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# DISTRIBUTION OF THE QUATERNARY HEAVY MINERALS OF HEBEI PLAIN

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ABSTRACT

This article is a result of the synthetic analysis and study of the heavy minerals from nearly eightly boreholes in the Hebei plain. According to the resistance of minerals to weathering, heavy minerals (generally taking the specific gravity of 5 as a dividing line) are divided into two kinds——stable minerals and unstable minerals. Since unstable minerals (especially amphibole) which are very sensitive to climate are widespread in this district, they have typical representative significance. Emphasis is laid on the study of the vertical and lateral distributions of the unstable minerals and their variation. The dominant factors that control and influence their variation are also discussed.

## I. GENERAL SITUATION

The Hebei plain is part of the North China Plain. Tectonically it is a downfaulted basin of the North China downwarping-faulting zone of the North China platform caused mainly by subsidence accompanied by local uplifting since the Mesozoic. The Cenozoic strata are widespread over this district with a thickness of generally 1000—3500 m. The Quaternary sediments are generally 350—550 m thick, with a maximum of 650 m or so, and a minimum of less than 100 m, consisting mainly of loose alluvial, diluvial, lacustrine and marine deposits and glaciofluvial deposits. By a combination of climate-stratigraphy with lithostratigraphy, biostratigraphy and chronostratigraphy, and also of macroscopic characteristics with microscopic characteristics, the Pleistocene can be divided into three formations[1)] and seven members and the Holocene into three formations.

According to the basement structure and the development of the Tertiary strata, it is subdivided into six third order tectonic elements bounded by faults (Fig. 1).

The results of the analyses and determination of heavy minerals are used not only in searching for mineral resources, but also in the researches on various Quaternary geological problems[1—6],[2—9)].

1) 河北省地质局水文地质研究室，河北第四系，1979年.
2) 河北省地质局第七地质队等单位，沧州及邻近地区第四系划分问题，1976年.
3) 周延兴，从重砂分析试谈沧州地区第四系划分，1976年.
4) 广东省地质局水文工程地质一队，雷州半岛应用重矿物对比地层和岩相分析的初步效果，1974年.
5) 河南省地质矿产局水文地质管理处实验室、水文地质一队开封地质组，河南平原重矿物变化特征及其在第四纪地质中的应用，1983年.

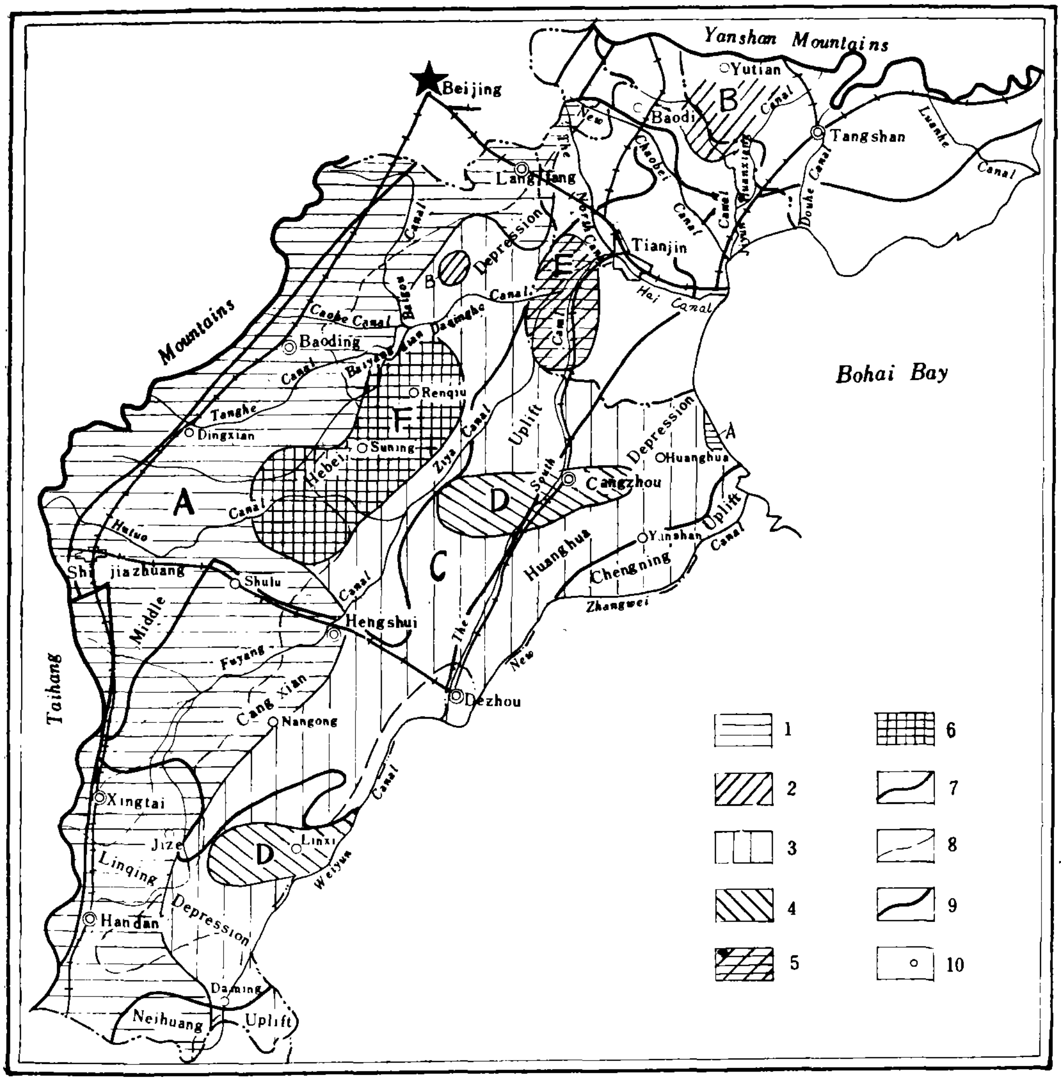


Fig. 1. Zonation of curve patterns of variation of content of heavy minerals of the Quaternary in the Hebei plain.

1, Distributional region of pattern A curves; 2, that of pattern B curves; 3, that of pattern C curves; 4, that of pattern D curves; 5, that of pattern E curves; 6, that of pattern F curves; 7, division boundary of curve form; 8, area of outwash fans of 1st and 2nd glacial epochs; 9, boundary of 3rd order tectonic unit; 10, nos. of borehole and locations.

The heavy minerals are expressed in gram per ton in combination unit percentage by weight (ratio of the weight of a single mineral to that of the total heavy minerals). As the unstable minerals are less resistant to weathering than the stable minerals, they are more sensitive to climate, e.g., amphibole. Amphibole is the most common major mineral in the Quaternary strata in this district, that determines the heavy mineral con-

6) 李 萍，现代沉积物中重矿物组合变化规律及影响因素，1983年.
7) 倪明云、陈望和，从海绿石的含量变化探讨河北平原南部第四纪时期的海侵，1981年.
8) 张慧敏等，应用重矿物组合特征研究苏南某地第四纪自然环境的演变，1983年.
9) 郑子娅，重砂矿物分析在地层对比中的应用，1983年.

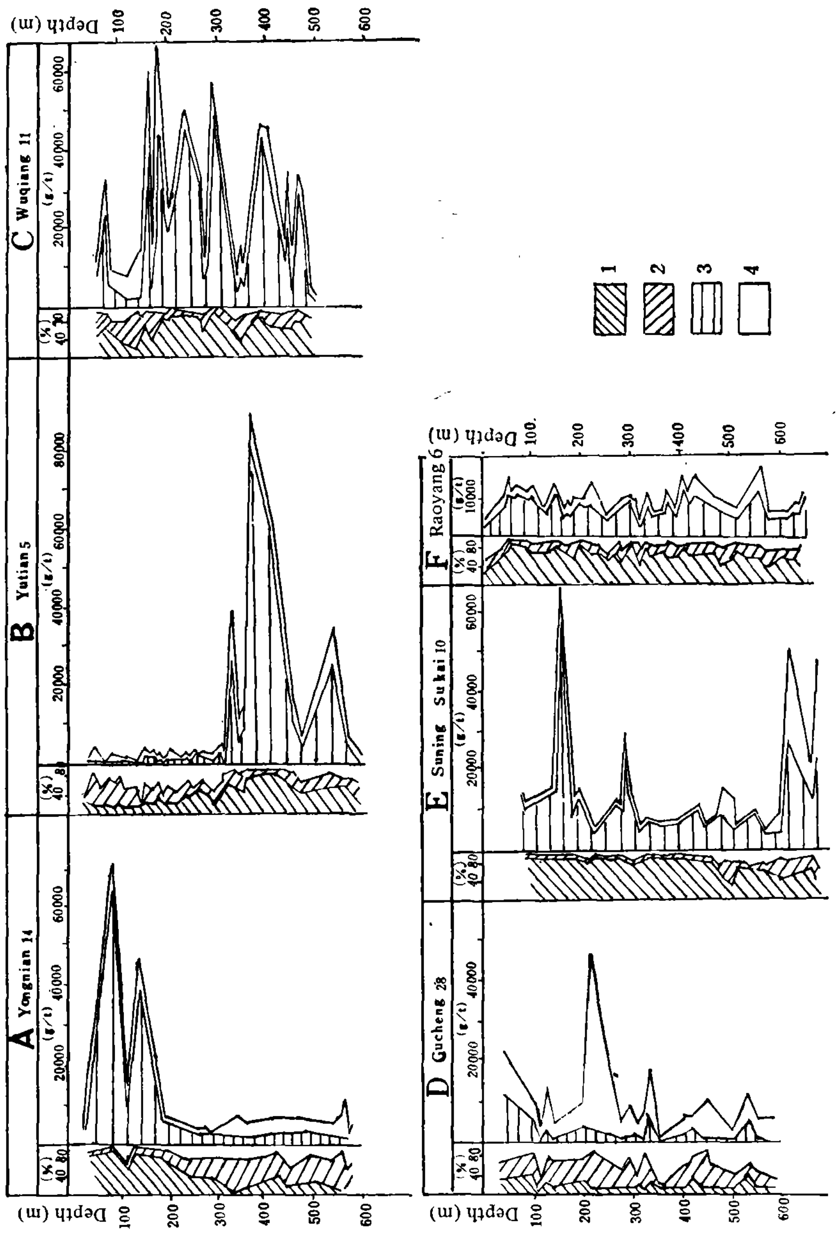


Fig. 2. Curve patterns showing the variation of contents of unstable mineral contents of the Quaternary.
1, percentage of amphibole contents; 2, percentage of unstable mineral contents; 3, amphibole contents in g/t; 4, unstable mineral contents in g/t.

tents and the combination variation. The present paper aims at the study of the vertical and lateral distributions of the Quaternary heavy minerals, their characteristics and the major factors controlling and influencing the heavy mineral variation, as well as problems concerning the Quaternary geology mainly by an analysis of the amphibole.

## II. Vertical and Lateral Distributions of Heavy Minerals

The vertical variation of the heavy mineral contents is the reflection of the combined action of various factors on the deposits during successive sedimentations in the Quaternary. From the synthetic analysis of the vertical variation of the heavy minerals from each borehole, the variation curves of the unstable mineral (especially amphibole) contents in g/t in the Quaternary strata in this district (especially amphibole) may be divided into 6 pattern curves (Fig. 2).

### 1. *Pattern* A *curve*

The curve form of this pattern shows high content in the upper part and low content in the lower part with respect to unstable minerals. The amphibole content in the upper part is generally greater than 10,000—40,000 g/t. The weathering coefficient (the ratio of the contents of the total stable minerals to those of the total unstable minerals) is less than 1. The dominant unstable mineral combination is composed largely of amphibole and delphinite, appearing above the depth of 200—300 m. The amphibole content in the lower part is generally less than 300—2000 g/t, dropping down abruptly as compared with that in the upper part. The weathering coefficient is greater than 1——a diminantly stable mineral association consisting mainly of magnetite and garnet, appearing at a depth between 200—300 m and 550—650 m. Below 300—650 m amphibole and other unstable minerals decrease considerably or nearly to nil. The sections from boreholes showing this pattern account for 48% of the total in this district and are mostly distributed in the inclined piedmont of the Taihang Mountains from Baoding to Shijiazhuang, Xingtai and Handan Prefectures, largely coinciding with the outwash fans of the first and the second glacial epochs (Fig. 1).

### 2. *Pattern* B *curve*

The curve form of this pattern shows much lower unstable minerals in the upper part than those in the lower part, just opposite to Pattern A. The amphibole content in the upper part is generally less than 3000 g/t. The weathering coefficient is greater than 1—4——a dominantly stable mineral association composed principally of garnet and ferroferrite, being present at a depth above 240—340 m. There is a sharp increase of amphibole in the lower part, generally greater than 20,000 g/t, with a maximum of more than 90,000 g/t, appearing at a depth between 240—340 m and 600—650 m. The weathering coefficient is less than 1——an unstable mineral association composed mainly of amphibole. Below 340—650 m, amphibole and other unstable minerals decrease markedly.

The sections from boreholes showing this curve form make up about 5% of the total and are mainly distributed in the inclined piedmont of the Yanshan Mountain from Yutian to Baodi, though also scattered in the area of Baxian County.

3. *Pattern* C *curve*

The curve form of this pattern takes the shape of sawtooth. The amphibole content reaches a maximum of 20,000—50,000 g/t and a minimum of only 500—1000 g/t. The weathering coefficient varies greatly, ranging from 0.1 to 8. The variation of the curves shows a general tendency of gradual decrease of amphibole from the top to the bottom. It is characterized by an alternation of unstable mineral association composed mainly of amphibole and delphinite and stable mineral association composed mainly of maghemite and garnet and mixed mineral association of amphibole, ferroferrite, delphinite and garnet. Below 500—600 m, there is a marked decrease of amphibole and other unstable minerals.

Boreholes giving this curve pattern are mainly distributed in most part of the central and eastern plain east of the line from Baodi, through Baiyangdian, Hengshui, Nangong and Feixiang, covering an area next to that of Pattern A holes, accounting for 20% of the total.

4. *Pattern* D *curve*

The curve form of this pattern shows a "low-high-low" pattern. The amphibole content in the upper part is less than 5000 g/t. The weathering coefficient is greater than 1——a stable mineral association with garnet and hematite in the majority, appearing at the depth above 200 m. The amphibole content in the middle part is 5,000—20,000 g/t. The weathering coefficient is less than 1——an unstable mineral association composed mainly of amphibole. The amphibole content in the lower is generally less than 5000 g/t, with a minimum of about 100 g/t. The weathering coefficient is greater than 1 ——a stable mineral association with garnet and hematite in the majority . Below 300—500 m amphibole and other unstable minerals tend to disappear.

Boreholes giving this pattern make up 9% of the total and are confined to a small area from Changzhou to Jiaohe and Linxi.

5. *Pattern* E *curve*

The curve form of this pattern shows a "high-low-high" pattern, opposite to that of Pattern D. The amphibole content in the upper part is generally 10,000—50,000 g/t. The weathering coefficient is less than 1, characterized by an unstable mineral association with amphibole and delphinite in the majority, or by mixed mineral association, appearing at a depth of 180—300 m. The amphibole content in the middle part is about 10,000 g/t. The weathering coefficient is greater than 1——a stable mineral combination with garnet and gregorite in the majority, appearing at a depth of 300—500 m. The amphibole content in the lower part is generally 10,000—30,000 g/t. The weathering coefficient is less than 1——an unstable mineral association consisting mainly of amphibole and delphinite, being present at a depth of 300—500 m. Below 500—650 m there are marked decreases of amphibole, delphinite and other unstable minerals.

Boreholes yielding this curve pattern account for 5% of the total and are distributed in a limited area of Jinghai and Dacheng, south of Tianjin.

6. *Pattern* F *curve*

The curve form of this pattern shows a high amphibole content in both the upper part and the lower part. Despite the absence of significant variation in contents of unstable minerals there is a general tendency of decrease of their contents in descending order. The amphibole content is generally 10,000—20,000 g/t. The weathering coefficient is generally less than 1——characterized either by an unstable mineral association with amphibole and delphinite in the majority, or by a mixed mineral association. Below 650 m the amphibole and other unstable mineral contents become very low or tend to disappear.

Boreholes giving this curve pattern make up about 13% of the total and are mainly distributed in the area from Renqiu to Suning and Anping, i.e., the central area of the central Hebei downwarping-faulting zone.

It can be seen from the areal distribution that pattern A and pattern B curves are in the majority in this district, covering a large area accounting for more than two thirds of the total area of this district, and boreholes that give these two patterns of curves make up 70% of the total holes. From what has been mentioned above, we can sum up the vertical variation of the heavy minerals in this district as follows.

(1) The heavy minerals in the Tertiary strata are noticeably different from those in the Quaternary strata. In the former there is only a minor amount or trace of amphibole and also a low content of other unstable minerals. The resulting stable mineral association is composed mainly of maghemite, garnet and gregorite. The weathering coefficient is greater than 1. This suggests a strong weathering and a dominantly humid and hot climate in Tertiary time. In the Quaternary strata the high content of the most common amphibole indicates a weak weathering and a dominantly dry and cold climate.

(2) In the Quaternary strata there can be distinguished four segments of alternatively decreasing and increasing amounts of unstable minerals from the curve given above. This reflects four alternations of cold and warm periods during the dominantly dry and cold Quaternary climate.

(3) The above-mentioned 6 forms of the content variation curves for unstable minerals reflect the repeatedly alternating changes of cold and warm climate in the Quaternary period. The different patterns of the curves or the different parts of the same pattern of curve reflect not only the change of climate but also the difference in amplitude and speed of the vertical movement of the earth's crust, as well as the difference in landforms, which may have exerted a control on the depositional velocity of the heavy minerals, their weathering, and transportation and differentiation of rivers.

From the depositional velocity of heavy minerals and the speeds of their weathering and erosion the above-mentioned 6 curve forms can be grouped into three types.

(1) Quick deposition and slow weathering type, e.g., Pattern E and Pattern F curves.

(2) Quick deposition and intense weathering type, e.g., Pattern C and Pattern D curves.

(3) Slow deposition and intense weathering type, e.g., Pattern A curve and the upper part of Pattern B curve.

## III. Lateral Distribution of Heavy Minerals

From the profile (Fig. 3) from Baoding to Huanghua, the following variation can be found: the amphibole and the total unstable minerals in the samples from the borehole 7-3 located on the edge of the central Hebei sag amount to 2000 g/t. The amphibole decreases markedly or tend to disappear at a depth of about 30 m. The amphibole in the samples from the boreholes 7-6 and 7-8 located in the central part of the central Hebei sag increases to over 20,000 g/t. In the vertical direction the amphibole noticeably decreases at the depth of about 500 m in the borehole 7-6 and at a depth below 600 m in the borehole 7-8. The amphibole contents in the samples from the borehole 7-11 in the Changxian uplifted zone and from the borehole No. 3 located in the Changzhou Chemical Plant decrease considerably, generally less than 5000 g/t. In the vertical direction the amphibole contents in the samples from the borehole 7-13-1, Yugong hole No. 3 and others between them within the Huanghua downwarped region, are 1000—3000 g/t and decrease significantly at a depth of 550—630 m in the vertical direction.

The amphibole contents and the contents of the total unstable minerals in the above-mentioned profile show a lateral low-high-lower-low variation from the east to the west. This suggests that the central part of the central Hebei sag is a continually subsided depression close to the source area, and has many rivers flowing past and converging on it. Such a place favours rapid deposition of a great mass of material, which, in a reducing environment, is less weathered, accounting for the high contents of amphibole and other unstable minerals. The sediments revealed by boreholes located in the Cangxian uplifted zone and at the edge of the central Hebei sag have a small thickness, because the relatively high elevation and large topographic slope favour weathering and transportation. Thus, the contents of the amphibole and other unstable minerals are low. Though the Huanghua sag where some boreholes are located is tectonically a favourable site for the deposition of transported materials, it is so distant from the source area that little material can reach here due to the differentiated deposition on the way. In addition, it has experienced repeated marine transgressions and intense chemical weathering. All these make the contents of the amphibole and other unstable minerals in this region very low. However, there is a remarkable difference in the depth at which the amphibole contents become significantly decreased, as compared with the uplifted region. Similar variation is also found from the profile from Shijiazhuang to Dezhou.

In conclusion, we have:

(1) There is no significant difference in the heavy mineral species in the Quaternary strata in the Hebei plain. Among the unstable minerals, amphibole and delphinite are in the majority; among the stable minerals, ferroferrite, maghemite, garnet and gregorite are dominant.

(2) The lateral heavy mineral variation is apparently controlled and restricted by the structure of basement, neotectonic activity and palaeogeographic environment, as is

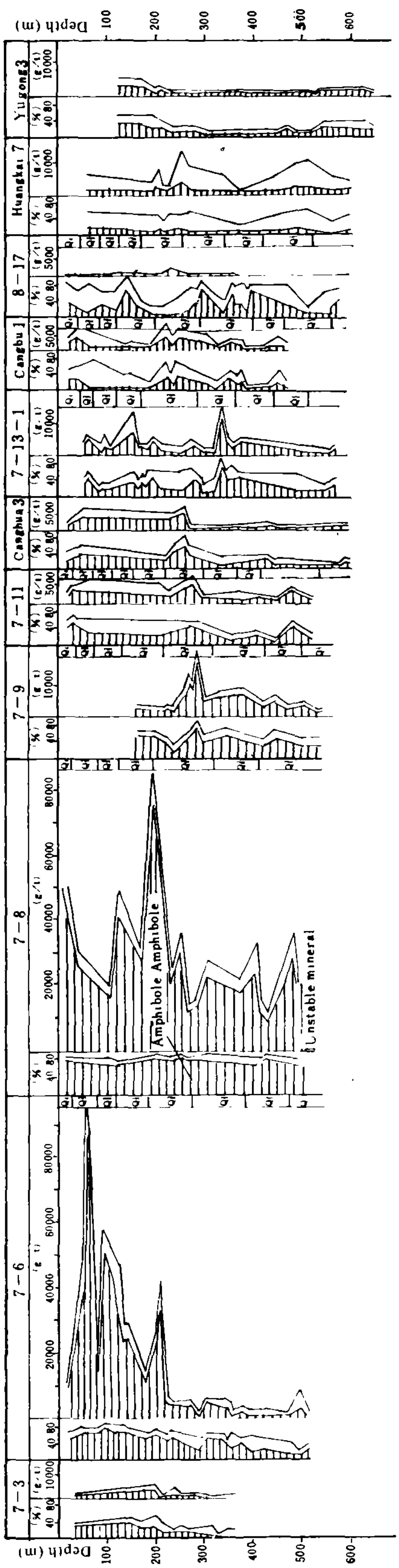


Fig. 3. Profile showing the variation of contents of amphibole and the total unstable minerals in the Huanghua region.

reflected by higher contents of amphibole and other unstable minerals in the downwarped region than in the upwarped region, in the center of the downwarped region than at its margin and in the reduction environment than in the oxidation environment. There is also a general tendency of decrease of their contents from the east to the west.

(3) River is the main agent of material transportation. Since the hydrodynamic conditions of rivers change with the changes of climate and landform, thus causing differentiated deposition along their courses. The heavy mineral contents are high in the region where many streams anastomose or become confluent, e.g., the area from Renqiu to Suning and Anping characterized by Pattern F curve and the area from Dacheng to Jinghai indicated by Pattern E curve, and are low in between. The region with the passage of many rivers has a higher heavy mineral content than the region with a single river passage. The content in the central plain is higher than that in the inclined piedmont and coastal plain.

## IV. Factors Controlling and Influencing Variation of Heavy Minerals

The vertical and lateral variation of the contents of heavy minerals is a result of the combined action of different factors, but their importance is different in different regions and in different geologic times. The main factors that control and influence the variation of heavy minerals are as follows.

(1) The climatic change is the main factor that determines the contents of heavy minerals and their association. Climatic change involves mainly the change of cold and heat expressed in terms of temperature and precipitation, which determines weathering[7]. And the variation of the contents of heavy minerals and their association depends on the extent of rock and minerals are weathered. Since unstable minerals, especially amphibole, have a weak resistance to weathering, the change in temperature and in weathering intensity should reflect the variation of mineral contents. Generally, the weathering is weak in cold climate, so amphibole and other unstable minerals can be well preserved, leading to high contents of minerals. In warm and humid climate, the consequent strong weathering of these minerals will result in their low contents in sediments. It is proved by the various curves given above, in cold climatic condition amphibole content, for instance, can reach over 20,000—50,000 g/t, while in warm climatic condition the content is generally less than 5000 g/t.

The common presence and high contents of amphibole and unstable minerals in the Quaternary strata suggests a dominantly dry and cold climate in the Quaternary. The four segments of alternatively high and low contents of amphibole in the Quaternary strata indicate four alternations of cold and warm climate during the dominantly cold and dry Quaternary time. This well agrees with the reported four cold glacial climates with aciculisilvae or dark aciculisilvae vegetation represented by pine (genus), dragon spruces and fir trees and three warm interglacial climates with broadleaf trees, elm trees, oak trees and birch trees in the Pleistocene and a warm postglacial climate in the Holocene from sporo-pollen analysis[1)].

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1) 河北省地质局水文地质研究室，河北第四系，1979年.

(2) The composition of parent rocks determines the variation of heavy mineral species. There is no significant difference in the heavy mineral species in the Hebei plain. From the nearly 70 mineral species now known in this district, the parent rocks are largely silicate rocks and oxide-hydroxide rocks. From Fig. 4 and other maps compiled, we can see that the lateral distribution of heavy minerals is apparently controlled by the structure of basement and follows, on the whole, the river courses which largely rise in the Taihang Mountains. It is therefore, considered that the source area of the Quaternary heavy minerals in the Hobei plain is the Taihang Mountains. The coastal plain east of Cangzhou is farther away from the source and the sediment laid down there may be carried by the Huanghe River. The source area for sediments of the piedmont from Yutian to Baodi is the Yanshan Mountain.

(3) The structure of basement has a control on the variation of heavy minerals. Aside from the widespread and principal influence of climate the basement structural control on the local distribution of heavy minerals is prominent. Minerals located in different tectonic units may have experienced weathering to different extents, due to their different transportation conditions and sedimentary environments.

These differences in weathering are reflected as variation of the contents of heavy minerals and the consequent variation of their association. In the downwarped region weathering is weak since it is usually a depression to receive sediments and exists in a reduction environment. The contents of amphibole and other unstable minerals here are therefore generally high. On the contrary, the contents of these minerals in an uplifted region are very low.

Neotectonic activity tends generally to recur along the existing faults, that is to say, it takes place along the faults of the basement. Neotectonism not only speeds up the change of the sedimentary environments, but enlarges the difference in heavy mineral contents. So, a comparison of the corresponding stratigraphic horizons bearing these differences from two adjacent boreholes may reveal the neotectonic activity. Although each of the following pairs of near boreholes 7-3/7-6, 7-8/7-9, Gaocheng 9-1/Shulu-8, S-10/C-7, B-18/Y-16 give similar curve patterns, the horizons of both the high and trivial difference between the contents of amphibole and other unstable minerals occur at different depths in each hole of each pair, commonly with a difference of over 150 m. From this we can draw the inference that there will be a fault between each pair of the above-mentioned holes and the throw is 150 m or so. The side with a smaller depth of the said horizon is the upthrown side; the other side is the downthrown side. From this we can also infer that the central Hebei sag is characterized by step subsidence.

(4) The change in palaeogeographic environment has a restriction on the variation of heavy minerals. In the same climatic condition and in the same tectonic unit, the variation of heavy minerals, apart from the effect of climate, basement structure and neotectonism, is generally restricted by palaeogeographic environment. In Fig. 3, boreholes 7-3 and 7-6 are located at the center of the central Hebei sag, most likely the central part of ancient lakes. The main channel of the then Hutuo River might flow past these ancient lakes from the southwest to the northeast and laid down a large amount of material carried rapidly along its course at proper places (low and gentle central

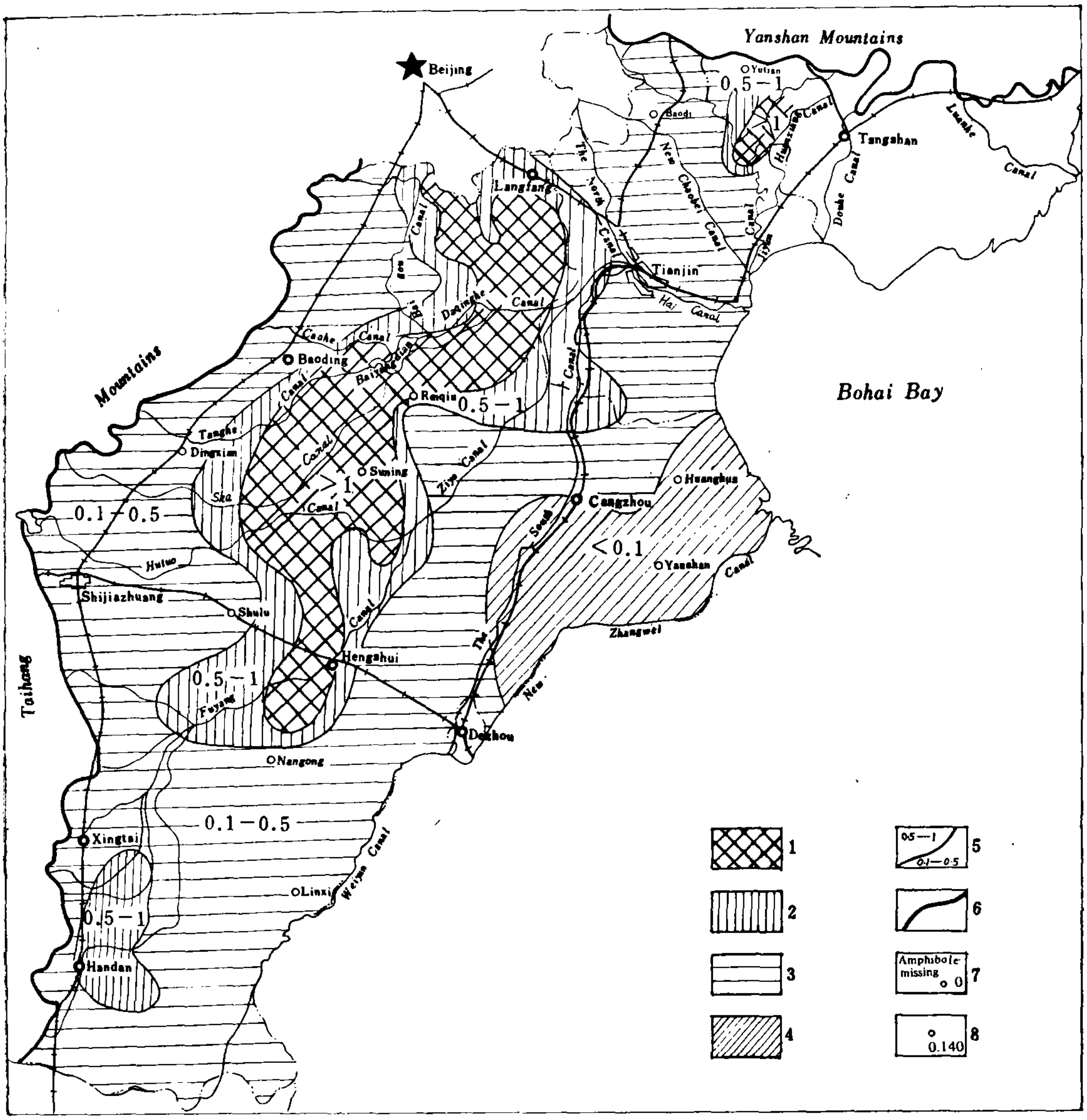


Fig. 4. Zonation of midvalue of total contents of amphibole from each hole of the boreholes in the Quaternary of the Hebei plain.

1, region where the midvalue>10,000 g/t; 2, region where the midvalue is 5000—10,000 g/t; 3, region where the midvalue is 1000—5000 g/t; 4, region where the midvalue<1000 g/t; 5, boundary between regions; 6, boundary between plain and mountainous land; 7, borehole in which amphibole is missing; 8, serial numbers and symbols of boreholes and the midvalue of amphibole contents from each hole (g/t).

part of lakes). As the central channel of the river has greater transport capacity, more sediments would be deposited in it than on its two sides. With the increase of distance from the main channel coastward the sediments will become finer and less in amount. Thus, the heavy mineral contents in the central part of the downwarped region, namely the central part of ancient lakes and the main course of the ancient river, are high, and decrease toward the two sides. From this we can infer the advance and retreat of ancient lakes and depressions, and the direction and the extent of the swing of the river, and recover the palaeogeographic environment. It is therefore evident that the downwarped region is generally the environment of ancient lakes and depressions where many rivers run past and converge——a favourable environment to receive sediments, so the heavy mineral contents in this region are higher than elsewhere.

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