Original paper

On the estimation of the maximum depth of investigation of transient electromagnetic soundings: the case of the Vizcaino transect, Mexico

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Resumen

Probamos un método propuesto en la literatura para estimar la profundidad máxima de investigación (PMI) de sondeos electromagnéticos transitorios (TEM) de bobina central con datos del transecto Vizcaíno; un perfil de 38 sondeos TEM que cruza la península de Baja California. Se confirma la validez de esta técnica al comparar la PMI con la interfase más profunda de 16 modelos estratificados. En estos sondeos, todos ellos localizados en la cuenca Vizcaíno, los datos medidos no están afectados por polarización inducida. Los modelos indican la presencia de un conductor buzante interpretado como una zona de intrusión salina con una gran extensión lateral de más de 70 km. Los otros 22 sondeos, localizados sobre rocas ígneas y metamórficas, muestran cambios en la polaridad de los voltajes que indican la presencia de efectos de polarización inducida. Los modelos estratificados Cole-Cole de estos sondeos sugieren una disminución importante en la PMI. Esto es confirmado al analizar el comportamiento en profundidad de las densidades de corriente. También se analiza el nivel de ruido de un conjunto de datos que comprende cerca de 2000 voltajes de tiempo tardío de aproximadamente 400 sitios TEM adquiridos en el noroeste de México. No se encontró una diferencia entre los niveles de ruido estacionario de invierno y verano, posiblemente debido a que prácticamente no hay tormentas eléctricas en esta parte de México.

Palabras clave: sondeos electromagnéticos transitorios, profundidad máxima de investigación, polarización inducida.

Abstract

We test an approach proposed in the literature for estimating the maximum depth of investigation (MDI) of in-loop transient electromagnetic soundings (TEM) with data from the Vizcaino transect, a profile of 38 TEM soundings crossing the Baja California peninsula. The validity of this approach is confirmed by comparing the MDI with the deepest interface of 16 stratified models. In these soundings, all located over the Vizcaino basin, the measured data are not affected by induced polarization. The models indicate the presence of a dipping conductor interpreted as a zone of seawater intrusion with a large lateral extension of over 70 km. The remaining 22 soundings, located over igneous and metamorphic rocks, show reversals in the voltage polarity, indicating the presence of induced polarization effects. The layered Cole-Cole models for these soundings suggest a significant decrease in the MDI. This is confirmed by analyzing the depth behavior of the subsurface current densities. We further analyze the noise level of a data set comprising close to 2000 late-time voltages of about 400 TEM sites acquired in northwestern Mexico. No difference was found between the stationary noise levels of winter and summer, presumably because near thunderstorms are practically absent in this part of Mexico.

Key words: transient electromagnetic soundings, maximum depth of investigation, induced polarization.

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Introduction

The transient electromagnetic (TEM) method is based on the induction of electric current in the ground by a transmitter loop. When a DC current injected into the loop is abruptly turned off, an electric field is induced in the ground, which generates the flow of subsurface currents. These currents rapidly vary in time and space, producing a transient magnetic field in the vicinity of the transmitter. The time variation of this field is sensed with the voltage induced in a coil laid on the ground surface. Placing this coil at the center of the loop is known as the in-loop array. The shape and intensity of the measured voltage is a function of the resistivity subsurface distribution. The method has been used extensively in a variety of applications, such as groundwater exploration, mineral and oil prospecting, buried-metal detection, and geologic mapping.

A frequently asked question during the planning of in-loop transient electromagnetic soundings is, "What is the maximum depth of investigation (MDI) if a square loop of dimensions L by L is used as the transmitting source?" There is no simple answer to this question. Although the MDI does depend on the loop dimensions, it also depends on other parameters. Several estimates of the MDI have been reported in the literature (McNeill, 1980; Fitterman, 1989; Spies, 1989). In this work we adopt and test that proposed by Spies (1989), which is the most clear and complete.

In this paper we start with a brief description of Spies method followed by a presentation of the Vizcaino data and inverted models. Then, we discuss some modifications to Spies expression to be applied to the inverted models. Finally, soundings affected by induced polarization are analyzed.

The maximum depth of investigation

Based on the asymptotic behavior of the late-time voltages at the center of a circular loop over a two-layered earth, Spies (1989) proposed the following expression for the MDI,

$$D_{\max} \approx 0.55\left(\frac{I\,A_T\,\rho_1}{\beta}\right)^{0.2} \tag{1}$$

where I is the current injected into the loop, A_T is the area of the loop, ρ_1 is the resistivity of the first layer, and β is V_N/A_R, the voltage noise level (V_N) over the effective area of the receiving coil (A_R). Clearly, this depth not only depends on the size of the transmitting loop, but also on four other parameters; two of them of instrumental character (injected current and area of the receiving coil), a subsurface geophysical parameter (layer resistivity), and an environmental parameter (voltage noise level).

Figure 1 shows the behavior of the normalized voltages induced in a horizontal coil located at the center of an L by L square loop over a two-layer earth for three L/d ratios and five ρ_2/ρ_1 ratios, where d is the first layer thickness and ρ_1 and ρ_2 are the layer resistivities. These curves for a square loop are similar to the circular loop responses presented by Spies (1989). Both axes are dimensionless. In the abscissas the variable τ is a normalized time, being the square root of the diffusion depth $\left(\delta=\sqrt{2t\rho/\mu_0}\right)$ in the first layer over its thickness. Spies noticed that the time at which the different curves separate at least 20% (denoted as departure time) does not have a strong dependency on the L/d or ρ_2/ρ_1 ratios, so he approximated it as unity. That is,

$$\tau_d = \frac{2t\,\rho_1}{\mu_0\,d^2} \approx 1 \tag{2}$$

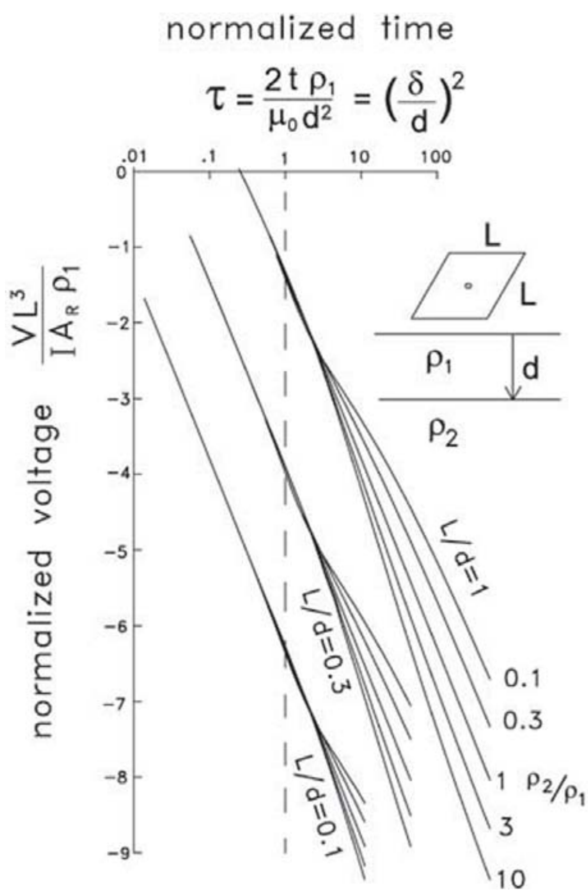

Figure 1. Log-log plots of the in-loop normalized voltage against normalized time for a square loop over a two-layered earth. Three L/d ratios and five ρ_2/ρ_1 ratios are considered. The unity departure time is indicated