The Detection of the Low Velocity Body using Seismic Waves

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ABSTRACT

The low velocity body was detected during the investigation of the crustal structure and upper mantle in the Korean I'eninsula using ray method and observational seismic data. We observed the arrival time delays of I' and S waves that pass through the Bugok hot spring area and the Chugaryong rift zone in the Korean Peninsula. The present geothermal exploration accounts for the high heat flow in these regions, suggesting that the area are the ' delay shadows' produced by a deep, low velocity body(Resenberg el al., 1980). We tried to verify the hypothesis that the low-velocity body is caused by the partial melting in the lower crust can be explained by the lateral variation(inhomogeneous model) of the lower crust using Hay Method.

INI'RODUC'I'ION

Several seismologists and geophysicists tried to use the seismological method to the geothermal exploration(e.g. Bodvarsson, 1970; Jackson et al., 1982; Ehara, 1989; Pujol and Aster, 1990). In order to apply seismology to geothermal exploration. there are two ways. One is the study of micro-seismicity of the region that accounts for micro-cracks due to the abrupt change of the thermal gradient under the interior of the earth(Bodvarson, 1970; Ehara, 1989). The other is to study the arrival time delays of P and S waves and large velocity ratio(α/β) that pass through a certain region and can be explained by a low velocity body in the lower crust of its region.

The low velocity anomalies were detected during the investigation of the crustal modelling of the Korean I'eninsula using seismic data and ray method. 'The amval time delays of 1 second or greater are observed at the travel path through the Bugok hot spring area from Mt. Kyeryong earthquake, Feb. 12, 1994 and at the travel path through the Chugaryong rift zone from W. Pyongyang earthquake, Nov. 12, 1992, Anak earthquake, Nov. 13, 1993, and N. Soonchan earthquake for Dec. 8, 1993 of North Korea.

In spite of a good method of seismology to geothermal exploration, we always face the difficulties of data acquisition that can be attributed to the inhomogeneous seismic station distribution and lack of data exchange of North and South Koreas.

For the sake of qualitative interpretation of data, we especilly selected representative earthquakes such as Mt. Kyeryong W. Pyongyang. Anak, and Soonchon earthquakes determined by KMA(Korea Meteorological Administration).

The large teleseismic delays exceeding 1 second or greater are found near Mount Hunnah in the Clear volcanic field and in the stream-production at the Geyser(Iyer at al., 1979). A magma chamber under the surface volcanic rocks and highly fracture stream reservoir probably underlain by partially molten rock at the Geyser are responsible for the observed delays. Robinson et al., 1981, however, could not find a low velocity body in the study of the crust under the hydrothermal area of the Taupo volcanic zone, New Zealand, indicating that intrusion into the crust from depper level occur only in a quite limited area in this region.

DATA ANALYSIS AND INTERPRETATION

We tried to use Kay Method(Kim and Lee, 1994) using observational seismological data of the Korean earthquakes in order to find the low velocity zones of the seismic waves in the Moho discontinuity. We took P_n and P_mP phases into account for the theoretical as well as for the observational models using Ray Method. We have found that there are large travel time delays of P and S waves which propagate through the Chugaryong rift zone and the Bugok thermal area of the southern part of the Korean Peninsula. This provides a means of ascertaining the low velocity ratio of I' and S waves (α/β) compared to the normal case of 1.752. The first amval amplitudes of S waves are also found to be weak in the seismograms of interesting earthquakes that pass through the anomalous zones.

We detected the low velocity body during the investigation of the crustal structure and tomography of the Moho discontinuity in the Korean Peninsula(Kim and Lee, 1994). Four earthquakes which can detect the low velocity body are presented in Table 1. We used W. Pyongyang earthquake of Nov. 13, 1992 and N. Soonchon of earthquake Dec. 8, 1993 in North Korea and Mt. Kyeryong earthquake of Feb. 12, 1994. Fig. 1 shows the ray paths of four earthquakes that pass through the Rugok hot spring area and the Chugaryong rift zone. As shown of the map on Fig. 1 the ray paths of the North Korean earthquakes such as N. Soonchon, W. Pyongyang and Anak earthquakes pass through the Chugaryong rift zone that streches from Wonsan to Seoul.

The best estimation of the travel-time curves for the Korean Peninsula is given in Fig. 2, indicating that the crustal structure of the Korean Peninsula consists of three layers, which have 2.85 km/s, 5.75 km/s, and 6.80 km/s for 1'-wave velocities and 1.45 km/s, 3.38 km/s, and 3.97 km/s for S-wave velocities respectably. P- and S-wave velocities for Moho discontinuity are found to be a = 7.94 km/s and β = 4.65 km/s. The velocity of 2.85 km/s and the very shallow subsurface layer are adapted from explosion

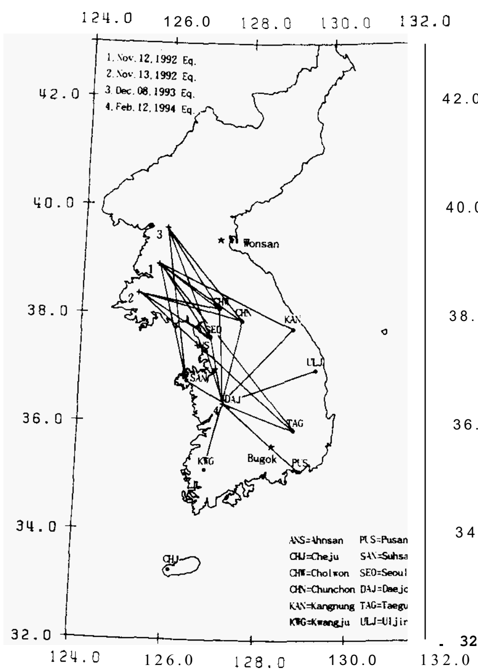


Fig. 1 Station locations(black dot) and epicenter(numbers) for this *study*.

data and subjected to change depending on the region. From Fig. 3, the travel time delays of P and S waves are found at the stations whose ray paths pass through Chugaryong rift zone and Bugok hot spring region. Our findings of largely positive residuals of P and S waves at Cholwon, Chunchon, and Pusan stations suggest that the velocity of Moho

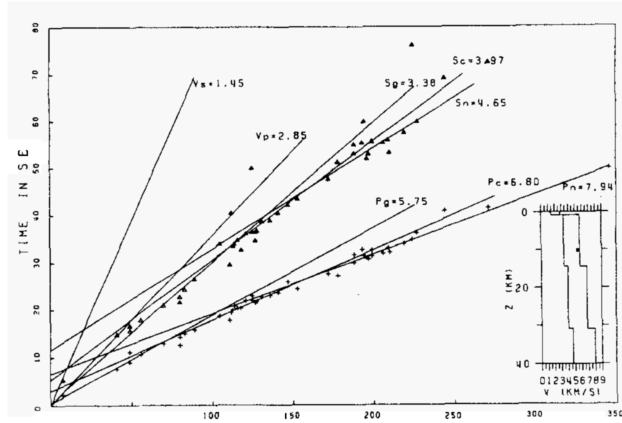


Fig. 2 The travel-time curves in the Korean Peninsula.

discontinuity could not be constant if its depth variation is not relatively large. It is also observed that the Anak earthquake gives rise to large residuals at Daegu station. The velocity ratio of P and S waves (α/β) is in the range from 1.76 to 1.84 for these stations. In Fig. 4, the relative low amplitudes of S waves presented here for the low-velocity path stations offer an additional means of investigating the low-velocity body. Figs. 5a and 5b represent the lateral variation(inhomogeneity model) of the Moho discontinuity andor the vertical variation(homogeneity model) of the Moho discontinuity for the Mt. Keyryong earthquake. Fig. 6a and 6b account for the same phenomena for the W. Pyongyang earthquake. The low velocity anomalies to the path of the Pusan station account for the low vwlocity body through the Bugok hot spring field(see Figs. 5a and 5b). The low velocity anomalies are also found at the Chunchon, Cholwon. and Kangnung stations for the W. Pyongyang earthquake that passes through the Cugaryong rift zone. We can see strong reflected waves(P_mP) from mantle, while weak refracted waves(P_n) from mantle beyond 200 km of the epicentral distance, suggesting that the Moho discontinuity exists 30 km deep(see Figs. 6a and 6b)

RESULTS

1)The crustal structure of the Korean Peninsula is found to be as follows.

a and β are P- and S-waves velocities(km/s)

Depth (km)	a	β
0.0–0.8	*a* = 2.85	β = 1.45
0.8–14.4	*a* = 5.75	β = 3.38
14.4–30.9	*a* = 6.80	β = 3.97
30.9–	*a* = 7.94	β = 4.65

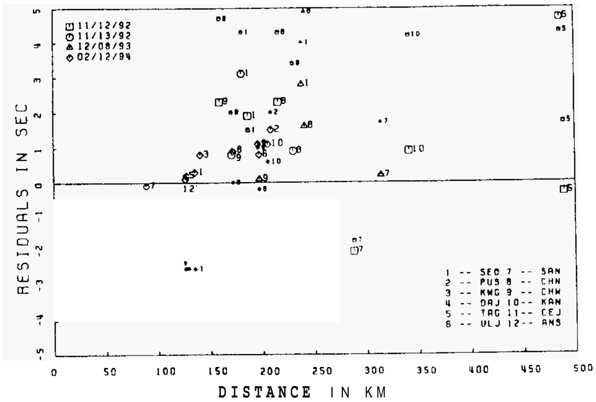


Fig. 3 The arrival time residuals of P and S waves for this study. Large and small symbols indicate P- and S-wave residuals respectably

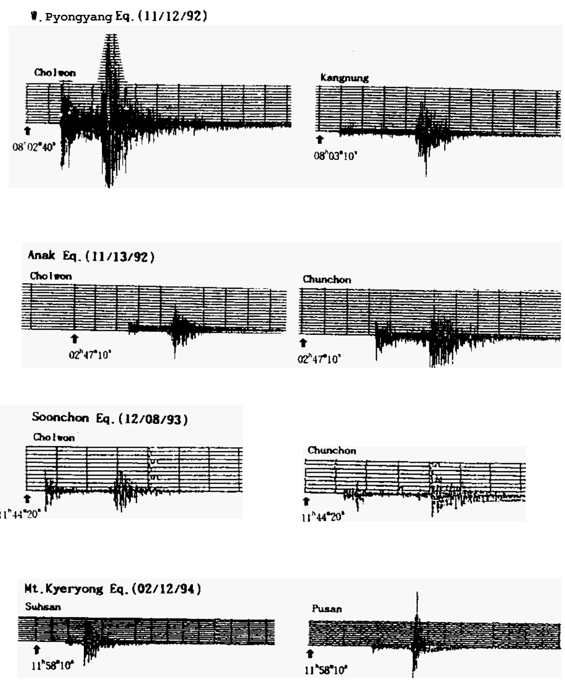
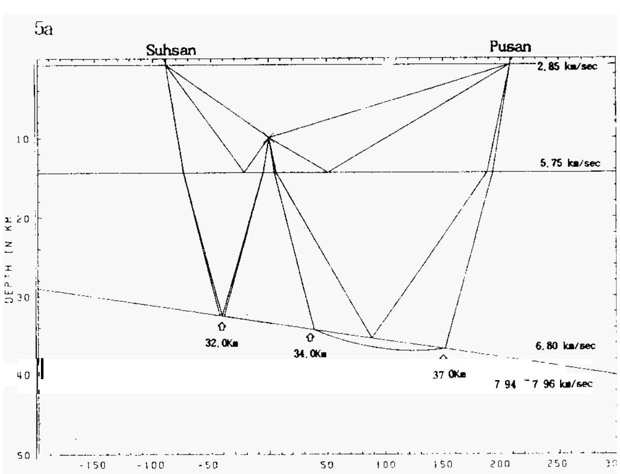


Fig. 4 Seismograms of Mt. Pyongyang earthquake at Chulwon and Kangnung stations, Anak earthquake at Cholwon and Chunchon stations, and Mt. Keyryong earthquake at Suhsan and Pusan stations.



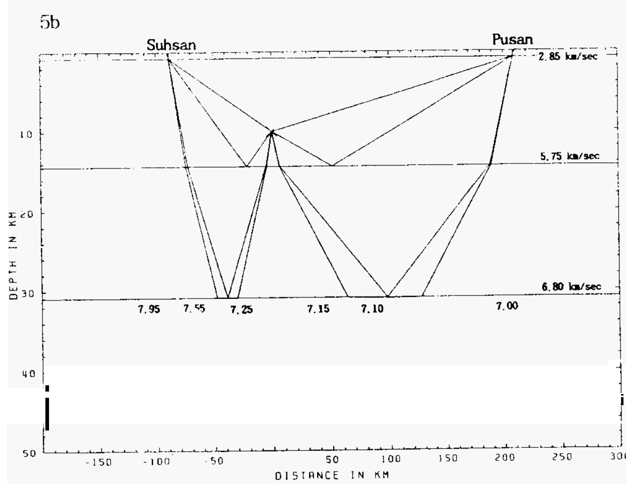
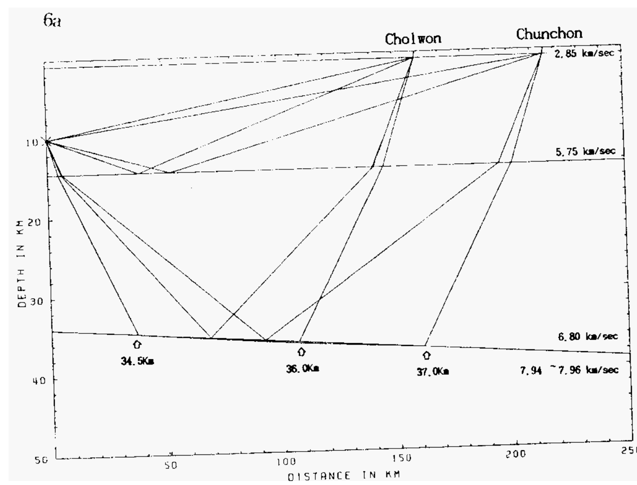


Fig. 5 Ray-method diagram of the Mt. Keyryong earthquake for homogeneous(a) and inhomogeneous model(b).



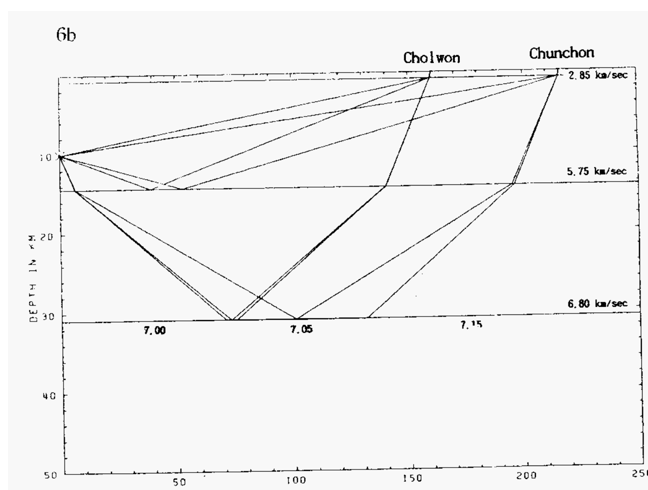


Fig. 6 Ray-method diagram of the W. Pyongyang earthquake for homogeneous(a) and inhomogeneous model(b).

2) The low velocity bodies in the Korean Peninsula are detected in the Rugok hot spring field in the Kyongnam region and the Chugaryong rift zone that streches from Wonsan to Seoul.

3) With finding of the low velocity anomalies of seismic waves, the seismological study needs further investigation of micro-seismicity that is derived from micro-cracks due to abrubt change of thermal gradient within the interior of the lower crust.

Table 1. Earthquake parameters in this study.

Date M/D/Y	Origin time H-M-S	Hypocenter Lat.(N)	Hypocenter Long.(E)	M	h Km	Region
11/12/92	08-02-26.8	38.9	125.7	4.3	10.0	W.Pyongyang
11/13/92	02-47-09.0	38.4	125.3	3.4	30.0	Anak
12/08/93	11-43-57.1	39.6	125.9	3.4	20.0	N.Soonchon
02/12/94	11-58-14.2	36.4	127.3	3.5	10.0	Mt.Keyryong

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