Kỷ yếu Hội nghị: Nghiên cứu cơ bản trong “Khoa học Trái đất và Môi trường”
DOI: 10.15625/vap.2019.000117

DETERMINATION OF SEISMIC ATTENUATION BENEATH EAST SEA

Nguyen Le Minh[1], Satoru Tanaka[2], Yasushi Ishihara[2], Nguyen Tien Hung[1], Ha Vinh Long[1], Le Quang Khoi[1], Nguyen Van Duong[1]

[1]*Institute of Geology, Vietnam Academy of Science and Technology*

[2]*Cục Khoa học và Công nghệ Địa – Biển Nhật Bản*

ABSTRACT

We investigate the seismic attenuation in the mantle beneath the East Sea (ES) by using ScS_2 and ScS_3 phases that are recorded by broadband stations in Vietnam and the surrounding regions. Using 90 seismograms with high quality ScS_n phases obtained from 15 earthquakes and 38 stations and applying the spectral ratio method (ScS_3/ScS_2), we derive the average Q value for ES region, Q_{ES}, to be 191±63. The average Q_{ES} value is consistent with the previous results obtained in some back-arc regions such as Japan Sea and may suggest a similar termination age of spreading process. However, since the distribution of 90 ray paths can be roughly classified into two directions, northeast-southwest (NE-SW) and northwest-southeast (NW-SE), the average Q values of these two directions are derived to be $Q_{NE\text{-}SW} = 455 \pm 109$ and $Q_{NW\text{-}SE} = 133 \pm 50$, respectively. The significant high $Q_{NE\text{-}SW}$ implies low temperature beneath this region or an existence of very low-Q region along the ray paths of ScS_2. Based on very low Q values (~50) in the upper mantle beneath the subduction zones of Philippine and Indonesia that obtained by using $sScS_2/ScS_2$ and $sScS_3/ScS_3$, the significant low $Q_{NW\text{-}SE}$ can be affected by seismic attenuation in these regions.

Keywords: Seismic attenuation, Q value, attenuation structure, East Sea.

1. INTRODUCTION

Seismic attenuation had been available determined since the 1960s by using seismic records or laboratory measurements. It is a potentially valuable source that can provide the information of Earth’s properties such as temperature, partial melting and water content [1]. It also provides anelastic model that can be joined with elastic velocity model to improve constraints or understanding Earth’s structure. Regional Q values derived by the attenuation of body waves, ScS, ScS_2, ScS_3, generally called as multiple ScS phases (ScS_n, see Figure 1) has been studied by many authors. Recently, the number of broadband seismic stations in southeastern Asia is much increased. Therefore, it is a good time to acquire more data, and re-examine the seismic attenuation by using multiple ScS phases beneath the East Sea (ES) and surrounding region for the further understanding of the tectonics in southeastern Asia in terms of seismic attenuation structure. From approximately 100 earthquakes ($M_w > 5.5$, the region: 85° – 140°E and 15°S – 40°N. and the period: 2000–2009), we selected and used 90 seismograms with good quality of ScS_n phases obtained from 15 earthquakes and 38 stations (Figure 2). To avoid the effect of shallow structure, selected seismograms were filtered in the bandpass of 0.01–0.03 Hz.

2. SPECTRAL RATIO METHOD

In general, seismic wave can be expressed in a frequency domain as following [2]:

$$U_n(f) = G_n \cdot F_n \cdot S_n(f) \cdot R_n(f) \cdot T_n(f) \cdot I(f) \cdot A_n(f) \qquad (1)$$

where U_n is displacement of ScS_n, the subscript n is the number of the reflection at the core-mantle boundary, f is frequency, G_n is a geometrical spreading factor, F_n is a radiation pattern, S_n is a source spectrum, R_n is a crustal response, T_n is a structural response in the mantle, I_n is an instrumental response, A_n is an attenuation operator.

For a specific seismogram the ScS_n and ScS_{n+1} phase will have the same wave propagation medium. Therefore, base on the equation (1), we can assume that $F_{n+1} \sim F_n$, $S_{n+1} \sim S_n$, $I_{n+1} \sim I_n$, $R_{n+1} \sim R_n$, $T_{n+1} \sim T_n$. So that, when we take the spectral ratio between U_{n+1} and U_n, it becomes as following:

$$U_{n+1}/U_n \sim G_{n+1}\cdot A_{n+1}(f)/G_n\cdot A_n(f) \qquad (2)$$

If we assume $A_{n+1}(f)/A_n(f)$ as a exponense function of f and Δt^*, where □t^* is the difference of t^*_{n+1} and t^*_n, t^* is an attenuation parameter.

$$t_n^* = \int \frac{ds}{v\cdot q} = \frac{T_n}{Q_n} \qquad (3).$$

where the parameters v and q are the seismic velocity and Q values along a ray path, T_n *and* Q_n are an integrated travel time and averaged Q value along the ray path of the ScS_n phase.

From the equation (3), the equation (2) becomes:

$$U_{n+1}/U_n \sim G_{n+1}/G_n\cdot \exp(-\pi f\Delta t^*) \qquad (4)$$

When we take natural logarithm from both sides of (4), because G_n/G_{n+1} is constant, the equation (4) becomes:

$$\ln(U_{n+1}/U_n) \sim C + (-\pi f\Delta t^*) \qquad (5)$$

As in the many previous studies, in the concerned frequency band (0.01Hz – 0.06Hz), Q value is assumed to be a constant with respect to frequency [3,4,5]. Therefore, from the equation (3), Δt^* can be rewritten as:

$$\Delta t^* = t^*_{n+1} - t^*_n = (T_{n+1} - T_n)/Q_n \qquad (6),$$

Using equations (5) and (6), we can calculate Q_{ScS} value for each station – event pair from the measured Δt^*.

3. RESULTS AND DISCUSSION

3.1. Results

We applied the spectral ratio method to the 90 pairs of ScS_3/ScS_2. After unifying all the data rather than individual measurements, we got the average $\boldsymbol{Q_{SCS}}$, Q value below ES region, of 191±63 (Figure 3). From the distribution of 90 ray paths (Figure 2), it is easily to realize two perpendicular directions of ray paths, NE-SW and NE-SW, which mainly contribute to the measurement of Q_{SCS}. By combining all the spectral ratios of ScS_3/ScS_2 in NE-SW direction, we obtained the average $Q_{NE\text{-}SW}$ value and $\Delta t^*_{NE\text{-}SW}$ in NE – SW direction are 455±109 and 2.01±0.99 s, respectively. Applying the same procedure into NW-SE direction, we obtained the average $Q_{NW\text{-}SE}$ value and $\Delta t^*_{NW\text{-}SE}$ in NW – SE direction are 133±50 and 6.9±2.58 s, respectively.

To determine the Q_{UM} for upper mantle beneath the subduction zones of Philippine and Indonesia, we can use deep earthquakes (deeper than 500 km) and apply the same spectral ratio method described above tosScS_1 - ScS_1, sScS_2 – ScS_2, or sScS_3 – ScS_3 pairs. Finally, we picked up 20 seismograms from three deep earthquakes. The hypocenters of these three earthquakes and individual Q_{UM} values measured for each event are shown in Table 1. The sScS_3/ScS_3 and sScS_2/ScS_2 pairs were used to calculate Q_{UM} of each event. The individual measurements of the Q_{UM} value were obtained to be 48, 44, and 14 and the average value calculated from fisrt two events is 64 (Figure 4).

3.2. Discussion

The estimated average Q_{SCS} (Q_{SCS} = 191±61) is consistent with the previous result of Q = 181 ± 30 for the region obtained by the pairs of the events occurred in Sumba, Philippines and station of CHTO that overlaps our study region [6]. It is also close to Q values in Japan Sea that are Q ~ 290 [7], Q ~ 160-170 [4], Q ~ 211 [7].

The estimation of $Q_{NE\text{-}SW}$ of 455±109, however, shows a significant higher than the average one. We suppose that it could be an indication of very low temperature in the center of ES. However, it can be also speculated as anisotropy of a Q value or an existence of very low-Q at some reflection points at the surface or core-mantle boundary along the path of ScS_2 in this direction. This implication should be further clarified in future studies.

Regarding another direction, we can realize that $Q_{NW\text{-}SE}$ of 133±50 is significantly lower than $Q_{NE\text{-}SW}$. We suppose the significant lower value of $Q_{NW\text{-}SE}$ could be effected by upper mantle part beneath the subduction zones of Philippines and Indonesia and adjacent area where bounce point of ScS_3 phase located. The three low Q_{UM} values of 48, 44, and 14 suggest that the upper mantle beneath the subduction zones of Philippines and Indonesia and adjacent area is a high attenuation area and it strongly reduces the $Q_{NW\text{-}SE}$ value as we observed.

4. CONCLUSIONS

In this study, we have derived an average Q value in the mantle beneath East Sea (ES) and those for two perpendicular propagation directions. The whole average Q = 191±63 is consistent with the previous result from [6] and similar to other back arc regions.

The significant high and untypical $Q_{NE\text{-}SW}$ of 455±109 in NE-SW direction that first obtained in this study, can be interpreted as an indication of very low temperature beneath center of ES or an existence of very low-Q at some reflection points at the surface or core-mantle boundary along the path of ScS_2 in this direction.

On the other hand, the lower $Q_{NW\text{-}SE}$ value of 133±50 in NW-SE direction can be explained by the strong influence of the attenuation in the upper mantle beneath active subduction regions in Philippines. This hypothesis has been verified by the very low Q_{UM} values (~50) which were obtained by using some $sScS_2/ScS_2$ and $sScS_3/ScS_3$ pairs of three deep earthquakes beneath this region. The very low Q_{UM} values suggest that the upper mantle beneath the subduction zones of Philippines and Indonesia and adjacent area is a high attenuation area or associated with incipient melting in an area of back arc upwelling [6].

REFERENCES

[1]. Romanowicz, B., Mitchell, B.J., (2007). Deep earth structure: Q of the Earth from crust to core, in: Romanowicz, B., Dziewonski, A. M. (Eds.), Treatise on Geophysics, Elsevier, vol.1, pp. 731-774.

[2]. Lay, T., Wallace, T.C., (1988). Multiple ScS attenuation and travel times beneath western North America, Bull. Seism. Soc. Am., 78, 2041-2061.

[3]. Jordan, T.H., Sipkin, S.A., (1977). Estimation of the attenuation operator for multiple ScS waves (Paper I), Geophys. Res. Letters 4, 167-170.

[4]. Nakanishi I., (1979). Attenuation of multiple ScS waves beneath the Japanese arc, *Phys. Earth Planet. Inter.*, 19, 337–347.

[5]. Chan W.W. and Der, Z.A., (1988). Attenuation of multiple ScS in various parts of the world, *Geophys. J.*, 92, 303-314.

[6]. Revenaugh, J., Jordan, T. H, (1991). Mantle layering from ScS reverberations: 1. Waveform inversion of zeroth-order reverberations, J. Geophys. Res., 96, 19,749-19,762, doi:10.1029/91JB01659.

[7]. Yoshida, M., Tsujiura M., (1975). Spectrum and attenuation of multiply reflected core phases, *J. Phys. Earth*, 23, 31–42.

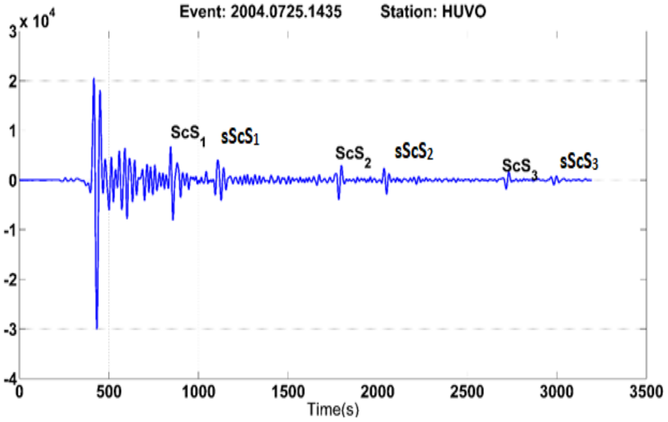

Figure 1: An example of a seismogram at HUVO station with high quality ScS_n phases from the earthquake M = 7.3, 25/7/2004 in Southern Sumatra, Indonesia.

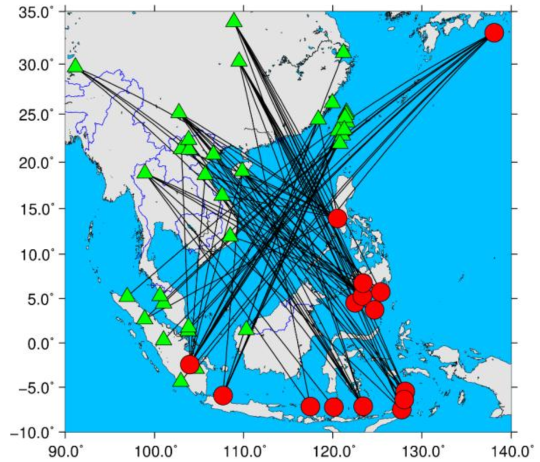

Figure 2: Map of 15 earthquakes, 38 stations and their ray path used to measure attenuation value in this study.

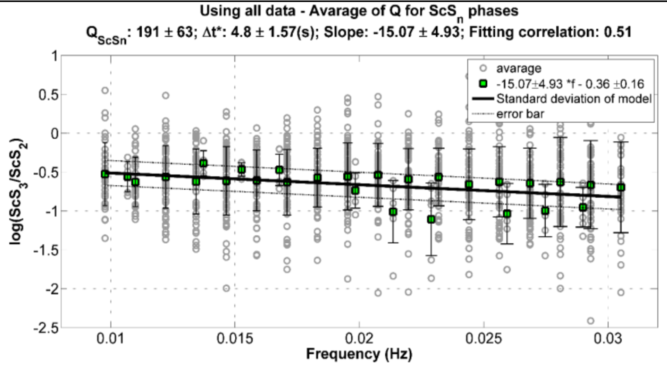

Figure 3: The estimation of linear fitting for spectral ratio of ScS_3/ScS_2 by unifying all the 90 event-station pairs.

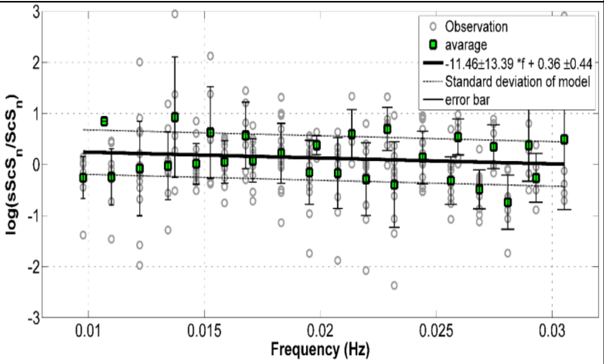

Figure 4: The linear fitting of spectra ratio $sScS_n$ and ScS_n phases by combining all seismogram of the events 1 and 2 in the Table 1

Table 1. Hypocenter information of the events used to measure Q for upper mantle part beneath subduction zones of Philippine and Indonesia and adjacent area.

No	Date	Time (UTC)	Lat.	Lon.	Mw	Depth	Individual Q_{UM}
1	01/07/2003	05:52:25	122.511	4.529	6.0	635.4	48
2	05/02/2005	12:23:18	123.337	5.293	7.1	525.0	44
3	28/08/2009	01:51:20	123.427	-7.146	6.9	642.4	14