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PPS23-P01 Room:Convention Hall Time:May 25 18:15-19:30

Mare basalt volcanism within the giant impact structure of the Moon

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Toward an understanding of the evolution of the Earth and other terrestrial planets, it is important to study the thermal evolution of the Moon. Estimate of volumes and eruption ages of lava ponds is essential to construct the volcanic history of the Moon. Therefore, these estimates have been performed in the lunar maria, a lowland area covered with basalt.

The South Pole-Aitken (SPA) basin, located on southern lunar farside, is one of the oldest and largest impact structures in the solar system. The basin ranges ~13 km in depth, and its rim crest diameter is about 2500 km. Previous studies of numerical simulation for SPA-forming impact indicate that the large impact generated a melting zone ranging 500 km depth and changed the thermal condition of the underlying mantle.

In order to evaluate the effect of the SPA-forming impact on volcanic activity, we estimated the thickness and the volumes of lava ponds of Apollo, Leibnitz, Ingenii, located within the SPA, using high-resolution image data obtained by Kaguya. Volumes of these maria were estimated as 4440-7330 km3, 4880-12580 km3, and 5830-53570km3, slightly smaller than estimate of previous study. In comparing the volumes of lava ponds of northern lunar farside, there is no significant difference, suggesting that SPA-forming impact did not contribute to magma production.

Keywords: SPA, mare volcanism, Apollo, Leibnitz, Ingenii

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PPS23-P02 Room:Convention Hall Time:May 25 18:15-19:30

Global spatial distribution of the lunar craters characterized by the Voronoi tessellation

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A surface of bodies in the solar system has been exposed by numerous numbers of impact craterings. The impact craters are formed by the hypervelocity impact of meteorites or interplanetary bodies. The impact craterings basically occur at random on the planetary surface. However, the surface of the Moon, which has same rotation and revolution periods, is expected to indicate a bias of spatial distribution of craters even though the surface has a same formation age. According to theoretical analyses, cratering rate altered by this synchronized rotation effect indicates maximum at the apex of leading side and minimum at the trailing side (Zahnle et al., 2001; Le Feuvre and Wieczorek, 2011). On the other hand, this asymmetry of crater spatial distribution by synchronized rotation effect was assessed by Morota et al. (2005) and Werner and Medvedev (2010). Morota et al. (2005) showed that number density of rayed craters at the apex is the highest on the lunar surface. Werner and Medvedev (2010) showed that peak of high number density of rayed craters observed at the distance of about 60? from the apex where is at the leading side including the apex. Because the formation term of rayed craters is in the past from the present to 1 Ga, the synchronized rotation effect of impact cratering had been achieved in this term.

A purpose of this research is to assess the spatial distribution of the global lunar craters without distinction of rayed or not. The assessed craters contain older craters than that of rayed craters, so we could evaluate the synchronized rotation effect at the ancient time before the rayed crater formation. By using the Voronoi tessellation, the global spatial distribution of the lunar craters have the potential of differences by assessing several crater-sets. A result of this research might suggest that the synchronized rotation effect to the lunar craters was not identified in the term before rayed crater formation. In addition to this result, we confirmed the effect of secondary craters which were produced by the Orientale basin formation near the apex.

Keywords: lunar craters, spatial distribution, Vonoroi tessellation

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PPS23-P03 Room:Convention Hall Time:May 25 18:15-19:30

Three-dimensional lunar mare subsurface structures based on the SELENE radar soundering

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In order to discuss the history of the lunar volcanic activity, the lunar geological maps have been produced on the basis of the surface crater age [e.g., Hiesinger et al., 2000], surface composition [e.g., Lucey et al., 2000], and terrain morphology [e.g., Haruyama et al., 2008] of the lava flow units in the mare region [e.g., Hiesinger et al., 2000; Hackwill et al., 2006; Bugiolacchi and Guest, 2008]. These maps lack subsurface information, although the lunar mare subsurface structure was obtained from the radar soundering of the Apollo 17 mission in 1972 and the SELENE (KAGUYA) mission during 2007-2008. Subsurface information provides useful data for discussing the continuity and discontinuity of the geological strata. Thus, we will verify the lunar geological interpretation based on the lunar surface information.

The Lunar Radar Sounder (LRS) onboard the SELENE spacecraft carried out the global exploration of lunar mare subsurface structures by radiating the electromagnetic wave (4-6 MHz) and detecting the reflectors from the surface and subsurface boundary [Ono et al., 2009]. Compared to the LRS data with the preexisting geological maps, previous studies have been discussed the eruption flux of the lava flow [Oshigami et al., 2014] and geological condition (i.e., porosity and density) of the mare region [Ishiyama et al., 2013]. In order to merge the subsurface information into the geological map, we investigated the depth of the subsurface reflectors at the interval of 1 deg. in latitude and <~2 deg. in longitude and produced the three-dimensional database of the subsurface structures. In the presentation, we will show three-dimensional mare subsurface structures found in this study.

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PPS23-P04 Room:Convention Hall Time:May 25 18:15-19:30

An interpretation of formation process of the lunar highland crust using Th distribution map and crustal thickness data

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On the lunar highland area, correlation between spatial patterns of the surface Thorium abundance measured by SELENE gamma-ray spectrometer and the crustal thickness from GRAIL gravity field and LRO topography was investigated. Although several local minima areas exist in Thorium abundance map, each of these minima is not as significant as the others. On the other hand, in crustal thickness map, one of the areas has significantly large magnitude compared to others. To explain the discrepancy, we propose a two-stage process scenario of the crustal formation, i.e., formation of plural thin plateaux on the surface of the Moon, which correspond to the observed surface Thorium distribution, and following development to enlarge lunar dichotomic feature by downward growth of the plateaux. Our interpretation for the discrepancy is consistent with the previously proposed crustal formation scenarios that the dichotomy was developed during the crustal formation process.

Keywords: Thorium abundance, lunar crustal thickness, SELENE, GRAIL, lunar crustal formation

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PPS23-P05 Room:Convention Hall Time:May 25 18:15-19:30

Mineral distribution on lunar highland in the southwest sector of the Crisium basin with SELENE MI

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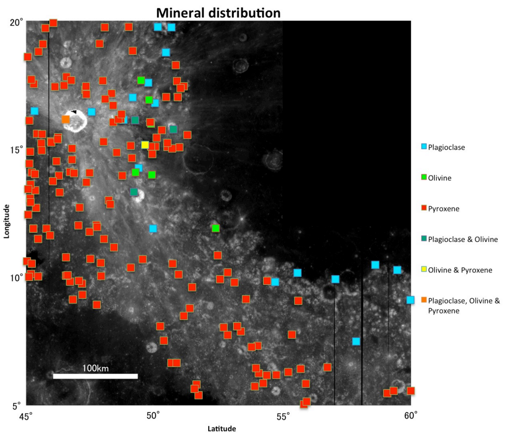
SELENE (Kaguya) Multiband Imager (MI) provides a global and homogeneous spatial coverage of multiband data set of the moon. Its spectral coverage ranges visible and near infrared wavelength including absorption features of major lunar highland minerals: plagioclase, olivine, and pyroxene. We perform an extensive survey of mineral outcrops with MI multiband data on lunar highland in the southwest sector of the Crisium basin. It is reported that outcrops of these major minerals are found in this region by sparse survey with SELENE (Kaguya) Spectral Profiler observation (Nakamura et al., 2012; Yamamoto et al., 2010, 2012, 2014). It is also expected that a large impact event forming the Crisium basin excavate vertical stratigraphy of lunar highland, and possibly mantle materials.

Possible mineral outcrops are identified at which deep absorptions are found in continuum-removed spectra of MI. Position of absorption centers of plagioclase, olivine, and pyroxene are 1250, 1050, and 950 nm, respectively. Most outcrops are associated to craters in the target regions. They are often found on the inner wall and the ejecta blanket of craters.

Plagioclase outcrops exhibit PAN (purest-anorthosite) like spectra with the clear 1250 nm absorption that was reported by Ohtake et al. (2009) and Yamamoto et al. (2012). Most of them are found at small craters with diameter of <1 km, whereas Ohtake et al. (2009) reported that PAN were found mainly on craters with diameter of >30 km. However, our researched region is placed adjacent or within the Crisium basin. As Yamamoto et al. (2012) suggested, PAN blocks could be excavated from deep region of the highland crust by the Crisium basin impact event. We also confirm an observation by Yamamoto et al. (2012) that olivine outcrops also associate with PAN exposures in this region.

Keywords: SELENE, MI, the Moon, Highland, Plagioclase, Mare Crisium



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PPS23-P06 Room:Convention Hall Time:May 25 18:15-19:30

Unsupervised Classification of the Moon's Surface Reflectance Spectra and Geological Significance (2)

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Clarifying of lunar geological map is essential in understanding the initial formation of lunar crust and the mixing process of lunar surface rocks due to igneous activities and meteorite impacts. However, the global geological map shown today has been published in the 1980s after the Apollo era, which does not include various new knowledge found in recent exploration. Therefore, we started a project to make a new global geological map of the Moon based on new data as topography, mineral and elemental composition acquired by Japanese lunar explorer "Kaguya".

A basic item for the project is a classification map of reflectance spectra obtained by Maltiband Imager (MI) and Spectral Profiler (SP) aboard Kaguya, which include information of rock and mineral kinds. However, since the data collected by MI and SP is very huge, data processing for whole moon is impossible to complete by working of only human's eyes and hands. And, the classification should be exclude researcher's subjective or philosophy as possible, especially in the first phase of analysis. Standing this point of view, we adopt ISODATA (Iterative Self-Organizing Data Analysis Technique) method as Unsupervised Classification (UC) with Independent Component Analysis (ICA) for classification of the reflectance spectra.

ICA is a powerful tool for analysis of multispectral or hyperspectral datasets to extract mutually independent components (ICs) from a set of mixed-random signals. This work is the first examination to apply ICA to the reflectance spectra from lunar surface, though ICA has been adopted to lunar gamma-ray spectra obtained gamma-ray spectrometer onboard Kaguya [10]. It was found that the global maps of extracted ICs clearly showed some mineral and/or rocks distributions as true signals, some characteristic patterns as noises due to mechanical and observational conditions and many random noises.

After ICA, the signal ICs are put in UC. This work employed ISODATA method as UC. ISODATA calculates class means evenly distributed in the data space then iteratively clusters the remaining pixels using minimum distance techniques. Users do not need to know the number of clusters and can define threshold values for parameters as minimum distance or minimum number of pixels for a class and so on. As a result, whole moon were divided into 50 -100 classes, though it was depended on the threshold values.

This report will shows the detail procedure for classification of lunar reflectance spectra and discusses validity and applicability of this procedure based on the results.

Keywords: Moon, Geological Classification, Reflectance, Independent Component Analysis, Unsupervised Classification, Kaguya

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PPS23-P07 Room:Convention Hall Time:May 25 18:15-19:30

Gravity anomaly uncorrelated with topography in the Moon and its origin

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Based on the gravity field model with the spherical harmonics up to degree and order 420 estimated from the observation data of the initial mission phase of GRAIL, Zuber et al. (2013) reported that, from order and degree of 80 to 300, 98% of the gravity disturbance potential of the Moon is caused by the topography and the remaining 2% of it is uncorrelated with the topography but is caused by subsurface high-density materials. Recent analysis of GRAIL data of the all mission phases provides the gravity field model with the spherical harmonics up to degree and order 900 (Lemoine et al. 2014; Konopliv et al., 2014). We can, therefore, expect to obtain detailed information of the interior of the Moon from this model. In this study, from the latest selenodetic data, we detect areas where gravity anomaly is uncorrelated with lunar topography, estimate the density structure of the crust beneath the areas, and infer its origin.

We use the topographic model of LRO_LTM01_PA_1080 with the spherical harmonics of degree and order 1080 (Neumann, 2013). Bouguer anomaly is calculated from the topographic data and the gravity potential data of GRGM900C (Lemoine et al., 2014) with the Bouguer correction density of 2560 kg/m3 and is expanded by the spherical harmonics of degree and order 600 based on the accuracy of the gravity data (Lemoine et al., 2014). We estimate the depth of the lunar Moho using a gravity inversion of Wieczorek and Phillips (1998) and subtract the Bouguer anomaly caused by the relief of the Moho from the original one. This Bouguer anomaly, hereafter referred to as the residual Bouguer anomaly, represents gravity anomaly caused by density anomalies in the crust. In the estimation of the Moho depth, we set the crustal density of 2750 kg/m3 and the mantle density of 3360 kg/m3 so that our estimation coincides with seismological estimations of the crustal thickness at Apollo 12/14 sites and the average crustal thickness reported by previous works. We detect 23 areas where the residual Bouguer anomaly is uncorrelated with the topography. For 14 areas where distinct positive anomaly is recognized, we estimate the shape and the position of a high-density body (a density contrast of 610 kg/m3) in the crust using the prism approximation of Banerjee and Gupta (1977). The other 9 areas are characterized by nearly zero residual Bouguer anomaly, suggesting that the relief of the Moho causes the gravity anomaly uncorrelated with the topography.

The estimations for all 14 areas show that the shape of the high-density body is sill-like and the body is located at the base of the crust, in other words adjacent to the Moho. Comparing the reflectivity map of the wavelength of 750 nm produced by the multi-band imager of the SELENE (Ohtake et al., 2008) to the location of the 14 areas, we reveal that the 14 areas are distributed in the lunar mare with low reflectivity. The 14 areas are distributed along ridges and/or rings of impact basins. These facts suggest that the high-density bodies are related to past igneous activity and the formation process of the ridges and impact basins.

From the above, we propose a following scenario. The formation of cracks in the crust accompanied with the formation of the ridges and impact basins promotes the magma intrusion into the crust. Insufficient pressure and buoyancy due to poor volatiles makes the magma intrude laterally like sill at the base of the crust near the Moho. We suggest that high-density bodies with long wavelength are modeled as the relief of the lunar Moho because the density of the bodies is considered to be comparable to the mantle density.

Acknowledgements: We use the topographic data released by the LOLA Data Archive (http://imbrium.mit.edu/LOLA.html) and the gravity data released by the NASA PDS Geoscience Node (http://pds-geosciences.wustl.edu/missions/grail/default.htm). We also use the SHTOOLS (http://shtools.ipgp.fr) for the calculations in this study.

Keywords: ridge, impact basin, gravity inversion, intrusion, magmatism

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PPS23-P08 Room:Convention Hall Time:May 25 18:15-19:30

The effect of thermal fatigue on the moon surface

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The surface condition of the Moon and asteroids reflects its geological evolution. In fact, the surface conditions are very different between celestial bodies. For example, the Moon is almost covered with fine regolith layer, on the other hand, boulders and regolith cover an asteroid Itokawa.

As usual, it has been thought that the collision of micro bodies was dominant as for the origin of regolith. However, recently, it is pointed the possibility that thermal fatigue is more dominant than collision on asteroids (Delbo et al., 2014). In this study, we investigate the size distribution of boulders around small craters at equator and high latitude, and discuss the effect of thermal fatigue on grain refining of boulders. In this study, we used the high-resolution images obtained by LRO.

The result shows that the size distributions of boulders around and in small craters differ with craters, reflecting the ages of small craters. Fresher craters have large boulders, and older craters have less large ones because boulders are destroyed with time. We will discuss the latitude dependence of the boulder destruction rate.

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PPS23-P09 Room:Convention Hall Time:May 25 18:15-19:30

Water trapped at lunar regolith

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We simulated the behavior of water in lunar regolith, and examined if water could be trapped for a long term. The situation for our simulation corresponds to the lunar surface shined by the Sun at noon, whereas the situation at permanently shaded areas is simulated by Schorghofer1 and Taylor (2007). Transportations of heat and water vapor could be expressed by similar-form equations, namely the diffusion equations. We observed condensation of ice at the deep part of the regolith, at latitudes higher than 84o. Our results indicate that water could be trapped at >10 cm depth layer of the lunar regolith. The trapped water could correspond to the ”hidden” water resource at lunar surface, which is not visible by remote-sensing observation.

Keywords: moon, regolith, water, simulation

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PPS23-P10 Room:Convention Hall Time:May 25 18:15-19:30

Features of 3D shapes of lunar regolith particles: comparison with Itokawa particles and experimental impact fragments

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To understand formation and evolution of regolith on airless bodies such as the moon and asteroids, 3D shape distributions of regolith particles have been measured and compared with those of experimental high-speed impact fragments. The 3D shapes of asteroid Itokawa particles recovered by the Hayabusa spacecraft were measured using X-ray microtomography [1], and it was proposed that the 3D shape distributions of Itokawa particles are undistinguishable from those of experimental impact fragments [2], but lunar particles from Descartes Highlands (Apollo 16 sample; 60501) [3] are more spherical than Itokawa particles. Lunar particles from Mare Tranquillitatis (Apollo 11 sample; 10084) are also more spherical than Itokawa particles [4]. However, as these returned samples were imaged grain by grain, the data collection was time-consuming, and thus the numbers of particles measured were limited up to about sixty. In addition, it is necessary to obtain more data efficiently for lunar samples, which may have variety. In this study, more lunar regolith samples were efficiently examined by tomography to understand 3D shape features of lunar regolith particles and compare those with Itokawa particles and experimental impact fragments.

In the present study, in addition to the Apollo samples (10084 and 60501), we used Luna samples; L1613-3 (Luna 16: Mare Fecunditatis), L2001-4 (Luna 20: Apollonius Highlands) and L24130.3-2,3,4 (Luna 24: Mare Crisium). The sample particles were attached on a toothpick with double-sided tape to take CT images at once by X-ray microtomography. Imaging experiments were made at BL20B2 of SPring-8 with the X-ray energies of 17.9, 18.1 or 20 keV and voxel size of 1.73 um. Particles were extracted by binarization. The isolated particles having more than 10,000 voxels, which are possible for significant 3D shape measurement [5], were analyzed. So far, we have examined 156 and 90 particles of 10084 and L2001-4, respectively.

The axial lengths of particles were measured by ovoid approximation (OA) and bounding box (BB) method [4]. In BB method, the axial lengths differ if the order of determination of the shortest, intermediate and longest lengths (S, I and L, respectively) is different. We adopted two methods, where S was determined first followed by I and L corresponding to the impact fragments of [6] and L was determined first followed by I and S corresponding to [2]. The axial ratios, I/L and S/I, were plotted as Zingg diagrams. These 3D shape distributions were compared with the previous data of lunar regolith particles [3,4], Itokawa particles [7] and experimental impact fragments [2,5,6] using Kolmogolov-Smilnov (K-S) test.

There is no significant difference between the particle shape distributions of the same sample with different imaging methods (grain by grain or many particles at once) at least for 10084. As far as the samples analyzed and the previous samples concerned, there are basically no significant differences of the shape distributions among lunar samples irrespective of mare and highland samples. In contrast, the lunar particles are more spherical than the Itokawa particles and the experimental impact fragments. Because residence time scale of particles in lunar regolith is long (the order of one billion years) [8], it is possible for lunar regolith particles to become spherical by abrasion due to gardening. We are planning to report the results of more samples in the presentation.

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Keywords: Apollo mission, Luna mission, Hayabusa mission, X-ray tomography, SPring-8

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PPS23-P11 Room:Convention Hall Time:May 25 18:15-19:30

Development of hollow type retroreflector for future LLR - thermal tolerance test of the optical contact surface -

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The contribution of Lunar Laser Ranging (LLR) since its installation in 1969 is quite significant, for example, to the construction of lunar ephemeris and celestial reference frame, gravitational physics, Earth-Moon dynamics, and lunar interior structure. However, one order or more accurate ranging data than present level (2cm as normal point) are needed to enhance our understanding on the lunar deep structure. We are developing "single aperture and hollow" retroreflector (Corner Cube Mirror; CCM) having no optical pass difference for future lunar landing missions. Last year we presented CCM made of mono crystalline silicon shows the best performance through thermal and optical simulations in the lunar thermal environment. As for the fabrication method of CCM, we investigate mainly "three-plane bonding" with the optical contact technique, by which three plane mirrors are optically contacted on side with each other. It is known the shear strength of optically contacted surface increases as the annealing temperature becomes high. Quantitative data on this hardening effect are crucial for design and fabrication of CCM. We, therefore, have conducted high temperature exposing experiment of the optically contacted test pieces of mono crystalline silicon in the air from 100 ℃ to 1000 ℃ and confirmed that the shear strength along the thermally processed surface at 1000 ℃ becomes 5 or 6 times higher than original strength and the degradation of surface accuracy and roughness can be ignored. The 20cm aperture CCM model is under fabrication now. Results of accurate measurements of the dihedral angles of the CCM model by ZYGO interferometer will be presented to quantify the effect of the thermal annealing.

Keywords: LLR, CCM, hollow, optical contact, thermal, strength

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PPS23-P12 Room:Convention Hall Time:May 25 18:15-19:30

SELENE-2/Lunar ElectroMagnetic Sounder (LEMS): a test of inversion (2)

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The so-called giant impact hypothesis is likely to explain the origin of the Moon in view of physical and chemical evidence such as angular momentum, materials possibly through magma ocean processes, and compositional similarity of the Earth and the Moon. Numerical simulations of such a giant impact indicate that most of the Moon-forming material around the proto-Earth originates from the projectile. This means that such a standard giant impact is difficult to form the Moon whose isotopic composition is essentially identical to the Earth's as found from the lunar samples in the Apollo mission. This would be a reason why new giant-impact models are devised. It should be noted that the lunar samples were obtained only from the lunar surface, and that information on bulk composition and interior structure of the Moon is still insufficient. Therefore it is of significance to obtain information regarding the whole lunar composition and interior structure, which can advance our understanding of lunar origin and evolution.

In the SELENE-2 mission, we propose a lunar electromagnetic sounder (LEMS) to estimate the electrical conductivity structure of the Moon. The electrical conductivity varies with temperature even for the same composition, and therefore it can be used to deduce the present thermal structure of the Moon.

Temporal variations in the magnetic field of lunar external origin, which can be observed by magnetometers onboard a lunar orbiter and a lunar lander, induce eddy currents in the lunar interior depending on the electrical conductivity distribution and frequencies of the temporal variations. The eddy currents, in turn, generate temporal variations in the magnetic field of lunar internal origin, which can be observed by a magnetometer onboard a lunar lander. Thus electromagnetic response of the Moon is obtained by magnetic field measurements. Then the electromagnetic response function is used to estimate the electrical conductivity structure by solving an inverse problem. We show results for some tests of inversion, assuming a one-dimensional interior structure for electrical conductivity distribution.

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