IDENTIFICATION OF MINERALS AND VOLATILES FOR LUNAR SCIENCE, RESOURCE UTILIZATION, AND LANDING SITE SELECTION USING HIGH ENERGY RESOLUTION GAMMA-RAY SPECTROSCOPY. N. Yamashita[1] and T. H. Prettyman[1], [1]Planetary Science Institute, Tucson, AZ 85719 (yamashita @ psi.edu).

Introduction: We seek to improve our knowledge of minerals and volatiles on the Moon using data acquired by the Kaguya (a.k.a. SELENE) Gamma-Ray Spectrometer (KGRS). Better characterization of subsurface geochemistry as well as identification and assessment of potentially useful minerals for in situ resource utilization will pave the way for future human and robotic exploration.

The Moon is a convenient laboratory for understanding processes underlying planetary formation and evolution. The surface of the Moon preserves a record of geochemical processes that occurred primarily during the past 3–4 billion years [e.g., 1, 2]. Several countries are proposing landed lunar missions, leveraging recent advances in space technology. In addition, evidence for ice in permanently shadowed craters has led to interest in using the Moon as a refueling base for human exploration of the solar system [3].

The elemental composition of the lunar surface provides crucial information needed to understand lunar formation and evolution as well as to identify and extract resources. JAXA's KGRS employed a high energy resolution HPGe to determine subsurface elemental composition [4, 5]. This data set will complement the Lunar Prospector (LP) mission, which had a high efficiency gamma-ray spectrometer (GRS) [6].

Data Set: The calibrated gamma-ray spectra acquired by the KGRS is being archived at NASA's Planetary Data System (PDS) Geosciences node, together with ephemerides, correction factors, and documentations [7, 8]. The data set is expected to be released by the end of January, 2020. Once it is available to public, we will spatially and temporally accumulate the time-series spectra to search for spectrum signatures of individual elements. Many of elemental signatures in spectra are interfered by nearby gamma-ray peaks. Therefore, sufficient spectrum (energy) resolution is essential to uniquely and precisely retrieve additional elemental information. The KGRS had an energy resolution of 4 keV (full width at half maximum at 662 keV), while the LP-GRS had that of 80 keV [4-6].

Elemental Investigations: We are using the KGRS data to determine the abundance and distribution of more elements than those previously studied, enabling investigation of minerals and volatiles for lunar science, resource utilization, and landing site selection. Our research focuses on the following investigations:

Outgassing and Transport of volatiles. Transport and dispersion of volatiles in non-polar regions of the Moon can be characterized using progenies of radon (^{222}Rn) as a proxy. Radon is produced by the spontaneous decay in the uranium series which begins with naturally occurring ^{238}U on the lunar surface. ^{222}Rn is gaseous with the half-life of 3.8 days. The study of Rn emanation was first suggested by [9]. Apollo, Kaguya and LP alpha-ray spectrometers measured increased Rn abundances specifically over the Aristarchus region, which suggests the Moon may still be geologically active [10-12]. Light lunar volatiles (H, He, and Ne) behave differently from heavier gases (Ar) that condense onto the lunar surface at night [13]. Radon should behave more like Ar than the light gases, at least within the atmosphere [13]. We will determine if allowances are needed in extrapolation from Rn behavior to that of lighter lunar volatiles (especially H). For better characterization of radon daughter products, it would be ideal to additionally measure very low-energy (40–100 keV) gamma rays, as proposed by the Chandrayaan-1 and Korea Pathfinder Lunar Orbiter (KPLO) missions [14, 15]. Even though the threshold energies of KGRS and LP-GRS were ~200 keV and ~500 keV, respectively, the KGRS data would provide a precursor study for the future low-energy gamma-ray observation from the orbit by KPLO-GRS, and for the landing site selection for the in-situ alpha-ray observation of radon by the French DOWN instrument [16, 17] onboard Chang'E-6 in 2023.

Better characterization of highland plagioclase feldspar series to constrain the formation and differentiation. Sodium (Na) is a moderately volatile lithophile element found to be depleted on the surface of the Moon, Mars, and Vesta [18]. The lack of Na (and K) is responsible for a much higher anorthite content on the Moon than that that typically found in plagioclase in terrestrial rocks [2]. However, the existence of a Na-rich crust was inferred by X-ray observations [19] of the Moon and by gamma-ray observations of Mercury [20]. That would require a complex evolution mechanism such as serial magmatism [e.g., 21] rather than the simple magma ocean [22] to form today's feldspathic crust. This would force us to change our current understanding of the crustal formation. The lack of Na on the Moon is typically explained by the Giant Impact Theory, in which the volatiles are lost in high temperature process. The bulk abundance of Na on the Moon can impose restrictions on temperature of formation and loss mechanisms.

Unambiguous detection of hydrogen. The H gamma-ray peak at 2.223 MeV can be used for unambiguous detection of hydrogen on the lunar surface to search for water and help select potential landing sites. H detection and its quantification are essential to understand the delivery and storage mechanism of the exogenic highly-volatile species on planets, not only at the poles but also in equatorial regions [23-31]. H is also considered a potential resource, useful as a rocket fuel and a reducing agent [e.g., 3]. Unambiguous detection of H will help plan future missions that explore the lunar polar region (e.g., LunaH-Map [32], VIPER [33], SELENE-R [34], and Artemis [35]).

Results: Preliminary results of these investigations will be presented at the conference. For example, the distribution of water ice was explored using the hydrogen gamma rays at 2.223 MeV observed in the lowest orbits (10–35 km) as shown in Fig. 1. In this analysis, the interferences from the nearby peaks in the spectrum were removed by the peak fitting method. Only preliminary corrections including the variations in the altitude were applied to the map. The general trend of the oblique distribution of the counts around the south pole was obtained, which is consistent with prior studies by neutrons [e.g., 36]. However, we also see anomalously high counts between 210° and 270°E at ~75°S where ice is not expected at depths sensed by the spectrometer. Further study of these regions, spectra, and observation conditions are needed to ensure accurate mapping of the lunar poles.

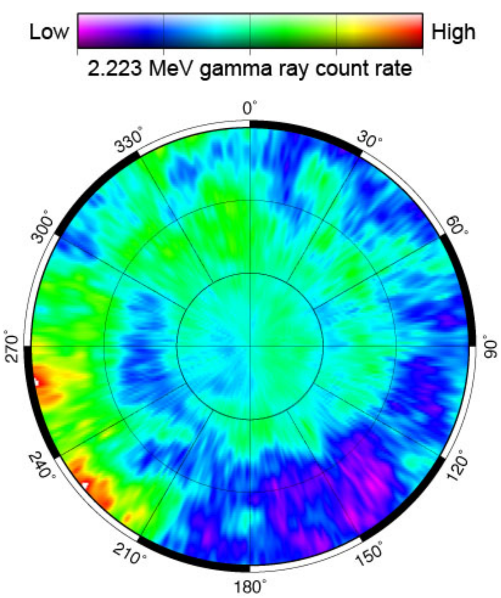

Fig. 1 Preliminary distribution map of hydrogen gamma rays at 2.223 MeV acquired by KGRS poleward of 75°S. See main text for details.

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