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Crystallographic Characterization of Extraterrestrial Materials by Energy-Scanning X-ray Diffraction.

Kenji Hagiya[1], Takashi Mikouchi[2], Kazumasa Ohsumi[3], Yasuko Terada[3], Naoto Yagi[3], Mutsumi Komatsu[4], Shoki Yamaguchi[1], Arashi Hirata[1], Ayaka Kurokawa[1], Michael E. Zolensky[5] (Principal Investigator). [1]Graduate School of Life Science, Univ. of Hyogo (Japan), [2]Univ. of Tokyo (Japan), [3]JASRI (Japan), [4]SOKENDAI (Japan), [5]NASA-JSC (U.S.A.)

Introduction: We have continued our long-term project using X-ray diffraction to characterize a wide range of extraterrestrial samples. The stationary sample method with polychromatic X-rays is advantageous because the irradiated area of the sample is always same and fixed, meaning that all diffraction spots occur from the same area of the sample, however, unit cell parameters cannot be directly obtained by this method though they are very important for identification of mineral and for determination of crystal structures. In order to obtain the cell parameters even in the case of the sample stationary method, we apply energy scanning of a micro-beam of monochromatic SR at SPring-8.

Results: The following a brief summary of a few of our research topics. C-Class Asteroid Samples: We have been analyzing the crystal structure of secondary minerals in brecciated meteorites from C-class asteroids, including Kaidun, Jbilet Winselwan, and Sutter's Mill [1]. These are very unusual because they are the only samples we have of hydrous, very reduced astromaterials, giving us a unique ability to determine the physico-chemical conditions of aqueous alteration on primitive asteroids. This material is the best available match to probable building blocks of the terrestrial planets, a preview of material that will be returned from Asteroid Ryugu by the Hayabusa2 Spacecraft. Samples of early solar system hydro-volcanism: Crystal structures of mineral grains separated from within salt crystals found in ordinary chondrite meteorites [2]. These are derived from the mantle of a hydro-volcanically active early solar system body – possibly dwarf planet Ceres. These analyses are critical to understanding the results of NASA's Dawn Mission to Ceres, and are our only samples of hydrous volcanism. This far we have been able to make very accurate cell dimensions of olivine and low-Ca pyroxene and assess the shock state of the solids erupted along with the brine fluids. Hayabusa Mission Samples: We are trying to determine thermal metamorphic peak equilibration temperatures for Itokawa's parent asteroid using the low-calcium pyroxene structure, and albite structures. Also we are determining the shock state of the minerals, to better understand asteroid-asteroid interactions. Zolensky was one of only 3 foreign participants in the preliminary examination (PET) of the returned asteroid Itokawa samples. The results from our study of Itokawa sample 49-1 are very interesting, since this particular sample was essentially unshocked, despite the fact that the vast majority of the returned Itokawa samples have a record of moderate shock deformation [3]. Ordinary Chondrite Meteorites: The Itokawa samples returned by the Hayabusa Spacecraft are almost identical to the LL ordinary chondrite meteorites. We are examining the impact shock records of LL chondrite meteorites [4]. For example, for the Chelyabinsk meteorite the shocked phases have witnessed repeated parent body shock metamorphic events whose timings have been measured by several radiogenic methods. Thus our work is critical to understand what the dates actually represent.

References: [1] Zolensky et al. (2016) *47th Lunar Planet. Sci. Conf. Abstracts*; [2] Zolensky et al. (2015) *Abstracts, 78th Annual Meeting of the Meteoritical Society*; [3] Mikouchi et al. (2014) *EPS* **49**, 1305-1314; [4] Takenouchi et al. (2015) *46th Lunar Planet. Sci. Conf. Abstracts.*