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McPHAR

A RECONNAISSANCE DOWNHOLE INDUCED POLARIZATION AND RESISTIVITY SURVEY METHOD

Bisbee, Az

by Anthony M. Hauck III

Presented at the S.E.G. Annual Meeting
New Orleans, Louisiana, November 1970

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139 BOND AVENUE, DON MILLS, ONTARIO, CANADA

ABSTRACT

The downhole-radial induced polarization and resistivity method utilizes three current electrodes: a downhole electrode within the drill hole, a surface electrode near the drill hole collar, and a remote electrode located on the surface at a distance from the drill hole. Current is sent on three different dipoles: downhole-remote, surface-remote, and surface-downhole. Voltage and induced polarization measurements are made along radial lines extending from the drill hole.

Comparison of data obtained from the downhole-remote sending dipole with that obtained from the surface-remote sending dipole permits an estimate of the lateral position and depth of the anomaly along the receiving line. Data from the surface-downhole sending dipole provides a check on the accuracy of the downhole-remote and surface-remote dipole data, and is useful for evaluating the ground at shallow depth near the drill hole.

In practice, four or more receiving lines are run from the drill hole. If an anomaly is detected, it can be assigned to a particular quadrant so that the next drill hole location can be determined. In exploratory grid drilling, use of the downhole-radial method permits the drill holes to be spaced farther apart. The method is most applicable when the expected ore zones are discrete, but it also has applications in delineating large buried disseminated zones. Model results and case histories for both massive and disseminated sulphide zones are presented.

INTRODUCTION

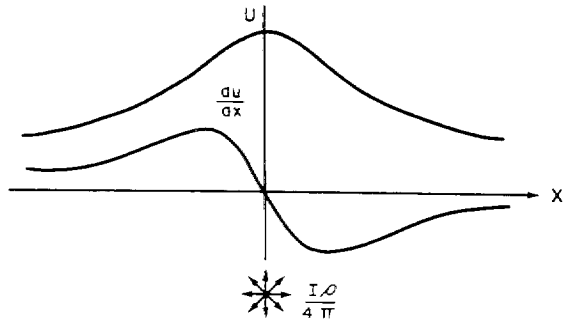
The downhole-radial induced polarization and resistivity survey method was developed intermittently over a period of years at Phelps Dodge Corporation, beginning in 1963. Several mining companies have experimented at various times with drill hole induced polarization and resistivity methods. The azimuth method, developed by Newmont Mining and described by Baldwin, and Wagg and Seigel, utilizes a potential electrode within the drill hole and surface current electrodes. The downhole-radial method described in this paper is a reconnaissance method which utilizes a current electrode within the drill hole and surface potential electrodes.

The use of an underground current electrode and its advantages over a surface current electrode in certain horizontally-layered situations have been described by Luigi Alfano, Geophysical Prospecting, in 1962. The Russians at the Trudy Institute of Geophysics also in 1962 published a series of papers describing the field of a point source of current situated at depth in horizontally-layered and vertically-layered mediums, and also the field of a point source located at depth in the presence of an ideally conducting sphere.

Figure 1 shows a schematic of the surface potential and gradient of potential due to a buried point source of current. The potential curve flattens with increasing depth of burial. The positive gradient, which is measured in field practice, shows first an increase and then a decay as one travels outward from a point above the source.

Sunde has shown by the method of images that the potential due to a current electrode below the surface of the earth is obtained from expression (1), where s is the distance from a point on the earth to the electrode and s^1 is the distance to its image above the surface of the earth. For a flat earth, which is assumed in all the model and field results which follow, the distance s and s^1 are equal, and the potential is equal to the source strength $I\rho$, normalized by 2π, times the reciprocal of the distance between the measuring point and the source.

FIGURE 1



(1) $U = \frac{I\rho}{4\pi}\left(\frac{1}{S}+\frac{1}{S'}\right)$

FOR A FLAT EARTH $S = S'$, AND

(2) $U = \frac{I\rho}{2\pi}\left(\frac{1}{S}\right)$

(SUNDE, 2.26)

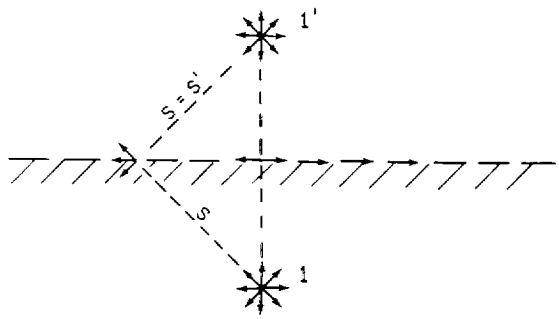
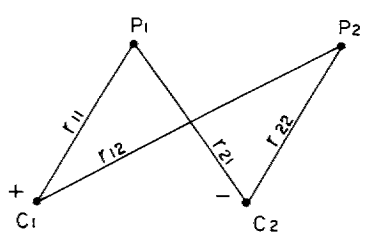


FIGURE 2



GENERAL IMPEDANCE FORMULA FOR A DIPOLE – DIPOLE GEOMETRY IS

(3) $\frac{V_{12}}{I} = \frac{\rho}{2\pi}\left[\left(\frac{1}{r_{11}}-\frac{1}{r_{12}}\right)-\left(\frac{1}{r_{21}}-\frac{1}{r_{22}}\right)\right]$

THE GENERAL FORMULA IS A SUPERPOSITION OF TWO POLE – DIPOLE IMPEDANCES

(4) $\frac{V_{12}}{I} = \frac{\rho}{2\pi}\left[\left(\frac{1}{GF}\right)_1 - \left(\frac{1}{GF}\right)_2\right]$ WHERE GF = GEOMETRIC FACTOR

(5) $\frac{V_{12}}{I} = \frac{V_1}{I} - \frac{V_2}{I} = \frac{\rho_1}{2\pi}\left(\frac{1}{GF}\right)_1 - \frac{\rho_2}{2\pi}\left(\frac{1}{GF}\right)_2$

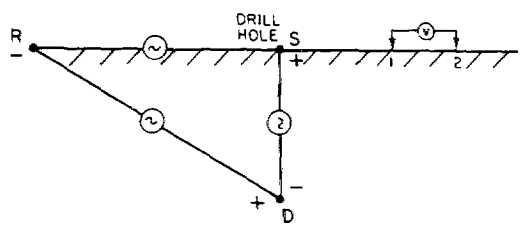
FOR A HOMOGENOUS MEDIUM $\rho = \rho_1 = \rho_2$

Figure 2 shows the familiar general impedance formula for a dipole-dipole geometry (3). The general formula can be written as a superposition of two separate, pole-dipole impedances, with current poles at C_1 and C_2 and a receiving dipole at $P_1 - P_2$. For a dipole-dipole geometry, the apparent resistivity ρ is assumed equal to ρ_1 and ρ_2. However, this is only true for a homogeneous medium.

As shown in Figure 3, the downhole-radial induced polarization and resistivity survey method utilizes three current electrodes: a downhole electrode (D) within the drill hole, a surface electrode (S) near the drill hole collar, and a remote electrode (R) at a distance from the drill hole. Current is sent on three different dipoles: S-R, D-R, and S-D. Voltage and induced polarization measurements are made on the surface along radial lines extending from the drill hole. The impedances at the receiving dipole are given in expression (5), (6), and (7). The right-hand portion shows the impedance as the summation of two pole-dipole impedances. The choice of sending electrode sign is arbitrary. Expression (8) follows, and shows that the impedance measured between any two points on the surface due to the S-R dipole is equal to the sum of the impedances due to the D-R and S-D dipoles. Thus, data from the S-D dipole is redundant. However, by measuring the impedances due to all three dipoles, it is possible to obtain a check of data quality and accuracy for both modelling and field work. The expression (8) holds true for an inhomogeneous medium. In most instances the impedance due to the S-R dipole is the highest, but occasionally the D-R or S-D dipole may yield the highest impedance. The geometric factors for any one of the three sending dipoles can be calculated from those for the other two, as shown in expression (9).

In 1964 a resistivity modelling study was made in order to demonstrate the advantage of using a downhole current electrode, and to demonstrate that a comparison of the D-R sending dipole data with the S-R dipole data is a useful means of evaluating the D-R dipole data.

FIGURE 3



DIPOLE - DIPOLE POLE - DIPOLE

(5) $$\frac{V_{12}}{I_{S-R}} = \frac{\rho_{S-R}}{2\pi}\left(\frac{1}{GF}\right)_{S-R} = -\frac{\rho_R}{2\pi}\left(\frac{1}{GF}\right)_R + \frac{\rho_S}{2\pi}\left(\frac{1}{GF}\right)_S$$

(6) $$\frac{V_{12}}{I_{D-R}} = \frac{\rho_{D-R}}{2\pi}\left(\frac{1}{GF}\right)_{D-R} = -\frac{\rho_R}{2\pi}\left(\frac{1}{GF}\right)_R + \frac{\rho_D}{2\pi}\left(\frac{1}{GF}\right)_D$$

(7) $$\frac{V_{12}}{I_{S-D}} = \frac{\rho_{S-D}}{2\pi}\left(\frac{1}{GF}\right)_{S-D} = -\frac{\rho_D}{2\pi}\left(\frac{1}{GF}\right)_D + \frac{\rho_S}{2\pi}\left(\frac{1}{GF}\right)_S$$

FROM THE ABOVE EXPRESSIONS,

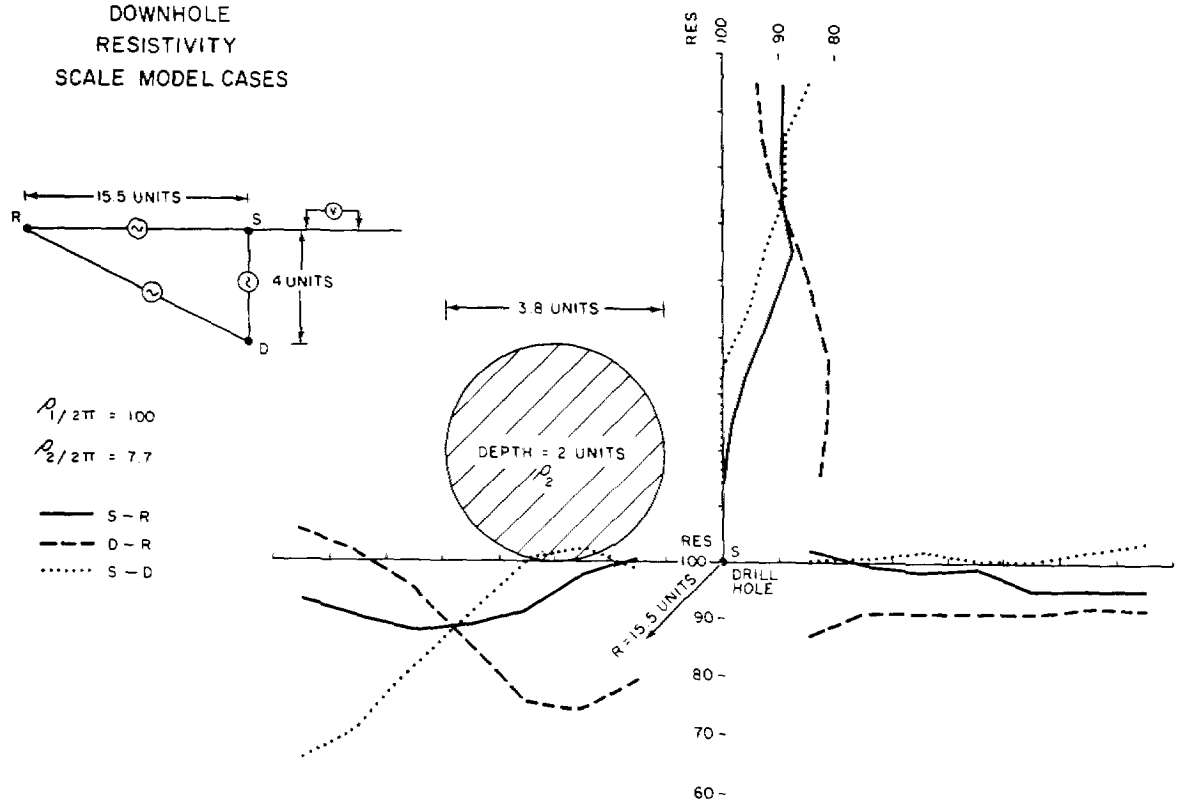
(8) $$\frac{V_{12}}{I_{S-R}} = \frac{V_{12}}{I_{D-R}} + \frac{V_{12}}{I_{S-D}}$$

IT CAN ALSO BE SHOWN THAT

(9) $$\left(\frac{1}{GF}\right)_{S-R} = \left(\frac{1}{GF}\right)_{D-R} + \left(\frac{1}{GF}\right)_{S-D}$$

FIGURE 4

DOWNHOLE
RESISTIVITY
SCALE MODEL CASES



The work was performed using Dr. John S. Sumner's modelling tank at the University of Arizona. The next four figures show the results of resistivity quadrant studies using a large spherical conductive body.

Figure 4 shows the resistivity results obtained along west, north, and east receiving lines. The conductive sphere is 3.8 units in diameter, and is located 2 units deep to the top in the northwest quadrant, 1.5 units from the drill hole. The downhole electrode is 4 units deep, and the remote electrode is located in the southwest quadrant, 15.5 units from the drill hole. The resistivity contrast is 1:13, and the resistivity responses are relative to a background of 100 ohm-feet. In this figure and in all the figures that follow, the response from the S-R dipole is shown as a solid line, the response from the D-R dipole is shown as a dashed line, and the response from the S-D dipole is shown as a dotted line.

In Figure 4, the D-R resistivity profile shows a strong low opposite the body and above-background resistivities along the western portion of the receiving line beyond the body. The S-R profile shows a low which is not as strong as the D-R low, and which is centered at the far edge of the body. The S-D profile shows above-background resistivities opposite the body and a strong resistivity low beyond the body. The three resistivity profiles cross at a point of equi-resistivity which is fairly close to the far edge of the body. The north D-R profile also shows a resistivity low opposite the body. The north S-R and S-D profiles show weaker lows along the northern portion of the line. The east D-R resistivity profile shows a resistivity low in the immediate vicinity of the drill hole, and low resistivities throughout the remainder of the line. The corresponding S-D resistivities are slightly above background.

Figure 5 shows the resistivity results obtained when the conductive body is in the same lateral position but 4 units deep, the depth of the downhole electrode. The west and north D-R resistivity profiles

FIGURE 5

DOWNHOLE
RESISTIVITY
SCALE MODEL CASES

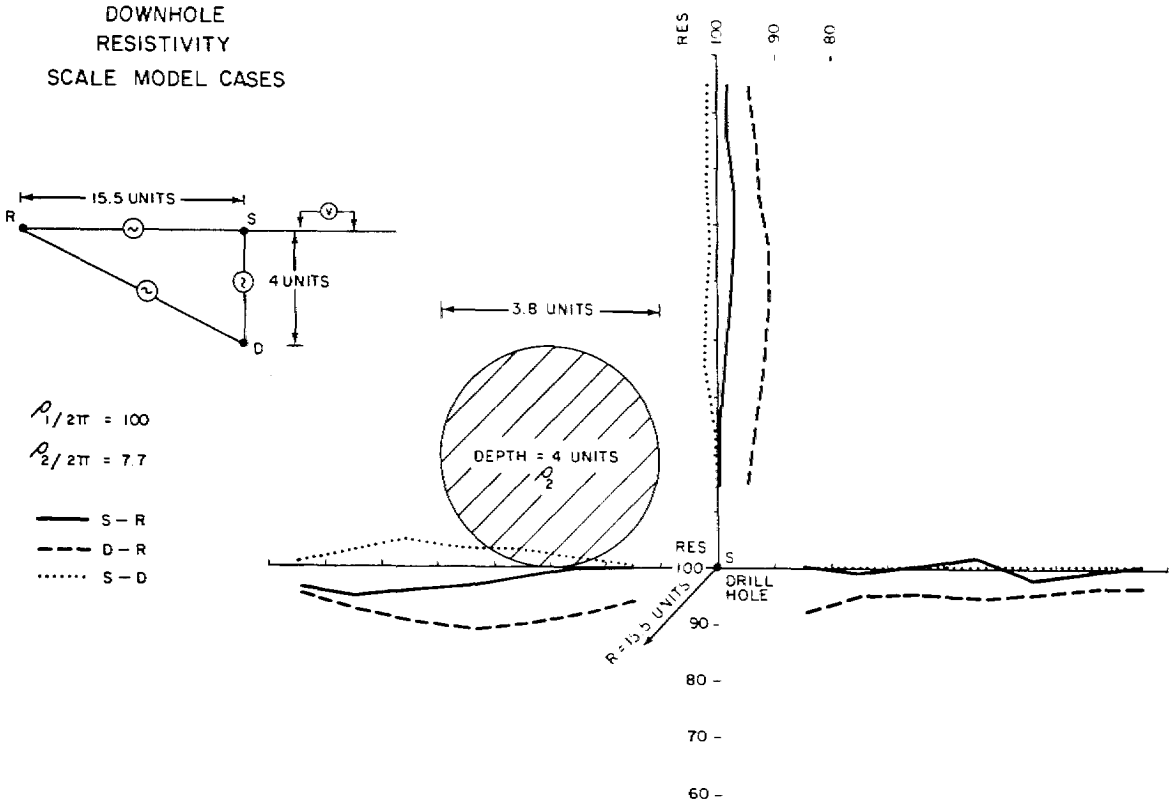
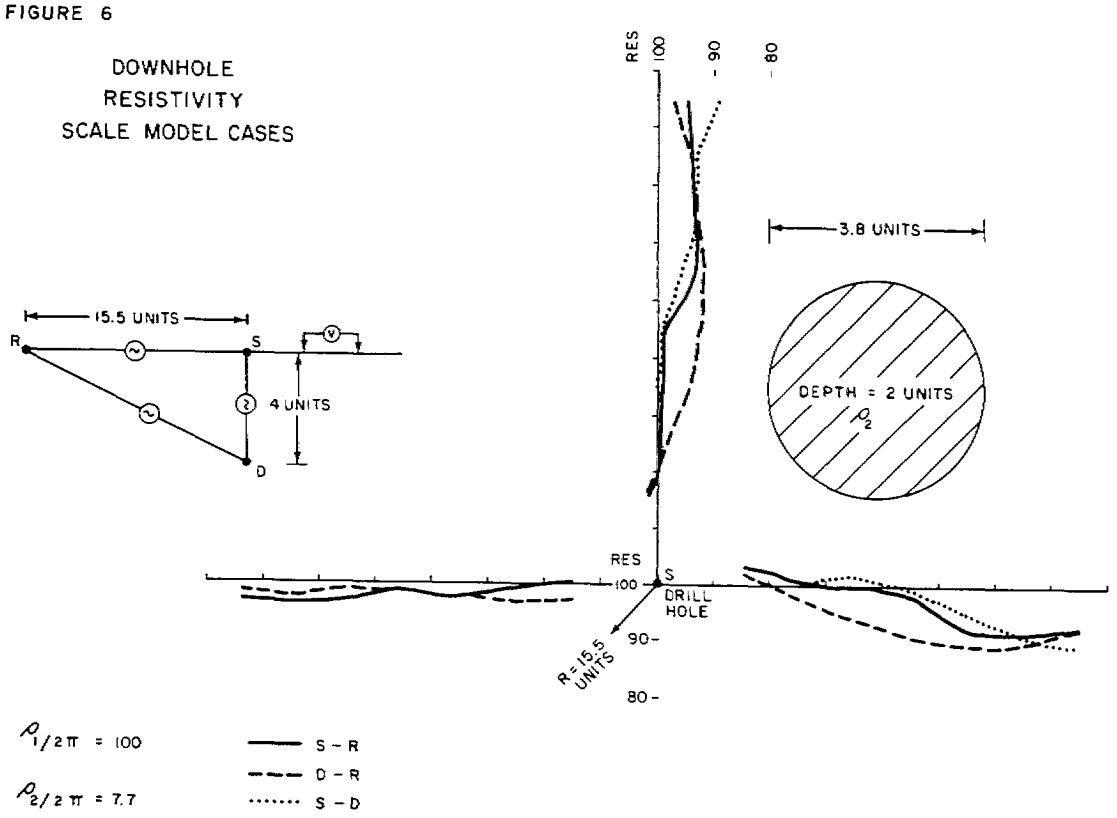


FIGURE 6

DOWNHOLE
RESISTIVITY
SCALE MODEL CASES



show broad lows. The corresponding S-R profiles show slight lows beyond the far edge of the body. The corresponding S-D profiles show above-background or high resistivities. The east D-R resistivity profile shows low resistivities throughout, but the resistivities are not as low as those obtained when the body is 2 units deep.

Figure 6 shows the resistivity results obtained along west, north, and east receiving lines when the conductive body is in the northeast quadrant, 2 units deep, and 3.3 units from the drill hole. The north and east D-R resistivity profiles show broad resistivity lows opposite the far edge of the body.

Figure 7 shows the resistivity results obtained when the conductive body is in the same lateral position, but 4 units deep, the depth of the downhole electrode. Here the body is barely detectable, but the east D-R profile does show a slight resistivity low at the far end of the line.

The resistivity quadrant studies indicated that it would be possible to assign a large conductive body to a particular quadrant and run additional lines within that quadrant in order to better delineate the anomaly.

The next series of figures show the results of both resistivity and induced polarization modelling performed in McPhar's Toronto laboratory. Except where noted, the R electrode consisted of four remote electrodes, each being located in a corner of the modelling tank, 31.0 units from the drill hole. Thus the S-R and D-R results are essentially those for point sources at S and D.

Figure 8 shows the resistivity and induced polarization results for a flat-lying ore body 1.0 unit deep and 3.0 units from the drill hole. The resistivity contrast is 1:100, and the resistivity results are relative to a background of 250 ohm-feet. The ore body is 1.2 units thick, 3.6 units long, and 4.2 units wide, and has a PFE of 22 percent and a metal factor of 8800 mhos/foot. The downhole electrode is 6.0 units deep. For this shallow source, all three sending dipoles, the S-R, D-R,

FIGURE 7

DOWNHOLE
RESISTIVITY
SCALE MODEL CASES

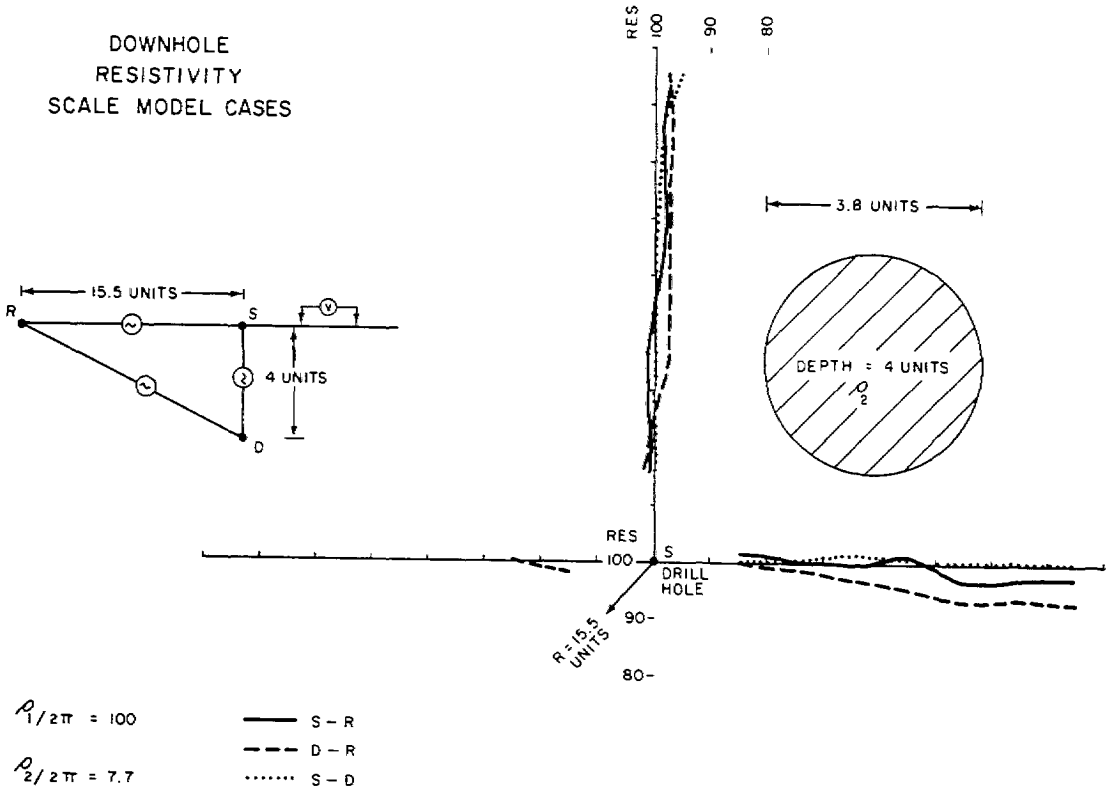
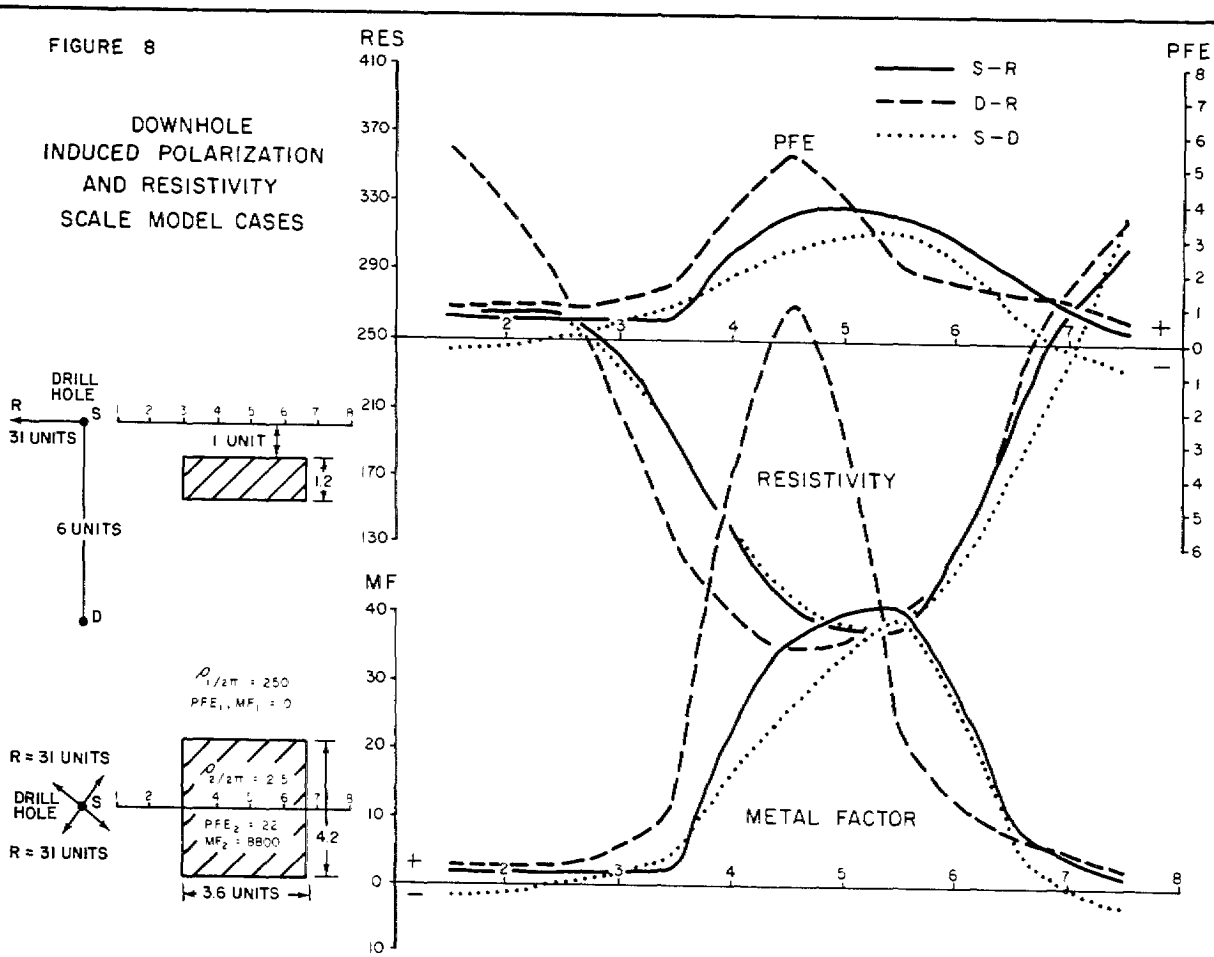


FIGURE 8

DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES



and S-D show a strong resistivity low with a minimum over the ore body. All three sending dipoles produce an anomalous percent frequency effect (PFE) response, with the D-R PFE profile showing a maximum of about 5 percent over the center of the ore body. The corresponding metal factor response, which is a combination of both the PFE and resistivity responses, is about 85 mhos/foot. Thus, when the source is shallow, all three sending dipoles produce an anomalous response.

Figure 9 shows conventional dipole-dipole resistivity and induced polarization model results obtained over an almost identical ore body, also 1.0 unit deep. Here the maximum PFE, measured at five dipole separations, is 4.0 percent and the maximum metal factor is 47 mhos/foot. These results are comparable in magnitude to the S-R dipole results shown in Figure 8. The maximum D-R PFE is slightly stronger than the maximum dipole-dipole PFE, and the maximum D-R metal factor is almost twice the maximum dipole-dipole metal factor.

Figure 10 shows the results with the same ore body in the same position relative to the drill hole, but at 3.0 units depth. The downhole electrode is 6.0 units deep, 2.0 units below the ore body. The D-R resistivity profile shows a broad low with a minimum over the ore body. The D-R PFE maximum is about 2.5 percent and the corresponding metal factor maximum is about 15 mhos/foot. The S-R and S-D results do not show diagnostic PFE or metal factor responses.

Figure 11 shows conventional dipole-dipole resistivity and induced polarization model results obtained over an almost identical ore body which is only 1.5 units deep. Here the maximum PFE, measured at five dipole separations, is 2.3 percent, and the maximum metal factor is 15-18 mhos/foot. The anomaly magnitudes in Figure 10 and Figure 11 are almost the same, but the source of the anomaly detected by the downhole survey is twice as deep as that detected by the conventional survey!

Figure 12 shows the results obtained over the same ore body 3.0 units from the drill hole, but now at a depth of 6.0 units, the depth of the downhole electrode. The D-R resistivity profile shows a very

FIGURE 9

DIPOLE – DIPOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES

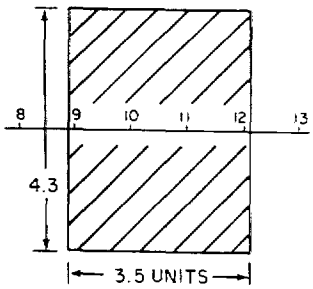
$(\rho/2\pi)_1 = 250$

$(MF)_1 = 0$

$(\rho/2\pi)_2 = 2.5$

$(MF)_2 = 10{,}000$

$(PFE)_2 = 25\%$



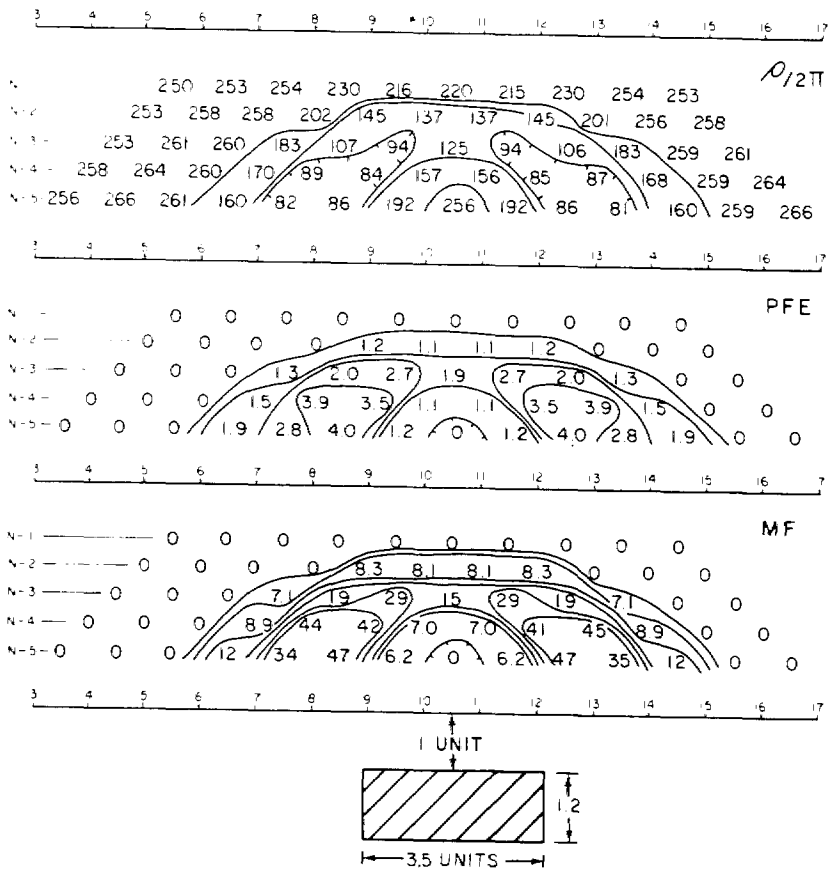
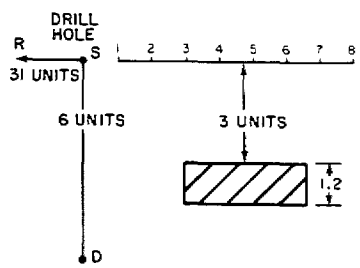
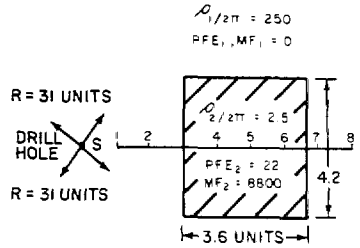


FIGURE 10

DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES





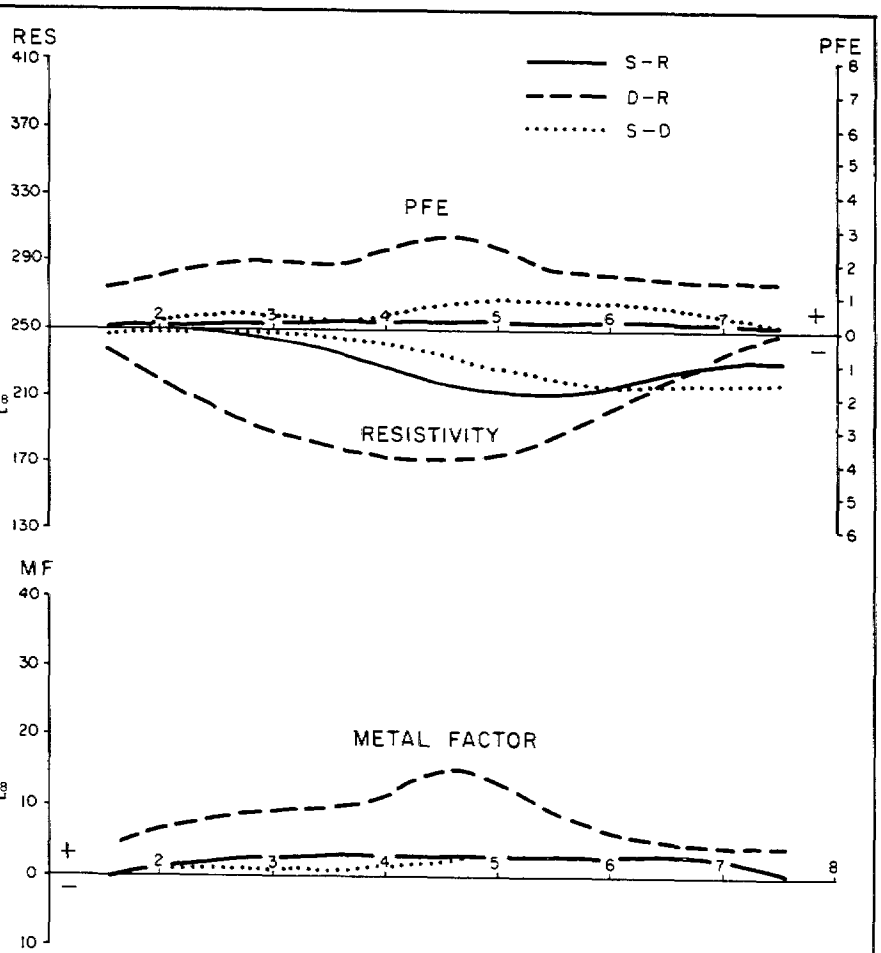
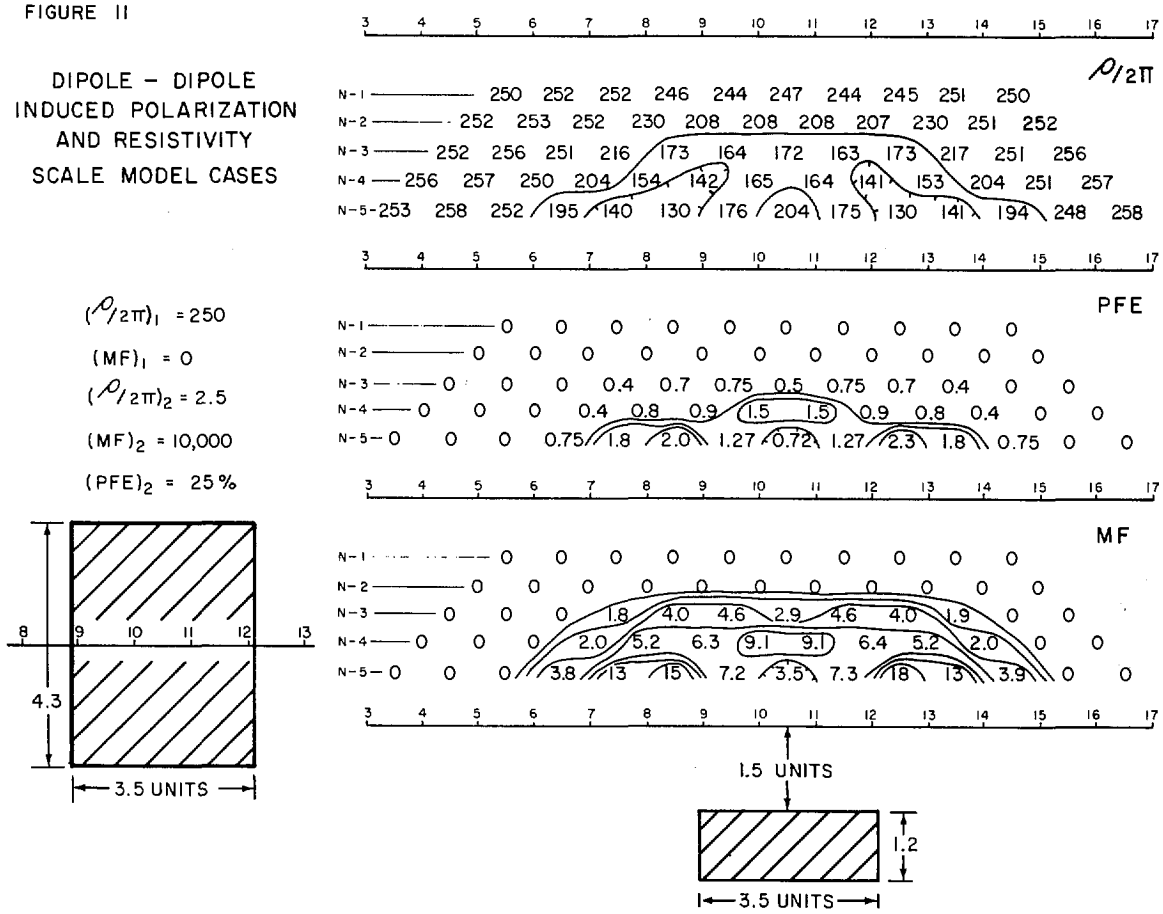


FIGURE 11

DIPOLE – DIPOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES



$(\rho/2\pi)_1 = 250$

$(MF)_1 = 0$

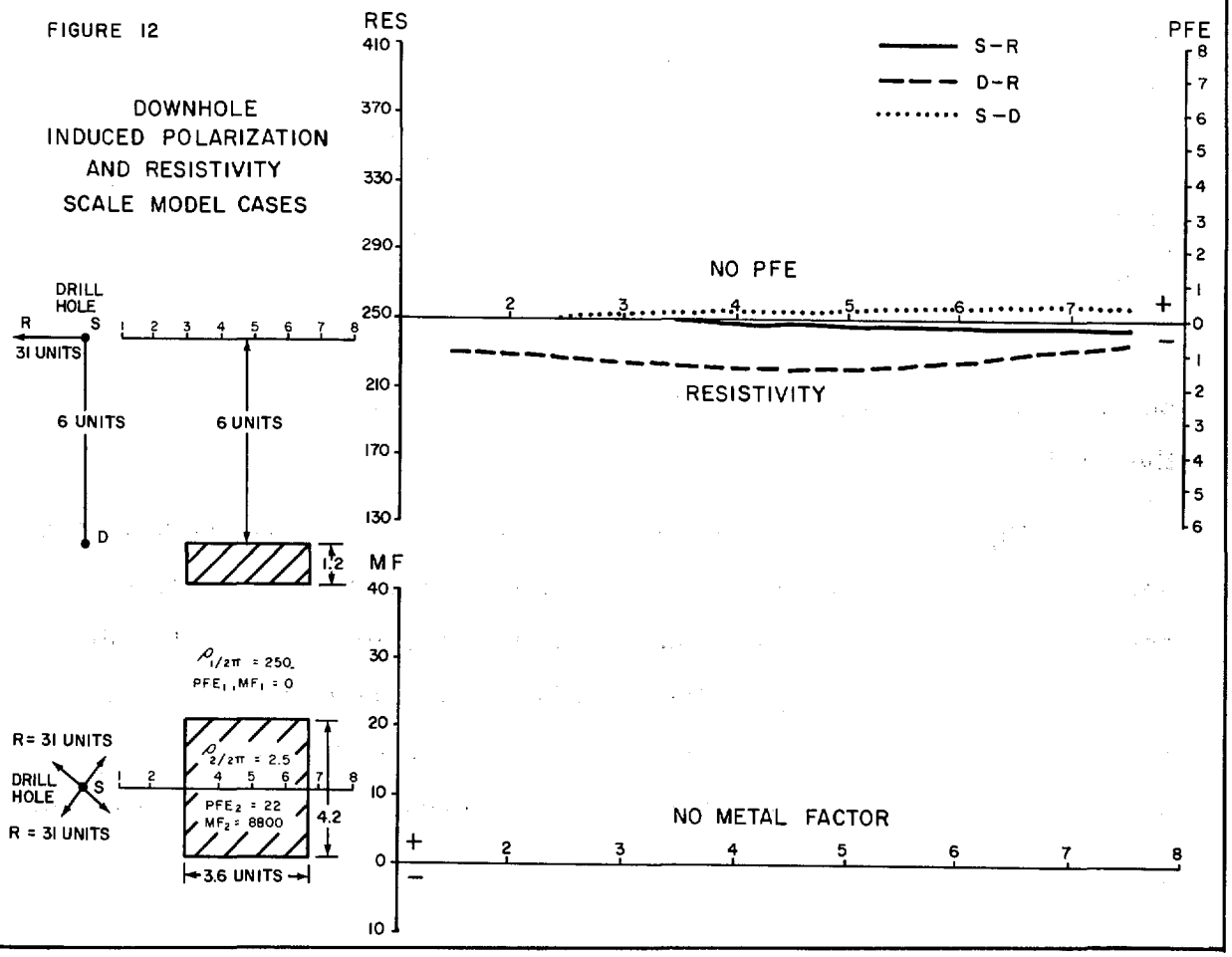
$(\rho/2\pi)_2 = 2.5$

$(MF)_2 = 10{,}000$

$(PFE)_2 = 25\%$

FIGURE 12

DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES



broad, weak resistivity low. The S-R resistivity profile shows a very slight low, and the S-D resistivity profile shows above-background resistivities. None of the sending dipoles produce a PFE response.

In Figure 13, the downhole electrode has been lowered to a depth of 8.0 units, about one unit below the bottom of the ore body. The D-R resistivity profile shows a resistivity low which extends outward from the drill hole. The D-R dipole now produces a very weak, but measurable PFE anomaly which is centered over the ore body. The ore body is 6.0 units deep and 3.0 units away from the drill hole! Comparison of Figure 12 and Figure 13 indicates that when the ore body is at a distance from the drill hole, the downhole electrode must be at a depth below the ore body in order to produce a measurable induced polarization response at the surface.

The foregoing modelling results demonstrate that the downhole-radial method is capable of detecting an ore body at a distance from a drill hole at depths beyond the capability of conventional surface surveys. In exploratory grid drilling it would be possible to space the drill holes farther apart. However, it would be necessary to have the downhole electrode below the expected ore body depth in order to obtain the maximum anomalous response. The results also show that a comparison of the D-R data with the S-R and the S-D data is a useful means of interpreting the D-R data.

The next series of figures show the resistivity and induced polarization results obtained when the same ore body is 1.0 unit from the drill hole.

Figure 14 shows the results obtained when the ore body is 3.0 units deep and the downhole electrode is 6.0 units deep. The D-R resistivity profile shows a strong low in the vicinity of the drill hole and a resistivity high beyond the far edge of the ore body. The S-R resistivity profile shows a weak low with a minimum at the far edge of the ore body. The S-D resistivity profile shows a minimum well beyond

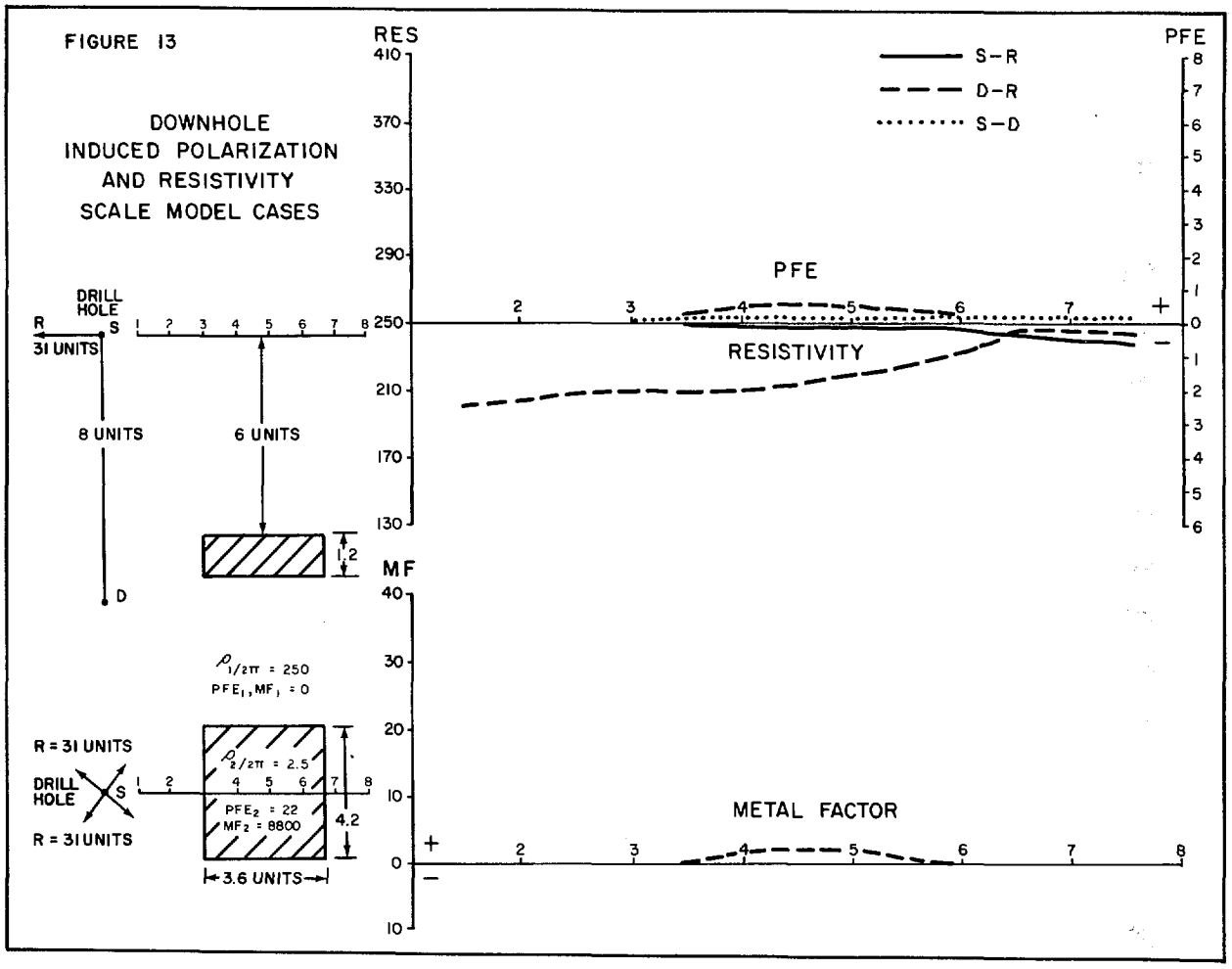


FIGURE 13
DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES
RES
PFE
S-R
D-R
S-D
PFE
RESISTIVITY
DRILL HOLE
R
S
31 UNITS
8 UNITS
6 UNITS
1.2
D
MF
METAL FACTOR
ρ1/2π = 250
PFE1, MF1 = 0
R = 31 UNITS
DRILL HOLE
R = 31 UNITS
ρ2/2π = 2.5
PFE2 = 22
MF2 = 8800
4.2
3.6 UNITS

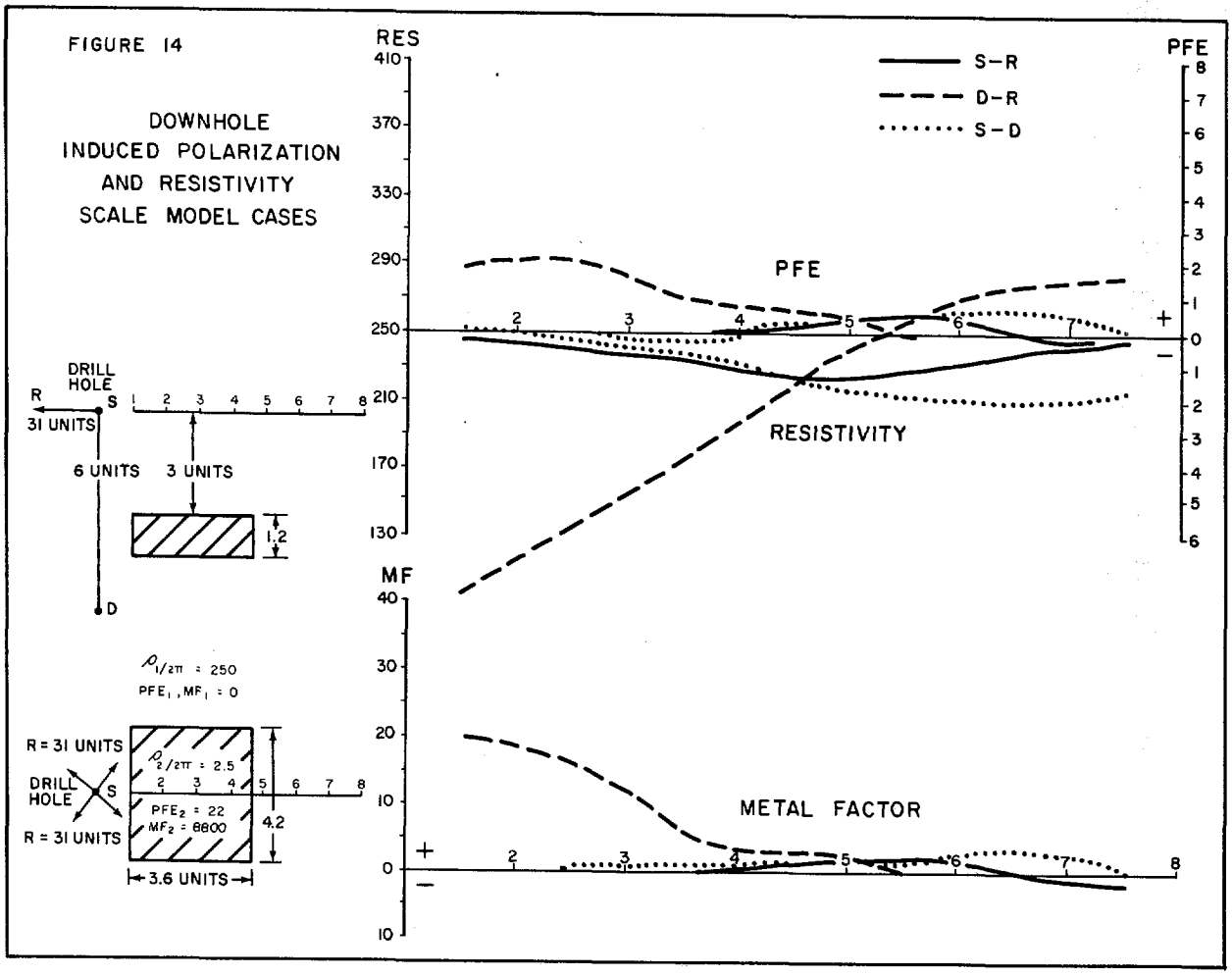


FIGURE 14
DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES
RES
PFE
S-R
D-R
S-D
PFE
RESISTIVITY
DRILL HOLE
R
S
31 UNITS
6 UNITS
3 UNITS
1.2
D
MF
METAL FACTOR
ρ1/2π = 250
PFE1, MF1 = 0
R = 31 UNITS
DRILL HOLE
R = 31 UNITS
ρ2/2π = 2.5
PFE2 = 22
MF2 = 8800
4.2
3.6 UNITS

the far edge of the ore body. The three resistivity profiles intersect at a point very close to the far edge of the body. The D-R PFE and metal factor profiles show an anomalous response in the vicinity of the drill hole. The magnitude of the response is about the same as that obtained when the ore body was at the same depth and 3.0 units from the drill hole.

Figure 15 shows the results obtained when the ore body is 1.0 unit from the drill hole and 6.0 units deep, the depth of the downhole electrode. The D-R resistivity profile shows low resistivities in the vicinity of the drill hole and a gradual increase in resistivity outward along the receiving line. The S-R resistivity profile shows a negligible, slightly below-background resistivity response, and the S-D resistivity profile shows above-background resistivities along the far portion of the receiving line. The D-R dipole produces a weak, but measurable PFE response over the ore body, and the S-D dipole produces a weak, negative PFE anomaly over the ore body. The anomalous response produced by the D-R dipole is stronger than that obtained when the ore body was at the same depth but 3.0 units from the drill hole, and with the downhole electrode 8.0 units deep.

Figure 16 shows the results when the ore body is 1.0 units from the drill hole, but with the downhole electrode 4.5 units deep, just below the bottom of the ore body. These results can be compared with those in Figure 14, with the downhole electrode 6.0 units deep. The point of equi-resistivity has migrated from a point 4.5 units from the drill hole to a point between 5.0 and 5.5 units from the drill hole. The D-R PFE and metal factor profiles show an anomaly over the ore body, but the amplitudes are somewhat lower than those obtained with the electrode 6.0 units deep. The S-D dipole produces above-background resistivities and a negative PFE anomaly over the ore body.

Figure 17 shows the results obtained when the ore body is 3.0 units deep and 1.0 units from the drill hole. The downhole electrode is 4.5 units deep, but the remote electrode is 6.0 units from the drill hole

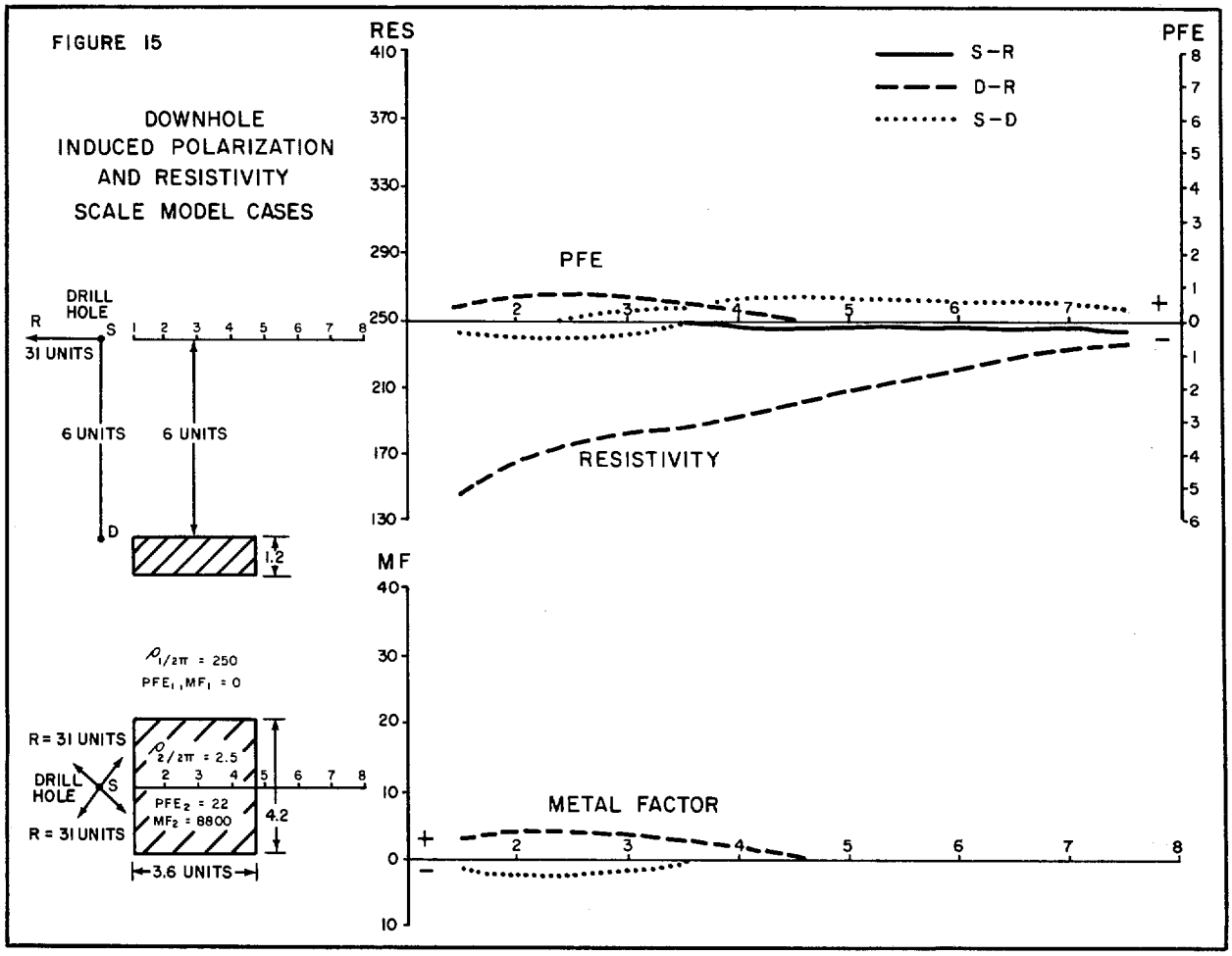


FIGURE 15
DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES
DRILL HOLE
R
S
D
31 UNITS
6 UNITS
6 UNITS
1.2
$\rho_{1/2\pi}$ = 250
PFE$_1$, MF$_1$ = 0
R = 31 UNITS
DRILL HOLE
R = 31 UNITS
$\rho_{2/2\pi}$ = 2.5
PFE$_2$ = 22
MF$_2$ = 8800
4.2
3.6 UNITS
RES
PFE
S-R
D-R
S-D
PFE
RESISTIVITY
MF
METAL FACTOR

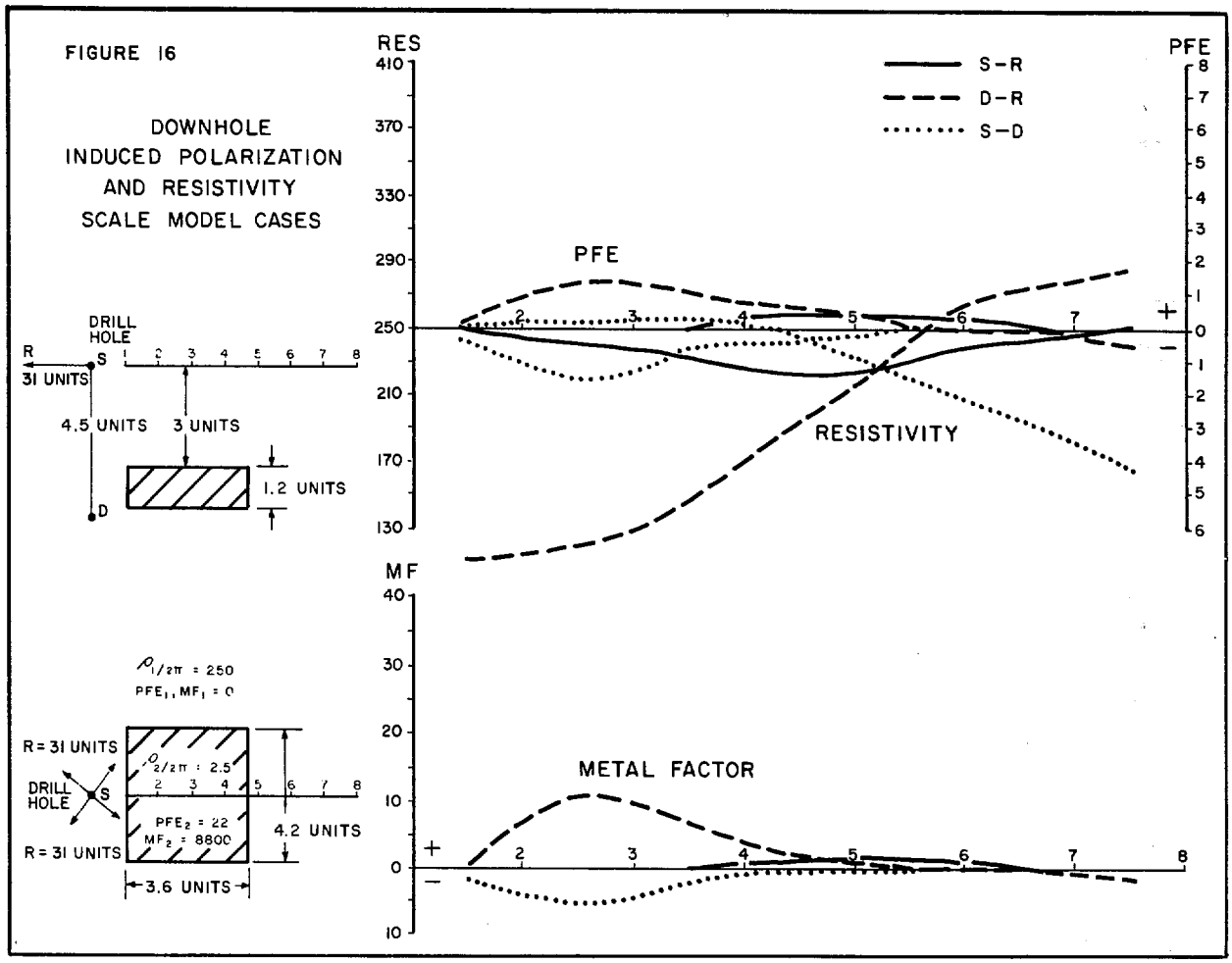


FIGURE 16
DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES
DRILL HOLE
R
S
D
31 UNITS
4.5 UNITS
3 UNITS
1.2 UNITS
$\rho_{1/2\pi}$ = 250
PFE$_1$, MF$_1$ = 0
R = 31 UNITS
DRILL HOLE
R = 31 UNITS
$\rho_{2/2\pi}$ = 2.5
PFE$_2$ = 22
MF$_2$ = 8800
4.2 UNITS
3.6 UNITS
RES
PFE
S-R
D-R
S-D
PFE
RESISTIVITY
MF
METAL FACTOR

along a line normal to the receiving line rather than at infinity. Surprisingly, in comparison with Figure 16, the D-R resistivity and PFE responses are greatly intensified, and the resulting metal factor anomaly is enormous. The S-R resistivity profile shows very little change, and the S-R dipole produces no PFE anomaly. The S-D dipole results are, of course, identical.

Figure 18 and Figure 19 show an identical set of results obtained when the downhole electrode is raised to 3.5 units depth, at approximately the middle of the ore body. In Figure 18, the remote electrode is at infinity and in Figure 19 the remote electrode is 6.0 units from the drill hole and along a line normal to the receiving line. Both figures show an anomalous response which is lower than that obtained with the downhole electrode at 4.5 units depth. The S-D PFE's are also a bit less negative. In Figure 19, the D-R anomalous response obtained with the finite remote electrode is slightly stronger than that obtained with an infinite remote electrode.

Figure 20 shows the results obtained over a narrow vertical ore body, 0.25 units wide, 1.25 units high, 2.5 units long, and located at a depth of 2.0 units, 1.0 unit from the drill hole. The downhole electrode is 3.5 units deep, 0.25 units below the ore body, and the remote electrode is 4.0 units from the drill hole. The D-R resistivity profile shows a pronounced low in the vicinity of the ore body and low but increasing resistivity values throughout the remainder of the line. The D-R PFE and metal factor profiles show very strong anomalies over the ore body. The D-R anomalies drop off abruptly in the vicinity of the far edge of the ore body.

The foregoing modelling results show that when an ore body is at depth close to the drill hole, the D-R dipole produces a strong anomaly, whereas the S-R dipole produces at best a very weak anomaly. The S-D dipole may produce a negative induced polarization response when the downhole electrode is near the ore body. The D-R anomaly response is enhanced when the remote electrode is at a finite distance from the

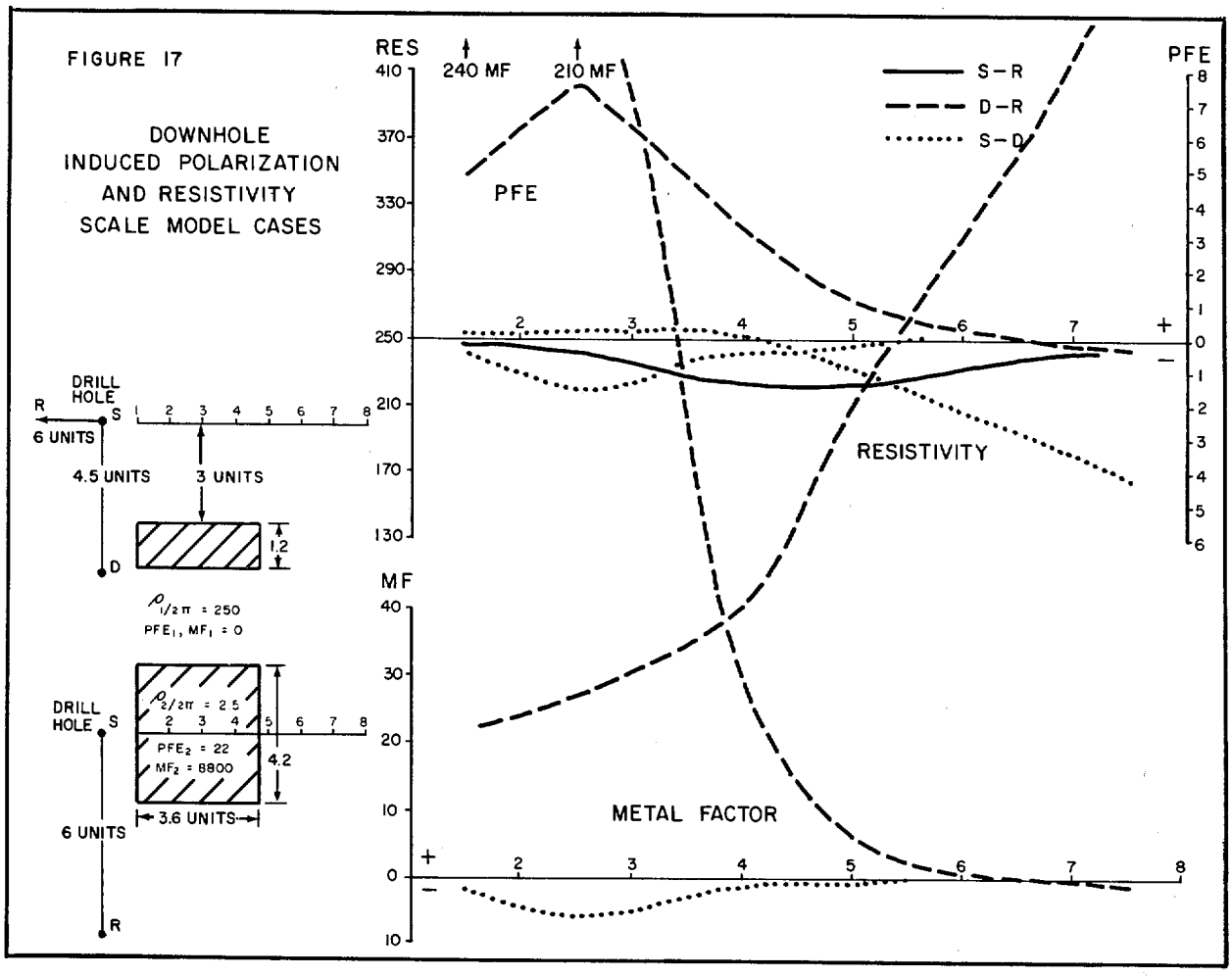


FIGURE 17
DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES
RES
PFE
240 MF
210 MF
S-R
D-R
S-D
PFE
RESISTIVITY
MF
METAL FACTOR
DRILL HOLE
R
S
D
6 UNITS
4.5 UNITS
3 UNITS
1.2
ρ1/2π = 250
PFE1, MF1 = 0
ρ2/2π = 2.5
PFE2 = 22
MF2 = 8800
4.2
3.6 UNITS

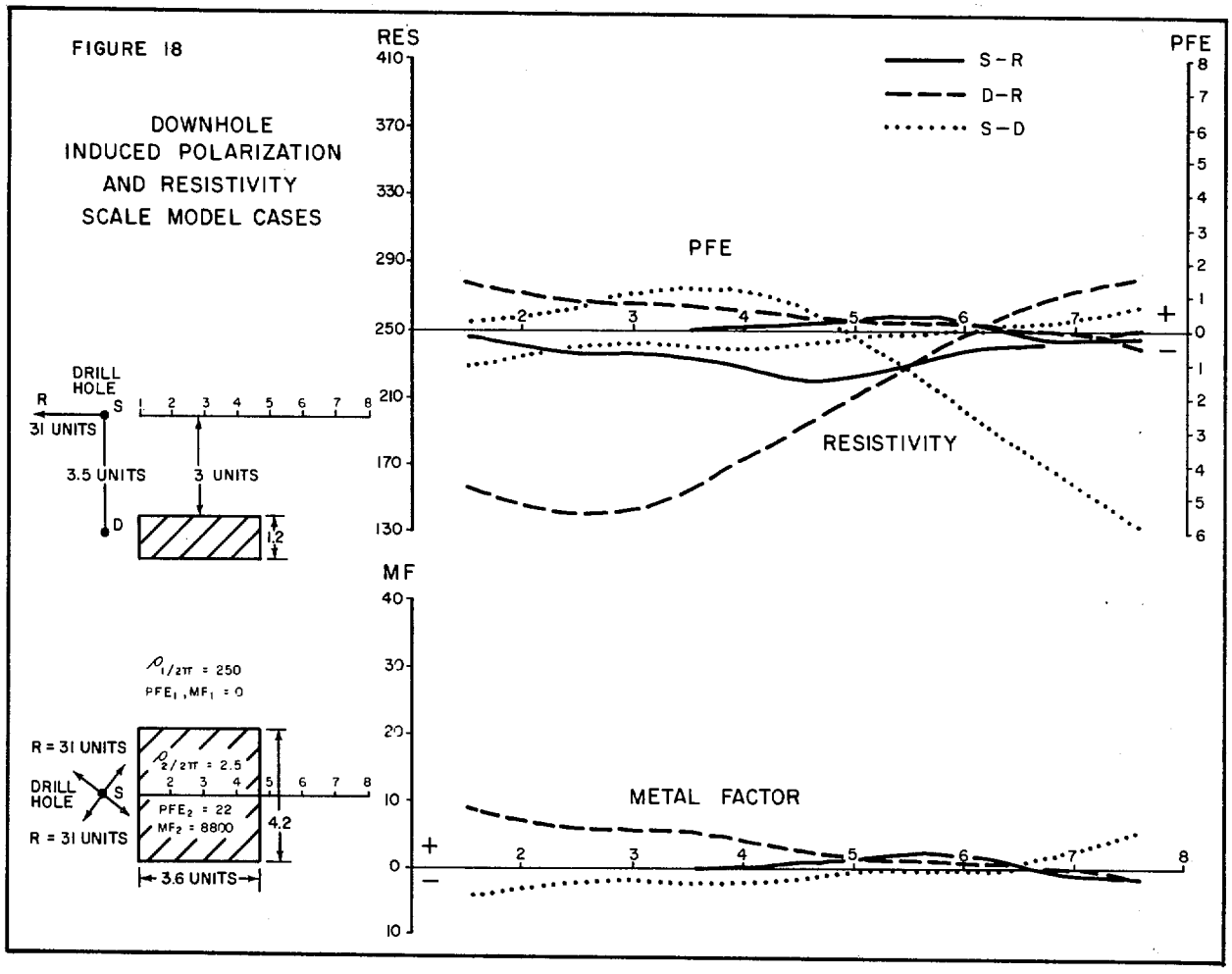


FIGURE 18
DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES
RES
PFE
S-R
D-R
S-D
PFE
RESISTIVITY
MF
METAL FACTOR
DRILL HOLE
R
S
D
31 UNITS
3.5 UNITS
3 UNITS
1.2
ρ1/2π = 250
PFE1, MF1 = 0
R = 31 UNITS
ρ2/2π = 2.5
PFE2 = 22
MF2 = 8800
4.2
3.6 UNITS

FIGURE 19

DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES

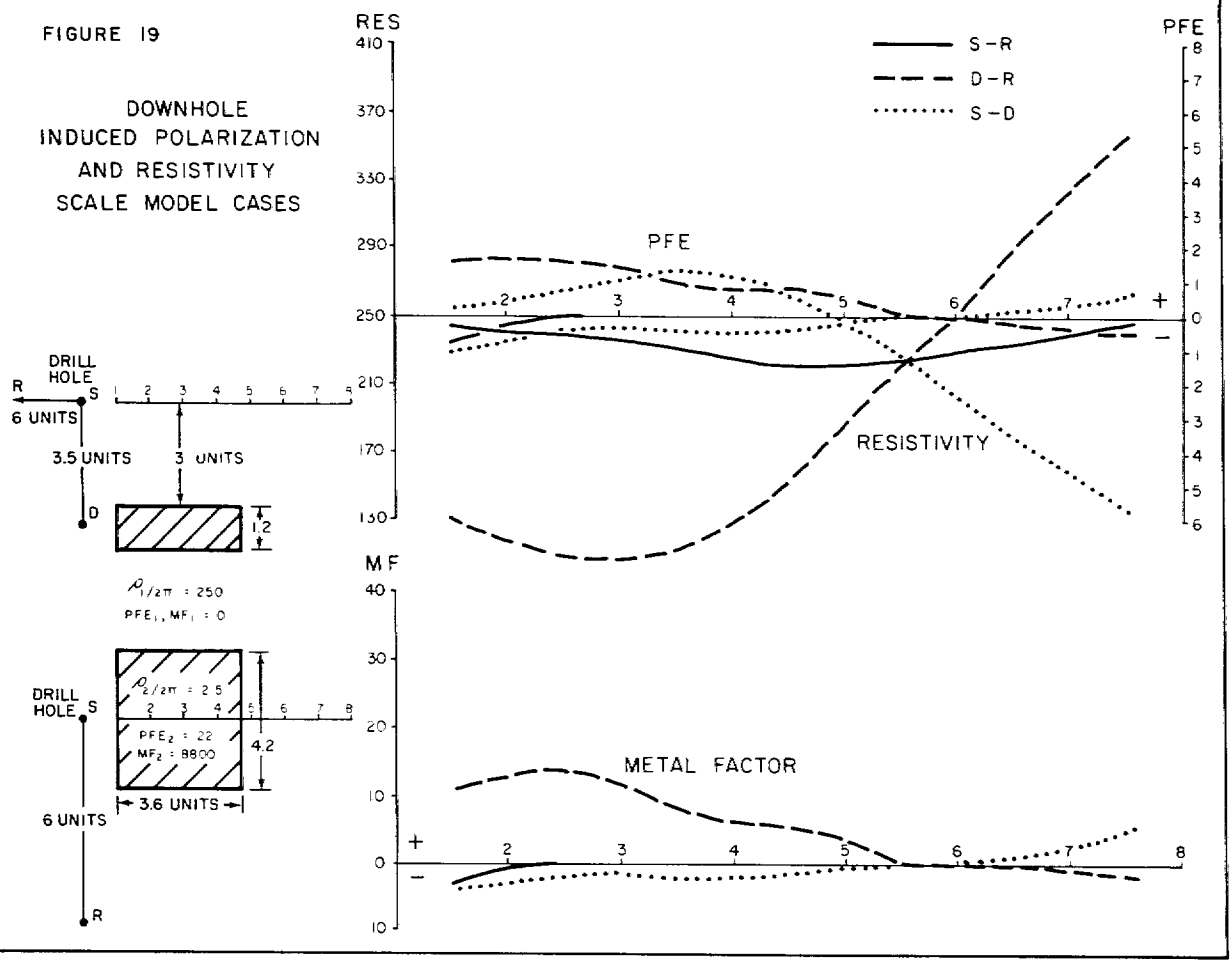
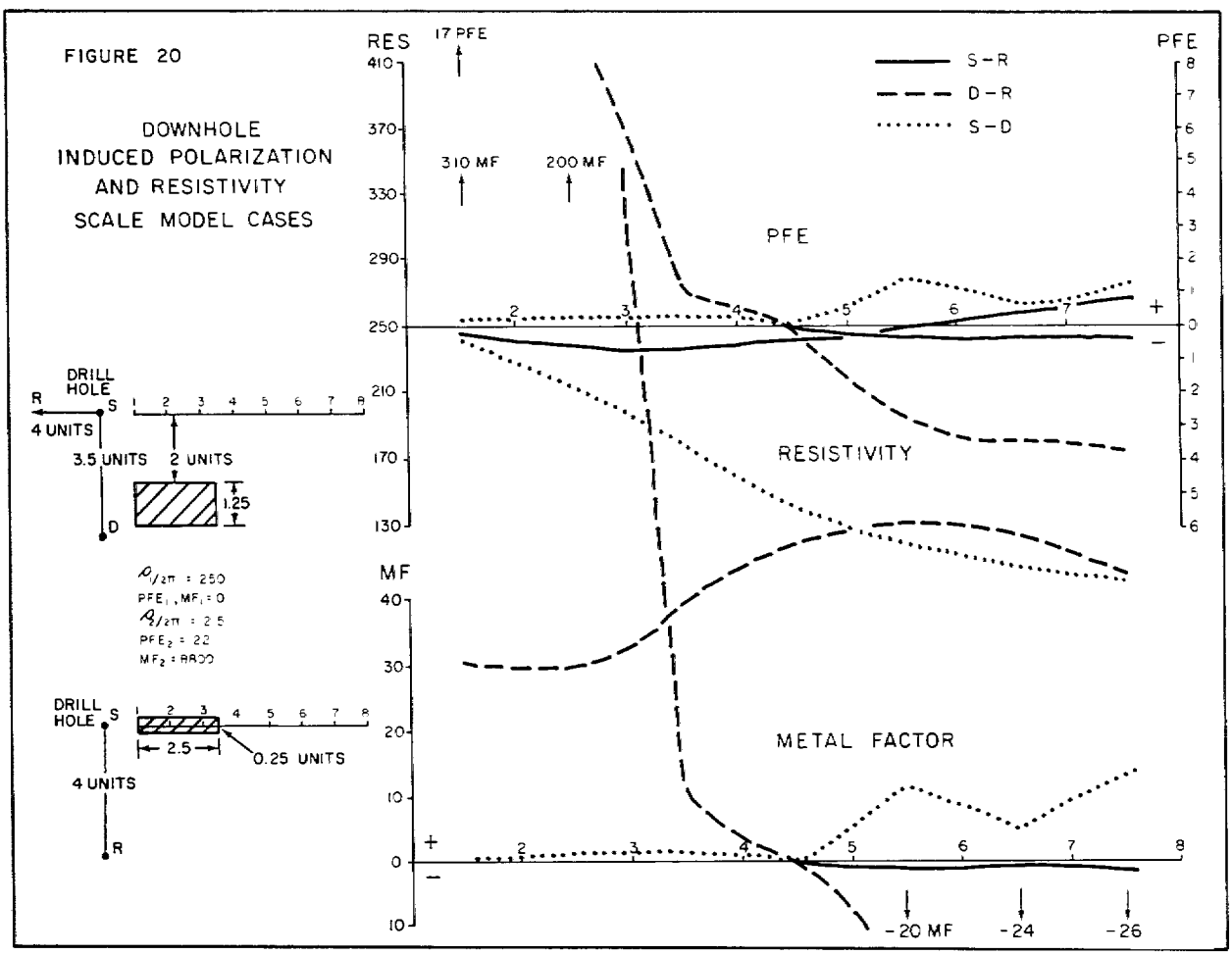


FIGURE 20

DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES



drill hole, but at a distance greater than the depth of the downhole electrode. At remote electrode distances less than the depth of the downhole electrode, the D-R response would approach that produced by the S-D dipole. The modelling results also show that when an ore body is at depth close to the drill hole, the D-R anomalous response may show a dropoff which permits an estimate of the far edge of the body. This would, of course, be dependent on the position of the downhole electrode relative to the ore body.

In field practice it has been found that meaningless negative PFE's are measured when the near potential electrode of the receiving dipole is located at the drill hole collar. These have been attributed to displacement currents which would die out very rapidly with distance from the drill hole. Thus, in field practice, measurements are usually made beginning at 250 feet or 500 feet from the drill hole.

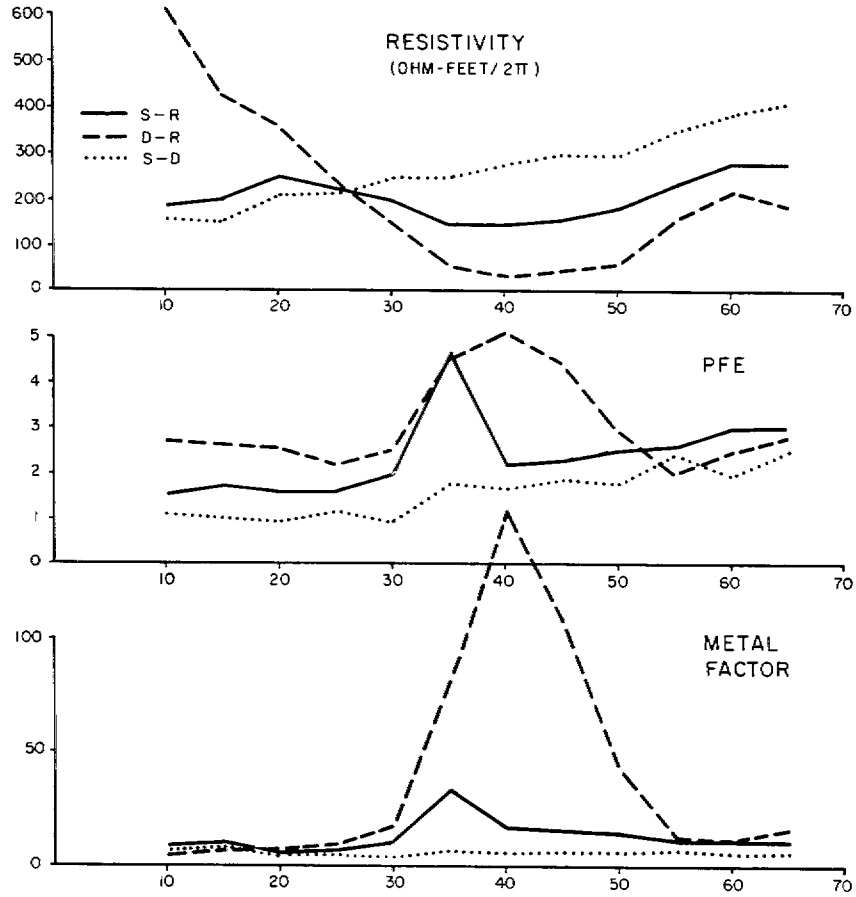
The next series of figures show the field results obtained during surveys in three different environments: Precambrian-massive sulphides, Paleozoic contact-replacement, and porphyry copper.

Figure 21 shows the results obtained along a line run during a downhole survey in a Precambrian environment. The line was run S 73°E along a contact between acidic and basic volcanics. The downhole electrode was located at a depth of 2,150 feet within a mine shaft. The surface electrode was located at a point above the downhole electrode, and the remote electrode was located 5,000 feet south of the surface electrode. Measurements were made with a 1,000-foot receiving dipole in 500-foot increments, beginning 500 feet from the surface electrode. The D-R results show a resistivity low, PFE high, and sharp metal factor anomaly 3,500 - 4,500 feet from the mine shaft. A vertical drill hole at station 40 encountered disseminated sulphides assaying 0.3 - 0.4 percent copper at a depth of 1,100 feet, but unfortunately had to be abandoned because of drilling difficulties encountered within a fault zone. Additional drill holes to test the anomaly are planned.

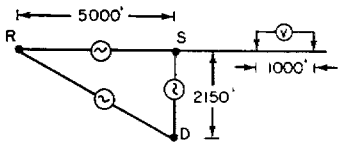
FIGURE 21

DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY SURVEY

PRECAMBRIAN ENVIRONMENT



FREQUENCIES : 0.125 – 1.25 Hz



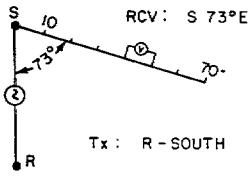
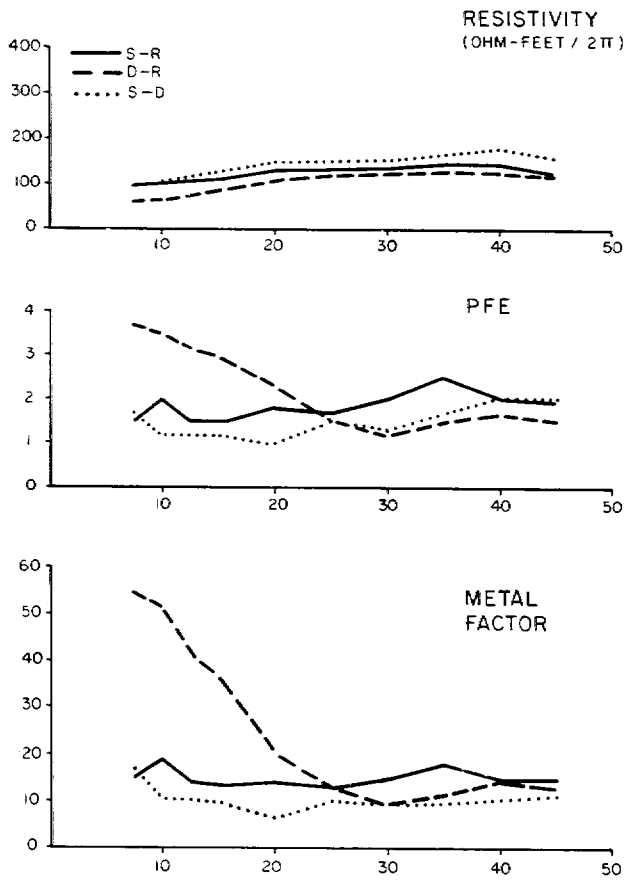


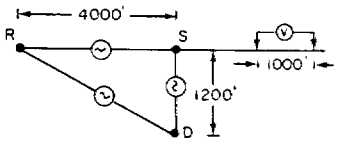
FIGURE 22

DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY SURVEY

PALEOZOIC ENVIRONMENT



FREQUENCIES : 0.125 – 1.25 Hz



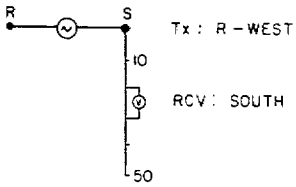


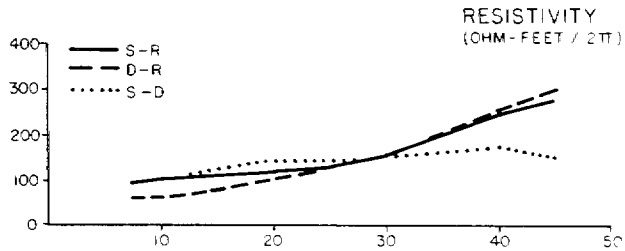
Figure 22 and Figure 23 show the results obtained along a line run during a downhole survey in a Paleozoic environment. The downhole electrode was located at a depth of 1,200 feet within mineralized Paleozoic limestones containing 0.3 - 0.4 percent copper in disseminated sulphides. The drill hole encountered alluvium and gravels through a depth of 500 feet. Figure 22 shows the results obtained along a line running south from the drill hole with the remote electrode located 4,000 feet west of the drill hole along a line normal to the receiving line. Figure 23 shows the results obtained along the same line, but with the remote electrode located 4,000 feet east of the drill hole along a line normal to the receiving line. Measurements were made with a 1,000-foot receiving dipole in 500-foot increments beginning 250 feet from the drill hole. In both figures the D-R results indicate a PFE and metal factor anomaly that extends outward from the drill hole to a point 1,500 - 2,000 feet along the line. The anomalous responses obtained while sending with the remote electrodes on either side of the receiving line are nearly the same, indicating that the source is at depth below the line rather than to one side of the line. A drill hole, at least 1200 feet deep, located at station 10 has been recommended.

Figure 24 and Figure 25 show the downhole induced polarization and resistivity survey results obtained along a line run north over a buried porphyry copper deposit. The downhole electrode is located at a depth of 1,050 feet in a barren drill hole approximately 3,500 feet south of the ore zone. Figure 24 shows the results obtained with the remote electrode located 4,000 feet west of the drill hole and Figure 25 shows the results obtained with the remote electrode located 4,000 feet east of the drill hole. In Figure 24 the resistivities obtained with D-R and S-R are about the same, and are only slightly lower than those obtained with the S-D dipole. The D-R and S-R PFE's are slightly higher than the S-D PFE's, but are only weakly anomalous and of similar magnitude. In contrast, as shown in Figure 25, the D-R and S-R resistivities obtained while sending on the east remote electrode are significantly lower than the

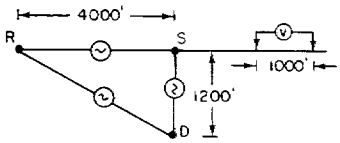
FIGURE 23

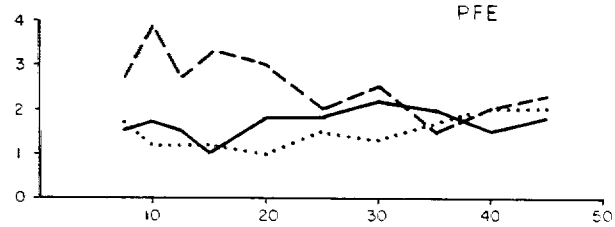
DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY SURVEY

PALEOZOIC ENVIRONMENT



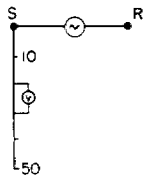
FREQUENCIES : 0.125 - 1.25 Hz





Tx: R - EAST

RCV: SOUTH



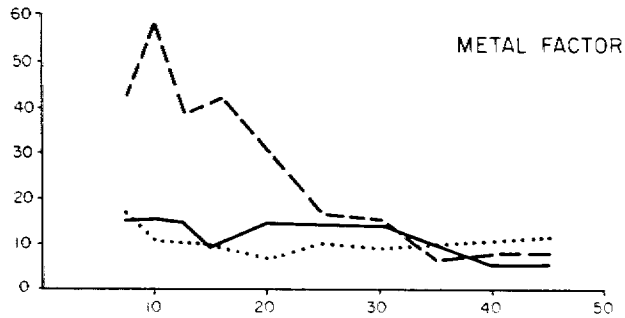
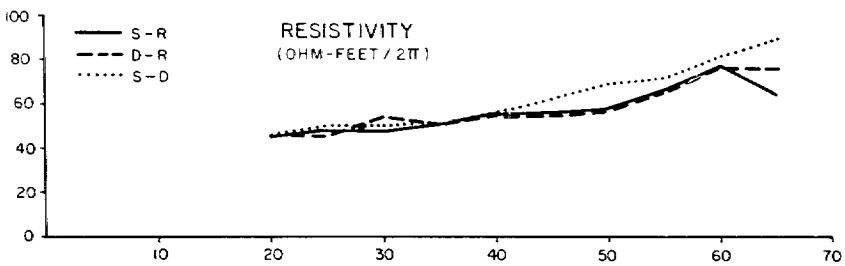


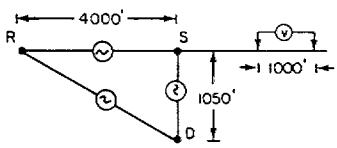
FIGURE 24

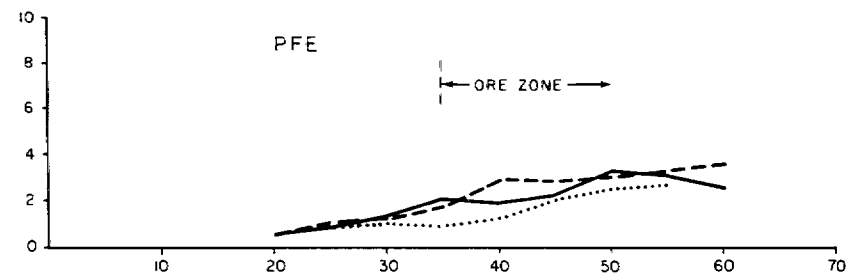
DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY SURVEY

PORPHYRY COPPER
ENVIRONMENT



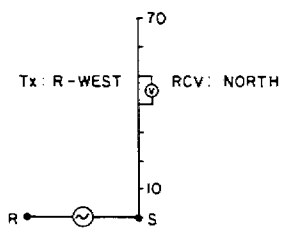
FREQUENCIES : 0.125 - 1.25 Hz

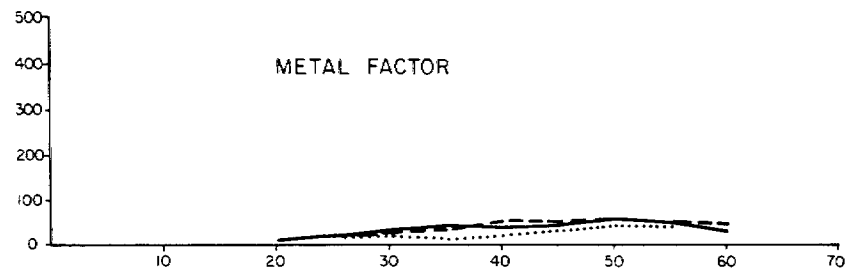




Tx: R-WEST

RCV: NORTH





S-D resistivities. Both the D-R and S-R PFE's over the ore zone, are much higher than the S-D PFE's. In the interval 40 N - 50 N the line crosses a substantial concentration of ore which extends 500 - 750 feet on each side of the line. Depths to ore in this interval are 750 - 1,000 feet on the east, and 1,500 - 1,750 feet on the west. The strong D-R and S-R PFE and MF responses obtained while sending on the east remote electrode reflect the more shallow ore on the east side of the line.

The types of response obtained over the porphyry copper deposit can be further illustrated by a modelling case, shown in Figure 26. Here the ore body is a vertical cylinder, 0.9 units in diameter and 4.1 units high, located in the northeast quadrant 1.4 units from the drill hole at a depth of 1.3 units. The downhole electrode is at a depth of 2.0 units, 0.7 units below the top of the ore body, and the remote electrodes are located 6.0 units west and east of the drill hole along a line normal to the receiving line. The PFE's obtained along the north receiving line are tabulated opposite the receiving dipole locations. The west S-R and D-R sending dipoles produced no measurable PFE's. The S-D results show a PFE high of 1.3 percent at 4 N - 5 N. The strongest response is produced by the east D-R dipole, a PFE of 2.1 percent measured in the interval 2 N - 3 N, just beyond the far edge of the ore body. The corresponding S-R PFE's are half as strong. The cylindrical ore body is located at maximum depth and distance from the drill hole for detectability with this particular sending and receiving configuration.

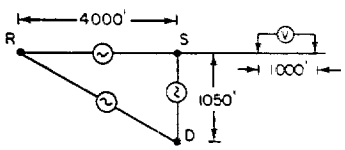
Thus, the downhole-radial induced polarization and resistivity survey method is a useful reconnaissance tool that should be considered when a drill hole is available. Although the modelling and field results shown are frequency domain induced polarization results, the method should be equally applicable to the time domain. The most serious limitation of the method is that it fails to obtain data directly over the drill hole. When a narrow ore zone is encountered within a drill hole or a small ore zone is expected near the drill hole, inhole methods such as the azimuth method would be a better choice. The downhole-radial

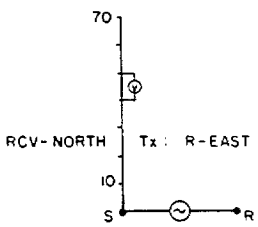
FIGURE 25

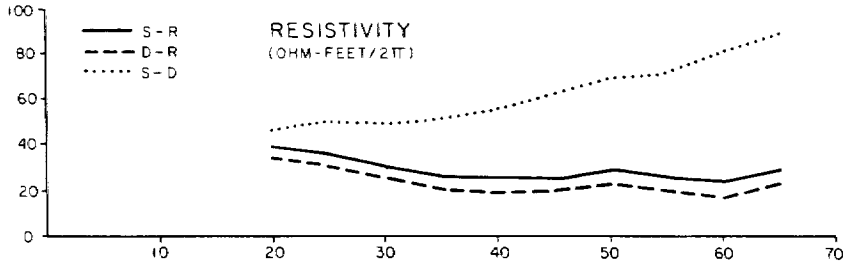
DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY SURVEY

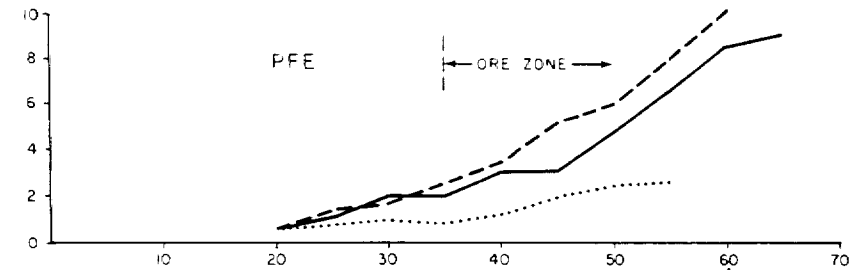
PORPHYRY COPPER
ENVIRONMENT

FREQUENCIES : 0.125 – 1.25 Hz









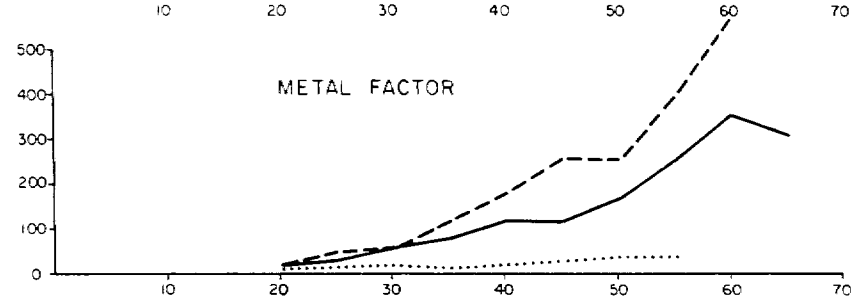


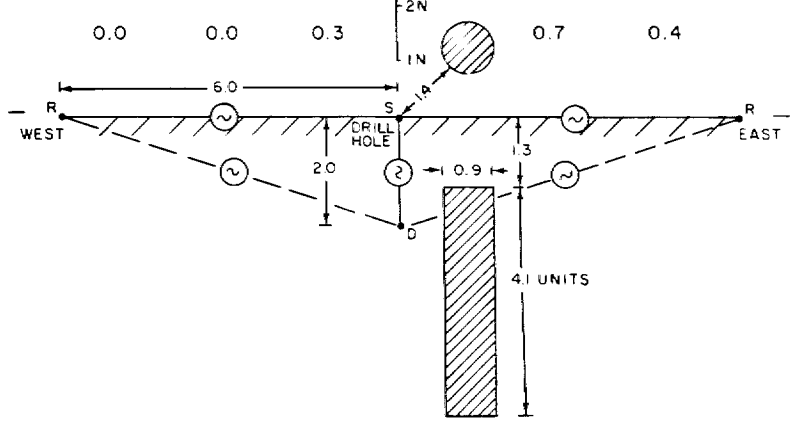
FIGURE 26

DOWNHOLE
INDUCED POLARIZATION
AND RESISTIVITY
SCALE MODEL CASES

Tx: R – WEST PFE'S			RCV: NORTH	Tx: R – EAST PFE'S	
S-R	D-R	S-D		D-R	S-R
0.0	0.0	0.7	8N	0.0	0.0
0.0	0.0	1.0	1.0	0.6	0.0
0.0	0.0	0.9	5N	0.4	0.0
0.0	0.0	1.3	4N	0.8	0.6
0.0	0.0	0.9	3N	0.3	0.9
0.0	0.0	0.0	2N	2.1	0.8
0.0	0.0	0.3	1N	0.7	0.4

$\rho_1/2\pi$ = 250
PFE_1 = 0
MF_1 = 0

$\rho_2/2\pi$ = 2.5
PFE_2 = 25 %
MF_2 = 10,000



method should be viewed as complementary to, rather than competitive with, the inhole and conventional surface methods.

ACKNOWLEDGEMENTS

The author wishes to thank Phelps Dodge Corporation for permission to describe the downhole-radial induced polarization and resistivity method, and especially Mr. George R. Rogers, Chief Geophysicist. Mr. Rogers originally suggested using a buried current source electrode and making voltage measurements along lines radiating from the drill hole. The McPhar model studies were made by Mr. P.T. Makulowich of McPhar Geophysics Limited. Preparation of drawings and slides was carried out by Mr. John Kelly of McPhar Geophysics Incorporated.

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