Structure of the South Pole-Aitken Basin from KAGUYA Selenodesy Data

By Sho SASAKI¹⁾, Yoshiaki ISHIHARA¹⁾, Sander GOOSSENS^{1,2)}, Hiroshi ARAKI¹⁾, Koji MATSUMOTO¹⁾, Hideo HANADA¹⁾,
and Makiko OHTAKE³⁾

¹⁾RISE Project, National Astronomical Observatory of Japan, Oshu, Japan

²⁾Goddard Space Flight Center/NASA, USA

³⁾The Institute of Space and Astronautical Science, JAXA, Sagami-hara, Japan

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The South Pole-Aitken basin (SPA) is the largest (2500km in diameter), deepest and presumably oldest impact basin in the solar system. SPA was characterized by an ellipse with axes 2400 by 2050 km, but more precise topography and gravity data are necessary to discuss the structure of large basin like SPA. We use localized representation of gravity potential where Slepian functions were used to estimate the gravity field over certain areas of the Moon and a spherical cap area with a radius of 40 degree from the SPA center. The direction of an ellipse denoting the depression is found to be similar to the previous result. The region with the thinnest crust is offset southward from the center of SPA. We analyzed interior structure of small basins in and around SPA. We interpret that a positive gravity anomaly corresponds to a Moho uplift. Just around the rim of SPA, a distinct Moho uplift beneath Schrödinger corresponds to the presence of olivine and obscure circular structure Amundsen-Ganswindt has a significant Moho uplift, suggesting a buried impact structure.

Key Words: Lunar Gravity, Crustal Thickness, South Pole Aitken Basin, Moho Uplift

1. Introduction

KAGUYA (SELENE) was launched on September 14th, 2007. From the end of October 2007, it started observation of the Moon from polar orbits and continued its operation by June 11th, 2009. KAGUYA had two subsatellites (OKINA and OUNA) for gravity measurements. Using 4-way Doppler tracking with relay satellite OKINA, KAGUYA obtained the first precise gravity field of the lunar farside¹⁾. Multi-frequency differential (VLBI) observation of OKINA and OUNA improved the accuracy of gravity. From one-year tracking data, lunar gravity field model SGM100h was obtained²⁾ and the model was refined into SGM100i taking into account VLBI data³⁾. KAGUYA has a laser altimeter (LALT) which measures the distance between the satellite and the lunar surface with accuracy of 1 m⁴⁾. The gravity and topography data have been processed mainly at National Astronomical Observatory of Japan.

Bouguer gravity anomaly, Moho depth, and crustal thickness are obtained⁵⁾, using crustal density 2800 kg/m³, mantle density 3360 kg/m³, and mare basalt density 3200 kg/m³. The crustal thickness was constrained assuming that the minimum thickness is not negative. The crustal thickness is nearly zero beneath Mare Moscovense⁵⁾, which would have been formed by twice excavations by impacts and resulting a stronger Moho uplift⁶⁾. In the present study, we investigate the structure of South Pole-Aitken on the lunar farside using the first precise global lunar gravity and topography data obtained by KAGUYA mission.

2. South Pole Aitken Basin

The South Pole-Aitken basin (hereafter SPA) is the largest (2500km in diameter), deepest and presumably oldest impact basin in the solar system. It has a degraded morphology and abundant superimposed craters. On the basis of topography, Fe and Th abundance data, Garrick-Bethell and Zuber (2009) (GZ09)⁷⁾ showed that the SPA is characterized by an ellipse with axes 2400 by 2050 km with the center at 53S - 191E. More precise topography data (including polar region) and gravity data (including farside) are necessary to decipher the structure of large farside basin like SPA.

From the topography and the crustal thickness by KAGUYA, we confirmed that the direction of an ellipse denoting the depression is similar to that of GZ09. The region with the thinnest crust is offset southward from the center of SPA. In Fig. 1, Moho depth at the central region of SPA is around 30km (25km in crustal thickness) and shallower to the southward. This may be explained by the oblique impact hypothesis advocated by GZ09.

Our crustal thickness is affected by the assumed anorthosite crustal density 2800 kg/m³. KAGUYA MI showed evidence of anorthosite in SPA⁸⁾. But spectral data of central peaks of craters inside SPA show ultramafic assemblage dominated by magnesium rich orthopyroxene, suggesting the presence impact melt sheet⁹⁾. This is compatible with previous remote-sensing data^{10,11)}. Then, higher crustal density would result in larger crustal thickness. The presence of lower crust in SPA was also discussed by previous gravity analysis¹²⁾.

3. Improvement of SPA Basin Gravity

We use localized representation of gravity potential according to the Han (2008)¹³⁾ where Slepian functions were applied to estimate the gravity field over certain areas of the Moon. Using localized functions, we express the gravitational potential with localized spherical harmonics functions. We include data in a spherical cap area with a radius of 40 degree from the SPA center¹⁴⁾. This area is fully covered by 4-way Doppler tracking of KAGUYA. We obtained gravity adjustment between plus and minus 68 mGal with an (RMS) of 17 mGal¹⁴⁾. The improved gravity field would supply better data of crustal thickness with slightly higher resolutions.

4. Small Basins Within and Around SPA

SPA has overprinted by small impact basins, some of which are accompanied by gravity anomaly. We analyzed interior structure of small basins in and around SPA (Fig. 2 and Table 1) using newly estimated localized gravity model¹⁴⁾. We interpret that a positive gravity anomaly observed at some basins corresponds to change of crust-mantle boundary, i. e., a Moho uplift (a mantle plug).

There is a distinct gravity anomaly beneath Apollo (Fig. 3). This corresponds to thin crust with a large mantle plug. Just around the rim of SPA, obscure circular structure Amundsen-Ganswindt has a apparent Moho uplift, suggesting a buried impact structure (Fig. 3). Amundsen-Ganswindt is considered older than Schrödinger (Table 1) and probably buried by ejecta of impacts forming Schrödinger and other neighboring basins. A distinct Moho uplift beneath Schrödinger corresponds to the presence of olivine at the central peak rings there¹⁵⁾. In comparison between adjacent Poincaré and Planck basins of similar size, older, less distinct Poincaré shows stronger positive gravity anomaly suggesting a stronger Moho uplift. The observed anomaly beneath these basins corresponds to Type 2 like anomaly¹⁾, where a significant uplift at basin center is probably due to overcompensation just after the impact. Probably thermo-mechanical properties of materials beneath Poincaré and Planck basins were different, or subsurface temperature under Planck was higher than that under Poincaré: later relaxation would have depressed or relaxed a Moho uplift beneath Planck.

Basin structures in the central SPA, on the other hand, show little gravity anomaly. Although it might be due to lower spatial resolution, there are several possibilities such as less density difference between crust and mantle and rapid relaxation of the uplift.

Fig. 1. Cross section of Moho depth of SPA.. Red curve and lines correspond to the long axis of ellipse by GZ09. Blue curve and lines correspond to the short axis by GZ09.

Fig. 2. Topography of the South Pole Aitken basin with overprinted impact basins which are investigated in this study.

Fig. 3. Moho depth map of SPA region, indicating basins with distinct Moho uplift. Red and blue lines correspond to cross sections in Fig.1.

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Table 1. Impact basins within and around SPA.

			Diameter[km]	Clarity	Mare	Moho Uplift	Crustal Thickness	Age (Wilhelms age)
Apollo	36.1S	151.8W	538	○	○	○	7	Pre-Nec(9)
Amundsen-Ganswindt	81S	120E	335	×	×	○	26	Pre-Nec(7)
Poincaré	56.7S	163.6E	319	○	○	○	13	Pre-Nec(4)
Ingenii	33.7S	163.5E	315-660	○	○	○	25	Pre-Nec(4)
Planck	57.9S	136.8E	314	○	×	○	33	Pre-Nec(7)
Schrödinger	75S	132.4E	312	○	○	○	22	Imbrian(12)
Sikorsky-Rittenhouse	68S	111E	310	×	×	×	48	Nectarian(11)
Bailly	66.5S	69.1W	300	○	×	△	47	Nectarian(11)
Schrödinger-Zeeman	81S	165W	250	×	×	△	28	12
Leibnitz	38.3S	179.2E	245	○	○	×	25	Pre-Nec
Oppenheimer	35.2S	166.3W	208	○	○	△	23	
Zeeman	75.2S	133.6W	190	○	×	△	31	
Von Kármán	44.8S	175.9E	180	○	○	×	21	Pre-Nec
Hausen	65.0S	88.1W	167	○	×	×	60	
Ashbrook	81.4S	112.5W	156	○	×	×	39	
Drygalski	79.3S	84.9W	149	○	×	×	45	
Antoniadi	69.7S	172W	143	○	○	×	25	Imbrian(12)