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.

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

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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

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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.

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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

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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

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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

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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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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

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

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

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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

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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

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

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

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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