STXM-XANES analyses of Murchison meteorite powders captured by aerogel after hypervelocity impacts: A potential implication of organic matter degradation for micrometeoroid collection experiments

*Yoko Kebukawa[1], Kyoko Okudaira[2], Hikaru Yabuta[3], Aiko Nakato[4], David Kilcoyne[5], Sunao Hasegawa[4], Makoto Tabata[6], Kensei Kobayashi[1], Shin-ichi Yokobori[7], Ei-ichi Imai[8], Yuko Kawaguchi[7], Hajime Yano[4], Akihiko Yamagishi[7]

1.Yokohama National University, 2.University of Aizu, 3.Osaka University, 4.Japan Aerospace Exploration Agency, 5.Lawrence Berkeley National Laboratory, 6.Chiba University, 7.Tokyo University of Pharmacy and Life Sciences, 8.Nagaoka University of Technology

The ultralow-density silica aerogel (0.01 g/cm^3) has been developed at Chiba University [1], and is used as a dust capture medium in the Tanpopo mission that is an ongoing Japanese astrobiology space experiment at the Japanese Experiment Module (JEM) 'Kibo' on the International Space Station (ISS) [2]. One of the purposes of this mission is capturing micrometeoroids around the ISS orbit. The low-density aerogel is expected to reduce shock-degradation of materials by hypervelocity impacts (several kilometers per second), as previously used to capture the cometary dust particles from the Comet 81P/Wild 2 in the STARDUST mission [e.g. 3]. In order to evaluate potential degradation of the micrometeoroids by hypervelocity impact to the aerogel, we conducted the simulation experiments using a two-stage light-gas gun and Murchison meteorite as a micrometeoroid analog material. We conducted X-ray absorption near edge structure (XANES) analyses for the particles recovered from the impacts, using a scanning transmission X-ray microscopy (STXM).

Two-stage light-gas gun experiments were conducted at the Space Plasma Laboratory, ISAS/JAXA. We fired Murchison powder (micron-sized grains) into silica aerogels (0.01 g/cm^3) by shotgun method. In shot #399, 30-100 micron sized powder was fired at 4.4 km/s at a vacuum degree of 7.5 Pa, while in shot #1473, 37-60 micron sized powder was fired at 5.9 km/s at a vacuum degree of 9.5 Pa. Several grains of the Murchison meteorite manually extracted from the aerogel were embedded in sulfur separately, and sliced into 100 nm-thick sections with an ultramicrotome equipped with a diamond knife. Before analysis, the sections on the SiO-coated Cu TEM grids were mildly heated (<100°C, <15 min) until the sulfur sublimated off the grids. C-, N- and O-XANES analyses were performed for two grains from each shot (4 in total) using the STXM at beam line 5.3.2.2 in the Advanced Light Source, Lawrence Berkeley National Laboratory.

STXM images and elemental maps for C, N and O showed no clear evidences for surface degradation, nor differences between surface and interior of the sections of the Murchison grains after the experiments, although there were some heterogeneity of the elemental distributions and textures. Note that the heterogeneity of the elemental maps partially attribute to heterogeneity of the sample thickness that is mostly due to large porosity of this meteorite. The sizes of the analyzed ultramicrotomed sections that roughly represent the recovered grain sizes were in the range of 10 to 25 μm for shot #399, and in the range of 10 to 40 μm for #1473. The C-XANES were obtained at least a few micrometer inside of the grains. The C-XANES spectra of the Murchison after the 4.4 km/s shot have organic features at 285.0 eV assigned to aromatic/alkene C=C, absorption at 286.7 eV is assigned to ketone C=O, absorption at 287.5 eV is assigned to aliphatic C–C, absorption at 288.7 eV is assigned to carboxyl O–C=O, but in the case of the 5.9 km/s shot, most of these features disappeared. All sections show abundant oxygen mainly from silicates with some contributions from organics, but show low nitrogen contents. The results indicate that the Murchison grains recovered

after 4.4 km/s impact into the 0.01 g/cm^3 aerogel seem generally intact, but the grains recovered after 5.9 km/s impact show drastic changes in organic structure. Although further discussion is required on the size effects, the threshold impact velocity for organic survivability might be between 4.4 and 5.9 km/s. At least, organic matter in micrometeoroids with entry velocity of ~4.4 km/s or less can survive from the impact to the 0.01 g/cm^3 silica aerogel.

References:
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