FORWARD MODELLING OF TIME DOMAIN INDUCED POLARIZATION (TDIP) RESPONSE FOR SIMPLE EARTH GEOMETRIES

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Abstract— *The IP response parameters are very important variable in the method of Time Domain Induced Polarization (TDIP). IP response is happened due to the geometry of the polarisable target at the subsurface. Theoretically, IP response is obtained by solving the Laplace equation ($\nabla^2\Phi = 0$), with boundary condition and at the coordinate system. Simple geometry in subsurface is a sphere and block as approach of a geological models' ore and dike. Retrieved curves that describe the relationship between the TDIP response parameters and subsurface parameters. Forward modelling uses Res2Dmod and the results are useful as a parameterization on physical modelling*

Key words : Respon IP parameters, Laplace equation, forward modelling.

INTRODUCTION

Induced Polarization (IP) method is a widely used method for conductive subsurface mineral exploration since last 50 years. The basic concept of IP published by Siegel (1959). Siegel formulated basic relationship polarization caused by the current density that is defined as chargeability (m) in the form of changes in resistivity. Apparent chargeability in the surface is caused by the presence of polarisable medium at subsurface at several electrode configurations. Apparent chargeabilty in the surface is the sum of all chargeability at the subsurface.

Siegel [1] obtained IP response of polarisable sphere and two-layer models by using selected electrode array. Bhattacharya and Biswas [2] differentiated IP response caused by a 2D horizontal cylinder. All of the differentiation is based on Siegel's definition of apparent chargeability[1].

In this paper, IP response that is caused by ideal geometry of the target at subsurface is calculated. Numerical calculation produces a curve of IP response to the depth variation and electrode spacing. The purpose of this study is obtaining an IP response of the simple model of earth's subsurface. TDIP response curve is searched by a numerical way. In obtaining the curves of models selected, Res2Dmod was used. Forward modelling of the theoretical curve obtained will be compared with the curve obtained from measurements TDIP response on physical modelling.

METHOD

In general, a homogeneous isotropic medium which passed through by current with density J will apply Ohm's law. The electric field is the scalar gradient of potential, then the relationship between potential and current density can be a potential grad $J=\sigma E=-\sigma\nabla V$. Therefore div current density is zero $\nabla.J=0$ and resistivity or conductivity of the medium is constant, then the Laplace equation can be obtained.

$$\nabla^2 V = 0 \qquad \text{........................(1)}$$

In the subsurface conditions there are objects with different resistivity around them (Figure 1), then to obtain TDIP response, the potential on surface must be counted. Laplace equation must be solved with boundary conditions which appropriate with subsurface conditions. In general, the boundary conditions are:

- On the surface, normal current density is equal to zero.
- At the boundary of two mediums, the current density normally is same.
- At the boundary of two mediums, the potential is same.

Some assumptions used as a response calculation IP are:

- Target and host polarized homogenizing.
- Primary homogeneous electric field.
- Resistivity and chargeability of homogeneous isotropic target

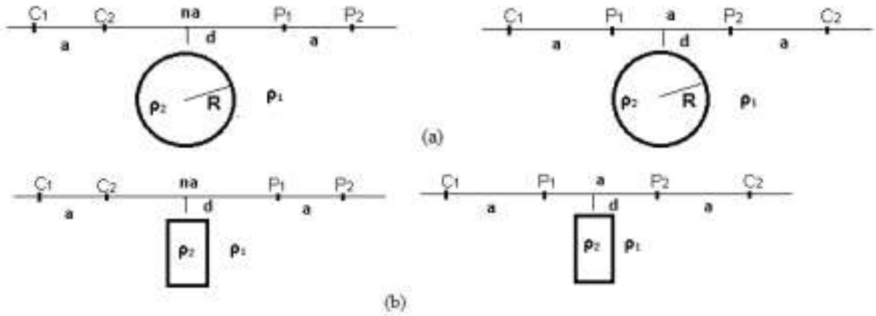

Figure1. Simple geometry model (a). sphere and (b) block with Dipole-dipole and Wenner configuration.

Laplace equation must be changed first in spherical coordinates, then can be solved to obtain TDIP response on the surface. Potential is caused by solid sphere at subsurface of a homogeneous and isotropic. Solution of Laplace equation $\nabla^2 V = 0$ by entering the limit condition:

(1) $\frac{\partial V^{(s)}}{\partial \mu} = 0\ ,\ \mu = 0$

(2) $V_1 = V_2,\ \mu = \mu_o$

(3) $\sigma_1 \frac{\partial V_1}{\partial \mu} = \sigma_2 \frac{\partial V_2}{\partial \mu},\ \ \mu = \mu_o$

In order to obtain the surface potential at the point,

$$V^{(s)} = -\left(\frac{\sigma_2 - \sigma_1}{\sigma_2 + 2\sigma_1}\right)\frac{E_O R^3 x}{(x^2 + d^2)^{3/2}} \qquad \text{........................(2)}$$

Total potential on surface caused by sphere in subsurface is normal potential and anomalies potential.

$$V_1 = -E_O x \left\{1 - 2\left(\frac{\rho_1 - \rho_2}{\rho_1 + 2\rho_2}\right)\frac{R^3}{(x^2 + d^2)^{\frac{3}{2}}}\right\} \qquad \text{........................(3)}$$

If there is a current source surface (C1), the measured potential at P1 is:

$$V_1 = -\frac{I\rho_1}{2\pi R_1^2}\left[1 - 2\left(\frac{\rho_1 - \rho_2}{\rho_1 + 2\rho_2}\right)\frac{R^3}{(x^2 + d^2)^{\frac{3}{2}}}\right]x \qquad \text{........................(4)}$$

Where x is the distance of the center of the sphere toward the receiver (P1), R is the radius of the sphere, R1 is the distance of the center of the sphere toward the current source (C1). If the source of distant current (electric field is homogeneous), then the potential which measured at two potential electrodes is a derivative of equation (4) toward x. So, IP response can be obtained for configuration of two potentials on the surface

IP configuration for the two potential surface.

$$\frac{\rho_a}{\rho_1} = \left[1 + \left(\frac{\rho_1 - \rho_2}{\rho_1 + 2\rho_2}\right)R^3\left(\frac{(2x^2 - d^2)}{(x^2 + d^2)^{5/2}}\right)\right] \qquad \text{........................(5)}$$

$$\frac{m_a}{m_2} = -3\left[\frac{\rho_1^2}{(\rho_1 + 2\rho_2)^2}\right]R^3\left[\frac{(2x^2 - d^2)}{(x^2 + d^2)^{5/2}}\right] \qquad \text{........................(6)}$$

The same thing was done for the dike model. Completion of Laplace equation for dike model with Pole- and Dipole-dipole pole electrode configuration was done by Akman [3]. There are two ways to solve the Laplace equation on the dike model boundary conditions, those are reflection and the use of Bessel Integral.

Completion of Laplace equation results TDIP response caused by objects subsurface. TDIP response in form of chargeability and resistivity as in equation (5) and (6). TDIP response can be expressed as a curve which describes the change in value of lateral TDIP response. The process of obtaining the curves of the simple forms called a forward modelling. Forward modelling using Res2DMod Ver3.01 [4], because that is more adapted with physical modelling condition. The description of the curves obtained using Microsoft Excel Graphic.

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RESULT AND DISCUSSION

The theoretical curve obtained from forward modelling is a sphere with radius of 1 cm to 5 cm depth using Dipole-dipole and Wenner configuration in Figures 2 and 3. Forward modelling for a sphere with 5 cm and 10 cm depth and 2 cm and 10 cm spacing wass also done. Therefore obtained curves with the variation of depth and spacing for Dipole-dipole and Wenner configuration as in Figure 4.and 5.

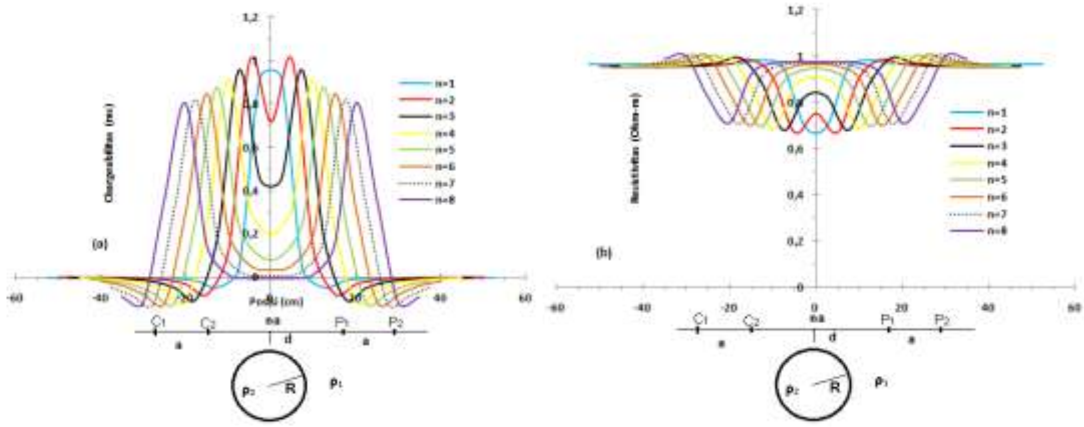

Figure 2. Theoretical TDIP response normalized (a). Chargeability and (b). Resistivity of sphere with radius R = 5 cm and depth d = 1 cm, Dipole-dipole configuration.

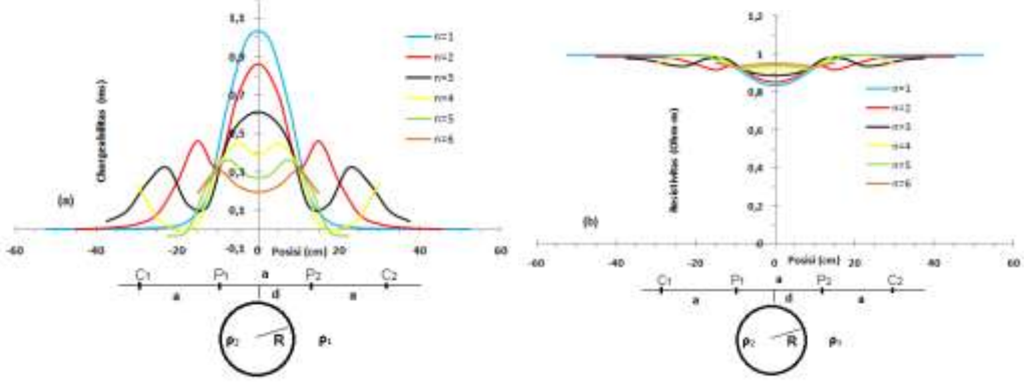

Figure 3. Theoretical TDIP response normalized (a). Chargeability and (b). Resistivity of sphere with radius R = 5 cm and depth d = 1 cm, Wenner configuration

Forward modelling results in a curve that describes the relationship of TDIP response to subsurface parameters, those are depth of radius, resistivity of target and background medium. This curve can be used as consideration for the selection of appropriate parameters applied on a physical modeling in laboratory scale so the result can be optimized.

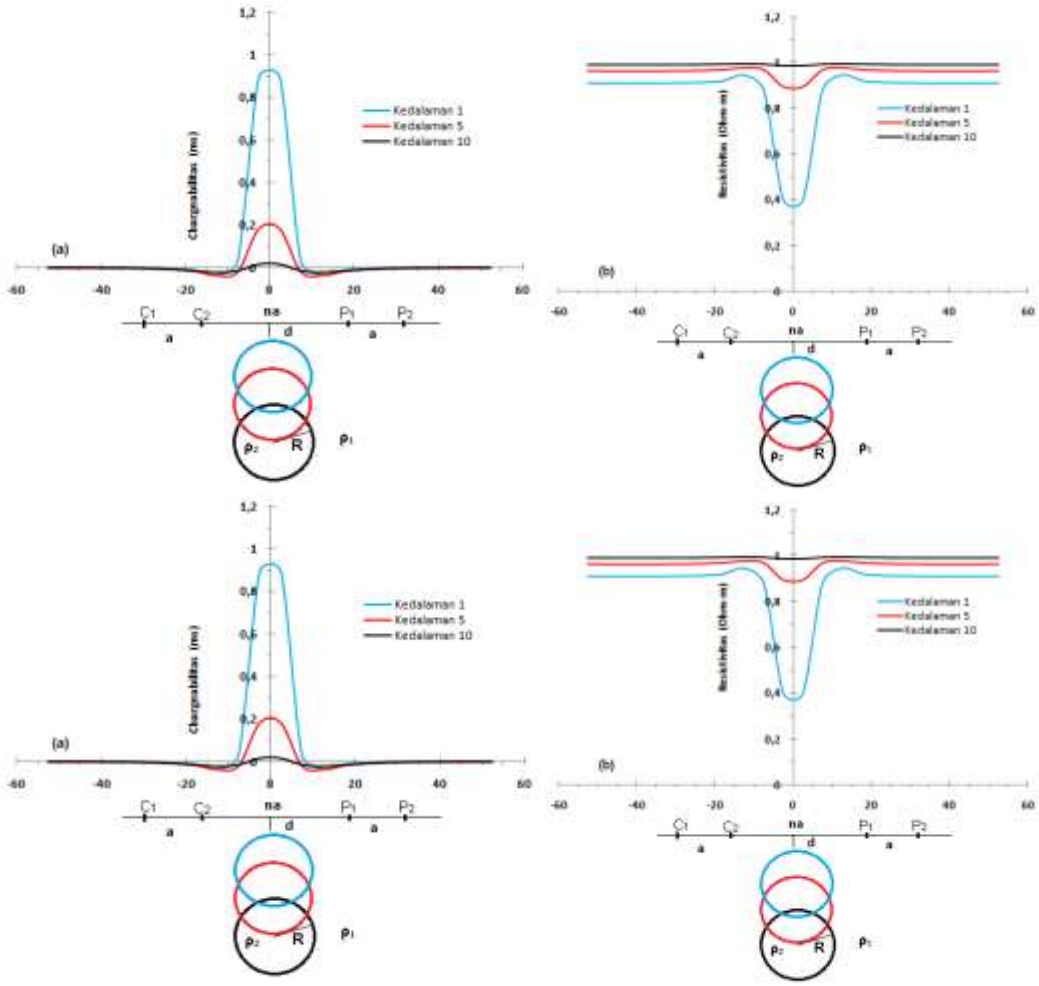

Figure 4. Theoretical TDIP response normalized (a). Chargeability and (b). Resistivity of sphere with radius R = 5 cm in depth d = 1.5 cm and d = 10 cm, Dipole-dipole configuration with spacing of 5 cm and n=1.

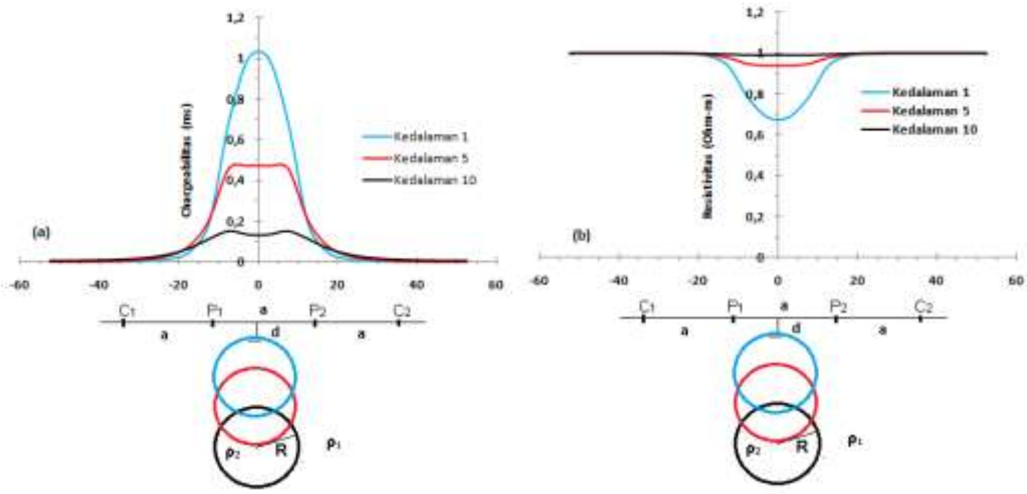

Figure 5. Theoretical TDIP response normalized (a). Chargeability and (b). Resistivity of sphere with radius R = 5 cm in depth d = 1.5 cm and d = 10 cm, Wenner configuration with spacing of 5 cm and n=1.

In the case of a sphere with radius of 5 cm in a depth of 1 cm (Figures 2 and 3) using Dipole-dipole and Wenner configuration, can be seen that the amplitude TDIP responses those are chargeability and resistivity will be maximum at n = 1. This suggests that it is the best for spacing of 5 cm.

Figure 4 and 5 are comparison of TDIP response to depth of 1, 5 and 10 cm using a Dipole-dipole and Wenner configuration. The greatest response is obtained for n = 1, if the depth of sphere is 1 cm. From these curves can be seen that the deeper the target position results in the smaller TDIP response will be. The greatest response can be obtained if the object is located near the surface. Therefore, in spacing of 5 cm, the maximum result can be gained in the depth of 1 cm.

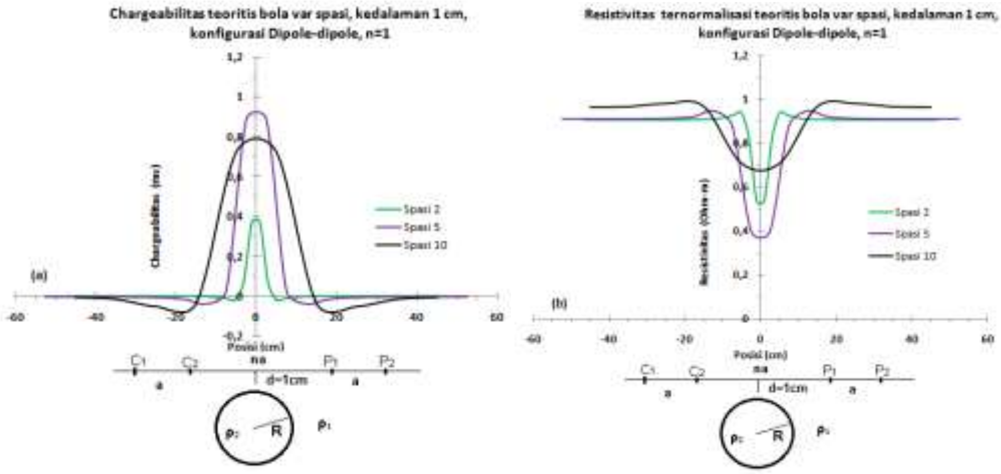

Figure 6. Theoretical TDIP response normalized (a). Chargeability and (b). Resistivity of sphere with radius R = 5 cm in depth d = 1 cm, Dipole-dipole configuration with spacing of 2.5 cm and 10 cm, n=1.

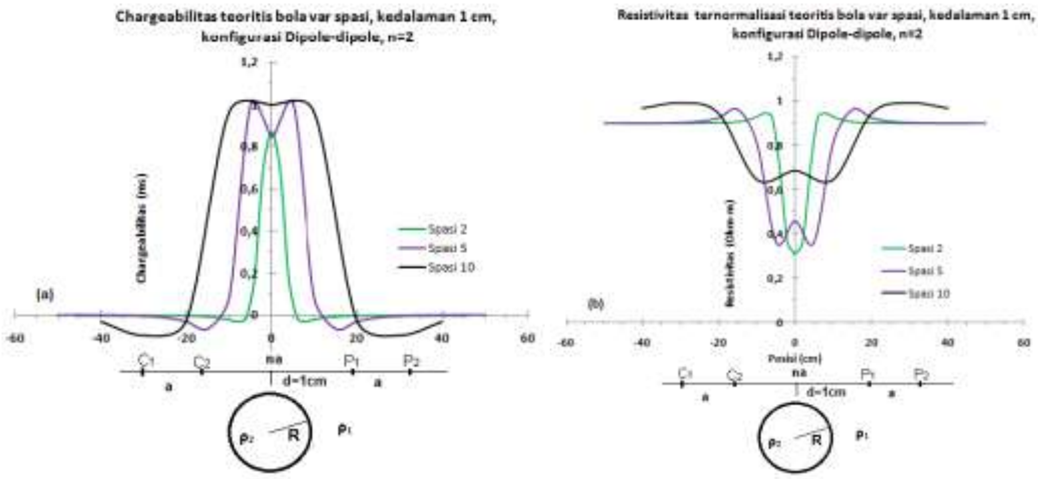

Figure 7. Theoretical TDIP response normalized (a). Chargeability and (b). Resistivity of sphere with radius R = 5 cm in depth d = 1 cm, Dipole-dipole configuration with spacing of 2.5 cm and 10 cm, n=2.

Figure 6 and 7 are comparison of curve at the same depth and spacing. Those curves can be used to select the appropriate spacing on the target's depth desired. The results will be optimum if it is applied to the physical modelling. In a case of the sphere at a depth of 1 cm, the best of spacing used is 5 cm.

Forward modelling is also done on the block (5x20x40) cm^3 of 1 cm using Dipole-dipole and Wenner configuration with spacing 5 cm (Figure 8 and 9). Forward modelling of 5 cm and 10 cm depth and 2 cm and 10 cm spacing were also made.

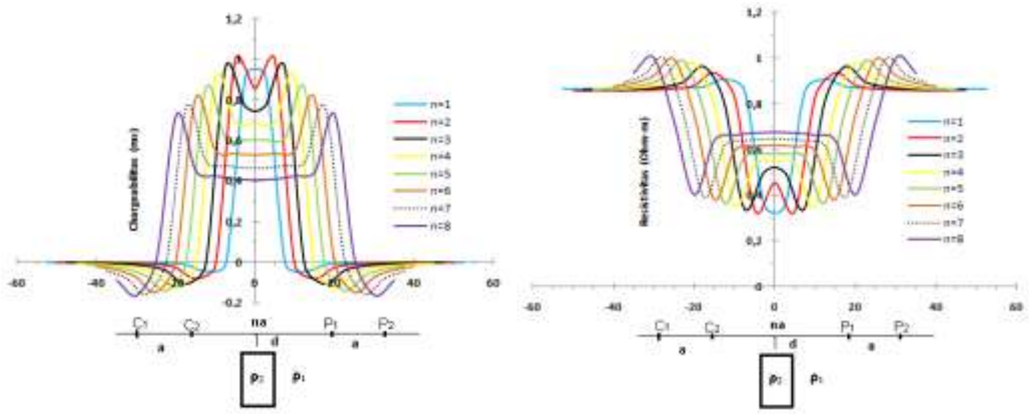

Figure 8. Theoretical TDIP response normalized (a). Chargeability and (b). Resistivity of block with (5x20x40) cm^3 in depth d = 1 cm, Dipole-dipole configuration.

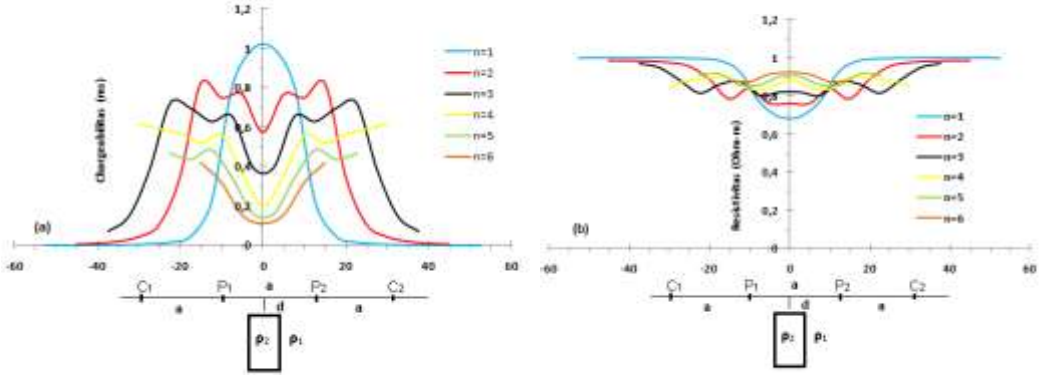

Figure 9. Theoretical TDIP response normalized (a). Chargeability and (b). Resistivity of block with (5x20x40) cm^3 in depth d = 1 cm, Wenner configuration

The curves obtained from TDIP response using forward modelling of the sphere or dike target is theoretical curves. These curves are used as a benchmark for measurement curve on physical modeling. Of course in reality it will be different between theory and measurement results. If the measurement procedures are correct, the equipment used is not problematic and physical modelling conditions are in qualify then the difference will be quite small.

CONCLUSION

1. Forward modeling results in curve that describes the relationship of TDIP response toward subsurface parameters. This curve can be used as consideration for the selection of appropriate parameters applied on a physical modeling in laboratory scale
2. From comparison curve of depth, the deeper the target position results in the smaller TDIP response will be.
3. Comparison curves of the same depth and spacing can be used to select the appropriate spacing on the target's depth desired. In a case of the sphere at a depth of 1 cm, the best of spacing used is 5 cm.

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