[E] 口頭発表 | セッション記号 P (宇宙惑星科学)：P-PS 惑星科学

2019年5月29日(水) 13:45 ~ 15:15 | A01 東京ベイ幕張ホール

[P-PS02] Regolith Science

コンビーナ:和田 浩二(千葉工業大学惑星探査研究センター)、中村 昭子(神戸大学大学院理学研究科地球惑星科学専攻)、Patrick Michel(Observatoire De La Cote D'Azur)、Kevin John Walsh(Southwest Research Institute Boulder)、座長:和田 浩二(千葉工業大学惑星探査研究センター)

Recent planetary explorations have revealed that almost all solid bodies in the solar system are covered with small particles, called regolith. The surface geology, especially regolith behavior on the surfaces of solid bodies, becomes increasingly more important as represented by Hayabusa mission and other on-going and planned sample-return missions such as Hayabusa2, OSIRIS-REx, and MMX.

For fully understanding the regolith science, it is required to know and compare the regolith conditions on various celestial bodies, from asteroids to planets, with various methods.

Therefore, this session welcomes broad topics related to regolith on various celestial bodies, such as asteroids, comets, the Moon, the martian moons, Mars, etc. Papers on the formation, evolution, and alteration processes of regolith particles and regolith systems on the surface of planetary bodies, remote and in-situ observational results and techniques, analyses and results of returned samples, and laboratory, numerical, and theoretical studies on the fundamental physical and chemical processes are all welcome.

Note that what we call regolith is not just fine grains: all kinds of materials (more or less loose) that lie on the surface, from cobbles to finer grains, are our targets.

13:45 ~ 14:00

[PPS02-01] Moganite in a lunar meteorite as a trace of H_2O ice in the lunar regolith

★Invited Papers

*鹿山 雅裕[1] (1.東北大学)

14:00 ~ 14:15

[PPS02-02] Simulating the Lunar Soil: a Japanese Lunar Soil Simulant FJS-1 and Its Properties

★Invited Papers

*鵜山 尚大[1]、金森 洋史[1]、青木 滋[1] (1.清水建設株式会社)

14:15 ~ 14:30

[PPS02-03] Experimental estimation of regolith scattering behavior when a space lander touches on a planetary body

★Invited Papers

*馬場 満久[1]、Ronald Ballouz[2]、大槻 真嗣[1] (1.国立研究開発法人宇宙航空研究開発機構、2.アリゾナ大学)

14:30 ~ 14:45

[PPS02-04] Ray systems in granular cratering

*Tapan Sabuwala[1]、Christian Butcher[1]、Gustavo Gioia[1]、Pinaki Chakraborty[1] (1.Okinawa Institute of Science and Technology Graduate University)

14:45 ~ 15:00

[PPS02-05] Scaling of oblique impact cratering onto inclined granular layer

滝澤 真太[1]、*桂木 洋光[1] (1.名古屋大学大学院環境学研究科)

15:00 ~ 15:15

[PPS02-06] Experimental study on gravitational effects on crater size formed by low-velocity impacts into granular media

*木内 真人[1]、中村 昭子[2]、和田 浩二[3] (1.国立研究開発法人宇宙航空研究開発機構宇宙科学研究所、2.神戸大学大学院理学研究科、3.千葉工業大学惑星探査センター)

Moganite in a lunar meteorite as a trace of H_2O ice in the lunar regolith

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A large amount of H_2O ice has been observed on the regolith surface near the lunar poles by remote sensing spacecraft. However, only sparse evidence for H_2O ice beneath the top few millimeters of the regolith exists because neutron spectrometers cannot distinguish forms of H and near-infrared spectrometers are only sensitive to the optical surface. Furthermore, traces of H_2O ice have not yet been found from the lunar samples. Here, 13 different lunar meteorites with various lithologies have been investigated using micro-Raman spectrometry, electron microscopy, and synchrotron angle-dispersive x-ray diffraction (SR-XRD) to find a trace of H_2O ice in the subsurface. Consequently, moganite has been discovered from the KREEP (high potassium, rare-earth element, and phosphorous)-like gabbroic-basaltic brecciated meteorite NWA 2727 that may originate from the local crater sites within the Procellarum terranes.

Moganite (monoclinic SiO_2 phase that belongs to the *I2/a* space group) coexisting with coesite and stishovite (high-pressure SiO_2 polymorphs) was discovered only in NWA2727 by the micro-Raman spectrometry. NWA 2727 is mainly composed of gabbroic and basaltic clasts containing their breccia matrix, where only the breccia matrix contain moganite-bearing silica micrograins (2 to 13 mm in radius) between the constituent minerals (olivine, pyroxene and plagioclase). The SR-XRD analyses of these silica micrograins in the breccia matrix indicate a characteristic diffraction pattern that is in good agreement with the structure of moganite. However, no moganite was discovered from the basaltic and gabbroic clasts of NWA 2727 as well as in the other lunar meteorites selected here. Transmission electron microscopy of the silica micrograins demonstrates the aggregates of numerous euhedral or subhedral moganite nanoparticles (average radius of 4.5 nm).

Moganite was discovered in only one of those 13 samples. If terrestrial weathering had produced moganite in the lunar meteorites, there should be moganite present in all the samples, especially lunar meteorites fell to Earth around the same time (NWA 2977, 3333, and 6950 as measured here), but this was not the case. Furthermore, many previous researches on natural occurrences and laboratory experiments conclude that moganite is restricted to formation by precipitating from alkaline silicic acid (H_4SiO_4) water under high-pressure consolidation at >100 MPa, which is distinctly different environment from the desert that NWA 2727 found. A part of the moganite had changed into the coesite and stishovite, indicating their formation through heavy impact collisions on the Moon. These facts confirm our theory that it could not have formed in the desert.

Formation of lunar moganite can be interpreted based on the present and previous works as follows. Alkaline water-bearing carbonaceous chondrite collisions delivered abundant alkaline water to the lunar surface at <2.67 Ga. After the collisions, the delivered water was captured as fluid inside the breccia during the shock-induced consolidation. On the sunlit surface, lunar moganite precipitated from this captured alkaline water. Simultaneously, such captured water got cold-trapped at the lunar regolith in the subsurface and may still remain as ice underneath the local crater sites within the Procellarum terranes.

Lunar moganite coexists with coesite and stishovite, thereby implying that a trace of the subsurface water ice was brought from the Moon by the recent impact at <1–30 Ma. Our moganite-precipitation simulation modeling concludes a subsurface H_2O concentration higher than the estimated bulk content of 0.6 wt % is expected to still remain as ice. This value is in excellent agreement with the concentrations of H_2O ice on the poles by remote sensing spacecraft observation. Thus, the subsurface is expected to be the abundant and available water resource for future lunar explorations.

キーワード：モガナイト、月隕石、氷、レゴリス
Keywords: Moganite, Lunar meteorite, H2O ice, Regolith

Simulating the Lunar Soil: a Japanese Lunar Soil Simulant FJS-1 and Its Properties

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Going back to the Moon is a world-wide trend of space exploration based on the international cooperation as the Global Exploration Roadmap (GER3) stated. JAXA also proposed future human exploration missions around 2030 within the international cooperation. All scenarios have their bases on the scientific observation that a plenty of water (hydrogen) is trapped in the polar regions, especially inside the craters of permanent shadow. In order to investigate those water and other existing volatiles, however, many engineering challenges wait for human and robotic missions even only from the view of lunar soil, such as traversing the soft soil, drilling and/or excavating the soil, and handling the soil for desired sample collections and scientific processes, and more for the in-situ resource utilization and human missions. Thus, the ground tests prior to launches are of great importance to increase the possibility of mission success.

In order to offer opportunities for the community to perform ground tests, we have manufactured a lunar soil simulant, called FJS-1. The investigation of FJS-1 shows that many properties of FJS-1 lies close to the data collected from Apollo samples. For instance, the particle size distribution lies below 2 [mm]; the median particle size is between 70 and 75 [micro-m]; the shear strength, i.e. cohesion c, is 0 to 10 [kN/m2]; and the internal friction angle, phi, is 30 to 50 [deg]. The chemical composition is also close to Apollo samples with slight difference that FJS-1 contains more ferric oxide and Alkaline components than Apollo samples.

In addition to the basic properties, we started investigating the strength of frozen lunar soil using FJS-1. Determining the optimized configuration of a sampler such as a drill or an excavator needs the information of actual lunar soil; however, nobody knows the actual state, in other words, the ground truth of lunar water/ice yet. We therefore decided to investigate the strength of frozen soil, utilizing FJS-1, for the future use for drill or excavator designs. The qualitative observation from our first experiment is that the frozen FJS-1 at temperature below 0 [degC] became slightly loose when FJS-1 contained 0.5 to 1.0 [wt%] of water, and that the strength drastically increased above 2 [wt%]. We will conduct more experiments to collect a set of frozen soil strength to offer the estimates of the strength of lunar soil for future lunar exploration missions.

キーワード：月土壌、模擬土壌、FJS-1、模擬土壌特性、凍結土壌
Keywords: Lunar soil, Soil simulant, FJS-1, Soil simulant properties, Frozen soil

Experimental estimation of regolith scattering behavior when a space lander touches on a planetary body

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A planetary lander, which needs to land on and lift up from a planetary surface, needs to be concerned with levitated regolith. Regolith scattered by the landing foot pad might attach to or damage on-board instruments, such as the spacecraft' s camera suite. To design the landing probe, it is necessary to estimate the expected area of the regolith that the probe may scatter. Here we show an experimental approach that was developed to study the behavior of scattered regolith under a vacuum environment. For the probe design, it is necessary to precisely measure the initial ejection angle, ejection velocity, and the amount of regolith that the landing foot pad scatters.

In order to characterize scattered-particle behavior, drop tests in a large vacuum chamber were conducted. A cylindrical mass projectile, mimicking the lander foot pad, fell freely from various heights in the vacuum chamber. The mass lands in a sandbox filled with silica sand and forms a crater with scattered sand particles. During silica sand scattering, a high-speed camera detected particle highlighted by a line laser. Initial ejection velocities and the ejection angles were estimated by processing the images of the impact site, captured by the high-speed camera.

The result of our study revealed that the ejection angle of scattered grains is not sensitive to the impact kinetic energy of the projectile. Our results are consistent with previous studies that showed a similar relationship between impact kinetic energy and ejection angle, but for lower impact energies. Moreover, we find that for impact speeds of ~ 4 m/s, the initial ejection velocity of a majority of the silica sand particle is distributed around 1 m/s.

Our experimental approach can be applied to various kinds of planetary regolith, such as Phobos simulant for the Martian Moons eXploration(MMX). These results help us to understand how to determine the optimal design conditions for a landing probe. Further studies that account for the effect of microgravity and changes to the bulk density and porosity of the regolith need to be undertaken based on drop tower test and numerical simulation.

キーワード：レゴリス、室内実験、着陸装置
Keywords: Regolith, Laboratory Experiment, Landing Gear

Ray systems in granular cratering

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In classical experiments of granular cratering, a ball dropped on a smooth bed of grains ends up within a crater surrounded by a uniform blanket of ejecta. We show that such a uniform blanket of ejecta changes to a ray system, or set of radial streaks of ejecta, where the surface of the granular bed includes undulations. By carrying out numerous experiments and computational simulations thereof, we ascertain that the number of rays in a ray system $\propto D/\lambda$, where D is the diameter of the ball and λ the wavelength of the undulations. Further, we show that the ejecta in a ray system originates from valleys located in a narrow annulus of diameter D with center at the site of impact. The impacting ball creates a hemispherical shockwave, whose interaction with the surficial valleys engenders the ray system. Our findings may help shed light on the enigmatic ray systems that ring many impact craters on the Moon and other planetary bodies.

Keywords: impact crater, crater rays, granular cratering

Scaling of oblique impact cratering onto inclined granular layer

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Empirical (Pi-group) scaling laws for craters created on an inclined granular layer by an oblique impact of a spherical projectile were experimentally obtained. In the experiment, inclination angle and incident angle were systematically (and independently) varied in the ranges of 0 to 33 degree and 10 to 170 degree, respectively. A spherical projectile (diameter 6 mm) was impacted onto a surface of inclined granular layer with an impact speed 10 - 100 m/s. Two high-speed cameras and laser profilometry system were used to measure the impact speed, angle, and final crater shape. From the experimental results, we found following behaviors. When the incident angle is small, almost symmetric craters were observed. However, the collapse of the upper crater wall was triggered when the inclination angle is large enough. The scale of the collapse grows as the inclination angle is increased. In addition, the crater volume strongly depends on inclination angle. By combining these experimental findings, we developed the empirical scaling for crater dimensions and aspect ratios. The obtained scaling is consistent with previous works on the normal impact to horizontal granular surface with high impact speed. We also discuss a possible way to evaluate the impact conditions from the actual astronomical impact craters.

キーワード：斜め衝突、傾斜粉体層
Keywords: oblique impact , inclined granular layer

Experimental study on gravitational effects on crater size formed by low-velocity impacts into granular media

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Craters on regolith surface can be formed at various impact velocities. When secondary craters form on the surface of small bodies, such as asteroids and comets, the impactors have very low-velocities of several m s^{-1} or less due to the small escape velocity of the bodies. These secondary collisions can increase the number of small craters on the surface and will affect the surface topography of small bodies. Therefore, it is important to investigate low-velocity impacts on granular materials that simulate regolith particles to understand the low-velocity cratering process on the surface of small bodies.

Low-velocity impact experiments with velocities in the range of several m s^{-1} and granular targets have been conducted to investigate crater size and develop empirical relationships between impact conditions and crater size under 1 G (e.g., Uehara et al., 2003; Walsh et al., 2003). However, it was found that the impact velocity dependence of crater diameter was inconsistent between the hypervelocity impact experiments conducted at low and high-gravity conditions (Gault and Wedekind, 1977; Schmidt and Housen, 1987) and the low-velocity impact experiments conducted under 1 G (Kiuchi et al., 2018, JpGU meeting).

We collected data of crater diameter on granular materials with impact velocities ranging from 1 to 4.6 m s^{-1} under a gravity range of 0.20 to 1 G to investigate the effects of gravity on crater diameter using a drop system developed for reduced gravity impact experiments (Kiuchi and Nakamura, 2015 JPGU meeting). Most of our experiments were conducted under 10^5 Pa for comparison with the low-velocity experiments under 1 G reported in previous studies, but we also conducted several experiments under 7 Pa according to the atmosphere-less condition of small bodies.

This time we newly organized our experimental results in which the gravity was changed using the atmospheric pressure dependence. As a result, the exponent values of gravity became close to that obtained by the high-velocity experiment (Gault and Wedekind, 1977). We compared our results with high-velocity experiments reported in previous studies. Our results for the glass projectile and the sand target almost agreed with the previous high-velocity crater-size scaling- law (Housen and Holsapple, 2011) when the atmospheric effect was taken into account, but the crater diameter for the steel projectile and the sand target was lower than that for the glass projectile. This result shows that the crater-size scaling- law obtained for high-velocity impact can be applied to low-velocity impacts of several m s^{-1} under reduced pressure when the density ratio of the projectile to the target is close to unity. The same scaling applies over a very wide range of impact velocities.

キーワード：低速度衝突実験、クレーターサイズの重力依存性
Keywords: Impact experiments at low-velocity, Gravitational effects on crater size

