PROSPECTS FOR DERIVING LUNAR ELEMENTAL MAPS BY INELASTIC SCATTERING GAMMA RAYS. N. Yamashita[1], O. Gasnault[1], O. Forni[1], C. d'Uston[1], S. Chevrel[1], R. C. Reedy[2], N. Hasebe[3], Y. Karouji[3], O. Okudaira[3], S. Kobayashi[4], M. Hareyama[4], M. -N. Kobayashi[5], E. Shibamura[6], and K. J. Kim[7], [1]Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse / CNRS, France (naoyuki.yamashita@cesr.fr), [2]Planetary Science Institute, USA, [3]Waseda University, Japan, [4]Japan Aerospace Exploration Agency, Japan, [5]Chiba Institute of Technology, Japan, [6]Saitama Prefectural University, Japan, [7]Korea Institute of Geoscience & Mineral Resources, Korea.

Introduction: The Kaguya Gamma-Ray Spectrometer (GRS) [1] successfully observed the entire surface of the Moon. Radioactive elements K, Th, and U [2,3] as well as some of the heavy major elements such as Fe and Ti have been mapped [4,5]. The next target would be lighter elements that emit less intense gamma rays [6], including Ca, Al, and Mg.

Since intensities of gamma rays from the major elements on the Moon are proportional to both elemental abundance and neutron intensity [7], lunar gamma rays should be corrected for neutrons of corresponding energy range. Variations of observed neutron-capture gamma rays for some elements are dominated by the large range for the fluxes of thermal (~0.02 eV) neutrons. Therefore this work probes the usage of inelastic scattering gamma rays induced by high-energy (~1-20 MeV) neutrons to derive the distributions of lighter major elements on the Moon.

Data Processing: Kaguya GRS data obtained in the lower altitude (~50 km in Feb.-June 2008) portion of its mission were used. Gamma-ray counts were accumulated using the moving-average technique, i.e., every 2° with the radius of 450 km (15° at the equator). Noises in resultant spectra were filtered out. Net counting rates of gamma rays were determined by peak fitting for a better understanding of the complicated spectra [8]. When it was appropriate, data and knowledge obtained from the background measurements in which the detector was pointed away from the Moon [9] were utilized.

Analysis: To derive elemental distribution of Ca, Al, and Mg, the following gamma rays were selected for analyses. After deriving net counting rates, altitude and neutron correction was applied with corresponding energies using Lunar Prospector (LP) fast neutron data [10].

Calcium. The Ca distribution was investigated using 3736.5 keV peak from ^{40}Ca induced by inelastic scattering of high-energy (fast) neutrons. The stronger 1942.7 keV peak of Ca, induced by low-energy (thermal) neutrons, were rejected because of the reason mentioned above. The Ca peak and the baseline were carefully fitted so that the net count of the signal was obtained. The possible interference from the Ti 3733.6 keV peak was evaluated using other much stronger 6760.1 and 1381.7 keV Ti peaks. The weighted average of expected 3733.6 keV counting rates shows that the Ti can contribute as much as 10% of the Ca signal, with the average of 2.1%, depending on the Ti and Ca distributions on the Moon. The estimated Ti contribution was subtracted from the Ca intensities accordingly.

Aluminum. The Kaguya GRS had many significant Al peaks in its spectrum [8]. Since the detector cases and the body of the spacecraft were mainly made of Al, large ratios of background to lunar counts were expected. Therefore, we chose the 1014 keV inelastic scattering gamma rays from ^{27}Al, to minimize the variation of background counting rates over the lunar surface. The 7724.0 keV peak by Al neutron capture was also analyzed, only to produce a less precise map because of the large variation of the neutron number density. The good knowledge of the Al distribution is important for the analysis of Mg.

Magnesium. The observation of Mg on the Moon is difficult because the dominant Mg gamma ray at 1368.6 keV is being continuously made from Al and Si, elements that are abundant around the detector and in the lunar surface. That means the true signal and background signal have exactly the same energies. Therefore the big challenge to analyze Mg requires a good understanding of Al on the Moon and in the satellite and we commence the attempt by utilizing the knowledge of nuclear interaction of those elements.

The 1368.6 and 2754.0 keV peaks from ^{24}Mg were mainly used for this purpose. We assume there is no natural Mg in the satellite. We consider the "true" Mg signals from ^{24}Mg(n,n'γ) reaction, and the "background" signals from ^{27}Al(n,α)^{24}Na->^{24}Mg*, ^{28}Si(n,x)^{24}Na->^{24}Mg*, ^{23}Na(n,γ) reactions, and the prompt emission from ^{27}Al(p,x)^{24}Mg* ("->" indicates a β- decay). The contribution from other reactions that are not associated with a β- decay of ^{24}Na was not considered. For a zeroth approximation, the emission rates of the two peaks from the Moon and the satellite were calculated. Then, we take it for granted the fact that the ratio of the emission ratios of the two lines differs depending on the reaction type, i.e., the signal or the background, and we use the one to estimate the background of the other, after consideration of the change in attenuation rates in the lunar subsurface and detection efficiency. The derived map is qualitatively consistent with the LP map [11] in general.

The change in effective solid angles of each terms attributed to the difference in energies of the two gamma rays were temporary considered negligible in this work. Consideration of such effect is certainly the next step to improve the Mg map.

Results: The derived maps are presented as Fig. 1 for Ca and Fig. 2 for Al. The maps have not yet been calibrated to the absolute abundances and are expressed in units of counts per minute.

The Ca map exhibits general trends of low counting rates of the 3736.5 keV gamma rays in mare regions such as Procellarum, Imbrium, and Serenitatis, and high counting rates in feldspathic highland regions. The rim of Maria Crisium, Fecunditatis, and Nectaris in the eastern nearside show very high Ca counting rates. The floors of these maria also have moderate counting rates, which might possibly contradict with our previous knowledge of anti-correlation between Fe and Ca. Even thought there is a room for discussion for possible existence of high-Ca pyroxene in these regions [12], geological grounding will be necessary to confirm this estimate. Relatively low Ca counts at Mare Tranquillitatis and Oceanus Procellarum, which are both rich in Ti, show that the interference from the Ti gamma ray was effectively removed. A reflectance spectrometer on Kaguya reported the presence of pure anorthosite rock sites [13], most of which fall in the area of high Ca regions located in the highlands as shown in Fig. 1.

The Al map, on the other hand, presents a very good anti-correlation with Fe [cf. 4, 14]. This is believed to be one of the benefits from using inelastic scattering gamma rays, since the small variation of the lunar fast neutrons (and therefore albedo fast neutrons) contributes to the relatively constant background from Al near the detector all over the Moon, which can be removed by neutron correction. The resultant map in Fig. 2 shows the depletion of Al in both eastern and western maria as well as the South-Pole Aitken region. Maria Orientale and Moscoviense also show depletion of Al compared to their surrounding regions.

References: [1] Hasebe, N. et al., (2008) *Earth, Planets, and Space, 60*, 299-312. [2] Kobayashi, S. et al., (2010) *Space Science Reviews, 154*, 193-218. [3] Yamashita, N. et al., (2010) *Geophys. Res. Lett. 37*, L10201. [4] Gasnault, O. et al., (2009) *Lunar Planet. Sci. XL* Abstract #2253. [5] Karouji, Y. et al., (2010) presented at *Japan Geoscience Union Meeting 2010*, May 23-28, Chiba, Japan. [6] Reedy, R. C., (1978) , *Proc. Lunar Planet. Sci. Conf., 9*, 2961–2984. [7] Lawrence, D. J. et al., (2002) *JGR, 107, E12*, 5130. [8] Reedy, R. C. et al., (2009) *Lunar Planet. Sci. XL,* Abstract #1788. [9] Yamashita, N. et al. (2010) *European Planet. Sci. Congress 5*, #580. [10] Maurice, S. et al. (2004) *JGR 109*, E07S04. [11] Prettyman T. H. et al. (2006) *JGR 111*, E12007. [12] Lunar Sourcebook, pp. 357-474, Cambridge University Press, Cambridge, 1991. [13] Ohtake M. et al., (2009) *Nature 461*, 236.

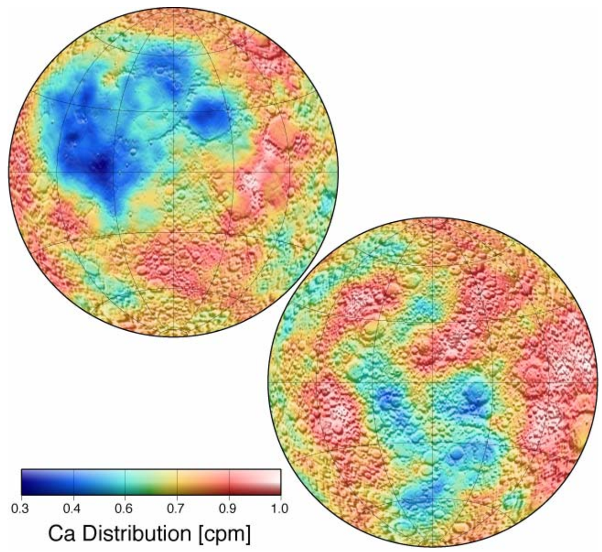

Fig. 1. Ca distribution on the nearside (upper left) and farside (lower right) of the Moon observed by Kaguya GRS.

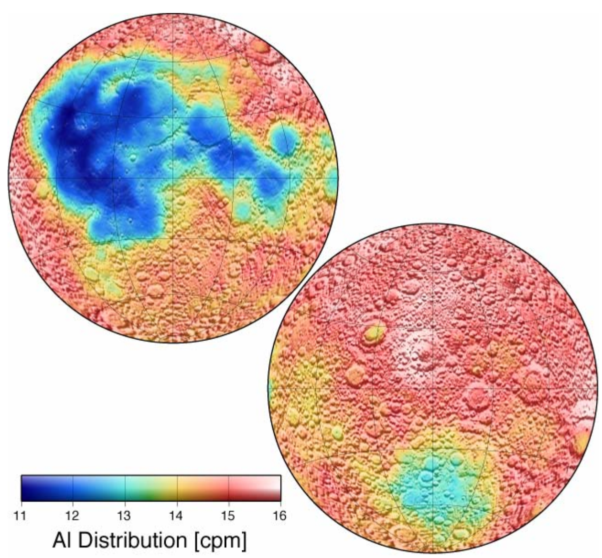

Fig. 2. Al distribution on the nearside (upper left) and farside (lower right) of the Moon observed by Kaguya GRS.