MATRIX MINERALOGY OF THE LEAST ALTERED CM-RELATED CHONDRITE ASUKA 12169. T. Noguci[1], M. Yasutake[2], A. Tsuchiyama[2,3], A. Miyake[4], M. Kimura[5], A. Yamaguchi[5], N. Imae[5], K. Uesugi[6], and A. Takeuchi[6]. [1]Faculty of Arts and Science, Kyushu University (744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan; tnoguchi@artsci.kyushu-u.ac.jp), [2]Research Organization of Science and Technology, Ritsumeikan University (1-1-1 Nojihigashi, Kusatsu, Shiga 525-8577, Japan. yasutakemasahiro.meteo@gmail.com, atsuchi@fc.ritsumei.ac.jp), [3]Guangzhou Institute of Geochemistry, Chinese Academy of Sciences (511 Kehua Street, Wushan, Tianhe District, Guangzhou, GD 510640, China), [4]Division of Earth and Planetary Sciences, Graduate School of Science, Kyoto University (Kitashirakawaoiwake-cho, Sakyo-ku, Kyoto 606-8502, Japan; miya@kueps.kyoto-u.ac.jp), [5]National Institute of Polar Research (10-3 Midori-cho, Tachikawa 190-8518, Tokyo, Japan; kimura.makoto@nipr.ac.jp, yamaguch@nipr.ac.jp; imae@nipr.ac.jp), [6]Japan Synchrotron Radiation Research Institute (1-1-1, Kouto, Sayo-cho, Sayo-gun, Hyogo 679-5198, Japan; ueken@spring8.or.jp, take@spring8.or.jp)

Introduction: Almost all CM chondrites experienced varying degrees of interaction between anhydrous phases and liquid water (aqueous alteration) and thermal metamorphism [1, 2]. Reflectance spectra of the asteroid Ryugu that has been explored by Hayabusa 2 spacecraft suggest that the surface of Ryugu experienced partial dehydration due to thermal metamorphism and/or shock heating [3, 4]. It is also pointed out that Ryugu may consist of carbon-rich, partially hydrated, possibly comet-like material [4]. In addition, it is worthwhile to examine the possibility if the surface material experienced weak aqueous alteration. Therefore, it is important to understand CM chondrites that experienced an early stage of aqueous alteration. Just a few such meteorites fall into such category: Paris and Yamato 791198 [5-7]. Recently, it was pointed out that Asuka (A) 12169 experienced very low degree of thermal metamorphism and aqueous alteration [8]. Here we present our preliminary results on the mineralogy of matrix of this meteorite.

SEM observation and nanotomography: We observed a polished chip of A12169 (5.1 mm x 3.4 mm) by JEOL JSM-7100F FE-SEM. Backscattered electron (BSE) images of the fine-grained matrix show that it is not porous and that fibrous materials do not develop in the matrix except for <~3 μm across patches. Abundant sub-μm-sized Fe sulfide grains are widely distributed in the matrix. By contrast, the surfaces of some chondrules show evidence of aqueous alteration. Mesostases of chondrules that contact chondrule rims and/or fine-grained matrix are replaced by alteration products. Thin (<10 μm) chondrule rims intermittently cover chondrules, which are composed of continuous groundmass with various brightness in BSE images embedding ~200 to 300 nm-sized euhedral to subhedral Fe sulfide.

We selected two ~30 μm x ~30 μm areas for detailed examination; one area composed of the fine-grained matrix and another containing altered area of a chondrule, chondrule rim, and fine-grained matrix (Fig. 1). House-shaped blocks were cut out from the chip. Nano X-ray tomography was performed at SPring-8 synchrotron facility. The result is presented elsewhere [9]. In the following sections, mineralogy of typical fine-grained matrix hewn out from the blocks is described.

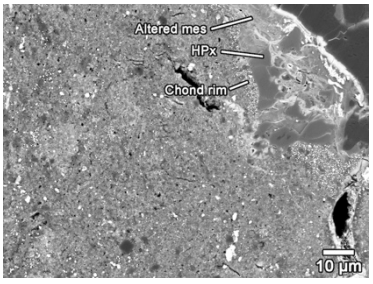

Fig. 1 BSE image of typical fine-grained matrix of A12169. Upper right corner of the image shows that the surface of chondrules experienced aqueous alteration. Thin chondrule rim has a texture different from the fine-grained matrix. mes: mesostasis, HPx: high-Ca pyroxene, Chond: chondrule.

TEM observation and STXM-XANES: We observed FIB sections by using FEI Tecnai G2-F20 and JEOL JEM-ARM200F. Figure 2 shows a HAADF-STEM image of the typical matrix. The matrix is composed of densely packed ~0.5- to ~1-μm sized domains containing abundant tiny (typically <~100 nm) Fe sulfide. The texture is similar to that of the least altered areas of the fine-grained matrix of Paris CM chondrite [6] but the porosity is much lower than the case of Paris. Different from Paris meteorite, there is no area filled by fibrous phyllosilicate. The absence of fibrous materials in the fine-grained matrix suggests that the matrix is composed mainly of amorphous silicate containing abundant small (>~50 nm) Fe sulfide. Analysis of CT images revealed that the matrix contained abundant elongated crystals. Some of them show selected area electron diffraction (SAED) patterns indicating that they are low-Ca clinopyroxene with minor orthopyroxene and abundant stacking disorder and that they are elongated along a crystallographic axis. These features clearly show that

the matrix contain relatively abundant enstatite whiskers and platelets. A ring-shaped aggregate of Fe-rich olivine (~Fo_{50}) is also encountered (Fig. 2). There are <2-3 μm across patches composed of loosely packed fibrous materials, which are not shown in Fig. 2. But the fibrous phases have not been identified by SAED patterns yet.

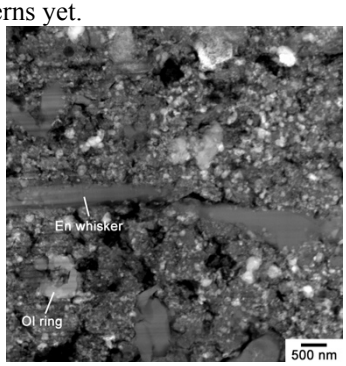

Fig. 2 HAADF-STEM image of the fine-grained matrix of A12169. The matrix is composed of densely packed ~0.5- to ~1-μm sized domains containing abundant tiny (typically <~0.1 μm) Fe sulfide. En: enstatite, Ol: olivine.

Si-Mg-Fe relative elemental abundances of the fine-grained matrix and small patches containing abundant fibrous materials are plotted in Fig. 3. Despite the absence of fibrous phases in the fine-grained matrix, the compositions of the fine-grained matrix are plotted along the solid solution line of Mg-Fe serpentine. Their compositional field is within the field of the least altered matrix of Paris and the variation of Si relative to Mg+Fe in the fine-grained matrix is more restricted than that of the case of Paris. The fibrous material-rich patches clearly deviate from the solid solution line and have a trend to the Fe apex. Because relative abundance of S in the patches is higher than that of the fine-grained matrix, they may contain poorly crystalline tochilinite. These patches may be precursors of tochilinite-cronstedtite intergrowth (TCI).

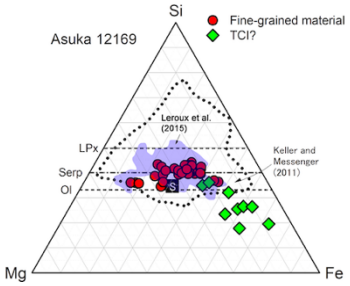

Fig. 3 Ternary diagram between Si, Mg, and Fe atomic ratios shows the compositions of the fine-grained matrix and possible precursor of TCI.

Because the morphology and chemical compositions of the fine-grained matrix are similar to those of the least altered areas of matrix of Paris, we performed elemental mapping of the matrix. Figure 4 shows a high-spatial resolution elemental map of the matrix. There are abundant tiny (<~30 nm) Ni-rich nanophases. Because Fe and S are not enriched in the nanophases and because Ni $L_{2,3}$ XANES suggests of the presence of Ni metal, these nanophases may be metallic nanograins highly enriched in Ni.

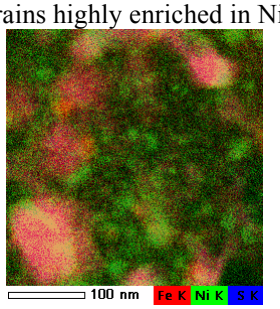

Fig. 4 High-spatial resolution composite pseudo color map of Fe Kα, Ni Kα, and S Kα lines of typical matrix of A12169. There are abundant tiny (<~20 nm) Ni-enriched nanograins.

Discussion: Mineralogy of the matrix of A 12169 is very similar to the least altered areas of the matrix of Paris. The presence of abundant amorphous silicate containing abundant tiny Fe sulfide and enstatite whiskers. Because there is no area that experienced severe aqueous alteration in A 12169, the overall degree of aqueous alteration of A 12169 may be weaker than that of Paris, as suggested by [8]. Enstatite whiskers have been also reported from the matrices of El Quss Abu Said CM chondrite [10] and Acfer 094 ungrouped C chondrite [11]. Enstatite whiskers may be much more common among the matrices of primitive carbonaceous chondrites. The amorphous silicate in the matrix contains abundant Fe sulfide as well as abundant metal nanograins highly enriched in Ni. This feature is different from GEMS (glass with embedded metal and sulfide) in IDPs. Further study is needed to clarify the difference is primary or secondary in origin.

References: [1] Rubin A. E. et al. (2007). *Geochim. Cosmochim. Acta* 71, 2361-2382. [2] Nakamura T. (2005). *J. Mineral. Petrol. Sci.* 100, 260-272. [3] Sugita, S. et al. (2019) *Science* Vol. 364, 6437, eaaw0422. [4] Kitazato, K. et al. *Science* 364, 272-275. [5] Hewins, R. H. et al. (2014) *Geochim. Cosmochim. Acta*, 124, 190–222. [6] Leroux H. et al. (2015) *Geochim. Cosmochim. Acta* 170, 247-265. [7] Chizmadia, L. J. et al. (2002) *Meteori. Planet. Sci.* 37, 1781-1796. [8] Kimura, M. et al. (2019) *Meteoritics & Planet. Sci., 32,* #6042. [9] Tsuchiyama, A. et al. (2020) *LPSC* 51, in this volume. [10] Nakamura, T. et al. (2008) *Meteorit. Planet. Sci.* 43, A110. [11] Matsumoto, M. et al. (2019) *Sci. Adv.* 5, eaax5078.