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GEOPHYSICAL STUDY ON THE CRUST AND UPPER MANTLE STRUCTURE IN CHINA

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Crust and Upper mantle is the important place in which human beings live and obtain all sorts of resources, energy sources, transform and make use of the nature, and a place for the basic study of Geoscience,Since 1960s, the study of it develops rapidly. The physical exploration on the crust and Upper mantle of China's continent, costal area and transitional zones has a special position in the study of global plate tectonics and its driving mechanism.

1.The crustal structure of Qinghai-Tibetan Plateau.

Qinghai-Xizang plateau is a very active region with its spectacular Himalayas. In order to investigate the uplift of the plateau and the formation of the immensely thick crust as well as the characteristics of the collcsion between the Indian and Eurasion plates, the Institute of Geophysis, Academia Science has carried out explosive seismic soundings in that area from 1975 to 1977. From 1981 to 1982 studies of the structure of crust and Upper mantle in Xizang plateau were made through the cooperation between China and France. Four seismic profiles were completed, Some with sources under lake water.

Profile 1. Yadong-Nimu-Dangxing profile is about 450 km long which is the main profile. Secondary profiles along Dalong-Qushur-Dangxiong and along Langkaze-Kangma-Yadong were also made with a total length of about 1000km

Profile 2. Pu Muo Lake-Ding Jic-Pegu Lake is about 470 km long which is also a main profile. Secondary profiles were along Langkazi-Rikage-Pegu Lake and along Tingjie-Lajie-60 Daoban-Nyanang.The accumulated length of the profiles is over 1000km.

Profile 3. Serlin Lake-Peng Lake-Baqen county profile is about 500 km long.

Profile 4. Kaba-Renbu-Damxung-Amdo Profile is about 500km long.

Data obtained from the above profiles were processed and inverted, the characteristics of the layered structure and velocity distribution were obtained (Table 1). It was found that there was a low-velocity layer in the crust.[1;2] (Fig 1).

Table 1. Average velocities along Yadong-Namu Lake profile.

Wave names	average velocity (km/sec)	layering velocity (km/sec)	remarks
t_1	4.69±0.12		
t_2		5.99±0.06	
t_3^0	5.82±0.03		
t_3		6.22±0.05	
t_4^0	5.94±0.03		The layer velocity of the medium between t_4^0 and t_5^0 is 5.69±0.3km/sec, This is one Low velocity layer.
t_5		7.24±0.3	
t_5^0	5.75±0.20		
t_6^0	6.23±0.08		
t_6		8.15±0.03	

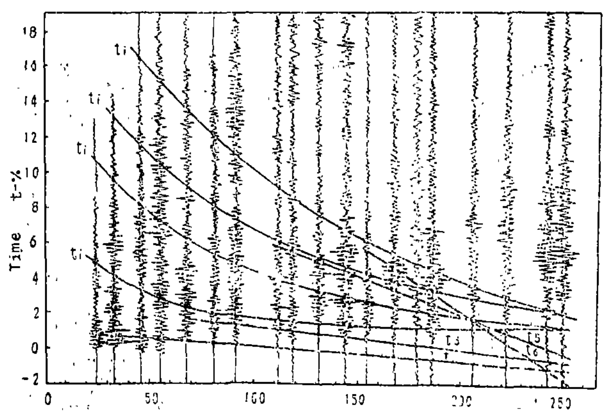

Fig 1. A record section along profile Yarzhoyum Lake-Qushu-Damxung

The Crust of Tibetan Plateau is tremendously thick reaching 70-75km, and is composed alternating layers with higher and lower velocities. The velocity distribution of the wave field indicates that although the crust is thick, it is not formed by the superposition of two crusts. The average depth of the low velocity layer at the north part of Yalongzangbo river is 40—45km; at south Xizang, it is 29—45 km. The thickness of the low velocity layer is about 10 km. Yalongzangbo river is a deep fault zone, which may extend to the top of the Upper mantle(Fig 2).

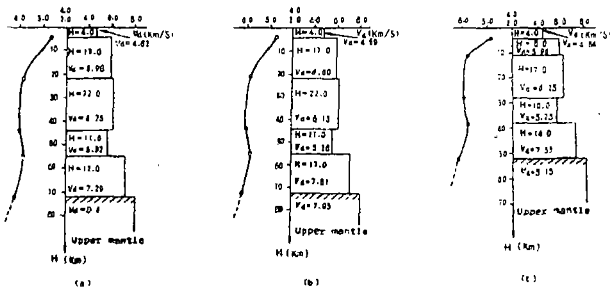

Fig 2. The average crustal model of north part (a). South Part (b) ofYaluzangbo river and Himalaya region (c) .

The Vo (r_0 • P) and Vo(r_0 • T)curves along the east-west profile of Bumu lake-Tingjie-pegu Lake also indicate the existence of low velocity layer in the crust. The result of ray tracing shows that along this profile, the underlying medium is laterally inhomogenous and there is relief of the interface comparing the theoretical seismograms with the observed seismic recordings, it shows that Moho interface is a very strong reflector and further confirms the existence of the low velocity layer in the crust and the crustal velocity structure[2].

Yalongzangbo river is a great fault that extends to the top of the upper mantle, with steep angles and there exists a rupture zone of about 30-50 km width.[1] The enormously thick crust of the Xizang plateau was formed by north-east motion of the Indian plate colliding with the Eurasion plate during the course of continual compression, the rising temperture in the crust caused the partial melting of the medium and gravitational differentiation.[3]This also caused the great difference between the south part and the north part of the plateau. Owing to the obstruction of the hard block at the north margin of the plateau, at the force constrained boundary, there resulted voilent deformation of the Himalaya zone and a series of strong reversed thrusting were formed between the main boundary fault and the main central fault, accompanied by horizontal contraction and increased thickness of the crust. Thus the pattern was formed so that the plateau itsself was thickened, but its north and south margins were relatively thinner. In the transition zone of collision and compression between the Indian plate and Eurasian plate [4], the Himalaya region is not only strongly deformed and complicated in its upper surface,it must have caused great relief in its lower boundary, which formed the interface between the crust and upper mantle.

The studies of earthquake body waves reveal that the upper mantle structure under the plateau and its vicinity have different regional characters. The P wave velocity of the top of the upper mantle under the plateau is Vp = 8.11 ± 0.04km/sec on the average. In the Tengchong region, there exists a low velocity layer, its velocity being 7.59 ± 0.09 km/sec. In north east Indian plate, the velocity is 8.19 ± 0.13 km/sec, at depth between 40—170 km[5]. The depth of 20° discontinuity (here is 19°) is 450—500km, and the velocity under the interface is 9.9 km/sec. The p wave velocity between 20° discontinuity and Moho interface increases with depth and also near to that in the platform. The velocity at the top of the upper mantle under the plateau is higher that under the Himalayas, but lower than that of the Indian peninsula. This indicates that the strength of the lithosphere varies with smaller deformation associated with smaller strength. Possiblely this is one of the reasons that the movement at depths under the Himalayan range is much stronger than that under the plateau. The Himalayan zone is not in isostatic[6] equilibrium and the plateau is still rising.

In addition, the group velocity of the surface wave in the plateau with period less than 120 sec is lower than the average value in world. This shows that the tectonic anomaly is very deep, perhaps extending to the upper mantle. The mantle low velocity layer is about at the depth of 90 km[7]. Other data also confirmed this conclusion[8—9].

2. The crustal structure and its high velocity interlayer at Qinghai-Gansu area.

At Qaidam basin of Qinghai province and Baiyinchang-Jingta of Ningxia province, seismic explosions were carried out to study the top structure and velocity distribution of the crust and upper mantle in detail. The distance between the observing points was 100 meters and reversed shootings were made.

The velocity in the crystalline basement rocks at Qaidam basin is quite high and they covered with Mesozic and Cenozoic sediments which are Oil-bearing structure[10]. Good reflections and refractions seismic waves were recorded on the west Yuka-Gansen and east Doqaidam-Garmu profiles in Qaidam basin each of them being over 120 km long. Clear phases could be discerned at distances as far as 40 km from the shot points and beyond, and continuonsly traced. Here the crust is composed of 7 layers and its total thikness amounts to 50—51 km. The velocity at the top of upper mantle is 8.2 km/sec and there are two low velocity layers in the crust: the first is at depth 30.7 km with velocity 5.4 km/sec; the second is at depth 38 km with velocity 5.9 km/sec(11).

At Jingtai-Baiyinchang region of Gansu province the crust is composed of layers, with total thickness about 50—52 km(12). This profile passes through the vicinity of the famous Hai Yuan earthquake of 1920.

In both Baiyinchang Jingtai region in Gansu and Qaidam basin in Qinghai, a group of reflected waves with very strong energy were observed. They are different from the ordinary reflected waves in that their apparent velocity is very large, but does not very much with distance; they have rather clear terminal points. Their time distance curves intersect with the time distance curves of the ordinary reflected waves. The various parameters of these layers are listed in Table 2

Further investigations are needed on the buried depth and property of this high velocity gradient interlayer and its relation with the evolution of the crust.

Table 2. parameters of the high velocity interlayer madiums.

Parameters region	Jingtai region of Gansu	east Qaidam basin of Qinghai
Thickness of overlying medium of the high velocity interface (km).	18.8	30.5
Velocity of the overlying medium (km/sec).	5.5	3.3
thinkness of high velocity layer (km)	6.0	3.2
velocity in the high velocity layer (km/sec).	7.5—6.5	7.5—8.0
velocity gradient coefficient in the high velocity layer (a)	0.167	0.156

3. The crust and Upper mantle structure in the central part of Eastern China.

A. Yuanshi-Jinan profile in the central part of East China plain.

The crystalline basement of north China plain has metamorphosed greatly, resulting in very irregular changes of the t_3^0 phase and making it difficult to trace continuously. There is a local rise at the sides of the epicentral area of the Dongwang earthquake region with width of about 60—70 km. At the Taihang mountain in the west, the Moho surface is deep. Here is a deep fracture zone which may extend to the Upper mantle. A concentration of epicenters of shallow earthquakes is found here. The traval time apparent velocities energy variations and attenuation properties indicated formed. The characteristics that there exists a fractured zone width a width of about 30 km and crustal thickness there is about 35 km in the epicentral region in the region above the uplifted upper mantle, the earth surface clearly sinkes 27.8 cm, but the two sides of the sinking area rise to 3 cm[13,14].

Under the crust of this region, reflecting waves of t_9^0, t_{10}^0, t_{11}^0, t_{12}^0 and t_{13}^0 have been recorded. The property of t_{14}^0 wave has not been determined. The layer velocity difference of t_8^0 and t_9^0 is $\Delta V = 1.0$ km/sec (1) or 0.7km/sec (2)[16]. t_3^0 wave is the strongest phase among all of the reflected waves. Near the critical reflecting point the amplitude is maximum which implies the great difference of properties of the crust and upper mantle. Between $t_9^0 - t_{10}^0$, the layer velocity $V = 7.6$ km/sec, between $t_{10}^0 - t_{11}^0$, $V = 7.8$ km/sec; between $t_{11}^0 - t_{12}^0$, $V = 8.1$ km/sec; between $t_{12}^0 - t_{13}^0$, clearly drops to 7.2–7.4 km/sec; the buried depth is 83 km[16]. This is the depth of the low velocity layer and velocity distribution of the mantle at this zone (Fig 3). Comparing this result with the low velocity layer depth and velocity distribution in the Upper mantle at different tectonic units in the

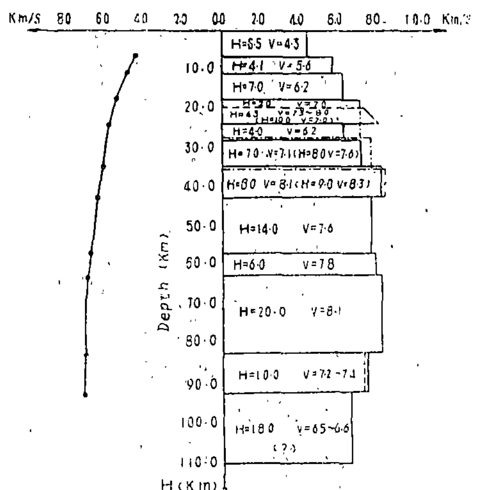

Fig 3　Velocity distribution and model of the crust and upper mantle in North China.

world, we find that in the zones of active tectonics, volcanos and seismicity, the depth of mantle low velocity layer may be quite shallow and its velocity value quite low. From this we can see that in the seismic region of Xingtai the mantle is inhomogeneous.

B. The crustal structure at Lianyungang and Chang Zhi regions.

The strike of Lianyungang linyi-Sishui profile is northwest and it crosses the Tanlu great rift zone. The maximum depth of Moho interface here is 35 km, and near Sishui, it is 34 km[15, 17]. From linyi to FeiXian the crust is only about 30 km. There exists a large scale rift near linyi(Fig4).

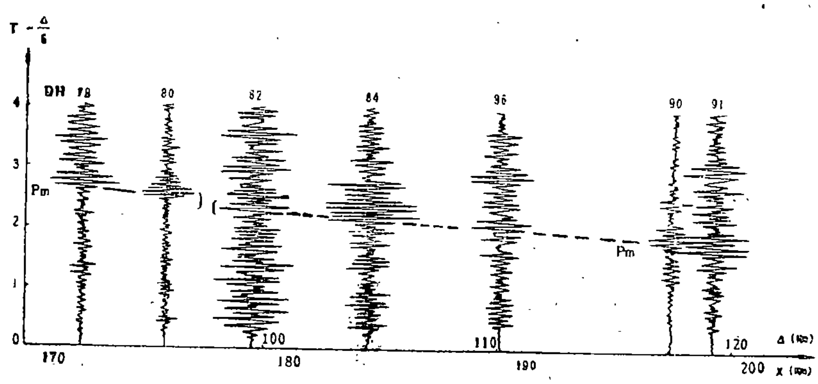

Fig 4 A recording section of a large scale rift near linyi

Along Changzhi—Lin Xian—Heze profile, the crustal thickness varies greatly, that is, from 29 km near Pu Yang 35 km at Linxian and 38 km at Dongyngou(13).

4. Crustal structure at Beijing and Tianjing and their surrounding areas。

In recent years, explosive seismic sounding has been done in Beijing, Tianjing and their surrounding areas. The region is located in the north part of North China Plain, and belongs to North China seismic zone. This region is located at the south of the Yan Shan depression zone which strikes nearly east-west and at the east of Tai Hang uplift which strikse NNE. Its shallow tectonics is very complet. From 1968 to 1982 seismic sounding were carried out along 12 profiles with a total length of 5150 km.

By inverting the data obtained from these profiles, the result shows that the crust here is clearly layered with velocity increasing with depth. but there also exist lateral variations.

In order to reveal the deep structure background of the Tang Shan and Ning He earthquakes which have caused severe disaster in 1976, we used the data from the east part of Le Ting-Zhangjiakou profile which has passed by the earthquake area(18). Through comparisons of the recordings, we have got 4 wave groups, P_1、P_2、P_3 and P_4. From the results of the interpretation of these four groups of waves, we proposed a model of the crustal structure (Fig 5) in Tang Shan-Ning He earthquake region. The model is composed of sedimentary and two crystalline strata separated by a high and low velocity interlayers. There are velocity gradients in both the upper and the lower strata.

In this earthquake area, the P_4 wave group is very strong, which reflects the velocity stucture of the lower crust. P_4 data are used to inverse the structure and the results are shown in Fig 5b. From the figure, we can

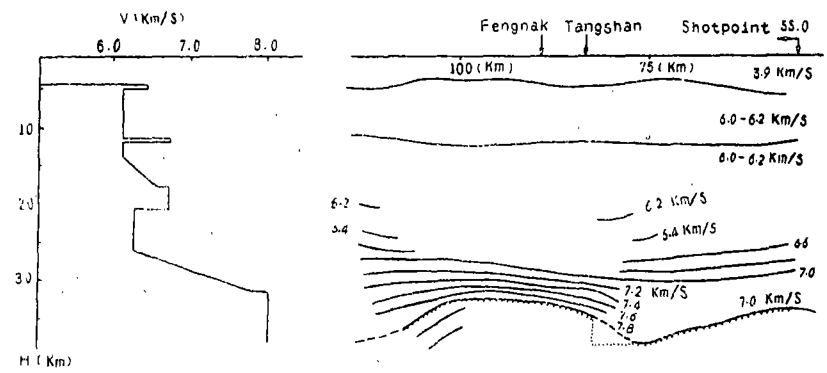

Fig 5　Deep structure of the Tang Shan-Ning He earthquake area
a. veloity-depth model
b. horizontal velocity variation

see that the variation of velocity in the lower crust is greater than that in the upper crust (not including shallow sediment). The crustal velocity at Tangshan area increases from 6.7 km/sec at 25 km depth to 7.8 km/ses near Moho. Under the Moho, the velocity still has apparent gradient. The depth of Moho under Tang Shan is 31 km and it suddenly increases to 36 km at about 15 km south-east of Tang Shan and whence it rises a little and then an obvious rift of the Moho seems to have occurred. Corresponding to this, the layer of equal velocity in the lower crust also shows disconformity at the same place.

Since 1974, depth sounding by use of converted waves in natural earthquakes has been done in this region[19,20,22]. Observations were made at Luxi, Beijing, Tianjing, Tang Shan, Wenba, Linyi of Shan Dong province and Da Ya Wan of Guang Dong province.

In order to get a general picture of the deep structure of Beijing—Tianjing area and neighbouring regions (Fig 6). By using the telecommunicated network of stations of natural earthquakes to study the three—layered crustal model and division of crustal thickness[21], the shape of the Moho at this area[23], and the three dimentional velocity structure of P waves in the crust and upper mantle[24]. Gravity data are also used to estimate the crustal structure of this area[25].

6. Profile of Sui Xian—Nanjing—Qidong and Sui Xian—Anyang.

The Institute of Geophysics, Academia Sinica has carried out explosive seismic soundings in eastern China, from Sui Xian eastwards, passing by Hefei, Nanjing, to Qidong at the entrance of Yangzi River along a profile

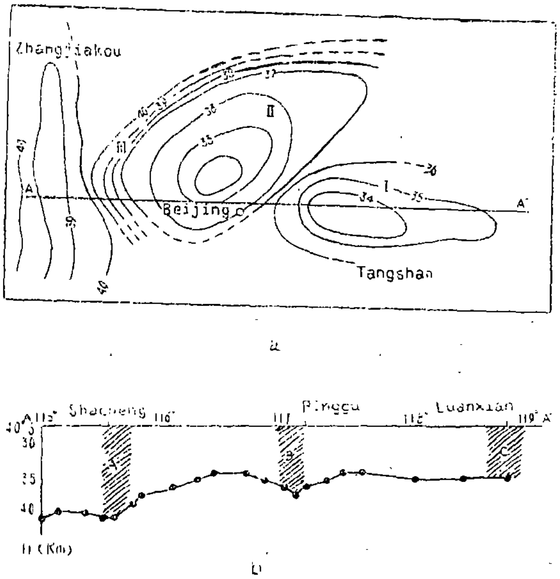

Fig 6 Distribution for the depth of Moho interface (a) and section(b) of Beijing-Tianjin Tangshan-Zhangjiakou.

of over 900 km long. Great amount of data have being obtained. The result shows that the crust at the east end of the profile is slightly thinner than at the west end. The crustal thickness is between 31—34 km, with mild relief. There is a fault with insignificant dislocation in the Ligang earthquake region. Along the great Tan-Lu rift the crustal thickness varies: This is a broad fractured zone with deep rifts when seismic waves pass by the wave form, frequency spectrum and energy change conspicuously. Low velocity layer exists in the crust. The data obtained from this profile are still under processing.

The Geophysical Institute of the Seismological Bureau has also carried out investigations along a profile from Sui Xian to Angang. There, the depth of Moho is 28—36 km, and the average velocity in the crustal medium is 6.24 km/sec. At Xinzheng and Qi Xian the Moho depth is quite large. In the sedimentary layer, the velocity is about 3.5 km/sec, in the Yellow River area its thickness is 5—6 km. At the south end of the profile, granitic rocks outcrop to the surface. At the bottom of the sedimentary layer, the head wave velocity is 6.0 km/sec. Between this layer and the Moho three layers can be discerned namely P_2, P_3^0, P_4^0 and among them P_3^0 is comparatively stable, corresponding to a layer of depth of 16—24 km, and the average velocity in its overlying medium is 5.97 km/sec. At Wuyang region there is possiblely a great deep rift.

6. Observations by use of surface waves and teleseismic P waves.

A. The result of surface wave study of the crustal structure.

Based on the inversion of surface wave data, Chinese continent can be divided into 5 blocks[26—30]; the Qinghai-Xizang plateau, Tarim basin, North China block, Mongolian block and south China block (Fig 6). In the crust of Qinghai-Xizang plateau and North China block, there exists low velocity layer. The average velocity in the crust is quite low, especially in the crust and upper mantle of Qinghai Xizang plateau the average velocities of S waves are respectively 3.43—3.49 km/sec and 4.37—44.4 km/sec. In these two blocks, the Conrad discontinuity does not exist or only intermite and there is lateral variation of structure. The seismicity in these blocks is quite active. In the other three blocks, there is no low velocity layer in the crust, but the Conrad discontinuity exists. There is no great difference among the various regions which thus exhibits the characteristics of a stable platform. Generally, the thickness distribution of the crust and sedimental layers is like this; to the east of the line joining Beijing—Wuhan—Guangzhou, including the continental shelf, the crustal thickness is 30—35 km; to the west of this line, the crustal thickness is 40—45 km and it is thicker in the north part than in the south part. At Qinghai Xizang plateau it is 60—70 km, and at Tarim basin it is about 50 km, with the thickest sedimentary layer up to 10 km. In the Mongolian block, the thickness of the sedimentary layer is 6—8 km; in the South China block, it is only 3 km. The structure of Yellow Sea is different from that of East China Sea and the South China Sea; They belong to North China block and South China block respectively. Their boundary is probably near the entrance of the Yantze River.

B. The study of upper mantle structure by use of natural earthquakes.

Previously, we have used Pa and Sa seismic phases to study the structure of upper mantle and estimate the depth of low velocity layer[31]. In recent years, we have turned to the method of Gerver and Mar—Kushevich formulation[32, 28], we have used the initial and later arrivals P waves and the slowness curves of continous arrials along the Beijing—Sahalin proflie to invert the velocity structure of the upper mantle in middle and south parts of North China (Fig 7).

The velocity model of this region[28, 33] is as follows: in the overlayer of the upper mantle, the velocity is 7.80—7.95 km/sec; the low velocity layer is quite shallow with depth of about 60 km, and the lowest velocity is 7.65—7.80 km/sec. The first transition zone is between 360—420 km depth. Starting from 620 km depth, the second transistional zone appears, both of these zones possess positive velocity gradients.

7. A general outline of the crustal structure in our country[34—37].

In the above we have mainly discussed about the long profile observa-

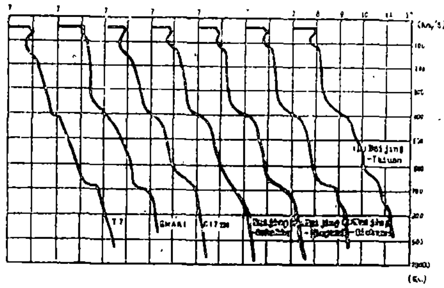

Fig7 Velocity model of the upper mantle.

tions on the Tibetan plateau, North China region, Beijing-Tianjin region, Sui Xian-Nanjing-Qidong and Sui Xian-Anyang regions. Through exploration in the crust and upper mantle with artificial seicmic source as the main means and through studies on the natural earthquake (body wave and surface wave), we have also discussed the crustal and uppermantle structures, the low velocity layer of the crust, the low velocity layer and 20° discontinuity in those regions, and their relationship with the occurrence and development of earthquakes, mineral distributions and plate tectonics and so on. It is clearly indicated that the crustal and upper mantle structure in China have its own remarkable characteristics as well its own ways in regional distribution. However this is not all the work in our counrry. For the same purpose of the above-mention, a great deal of regional studies have been made based on artifical seismic source, industrial explosions as well as on natural earthquakes. For instance, significant results have being obtained in north cast, Shandong, mid and south Shanxi, Yunnan, Gansu, Xinjing basic paraplatform region, Sichuan, South Liao, Qinghai and so on. Certain progress has also been medium the fields of seismic wave propogation and seismic source parameters, theoretical seismogram, ray tracing and inversion studies under different circumstances. The Q Value of seimic Wave in the process of medium propagation at the crust and upper, mantle energy variation of seismic waves in the great fault system zone, its property for absorption and the law of variation of the frequency spectrum will be important subjects for study. Further study and extensive application are made at present on the kinematic properties of waves during the medium propogation with a view to raising the extracted ability of imformation and obtaining data with much better precision.

The distributional property of the area under observation has indicated that Yangtze paraplatform crosses the whole region, in the north it is the Sino-Korean paraplatform and Qinling fold system; in the south it is the south China fold system and the south-east coastal fold system and there develops great deep rift within the region. Besides, at different geological periods, the magma activity anomlies are rather violent. The main seismic phases have being obtained through observation and analyses made in north east, South east, north west and south west Yong Ping county. The velocity value obtained are not identical with the crustal thickness on the profils. The lateral velocity distribution is inhomoeneous. The variation of the crustal thickness in the whole region is generally less than 7km. Based on a comprehensive study and analysis of data obtained with the artificial seismic source the surface waves and body waves (including P wave, S wave and transformed wave) of natural earthquakes, as well as studies about the crust and upper mantle through gravity and aeromagnetics, the variation of the crustal thickness and regional features as different places in our country have being obtained. In particular, the basic outline of China's crustal tectonics have being drawn on the basis of the clarification of the crustal thickness and deep fault.

The sedimental layer of the crust and the crustal thickness in China as a whole become thinner and thinner from east to west, But their distribution is inhomogennous. The abrupt change in crustal thickness have something to do with the earthquake activities and the tectonic motion. At the same time these zones are also a geophysical field zone with remarkable changes and geological zone with ophiolite set and melange, as well as a zone concentrated with large scale rifts. Based on those factors, the whole country and its neighbouring regions can be divided into 9 blocks such as A, B,C,D,E,F,G,H,I. As the boundaries of the blocks are cut by the longitudinal large scale rift, so many inlaid tectonic blocks have been formed in the mainland of China, its neighbouring regions and the sea. The size and morphology of those blocks varied which reflect the property of the motional matter at the deep crust and upper mantle and their impact on the crustal tectonics and morphology. This is an important basis the study of the intraplate tectonics, mineral distributions and seismogenesis in the China continent.

9. Conclusion

China is situated under coeffects of the Indian plate, Pacific ocean plate and Eurasian plate. Either from the geological tectonics or from the division of geotectonic units properties, tectonics of intraplate and plate margin are quite complicated and the features of activity are different. The crust and upper mantle structures have obviously unique regional characteristics.

International solid earth science program for 1980s centers on the study of lithosphere. This shows that the study of crust and upper mantle has far reaching significance in recognizing the evolution of the earth the law for minenalization, the formation of oil and gas basins, seismic pregnancy and seismogenesis, and pushing the earth science towards a new depth. Physical exploration on transitional and marginal zones of the crust and upper mantle of the China continent, it has special position in the investigation of the global plate tectonics and its driving mechanism.

Significant results have being achieved in recent years, which have laid a foundation for the deep study at this field in our country. As the earth is a comprehensive system, in order to get a better understanding of the lithosphere in an all around way, coordinated and more profound studies in the depth of the crust and upper mantle are needed. This will be an important fields for the study of solid geophysics as well as the structure of the core, the state and composition of the matter in our country, which has already been listed as an important subject in our natinal program.

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中国地壳与上地幔结构的地球物理研究

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摘　　要

地壳与上地幔是人类居住与获取各种资源、能源，改造和利用自然的重要场所，是地球科学的基础与生长点，六十年代以来发展迅猛。中国大陆、海域和过渡带地区的地壳和上地幔物理探索，在全球板块构造和驱动机制的研究具有特殊地位，文中分别就 1）青藏高原地区的地壳结构，2）青海、甘肃地区地壳结构和地壳中的高速块层，3）中原地区的地壳与上地幔结构，4）京津及外围地区的地壳结构，5）隋县—南京—启东和隋县—安阳人工地震探测面的观测，6）利用面波和远震P 波确定中国地壳和上地幔结构，7）中国地壳结构的基本轮廓等方面进行了讨论。