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REFRACTORY SOLIDS IN CHONDRITES AND COMETS: HOW SIMILAR?

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The grains of ice, dust, and organic material that came together to form the solar system have been preserved to differing degrees in the most primitive solar system bodies, asteroids and comets. The study of samples of asteroids (in the form of chondritic meteorites) reveals that the dust component was extensively altered by high-temperature events and processes in the early solar system, before it was aggregated into chondritic planetesimals. The nature of these high-temperature events and processes is not known, but the evidence of their operation is pervasive and unequivocal. Reviewing properties of the three principal types of particulate matter in chondrites:

CA,AL-RICH INCLUSIONS (CAI's) are depleted in relatively volatile elements. High-temperature events either incompletely vaporized precursor material; or totally vaporized it, after which the system cooled and recondensed selectively, such that the CAI's incorporated only early high-temperature condensates. Isotopic mass-fractionation effects measured in Mg, Si, Ca, and Ti in CAI's indicate that the latter experienced a complex history of both partial vaporization and condensation. On the other hand, the fact that some CAI's contain O, Mg, Si, Ca, Sr, Ba, Nd, and Sm with anomalous isotopic compositions that are not attributable to mass fractionation or radioactive decay, but must be the signatures of particular nucleosynthetic sources, indicates that these objects contain a <u>component</u> that was never vaporized and mixed with other solar system material. Many CAI's display mineralogical and textural evidence of having been melted.

Similar evidence shows that virtually all CHONDRULES were largely or wholly melted. Many chondrules contain <u>relic grains</u> of mineral matter that survived the chondrule-melting event, and which represent an earlier state of solar system solids. Whether these are condensate grains, fragments from an earlier generation of igneous chondrules, or (conceivably) presolar grains is not known. Generalizing from limited data, chondrules show the same kinds of isotopic mass fractionation effects and presolar isotopic anomalies as CAI's, but the extent of the effects (ranges of <u>del</u> values found) is more modest.

MATRIX in chondrites consists of aggregated mineral grains, mostly in the 1-10 micron size range. Where the grains are not obviously secondary (postaccretional) alteration products, they have been variously interpreted to be nebular condensates or comminuted debris from the collisions of larger objects. The only known <u>bona fide</u> presolar interstellar grains in chondrites occur in the matrix. These are submicron grains of carbonaceous matter: organic carbon, diamond, graphitic or amorphous carbon, and SiC. Each exhibits a different anomalous isotopic signature (for C, included noble gases, and Si, where present), presumably impressed upon it by a different nucleosynthetic site. The matrix may also contain a minor component of other interstellar phases, such as silicates, but these have not been identified.

Are the refractory particles in comets likely to be similar to these chondrite components? Probably not (except for the presolar carbonaceous grains in chondrites), because the chondritic components are products of severe thermal processing, and all imaginable energy sources that could have provided the heat tend to diminish with distance from the sun. Every indication is that comets formed at much greater radial distances than asteroids, so the particles they incorporated would have experienced less heating. The possibilities cannot be completely ruled out that comets, too, formed inside the present orbit of Jupiter (this was part of Oort's [1950] original concept), or that thermally-processed grains were able to diffuse great radial distances before being incorporated in accreting objects, but it is far more likely that most of the refractory grains in comets have been spared the extreme thermal processing that shaped the character of chondritic components. Perhaps some of the grains are presolar material that has experienced only a minor degree of nebular processing. The study of grains in the first stage of conversion to CAI's and chondrules could help us understand what was accomplished much more thoroughly in the inner solar system.

Almost certainly a major proportion of the refractory solids in comet nuclei consist of essentially pristine presolar interstellar grains. Spectral studies of interstellar and circumstellar grains provide only an approximate picture of their nature. The grains are small, the order of 0.1 micron, but it is unclear whether the size distribution also includes populations of much smaller and much larger grains. Magnesian silicate and carbonaceous grains are present. The silicates may be amorphous or crystalline, or anything between. The spectral information comes only from the Mg-silicates, which are most abundant; there is no information on the interstellar carriers of Ca, Al, and the less abundant condensable elements, and even the major carriers of Fe are conjectural. The carbonaceous component consists of SiC, elemental C in one or more forms (amorphous C, graphite, turbostratic graphite, diamond), and, probably, complex organic compounds.

At this point we have had two glimpses of the nature of cometary refractory particles: as interplanetary dust particles (IDP's) collected in the stratosphere, and from analyses by the instruments of Giotto and Vega during the 1986 encounter of Halley's comet.

It is likely, though not certain, that a subset of IDP's (the chondritic porous aggregates) consists of cometary particles. These are aggregates of 0.1-1 micron crystals of mafic and other minerals, coated and cemented together by carbonaceous material. Highly anomalous D/H ratios have been found associated with the carbonaceous material, presumably resulting from mass fractionation in the very cold presolar dense interstellar medium. However, most ion microprobe analyses of (clusters of) embedded silicate grains have not revealed isotopic anomalies.

Halley particles collected and analyzed by the Vega 1 impact mass spectrometer were mostly in the 0.1-1 micron size range. The particles were highly variable in composition, but typically consisted of mineral cores of more or less chondritic composition surrounded by carbonaceous mantles.

The question of whether involatile particles collected by a comet nucleus sample return mission are nebular condensates or presolar interstellar grains is most likely to be settled by isotopic analysis, using improved ion microprobe mass spectrometers. The latter will have sensitivities and spatial resolutions that permit analysis of individual 0.1-1 micron cometary grains. They will detect the differing isotopic signatures of condensates derived from multiple nucleosynthetic sources, if the grains are presolar. If the grains condensed from the nebula, on the other hand, these signatures cannot have survived, and this will be readily apparent.