Distributions of Seismic Moments of Deep Moonquakes and Estimation of Lunar Mantle Structure.

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Introduction: Through NASA Apollo mission, first and only lunar seismic network consisting of 4 seismic stations (Apollo 12, 14, 15 and 16 stations) was constructed on the Moon. The seismic observations by the network have revealed that the most active lunar seismic event occurred in lunar deep region at depth from about 700 km to 1200 km; that is deep moonquake (e.g., [1] and [2]). The deep moonquakes repeatedly occur from identical source depending on positions of the Moon, the Earth and the Sun; lunar tidal cycle (e.g., [3]). On the other hand, we don't successfully understand occurrence mechanism of the deep moonquake whether the tidal-induced stress itself generate the events or other tectonic stress are necessary in addition to the ambient tidal stresses [4]. In addition, Araki (2001) [5] describes that the occurrence mechanisms are different among deep moonquake sources.

Weber et al., (2009) [6] investigated the relationship between tidal stress computed from possible failure planes and deep moonquake occurrence to constrain the deep moonquake fault mechanism for different deep moonquake sources. In this study, we investigated the distributions of seismic moments of deep moonquakes occurred from some active deep sources based on 3 seismic station data. The seismic moment can be represented by stress drop and slipping area of fault in source region and related with the occurrence mechanism. The distribution of seismic moment for each deep source is useful to estimate differences of activities and mechanisms among the sources.

Method and Results: In past, a seismic moment was evaluated from a large deep moonquake in Goins et al., (1981) [7], however the deep moonquake of the same source have various amplitudes; suggesting variations of the seismic moments. For the reason, Yamada et al., (2013) [8] analyzed many deep moonquake events detected by the seismometer deployed on the Apollo 12 station, and then investigated distribution of seismic moments of about 600 deep events occurred from active 15 deep sources.

We derived the seismic moment from S-waveform amplitude of each deep event following the method described in [7] and [8]. The observed S-waveform amplitude is corrected for the response of the seismometer, characteristic of lunar interior structure where the seismic phase travels, geometrical spreading and radiation pattern at the source in frequency range, and then the value of seismic moment can be derived. In this calculation, we applied recent lunar interior model VPREMOON [9] and adopted constant value as the radiation pattern because we have little information about radiation patterns of moonquakes.

Figure 1 shows distributions of seismic moments of deep moonquakes obtained in Apollo 12 station [8]. This result indicates that the distributions of seismic moments are different among deep moonquake sources and the sources in far range have to generate the deep events with larger seismic moments compared with near sources. The result may show the fact that the occurrence mechanisms are different among the sources.

To ensure the result, we analyzed the deep events detected by the Apollo 15 and 16 seismometers by applying the same method. The distributions of seismic moments of deep moonquakes are derived from about 450 data for Apollo 15 station and about 500 data for Apollo 16 station. From comparison among the seismic moment distributions derived from Apollo 12, 15 and 16 stations data, we found that the values of seismic moments derived from different seismic station data are different even if the value is derived from same event. Especially, the values of seismic moments have larger differences among each station data for the sources far from the seismic network compared with near sources. The differences may be generated from difference of the radiation pattern and/or incorrectness of the lunar interior structure used to derive the seismic moment.

Discussion: As described above, the characteristic of the lunar interior structure have to be corrected from the amplitude of S-waveform to derive the seismic moment. We need information about S-wave velocity, density and seismic quality factor Q of the lunar crust and mantle. The value of Q means degree of attenuation of seismic energy and it mostly affects amplitude of the seismic waveform among the parameters. In the VPREMOON, values of Q are referred from [1] and [10], but the values still have uncertainty especially in the lunar deep mantle. We, therefore, changed the values of Q in the lunar mantle and estimated the seismic quality factor so as to explain differences of distributions of seismic moments obtained from 3 station data on the assumption of constant value of radiation pattern. This result shows that the seismic quality factor must have much larger values in lower mantle. In current interior model, the seismic amplitude may be attenuated too much.

On the other hand, we have to consider orientation of fault plane and difference of radiation pattern to explain the differences of the seismic moments. In this presentation, we will also show improved distribution of seismic moments of deep moonquake considering possible difference of radiation pattern and more appropriates values of Q in lunar mantle, and then the new estimated Q structure will also be discussed. The correct distribution of seismic moment on each deep moonquake source must be important to study occurrence mechanism of the deep moonquake.

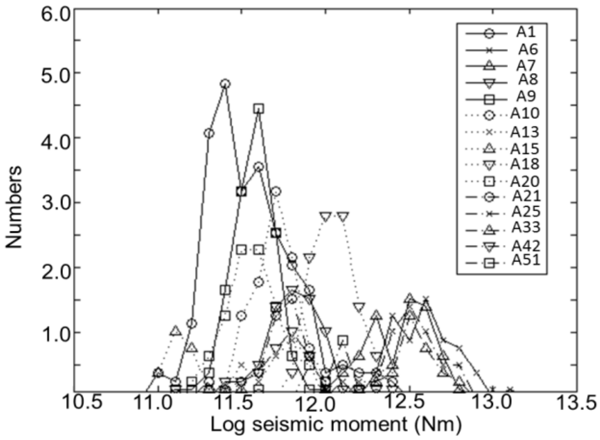

Fig.1. Distributions of seismic moments of deep moonquake events of each active 15 sources [8]. The number of event for each seismic moment is represented as number per year at intervals of 0.1 Nm in logarithimic expression. “A--“ means label of each deep moonquake source.

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