PARTICLE SIZE EFFECT IN X-RAY FLUORESCENCE AND ITS IMPLICATION TO PLANETARY XRF SPECTROSCOPY.

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Laboratory experiments to investigate particle size effect in X-ray fluorescence were performed for the interpretation of planetary remote X-ray spectrometry. In this study fractured/crashed powdery specimens of rocks are used to simulate the microscopic roughness of uppermost planetary regolith surface. Importance of this effect should be addressed for XRF experiments when performed at higher phase angles.

Introduction: Irradiation of solar X-rays to atmosphere-free planetary surfaces excites X-ray fluorescence (XRF) radiation characteristic to elements. Major elemental mapping of the planetary surfaces can be carried out with concurrent observation of X-rays from the Sun and the planet. In laboratory experiments, we usually use polished flat samples or compacted powders whose particle size is typically less than 10 micrometers. However, the planetary surfaces are often covered with soils and breccias called regolith whose average diameter ranges ten to hundreds micrometers and sometimes covered with rugged rocks, in both cases far from the ideal surface for detailed analysis. It is generally believed that the XRF intensity falls down gradually with increase in particle size of powders. Such trend is more remarkable for the lager phase angles between incident and emission angles [1, 2]. Therefore, understanding the effects by particle size of planetary surface is important for quantitative elemental analysis through remote XRF spectrometry. This study aims at thorough investigation of angular dependency of XRF intensity at rough surface applicable to data analysis for planetary missions.

Laboratory experiments: We developed an apparatus for this experiment consisted of a helium chamber with incident and emission X-ray windows, a sample holder along with an X-ray tube and an X-ray detector. X-ray incident and emission angles are changeable. The powdery specimen is mounted on the holder inside the helium filled chamber. The holder can incline up to 30 deg. Fluorescent X-rays from the specimen are excited by irradiation of X-ray tube generated primary X-rays and are observed with the PIN photodiode based spectrometer. The detector has energy resolution good enough to discriminate XRF of each major element and simultaneously observe them.

We prepared the specimens by crushing rocks and sieving them into five different sizes. Those specimens used here include olivine basalt, dacite, and dunite whose particle sizes are 25-45, 45-90, 90-180, 180-250, and 250-500 microns.

In this experimental study, we attempted 1) obtaining detail data of XRF under a variety of incidence angle and constant emission angle (e=0deg) aiming at observation by the X-ray fluorescence spectrometer (XRS) onboard the lunar polar orbiter SELENE, 2) understanding of behavior of XRF under such condition that phase angle is almost 90 deg as performed in the NASA’s NEAR (Near-Earth Asteroid Rendezvous) Shoemaker asteroid mission.

Surface Modeling: We try to explain the particle size effects due to shadowing of incident X-rays and shielding of fluorescent X-rays by surface roughness. We made a model of surface roughness by two dimensional rectangular wave form characterized by half-wavelength and amplitude, W and H, respectively. The two-dimensional surface profiles for powdered specimen were measured by using a scanning laser microscope (Violet Laser VK-9700). These data were filtered with an appropriate bandpass to derive the averaged height-distance curves. The dependency of parameters, W and H, on particle size D was found linear and we performed the numerical studies by using the linear fits of them as functions of particle size as follows, $W = 0.430D + 5.05$, and $H = 0.37D + 9.46$, respectively.

Results and discussions: Si XRF intensities excited from powdery sample (olivine basalt) normalized to those observed for original flat rock sample are shown as a function of particle size (Fig.1). Diamonds show experimental results at incident angles from 35 to 65 degrees with constant emission angle perpendicular to the surface of specimen, and lines show numerical results under the same conditions. Both results show in good agreement except for largest grain size. Relative XRF intensity decreases with increase in average grain size, and slowly levels off. It is also more effective for larger incident angle. Dependency of XRF intensity of each major element is shown in Fig.2. Although almost the same decline can be seen in each element, the lighter elements have steeper decline at smaller particle size and show smaller intensity ratios at any particle size investigated here.

The surface of planets, the Moon, and relatively large asteroids is expected to have regolith, covered with crashed sandy material, on the uppermost surface due to impact ejecta sedimentation since the production mechanism is physically common. Thus, from these results, the effects of grain size and phase angle should require corrections for quantitative elemental analysis by remote XRF spectrometry.

We also discuss on the effects for application to planetary missions. Suppose a typical solar X-ray profile in C-Flare (8MK) [3] and a surface elemental composition of soils at Apollo 12 site [4], numerical studies of relative XRF intensity were carried out with phase angle varied from 35deg to 75deg. The XRF intensities can be calculated as functions of incident angles, and surface particle sizes (W and H).

Fig.3 shows the estimation of XRF intensities from planetary surface excited by solar X-rays (in C-Flare). XRF intensities are normalized by that of flat surface. There are found clear decrease of absolute intensities for larger phase angles. Such trend is more remarkable for lighter elements. Furthermore, in order to obtain XRF intensity within 10 percent accuracy, almost all the major elements except Fe need some corrections at larger phase angles. This means higher abundance ratios for Fe/Si or Ca/Si would be estimated without any corrections.

Further information on the method and the results of this study will be reported in detail.

References: [1]Kuwada, Y., Okada, T., and Mizutani, H., Proc. 30th ISAS Lunar Planet. Symp., 30, 212-215, 1997. [2]Kuwada, Y., MSc. Thesis, Aoyama Gakuin University, 1998. [3] Mewe, R., et al., A&AS, 65, 511, 1986. [4] Heiken, G. et al. (Ed), Lunar Sourcebook, 736p, 1991.

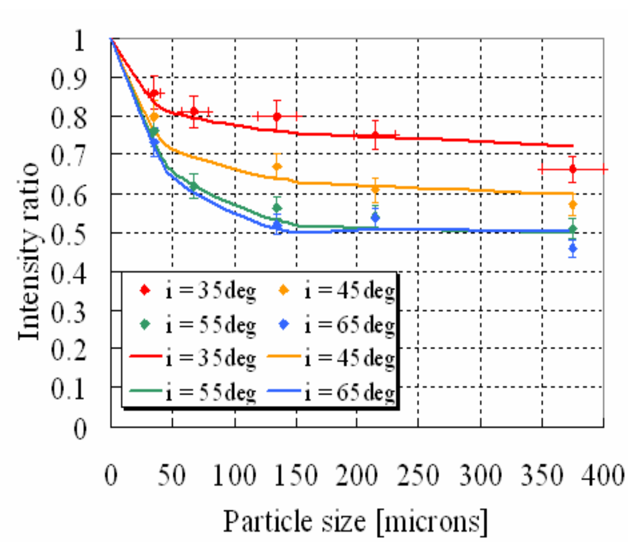

Fig.1. Si XRF intensities for crashed powdery sample (olivine basalt) normalized to those observed for original flat rock sample are shown as a function of particle size. Solid diamonds denote experimental results while lines show numerical results. Emission angles were fixed to 0 deg with incident angles varying from 35 to 65 deg.

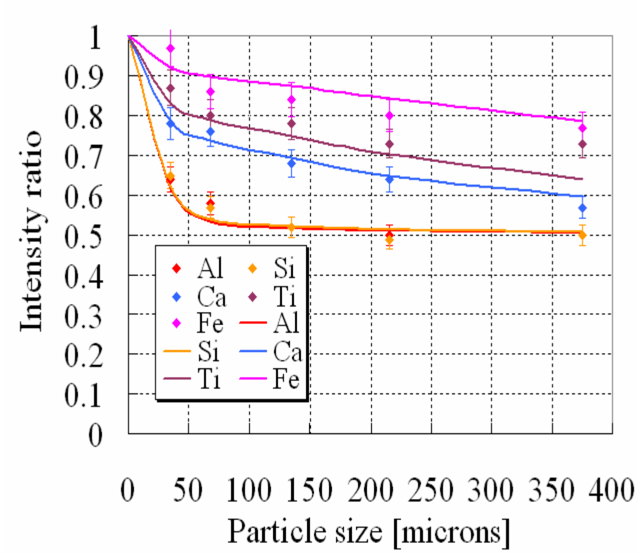

Fig.2. The same as in Fig.1, but the plots are shown for five major elements when observed with fixed emission and incident angles at 0 and 65deg, respectively. The lighter elements are more effective while the heavier elements are less effective.

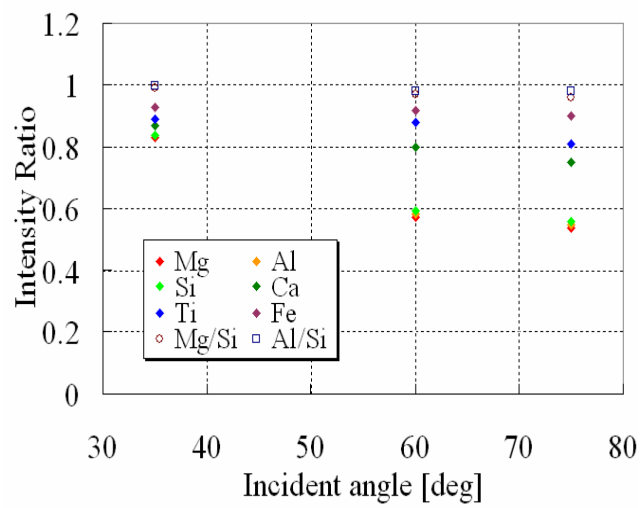

Fig.3. Numerical estimation of relative XRF intensities from planetary surface (average grain size is 75 microns and typical soil composition at Apollo 12 site is assumed) normalized by those from flat surface is shown. Excitation source is a typical solar X-rays at 8MK. Emission angle were fixed to 0 deg with incident angle varying from 35 deg to 75 deg.