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Retraction

Retracted: Exploration of Erdaohe Silver Polymetallic Deposit in Inner Mongolia based on Induced Polarization Method

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] B. Li, Z. Shi, Z. Yang, L. Xu, H. Cheng, and D. Sturdivant, "Exploration of Erdaohe Silver Polymetallic Deposit in Inner Mongolia based on Induced Polarization Method," *Journal of Chemistry*, vol. 2022, Article ID 7053491, 9 pages, 2022.

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Research Article

Exploration of Erdaohe Silver Polymetallic Deposit in Inner Mongolia based on Induced Polarization Method

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The exploration of Erdaohe Cu-Ag-Pb-Zn deposit in Zhalantun City, Inner Mongolia has entered the stage of blind exploration. It is a difficult problem at this stage whether common geophysical methods can find anomalies caused by 300~1000 m or deeper Pb-Zn deposits in this area. Whether the problem is solved or not has a strong practical significance for the current and future prospecting work in this area. According to the theory of induced polarization sounding in time domain, it is considered in this paper that when the parameters such as high power, suitable device, and time delay are well coupled with the deep blind ore, it is possible to find anomalies caused by deep lead-zinc ore larger than 300 m. In order to prove the feasibility of the deep application of this method, the high-power induced polarization sounding experiment with different devices and different power supply cycles was carried out in Erdaohe copper-silver lead-zinc mine. The test results show that by adopting the measurement method of the encrypted equipotential device and selecting the appropriate polar distance, when the power supply period is 32 s, the time delay is 200 s and the sampling width is 200 s, a good deep lead-zinc mine anomaly can be found. The equipotential symmetrical quadrupole sounding MN/AB = 1/10 and the depth correction coefficient is 0.41 for inversion can accurately determine the anomaly location, which is worthy of popularization and application in this area. The ore bodies in this area are controlled by structures and distributed in lenticular layers along the fault footwall interlayer fracture zone. The ore bodies may change with the occurrence of the fracture surface. The characteristics of low resistivity, low slow, and high polarization of IP and single peak anomaly of IP sounding are important signs of lead-zinc prospecting in this area.

1. Introduction

With the increasing difficulty of prospecting and the progress of science and technology, geophysical instruments have been widely used in the exploration and evaluation of ore bodies. For the mining areas in the stage of presurvey and general survey, geophysical methods play a more prominent role. Induced polarization method (IP) has been applied in China for more than 50 years. It is a traditional and effective geophysical method. Based on different devices, this method can meet a variety of geological conditions and work purposes.

Erdaohe copper-silver-lead-zinc mine is located in the forest swamp area of Daxing' anling, with serious forest vegetation coverage, few outcrops of surface bedrock, and great difficulty in prospecting [1–5]. As an effective combination of exploration methods, induced polarization ladder device and symmetrical four-level sounding have been applied in this area, and good exploration results have been achieved [6–8]. Induced polarization method is an electrical exploration method based on the difference of induced polarization effect of rock and ore, which aims at finding underground minerals or solving geological problems by observing and studying the distribution law of induced polarization effect of underground media. In recent years, the induced polarization method has played an important role in the exploration of metal ore and graphite ore, especially in the search for hidden ore and deep ore. The deeper buried lead-zinc ore body can be found by increasing power, changing equipment, and measuring parameters. Previous studies have held that improving signal-to-noise ratio, selecting the array with large detection depth, and under the condition that proper sampling parameters are well coupled with deep ore, high-power IP measurement can obtain better deep lead-zinc ore anomalies, which is the key of IP method to search for deep concealed ore [9–12]. On the basis of previous studies, this paper carried out high-power induced polarization experiments on the known ore bodies in Erdaohe copper-silver-lead-zinc mine, Inner Mongolia, with different devices, different power supply cycles, different time delays and different sampling widths, and summarized the application effect of this method, so as to provide reference for future deep prospecting research and metallogenic prognosis.

IP survey provides an important geophysical basis for the discovery of Erdaohe silver lead-zinc deposit. According to the time domain-induced polarization sounding theory, when the parameters such as high power, appropriate instruments, and time delay are well coupled with the deep blind ore, it is possible to find the anomalies caused by the deep lead-zinc ore body more than 300 m. In order to prove the feasibility of the deep application of this method, high-power induced polarization sounding experiments with different devices and power supply periods were carried out in Erdaohe copper-silver-lead-zinc mine, Inner Mongolia. The test results show that the measurement method of densified equipotential device can accurately determine the abnormal position, which is worthy of popularization and application in this area.

2. Geological Background and Geological Characteristics of Mining Area

The working area of this paper is located in the southwest of Zhalantun City, Inner Mongolia, the middle section of Daxinganling metallogenic belt and the south section of Delbe dry metallogenic belt, which is the intersection of the ancient Asian tectonic domain vein and the Pacific Rim tectonic domain. The northern Daxing' anling-Late Paleozoic accretionary orogenic belt is located between Hegenshan, Urn-Oroqen fault, and Delbe main fault. The southern accretion part of the continental margin of the Siberian ancient plate (Northeast Asia and craton) is the first-order tectonic unit, the Daxinganling-Zhonghua and the western part of the Yougeosyncline fold belt, and it is located in the third-order tectonic unit-Aershan, the southeast wing of anticlinorium, Wulanhaote and the west side of the syncline north [13, 14]. Aeromagnetic characteristics of Erdaohe mining area are mainly stable positive magnetic field, which is distributed in the magnetic field area, showing irregular northeast strip distribution, reflecting the magnetic characteristics of Indosinian fine-grained granite, Jurassic volcanic rocks, Ordovician sandstone, and slate distributed in the mining area.

The exposed stratum in the area is the Permian Linxi formation. The main lithology is argillaceous, silty, and siliceous slate. The argillaceous and silty slate are relatively broken and the siliceous slate is relatively complete. Affected by the later structure, the slate at the known mineralization outcrop is strongly broken, forming an obvious broken alteration zone. The broken alteration zone is generally ferritized, and there are alteration marks reflecting hydrothermal activities such as silicification and calcitization. Limonite and lead alum are developed on the surface of silicified vein, and a small amount of galena is occasionally seen in the fresh section.

42 copper, lead-zinc, and silver ore bodies have been discovered, including 28 exposed on the surface and 14 blind ore bodies. According to the content of lead, zinc, silver, and copper components, there are 8 lead ore bodies, 8 zinc ore bodies, 4 silver ore bodies, 1 copper ore body, 7 lead-zinc ore bodies, 2 lead-zinc silver copper ore bodies, 8 lead-zinc silver ore bodies, 1 zinc silver ore body, 2 silver copper ore bodies, and 1 lead silver ore body. The ore body is lenticular, veined, or layered.

3. Geophysical Characteristics of Mining Area

3.1. Magnetism. Geophysical exploration methods are based on the study of certain physical properties of rocks, which are often expressed as physical characteristic parameters such as gravity, magnetic parameters, electrical parameters, and seismic wave parameters. Based on the study of the physical properties of rock mass, many geophysical exploration methods have been derived, mainly including the following four types of exploration methods, namely, gravity exploration, magnetic exploration, electrical exploration, and seismic exploration.

The lead-zinc ore and skarn containing magnetite in this area have strong magnetism, while tuff, andesite, metamorphic sandstone, and granite porphyry have medium magnetism, while granite and lead-zinc ore have weak magnetism. See Table 1 for statistical results.

3.2. Electrical Properties. The instrument used in this electrical test is SCIP sample core IP tester, and the tests are all completed in the field. The cores and samples are cut into regular columns by cutting machine, and after 24 hours of soaking, the dimensions are measured by multifunctional vernier caliper, and the process is carried out in strict accordance with Technical Specification for Physical Property Investigation of Rock and Ore (DD 2006-03) 8.2.5.3 [15–17]. The core electrical test is carried out by the core taken from the ore-finding borehole ZK4701 in Erdaohe copper-silver-lead-zinc mine. See Table 2 for the test statistics of the electrical parameters of rock and ore [18–21].

Table 1: Measurement results of magnetic parameters of surface rock ore.

Rock character	Quantity (pieces)	Magnetic susceptibility κ ($4\pi \times 10^{-6}$ SI)			The remanent magnetization Jr (10^{-3} A/m)		
		Average/mean value	Maximum	Minimum value	Average/mean value	Maximum	Minimum value
Tuff	32	200	670	10	Four hundred	830	230
Andesite	36	320	750	60	310	640	110
Skarn	32	800	2500	200	600	1500	400
Metamorphic sandstone	33	90	340	40	80	320	60
Granite porphyry	30	90	450	0	170	640	0
Granite	32	60	770	0	120	510	0
Lead-zinc ore	40	50	210	0	70	220	0
Pyritized lead-zinc ore	37	560	820	330	380	750	190

Table 2: Measurement results of electrical parameters of super rock ore.

Rock character	Quantity (pieces)	Polarizability η (%)			Resistivity ρ (ω m)		
		Minimum value	Maximum	Average/mean value	Minimum value	Maximum	Average/mean value
Tuff	36	1.5	3.1	1.8	976	2816	2775
Andesite	35	1.5	4.4	1.7	1322	8552	3622
Skarn	31	2.4	9.3	3.9	900	6718	2865
Metamorphic sandstone	30	1.7	4.8	1.8	491	4075	2263
Slate	33	1.5	4.2	2.6	552	4718	1665
Granite porphyry	32	0.9	3.2	1.1	535	4971	2475
Granite	40	0.8	3.9	1.8	1495	9182	3063
Lead-zinc ore	33	8.9	29.5	12.5	99	848	590
Pyrite tuff	34	4.2	24.1	10.2	736	2930	1036
Pyrite fine-grained diorite	34	10.5	34.1	15.2	748	2970	1074

According to the data in Table 2, the polarizability η values of granite, tuff, andesite, sandstone, and slate in the area are low, with an average value of 1.7%–2.6%, forming a normal field in the area, with a resistivity ρ value of 1,500 Ω m–3,600 Ω·m, which is characterized by relatively high resistivity. However, the polarizability η of lead-zinc ore and sulfide ore increases obviously, with the highest value of 34.1% and the highest average value of 15.2%. Corresponding to the characteristics of low resistance, lead-zinc, sulfide ores form obvious high polarization and low resistance anomalies, which is one of the important prospecting indicators in this area, while its surrounding rocks, such as granite and tuff, are characterized by low polarization and relatively high resistance, and the electrical differences between the ore and surrounding rocks are obvious [22]. Combined with the strong magnetic characteristics of lead-zinc ores and skarns containing magnetite in this area, it has obvious geophysical premise to search for sulfide deposits containing magnetite by high-precision magnetic method and IP area measurement in this area. However, pyritization rocks can form high polarization interference [23].

From 2009 to 2010, Inner Mongolia, No. 3 geological exploration Co., Ltd. carried out 1 : 10000 magnetic method and IP medium ladder short traverse survey, respectively, in Erdaohe copper polymetallic survey area, and circled a number of irregular sheets and band shaped electrical and magnetic anomalies [24–26]. When carrying out the integrated exploration project in 2014, we mainly carried out IP middle ladder profile survey, high-precision magnetic profile survey, IP sounding and audio frequency large IP sounding in No. 2 mining area. The electrical and magnetic anomalies are consistent with the stratigraphic trend, with regular shape and good coincidence. Most of the magnetic anomalies are related to the contact zones and structures, which basically reflect the overall lithology and structural pattern of the northeast and northwest directions in this area, mainly in the northeast direction, and show obvious regularity.

IP anomalies are distributed in the strata of the bare River formation of the Ordovician system and the OBO formation of the Manketou formation of the Jurassic system, and are distributed in a belt shape along the northeast direction, consistent with the direction of the main structural line [27]. The main part of the apparent charge rate anomaly is located in the low resistivity zone, showing the characteristics of low resistivity and high polarization. The main IP anomaly distributed in the Jurassic volcanic rocks is consistent with the geochemical anomaly, which is verified as a lead-zinc silver ore body by engineering [28].

4. Working Methods of Geophysical Prospecting in Mining Area

4.1. Methods and Equipment. The measurement results of rock and ore electrical parameters show that this area has the premise of induced polarization measurement. However, according to past experience, if induced polarization method wants to reach deeper exploration depth, it must have higher power, appropriate polar distance, and the best measurement parameters. In order to solve these problems and get better results in the measurement, this time, the experimental-induced polarization measurement was carried out centering on the borehole ZK4701 (see the ore depth $H = 468$). The instrument adopts WDFZ-10T high-power IP transmission system produced by Chongqing Pentium Instrument Factory, and the receiving system adopts WDJS-3 multichannel digital DC IP receiver.

4.2. Selection of Electrode Arrangement Direction. The working section is centered on the drilling hole ZK4701, which is basically vertical in structure, stratigraphic strike, and ore body strike. In order to further study the layout of polarizer, the direction of electrode arrangement is perpendicular to the direction of polarizer along the section, and the direction of electrode arrangement is as consistent as possible with the topographic contour. Therefore, the electrode arrangement direction is set to 26.

4.3. IP Ladder Measurement. According to the characteristics of ore bodies in the mining area, the width of ore bodies in this area is 30~350 m. In order to obtain a better step anomaly of induced IP with the increase of exploration depth, lMN polar distance, which is equivalent to the maximum width of deep ore body, is considered in this experiment. According to the symmetrical four-stage exploration with equal ratio, lAB/2 is at 1150 m and lMN is at 115 m, which can obtain good deep ore-induced anomalies. Comprehensive measurement of various factors shows that the measurement parameters of IP middle ladder section are lMN/2 = 100 m, lAB/2 = 1500 m, measuring point distance 20 m, power supply period 32 s, time delay 200 ms, and sampling width 200.

The ore body has obvious IP anomaly, which reflects the characteristics of high charging rate and low resistivity. The apparent charge rate is 100 ms~130 ms and the apparent resistivity is 600 m~1800 gm. IP anomaly is the main ore prospecting sign. The inversion section of audio magneto telluric sounding is in good agreement with the ore body and geological content (ore bearing structural fracture zone). The corresponding Kania resistivity on the ore body is of low resistance, with a value of 200 Ω·m~600 Ω·m. Audio magneto telluric sounding can be used to search for ore bearing structures as an indirect ore prospecting sign.

5. Data Processing and Results Analysis

5.1. Analysis of Polarizability and Resistivity of Different MN/2 Polar Distances. At borehole ZK4701, the field data of symmetrical four-level sounding were collected by induced polarization method, and the measured data were Vp (mV), I (mA), and η (%). By calculating the device coefficients k and ρ, lglAB/2 is used as the abscissa of unequal devices, the arithmetic average of the measured values of small lMN and large lMN is used as the mapping data of the polar distance change part, lAB/2 is used as the abscissa of equipotential devices, and the polarizability and resistivity are used as the ordinate of each device. The experimental results are shown in Figures 1 and 2.

It can be seen from Figure 1 that the induced polarization sounding anomalies obtained by different lMN/lAB have similar polarizability curves in the shallow part, while each polarizability curve in the deep part shows different morphological characteristics, although it has an attenuation trend. LAB/2 starts from 250, the peak characteristic of lMN/lAB ≈ 0.18 is more obvious than that of lMN/lAB ≈ 0.3, but both of them show the characteristics of sharp data jump and weak continuity. LMN/lAB = 0.10 not only has obvious peak anomaly and anomaly width, but also has good anomaly continuity, rich data information, and large amount of information. It can be seen from Figure 2 that lMN/lAB = 0.10 also has better high resistance abnormal reflection than the other two groups, with obvious abnormal peak and width, and smooth and continuous curve shape. The above situation shows that lMN/lAB = 0.10 has good polarizability and resistivity anomalies, and the obtained deep information is more reliable, which is more conducive to inferring deep geological bodies.

5.2. Analysis of Polarizability and Resistivity in Different Power Supply Cycles. It can be seen from the curve of lMN/lAB with a power cycle of 16 s as a constant ratio device that the depth attenuation is very obvious. During the measurement process, by increasing the power supply voltage and current, and decreasing or increasing lMN, the normal measurement values could not be continued or obtained, which indicates that the measurement depth may be limited when the power supply period is 16 s. Therefore, in this paper, two groups of data with longer power supply period of 32 s and 64 s are added by encrypting the equipotential device.

Figures 3 and 4 show that Lab/2 is less than 1000 m, and the curve shape characteristics of polarizability and resistivity are similar in different power supply cycles of the encrypted equal ratio device. The overall characteristics of the curve are single peak, high polarizability, high resistivity, obvious peak value, abnormal continuity, and wide multipoint width. The polarizability of the two groups with short power supply period has large and strong abnormal amplitude. When the power supply period is 16 s, the lAB/2 starts to exceed 950 m, and the polarization curve decays rapidly, and the measured value is less than 0.02%. There is no measured value after lAB/2 greater than 1100 m. The resistivity curve shows that the high resistivity peak in the shallow part is obviously abnormal, and the low resistivity anomaly in the deep part is not reflected. When the power supply period is 32 s, lAB/2 starts to exceed 950 m, and the

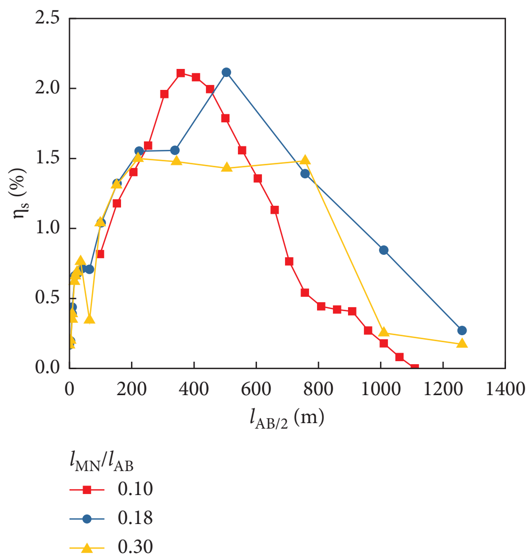

Figure 1: Polarization curves of different MN/2 polar distances.

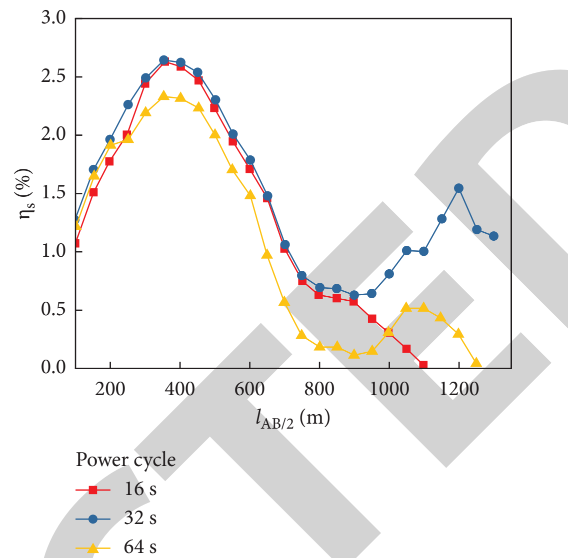

Figure 3: Polarization curves of different power supply cycles.

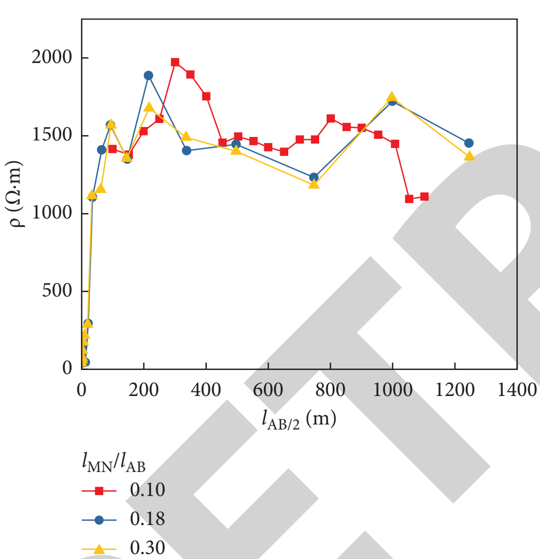

Figure 2: Resistivity curves of different MN/2 polar distances.

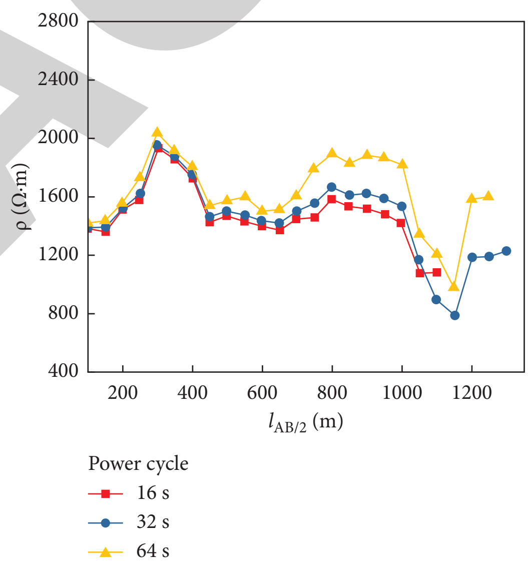

Figure 4: Resistivity curves of different power supply cycles.

polarizability gradually increases, forming a deep single peak anomaly, reaching the highest value of 1.55% at lAB/2 = 1200 m, then gradually becoming stable, and the high polarizability anomaly is obvious. The resistivity at Lab/2 = 250~450 m is basically the same as that in a short power supply period, and the high resistivity is extremely obvious, and the curve shape is continuous and smooth. In the deep section of lAB/2 = 1000–1200 m, there is a *V*-shaped low resistivity anomaly, which is obvious and the resistivity is as low as 400 Ω·m. When the power supply period is 64 s and lAB/2 is greater than 950 m, the polarizability value gradually increases, and there is a high polarizability anomaly, but the anomaly amplitude is not large, the intensity is not high, and the anomaly width is large and gentle. The resistivity is basically the same as that of the smaller power supply period, and the high resistance is unusually obvious. When lAB/2 > 450 m, the amplitude increases, which is higher than the sounding values of two groups with short power supply period. At the deep section of lAB/2 = 1000–1200 m, the profile shows "*V*"-shaped low resistance anomaly, and the resistivity is as low as 520 *ω*·m.

To sum up, when the power-off time is 16 s, 32 s, and 64 s, it can well reflect the shallow lAB/2 < 1000 m with shallow polarizability anomaly; When the deep lAB/2 > 1000 m, the smaller power supply period is affected by the measurement time, and the measurement depth is limited. The power supply period of 16 s fails to reflect the deep low resistance and high-grade anomaly. The power supply periods of 32 s and 64 s can well reflect the deep low resistance and high-grade anomaly, and there is no big difference in resistivity characteristics. However, the peak value of polarization

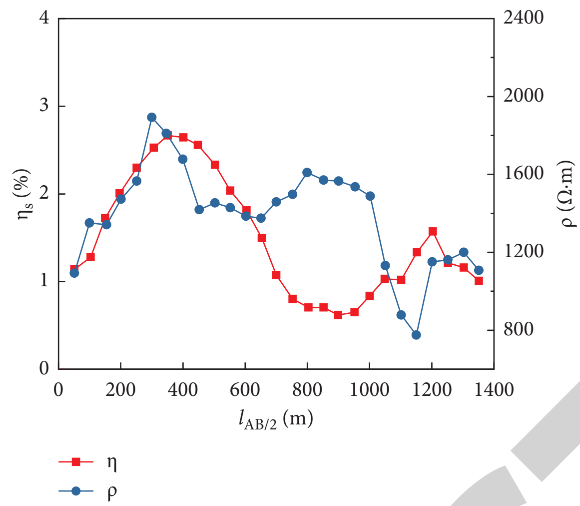

Figure 5: $T = 32$ s polarizability resistivity curve of sounding.

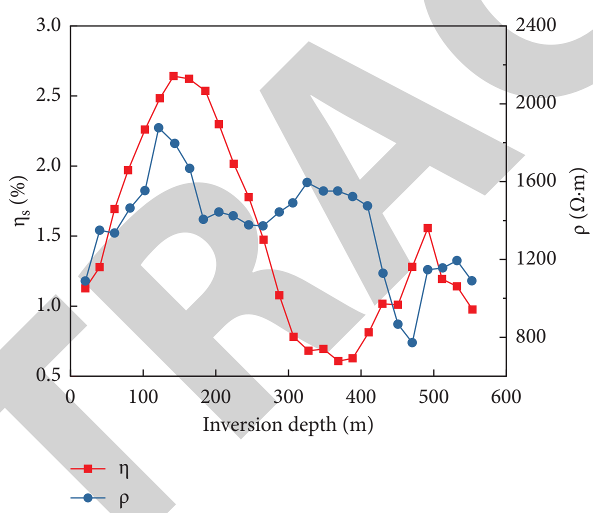

Figure 6: $T = 32$ s polarizability resistivity inversion curve of sounding.

anomaly obtained by the power supply period of 32 s is more obvious, and the abnormal amplitude is larger, which indicates that the power supply period of 32 s has low resistance and high polarization in this area.

5.3. Application Effect of Induced Polarization Method in Geological Geophysical Prospecting. Through the comparative analysis of several groups of sounding data and borehole ZK7401, it is found that there is a big difference between each abnormal depth and the actual mineralized alteration zone and ore-finding location, which needs to be corrected empirically by combining physical property test and known ore-finding location in the working process.

And the test results of the power supply period of the device show that when $T = 32$ s, it can better reflect the deep geological body anomalies. According to its polarizability and resistivity anomalies (Figure 5), compared with the test results of electrical parameters, we find that the high resistivity and high polarizability anomalies in the shallow part are consistent with the mineralization alteration characteristics. lAB/2 = 350 m, the maximum polarizability of 2.63% is taken as the buried depth of the mineralized zone, and the depth correction coefficient is 0.41. After correcting the sounding curve of $T = 32$ s (Figure 6), the abnormal depth of high resistivity and high polarization in the shallow part is 143~164 m, and the abnormal depth of low resistivity and high polarization in the deep part is 471~492 m, which is basically consistent with the ore-finding depth of 468 m.

Through the sounding test, it is considered that the deep IP sounding anomaly can be obtained under the conditions of proper power supply period, large power supply polar distance, and measuring polar distance. However, induced polarization method is difficult and inefficient in field data acquisition. If the ladder device can find the abnormal position on the plane by induced polarization method, and

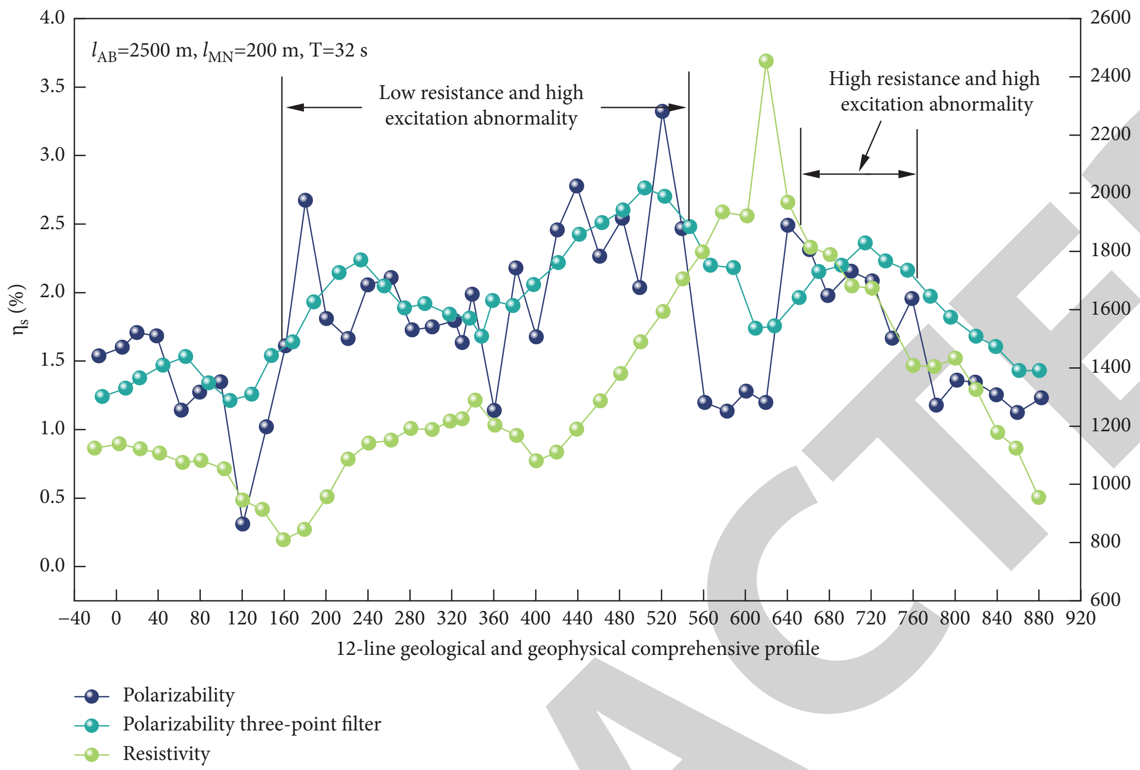

FIGURE 7: Comprehensive profile of geological and geophysical exploration of Line 12.

then carry out sounding verification, it can get twice the result with half the effort. According to the test results, the power supply pole distance lAB = 2500 m, the measuring pole distance lMN = 200 m, and $T = 32$ s are selected, and the middle ladder measurement is made online 12. From the measurement results, the section 160/12–560/12 has obvious low resistance and high polarization, and the section 640/12–760/12 has obvious high resistance and high polarization. However, the curve of polarizability jumps. Through three-point filtering of polarizability data, the jump points are removed, and the anomaly becomes obvious (Figure 7). According to the physical property test results, the low resistivity and high polarizability anomalies in section 160/12–560/12 are in line with the characteristics of ore-induced anomalies. It is inferred that this anomaly is caused by the deep lenticular ore body caused by ore, which corresponds to the ore body ZK4701. The anomaly of high resistance and high-grade rate in section 60/12–760/12 may be caused by the anomaly of deep low-grade ore bodies, which has deep prospecting significance.

Induced polarization method is an important method to explore various metallic minerals. This method has achieved good ore prospecting results in this area, and has brought into play the specialty of IP in finding concealed metal ore bodies. With the continuous progress of electronic technology and the research of exploration technology, the pseudo-random multifrequency-induced polarization method can be used to identify “carbonaceous” interference anomalies. The development and production of induced polarization instruments at home and abroad have also made great progress, and the exploration depth has reached more than 2000 meters. It can be expected that the application of induced polarization method in other fields will be more and more extensive.

6. Conclusion

According to the time domain induced polarization sounding theory, when the parameters such as high power, appropriate instruments, and time delay are well coupled with the deep blind ore, it is possible to find the anomalies caused by the deep lead-zinc ore body more than 300 m. In order to prove the feasibility of the deep application of this method, high-power induced polarization sounding experiments with different devices and power supply periods were carried out in Erdaohe copper-silver-lead-zinc mine, Inner Mongolia. The results are as follows:

(1) Based on the significant difference of electrical characteristics between ore and surrounding rock, combined with the geophysical data mining of ore-finding borehole, the correction coefficient of data processing inversion depth is 0.41, which can improve the accuracy of inference of mine-induced anomalies, and the adjacent areas can be used for reference.

(2) According to the test results of high-power induced polarization method with different polar distances and different parameters, the IP-induced anomalies with a depth of more than 300 m can be obtained by encrypting the 1AB and 1M middle ladder scanning surfaces with large polar distances, and selecting an

appropriate power supply period T (the best period in this test is 32 s).

(3) The ore bodies in this area are controlled by the structure, and distributed along the lenticular layered features of the interlayer fracture zone in the footwall of the fault, and the ore bodies may change with the occurrence of the fracture plane. The characteristics of low resistance, low slow, and high polarization in IP and single peak anomaly in IP sounding are the important signs of prospecting for lead and zinc in this area.

Data Availability

The figures and tables used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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