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The Applicability of Seismic Waves to Detect a Low Velocity Body of the Geothermal Area

지열부지의 저속도층을 탐지하기 위한 지진파의 응용성

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요약/Abstract

Ray Method와 관측지진 자료에 의해서 지각구조 상부 Mantle을 연구하면서 저속도층이 탐지되었다. 우리는 한반도에서 부곡 온천 지역과 추가령 지구대를 통과하는 P파와 S의 도착 시간 지연을 관측했다. 현재 지열 탐사는 이 지역이 심부 저속도 물체는 "지연 암영"이라고 불리우는 높은 지열 이상을 설명 해주고 있다. 우리는 하부지각의 부분 용융에 기인한 저속도 물체의 가설을 하부지각의 이차원 비등질 모델의 속도변화가 있음을 Ray Method(Cerveny and Psencik, 1983)에 의해서 분석 하였다.

The low velocity body was detected during the investigation of the crustal structure and upper mantle in the Korean Peninsula using ray method and observational seismic data. We observed the arrival time delays of P 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 et 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 velocity using Ray Method(Cerveny and Psencik, 1983).

INTRODUCTION

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 the geothermal exploration, there are two ways. One is the study of micro-seismicity of the region that accounts for micro-cracks (rock burst) 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 Peninsula using seismic data and ray method. The arrival 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. Soonchon earthquake for Dec. 8, 1993 of North Korea. In spite of a good method of seismology to the 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. The present studies are limited for three North Korean earthquakes Pyongyang, Anak, Soonchon earthquakes and one South Korean earthquake the Mt. Kyeryong earthquake whose earthquake parameters are relatively determined with accuracy.

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(Korean Meteological 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 et 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 hydro-thermal area of the Taupo volcanic zone, New Zealand, indicating that intrusion into the crust from deeper level occur only in a quite limited area in this region.

DATA AND METHOD

We tried to use Ray 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 Pn and PmP phases into account for the theoretical as well as for the observational models using Ray Method. We have found thatq 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 P nad S waves (α/β) compared to the normal case of 1.752. The first arrival amplitudes of S waves are also found to be weak on 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 presentq in Table 1. We used W. Pyongyang earthquake Nov. 13, 1992 and N. Soonchon earthquake Dec. 8, 1993 in North Korea and Mt. Kyeryong earthquake Feb. 12, 1994. Fig. 1 shows the ray paths of four earthquakes that pass through the Bugok hot spring area and the Chugaryong rift zone. As shown on the map on Fig. 1 the ray paths of the North Korean earthquakes such as N. Soonchon, W. Pyongyang and Anak earthquakes pass

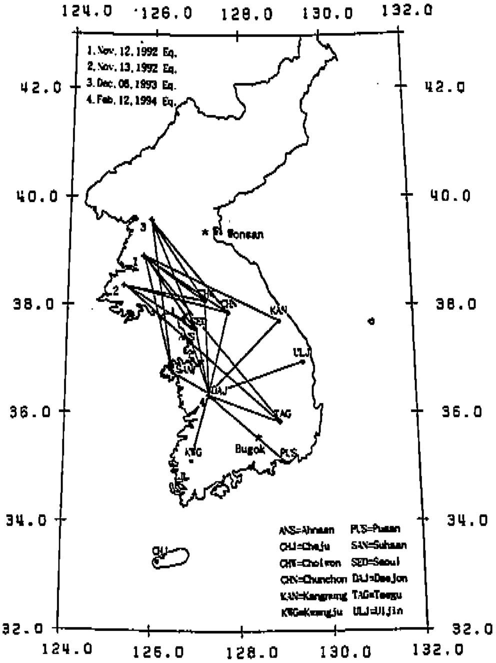

Fig. 1 Station locations(black dot) and epicenter(numbers) for this study.

Table 1. Earthquake parameters in this study.

Date M/D/Y	Origin time H—M—S	Hypocenter Lat.(N)	 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

through the Chugaryong rift zone that streches that 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 2.85km/s, 5.75km/s, and 6.80km/s for P-wave velocities and 1.45km/s, 3.38km/s, and 3.97km/s for S-wave velocities respectably. P- and S-waves velocities for Moho discontinuity are found to be =7.94km/s and =4.65km/s. The velocity of 2.85km/s for the very shallow subsurface layer are adapted from the explosion data and subjected to change depending on the region. From Fig. 3, the travel time delays P- and S-wave are found at the station where ray paths pass through Chugaryong rift zone and Bugok hot spring region. Our finding of large positive residuals of P- and S-wave at Cholwon, Chunchon, and Pusan stations suggest that the discontinuity could be content 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 amplitude of S

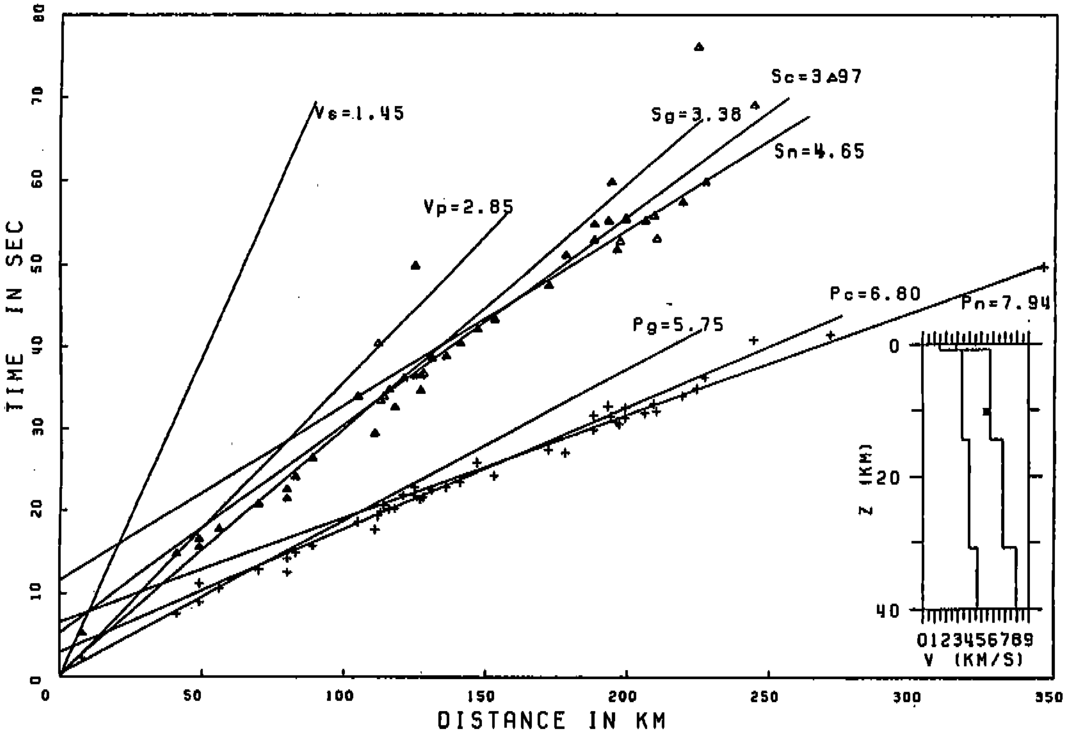

Fig. 2 The travel-time curves in the Korean Peninsula.

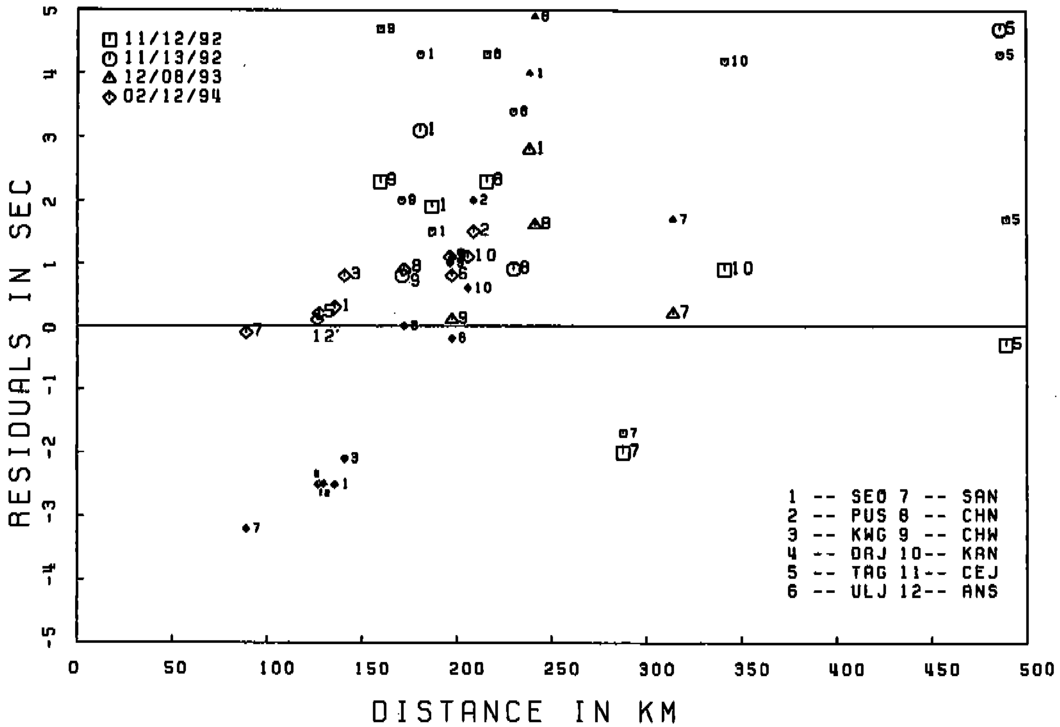

Fig. 3 The arrival time residuals of P and S waves for this study. Large and small symbols indicate P— and S—wave residuals respectively.

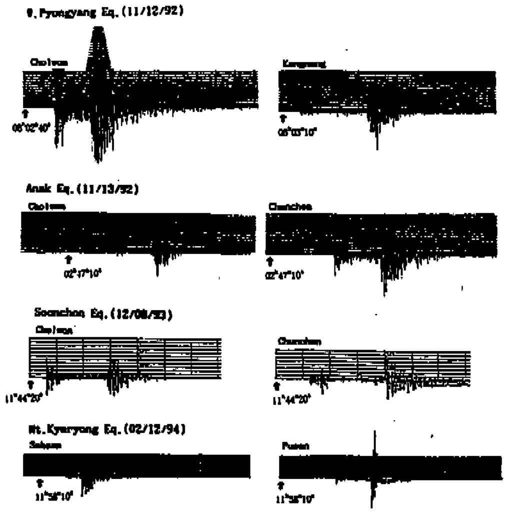

Fig. 4 Seismograms of W. Pyongyang earthquake at Cholwon and Kangnung station, Anak earthquake at Cholwon and Chunchon stations, and Mt. Keyryong earthquake at Suhsan and Pusan station.

waves prevented here for the low-velocity path station offer an additional means of investigating the low-velocity fields. Figs. 5a, 5b represent the lateral variation (inhomogenesity model) of the Moho discsontinuity and/or the vertical variation (homogenesity model) of the Moho discontinuity for the Mt. Kyeryong earthquake. Fig. 6a and 6b account for the low velocity 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 Chugaryong rift zone. We can see

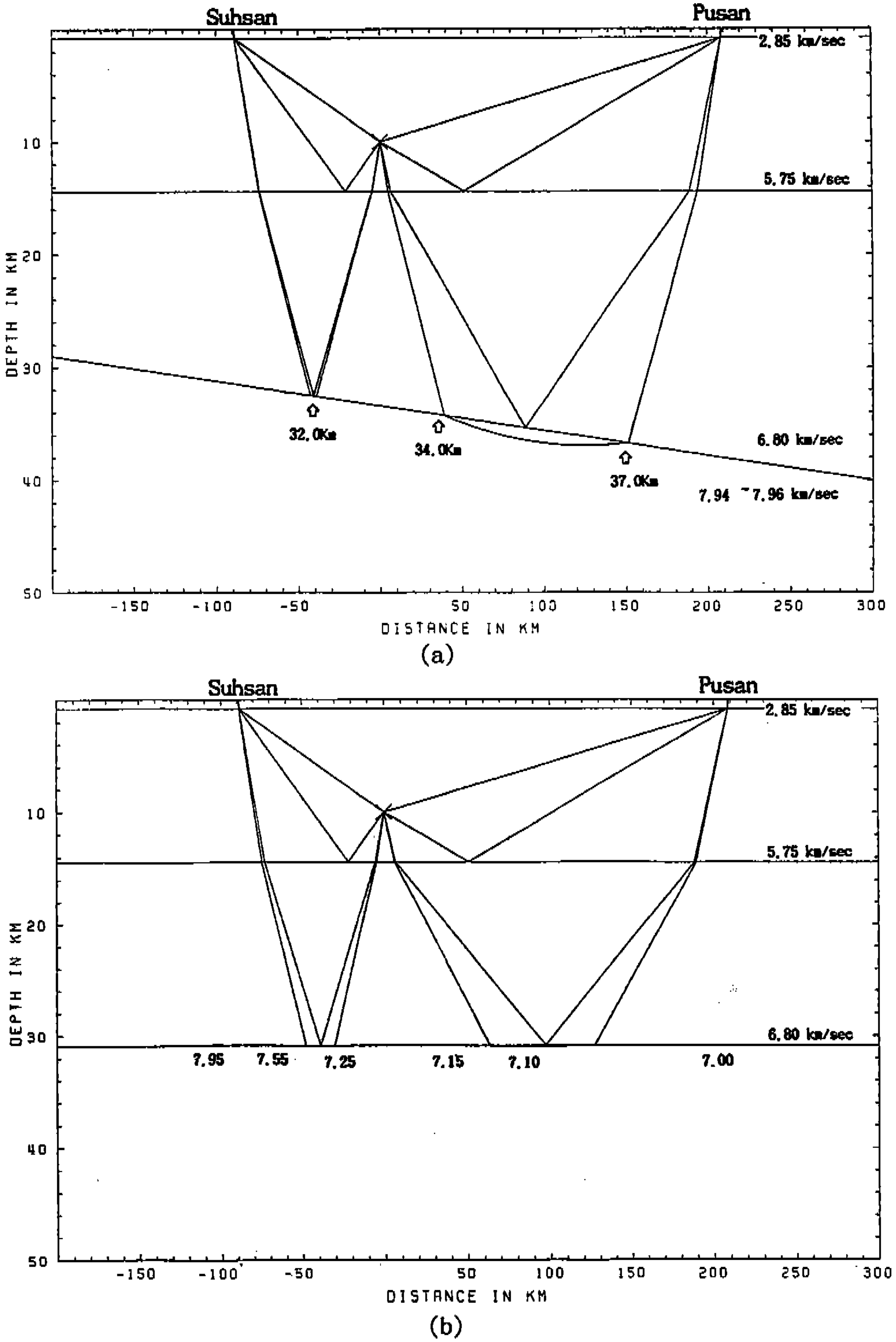

Fig. 5 Ray Method diagram of the Mt. Keyryong earthquake for homogeneous(a) and inhomogeneous model(b).

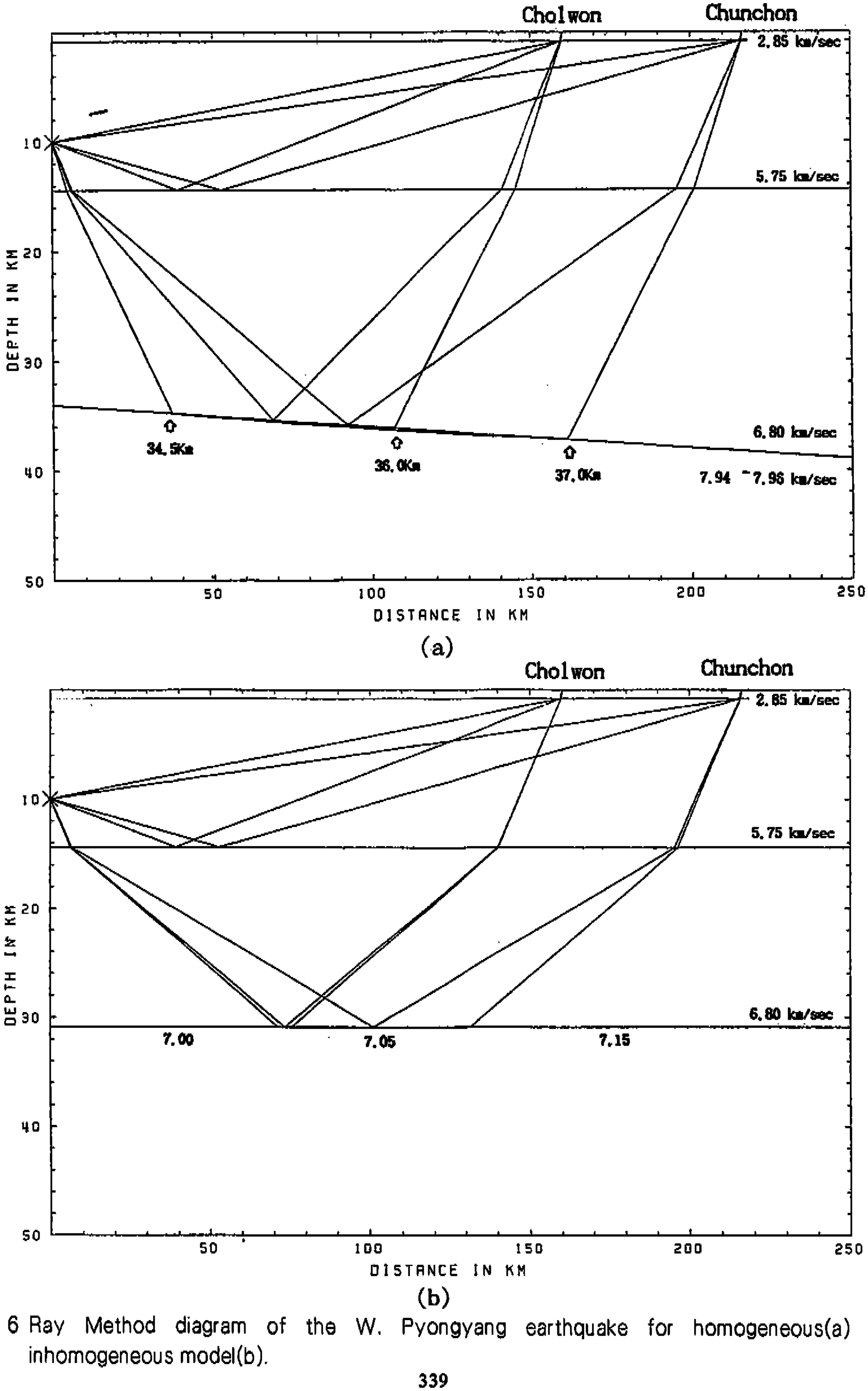

Fig. 6 Ray Method diagram of the W. Pyongyang earthquake for homogeneous(a) and inhomogeneous model(b).

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 seismologically found to be as follows.

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

0.0		
	α=2.85	β=1.45
0.8		
	α=5.75	β=3.38
14.4		
	α=6.80	β=3.97
30.9		
	α=7.94	β=4.65

2) The low velocity bodies in the Korean Peninsula are detected in the Bugok 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.

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