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FURTHER ANALYSIS OF LDEF FRECOPA MICROMETEROID REMNANTS

Janet Borg
Institut d'Astrophysique Spatiale, Bat.121
91405 Orsay (France)
Phone: (33) 1 6941 5255, Fax: (33) 1 6941 5268

Ted E. Bunch
Planetary Biology Branch, NASA AMES Research Center
Moffett Field, CA 94035 (USA)
Phone: 415/604 6058, Fax: 415/604 6779

Filipo Radicati di Brozolo
Charles Evans & Associates
301 Chesapeake Drive, Redwood City, CA 94063 (USA)
Phone: 415/369 3867, Fax: 415/369 7921

Jean Claude Mandeville
ONERA/CERT Space Technology Department
BP 4025, 31055 Toulouse cedex (France)
Phone: (33) 6155 7117, Fax: (33) 6155 7172

ABSTRACT

In the Al collectors of experiment AO138-1 of the French Cooperative Payload (FRECOPA) payload, we identified a population of small craters (3-9 microns in dia.) induced by the impacts of micron-sized grains, mainly of extraterrestrial origin. Chemical analyses of the Interplanetary Dust Particle (IDP) remnants were made in the bottoms and on the rims of the craters, in addition to immediate off-rim areas. So far, the compositional investigation of the craters by Energy Dispersive Spectroscopy (EDS) has shown evidence of an extraterrestrial origin for the impacting grains. The systematic presence of C and O in the residues has been reported and may be compared with the existence of particles showing high proportions of biogenic light elements and detected in the close environment of P-Halley comet nucleus (called CHON particles). An analytical protocol has been established in order to extract molecular and possible isotopic information on these grains, a fraction of which could be of cometary origin. Although these very small craters may show crater features that are typical of the larger Long Duration Exposure Facility (LDEF) population (> 50 microns in dia.), some show unique morphologies that we have not previously observed. Our initial Laser Induced Mass Spectrometry (LIMS) analytical results show strong signals for nitrogen-bearing ions in craters characterized by high C and O contents; they also suggest that carbon contents in some craters could exceed that known for carbonaceous chondrites.

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INTRODUCTION

Since the first NASA U-2 flight collection in 1974 (ref. 1), the collection and analysis of IDPs orbiting around the Earth have been greatly enhanced. This enhancement occurred especially by the analyses of hard collectors that were exposed in Low Earth Orbits, before the impacting grains could have been processed by their entry in the Earth's atmosphere.

Our primary interest in the analysis of IDPs arises from the possibility that an unknown fraction of these particles could be of cometary origin and thus contain information on the early history of the solar system. In addition, asteroidal and interstellar particles may also be present. Cometary material is likely to be the most primitive material accessible for analysis. It is thought that grains once present in the cometary nuclei and now present as individual grains in interplanetary space are the best candidates for having remnant properties that were acquired before and/or during condensation in the protosolar nebula. The smaller size fraction (grains < 10 microns in diameter) is assumed to be enriched in grains of cometary origin (ref. 2). Our collected IDPs have been subjected to various kinds of irradiations, inside the past and present solar system. Bénit and Bibring (ref. 3) have theorized that these different irradiations of grains could result in different physical, chemical and isotopical properties. In particular, carbonaceous material present in some grains could have been synthesized during early periods of intense solar irradiation. Manmade orbital debris is also present and many of these particles had velocities similar to some IDPs (ref. 4). Debris particles are recognizable by their compositional signature (Ti or Zn of paint flakes, aluminium oxide spheres or lack of a "chondritic"composition, etc).

Among all the spacecrafts returned, LDEF was the first one designed to study the effects of space environment and to determine particle flux and orbital parameters. The FRECOPA experiment, in particular, was devoted to the study of dust particles and contained two entirely passive experiments that were flown for the detection of microparticles - AO138-1 and AO138-2. It was located on the west-facing side (location B3) of LDEF directly opposed to the velocity vector. Its position is assumed to have been exposed mostly to grains of extraterrestrial origin (ref. 5). Our primary objective was to gain information on the micron-size fraction of IDPs by hard capture into a high purity Al surface. Even though the impacted paricles were mostly destroyed (some intact grains survived moderate to low velocity impacts), meaningful information on composition, flux and particle size can still be obtained. Moreover, the light elements, particularly the biogenic elements C, H and N, and possibly intact carbonaceous compounds, can be suitably analyzed which is essential for characterizing possible cometary particles.

EXPERIMENTAL APPROACH

We are mainly interested in the analysis of IDP impact residue found in some small craters ($\leq 10\ \mu m$ in diameter) that formed in thick (250 microns) Al targets of the FRECOPA experiment AO138-1. During an impact, the impacting particle (impactor) is melted to partially melted and/or vaporized. Some of the target material (Al) is admixed with the impactor during the time of crater formation. Cratering by light gas gun hypervelocity impact experiments have shown that meaningful biogenic element and organic compound information may be obtained from IDP residues formed from impacts of $\leq 6\ km\ sec^{-1}$, which is the experimental limit (ref. 6). We suggest that most of the small crater impactors collided with LDEF at velocities equal to or greater than the spaececraft velocity (7.5 km sec^{-1}; ref. 7).

An initial survey of the sample was accomplished by using a scanning electron microscope (JEOL JSM-840A), at low magnification (x750), in order to locate the craters. The JEOL SEM is equipped with an EDS Analysis TRACOR System in which the X ray detector is protected by a very thin (15 μm) carbon window, which allows for semi quantitative analysis down to the element Na, and qualitative detection down to C; N is not detected, due to absorption of its X rays by the C window. Thus, energy dispersive analyses (EDAX) allowed us to characterize the impactor composition including the light elements carbon and oxygen. Aluminium was disregarded because of its incorporation from the target into the impactor residue during impact melting.

The samples were then subjected to an imagery and analytical protocol that includes FESEM (field emission scanning electron microscopy) and LIMS. The FESEM observations were performed by using a HITACHI S-4000, located at NASA AMES. LIMS analyses were performed by using a LIMA-2A instrument at CHARLES EVANS & ASSOCIATES. This instrument was operated in the single laser probe mode, which allows for atomic and molecular identification. At some future time, residues that are characterised by high C/O ratios from EDAX analyses will be analysed by the 2-stage laser mode technique which allows for more complete molecular identification.These samples may be finally analyzed by a CAMECA 4F ionprobe for determination of D/H ratios.

ANALYTICAL AND OBSERVATIONAL RESULTS

Flux and EDAX Measurements

An earlier effort showed that the cumulative flux for impact features smaller than 10 μm in diameter is ~ $5 \cdot 10^3$ m^{-2} $year^{-1}$ (ref. 8). These particles consisted mostly of extraterrestrial particles, which was confirmed by EDAX analyses. The measurements were made on ~ 10 cm^2 of exposed surface and are consistent with the previous estimates of the micrometeroid particle mass distribution given in Figure 1, although slightly higher. The extraterrestrial particles show various proportions of chondritic elements (Na, Al, Mg, Si, S, Ca and Fe), intrinsic Al being masked by the Al target. We noticed a strong depletion in Ni which was not observed above the analytical detection limits in our samples. Furthermore, C and O are present in 90% of the cases; the C/O peak height ratio varies from 0.1 to 3 (ref. 9). The systematic presence of low Z elements, associated with other elements whose abundances reflect a chondritic type composition, can be compared to results obtained by the PUMA and PIA experiments (ref. 10). These experiments analyzed grains in the close environment of the Halley comet's nucleus and demonstrated that at least 50% of the grains within the nucleus contain a phase made of C,H,O and N atoms (CHON particles). The existence of grains with similar compositions, close to the nucleus and in terrestrial orbit, means that they are stable and refractory enough to survive long-term irradiation in the intense solar UV field. Such refractory phases may have had an irradiation origin.

FESEM Observations

FESEM images show several characteristics unique to very small craters and impactor residues: i) Some craters have raised rims and depth/diameter ratios (D/d) ~ 0.7 similar to those of larger craters. However, instead of peeled-back rim structures commonly seen in the large craters, these small raised rims have a vermicular appearance (Figs. 2a & b). In addition, the rim is symmetrical with no missing parts which implies a high angle impact. Impactor residue thinly covers the crater cavity; some melt balls or droplets can be seen in the crater bottom (Fig. 2b). These features may be characteristic of high impact velocities (> 10 km sec^{-1}). ii) Other very small craters have no raised rims and are shallower than those in i; D/d = < 0.5. Moreover, the Al within the crater has a peculiar polygonal structure (Figs. 2c & d). Figure 2c shows a crater with gently sloping walls except on the left side of the crater where the wall is vertical. This feature may imply that the crater formed at a low impact angle, impacting from right to left in the figure (P. Schulz; pers. comm.). These craters are subrounded to elongated in shape with or without visible impactor residue. In some craters of this type, C-bearing residue has a puddle-like appearance and, in some areas, has separated from the crater wall (Fig. 2d). Crater features like these have not been reported for larger LDEF craters. The lack of rims in some small craters may be the result of low velocity impacts, low angle impacts and/or spallation. The cause of the polygonal structure in the cratered Al is unknown.

LIMS Analyses

The single laser ionization technique is limited in its ability to identify primary organic molecules. This method uses a high power density pulsed laser irradiation, which tends to fragment most, though not all, parent molecules into smaller fragment ions. Despite this drawback, significant information can be obtained. For example, Fig. 3a shows the LIMS negative ion mass spectrum for crater P6 (shown in Fig. 2c). This spectrum is dominated by carbon clusters (C_2^- and C_{12}^-) and these are accompanied by protonated clusters (C_xH^-). In addition, nitrogen is present as CN^- and CNO^-; sulfur is present either as S^- or as SO_2^-. This carbon cluster pattern is typical of laser fragmentation of a carbon precursor (e.g., graphite or amorphous). Since N and H are present, this suggests that the impactor contained organic species, although no identifiable parent molecules were found up to ionic mass (m/z) 250. The spectrum of crater P10 (shown in Fig. 2d) is even more informative and suggests large amounts of N in the preimpact particle. Figure 3b shows prominent carbon clusters up to C_{15}^-, protonated clusters and very strong CN^-, CNO^- and C_3N^- features, in addition to other unidentified ionized masses. Chlorine, F, and OH^- are also present, although these may be contaminates.

CONCLUSIONS

LDEF was impacted by millions of very small particles that constitute the bulk of extraterrestrial impactors (ref. 11). We have demonstrated that very useful information can be obtained on the carbonaceous chemistry of residual impactors on very small craters. The results of our FRECOPA test cases indicate that craters as small as 3 microns contain particle residues that have "chondritic" signatures as well as carbonaceous material. Although the amount of carbonaceous material is not accurately known, estimates indicate that carbon contents in some craters exceed that which is known for carbonaceous chondrites with the C/O ratios being more consistent with cometary particles than with bulk CM2 carbonaceous chondrites (ref. 10). In addition, the strong signals for nitrogen-bearing ions in the LIMS analyses suggest concentrations greater than that of carbonaceous chondrites and possibly consistent with Halley CHON particles (ref. 10).

At this time, it is premature to conclude that the particles responsible for the production of the small craters analyzed in our study were cometary in origin. However, the analytical techniques that we used and others that we plan to use in the near future on tens of small craters may allow us to clearly distinguish between cometary and asteroidal particle impactors. The LDEF data base pertaining to composition and origin of particle impactors can be greatly enhanced by detailed characterizations of large numbers of small craters.

AKNOWLEDGEMENTS

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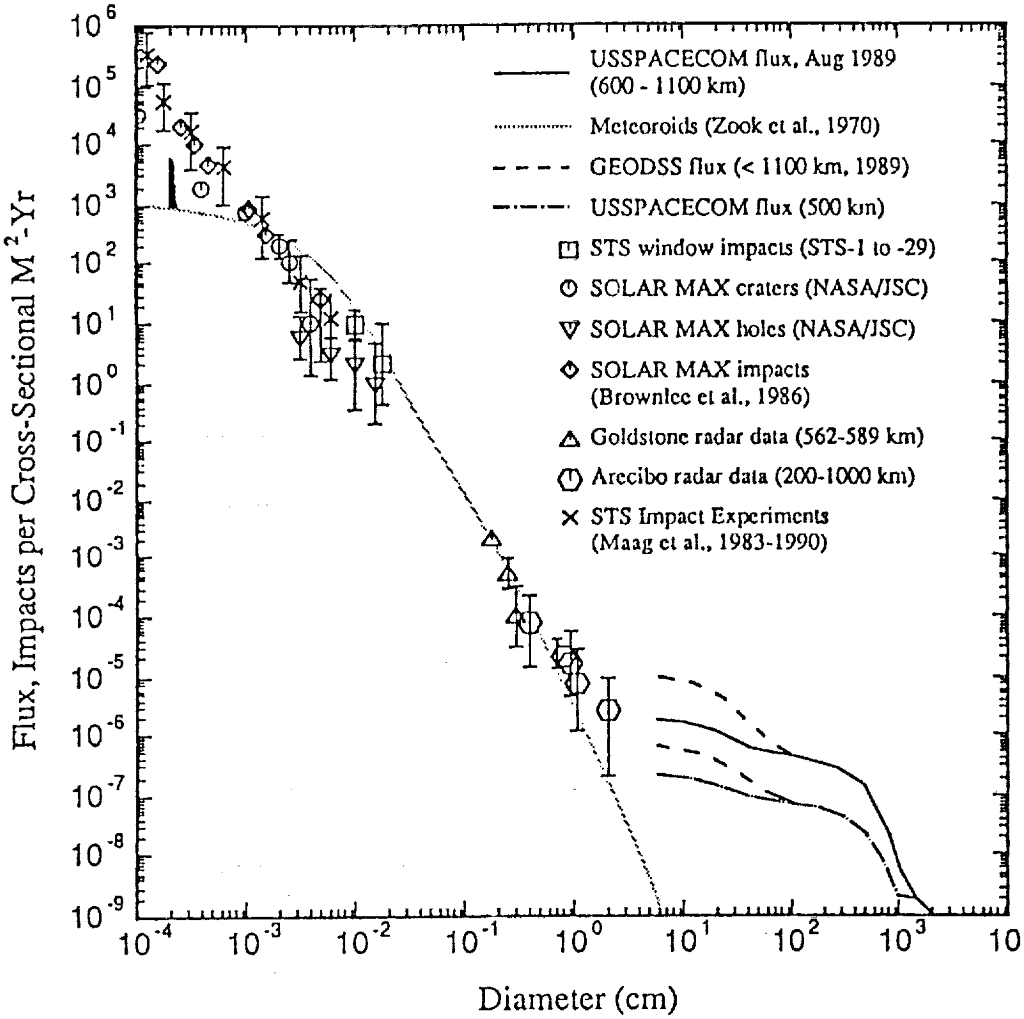
FIGURE CAPTIONS

Figure 1. The flux of natural objects compared at 1 AU with that of manmade debris. The large black square represents results obtained on Al collectors of the FRECOPA AO138-1 experiment (refs. 8, 9), for events ≤ 10 microns in size, compared with other natural and manmade debris flux measurements.

Figure 2. FESEM images of very small LDEF impact craters. (a) Image of a small crater in Al with a prominent raised rim (~ 3 µm diameter); arrows point to melt ejecta which is mostly Al. (b) Enlarged view of the crater in a showing the vermicular morphology of the rim and a melt ball in the crater bottom. (c) Shallow crater with little residual impactor and no raised rim. Arrows point to contamination grains. Note the peculiar polygonal structure of the Al. (d) Another polygonally textured crater with impactor melt residue. Short arrow points to the seperation of residue from Al; long arrow points to a contaminant.

Figure 3. Laser ion microprobe negative ion mass spectra acquired from inside craters P6 (3a) and P10 (3b) respectively. Each spectrum is produced by a single laser pulse. Estimated power density ~ 10^9 W/cm^2 per pulse. The intensity (vertical) scale is in arbitrary units. Both spectra exhibit intense signals of $C_xH_y^-$ clusters, which follow a pattern consistent with a carbonaceous or organic composition of the analysed area. Other notable peaks include CN^- and CNO^-. A weak signal of S_2^- (or SO_2^-) is observed at m/z 64 in crater P6 (Fig. 3b). Signals of Cl^- (Figs. 3a and 3b), O^-, OH^- and F^- may be contaminants.



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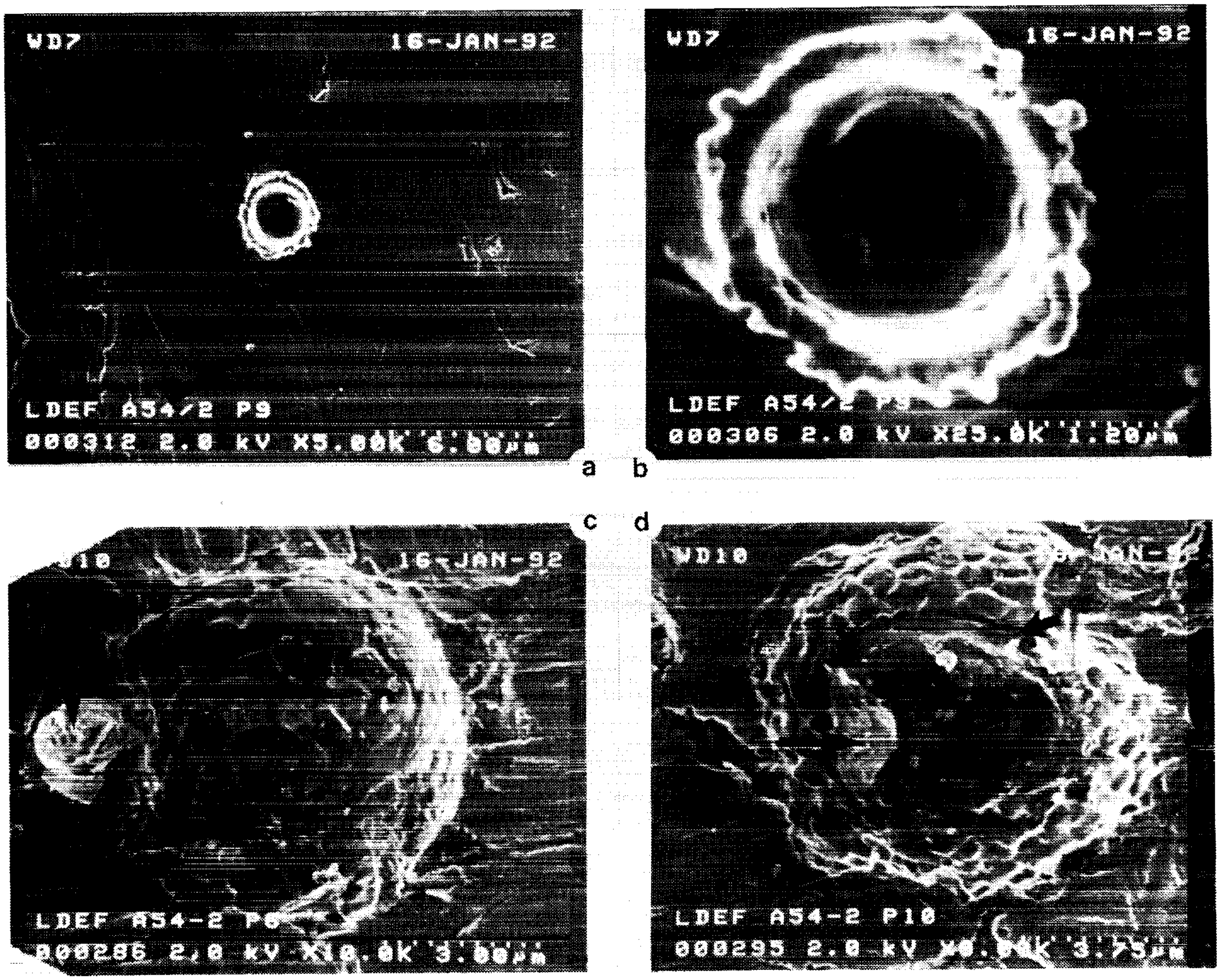

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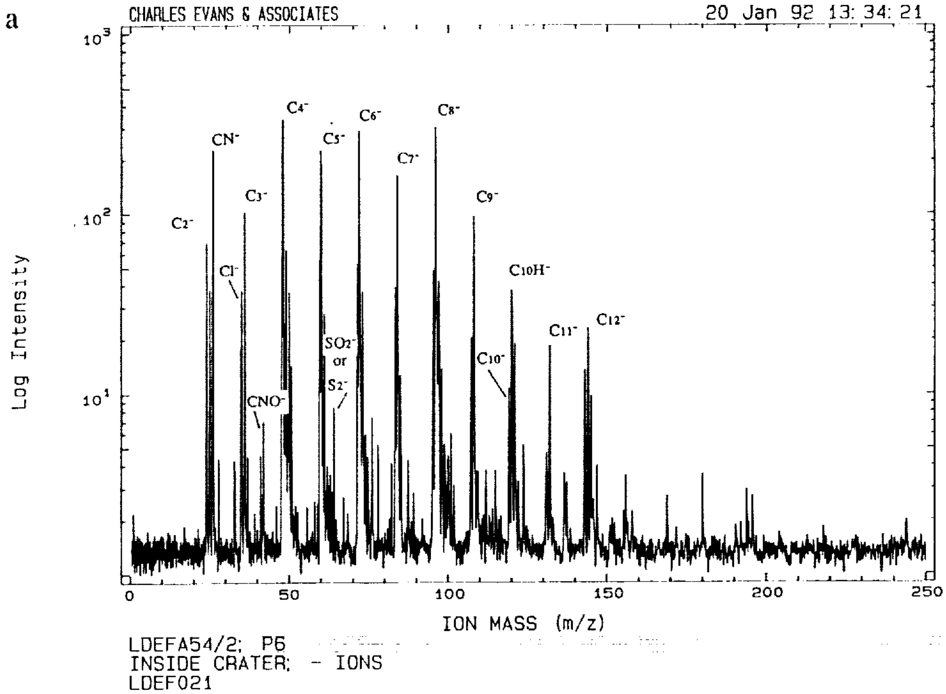

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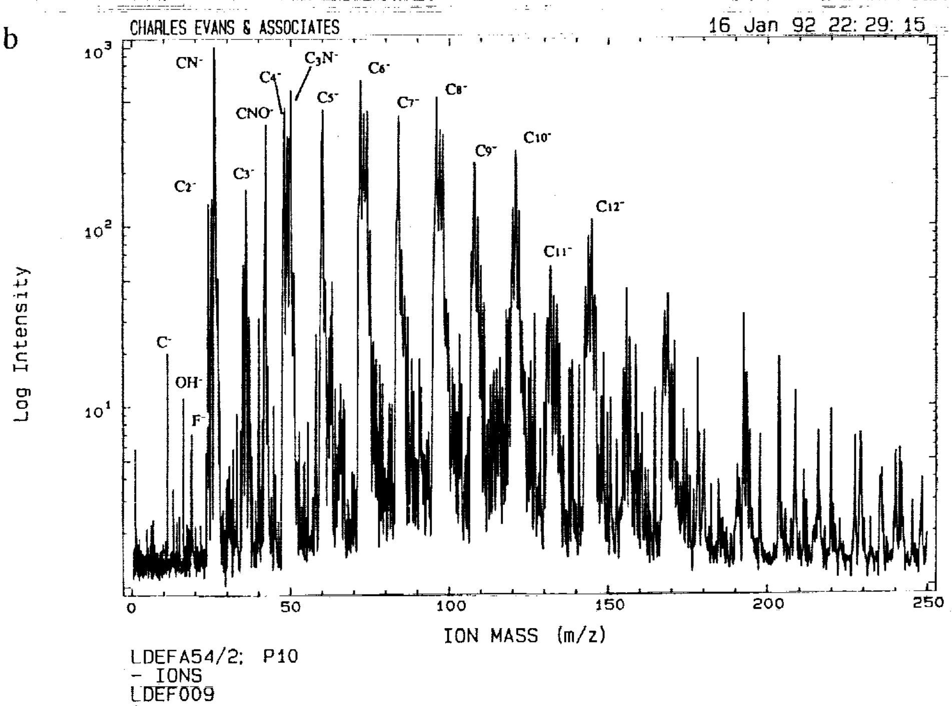

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