Re-analysis of HFT data using the Apollo Lunar Surface Gravimeter data. T. Kawamura[1] ,Y. Saito[1], S. Tanaka[2], K. Horai[2], A. Hagermann[3], [1]The University of Tokyo(Hongo, Bunkyo-ku Tokyo 113-0033 e-mail: kawamura@planeta.sci.isas.jaxa.jp), [2]Institute of Space and Astronautical Science(Yoshinodai, Sagamihara, Kanagawa, 229-8510 e-mail: tanaka@planeta.sci.isas.jaxa. jp),[3]Open University(e-mail: a.hagermann@open.ac.uk)

Introduction: The Apollo Passive Seismic Experiment (PSE) was carried out on Apollo 12, 14, 15 and 16. Network observations of four seismic stations were performed for five years from 1972 to 1977. The PSE was a successful mission that informed us of the lunar crustal thickness and seismic velocity structure of the Moon from direct observations of the lunar interior (e.g. [1]). However, the paucity of seismic stations and the limited number of usable seismic events have been a major problem of lunar seismology. An additional observation point enables us to expand the network and the observable area will expand accordingly. Using a data set called the Work Tape, Kawamura et al. (2008) [2] showed that the Lunar Surface Gravimeter (LSG) on Apollo 17 functioned as a seismograph. With this additional seismic station, we tried the first seismic analysis using the LSG data.

Re-analysis of HFT data: For the first analysis, we redetermined the seismic source of the moonquakes called High Frequency Teleseismic (HFT). HFT are said to be a shallow moonquakes with hypocenters from 100km to 300km deep [3], [4] However, the depth of hypocenters obtained by past studies varies from 0km ~ 300km[3],[4],[5] and hence it is not clear whether HFTs are triggered by meteorite impacts or tectonic activities [3],[4]. By using the expanded network, we may distinguish the two possibilities. Also, since the HFTs are one of the most intensive seismic events, the accuracy achieved by its analysis can be viewed as an upper limit of the LSG data.

We used the data from the Work Tape, which covers the period from 1976 3/1 to 1977 9/30.There were three HFTs in the Work Tape and signals of all three HFTs were detected by the LSG. First, we determined the arrival times of the HFTs for each station. We reduced the noise by using a band-pass filter and moving average. Then we defined a threshold of seismic signals from the average and the variance of the signal before the arrival of the seismic signal. By defining the arrival time using the threshold, we were able to read the arrival time within an error of ±5 seconds for LSG data and ±2 seconds for other PSE data (Fig.1, Table1) for the HFT on 1976 3/6. However, arrival times of HFT on 1976 3/8 and 1976 5/14 contained an error bigger than 10 seconds. This is too large to compile with other seismic data whose errors are a few seconds or less. Therefore, further calculation was done only for the HFT on 1976 3/6. We calculated the travel time of the moonquake for each seismic station by using the seismic velocity model of Nakamura (1983) [1]. From the arrival time and travel time for each seismic station, the event time of the moonquake is calculated respectively. We used the variance of the events time as a criterion for defining the hypocenter. Assuming that each event time contains an error comparable to that of arrival time, the average of errors for arrival times was used as a threshold, which was 2.5 seconds for this HFT. The result of the calculation is shown on Fig 2. We can see that the variance decreases with the depth and become lower than 2.5 second around 100km. From this analysis it was found that the hypocenter was 100 km deep or shallower and was more likely to be near the surface. This result implies the possibility that HFTs are triggered by meteorite impacts at the lunar surface.

Conclusion: We are able to show that the LSG had been detecting lunar seismic signals accurately enough for seismic analyses with other PSE data. Since the HFT discussed above has the highest accuracy, other events are expected to have bigger errors. For HFTs, 10 to 20 seconds of errors are expected for the arrival time of P-waves. We may improve this error by using the stronger signal of S-Wave. Since deep moonquakes have weaker signals, the associated error may be as large as several tens of seconds and hence the seismic source will be determined within an error of a few hundreds of kilometers.

If we can improve the accuracy of determination of hypocenters for seismic events by expanding the observation range with LSG, a more precise discussion of moonquakes and the lunar interior will be possible. As the first report, this study showed a possibility that depth of hypocenter of an HFT is shallower than previously reported [3], [4], [5]. For future works, we are working on analyses using S-waves. New information of HFTs such as their origin may be obtained from further analyses.

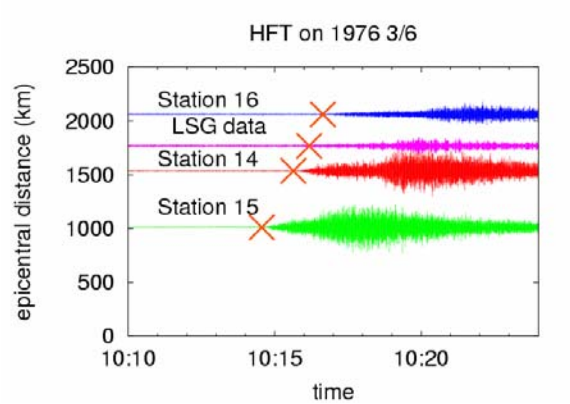

Fig.1: Time-distance curve of HFT on 1976 3/6. The x indicates the arrival time for each seismic station read in this study. The error for each arrival time is ±1 second for Station 15, ±2 seconds for Station 14 and 16, and ±5 seconds for LSG data.

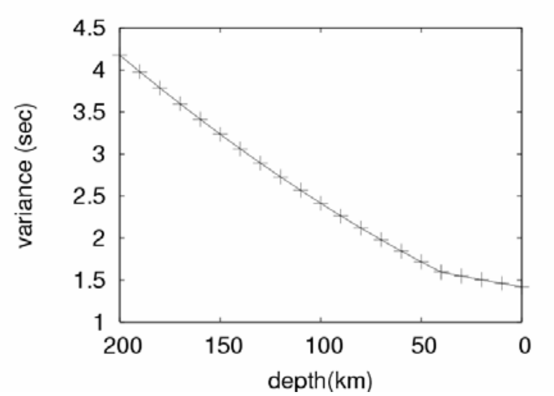

Fig.2: Reliability of hypocenter defined in this study according to hypocentral depth. The x axis indicate the depth of the hypocenter and y axis indicates the variance of event time obtained for each seismic station. The variance corresponds to the reliability of defined hypocenter, the lower the variances, the higher the reliability. The calculation was carried out for crustal thickness from 0km to 100km and the figure shows the result of crustal thickness of 40 km but the same feature was seen for every calculation. Epicenter was fixed to (42°,-17°) which was calculated in this study. From the error of arrival time, the variance should be lower than 2.5 seconds. The hypocenter of the HFT is shallower than 100km and more likely to be near the lunar surface.

date 1976		this study	Nakamura (1983)	Lognonnè et al. (2003)
3/6	14	10:15:38	10:15:55.6	10:15:53.2
	15	10:14:34	10:14:35.1	10:14:38.6
	16	10:16:38	10:16:41.5	10:16:42.6
	LSG	10:16:11		
3/8	14	14:43:16	14:43:21.8	
	15	14:45:19	14:45:18.3	
	16	14:43:58	14:44:05	
	LSG	14:48:05		
5/14	14			
	15	12:49:48		
	16	12:47:28		
	LSG	12:51:25		

Table1: Arrival time for all the HFTs in the Work Tape read in this study, Nakamura (1983) [1] and Lognonnè et al. (2003) [3]. Since the S/N ratio for the HFT on 3/8 was low, we could not distinguish the arrival time of P-wave from that of S-wave. The HFT event on 5/14 was not detected by the seismograph at Apollo 14 landing site. The LSG did detect some signal for the HFT event on 5/14 but it was difficult to identify the signal because of other unclassified signals.

References: [1] Nakamura, Y., (1983) Seismic Velocity Structure of the Lunar Mantle, *J. Geophy. Res.*, *88, 677 – 686*. [2] Kawamura T. et al., (2008) The Lunar Surface Gravimeter as a Lunar Seismograph, this issue. [5] Nakamura, Y. et al., (1974) High-frequency lunar teleseismic events, *Proc. Lunar Sci. Conf. 5th, 2883-2890*. [4] Nakamura, Y. et al., (1979) Shallow moonquakes: Depth, distribution and implications as to the present state of the lunar interior, *Proc. Lunar Planet.Sci, Conf. 10th, 2299-2309.* [5] Lognonnè et al., (2003), A new model of the Moon: implications for structure, thermal evolution and formation of the Moon, *Earth Planet. Sci. Lett. 211 27-44.*