The forward modeling for surface-borehole observation responses of polarized sphere in uniform electric field

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Abstract. Surface-borehole induced polarization method is a common geophysical method in metal exploration. The forward calculation results of the borehole observation responses can provide reference and support for practical work. In particular, the forward results of spherical polarized target can be equivalent to massive ore body or karst caves and other low-resistivity anomalies. In this paper, the forward simulation of borehole induced polarization responses is carried out by using the electric dipole model equivalent spherical polarized body. The results show that the polarization degree of the excitation source at different positions is different, and the closer the proximity is, the stronger the secondary field anomaly is. Borehole observation has advantages for the identification of deep ore bodies. Under the same offset condition, the closer the distance from the borehole is, the stronger the responses will be. The results of this paper can provide reference and basis for relevant research work.

1. Introduction

Borehole induced polarization (IP) method is an important deep exploration technology, which is mainly used in the exploration of metal ore bodies, but also can be used in hydrology or engineering exploration [1]. The surface-borehole observation is the most commonly used exploration device in various borehole IP method [2]. After decades of research and application, it has achieved good results in various exploration work [3].

For the surface-borehole observation, the data amount of is small and multi-solution is strong. Its data processing and interpretation need to be based on the recognition of the response and the prediction of the target [4]. Therefore, forward has become an important research content and plays an important supporting role in borehole observation [5]. For metal ore targets, the commonly used polarized equivalent theoretical models are sphere, ellipsoid, plate and so on. Among them, the sphere model can be equivalent to the typical low resistivity anomaly targets such as massive orebodies and karst caves, which is a suitable theoretical model [6][7]. The forward method of the polarized sphere includes numerical simulation, numerical calculation and equivalent model [8]. The calculation of numerical simulation is large and inefficient. Numerical calculations require Legendre polynomials. In contrast, the equivalent model is more applicable and the algorithm is simple and intuitive [9][10].

In this paper, we choose the electric dipole equivalent model to approximate the polarized sphere, and carry out forward calculation by changing the parameters [11][12]. Through the analysis of forward modelling results, the characteristics and rules of well observation response are obtained, and the advantages and characteristics of surface-borehole observation are deduced. The results of forward
calculation and analysis in this paper can provide basis and theoretical support for related work and research.

2. Forward algorithm

We choose the electric dipole equivalent model as the basic algorithm, as shown in equation (1):

$$V_2 = K \left[ \frac{d^2 - 2(z - h)^2}{d^2 + 2(z - h)^2} \right]^{2.5} \sin i - 3d(z - h) \cos i MN.$$

Where $d$ is distance between the borehole and midpoint of the sphere, the $h$ is the depth of midpoint of the sphere, the $z$ is the observation point in the borehole, the $i$ is the polarized angle, the $MN$ is the distance between observation electrodes M and N, the $r$ is the offset, the $K$ is a parameter related to observation conditions. The geoelectric model of the observation device and the sphere nearby the borehole is shown in Figure 1.

3. Forward modeling

The geoelectric model and configuration as shown in the Figure 1. The surface source at different position, and electrodes M and N observed secondary fields in the borehole.

Figure 1. Half-space 2-D geo-electric models with polarization sphere.

The ground field sources include A0, A1, A2, A3 and A4. The observation electrodes M and N in vertical borehole.

Figure 2. The secondary fields of polarized sphere nearby hole for different field source.
The parameters of 2-D geo-electric models and configuration: $h$ is 300 m, $d$ is 100 m, $MN$ is 20 m, $r$ is 0 m for A0, $r$ is 100 m for A1, $r$ is 200 m for A2, $r$ is 300 m for A3, $r$ is -100 m for A4, observation depth 60 to 580 m, observation point distance is 10 m.

As shown in Figure 2, both the strength of the response and the profile characteristics change with the offset. The closer the field source is to the target, the stronger the response is. As shown in Figure 3, although the depth of the polarized sphere is increasing, the response is still identifiable, indicating that borehole observation has an advantage over deep anomalous bodies. As shown in Figure 4, under fixed observation conditions, the response strength decreases with the increase of $d$, indicating the need to improve observation conditions to enhance the detection capability of observation in borehole.

Figure 3. The secondary fields of polarized sphere nearby borehole for different depth. The parameters of 2-D geo-electric models and configuration: $d$ is 100 m, $MN$ is 20 m, $r$ is 100 m for A1, observation depth 60 to 580 m, observation point distance is 10 m.

Figure 4. The secondary fields of polarized sphere nearby borehole for different $d$. The parameters of 2-D geo-electric models and configuration: $z$ is 300 m, $MN$ is 20 m, $r$ is 100 m for A1, observation depth 60 to 580 m, observation point distance is 10 m.
4. Conclusion
First of all, surface-borehole observation method is an effective exploration device, which has a good
detection ability for deep anomalous bodies.
Secondly, different field source locations will produce different abnormal responses, showing
different states in profile characteristics and response intensity.
Finally, although surface-borehole observation has a certain survey ability, it is necessary to
improve observation conditions to obtain better observation results for anomalous bodies far from the
borehole.

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