論文内容の要旨

論文題目：

New Development of Lunar Seismology
from Re-analyses of Apollo Seismic Data

（アポロ月震データの再解析による月震学の新展開）

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The inner structure of the Moon provides us some important constraints on its bulk composition, thermal state and thermal history. To infer the origin and the evolution of the Moon, information on its inner structure is essential. Various methods were applied for its estimation and the observation of moonquakes was one of the most successful methods carried out. Observations of moonquakes were carried out in the Passive Seismic Experiment of Apollo missions. It carried out about 5 and half years of network observation with 4 seismic stations and succeeded in estimating some important geophysical parameter such as seismic velocity model of the Moon or the thickness of the crust. This gave us various implications on the lunar science and its contribution is remarkable. However, limited observation of the Apollo seismic network could not fully uncover the seismic features of the Moon and many important questions in the lunar seismology are yet to be solved. On the other hand, since the termination of the Apollo observation, no seismic observation was carried out on the Moon and the Apollo seismic data is still one of the most important sources of information of the lunar seismology. In this study, I will re-analyze the Apollo seismic data in new points of view to overcome some remaining questions of the lunar seismology.

In this study, I will discuss 3 topics.

First, I tried to extend the lunar seismic network by using the data of Apollo 17 Lunar Surface Gravimeter as seismic data. The limited number of seismic stations and the limited seismic network has been a major problem in the lunar seismology. All the seismic stations were on the lunar nearside and the observable area of the network could not fully cover the lunar surface. Thus, we are missing seismic sources on the lunar farside and this is one of the reasons that the deep inner structure of the Moon is poorly constrained seismically. Additional seismic data are desired for further investigation. To obtain additional seismic information, I focused on the data of the Lunar Surface Gravimeter and succeeded in extracting seismic information from the data. I evaluated the gravimeter data in a seismological point of view and used them in seismic analyses with other Apollo seismic data. With this additional data, I examined the unlocated deep moonquakes reported in the previous study. I succeeded in identifying 5 new deep moonquakes out of 60 unlocated deep moonquakes. One of the newly located deep moonquakes was located on the lunar farside. Only 8 farside deep moonquakes were reported so far and the new farside deep moonquake can pose a new constraint on the seismic feature of the Moon. In this study, I used this deep moonquake to evaluate the deep moonquake activity of the lunar farside. Weather the seismicity differ between the lunar nearside and the farside has been an important question in the lunar seismology and it is meaningful to pose a new constraints with newly identified sources. The size-frequency distribution of the deep moonquake on the nearside and the farside of the Moon implies that the deep moonquake activity on the farside is comparable or higher than that of the lunar nearside.

Second, I extended the effective frequency range of the observation to investigate the source parameters and the source mechanisms of the lunar seismic events through spectral analyses. Apollo seismic observations were carried out with Long Period (LP) and Short Period (SP) seismometers but previous studies used the data of the two seismometers independently. Thus, their analyses were limited to narrow frequency range of each seismometer. In this study, I combined the data of the two seismometers numerically and estimated continuous spectra that cover the both frequency ranges. The combined spectrum enables us spectral analyses with wider frequency range. From the estimated spectral feature, source parameters of lunar seismic events were estimated. Source parameters of seismic events are closely related to their source mechanisms.

Since the details of the source mechanisms of the lunar seismic events are still unclear, the quantitative estimations of the source parameters are meaningful. I estimated the corner frequencies and seismic moments of lunar seismic events from the spectra. The obtained corner frequencies showed wider range of values compared to previous studies and distributed between 1-10 Hz. On the other hand, the seismic moments were estimated to be smaller than the previous estimation. These results imply small stress drops of about 0.01 MPa, which is comparable with the previous estimations. For deep moonquakes, the stress drops were estimated to be 0.005~0.02 MPa. This is comparable with the stress variation caused by the tidal stress between the Moon, the Earth and the Sun. This result implies that the tidal stress is responsible of the occurrence of the deep moonquake.

Finally, I regarded the seismic data as a lunar bombardment record and attempted their new application. When we view the seismic data as an impact records, it is notable in 3 points. First, they provide 8 years of continuous observation of the lunar surface that does not suffer from the observation or lunar illumination condition like terrestrial observation of impact flashes. Second, they focus on relatively small events compared to those studied in crater countings or numerical simulations. Finally, they are bombardment records of current Earth-Moon system, unlike crater records, which are records of impact events within a geological time scale. Thus, it is meaningful to investigate the impact records left in the seismic data. In this study the spatial distribution of the impact events was examined. It is theoretically predicted that the cratering rate on the Moon is asymmetric because it is in the state of rotation-revolution synchronization. The cratering rate on the leading side of the Moon is predicted to exceed that of the trailing side. I examined whether such feature is detected with the seismically identified impact events. From the spatial distribution, I obtained leading/trailing asymmetry of 1.8 ± 0.4. I also evaluated the observation bias of the seismic network and concluded that the cratering rate of the leading side is significantly higher than that of the trailing side even if we consider the effect of the observation bias. The higher asymmetry I obtained may imply that the feature of the source of impactors for small, meter-sized crater that is examined in this study, differ from that for kilometer size craters studied in the previous studies.

In all 3 topics, I succeeded in obtaining new understandings of the lunar seismic activity by re-analyzing the Apollo seismic data. It is true that the various limitations of the seismic data make it difficult to investigate the lunar seismic feature more in depth. However, with special care and careful data processing, the seismic data can still be used as an important source of information.