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The 3D Forward of Vertical Current Source Electromagnetic Method

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SUMMARY

A special CSEM in frequency-domain method, using a vertical current source place on the wall of a borehole and measures the horizontal electric fields on the surface, is named Vertical Current Source Electromagnetic (VCSEM) method is introduced in this paper to study the feasibility of the method. The 3D responses calculated using finite difference simulation scheme to analyze the 3D responses in case of the source being buried different depth. The results show that the multiple information about the object can be obtain using the observation data of the different depths of the VCS. Therefore, the vertical CSEM method is a high-precision electromagnetic method and have the potential to be applied in prospecting minerals, predicting water inflow or mapping reservoir boundary and monitoring the variations of oil-gas contact, and so on.

Introduction

The conventional controlled-source electromagnetic (CSEM) method in frequency domain, is often placed the horizontal current source on the earth surface. However, if there has vertical borehole such as mine and oil well, the two electrodes can be placed on the wall of the well to excite a high-power harmonic current, then a higher signal to Noise Ratio (SNR) and more effective information within the observed data on surface for a shorter distance between the source and the deep object underground than the one of the ground CSEM method. We see this method as a Vertical Current Source Electromagnetic (VCSEM) method. It can be applied in prospecting minerals, predicting water inflow or mapping reservoir boundary (He et al., 2005) and monitoring the variations of oil-gas contact, and so on. In this paper, a 3D Finite Difference in Frequency-Domain (FDFD) scheme is implemented to simulate the response of the method, and the response characteristic is analysed to verify the feasibility of the method and to provide the theoretical supports.

Method

The center of the well on the surface is set as the coordinate origin, and z-axis points to the subsurface along the direction of the vertical well. A Vertical Current Source (VCS) can be seen as a Vertical Electric Dipole (VED) or Vertical Line Current Source (VLCS), using two electrodes placed on the wall of the well whose z-coordinates are z_A and z_B respectively. A measured electric field $\mathbf{E}$ is divided into two parts. The one is the primary or background field $\mathbf{E}_p$ from the homogeneous space or layered half-space, the other is the abnormal electric field or second field $\mathbf{E}_s$ generated by a VCS. $\mathbf{E}_p$ can be obtained by the 1D semi-analytic solution (Kerry Key, 2009). $\mathbf{E}_s$ is calculated using 3D numerical scheme.

Typically only low frequencies are used and therefore displacement currents can be neglected. Assuming an uniform magnetic permeability $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$ and an $e^{i\omega t}$ time dependence, the differential form of the electric field can be wrote as (Newman and Alumbaugh, 1995):

$$\nabla \times \nabla \times \mathbf{E}_s + i\omega\mu_0\sigma\mathbf{E}_s = -i\omega\mu_0[\sigma - \sigma_p]\mathbf{E}_p \quad (2)$$

σ_p is the conductivity of the background model, and $\sigma - \sigma_p$ is the conductivity anomaly. Equation 2 is solved using FDFD scheme (Newman and Alumbaugh, 1995), and using the Dirichlet boundary condition yields a linear system of equations

$$\mathbf{K}\mathbf{E}_s = \mathbf{Q} \quad (3)$$

The BICGSTAB(L) method (Sleijpen and Fokkema, 1993) and an zero-fill incomplete LU decomposition is applied as a preconditioner to solve equation 3. L is equate to 3 in this paper.

Synthetic data examples

The test model is a halfspace model with resistivity $100 \Omega \cdot m$ and contains a 3D platelike object with resistivity $500 \Omega \cdot m$. The geometric position of the object is $[2000, 3000] \times [-500, 500] \times [300, 800]m$. The frequency and amplitude of the current are 4Hz and 1A respectively. The responses for different burial depths of z_A and z_B are calculation using FD method mentioned above.

Figure 1 shown the curves of the amplitude of E_y component $|E_y|$ and the curves of $\Delta|E_y|$ of the survey line $y=0m$ in case of the different depths of VCS. $\Delta|E_y|$ is the difference between $|E_y|$ and the background value $|E_{y0}|$. If the burial depth of the source is much less than that of the object, both $|E_y|$ and $\Delta|E_y|$ are small at the correspond horizontal position of the object. If the depth of the source is close to or deeper than that of the object, the responses of the correspond place are larger and therefore give a larger SNR. But if the burial depth of the source is much deeper than that of the object, the values of $|E_y|$ and $\Delta|E_y|$ may become very small. Figure 2 shows the distribution of the

logarithm of $|E_y|$ of the XZ section of $y=450\text{m}$. The black rectangle frame denotes the position of the object in the section. The distribution of the field influenced and distorted obviously by position of the VCS, and a more distorted field in the area of the anomaly appears near the source.

Figure 1 The curves of $|E_y|$ (left) and $\Delta|E_y|$ (right) of $y=0\text{m}$ on surface for different depths of the buried source.

Figure 2 The distribution of the logarithm of $|E_y|$ of the section $y=450\text{m}$ for different depths of the buried source.

Conclusions

The 3D FDFD numerical results demonstrate the feasibility of the VCSEM method to exploration the electrical structures. The two electrodes can be placed any depths in the vertical well, and the multiple information about the underground abnormality can be obtained from the observed data on surface.

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