THE MULTI-EVOLUTION OF MANTLE PLUME AND THE MECHANISM OF GEOTHERMAL ORIGIN IN THE EASTERN NORTH CHINA

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ABSTRACT

The characteristics, distribution and the origin mechanism of geothermal anomaly in the North China Basin were discussed in this study. It is proposed that the uplifting of the giant sub-mantle plume is the dominant power for the crust breaking, faulted depression as well as the origin and evolution of geothermal fields in the North China. And the geothermal gradient distribution resulted from secondary uplifts and depressions within the North China faulted depression shows the representation of structure controlled geothermal anomaly.

Key words: The North China, faulted depression, mantle plume, geothermal anomaly

1.INTRODUCTION

The Earth is a giant heat reservoir, high temperature of its deep materials contains enormous energy which successively moves towards the surface. So, many scientists focus their eyes on trapping, studying, exploiting and utilization of geothermal anomaly. Much progresses have been made about the distribution of geothermal fields, the relationship between geothermal fields and deep structures, the geothermal field characteristics in uplifts and depressions, geothermal water characters and its distribution pattern (J. S. Lee, 1970; L. P.Xiong & J. M. Zhang, 1988; J. Wang etc., 1983; M. X. Chen etc., 1985; N. X. Chang, 1989; J. Y. Wang, 1997). But, there still have controversies about the regional geological background and heat origins for the North China geothermal anomaly.

Based on the study on the structure of the North China sub-mantle plume, the authors proposed that the uplifting of the North China sub-mantle plume is the deep structural background of geothermal anomaly in the North China faulted depression which was resulted from the later stage heating and thinning during the process of mantle plume evolution.

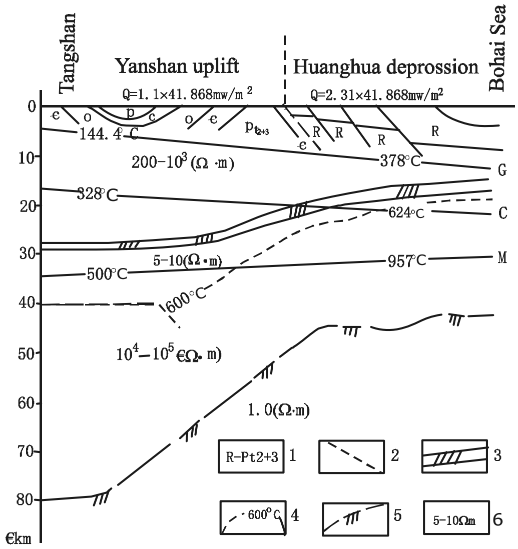
2. CHARACTERISTICS OF GEOTHERMAL ANOMALY IN THE NORTH CHINA FAULTED DEPRESSION

The geothermal anomaly in the North China depression is not only characterized by wide distribution and high geothermal gradient, but also is controlled by deep structures. Generally speaking, it can be concluded as three characters: ① the basin is hot inside and cold outside; ② the basin is hot in low velocity layers and cold in high velocity layers; ③ the basin is hot in active zones and cold in stable zones. It may be controlled by a uniform mechanism.

2.1 Hot Inside and Cold Outside

Generally the geothermal anomaly mainly distribute within the basin, the anomaly is gradually decreased towards the surrounding. This is related with the thickness of lithosphere. Within the north China faulted depression, the mantle is intensively uplifted, and the crust is intensively faulted, the lithosphere is only 60km in thickness. But for the surrounding mountains, the thickness of lithosphere rapidly increases to 100km, even up to 160km in Taihang mountains and Yanshan mountains. Based on the survey data of average heat flows and seismic sounding, the workers in The National Bureau of Seismology use two dimension finite method to calculate the distribution of crust and mantle geothermal state in Tangshan-Bohai area (Fig.1).

The temperature in the bottom of all crustal beds displayed the change trend of the hot inner and cold outer, of which from the basin to mountain area, the temperature in the bottom of the upper crust decrease from 387°C to 144 °C, that of the middle crust from 624 °C to 328 °C, that of the lower crust from 957 °C to 530 °C. Obviously, the temperature of the bottom of all crustal beds in the fault depression area is higher than that in the mountain area. Especially, the temperature of the bottom (Mohorovicic discontinuity) in the faulted depression area is about 400 °C higher than that in the mountainous area. The temperature difference in the upper mantle is all the more obvious.



1-sedimentary layers; 2-faults; 3- intracrustal high-conductivity layers; 4-buried depth for 600°C;
5- high-conductivity layers in upper mantle; 6-resistivity value, unit (Ω m)

Fig.1 Profile showing the electromagnetic sounding and the temperature-depth of Tangshan to Bohai Sea (after Chang Enxiang, 1989).

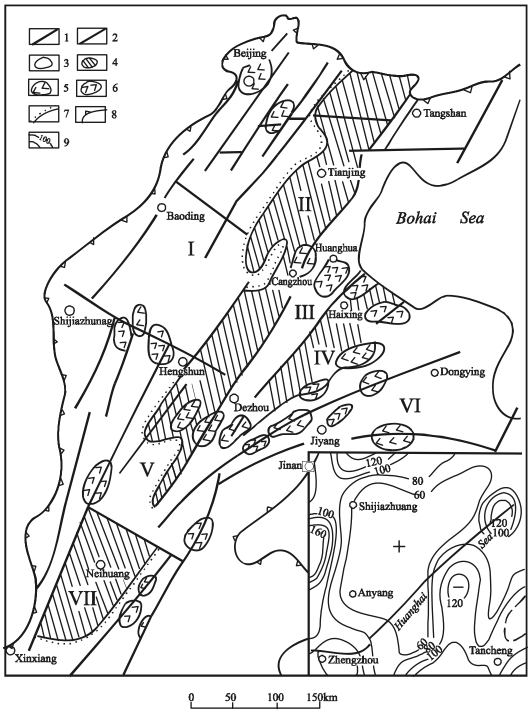
2.2 The Important Source of Heat the Lower- Velocity and High- Conductance Beds in the Crust and Mantle

The lower- velocity and high- conductance layers in the crust and mantle are two important structure beds, and important source of heat, too. Contrasted to adjacent layers, they are high temperature beds, characterized by lower density, lower seismic velocity, high conductance, and high temperature. The lower- velocity layers in the crust develop well in the faulted depression area. They are located in the middle crust, about 12～15km in buried depth, with 3～10km in thickness. Their variation of the thickness is closed related with the thickness of crust and hunch and depression of upper mantle, and controlled by deepseated structure. In the upwelling area of thin crust, the lower- velocity and high- conductance layers developed well. Their thickness is bigger, and their temperature is up to 500～600 °C, whereas the thickness is smaller, and their temperature is lower.

The lower- velocity and high- conductance layers in the mantle occurred both in the faulted depression area and in the peripheral upwelling area. Their buried depth varied largely from several tens kilometer in the faulted depression area to up to a hundred kilometer, such as 45km in Haizhong upwelling block, 50～60km in Jiyang and Huanghua depression area, 50～70km in Jizhong depression area, and 80～90km in Chengning and Cangzhou upwelling blocks, whereas up to 150～200km in the peripheral mountainous area. Within faulted depression area, the buried depth in the secondary faulted depression unit is smaller than that in the subsidiary uplifted unit, and the undulation is consistent with the upper mantle bulge or depression. Existing information indicate that partial melting material in the lower- velocity and high- conductance layers of the upper the mantle is up to 15%, and their temperature up to 1000～1300℃.

2.3 High Geothermal Anomaly Gradient in the Active Area

The geothermal anomaly in the North China is related not only to the inner and outer of the basin, but also to structural activity. Obviously, the faulted depression area in the North China is the most active, and the geothermal anomaly is the highest. In the high geotemperature background, the geothermal anomaly has a bearing on structural feature. According to structural controlling, the North China faulted depression area can be subdivided into a series of secondary-structural units, such as Jizhong depression, Cangxian upwelling, Huanghua depression, Chengning upwelling, Jiyang depression, Linqing depression, Neihuang upwelling etc., and about 100 third- order structural units. They constituted the structural framework characterized by interlaced arrangement of secondary and third order upwelling and depression (Fig.2).



1-transcrust fractures; 2-intracrustal fractures; 3-depression in plain; 4- apophysis in plain; 5- Tertiary blind basalt; 6-Quaternary blin d basalt; 7- Paleogene overlap line; 8- boundary of mountain and plain; 9- depth of low-V layer
I- middle Hebei depression ; II- Cangxian apophysis; III-huanghua depression; IV-Chengning apophysis; V-Linqing depressio; VI-Ji yang depression; VII-Neihuang apophysis

Fig.2 Distribution of faults in the northern part of the North China plain.

The results from actual measurement manifest that the geothermal gradients are the highest in the active area, and are the lowest in the margin of the basin and mountainous area. The drilling has revealed that in the margin of the basin and mountainous area, the average geothermal gradient is lower than 3.0 ^{o}C /100m, the geotemperature in 1000m depth is lower than 30 ^{o}C; in the depression area of the basin, the average geothermal gradient and geotemperature in 1000m depth are lower, the former is about 3.0～3.5 ^{o}C /100m, the latter is about 30～45 ^{o}C; whereas in the secondary and third upwelling blocks within the fault depression, the average geothermal gradient and geotemperature in 1000m depth are higher, the former is about 3.5～6 ^{o}C /100m, individual up to 12.6 ^{o}C /100m, the latter is about 45～60 ^{o}C, individual up to 80 ^{o}C. The distribution of higher or lower geothermal gradient and geotemperature is structurally in accordance with the upwelling or depression of the basement. Overall, the average geothermal gradient and geotemperature in same depth increase gradually from peripheral mountainous area to the center of the faulted depression, and from shallow fault depressions to deep ones.

3. THE CHARACTERISTICS OF FAULT MOVEMENT IN THE NORTH CHINA FAULTED DEPRESSION AREA

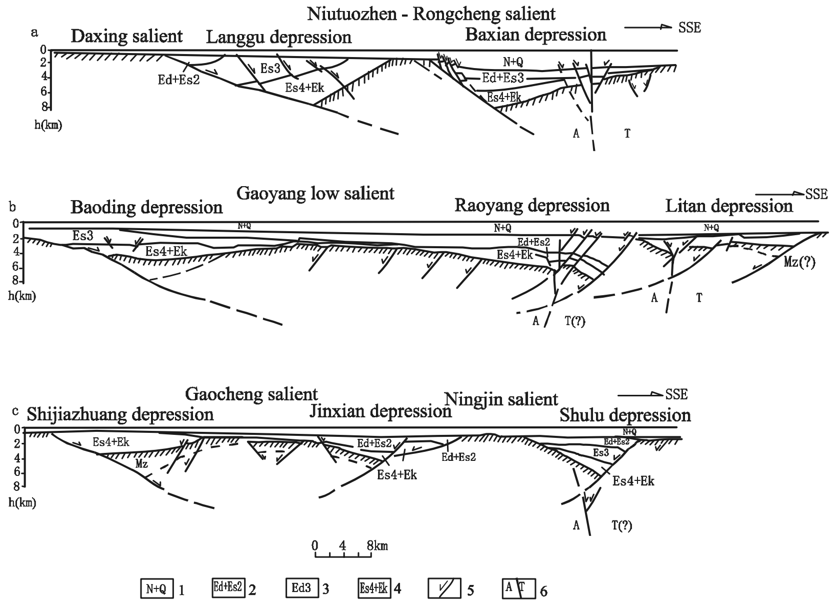
The structural movements have been relatively violent since Mesozoic Era in the North China faulted depression area, where occur not only the North China faulted depression basin, but also intensive fault structure, magmatic intrusion and volcanic eruption. The Cenozoic structural movements succeed to the Mesozoic ones. The faulted depression area further cracked, and the peripheral upwelling blocks intensively uplifted. This obvious differential ascent and descent resulted in typical basin- mountain structure.

Regional faults, as controlling the faulted depression basin, can be subdivided into two types, one is boundary fault, such as Taihang mountain piedmont fault, southern Yanshan mountain marginal fault, and Tanlu fault etc. these faults, with large scale, and as transform zones between mountains and basins, cut the crust or upper mantle, and control the differential ascent and descent between mountains and basins. Although they took place change once, the nature of the faults are dominated by normal faults, the slip of faults are more than several kilometer in total.

The faults within basins control the formation of the basins and the secondary structure such as graben and horst. They are determined by deep seismic detection, natural seismic converted wave sounding, gravitational measurement, the occurrence of Cenozoic basalt, and the distribution of recent earthquake. The faults within basins roughly divided into three groups: NE- NNE trending, NW- trending and EW-trending, of which the earliest faults is EW- trending, and the latest faults is NW- trending, whereas the most intensive faults is NNE- trending. Of course, these are general characteristics, and the three groups of faults also experience multiple activities and mutual crosscut (Fig. 2).

Most faults are inherited, some are fresh. They are generally characterized by large-scale, steep occurrence, deep cutting, and diverse direction of dip. EW-trending faults generally dip south, and NE- NNE trending mostly dip SE, some dip NW, NW- trending generally dip SW. most of them are normal faults, or dominated by normal faults. Most faults cut- through crystalline basement and crust, some cut- through Mohorovicic discontinuity even up to upper mantle. These faults controlled the development and evolution of the basins, and controlled the secondary and tertiary structural units within basins. Such as Jixian-Baxian fault, Cangdong fault, Chengxi fault, and Cangnan fault.

They are boundary faults controlled secondary graben and horst structure within the basins, and even have very large slip of faults. Taking relative drop in level of secondary order graben and horst within the basin as reference system, the largest thickness of Cenozoic sedimentary materials is more than 8000m in Jizhong faulted depression, whereas the thickness of Cenozoic sedimentary materials is commonly less than 1,000m in Cangxian upwelling block. The thickness of Cenozoic deposits is more than 10,000m, but some drilling holes indicate that metamorphic rock of the basement was exposed under several hundred meters in Chengning upwelling block. The vertical fault displacement of some boundary faults of graben and horst can reach more than 5,000～7,000m (Fig. 3).



a- Cross section in north basin; b- Cross section in middle basin; c- Cross section in south basin
1-Neogene and Quaternary; 2-Dongying Formation and 1st and 2nd members of the Shahejie Fromation; 3-3rd members of the Shahejie Fromation; 4-4th members of the Shahejie Fromation and Kongdian Fromation; 5-normal fault; 6-strike fault (A: fault wall moving away from the observer, T: fault wall moving towards the observer)

Fig.3 Cross section of central Hebei basin (modified from Lu kezheng et al. 1997).

4. EXTENSIVE MAGMATISM AND LARGE SEDIMENTARY FAULTED DEPRESSION

During Mesozoic, the magmatism came to the fastigium and covered whole eastern China, even it is named as Yanshanian Volcano-magma explosion (K.Y.Tao,1999). For the North China, the magma activity doesn't related with the subduction of Pacific plate, but shows the characteristics of within-plate activity. The magma activity began in Triassic, there are some S-type granite intrusions in the margin of the North China area. Some basic magma intruded along some places of deep fractures, their K-Ar and Ru-Sr geochronology is 160～238Ma. The magmatism extended throughout this area in early and middle Jurassic, the peak activity appeared in late Jurassic and Early Cretaceous. Influenced by basement faults, the Mesozoic magmatic rocks are zoned in E-W direction and differentiated in S-N direction in the south and north margins of the North China, but are zoned in S-N direction and differentiated in E-W direction in the east and west areas. The Mesozoic magmatism shows two different structure-magma associations, one is the association of sub alkaline volcanic rocks and granitic intrusions with some alkaline rocks, it mainly distributes along the margin of the North China faulted depression; another is within plate rift igneous rocks, it contains several series of alkaline rocks with some sub alkaline rocks. On the diagram of $\log\delta$-$\log\tau$ (Rittmann, 1973), more than 1,000 projected samples show that two associations have different differentiation trends which indicate different formation mechanism. The former is crust and crust-mantle mixed magma; the later is mantle derived magma.

From the exploitation of the North China oil field, geologists have opportunity to make out the characteristics of magmatism in faulted depression basin. X.D.Du (1999) studied the Mesozoic volcanic rocks in Wangguantong, Kongdian, Dagang of Huanghua depression and correlated them with regional terranes. It is indicated that there are many layers of volcanic rocks with considerable extension, they erupted during late Jurassic and early Cretaceous. On the TAS discrimination diagram, 30 samples (J_3-K_1) from Huanghua depression show the evolution series of trachytic basalt, basaltic trachyte, trachyte and rhyolite, which can be correlated with the early Cretaceous basalt, trachyte and alkaline rocks in Linyi-Linshu fault of Tancheng-Lujiang fault zone.

Because of the intensive uplifting of mantle under the North China faulted depression, the upwelling of low density and high temperature materials causes the breakdown of crust, then the faulted depressions developed, basaltic magma was intensively erupted and lithosphere was heated. In addition, middle to low crust would detach in side direction, crust become thinner, upper crust would slip down to side direction, the subsided surface would receive sedimentation and form a series of rift valleys and horsts, which constitutes typical basin-mountain structures. With the development of mantle uplifting, the whole North China faulted depression subsided, the upper Tertiary and Quaternary sediments cover the whole depression, which forms huge North China faulted depression basin.

The thickness of Cenozoic sediments is up to ten thousand meters, among them, the low Tertiary is 6,000-8,000m, the upper Tertiary is 2,000-2,500m, the subsiding speed during faulted depressing is 160～200m/Ma, the depression speed is 88～110m/Ma. According to the calculations made by G.D.Liu (1982), the subsiding speed is 0.16mm/a in early Tertiary, 0.2mm/a in late Tertiary, and 0.3mm/a in Quaternary. Based on the modern leveling and analysis on intensive and frequent earthquakes, the North China depression is still in activation, the C^{14} age of marine transgression stratum in the depth of 34m in Xialiaohe depression is 9,650 years. Level measurement indicates a 160mm subsiding amplitude during 1937 and 1980, its speed is 3.4～4.0mm/a.

5. DISCUSSION ON THE GENESIS OF GEOTHERMAL ANOMALY IN THE NORTH CHINA

All studies on tectonic setting, geological and geophysical evolution, mantle-crust structure, fracturing, magmatism, sedimentation, earthquake, geothermal evidence, and mineral resources in the North China indicate that there is a huge mantle uplift under the North China faulted depression， it is the North China sub-mantle plume.

5.1 Characteristics of the North China sub-Mantle Plume

Although there are some controversies about the origin, character, demission and uplifting speed of mantle plume, no disputes on the fact that the mantle is the upwelling of deep materials. It is accorded with the objective disciplinary.

Based on the studies made by scholars (Maruyama,1994;Fukao,1994)on the characteristics of mantle plume and the correlation of geological evolution and tectonics, we can conclude that there is a typical sub-mantle plume under the North China faulted depression. Deep survey indicates that basin-mountains in the east of North China is an intensive mantle uplift, it takes a mushroom shape to extend out. On the top of sub-mantle plume, light mantle materials move up as basic dykes or basaltic lavas, it makes the crust heated and faulted, forming a series of large fault basins which controlled by listric faults and receiving huge Cenozoic deposits. The lithosphere is only 60-80km in thickness. Around the sub-mantle plume, mantle materials extend as mushroom shape, the lithosphere rapidly increases to 100-120km in thickness, especially towards the west and north. In Taihangshan and Yanshan mountains, the lithosphere is up to 120-160km in thickness, which forms mantle ridge and mantle steps. Geologically it usually expresses as sharp thickness variation zone, gravity gradient zone, earthquake zone and hot spring zone in the crust.

Moreover, there exists obvious velocity layering in the lithosphere. The up crust is dominated by sedimentary rocks, its thickness is 10km± on the top of sub-mantle plume, which can be divided into Mesozoic and Cenozoic covers, Paleozoic cover and crystallized basement velocity layers. The middle crust is dominated by low velocity layers and is characterized by an alternative distribution of high and low velocity layers. The minimum velocity is 5.8～6.0km/s, the thickness is only 8-10km on the top of sub-mantle plume, then increases to 12-20km in the surrounding. The lower crust is a positive gradient zone, the top speed is 6.2～6.4km/s, and the bottom speed is 7.3～7.6km/s，it also is characterized by thickening towards the surrounding. In addition, the velocity gradient obviously increases near the division between mantle and crust, the thickness of this transition zone increases from 2km in sub-mantle plume to 5-6km in surrounding. There is a velocity leap from 7.3～7.6km/s to 8.0～8.1km/s in the transition zone (W.C. Sun, 1988).

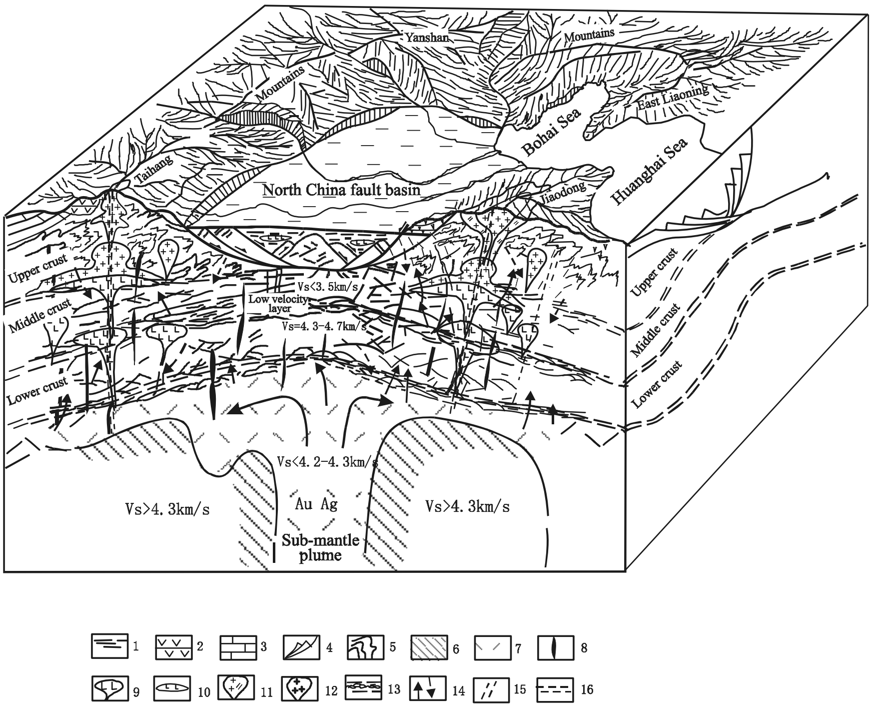
It is the extension of sub-mantle plume and the mantle potential difference to make the deep lithosphere materials detached towards the bottom of orogenic belts through mantle-crust transition zone and middle crust low velocity zone (ductile shearing zone). However, once the low velocity layers were cut through by active steep-declined ductile shearing zones, the decompression and load-releasing from the shearing zone will cause the soft materials in low velocity zone become anatectic magma which move up along the ductile zone, even pass through the shallow brittle fractures, come to the surface and form volcanic eruption. This will result in the dot-like or linear magma chambers along the orogenic belt, which represent the third grade evolution of mantle plume, and is named as mantle-branch structures. The density inversion of magma (especially for granitic magma) could promote the velocity and amplitude of orogeny uplifting, they usually express as rise structures which take the structure-magma zone in mantle-branch axis as a center. The rapidly uplifted part will develop into typical metamorphic core complex.

5.2 The Structural Evolution of the North China sub-Mantle Plume

Since the Yanshanian, eastern China became intensively active, the deep mechanism mainly dominated by hot mantle upwelling, which makes the eastern China continent come to the lithosphere detachment stage. Large scale of Yanshanian magmatism in the North China evolved from mantle origin, mantle-crust mixture, then to crust origin. This is a complete magmatic series and an important representation of continental activation in eastern China.

The location of eastern China-west Pacific mantle plume still need to be studied. The existed data interpretation shows two orientations: one is north continent mantle plume which includes Japanese sea, the other is south continent mantle plume which includes south China sea.

The North China sub-mantle plume is the secondary one of north continent mantle plume, its coronet is up to 400km in diameter. The structures of intensively uplifted sub-mantle plume are different in different periods. In the early stage of sub-mantle plume evolution, it mainly expressed as regional uplifting. As the evolution continued, a series of faulted basins developed on the background of regional uplift. Mantle-crust mixed magmatism was well developed. With the continuous uplifting of sub-mantle plume, thermal thinning was also enhanced, the crust on the top of coronet was more fractured, which formed a series of large regional rift basins controlled by listric faults. Mantle uplifted to the 50～60km beneath the surface, the Moho discontinuous plane is only 30km in depth, the geothermal anomaly is up to 80～100mW/m^2. It is indicated that the intensive Cenozoic mantle materials activity took place near the surface, this is rare within the continent(Fig.4). Huanghua depression and Liaohe fault depression are two high geothermal anomaly, they are the most active areas for Tertiary volcanism, the basalt in E_1k, E_2s, E_3d, N_1g, N_2m is several hundreds meters in thickness, the maximum thickness is up to 1900m. the peak eruption is in E_3d, the volcanic rocks cover several thousands square kilometers. Meanwhile, this area is an earthquake frequent area, most shallow earthquakes in the North China are closely related with this tectonic setting in recent years.



1-Cenozoic sediment; 2-Mesozoic volcanics; 3-cover rocks; 4-detachment zone; 5-Archeozoic metamorphic series; 6-cold mantle; 7-sub-plume; 8-basic vein; 9- basic intrusion; 10- bedded basalt; 11-intermediate-basic intrusion; 12-acidic intrusion; 13-transform zone of upper, middle and lower crust; 14-periodic direction of geothermal; 15-high-angle ductile zone; 16-low-angle ductile zone.

Fig.4 The geothermal genetic model of the North China mantle sub-plume.

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This Study is Sponsored by NSFC(40272088)and China Bureau of Geological Survey (200110200038)