COLLECTION AND ANALYSIS OF SEISMIC AND GROUND-TRUTH INFORMATION IN NORTHEASTERN CHINA

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ABSTRACT

This research is aimed at obtaining a database of historical seismological, geophysical, and geological data for East Asia. By obtaining the local Chinese data, better models of the regional crustal structure can be made. We have established a process and procedures for doing this type of reconnaissance and data collection studies.

We have collected the historical earthquake data in northeastern China recorded by the local seismic network and constructed a database of phase arrival times, amplitudes and waveforms. The database consists of nearly 700 seismic events from 1986 to 1999 with over 13,000 entries of seismic phase arrival times and amplitudes. Over 900 analog seismograms were also scanned and stored in JPEG format. The seismic events occurred in northeastern China and the vicinity with an area of over 1,300,000 km^2. The events were recorded by the local seismic network operated by the provincial seismic bureau in northeastern China with over 35 seismic stations that mainly cover Liaoning province and the neighboring provinces. The phase arrival time and amplitude data are verified and validated independently. The location of the events is examined, and re-location is performed on questionable events to correct errors in the raw data. For the events with waveform data available, re-measurement is done to ensure the quality of the phase picks. The data is compiled in MS Excel format with hyperlinks to the seismic waveform data. The historical earthquake data provide a unique seismic database for further refinement of the regional crustal structure.

We performed a 3-D tomographic inversion of the crustal structure in northeastern China utilizing the obtained seismic data. Previous research on the crustal structure in northeastern China is analyzed and summarized to set up a I-D starting model. Both P and S phases are adopted to carry out a tomographic inversion of the crustal velocity structure from the regional seismic events. The results reveal complex lateral heterogeneity of the crustal structure in northeastern China. We find correlation among the velocity structure, the topography and the tectonic structures in the region. The deduced 3-D crustal structure improves the quality of re-location of the seismic events.

Key Words: Ground-truth database, phase arrival time data, waveform data, 3-D tomographic inversion, re-location

OBJECTIVE

At present, regional seismic data is not easily available for East Asia. Without a good seismic database, detection of violations of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) will be extremely challenging. This effort is limited to the collection and analysis of seismological, geophysical, and geological data for East Asia.

The objective of this effort is to obtain a database of historical seismological, geophysical, and geological data for East Asia. By obtaining Chinese data, better models of the Korean Peninsula can be made.

RESEARCH ACCOMPLISHED

Geological Background

The northeastern China region is located at the eastern edge of the Eurasian plate, adjacent to the Pacific plate. The region is divided into two tectonic elements by the Chifeng-Kaiyuan fault. North of the Chifeng-Kaiyuan fault is the Northeastern China tectonic element which is a part of the Tianshan-Xinggan geosynclinal fold belt. South of the Chifeng-Kaiyuan fault is the Northern China tectonic element which lies in the Sino-Korean platform. The two regions are distinctive from each other in geological structure, seismicity, gravity and tectonic stress. The Northeastern China tectonic element undergoes large scale deformation due to the under-thrusting of the Pacific plate into the Heilongjiang plate. It is a region with active deep seismicity and volcanic activity. There are several secondary formations in the region, such as Da Xinggan fold uplift, Jihei fold uplift and Songnen subsidence. The Northern China tectonic element deforms due to the collision between the Northern China plate and the Heilongjiang plate. There are frequent shallow earthquakes within the region. There are also secondary formations in the Northern China tectonic element, such as Yanshan fold belt, Xiaoliaohe fault depression and Liaodong platformal uplift.

Geological structures are abundant in northeastern China, including mountains, basins, faults, volcanoes and hot springs. The gravity anomaly in northeastern China trends in NE direction. The central region has higher gravity than the western and the eastern regions. There are over 350 earthquake faults with lengths greater than 20km in the region. According to historical records and modem observations, over 180 earthquakes with magnitude Ms > 4.75 happened in the region, the greatest among which is the 1975 Haicheng earthquake with Ms = 7.3. Focal mechanism shows that the shallow earthquakes in northeastern China are mainly strike-slip events on nearly vertical faults. The average maximum principal stress is in the NEE-SWW direction.

Previous work

There have been four deep seismic sounding profiles implemented in the northeastern China region. They are Luyang-Haicheng-Donggou profile, Xiongyue-Bengxi profile, Yingkou-Shenyang profile and Dong Ujimqin Qi-Donggou profile. The first three profiles passed the seismogenic zone where the 1975 Ms=7.3 Haicheng earthquake occurred, with a total length of 640 km. The Dong Ujimqin Qi-Donggou profile was a part of the Global Geoscience Transect project. It ran from Dong Ujimqin Qi, Inner Mongolia to Donggou, Liaoning with a length of 960 km. The crustal and upper mantle velocity structure along the profiles were deduced. It is found that the crustal and upper mantle structure are complicated in the region. Typically, three layers are found in the crust (Lu, *et al*., 1991). The thickness of the upper layer is from 13 to 15km and the P-wave velocity within the layer is from 2.0 to 6.3km/s. The middle layer usually consists of two sub-layers. The upper sub-layer in the middle layer has a thickness of 4~9km. The velocity in the layer is from 6.0 to 6.2km/s. The lower sub-layer in the middle layer has a thickness of 2~9km and the velocity in the layer is from 6.3~6.6km/s. The lower layer of the crust has a thickness of 5~10km and the velocity in the layer is from 6.5~7.5km/s. Considerable lateral variation of the velocity in the crust is found in the area. Localized low velocity zones are identified in some regions, e.g., under Haicheng along the Dong Ujimqin Qi-Donggou profile.

The velocity structure deduced from the deep seismic sounding profiles can be utilized for re-location of the earthquakes in northeastern China recorded by the local seismic network. To the best of our knowledge, only 2-D velocity structures along the existing profiles are known in northeastern China. Large scale lateral variations are present in the region. Study of the 3-D velocity structure in northeastern China is important for high precision re-

location of the earthquakes in northeastern China and the Korean Peninsula recorded by the local seismic network.

Ground-truth database

We have collected seismic data in northeastern China from January 1997 to May 1999 plus a limited number of seismic events from 1986-1994. A database has been constructed with over 700 seismic events in northeastern China and North Korea that were recorded by the local seismic network with over 35 stations operated mainly in Liaoning province. For the first time, we were able to obtain a comprehensive listing of over 13,000 seismic phase arrival time picks and amplitude data. Waveform data are also available for 44 events with over 900 analog seismograms. The seismic events cover the area 116W to 130W and 36N to 46N, with magnitudes M1= 1.4~ 4.9 and a maximum depth of 26km. The data listing in the database is raw data information and contains a comprehensive listing of all phases that were detected. The listed information of the earthquakes includes origin time, epicenter location, magnitude, focal depth and precision. Major phase picks, such as Pn, Pg, Sg were reported. The information listed in the station report includes the arrival time, amplitude, station magnitude and epicentral distance. The data is compiled in MS Excel format with hyperlinks to the seismic waveform data. The location of all the seismic events in the database is shown in Figure I along with the seismic stations.

This data set forms the basis of an initial input to a ground-truth database for northeastern China and vicinity. Analysis of the data may be performed to yield preliminary velocity model and event re-location. These data may also be correlated with data obtained from the Chinese Digital Seismic Network (CDSN) to establish ground-truth database information for the region.

We performed quality control on the raw data. The phase arrival time and amplitude data are verified and validated independently. The location of the events is examined, and re-location is performed on questionable events to correct errors in the raw data. For the events with waveform data available, remeasurement is done to ensure the quality of the phase picks. To illustrate the quality of the seismic data, we check the travel time curves for all stations included in the database. Overall, the fluctuations in the travel time curves are small, which shows that the phase pick data are of good quality (Figure 2).

Preliminary Results of 3-D Tomographic Inversion and Re-location

We use the computer code *SPHYPIT90* by Steve Roecker for a 3-D tomographic inversion of the crustal structure in northeastern China. *SPHYPIT90* is a FORTRAN program designed to invert P and S wave arrival times locally recorded and/or P times teleseismically recorded by an array of local to regional dimensions for P and S wave velocities beneath the array (Roecker, 1987; Roecker, 1991). The tomographic method used is based on that of Aki, et a]. (1976) but with many extensions and modifications. The inversion procedure is based on that discussed by Tarantola and Valette (1982). *SPHYPIT90* can analyze locally and/or teleseismically recorded data. In the case of locally recorded data, the velocities determined are those that would be obtained through a joint inversion with hypocenters, but the hypocenters are removed through parameter separation and are relocated in a separate step. The starting model can be either one-dimensional or three-dimensional.

We picked up 226 seismic events with defined depth from the compiled database. The event location, seismic station location and ray path projection are shown in Figure 3. The events were recorded from December 1990 to December 1998 by the local seismic network with over 35 seismic stations. The spatial distribution of the events covers northeastern China in the area 120E-125E, 38N-43N with depths up to 26km. Most of the events were determined with precision 1, the highest confidence in a 4-level precision system employed by the local seismic network. Only a handful of events have precision 2.

A 1-D starting model of the velocity structure of northeastern China was set up according to the previous seismic profiling in the region (Lu *et al*., 1991). The crust in the region was divided into 6 layers (Table 1). The region under investigation is partitioned into 16 by 10 cells in each layer. The resulting P-wave velocity after the 5th iteration of the tomographic inversion is shown in Figure 4. Both lateral heterogeneity and vertical variation are observed through the results. The variation of the P-wave velocity in the first layer trends mainly in the NE direction, which is well correlated with the topography and tectonic settings in the region.

Table 1. Starting model of crustal structure in NE China

Layer	Depth (km)	P-wave velocity (km/s)
1	3.0	4.00
2	9.0	6.10
3	15.0	6.10
4	21.0	6.15
5	24.0	6.45
6	32.0	7.20

The earthquakes adopted in the tomographic inversion are re-located based on the 3-D crustal structure from the inversion (Figure 5). A 73% reduction of variance of the data is achieved after the 5th iteration. The standard error in the re-location of the events is less than 5krn in epicenter and less than 10km in depth. A close look of the Haicheng area shows systematic errors mainly in the east direction (Figure 6), which is evidence that the regionalized 3-D crustal structure is important to the improvement of re-location of the seismic events in the region.

CONCLUSIONS AND RECOMMENDATIONS

A comprehensive database of phase arrival time, amplitude and waveform is compiled for northeastern China, which consists of over 700 events and 12,000 phase arrival times recorded at more than 35 regional seismic stations. The data constitute a ground-truth database for the region and is valuable for study of the crustal structure and re-location of the seismic events in the region.

A 3-D tomographic inversion based on the phase picks data in the database is performed and significant lateral variation in the crustal structure is found in the region. Re-location of the seismic events based on the 3-D crustal velocity structure shows improvement of the location of the events.

A more complete coverage of northeastern China region is desirable for more reliable inversion of the 3-D crustal structure. We will continue to incorporate the newly recorded seismic events in the region and improve the resolution and precision of the 3-D tomographic inversion of the crustal velocity structure and re-location of the seismic events.

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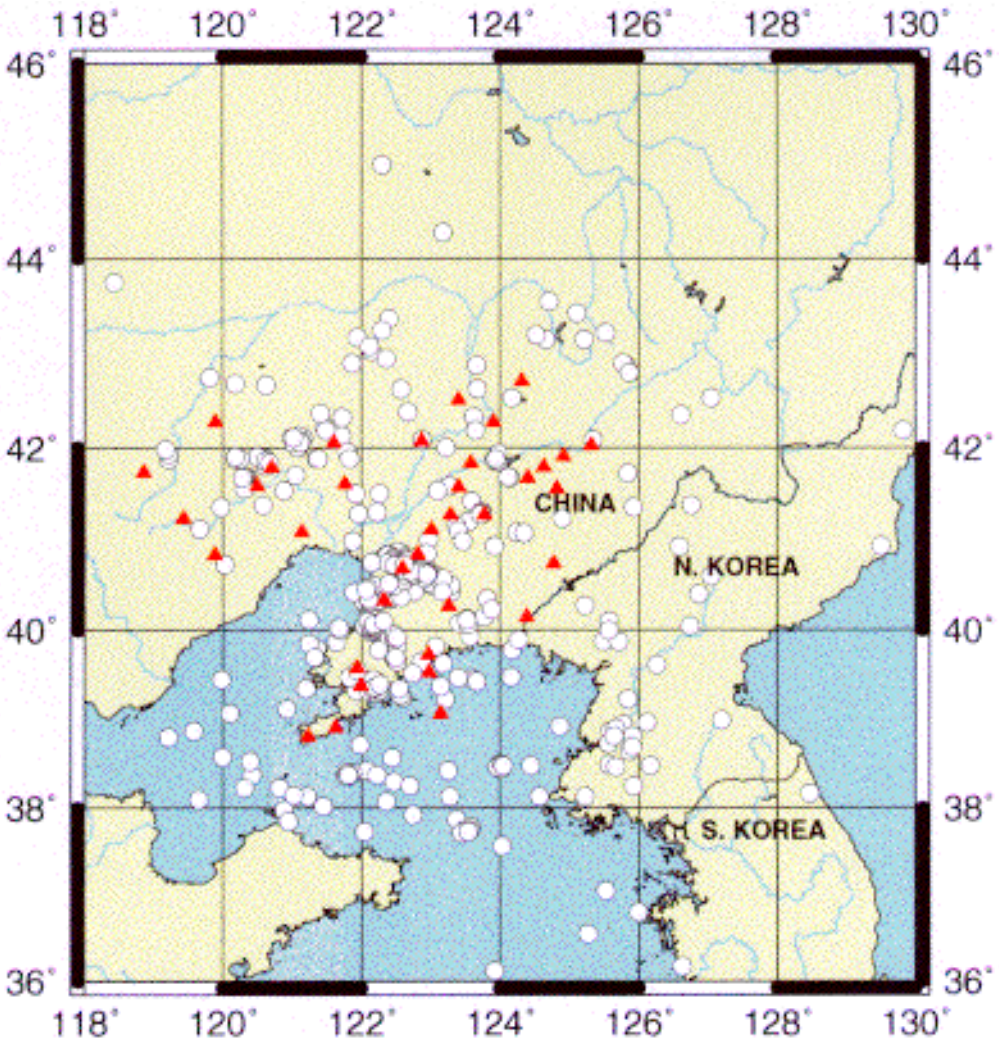

Figure 1. Distribution of earthquakes included in the database (open circles) and the seismic stations (red triangles in the local seismic network in northeastern China.

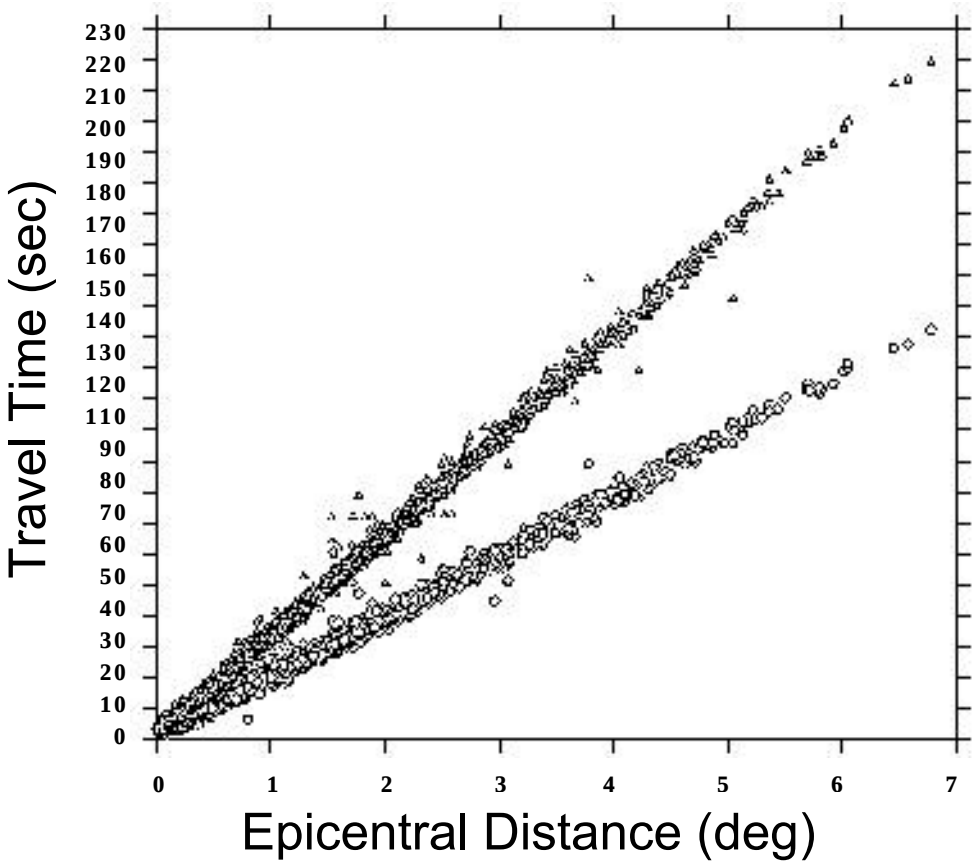

Figure 2. P-wave (open circle) and S-wave (open triangle) travel times observed at all stations in the database.

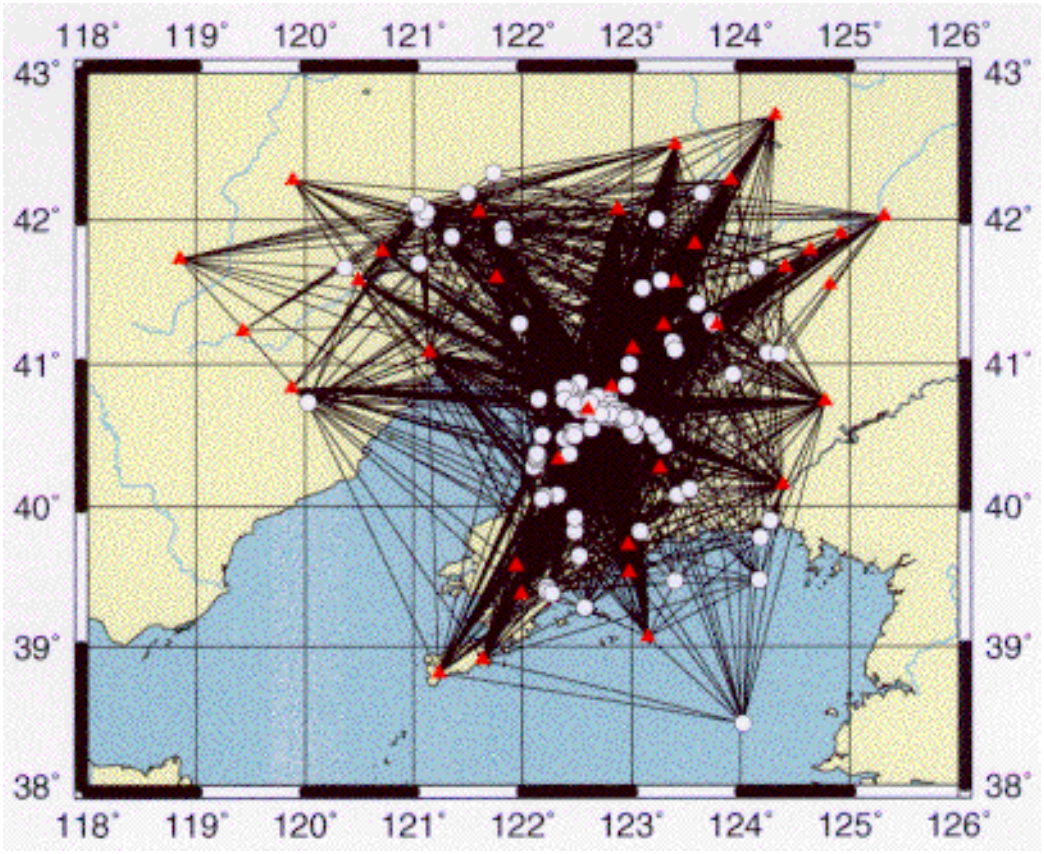

Figure 3. Ray path projection on the earth surface for 226 seismic events used in the inversion. The earthquakes are indicated by open circles and the seismic stations are identified by red triangles.

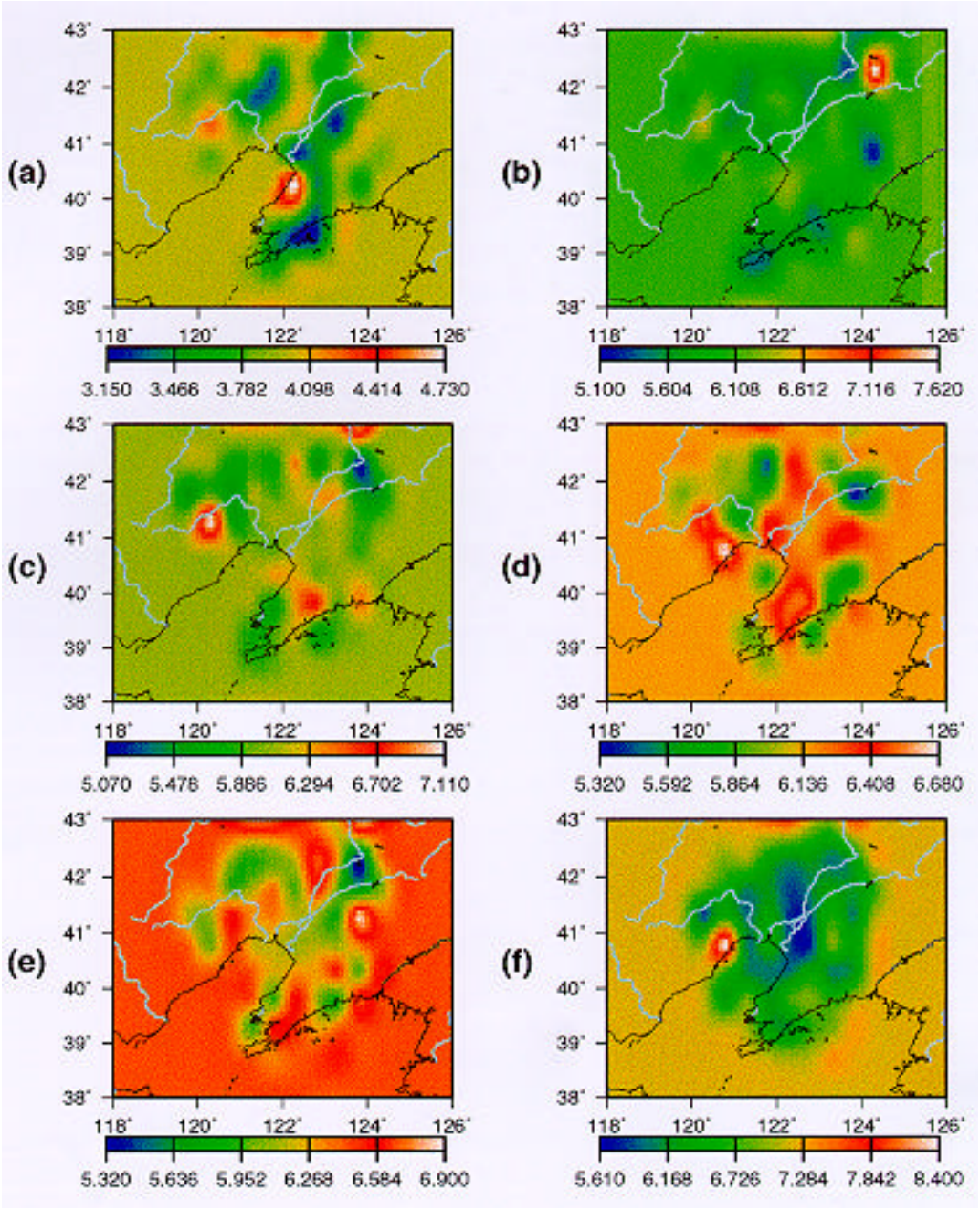

Figure 4. Deduced P-wave velocity after the 5th iteration of 3-D tomographic inversion. Panels (a)-(f) denote layers at different depths corresponding to Table 1.

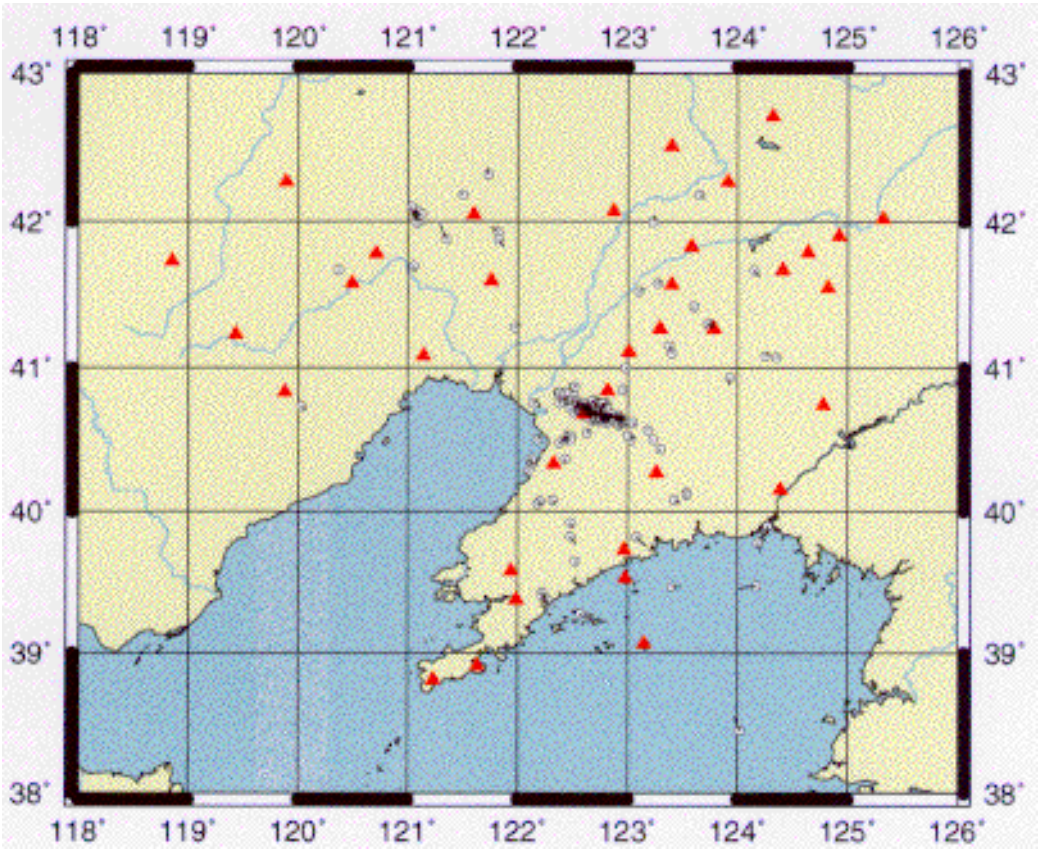

Figure 5. Re-location of the 226 seismic events on the deduced 3-D crustal structure. Short bars represent deviation from the original locations.

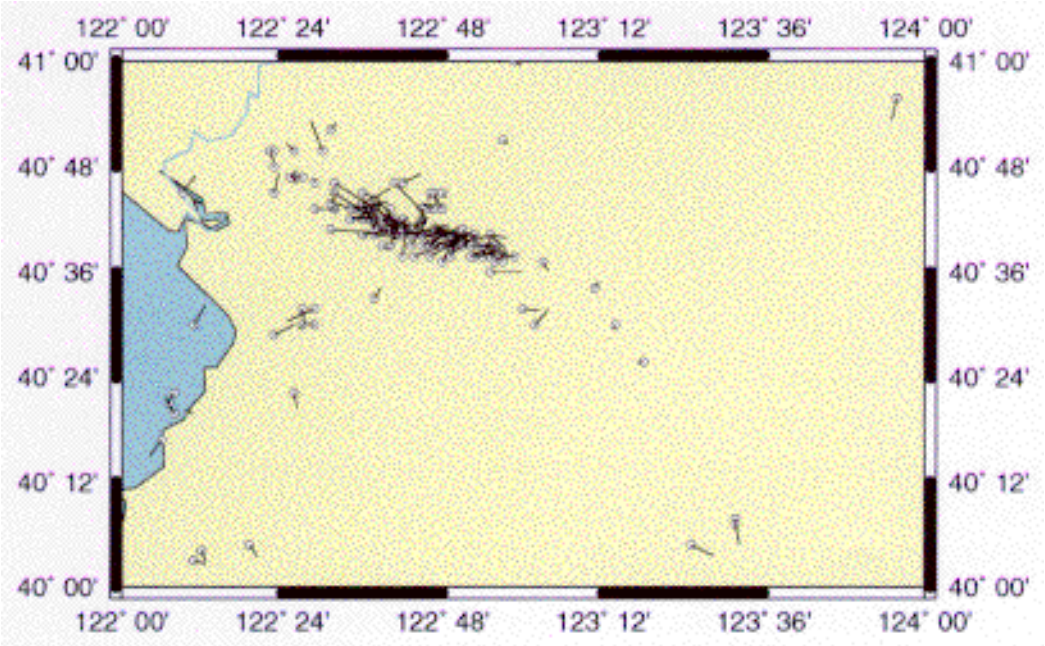

Figure 6. An enlargement of Haicheng area in Figure 5.