SEARCH FOR FARSIDE DEEP MOONQUAKES: SOURCE DETERMINATION OF UNLOCATED DEEP MOONQUAKES WITH APOLLO 17 LUNAR SURFACE GRAVIMETER. T. Kawamura[1,2,3] and N. Kobayashi[2], S. Tanaka[2], P. Lognonné[1], J. Gagnepain -Beyneix[1], [1]IPGP (4 avenue de Neptune, 94107 Saint-Maur-des-Fossés France, kawamura@ipgp.jussieu.fr), [2]ISAS/JAXA (3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan, kawamura@planeta.sci.isas.jaxa.jp), [3]The University of Tokyo (7-3-1 Hongo, Bunkyo-Ku, Tokyo 113-0033, Japan).

Introduction: The internal structure of the Moon is a key piece of information to understand its origin and evolution. Various attempts have been made to estimate the internal structure of the Moon and the seismic analyses with Apollo Passive Seismic Experiment (PSE) data is one of the most successful methods carried out. Though the seismic analyses enabled us to estimate some important geophysical parameters, such as the crustal thickness or the seismic velocity of the mantle, it could not fully resolve the inner structure of the Moon. Especially the deep structure of the Moon is still unknown because of the limitation of seismic observation of Apollo PSE. One way to probe the deep structure of the Moon is to search for the moonquakes whose sources are far from the seismic stations. In this study we search for new farside deep moonquakes by using the data from Apollo 17 Lunar Surface Gravimeter as seismic data.

Farside Deep Moonquakes: Deep moonquakes are most frequent seismic events observed on the Moon. Their sources are located at depths of about 800-1000 km and they are known to occur periodically at specific source regions according to the tidal force between the Moon, the Earth and the sun. Deep moonquakes are classified into some groups according to their source regions or "nests". Seismic signals from the same nests are known to have almost identical waveforms when they are observed at the same station. Thus, the cross-correlation technique was used for the classification of deep moonquakes and 166 nests are identified so far[1]. Deep moonquakes are divided into nests by calculating cross correlation coefficient and since high cross correlation of waveforms are the unique feature in deep moonquake signals from the same nest, some events are classified as deep moonquakes without determining its source region. Among 166 deep moonquakes, 106 are located and the rest remains unlocated since they did not provide sufficient number of arrival picks of seismic phases.

Of these deep moonquakes, those with source regions far from the seismic stations are needed to probe the deep inner structure of the Moon. Since all the Apollo seismic stations are on the lunar nearside, the deep moonquakes on the lunar farside will be important source of information for this. Among the previously located deep moonquakes, 8 of them are located on the farside[1]. The deepest rays from these deep moonquakes propagate regions as deep as 1000 km while the radius of the Moon is about 1737 km. That leaves 1/2 to 1/3 of the Moon's inner region unprobed. On the other hand, Nakamura (2005)[1] also points out that there may be more farside deep moonquakes among deep moonquakes unlocated with previous dataset. In our previous studies we showed that the Apollo 17 Lunar Surface Gravimeter (LSG) was functioning as a lunar seismometer and the data can be used for seismic analyses with other Apollo seismic data[2][3]. With this additional seismic data, we attempt to locate the previously unlocated deep moonquakes.

Methods and Results: We attempted to check all of 60 events that were identified as unlocatable in Nakamura (2005)[1] with the LSG. However, the LSG data is available only for period March 1, 1976 to September 30, 1977, and 20 of the 60 unlocated nests did not have seismic event during this period. These nests were excluded from the analyses. To enhance the signal to noise ratio of the seismic signal, waveform stacking is commonly used[4],[5],[6]. Thus for the nests with available events, the waveforms were cross-correlated within each nests and we constructed stacked waveforms. We searched for the seismic signal for 40 unlocated deep moonquakes with the LSG to add new information to the previous dataset. Among the events from 40 examined deep moonquake nests, 5 nests were detected by the LSG. The arrival time readings for these 5 deep moonquake nests were done by using the stacked waveforms. For 3 events we were able to identify the seismic signal but the signal to noise ratios were not enough to read arrival times from the data. This leaves 2 deep moonquake nests for source determination. We processed seismic data from all the Apollo seismic stations. Waveform stackings and arrival time readings were also carried out for these data and finally, we estimated the source by linearized least squares inversion. As the preliminary result, one of the sources, A284 was located on the farside[Fig. 1]. This newly identified source may be one of the furthest deep moonquake nests that were identified so far. However, since the signal to noise ratio of the data is poor, there are large errors in the arrival time readings and the result may still contain large uncertainties. For more detailed discussion, we need to enhance the signal to noise ratio in some way. We are expecting that the further optimization of filter used for the data reduction may enhance the signal to noise ratio. This may improve the number of seismic events that are detected by the LSG as well and improve the number of newly locatable deep moonquake nests accordingly.

Summary: We located the deep moonquake nests that were unlocatable from the previous Apollo seismic dataset by using the additional data of Apollo 17 Lunar Surface Gravimeter. We found that seismic events from 5 nests were detected with the LSG and 2 of the detected seismic signals were able to read arrival times from the data. We identified 2 new nests and one of them is likely on the lunar farside, which is one of the furthest regions that deep moonquakes were located before. We are confident that this additional seismic data of the LSG can be used as an efficient tool to locate the previously unlocated deep moonquakes nests as well as to examine more than 3000 seismic events that are still unclassified within the reported lunar seismic events. In addition, further optimization of the data reduction may enhance the signal to noise ratio of the data and may enable us to discuss the location of the source more in detail and extract more information of the lunar deep interior.

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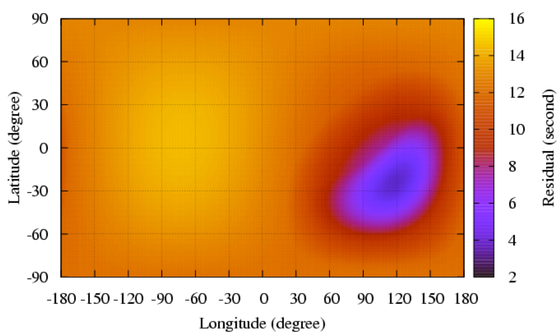

Fig. 1 The newly determined deep moonquake nest A284. The figure shows the global distribution of the residuals and the point with the least residual (the darkest region in the figure) is the most probable source. This is one of the most furthest regions from the Apollo seismic stations that deep moonquake was located.