CHAPTER 3
COMETARY DUST COMPOSITION

R. D. Gehrz
University of Minnesota

and

M. S. Hanner
Jet Propulsion Laboratory

with contributions from Session III speakers

1.0 INTRODUCTION

The earth-based measurements and *in situ* sampling of Comet Halley have provided intriguing new data about the chemical composition of cometary grains. Recent progress in laboratory studies of interplanetary dust particles (IDPs) complements the comet data, allowing inferences about the mineralogy and physical structure of the comet dust to be drawn from the observed elemental composition and infrared spectra.

Seven speakers presented talks in this session, discussing the *in situ* dust composition measurements at Halley, the composition of IDPs and their relation to comet dust, and the origin of the 3.4μm hydrocarbon feature. They were requested to prepare written versions of their talks, which are included here in this chapter. Related poster papers on aromatic components in comets (Allamandola *et al.*) and the 3.4μm feature (Danks *et al.*, Encrenaz *et al.*) are also included here for completeness.

The topics discussed in the session are briefly summarized below. Further discussion and recommendations for future research are included at the end of the chapter. How well the conclusions from independent research techniques fit together was one of the exciting aspects of the Workshop.

2.0 *IN SITU* MEASUREMENTS

A time-of-flight mass spectrometer was carried on board the Vega (PUMA) and Giotto (PIA) spacecraft to record the composition of impacting dust particles (Kissel *et al.*, 1986). Particles striking the target generated a cloud of ions which were accelerated down a drift tube and counted by the detector, as a function of mass/charge ratio. Several thousand mass spectra of dust particles in the mass range 10^{-16} to 10^{-12} g were recorded by the three instruments.

From a sample of PUMA spectra, the relative abundances of the major rock -forming elements are chondritic within a factor of 2 (Jessberger *et al.* 1986, 1987). Carbon, however, is enhanced by a factor of $\sim$ 10 in this sample, compared to CI carbonaceous chondrites. A class of particles containing primarily H,C,N,O was discovered ("CHON" particles; Kissel *et al.* 1986), supporting the evidence from the infrared spectra that Halley was rich in organic materials.

At the Workshop, Mason reported on correlation analyses of elemental abundances in over 8,000 PIA spectra (Mason and Clark, this Chapter). Carbon is the most abundant element, appearing in 74 percent of all the spectra, while highest correlation occurs for the pair C,O. The presence of molecular ions, such as $MgOH^+$ and CN^+ is suggested by the data.

Initially, it was thought that molecular ions would not be formed during particle impact. The appearance of the spectra, however, particularly the peaks at large amu, has caused a reconsideration of the theoretical model for the impact process. Kissel and Krueger (1987) have concluded that molecular ions are present in the data and have constructed a model for the ion chemistry and the kinds of organic molecules present. They argue that their model is indicative of the silicate cores with organic refractory mantles, predicted for interstellar grains by Greenberg.

Further analysis of the PUMA and PIA data is in progress by several groups, and we can expect interesting new results to emerge in the next few years. However, it must be kept in mind that the instruments sampled only the smallest grains in the coma, whereas most of the mass in the comet grains lies in particles larger than 10^{-11} g (see Chapter 2).

3.0 INTERPLANETARY DUST PARTICLES

For more than 15 years, IDPs collected in the stratosphere have been available for laboratory study. Recent advances in techniques for analyzing submicron sections of these grains and for obtaining infrared spectra make possible a comparison with Halley data. These techniques, including thin sections, EDX spectra, and ion-probe imaging, are reviewed in the paper by Walker, along with a discussion of results relevant to the comparison with comet dust.

Using a different approach, Brownlee compared the degree of variability in the mineral composition for the Halley dust, carbonaceous chondrites, and IDPs. The CI and CM meteorite samples contain primarily hydrated silicates, with a narrow range in Mg/Si ratio, in contrast to the broad dispersion in composition and prevalence of pure Mg silicates in the Halley particles. Hydrated IDPs show a narrow range of Mg/Si similar to the meteorite samples. The anhydrous chondritic aggregate IDPs, on the other hand, display a broad compositional dispersion similar to that seen in the Halley spectra. These IDPs even look like plausible cometary particles, perhaps with ice originally filling the voids. Walker cautioned that one should not rule out other kinds of IDPs as potential cometary grains, for example the Ca and Al rich refractory particles and FSN particles as well as hydrated silicates.

Relationships between CHON particles and IDPs were also discussed. The chondritic aggregate IDPs contain dark, carbon-rich matrix material. Some IDPs may have a 3.4μm absorption feature, although possible contamination is difficult to rule out (see discussion by Walker). Raman spectra of IDPs, described by Allamandola and by Sandford, exhibit bands characteristic of aromatic molecular units of size $\leq$25A, and some showed red luminescence as well. The band positions are similar to the interstellar infrared emission features. Some IDPs have strong D/H enrichment in localized areas correlated with high carbon concentration. Allamandola *et al.* associate the high D/H enrichment with polycyclic aromatic hydrocarbons in the grains and suggest that these may be only slightly modified interstellar grains. Walker presented an ion image of an IDP containing a fragment rich in C,H,N, perhaps related to a subset of the "CHON" particles seen in Halley. Thus, laboratory evidence regarding hydrocarbons in IDPs seems to be consistent with what we have learned about the organic material in Comet Halley, although further investigations of both IDPs and comets are clearly important. Better understanding of the organic material in the grains is one goal of the CRAF mission.

4.0 INFRARED SPECTRA OF IDPs AND IDENTIFICATION OF SILICATES

Sandford reviewed the 5-20μm infrared spectra of IDPs. These fall into three groups, identified respectively with terrestrial olivine, pyroxene and hydrated silicates. Composition analysis of the IDPs confirms the spectral identifications. A 6.8μm feature seen in hydrated IDPs is associated with carbonate; a weak 6.8μm emission may have been present in the spectrum of Halley (Chapter 1). The silicate feature observed in Halley can be fitted with a combination of the three spectral types, primarily olivine and pyroxene. This result is in agreement with Brownlee's conclusion that anhydrous silicates dominate the dust composition. In contrast, the 10μm spectrum of Comet Kohoutek at 0.3 AU showed a broad smooth silicate feature, resembling the hydrated silicates and inconsistent with more than a small per cent crystalline olivine.

Caution should be exercised, however, in attempting to make a detailed fit of laboratory transmission spectra to cometary emission spectra. As discussed in Chapter 4, a transmission spectrum generally includes scattering as well as absorption, which can distort the shape of the band. The temperature and size of the emitting grains also have to be taken into account. One also has to consider the processing history of IDPs since their ejection from a parent body and the extent to which they may have been altered by heating. Nevertheless, given the difficulty of predicting accurately the band shape for a mixture of inhomogeneous, irregular particles (Chapter 2), the direct laboratory comparison is a valuable first step, and it is significant that crystalline silicates seem to be present in Halley.

5.0 THE 3.4-MICRON FEATURE

The observed spectrum of the 3μm region was described in Chapter 1. The main emission peak occurs at 3.36μm, with weaker features at 3.29 and 3.52μm. Tokunaga and Brooke stressed that the 3.36μm feature seen in Halley and Wilson is not matched by any interstellar source. Although the Galactic Center has a feature centered near 3.4μm, the detailed shape differs and the feature is seen in absorption, not emission. Of the set of unidentified infrared emission features usually occurring together in interstellar sources, only the 3.29μm band seems to be present in Halley. Thus, the task for theoreticians is to explain not only the origin of the 3.36μm cometary emission, but also why it differs from that seen in the ISM and why no corresponding emission bands are present at longer wavelengths.

Moreover, it appears that not all comets exhibit 3.4μm emission (Tokunaga and Brooke), and Danks pointed out that no feature was evident in a preperihelion CVF spectrum of Halley in December 1985.

While the consensus is that the emission probably arises from C-H vibrations in organic molecules, the specific molecule(s) and emission mechanism are unknown, and it is not even clear whether the carrier is in the gas or solid phase. Several possible emission mechanisms were discussed at the Workshop and are described in the papers in this chapter. These include resonance scattering by gas molecules, UV-pumped fluorescence in gas molecules or small grains, and thermal emission from small grains. Because the derived carbon abundance depends strongly on the emission mechanism, clarification of the 3.36μm feature is necessary for understanding the carbon budget of the comet.

References

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2. Jessberger, E. K., Kissel, J., Fechtig, H. and Krueger, F. R. 1986, *The Comet Nucleus Sample Return*, ESA SP-249, p. 27.
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