PARTICLE SIZE EFFECT IN X-RAY FLUORESCENCE AT A LARGE PHASE ANGLE: IMPORTANCE ON ELEMENTAL ANALYSIS OF ASTEROID EROS(433) . T. Okada[1], [1]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (3-1-1 Yoshino-dai, Sagamihara, Kanagawa, 229-8510 Japan. okada@planeta.sci.isas.ac.jp)

Introduction: Laboratory experiments have been performed to show that microscopic roughness in the uppermost layer of planetary surface results in remarkable alteration of intensities and spectral profiles of X-ray fluorescence, especially at large phase angles.

Key objective of NEAR-Shoemaker mission was to evidence a linkage between an S(IV)-class asteroid and the corresponding meteorite. During one-year long observation around 433 Eros, the NEAR has conducted visible to near-infrared spectroscopy as well as X-ray and gamma-ray spectroscopy for surface mineralogy and elemental composition, respectively [1].

Spectral profile by the MSI/NIS was investigated to indicate that the surface mineralogy appears homogeneous region to region but any kinds of meteorites do not match the spectral profile quite well [2-3]. Derived abundance ratios of OL/PX and OPX/CPX suggests that the most probable material is L-chondrite. But the XRS data reveals agreement to H-chondrite, and consistent with R-chondrite or primitive achondrite as well, in major elemental ratios of Mg/Si, Al/Si, Ca/Si, and Fe/Si [4]. McCoy *et al.* (2001) concluded that 433 Eros is among ordinary chondrites with a little processed surface or a kind of primitive achondrite with same major elemental composition and mineralogy as ordinary chondrites [5].

How comes the unsatisfied conclusion that there remains large uncertainty of linkage between asteroid and meteorite? The reason is due to observation conducted at large solar phase angle during the NEAR mission. The spacecraft has a fixed high-gain antenna pointed to the Earth, which direction is almost towards to the Sun. To keep continuous link to the Earth, the spacecraft has been restricted to orbit Eros along the terminator so that the phase angle becomes almost 90 degree. In addition, the surface of Eros is covered with regolith typically from several tens to one-hundred microns in diameter. This scale is compared to the absorption depth of incident and emission X-rays of planetary XRF spectroscopy, so that shading and shadowing of X-rays is sufficiently enhanced to change the X-ray spectral profile itself.

In this study, laboratory experiments have been performed to simulate the observation in both of surface and geometric conditions. Results of the experiments lead to a conclusion that the microscopic surface roughness by particle size gives remarkable effect in X-ray fluorescence, especially at larger phase angles.

Experiments of Particle Size Effects at Large Phase Angles: Some studies have been reported on the particle size effect in X-ray fluorescence from the viewpoint of planetary exploration [6-7]. In the previous studies, surface roughness was directly measured by laser microscopy. The measured surface profiles were smoothed and approximated into a single cyclic function of best-fit wavelength and width by FFT. In those cases, rectangular shape model has been constructed, since only two parameters are required to express and it has been better fit relative to sinuous or triangular shape. For any shock-induced cracked powders of oxides and silicates, two parameters of wavelength, 2W, and depth, H, are investigated to express in the following formulae,

$$W = 14.95 + 0.231D, \quad (1)$$

$$H = 9.075 + 0.211D, \quad (2)$$

where D denotes the typical particle size. Using this model for powdered surface, we numerically estimated intensities of X-ray fluorescence at any solar phase angle. Assuming the asteroid in chondritic composition and the solar activity in low-level flare, our calculation exhibits that increase of Fe/Si by 10 to 30% and Ca/Si by 5 to 10% might be observed for phase angle of 90 degree,which is the case with the NEAR observation.

In the previous studies, samples with simplest composition were used such as alumina, quartz, or SiC, since it is convenient to understand physical processes. In this study, experiments with powdered basalt have been conducted to confirm the physical phenomenon by using more complicated or realistic material.

Specimen of various size distribution has been prepared from a single basalt rock, which is cracked and sieved into four groups: 1) $D<45\mu m$, 2) $45<D<106\mu m$, 3) $106<D<180\mu m$, and 4) $D>180\mu m$. A Cr-target X-ray tube (RIGAKU, Rint2000) is used as the incident X-ray generator. Intensity ratios of Ca-Kα and Ti-Kα relative to Fe-Kα are measured with a Si-PIN diode (AMPTEK, XR-100CR). Results are shown in Figure a-d, as functions of particle size and phase angle. Those results reveal the decrease of relative intensities of X-rays characteristic of the lighter elements since intensity ratios of Ca/Fe are always smaller than those of Ti/Fe. Tendency of decrease becomes more remarkable with increasing the phase angle and the surface roughness. For example, 15 to 20% decrease of relative intensity was found at large phase angle with powder of more than 45 micron size.

Implication to the EROS Composition: Results imply that particle size effect plays an essential role for quantitative elemental analysis for remote XRF, especially for observation from large solar phase angle. That configuration was conducted in the NEAR mission and some corrections are required to improve the accuracy of elemental analysis. Almost whole surface of Eros seems covered with regolith thicker than 1m, which is suggested from geomorphology imaged from orbit and taken as close-up views during the descent to surface. No evident information on the particle size are obtained, but the disk-integrated photometry by the MSI and the ground-based telescopic observation shows the same physical properties as the other S-class asteroids and the lunar regolith [8]. Then the typical size has been assumed by using lunar analogue. In this study are assumed four kinds of given typical size as flat or smooth surface, fine regolith of 40μm, typical lunar regolith of 80μm, and rough regolith of 160μm.

When a typical chondritic composition is assumed for surface material as well as the solar activity is in a low-level solar flare, those corrected elemental ratios of Mg/Si, Fe/Si, and Ca/Si are estimated for the four kinds of surface particle size, in comparison with the XRS data shown in Figure 4 of Nittler *et al.*(2001) [4]. These results are considered to represent in the case of the flat-flour that Eros would have composition of H-chondrite. When we go for the fine regolith, the composition of Eros is fallen between H- to L-chondrite. For the typical lunar regolith, most favorite composition appears L- or LL-chondrite. Furthermore, LL-chondrite is most likely for the rough regolith. In general, due to microgravity on the asteroid surface, the finer particles are easy to escape and relatively lost away during impact process. Surface roughness of Eros is most probably similar to or even rougher than that of the Moon. Therefore, elemental composition of L- or LL-chondrite is the candidate of Eros. That conclusion is consistent with the other evidence such as mineralogy derived from the MSI/NIS observation.

It is concluded that, as the surface material of 433 Eros, L-chondrite is most likely when the lunar analogy holds good, and LL-chondrite is maybe possible.

References: .

[1] Cheng A. F. et al. (1997), *JGR, **102***, 23,659-23,708. [2] Murchie S. et al. (2002), *Icarus **155***, 145-168. [3] Bell J. F. III et al. (2002), *Icarus **155***, 119-144. [4] Nittler L. et al. (2001), *Meteorit. Planet. Sci.*, ***36***, 1673-1696. [5] McCoy T. J. et al (2001), *Meteorit. Planet. Sci.* **36**, 1661-1672. [6] Kuwada Y. et al. (1997), *Proc. 30th ISAS Lunar Planet. Symp.*, **30**, 212-215. [7] Okada T. (1998), *Proc. 31th ISAS Lunar Planet. Symp.*, **31**, 218-221. [8] Domingue D. L. et al. (2002), *Icarus* **155**, 205-219.

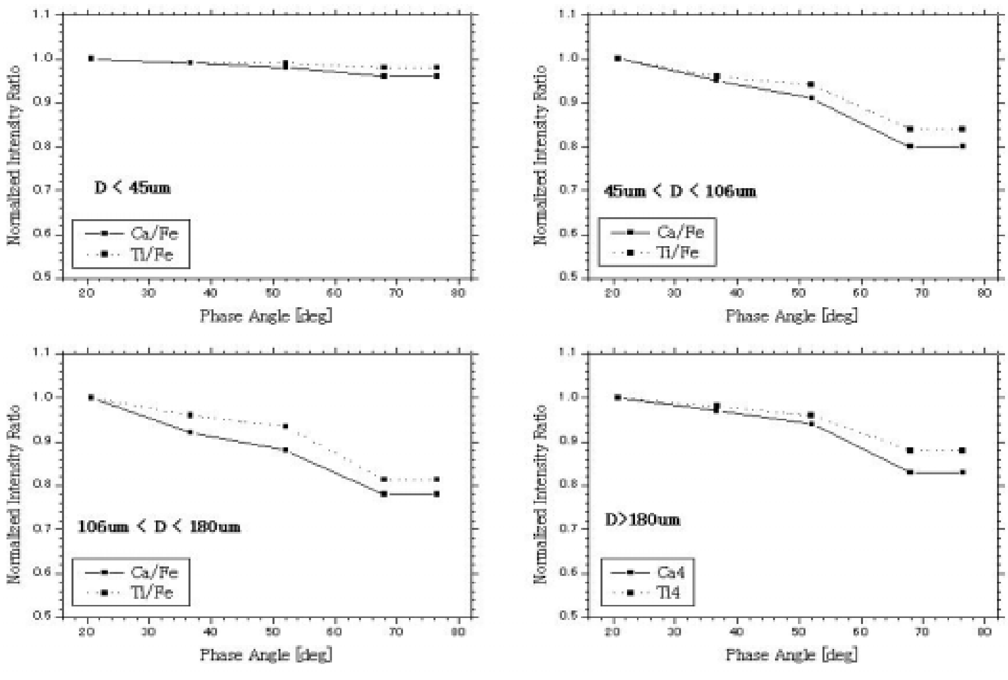

Figure. Results of experiment for particle size effect in X-ray fluorescence are shown with the plots of Ca/Fe and Ti/Fe intensity ratios as a function of phase angle for each sample particle size from (a) to (d).