DESIGN OF AN OPTIMIZED SEISMIC NETWORK FOR FUTURE LUNAR MISSIONS. R. Yamada[1] , R. Garcia[1] , M. Calvet[1] and J. Gagnepain-Beyneix[2], [1]Université de Toulouse, Observatoire Midi Pyrénées, Laboratoire de Dynamique Terrestre et Planétaire (14 avenue Edouard Belin 31400 Toulouse France, ryamada@planeta.sci.isas.jaxa.jp) [2]Institut de Physique du Globe de Paris.

Introduction: In this presentation, we will describe how to design an optimized seismic network on the Moon and some results using the method. Recently, many space agencies are interested in constructing a new geophysical network on the lunar surface. For example, some new seismic experiments are planned in future lunar landing missions; International Lunar Network Anchor Nodes NASA mission and SELENE-2 JAXA mission and so on. The deployment of new seismic stations in these missions since Apollo lunar seismic experiment (e.g., [1]) will give us new information about lunar interior including the core size. We studied the optimization of the geometry of the lunar seismic network with a small numbers of seismic stations depending on the scientific objectives. This study will be help for selection of the landing sites in the future lunar seismic missions.

Scientific Objectives: We studied the geometry of the lunar seismic network so as to obtain the best gain for some scientific objectives. The primary science objective on current lunar geophysics is to reveal the lunar core size and its composition. We did not identify any core seismic phases in the Apollo recordings due to limited bandwidth of the instruments and the network configuration. The understanding of the core size and the composition will improve our knowledge of the initial materials which constitute the Moon and of the origin of the Earth-Moon system.

In addition, we are also interested in the structure of the lunar mantle which has not been fully revealed from Apollo data. The information about the depth of the velocity discontinuity in the mantle and its state (partial melting or not?) will improve our knowledge of lunar evolution and its thermal history.

Recent study using gravity data of Japanese Kaguya mission has identified clear gravity anomalies on some mascon basins [2]. Because the investigations of crust-mantle boundary in these mascon regions are significant, we also considered this scientific objective to design the optimized lunar seismic network.

Methods: We describe the methods to design the seismic network to satisfy above scientific objectives. First, we assume that first new seismic station is set to quantify the core size. Then, we have to design the position of first station so as to detect core-phases as much as possible. We assume that we can use the deep moonquake events from already identified nests through Apollo experiment, because it is known that the events occur repeatedly at identical sources depending on tides constraints [3]. If PKP phases which arrive as secondary wave from the located nests are detected at new seismic stations, P-PKP times can be used to evaluate the core-size and its composition. Therefore, we calculated the travel times of P, S and PKP phases from the 36 selected deep moonquake nests and the numbers of detection of the PKP phases as secondary wave at all positions with 2° by 2° grids on lunar surface using best lunar interior model [4].

On the other hand, because the lunar core size is unrevealed, we have to consider the numbers of detection of PKP phases at each position using various core sizes. We assumed that the core radius is restricted to be 200-450km range [5,6], and calculated the travel times and the numbers of detection at all positions with a step of 50 km of core radius. Then, using the numbers of detection of PKP phases as secondary wave at all steps, probabilities of the detection from more than a certain number of nests were derived on lunar surface.

Next, we designed the positions of second and third new seismic stations so as to improve the location of deep moonquake nests, locate new impact events at best and improve our knowledge of lunar mantle structure. Because these problems are resolved by linear inverse method using data from new seismic stations, we computed covariance matrix of a posteriori errors of the model parameters as function of the positions of new stations, and the optimized network geometry was chosen to minimize the error on the inverted parameters.

The posteriori covariance matrix C_m^P is calculated by following equation for problems of source locations assuming a perfectly known interior structure,

$$C_m^P = \left(G^T C_d^{-1} G\right)^{-1} C_m^{-1}$$

where, data kernel G consists of the calculated travel times differentiated with respect to the model parameter, C_d and C_m are diagonal matrixes containing a priori errors of arrival time reading and model parameters. These posteriori errors were calculated at all station positions with 2° by 2° grids on lunar surface, and a “cost function“ AJ was chosen as the average value of a posteriori errors scaled by a priori errors,

$$AJ = \frac{1}{N}\sum_{i=1}^{N}\left(C_m^P(i,i) \Big/ C_m(i,i) \right)$$

where, N is total number of model parameters. The best position to locate seismic sources is selected as a place where AJ is minimum.

Results: Figure 1 shows the probability of detection of PKP phases as secondary wave from more than 5 nests as example. We constrained the positions of new seismic stations on lunar nearside excluding the rims because of direct communication to the Earth. Then, the derived probabilities showed that the southern west area on lunar nearside is good region for detection of PKP phases coming from known deep moonquake nests. Therefore, we selected three candidates as the position of first station in this region. They are on the Mare Humorum (42W, 28S), the Grimaldi crater (68S, 6S), and the Schichard crater (54W, 46S).

Mare Humorum and Grimaldi crater have significant gravity anomalies and high probabilities of detection of PKP phases. These positions will be meaningful to satisfy our science objectives. Schichard crater is one of the places which have the highest probabilities on the lunar nearside excluding the rims. For these 3 candidates as the first station position, we selected the positions of second and third new stations.

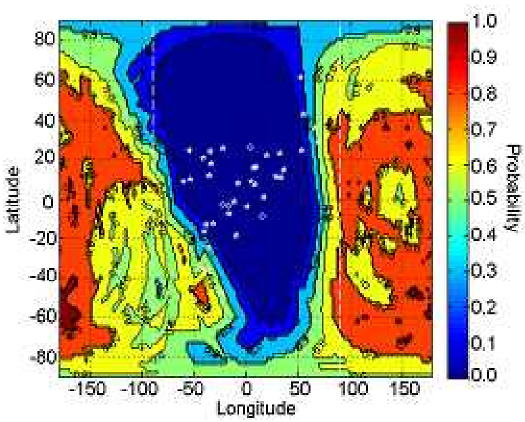

Fig.1 The probability of detection of the PKP phases which arrive as secondary waveform from more than 5 deep moonquake nests on 2° by 2° grids. The stars indicate the epicenters of the selected deep moonquake nests. The diamonds indicates the positions of Apollo seismic stations.

Figure 2 shows an example of the second and third station positions when we set the first station on Mare Humorum. This figure shows also shows logarithm of AJ calculated at each position for parameters of location of deep moonquake and new impact events.

The position of second station was set at the place of minimum AJ for locating parameters of deep moonquake nests. We can re-locate deep moonquake nests using the past Apollo seismic data and new seismic data. The third station was selected depending on first and second station positions, and was set on the position which indicated the minimum AJ for locating parameters of the deep and impact events.

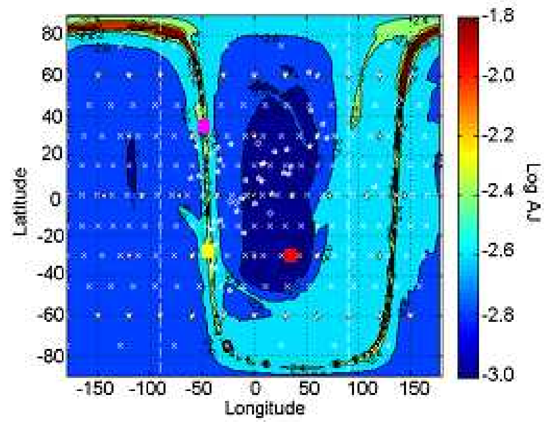

Fig.2 Logarithm of AJ calculated for the problem of locating deep and new impact events as function of the third station position. An example of optimized network using three stations is also shown (The yellow square indicates the position of first station, the purple and red squares indicate those of second and third stations). The cross marks indicates the assumed epicenters of new impact events used for the inversion (step of 15° along latitude on unevenly spaced grid).

We will also describe the optimized network to determine the lunar mantle structure with better resolution. The seismic velocities in the lunar mantle will be derived using underdetermined inversion problem. We expect that this study will suggest the useful indications for construction of geophysical networks in future lunar missions and the seismic network designed in this study will give us important information about origin and evolution of the Moon

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