Preliminary developments of simplified lunar regolith simulants for Japanese future lunar missions. T. Takemura[1], T. Niihara[2], T. Kanzaki[1], M. Kobayashi[3], Y. Shimizu[1], and H. Miyamoto[1,3], [1]Department of Systems Innovation, School of Engineering, the University of Tokyo (takemura@seed.um.u-tokyo.ac.jp), [2]Department of Applied Science, Faculty of Science, Okayama University of Science, [3]Department of Earth and Planetary Science, School of Science, the University of Tokyo.

Introduction: Several space agencies and private companies have announced new lunar missions focusing on lunar resources, further increasing the demands of lunar simulants. Preparation of lunar regolith simulants has become an essential part of a mission for appropriate developments of instruments and designs of rovers and landing systems. Many types of lunar regolith simulants were previously developed [e.g., 1, 2], and some of them were used as a standard material for general purposes. There is a long history of developing lunar simulants for various purposes and debates on chemical compositions, mineralogy, particle size distributions, and other engineering properties. A simulant made for one purpose may be entirely unsatisfactory for another [3]. For example, if soil compositions are made similar to Apollo landing sites, they are different from those of the other unexplored sites. Other physical properties, such as microvesicles, were also not easily achieved to be satisfactory level [4]. On the other hand, adjusting a bulk chemical composition can be essential for simple engineering or instrumental tests. At an earlier stage of mission design, simulated materials, which are adjustable for parameters, such as mineral compositions and textures, particle size distributions, and particle shapes, could be the most convenient. We have been actively involved in the LUPEX and TSUKIMI (Lunar Terahertz Surveyor for KIlometer-scale MappIng) missions to map the lunar surface's water-ice. We develop simplified simulants for specific purposes regarding these missions.

Methods: The simulant prototypes of this work are created through the following procedure:

1) Preparing raw materials, which appear to have similar textures with lunar regolith particles
2) Estimating the simulant's particle size distribution based on Apollo regolith samples
3) Crushing and sieving raw materials to satisfy the particle size distribution
4) Mixing raw materials with calculated appropriate mixing ratio to adjust the chemical composition

The petrographic analysis is conducted by Scanning electron microscope (JEOL JSM-6510 and JCM-6000Plus) with an accelerating voltage of 15 kV. Bulk chemical compositions of raw materials and developed regolith simulants are analyzed by an X-ray fluorescence spectrometer (XRF: Rigaku ZSX Primus II) at the University of Tokyo. Glass bead samples are prepared for all samples. The Rh is the target of the X-ray tube, the applied voltage was 50 kV, and the applied current was 60 mA. The calibration curve for the analyses is obtained by using geochemical standards of terrestrial silicate rock samples.

Raw materials were selected based on the major element, texture, and mineral assemblage. Texture and composed minerals of collected materials are tested using petrological thin sections with a microscope.

We collect anorthosite, dunite, and gabbroic rocks, which somehow resemble lunar plutonic rocks. Fresh basaltic scorias are also incorporated to simulate agglutinates. Due to the Earth's environments different from the Moon, some minerals such as armalcolite [(Mg, Fe^{2+}) Ti_2O_5], which is found in Apollo samples, cannot be easily simulated. Without such minerals, resulting compositions become poor in Fe and Ti. To compensate for this effect, we add other oxide minerals of magnetite (Fe^{2+}, $Fe^{3+}_2O_4$) and ilmenite ($FeTiO_3$).

Fixed particle size distribution: To define the particle size distribution of simulants prototypes, we compiled all Apollo sample data in the catalog of the size distribution [5]. The cumulative particle size distribution does not show significant variations in the Apollo landing site, even between the mare and highland samples. Therefore, we use the average particle size distribution for our simulant prototypes (Figure 1).

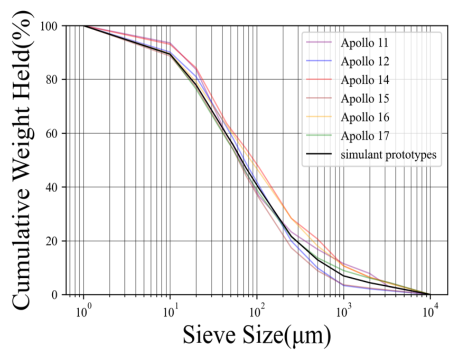

Figure 1: The averaged particle size distributions of Apollo sample and simulant prototypes.

The shape of simulant particles: The lunar regolith has highly angular particles, as explained by their formational history of repetitious hypervelocity impacts. As not like the Earth, the airless and waterless environment does not cause alteration effects and keeps the angular or jagged shape of the regolith particle [4]. Using Jaw crusher and stamp mill, we crushed the raw materials to a fine powder with the angular shape and jagged surface textures as seen in the lunar surface (Figure 2). Their particle size distributions are adjusted by sieves.

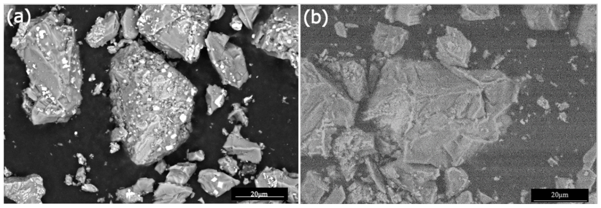

Figure 2: Basalt particles crushed by (a) Jaw crusher, (b) Stamp mill.

Simulant prototypes for Apollo landing sites: In this research, we aim to develop rough and simple simulants for the specific areas, including target sights for future explorations. For this purpose, we need to constrain the bulk compositions of target areas only from remote sensing data, which is challenging due to their limited resolutions. We use six Apollo landing sites to calibrate our methodology. First, the six Apollo landing sites' averaged ten major elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, and P) compositions are used as the sample analysis data. Then, five elements (Ti, Al, Fe, Mg, and Ca) data calculated from NIR + UVVIS data of the Clementine spacecraft using LP GRS data as ground-truth [6] are used as the remote sensing data. Using these data and mixing raw materials, we make six simulant prototypes for the two different previous data, the sample analysis data and the remote sensing data. The optimal mixing ratio of raw materials is calculated using XRF results of raw materials, minimizing the squared errors of compositional differences from the target.

The chemical composition of each simulant was analyzed by XRF. For the simulant prototypes based on sample analysis data and remote sensing data, the abundance of ten major elements are within 2.3 wt% and 2.7 wt% difference from the elemental abundances of each Apollo landing site, respectively. These preliminary results show that simulants prototypes created from remote sensing data can roughly simulate the bulk composition of specific target sites as well as sample analysis data.

South-Pole Aitken and farside highland simulants: We obtain target composition for the inside of Von Kármán crater (44.8°S , 175.9°E) in the South Pole-Aitken Basin and the highland area of the lunar farside (0.0°, 150.0°E) from NIR + UVVIS data of the Clementine spacecraft [6]. Based on the compositional information, we create prototypes in the same way with the Apollo landing site simulant (Figure 3).

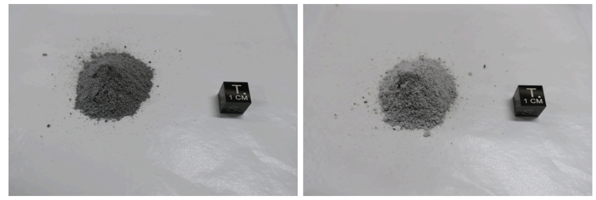

Figure 3: Simulant prototypes of (a) Von Kármán crater (44.8°S, 175.9°E) and (b) the lunar farside highland (0.0°, 150.0°E).

Mechanical properties of each simulant: We measured the poured density (i.e., the bulk density just poured into a cylinder), tapped density (i.e., the bulk density after tapping the cylinder), Hausner ratio, and angle of repose of the simulant prototypes (for Apollo lading sites, South-Pole Aitken, and farside highland). Even though the results are preliminary, poured density (1.60-1.83 g/cm^3), tapped density (2.15-2.44 g/cm^3), Hausner ratio (1.24-1.40), and angle of repose (54.4-63.2 deg) roughly simulate the values of the mechanical properties of the samples obtained from the lunar surface [7, 8].

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