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3-D Seismic Images of Crust and Upper Mantle beneath Bohai Basin and its adjacent regions, Eastern China

Liu Jianhua, Liu Futain, He Jiankun, and Chen Hui
Institute of Geophysics, Chinese Academy of Sciences, Beijing 100101

ABSTRACT

This research was carried out in order to give some reasonable solutions on basin tectonics and on continental geodynamics, which are approached by using integrative researches on crustal deformation, 3-D seismic velocity reconstruction and geochemical tracing of volcanic rocks in the eastern China basin system.

Key words: Seismic Tomography, Basin Tectonics, Continental Geodynamics, Bohai sea Basin and its adjacent regions

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요 약: 본 연구는 동지나 분지에서의 지각변형, 3차원적 지진파 속도 분포 및 화산암 원소의 지화학적 추적을 통하여, 분지의 지체구조적 및 대륙의 지체동역학적인 해석을 목적으로 수행되었다

주요어: 지진파 토모그라피, 분지지체구조, 대축지체동역학, 보하이해 분지와 주변지역

(Liu Jianhua, Liu Futain, He Jiankun, and Chen hui, Institute of Geophysics, Chinese Academy of Sciences, Beijing 100101)

1. Introduction

It is well known that Bohai sea basin and its adjacent regions are one of the most complicated tectonic unit in the east part of North China plate. The alteration of the lithosphere and deep processes are very strong. Besides, it is also a disputed area for the feature of the geophysical field on the shape of crustal extension structural deformation and the geo-dynamic mechanism of the development of extensional structure. In order to study geo-dynamic processes of crustal deformation and structural development in the eastern China basin system, we made the reconstruction of the velocity image beneath Bohai sea basin and its adjacent regions.

2. Geological Background in Bohai Sea Basin

Fig. 1 is the map of extensional structure in North China area. Since the pre - Mesozoic, the structural extension began to take place in the middle-and-upper crust within North China plate, resulting in the late Mesozoic whole base fracture. In the eastern part of North China plate, the main structural extension is located in North China place in the eastern part of Taihang mountain uplift and the west-southern part of Shandong province. The extensional structure is strictly controlled by large-scale main boundary faults. In the western part, the main fault is Taihang mountain fault, and in the eastern part, the main fault is the northern section of Tan-Lu fault. In the east-south part, there are Guangrao-Qihe-Liaocheng-Lankao faults.

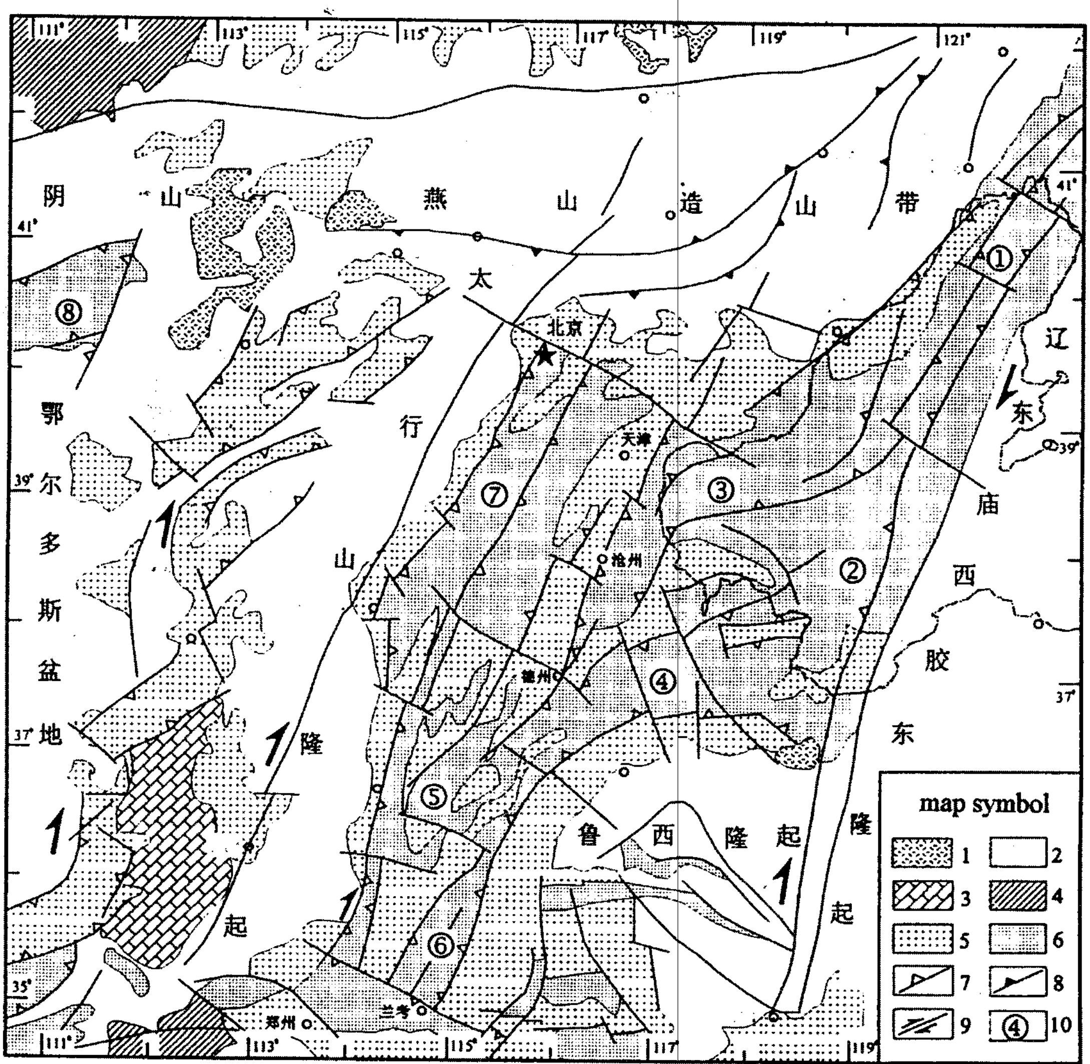

Fig. 1. The Mesozoic-Cenozoic extension structure map on the eatern fringe of Noth China. **1.** Cenozoic volcanic rock **2.** pre-Cenozoic uplift area **3.** Mesozoic basin **4.** Tertiary period basin **5.** late-Tertiaiy-Quaternary period basin **6.** Cenozoic basin **7.** main extension fault **8.** main thrust fault **9.** main strike-slip fault **10.** the code of Cenozoic extension basin.

Controlling by main extension faults, the intensity of structural deformation is different. It is apparent that the width of the extensional deformation belt gradually becomes narrow from the central part of Jizhong-Bohai sea belt toward both south and north ends. The shape of the extensional deformation belt prevails a inverse "S". The width of the basin is about 150 km in the central part, and in the both ends are about between 50 and 70 km. The deformation feature of Bohai sea basin is the most complicated.

3. Study Area and Data Base

The study area is between 36°N and 45°N in latitude and between 116°E and 126°E in longitude, which covers the whole Bohai sea basin and some adjacent regions.

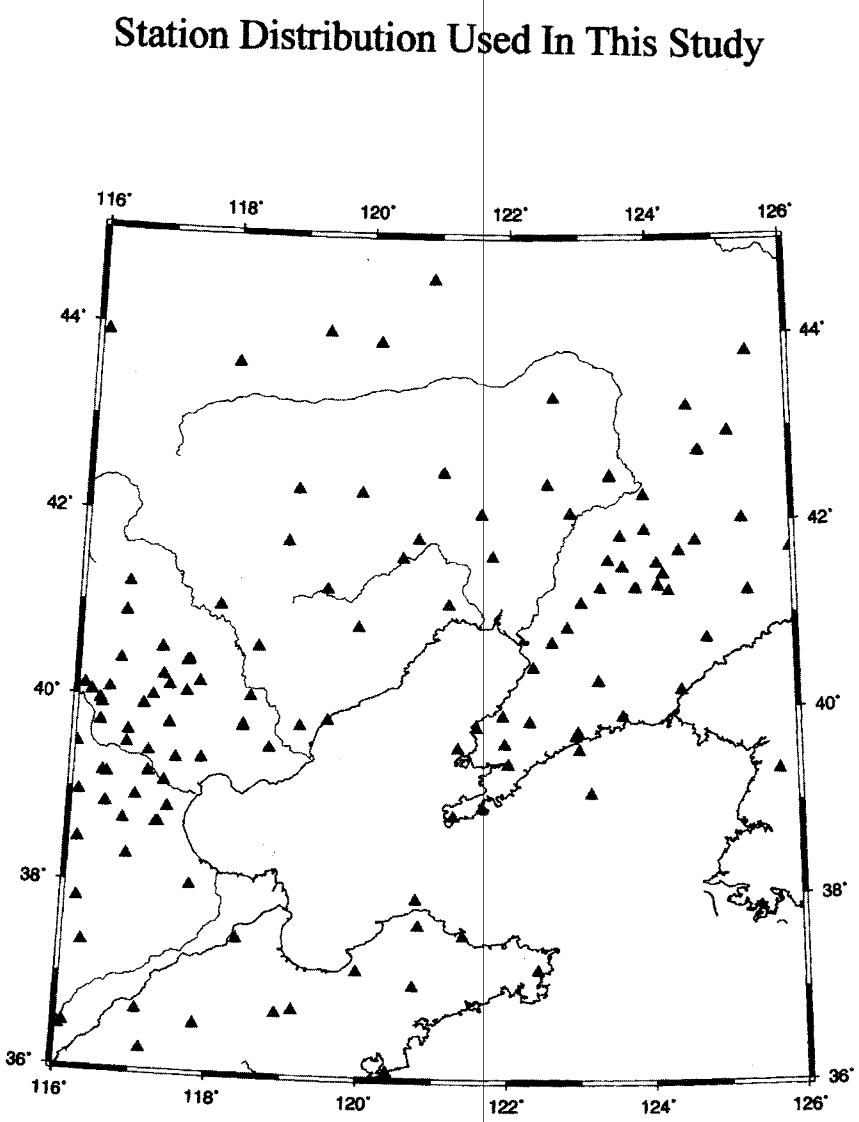

Fig. 2. Distribution of seismic station used for this study.

The data were recorded from Liaoning, Jilin, Neimeng, Hebei, Shanxi, Shandong provinces, Beijing, and Tianjin seismic networks. The total of more than 20,000 travel-times for the study, including some regional and teleseismic earthquake events (epicentral distance between 30° and 90°). The errors in the arrival time are generally smaller than 0.3s. The epicenter and station distributions used in the study are shown in Figs. 2 and 3, respectively. Figs. 2 and 3 show that the ray numbers are uneven but are enough, indicating that the inversion solution is reliable.

4. Results

Using seismic tomography method proposed by Liu Futian *et al.* (1989), we obtained velocity images beneath Bohai sea and its adjacent regions. The

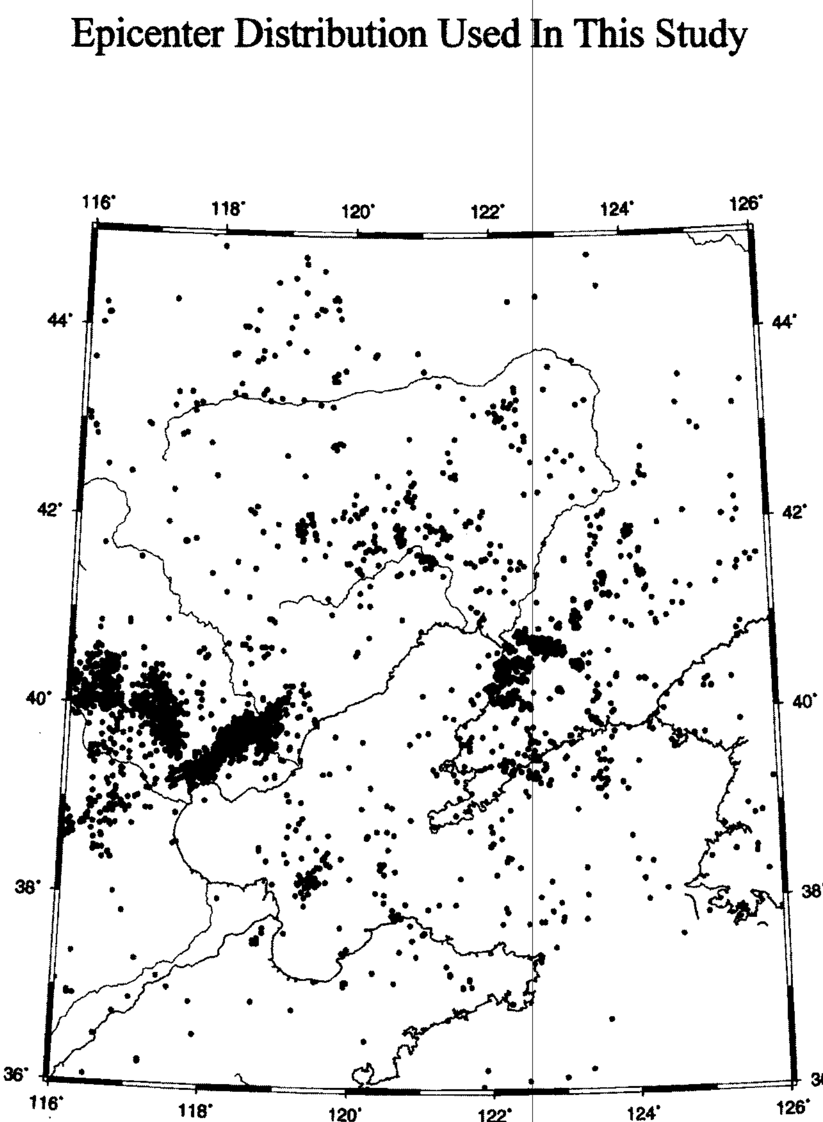

Fig. 3. Distribution of the earthquake epicenters used in this study.

blue represents high velocity and the red represents low velocity in every images. The velocity distribution shows disturbance value related with the reference velocity model.

4.1 The Velocity Image of the Upper Crust

The velocity image in the depth of 3 km is shown in Fig. 4. It outlines whole extension frame of structural deformation in the Bohai sea basin and its adjacent regions. Based on sediment thickness of North China basin in the Cenozoic third system, basement bottom which lies hidden in the earth is the deepest beneath Liaozhong and Bozhong depressions. The sedimentation thickness is about 5 km, and the highest depth is over 10 km. Based on the image in the depth of 3 km, the Bohai sea basin has low velocity, and Yanshan mountain in the north of 40° Shenyang - the eastern part of Liaoning

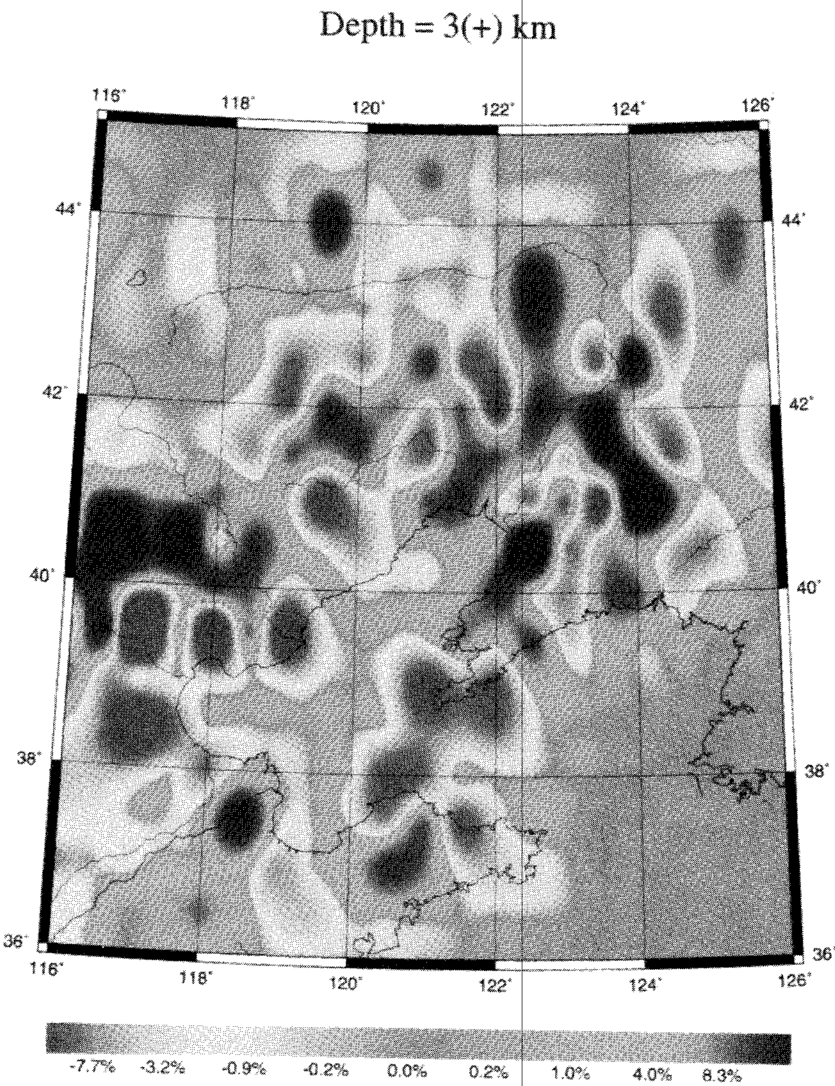

Fig. 4. the velocity image in the depth of 3 km.

province, Shandong province and Yellow river mouth have high velocity. The velocity distribution is related with geological structure in the surface.

The velocity image in the depth of 14 km is given in Fig. 5, showing velocity distribution feature in the upper crust. Controlling by extensional deformation, Bohai sea basin has low velocity due to the strong structure extension. There still is the Cenozoic cover rock. The high velocity regions are located in west Shangdong rift, Yanshan mountain rift - east Liaoning province and Changchun region. The low velocity regions are located in Dalian - Bohai sea basin - Weifang Shandong province, Suizhong - Qinhuangdao - Tanggu - Huanghua depression, and Dandong - Kuandian area.

The feature of the above-mentioned velocity distribution indicates that the velocity anomalies are mainly controlled by the development of the extensional

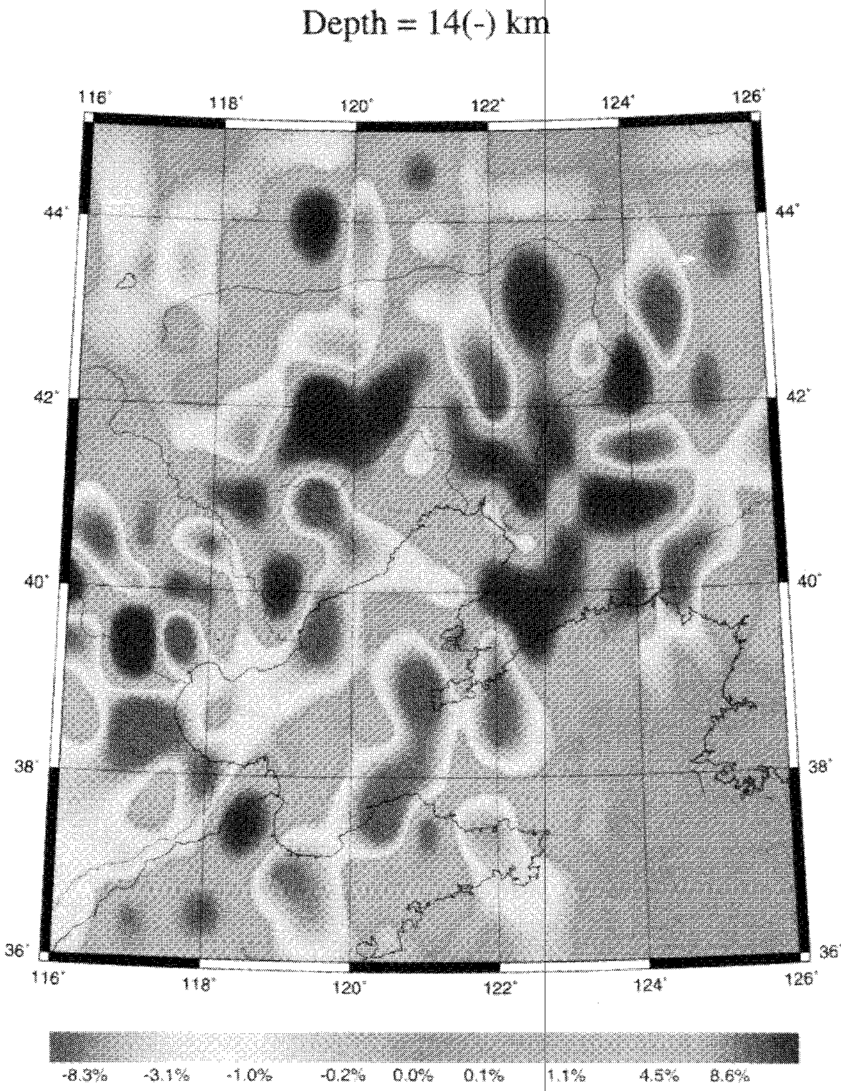

Fig. 5. The velocity image in the depth of 14 km.

deformation in whole upper crust and partly in middle crust of the study region. It is very obvious in the Bohai and its adjacent regions. It can be found that there is a clear difference in the north-south deformation region, and its boundary is about 40°N. It illustrates that the late Cenozoic basement is different in the different extensional deformation regions before forming the extension deformation of the eastern region of North China. We can infer that the late Cenozoic basement may be close to that of Yanshan orogenic belt, and of Bohai sea basin may belong to the basement of the part of North China plate.

4.2 The velocity image of the top of upper mantle

The velocity image in the depth of 34 km is shown in Fig. 6. The previous study results show that the depth of Moho interface is about 30-35 km in Bohai

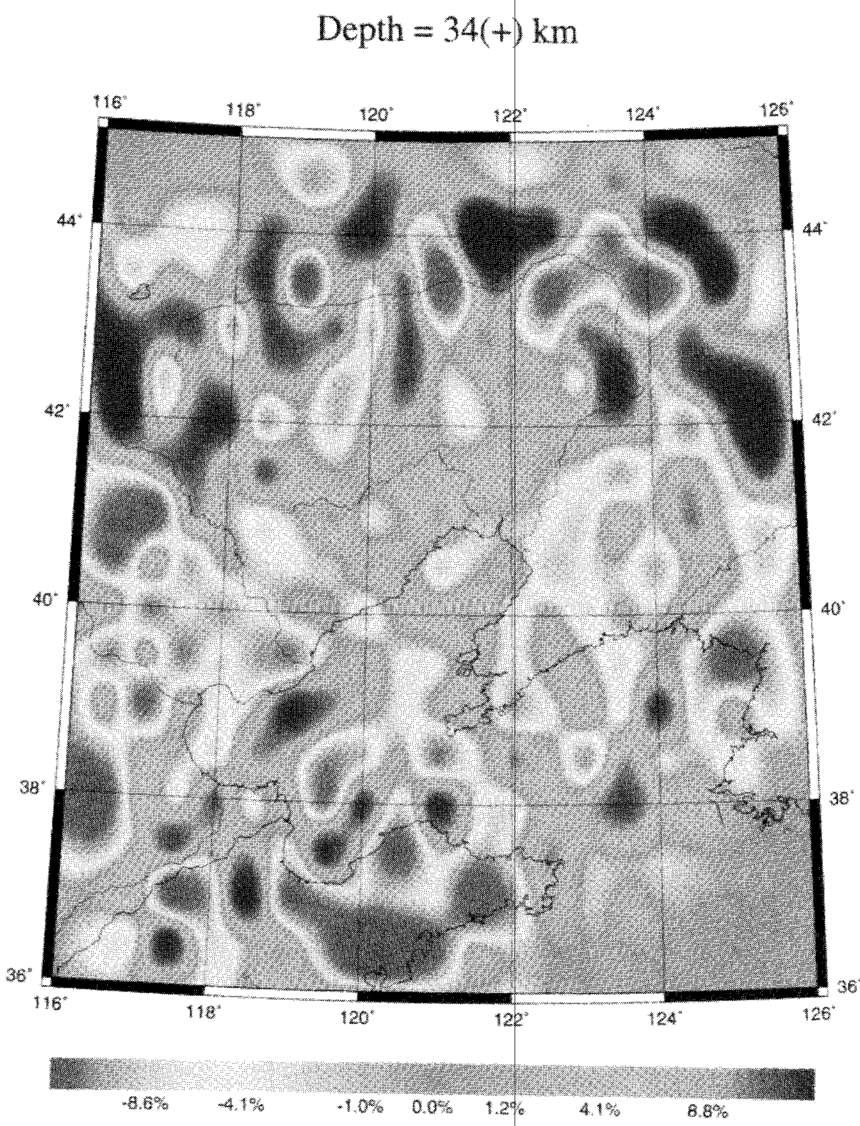

Fig. 6. The velocity image in the depth of 34 km.

basin and its adjacent regions. So in the velocity model we take a depth of 34 km as Moho interface in the study region. The velocity image revealed the variety of Moho interface in the study region. Generally speaking, the high velocity anomaly region represents the Moho interface uplifting, the low velocity anomaly region represents the Moho interface falling. It can be seen in Fig. 6 that the high velocity regions mainly are located in the west Liaozhong - east Bozhong depressions - Dongying - Liaocheng Shandong province belt, the east Luxi uplift , the wide Yanshan mountain orogenic belt and Changbai mountain regions located in north of 41°N. These velocity anomaly regions represent that the Moho interface depth is smaller than 34 km. The low velocity regions locate in Tangshan - Tianjin - west Cangzhou - Dezhou belt, Ludong uprift - Liaodong peninsula belt, the north Bozhong depression - Bozhong convex - Liaodong bay - Haicheng - Benxi

- Fushun belt, Cheng and Yanqing located on the southern fringe of Yanshan mountain - Jixian - Baodi strip. We can infer that the Moho interface is deeper than 34 km.

It is needed to point that the feature of the shape and properties of Moho interface are very complicated beneath Bohai basin and its adjacent regions where the extension deformation is the most strong. Though the Moho interface obvious uplifts within the extension structural deformation belt, the uplifting amplitude is still different in different extension structure location, for example in the center of Bohai basin the Moho interface is shallower than that in Liaodong bay.

4.3 The velocity image in the depth of 71 km

The velocity image in the depth of 71 km is shown in Fig. 7. The lithospheric thickness is about 70 km - 80 km in the eastern part of North China plate. In the regional scale, the velocity distribution in the depth of 71 km shows obviously low velocity anomaly in

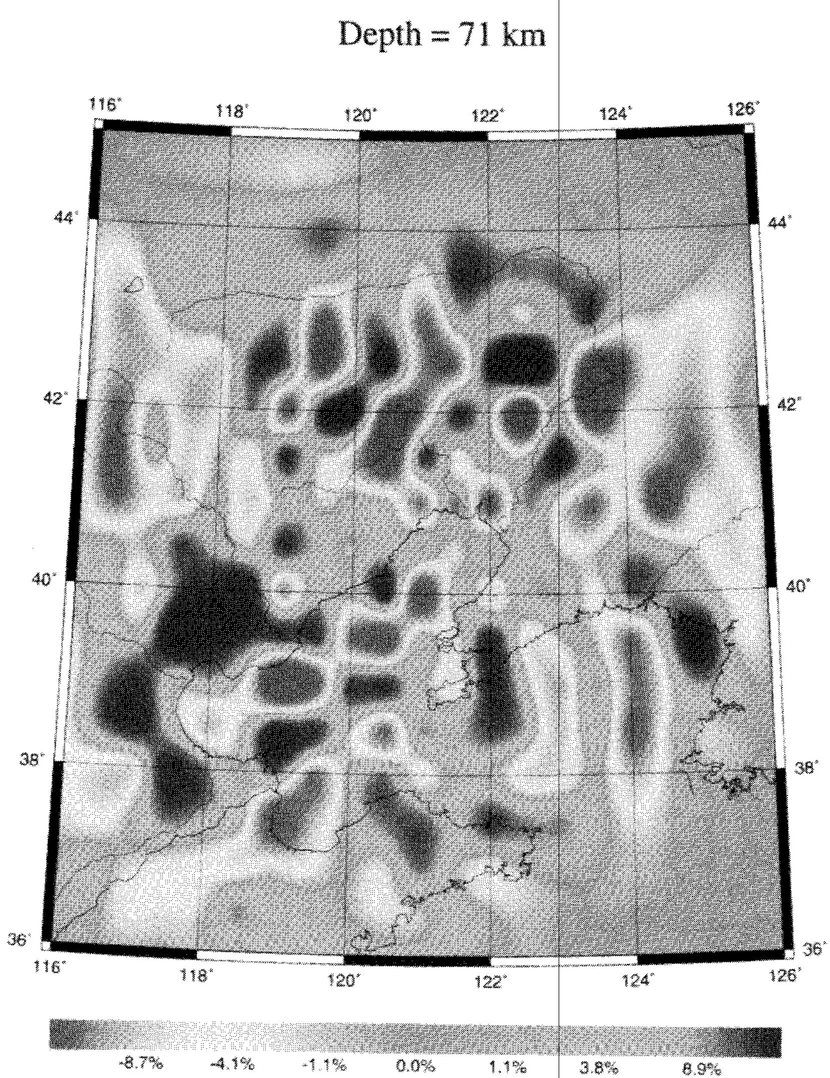

Fig. 7. The velocity image in the depth 71 km.

the south part of Jizhong depression , the north - west part of the center Bohai depression and Liaodong bay, indicating the asthenosphere uplift. In the velocity image of the depth of 71 km, the high velocity regions are in Huimin depression - Yellow mouth - the southern fringe of Liaozhong depression strip, Cangzhou - Tianjin - Tangshan - Qinhuangdao - Suizhong strip located on the western fringe of Bohai sea basin, Jiaodong peninsula - Penglai - Liaodong peninsula strip, Jianchang - west Kulun located in Yanshan mountain area and north-west Chifeng, Jinzhou - Fujin - Zhangwu -Changchun strip in North-East China region. The low velocity anomaly is in Taian - Jinan -Laizhou bay strip, Qikou depression located on the west fringe within Bohai basin - the west fringe of Bozhong depression - the center zone of Liaodong bay - Panjin - Zhangwu strip, Chaoyang - Kulun strip, Chengde - Chifeng strip.

The features of the velocity distribution may be related with the deep processes of the lithosphere and asthenosphere in the upper mantle. With regard to the low velocity areas, the velocity values are lower than that of the rock association of eclogire facies (8.13 km/s - 8.58 km/s) and ultramafic rock(8. 19 km/s - 8.59 km/s) in upper mantle, and is close to the velocity value of the asthenosphere in the upper mantle (7.7 km/s). So it is quite evident that the low velocity areas of the depth of 71 km is probably not the rock association of the lithosphere in the upper mantle, indicating that there is asthenosphere uplifting and falling in the low velocity material under the low velocity area.

5. Conclusion and Discussion

1) The velocity images given in this paper indicate the lateral heterogeneity of the crust and upper mantle beneath the Bohai sea basin and its adjacent regions, which persist down to the bottom of the study area. The correlation between the velocity image and the known surface geological feature can be traced down to the depth of 71 km.

2) In the eastern region of north China plate, the late Mesozoic to Cenozoic geological events are characterized by the intense continental extension, the lithospheric thinning and the volcanic extrusion or eruption. Researches show that the lithospheric extension is dominantly formed by the listric detachment faulting which is developed in the upper and middle crust.

3) In the extensional domain, the seismic velocity in different tectono-layers is still in the form of heterogeneity. But the geodynamic processes to form the unique heterogeneity of crust and upper mantle are obviously different. The probable factors to develop the middle-and-upper crustal heterogeneity resulted from the crustal extension and the footwall tilting of major detachment faults, that the lower crust resulted from the formation of crust-mantle mix layer and the uplifting of Moho discontinuity, respectively. The processes to thin the continental lithosphere are not wholly from the effect of asthenospheric uplifting but on the most extent from effect of some lithospheric mantle having been transformed to the asthenospheric mantle (metasomatism) accomplished by the interaction of asthenospheric liquid with the lithospheric mantle. Which is characterized by the occurrence of high-velocity upper mantle anomaly in upper mantle.

4) The continental geodynamic processes to control the within-plate continental extension can be outlined as follows. At first owing to the pre-Cenozoic geological activities of peripheral plates, the lithosphere in the eastern region of north China plate had already undergone sinistral transpressive fracturing. Lately with the horizontal decompression, the upper mantle partial melting had initiated near some formed fractures and gradually some magma chambers developed. With the extraction of magmas from the different magma sources and the upwelling of extracted magmas, the metasome of upwelling magma with lower crust had formed the mantle-crust mix layer which had caused the Moho discontinuity further uplifting. On the other hand, some magma chamber had been transformed to the high-velocity upper mantle anomaly owing to the accumulation of high-density minerals such as the garnet and olivine.

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