N93-26062

VOLATILES IN INTERPLANETARY DUST PARTICLES - A COMPARISON WITH CI AND CM CHONDRITES

Final Report
NASA/ASEE Summer Faculty Fellowship Program--1992

Johnson Space Center

Prepared By:	Roberta Bustin
Academic Rank:	Professor
University & Department:	Natural Science and Mathematics Division Arkansas College Batesville, AR 72501

NASA/JSC	
Directorate:	Space and Life Sciences
Division:	Solar System Exploration
Branch:	Planetary Science
JSC Colleague:	Everett K. Gibson, Jr.
Date Submitted:	August 21, 1992
Contract Number:	NGT-44-005-803

ABSTRACT

In an effort to classify and determine the origin of interplanetary dust particles (IDPs), 14 of these particles were studied using a laser microprobe/mass spectrometer. The mass spectra for these particles varied dramatically. Some particles released hydroxide or water which probably originated in hydroxide-bearing minerals or hydrates. Others produced spectra which included a number of hydrocarbons and resembled meteorite spectra. However, none of the individual IDPs gave spectra which could be matched identically with a particular meteorite type such as a CI or CM carbonaceous chondrite. We believe this was due to the fact that 10-20 μm size IDPs are too small to be representative of the parent body. To verify that the diversity was due primarily to the small particle sizes, small grains of approximately the same size range as the IDPs were obtained from two primitive meteorites, Murchison and Orgueil, and these small meteorite particles were treated exactly like the IDPs. Considerable diversity was observed among individual grains, but a composite spectrum of all the grains from one meteorite closely resembled the spectrum obtained from a much larger sample of that meteorite. A composite spectrum of the 14 IDPs also resembled the spectra of the CM and CI meteorites, pointing to a possible link between IDPs and carbonaceous chondrites. This also illustrates that despite the inherent diversity in particles as small as 10-20 μm, conclusions can be drawn about the possible origin and overall composition of such particles by looking not only at results from individual particles but also by including many particles in a study and basing conclusions on some kind of composite data.

INTRODUCTION

Interplanetary dust particles (IDPs) are extraterrestrial materials consisting of primitive substances originating in small solar system bodies such as comets and asteroids (Mackinnon and Rietmeijer, 1987). IDPs are recovered from satellites and from collectors flown aboard specially designed aircraft flying in the stratosphere. A Cosmic Dust Collection Facility for obtaining additional IDPs has been proposed for Space Station Freedom.

In order to understand not only the composition but also the past histories of IDPs, it is particularly important to know the nature of the volatiles present. Gibson and Sommer (1986), Gibson et al. (1989), and Hartmetz et al. (1990, 1991b) have studied volatiles released from a number of IDPs. However, a large number of particles must be studied in order to establish trends, to classify types of IDPs, and to have comparison data for determining the origins of IDPs.

EXPERIMENTAL

Collection and Processing

The IDPs in this study were from the Large Area Collectors L2005 and L2006 flown aboard a NASA ER-2 aircraft during a series of flights that were made within west-central North America during the fall of 1989. The collectors were coated with a 20:1 mixture of silicone oil and freon. They were installed in a specially constructed wing pylon, exposed to the stratosphere at an altitude of 20 km by barometric controls, and then retracted into sealed storage containers prior to descent (Zolensky et al., 1990, 1991).

The IDPs were processed in an ultraclean (Class-100) laboratory at Johnson Space Center. The particles were removed from the collection flag and rinsed with hexane to remove the silicone oil remaining on the surface from the collection procedure. They were then mounted on small pieces of gold which had been cleaned with ethanol in an ultrasonic cleaner followed by surface cleaning in an oxygen plasma. The particles in this study were all cluster particles, small pieces of larger, friable particles which fragmented during collection.

Analysis

The 14 IDPs in this study were classified as cosmic dust by the examination team (Zolensky et al., 1990, 1991). An SEM photomicrograph was taken of each of the particles, and an energy dispersive X-ray (EDX) analysis was done using a JEOL-35CF Scanning Electron Microscope. Results of the EDX analyses are shown in Table 1.

The piece of gold containing the IDP was placed in the sample chamber of the apparatus shown in Figure 1, and the system was evacuated to a pressure of 2×10^{-7} torr. The IDP was then hit with a focused laser beam from a Jarrell-Ash neodymium-glass, Q-switched laser. Volatiles released were analyzed by a Hewlett Packard 5970 Mass Selective Detector. The particles were so small that the laser beam hit not only the particle but also the surrounding gold. To account for the volatiles coming from the surface of the gold, an average "gold" spectrum was obtained from several laser hits on the clean gold away from the particle, and this spectrum was subtracted from the spectrum of the particle. This also had the advantage of subtracting out the majority of the peaks due to surface contaminants left from processing and cleaning the IDP.

The data were normalized (Hartmetz et al., 1990) in order to compare them with analyses of other IDPs, and only those peaks that were greater than one standard deviation (calculated from the gold measurements) above the gold background were displayed.

To help in evaluating the spectra of the IDPs, spectra were obtained from three minerals (azurite, calcite, and troilite), from three meteorites (Murchison, Orgueil, and Allende), and from several small particles of Murchison and Orgueil of approximately the same size range as the IDPs.

RESULTS AND DISCUSSION

The EDX spectra indicated that all IDPs studied except possibly L2006A6,7 were chondritic, based on the similarity of their elemental compositions and those of the chondritic meteorites, particularly the carbonaceous chondrites.

Individual IDPs can be classified according to the volatiles identified in the mass spectrum. Table 3 lists the major classes, and Figures 2 through 7 are examples of each class.

The mass spectra showed that the volatile inventories of the IDPs varied dramatically from almost no volatiles (Figure 2) to what is considered volatile-rich (Figure 3) because of the presence of several hydrocarbon "families" in addition to species such as C, O, CO, CO_2, and COS. Table 2 lists the indigenous volatile species found in all 14 IDPs studied. Because many IDPs are porous and may retain some silicone oil or freon from the collection device or some hexane used to remove the silicone oil from the surface, a species is considered to be indigenous only if it does not occur in the mass spectrum of silicone oil, freon, or hexane.

None of the IDPs studied has all the peaks expected from a sulfur-rich species such as a sulfide or sulfate. However, several particles appear to contain some sulfur. An example is L2005E38 (Figure 4). Even though this particle does not contain many volatiles, three peaks are due at least partially to sulfur-containing species (S, SO, and CS_2). CS_2 is a major species released from both terrestrial sulfides and elemental sulfur.

Information about carbonaceous matter, particularly hydrocarbons, in IDPs is important not only for classification purposes but also in determining sources and origins of IDPs. High abundances of carbon-bearing compounds have been found in the dust released from Comet Halley (Kissel and Krueger, 1987). Carbonaceous chondrites also contain hydrocarbons (Hartmetz et al. 1991a). Blanford et al. (1988) found that some anhydrous chondritic IDPs contain as much as 49 wt. % carbon which has not been fully characterized. Carbonaceous material was found in six of the IDPs in this study.

In studying hydrated IDPs, Tomeoka and Buseck (1986) found a carbonate-rich, hydrated IDP. Infrared studies of IDPs revealed a band associated with carbonate (Sandford, 1986). Two IDPs in this study, L2006A6,7 and L2006A12, contained large peaks for both CO and CO_2, indicating the likelihood of a carbonate phase. Both of these also contained carbon, a prominent peak in the spectra of known carbonate-containing minerals.

Nine of the 14 particles studied had a peak at either 17 or 18, indicating the presence of either hydroxide-bearing minerals or hydrated species.

To give some idea of how representative of the parent body a 10-20 μm particle really is, spectra were obtained from several small particles each of Murchison and Orgueil, a CM and a CI chondrite, respectively. There was considerable diversity in the individual spectra (Figures 8-11). Some particles appeared to be mineral grains; some could not even have been identified as being meteoritic; and others were fairly representative of the typical meteorite matrix. All meteorite particles were not the same size. In most cases, the larger particles gave spectra most similar to the parent meteorite. For both Orgueil and Murchison, a composite of all particles yielded a spectrum similar to that of the parent meteorite (Figures 12-15). Sulfur-bearing species, aliphatic hydrocarbon groups, aromatics, carbonates, and water were present in each of these. Based on the total ion chromatograms, the IDPs had the least amount of total volatiles; small Murchison particles had only slightly more volatiles (about 1.15 times); and small Orgueil particles had about 2.3 times as much volatile material as the IDPs. A large piece of Murchison was only 1.4 times as volatile-rich as the IDPs, but the large grains of Orgueil evolved 20 times as much volatile material as the IDPs. This is in keeping with previous studies which reported Orgueil to be more volatile-rich than Murchison (Wiik, 1956 and Hartmetz et al., 1991).

In order to envision what a parent body containing all 14 of our IDPs might resemble, a composite spectrum was prepared (Figure 16), using a typical gold spectrum for the subtracted background. It is not necessary to use a large number of particles to give a representative composite spectrum. The composite from eight spectra looked almost identical to this 14-particle composite. The IDP composite spectrum is very much like the spectra from the carbonaceous chondrites. The most obvious difference is the decreased intensity of the sulfur-related peaks. Although clearly present, the SO and SO_2 peaks are much smaller than the same peaks in either meteorite spectrum, indicating that the IDPs in this study probably contained sulfate but not in large amounts. The intensity of the COS peak in the IDP spectrum is about the same as that of SO_2 whereas in the meteorite spectra, the SO_2 peak is much larger than the COS peak; the CS_2 peak is small, and the H_2S peak is barely noticeable. The H_2S, COS and CS_2 peaks are significant peaks in the Murchison spectrum but are not as intense as they are in the spectrum of Orgueil. Because of this, the IDP spectrum resembles the Murchison spectrum a little more closely than that of Orgueil.

SUMMARY

Despite the inherent diversity in particles the size of IDPs, it is possible to identify specific mineral fragments and classes of compounds which occur in such particles. By comparing results from analyses of many particles, it is clear that IDPs may contain sulfur-bearing species, water or hydroxyl groups, and carbonaceous material, including carbonates. By looking at composite data and comparing with data from meteorites, a definite resemblance is seen between IDPs and carbonaceous chondrites.

TABLE 1. EDX MAJOR ELEMENT ANALYSIS[i]

Particle	Major Components
L2005B21	Si, Fe, Mg, O, (Al)
L2005C21	Si, S, Mg, O, Fe, Ca, Na, Al
L2005C24	Si, Mg, Fe, O, Ca, (Al)
L2005C26	Si, Mg, Fe, O, (Ca), (Al), (Ni)
L2005C28	S, Si, Fe, Mg, O, (Al), (Ni)
L2005C30	Si, Mg, Fe, O, (Ca), (Ti), (Al), (Na)
L2005D27	Si, Mg, O, S, Fe, (Na), (Al), (Ca)
L2005D34	Si, Mg, O, Na, Fe
L2005E38	Si, Mg, Fe, O, (Na)
L2005E39	Si, Mg, C, Fe, O, (Na)
L2006A6,7	C, Si, Na, (O)
L2006A12	Si, Mg, O, Fe, (Ca), (C), (Na), (Al)
L2006A26	Si, Ca, Mg, O, Fe, C
L2006B16	Si, Mg, O, Fe, C

[i]Elements are listed in order of abundances, and trace amounts are placed in parentheses. It was difficult to detect whether or not sulfur was present in some species because of the overlap with the intense gold peak from the sample mount.

TABLE 2. INDIGENOUS VOLATILE SPECIES

Particle	Volatile Components
L2005B21	OH
L2005C21	C, C_2H_5, O_2 or S, SO_2, C_5H_6, C_6H_6, C_6H_7, $C_6H_5CH_3$
L2005C24	OH, C_2H_5, C_2H_6, C_4 or SO, C_4H, C_5H_8, C_5H_9, C_6H_6, $C_6H_5CH_3$
L2005C26	C, CH, and some high m.w. hydrocarbons
L2005C28	CH, OH, SOH?, C_5H_7, CS_2, C_6H_6, C_6H_7, C_7H_{11}
L2005C30	OH, C_2H_5, C_2H_6, CO_2, C_5H_8, C_5H_9
L2005D27	C, C_2H_5, CO_2, SOH?, SO_2, CS_2, C_6H_6, C_6H_7, $C_6H_5CH_3$, C_7H_9, C_7H_{11}, C_7H_{16}
L2005D34	CH, OH, C_6H_6
L2005E38	OH, O_2 or S, SO
L2005E39	C, C_2H_5, C_5H_5, C_5H_6, C_5H_7
L2006A6,7	C, OH, C_2H_5, CO_2, C_5H_5, C_5H_6, C_6H_6
L2006A12	C, CC_2H_5, CO_2, C_5H_5, C_5H_7, C_6H_6
L2006A26	None
L2006B16	SO

TABLE 3. OVERVIEW OF VOLATILE SPECIES FOUND IN 28 IDPs ANALYZED BY LASER MICROPROBE/ MASS SPECTROMETRY[i]

Little or No Indigenous Volatiles	Large Amount of Indigenous Volatiles	Sulfur Species	Carbonaceous Material	Carbonate	Water or Hydroxyl
L2001D3	L2002C4	(L2002C4)[ii]	L2002C4	L2003D2	**L2005B21**
L2004D3	L2003D2	(L2003D2)	L2003D2	**L2006A6,7**	**L2005C24**
L2005B21	L2003E3	(L2004C3)	L2004C3	**L2006A12**	**L2005C28**
L2005C21	L2004C3	(L2004D3)	**L2003E3**	U2034D7	**L2005C30**
L2005C24	**L2006A12**	**L2005C21**	**L2005C21**		**L2005D34**
L2005C26	**U2017A4**	**L2005C24**	**L2005C24**		**L2005E38**
L2005C28	**U2017A5**	**L2005C26**	**L2005C26**		**L2006A6,7**
L2005C30	**U2022G13**	**L2005E38**	**L2005D34**		**L2006B16**
L2005D27	**U2034D7**	**L2006A12**	L2005E39		U2022F5
L2005D34		**(L2006B16)**	L2006A6,7		U2022F20
L2005E38		U2017A4	U2034D7		U2034D7
L2006A26		U2017A5			
L2006B16		U2022G13			
U2015B20		(U2034D7)			
U2015F20					
U2022F5					
U2034D1					

[i]Samples in bold print are those analyzed in this investigation. Others are from Hartmetz et al., 1990,1991b.

[ii]Parentheses indicate that the IDP contained only one type of sulfur species, often in very small amounts.

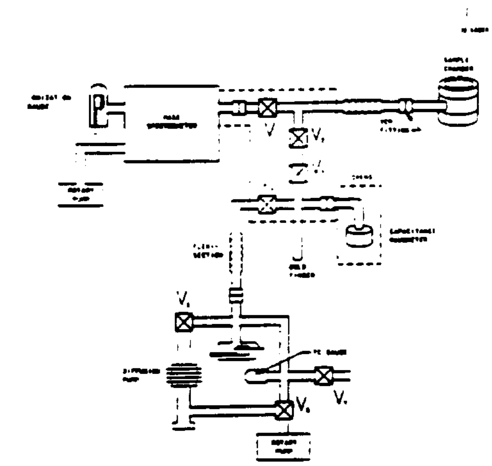

Figure 1. Schematic of the laser microprobe-mass spectrometer, from Gibson and Carr (1989)

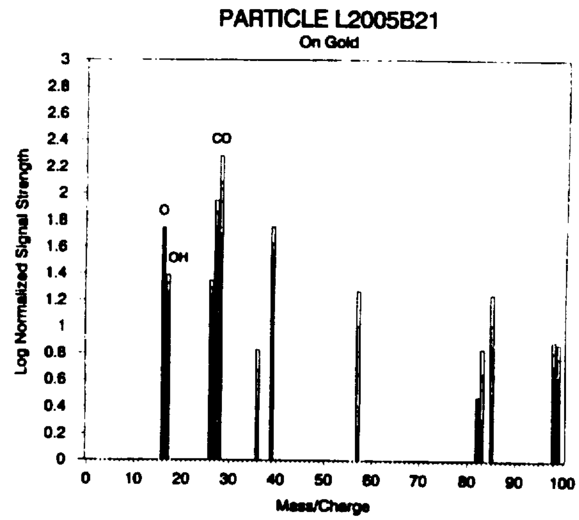

Figure 2. Mass spectrum of an IDP containing very few volatiles

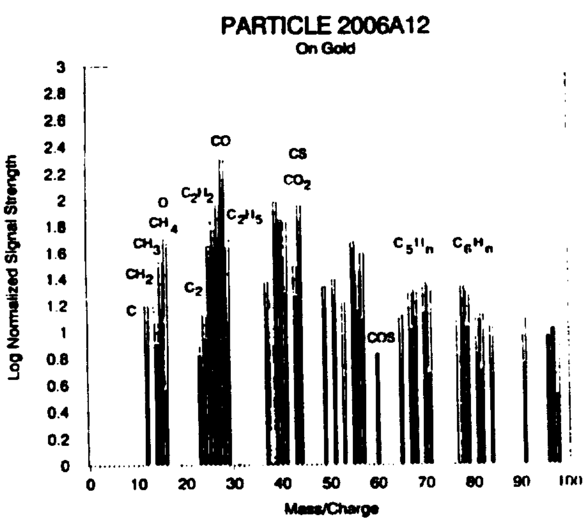

Figure 3. Mass spectrum of a volatile-rich IDP

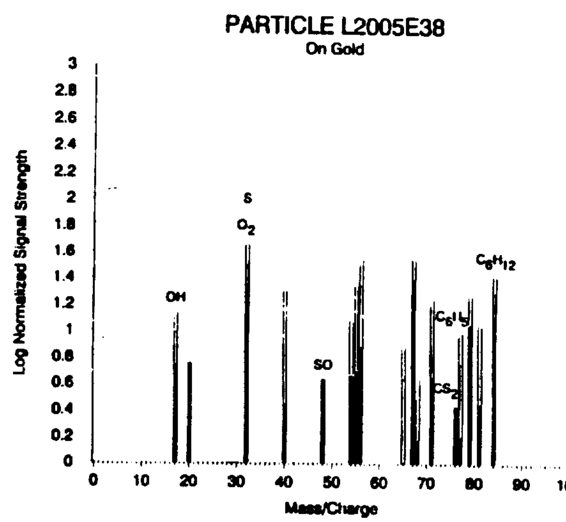

Figure 4. Mass spectrum of a sulfur-containing IDP

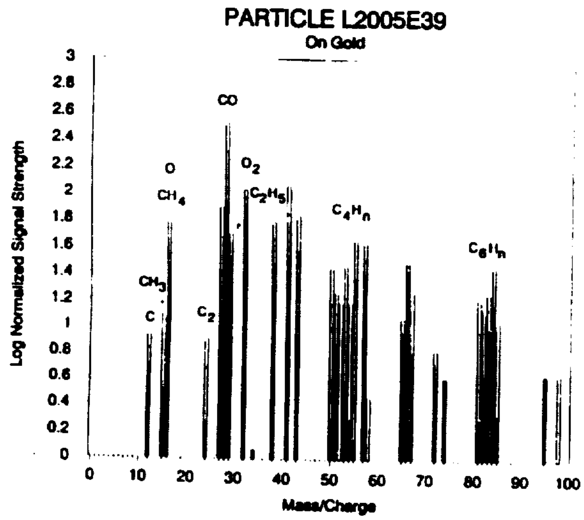

Figure 5. Mass spectrum of an IDP containing carbonaceous material

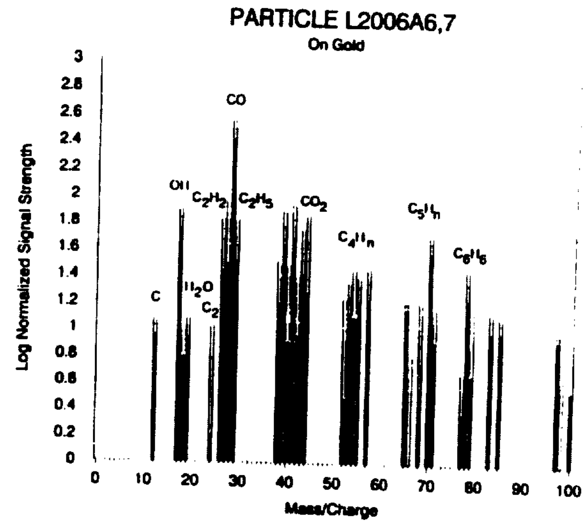

Figure 6. Mass spectrum of an IDP containing carbonate

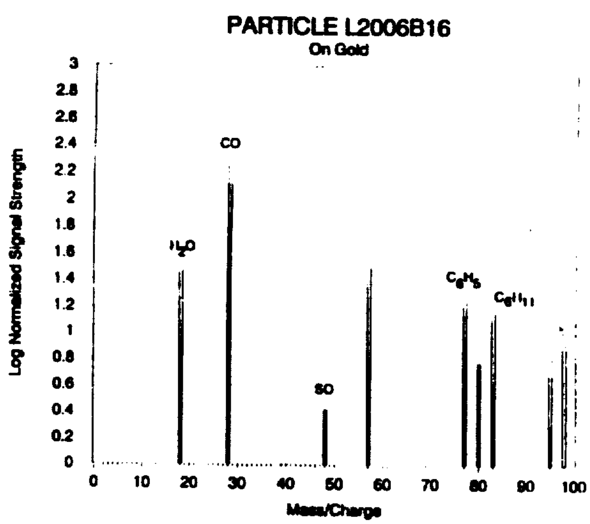

Figure 7. Mass spectrum of an IDP containing water

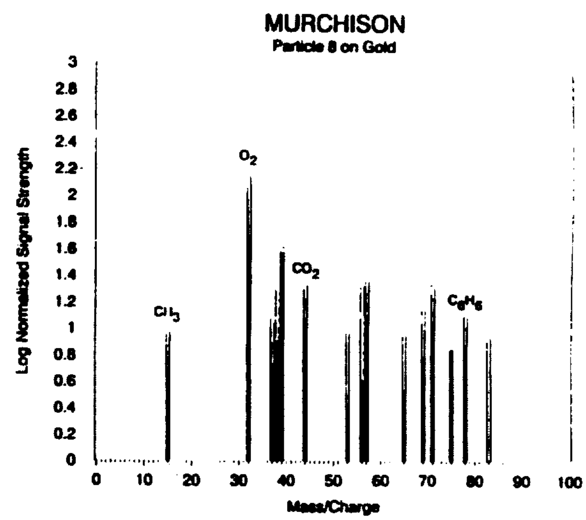

Figure 8. Mass spectrum of a Murchison particle with few volatiles

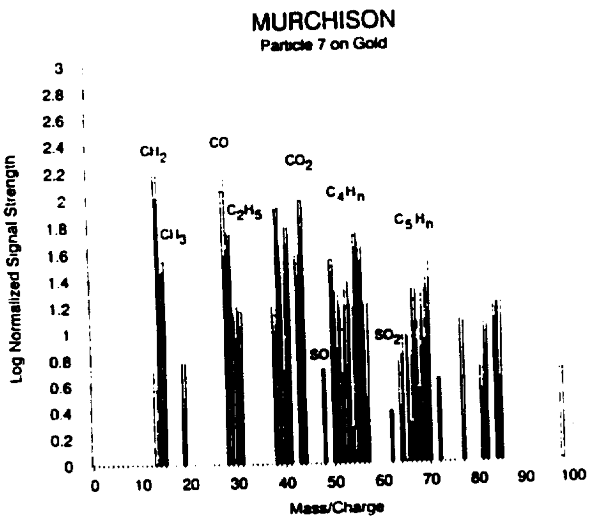

Figure 9. Mass spectrum of a volatile-rich Murchison particle

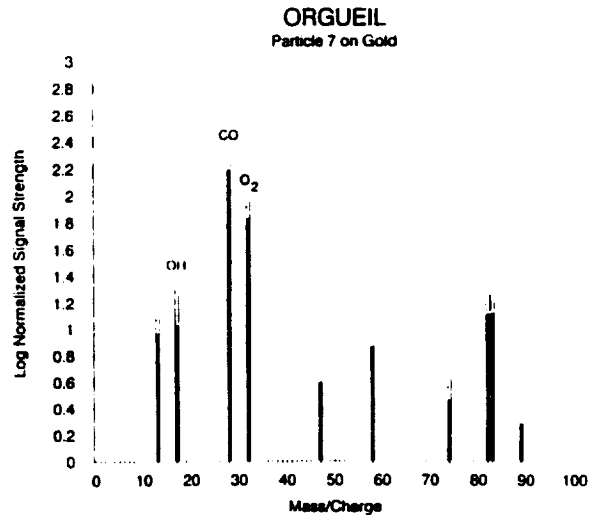

Figure 10. Mass spectrum of an Orgueil particle with few volatiles

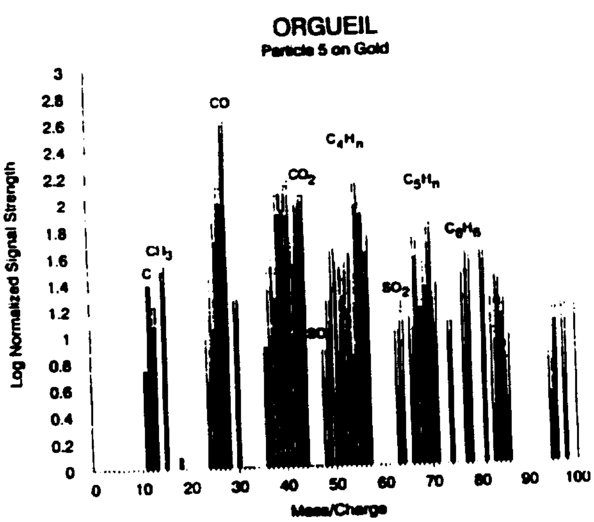

Figure 11. Mass spectrum of a volatile-rich Orgueil particle

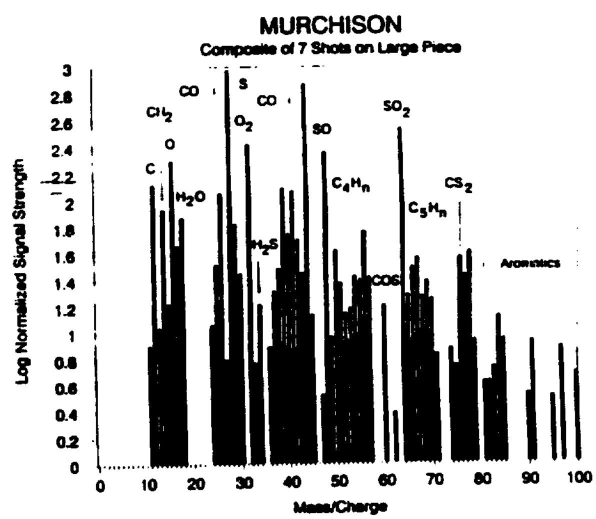

Figure 12. Composite of mass spectra of 7 different locations on a large piece of Murchison

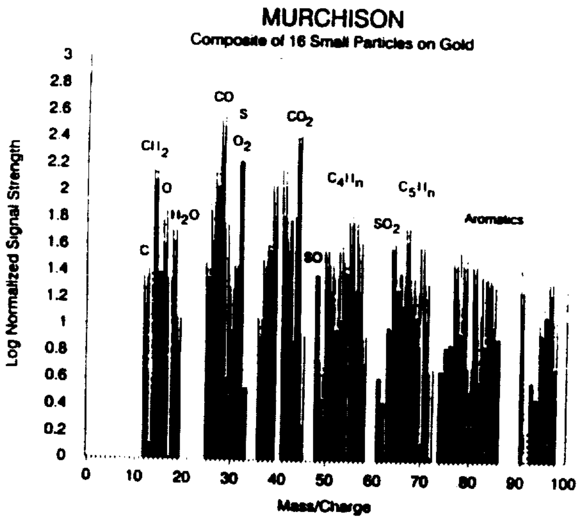

Figure 13. Composite of mass spectra of 16 small particles from Murchison

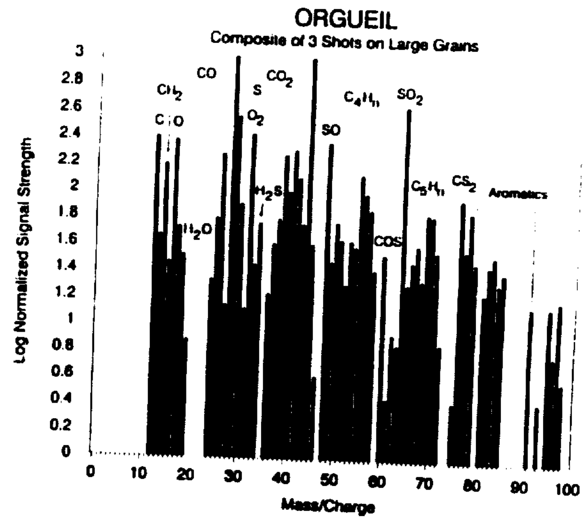

Figure 14. Composite of mass spectra of 3 different locations on large grains of Orgueil

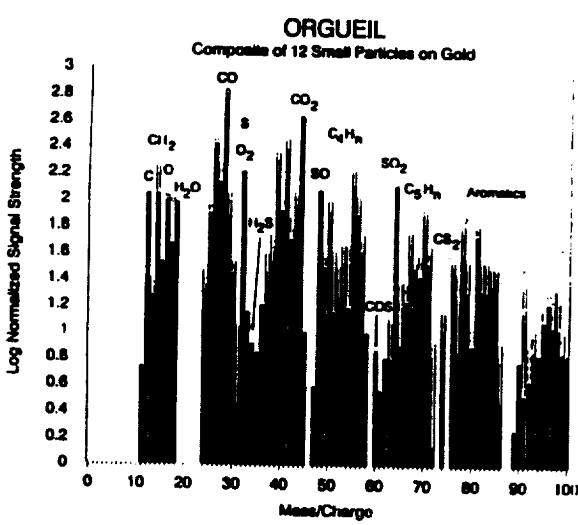

Figure 15. Composite of mass spectra of 12 small particles from Orgueil

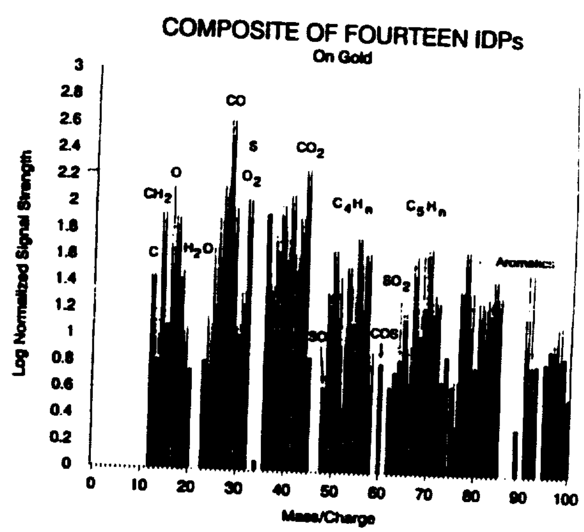

Figure 16. Composite of mass spectra of the 14 IDPs examined in this study

REFERENCES

Blanford, G. E., Thomas K. L., and McKay D. S., Microbeam analysis of four chondritic interplanetary dust particles for major elements, carbon, and oxygen, Meteoritics, 23, 113-121, 1988.

Gibson E. K. Jr. and Carr R. H. (1989) Laser microprobe-quadrupole mass spectrometer system for the analysis of gases and volatiles from geologic materials. In New Frontiers in Stable Isotope Research: Laser Probes, Ion Probes, and Small Sample Analysis, pp. 35-49. U. S. Geol. Surv. Bull. 1890.

Gibson E. K. Jr. and Sommer, M. A. (1986) Laser microprobe study of cosmic dust (IDPs) and potential source materials. Lunar and Planetary Science XVII, 260-261.

Gibson E. K. Jr., Hartmetz, C. P. and Blanford, B. E. (1989) Analysis of interplanetary dust particles for volatiles and simple molecules. Lunar and Planetary Science XX, 339-340.

Hartmetz C. P., Gibson E. K. Jr., and Blanford G. E. (1990) In situ extraction and analysis of volatiles and simple molecules in interplanetary dust particles, contaminants, and silica aerogel, Proc. Lunar Planet. Sci. 20, 343-355.

Hartmetz C. P., Gibson E. K. Jr., and Blanford G. E. (1991) In situ extraction and Analysis of volatile elements and molecules from carbonaceous chondrites, Proc. Lunar Planet. Sci. 21, 527-539.

Hartmetz C. P., Gibson E. K. Jr., and Blanford G. E. (1991) Analysis of volatiles present in interplanetary dust and stratospheric particles collected on Large Area Collectors. Proc. Lunar Planet. Sci. 21, 557-567.

Kissel J. and Krueger F. R., The organic component in dust from Comet Halley as measured by the PUMA mass spectrometer on board Vega 1, Nature, 326, 755-761, 1987.

MacKinnon I. D. R. and Rietmeijer F. J. M. (1987) Mineralogy of chondritic interplanetary dust particles, Rev. Geophys., 25, 1527-1553.

Sandford S. A. (1986) The world's smallest acid residue: The source of the 6.8 micron band seen in some IDP spectra, Lunar Planet. Sci. XVII, 756-757.

Tomeoka K. and Buseck P. R. (1986) A carbonate-rich, hydrated interplanetary dust particle: Possible residue form protostellar clouds, Science 231, 1544-1546.

Wiik H. B. (1956) The chemical composition of some stony meteorites. Geochim. Cosmochim. Acta. 9, 279-289.

Zolensky M. E., Barrett R. A., Dodson A. L., Thomas K. L., Warren J. L., and Watts L. A. (1990, 1991) Cosmic Dust Catalogs 11 and 12, NASA Johnson Space Center.