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Synchrotron X-ray Diffraction Analysis of Stardust Particles and Related Extraterrestrial Samples

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Introduction

Many small particles extracted from the Jupiter-family short-period comet 81P/Wild 2 were successively recovered by the Stardust mission [1]. Although the particles are very small typically smaller than 20 µm, they are expected to retain characteristics of primitive dust that was present in the outer regions of the early solar system, because short-period comets formed as Kuiper-belt objects currently located at 30-50AU from the Sun. We have performed X-ray diffraction analysis of particles from the comet Wild 2 and interplanetary dust particles recovered on the Earth.

Experimental Procedures

Each particle was glued on a thin glass fiber of 3 µm thickness and placed in the Gandolfi camera. The sample particle was exposed to a monochromatic synchrotron X-ray beam with a wavelength of 2.161 ± 0.001 Å and a diameter of 0.3 mm with an exposure duration up to 3 hours. The experiments were performed at the beam lines 9C and 3A: the former is a normal bending-magnet line while the latter is the newly developed undulator line. The 9C optical system consists of a short-duration undulator, a monochoromator, a diamond phase retarder, and a focusing mirror [3]. The high intensity of X-rays at the beam line 3A shortens the exposure durations down to approximately 1 hour for small Stardust samples. The X-ray diffraction pattern was recorded on a high-resolution imaging plate with a resolution of diffraction angle is 0.05 degree. Determination of interlayer spacings, integrated intensities of reflections, and identification of minerals were performed using the software that we developed.

Results and discussion

The results of only X-ray diffraction are reported here and those of all analysis were reported elsewhere [2]. At present, 50 particles were analyzed by X-ray diffraction. All particles are classified into two groups based on silicate crystallinity inferred from X-ray diffraction patterns: crystalline type and amorphous-rich type. The abundance of the former is approximately 10-15% of the particles investigated. Crystalline type shows very sharp reflections of olivine and low-Ca pyroxene. Crystalline type particles formed at temperatures higher than 1500°C in the protoplanetary disk prior to formation of the short-period comet. In the protoplanetary disk, the gas density in the outer regions is very low compared with that in the inner region. Therefore, in order to raise temperatures of solid dust particles by the passage of shock waves, the gas density should have been much higher than that envisaged by the standard solar nebular model [4].

On the other hand, the amorphous-rich type gives broad reflections of Fe sulfide and Fe metal and no silicate reflections, suggesting that the metal and the sulfide are poorly crystalline and silicates are amorphous. The interlayer spacing of Fe metal in the particles shows a slight shrinkage. This is probably due to incorporation of metallic Si into Fe, which induces overall downsizing of unit cell forming Fe_3Si suessite. The suessite unit cell is smaller than kamacite by approximately 1% due to substitution of Fe by the smaller Si atom. The formation of suessite suggests that, upon impacts of cometary particles into the SiO_2-aerogel onboard the Stardust spacecraft, SiO_2 was melted and reduced to form metallic Si due to extremely low oxygen fugacity in space, and the metallic Si was mixed with cometary metallic Fe. Therefore, the presence of suessitein the amorphous-rich type particles suggests that they were melted in the silica aerogel during capture.

References

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