Japan Geoscience Union Meeting 2013
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PPS23-01 Room:201A Time:May 23 09:00-09:15

Development of a lunar broadband seismometer system for SELENE-2

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SELENE-2 is planed to be the first Japanese landing mission on the moon. As a strong candidate for an onboard instrument, we propose a lunar broadband seismometer system (LBBS). We have already presented the necessity of the broadband seismic observation beyond the Apollo seismic observation, requirements for the system, scientific objectives from the analyses of Apollo seismic data and the status of the development of LBBS. In this presentation, we introduce the recent progress in the development.

LBBS is a seismometer system having a broader bandwidth of 0.02 to 50 Hz and higher sensitivity than the seismic sensors of the Apollo project. To achieve the required performance at low risk, we decided to integrate an existing short period sensor (SP) and long period sensor (LP) in one package. The SP sensor is based on the velocity sensor developed in the course of the former Lunar-A project and has very high shock durability. The LP sensor is the VBB seismometer developed in France for the ExoMars project of ESA. These sensors shall be modified to satisfy the requirements of very high sensitivity and high stability against the severe surface environment on the moon. In addition, LBBS is composed of measurement and control electronics (ETHZ, Switzerland), leveling system (MPI, Germany) and a thermal shield, called survival module, with a recorder, communication circuits and batteries (JAXA, Japan).

We have carried out interface tests of 7 combinations among the components since autumn of 2010. In particular, we confirmed wellness of a partially integrated system of the SP sensor, measurement electronics and leveling system in an interface test at Zurich from Dec 2010 to Mar 2011. We successfully observed faint seismic tremors in ground motions. In July 2012, we carried out an interface test in which we integrated the SP, LP and leveling system at the Black Forest Observatory, Germany. For comparison, we also recorded outputs of a standard broadband sensor STS-2. All data outputs were recorded by an acquisition system of Quanterra Q330HR.

We analyzed the data so obtained, and found that waveforms obtained by LP and STS-2 almost similar one another and confirmed that LP can faithfully acquire ground motions irrespective of the neighboring SP. It, however, sometimes shows different waveforms from those of STS-2. The cause of this phenomenon is under investigation. On the other hand, SP data show very noisy time series not considered as ground motions. Spectra of the SP data show a flat shape and we cannot recognize spectral features of seismic tremors. Moreover, two horizontal SP sensors with an eigenperiod of 1 sec commonly took boxcar type off sets in the long period waveforms low-pass-filtered with a corner frequency of 0.1 Hz. This is an unacceptable result. They should show independent noises at such a low frequency much below 1 Hz. Thus we conclude that the SP data were polluted from an unknown source.

Potential causes of this phenomenon is (1) noises and instability in a 20 times amplifier, (2) an interference due to output impedance of the 20 times amplifier which may be out of range of the guarantee of Q330HR and (3) an electro-magnetic interference of LP on SP. We have already excluded the possibility of (1) by measuring the response of the amplifier using another acquisition device. In order to distinguish (2) and (3), we plan to obtain SP data without LP using Q330HR which will be rented.

In addition to the report on the above interface test, we also report results of vibration and thermal environment tests for two new manufacturing SP sensor models, and conceptual design of the survival module.

Keywords: seismometer, noise, interference, moonquake, ground motion, measurement

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PPS23-02 Room:201A Time:May 23 09:15-09:30

Development of an in-site rock observation system onboard the next lunar landing mission SELENE-2

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Compositional information of the lunar and planetary surface is important for understanding the bulk composition and evolution of the lunar and planetary bodies. For example, the information of the lunar highland could help us to know the solidification of the lunar magma ocean and to estimate the internal structure of the Moon. Previous studies had been done by using the lunar returned samples which have bias composition, so, it is important to select samples for well-understanding of more primitive highland materials by an in-situ observation.

We are now planning to develop a visible-SWIR macro camera with rock abrasion tool (RAT) which is required to establish a light-weighting for setting on a head of rover's arm. The RAT system will be required to observe the rock sample's texture and composition. An important issue is to grind the surface of rock under vacuum condition. We examined to make a grind test which was done to grind an anorthosite rock sample under a very low pressure of atmosphere by using a RAT developed by HONEYBEE ROBOTICS. As a result, we could confirm to be able to grind the rock sample with very low preload (< 5 N), however, additional bit development work is required to increase the bit life margin (more than 10 grinds). We'll report the details of the examinations about the RAT system, optical design of a visible-SWIR macro camera, and a dark current test of a visible-InGaAs sensor.

Keywords: visible-SWIR macro camera, rock abrasion tool

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PPS23-03 Room:201A Time:May 23 09:30-09:45

SELENE-2/Lunar ElectroMagnetic Sounder (LEMS): The effect of lunar crust on electromagnetic response

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In the SELENE-2 mission, we propose a lunar electromagnetic sounder (LEMS) to estimate the electrical conductivity structure of the Moon, from which the thermal structure in the lunar interior can be deduced. This means that electromagnetic sounding of the Moon provides any constraints on the lunar origin and evolution. It should also be noted that the electrical conductivity structure is independent of the seismic velocity structure derived from seismic measurements. Hence multiple mission instruments for geophysical exploration of the Moon are significant to investigate the lunar interior from various angles.

Magnetometers onboard a lunar orbiter measure temporal variations in the magnetic field of lunar external origin (the inducing field), which induce eddy currents in the lunar interior depending on the electrical conductivity distribution and frequencies of magnetic field. Magnetometers onboard a lunar lander measure temporal variations in the magnetic field of lunar internal origin (the induced field) generated by the eddy currents, as well as those in the inducing field. Electromagnetic response of the Moon can be obtained from these magnetic field measurements, and the response function is used to estimate the electrical conductivity structure by solving an inverse problem.

We have so far paid attention to the electrical conductivity structure of mantle which is the bulk of the Moon. We have investigated electromagnetic response of the Moon for prescribed conductivity models. The response function at higher frequencies obviously depends on the shallow structure, such as lunar crustal thickness and its electrical conductivity. Hence we examine the effect of lunar crust on electromagnetic response of the Moon. The result suggests that crustal thickness at the landing site may be estimated electromagnetically.

Keywords: electromagnetic sounding, lunar interior structure, SELENE-2

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PPS23-04 Room:201A Time:May 23 09:45-10:00

Constrains on the igneous activity of basaltic magma based on the distribution of radioactive elements on the Moon

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Investigation for the eruption ages and causes of mare volcanism on the Moon is essential for understanding the thermal evolution inside the Moon. Morota et al. [1] estimated the eruption ages of mare basalt units in the nearside of the Moon by using the image data obtained by the Terrain Camera (TC) [2] onboard Kaguya. In addition, Kaguya Gamma-Ray Spectrometer (KGRS) [3] successfully observed global distributions of radioactive elements (K, Th, and U) on the Moon [4, 5]. These observations present that most of the relatively young basalt units ($<$ 2.5 Ga) locate in the Procellarum KREEP Terrane (PKT) [6] enriched in radioactive elements. The radioactive heating produced by the decay of the radioactive elements in KREEP may affect the volcanic activities in the PKT [e.g., 7]. Studies of lunar basaltic meteorites indicate that the younger basalt is more enriched in K and Th than the older basalts. However, such an investigation has not been conducted for globally distributed maria using remote sensing data. Therefore, we investigated the relationship between the abundance of radioactive elements and eruption ages of mare basalts by Kaguya data in this study. Moreover, we discussed the effect of radioactive heating for the igneous activity of the Moon.

We used the gamma-ray spectral data obtained by the KGRS at the low altitude (50 +- 20 km) from February to May, 2009. The gamma-ray counts observed by the KGRS were integrated on each of basalt units defined by previous studies [e.g., 8]. The peaks at 1461 keV (^{40}K) and 2615 keV (^{232}Th-^{208}Tl) were used to estimate their intensities. The eruption ages of each mare basalt unit are derived by [e.g., 1]. The counting rates of gamma-rays from K and Th were calibrated to elemental concentrations by an empirical method using returned samples as ground truth. We have chosen Apollo and Luna soil samples as ground truth [9].

The K and Th contents of mare basalts in PKT are higher than those of mare basalts outside PKT. In the PKT, the eruption lasted for a long time, and each unit is enriched in K and Th. As the eruption ages of basalt units in the PKT are younger, their K and Th contents increased more. It seems reasonable that a region in PKT has more heat source elements, more magma might have been generated. The partial melting zone below the layers enriched in heat source elements might last longer time than other regions in PKT. The source regions of younger magma needed more heating by the decay of radioactive elements for its remelting to offset cooling associated with heat loss of the Moon as a time went on. Thus, the younger basalts contain more K and Th contents than the older basalts.

In contrast, most of the basalt units outside the PKT have low abundances of K and Th. This implies that the effect of radioactive heating by the KREEP layer is small. In other words, there must be no or very small volume of KREEP layer outside the PKT. Moreover, most units erupted by 2.5 Ga. This result implies that the mare eruption without heat from KREEP layer drastically decreased around 2.5 Ga. Previous calculations of lunar thermal evolution suggest that the volume of partial melting zone decreases with time and may be very small around 2.5 Ga without KREEP layer [e.g., 10]. Our results of mare basalts outside the PKT are supported by the assumption inferred from thermal evolution calculations.

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Keywords: igneous activity, basaltic volcanism, radioactive elements, Kaguya (SELENE), gamma-ray spectrometer

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Relationship between compositions and ages of lunar mare basalts

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Toward a systematic understanding of the formation and evolution of terrestrial planets, it is necessary to understand the early evolution of the Moon, an endmember of differentiated planetary bodies. However, the process of magma ocean solidification and the thermal and structural evolution of the mantle are still unknown.

Lunar mare basalts provide insight into horizontal and vertical compositional structure and the thermal history of the lunar mantle. In this study, we investigated titanium contents of mare basalts using high-resolution image data obtained by Kaguya Multi-band Imager. Our results show that mare basalts exhibit typical variations in titanium content, which may reflect differences in chemical composition of the magma source.

Previous studies with remote-sensing data have suggested that no simple relationship exists between titanium contents and ages of mare basalts. However, our new analysis indicates an obvious increase in mean titanium content at 2.3 Ga, implying that the mechanism for magma production changed at that time. The high-titanium basaltic eruption, which occurred at the late stage of mare volcanism, can be correlated with a peak of volcanic activity at ˜2 Ga revealed from crater counts for mare basalts. One possible explanation for the massive eruption of high titanium basalt is the development of hot super-plume rising into the mantle from the core-mantle boundary.

Keywords: Moon, lunar mare basalts, titanium content, lunar mantle, the Procellarum KREEP Terrane, mantle over turn

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PPS23-06 Room:201A Time:May 23 10:15-10:30

Development of evaluating method of Spatial distribution of craters on Lunar Surface for detection of secondary craters

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Secondary craters are impact craters formed by ejecta blocks that were thrown out of a primary crater formation. The secondary craters give a biased spatial distribution of craters. For a crater chronology, researchers extract the secondary craters from the surface including primary and secondary craters based on his or her subjective views.

The purpose of this research is to develop an algorithm for evaluating spatial distribution of craters on lunar and planetary images. In our algorithm, clustering analysis (S-LINK, Group average etc.) applies to ideal spatial distribution of craters and observed spatial distribution of craters, and evaluates whether a non-random portion in obtained image by comparing clustering analysis results of ideal and observed craters. We demonstrated for two regions in Mare Crisium and some Apollo landing sites. As a result, most of clustered secondary craters are detected quantitatively by our algorithm.

Keywords: Moon, Secondary crater, Cluster analysis

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PPS23-07 Room:201A Time:May 23 10:30-10:45

Study on New Model of Interior Reservoir of Light Elements on the Moon and Earth-Type Planets

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The following problems are existed interior reservoir and circulation of light elements on the Moon and Earth-type planets (i.e. primordial Earth and water-less planets of Mars and Venus) as follows:

1)Few systematic models of light elements and the Solar System materials of the Moon, Earth-type planets and smaller bodies are proposed, but only time and location data of the remained solid rocks are obtained at the primordial to the present bodies.
2)Little hard and wide rocks on the water-less Moon are existed except the breccias and fine void-rich regolith soils.
3)Light elements on the Moon are lost to form high-temperature minerals and rocks.
4)Few models of light elements to penetrate and reserve in the interior against the gravitational forces are proposed on water-less Moon and other planets.

The following models of impact growth process are proposed to explain the above problems (Miura, 2013; in press).
1)Impact growth model is applied to remained solid rocks from fine-grains to breccias.
2)Wide and hard continental rocks which have been formed by plate-movements, subduction and magmatic melting with lift-up eruption of ocean-planet Earth, cannot be applied for the Moon and other water-less planets.
3)The Moon rocks without light elements and high-temperature minerals and rocks are not formed by continuous smaller impacts, but by giant impacts with two planetary bodies with much light contents), called as step 1 process.
4)On the later Moon surfaces with mixed with smaller blocks, light elements are penetrated and stored in the interior by later impact, called as step 2 process.

In short, there are major two types light elements of steps 1 and 2 processes on solidified rock and regolith on the Moon The process of light elements as multi-steps are applied to wat4erless Venus and Mar.
The present Earth light elements are not used for the Moon and primordial Earth-type planets model, because the Earth is changed so much by ocean water system.

Keywords: The Moon, Earth-type Planets, Light elemets, Interior reservoir, New model, Giant planetary impact

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PPS23-08 Room:201A Time:May 23 11:00-11:15

Sites of radon gas emission on the lunar surface obtained from the SELENE Alpha-Ray Detector (ARD)

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We report results from the observations by Alpha Ray Detector (ARD) onboard SELENE. ARD observes the alpha-particles from Rn-222 and its radioactive decay products including Po-210. Rn-222 is in the decay sequence of U-238. Since radon is rare gas, it diffuses through the fissures or porosity of the lunar surface structure upon its production and decays with the half life of 3.8 days. About half of the daughter nuclei are adsorbed on the lunar surface, and Po-210 is produced after several radioactive decay stages of which time scale is regulated by one of the intermediate products' half life of 22 years. Thus, the intensity of Po-210 alpha-particles gives information on the radon gas emission integrated over the last several decades whereas that of Rn-222 alpha-particles is an indicator of the current gas emission. By analyzing the ARD data, we obtained the Rn-222 and Po-210 distribution on the lunar surface with the spatial resolution of about 80 km (FWHM) which is about a factor of 4 or 5 times better than the observations in the past. One of the most intense peaks of the alpha-particle signal was at the Aristarchus region where Apollo 15, 16, and Lunar Prospector reported detection of radon alpha-particles. Another peak of Po-210 alpha-particle intensity was discovered in the region of Mare Moscovience on the far side of the moon, where the crust thickness has been found to be exceptionally thin. In terms of large-scale intensity distribution of the Po-210 alpha-particles, northern part of the PKT region showed higher intensity than the southern part of the PKT and FHT regions. This trend is not in complete accordance with the U-238 distribution on the lunar surface derived from gamma-ray observations which shows the highest intensity in the southern part of the PKT region. This is probably because the radon alpha-particle intensity reflects the subsurface distribution of U-238. We will discuss the overall picture of the radon gas emission on the lunar surface based on the results of the ARD observations.

Keywords: Moon, radon gas, alpha particle, lunar crust, SELENE

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PPS23-09 Room:201A Time:May 23 11:15-11:30

Heterogeneity of lunar mantle composition estimated by spectral analyses of Dark Mantle Deposits

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The lunar mantle makes up 90% of the lunar volume. Therefore, it is important to determine the mantle composition for understanding the lunar bulk composition and the process of its differentiation from the lunar magmatic ocean. However, the composition of the lunar mantle remains unclear. On the other hand, pyroclastic beads which are volcanic glass or partially crystallized spheres provide a direct clue to lunar mantle composition. Previous studies suggested that pyroclastic beads are the result of an explosive fire-fountain originating deeper (300 to 500 km) in the mantle than basaltic magma and retain the original composition of the magma because the beads have higher Mg# than mare basalts and do not completely crystallize during eruption, due to the high upward speed. It is also reported that the color variation of pyroclastic beads correspond to their composition, in particular TiO_2 content, and the crystallinity of the beads. Also, the crystallinity of the beads correlates with quenching rate of the erupted magma formed them and the volatile content in the magma.

Dark Mantle Deposits (DMDs) are darkest regions on the Moon and are believed to contain pyroclastic beads. Thus, by estimating the composition and crystallinity of DMD based on remote-sensing data, we can investigate the composition and volatile content of the magma generated in the deeper lunar mantle on a global scale.

In this study we estimated the TiO_2 content and crystallinity of the largest 20 DMDs distributed globally over the Moon and investigates the compositional relationships of the magmatic sources, among DMDs and between DMDs and the surrounding mare basalt using spectral data obtained by the Multiband Imager (MI) on SELENE. First, we selected DMD locations which have the lowest reflectance and spectral absorption features of pyroclastic beads. Second, we judged the types of pyroclastic beads by comparing the spectral absorption shapes of DMDs in the MI data with that of the laboratory-measured data for Apollo pyroclastic beads. Finally, by comparing the spectra of different mixing ratios of glass and crystallized beads, we estimated the crystallinity and TiO_2 content of the DMD. We also estimated the TiO_2 content of mare basalts surrounding the DMDs in order to compare the composition of the DMDs with that of the mare basalts by producing Ti-maps based on MI spectral data.

Our results suggest that the TiO_2 estimates of DMDs had 2 groups including intermediate-Ti group ranged from 5.4 to 6.3wt% and high-Ti group with 9.1wt%. Also, the crystallinity of the pyroclastic beads of DMDs had 2 groups, including low crystallinity group ranged from 3 to 35%, and high crystallinity group ranged from 72 to 85%.

In addition, a comparison of Ti estimates for DMDs and the surrounding mare basalts indicated that DMDs tend toward higher TiO_2 content than mare.

This variation of composition and crystallinity of DMDs indicates the presence of an azimuthal heterogeneity of composition and volatile content in the lunar mantle, assuming that the depth of the magma source for each DMD has the same range.

The possibility of azimuthal compositional heterogeneity in the lunar mantle is consistent with and may suggest compositional diversity after a mantle overturn, which is the vertical transport of the mantle caused by gravitational instability of the high-Ti cumulate layer produced during the final solidification step of a magma ocean.

Keywords: Dark Mantle Deposit, Moon, SELENE, pyroclastic beads, Ti, crystallinity

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PPS23-10 Room:201A Time:May 23 11:30-11:45

Consideration of causes of deep moonquake generation and heterogeneity of the lunar mantle

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The Apollo lunar seismic experiments have revealed that lunar seismic events; deep moonquakes, occur repeatedly from specific source regions at depth of 700-1400 km in the lunar interior. The deep moonquake occurs periodically related with positions of Earth, Moon and Sun; that is tidal forces (e.g., Lammlein, 1977, Bulow et al., 2007), but the generation mechanism of deep moonquake is not understood well regardless of some theories (e.g., Cheng and Toksoz, 1978, Araki, 2001).

In this study, we investigated characteristics and mechanism of deep moonquake generations from active well-located 15 deep nests. From previous analysis of Apollo seismic data, we know that deep moonquake occurs with different amplitudes among each deep nest (Lammlein, 1977). We, therefore, derived seismic moment from each deep moonquake event and analyzed the variation of the amplitude and the difference among deep nests. This investigation showed that amplitudes of seismic moments of the deep events are different among the active nests and they have regional characteristic.

Then, we calculated tidal stresses worked on region of each active nest during Apollo-era to reveal the correlation between the seismic moments and the tidal stress in terms of the amplitude and the time variation. From this analysis, we do not clearly identify the correlation between amplitudes of the seismic moments and those of the tidal stresses, but the deep nests occur the events with large seismic moment tend to have lower correlation between the occurrences and time variation of the tidal stresses than the nests with lower seismic moment. These results indicate that generation mechanism of deep moonquake may be different among each deep nest and/or the lunar mantle may have different elastic characteristics around each region of deep nests.

In this presentation, we will show the results derived from further analysis of more deep moonquake events and validation of previous results. Then, we will progress the discussion about the mechanism of deep moonquake generations and heterogeneity of the lunar mantle.

Keywords: Deep moonquake, Seismic moment, Tidal stress, Generation mechanism of deep moonquake, Lunar interior structure, Lunar exploration

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Early formations of lunar impact basins inferred from their viscoelastic states: Implication for the heavy bombardment

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Formations of impact basins are major geologic processes that had occurred on the early Moon [e.g., 1]. Because the upper part of the Moon probably cooled rapidly during its early history, the viscoelastic relaxation of topography would have occurred more vigorously immediately after the basin formation than later [e.g., 2]. Consequently, topographic undulations both at the surface and at the Moho (i.e., the boundary between the crust and mantle) around impact basins would reflect the thermal state of the lunar interior during basin formation ages. Thus, global survey of deformation states of impact basins is important for investigating the early thermal state of the Moon.

Using recent Kaguya geodetic data, Kamata et al. [3] investigate viscoelastic states of major lunar impact basins and obtain upper limit values for surface temperature gradient and for temperature at the Moho. However, no significant information about the thermal state for impact basins earlier than pre-Nectarian (PN) 5 is obtained. In this study, we investigate the thermal structure that can reproduce current crustal structures around early PN impact basins.

Our results indicate that a Moho temperature higher than the solidus of peridotite is necessary to reproduce early PN impact basins when the surrounding crustal thickness is thinner than 60 km. Both our crustal thickness model and a recent crustal thickness model based on LRO and GRAIL data [4] suggest that surrounding crustal thicknesses around degraded impact basins are less than 60 km. Consequently, if such degraded topographies for early PN ”basins” are actually remnants of ancient impact basin topographies, the mantle underneath these basins around their formation ages may be partially melted. This result further suggests that the timing of the complete solidification of the lunar magma ocean corresponds to the boundary between PN 4 and 5. Considering the duration of liquid magma ocean [e.g., 5], this boundary is about 4.1-4.3 Gy ago.

An important implication for the impact history of the Moon is obtained from our results. Based on Apollo sample analyses, a large increase in impact flux on the Moon around 3.9-4.1 Gy ago is proposed [e.g., 6]. This event is often called the Late Heavy Bombardment (LHB) and is very important for understanding the surface environment of the early Earth and the dynamical evolution of the Solar System [e.g., 7]. The absolute formation ages of impact basins, however, are still controversial [e.g., 8]. Because of this, the impact rate on the Moon during the LHB is highly unknown. Ryder [9] suggests an extremely large impact rate during the LHB and suggests that almost all impact basins are formed during the LHB. This speculation, however, is not consistent with our result because our results suggest that 20 out of 45 impact basins are formed before 4.1 Gy ago. This result is further consistent with recent E-belt impactor model [10, 11].

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Keywords: Impact basin, Thermal evolution, Viscoelasticity, Magma ocean, Late Heavy Bombardment

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Formation mechanism of the lunar highland crust indicated by correlation between Mg# and Th content

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Mg# (Mg/[Mg+Fe] in mole percent in mafic minerals) is a key geochemical parameter of lunar highland rock for addressing the crustal formation process because it provides the degree of differentiation of the magma ocean at the time of its solidification. In a previous study, we reported the Mg# distribution of the lunar highlands by using spectral data obtained by Kaguya, which clearly indicates a dichotomic distribution, with a higher Mg# in the far-side highlands than in the near-side highlands. A simple yet plausible model for interpreting the observation is dichotomic crustal growth from the magma ocean (the farside crustal material solidified from a less evolved magma than did the nearside crustal material). Th abundance data obtained by Kaguya also suggested similar solidification of the highland crustal material (less evolved on the farside than on the nearside).

This study investigates the correlation between the Mg# and Th abundances of the lunar highland crust of the same area by combining Kaguya spectral and gamma-ray data to check the validity of the previous interpretation derived by the Mg# and Th abundances of the highland material.

The results indicate a weak negative correlation of the Mg# decrease with increasing Th abundance, which is consistent with a prediction based on the magmatic evolution process. This result confirms the suggested process based on the individual observation (Mg# and Th abundances) of the highland formation of the farside material solidifying earlier than did the nearside material.

Keywords: Kaguya, moon, highland crust

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS23-13 Room:201A Time:May 23 14:30-14:45

Global Survey of Lunar Spinel-Rich Exposures by Satellite Hyperspectral Remote Sensing

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The studies using the spectral data obtained by Spectral Profiler (SP) and Multiband Imager (MI) onboard the Japanese lunar explorer SELENE/Kaguya revealed the global distributions of the purest anorthosite (PAN), olivine-rich materials, and orthopyroxene-rich materials over the entire Moon. These results were based on the diagnostic bands of these lunar major minerals in spectral data with wavelength less than 1.7 micron. Recently, a prominent Mg-spinel-rich material (hereafter, Mg-spinel) on the lunar surface has been identified by Moon Mineralogy Mapper onboard Chandrayaan-1. Since the Mg-spinel is characterized by a strong absorption band around 2 micorn, the spectral data with wavelength longer than 1.7 micron are needed to find the Mg-spinel by remote-sensing spectral data. We have recently updated the radiometric calibration for SP NIR 2 data with wavelength longer than 1.7 micron. Based on the entire data set of SP, including the SP NIR 2 data, we conducted the global survey to find the Mg-spinel on the Moon. Here, we report the global distribution of the Mg-spinel sites based on this survey.

Keywords: remote-sensing, hyperspectral

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PPS23-14 Room:201A Time:May 23 14:45-15:00

Differentiation of impact-induced magma seas on the Moon

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It is widely accepted that a huge impact on the Moon, such as the South Pole-Aiken (SPA) basin forming event, entirely removed the feldspathic crust and melted the mantle below . The tremendous amount of impact melt must have formed a magma sea in the excavated basin. Such magma seas likely have experienced a significant differentiation as global magma ocean. In this presentation, we summarize recent results of global hyperspectral mapping of the Moon by Spectral Profiler (SP) onboard Kaguya and discuss the implications on the differentiation processes of magma seas.

Keywords: Moon, Spectra, Infrared, Mantle, Impact, Crust

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(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS23-15 Room:201A Time:May 23 15:00-15:15

Radar observation of lunar surface by KAGUYA LRS

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We present recent result of lunar surface observation of KAGUYA Lunar Radar Sounder (LRS).

Extracting nadir surface echoes out of LRS observation data, we made a surface echo map of the Moon, i.e. LRS lunar surface image. Nadir surface echo was defined as the most intense peak of an A-scope data. More than 10^8 observation data was used. The LRS lunar surface image has a wide dynamic range of 20 dB, and shows variety of radar surface features as follows;

1. Highland surface appears darker while mare surface appears brighter.
2. Statistical property of surface echoes is different in highland and mare.
3. A crater whose diameter is larger than a few tens of kilometers can be recognized in the image.
4. The central peak of a middle sized crater is recognized as a dark spot.
5. Wrinkle ridges in maria appeared dark linear features.
6. Surface echo intensity of mare surface has a strong correlation with the surface age.

Keywords: KAGUYA, LRS, Moon, Surface, Radar

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PPS23-16 Room:201A Time:May 23 15:15-15:30

Determination of the permittivity of the lunar surface based on the radar echo intensity observed by the Kaguya

Atsushi Kumamoto[1*], Takayuki Ono[1], Takao Kobayashi[2], Junichi Haruyama[3]

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The permittivity of the lunar surface is considered to depend on the compositions and porosity of the surface materials. Therefore the determination of the permittivity is important for discussion of the geological conditions of the lunar surface. If we are going to use echo power for determination of the permittivity, we should note that the radar echo intensity depends not only on the permittivity but also on the roughness of the surface. Therefore, we have determined the permittivity of the lunar surface with considering the surface roughness. In the analysis, the permittivity is determined by using the radar echo intensity obtained by Kaguya Lunar Radar Sounder (LRS) [Ono et al, 2000; 2008; 2010], and the surface roughness parameters derived from Digital Terrain Model (DTM) based on Kaguya Terrain Camera (TC) observation [Haruyama et al., 2008].

The global distributions of the echo powers in a frequency range of 4-6 MHz were derived from the Kaguya/LRS dataset. We have used the intensity of off-nadir echoes in an incident angle larger than 3 degree. The reason why nadir echoes are not used in the analysis is because the echo intensity changes drastically in small incident angle especially at the smooth surface. The echoes arrived after the arrival of the nadir surface echo were identified as off-nadir echoes in this study. In addition, we have also derived the global distribution of the surface roughness parameters. The RMS height sigma of the surface can be obtained by $sigma^2 = <(h(x+dx)-h(x))^2>$, where h(x) is height of the surface derived from the Kaguya TC/DTM, dx is baseline length, and <> denotes the average. If we assume the self-affine surface model, the roughness parameters H and s can be obtained by the least square fitting of the RMS heights to $sigma = s(dx)^H$. The off-nadir surface echo power can be calculated based on the radar equation. Assuming Kirchhoff Approximation (KA), the backscattering coefficient in the radar equation can be obtained from the roughness parameters H and s, and permittivity [cf. Bruzzone et al., 2011]. Using the roughness parameters H and s obtained by Kaguya TC/DTM and changing the assumed permittivity, we can calculate the expected off-nadir surface echo powers and compare them with observed off-nadir surface echo power. Based on the comparison, we can determine most plausible permittivity.

The obtained Hurst exponent H is less than 0.5 in the maria, and about 0.9 in the highlands. The parameter s is about 1 in the maria, and about 0.3 in the highlands. The global distribution of H is similar with that reported by Lunar Reconnaissance Orbiter (LRO) laser altimeter [Rosenburg et al., 2011]. By applying the analysis method mentioned above, we could obtain the observed and calculated surface echo powers in the regions where $0.25<H<0.35$, and $0.85<H<0.95$. Based on them, we could estimate the average permittivity in the maria (H˜0.3) to be 4-5, and that in the highlands (H˜0.9) to be 2.

It is inferred that the lunar basalt below the surface consists of grains and voids. The bulk permittivity of the lunar uppermost basalt layer depends on the permittivity of the grains and the ratio of the voids, or porosity. According to the previous studies based on the Apollo lunar samples [cf. Shkuratov et al., 2001], the grain permittivity can be estimated based on the ilmenite abundance. The ilmenite abundance can be derived from the Clementine multiband image data [Lucey et al., 2000].

Based on the bulk permittivity and grain permittivity determined in this study, we also estimated the porosity in the maria (H˜0.3) to be 30 % and that in the highland (H˜0.9) to be 60 %. It is considered that the surface of the highlands is older than that of the maria. Due to the longtime exposure to the impacts of the meteorites, the porosity of the lunar basalt in the highlands can be larger than that in the maria.

Keywords: Kaguya (SELENE), Lunar Radar Sounder (LRS), Terrain Camera (TC), Electric permittivity, Porosity, Surface roughness

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PPS23-17 Room:201A Time:May 23 15:30-15:45

Estimation of the permittivity and porosity of the lunar uppermost basalt layer based on the SELENE observation data

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Permittivity is an important parameter for understanding the results obtained from various radar observations. For the investigation of lunar subsurface structures, Lunar Radar Sounder (LRS) onboard the SELENE (KAGUYA) spacecraft emitted the electromagnetic wave (4 - 6 MHz), and measured the delay (dt) between the electromagnetic waves reflected at a lunar surface and at subsurface boundaries [Ono et al., 2009]. In this study, we define an apparent radar depth (D), which is expressed as a function of D=(c∗dt)/2, where c is the speed of light in vacuum. The apparent radar depth relates to the thickness (T) between the surface and subsurface boundaries, at which the electromagnetic wave is reflected. However, we must note that the apparent radar depth is not equal to its thickness. Because the lunar subsurface layer has a bulk permittivity (E_{bulk}), it varies the velocity (v) of the electromagnetic wave in the subsurface layer. The thickness can thus be given as T=v∗dt/2=(c/(E_bulk)$^{0.5}$)∗dt)/2=D/(E_{bulk})$^{0.5}$. In radar observations, the information of the thickness of lunar basalt layer is significant for discussing the lunar volcanic activity [e.g., Hiesinger et al., 2003].

The values of the bulk permittivity (4 - 11), based on Apollo basalt samples, have been used in previous works [e.g., Peeple et al., 1978; Cooper et al., 1994; Oshigami et al., 2009]. We, however, cannot easily use the bulk permittivity. Because Apollo samples were collected on the lunar surface, we suspect whether the bulk permittivities based on Apollo basalt samples reflect the bulk permittivity of the lunar basalt layer. In this study, the bulk permittivity of the lunar uppermost basalt layer is estimated from the rate of D and T. In general, the subsurface bulk permittivity relates to the subsurface porosity [e.g., Shkuratov and Bondarenko, 2001]. The information of the porosity is important for discussing lunar geological conditions, so that the porosity is also estimated by using an empirical relationship between the bulk permittivity and porosity [Shkuratov and Bondarenko, 2001; Huang and Wieczorek, 2012].

We have used data sets obtained from three instruments onboard SELENE: LRS, Multiband Imager (MI), and Terrain Camera (TC). We first focused on the ejecta composition (FeO and TiO_2) around two types of impact craters (the haloed crater and non-haloed crater) due to the estimation of T. The non-haloed crater has the same ejecta composition with the surface composition of uppermost subsurface layer, while the haloed crater has the different ejecta composition from the surface composition of uppermost basalt layer. The haloed craters would be formed when meteorites excavate a lower basalt layer with the different composition from the uppermost basalt, which is lied on the lower basalt layer. The haloed crater and non-haloed crater are identified on the basis of FeO and/or TiO_2 maps created from the MI data. We would therefore constrain T from the depths of haloed crater and non-haloed crater (d_h and d_{non}) measured from the TC data: $d_{non}<T<d_h$. We note that the distance between haloed crater and non-haloed crater should be as short as possible. The true lunar subsurface boundary is probably oblique, so that the oblique subsurface boundary produces a bad limitation of T. In this study, the distance is limited within 6 km. D is also determined within 6 km from these craters by using the LRS data.

As the results, the bulk permittivity was estimated to be 2.3 - 4.2 in Unit 85 of Mare Humorum and 1.8 - 13.1 in Unit S13 of Mare Serenitatis. In particular, the bulk permittivity of Unit 85 of Mare Humorum was limited within a low bulk permittivity. This low bulk permittivity is indicative of a porous basalt layer with a porosity of 36 - 58%. This estimated porosity would be explained mainly by two different sources: intrinsic voids (vesicles and micro cracks) and impact-induced cracks (micro and macro cracks).

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PPS23-18 Room:201A Time:May 23 15:45-16:00

ARTEMIS observations of lunar dayside plasma in the terrestrial magnetotail lobe

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We report observations by the dual-probe ARTEMIS mission of Moon-related electron and ion signatures obtained above the dayside lunar surface in the terrestrial magnetotail lobes. While the Moon is often thought of as a passive absorber, recent observations from Kaguya, Chandrayaan, Chang'E, and ARTEMIS indicate that plasma of lunar origin can have significant effects on the near-lunar environment. We now present new observations from ARTEMIS showing that lunar plasma can play a dominant role in the low-density environment of the terrestrial magnetotail. Two-point observations reveal that the density of plasma of lunar origin is higher than that of the ambient lobe plasma even several hundreds of kilometers above the Moon's dayside. Meanwhile, the distributions of incoming electrons exhibit modifications correlated with Moon-related populations, suggesting direct or indirect interactions of the lobe electrons with plasma of lunar origin. We also observe high-energy photoelectron emission from the dayside lunar surface, supporting the existence of large positive potentials on the lunar surface. Pickup ions with nonzero parallel-velocity components provide further evidence for positive surface potentials of tens of volts or more. ARTEMIS data reveal not only the existence of the large surface potentials first inferred from Apollo CPLEE measurements, but also their significant implications for the dynamics of both the dominant Moon-originating ions and the tenuous ambient plasma populations in the tail lobe.

Keywords: Moon, plasma, surface charging, pickup ion, photoelectron

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PPS23-19 Room:201A Time:May 23 16:15-16:30

Electron cycltron harmonic waves observed around the moon

Yumiko Katayama[1], Hirotsugu Kojima[1*], Yoshifumi Saito[2], Yoshiya Kasahara[3], Yoshiharu Omura[1], Tadateru Yamamoto[4], Shoichiro Yokota[2], Masaki N Nishino[2], Kozo Hashimoto[1], Takayuki Ono[5], Hideo Tsunakawa[6]

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The present paper discusses the generation of Electron Cyclotron Harmonic (ECH) waves observed around the Moon. Plasma wave data obtained by the KAGUYA satellite show the existence of two kinds of ECH waves. They are:the

ECH waves with lower order harmonics and ones with higher order harmonics which frequencies are close to the upper hybrid resonance frequency. ECH waves can be observed only when the moon is inside the terrestrial magnetosphere. They never appear in the solar wind. The configuration of local magnetic fields is also important. KAGUYA observes the both types of ECH waves along the magnetic field lines which are connected with magnetic anomalies which are scattered on the moon surface. Furthermore, while the lower order harmonics are observed in the nightside of the Moon in the plasma sheet and lobe regions, the higher order harmonics are observed in the dayside in the lobe region. The correlation studies between waves and particles show that the existence of two components of electrons is essential for the observation of the both types of ECH waves. Two components of electrons mean hot electrons with the loss cone velocity distribution and cold electrons. On the other hand, the generation of cold electrons is classified into two echanisms. One is the acceleration over the nightside moon surface which is negatively charged and the other is the emission of photo electrons while the spacecraft gets sunlight. In order to make sure the relation of ECH waves and electron distribution, we conducted the linear dispersion relation analysis and particle simulation using the realistic plasma parameters of electromagnetic environment based on the KAGUYA observation. The results clearly showed the parametric dependence of the ECH wave growth under the co-existence of the loss cone distribution of hot electrons and cold electrons. We discuss the generation of ECH waves consulting the parametric dependence and explain the relation of the ECH waves with the moon location in the magnetosphere.

Keywords: Electron cyclotron harmonic waves, Plasma waves, KAGUYA, moon

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PPS23-20 Room:201A Time:May 23 16:30-16:45

Electrostatic Solitary Waves (ESWs) and electron beams observed by Kaguya near the Moon

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In KAGUYA (SELENE) LRS[1], WFC-L[2] observes waveforms of plasma waves in 100Hz-100kHz and a lot of electrostatic solitary waves (ESWs) have been observed[3]. Although the orthogonal dipole antennas are generally used in the observations, sometimes a pair of monopole antennas were used. We analyze the magnetic field[4] and plasma environment[5] around the observed regions.

Observed waveforms are fitted to ideal ESW waveforms parallel to the magnetic field and the perpendicular component. The propagation velocities and the potential scales are also evaluated in the case of the monopole observations.

In the present report, electron distribution functions are analyzed. Electron beam components are derived by subtracting background thermal Maxwellian distribution from parallel distribution integrated over perpendicular component based on the electron beam analysis for ESW observed by Geotail[6]. Relation among ESW, electron beam, and magnetic field observed in the solar wind, above the magnetic anomalies, in the wake boundaries, and inside the wake will be discussed.

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Keywords: Kaguya, ESW, electron beam

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PPS23-21 Room:201A Time:May 23 16:45-17:00

Type-II entry of solar wind protons into the lunar wake as a general phenomenon

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We study a type of solar wind entry into the lunar wake under various interplanetary magnetic field (IMF) conditions using SELENE (Kaguya) data. Our recent observations around the Moon revealed that so-called type-II (T2) entry of the solar wind protons into the near-Moon wake occurs when the IMF is dominated by the non-radial components (i.e. B_Y and/or B_Z). Under this condition a part of the solar wind protons scattered/reflected at the lunar dayside surface subsequently enters the central region of the near-Moon wake after a large-scale cycloid motion, which gives rise to electron acceleration and wave generation. The situation handled in the previous studies is that the magnetic field line around which the solar wind protons entering the wake are gyrating is detached from the lunar surface, and thus a possibility of the T2 proton entry into the region where field lines are connected to the lunar surface has not been considered yet. Here we report that the T2 entry process takes place under various IMF conditions, and that the protons can access the central wake region that is magnetically connected to the lunar nightside surface, which we categorize into the T2 entry with magnetic connection to the lunar surface (T2MC). Furthermore we show that the energy of the electron beams associated with the entered protons depends on the magnetic connectivity to the lunar nightside surface. Strong electron acceleration (up to several hundred eV to 1 keV) along the magnetic field associated with the T2 entry is prominent when the field line has its both ends in the solar wind, that is, when the magnetic field is detached from the lunar surface (i.e. the ”original” T2 entry that we rename to T2MD). On the other hand, no significant electron acceleration is found in the T2MC cases, although an enhancement of the electron flux associated with the T2 proton entry is evident. Our results indicate that, while the T2 entry of solar wind protons into the wake itself does not require a special IMF condition but is a rather general phenomenon, the characteristic energy of associated electrons does show a strong dependence on the magnetic connectivity to the lunar surface.

Keywords: Solar wind-Moon interaction, Lunar wake, SELENE, Wave-particle interaction, Plasma entry into wake

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PPS23-22 Room:201A Time:May 23 17:00-17:15

Magnetic fluctuations detected by Kaguya in the central wake

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Since the moon does not have a global magnetic field system, the solar wind particles can access the lunar surface directly. The solar wind particles that hit the moon are absorbed by the dayside lunar surface, and the solar wind plasma are essentially absent on the downstream side of the moon (the lunar wake). Kaguya MAP-PACE instrument has revealed that not all the solar wind particles are absorbed, but 0.1 - 1% of the solar wind protons are reflected by the lunar surface (Saito et al., 2008).

Due to the reflection of the solar wind particles, the magnetic field is almost always fluctuating over the frequency range of 0.03 - 10 Hz (Nakagawa et al., 2011). They were basically absent in the central wake.

Magnetic fluctuations of about 0.1-10 Hz are found by Kaguya MAP-LMAG magnetometer in the deepest wake region, where magnetic fluctuations were rarely expected. The magnetic fluctuations were rather 1-dimensional, showing no preferred polarity. They were often detected when the SSE-y component of the solar wind magnetic field was dominant. At least 80 percent of them were accompanied by ions, which are thought to be the solar wind protons once reflected by the dayside surface, picked up by the solar wind electric field and entered the deepest wake (Type-II entry protons, Nishino et al., 2009). Accordingly, the magnetic fluctuations in the central wake are thought to be generated by the type-II protons.

Keywords: lunar wake, SELENE, magnetic fluctuations, solar wind, nightside, type-II entry

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PPS23-23 Room:201A Time:May 23 17:15-17:30

PIC simulation on the solar wind interactions with meso-scale magnetic dipole and its application to Reiner Gamma

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We have been studying the solar wind interactions with a small-scale magnetic dipole by means of plasma particle simulations. In the current presentation, we will report some of the simulation results including a case of magnetic anomaly found in Reiner Gamma on the moon. If we define the dipole size L as the distance between the dipole center and a position where the solar wind dynamic pressure balances the magnetic pressure, L of our interest is in the meso-scale which implies the size smaller than the ion's inertia length and sufficiently larger than the electron Larmor radius in the solar wind. Contrary to the Earth's magnetosphere, difference of dynamics between ions and electrons with respect to the local magnetic field play an important role in the magnetosphere formation. In other words, electron-ion coupling through a dipole field becomes important. However, very little analysis has been done so far on the interactions between meso-scale dipole field and plasma flows.

Plasma particle simulation is appropriate for the investigation on the interactions between the solar wind and meso-scale dipole magnetic fields because plasma kinetics is considered. The simulation results obtained with the plasma particle simulations we performed so far show that electron interactions are important in the process of meso-scale magnetosphere formation. Around the distance of L from the dipole center, charge separation occurs because of the difference of dynamics between electrons and ions. Then intense electrostatic field is induced and ions, which can be assumed unmagnetized in the present dipole size, are eventually influenced by this electric field. At the distance of L from the dipole center, magnetic fields are also compressed. The width of the boundary current layer as well as the spatial gradient of the local magnetic field compression found on the dayside can be characterized by the electron Larmor radius. When IMF is considered, it is found that the formation of shock structure and magnetic field reconnection can affect the formation of the magnetosphere.

As one application, we studied the solar wind interactions with magnetic anomaly found in Reiner Gamma by performing plasma particle simulations. Since the magnetic field is almost perpendicular to the solar wind, increase of plasma and magnetic field densities is found at the dayside region in the simulation results. When the direction of IMF changes, their increase fluctuates because of the magnetic field reconnection. One of the interesting findings is that the solar wind ions do not reach the moon surface in Reiner Gamma. We will discuss this point by considering the plasma dynamics as well as the electrostatic field observed over the Reiner Gamma region.

Keywords: Plasma particle simulation, magnetic anomaly, small-scale magnetic dipole, solar wind, Reiner Gamma

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PPS23-24 Room:201A Time:May 23 17:30-17:45

The effect of magnetic anomalies on the detection of Moon originating ions

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The Moon has only thin atmosphere and local magnetic field called ”magnetic anomalies”, which makes the Moon intriguing in terms of interaction between the solar wind and surfaces of astronomical bodies. In the second half of the 20th century, the Apollo series and ground-based observation revealed the existence of the thin atmosphere and heavy ions around the Moon. Although the generation / transportation processes of the ions originating from the Moon have long been discussed, they have not been sufficiently understood yet. At present, it is supposed that ions are generated by multiple processes including ionization of neutral exosphere by solar wind, processes at the lunar surface such as thermal desorption, photon / charged-particle / chemical sputtering, meteoric impact, and interior release. The generated ions are accelerated by surface potential / convection electric field in the solar wind, and then released to space [Vondrak, 1988].

An ion energy mass spectrometer MAP-PACE IMA on Kaguya first made in-situ observation of Moon originating ions. Yokota et al [2009] identified heavy ions such as C^+, O^+, Na^+, K^+, Ar^+ in the mass spectra obtained by integrating the ion counts observed by IMA (Ion Mass Analyzer) on Kaguya, when the Moon was in the solar wind. They showed that in general the energies of the ions could be explained by assuming that ions were accelerated by convection electric field in the solar wind.

Since the amount of detected ions would be affected by many factors, including electric field, magnetic field, positional relation between the Sun and the Moon, selenographical features and so on, to understand how detected ions are affected by these factors should be an important clue to reveal the generation / transportation processes.

We study how convention electric field and magnetic anomalies affect the Moon originating ions. Comparing the convection electric field and fluxes of the Moon originating ions detected by IMA at ˜100km altitude, we confirmed that the radial component of convection electric field has relatively good correlation with detected fluxes. This means that the quantity of the transported ions is in general dominated by the direction and intensity of the convection electric field. On the other hand, IMA detected less Moon originating ion fluxes whose energies are under ˜250eV above magnetic anomalies even when the radial component of electric field was positive. This indicates that magnetic anomalies affect generation or transportation of ions originating from the Moon.

Keywords: Moon, plasma, magnetic anomaly

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PPS23-P01 Room:Convention Hall Time:May 23 18:15-19:30

The newest lunar digital elevation model (DEM) from SELENE and LRO data

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In this presentation, we will introduce the newest lunar digital elevation model (DEM) based on data from SELENE Terrain Camera (TC) and Multi-band Imager (MI), and LRO Lunar Orbiter Laser Altimeter (LOLA). The elevation and horizontal accuracies of this DEM are very high, perhaps higher than those of any previously released elevation mosaicked data covering all over the Moon. This DEM will be fundamental for various fields of lunar science and for planning of future lunar missions in detail.

Keywords: Moon, digital elevation model, DEM, Terrain Camera, SELENE, Kaguya

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Mare volcanism: Reinterpretation based on Kaguya Lunar Radar Sounder data

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The volumes of single geological units with different ages and compositions are essential for revealing characteristics of mare volcanisms and for constraining the thermal history of the Moon. Recently, the thicknesses of mare basalt units defined by previous lithofacies maps were indirectly estimated from Clementine multispectral data. That is, the depth-diameter relationship of the craters fringed with ejecta from the underlying basaltic units placed the constraints for the estimation. The results are derived for only limited areas in Oceanus Procellarum and Mare Serenitatis.

At present, the geological structures under the lunar maria are directly investigated using sounder observations. The Lunar Radar Sounder (LRS) onboard Kaguya (SELENE) detected widespread horizontal reflectors under some nearside maria. The LRS detects, using FM-CW radar (4-6 MHz), echoes from subsurface horizons with abrupt changes in dielectric constants at the apparent depths smaller than about 1 km. Oshigami et al. [2012] concluded that the reflectors correspond to the interfaces between basalt units with different FeO contents, suggesting that buried regolith layers were responsible for the radar returns. Therefore the LRS data have great potential to determine a lava effusion volume during a series of magmatism in lunar maria and its time dependence.

Thicknesses of mare basalt units with different ages and compositions are directly estimated from the LRS data in the several regions of lunar maria. Using the technique of Ono et al. [2009], we correlate subsurface reflectors with the surface geologic units, the ages of which have been estimated by several researchers, to evaluate the volumes of the units.

The estimated thicknesses of the geologic units were of the order of 10^1-10^2 meter, and showed a positive correlation with their ages. The resolution of our estimation was limited by the range resolution of the LRS data. Previous studies indicated that the typical thicknesses of single basalt flows were about 10 m or less in most of the studied sites. These estimations suggest that the geologic units are made up of dozens of lava flows.

Weider et al. [2010] estimated the thicknesses of a number of mare basalt units in Oceanus Procellarum and Mare Serenitatis, ranging from about 80 to 600 m. For the purpose of comparison, we took the unit S15 in Serenitatis defined by Hiesinger et al. [2000]: Weider et al. concluded that the representative thickness was about 500 m although individual data derived from craters located on the unit showed a wide variation, implying large uncertainty of thier estimation. In contrast, the LRS data exhibit that the averaged thickness of the unit S15 is about 150 m.

The volumes of the geologic units estimated in this study were of the order of 10^3 km^3, and showed a clear positive correlation with their ages. Again, the resolution of our method was limited by the range resolution of the LRS data. This volume range is consistent with flow volumes derived from numerical simulations of thermal erosion model for lunar sinuous rilles formation. The large sinuous rilles are estimated to have formed by thermal erosion with sustained lava flows of volume in the range 300-1200 km^3. The volume range derived from our study also comparable to the average flow volumes of continental flood basalt units forming after the Paleozoic and calculated flow volumes of Archean komatiite flows, both possibly originated from mantle plume activities on the Earth. The estimated volumes of the geologic mare units and their age variation on each maria potentially constrain key factors for the thermal evolution of the Moon; magma buoyancy and crustal thickness, impact basin topography effects on the ascent of magma, and thermal evolution trend.

Keywords: Kaguya, Lunar Radar Sounder, Lunar maria, Subsurface structure, Volcanism

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Melting of the Fe-O-S system and reaction between olivine and iron melt at lunar core conditions

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Despite recent insight regarding the Moon from satellite sensing and analyses of Apollo-era seismic data, there are still several unknown issues on the deep lunar interior. It is suggested that the Moon has a small iron-rich core with a radius between 220 and 450 km based on the calculated value of the mass and moments of interior (Konopliv et al., 1998), but the question about its feature is still under debate. Recent studies suggest the presence of a solid inner core and liquid outer core in the Moon (Weber et al., 2011). If we could constrain the temperature and composition of the lunar outer core, this would help us for better understanding of the lunar interior. Here, we focused on the interaction between liquid iron-alloy and solid silicate, and revealed the nature of the outer core of the Moon. The lunar mantle is characterizes by high FeO content compared to the Earth's mantle. This implies that Moon is oxidizing and oxygen can be in the lunar core. Therefore, Fe-O-S system is considered and we performed the partition experiments of oxygen between silicate and molten metal in this study.

High pressure experiments were conducted at 5 GPa from 760 C to 1400 C using 3000 ton Kawai-type multi-anvil apparatus of Tohoku University. We used powder mixtures of Fe, FeO and FeS as the metallic component of the starting material. Olivine crystals with Mg number of about 83 from Miyakejima, which is similar to the lunar mantle olivine, were used for the silicate component of the starting material. The sulfur content was 24 wt.% and the oxygen content varies 0 ~ 7 wt.% for the starting iron-alloys. Scanning electron microscope (SEM) was used for the texture observation of the recovered samples, and the electron probe micros-analyzers (EPMA) with Energy-dispersive X-ray spectroscopy (EDS) and wavelength-dispersive X-ray spectroscopy (WDS) were used to obtain the chemical compositions of recovered run products.

Some differences in reactions between the experiments made at 1000 C and at 1400 C were observed in the recovered samples. At 1000 C, the metallic sample melted partially and liquid phase had magnesiowustite crystals were observed at the boundary between the molten iron alloy and olivine. The Mg number of the olivine crystals increased with increasing the distance from the metal phase. At 1400 C, the metallic sample was totally-melted. Pyroxene and olivine crystals with reverse zoning were observed in the silicate phase, whose Mg number was higher than starting materials. The effects of oxygen content in metallic phase on silicate phase were not observed in this experimental condition. We calculated the distribution coefficient D of FeO between metal liquid and olivine crystal. Using this value, the amount of FeO in the lunar liquid outer core is 4.45 at.% at 1000 C and 1.63 at.% at 1400 C when the mantle Mg number is 80. If the amount of FeO is 4.45 at.%, the lunar outer core might have two layers because of existence of the immiscible two-liquid regions in the Fe-S-O system.

Keywords: lunar core-mantle boundary, Fe-O-S system, olivine, melting, high pressure

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Crustal materials around Mare Imbrium: result of Kaguya data integration science

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In order to understand lithological distribution and geological structure of the lunar crust, it is important to conduct analysis of spectral images with high spatial resolution considering 3D geological structure by using high-spatial resolution topographic map. In this presentation, lithological distribution and it relationship with geological structure around Mare Imbrium will be discussed by using the Kaguya data acquired by MI, TC, KGRS and LALT. As well known, Imbrium basin is situated in Procellarum KREEP Terrane (PKT). Therefore this investigation would contributes to understand lithological structure of the PKT and influence of Imbrium basin formation on the PKT evolution. In addition to discussion on crustal materials around the PKT, implication for origin of high-Th (i.e. KREEPy) crustal materials will be discussed.

Keywords: The Moon, Lunar crust, Kaguya/SELENE, Procellarum KREEP Terrane, Magma ocean, Early evolution

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Presence of impact melts on central peaks of lunar craters and its implications

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Introduction: Impact melts within complex impact craters are known to be flat and smooth deposits filling the floors or wall terraces [1]. Recent studies suggest that compositionally different layers with smooth surfaces are present on the central peaks in several lunar craters, implying impact melts [2, 3]. Impact melts on the central peaks could constrain the central peak formation timescale because impact melts will flow out if peaks are uplifted too quickly. However, little evidence and few examples of impact melts on the central peaks were reported. In this study, we investigate the central peaks of the all lunar complex craters listed by [4] to check for the presence of impact melts morphologically and compositionally.

Methods: Central peak morphologies and topographies are identified using SELENE data obtained by the Terrain Camera (TC, 7.4 m/pixel) and Multiband Imager (MI, visible: 20 m/pixel and near- infrared: 60 m/pixel); MI spectral data also provide compositions of geologic units. Impact melt textures are identified by characteristic features, such as cooling cracks and flowing features (lobes or levees), using data from the Narrow Angle Camera (NAC, 0.5-1.2 m/pixel) abroad the Lunar Reconnaissance Orbiter (LRO) in addition to SELENE data.

Results: At least 13 of the analyzed central peaks have distinctive impact melt morphologies on their slopes. Seventy craters (including the above mentioned 13 craters) have spectrally unique geologic units on their gentler slopes with smooth surfaces exhibiting low albedo and weak absorption depth similar to their floor melts. The 70 craters vary in setting, diameter, and formation age, while almost all the 13 distinctive melt morphologies are observed in the craters formed in Copernican period [4], which is the latest selenogical period.

Discussion and Conclusions: Our observation that impact melts are found on the central peaks of more than half of the Copernican period craters implies that many central peaks could have impact melts. My analysis suggests that the unique geological units on the 70 central peaks are possibly impact melt origin, and melt morphologies on the older central peaks are probably obscured by erosion, which implies it is common that impact melts did not flow out completely from the central peaks when the peaks were uplifted. This suggests that impact melts already had relatively high viscosity but were not completely solidified when central peaks were uplifted.

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Keywords: central peak, moon, SELENE, impact crater, impact melt

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Estimating the origin and thickness of high-thorium-content rock units on the lunar surface

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The abundance and distribution of thorium, an incompatible element, within a planetary body are very important for understanding the thermal history of a terrestrial planet because it correlates to the heat-source elemental abundance of these planets. Gamma-ray remote-sensing data depicts the global distribution of thorium of the lunar surface, in which thorium concentrates in the western hemisphere of the lunar near side around the mare region. Within this high thorium area are several hot spots, which have significantly higher thorium content. Lunar rocks containing abundant incompatible elements are called KREEP-rich rocks based on the Apollo sample analyses. KREEP should be formed in the boundary area between the lower crust and the upper mantle. However, the KREEP-rich rock is exposed on the lunar surface. Two processes were proposed as the mechanism for transporting KREEP-rich rocks from under the crust to the surface. One is an igneous process, in which KREEP-rich basalts erupt from magma generated in a deep area at the bottom of the crust. The other mechanism is the ejecta origin of Imbrium basin, in which a basin-formation event excavated the lower crust including KREEP-rich rocks and spread it as ejecta on the surface. The thorium hot spots can be considered to have been formed by either mechanism. However, because of a low spatial resolution of gamma-ray observation from orbit, we cannot identify the corresponding rock types of the thorium hot spots. Therefore, the actual distribution of the high thorium unit and its thorium abundance has not been well understood.

In this study, we used high-resolution visible to near-infrared band images obtained by Kaguya (SELENE) and combined them with a simulated thorium abundance based on Lunar Prospector gamma-ray data to estimate the origin of the thorium-rich rocks and their thorium concentrations. We selected two hot spots (Aristillus and Copernicus) to analyze as candidates of the two KREEP origins. Aristillus is a crater within the Imbrium basin, while Copernicus is located outside of the Imbrium basin.

Our results indicate that KREEP-rich rocks around Aristillus contain high calcium pyroxene, and its thorium abundance is estimated to 35 ppm, while there appears to be no thorium inside the crater. In contrast, KREEP-rich rocks around Copernicus contain low-calcium pyroxene with 12 ppm thorium content. By combining the results with their geologic contexts, KREEP rick rocks in Aristillus (Copernicus) are estimated to originate from KREEP basalts (Imbrium ejecta). The KREEP layer around Aristillus is estimated to be 1.6 km thick, and that around Copernicus is estimated to be 9 km thick. These results suggest that the thorium concentration within the crust is not uniform as assumed in a previous model but it forms a layer. It also clearly demonstrates that the previous model assuming constant thorium content within the crust from surface to the bottom (60 km deep) needs modification. Our estimation based on our new thorium abundance model for the Procellarum KREEP terrane derives much lower thorium abundance (50% less) than previously estimated.

Keywords: moon, thorium, thermal history

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The formation and reactivation of a mare ridges in northern Imbrium

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Mare ridges are the manifestations of horizontal compressions in the shallow part of the lunar crust. They have been interpreted as the folds that determined the basaltic lava layers in mare basins. Since the distribution of the ridges is usually concentric with respect to basin centers, the compressional stress is thought to be originated from the flexure of lithosphere caused by the loading of mare basalts, which is called mascon tectonics. Possible mantle viscosity allowed such deformations to have had delay time of the order of 0.1 Gyr from the deposition of the basalt, which means the deformation was almost syndepositional. However, recent investigations on the underground structures showed that there is no lateral change of thickness of basalt lava around ridges, and this fact supports the post-depositional formation of ridges. On the lunar surface, the majority of mare basalts deposited before 3.0 Ga. Thus, the most of the ridge formation should have occurred before 3.0 Ga. The timing of the formation will be the clue to distinguish their origin, among global cooling, orbital evolution of the Earth?Moon system and mascon tectonics. This study found a crosscutting relationship between a ridge and a basalt unit, then constrained the formation age of the ridge using depositional ages of basalt lava units derived from the crater-size frequency distribution (CSFD).

By means of optical data taken by the cameras onboard SELENE (Kaguya), an ENE-WSW trending mare ridge that dammed up a relatively high-Ti basaltic unit was found near Sinus Iridum, northern Imbrium. The ridge is 300–400 m high, ˜30 km wide and ˜150 km long. Relatively high-Ti unit is dammed up by the ridge and relatively low-Ti unit made up the ridge. It was also found that the lowermost part of the ridge is partially covered by high-Ti unit, that is, a part of the ridge was uplifted after the deposition of the high-Ti basalt. In addition, there is a smaller ridge of ˜50 m in the younger unit. The smaller ridge runs roughly parallel to the ridge mentioned above. The reactivation and the formation of the small ridge showed that a compressional deformation occurred in the area after the deposition of high-Ti basalt. This study determined the depositional ages of high-Ti unit and low-Ti unit by performing CSFD measurements. The estimated ages were 3.0 Ga and 2.1 Ga for low-Ti unit and for high-Ti unit, respectively. The cross-cutting relationship showed that the major formation age of the ridge was between 3.0 to 2.1 Ga. Furthermore, it was revealed that the reactivation and the smaller ridge formation occurred after ˜2.1 Ga. Since most of the mare basalts were deposited before 3.0 Ga in the Imbrium basin and the ridge is a part of concentric ridges of the basin, the formation of the ridge was possibly induced by the latest stage of the mascon loading. However, the reactivation of the large ridge and the formation of the small ridge were too young for the mascon, requiring some mechanisms other than the loading. Global cooling and the increasing Earth-Moon distance are possible explanation.

Keywords: mare ridge, chronology, formation age

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Assessment of Hemispherical Spatial Distribution of Craters on the Lunar Farside.

Riho Ito[1*], Tatsuo Kinoshita[1], Chikatoshi Honda[1], Naru Hirata[1], Tomokatsu Morota[2]

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The impact craters on planetary surface show random spatial distribution. However, lunar surface expect to have a bias of spatial distribution of crater because the Moon have same rotation and revolution periods.

The previous research showed that rayed crater density at the apex (0 N, 270 E) is highest than antapex (0 N, 90 E). I compared crater size-frequency distribution of apex and antapex side about craters of over 20 km in diameter. In the result, the crater size-frequency distribution of the antapex side was higher than the apex side.

Purpose of this research is to develop an algorithm to assess spatial distribution of craters on lunar farside by using clustering analysis for finding where bias of craters is. In this algorithm, I apply the nearest single-linkage clustering (S-LINK) to simulated and actual craters, and assess whether the crater is random or not by comparing both of results. As a result, 2870 of 3112 craters were decided to non-random (1403 craters are at the apex side, and 1467 craters are at the anapex side). I investigated the crater frequency variation with longitude and latitude. The high frequency of non-random craters was found at north high latitude region, apex side (210 to 270 E) and antapex side (90 to 150 E).

Keywords: Crater, Spatial distribution, Clustering analysis, apex

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Present Status of the next lunar landing mission SELENE-2 (3)

Satoshi Tanaka[1*], Takefumi Mitani[1], Hisashi Otake[1], Kazunori Ogawa[1], Naoki Kobayashi[1], Tatsuaki Hashimoto[1], Takeshi Hoshino[1], Masatsugu Otuki[1], Sachiko Wakabayashi[1], Jun Kimura[2]

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SELENE-2 project has been started from 2007 as the first Japanese lunar lander. The main prior object of the SELENE-2 mission is to develop safe and precise landing system on middle to large planets and satellites such as the Moon and Mars for a future lunar and planetary exploration. Another key technologies under investigation are surface mobility by a rover, and long night survival module without using nuclear power. In addition, some instruments for lunar science and future utilization have been so far investigated.

The Strategic Headquarters for Space Policy of Japanese government established ”Basic Plan for Space Policy” in June, 2009. Following the plan, a concrete strategy of Japanese lunar exploration had been discussed in ”Study group for lunar exploration” of Japanese government which was organized from August, 2009 to July, 2010. The final report of the group indicates that a spacecraft should land on lunar surface in around 2015 to promote lunar exploration using advanced robot technology in 2020. Despite of this result, the SELENE-2 is delayed and still remains as the Phase-A study. Presently, the earliest launch date is 2018 when we successfully proceed to Phase-B within the fiscal year 2013.

One of our meager but important progresses are that technological development of candidate instruments, especially, we have developed seismometry system and camera system, both of which were considered to be main scientific instruments for geophysical and geological instruments. As for the seismometry system, we have almost successfully performed interface tests which were done by international collaboration. Development of a sensor of the visible to near infrared camera system, on the other hand, also conducted good performance under the suitable temperature condition on board the rover.

We are preparing for the upcoming review board to proceed to phase-B study. In order to achieve it, we are under investigation to make high reliable system, and realistic scenario of the mission profile assuming some appropriate landing sites which have been selected among the Japanese lunar scientists. Further technical development is also to be aggressively continued for reducing risks.

Keywords: Moon, Lunar exploration, SELENE-2

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Recent status of SELENE-2/VLBI instrument

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We proposed a VLBI (very long baseline interferometry) radio source mission for the Moon lander SELENE-2. The purpose of our mission is to improve the lunar gravity field and to estimate the lunar interior structure. Differential VLBI observations between an orbiter and a lander are carried out to determine the position of the orbiter and the lander in addition to the conventional 2-way Doppler observation (Fig.1). VLBI measures a difference in an arrival time of a signal transmitted from a radio source to two ground stations. This measurement gives plane-of-sky position information of the radio source in contrast to 2-way Doppler measurement that gives line-of-sight position information. The combination of VLBI with Doppler is effective for precise position determination of the spacecraft.

This presentation shows the recent status of the VLBI radio source mission of SELENE-2.

1. A simulation study of the lunar gravity field estimation is carried out. The result shows that a potential Love number k2 accuracy better than 1 % can be achieved by 3 months of the VLBI mission duration provided that arc length is 14 days and that historical tracking data including SELENE are combined with.
2. The sensitivity of the geophysical parameters, in particular that of k2, the moment inertia of the Moon, and the seismic travel time, for the lunar deep interior structure is evaluated. A preliminary result shows that a density and a radius of the lunar core can be estimated within the error of 10 %.
3. We have conceptual design for an antenna that will be used on the lunar surface. A simulation evaluates the electric characters of the antenna, which are the gain, the beam pattern, and its temperature characteristics.
4. In order to decrease the power consumption of the VLBI radio source, the observation method and the manner of the operation are reconsidered.

Keywords: selene-2, vlbi, moon, internal structure

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An implementation of a visualization system for large scale moonquake data considering waveform similarity

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Large-scale seismic data were obtained from seismometers located on the Moon by the NASA Apollo missions from 1969 to 1977. According to previous analysis of the lunar seismic data (e.g., Lammlein, 1977), we found that deep moonquakes occur periodically from identical sources at a depth of about 700 to 1200km. The deep moonquakes occurred from identical sources have high similarities among each waveform (e.g., Nakamura, 2003). This similarity is important to classify the sources and investigate the generation mechanism of moonquakes. From the reason, classification of moonquakes has been processed, and much of lunar seismic data observed by long-period seismometers are labeled in term of type of moonquakes and location of sources (Nakamura et al., 2008).

However, classification of enormous moonquake data is usually difficult even if we use the computers, because we don't have any true references and the lunar seismic data are contaminated by large noises. We may not necessarily obtain useful results using classical cross-correlation method to all lunar seismic data.

We, therefore, develop the web system for visualizing moonquakes considering waveform similarity to progress study of moonquake classification. Our system maps moonquakes data to two dimensional output space using Self-Organizing Map (SOM). We use Hadoop in the back-end system to apply visualization methods to enormous moonquakes data. We will be able to indicate the results of classification in terms of various physical conditions, because SOM can automatically classify the waveforms based on our designed characteristics. Through development of this Web interface system, it will be expected that many researchers can utilize our indicated results and moonquake data to their analysis. In this presentation, we will show results of the classification of moonquakes by the SOM and current situation of our development.

Keywords: Moonquake, Visualization, Self-Organizing Map, Hadoop

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Develpoment of the retro-reflector on the moon for the future lunar laser ranging

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Lunar Laser Ranging (LLR) data are important for the investigations of the lunar rotation, tide, and lunar deep interior structure. The range accuracy of LLR has been less than 2 cm for the last 20 years due to the progress of laser transmit/receive system on the ground stations and the atmospheric signal delay model, however, one order or more accurate ranging than 2cm is needed for better understanding of the lunar deep interior. Murphy et al. [1] showed that the main source of range error comes from the fact that the existing retro-reflectors on the lunar surface are array-type ones which consist of arrays of small corner cube prisms (CCP).

To overcome this problem, large single aperture retro-reflectors are necessary with very small offset angles (dihedral angle offset; DAO) between reflecting surfaces, which must be employed for the management of the 'velocity aberration problem' [2,3]. We are developing 'single aperture and hollow' retro-reflector (corner cube mirror; CCM) to be aboard future lunar landing missions. The aperture of CCM is 20cm because the reflection efficiency of that size is found to be higher than that of Apollo 11 array CCP, and 'ultra low expansion glass-ceramic (CCZ-EX; OHARA Inc.)' or 'single crystal Si' are selected for candidate material of CCM in terms of small |CTE|/K (Thermal expansion coefficient over thermal diffusivity). The optical performance of CCM deformed by lunar gravity or solar illumination in the gimbal model will be presented for some cases. We are now trying to fabricate CCM test model made from CCZ-EX using the optical contacting method that is applicable to single crystal Si, too.

References: [1] Murphy T. et al. (2008) PAPS, 120, 20-37. [2] Otsubo T. et al. (2010) Adv. Space Res., 45, 733-740. [3] Otsubo T. et al. (2011) Earth Planet Space, 63, e13-e16.

Keywords: Lunar Laser Ranging, Retroreflector, Single, Hollow, CCZ-EX, Single crystal silicon

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS23-P14 Room:Convention Hall Time:May 23 18:15-19:30

Developing a test model of Laser-Induced Breakdown Spectroscopy for mounting lunar and planetary rovers

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JAXA is currently planning the moon lander SELENE-2 project, a follow-on mission of SELENE. This project involves the dispatch of a lunar rover to investigate the lunar surface and rocks. JAXA has nominated Laser-Induced Breakdown Spectroscopy (LIBS) as instrument for mounting rovers. The LIBS determines the elemental compositions right on-the-spot. The Curiosity rover, part of NASA's Mars Science Laboratory mission, used LIBS to obtain the spectra of rocks present on the Mars surface.

The LIBS instrument uses a powerful laser pulse and induced plasma. The plasma emits energy in the form of photons. The analysis of the plasma via spectroscopy enables the determination of the elemental composition.

Test model LIBS uses a lens to obtain the breakdown threshold of the energy density and can automatically set the target at a focal point within 1.0-1.5 m.

We developed a software for the test model LIBS. We also attended the field-roving test of one of the prototype lunar and planetary exploration rovers, Micro-6, at Mt. Mihara on Izu ?shima in the Izu Islands in Tokyo from October 28 to November 3, 2012. We conducted a successful rock-surface breakdown using LIBS. Furthermore, we carried out this operation via radio communication. However, we could not always set the focal point target via auto-focus because the charge-coupled device (CCD) camera causes electronic saturation, probably the result of the difference in reflection of the target rock. To address this issue, we developed a new program that automatically adjusts the exposure time of the CCD camera and provides a new method for auto-focusing.

Keywords: elemental compositions, LIBS, Moon, Mars

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Performance of a visible-InGaAs sensor onboard a lunar exploration camera

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Information of the lunar highland could help us to know the solidification of the lunar magma ocean and to estimate the internal structure of the Moon. We are now planning to develop a visible-SWIR macro camera with rock abrasion tool (RAT) which is required to establish a light-weighting for setting on a head of rover's arm. The purpose of this camera is to observe the texture of polished rock surface (grain size, shape, species, and crystal configuration) to investigate the geologic history of the rock. The target crystal grain size is about 200 um in average diameter. We thus need a 500 x 500 pixel sensor to achieve 20 um/pixel spatial resolution with fields of view exceeding 100 mmphi. Spectra in the 0.8 ? 1.7 um region is important to analyze major mineral species found on the Moon. So, these requirements are achieved by a visible-InGaAs sensor which has sensitivity from visible to infrared wavelength. It is important to know the performance for using space exploration, especially, an environment at the lunar surface. We'll report the details of the examinations about a dark current test of a visible-InGaAs sensor.

Keywords: visible-InGaAs sensor, dark current

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High-resolution spectroscopic observation of sodium atom emitted from the lunar surface using a Haleakala 40cm telescope

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The Moon has completely collision-free atmosphere with its surface pressure of about 10^{-17} times compared to that of the Earth. Previous studies showed that the lunar exosphere is consisted of He, Ar, Na, K, H, O. Among these constituents, Na anc K have large resonant scattering cross sections, making ground-based observation of these atoms in the lunar exosphere relatively easy and a variety of observations has been made in the past.

Locality of Lunar sodium exosphere was suggested by observation of Lunar sodium atmospheric emission using Lunar circular orbit satellite Kaguya [Kagitani et al., 2010]. Lunar surface has Mare and Highland, those rock and telluric accidents are different. It is expected that these differences make locality of Lunar sodium exosphere. And, there are 4 source process mechanisms of Lunar exosphere, Photo-stimulated desorption (PSD), solar wind ion sputtering, vaporization by micrometeoroid impacts and thermal desorption, but contribution to quantitative source amounts and variety about time and space of each processes are not clear. From the above, purpose of our research is investigation into locality and time variance of Lunar sodium exosphere.

We observed at summit of Mt. Haleakala, Maui island, Hawaii, America, in the period of 18-25, 2011 and August 8-9, 2012 using our 40cm Schmidt-Cassegrain telescope and a high dispersion Echelle spectrograph. When we observed, we put on slit that length is 500 arcsec. at right angles to Lunar rim, made clear about distribution of sodium emission from surface to a height of 300km. On July 2011, we observed on Mare Orientale located at Long. 90 deg. W Lat. 20 deg. S, and Highland that located on a point of symmetry, Long. 90 deg. W Lat. 20 deg. N.. On August 2012, we focused on Oceanus Procellarum and expected to change amounts of Lunar sodium atmospheric emission from south to north, we observed on 5 points, Long. 90 W Lat. 50 deg. N, 20 deg. N, 0 deg., 20 deg. S, and 50 deg. S. From these observation, it was revealed that height distribution of sodium emission have thermal component (about 100K) and suprathermal component (about 1000K) in many cases.

About result of observation on July 2011, we investigated time variation of absolute emission intensity of suprathermal component, and saw brightening on July 19. At same time, number density of solar wind proton increased, so we thought that this brightening is result of contribution to PSD from gardening effect by solar wind ion sputtering. And, because this brightening is seen more at south hemisphere especially, it is suggested that gardening effect become intense especially at south hemisphere.

From result of observation on August 2012, about absolute emission intensity of both of suprathermal component and thermal component, that of south hemisphere is tend to be more than that of north hemisphere. About suprathermal component, from same discussion of observation of July 2011, we can interpret that gardening effect become more intense at south hemisphere. On the other hand, about thermal component, we take account of contribution of rebound particles of suprathermal component in source process, it is expected that encouragement of gardening effect to PSD of suprathermal component is reflected to thermal component. From this result, it is assumed that thermal component also has asymmetry of north and south.

South hemisphere has more area of highland than north hemisphere. So increase of absolute emission intensity at south hemisphere indicates that release rate of sodium at highland is higher than that of mare. Or, highland is more ups and downs and have large surface area per a unit surface, so it is thought that gardening effect with incidence of solar wind proton become more intense.

Kagitani et al., 2010, Planetary and Space Science, 58, 1660-1664, Variation in lunar sodium exosphere measured from lunar orbiter SELENE (Kaguya)

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Subsurface magnetization source of Reiner Gamma and Rima Sirsalis magnetic anomalies on the Moon

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Since the Apollo missions, observations by magnetometer and electron reflectometer disclose presence of magnetic anomalies on the Moon. However, the origin of the lunar magnetic anomaly is still controversial. To infer the origin, it is essentially important to have information on magnetization of magnetic anomaly source. In this study, we have modeled lunar magnetic anomalies in two regions to gain insights into their formation process. Here the Reiner Gamma and Rima Sirsalis anomalies are focused. We use Lunar Prospector magnetometer data obtained during the low-altitude observation period. As a first step, a simple dipole source is assumed for modeling. Then, based on the results from the dipole model, the magnetic anomaly is modeled by a uniformly magnetized vertical prism. As a result of forward modeling approach, five magnetic anomalies within the two regions are suitably modeled. As for the Reiner Gamma anomaly it is found that locations and shapes of the prisms correspond well with the surface feature such as high albedo swirl morphology. Such correspondence suggests association of a magnetic anomaly source with high albedo feature. For the Rima Sirsalis anomaly, two slender sources are located at the depth of 8 km, which extend along the Rima Sirsalis rille. According to the result, the magnetic anomaly source may be related with the rille below the surface. The present study demonstrates that adopting a finite-size magnetized body such as prism is more beneficial rather than a dipole to discuss correlation of magnetic anomaly with other structures at the surface and below.

Keywords: moon, magnetic anomaly, prism source, swirl, rille