INTRODUCTION TO THE SCIENTIFIC INVESTIGATIONS OF AN ACTIVE X-RAY SPECTROMETER FOR THE SELENE-2 ROVER.

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Introduction: Active X-ray Spectrometers (AXS) using radioactive sources have been frequently used to chemically characterize planetary surfaces. Especially, using an Alpha Particle X-Ray Spectrometer (APXS), Mars missions as the Mars Pathfinder and the two Mars Exploration Rovers (MER) missions have successfully determined the chemical composition of rocks and soils along their traverses. For these missions double excitation by the decay of Cm-244 was used: X-rays for X-ray fluorescence (XRF) and alpha particles for particle X-ray emission (PIXE). The technique of APXS for the recently launched Mars Science Laboratory (MSL) rover is similar to the previous Mars rover missions. MSL's APXS being very sensitive to high and low Z elements can measure about 20 elements with a 0.5 wt-% detection limit. [1,3]

A modified AXS instrument is envisaged to be on board of the Japanese SELENE-2 rover, which has a proposed launch date in the mid-2010s. The new AXS instrument will consist of a X-ray generator using a pyroelectric crystal and a large-area X-ray silicon drift detector (SDD) with an integrated field effect transistor similar to the detector of the MER APXS [2,3].

A laboratory version of the proposed AXS spectrometer for the SELENE-2 rover can be built with commercially available products. Using Amptek's X-ray generator, named COOL-X, and one of Amptek's silicon drift detectors, we investigated the effects of surface roughness on X-ray fluorescence induced by the 8-keV X-rays emitted by the generator COOL-X. This paper describes the preliminary experimental results.

Experimental approach: Investigation of surface roughness of a sample before an AXS measurement was carried out because roughness could affect the quality of the determination of the chemical composition of the sample. It was suspected that a roughness effect of the sample surface would exist. Hence, surface roughness of various samples was examined in order to find out what is the optimal surface roughness condition and how to minimize potential errors. For an investigation of elemental compositions as function of various surface roughnesses, we selected two basalt rock core samples, whose compositions are very uniform over a large volume. We cut each core into several disks of 5 cm in diameter (DI) and 1.2 cm thickness. Then we carved and/or polished each disk surface to obtain a different roughness. The surface roughness of each disk was quantified using a surface profiler. The roughness values ranged from 8.7 to 502.3 µm for core A and 6.5 to 377.0 µm for core B, respectively. Figure 1 shows samples with different surface roughness. Figure 2 shows three surface samples taken with different image resolutions. In order to examine the surface roughness, a camera with a resolution of lower than 14.7 µm/pixel can provide a clear image and sufficiently large area of the sample. The proposed field of view (FOV) of 25 mm for the SELENE-2 AXS and a camera with a resolution of about 20 µm/pixel was based on these experimental results. Note, the cameras on board of MER and MSL have a FOV of 31 x 31 mm at 30 µm/pixel and 18.3 x 21.3 mm at13.9 µm/pixel, respectively.

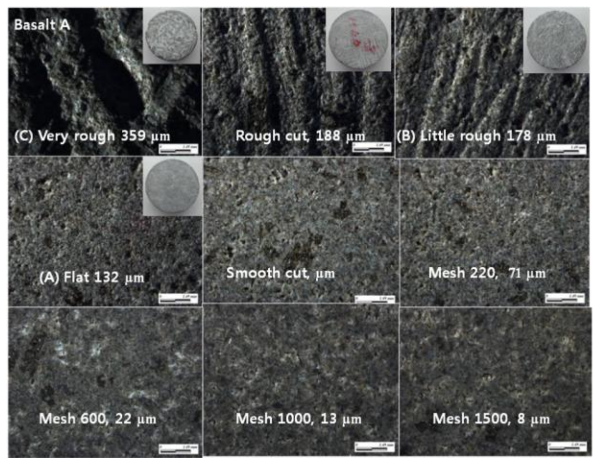

Fig. 1. Nine different surface roughnesses taken at a resolution of 27.5 µm/pixel by an Olympus microscope.

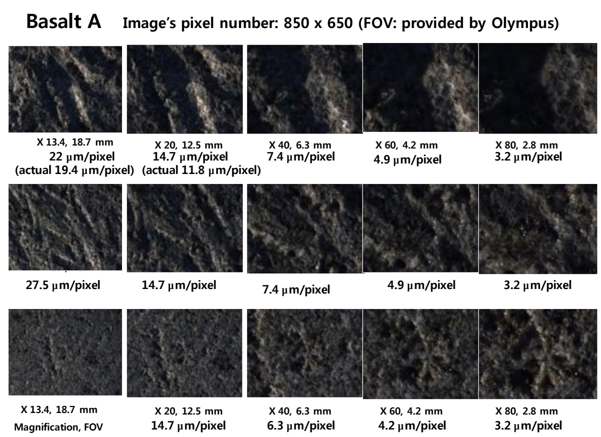

Fig. 2. Very rough, little rough, and flat surfaces shown at different resolutions. About 20 to 30 µm/pixel seems to be appropriate with respect to clarity.

Results of X-ray analysis: XRF analyses of Fe and Ca of each basalt disk sample were performed. Average surface roughness was estimated by averaging 20 data points of roughness. Figure 3 shows that Fe counts deviate at a very rough or very smooth surface from the general trend measured between 30 to 200 µm roughness. At very rough or very smooth surfaces the resulting elemental composition would be too low. Having a rock grinding tool on board, the above roughnesses range would be sufficient for a lunar mission.

The physics behind the decrease of X-ray fluxes for very rough or very smooth surfaces are known to be the effects of X-ray diffusion and reflectance as well as grazing-incident small-angle scattering, respectively [4-8]. X-rays exhibit total external reflection when impinged on a sample below a critical incidence angle. As the angle of reflection is increased above the critical angle, X-ray penetration occurs and reflections from sub-surface layers interfere with surface reflected radiation causing interference fringes indicating thickness and interfacial roughness [7].

Figure 4 shows that the pattern of Fe/Ca ratios is similar to Ca counts. This is caused by the fact that the characteristics of Ca and Fe with respect to incident energy of X-rays are different [4]. X-ray mass attenuation coefficient for Ca is higher at energies below 8 keV compared to Fe (Figure 5). This explains the pattern of Fe/Ca in region A of Figure 4. For region C, the decrease of Fe/Ca could be associated with relatively more low energy X-rays which are produced by grazing-incidence small-angle scattering at a smooth surface [6-8]. Photoelectric absorption is the dominant effect in the used energy regime. The photoelectric coefficient of Ca is larger than that of Fe at X-rays below 8 keV. Therefore, if lower energy X-rays are available via X-ray diffusion and scattering (very rough surface) and reflectivity and grazing-incidence small-angle scattering (very smooth surface), Fe/Ca ratios are decreased as it was observed.

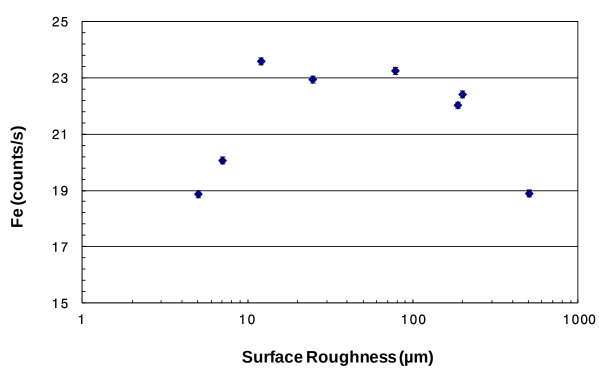

Fig. 3. Results of Fe counts as function of surface roughness. Data points show that a suitable surface roughness ranges within ~30 µm and 200 µm.

Summary: Our preliminary study for the AXS, proposed for the SELENE-2 rover mission, was accomplished using a commercially available X-ray generator and X-ray detector. This study revealed that the required surface roughness should range between ~30 to 200 µm. Outside this range, a bias in the estimation of elemental abundance can be expected because of the relationship of X-ray interaction with the surface morphology. To examine the surface, visible information is needed. The appropriate FOV was found to be about 25 mm (DI) at a resolution of 20 µm/pixel to obtain sufficient clarity of the image. The proposed AXS system using a pyroelectric crystal to generate 8-keV X-rays and a silicon drift detector would minimize radiation hazard and provide good XRF performance.

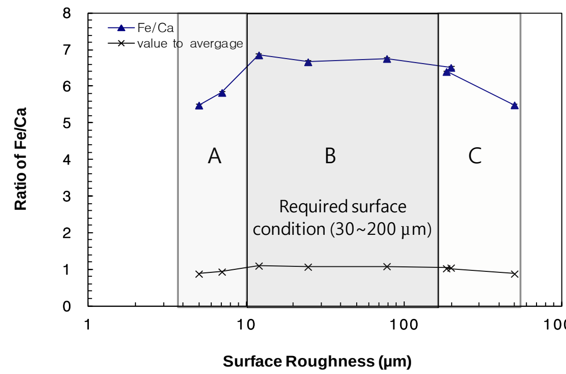

Fig. 4. Ratios of Fe/Ca (counts/counts) as function of surface roughness. Region B is a suitable for XRF analysis.

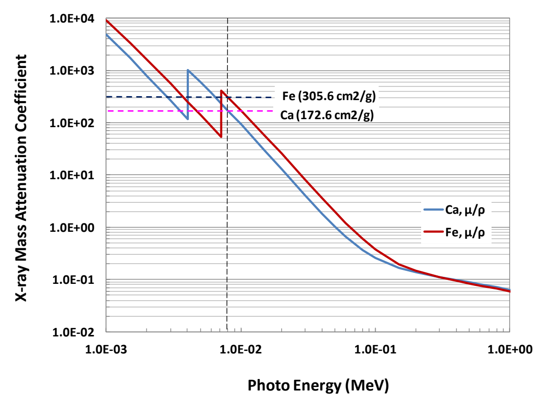

Fig. 5. Comparison of X-ray mass attenuation coefficients for Fe and Ca.

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