sPg WAVES OBSERVED FOR THE 2012 BAYANBULAG EARTHQUAKE

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ABSTRACT

The sPg wave is one of the regional depth phases useful for focal depth determination in the Regional Depth Phase Modeling Technique. We investigated whether sPg phases were observed for events in Mongolia. We analyzed data from the Central Mongolia Seismic Experiment for the 2012 Bayanbulag earthquake to investigate whether sPg were observed. There are phases that arrived after Pg on the observed records. The arrival time differences in the distance range between these phases and Pg do not change much in the epicentral distance range from 55 km to 70 km, which suggests that the observed phases are sPg waves.

We calculated synthetic seismograms using the code of the reflectivity method using a model recently obtained for South-Central Mongolia and measured arrival time differences between sPg and Pg waves from them. Comparison of the arrival times from the synthetic and observed seismograms in the epicentral distance range from 55 km to 70 km suggests that the depth of the Bayanbulag earthquake is around 10 km. It indicates that this epicentral distance range (55 km to 70 km) is good to be used to determine focal depths using the sPg-Pg pair based on the synthetic waveforms.

Keywords: Focal depth, Regional depth phase, sPg, Bayanbulag earthquake, Synthetic waveform.

1. INTRODUCTION

Focal depth is one of the important parameters in earthquake monitoring and understanding seismicity in an area of interest. Well constrained focal depths can provide information for researches such as studies of seismogenic layers, seismic hazard assessments, etc. There are some previous studies about earthquake focal depths in Mongolia, especially for some significant events in active regions (Huang and Chen, 1986; Schlupp and Cisternas, 2007).

In routine analyses of the Mongolian National Data Center, the epicenters, origin times, and depths are determined for events that are recorded by seismic stations in Mongolia. Most of the events occur with magnitudes of less than 4.0 in and around the whole territory of Mongolia. In the routine processing, focal depths are determined to 2 km or 15 km for most of the events automatically, which suggests that they are not well constrained. For further detailed studies, it is desirable to improve the accuracy of focal depths. In this study, we investigate whether sPg phase, one of the regional depth phases which can be used to determine focal depths, is observed in Mongolia and the applicability of the Regional Depth Phase Modeling technique (RDPM; Ma et al., 2003; Ma and Atkinson, 2006; Ma, 2010). More else, the RDPM is applicable to small events. Ma and Atkinson (2006) and Ma (2010) analyzed events whose magnitude (m_N) is equal to or greater than 2.8.

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2. DATA

We used data from the Hangay dome subarray of the Central Mongolia seismic experiment (Meltzer et al.,2012). The Hangay dome subarray was deployed in the period from June 2012 to April 2014, and it consists of 72 stations (the blue triangles in Figure 1). It extended to approximately 500 x 600 km. The station code starts from "HD," which stands for "Hangay Dome." The observed seismograms were archived in the Incorporated Research Institutions for Seismology (IRIS) data management center (DMC). The network code is XL-2012-2016 (Meltzer et al.,2012). In this study, we mainly analyzed the 2012 Bayanbulag earthquake that occurred on October 3.

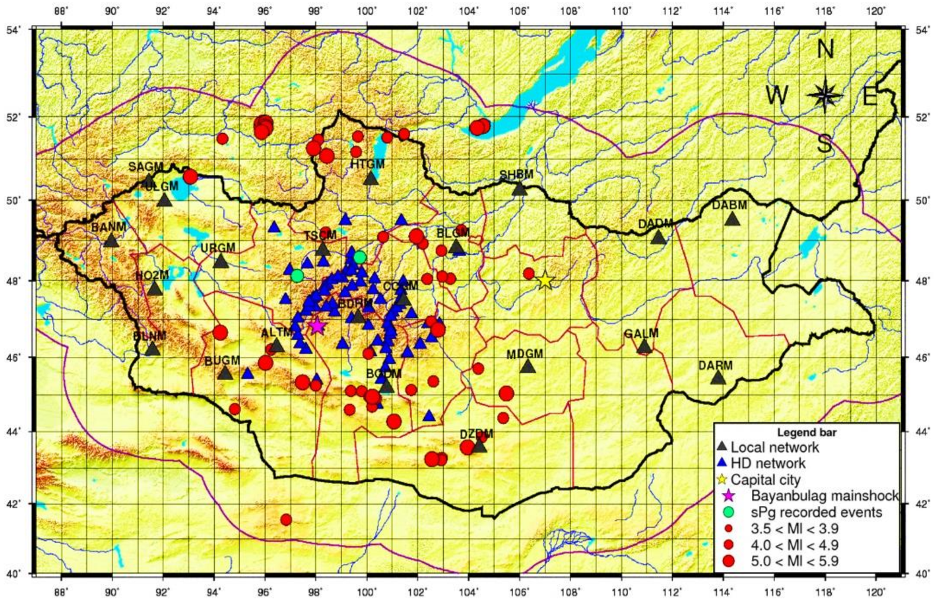

Figure 1. The station distribution of the HD (Hangay dome) subarray of the Central Mongolia Seismic Experiment (Meltzer et al., 2012).

3. THEORY AND METHODOLOGY

3.1. Regional depth phase modeling

The Regional Depth Phase Modeling (RDPM) method (Ma et al., 2003; Ma and Atkinson 2006, Ma 2010) is a technique to determine focal depths using arrival time differences between regional depth phases and their corresponding reference phases. Ma (2010) showed that their time differences are sensitive to focal depths, and their epicentral distance dependence is small. In our study, we investigate the observability of sPg and try to model it by calculation of synthetic seismograms.

The sPg phase is a seismic wave that propagates to the surface as the S wave, and then it travels and arrives at a station as a converted P wave. It arrives just after the arrival of Pg in the short epicentral distance range.

In this study, we investigate whether there are phases that arrive following the arrivals of Pg. As we show later, there exist such phases for some events. Then, we compute the theoretical seismograms with the reflectivity method to examine whether the measured time differences can be modeled for the selected event.

3.2. Reflectivity method

The reflectivity method is a technique to compute synthetic seismograms (Fuchs, 1968; Fuchs and Muller, 1971). Synthetic seismograms in the frequency domain are integrated over slowness, and then they are converted to synthetic seismograms in the time domain using the Fast Fourier Transform.

We used the program package ERSZOL3, which was developed by B.L.N. Kennett (1993). It is possible to compute the seismic response of a horizontally layered structure for a point moment tensor source.

We set the minimum slowness to 0.0001, maximum slowness to 0.3001, and the number of slowness to 3600, respectively. In this program package, a cosine taper in frequency applied between two specific frequencies. We chose 0.25 and 0.5 Hz for the low-frequency, 2, and 4 Hz for the high-frequency, respectively. For the surface condition, we chose the full calculation for half-space with elastic-free surface conditions.

4. OBSERVATION OF THE sPg WAVE

We show an example of observation of sPg waves for the event named the Bayanbulag earthquake on October 3, 2012. This event occurred along the South Hangay fault, with body wave magnitude mb 4.6. The epicenter is 46.8105°N and 98.0587°E by MNDC (Figure 2), and the focal depth is 10 km according to the USGS information.

To measure the time differences between these phases and Pg waves, we conduct deconvolution to obtain displacement records (the band pass is set to that between 0.5 and 2 Hz). The displacement records are shown in Figure 3, 4 and 5. Following Ma (2010), we took times for the maximum amplitudes caused by the peaks to reduce reading errors in picking the phase arrival times in these measurements. They are denoted by "T5" and "T6," respectively, in Figures 3, 4 and 5.

Currently, we found two more events that recorded possible sPg phases from the retrieved data. The one is the event which occurred on June 28, 2012 with magnitude mb =3.8; the epicenter is 48.1211 and 97.2674. The other is the event which occurred on May 03, 2013 with magnitude mb =3.5; the epicenter is 48.5846 and 99.7209.

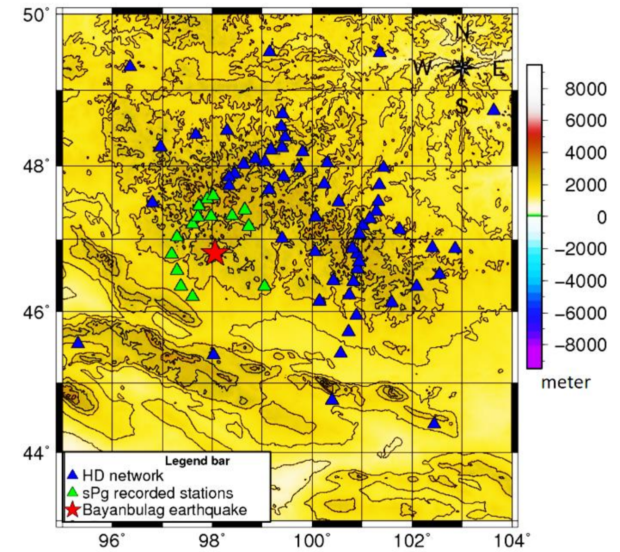

Figure 2. The epicenter (the red star) of the selected event with mb =4.6 occurred near the village of Bayanbulag in Bayankhongor province in Southern Mongolia on October 3, 2012 (latitude:46.812 longitude:98.058).

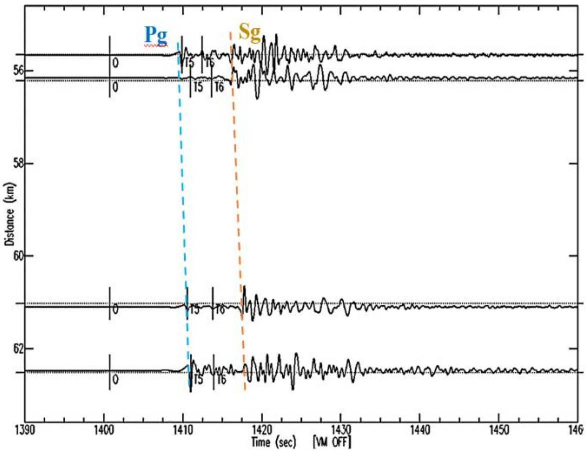

Figure 3. The displacement record section of the observed seismograms in the epicentral distance range from 50 km to 64 km. T5 denotes the time of the maximum amplitude of Pg. T6 denotes the time of the maximum amplitude of sPg. “o” denotes the origin time.

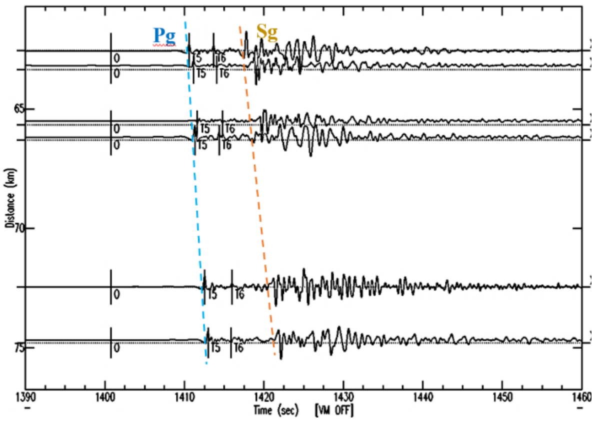

Figure 4. The displacement records section of the observed seismograms in the epicentral distance range from 64 km to 74 km. T5 denotes the time of the maximum amplitude of Pg. T6 denotes the time of the maximum amplitude of sPg. “o” denotes the origin time.

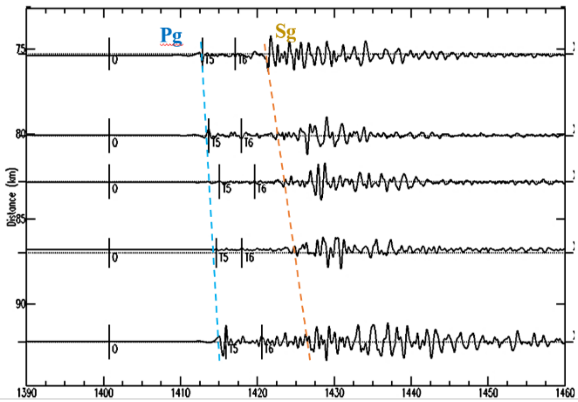

Figure 5. The displacement records section of the observed seismograms in the epicentral distance range from 76 km to 100 km. T5 denotes the time of the maximum amplitude of Pg. T6 denotes the time of the maximum amplitude of sPg. “o” denotes the origin time.

5. SYNTHETIC SEISMOGRAM CALCULATIONS AND COMPARISON OF ARRIVAL TIME DIFFERENCES

5.1. Crust model

We use a model based on that named "1D velocity model for South-Central Mongolia" (Batkhuu 2015, Progress Report of the 3D tomography research) for our calculation of synthetic seismograms, using the code of the reflectivity method and measured arrival time differences between sPg and Pg waves from them. This model can be used for the whole central and southern parts of Mongolian territory. In order to use this model for the ERZSOL program package, we have to calculate the value of the S velocities and densities for each layer, respectively. Figure 6 shows the P wave velocity model used for the calculation of synthetic seismograms based on his work. We computed densities using the empirical equation of Kurita (1973). For S wave velocities, we set the velocity ratio Vp/Vs=1.70, based on the analyses of Batkhuu (2015).

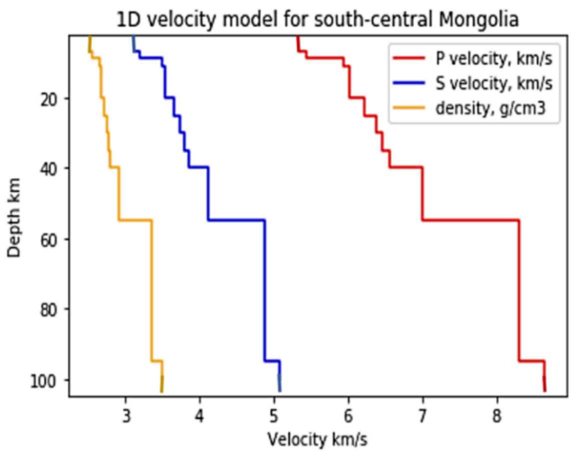

Figure 6. The red line denotes the P wave velocity (km/s) model used, which is based on the study done by Batkhuu.B. The yellow line indicates the calculated density (g/cm3). The blue line represents the calculated S velocity by km/s.

5.2. Synthetic seismograms computed by the reflectivity method

We used a double couple source based on the moment tensor solution of the 2012 Bayanbulag event in the Global Centroid Moment Tensor catalog. We set the source duration to 0.8 sec referring to Singh et al (2000). The time differences between the Pg wave and the phases which arrive following Pg in the synthetic seismograms do not change much with respect to the epicentral distance. Although they do change for a larger epicentral distance, as is shown later. This suggests they are sPg. We calculated synthetic seismograms in the epicentral distance range from 50 km to 100 km for focal depths of 5 km, 10 km, 15 km and 20 km, respectively. Figures 7 and 8 show the examples of the generated synthetic seismograms obtained from the above-mentioned calculation.

From the generated seismograms, we can see some important characteristics. For example: the synthetic traces show that the time differences between sPg and Pg become progressively larger, while they do not change much with respect to epicentral distance.

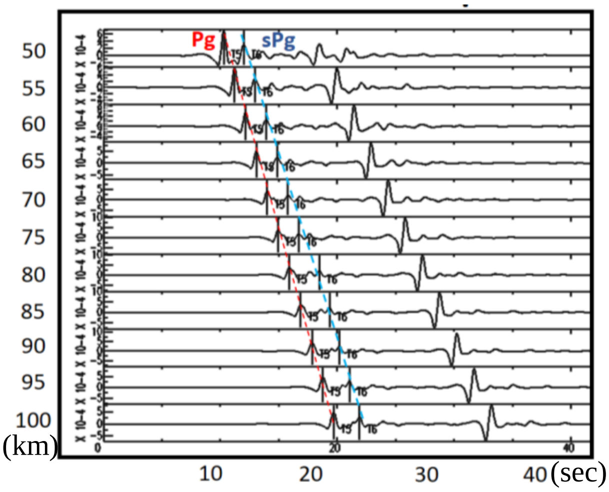

Figure 7. Synthetic seismograms generated for a focal depth of 5 km. T5 and T6 denote the times for the maximum amplitudes for Pg and sPg, respectively.

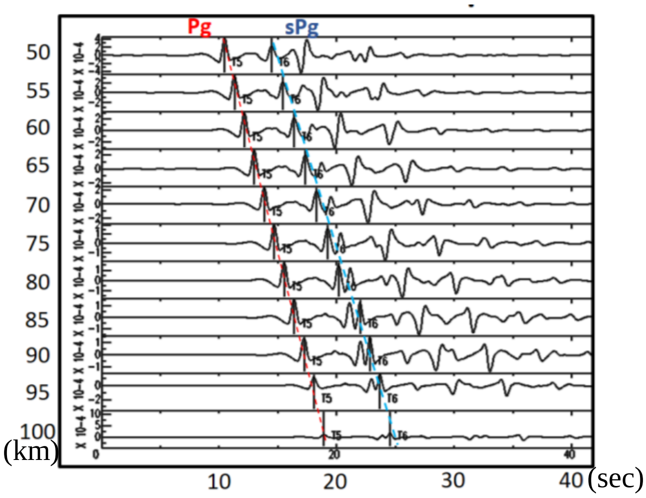

Figure 8. Synthetic seismograms generated for a focal depth of 15 km. T5 and T6 denote the times for the maximum amplitudes for Pg and sPg, respectively.

5.3. Preliminary focal depth determination

The observed time differences between sPg and Pg are almost constant in the epicentral distance range between 55 and 70 km. We used the data in the epicentral distance range between 55 and 70 km for preliminary focal depth determination in this study. Figure 9 shows the comparison of the arrival time differences between sPg and Pg based on the measurements from the synthetic and observed waveforms. The observed time differences are consistent with those for a focal depth of 10 km.

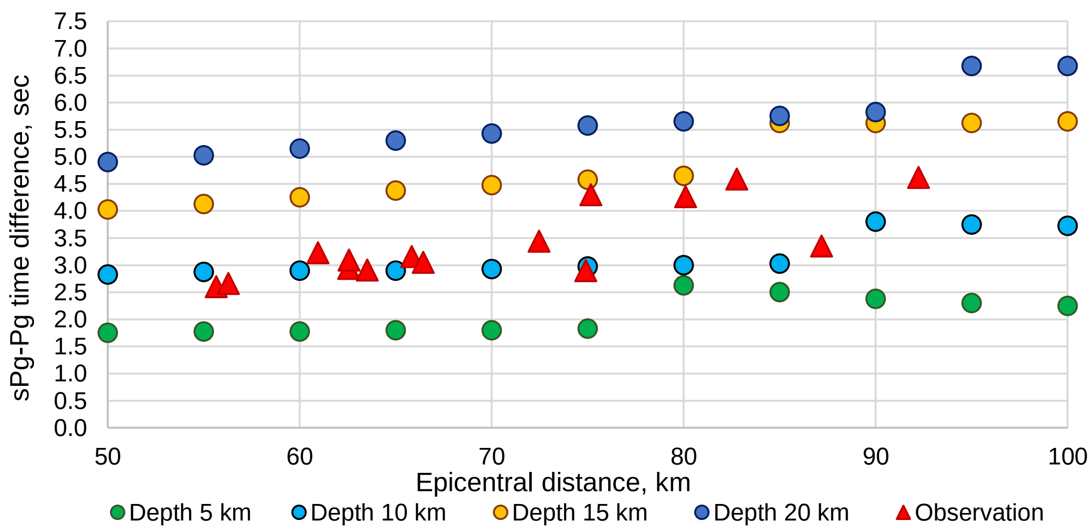

Figure 9. Comparison of the arrival time differences from the observed seismograms to those from the synthetic seismograms computed for depths of 5 km, 10 km, 15 km, and 20 km, respectively.

This indicates that the focal depth is around 10 km. This depth is close to 11 km determined by Meltzer et al (2019). The focal depth from the ISC catalog is 15.9 km which includes teleseismic depth phase pP; it is necessary to conduct further analyses for teleseismic data for this event.

6. CONCLUSION

In this study, we investigated whether sPg phases were observed in Mongolia and the applicability of the regional depth phase modeling technique. We have found that there are some events for which there are possible sPg phases on their observed seismograms. We analyzed one of events, the 2012 Bayanbulag earthquake mb=4.6 which occurred along the South Hangay fault. The arrival time differences between possible sPg waves and Pg waves are almost constant in the distance range from 55 km to 75 km and they are around 3 seconds. We calculated synthetic seismograms using the reflectivity method using a crust and upper mantle model which is recently obtained for the Central and Southern parts of Mongolia. We measured time differences between Pg and sPg waves from the synthetic seismograms. Based on comparison between the time differences from the synthetic seismograms and those from the observed records, it is suggested that the depth of the Bayanbulag earthquake is around 10 km. This result indicates that the epicentral distance range from 55 km to 70 km can be used to determine focal depths using the sPg-Pg pair.

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