Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS25-01 Room:201B Time:May 23 09:00-09:15

SELENE: its data archive status, scientific results, and a vista of the future

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Three years have passed since the Selenological and Engineering Explorer (SELENE) ended its mission in June 2009. SELENE science-and-project team members have made efforts to improve the accuracy of the data, and many data products have been registered in the SELENE data archive system. Numbers of published scientific papers and peer reviewed in international journals are reached to be almost 100; nearly half of them have been published in these years. SELENE data are highly contributing on the lunar sciences. Taking into account of this situation, SELENE team members are planning to hold an international science symposium for SELENE achievements on January, 2013, aiming to keep and further acquisition of initiative on the lunar science in the international lunar science community, and to encourage lunar scientists to realize post-SELENE lunar explorations. In this paper, we report the status of data archive, scientific results including individual and integrated sciences, and a vista of the future activities.

Keywords: Moon, SELENE, Kaguya, data archive

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PPS25-02 Room:201B Time:May 23 09:15-09:30

Generation of Electron Cyclotron Harmonic waves around the Moon

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We study plasma wave generations around the moon based on the plasma wave data observed by the KAGUYA spacecraft which is the Japanese mission to the moon. The WaveForm Capture receiver revealed that various plasma waves are excited due to moon-space plasma interactions. In the present paper, we focus on the Electron Cyclotron Harmonics (ECH) among the plasma wave phenomena taking place around the moon. The ECH waves have been widely studied in the relation to the electron precipitation in the terrestrial magnetosphere due to the loss cone in-stability. However, that does not directly link to the observation of the ECH around the moon orbit. KAGUYA observes the ECH around its orbit very frequently. That is unlikely to occur without the moon at the distance of 60RE from the Earth.. ECH waves are observed around the moon with KAGUYA plasma wave data.

First, we analyze the observation points to know why ECH waves are observed under the environment around the moon. By examining observation points in the SSE coordinates, it is revealed that ECH waves are observed only when the moon stays inside the magnetosphere. Furthermore, we found ECH waves are mostly observed on the night side, where surface of the moon is not lit by the sunlight. We also found the existence of the good correlation between the observation of ECH and magnetic anomalies.

Next, we examine plasma particle data. Lunar Prospector found that once ambient magnetic fields connect to the magnetic anomaly, the resultant mirror force causes the reflection of electrons with their velocity distributions above the loss cone angle. In addition to the loss cone distribution, Lunar Prospector also found the existence of low energy electron beams that are accelerated by the negative potential of the moon surface on the night side. We found the good correlation of the ECH waves to the loss cone electron distribution with low energy electron beams. We assumed low energy beam is necessary to excite ECH waves as well loss cone distribution. However, loss cone distribution and low energy beam are observed not only in the magnetosphere but also in the wake region which is found when the moon is in the solar wind. However, we never observe of ECH waves in the lunar wake region. We assumed ECH waves are generated only under the parametric condition in the magnetosphere.

Next, in order to study the generation of the ECH waves, we calculated the linear growth rate by solving the kinetic plasma dispersion relation using the realistic plasma parameters of electromagnetic environment of lobe, plasma sheet and wake based on the KAGUYA observation. The result shows fundamental harmonic and second harmonic are unstable under the coexistence of the electron of the electron loss cone and the low energy electron beam.

In the present paper, we examine the parametric dependence of the destabilization of the ECH waves by the liner dispersion analysis and we establish the comprehensive generation model of the ECH waves around the moon.

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PPS25-03 Room:201B Time:May 23 09:30-09:45

Global mapping of the lunar magnetic anomalies at the surface: implications for the subsurface igneous event

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We have developed a new method to map three components of the lunar magnetic anomaly field at the surface with a high spatial resolution. This method has been applied to the low altitude observations by the magnetometer of Kaguya (MAP-LMAG) and Lunar Prospector. Regional maps at the same altitudes from the two datasets show good agreement, for example, the anomalies in and around the South Pole-Aitken basin. Connecting regional maps of 15 deg x 15 deg size, a global map of the lunar magnetic anomalies was provided for three components from the Lunar Prospector dataset. As a result, the lunar magnetic anomalies are distributed almost over the lunar surface and show many lineated patterns with some spot-like ones. These patterns suggest ~4 Ga global event of the magnetic anomaly formation in the dynamo field of the early Moon. It is inferred from the Rima Sirsalis anomaly region that the lineated magnetic anomalies are originated from dike-like intrusions. If it is a case, the lineation indicates a direction of the horizontal maximum stress field in the early lunar crust. We will discuss a possible subsurface igneous event of the early Moon.

Keywords: moon, magnetic anomaly, dynamo, Kaguya, igneous activity, stress field

PPS25-04 Room:201B Time:May 23 09:45-10:00

Electrical Conductivity of the Lunar Interior from Magnetic Transient-Response

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The electrical conductivity structure of the lunar interior provides us very important information for investigation of the lunar origin and evolution. We attempt to give a constraint on the lunar electrical conductivity from magnetic field measurements by the Lunar MAGnetometer (LMAG) onboard SELENE (KAGUYA). The primary science goal of LMAG was global mapping of lunar surface magnetic anomalies, and secondary purpose was to measure time-dependent magnetic responses containing information on the electrical conductivity of the lunar interior. We investigate whether the signals of lunar induced magnetic field are recorded as well as magnetic anomalies during the period from 21 December 2007 to 31 October 2008, when SELENE was in the orbit of 100-km altitude.

Magnetic fields are induced in the moon by changes in the interplanetary field (IMF). LMAG measures inducing and induced fields simultaneously. So, to confirm the inducing field generated by changes in the IMF, we also examine the magnetic data measured by magnetometers of ACE or WIND satellites, which are moving around the Lagrange point (L1) where the gravity of the sun balances with that of the earth. Twenty-two events showing damped response curves against the step-function transients in the IMF are selected. In the second step for quantitative analysis, we further selected three events among twenty-two events, which show relatively low noise and good geometry of satellites' positions when step-function transients are measured by ACE or WIND.

In the three events, the apparent differences in magnetic responses measured by LMAG are seen depending on the relative position between SELENE and the moon by reference to the direction of the magnetic transient field. However, a moon model of uniform conductivity explains well the apparent differences. The induced fields in the three events show the step amplitudes of 10 nT and the decay times of 500 s. Using the homogeneous moon model, having a uniform conductivity inner sphere with radius 1738 km (lunar radius) and non-conducting outer shell with thickness 100 km (SELENE altitude), we estimated the homogeneous conductivity to be 1.0 - 4.0$*$10-4 S/m.

Keywords: Moon, KAGUYA, SELENE, LMAG, induction, conductivity

PPS25-05 Room:201B Time:May 23 10:00-10:15

Subsurface magnetized basalt layers underneath the Mare Crisium by Lunar Radar Sounder

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Paleomagnetic measurements of 3.7-billion-year-old mare basalt sample 10020 revealed the presence of strong intensity of mean 60 microteslas as the lunar paleofield. Current lunar dynamo theory (continuous mechanical stirring dynamo) generates a long-lived lunar magnetic field for more than one billion years with an intensity of 1-10 microteslas, contradicting such intense paleomagnetic record. There are several regions showing strong lunar magnetic anomalies around the mare. The orbital magnetic field measurements with magnetic inversion techniques on the mare Crisium suggested that subsurface basalt layers ~ 1 km depth are magnetized with an intensity of 1 A/m from the estimation of Apollo return samples. However, there is no data for subsurface structure underneath the mare Crisium. In this presentation, we report the subsurface structure of layered basalt lava by using the lunar radar sounder onboard Kaguya. Lunar Radar Sounder imaging with a synthetic aperture radar analysis revealed the cryptic subsurface basalt layer of 500 m thickness at 360 m underneath the Crisium basin. Considering the surface crater age and the duration for hiatus of two paleo-regoliths as LRS reflectors, the age of the basalt is about 3.7 billion years. This thick basalt layer explains total magnetic field strength above the Crisium basin from lunar prospector data if the basalt acquired a thermo remanent magnetization under 100 microteslas with 1 % iron content. Such high iron content and large volume of basalt lava plausibly results from the eruption of thorium- and titanium-rich lunar mare basalts due to the removal of the ilmenite-rich thermal blanket at the base of the lunar mantle. Our results support the presence of the late, intense lunar paleofield.

PPS25-06 Room:201B Time:May 23 10:15-10:30

Evaluation of the maximum detection depth of the Kaguya Lunar Radar Sounder

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Introduction: Recent studies based on the subsurface radar sounding of the Moon by Kaguya Lunar Radar Sounder (LRS) have prominently shown that the radar sounder is a powerful tool for geological investigations of the planets and satellites [cf. Ono et al., 2009; 2010]. On the other hand, we have also recognized several limitations in the actual radar sounder observations. Based on Kaguya/LRS data, it was reported that there were found inhomogeneity of the subsurface reflectors in the Oceanus Procellarum [Oshigami et al., 2009]. As for the inhomogeneity, it was also pointed out that the abundance of the ilmenite such as FeO and TiO_2 affects the detectability of the subsurface echoes [Pommerol et al., 2010]. The result suggests that rich ilmenite in the lunar surface material could cause the radio wave attenuation and degrade the detectability of the subsurface echoes and maximum detection depth of the radar sounder. In the present study, we performed estimation of the subsurface echo powers based on the reflection coefficient at the buried regolith layers and attenuation rate in the basalt lava flow layers. Then we also estimate the maximum detection depth of Kaguya/LRS.

Estimation of Subsurface Echo Power: We made the following assumptions: (i) The subsurface reflectors detected by LRS are buried regolith layers. Their thickness is several meters, which is much less than LRS range resolution (75 m in vacuum). Their permittivity is ˜4. (ii) The layers between the subsurface reflectors are basalt lava flow layers. Their thickness is several hundred meters, which can be determined by LRS. Their permittivity is ˜6.25. The mass density is ˜3 g/cm^3. (iii) The abundances of FeO and TiO_2 of the subsurface basalt layers are almost similar with those on the lunar surface, which can be derived from Clementine UV-Visible image data [Lucey et al., 2000]. Based on the assumptions, we can calculate the reflectance at the buried regolith layers, and attenuation per meter in the basalt lava flow layers. Due to the interference between radio wave reflected at the upper and lower boundaries of the buried regolith layer, the total reflectance at the buried regolith layer depends on the thickness of the buried regolith layer. It also depends on the permittivity gap between basalt layers above and below the buried regolith layer. The loss tangent map was derived from the FeO and TiO_2 map. The loss tangent in the nearside maria was estimated to be ˜0.016, which is much more than that assumed in the prelaunch estimations [Ono et al., 2000; 2008]. Based on the calculated reflectance and attenuation rate, and noise level of Kaguya/LRS, which is 50 dB less than the nadir surface echo level, the maximum detection depth of Kaguya/LRS, Dmax, can be estimated. Dmax in the nearside maria is estimated at ˜1 km if assuming permittivity of ˜6.25.

Discussion: In the prelaunch studies, maximum detection depth of the Kaguya/LRS was estimated to be 5 km because loss tangent of 0.006 was assumed in them. That was, however, too small in the nearside maria. It was reported that Apollo Lunar Sounder Experiment (ALSE) detected the subsurface reflectors at depths of 1 km and 2 km in Mare Serenitatis [Peeples et al., 1978]. Because the transmitting power and dynamic range of ALSE are almost the same with those of Kaguya/LRS, the maximum detection depth of ALSE should be about 1 km. Therefore, it is quite unnatural that ALSE detected reflectors at a depth of 2 km. It was found in the present study that the subsurfcae echo power depends on the thickness of the buried regolith layers and permittivity gap among the basalt lava flow layers. The results will enable us to discuss the regolith accumulation rate, deference of lava flow compositions, and the evolution of the volcanic activity in the lunar maria in future works.

Keywords: Kaguya (SELENE), Lunar Radar Sounder (LRS), Subsurface radar sounding, Buried regolith layers, Basalt lava flow layers, Ilmenite abundance

PPS25-07 Room:201B Time:May 23 10:45-11:00

Comparison of reflectance spectra of sintered olivine with those of olivine powder.

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Global lunar remote-sensing data acquired through visible to near-infrared reflectance spectroscopy is used to identify rock types and rock-forming mineral compositions of the lunar surface. There is some debate over whether the grain sizes of rock-forming minerals can be estimated like powders or not. We studied the difference of reflectance spectra between sintered olivine as a quasi-rock and olivine powders.

We used olivine because it is one of the major constituent minerals of the lunar crust and the crystal structure does not change when it is sintered. The olivine used in this study is from San Carlos. To prepare sintered olivine, the samples were crushed into powders, sieved into two size fractions (75-10 micrometers, 230-250 micrometers) and pressed and sintered (1GPa, 1400-1500 degrees). The sintered olivine was cut into two pieces and one was polished with 0.1 micrometers diamond paste and sand paper (#1000). Another sintered olivine was slice into a thin section and observed under a polarizing microscope to measure their grain sizes. Powders which have the same grain size were prepared. Powders were poured into an aluminum pan and its surface was smoothed. At reflectance spectrum measurement, a halogen lamp was used as a light source and a hyper-spectral microscope (range(wavelength):380-1100nm, wavelength resolution:5nm) was used as a detector. The light reflected on the samples was dispersed by a grism. Spectralon was used for a reflectance standard. The incident angle was 40 degree and observed angle was 0 degree. The results of reflectance spectra of sintered olivine and olivine powders were widely different at their reflectance. The reflectance of the sintered olivine was extremely lower than that of olivine powders. The effect of the difference of surface roughness of the sintered olivine on reflectance spectra remained unclear within our measurements. Concerning the grain size, smaller the grain sizes of olivine powders were, the higher their reflectance was. On the other hand, smaller the grain sizes of the sintered olivine were, the lower their reflectance was. These results suggest that a new scattering model for rocks different from that for powders is required to estimate grain sizes of the sintered olivine.

Keywords: reflectance spectrum, olivine, sintered olivine, remote-sensing, lunar surface, hyper-spectral sensor

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PPS25-08 Room:201B Time:May 23 11:00-11:15

Regions with the Oldest Crust for Future Sample Return Missions as Inferred from Lunar Meteorites and the Kaguya Data.

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In the preface of his textbook, J. Wood [1] wrote that Men have always wondered about the beginning of things. One of the goals of our lunar missions is to explore the oldest anorthositic lunar highland crust. Nyquist et al. [2] performed Sm-Nd and Ar-Ar studies of pristine ferroan anorthosites (FANs) of the returned Apollo samples and showed that a whole rock Sm-Nd isochron for selected FANs yields an isochron age of 4.47 Ga. These ages are not as old as the oldest cumulate eucrites of the Vesta-like crust [3]. Mineralogical and chemical data of the Dhofar 489 group [4] and Yamato (Y-) 86032 [5] are different from common lunar rocks.

In order to deduce the ejection site of the Dhofar 489 group, we have investigated three common olivine-bearing crystalline anorthositic clasts in these groups [7]. Dhofar 307 PTS [8] contains a fine-grained magnesian granulitic clast (GR), and Dhofar 309 [9] contains many crystalline clasts with rapid growth features, suggesting crystallization from an impact melt pool (IM). Mineral chemistry and modal abundances of these clasts are similar to the spinel troctolite (ST) clast in Dhofar 489 [4]. A large impact, which excavated a basin might have produced impact melts at the basin floor and crystallized an IM-like clast by rapid cooling. Granulites were produced by thermal metamorphism at the floor of a large basin or in deep ejecta of a smaller impact. Other small impacts within the basin produced breccias of ST, IM and GR materials. Among a few large basins of the farside, the Dirichlet-Jackson (DJ) basin (Diameter 480km) has a few large craters on the floor, and the formation age by Morota et al. [9] is 4.25 Ga, which agrees with the Ar-Ar age (4.23 Ga) of Dhofar 489 [4]. The Th concentration of the d2 anorthositic clast of 0.011 ppm of Dhofar 489 [4], are lower than those of the lowest-Th region (ca.0.5 ppm, 450km x 450km average) found in the Th map of Kobayashi et al. by the KGRS [10], where the D-J basin is located. Anorthosites composed of nearly pure anorthite (PAN) at many locations in the farside highlands [11] and a map of the Mg numbers [12] deduced from the Kaguya multiband imager and spectral profiler also showed that the region around the D-J basin is consistent with the Mg numbers (70 to 76) of the magnesian anorthositic clast of Dhofar 489, and showed that the earliest crustal anorthositic rocks may be preserved there.

Although a sample return mission to bring back such samples from the above region is the most desirable mission, we will land on a region of the extension of the low-Th region by the SELENE 2 mission to prove the presence of such region. The proposed region is north east of the Bailly basin, especially the Zucchius crater with the central peak and the Pingre crater. Lunar Magma Ocean (LMO) model deduced from the Apollo samples is not be able to explain the dichotmy of the Moon. Tilted Convection model based on fluid dynamics [13], or a putative Procellum basin impact hypothesis may explain the problems resulted from the above new findings.

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Keywords: Lunar farside, basin, lunar meteorites, lunar crust, Kaguya mission, Dirichlet-Jackson Basin

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PPS25-09 Room:201B Time:May 23 11:15-11:30

Lunar Bulk Composition Constrained by Reevaluation for Formation Mechanism of Anorthosite Crust

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Recent observations by lunar explorations have shown that the lunar highland crust is highly anorthositic in composition and is ~45-60 km thick. The Moon has been thought to have undergone a global magma ocean stage very early in its history and the anorthositic crust was formed by accumulation of anorthite crystallized in the lunar magma ocean (LMO).

The bulk composition of the Moon has been estimated by previous studies from geochemical and geophysical data. There are, however, large disparities among the estimates, because of the lack of direct chemical and structural information on the lunar interior right after the solidification of the magma ocean. The initial composition of the LMO, particularly FeO and refractory elements (Al2O3 and CaO), largely affects physical properties of melts as well as the phase relation of anorthite crystallization, and thus the dynamics of the cooling LMO.

Tonks & Melosh (1990) suggested that crystals could be separated from the magma when a settling/floating velocity for crystals calculated from Stokes' law are much larger than a convective velocity in magma ocean. The laboratory experiments intended for a terrestrial magma chamber, however, have revealed that the crystal separation does not take place at the convective region, but at the boundary layer of fluid, where the effects of viscosity are significant (Martin and Nokes, 1989, Solomatov et al. 1993).

We have developed a fractional crystallization model of LMO and investigated the conditions for the effective floatation of anorthite in the LMO to reproduce the observed critical features of the lunar crust to constrain the FeO and refractory element contents (Sakai et al., 2010, 2011). In this study, we refined our model by considering crystal separation in the boundary layer (Solomatov et al., 2003) and tried to constrain the contents of FeO and refractory elements in the initial LMO more rigorously.

The results showed that the initial FeO content should be more abundant than that of BSE, and the degree of enrichment of refractory elements should be $<$ less than 2.3 times of the BSE. These values satisfy the conditions for floatation of anorthtie found in the Apollo sample (James, 1972; Wilshire et al., 1972). The new model with boundary layer fractionation supports our previous conclusion that the FeO content of the LMO is larger than that of the BSE.

The higher FeO content estimated for the LMO than the BSE implies that the impactor that hit the proto-Earth was enriched in FeO than the BSE or that the oxygen fugacity of the LMO was higher than the BSE.

Keywords: Lunar Bulk Composition, Magma Ocean, Anorthosite Crust, Differentiation Model

PPS25-10 Room:201B Time:May 23 11:30-11:45

Cratering chronology for small lunar craters

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We performed size-frequency measurements for lunar craters smaller than ~500 m in diameter using Kaguya and LRO image data to construct the new lunar production function.

Keywords: Moon, crater, size-frequency distribution, cratering chronology

PPS25-11 Room:201B Time:May 23 11:45-12:00

Retention time of crater rays materials in Mare Humorum

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Surfaces of astronomical objects are scarred with millions of impact craters. Impact craters are the remains of collisions between, for example, asteroids, comets, or meteorites and the Moon. Such objects hit the Moon at a wide range of speeds, and impact craters are formed. Relatively fresh craters have crater rays. Crater rays are obviously bright streaks of materials that we can see extending radially away from host craters. The most recently formed craters on the lunar surface have bright and more or less radial rays, which are usually superimposed over all other terrains. In general, rays are bright because they excavate immature soils.

Lunar crater rays disappear over time, and it is considered that the reason of it is space weathering that is a process of surface materials being altered by exposure of solar wind, cosmic rays, and micrometeorite bombardments. Wilhelms et al. (1987) and Werner and Medvedev (2010) described the crater rays disappearance occurs in about 1.1 Gyr and 750 Myr, respectively. However, as a result of analyzing the retention time of the crater rays of highlands, it turned out that the new result time was longer than the time from the previous studies (Suzuki, 2011).

This study focuses on space weathering effect to understand why the disappearance time of the crater rays in highlands is longer. We suppose that a degree of space weathering relates to iron content on the lunar surface. Lunar highlands are iron-poor areas. In contrast, lunar maria are iron-rich areas. The purpose of this research is to investigate that crater ray disappearance time in maria is different in lunar highlands. We examined the time in Mare Humorum which is filled in iron-rich basaltic materials. As a result, the disappearance time of crater rays in Mare Humorum is 250 Myr (2.0 Gyr at highlands). This implies that the space weathering effect depends on the iron content on the lunar surface.

Keywords: crater, ray, space weathering

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PPS25-12 Room:201B Time:May 23 12:00-12:15

Planetesimal collision on the Moon at 2.7 Ga indicated by silica high-pressure polymorph

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The existence of a high-pressure polymorph in a meteorite is suggestive of its parent body having gone through a dynamic event. The moon's many craters and thick regoliths imply that it has experienced heavy meteorite bombardments. Several previous studies proposed that only a very few high-pressure polymorphs are contained in lunar surface materials (lunar meteorite and Apollo samples) because most high-pressure polymorphs melted and disappeared through high-temperature condition induced by a dynamic event under rarefied atmosphere on the moon [1-2]. However, Ohtani et al (2011) [3] studied lunar meteorite, Asuka 881757 in detail, and identified high-pressure polymorphs of silica, coesite and stishovite. ^{40}Ar-^{39}Ar radiometric age of Asuka 881757 indicates that coesite and stishovite were formed by a dynamic event occurred at 3.8 Ga, which is relevant to a planetesimal collision occurred during late heavy bombardment. In this study, we studied another lunar meteorite, NWA 4734 by a Raman spectroscopy, scanning electron microscope (SEM), synchrotron X-ray diffraction (XRD) and transmission electron microscope (TEM) to search for high-pressure polymorphs and clarify planetesimal collision history on the Moon.

NWA 4734 originates from lunar basalt, and contains many shock-melt veins and melt-pockets, implying that NWA 4734 was heavily shocked. Many cristobalite grains with mosaic-like textures exist in NWA 4734. Back-scattered electron (BSE) images show that cristobalite adjacent to the shock-melt veins and melt-pockets have tweed-like textures. Such portions including tweed-like textures were excavated with a focused ion beam (FIB) system, and became block pieces. We scanned the block pieces with a synchrotron X-ray at SPring-8 BL-10. We identified a high-pressure polymorph of silica, alpha-PbO2 type silica (seifertite) based on the X-ray diffraction (XRD) patterns. Seifertite was reported only from shocked Martian meteorites up to now [4]. BSE images show that cristobalite grains in the host-rock of NWA 4734 have lamellae-like textures. Raman spectroscopy analysis and XRD patterns reveal that such portions include stishovite. Dendritic coesite was also found in the shock-melt veins. Phase equilibrium diagram deduced from high-temperature and -pressure synthetic experiments indicate that the stable pressure filed of seifertite is ~100 GPa or more. On the other hand, recent several studies propose that the stable pressure filed depends on the differences of starting materials for the synthetic experiments and impurities (e.g., Al)[5-6]. Original silica in NWA 4734 is not quartz but cristobalite and contains small amounts of Al and Na. Accordingly, now, it is difficult to estimate shock-pressure condition recorded in NWA 4734 based on present phase equilibrium diagram. Nonetheless, high-pressure condition of ~40 GPa or more would be essential for the formation of seifertite at least [6]. ^{40}Ar-^{39}Ar radiometric age of NWA 4734 is 2.7 Ga [7], which is the one of the youngest age among lunar meteorites. We could regard 2.7 Ga as planetesimal collision age because 40Ar-39Ar radiometric age is very sensitive to thermal metamorphism. Our present study allows us to infer that catastrophic planetesimal collision had continued on the Moon till 2.7 Ga at least.

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Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS25-13 Room:201B Time:May 23 13:45-14:00

Study on impact formation of lunar mineral rocks and interior reservoir of light elements

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The following problems are pointed out on lunar mineral rocks and circulation of light elements:

1) Airless dry Moon has no Earth-type three material states with circulation system.
2) Large chunks of mineral rocks are remained on the Apollo lunar basalt rocks, but Basement rocks with clear gorge features cannot be found so far.
3) Instead of wide crystalline basement rocks in the Earth planet, the lunar surface rocks are porous glassy regolith soils and impact breccias as thick and wide distribution.

The following results can be summarized in this study (Miura, 2012 in press).

1) Present lunar surface is considered to be formed at heterogeneous surface due to little light elements to generate wide atmosphere and ocean water. In fact, pristine Apollo voids- and carbon light elements-rich lunar rocks are obtained by the previous reported data.

2) Those problems on the Moon cannot be explained by the formation model MO of the pristine large lunar basement rocks crashed destroying largely, but can be easily explained by the present impact formation model IE irregular lunar rocks collided and evolved by extra-lunar bodies of the asteroids and water planets with the giant impact. The former model MO has basement rocks remained deeply due to mega-regolith, but close to impossible even by drilled deeply. The latter model IE shows surface material crystallized regolith soils, but the central peaks of impact craters with relatively cooled slowly from glassy regolith soils are not direct deep interior basement rocks lifted largely.

3)Another strong supports to the present irregular impact layering IE are data analytical results of enriched carbon, Ca and rare-earth-elements (REE) especially in impact-related samples of regolith soils and impact-melt breccias (compared with the Mare basalts)(cf. Miura, 2012 in press).

4) Mineral rocks on the airless Moon are impact evolved products with compositional and textural changes to repeat material changes between glasses and crystals due to differences in cooling history at different impact sites. In fact the composition of Ca-rich plagioclases are mixed during formation. Low-temeparture quartz minerals formed at stable magmatic
final-product of terrestrial crust-rocks cannot be found largely on the Moon surface so far.

Keywords: lunar mineral rocks, carbon light elements, interior reservoir, impact evolved formation, porous materials, glassy materials

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PPS25-14 Room:201B Time:May 23 14:00-14:15

Lunar Polar Region, Lunar Water

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The lunar polar regions are often referred to be attractive as locations for a lunar exploration target, and where humans start colonization. The reasons of the assertion are for instance, first, water "must" be present in some permanently shadowed areas near the poles, and second, there are locations near the poles where the sun illuminates in long duration time, supplying energy continuously, and third the stable temperature conditions could be attained which is very convenient for astronauts and instrument to operate. However, these reasons should be reconsidered with recent observation results attained by SELENE, LRO, and other lunar explorers. On the other hand, the scientific interests on the regions have been highly grown. In this presentation, we outlook and discuss the new views of the lunar polar region.

Keywords: moon, exploration, polar region, water, ice, SELENE

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(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS25-15 Room:201B Time:May 23 14:15-14:30

Deformation of lunar maria inferred from Kaguya geodetic data

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Spatial and temporal scales of deformation on the Moon are important keys for understandings of the lunar evolution, particularly of its thermal evolution. The aim of this study is to understand the history of large-scale deformation of lunar maria using latest version of Kaguya topography and gravity field data (i.e., LALT 1/16 degree grid data Ver. 2.0 and SGM150j [1]).

The viscosity of lunar mare basaltic magma is extremely low compared to terrestrial magma [e.g., 2]. Consequently, surface topography of thick maria may be parallel to selenoid, the lunar geoid, at the time of the eruption of mare basaltic lava. Thus, the difference between present-day topography and selenoid may indicate deformation occurred after the eruption of lava. In order to extract information of large-scale deformation, we first calculate the slope of surface topography respect to selenoid for mare basalt units, whose the model age is determined based on crater chronology [e.g., 3]. We found that the slope is not zero for most of units (confidence interval of 99%). This result suggests that large-scale deformation occurred after the eruption of lava. We also find that the absolute value of the slope for younger units (i.e., $<=2.5$ Ga) is smaller than that for older units (i.e., >2.5 Ga). This result may reflect the history of large-scale deformation for billions of years.

In order to investigate larger deformation for maria, we fit a sphere to topography of maria. An elevation profile directly below an orbit of Apollo 17 (Revolution 16) indicates that several mare units share a common "circle" [4]. This circle may be a first-order approximation of selenoid at the time of eruption of mare lava. Since the center of maria is not coincide with the present-day center of mass (COM), results shown by [4] may indicate extremely-large-scale deformation, such as a displacement of the COM. However, further investigations are necessary because the analysis has conducted only for a single along-track elevation profile. In this study, we use LALT topography data and fit a sphere (instead of a circle used by [4]) to topography of maria. We found that the center of maria is not coincide with the COM even if we consider the effect of tidal deformation. This result suggests that extremely-large-scale deformation had occurred on the Moon after the time of major mare volcanism.

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Keywords: Moon, Mare, Selenoid, Geoid, Large-scale deformation

PPS25-16 Room:201B Time:May 23 14:30-14:45

Global seismic waveform modeling in the whole Moon

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We calculate global seismic wave propagation on cross sections of the realistic whole Moon models.

The U.S. Apollo missions installed five seismometers on the lunar surface. Seismograms obtained during 1969 to 1977 have widely been used for investigation of the lunar interior. For example, many researchers have been working on construction of the 1-D structure models (e.g., Nakamura, 1983, *JGR*; Garcia et al., 2011, *PEPI*). Zhao et al. (2008, *Chinese Sci. Bull.*) further estimated the 3-D velocity structure of the Moon by applying seismic tomography to the moonquake traveltime data.

Now the Japanese next lunar mission "SELENE-II" is planning installation of broad-band seismometers, which are expected to greatly increase resolution of the lunar interior images. Looking back on investigation history of the Earth's interior, our knowledge has been enhanced by mutual progress of observation and numerical methods. Increased enthusiasm for the Moon exploration in recent years strongly requires developing a method for numerical modeling of global seismic wave propagation based on our current knowledge of the lunar interior.

We have been constructing numerical schemes using the finite-difference method (FDM) for accurate and efficient modeling of global seismic wave propagation through realistic Earth models with lateral heterogeneity (e.g., Toyokuni et al., 2005, *GRL*; Toyokuni & Takenaka, 2006, *EPS*). Our scheme calculates the 3-D equations of seismic waves in spherical coordinates only on a 2-D cross section of the whole Earth including a seismic source and receivers ("spherical 2.5-D FDM"), which enables global waveform modeling with a similar computation time and memory as for 2-D modeling with consideration of full 3-D geometrical spreading. This time we apply it to model global seismic wave propagation in the whole Moon. In the presentation, we will show some numerical examples using models by Nakamura (1983, *JGR*) and Garcia et al. (2011, *PEPI*).

Keywords: Moon, seismology, seismic wave propagation, synthetic seismogram, global modeling, finite-difference method (FDM)

PPS25-17 Room:201B Time:May 23 14:45-15:00

Improvement of lunar interior model by SELENE2 geodetic and seismic observations

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On a future Japanese lunar landing mission, the SELENE-2 project, some geophysical observations are planned to improve current knowledge of lunar interior structure. Since both geodetic and seismic observations planned in SELENE-2 mission are useful to constrain the elastic properties and densities of interior materials, combined analyses are more effective to infer the lunar interior structure (e.g., Garcia et al., 2011).

As geodetic observations, VLBI (Very Long Baseline Interferometry) and LLR (Lunar Laser Ranging) are planned. On the VLBI, radio source antennas are mounted on the SELENE-2 lander and orbiter, and both radio waves on lander and orbiter are received at two ground stations. Since one radio source is fixed on the ground, we will be able to measure the trajectory of the orbiter with better accuracy compared with the first SELENE mission on the lunar near-side. Through this observation, we intend to improve the low-order coefficients of gravity field and tidal potential Love number k2 by designing high average altitude of the orbiter. On the LLR, a laser reflector is mounted on the SELENE-2 lander, and distance between the Earth and the Moon is measured with accuracy of about 1 cm using reflection of the laser emitted from the Earth. Through this accurate measurement, we can investigate the lunar rotational motion and tidal deformation, and will obtain information on elastic properties of the lunar interior, flatness of the core-mantle boundary and so on. Finally, combined results of VLBI and LLR observations can be used to improve the values of the moment of inertia and tidal potential Love numbers (h2, k2) which are parameters to constrain lunar interior structures in comparison with results of the first SELENE mission.

On the seismic observation, the Very Broadband (VBB) and the Short Period (SP) seismometers are deployed on the lunar surface by a robotic arm of the SELENE-2 lander. Though we have only one seismic station in the mission and, therefore, can not locate the seismic sources, we can utilize the deep moonquake events (e.g., Nakamura et al., 1982) occurred at the nests located by the past Apollo missions and the meteoroid impact events locatable by impact flashes from the ground observations. In the seismic observation, detections of seismic phases reflected from the core-mantle boundary and refracted converted phases at the crust-mantle boundary are main targets, and these detected seismic phases are important to reveal the lunar core size and crustal thickness beneath the landing site with better accuracy.

In this study, we have performed a simulation to ensure how we can improve a current lunar interior model by combining the expected geodetic and seismic data in the SELENE-2 mission. In this simulation, we utilize the lunar moment of inertia, the mass and the Love numbers as the geodetic data and travel times of the seismic phases as the seismic data to constrain lunar interior. Then, we evaluate a posteriori errors of model parameters such as seismic velocities and density by resolving a linear inversion method using these geodetic and seismic data. In current evaluations, we have preliminary quantitative results that errors of S-wave velocity in lower mantle would be improved by adding the geodetic data to the seismic data, because the geodetic data is sensitive to the deep region and S-wave is hard to pass the region. Then, we could determine the average densities of lunar crust, mantle and core respectively with better accuracy by SELENE-2 geodetic data, if we can reveal the core size and the crustal thickness precisely using the seismic data. We report the results of the simulations, and then discuss especially usefulness of the SELENE-2 geodetic observations in this presentation.

Keywords: Lunar exploration, Lunar interior structure, Gravity observation, Lunar laser ranging, Seismic observation, VLBI

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PPS25-18 Room:201B Time:May 23 15:00-15:15

Exploration of lunar deep interior state: Tactics of SELENE-2 selenodesy

SASAKI, Sho[1*], KIKUCHI, Fuyuhiko[1], MATSUMOTO, Koji[1], HANADA, Hideo[1], NODA, Hirotomo[1], ARAKI, Hiroshi[1], KUNIMORI, Hiroo[2], IWATA, Takahiro[3], Kenichi Funazaki[4], Hideo Taniguchi[4], OTSUBO, Toshimichi[5], YAMADA, Ryuhei[1], Seiitsu Tsuruta[1], Kazuyoshi Asari[1], Toshiaki Ishikawa[1], TAZAWA, Seiichi[1], KOKUBO, Eiichiro[1]

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Precise measurements of gravity and rotation of planets are important methods to obtain the information of the their internal structure. The Moon with synchronous rotation is tidally deformed by the Earth and irregular motions of the lunar rotation with small amplitude, which is called forced librations, are excited. Moreover free libration would be excited by impacts, fluid core, and orbital resonance. Dissipation of the libration terms of lunar rotation depends on the interior of the Moon, especially the state of the core and lower mantle. Effect of tidal deformation should also appear on gravity. Long-term (longer than a few months) gravity measurements can provide information of the lunar tidal deformation, appearing on lower deree of spherical harmonics function. One important scale of tidal deformation is degree 2 potential Love number k_2, which could constrain the state of the core (solid or liquid) and viscosity of the lower mantle of the Moon. Liquid core should imply significant amount of sulfur in the core, whereas low-viscosity lower mantle should suggests the presence of water. In effect, the pressure level of lunar lower mantle is compatible with that of terrestrial asthenosphere, where water in silicate greatly reduces the viscosity. Since existence of volatiles would be incompatible with giant impact ? initially hot moon hypothesis, the result of our plan might modify the evolution scenario of the Moon. The Moon should have acquired volatiles by accretion of leftovers within the gravitational well of the Earth into the lunar magma ocean.

In SELENE-2 mission, we will have VLBI radio (VRAD) sources both in the lander and the orbiter. Then, using VLBI, we will determine the orbit of the orbiter precisely to have very accurate low degree gravity coefficients, and then k_2. A preliminary simulation has been conducted under the condition of 2-week arc length, 12-week mission length, 6 hours/day 2-way Doppler observation plus S-band same-beam VLBI observation with the VERA 4 stations. The k_2 uncertainty is evaluated as 10 times the formal error considering the errors in solar radiation pressure modeling and in lander position. Using combined the tracking data of SELENE and other missions the k_2 uncertainty is below 1 % when the orbiter inclination is 90 degree. The Love number k_2 is sensitive to the structure in deep interior. When the size of the core is 350 km in radius, k_2 value changes by about 5 % depending on the state of the core, liquid or solid.

The Lunar Laser Ranging (LLR) is the method to measure the distance between the Earth and the Moon using laser beam from the ground. For more than 40 years, LLR produced data on the lunar rotation as well as orbit. Using LLR data, the state of lunar interior is discussed. The dissipation between the solid mantle and a fluid core was discussed. LLR observation has also provided information of moment of inertia and tidal Love number of the Moon.

Instead of conventional corner cube reflector (CCR) array, we plan to have a larger single reflector in SELENE-2. The new reflector should be somewhere in the southern hemisphere on the nearside Moon. With pre-existed reflectors, latitudinal component of lunar libration and its dissipation can be measured precisely. However, among LLR parameters, k_2 and core oblateness is coupled. Once k_2 is determined by VLBI gravity measurement, we can estimate the core oblateness, which would also constrain the core and lower mantle state.

ILOM (In-situ Lunar Orientation Measurement) is an experiment to measure the lunar physical librations on the Moon by a small star-tracking telescope. Since ILOM on the Moon does not use the distance between the Earth and the Moon, the effect of orbital motion is clearly separated from the observed data of lunar rotation. ILOM will observe the lunar physical and free librations with an accuracy of 1 mas.

Keywords: the Moon, lower mantle, core, gravity, lunar rotation, volatiles

PPS25-19 Room:201B Time:May 23 15:30-15:45

Present status of next lunar landing mission SELENE-2 (2)

TANAKA, Satoshi[1*], MITANI, Takefumi[1], OTAKE, Hisashi[1], OGAWA, Kazunori[1], KOBAYASHI, Naoki[1], Yu-ichi Iijima[1], Tatsuaki Hashimoto[1], Takeshi Hoshino[1], Masatsugi Otsuki[1], KIMURA, Jun[2], KURAMOTO, Kiyoshi[2], SAIKI, Kazuto[3]

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Japan Aerospace Exploration Agency (JAXA) considers a moon lander SELENE-2 as one of SELENE (Kaguya) follow-on missions. Mission definition of the SELENE-2 was completed in 2007 and Phase-A study has started. Concept design of the spacecraft is now undergoing. We report our up-dated mission status and development of candidate instruments onboard.

The mission status goes nowhere fast since previous report of this meeting. We are planning to take the System Requirements Review board (SRR), which is defined to be an interim review board of the phase-A study, until the second quarter of the fiscal year 2012.

For these years of Phase-A study, we have promoted technological development of the candidate instruments. Since then, our system study checked the feasibility and re-investigated configuration of the candidate instruments. As a result, some instruments were required to be major modification of the basic design and the specification for the severe limitation of the weight budget and the large change in temperature on the Moon.

In order to select the landing site candidates which maximizes the scientific return from the project, "SELENE-2 Landing Site Research Board" was organized in March, 2010 as one of the sub-teams of the SELENE-2 pre-project team. After vital discussion, the research board released an evaluation paper in Yu-seijin, the journal of the Japanese Society of Planetary Science (JSPS) this March.

In the near future, further selection board of the instruments will be held before the SRR. As of now, SELENE-2 mission team is elaborating a realistic proposal from the viewpoints of both technological readiness and severe financial condition.

Keywords: Moon, lunar exploration, SELENE-2

Japan Geoscience Union Meeting 2012
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PPS25-P01 Room:Convention Hall Time:May 23 17:15-18:30

Advanced Lunar Imaging Spectrometer for the Next Japanese Lunar Mission SELENE-2: Present State and Science Objectives

SAIKI, Kazuto[1*], MOROTA, Tomokatsu[2], OTAKE, Hisashi[3], OHTAKE, Makiko[3], SUGIHARA, Takamitsu[4], HONDA, Chikatoshi[5]

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A future lunar landing mission SELENE-2 is being planned by Japan Aerospace Exploration Agency (JAXA). In the present design, SELENE-2 consists of a lander, a rover, and a communication relay orbiter, but detailed configuration - landing site(s), mission life etc. - is now under investigation. Advanced Lunar Imaging Spectrometer (ALIS) is an imaging spectrometer which we are developing for SELENE-2 lander.

Scientific objectives of ALIS are geological investigation around the landing site by VIS/NIR (Visible and Near Infra-red light) spectroscopy, making of the photometric model of the lunar surface by repeated observation with various photometric conditions, and production of an operation map for the rover to access sampling targets such as ejecta from central peaks. ALIS has been miniaturized in order to reduce weight and electricity consumption. It has a VIS-NIR imaging spectrometer (700-1700 nm with 5 - 10 nm resolution) . The spectrometer is composed of an imaging sensor (InGaAs) and a diffraction grating unit. The spectrometers take '1-line spatial resolution' x 'wavelength resolution' image as one shot. Line images are assembled by scanning image on a slit of the spectrometer with rotating ALIS body. We conducted a concept design of new ALIS and computed its thermal model and optical model to confirm its feasibility. The idea of scientific operation also will be presented.

Keywords: the Moon, remote sensing, hyper spectral sensor, lander

Japan Geoscience Union Meeting 2012
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PPS25-P02 Room:Convention Hall Time:May 23 17:15-18:30

Development of gamma-ray spectrometer for in-situ observations of elemental composition for SELENE-2

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For in-situ elemental analysis of lunar surface, we are developing gamma-ray spectrometer (GRS) for SELENE-2 mission. The GRS primarily measures K, Th and U abundances of the lunar surface and also can measure Fe and possibly other major elements.

To determine the elemental abundances with satisfactory accuracy, the energy resolution of the gamma-ray detector is an important factor. In view of operation on the lunar surface during lunar day, thermal feasibility of the instruments is important. Therefore we decided to use $LaBr_3$ scintillator, which has high energy resolution and can be used in high temperature environment.

Here we summarize science goals of the gamma-ray detector, expected sensitivity and current status of GRS development.

Keywords: SELENE-2, Lunar exploration, gamma-ray spectrometer

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PPS25-P03 Room:Convention Hall Time:May 23 17:15-18:30

Development status of thermal control unit for lunar surface scientific instruments in SELENE-2 mission

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We are developing the temperature control unit for long-term survival instruments in the SELENE-2 mission. In the SELENE-2 mission, several geophysical instruments are being considered to deploy on the lunar ground surface, including a seismometer, a magnetometer, a heat flow meter, and a VLBI radio source. These types of instruments require a long-term observation term beyond the lunar nights to obtain statistically sufficient amount of data. The lunar survival module was designed for temperature control of the instruments in the severe temperature environment (variable in -200 to 100 degC) on the lunar surface.

Conceptual examinations were conducted by numerical thermal modeling and thermal vacuum tests with a bread board model. Results of both thermal calculations and thermal vacuum tests showed a sufficient potential of the long-term survival on the Moon without high power consumption by heaters. We started designing an engineering model of the module based on the above mentioned results. The status and recent progresses of the lunar survival module developments are reported in this presentation.

Keywords: SELENE-2, thermal design, Moon

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PPS25-P04 Room:Convention Hall Time:May 23 17:15-18:30

Recent status of SELENE-2/VLBI instrument

KIKUCHI, Fuyuhiko[1*], MATSUMOTO, Koji[1], IWATA, Takahiro[2], HANADA, Hideo[1], Seiitu Tsuruta[1], Kazuyoshi Asari[1], Yusuke Kono[3], YAMADA, Ryuhei[1], ISHIHARA, Yoshiaki[1], SASAKI, Sho[1], KAMATA, Shunichi[4], Sander Goossens[5]

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VLBI (very long baseline interferometry) technique is anticipated to be applied for precise positioning of an orbiter or a lander in lunar and planetary explorations. VLBI measures a difference in an arrival time of a signal transmitted from a radio source to two ground stations. The differential VLBI (DVLBI) measurement consists of the differenced delay between two radio sources (orbiter-orbiter or orbiter-quasar). The differential delays give plane-of-sky position differences of two radio sources in contrast to conventional 2-way Doppler measurements that give line-of-sight position information. The combination of VLBI with Doppler can be used for gravity field estimation of the Moon and planets, and for determining their rotations through the precise positioning of orbiters or landers.

VLBI observation is proposed for a lunar landing mission SELENE-2. The purpose is to investigate the internal structures through the estimation of the gravity field of the Moon. The VLBI technique is expected to contribute the understanding of the internal structure and leading the origin and thermal evolution of the Moon and planets. This presentation shows the recent status of SELENE-2 VLBI instruments.

Keywords: selene2, internal structure, VLBI

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PPS25-P05 Room:Convention Hall Time:May 23 17:15-18:30

Lunar electromagnetic response to be observed by Lunar ElectroMagnetic Sounder (LEMS) in the SELENE-2 mission

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The present status of lunar interior structure is a consequence of the thermal history of the Moon. Therefore information on its internal structure is a key issue to understand the lunar origin and evolution. The electrical conductivity structure, which is independent of the seismic velocity structure, is important to estimate the thermal structure in the lunar interior, since the electrical conductivity of silicates has a strong temperature dependence. Hence, we propose a lunar electromagnetic sounder (LEMS) to estimate the electrical conductivity structure of the Moon.

Temporal variations in the magnetic field of lunar external origin induce eddy currents in the lunar interior, which in turn generates the magnetic field of lunar internal origin. In the SELENE-2 mission, the inducing magnetic field is to be measured by two triaxial fluxgate magnetometers onboard a lunar orbiter, and the induced field as well as the inducing field is to be measured by two triaxial fluxgate magnetometers onboard a lunar lander. We plan to use dual magnetometer technique as mentioned above to avoid strict electromagnetic compatibility requirements like those for the Kaguya spacecraft.

Here we present a current status of the LEMS mission. We also show electromagnetic response of the Moon by assuming electrical conductivity structures of the lunar interior. It turns out that the magnetic field date as obtained in the Apollo mission are insufficient to estimate the electrical conductivity structure for the outermost few hundred kilometers of the Moon because of the low sampling frequency. Estimation of lunar electromagnetic response was attempted by using the magnetic field data obtained by the lunar magnetometer (LMAG) onboard the Kaguya spacecraft. Although the magnetic field data at higher frequencies are available, it is difficult to estimate electromagnetic response only by the lunar orbiter. Thus it is very significant to measure the magnetic field by both a lunar lander and a lunar orbiter in the SELENE-2 mission.

Keywords: electromagnetic sounding, lunar interior, SELENE-2

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PPS25-P06 Room:Convention Hall Time:May 23 17:15-18:30

On lunar broadband seismic observation in SELENE-2

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SELENE-2 is the first lunar landing mission of Japan. We are developing a broadband seismometer system as a powerful candidate for a payload instrument. In this presentation, we demonstrate the necessity of broadband seismometer observation, its scientific targets inspired by the results of the Apollo passive seismic experiment and current status of the development of the seismometer system. The Apollo projects in 1970's installed an equilateral triangle seismograph network at apexes where Apollo 12, 14, 15 and 16 landed, with a side of about 1,000 km long. The observation had lasted for over 7 years until September 1977 and it provided us with the first information on the lunar seismicity and the lunar structure down to a depth of 1,000 km. It, however, had two drawbacks: (1) the size of the network is limited within 1,000 km, and (2) the sensitivity of the seismometers with a limited narrow band of 0.17 Hz is marginal to detect the small deep moonquakes which occurred frequently. In addition, due to the strong scattering of seismic waves, P and S wave arrivals could not be picked up accurately, and the typical picking error is up to 10 sec. Because of these problems, the lunar velocity models obtained so far are less certain, in particular, at depths greater than 200 km. In the SELENE-2 project we plan to have only one landing site and so we cannot run a seismic network observation by the project alone. Thus, we need to obtain more information from the feeble seismic waveforms using a broadband (0.02-50 Hz) seismometer having 10 times higher sensitivity than that of the Apollo seismometers to overcome the drawback (2) as mentioned above. The characteristic frequency of the shal- low layer is about 0.12 Hz for the seismic velocity model of Nakamura (1981). Below that frequency, we expect clear detection of seismic phases reflected and converted at an internal discontinuity such as the core-mantle boundary. The long-period seismic waveforms may provide us not only information on the depth of an internal discontinuity but also seismic velocity contrast at the boundary. Long-period seismology will definitely open a new frontier of lunar science. Another scientific target of our project is to determine the corner frequency of deep moonquakes which can provide us information on the physical state in the source region. Although it was suggested that the corner frequency of deep moonquakes is much longer than that of earthquakes, the result is not conclusive because of the narrow band of the Apollo seismometers. To realize the highly sensitive broadband seismic observation in a timely manner, we make use of the heritage of a short-period seismometer (SP) developed in the past Lunar-A project and a long-period broadband seismometer VBB (LP) developed in the ExoMars project. We customize these seismic sensors to work properly under the severe conditions at the lunar surface. The thermal shield module is the key technology to realize high performance in the seismic observation on the moon.

Keywords: moon, moonquake, internal structure, broadband seismometer

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Development of separation mechanism of lunar penetrator module for installation in a three-axis stabilized satellite

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The lunar penetrator module (LPM) developed for the former LUNAR-A project consists of a hard landing probe "penetrator" itself, a de-orbit motor to cancel the orbital velocity and attitude control system for 90 deg re-orientation by so-called Rhumb Line Control during the free-fall phase. The total length of LPM is 1.5 meters, and the total weight is about 45 kilograms. Though the impact on the lunar surface nominally designed to be vertical with a velocity of 280~300 m/sec, there is a high possibility that the penetrator will hit on the surface with a finite attack angle, which is the offset angle between the longitudinal axis of LPM and the velocity vector. This will inevitably occur due to a possible misalignment of the separation mechanism w.r.t the carrier spacecraft, slight errors of the motor ignition, the attitude control of LPM, and other influences. In case of non-zero attack impact, rotational torque will be applied to the penetrator. And also, we concern that the large attack angle results in the deflection of penetration trajectory, and it provides the shock environment significantly different from the case of zero attack normal incidence. Therefore, the permissible range of initial attack angle at impact must be configured so that the lunar penetrator comes to rest with an adequate depth and a pitch angle. On the former LUNAR-A project, the maximum attack angle was set to 8 deg. We are conducting to design several types of separation mechanism for installation in a 3-axis stabilized satellite such as a series of Russian Luna-Glob and to make a trade-off study concerning assumed essential parameters and requirements with the carrier spacecraft. Furthermore, we should give careful consideration to allow us to make a full-size test on the ground facility. In this paper, we describe some formulas of newly designed separation mechanism and report a result of preliminary test using breadboard models.

Keywords: penetrator, separation mechanism, 3-axis stabilized satellite, lunar exploration, internal structure

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Development of a Small Digital Telescope for Observations of Lunar Rotation

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We have developed a BBM (Bread Board Model) of a digital telescope for ILOM (In-situ Lunar Orientation Measurement) and made some experiments in order to know the performance of the optical system and the driving mechanism under the lunar environment. It is a special small digital telescope like PZT (Photographic Zenith Tube) for study of lunar rotational dynamics with the target accuracy of 1 milli-second of arc (1 mas).

Effect of large temperature change is one of the most serious problem for such a precise observation. We propose two methods for reducing the effects of such a large temperature variation. One is to use a diffractive lens, and another is to correct the effects by making use of the characteristic patterns in the shifts of star images. Ray tracing simulations show that the tolerance for the temperature change becomes wider by about one order of magnitude by introducing the diffractive lens, and it suggests that the temperature change of up to 5 degrees is allowed for the observation change of 1 mas, which is more than one order of magnitude larger than that for conventional lenses. Regarding the another method, we succeeded in approximating the effects of uniform temperature change with better than 0.03nm on the CCD array or 10 micro-second of arc by using a linear function of temperature.

The attitude control system, on the other hand, can make the tube vertical within an error of 0.006 degrees (or about 20 arcseconds), which is within the tolerance for the measurement of 1 milli-arc-second accuracy by using PZT. Performance of the mechanical system on the Moon is evaluated by vacuum test, and there is no serious problem hitherto.

We also investigated possible optical effects upon the central position of star images such as the ghost, off focus, stray rays, scattered rays, diffractive rays of unnecessary degrees and vibration of mercury surface by using ray tracing simulations and experiments. The effects are proved to be far below the 1 mas level except the effect of vibration of the mercury surface which is under investigation.

Keywords: Lunar rotation, telescope, PZT, physical libration, internal structure

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A study of future lunar exploration system for sample return

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We report results of the design for the sample return system as a future lunar exploration which is planned to be launched after SELENE-2. Candidate missions for SELENE-3 are the sample return from the lunar surface, observations for inner structure, and lunar environment utilizations for astronomy and scientific experiment, therefore, the system is requested to realize these scientific missions. We studied the components of spacecraft, mass and power budgets, and mission profile and the sequence of events. We also investigated the bus equipments for the takeoff, rendezvous with an orbiter, and the navigation and control system to return to the earth. We displayed the restriction of systems under the assumption of landing sites; low latitude areas on the lunar near side, lunar far side, and polar areas.

Keywords: Moon, SELENE-3, sample return

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Evaluation of the lunar laser topographic data by KAGUYA-LALT - comparison with LRO-LOLA -

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The laser altimeter (LALT) on board Japanese lunar orbiter KAGUYA has obtained about 22.06 million lunar ranging data and 10.34 million of these data are selected for making the lunar topographic data. Further, global and polar (more than 79 degrees in both latitude) grid data whose resolution is 1/16 degree (1.895km in the equatorial region) and 1/32 degree (0.947km in longitude)$*$1/128 degree (0.237km in latitude) respectively, has been made and released from 1st November, 2009, followed by 2nd version of these data sets based on revised orbit data of the KAGUYA main orbiter from 19th January, 2012.

However, as pointed out by Korohkin et al. (2010), these grid data show several misfits comparing with the real topography, such that a small crater about 10km diameter is represented as a small dome by the false interpolation, probably caused by the sparse data distribution due to the small laser return rate on the rough terrain. In this poster presentation, we compare LALT grid data with Lunar Reconnaissance Orbiter (LRO)-LOLA for the evaluation of the global topographic accuracy of the LALT grid data, and also for the difference of the Mean Earth / Polar axis lunar reference system employed for both LALT and LOLA topography.

Korokhin et al., 2010, Removal of topographic effects from lunar images using Kaguya (LALT) and Earth-based observations, Planet. Space Sci., 58, 1298-1306.

Keywords: Lunar topography, Comparison, Laser altimeter, grid, LALT, LOLA

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On the range measurement error of LALT aboard KAGUYA

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The Laser Altimeter (LALT) aboard lunar explorer KAGUYA (SELENE), which was launched in September 2007 and operated until June 2009, measured the distance between the satellite and the lunar surface, and achieved the first accurate lunar topographic map including polar regions (Araki et al 2009). Originally it was designed so that range measurements could be done for slope terrain with 30 degrees from 100 km orbit with the laser energy of 100 mJ. However, decrease of the laser energy down to 70 mJ occurred in the beginning of the nominal mission phase. In addition, due to a sudden decrease in the laser energy on 14, April 2008, the observation was suspended for a while, and intermittent observation was carried out until the end of the nominal mission phase (October 2008) for the investigation. In the nominal mission period, range measurement sometimes failed in the slope regions because the light bounced on the surface was not detected with sufficient intensity. In this report we investigate such situation by using laser energy telemetry, distance between the satellite and the lunar surface, slope, and reflectance of the surface.

references: Araki et al. (2009) Science 323, 897-900.

Keywords: Kaguya, Laser altimeter, LALT

PPS25-P12 Room:Convention Hall Time:May 23 17:15-18:30

Estimation of the permittivity of the lunar basalt layer based on the Kaguya observation data

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Lunar Radar Sounder (LRS) onboard the SELENE [Ono et al., 2009] discovered subsurface layers in lunar maria. The depth, T, of the subsurface reflector is a few hundred meters, and is given by $T=(c/E_r^{0.5})t/2$, where c is the speed of the light in the vacuum, E_r is the permittivity of basalt, and t is delay time of the subsurface echo from the surface echo. The permittivity of Apollo basalt samples returned from the lunar surface was in a permittivity range from 4 to 11 [e.g., Carrier et al., 1991]. These values are useful for the rough estimation of the thickness of the basalt layer. However, in order to obtain accurate thickness of the lava flow layers, we need to know the reliable permittivity of the lunar basalt layers. Using the LRS data applied Synthetic Aperture Radar (SAR) processing [Kobayashi et al., 2011], Terrain Camera (TC) data [Haruyama et al., 2008], and Multiband Imager (MI) data [Ohtake et al., 2008], we estimate the permittivity in each lunar lava flow units: Unit 85 of Mare Humorum [Hackwill et al., 2006], Unit Unit Sy1 of Mare Smythii [Hiesinger et al., 2010], and S13 of Mare Serenitatis [Hiesinger et al., 2000]. The permittivity E_r is calculated as $E_r=(ct/(2T))^2$ [Ono and Oya, 2000].

In order to determine T, we focus on the ejecta composition (TiO_2 and FeO). When the meteorite digs up different subsurface layers from the lunar surface layer, the formed ejecta composition would differ from that of lunar surface layer if subsurface layers have the different composition. Firstly, we compare the composition of the ejecta with that of the lunar surface by MI data and distinguish the haleod crater, around which ejecta composition is different from that of the lunar surface layer, from the non-haloed crater, around which ejecta composition is the same with that of the lunar surface layer. Secondly, using TC data, we investigate the depth of these craters, and determine the boundary-depth range around these craters by a pair of the haloed and non-haloed craters. For assumption of the heterogeneity of subsurface structure, the non-haloed crater must be close to the haloed crater. The distance between these craters is limited within 6 km, and the deepest non-haloed crater is selected. Thirdly, in order to determine ct/2, we use the LRS data applied SAR processing. The synthetic aperture is 5 km, and the spatial resolution is 600 m on the lunar surface in the along-track direction [Kobayashi et al., 2011]. We use the LRS data within 2.5 km from the center of these craters. If the ejecta contains the much more highland material, we assume that the deepest subsurface echo shows the boundary between highland and mare, and calculate the permittivity by depth of the deepest subsurface echo. On the other hand, if the ejecta does not contain the mush more highland material, we assume that the shallowest subsurface shows the boundary between the lunar lava flow units, and calculate the permittivity by the depth of the shallowest subsurface echo. The exsitence of the highland material in the ejecta is decided by the abundance of TiO_2 and FeO.

As the results, the ejecta composition in Unit 85 and Sy1 indicates the rough intermediate composition.The derived relative permittivity ranges of Unit 85, Sy1, and S13 are 3.3-6.0, 3.0-5.7, and 1.7-5.8, respectively.The estimated bulk density ranges in Unit 85, Sy1, and S13 are 1.8-2.7 g/cm^3, 1.7-2.6 g/cm^3, and 0.8-2.7 g/cm^3, respectively. The average density for Apollo basalt particle is $>$3.32 g/cm^3 [Carrier et al., 1991]. Thus, even the derived maximum bulk density is lower evidently than that of the lunar basalt. It is considered that the bulk density of the lunar lava flow layers can decrease by several reasons: composition, vesicles, cracks, tubes, and the existence of the paleoregolith layer. If the low permittivity results only from the porosity in the rock, the derived porosity is about 18-20% in each unit.

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The layered structure of lunar maria: Identification of the HF-radar reflector in Mare Serenitatis using optical images

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Comparison of the Lunar Radar Sounder (LRS) data to the Multiband Imager (MI) data is performed to identify the subsurface reflectors in Mare Serenitatis. The LRS is FM-CW radar (4-6 MHz) and the 2 MHz bandwidth leads to the range resolution of 75 m in a vacuum vacuum, whereas the sampling interval in the flight direction is about 75 m when an altitude of the spacecraft with polar orbit is nominal (100 km). Horizontally continuous reflectors were clearly detected by LRS in limited areas that consist of about 9% of the whole maria. The typical depth of the reflectors is estimated to be a few hundred meters. Layered structures of mare basalts are also discernible on some crater walls in the MI data of the visible bands (VIS). The VIS range has 9 wavelengths of 415, 750, 900, 950, and 1000 nm, and their spatial resolution is 20 m/pixel at a nominal altitude. The stratigraphies around Bessel and Bessel-H craters in Mare Serenitatis are examined in this paper. It was revealed that the subsurface reflectors lie on the boundaries between basalt units with different chemical compositions. In addition, model calculations using the simplified radar equation indicate that the subsurface reflectors are not compositional interfaces but layer boundaries with a high-porosity contrast. These results suggest that the detected reflectors in Mare Serenitatis are regolith accumulated during so long hiatus of mare volcanisms enough for chemical composition of magma to change, not instantaneously. Therefore combination of the LRS and MI data has a potential to reveal characteristics of a series of magmatism forming each lithostratigraphic unit in Mare Serenitatis and other maira.

Keywords: radar sounder, lunar maria, layered structure, crater wall

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Young Mare Volcanism in the Orientale Region Contemporary with 2 Ga PKT Peak Period

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The crater retention ages of the mare deposits within the Orientale multi-ring impact basin are investigated using 10 m resolution images obtained by Selenological and Engineering Explorer (SELENE, nicknamed Kaguya) spacecraft, in order to constrain the volcanic history of the Moon around the nearside-farside boundary. Precise crater-counting analyses reveal that mare deposits in the Orientale region are much younger than previously thought: ˜2.8 Ga mare basalt in the eastern part of Mare Orientale and ˜1.7-2.2 Ga mare deposits in Lacus Veris and Lacus Autumni, maria along the northeastern rings of the basin. These results indicate that the central and periph-eral regions of the Orientale basin experienced volcanic activities ˜1 and ˜1.8 billion years after the basin-formation impact, respectively. The dominance of uniform surface age across the mare deposits in the peripheral regions strongly suggests that these volcanic eruptions are contempo-rary with the elevated volcanic activity episode proposed for the Procellarum KREEP Terrane (PKT) region on the lunar nearside at around ˜2 Ga and that this activity peak is much more widespread than previously estimated.

Keywords: Orientale Basin, Mare volcanism

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Numerical thermal erosion model of lava flow coupling with evolution of ground slope

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Schroter's Valley is one of the largest sinuous rilles on the Moon, a meandering negative-relief feature. The Schroter's Valley is located on the Aristarchus Plateau (305 ˜ 313^{o}E, 22 ˜ 30^{o}N), which is supposed to be an uplifted mare terrain. The rille appears as a singular sinuous rille as meandering primary rille including a more meandering inner rille. Typical sinuous rilles are 20 to 40 km in length and less than 1 km in width (Schubert et al., 1970), however, the primary rille of Schroter's Valley has been reported to be 125 km in length, up to 4.5 km in width, and 400 m in depth (Gornitz, 1973), and inner rille which is originated from the cobra-head of primary rille is reported to be ˜170 km in length, 640 m of average width, and 95 m in depth (Garry et al., 2008).

The origin of sinuous rille is poorly understood. Previous researches have supposed that sinuous rilles are related to the basaltic lava flow. In past research, Honda and Fujimura (2005) developed numerical model of the sinuous rille formation of lunar lava flow. In this model, cooling rate of lava temperature as a function of distance from the lava source was calculated for estimation of thermal erosion velocity. The variation of chemistry of lava, physical properties such as density and viscosity during solidification of lava flow are incorporated in this model. They considered the effect of shifting from turbulent flow in initial phase to laminar flow in the last stage in their model. This model assumes that the ground slope maintain constant with time. However, the slope of floor of lava flow is changing with time, an erosion velocity of lava flow decreases along the downstream of lava flow following the lava temperature decreasing along the downstream.

In this study, we constructed the numerical thermal erosion model of lava flow coupling with evolution of ground slope. By using this numerical model, more large volume of lava flow is needed to originate the Schroter's Valley, because the slope of ground becomes shallower than initial one with time. If the maximum volume of eruptive volume on the Moon (Head et al., 2000) constrains the formation of Schroter's Valley, the eruptive temperature and thickness of lava flow which originate the rille are more than 1600 ^{o}C and 30 ˜ 40 m, respectively.

Keywords: Sinuous rille, thermal erosion, numerical simulation

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Detection and Visualization of the Absorption Features of the Reflectance Spectra on the Moon based on Data from Spectra

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The Spectral Profile (SP) onboard Kaguya/SELENE is a visible and near-infrared spectrometer covering wavelengths of 0.5-2.6 micrometer and observed the Moon globally.Generally, the reflectance spectra contain mineral information. We can detect the lunar minerals by analyzing the SP spectra.

Modified Gaussian Model (MGM) developed by Sunshine et al. [1990] is one the methods of such analyses. MGM resolves the reflectance spectra and quantifies the features of the absorption bands. By comparing the results of MGM (detected features of the absorption bands) with those of the known samples, we can identify the observed minerals.

However, the original MGM tool has two problems, which are; (i) The tool is difficult to be applied to a large amount of spectral data, and (ii) The comprehension of the results of MGM tends to be complicated.

We focused on these two problems. A new produce was added to refer and access to the meta data of SP data. We also developed a visualization tool which helps to comprehend the detected features of the absorption bands easily on the lunar image. RGB color was allocated corresponding to the value of absorption features, such as central wavelength and strength of the absorption bands, and displayed on the observed spots in the lunar image.

We succeeded in customizing MGM tool and applied it to bunches of SP data.The visualization of the deconvolved absorption features was successful, too. The set of the two tools would enable us to analyze SP data efficiently, detect the minerals, and clarify their distribution on the surface of the Moon.

In the presentation, we show some examples. The target areas are the lunar swirls. We exhibit the results of our analyses of SP data using the set of developed tools and try to understand the spectral characteristics of the areas.

Keywords: Spectral Profiler/Kaguya, visible-near infrared spectrum, Moon, feature of absorption band, Modified Gaussian Model, Visualization

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Composition and Crystallinity of Dark Mantle Deposits on the Moon

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The lunar mantle makes up 90% of the lunar volume. Therefore, it is important to determine the mantle composition in order to understand the lunar bulk composition including information about origin and evolution of the Moon. However, the composition of the lunar mantle remains unclear.

Pyroclastic beads are a direct clue to lunar mantle composition. These very low-albedo beads on the lunar surface are Fe-bearing volcanic glass or partially crystallized spheres. The color variation of volcanic glass corresponds to its composition, in the order of higher TiO2 content (e.g., orange glass, yellow glass, green glass). It is believed that if the erupted magma is quenched slowly, the magma of intermediate to high TiO2 content can be small crystallized ilmenite grains and generate black beads, instead of generating orange and yellow glass. Thus, the TiO2 content of the beads and the quenching speed of the erupted magma correlate with the colors and crystallinities of the pyroclastic beads. Chemical studies of pyroclastic beads acquired by Apollo missions indicate that the beads were formed from erupted magma from deeper (300 to 400km) in the mantle than basaltic magma. It is also assumed that the beads retain the original composition of the magma.

Dark Mantle Deposits (DMDs) are one of the darkest and smoothest areas on the Moon and are believed to contain pyroclastic beads, as were found in the Taurus-Littrow region near Apollo 17 site. However, detailed spectral analysis of the DMDs is lacking because of the limited wavelength coverage and spatial resolution of the previous remote-sensing data.

This study focused on DMDs on the Aristarchus Plateau and used spectral data obtained by the Multiband Imager (MI) on the SELenological and ENgineering Explorer (SELENE). We chose this region because DMDs on the Aristarchus Plateau are the largest regional DMDs and because volcanic activity has lasted longer there than in other areas up to the Eratosthenian in this region. Previous studies reported that the crystallinity of this region is the lowest of all DMDs and that its composition is orange glass, indicating high TiO2 content.

This study re-evaluates composition and crystallinity of this region in more detail, using data with wider spectral coverage. The MI is a high-resolution (20m x 20m per pixel) spectral imager with both visible and near-infrared coverages at spectral 9 bands. Using MI spectral data, we can distinguish minerals and glass from the absorption features after removing the continuum.

In order to select locations representing DMDs suitable for checking their compositions, we mapped the Aristarchus Plateau area using the reflectance data at 750nm and then selected locations where reflectance is lower than 5.5%. We also produced an MI color-composite mosaic based on differences in absorption features, in order to distinguish pyroclastic beads from the surrounding mare. We then estimated the TiO2 content of pyroclastic beads by comparing the wavelength of the absorption center in the MI data with that of the laboratory-measured data of Apollo pyroclastic beads from the RELAB database. By comparing the spectra of different mixing ratios of glass (orange, yellow) and black beads from Apollo samples as endmembers, we estimated the crystallinity (estimated content of black beads) of the DMD.

The derived wavelength of the absorption center of the DMD spectra was 1050nm, which is similar to that of yellow glass. Thus, the pyroclastic beads of the DMD are assumed to be yellow glass, which has inter-mediate TiO2 content. Our results suggest that the crystallinity of the pyroclastic beads was 20%, and 40 to 50% of this region comprised materials ejected by the Aristarchus crater.

The result of low crystallinity of the beads possibly shows that only small volatile materials were contained in the magma source in this region because magma with higher volatile content cools more slowly and is likely to have higher crystal content.

Keywords: Dark Mantle Deposit, pyroclastic beads, Aristarchus plateau, Moon, composition, crystallinity

PPS25-P18 Room:Convention Hall Time:May 23 17:15-18:30

Vertical trend of modal mineralogy and Mg# of the lunar highland crust estimated from Kaguya spectral data

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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 mafic mineral abundance and the Mg# distribution of the lunar highlands, which clearly indicates a dichotomic distribution, with a higher Mg# in the farside highlands than in the nearside [1]. A simple yet plausible model for interpreting the observation is dichotomic crustal growth from the magma ocean.

This study investigates the vertical trend of mafic mineral abundance and Mg# of the lunar highland crust using Kaguya spectral data. We utilize a new algorithm that derives Mg# from spectral reflectance data to develop a global map of mafic mineral abundance and Mg# at high spatial resolution [1]. From the generated global map, we checked 1) the correlation between the basin radius (excavation depth) and the averaged mafic abundances and Mg#s of the major highland basin ejecta (averages were derived for the region from one to two radii from the basin center), and 2) the correlation between distance from the basin center, and mafic abundances and Mg#s of the individual basin ejecta (ejecta deposited nearer the rim are assumed to be excavated from deeper within the crust).

The results indicate a vertical trend within the highland crust; the mafic mineral abundance decreases with depth while the Mg# increases with depth. These results are inconsistent with previous studies about trends of mafic mineral abundance [2][3] and with the simple crustal formation (Mg#) model explained by flotation of plagioclase crystal, suggesting a need for further study.

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Keywords: Moon, Kaguya, highland crust, Mg#, spectral data

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GEOLOGICAL STRUCTURE OF THE LUNAR SOUTH POLE-AITKEN BASIN BASED ON DATA DERIVED FROM SELENE MULTIBAND IMAGER

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The SPA is the biggest impact basin on the lunar far side. Previous studies have suggested that the mantle materials have been exposed. This excavation depth has estimated about 120 km. Crustal thickness of lunar farside is about 100 km, so most of the anorthosite composing the crust may have been excavated and ejected from the basin. However, the basin formation process and consequent mineralogy of this basin are still unclear because of the degradation after the supposedly ancient the SPA basin generated impact. For example, it is averaged of the lunar surface elevation by the rock collapse or space weathering. Therefore, crater scaling law in previous studies may not be applied to this basin, and it is possible that the impact melt size, transient cavity size and excavation depth of the SPA basin will not be estimated using crater scaling law in previous studies. On the other hands, previous observations are indicated that the crustal material remembered on the center of the SPA basin, and are apparently inconsistent with the theory of previous studies. And we study about the impact melt of the SPA basin to extrapolate the scale and the azimuth of the impact. In this study, we analyzed the distribution of the minerals and the topographic feature (such a peak ring) within the SPA basin, and compared these results. Finally, we supposed the geological structure, for example, impact melt pool size, transient cavity size and excavation depth, of this large impact crater.

We used the topographic data derived from SELENE LALT and the mineralogical data derived from MI. There are four rings investigated from previous data such as altimetry data of Clementine. However, they are not uncovered the full ring structure of the rings. We extended the previous identification by plotting the points with the same altitude. On the other hands, mineral phases have diagnostic absorption features depending on the minerals. Plagioclase, olivine and pyroxene have absorption bands at around 1250 nm, 1050 nm and 950 nm, rerespectively. These minerals are the three commonest minerals on the Moon. We identified these three minerals within the SPA basin using MI data. Especially, to select anorthosite (plagioclase>90%) spectra, we detected a peak shoulder at around 1250 nm.We made a color-composite image (RGB image) in which red, green and blue are assigned to a continuum removed absorption depth at 950nm,1050nm and 1250nm,respectively. We provided the geological structure of the SPA basin by comparing these topographic rings and the mineralogical distribution.

We identified four rings from the LALT data. The West- East example diameter of the second ring estimated 1,330 km. The fourth ring estimated 610 km. The topography inside the fourth ring is smooth compared to the outside areas. On the other hands, from the RGB map, we found out the lithofacies distribution. First, plagioclase located near the fringe region within the SPA basin. Second, on the middle area, where is red and yellow patches presented area, there are low and high-Ca pyroxene. And third, on the center of the basin, high-Ca pyroxene present. The mineral composition of this area is uniformity than other area.

The boundary derived from topographic data matched the presence of the anorthosite distribution derived from mineralogical data. This suggests that second ring corresponds to a transient cavity within which crustal material is excavated. On the other hand, it is possible that impact melt filled within only the fourth ring, because this ring is the innermost ring. If impact melt filled within the second ring or the third ring, it might not present peak ring inside these rings. And, the mineral composition within the fourth ring is uniformity than outside this ring. If the impact melt filled within this ring, the diameter of impact melt pool of the SPA basin is about 610km. This estimate is about the same diameter of calculation from previous studies.

Keywords: moon, South Pole-Aitken, basin, geological structure

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PPS25-P20 Room:Convention Hall Time:May 23 17:15-18:30

Lithological variations in the Nearside of the Moon

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Procellarum KREEP Terrane (PKT) that is characterized by high-Th concentration has been recognized to be one of important crustal constituents. However spatial distribution of the PKT materials has not been precisely understood since most of the PKT area is covered by maria. High-Th concentration area in the PKT shows complex irregular shape and apparently seen as main constituents of Imbrium basin rims. Therefore origin of the high-Th area in the PKT have been considered to result from Imbrium forming impact. However the highest Th concentration is observed in Fra Mauro area where includes the Apollo 14 landing site but not in the Imbrium basin rims and interior of the Imbrium basin though some high-Th spots in Imbrium basin are observed in some small craters (e.g., Aristillus). Mineralogical and petrological characteristics of some regions in the PKT are investigated to make sure distribution of the Th-rich PKT materials. In this presentation, variations of petrological characteristics in and around the PKT are compared and addressed issue on distribution of the PKT materials.

Keywords: The Moon, Crust, Magma ocean, Kaguya, Remote-sensing, Procellarum KREEP Terrane

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Evaluation 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 that were thrown out of a primary crater. Secondary craters give a biased spatial distribution of craters. Researchers extract craters excluding a surface that contains secondary craters from lunar image 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 images. The algorithm applies to ideal spatial distribution of craters and real spatial distribution of craters, and evaluates whether a non-random portion in real area by comparing a single-linkage hierarchical clustering parameter.

We demonstrated for two regions on Mare Crisium. As a result of visual inspection, one region contains a lot of clustered secondary craters, and another region contains few clustered secondary craters. The clustered secondary craters could be evaluated non-random spatial distribution of craters quantitatively by our clustering analysis.

Keywords: moon, secondary crater, spatial distribution, clustering analysis

PPS25-P22 Room:Convention Hall Time:May 23 17:15-18:30

Observation of surface locality on the Moon for production of lunar sodium exosphere with a 40cm telescope at Haleakala

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The Moon has a 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 and 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.

Similar surface bounded exosphere does exist on Mercury. Production of the exosphere on Mercury looks to be dependent on its surface locality, and it is explained by local difference of the surface geology (e.g. Sprague et al., 1998). In addition, Kagitani et al. (2010) suggested local dependence on the lunar surface for production of lunar sodium tail based on the observation from Kaguya spacecraft. There is a surface geological difference between Lunar mare and mountain. There is more Na in Lunar mare than mountain, on the other hand, Lunar mountain were formed by meteoroid impacts, so Na particles are easy to be released. From this, we think that Lunar exosphere has local dependence for production.

We made observation of local dependence on the lunar surface for production of lunar sodium exosphere at 2 locations, one is Long. 90 deg. W Lat. 20 deg. N (mountain) and another is Long. 90 deg. W Lat. 20 deg. S (mare). The observation was continuously made at the summit of Mt. Haleakala with our 40cm Schmidt-Cassegrain telescope and a high dispersion Echelle spectrograph in the period of July 17-25, 2011. Results and the plan of next observations will be presented at the meeting.

Sprague et al., 1998, Icarus, 135, 60-68, Mercury: sodium atmospheric enhancements, radar bright spots, and visible surface features.

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

Keywords: Moon, Exosphere, Geological dependence, Sodium

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Angular dependence of the solar wind protons scattered at the lunar surface

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Since the Moon does not have neither global intrinsic magnetic field nor thick atmosphere, it is well known that the solar wind directly impacts the lunar surface. The behavior of low energy electrons around the moon has been investigated by the satellite observations such as Apollo Project and Luna Prospector. Previously there was almost no observation of the low energy ions around the Moon, and the solar wind ions after impacting the lunar surface was not understood. When arguing about the interaction of the lunar surface and the solar wind ions, the behavior of the solar wind ions after impacting the lunar surface has been regarded to be absorbed by the lunar surface from the knowledge obtained by laboratory experiments.

MAP-PACE on Kaguya (SELENE) observed scattering of the solar wind ions at the lunar surface. MAP-PACE on Kaguya (SELENE) completed observation of the low energy charged particles around the Moon from low altitude (less than 100km) polar orbit. MAP-PACE consists of 4 sensors: two electron sensors (ESA-S1, ESA-S2) and two ion sensors (IMA, IEA). Since each sensor has a hemispherical field of view, two electron sensors and two ion sensors that are installed on the spacecraft panels opposite to each other can make full 3-dimensional measurements of low energy electrons and ions. Initial analysis found that the scattered ions were almost protons and 0.1%~1% of the solar wind protons were scattered at the lunar surface. Although the feature of the scattered ions at the satellite altitude became clear by initial analysis, understanding the scattering characteristics at the lunar surface, such as a scattering angle, was not clear.

In order to understand the scattering characteristics at the lunar surface, we have investigated the relation between the incidence angle of the solar wind to the lunar surface and the output angle of the scattered protons from the lunar surface using the high angle resolution mode data of MAP-PACE-IMA. We also investigated the relation between the output angle and the energy. As a result, we have found that the protons are scattered back to the direction opposite to the incidence vector of the solar wind for all the incidence angles and they are scattered back inside a scattering cone with 40 degrees around the center axis. The energy loss of the scattered proton is largest along the axis of the scattering cone and it is smaller at the edge of the cone. In addition, we have succeeded in explaining these characteristics by a scattering model that considers the microscopic surface of the lunar regolith.

Keywords: solar wind, lunar surface, scattering

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Broadband whistler-mode waves detected by Kaguya near the lunar crustal magnetic anomalies

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Broadband magnetic waves with frequency range of 0.03-10 Hz in the spacecraft frame were observed by Kaguya near the Moon [Nakagawa et al., 2011]. The waves were not propagating parallel to the ambient magnetic ?eld direction and had a compressional component. There was neither peak frequency nor preferred polarization. Nakagawa et al. [2011] identified them as whistler-mode waves because of their large group velocity compared with the solar wind velocity as well as the observed frequency range. Although the generation mechanisms of the waves were suggested to be associated with ions reflected by the Moon, precise process has not been clarified yet.

Recently we have revealed the statistical properties of narrowband whistler-mode waves near the Moon [Tsugawa et al., 2011]. There would be a link in the generation mechanism of narrowband and broadband whistler-mode waves. In the present study, we perform statistical analyses to reveal the properties of the broadband whistler-mode waves near the Moon. The results reveal that the waves are mostly observed just near the lunar crustal magnetic anomalies in dayside. It suggests that most of the waves are generated by the solar wind interaction with the magnetic anomalies. Furthermore, we investigate the velocity distributions and fluxes of reflected ions by the magnetic anomalies and lunar surface. We also discuss other possible generation mechanisms of the waves based on the measured plasma parameters around the Moon.

Keywords: magnetic anomaly, reflected ions, upstream whistler waves

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Estimates of lunar crustal magnetic field distributions using plasma sheet electrons

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Lunar crustal magnetic anomalies have been observed by surface magnetometers at the Apollo landing sites, magnetometers onboard orbiting satellites, or the electron reflection method with the use of the electron's magnetic mirror effect. The spatial scale length of the lunar magnetic anomaly ranges from less than a few km up to several hundred kilometers. However, the measurement of lunar magnetic anomalies by satellite-borne magnetometer is limited by orbital altitudes, and further, the electron reflection method underestimates the strength of surface magnetic fields with wavelengths smaller than the electron gyrodiameter. Therefore, it is difficult to perform a precise measurement of weak and small-scale magnetic anomalies from the orbiting satellite. On the other hand, surface magnetometers can measure actual magnetic fields on the lunar surface but the observations were made at only a few points so far. The small-wavelength component may provide important information on the origins of lunar magnetic anomalies, which have been debated for a long time.

In this study, we estimate the lunar crustal magnetic field distributions using electrons observed by Kaguya when the Moon was located in the terrestrial plasma sheet. Electron velocity distribution functions obtained at low altitudes (~10-30 km) sometimes indicate relatively high-energy electrons ($>$ 1 keV) thought to strike the lunar surface within one gyromotion from our reversed particle trace calculations, which suggests that these electrons were nonadiabatically scattered by local surface magnetic fields. If we assume that these surface magnetic fields have vertical scale lengths much smaller than Kaguya's orbital altitude, we can infer their surface distributions from the observed electron velocity distribution functions. Electrons will be scattered upward from the lunar surface depending on the strength of the parallel magnetic field component with respect to the lunar surface. Therefore, a minimum value of the product of the strength and the horizontal scale length of the horizontal magnetic field component can be derived from the electron's scattered velocity obtained by the particle trace calculation. Thus, it is possible to infer small structures of the surface magnetic fields by using the high-angular resolution data of electrons obtained by Kaguya.

Keywords: Moon, magnetic anomaly, plasma, Kaguya