DEVELOPMENT ON NON-DESTRUCTIVE MUONIC X-RAY ANALYSIS OF CARBONACEOUS CHONDRITES: FEASIBILITY TEST FOR RETURNED SAMPLES FROM C-TYPE ASTEROIDS.

K. Terada[1], A. Sato[1], K. Ninomiya[1], Y. Kawashima[1], K. Shimomura[1, 2], D. Tomono[1], Y. Kawai[1], T. Osawa[3] and S. Tachibana[4], [1]Osaka University (include full mailing address and terada@ess.sci.osaka-u.ac.jp), [2]High Energy Accelerator Research Organization, [3]Japan Atomic Energy Agency and [4]The University of Tokyo.

Introduction: The muon is a lepton with a mass of 105.7 MeV/c^2, approximately 200 times heavier than the electron. So far, electron-induced characteristic X-ray analysis has been widely used to determine chemical compositions of materials in Earth and Planetary Science. In recent years, analysis of characteristic X-rays from muonic atoms, in which a muon is captured, has attracted attention because both a muon beam and a muon-induced characteristic X-ray have high transmission abilities, of which energies are about 200 times higher (e.g., muonic carbon-Kα is 75keV, whereas electron-induced carbon-Kα is 0.3 keV). From these features, a muonic X-ray analysis has great advantages in several ways; (1) non-destructive elemental analysis from light to heavy elements, (2) depth profile analysis, (3) isotopic measurement for heavy elements and (4) investigation of chemical condition (redox-state). Such a non-destructive muonic X-ray analysis has a great potential to characterize precious extraterrestrial samples returned by spacecraft such as Hayabusa2 and OSIRIS-REx in 2020's, before the sophisticated "destructive" analysis such as combustion, acid decomposition, polish, and sputtering so on.

Results and Discussion: We carried out the depth profile analysis of the four-layered sample that consists of SiO_2, C (graphite), BN (boron nitride) and SiO_2 using the D2 beam line at J-PARC MUSE. The negative muon beam was collimated to approximately 2.7 cm diameter and focus on the 50 mm × 75 mm × 4 mm sample that was oriented at 45 degree to the beam. Changing the Muon's momentum from 32.5 to 57.5 MeV/c, the generated high energy X-rays were measured by two Ge detectors. We also measured the Muonic X-rays from the Allende and Muchison meteorites. We also detected significant Mg and Fe signals from powered Murchison meteorite sealed in glass tube of which thickness is 1 mm.

Following our successful detection of muonic X-ray spectra from carbonaceous chondrites with intense pulsed Muon beam at J-PARC [1], we have developed on muonic X-ray analysis at the MuSIC (MuSIC; MUon Science Innovative Channel at Osaka University), and obtained the fundamental data for quantitative analysis of planetary materials. Using one of the world-leading intense direct current muon beam source, we successfully detected characteristic muonic X-rays of Mg, Si, Fe, O, S and C from Jbilet Winselwan CM chondrite, of which carbon content is about 2 wt%, and the obtained elemental abundance pattern was consistent with that of CM chondrites [2]. We also checked Muon irradiation damage of pellets of mixed organic chemical reagents (alanine, glucose, paraformaldehyde, phenanthrene, and stearic acid) after 3–12 hour exposure to check the irradiation damage, and confirmed that they do not show any systematic changes with either the exposure time or the depth, and are not different from those of non-exposed samples within the variation of initial reagent mixtures. We also performed the muonic X-ray analysis of terrestrial PbS (Galena) for Pb isotopes measurement [3] and iron meteorite to check the feasibility of chemical condition (redox-state) measurement. At the conference, we will report on our recent progress of muonic X-ray analysis and discuss on a future prospect for applications for Earth and planetary science.

References:

[1] Terada K. et al. (2014) *Sci. Rep.* 4: 5072. [2] Terada K. et al. (2017) *Sci. Rep.* 7: 15478. [3] Ninomiya K. et al. (2019) J Radioanal Nucl Chem. https://doi.org/10.1007/s10967-019-06506-9