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Interaction among minerals, organics and water in comets: insights from Antarctic micrometeorites

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The evolution and interaction of inorganic materials and organic materials are one of the crucial issues of space science, which is also a main topic of current planetary missions. In order to clarify the early stage of evo-lution of primitive materials in the solar system, we have carried out a comprehensive study on micrometeorites collected from the Antarctica virgin snow with SEM, TEM, Carbon-, N-, and O-XANES, and SIMS.

On the basis of observation, we estimate the primary materials and the sequence of aqueous reaction in the inorganic and organic materials. The most primitive materials are GEMS (amorphous silicate with Fe-metal and sulfide), small olivine and low-Ca pyroxene, and pyrrhotite, which are embedded in organic materials. The or-ganic materials are macromolecules being rich in C=O groups with subordinate amount of C≡N and/or C=N-C groups, and they accompany D and 15N enrichments. Due to the heavy hydrogen and nitrogen isotopic composi-tions, the organics are estimated to be originated at very low temperature in the molecular cloud or a prestellar environment, which also generated various organic molecules.

The aqueous alteration reaction started at first in organic materials, where N-heterocycle, δD, and δ15N are lost and the organics become aromatic-rich. GEMS altered next, where metallic Fe dissolved into water to form Fe-rich saponite remaining Mg-rich amorphous silicate (Stage I). The aromaticity of the organics increases, and the chemical nature of organics becomes close to insoluble organic materials in primitive chondrites. Then, sulfide in GEMS, small olivine and low-Ca pyroxene grains, and Fe-rich saponite react with water to form Mg-rich saponite and Fe-hydroxide (Stage II). Sulfur may have been incorporated into phyllosilicate and/or organics or flew away. Finally, heterogeneous phyllosilicates at Stage II were homogenized to be Mg-rich saponite with formation of carbonate and loss of organics (Stage III). Carbon to form carbonate were supplied from organics or carbon dioxide and/or methane ice. Finally, the assemblage of micrometeorites becomes Mg-saponite, magnetite, and carbonates, of which mineral assemblage and chemical compositions are very similar to those of primitive carbonaceous chondrites.

Stages I and II should have taken place at $\sim$0 °C and almost instantaneously, probably in hours to days, in order to prevent total aqueous alteration of silicates. Therefore, most plausible process would be transient heat-ing by an impact. On the other hand, Stage III was at a little higher temperature in order to homogenize Mg and Fe in heterogeneous phyllosilicates and/or lasted for a little longer duration. A possible process may be either by a shock or approaching of cometary bodies to the Sun. However, we should evaluate the temperature and dura-tion very carefully, because the Rosetta mission showed us extremely porous nature of comets.

It should be noted that the final products of aqueous reactions shown in the present study are the same as those of primitive carbonaceous chondrites. More compact nature of chondrites and probably higher temperature by short-lived radio-isotopes resulted in pervasive water flow in the bodies and through alteration of silicates into phyllosilicates.