra, whereby the time-of-flight mass spectrum is sampled intensively, once each 66.7 ns. For the CHON spectra, it seems clear from this sampling that measured amplitudes from the nitrogen peak exceed the signal from the oxygen peak. Ion yield corrections have not been applied to these data, and must be done so before the relative atomic proportions of these two elements can be estimated. Another set of CHON spectra are show in Figure 3. In this case, mode 1 data are shown, whereby only peaks and follow-up samples are shown. These particular spectra have been selected for N amplitudes less than O. A peak in the region 22-25, particularly at 23 or 24 AMU, is also often present, indicative of Na^+, Mg^+, and/or C_2^+ from this class of particle.

(H,C,O) Particles

Many particles contain H,C, and O with no observed N. These (H,C,O) particles also typically contain a specie producing a peak in the 23-24 region, as seen in the examples of Figure 4 and 5. It has previously been shown that this particle classification is distinct from the CHON particles by virtue of variable relative occurrence patterns during the flythough of the Halley coma (ref. 1, 2).

(H,C,N) Particles

Assigned to another class are particles each of which contains H, C, and N, but with no observed O, as seen in Figure 6. Again, these particles were interpreted as a distinct class because of their relative occurrence. It can now be reported that these particles only rarely produce a peak at 23-24, providing an independent verification of their distinctness from the (H,C,O) class.

(H,C) Particles

It should also be noted that many particles showing only evidence of hydrogen and carbon are present in the spectra. Further analysis will be required to explore the possibility that these grains might simply be a measurement artifact of one or more of the above light-element classes, but with N, O, or both elements not producing an observed peak. This is a possibility because of the fact that for all spectra other than the rare mode-zero samples, an automatic circuit within the PIA instrument must determine the presence of a peak at any given time before such peak is reported. Variability in peak shapes, not fully understood because of the difficulty in calibrating and characterizing the instrument in the laboratory environment, can cause peaks not to be detected. This is obvious in the occurrence of numerous spectra with only a single mass line and other spectra of doubtful chemical interpretation (e.g., a clearly silicate composition, but with the oxygen line missing).

DISCUSSION

Particle Characteristics

The discovery of jet patterns that imply gas-phase CN- correlated with a dust component not following the jets of the major dust pattern (A'Hearn et al., ref. 3), the so-called cyanojets, is presumably a result of volatilization or photo-release of from a <u>minor</u> particle component. The CHON particles were identified as the possible responsible agent. The (H,C,N) particles are, of

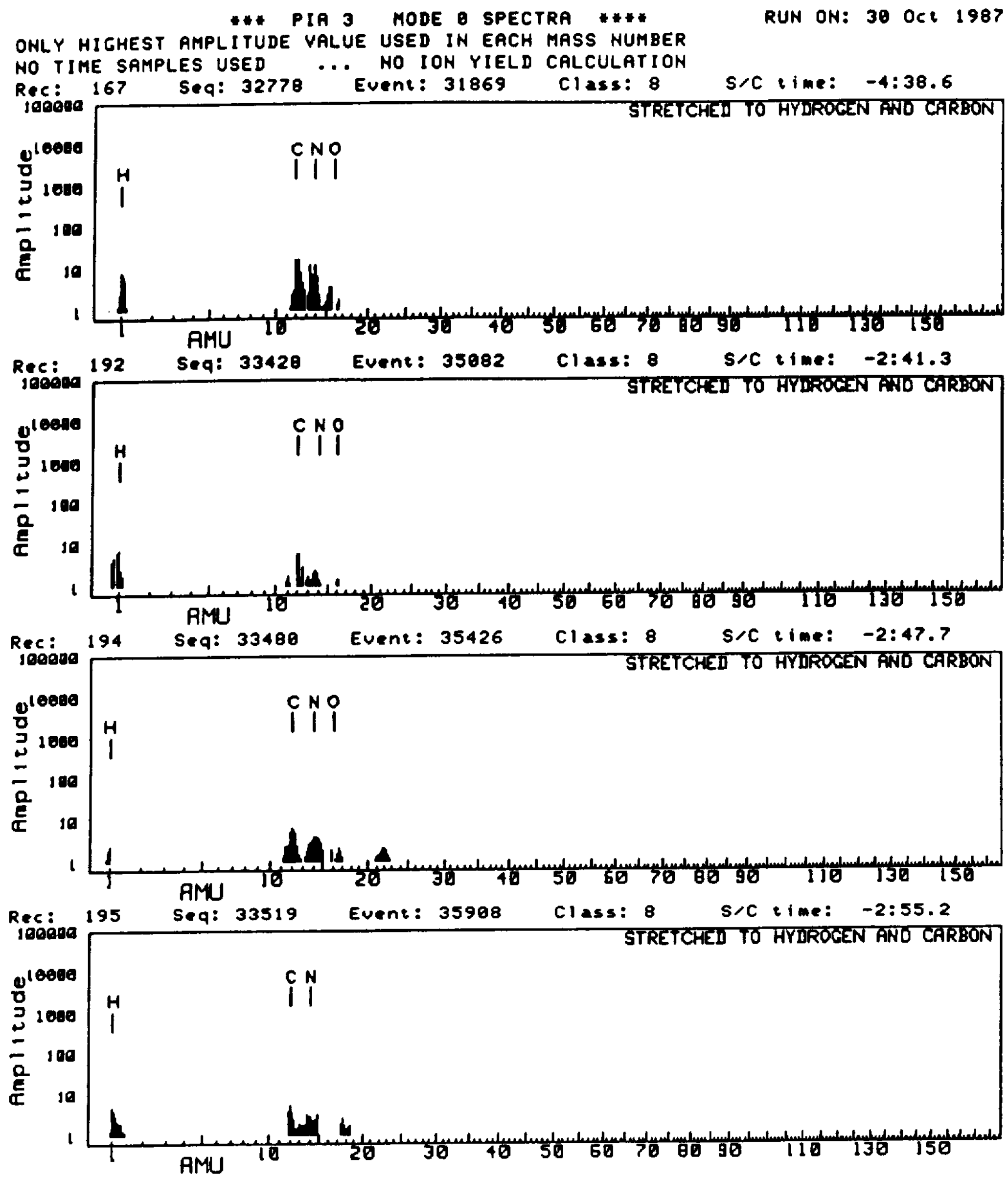

Figure 1. Selected CHON spectra from the mode zero data set.

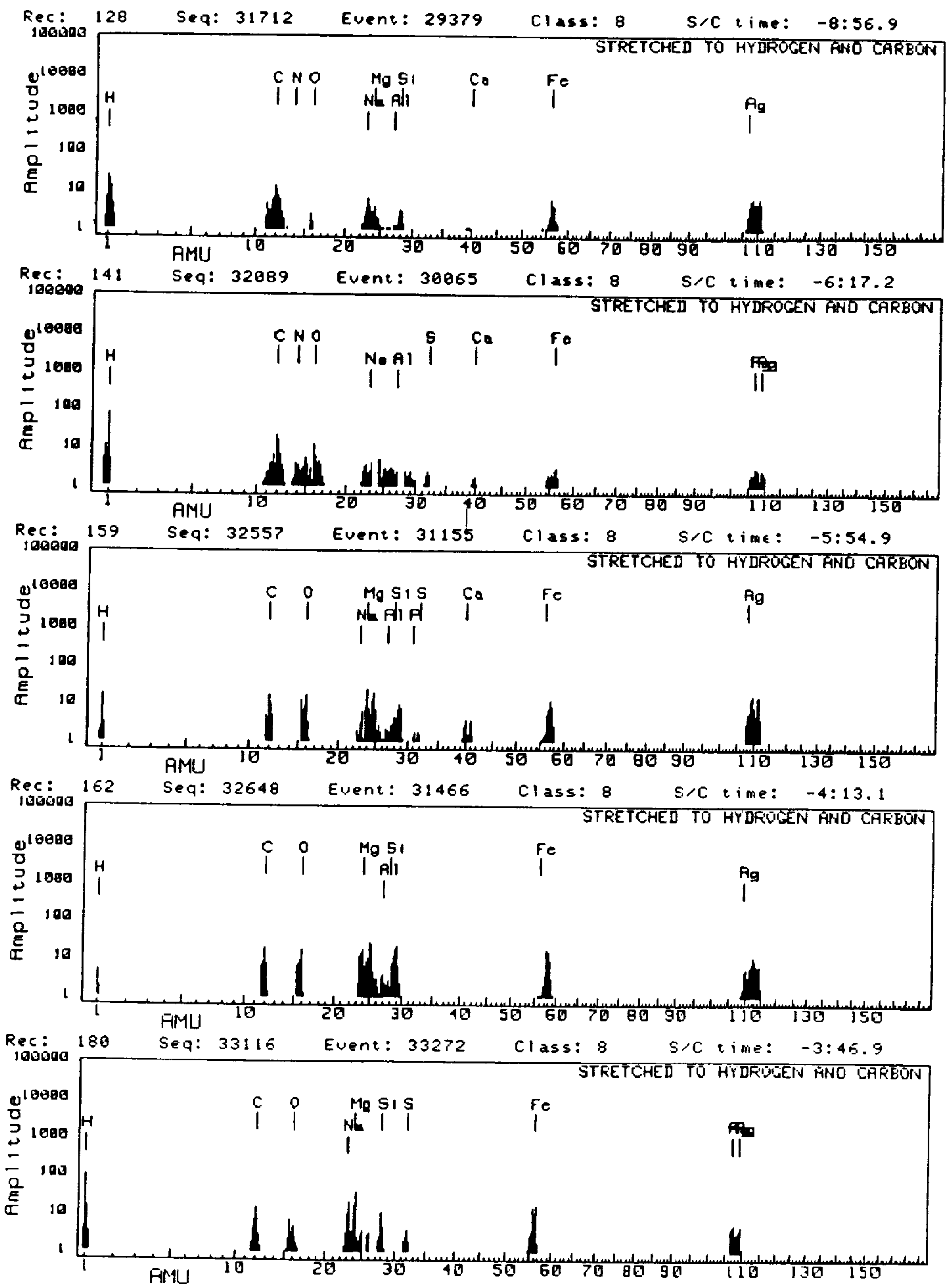

Figure 2. "Mixed" particles, mode zero data. Note the variation in distinctness of the peaks and the major variations of amplitude within a given element's mass range.

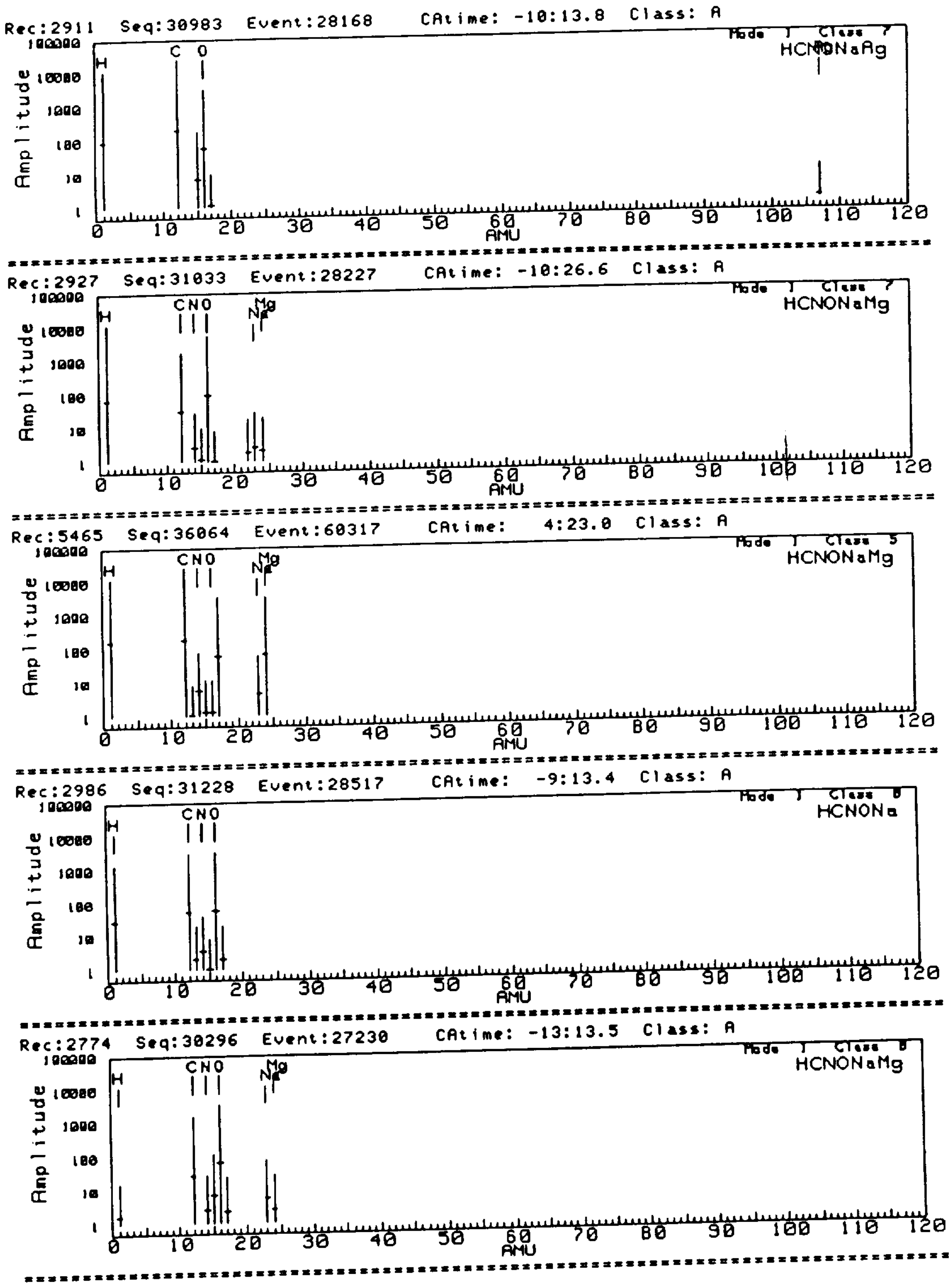

Figure 3. Selected mode 1 spectra showing large CHON particles. The topmost spectrum could also be classified as an (H,C,O) particle.

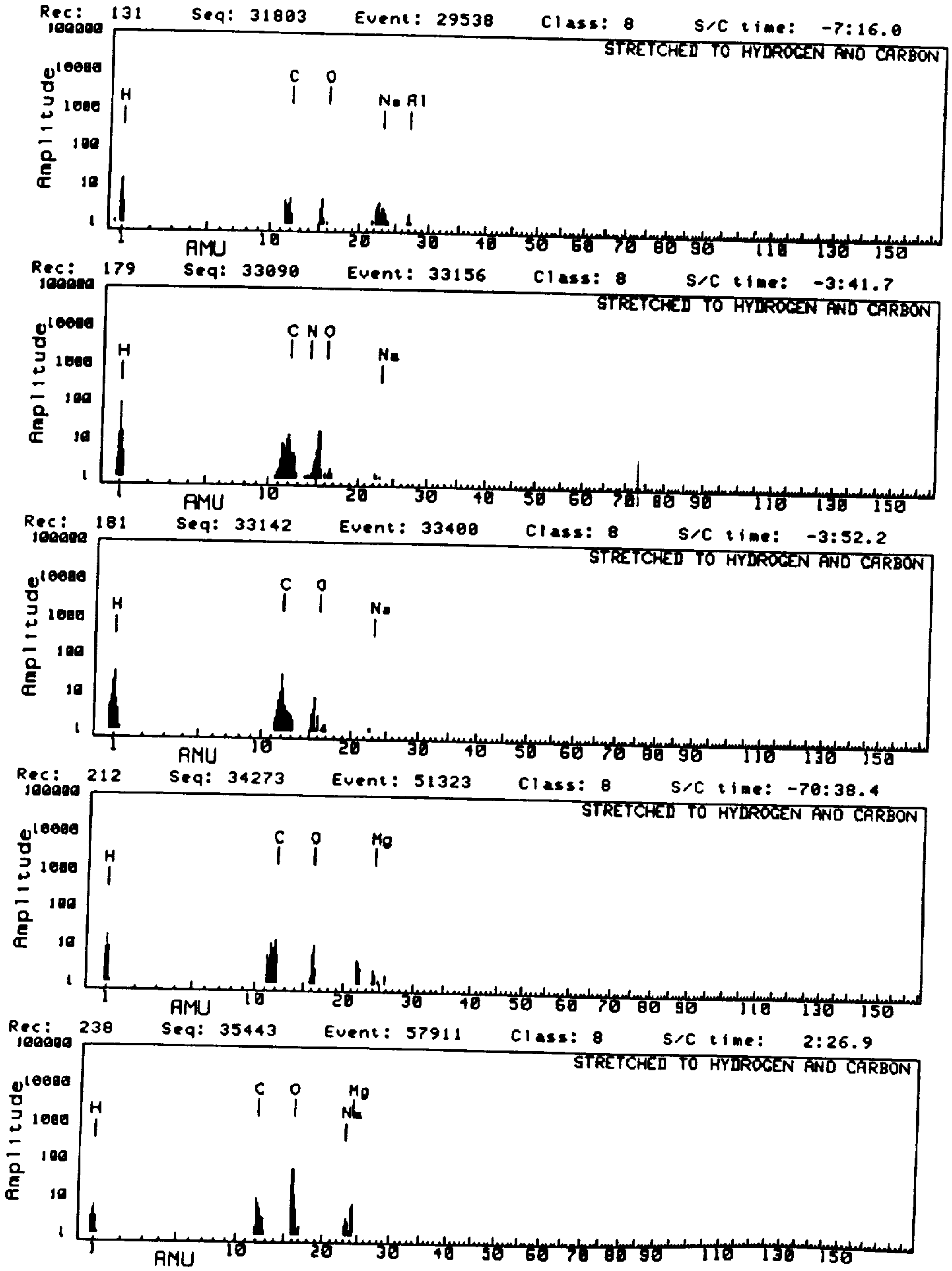

Figure 4. Mode zero spectra exhibiting the (H,C,O) classification.

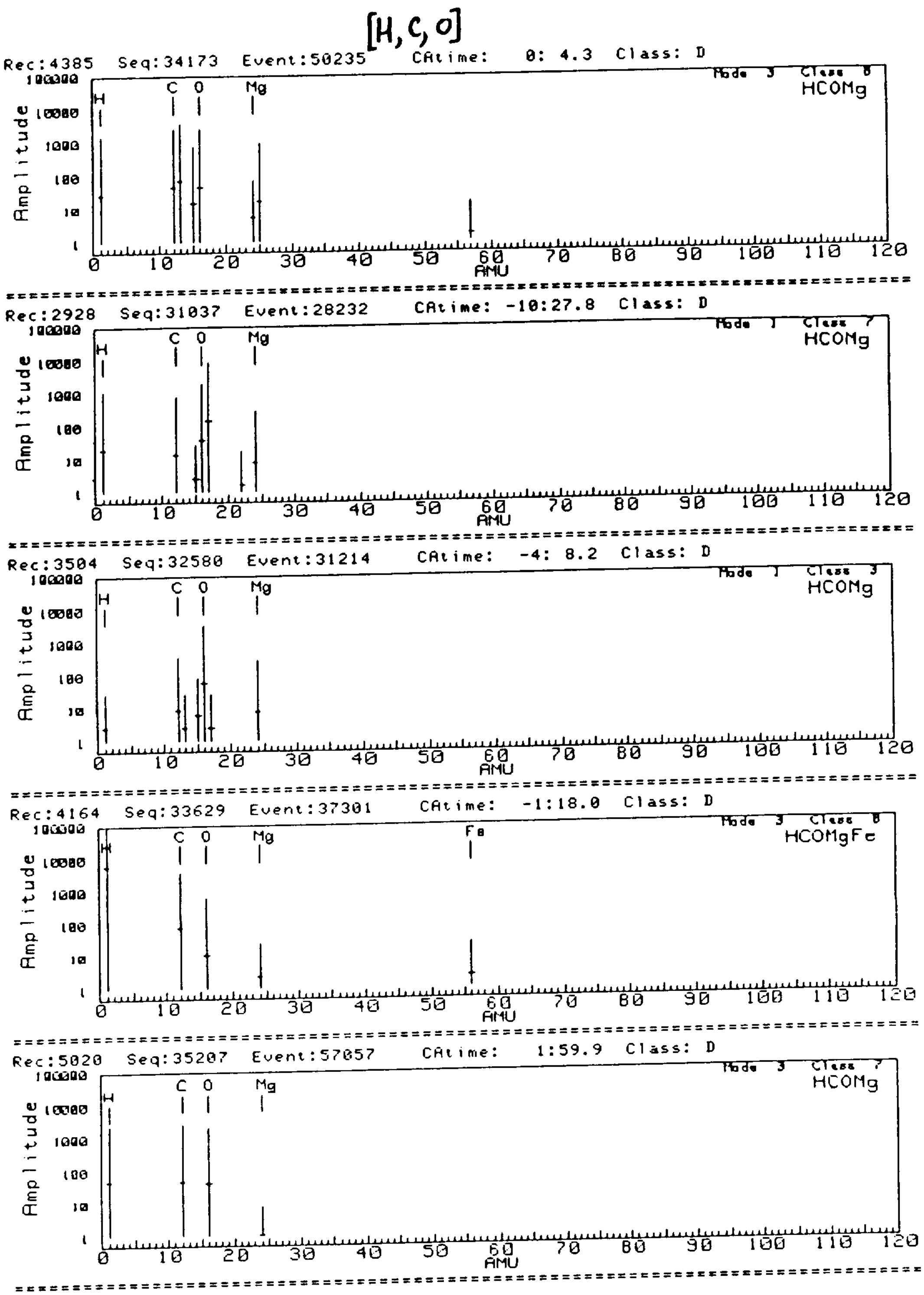

Figure 5. Additional examples of (H,C,O) particles. Note the occurrence of a peak in the 22-24 range in all of these spectra.

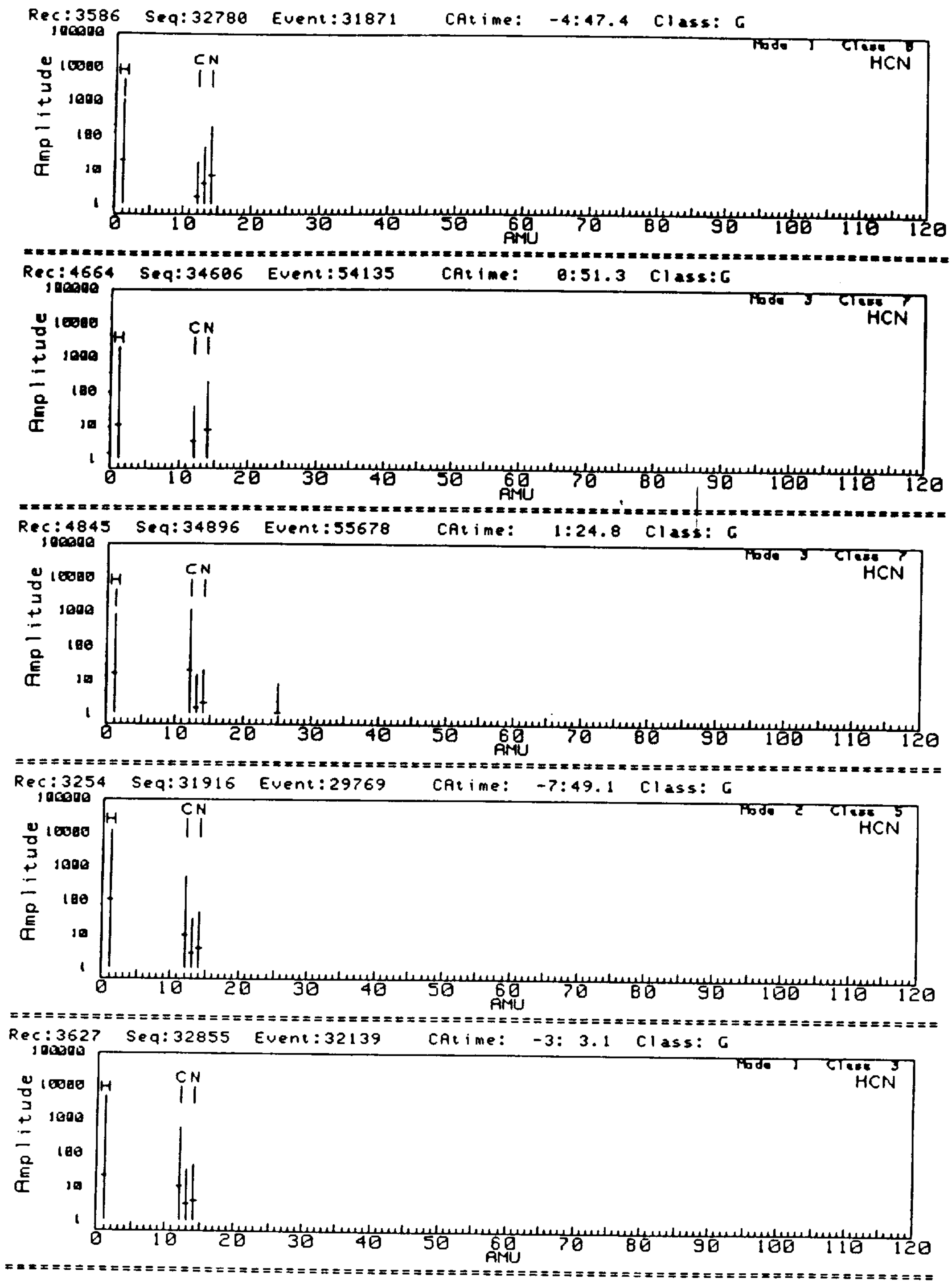

Figure 6. Examples of the (H,C,N) spectral class.

course, also a reasonable candidate. The possibility of polymerized hydrogen cyanide polymer in comets has been previously proposed (ref. 4).

Likewise, both CHON and (H,C,O) could release separately observable products. The recent recognition of polyoxymethylene (formaldehyde polymer) fragments in the gas phase (ref. 5, 6) opens the possibility that (H,C,O) grains could be the responsible source material.

The fact that the "23-24" peak occurrence pattern follows the relationship (H,C,O)>CHON>(H,C,N) in highly suggestive that CHON particles could be made up of (H,C,O) and (H,C,N) constituents, i.e., that CHON are also a mixture, or microconglomerate, or two or more particle types, just as are the "mixed" particles.

Kissel and Krueger (ref. 7) have inferred from minor peaks in spectra of the PUMA sister instrument flown on the Vega spacecraft during the Halley flyby missions that complex organic compounds may be present.

The overall impression is that comets are made up of a variety of primary grain types, each of which must have originated in separate times, places, and/or physicochemical conditions. As part of the accretion process, heterogeneous agglomeration on the particle-size scale anteceded formation of the macroscopic body we observe as the cometary nucleus.

Implications for the Origin of Life

I have recently pointed out that the diversity in cometary particulate types may have allowed the formation of organized prebiotic chemical entities, which in turn facilitated or enabled the origin of life. Carbon, the quintessential element in life as we understand it, is likewise the touchstone of cometary matter in so far as regards the possible connection with life's origin. Carbon is extraordinarily ubiquitous in Comet Halley particulates, far exceeding its relative occurrence in any abiotic natural material so far detected on any of the rocky planetary bodies or meteorites. Of even greater significance, however, is the apparent diversity of organic solid phases within comets. The "mixed", CHON, (H,C,O), (H,C,N), and (H,C) classes provide the possibility of at least five importantly different particle types, each of which is available across a range of sizes. In an aqueous environment, many specialized and semi-compartmentalized microenvironments would be created due to physi- and chemisorption processes as well as particle segregation according to size, density, and hydrophilic/hydrophobic tendencies.

Although rarely, *some* cometary nuclei (or fragments thereof) should survive accretive capture by planetary-sized bodies and thereby create a totally unique and localized, connected set of such microenvironments, providing one of the most favorable natural settings conceivable for the initiation of biogenic processes (Clark, ref. 8). The complexity of such an environment can only barely be imagined. Bulk, intact samples of cometary nucleus material will have to become available for direct laboratory analysis before the span of these possibilities can be comprehensively understood. Likewise, a retrieval and return to Earth of matter from a comet will permit a much richer understanding of the role of carbon in space chemistry and the anticipated multiphase distribution of this exceedingly important element.

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