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Application of EH4 Electromagnetic Imaging System in Gold Ore Exploration

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Abstract

EH4 electromagnetic imaging system is relatively advanced electromagnetic exploration instrument at home and abroad with the advantage of great exploration depth, intuitive and portable etc. In this paper, on the basis of the systematical collection of predecessors' research data and combined with the present situation of domestic and foreign researches, the author introduces the working principle of the EH4 electromagnetic imaging system, field-working method, scope, and possibly, and some geological problems that may be solved in gold prospecting. Apart from this, through exploration cases of in Zhangsangou Gold mining in Heilongjiang province, Yuerya gold deposit in Hebei province and in 460 gold mine in region of Beishan of Gansu, this paper illustrates that the effect of EH4 system in gold deposit exploration is remarkable.

***Keywords**: EH4 electromagnetic imaging system, Electrical survey, Gold ore exploration, Application effect*

1. EH4 Electromagnetic Imaging System Introduction

EH4 electromagnetic imaging system (“EH4” for short) is a magnetotelluric measurement system co-developed by the Geometrics and EMI in 1996. It combines the natural electromagnetic field and artificial electromagnetic field, which becomes the organic combination of MT and CSAMT. Taking differences between the electrical conductivity and magnetic conductivity of different rocks as physical basis, EH4 gets the apparent resistivity images of underground two-dimensional profile through measurement in continuous lattice and then conjecture the underground structures and distribution status of rock based on this.

2. EH4 System Working Principle

EH4 system realizes the probing of electrical resistivity or conductivity of sounding mainly through transmitting and receiving electromagnetic waves from the ground. The continuous probing lattice forms the underground two dimensional resistivity profiles and even some three-dimensional resistivity imaging. The basic parameters of observation can be seemed as the two orthogonal electric field components (Ex, Ey) and two magnetic field components (Hx, Hy) and thus the apparent resistivity of two different directions can be obtained from parameters of the above observations, and then calculate tensor impedance to acquire the stratal resistivity value[1-2].

2.1. Fundamental Principles of Telluric Electromagnetic Sounding

Based on the magnetotelluric theory based on Maxwell equations:

$$Z=\sqrt{\pi\rho\mu f}\,(1-i) \tag{1}$$

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In the above formula, f refers to frequency, μ refers to magnetic conductivity and the formula (1) can be used for the determination of telluric resistivity.

$$\rho=\frac{1}{5f}\left|\frac{E}{H}\right|^2 \quad (2)$$

In the above formula, unit of ρ is Ω•m, unit of E is mv/km and unit of H is nT.

The above expression can still be applied into the horizontal layered earth. However, the resistivity calculated through it shall be seemed as the apparent resistivity, and it would varies with frequency since there is a relation between the ground penetration of the electromagnetic wave or skin depth and the frequency, which can be showed as follows:

$$\delta=\sqrt{\frac{2}{\omega\mu\sigma}}\approx 500\sqrt{\frac{\rho}{f}} \quad (3)$$

In the above formula, unit of δ is m.

Though, at one level, there is some relation between the skin depth and the penetration depth of the electromagnetic wave in the medium; however, it does not represent the actual effective detecting depth. The actual effective detecting depth refers to the average volume detection depth of some sounding method and the empirical formula towards this is as follows:

$$D=\delta/\sqrt{2}\approx 356\approx\sqrt{\frac{\rho}{f}}\ (m) \quad (4)$$

It can be illustrated from the above formula that penetration depth can only depends on the earth resistivity and signal frequency employed. Penetration depth becomes smaller along with the decrease of the resistivity or the increase of frequency; on the contrary, penetration depth becomes larger along with the increase of the resistivity or the decrease of frequency. If the earth resistivity structure is constant, continuous vertical sounding can be reached through the change of the signal frequency, and this is the basic operation principle of magnetotelluric method.

2.2. EH4 Fieldwork Methods and Data Processing

EH4 system mainly consists of transmitting and receiving and data processing, with the working process of the system is as Figure1and field work arrangement as the Figure 2 [3-4].

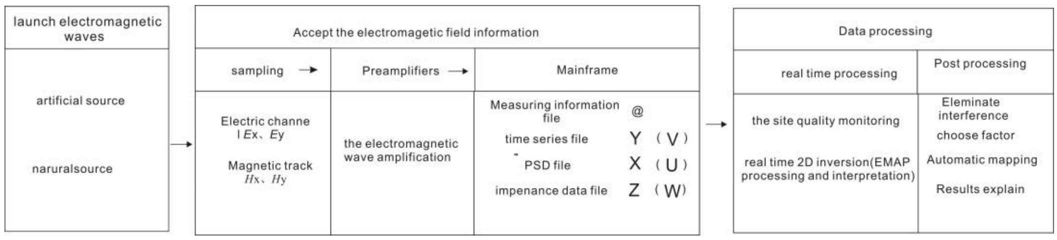


Figure 1. EH4 System Working Process [2-3]

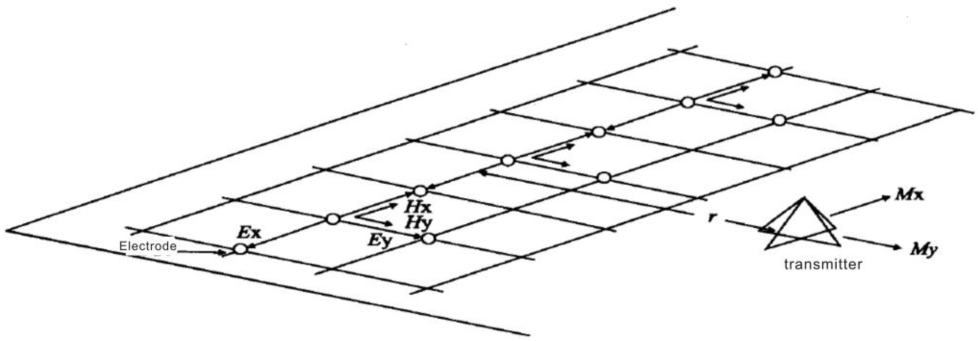


Figure 2. EH4 System Field Work Arrangement Schematic Diagram [2-3]

Receiving part is mainly composed of mainframe, preamplifier (AFE), magnetic sensors, electrode with a buffer and its ancillary equipment. Transmitting part is mainly consists of transmitting antenna, transmitter and 12 V DC power supply. Different transmitting antenna leads to different transmitting frequency with transmitting frequency as 1Hz ~ 64kHz of standard configuration of antenna and transmitting frequency as 500Hz ~ 32kHz when applied with the low frequency antenna configuration. Transmitter positioning transceiver (r) shall be three times of “skin depth” at the lowest operating frequency, which is $r=3\times\delta=3\times503(\rho/f)^{1/2}$. And in the above formula, r refers to space between receiver and transmitter; δ is skin depth; ρ refers to the average earth resistivity and f is the lowest working frequency.

There are two kinds of field work methods of EH4 electromagnetic imaging system, which consist of single point sounding and continuous profile sounding. The working electrode distance equals to distance of data acquisition at continuous profile sounding, which can effectively suppress the static effect but with a relatively heavy workload.

The data acquisition mode of this system is the time domain collection and then make Fourier transform to frequency domain signal. Data processing is divided into real-time processing and subsequent processing with the former refers to the real-time analysis of data quality based on the apparent resistivity and the amplitude, phase and correlation curve provided by each measuring point. When it is found that data quality of the observation curve is too poor, people can take measures and make repeated measurement in real time. At the continuous observation of the whole line, the grey-scale map of two dimensional inversion interpretation results can be given with the application of EMAP method at the scene. Subsequent processing is an indoor work after the field work which usually consists of two contents: ① Make the adjustments of correlation coefficient and filter coefficients towards the field data on the computer or retreat the timing data (Y or V files) such as picking one by one or removing and thus reduce the influence factors to the largest and highlight the useful exception; ② On the basis of the above work, output and mapping the destination papers after the eventual 2-D inversion processing and then make a further qualitative and quantitative interpretation combined with the other geological, geophysical and geochemical information[5].

3. Application Sphere of EH4

Application scope of EH4 magnetotelluric includes two aspects: the scope of observation method and the observing object. In fact, application of observation method is mainly determined by different objects and thus both of them belong to the application scope of observing objects [6].

3.1. Application Scope of Observing Methods

EH4 observation method is the end-to-end profile observation way which means the end-to-end of measuring point between electrodes and then makes the continuous observation, through which the geoelectric characteristics below the measuring line can be reflected and static effect can thus be suppressed to the largest extent. When choosing the observation way, it should better choose the end-to-end profile observation method and if it cannot meet the conditions, the side line and horizontal line shall be considered based on the comprehensive research of factors including goal and the cost efficiency. The reducing of static effect and the terrain effect should be fully given attention when the discontinuous section observation method should be applied.

3.2. Application Scope of Observing Objects

Magnetotelluric observation object can be generally divided into low resistance in high resistance states, high resistance in high resistance states, low resistance in low resistance states and high resistance in low resistance states. It is rather difficult for the exploration of relatively high resistance body; no matter it is the high resistance body exploration in high resistivity zone or the low resistivity zone. The resolving power of low resistance body is highly dependent on the ratio of low resistance body relative to the surrounding rock resistivity. Therefore, towards the low resistance in high resistance states, the resolution ratio is rather high with the application of electromagnetic method, but the resolution ratio is rather low as to the low resistance in low resistance states with low resistivity ratio. Thus we should pay attention to the following points when using this method:

(1) As to the magnetotelluric EH4, enough electrical conductivity difference or in other words, finding an enough low resistance in an enough high resistance is the premise of acquiring the accurate resolution as precisely as possible. However, it is difficult to find high resistance in low resistance state, whatever the difference it is.

(2) Deep abnormal should be determined reliable than the shallow, of which the depth should at least more than 100m. This is not only because the shallow electrical differences is not large enough, but also holds some relations with the point density of high frequency part and noise interference and other factors. Of course, if increase the emission sources in the high frequency part of the, the effect in the shallow part shall be improved, which undoubtedly improves the signal-to-noise ratio and increases the density of the trusted frequency point. However, whether the signal strength increase would help to improve the resolution is still a question.

(3) Even got enough resolution, EH4 electromagnetic is still unable to accurately determine the problems like fault width and it still depends on the synergy of other geophysical techniques to make the identification. In fact, the practical problems is far more complex and a lot of work need to be done as to the further understanding of the related problems including theoretical and practical levels.

4. Application Cases

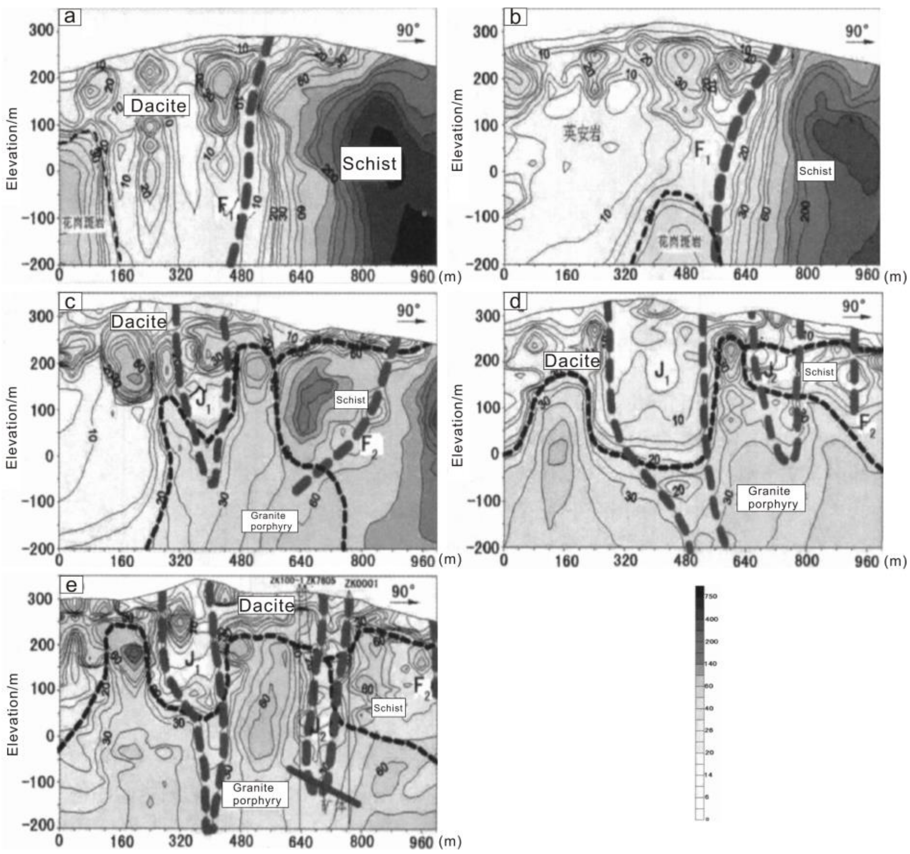
4.1. EH4's Application Direction in Gold Deposit Exploration

Gold deposit is mainly used in the exploration of groove, hole and drilling engineering to understand the distribution of mining area formation, structure and magmatic rocks. However, due to the large capital investment, relatively small work amount and local engineering layout, the information achieved has a certain limitation towards the overall understanding of the geological condition of the whole mining area, especially the geological situation in the deep mining area. Systematic survey of the mining area making use of the EH4's advantages such as great exploration depth, economy and high-efficiency etc. can help to acquire the detailed geoelectric information of the whole area, which can make more comprehensive and accurate stereoscopic geological mapping for deep mining [7-11].

4.2. Application of EH4 in Gold Deposit Exploration

Application effect of Zhangsangou Gold mining in Jiayin county, Heilongjiang province: Zhangsangou Gold Mining is a mine with a certain reserve force which is found by the the People's Armed Police Force Gold on the periphery of the porphyry gold deposit in Tuanjiegou in recent years. It is situated at the eastern part of the Tianshan - Inner Mongolia geosyncline and is also the secondary unit of fold system of Jilin-Heilongjiang geosyncline which is the northern margin of Jamusi uplift. The exposure strata in the region are mouthpiece Group's muscovite quartz schist in Heilongjiang Mountains in mid-proterozoic era, sodium long mica mylonite schist and tuff and dacite of Ningyuancun Group in Lower Cretaceous in mesozoic group. Granite-porphyry bodies are mainly concealed under dacite. Regional ore bodies are primarily distributed in granite porphyry in yanshan period and breccia belt within the surrounding rock. And then occurrences in the NNW and NWW extensional tectonic belt with interformational fracture structure of Heilongjiang crystalline schist Group also having some output. EH4 measurement shows that schist performance in this region is of high resistance with granite as the second-highest resistance and dacite is characterized by low resistance properties. Therefore, the prospecting targets in this area shall be the granite porphyry and fracture structure of northwest direction [12].

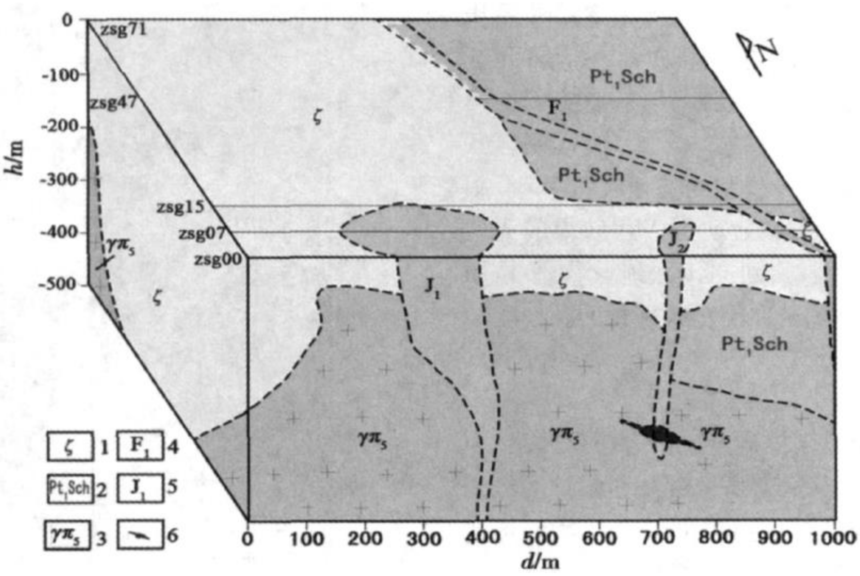
Figure3 is the two-dimensional joint section of EH4 electrical resistivity of Zhangsangou Gold mining's and it shows that: ① Schist is primarily distributed in the east of test area. There is a large area of high resistance body in the east part of zsg71 and zsg47 measuring line, which shall be seemed as the distribution area of schist. To the south, other east line high resistance area become scattered, which may be because of the invasion of the deep rock mass and distribution range and thickness of schist is shrinking and also concealed under dacite. ② Dacite is mainly distributed in the western part of the surveyed area. There is a large area of low resistance body in the west part of zsg71 and zsg47 measuring line which is the distribution area of dacite. Profile of high resistance and low resistance bodies have obvious gradient zone, which can deducted as the schist and dacite contact zone. Because the gradient zone has a large extension in vertical direction, it can be known that Schist and dacite should have contacted with each other in the form of fracture. ③ Granite porphyry bodies mainly concealed in the southern part of the surveyed area and two high resistance abnormal bodies appeared at the 200m and 560m of zsg00 measuring line on the north side, of which the two abnormal bodies contacted with each other in the deep side. It can be inferred that the two high resistance of abnormal body connected to each other are granite porphyry, with the width at the top is more than 500m. Zsg07 line also appears two parts of porphyry granites on the upward direction, with the width of the rock mass of zsg15 measuring line be shortened to 320m. To the zsg47 measuring line, there is a small part of intrusive body only at the 480m depth of the profile. Therefore, it can be seen that the rock mass invades along the contact area of the schist and dacite with the profile penetrated in the form of rock cone. Besides, the plane distributed in the southern part of the surveyed area in the shape of wedge and then expands at about zsg00 measuring line, and there should be some extension to the south. Scale of the extension to the north reduced obviously.



a-zsg71 Measuring Line; b-zsg47 Measuring Line; c-zsg15 Measuring Line; d-zsg07 Measuring Line; e-zsg00 Measuring Line

Figure 3. Two-Dimensional Joint Section of EH4 Electrical Resistivity of Zhangsangou Gold Mining's each Measuring Line [12]

And thus geological stereogram of spatial distribution of dacite, schist and granite porphyry is thus established (Figure4), and selects two low resistivity anomalies and one fracture structure. Combined with the regional metallogenic characteristics, prospecting targets in J1, J2 and J3 are determined. Up to now, rock mass have been found in J2 deep ore bodies, with the average thickness of ore bodies is 4.15m and average grade of 5.29×10^{-6}. Ⅱ# ore body has been found in F1, with the average thickness of ore bodies is 1.69m and average grade of20.43×10^{-6}, of which all the ore bodies are concealed ones. Surface of J1 area shows some corresponding induced polarization rate anomalies, which should be the next prospecting key target areas. The next prospecting direction in this area should be focused on concealed rock mass which has been found out, and then focus on the fault structure, especially the wear schist fracture structure shall be the favorable position in finding the high grade ore deposit.

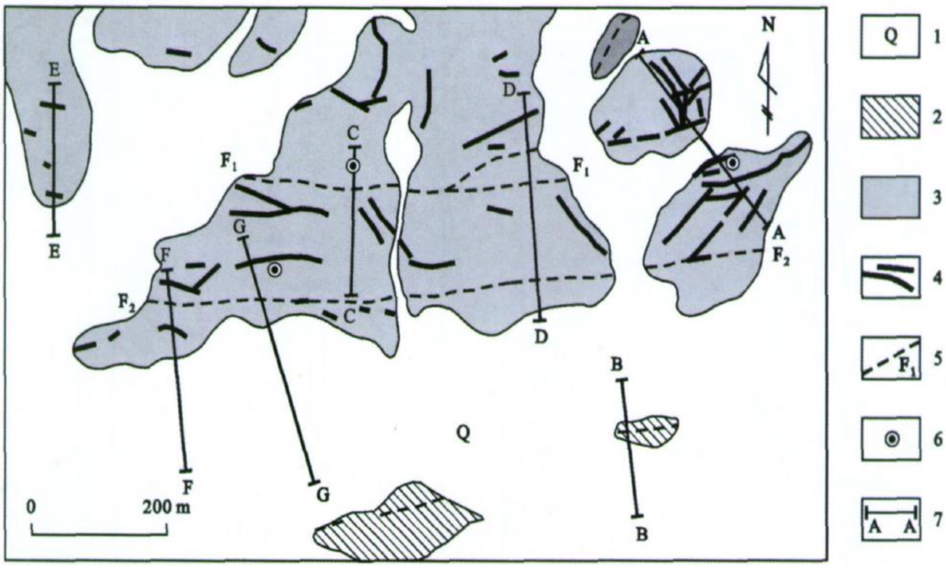


1- Dacite; 2 - Schist; 3- Granite Porphyry; 4- Infer Tectonic Fracture Zone; 5- Infer Breccia Belt; 6- Ore Body

Figure 4. Three-Dimensional Geological Sketch of Zhangsangou Gold Mine [12]

460 ductile shear zone type gold deposit in the metallogenic belt of Beishan, Gansu Province: Gansu Beishan metallogenic belt is located in the docking area of tarim plate and Kazakhstan, with the magmatic activity in this region was very fierce and frequent and represented by the quartz diorite bodies. The scale of quartz diorite bodies is the largest with 10 km from east to west and 1km from south to north part; it is called the “sole rock mass” because the rock mass appeared as the sole shape which becomes smaller at the middle part. Rock deposits is widely developed in this rock mass with 460 gold deposit located at the central section of it. Previous research on 460 gold deposits is rather little and thus it is unclear as to the deep reserve, only small-scale private mining is done within the scope of 50 m higher than the surface. Shen Ping etc. [13] has made the metallogenic prediction research towards the sole rock mass and gold deposit stored in it; she believes that ductile brittle structure superimposed on the sole of rock mass Is the main ore-controlling factors and there is still a certain extension in the ore-controlling structure to the deep side and also blind ore body may be reserved in the deep profiles.

An exposure stratum of the mine area is the subgroup of Baishan Formation of Lower Carboniferous Series, and the ore-hosted rocks are sericite chlorite quartz schist and middle variscan porphyritic quartz diorite. The ore-controlling structure is NWW-trending faults and the faults has swelled thinning phenomenon along the direction. The surface has auriferous quartz vein which showed concentrated distribution in large numbers (Figure7) with the NNW trend and northern trend with a steep angle of 60° ~ 80°. Besides, it is characterized by stigmas thinning, pinchout reproduce and lateral en echelon arrangement of structures on the trend and tendency. Mineralization type is given priority to quartz vein type. Metal mineral content in quartz vein type ore is less (1%-3%), and the nonmetal minerals are mainly quartz with a higher grade which could reach at 138g/t and the average grade larger than 10g/t.



1- The Quaternary Sediments; 2 - Chlorite Quartz Schist of Baishan Group in Lower Carboniferous Series; 3 - The Middle Hercynian Quartz Diorite; 4 - Gold-Containing Quartz Dike; 5 - Fault and Code; 6 - Drill; 7 - EH4 Line Position and Serial Number

Figure 7. Geological Sketch Map of 460 Gold Mine in Beishan, Gansu Province and EH4 Measuring Positions [13]

7 deep geophysical survey lines are arranged vertical tectonic line direction in a mining area, with the dispale moment of 10m. Apparent resistivity-depth profile map (Figure8) reflect that there are two different electrical bodies in the underground section: ① Electrical body of low resistivity (200Ω•m) which distributed in high resistivity electrical body in the form of vein and irregular lenticular shape and can reach to 300m to the maximum. ② Electrical body of intermediate and high-level resistivity (>300Ω•m), which is widely distributed and constitutes the main body of the electrical body. According to the resistivity values shown in the 2D profile size and combined with the characteristics of surface rock mass and rock occurrence in this area, it can be conclude from comprehensive analysis and judgment that electrical body of intermediate and high-level resistivity (>300Ω•m) may be the host rock of this area (formation and quartz diorite). Through the comparison of the low resistivity (200Ω•m) electrical body with the known mineralized body on the surface and the drill bore data, it can be found that: ① Lower resistivity anomalies appears on the known mineralized alteration zone on the surface; ② There is abnormity underground correspondingly with the ore body exposed on the surface. It can be deemed that a low resistivity anomaly is likely to reflect the mineralization abnormity. Mineralization floor of 460 Gold Mine may extend to underground 300 m from the known underground 50 m and thus expand deposit prospecting space.

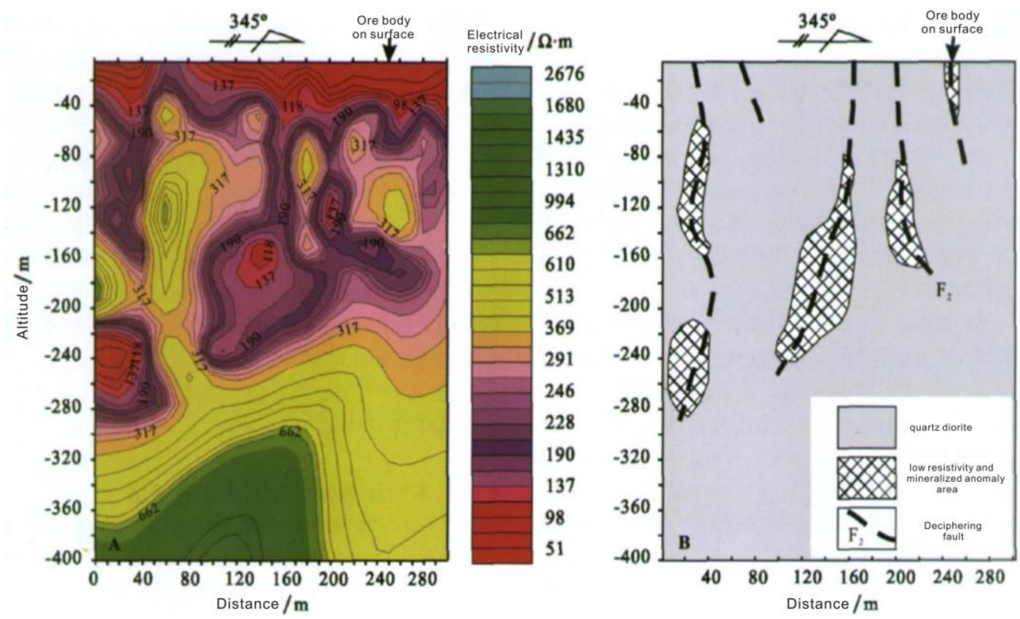


Figure 8. Apparent Resistivity-Depth Profile Map (a) of EH4 Survey of GG Exploration Line in 460 Gold Mine in Beishan, Gansu Province and the Geological Interpretation Chart (b) [13]

5. Problems and Prospects

5.1. Existing Problems

Although the application fields of EH4 electromagnetic imaging system has extended to all aspects in solid mineral, oil gas and water exploration, engineering exploration, environment monitoring and geoscience basic theory research and *etc.* [14-20], as one of the earth electromagnetic technology, EH4 also exists some common problems of magnetotelluric method and limited by the electromagnetic method itself.

In terms of data collection, terrain factors had a large influence towards the using effect of EH4 and the electrical interface occurrence obtained shall cause division at the rugged terrain [9]. Although in the continuous observation section, spatial filtering techniques of Bostic-inversion can be applied during the inversion process and thus weakened to some extent, the impact is much obvious when discontinuously observing the measuring point. As to the observation object, EH4 electromagnetic imaging system also has limitations. Enough electrical conductivity difference or in other word, finding an enough low resistance in an enough high resistance is the premise of acquiring the accurate resolution as precisely as possible and deep abnormal is more reliable than the shallow abnormal. Apart from this, the method to suppress abnormal shallow is still need further exploration.

5.2. Development Trend and Research Prospect

EH4 data processing has the following development tendencies: 1) EH4 data will gradually be more accurate and reliable; 2) With the rapid economic development, production efficiency improvement is the inevitable development trend of EH4 data processing; 3) Standardization; 4) Visualization, 3D visualization mapping has become the development trend of EH4 data processing; 5) EH4 data processing needs to be combined with other disciplines. With the diversified development of disciplines, EH4 data processing not only needs the base of geophysics, but also need to be combined with other disciplines, such as time series data acquired through the field data acquisition work should combined with the signal processing technology for analysis and processing. EH4's ultimate aim is to solve the problem of geological work, therefore the geological factors should also be considered in data processing [21].

As the national strategic resources demand increased with the peter out of superficial mineral resources, exploration for concealed mineral deposits and localization prognosis have become the top priorities. Shen Ping, etc [13, 22] adopting a research method which combined the geological with EH4 Double source magnetotelluric sounding method, made the location forecasting of the buried ore-body towards 38 metallic mineral deposits in China and achieved some relatively good metallogenic prediction results. Therefore, the joint connection of metallogenic theory forecast and prediction technique could help to establishment one geological-geophysical model and prediction criterion, which is an effective way to improve the prospecting effectiveness and thus acquire the more close-to-reality acquisition. EH4 will play a more and more important role in deep mineral exploration.

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