AN OUTLINE OF MINING GEOPHYSICS AND GEOCHEMISTRY IN CHINA

Delegation of geophysicists and geochemists, People's Republic of China
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Abstract

A great many developments and a number of outstanding achievements have occurred both in geophysics and geochemistry since the foundation of the People's Republic of China. In the field of mining exploration, geophysical techniques are used widely in both regional surveys and exploration. Under the guidance of the principle of self-reliance, a variety of geophysical instrumentation has been developed and manufactured in China, including airborne, ground and borehole geophysical instruments. The present paper provides a number of examples, illustrating some of the results obtained by Chinese geophysicists in their practical investigations through persistent summing-up of experience and raising the level of cognition. Some research programs to improve methodology and theory have been carried out to resolve problems which have originated from actual field work.

For regional surveys, a system of geochemical methods is now established and is becoming relatively mature, with a variety of terranes in consideration. Statistical and computer techniques are beginning to be widely used in the processing and assessment of geochemical prospecting data, especially those for stream-sediment surveys, which are carried out on a broad scale. The paper reviews some results from lithogeochemical surveys, with the following primary dispersion halos being discussed: 1. Anomalies having linear and complex nonlinear shapes; 2. Primary dispersion halos around a steeply dipping orebody; 3. Primary dispersion halos from a skarn-type ore deposit. The present paper also presents experimental results from a soil mercury-vapor survey carried out in a broad loess-covered area.

Résumé

De très nombreux développements et un grand nombre de réalisations importantes ont eu lieu dans les domaines de la géophysique et de la géochimie, depuis la fondation de la République populaire de Chine. Dans le domaine de la prospection minière, des techniques géophysiques sont utilisées sur une grande échelle lors des levés et de la prospection dans les régions. Dans l'esprit du principe d'autosuffisance, une gamme d'instruments de géophysique ont été mis au point et fabriqués en Chine, notamment des instruments de prospection par sondage. Le présent document fournit un certain nombre d'exemples, en expliquant quelques-uns des résultats obtenus par les géophysiciens chinois dans leurs recherches appliquées, grâce à la revue constante des progrès accomplis et au perfectionnement continuel des connaissances. Quelques programmes de recherche visant à améliorer les côtés pratique et théorique ont été mis en oeuvre, afin de résoudre les problèmes qui ont surgi lors des travaux sur le terrain.

En ce qui concerne les levés de régions, il existe maintenant un système de méthodes géochimiques qui est en train de devenir assez perfectionné, en ce qu'il tient compte d'une grande variété de terrains. Des techniques d'étude statistique et informatique commencent à être utilisées sur une grande échelle pour le traitement et l'évaluation de données de prospection géochimique, particulièrement les données relatives aux levés de sédiments fluviaux, levés qui sont effectués sur une grande échelle. Le document analyse quelques résultats obtenus à partir de levés lithogéochimiques, notamment les auréoles de dispersions primaires suivantes: 1) anomalies ayant des fa onnements linéraires et non linéaires complexes; 2) auréoles de dispersion primaire autour d'un gisement en amas à inclinaison raide; 3) auréoles de dispersion primaire à partir d'un gisement de type skarn. Le présent document contient aussi des résultats d'expériences à partir d'un levé de la vapeur de mercure du sol effectué dans une vaste zone couverte de loess.

INTRODUCTION

The history of the development of geophysics in China can be traced far back to ancient times. According to early records, it was in the third century B.C. that the phenomenon that "magnet attracts iron" was first observed, and in the early years of the first century A.D. the polarity of a magnet was known. The compass had been widely used by the beginning of the twelfth century A.D.

With respect to geochemistry, over 2000 years ago scientific ideas of applying geochemistry in ore prospecting were plainly put forward in China in the Spring and Autumn Period (770-475 B.C.), as described in the works Kuan Tze "where there is red sand (i.e. rusty quartz) above, there is gold below, where there are magnetic stones (i.e. magnetite) above, there are copper and gold below, where there is ochre (i.e. gossans) above, there is iron ore below, and where there is lead above, there is silver below". But owing to the long period of feudal domination and semi-feudal and semi-colonial rule, exploration geophysics and geochemistry, like other disciplines of science and technology did not progress in China. As a result before liberation in 1949 there were only a few mining geophysicists engaged in a very limited amount of experimental investigations. In geochemistry the situation was so bad that until the eve of liberation there was not even a single specialist in this field.

For more than twenty years since the founding of the People's Republic of China on October 1, 1949, under the leadership of the great leader Chairman Mao and the Communist Party of China, the geophysical and geochemical population of China has expanded from a small to a large force, with a total staff presently numbering tens of thousands; thus geophysical and geochemical methods have found a wide application in mining exploration in China; at the same time geophysical methods also have been used widely in the fields of petroleum and coal, as well as in hydrogeology and engineering geology. Under the guidance of dialectical materialism, Chinese geophysicists and geochemists have made their work more effective. In recent years most of the magnetic iron-ore deposits found have been discoveries resulting from geophysical exploration. Successful results have been also obtained from geophysical and geochemical prospecting for such mineral resources as copper, lead, zinc, chromium, nickel, molybdenum, vanadium, and radioactive elements. In order to support the nation-wide 1:200 000 scale geological mapping and areal airborne magnetic survey program and a regional geochemical investigation have been carried out, which have provided a large amount of fundamental information. Consequently mining geophysics and geochemistry have been taken more seriously in geological investigations with every passing day. A brief review of the application of geophysics and geochemistry to search for metallic ores in China follows.

GEOPHYSICAL PROSPECTING IN CHINA

The socialist system has provided a broad possibility for the rapid development of geophysical prospecting in China using the principles of independence, initiative and self-reliance. Geological instrument factories have been built-up step by step and research institutions have also been established. In addition to the foregoing, research projects of methodology and instrumentation have also been undertaken by the various universities and colleges concerned as well as by some of the geophysical field parties. With respect to magnetic instrumentation, suspension-wire magnetometers, quartz magnetometers, fluxgates, proton-procession and optically-pumped magnetometers have been successfully designed and manufactured. In the field of gravimetry high-precision portable gravimeters have been developed and fabricated. We have also developed and manufactured a variety of instruments for electrical exploration and for borehole investigations. In addition a compensation-type airborne EM system has been successfully developed. In respect to the treatment and interpretation of geophysical data we have established and are continuing to establish several data-processing centres equipped with computers.

While learning advanced techniques from abroad, we are developing instruments specifically suited to our actual geological and geophysical conditions. For instance, a horizontal magnetometer was designed for measurement of the horizontal magnetic component in an arbitrary direction. Such an instrument has proven to be applicable to prospecting for magnetic orebodies at low latitudes. In support of the scientific investigation in the Mt. Jolmo Lungma region, a "Mt. Jolma Lungma"-type gravimeter was successfully manufactured and used for station measurements at an altitude of 7790 m (Fig. 40.1) To enable the induced polarization method (IP) to prospect areas rapidly, a modified IP receiver has been developed. By using this instrument, the measurement line is separated from the current line without any synchronizing unit and the signal received by the receiver at the cutoff of the primary field serves as the triggering signal. Being portable, simple to read and permitting the simultaneous operation of several measuring groups. The instrument makes possible a high working efficiency for the IP method.

Chinese geophysicists in order to obtain the most reasonable interpretation examine anomalies and sum up their collective experience. Thus a number of successful results have been obtained. For example, Figure 40.2 shows

Figure 40.1. *Chinese mountaineers making measurements with the "Mt. Jolmo Lungma" type gravimeter in the Mt. Jolmo Lungma region. (GSC 203492-D)*

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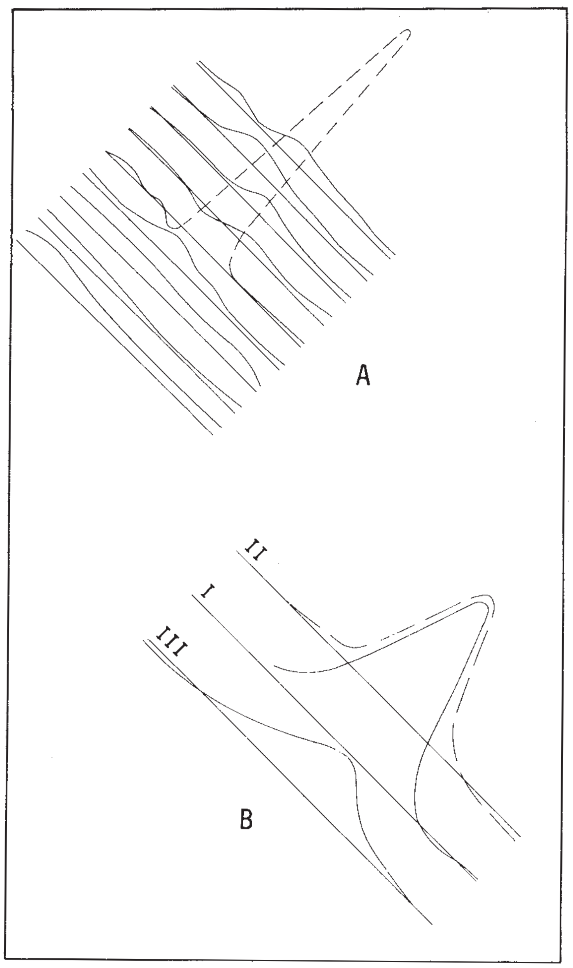
Anomaly M 85 indicated by airborne magnetic survey on the prairie of northeastern China. Judging by its intensity and shape and taking the geological environment into account this anomaly was considered to be caused by an ore occurrence. The ground magnetic follow-up survey also located the anomaly and the causative orebody was interpreted to be at a depth of about 210 m. Drilling of the anomaly followed and revealed a thick bedded magnetite orebody at a depth of 184 m. Then ground magnetic, gravimetric, electromagnetic and borehole three-component magnetic measurements were conducted to furnish information on the shape, mode of occurrence, and size of the orebody to guide further exploration. Figure 40.3 shows the ore occurrence with the result of the three-component magnetic measurement and the downward continuation of the vertical field (0Z) anomaly.

It should be noted that, so far as Anomaly M 85 is concerned, from the actual discovery of this anomaly by airborne magnetic survey to the final confirmation by drilling took less than 4 months.

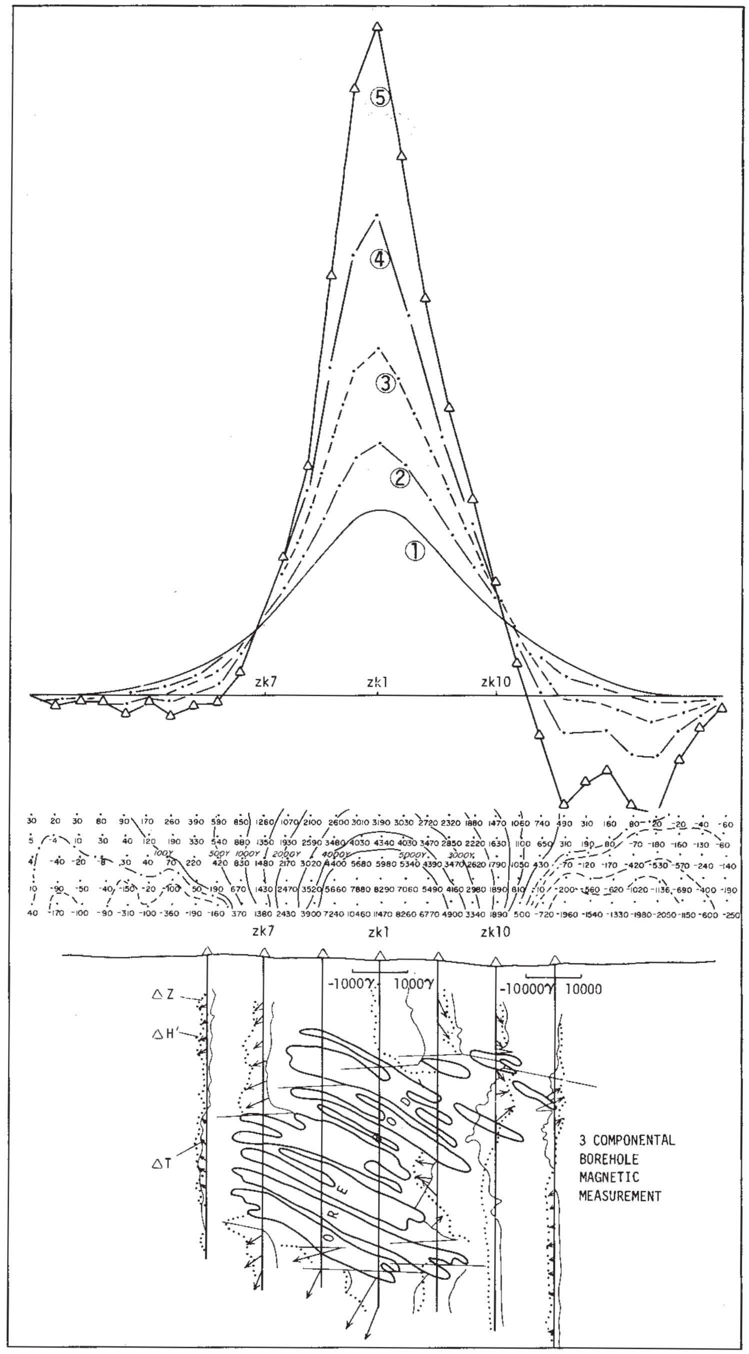
From many case histories we have come to realize that one should learn to see the essence through the appearance and that very often correct knowledge can be obtained only after a process of repeated practice and repeated cognition.



A. Aeromagnetic ΔT anomaly, 1 cm = 400γ
B. Ground magnetic ΔZ anomaly, 1 cm = 1000γ

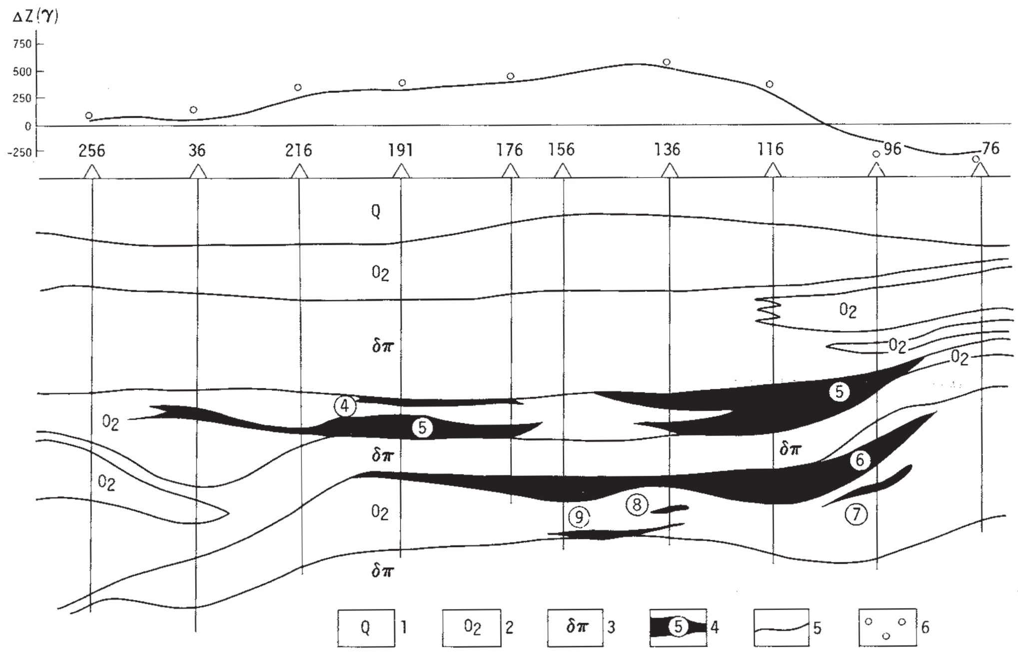
Figure 40.2. *Aeromagnetic Anomaly M-85 and ground magnetic follow-up results, northeastern China.*

For example, aeromagnetic Anomaly M 19, was delineated in the lower reaches of the Yangtze River. Within this anomaly zone three local anomalies, A, B, and C, were indicated by the subsequent ground magnetic follow-up. In 1962, a number of boreholes were drilled for verification of Anomaly A (Fig. 40.4) and only a limited quantity of iron reserves were obtained. Afterwards in 1970 when making a further investigation of this area, it was noted that apart from the local anomaly there exists around it still a broad and gentle anomaly of low intensity, which had been thought in



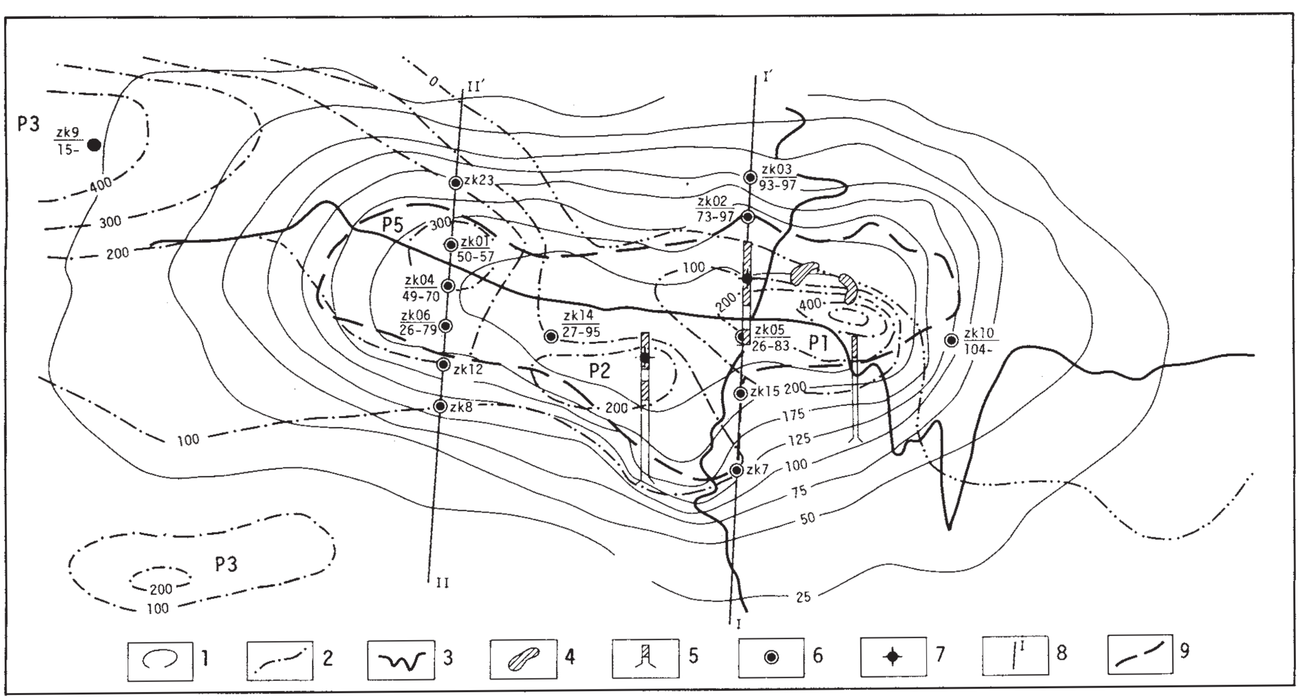
1. Measured curve
2. Continued downward to a level of 40 m below the surface
3. To a level of 80 m
4. To a level of 120 m
5. To a level of 160 m

Figure 40.3. *The vertical field (ΔZ) downward continuation, 3–component borehole magnetic measurements and geological section for Anomaly M-85.*



1. *Quaternary deposits*
2. *Ordovician limestone*
3. *Diorite*
4. *Magnetite ore and orebody number*
5. *ΔZ curve*
6. *Theoretical ΔZ curve*

Figure 40.4. *A composite section of Anomaly A along exploration line 3, Yangtze River.*



1. *Equipotentials of the Mise-à-la-masse method*
2. *Contour map of the self-potential measurement*
3. *Gradient curve of the Mise-à-la-masse method*
4. *Outcrop of the known orebody*
5. *Exposure of the orebody in trench*
6. *Borehole*
7. *Charging point*
8. *Exploration line*
9. *Orebody boundary located with geophysical method*

Figure 40.5. *A map showing the survey results by the self-potential and Mise-à-la-masse method over a deposit, Chinghai-Tibet Plateau.*

the past to be the effect of diorite-porphyrite. Magnetic susceptibility determination of the diorite-porphyrite, however, showed that it had too low a magnetization to give rise to such an anomaly. It was suggested that the boreholes drilled before had only intersected the upper contact orebodies, and all ended in the diorite-porphyrite. With this in consideration borehole ZK 191 was drilled and high-grade ores were encountered at a depth of 217 m underneath the diorite-porphyrite, leading to the discovery of the second and third ore beds. The theoretical curve calculated gave a fairly good coincidence with the one practically measured, indicating that the second and third ore beds appear to be the cause of the gentle low-intensity anomaly.

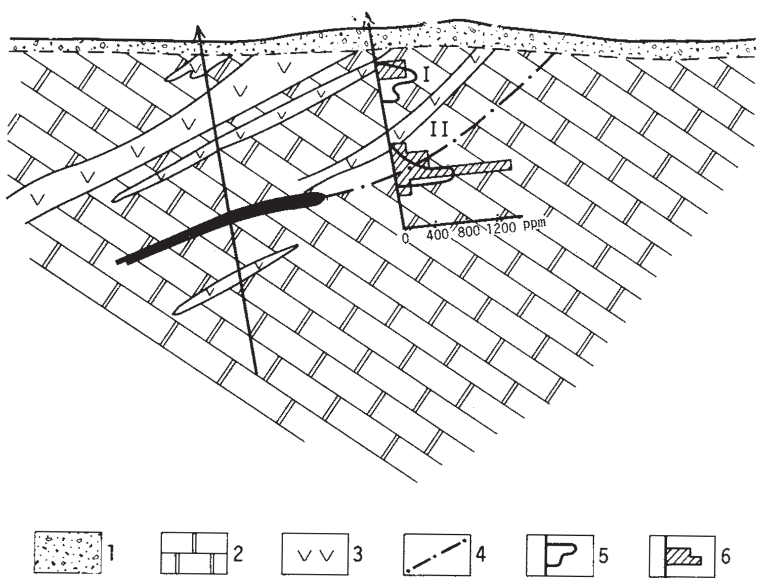
It is quite obvious that any single geophysical method can at best reflect only one aspect of the subsurface geology. It is for this reason that several methods reasonably integrated are usually employed in an exploration program to get a more comprehensive picture of the subsurface geology. Close co-operation of geological, geophysical and geochemical means of prospecting is also required to make up for the deficiency of any given technique. Figure 40.5 shows several self-potential anomalies indicated in reconnaissance surveys on the Chinghai-Tibet Plateau. Mineralization was revealed in all the three galleries driven initially on the self-potential anomalies P1 and P2. This mineralization, however, was then regarded as two small isolated bodies.

Sometime later when the work resumed in this area, the Mise-à-la-masse method was applied with the purpose of clarifying the relationship between these orebodies. The results obtained with all the three groundings used showed nearly the same picture, indicating that all these orebodies were connected with one another with an excellent electric conductivity, and therefore the size of the body tested by drilling appeared to be much larger than it was supposed before. Borehole ZK 14 and those on lines 1 and 2 drilled in accordance with the interpretation all intersected the body. Thus all the isolated self-potential anomalies appeared to be due to the local shallowest exposures of the body.

We have also carried out research programs into methodology so as to resolve prolems which have originated from actual field work; for example, the method of interpretation of magnetic anomalies in the case of oblique magnetization, the techniques for gravity survey in mountains with complicated terrain conditions, the potential application of IP method and the approaches for its interpretation as well as the possible application of holographic techniques to mineral exploration. In addition we are still expanding the aeromagnetic coverage of high-mountainous regions. The development and achievements of geophysical prospecting in China also should be attributed to the persistent implementation of the mass line. In addition to the specialized geophysical brigades, geophysical prospecting teams or groups have been organized in almost every geological field brigade, and the geological detachments of some counties are also equipped with magnetometers and potentiometers to do geophysical prospecting for mineral resources for the county and commune-run industries as well as groundwater investigations for the development of agriculture.

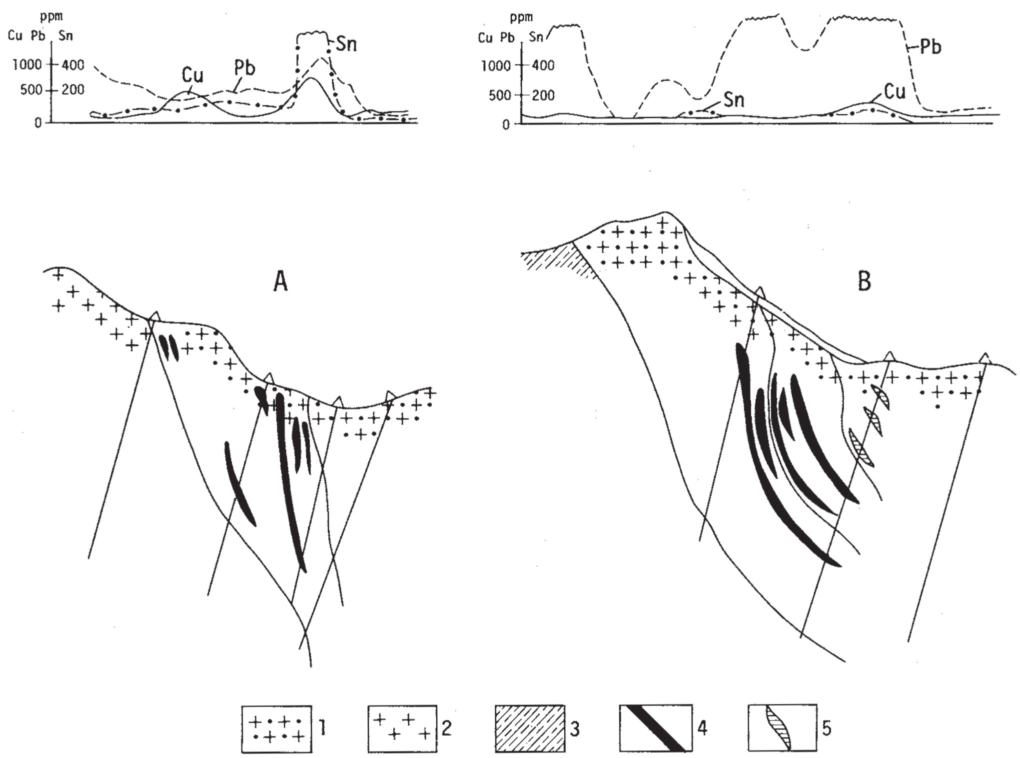
GEOCHEMICAL PROSPECTING IN CHINA

Since the late fifties, a more or less systematic investigation of the primary halos of mineral deposits has been carried out in combination with the mining geology mapping the prospecting for blind orebodies in/or around known mineral deposits. For example, a rock sampling program was carried out over a lead-zinc district of northeast China which had been exploited for some years. The primary halos controlled by tectonic fractures were found to be linearly distributed around lead-zinc bodies. However, the anomalies caused by the postmineral quartz veins appeared to greatly interfere with the resultant geochemical data because of their similarity to the ore minerals both in composition and configuration. But the Cu/Pb ratio of the anomalies was quite different. Based on a large amount of data, it was found that directly over blind Pb-Zn orebodies related to fracturing, lead was usually over 300 ppm, arsenic over 80 ppm, with the Cu/Pb ratio being less than 0.2. An attempt was made to use this criterion in an evaluation of other geochemical anomalies. As a result new blind lead-zinc orebodies of economic interest were discovered in the area (Fig. 40.6). Thus an old mine was renewed and its useful life extended. Many examples of complicated nonlinear anomalies observed during later geochemical prospecting activities on a broad scale have further enriched our knowledge of primary halos. Within these anomalies, element contents fluctuate locally over a wide range, so that mathematical methods are used to suppress noise and permit anomalies to be divided into three concentration zones: namely the inner zone, the middle zone and the outer zone, according to the geometrical series of the background values. In this way, the pattern, size, and internal structure of various nonlinear anomalies can be



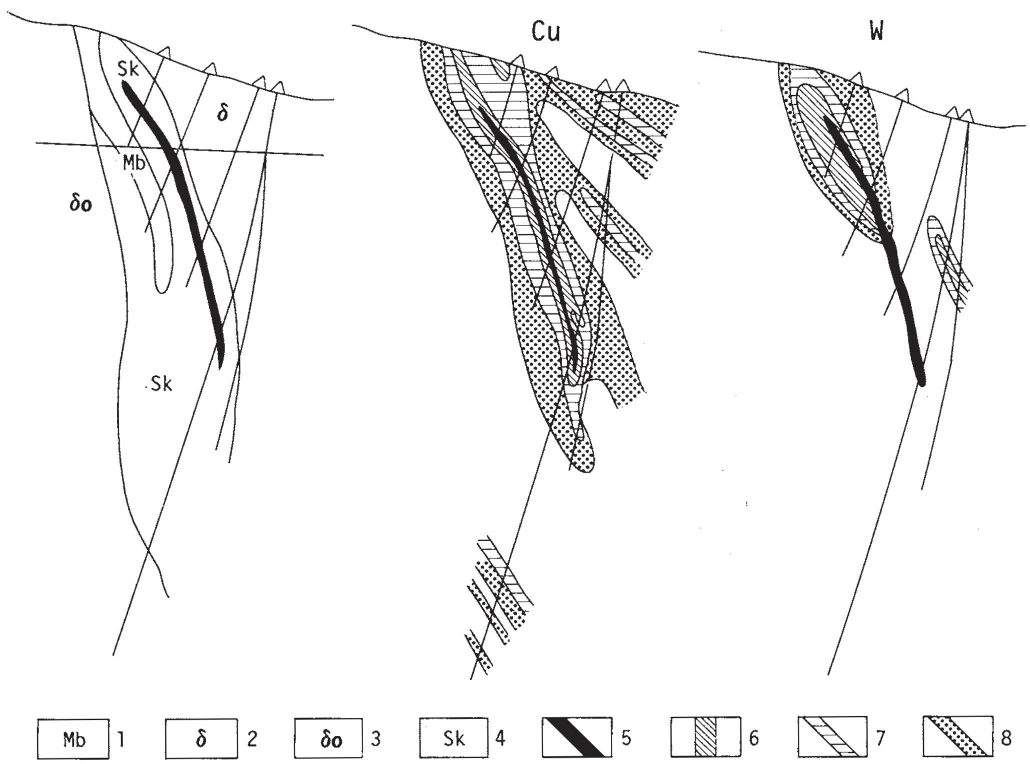
1. *regolith*
2. *marble*
3. *lamprophyre*
4. *fractured zone*
5. *Pb anomaly*
6. *As anomaly*

Figure 40.6. *A blind lead orebody discovered from the Pb and As anomalies in drill cores.*



A-profile at the southern part of the ore zone
B-profile at the middle part of the ore zone
1. liparite
2. muscovite granite
3. mica-quartz schist
4. copper orebody
5. lead-zinc mineralization.

Figure 40.7. *Primary anomalies over copper orebodies, southern China.*



1. marble
2. diorite
3. quartz diorite
4. skarn
5. copper orebody
6. inner concentration zone
7. middle zone
8. outer zone.

Figure 40.8. *Copper and tungsten halos around a skarn copper orebody.*

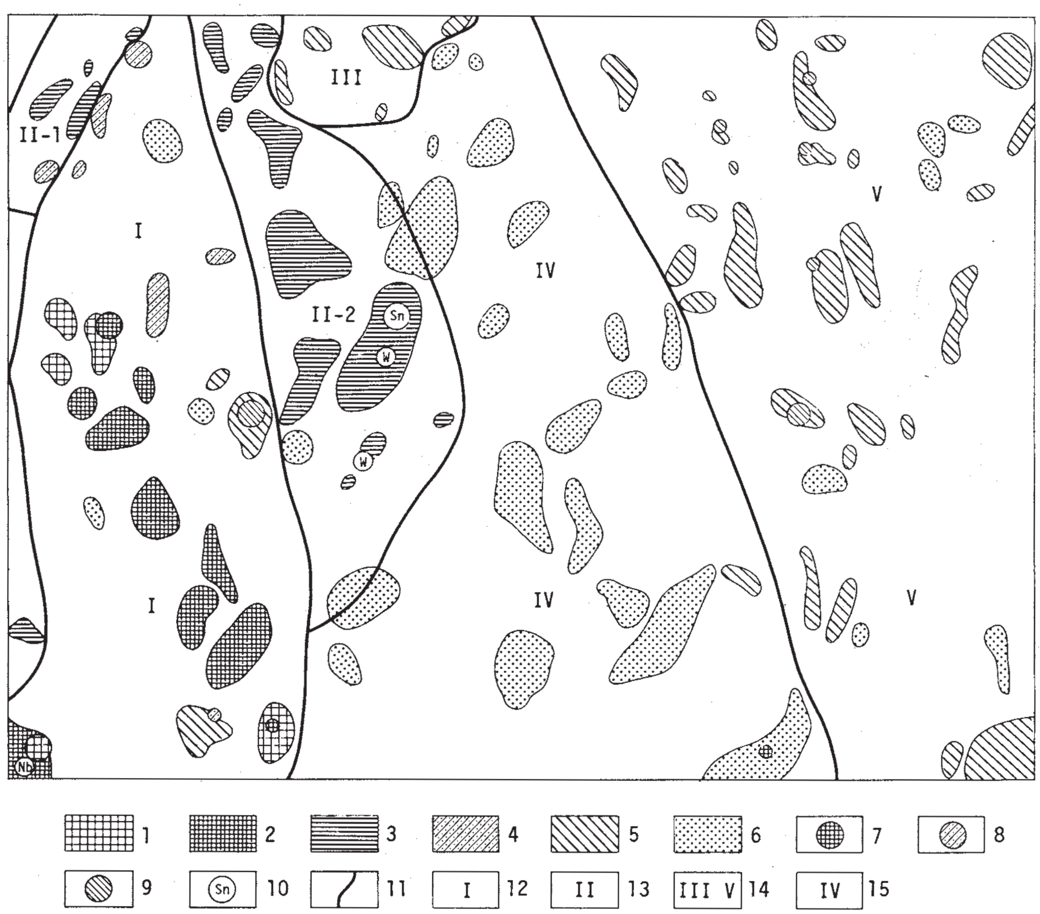
compared. It has been proven in practice that the presence of an outer zone at the ground surface and its size may be used to evaluate blind orebodies at depth, while a middle zone of fairly large scale is an indication of a shallow-buried one.

Based on a systematic study of a vast amount of data obtained in various areas, it is considered that a primary halo surrounding a steeply-dipping orebody may be divided into three parts: a front part (or front halo), an adjacent part (or adjacent halo) and a rear part (or rear halo). There are distinct longitudinal chemical zoning at the front and rear halos. The most developed elements within the front halo of a Pb-Zn hydrothermal deposit involve Hg, Ag, Ba, As, Mn, and Pb, whereas those developed at the adjacent and rear halos are Cu, Zn, Cd, Sn, W, Mo, and Bi. By investigating the characteristic chemical composition of primary halos on the land surface, predictions of blind ores at depth and an evaluation of the erosion level of outcropping orebodies can be made.

In south China, a geophysical prospecting team discovered an anomaly zone extending over 3000 metres on either side of a fault. The anomaly to the south of the fault was characterized by a Sn-Cu-Pb association, while that on the north was mainly characterized by a relatively high content of Pb, Zn, and Ag. At first sight the mineralization was widespread in the south where ancient workings were scattered everywhere, but it was not very noticeable in the north. According to the zoning of primary halos, the prospecting team came to the conclusion, that concealed ore might be encountered in the north and that the orebody in the south was either buried at a shallow depth or was already eroded to a certain level. This supposition was proved later by drilling (Fig. 40.7).

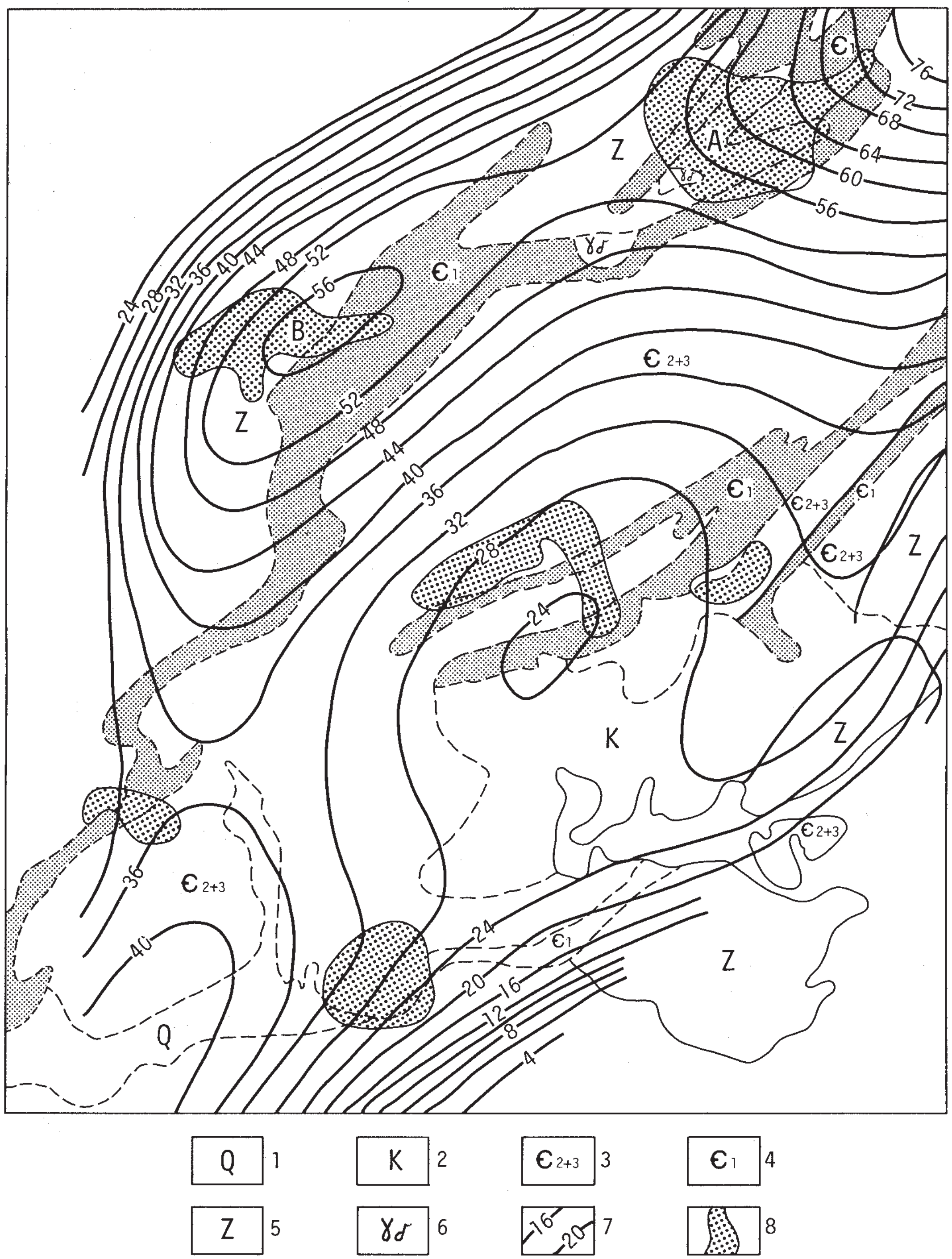
A more complicated picture was encountered in the study of the primary halos of skarn copper deposits. The "synthesized zoning sequence" established from hydrothermal infiltration halos is inapplicable to skarn copper deposits. For example, it can be seen from Figure 40.8 that W occupying a place usually at the end of the "synthesized zoning sequence" becomes the most typical front element. To study the primary halo of this type of deposit, factor analysis was first applied to discriminate the multistages of halo-formation.

Exploration geochemistry has already received a wide application in regional geological investigations. Through the repeated practices of many years, the method and techniques



1.-V, Ti, (Mn) anomalies
2.-Nb, Zn anomalies
3.-Sn anomalies
4.-Cu, Ni anomalies
5.-Pb, Zn anomalies
6.-Cu anomalies
7. known iron deposits
8.-known Cu-Ni deposits
9.-known Pb-Zn deposits
10.-deposits discovered by steam sediment survey
11.-boundaries of metallogenic zones
12.-Fe, Nb-Ta and base metal zones
13.-Sn, W zone
14.-Pb, Zn zone
15. Cu zone

Figure 40.9. *Spatial distribution of stream sediment anomalies.*



1. *Quaternary deposits*
2. *Cretaceous volcanic formations*
3. *Upper and Middle Cambrain carbonate rocks*
4. *Lower Cambrian carbonaceous rocks*
5. *Sinian carbonate rock, sandstone and volcanic rocks*
6. *Yenshan granite*
7. *contour of trend surface*
8. *positive deviation of copper (>20 ppm) from trend surface*

Figure 40.10. *Fourth degree trend surface for copper.*

of regional geochemistry have been improved and are taking shape in our country. In a country like China with vast mountainous terrain, stream-sediment surveys should be carried out on a large scale to enhance efficiency and effectiveness in ore prospecting instead of low-efficiency soil surveys.

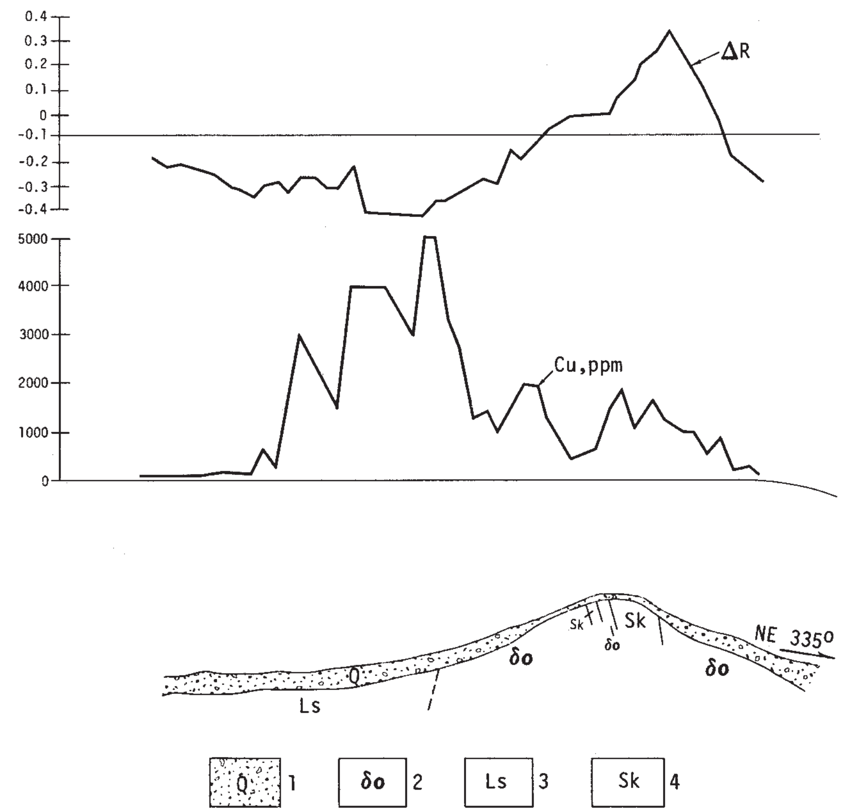
For example, in a mountainous area in southwest China, a stream-sediment survey was carried out in conjunction with 1:200,000 scale geological mapping. As a result, 86 anomalies were discovered, among which 19 anomalies were derived from known deposits, 72 being newly discovered and many of them were missed during the soil survey accompanying regional geological mapping. Five metallogenic zones were delineated according to the geological structures (Fig. 40.9), thus providing valuable information for further mineral exploration and theoretical research in this region. While making a further examination of 17 more promising anomalies, a large tin deposit of economic interest, a niobium-tantalum deposit, a tungsten deposit, two lead-zinc occurrences, and a gold prospect were discovered.

In recent years statistical methods using computers have been widely applied in China to process the vast amount of data obtained in regional geochemical surveys. The moving average method and trend surface analysis are considered as routine in compilation and map production. Cluster analysis, discriminant analysis, and factor analysis are used as tools for the evaluation of anomalies.

Figure 40.10 shows the result of trend surface analysis of copper in stream sediments (4th-degree trend surface). It can be noted clearly from the map, that there is a high-background zone with two large anomalies (A and B), superimposed on it, so it is necessary to delineate a more promising area in the high-background zone to the northeast. Figure 40.11 shows the result of the discriminant analysis. From the ΔR curve (ΔR=R-Ro, where R is the discriminant score, and Ro the discriminant index), it is obvious that the background anomaly has been effectively filtered out.

Though stream-sediment survey technique has proven to be an effective prospecting method in mountainous areas, in special cases, however, it is also subject to some limitations, so one must choose the particular geochemical method with the local conditions in mind. For example, in high mountainous areas with strongly dissected terrain, fine materials cannot remain in the drainage system owing to the frequent washing by torrential waterflow, in which case stream-sediment surveys can hardly reveal any distinct anomaly; as an alternative, soil surveys would give a better result. In some arid regions subjected to severe wind erosion such as in northwest China, there is usually neither soil cover, nor a well developed drainage system. In such a case only colluvium sampling or rock sampling may be used. While conducting a soil survey in a region, where a humus layer is developed, one can succeed sometimes in discovering anomalies even by sampling from the humus layer. But in a cold climate, high-altitude grassland or tundra where only herbage with shallow root systems grow, it is necessary to take samples from the upper permafrost under the humus layer owing to the impoverishment of the humus layer in metals by leaching. In regions where ancient or recent glaciation are noticeable, samples must be taken from eluvium beneath the glacial drift.

In south China, the open ground in mountainous terrain is mostly cultivated and has become paddy fields. In the past these areas were considered as being useless for geochemical sampling. In recent years, however, it has been recognized that soils in the paddy fields are mostly of eluvial origin, or have been transported only a short distance. In such cases, anomalies could be readily found by sampling from under the cultivated layer by augering. The Kwangtung Geophysical Team has discovered a copper anomaly extending over 3000 m with a Cu content mostly of 100–200 ppm, which was accompanied by several small separate magnetic anomalies, over a large area of paddy fields in the vicinity of a long-abandoned mine; subsequently a skarn-type copper orebody over 100 m thick was revealed by drilling under the 20-30 m of overburden (Fig. 40.12).



1. Quaternary deposits
2. quartz diorite
3. limestone
4. skarn

Figure 40.11

Distinction between superjacent anomaly and background anomaly by discriminant analysis.

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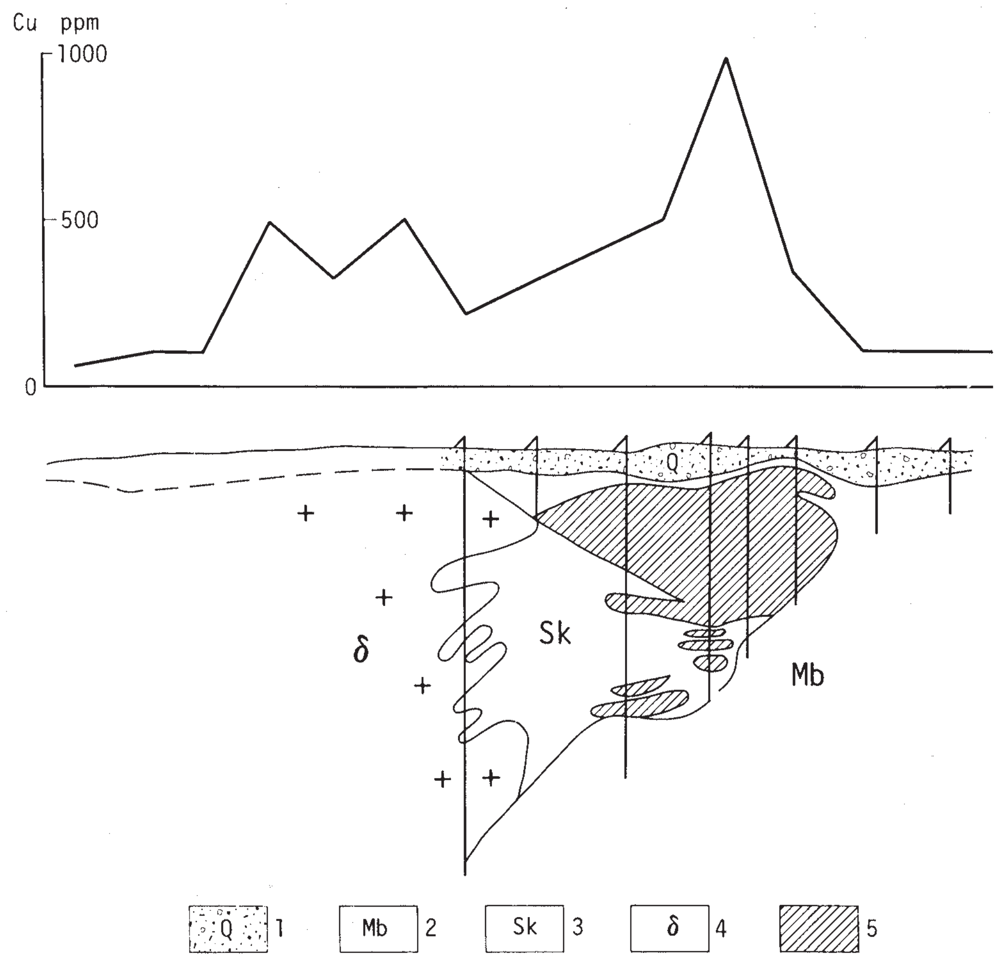
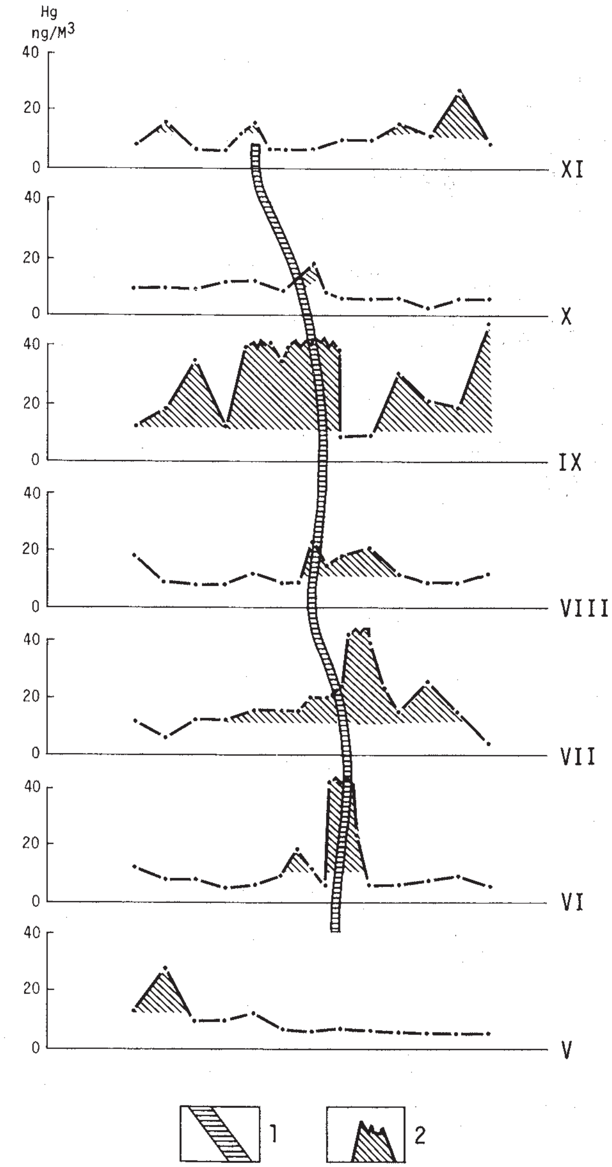


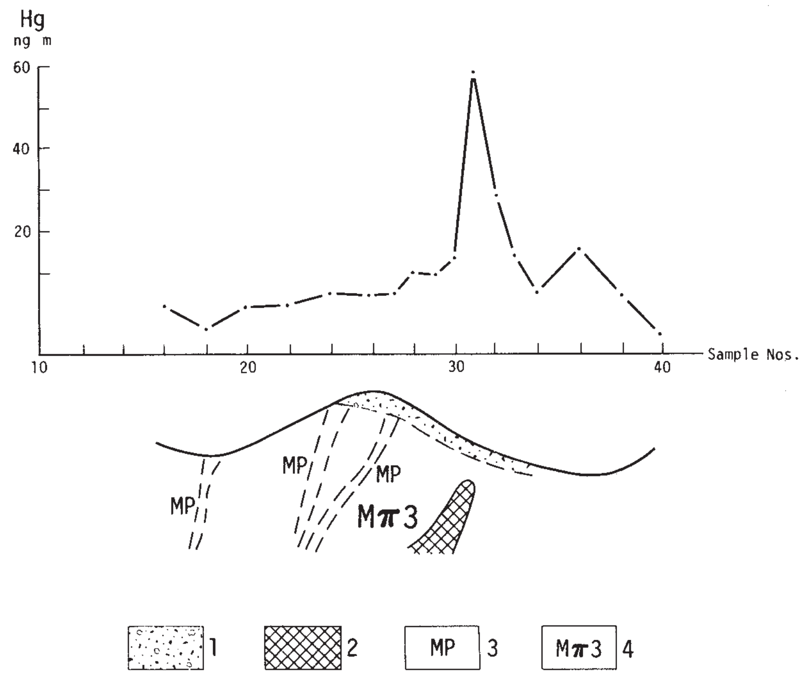
1. Quaternary deposit
2.-marble
3.-skarn
4.-quartz diorite
5. orebodies

Figure 40.12. *A copper anomaly in paddy field over a skarn copper deposit.*



1.-projection of orebody on land surface
2. mercury vapour anomaly

Figure 40.13. *Mercury vapour content in loess over a polymetallic ore deposit.*



1. loess
2. orebody
3. phyllite
4. quartz-keratophyre-tuff

Figure 40.14. *Variation of mercury content in soil gas profile VII of a polymetallic district.*

In the northern and northwestern parts of China, where loess covers a large percentage of the area, the application of coventional geochemical methods is quite ineffective. Consequently soil gas and atmosphere mercury-vapour surveys have been attempted. Figures 40.13 and 40.14 show the result of a soil mercury-vapour survey in loess over a polymetallic ore deposit.

In order to complement the wide application of geochemical prospecting methods along with carrying out research on methodology, a great deal of attention has been paid in China to the development of geochemical instruments for analysis and other applications. Mass production of medium and large-sized quartz or glass prism spectrographs, various types of grating spectrometers, and atomic absorption spectrophotometers has been effected. In addition various kinds of mercury spectrometer, a series of portable X-ray fluorescence spectrometers suitable for base or in situ analysis, gamma-spectrometers and cold-extraction field kits for the analysis of 7 elements have also been developed.

CONCLUSION

Although a notable success has been achieved in the fields of mining geophysics and geochemistry in our country, it is, however, far from the requirements of socialist construction. We wish to bring the spirit of self-reliance and hard struggle into full play in order to make an even greater contribution to the fulfilment of the various tasks put forward by the 11th Congress of the Communist Party of China.