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A computer program to calculate the resistivity and induced polarization response for a three-dimensional body in the presence of buried electrodes

by

Jeffrey J. Daniels

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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by Jeffrey J. Daniels
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Abstract

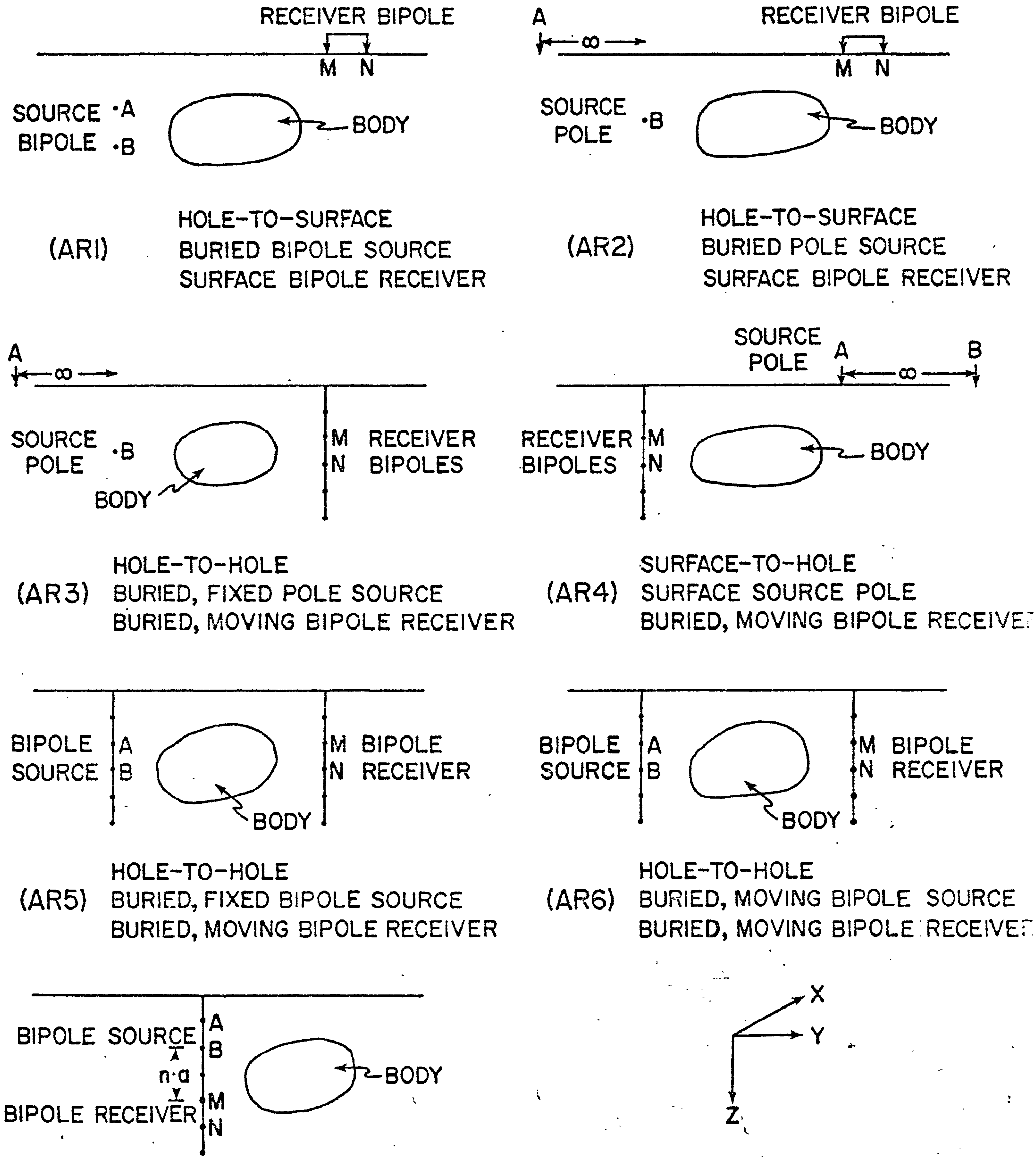
Three-dimensional induced polarization and resistivity modeling for buried electrode configurations can be achieved by adapting surface integral techniques for surface electrode configurations to buried electrodes. Modification of the surface technique is accomplished by considering the additional mathematical terms required to express the changes in the electrical potential and geometry caused by placing the source and receiver electrodes below the surface.

This report presents a listing of a computer program to calculate the resistivity and induced polarization response from a three-dimensional body for buried electrode configurations. The program is designed to calculate the response for the following electrode configurations: (1) hole-to-surface array with a buried bipole source and a surface bipole receiver, (2) hole-to-surface array with a buried pole source and a surface bipole receiver, (3) hole-to-hole array with a buried, fixed pole source and a moving bipole receiver, (4) surface-to-hole array with a fixed pole source on the surface and a moving bipole receiver in the borehole, (5) hole-to-hole array with

a buried, fixed bipole source and a buried, moving bipole receiver, (6) hole-to-hole array with a buried, moving bipole source and a buried, moving bipole receiver, and (7) single-hole, buried bipole-bipole array. Input and output examples are given for each of the arrays.

Introduction

A computer program was developed to calculate the theoretical apparent resistivity and apparent polarizability response for electrodes buried beneath the earth's surface in the presence of an arbitrarily shaped three-dimensional body. The program generates the response for three-dimensional ellipsoids of revolution for the following electrode configurations: (1) hole-to-surface with a buried bipole source and surface bipole receiver, (2) hole-to-surface with a buried pole source and a surface bipole receiver, (3) hole-to-hole array with a buried, fixed pole source and a moving bipole receiver, (4) surface-to-hole array with a fixed pole source on the surface and a moving bipole receiver in the borehole, (5) hole-to-hole array with a buried, fixed bipole source and buried, moving bipole receiver, (6) hole-to-hole array with a buried, moving bipole receiver, and (7) single-hole, buried bipole-bipole array. These arrays are illustrated in fig. 1 (AR1-AR7), and input and output examples for these are given in appendix A. The computer program is a modification of Barnett's (1972) three-dimensional IP modeling method for surface configurations to buried electrode configurations.



(AR7) SINGLE HOLE (BIPOLE-BIPOLE)
BURIED BIPOLE SOURCE
BURIED BIPOLE RECEIVER

FIGURE I.- ARRAYS FOR WHICH MODELS CAN BE GENERATED BY PROGRAM IP3DDH.

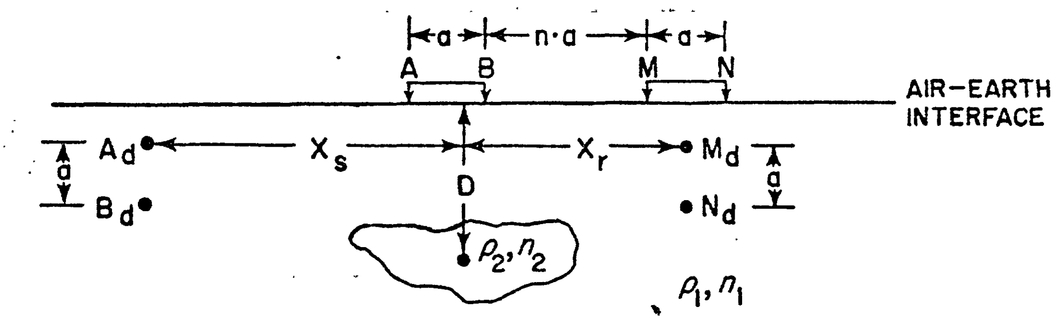
Hole-to-hole measurements are made by placing a current source pole or bipole in a borehole and a pole or bipole potential receiver in an adjacent borehole. The potential difference caused by the source is measured at discrete points in the receiver borehole. The source can be held at a stationary position (fixed source) for all of the potential measurements or the source can be moved when each potential measurement is made (moving source). A recent publication by Scott, et al. (1975) shows an application of hole-to-hole resistivity, induced polarization, and seismic measurements.

Hole-to-surface measurements are made by placing a pole or bipole source down a borehole and making surface bipole measurements radially away from the source hole. Theoretical studies of surface potentials due to inhole current sources have been described by Merkel (1971), Merkel and Alexander (1971), and Snyder and Merkel (1973).

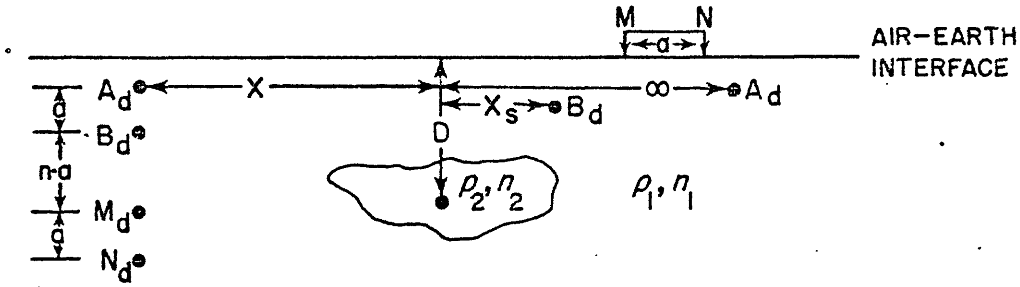
Wide-spaced single-hole arrays use a pole or bipole borehole source and a pole or bipole potential receiver in the same borehole. Several different source-receiver spacings can be used making a set of measurements similar to those made with a conventional surface dipole-dipole array. These measurements require only one borehole and can be made with a wireline device.

Theory

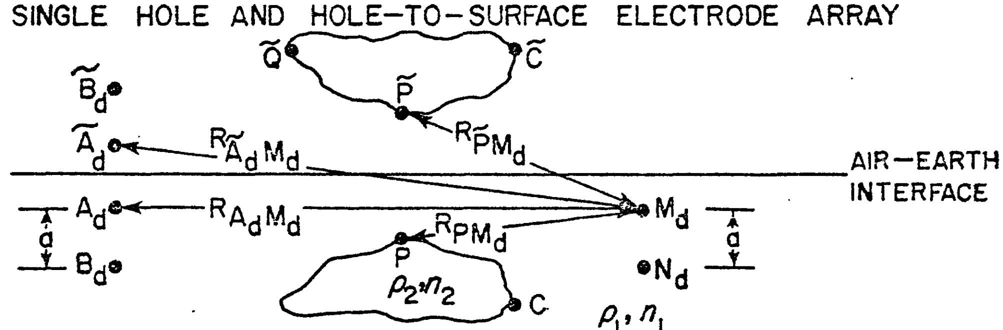
Figure 2 shows the combination of electrodes used in this study. The surface of the three-dimensional body is indicated by the letter "C", whereas the surface of the body's image in the upper halfspace is



ELECTRODE CONFIGURATIONS FOR HOLE-TO-HOLE AND SURFACE ARRAYS



SINGLE HOLE AND HOLE-TO-SURFACE ELECTRODE ARRAY



DISTANCES AND IMAGE TERMS FOR THE MODEL

EXPLANATION OF SYMBOLS:

ρ_1 = RESISTIVITY OF THE MEDIUM SURROUNDING THE BODY

ρ_2 = RESISTIVITY OF THE BODY

n_1 = INTRINSIC, INDUCED POLARIZATION OF THE MEDIUM SURROUNDING THE BODY

n_2 = INTRINSIC, INDUCED POLARIZATION OF THE BODY

A_d, B_d ARE THE BURIED SOURCE ELECTRODES

M_d, N_d ARE THE BURIED RECEIVER ELECTRODES

A,B ARE THE SURFACE SOURCE ELECTRODES

M,N ARE THE SURFACE RECEIVER ELECTRODES

$\tilde{A}_d$, $\tilde{B}_d$ ARE THE REFLECTIONS OF THE BURIED SOURCE ELECTRODES

X, X_s, X_r ARE HORIZONTAL DISTANCES

$\tilde{Q}$, $\tilde{P}$, $\tilde{C}$, P, C ARE POINTS REFERRED TO IN THE EQUATIONS IN THE TEXT

FIGURE 2 — THREE DIMENSIONAL BODY AND ELECTRODE POSITIONS FOR THE MODEL USED IN THIS STUDY

designated by the symbol "$\tilde{C}$". All depth and distance used are normalized by the receiver-bipole spacing "a". A bipole is a finitely spaced electrode pair. The following is a brief outline of the theory. A more complete outline is given in appendix B and in papers by Barnett (1972) and Daniels (1977).

For a conventional "bipole-bipole" surface configuration, where either the source and(or) the receiver is on the surface, the equation for apparent resistivity is

$$\rho_a = \frac{2\pi}{\frac{1}{R_{AM}} - \frac{1}{R_{AN}} - \frac{1}{R_{BM}} + \frac{1}{R_{BN}}} \frac{(U_M - U_N)}{I} \qquad (1)$$

where R_{AM}, R_{AN}, R_{BM}, and R_{BN} are the respective distances between electrodes A, M, N, and B; U_M is the electrical potential at point M; U_N is the electrical potential at point N; and I is the electric current. When both the source and receiver are buried, the apparent resistivity formula becomes

$$\rho_a = \frac{4\pi}{\frac{1}{R_{A_dM_d}} - \frac{1}{R_{A_dN_d}} - \frac{1}{R_{B_dM_d}} + \frac{1}{R_{B_dN_d}} + \frac{1}{R_{\tilde{A}_dM_d}} - \frac{1}{R_{\tilde{A}_dN_d}} - \frac{1}{R_{\tilde{B}_dM_d}} + \frac{1}{R_{\tilde{B}_dN_d}}} \cdot \left(\frac{(U_{M_d} - U_{N_d})}{I}\right) \qquad (2)$$

Barnett has shown that the expression for apparent polarizability can be expressed in a convenient computational form as

$$\frac{\eta_a - \eta_1}{\eta_2 - \eta_1} = \frac{(1 - K^2)}{2\rho_a} \frac{\partial \rho_a}{\partial K} \qquad (3)$$

where η_a is the apparent polarizability, η_2 is the polarizability of the body, η_1 is the polarizability of the surrounding medium,

$K = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1}$ = resistivity reflection coefficient, ρ_a is the apparent resistivity, ρ_2 is the resistivity of the body, and ρ_1 is the resistivity of the surrounding medium. $\frac{\eta_a}{\eta_2}$ x 100 is the same as B_2(%) presented by Snyder and Merkel (1973).

The expression for the potential U_{M_d} at a point M_d due to a current source at A_d has been written by Barnett (1972) as

$$U_{M_d} = \frac{\rho_1 I}{4\pi}\left(\frac{1}{R_{A_d M_d}} + \frac{1}{R_{\tilde{A}_d M_d}}\right) + \frac{1}{4\pi}\left\{\int_C \sigma_p \frac{1}{R_{pM_d}}\, dC + \int_{\tilde{C}} \sigma_{\tilde{p}} \frac{1}{R_{\tilde{p}M_d}}\, d\tilde{C}\right\} \quad (4)$$

where σ_p and $\sigma_{\tilde{p}}$ represent the equivalent surface charge density distributions at points p and $\tilde{p}$ on the body, C, and its image, $\tilde{C}$, and $R_{A_d M_d}$, $R_{\tilde{A}_d M_d}$, R_{pM_d}, and $R_{\tilde{p}M_d}$ are the distances shown in fig. 2. The computational form for this equation is

$$U_{M_d} = \frac{\rho_1 I}{4\pi}\left\{\frac{1}{R_{A_d M_d}} + \frac{1}{R_{\tilde{A}_d M_d}} + \sum_{i=1}^{N} S_i(A_d) H_i(M_d)\right\} \quad (5)$$

where the surface of the body is divided into N triangular facets and $S_i(A_d)$ and $H_i(M_d)$ are the source and receiver response contributions from each individual body-facet (Barnett, 1972). If the current source is at A_d, and a current sink is at B_d, the potential difference between points M_d and N_d becomes

$$U_{M_d} - U_{N_d} = \frac{\rho_1 I}{4\pi}\left\{\frac{1}{R_{A_dM_d}} + \frac{1}{R_{\tilde{A}_dM_d}} - \frac{1}{R_{B_dM_d}} - \frac{1}{R_{\tilde{B}_dM_d}} - \frac{1}{R_{A_dN_d}} - \frac{1}{R_{\tilde{A}_dN_d}} + \frac{1}{R_{B_dN_d}} + \frac{1}{R_{\tilde{B}_dN_d}} + \sum_{i=1}^{N}[(S_i(A_d) - S_i(B_d))\ (H_i(M_d) - H_i(N_d))]\right\} \quad (6)$$

The derivative of the potential difference with respect to the resistivity reflection coefficient is

$$\frac{\partial U_{M_d}}{\partial K} - \frac{\partial U_{N_d}}{\partial K} = \frac{\rho_1 I}{2\pi}\sum_{i=1}^{N}[(T_i(A_d) - T_i(B_d))\ (H_i(M_d) - H_i(N_d))] \quad (7)$$

where $T_i(A_d) = \frac{\partial S_i(A_d)}{\partial K}$ (Barrett, 1972). Substituting equations (6) and (7) into equations (2) and (3) respectively, the final computational form for the apparent resistivity normalized with respect to ρ_1 is

$$\frac{\rho_a}{\rho_1} = 1 + \frac{\sum_{i=1}^{N}[(S_i(A_d) - S_i(B_d))\ (H_i(M_d) - H_i(N_d))]}{\frac{1}{R_{A_dM_d}} + \frac{1}{R_{\tilde{A}_dM_d}} - \frac{1}{R_{B_dM_d}} - \frac{1}{R_{\tilde{B}_dM_d}} - \frac{1}{R_{A_dN_d}} - \frac{1}{R_{\tilde{A}_dN_d}} + \frac{1}{R_{B_dN_d}} + \frac{1}{R_{\tilde{B}_dN_d}}} \quad (8)$$

and the computational expression for apparent polarizability is

$$\frac{\eta_a - \eta_1}{\eta_2 + \eta_1} = \frac{(1 - K^2)\sum_{i=1}^{N}[(T_i(A_d) - T_i(B_d))\ (H_i(M_d) - H_i(N_d))]}{\frac{1}{R_{A_dM_d}} + \frac{1}{R_{\tilde{A}_dM_d}} - \frac{1}{R_{B_dM_d}} - \frac{1}{R_{\tilde{B}_dM_d}} - \frac{1}{R_{A_dN_d}} - \frac{1}{R_{\tilde{A}_dN_d}} + \frac{1}{R_{B_dN_d}} + \frac{1}{R_{\tilde{B}_dN_d}}}\left(\frac{\rho_1}{\rho_a}\right) \quad (9)$$

A more complete development is given in appendix B.

Explanation of the Computer Program

The computer program which generates the three-dimensional body and calculates the response for the various arrays was developed on a Digital Equipment Corporation (DEC) PDP-10 computer.[1/] The program outlined in fig. 3 is written in FORTRAN IV. The input and the output device is disk (input disk is specified as logical unit 13, output disk is logical unit 14), which is specified in "COMMON" and can be easily changed.

An ellipsoid of revolution, with 72 facets, is generated by the program when the x, y, and z half-width (a, b, and C) of the body are specified. The response for an arbitrarily shaped body may be calculated by eliminating the call to SUBROUTINE BODY3D and changing SUBROUTINE READ3D.

Input and output examples for the seven different arrays are given in appendix A. The sphere model used for these examples is shown in fig. 4. A listing of the computer program is given in appendix C. Computation time for one set of measurements is approximately 1 minute of CPU time on the PDP-10.

Since this is a one-of-a-kind computer program, it is impossible to absolutely verify the results. However, I have made a rough check with Snyder's and Merkel's (1973) hole-to-surface idealized sphere model.

1/ The use of brand names in this report is for descriptive purposes only and in no way constitutes endorsement by the U.S. Geological Survey.

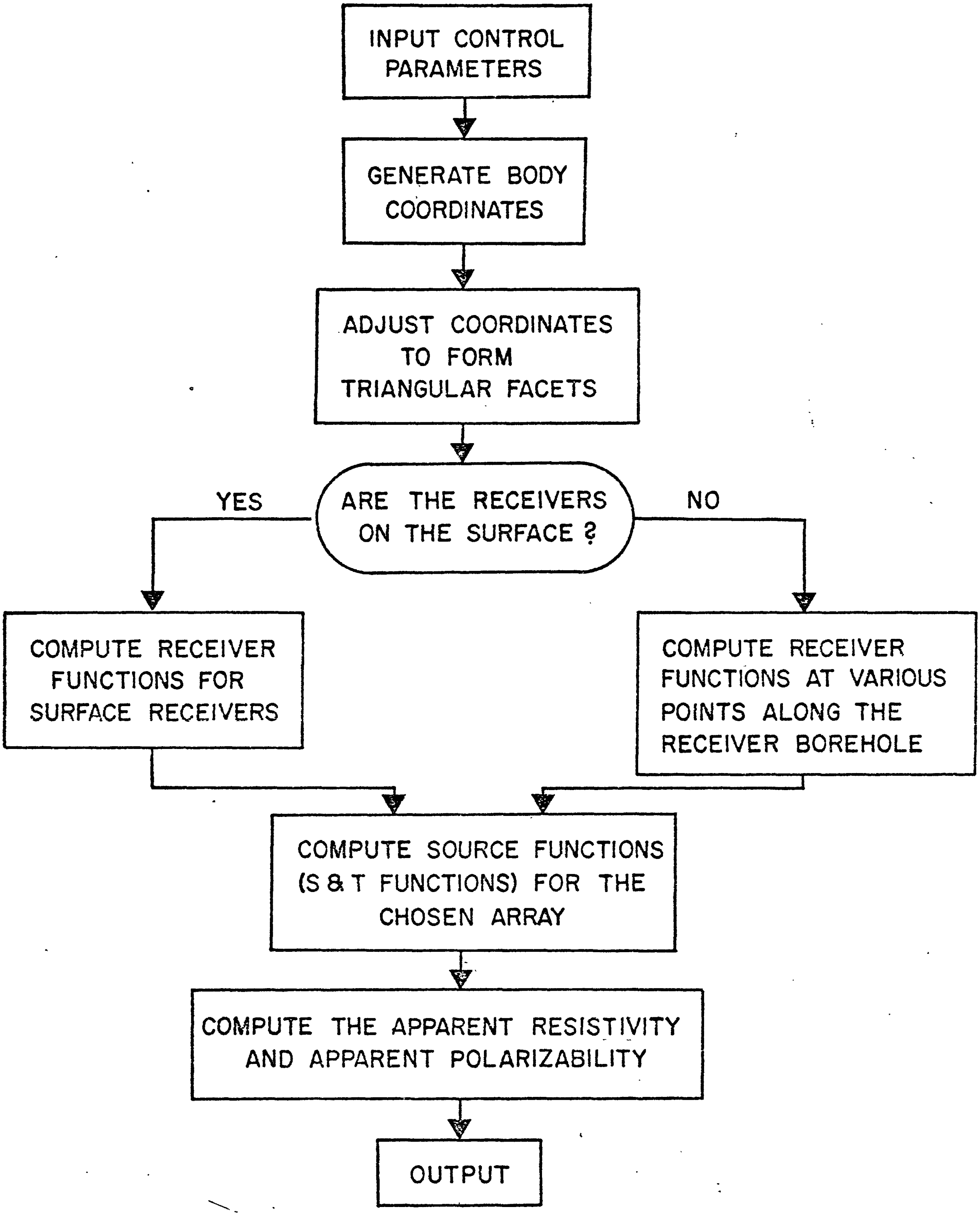


FIGURE 3.- COMPUTATIONAL FLOW OF IP3DDH.

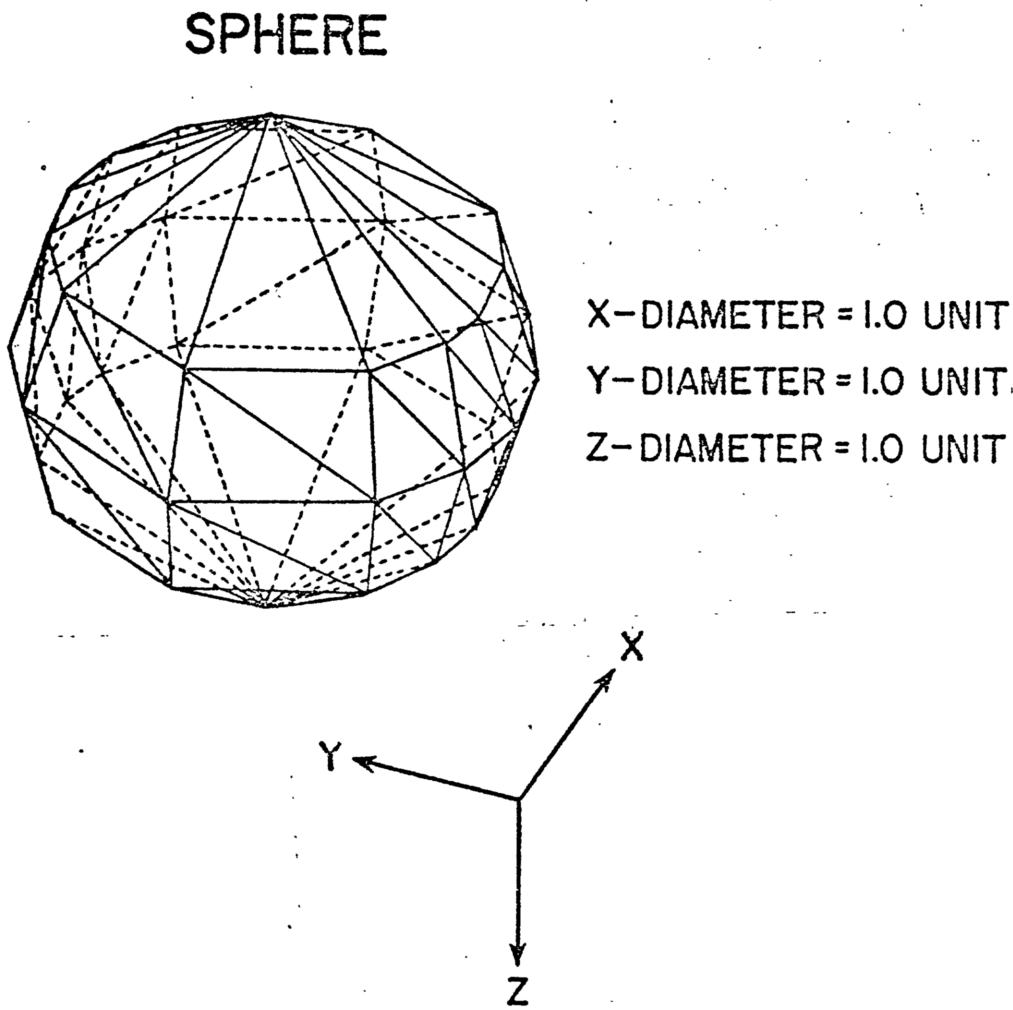


FIGURE 4.- THREE DIMENSIONAL MODEL USED FOR TEST CASES.

References

Barnett, C. T., 1972, Theoretical modeling of induced polarization effects due to arbitrarily shaped bodies: Colorado School of Mines, Ph.D. Thesis.

Daniels, J. J., 1977, Three-dimensional resistivity and induced polarization modeling using buried electrodes: Geophysics (in press).

Merkel, R. H., 1971, Resistivity analysis for plane-layer halfspace models with buried current sources: Geophys. Prosp., v. 19, no. 4, p. 626-639.

Merkel, R. H., and Alexander, S. S., 1971, Resistivity analysis for models of a sphere in a halfspace with buried current sources: Geophys. Prosp., v. 19, no. 4, p. 640-651.

Scott, J. H., Daniels, J. J., Hasbrouck, W. P., and Guu, J. Y., 1975, Hole-to-hole geophysical measurement research for mineral exploration: Trans. 16th Ann. Logging Symp.

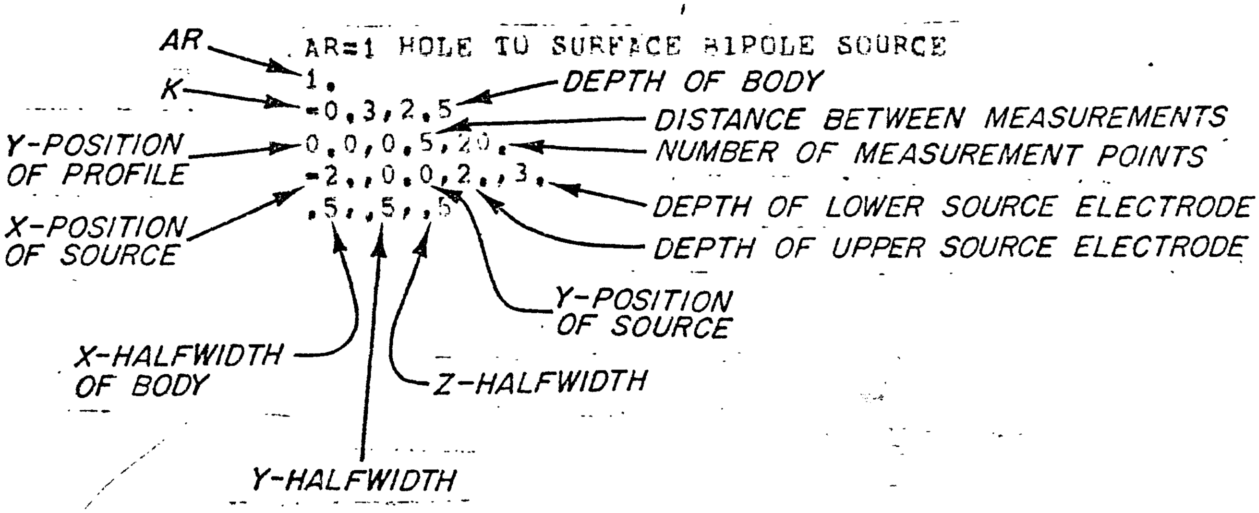
Snyder, D. D., and Merkel, R. M., 1973, Analytic models for the interpretation of electrical surveys using buried current electrodes: Geophysics, v. 28, p. 513-529.

Appendix A

Input-output examples

HOLE-TO-SURFACE
BURIED BIPOLE SOURCE
SURFACE BIPOLE RECEIVER

INPUT DATA



OUTPUT DATA

```
3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE:  24-JUN-76            TIME:  10:28          PAGE:

INPUT CONTROL PARAMETERS;

KVALU          -0,30000
DEPTH           2,50
EXECU


DESCRIPTION OF MODEL:     AR=1 HOLE TO SURFACE
                           BIPOLE SOURCE


               Z-COORDINATE     (X,Y)-COORDINATES IN PAIRS   -----------

TOP                 -0,5000000        0,0000000  0,0000000
CONTOUR 1           -0,2500000        0,2886751  0,3227486   0,1443376  0,4082483
                                      0,0000000  0,4330127  -0,1443376  0,4082483
-0,2886751  0,3227486  -0,4330127  0,0000000  -0,2886751 -0,3227486
-0,1443376 -0,4082483   0,0000000 -0,4330127   0,1443376 -0,4082483
 0,2886751 -0,3227486   0,4330127  0,0000000
CONTOUR 2            0,0000000        0,1666667  0,4714045   0,0000000  0,5000000
                                     -0,1666667  0,4714045  -0,3333333  0,3726780
-0,5000000  0,0000000  -0,3333333 -0,3726780  -0,1666667 -0,4714045
 0,0000000 -0,5000000   0,1666667 -0,4714045   0,3333333 -0,3726780
 0,5000000  0,0000000   0,3333333  0,3726780
CONTOUR 3            0,2500000        0,0000000  0,4330127  -0,1443376  0,4082483
                                     -0,2886751  0,3227486  -0,4330127  0,0000000
-0,2886751 -0,3227486  -0,1443376 -0,4082483   0,0000000 -0,4330127
 0,1443376 -0,4082483   0,2886751 -0,3227486   0,4330127  0,0000000
 0,2886751  0,3227486   0,1443376  0,4082483
BOTTOM               0,5000000         0,0000000  0,0000000
```

3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE: 24-JUN-76 TIME: 10:28

DESCRIPTION OF MODEL: AR=1 HOLE TO SURFACE
BIPOLE SOURCE

REFLECTION COEFF. K =-0.30000
DEPTH = 2.50

****
BURIED BIPOLE SOURCE,SURFACEBIPOLE RECEIVER
****

UPPER SOURCE= 2.000
LOWER SOURCE= 3.000
X-SOURCE= -2.000
Y-SOURCE= 0.000

Y-PROFILE= 0.000

X-RECEIVER POSITION	APPARENT RESISTIVITY	APPARENT POLARIZABILITY
-10.500	.998608E+00	.219814E-02
-10.000	.998663E+00	.210880E-02
-9.500	.998720E+00	.201754E-02
-9.000	.998778E+00	.192456E-02
-8.500	.998837E+00	.183029E-02
-8.000	.998897E+00	.173512E-02
-7.500	.998957E+00	.163985E-02
-7.000	.999016E+00	.154581E-02
-6.500	.999073E+00	.145493E-02
-6.000	.999127E+00	.137024E-02
-5.500	.999173E+00	.129664E-02
-5.000	.999207E+00	.124240E-02
-4.500	.999220E+00	.122253E-02
-4.000	.999193E+00	.126335E-02
-3.500	.999078E+00	.144302E-02
-3.000	.998726E+00	.199481E-02
-2.500	.997398E+00	.407686E-02
-2.000	.170141E+39	.100000E+01
-1.500	.100367E+01	-.571242E-02
-1.000	.100213E+01	-.332900E-02
-0.500	.100109E+01	-.170120E-02
0.000	.999446E+00	.859055E-03
0.500	.997121E+00	.450470E-02
1.000	.994683E+00	.835363E-02
1.500	.992815E+00	.113208E-01
2.000	.991791E+00	.129559E-01
2.500	.991465E+00	.134809E-01
3.000	.991581E+00	.132991E-01

3,500	,991964E+00	,126930E-01
4,000	,992430E+00	,119558E-01
4,500	,992871E+00	,112558E-01
5,000	,993300E+00	,105759E-01
5,500	,993694E+00	,995339E-02
6,000	,994048E+00	,939359E-02
6,500	,994365E+00	,889414E-02
7,000	,994647E+00	,844951E-02
7,500	,994899E+00	,805345E-02
8,000	,995125E+00	,769987E-02

HOLE-TO-HOLE
BURIED, FIXED POLE SOURCE
BURIED, MOVING BIPOLE RECEIVER

INPUT DATA

```
AR=3 HOLE TO HOLE   FIXED SOURCE POLE
3.
-0.3,1.5
2.,0.0,0.5,10.
-2.,0.0,2.
.5,.5,.5
```

OUTPUT DATA

```
3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE:  24-JUN-76              TIME:  11:28           PAGE:

INPUT CONTROL PARAMETERS:

KVALU          -0.30000
DEPTH           1.50
EXECU


DESCRIPTION OF MODEL:      AR=3 HOLE TO HOLE
                           FIXED SOURCE POLE



                  Z-COORDINATE      (X,Y)-COORDINATES IN PAIRS  -----------


 TOP                -0.5000000         0.0000000  0.0000000
 CONTOUR 1          -0.2500000         0.2886751  0.3227486   0.1443376   0.4082483
                                       0.0000000  0.4330127  -0.1443376   0.4082483
-0.2886751  0.3227486  -0.4330127  0.0000000  -0.2886751 -0.3227486
-0.1443376 -0.4082483   0.0000000 -0.4330127   0.1443376 -0.4082483
 0.2886751 -0.3227486   0.4330127  0.0000000
 CONTOUR 2           0.0000000         0.1666667  0.4714045   0.0000000   0.5000000
                                      -0.1666667  0.4714045  -0.3333333   0.3726780
-0.5000000  0.0000000  -0.3333333 -0.3726780  -0.1666667 -0.4714045
 0.0000000 -0.5000000   0.1666667 -0.4714045   0.3333333 -0.3726780
 0.5000000  0.0000000   0.3333333  0.3726780
 CONTOUR 3           0.2500000         0.0000000  0.4330127  -0.1443376   0.4082483
                                      -0.2886751  0.3227486  -0.4330127   0.0000000
-0.2886751 -0.3227486  -0.1443376 -0.4082483   0.0000000 -0.4330127
 0.1443376 -0.4082483   0.2886751 -0.3227486   0.4330127  0.0000000
 0.2886751  0.3227486   0.1443376  0.4082483
 BOTTOM              0.5000000          0.0000000  0.0000000
```

3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE: 24-JUN-76 TIME: 11:28

DESCRIPTION OF MODEL: AR=3 HOLE TO HOLE
FIXED SOURCE POLE

REFLECTION COEFF, K =-0.30000
DEPTH = 1.50

****
BURIED POLE SOURCE, BURIED BIPOLERECEIVER
****

UPPER SOURCE= 0.000
LOWER SOURCE= 2.000
X-SOURCE= -2.000
Y-SOURCE= 0.000

X-RECEIVER= 2.000
Y-RECEIVER= 0.000

RECEIVER DEPTH	APPARENT RESISTIVITY	APPARENT POLARIZABILITY
1.000	.988036E+00	.192324E-01
1.500	.100980E+01	-.154555E-01
2.000	.102068E+01	-.322144E-01
2.500	.102042E+01	-.318101E-01
3.000	.101539E+01	-.240850E-01
3.500	.101041E+01	-.163674E-01
4.000	.100689E+01	-.108710E-01
4.500	.100465E+01	-.736094E-02
5.000	.100325E+01	-.515087E-02
5.500	.100236E+01	-.373968E-02
6.000	.100178E+01	-.282628E-02
6.500	.100139E+01	-.220694E-02
7.000	.100111E+01	-.176749E-02
7.500	.100091E+01	-.144696E-02
8.000	.100076E+01	-.121151E-02
8.500	.100064E+01	-.103006E-02
9.000	.100055E+01	-.888375E-03
9.500	.100048E+01	-.775617E-03

HOLE-TO-HOLE
BURIED, FIXED BIPOLE SOURCE
BURIED, MOVING BIPOLE RECEIVER

INPUT DATA

```
R=5 HOLE-TO-HOLE      FIXED SOURCE
5.
-0.3,1.5
2.,0.0,.25,11.
-2.,0.0,2.,3.
.5,.5,.5
```

OUTPUT DATA

```
3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE:  24-JUN-76              TIME:  12:06            PAGE:


INPUT CONTROL PARAMETERS:

KVALU         -0.30000
DEPTH          1.50
EXECU



DESCRIPTION OF MODEL:     R=5 HOLE-TO-HOLE
                           FIXED SOURCE



                 Z-COORDINATE     (X,Y)-COORDINATES IN PAIRS   -----------


TOP                 -0.5000000      0.0000000  0.0000000
CONTOUR 1           -0.2500000      0.2886751  0.3227486   0.1443376  0.4082483
                                    0.0000000  0.4330127  -0.1443376  0.4082483
-0.2886751  0.3227486  -0.4330127  0.0000000  -0.2886751 -0.3227486
-0.1443376 -0.4082483   0.0000000 -0.4330127   0.1443376 -0.4082483
 0.2886751 -0.3227486   0.4330127  0.0000000
CONTOUR 2            0.0000000      0.1666667  0.4714045   0.0000000  0.5000000
                                   -0.1666667  0.4714045  -0.3333333  0.3726780
-0.5000000  0.0000000  -0.3333333 -0.3726780  -0.1666667 -0.4714045
 0.0000000 -0.5000000   0.1666667 -0.4714045   0.3333333 -0.3726780
 0.5000000  0.0000000   0.3333333  0.3726780
CONTOUR 3            0.2500000      0.0000000  0.4330127  -0.1443376  0.4082483
                                   -0.2886751  0.3227486  -0.4330127  0.0000000
-0.2886751 -0.3227486  -0.1443376 -0.4082483   0.0000000 -0.4330127
 0.1443376 -0.4082483   0.2886751 -0.3227486   0.4330127  0.0000000
 0.2886751  0.3227486   0.1443376  0.4082483
BOTTOM               0.5000000       0.0000000  0.0000000
```

3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE: 24-JUN-76 TIME: 12:06

DESCRIPTION OF MODEL: R=5 HOLE-TO-HOLE
FIXED SOURCE

REFLECTION COEFF, K =-0,30000
DEPTH = 1,50

****
BURIED BIPOLE FIXED SOURCE, BURIEDBIPOLE RECEIVER
****

UPPER SOURCE= 2,000
LOWER SOURCE= 3,000
X-SOURCE= -2,000
Y-SOURCE= 0,000

X-RECEIVER= 2,000
Y-RECEIVER= 0,000

RECEIVER DEPTH	APPARENT RESISTIVITY	APPARENT POLARIZABILITY
0,750	,978771E+00	,341950E-01
1,000	,983506E+00	,263412E-01
1,250	,989042E+00	,172621E-01
1,500	,994820E+00	,790791E-02
1,750	,100023E+01	-,729730E-03
2,000	,100475E+01	-,787284E-02
2,250	,100811E+01	-,131193E-01
2,500	,101030E+01	-,165037E-01
2,750	,101152E+01	-,183671E-01
3,000	,101206E+01	-,191650E-01
3,250	,101220E+01	-,193646E-01
3,500	,101219E+01	-,193361E-01
3,750	,101220E+01	-,193458E-01
4,000	,101236E+01	-,196034E-01
4,250	,101281E+01	-,203079E-01
4,500	,101364E+01	-,216319E-01
4,750	,101511E+01	-,239403E-01
5,000	,101763E+01	-,279027E-01
5,250	,102217E+01	-,349734E-01
5,500	,103193E+01	-,499566E-01
5,750	,106326E+01	-,961867E-01
6,000	,588944E-01	,258781E+02
6,250	,947078E+00	,906410E-01
6,500	,973251E+00	,446628E-01
6,750	,982209E+00	,294908E-01
7,000	,986583E+00	,220189E-01
7,250	,989339E+00	,176170E-01

7.500	.991082E+00	.147418E-01
7.750	.992305E+00	.127329E-01
8.000	.993204E+00	.112611E-01
8.250	.993888E+00	.101441E-01
8.500	.994423E+00	.927308E-02
8.750	.994851E+00	.857914E-02
9.000	.995199E+00	.801664E-02
9.250	.995487E+00	.755420E-02
9.500	.995727E+00	.716952E-02
9.750	.995929E+00	.684643E-02
10.000	.996102E+00	.657294E-02
10.250	.996250E+00	.633982E-02
10.500	.996377E+00	.614011E-02
10.750	.000000E+00	.000000E+00
11.000	.000000E+00	.000000E+00
11.250	.000000E+00	.000000E+00

HOLE-TO-HOLE
BURIED, MOVING BIPOLE SOURCE
BURIED, MOVING BIPOLE RECEIVER

INPUT DATA

```
AR=6 HOLE-TO-HOLE    MOVING SOURCE
6.
-0.3,1.5
2.,0.0,0.25,11.
-2.,0.0
.5,.5,.5
```

OUTPUT DATA

```
3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE:  24-JUN-76               TIME:  12:14           PAGE:

INPUT CONTROL PARAMETERS:

KVALU          -0.30000
DEPTH           1.50
EXECU


DESCRIPTION OF MODEL:     AR=6 HOLE-TO-HOLE
                           MOVING SOURCE


                Z-COORDINATE      (X,Y)-COORDINATES IN PAIRS   ------------

TOP                -0.5000000        0.0000000  0.0000000
CONTOUR 1          -0.2500000        0.2886751  0.3227486   0.1443376  0.4082483
                                     0.0000000  0.4330127  -0.1443376  0.4082483
-0.2886751  0.3227486  -0.4330127  0.0000000  -0.2886751 -0.3227486
-0.1443376 -0.4082483   0.0000000 -0.4330127   0.1443376 -0.4082483
 0.2886751 -0.3227486   0.4330127  0.0000000
CONTOUR 2           0.0000000        0.1666667  0.4714045   0.0000000  0.5000000
                                    -0.1666667  0.4714045  -0.3333333  0.3726780
-0.5000000  0.0000000  -0.3333333 -0.3726780  -0.1666667 -0.4714045
 0.0000000 -0.5000000   0.1666667 -0.4714045   0.3333333 -0.3726780
 0.5000000  0.0000000   0.3333333  0.3726780
CONTOUR 3           0.2500000        0.0000000  0.4330127  -0.1443376  0.4082483
                                    -0.2886751  0.3227486  -0.4330127  0.0000000
-0.2886751 -0.3227486  -0.1443376 -0.4082483   0.0000000 -0.4330127
 0.1443376 -0.4082483   0.2886751 -0.3227486   0.4330127  0.0000000
 0.2886751  0.3227486   0.1443376  0.4082483
BOTTOM              0.5000000        0.0000000  0.0000000
```

3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE: 24-JUN-76 TIME: 12:14

DESCRIPTION OF MODEL: AR=6 HOLE-TO-HOLE
MOVING SOURCE

REFLECTION COEFF, K =-0.30000
DEPTH = 1.50

****
BURIED BIPOLE MOVING SOURCE,BURIED BIPOLERECEIVER
****

X-SOURCE= -2.000
Y-SOURCE= 0.000

X-RECEIVER= 2.000
Y-RECEIVER= 0.000

RECEIVER DEPTH	APPARENT RESISTIVITY	APPARENT POLARIZABILITY
0.750	.981031E+00	.301491E-01
1.000	.977376E+00	.362583E-01
1.250	.976248E+00	.381801E-01
1.500	.979436E+00	.328914E-01
1.750	.986924E+00	.205667E-01
2.000	.996536E+00	.503984E-02
2.250	.100509E+01	-.846306E-02
2.500	.101030E+01	-.165037E-01
2.750	.101183E+01	-.187483E-01
3.000	.101076E+01	-.169747E-01
3.250	.100853E+01	-.134282E-01
3.500	.100618E+01	-.972554E-02
3.750	.100422E+01	-.663548E-02
4.000	.100277E+01	-.435051E-02
4.250	.100178E+01	-.277940E-02
4.500	.100112E+01	-.174295E-02
4.750	.100069E+01	-.107910E-02
5.000	.100043E+01	-.659909E-03
5.250	.100026E+01	-.400701E-03
5.500	.100016E+01	-.240227E-03
5.750	.100010E+01	-.141944E-03
6.000	.100006E+01	-.827301E-04
6.250	.100003E+01	-.457493E-04
6.500	.100002E+01	-.234697E-04
6.750	.100001E+01	-.102049E-04
7.000	.100000E+01	-.247960E-05
7.250	.100000E+01	.185553E-05
7.500	.999999E+00	.413070E-05
7.750	.999998E+00	.517104E-05

8,000	,999998E+00	,548506E-05
8,250	,999998E+00	,538617E-05
8,500	,999998E+00	,506644E-05
8,750	,999998E+00	,464168E-05
9,000	,999998E+00	,418133E-05
9,250	,999998E+00	,372468E-05
9,500	,999998E+00	,329306E-05
9,750	,999999E+00	,289674E-05
10,000	,999999E+00	,253971E-05
10,250	,999999E+00	,222248E-05
10,500	,999999E+00	,194278E-05

SINGLE HOLE
MOVING BIPOLE SOURCE
MOVING BIPOLE RECEIVER

INPUT DATA

```
AR=7 SINGLE-HOLE N=3
7.
-0.3,3.5
-2.,0.0,.5,10.
3
.5,.5,.5
```

OUTPUT DATA

```
3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE:  24-JUN-76              TIME:  12:27            PAGE:

INPUT CONTROL PARAMETERS:

KVALU          -0.30000
DEPTH           3.50
EXECU


DESCRIPTION OF MODEL:     AR=7 SINGLE-HOLE N=3



              Z-COORDINATE     (X,Y)-COORDINATES IN PAIRS  ------------

TOP              -0.5000000        0.0000000  0.0000000
CONTOUR 1        -0.2500000        0.2886751  0.3227486   0.1443376  0.4082483
                                   0.0000000  0.4330127  -0.1443376  0.4082483
-0.2886751  0.3227486  -0.4330127  0.0000000  -0.2886751 -0.3227486
-0.1443376 -0.4082483   0.0000000 -0.4330127   0.1443376 -0.4082483
 0.2886751 -0.3227486   0.4330127  0.0000000
CONTOUR 2         0.0000000        0.1666667  0.4714045   0.0000000  0.5000000
                                  -0.1666667  0.4714045  -0.3333333  0.3726780
-0.5000000  0.0000000  -0.3333333 -0.3726780  -0.1666667 -0.4714045
 0.0000000 -0.5000000   0.1666667 -0.4714045   0.3333333 -0.3726780
 0.5000000  0.0000000   0.3333333  0.3726780
CONTOUR 3         0.2500000        0.0000000  0.4330127  -0.1443376  0.4082483
                                  -0.2886751  0.3227486  -0.4330127  0.0000000
-0.2886751 -0.3227486  -0.1443376 -0.4082483   0.0000000 -0.4330127
 0.1443376 -0.4082483   0.2886751 -0.3227486   0.4330127  0.0000000
 0.2886751  0.3227486   0.1443376  0.4082483
BOTTOM            0.5000000         0.0000000  0.0000000
```

3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE: 24-JUN-76 TIME: 12:27

DESCRIPTION OF MODEL: AR=7 SINGLE-HOLE N=3

REFLECTION COEFF, K =-0,30000
DEPTH = 3,50

****
SINGLE HOLE,BIPOLE-BIPOLE
****

X-POSITION OF HOLE= -2,000
Y-POSITION OF HOLE= 0,000

RECEIVER DEPTH	APPARENT RESISTIVITY	APPARENT POLARIZABILITY
3,000	,997100E+00	,462375E-02
3,500	,997080E+00	,464685E-02
4,000	,997170E+00	,445965E-02
4,500	,997415E+00	,401191E-02
5,000	,997986E+00	,310014E-02
5,500	,998854E+00	,178910E-02
6,000	,999683E+00	,533146E-03
6,500	,100016E+01	-,218523E-03
7,000	,100028E+01	-,434588E-03
7,500	,100023E+01	-,371253E-03
8,000	,100055E+01	-,901999E-03
8,500	,100037E+01	-,612888E-03

HOLE-TO-SURFACE
BURIED POLE SOURCE
SURFACE BIPOLE RECEIVER

INPUT DATA

```
L AR=2 HOLE-TO-SURFACE SOURCE POLE
2,
-0,3,1,5
0,0,0.5,20,
-2.,0,0,2.5
.5,.5,.5
```

OUTPUT DATA

```
 3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE:  24-JUN-76            TIME:  10:36           PAGE:

INPUT CONTROL PARAMETERS:

KVALU          -0.30000
DEPTH           1.50
EXECU


DESCRIPTION OF MODEL:     AR=2 HOLE-TO-SURFACE
                           SOURCE POLE


                Z-COORDINATE      (X,Y)-COORDINATES IN PAIRS   ------------

TOP                 -0.5000000        0.0000000  0.0000000
CONTOUR 1           -0.2500000        0.2886751  0.3227486   0.1443376  0.4082483
                                      0.0000000  0.4330127  -0.1443376  0.4082483
-0.2886751  0.3227486  -0.4330127  0.0000000  -0.2886751 -0.3227486
-0.1443376 -0.4082483   0.0000000 -0.4330127   0.1443376 -0.4082483
 0.2886751 -0.3227486   0.4330127  0.0000000
CONTOUR 2            0.0000000        0.1666667  0.4714045   0.0000000  0.5000000
                                     -0.1666667  0.4714045  -0.3333333  0.3726780
-0.5000000  0.0000000  -0.3333333 -0.3726780  -0.1666667 -0.4714045
 0.0000000 -0.5000000   0.1666667 -0.4714045   0.3333333 -0.3726780
 0.5000000  0.0000000   0.3333333  0.3726780
CONTOUR 3            0.2500000        0.0000000  0.4330127  -0.1443376  0.4082483
                                     -0.2886751  0.3227486  -0.4330127  0.0000000
-0.2886751 -0.3227486  -0.1443376 -0.4082483   0.0000000 -0.4330127
 0.1443376 -0.4082483   0.2886751 -0.3227486   0.4330127  0.0000000
 0.2886751  0.3227486   0.1443376  0.4082483
BOTTOM               0.5000000        0.0000000  0.0000000
```

3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE: 24-JUN-76 TIME: 10:36

DESCRIPTION OF MODEL: AR=2 HOLE-TO-SURFACE
SOURCE POLE

REFLECTION COEFF. K =-0.30000
DEPTH = 1.50

****
BURIED POLE SOURCE,SURFACEBIPOLE RECEIVER
****

UPPER SOURCE= 0.000
LOWER SOURCE= 2.500
X-SOURCE= -2.000
Y-SOURCE= 0.000

Y-PROFILE= 0.000

X-RECEIVER POSITION	APPARENT RESISTIVITY	APPARENT POLARIZABILITY
-10.500	.999472E+00	.845910E-03
-10.000	.999455E+00	.872770E-03
-9.500	.999437E+00	.901742E-03
-9.000	.999417E+00	.933225E-03
-8.500	.999395E+00	.967768E-03
-8.000	.999371E+00	.100616E-02
-7.500	.999344E+00	.104957E-02
-7.000	.999312E+00	.109979E-02
-6.500	.999275E+00	.115970E-02
-6.000	.999228E+00	.123408E-02
-5.500	.999167E+00	.133128E-02
-5.000	.999082E+00	.146668E-02
-4.500	.998955E+00	.167017E-02
-4.000	.998743E+00	.200904E-02
-3.500	.998354E+00	.263302E-02
-3.000	.997521E+00	.397423E-02
-2.500	.995003E+00	.805302E-02
-2.000	.170141E+39	.100000E+01
-1.500	.100026E+01	-.637920E-03
-1.000	.992922E+00	.111229E-01
-0.500	.985694E+00	.229200E-01
0.000	.984036E+00	.257835E-01
0.500	.991517E+00	.137235E-01
1.000	.100140E+01	-.207615E-02
1.500	.100668E+01	-.104186E-01
2.000	.100775E+01	-.121172E-01
2.500	.100710E+01	-.111190E-01
3.000	.100608E+01	-.954312E-02

3,500	,100514E+01	-,806429E-02
4,000	,100434E+01	-,681831E-02
4,500	,100371E+01	-,582415E-02
5,000	,100320E+01	-,503712E-02
5,500	,100280E+01	-,440573E-02
6,000	,100248E+01	-,389492E-02
6,500	,100221E+01	-,347673E-02
7,000	,100199E+01	-,313029E-02
7,500	,100181E+01	-,284000E-02
8,000	,100165E+01	-,259418E-02

SURFACE-TO-HOLE
SURFACE, FIXED POLE SOURCE
BURIED, MOVING BIPOLE RECEIVER

INPUT DATA

```
AR=4 SURFACE-TO-HOLEFIXED SURFACE SOURCE MOVING BURIED        RECEIVER
4.
-0.3,2.5
2.,0.0,.5,10.
-2.,0.,0.
.5,.5,.5
```

OUTPUT DATA

```
3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE:  24-JUN-76             TIME:  11:36           PAGE:

INPUT CONTROL PARAMETERS:

KVALU          -0.30000
DEPTH           2.50
EXECU


DESCRIPTION OF MODEL:        AR=4 SURFACE-TO-HOLE
                             FIXED SURFACE SOURCE
                              MOVING BURIED
                             RECEIVER

                 Z-COORDINATE     (X,Y)-COORDINATES IN PAIRS  ------------

TOP                 -0.5000000        0.0000000  0.0000000
CONTOUR 1           -0.2500000        0.2886751  0.3227486   0.1443376  0.4082483
                                      0.0000000  0.4330127  -0.1443376  0.4082483
-0.2886751  0.3227486  -0.4330127  0.0000000  -0.2886751 -0.3227486
-0.1443376 -0.4082483   0.0000000 -0.4330127   0.1443376 -0.4082483
 0.2886751 -0.3227486   0.4330127  0.0000000
CONTOUR 2            0.0000000        0.1666667  0.4714045   0.0000000  0.5000000
                                     -0.1666667  0.4714045  -0.3333333  0.3726780
-0.5000000  0.0000000  -0.3333333 -0.3726780  -0.1666667 -0.4714045
 0.0000000 -0.5000000   0.1666667 -0.4714045   0.3333333 -0.3726780
 0.5000000  0.0000000   0.3333333  0.3726780
CONTOUR 3            0.2500000        0.0000000  0.4330127  -0.1443376  0.4082483
                                     -0.2886751  0.3227486  -0.4330127  0.0000000
-0.2886751 -0.3227486  -0.1443376 -0.4082483   0.0000000 -0.4330127
 0.1443376 -0.4082483   0.2886751 -0.3227486   0.4330127  0.0000000
 0.2886751  0.3227486   0.1443376  0.4082483
BOTTOM               0.5000000         0.0000000  0.0000000
```

3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROGRAM

DATE: 24-JUN-76 TIME: 11:36

DESCRIPTION OF MODEL: AR=4 SURFACE-TO-HOLE FIXED SURFACE SOURCE MOVING BURIED RECEIVER

REFLECTION COEFF, K =-0,30000
DEPTH = 2,50

****
SURFACE POLE SOURCE,BURIED BIPOLE RECEIVER
****

X-SOURCE= -2,000
Y-SOURCE= 0,000

X-RECEIVER= 2,000
Y-RECEIVER= 0,000

RECEIVER DEPTH	APPARENT RESISTIVITY	APPARENT POLARIZABILITY
1,000	,983445E+00	,265014E-01
1,500	,980005E+00	,320888E-01
2,000	,979539E+00	,328147E-01
2,500	,985392E+00	,232380E-01
3,000	,995893E+00	,639179E-02
3,500	,100507E+01	-,800211E-02
4,000	,100950E+01	-,148110E-01
4,500	,101014E+01	-,157462E-01
5,000	,100906E+01	-,140628E-01
5,500	,100760E+01	-,117716E-01
6,000	,100622E+01	-,962915E-02
6,500	,100506E+01	-,783020E-02
7,000	,100416E+01	-,642914E-02
7,500	,100347E+01	-,534990E-02
8,000	,100292E+01	-,448972E-02
8,500	,100248E+01	-,380896E-02
9,000	,100213E+01	-,326444E-02
9,500	,100185E+01	-,282392E-02

Appendix B

Development of theoretical expressions

Using image theory and applying the following boundary conditions:

(1) there is no vertical current flow at the air-earth interface,

(2) the potential must be continuous across regions of different conductivity,

(3) the normal component of current flow must be continuous across regions of different conductivity,

and (4) in the vicinity of the current electrode the expression for the potential must converge to the expression for a point source in a homogenous half-space.

The expression for the potential, U_M, given by Barnett (1972) can be modified for a buried point, M_d, due to a buried point source at A_d and can be written as

$$U_{M_d} = \frac{\rho_1 I}{4\pi}\left(\frac{1}{R_{A_d M_d}} + \frac{1}{R_{\tilde{A}_d M_d}}\right) + \left\{ \int_C \sigma_p \frac{1}{R_{pM_d}}\, dC + \int_{\tilde{C}} \sigma_{\tilde{p}} \frac{1}{R_{\tilde{p}M_d}}\, d\tilde{C} \right\} \qquad \text{(B1)}$$

where σ_p and $\sigma_{\tilde{p}}$ represent the fictitious surface charge density distributions for the body, C, and its image, $\tilde{C}$, and $R_{A_d M_d}$, $R_{\tilde{A}_d M_d}$, R_{pM_d}, and $R_{\tilde{p}M_d}$ are the distances shown in fig. 2. The problem of solving equation (7) is to solve for the fictitious charge densities and then to perform the necessary integrations over C and $\tilde{C}$.

The expression for σ_Q at a point Q on C is solved by applying boundary conditions (2) and (3). Boundary condition (2) can be satisfied by considering the potential at points Q_1 and Q_2 on opposite sides of the boundary. Then for a wholespace, the potential at points Q_1 and Q_2 can be expressed as

$$U_{Q_1} = \frac{\rho_1 I}{4\pi R_{A_dQ_1}} + \frac{1}{4\pi} \int_C \sigma_p \left(\frac{1}{R_{pQ_1}}\right) dC \quad , \tag{B2}$$

and

$$U_{Q_2} = \frac{\rho_1 I}{4\pi R_{A_dQ_2}} + \frac{1}{4\pi} \int_C \sigma_p \left(\frac{1}{R_{pQ_2}}\right) dC \quad , \tag{B3}$$

As Q_1 and Q_2 approach one another, $U_{Q_1}\Big|_Q = U_{Q_2}\Big|_Q$, and the second boundary condition is satisfied. Applying the third boundary condition,

$\frac{1}{\rho_1} \frac{\partial U_{Q_1}}{\partial \nu}\Big|_C = \frac{1}{\rho_2} \frac{\partial U_{Q_2}}{\partial \nu}$, we obtain the expression

$$\frac{1}{\rho_1} \frac{\partial}{\partial \nu} \left[\frac{\rho_1 I}{4\pi R_{A_dQ_1}} + \frac{1}{4\pi} \int_C \sigma_p \left(\frac{1}{R_{pQ_1}}\right) dC\right]\Bigg|_{Q_1 \to Q} = \frac{1}{\rho_2} \frac{\partial}{\partial \nu} \left[\frac{\rho_1 I}{4\pi R_{A_dQ_2}} + \frac{1}{4\pi} \int_C \sigma_p \left(\frac{1}{R_{pQ_2}}\right) dC\right]\Bigg|_{Q_2 \to Q} \tag{B4}$$

It is not obvious that the expressions on the left and right hand sides of the equal sign are equal. In fact, the integrals are improper when $p \to Q$. It can be shown (Barnett, 1972, p. 54) that these integrals can be solved so that

$$\lim_{\substack{Q_1 \to Q \\ p = q}} \left\{ \frac{1}{4\pi} \int_{C \text{ at } Q} \sigma_p \frac{\partial}{\partial \nu} \left(\frac{1}{R_{pQ_1}}\right) dC \right\} = -\frac{1}{2} \sigma_Q \tag{B5}$$

and

$$\lim_{\substack{Q_2 \to Q \\ p=q}} \left\{ \frac{1}{4\pi} \int_{C \text{ at } Q} \sigma_p \frac{\partial}{\partial \nu} \left(\frac{1}{R_{pQ_1}} \right) dC \right\} = + \frac{1}{2} \sigma_Q \quad \text{(B6)}$$

Utilizing this singularity, the boundary condition in the limit can be expressed as

$$\sigma_Q = \frac{K\rho_1 I}{2\pi} \frac{\partial}{\partial \nu} \left(\frac{1}{R_{A_d Q}} \right) + \frac{K}{2\pi} \int_{C'} \sigma_p \frac{\partial}{\partial \nu} \left(\frac{1}{R_{pQ}} \right) dC \quad \text{(B7)}$$

where $K = \dfrac{\rho_2 - \rho_1}{\rho_2 + \rho_1}$, and C' is the whole surface of the body excluding that element at point Q.

Applying image theory, the expressions for the halfspace can be written as:

$$\sigma_Q = \frac{K\rho_1 I}{2\pi} \left\{ \frac{\partial}{\partial \nu} \left(\frac{1}{R_{A_d Q}} \right) + \frac{\partial}{\partial \nu} \left(\frac{1}{R\tilde{}_{A_d Q}} \right) \right\} +$$

$$\frac{K}{2\pi} \left\{ \int_{C'} \sigma_p \frac{\partial}{\partial \nu} \left(\frac{1}{R_{pQ}} \right) dC + \int_{\tilde{C}} \sigma_p \frac{\partial}{\partial \nu} \left(\frac{1}{R\tilde{}_{pQ}} \right) d\tilde{C} \right\} \quad \text{(B8)}$$

and

$$U_{M_d} = \frac{\rho_1 I}{4\pi} \left\{ \frac{1}{R_{A_d M_d}} + \frac{1}{R\tilde{}_{A_d M_d}} \right\} + \frac{1}{4\pi} \left\{ \int_{C} \sigma_p \left(\frac{1}{R_{pM_d}} \right) dC + \int_{\tilde{C}} \sigma_p \left(\frac{1}{R\tilde{}_{pM_d}} \right) d\tilde{C} \right\} \quad \text{(B9)}$$

assuming that $\sigma_{\tilde{p}} = \sigma_p$.

The problem at this point is to solve the integral expressions in equations (B8) and (B9) for the charge density distribution, σ_p. The charge density can be expressed as $S_p = \frac{\sigma_p}{\rho_1 I}$, so that equations (B8) and (B9) become

$$\frac{2\pi}{K} S_Q = \left\{ \frac{\partial}{\partial \nu}\left(\frac{1}{R_{A_dQ}}\right) + \frac{\partial}{\partial \nu}\left(\frac{1}{R_{\tilde{A}_dQ}}\right)\right\} + \int_{C'} S_p \frac{\partial}{\partial \nu}\left(\frac{1}{R_{pQ}}\right) dC + \int_{\tilde{C}} S_p \frac{\partial}{\partial \nu}\left(\frac{1}{R_{\tilde{p}Q}}\right) d\tilde{C} \tag{B10}$$

and

$$U_M = \frac{\rho_1 I}{4\pi}\left\{\frac{1}{R_{A_dM_d}} + \frac{1}{R_{\tilde{A}_dM_d}} + \int_C S_p \left(\frac{1}{R_{pM_d}}\right) dC + \int_{\tilde{C}} S_p \left(\frac{1}{R_{\tilde{p}M_d}}\right) d\tilde{C}\right\} \tag{B11}$$

The unknown function S_p is approximated by a set of N discrete functions, so that

$$S_p \approx \sum_{j=1}^{N} S_j \alpha_j . \tag{B12}$$

The functions S_j are called the "expansion functions" or "basis functions" while α_j are constants to be determined (Harrington, 1968).

In order to put equation (B10) in terms of point p rather than point Q, the singularity condition (equations (B4), (B5), and (B6)) is applied to equation (B10) and the basis functions expressed in equation (B12), so that

$$\frac{2\pi}{K} S_i b_{ii} = \frac{\partial}{\partial \nu}\left(\frac{1}{R_{A_dQ}}\right) + \frac{\partial}{\partial \nu}\left(\frac{1}{R_{\tilde{A}_dQ}}\right) +$$

$$\sum_{\substack{j=1 \\ j\neq i}}^{N} S_j \int_{C'} \alpha_j \frac{\partial}{\partial \nu}\left(\frac{1}{R_{pQ}}\right) dC + \sum_{j=1}^{N} S_j \int_{\tilde{C}} \alpha_j \frac{\partial}{\partial \nu}\left(\frac{1}{R_{\tilde{p}Q}}\right) d\tilde{C} \tag{B13}$$

and

$$U_{M_d} = \frac{\rho_1 I}{4\pi}\left\{\frac{1}{R_{A_dM_d}} + \frac{1}{R_{\tilde{A}_dM_d}} + \sum_{j=1}^{N} S_j \int_{\tilde{C}} \alpha_j \left(\frac{1}{R_{\tilde{p}M_d}}\right) d\tilde{C} + \right.$$

$$\left. \sum_{j=1}^{N} S_j \int_{C} \alpha_j \left(\frac{1}{R_{pM_d}}\right) dC\right\} \tag{B14}$$

where

$$b_{ii} = -\frac{1}{4\pi}\int_C \alpha_j \frac{\partial}{\partial \nu}\left(\frac{1}{R_{pQ_1}}\right) dC - \int_C \alpha_j \frac{\partial}{\partial \nu}\left(\frac{1}{R_{pQ_2}}\right) dC \tag{B15}$$

as $p \to Q$ and $Q_1 \to Q$ and $Q_2 \to Q$.

The surface C can be divided into triangular subareas over which the source density is assumed to be constant. The constants for the basis functions can be expressed as follows:

$\alpha_j = 1$ over subarea C_j,

$= 0$ over C_i, where $i \neq j$.

Using this approximation and equations (B4), (B5), (B6), (B12), and (B15) we find that $b_{ii} = 1$. Substituting this into equation (B12), equations (B13) and (B14) can be put in matrix form by letting

$$F_i = \frac{\partial}{\partial \nu}\left(\frac{1}{R_{A_d Q}}\right) + \frac{\partial}{\partial \nu}\left(\frac{1}{R_{\tilde{A}_d Q}}\right), \tag{B16}$$

$$GB_{ij} = -\int_{C'} \alpha_j \frac{\partial}{\partial \nu}\left(\frac{1}{R_{pQ}}\right) dC \;, \quad i \neq j \tag{B17}$$

$$GB_{ii} = \frac{2\pi}{K}\, b_{ii} \;, \tag{B18}$$

$$GI_{ij} = -\int_{\tilde{C}} \alpha_j \frac{\partial}{\partial \nu}\left(\frac{1}{R_{\tilde{p}Q}}\right) d\tilde{C} \;, \tag{B19}$$

$$G_{ij} = GB_{ij} + GI_{ij} \;, \tag{B20}$$

and

$$H_i = \int_{\tilde{C}} \alpha_i \left(\frac{1}{R_{\tilde{p}M_d}}\right) d\tilde{C} + \int_{C} \alpha_i \left(\frac{1}{R_{pM_d}}\right) dC \;, \tag{B21}$$

Using these equations, the matrix form for equations (B13) and (B14) becomes:

$$F_i = \sum_{j=1}^{N} G_{ij} S_j \tag{B22}$$

and

$$U_{M_d} = \frac{\rho_1 I}{4\pi}\left\{\frac{1}{R_{A_d M_d}} + \frac{1}{R_{\tilde{A}_d M_d}} + \sum_{i=1}^{N} S_i H_i\right\} . \tag{B23}$$

In order to calculate the apparent polarizability the equation,

$$\frac{\partial U_{M_d}}{\partial K} = \frac{\rho_1 I}{4\pi} \sum_{i=1}^{N} \frac{\partial S_i}{\partial K} H_i \quad , \tag{B24}$$

needs to be calculated, Defining

$$T_i \triangleq \frac{\partial S_i}{\partial K} \text{ and } D_i \triangleq \frac{GB_{ii}S_i}{K} ,$$

we can write

$$\sum_{j=1}^{N} G_{ij} T_j = D_i \tag{B25}$$

and

$$\frac{\partial U_{M_d}}{\partial K} = \frac{\rho_1 I}{\pi} \sum_{i-1}^{N} T_i H_i \tag{B26}$$

The problem of mathematically modeling the resistivity and IP response at a buried receiver pair (M_d and N_d) due to a buried current source (A_d and B_d) in the presence of a three-dimensional body (C) reduces to the problem of solving equations (B22), (B23), (B25), and (B26) for the proper source-receiver combinations.

Appendix C

Program listing

```
C--IP3DDH-- INDUCED POLARIZATION (3-DIMENSIONAL) -- 7/23/74.
C
C--FILES:
C
C      ------------------------  PROGRAM IP3DDH  ------------------------
C
C
C      THIS PROGRAM COMPUTES DOWNHOLE AND SURFACE PROFILES OF  NORMALIZED
C APPARENT
C      RESISTIVITY (ρa/ρ1) AND NORMALIZED APPARENT POLARIZABILITY
C      (ηa-η1)/(η2-η1) ACROSS AN ARBITRARILY SHAPED THREE-DIMENSIONAL
C      BODY, OF RESISTIVITY ρ2 AND POLARIZABILITY η2, SET IN AN OTHERWISE
C      HOMOGENEOUS HALF-SPACE OF RESISTIVITY ρ1 AND POLARIZABILITY η1.
C      THREE-DIMENSIONAL (POINT-SOURCE) DOWNHOLE ELECTRODES ARE USED.
C
C
C      THE PROGRAM IS WRITTEN IN FORTRAN-IV, AND WAS DEVELOPED ON A
C      DIGITAL EQUIPMENT CORPORATION MODEL PDP-10 COMPUTER.
C
C      AN ELLIPSOID OF REVOLUTION (WITH 72 FACETS) IS GENERATED IN
C      SUBROUTINE BODY3D.  ALL THAT IS NEEDED TO GENERATE THIS BODY
C      ARE THE 'A','B', AND 'C' (X,Y,&Z) HALF WIDTHS OF THE BODY
C      (SEE SUBROUTINE BODY3D)
C
C
C
C
C      RESULTS ARE OUTPUT ON DISK
C      THE FIRST PAGE OF OUTPUT PROVIDES A RECORD OF THE INPUT DATA.
C      SUBSEQUENT PAGES GIVE APPARENT RESISTIVITY AND
C      APPARENT POLARIZABILITY VALUES.
C
C
C      PROGRAM IP3DDH DOES NOT CONTAIN A PROVISION FOR MULTIPLE BODIES
C
C
C
C      ..............................................................
C
C      PARAMETER DESCRIPTION:C
C    XPD AND YVAL ARE THE (X AND Y)RECEIVER POSITIONS
C      XDOWN,YDOWN,ZDOWN(XD,YD,ZD) ARE THE SOURCE CO-ORDINATES
C
C      TL=TOTAL LENGTH OF SURFACE PROFILE (PROFILE STARTS AT -11.
C         BIPOLE UNITS FROM THE BODY CENTER)
C      HD=HOLE DEPTH (IN RECEIVER BIPOLE UNITS)
C      PS= SPACING BETWEEN MEASUREMENT POINTS (MUST BE AN INTEGER
C          DIVISER OF 1,LESS THAN OR EQUAL TO 1)
C      (TL OR HD)/PS MUST BE LESS THAN 50. IF MORE THAN 50
C      DATA POINTS ARE DESIRED, THE DIMENSIONS CAN BE INCREASED
C
C      HSPA=N-SPACING FOR SINGLE HOLE BIPOLE-BIPOLE CONFIGURATION
C      FOR N=1 THE SPACING BETWEEN THE B SOURCE ELECTRODE AND THE M
C      RECEIVER ELECTRODE IS 1, FOR N=2 THE SPACING IS 2, ETC.
C
```

```
C****ARRAY CONFIGURATIONS**********
C   AR=1.,BURIED BIPOLE SOURCE,SURFACE BIPOLE RECEIVER
C   AR=2.,BURIED POLE SOURCE, SURFACE BIPOLE RECEIVER
C   AR=3.,BURIED POLE SOURCE, BURIED BIPOLE RECEIVER
C    AR=4.,SURFACE POLE FIXED SOURCE,BURIED BIPOLE RECEIVER
C   AR=5.,BURIED BIPOLE FIXED SOURCE, BURIED BIPOLE RECEIVER
C   AR=6.,BURIED BIPOLE MOVING SOURCE, BURIED BIPOLE RECEIVER
C   AR=7.,SINGLE HOLE CONFIGURATION
C
C
C      ALL READ STATEMENTS ARE IN THE MAIN PROGRAM AND SUBROUTINE BODY3D
C
C      ..................................................................
C
C      REQUIRED SUBROUTINES:  READ3D, IPAG3D,
C                            DIRC3D, GB3D, GI3D, H3D, F3D,
C                            GAUS10, FX1, FX2,
C                             DECOMP, SOLVE,
C                            NPAG3D, ARAY3D, OUTPUT,BODY3D.
C
C      DEVICE SPECIFICATIONS;
C
C      13  = IN1     INPUT  - CONTROL CARDS WITH PROGRAM PARAMETERS.
C      13  = IN2     INPUT  - DESCRIPTION OF MODEL, FOLLOWED BY COORDINATES
C                            OF THE VERTICES.
C      14 =IOUT1,IOUT2,IOUT3
C
C   NOTE: FOR HOLE-TO-SURFACE,SURFACE-TO-HOLE, AND HOLE-TO-HOLE ARRAYS
C   OUTPUT POINTS ARE AT THE MIDPOINT OF THE RECEIVER ELECTRODES.  FOR
C   SINGLE HOLE ARRAY OUTPUT POINTS ARE AT THE MIDPOINT BETWEEN THE
C   SOURCE AND RECEIVER ELECTRODES((B-M)/2)
C
C
C
C      ---------------C.T.BARNETT-----APRIL 1972--------------
C
C*********MODIFIED FOR BURIED ELECTRODE ARRAYS********
C                 JEFF DANIELS
C                 U.S.GEOLOGICAL SURVEY
C                 MAY 1976
C

      LOGICAL CHECK
      COMMON /BLOK2/ XM(75),YM(75),ZM(75)
      COMMON /BLOK7 / F(75)
      COMMON /BLOK13/ GB(75,75)
      COMMON /BLOK14/ HH(55,75),SS(75),TT(75),S(75),T(75)
      COMMON /BLOK15/ G(75,75)
      COMMON /BLOK17/ H(75)
      COMMON /ISPECS/ IN1,IN2,IOUT1,IOUT2,IOUT3
      COMMON /PARAM / IARRAY(7),ARVAL(7),DEPTH(7),ANGLE(8),YVAL(8),
     &               NARR,NKV,NDPTH,NDIP,NYV,IPLOT
      COMMON /DATIME/ LABEL(16),IDATE(2),ITIME,NPAGES,IPAGE
      COMMON /POLY  / NFACES
      COMMON /RESULT/ APRES(50),APIP(50),AR,PS,IR2,NSPA,ZPI
```

```
      DIMENSION D(75),GBDIAG(75),GIDIAG(75),
     &XDOWN(8),YDOWN(8),ZDOWN(8),H1(75)
      DATA IN1,IN2,IOUT1,IOUT2,IOUT3 /2*13,3*14/
C
      IPLOT=1
C***************
C INPUT THE CONTROL PARAMETERS
C***************
      READ(IN2,11)LABEL
      READ(IN1,10)AR
   14 FORMAT(3I)
      READ(IN1,10) AKVAL(1),DEPTH(1)
      IF(AR.EQ.1.) GO TO 71
      IF(AR.EQ.2.) GO TO 72
      IF(AR.EQ.3.)GO TO 73
      IF(AR.EQ.4.) GO TO 74
      IF(AR.EQ.5.) GO TO 75
      IF(AR.EQ.6.) GO TO 76
      IF(AR.EQ.7.) GO TO 77
   71 READ(IN1,10) YVAL(1),PS,TL
      READ(IN1,10) XDOWN(1),YDOWN(1),ZDOWN(1),ZDOWN(2)
      IDH=0
      GO TO 78
   72 READ(IN1,10) YVAL(1),PS,TL
      READ(IN1,10) XDOWN(1),YDOWN(1),ZDOWN(1)
      IDH=0
      GO TO 78
   73 READ(IN1,10) XPD,YVAL(1),PS,HD
      READ(IN1,10) XDOWN(1),YDOWN(1),ZDOWN(1)
      IDH=1
      GO TO 78
   74 READ(IN1,10) XPD,YVAL(1),PS,HD
      READ(IN1,10)XDOWN(1),YDOWN(1),ZDOWN(1)
      IDH=1
      GO TO 78
   75 READ(IN1,10) XPD,YVAL(1),PS,HD
      READ(IN1,10) XDOWN(1),YDOWN(1),ZDOWN(1),ZDOWN(2)
      IDH=1
      GO TO 78
   76 READ(IN1,10) XPD,YVAL(1),PS,HD
      READ(IN1,10) XDOWN(1),YDOWN(1)
      IDH=1
      GO TO 78
   77 READ(IN1,10) XPD,YVAL(1),PS,HD
      READ(IN1,14)NSPA
      XDOWN(1)=XPD
      YDOWN(1)=YVAL(1)
      IDH=1
   78 CONTINUE
   10 FORMAT(7F)
C
C     ---- INPUT CONTROL PARAMETERS
      NPAGES=1+NARR*NKV*NDPTH*NDIP*NYV
C
C     ---- INPUT DESCRIPTION OF MODEL
   11 FORMAT (16A5)
C
C     ---- INPUT COORDINATES OF APICES OF POLYHEDRON
C     ---- (INCREASE PROGRAM DIMENSION STATEMENTS IF NECESSARY)
      CALL READ3D
```

```
C
C      ---- OBTAIN TIME & DATE, THEN PRINT OUT PAGE 1
C      ---- (RECORD OF INPUT DATA)
       CALL DATE (IDATE)
       CALL TIME (ITIME)
       CALL IPAG3D
C
C      ---- DETERMINE OUTWARD-DIRECTED NORMALS AND
C      ---- TRANSFORM TO UVW-COORDINATES
       CALL DIRC3D
C
C      ---- COMPUTE BODY-BODY INTERACTION TERMS
       CALL GB3D
       DO 80 I=1,NFACES
    80 GBDIAG(I)=GB(I,I)
C
C      ---- ROTATE BODY TO REQUIRED DIP ANGLES
C      ---- RECOMPUTE OUTWARD-DIRECTED NORMALS
       CALL DIRC3D
    90 CONTINUE
C
C      ---- ADJUST BODY TO REQUIRED DEPTHS
       ZO=DEPTH(1)
C
C      ---- COMPUTE BODY-IMAGE INTERACTION TERMS
C      ---- ASSEMBLE OFF-DIAGONAL MATRIX ELEMENTS
       CALL GI3D (ZO)
       DO 100 I=1,NFACES
       GIDIAG(I)=G(I,I)
       DO 100 J=1,NFACES
       IF (J.EQ.I) GO TO 100
       G(I,J)=GB(I,J)+G(I,J)
  2068 FORMAT(2X,'ROW # ',I5)
   100 CONTINUE
C
C      ---- ADJUST Y-COORDINATE FOR REQUIRED PROFILES
       CHECK=.FALSE.
       DO 1000 IY=1,NYV
       YO=YVAL(IY)
       YPD=YO
C
C      ---- COMPUTE RECEIVER FUNCTIONS AT VARIOUS
C      ---- POSITIONS ALONG THE TRAVERSE
C****FOR HOLE TO SURFACE ARRAYS ONLY****
       IF(AR.GE.3.) GO TO 1003
  1002 CONTINUE
       IR1=1
       IR2=IFIX(TL/PS)
       DO 200 IX=IR1,IR2+1
       XP=-11.5+ FLOAT(IX)*PS
       CALL H3D (XP,YO,ZO,IDH)
  6020 FORMAT(2X,I5,3E12.6)
       DO 200 I=1,NFACES
   200 HH(IX,I)=H(I)
C
       GO TO 1001
C***COMPUTE RECEIVER FUNCTIONS AT VARIOUS POINTS (AT PS SPACING)
C      ALONG THE RECEIVER BOREHOLE.(FOR HOLE-TO-HOLE ARRAYS ONLY)
  1003 CONTINUE
       IR1=1
```

```
      IR2=IFIX(HD/PS)
      DO 201 IX=IR1,IR2
      ZP=PS*FLOAT(IX)
      ZPP=ZO+ZP
      CALL H3D(XPD,YPD,ZPP,IDH)
      DO 202 I5=1,NFACES
  202 H1(I5)=H(I5)
      ZPP=ZO-ZP
      CALL H3D(XPD,YPD,ZPP,IDH)
      DO 201 I=1,NFACES
  201 HH(IX,I)=H(I) +H1(I)
 1001 CONTINUE
C     ---- ADJUST TO REQUIRED REFLECTION COEFFICIENTS
      DO 1000 I4=1,NKV
      IF (CHECK.AND.NKV.EQ.1) GO TO 400
      AK=AKVAL(I4)
      BK=0.5*(1.0-AK*AK)
      AKI=1.0/AK
      AKISQ=AKI*AKI
C
C     ---- ASSEMBLE DIAGONAL MATRIX ELEMENTS
      DO 300 I=1,NFACES
  300 G(I,I)=AKI*GBDIAG(I)+GIDIAG(I)
C
C     ---- DECOMPOSE MATRIX INTO UPPER AND LOWER
C     ---- TRIANGULAR FACTORS
      CALL DECOMP
C
      CHECK=.TRUE.
  400 CONTINUE
C
C
C*******************************
C  ADJUST COORDINATES OF DOWNHOLE ELECTRODE
C*******************************
      ISPREV=0
      ZPT=0.0
      XD=XDOWN(1)
      YD=YDOWN(1)
      IF(AR.GE.2..AND.AR.LE.4.) GO TO 82
      IF(AR.EQ.6.) GO TO 83
      IF(AR.EQ.7) GO TO 84
   81 IS2=1
      ZDA=ZDOWN(1)
      ZDB=ZDOWN(2)
      XDDD=XD
      GO TO 88
   82 IS2=1
      ZDA=0.0
      ZDB=ZDOWN(1)
      XDDD=1.E+08
      GO TO 88
   83 IS2=IR2
      ZDA=0.0
      GO TO 88
   84 IS2=IR2-IFIX(1./PS+NSPA/PS)
   88 CONTINUE
      CALL NPAG3D(DIP,ZO,YO,AK,IPLOT,INDEX)
      DO 1000 I6=1,IS2
      IF(AR.GE.2..AND.AR.LE.4.) GO TO 96
```

```
      IF(AR.GE.6.) GO TO 93
   91 IF(ZDA)96,96,966
   93 ZDA=PS*FLOAT(I6)
      ZDB=ZDA+1.0
      GO TO 966
C*************************
C  COMPUTE S AND T FUNCTIONS FOR SURFACE ELECTRODE
  96  CALL F3D(XDDD,YD,ZO,0,ZDA)
      CALL SOLVE(F,S)
      DO 969 I=1,NFACES
  969 D(I)=S(I)*AKISQ*GBDIAG(I)
      CALL SOLVE(D,T)
      DO 962 I=1,NFACES
      SS(I)=S(I)
  962 TT(I)=T(I)
      IF(AP.NE.4) GO TO 963
      ZDB=ZDA
      CALL F3D(XD,YD,ZO,0,ZDB)
      CALL SOLVE (F,S)
      DO 959 I=1,NFACES
  959 D(I)=S(I)*AKISQ*GBDIAG(I)
      CALL SOLVE(D,T)
      GO TO 945
C***************
C  COMPUTE S AND T FUNCTIONS FOR DOWNHOLE ELECTRODES
  966 CALL F3D(XD,YD,ZO,1,ZDA)
      CALL SOLVE(F,S)
      DO 971 I=1,NFACES
  971 D(1)=S(I)*AKISQ*GBDIAG(I)
      CALL SOLVE(D,T)
      DO 967 I=1,NFACES
      SS(I)=S(I)
  967 TT(I)=T(I)
  963 CALL F3D (XD,YD,ZO,1,ZDB)
      CALL SOLVE(F,S)
      DO 964 I=1,NFACES
 5002 FORMAT(3(2X,E12.6))
 5001 FORMAT(10X,I5,2E12.6)
  964 D(I)=S(I)*AKISQ*GBDIAG(I)
      CALL SOLVE(D,T)
  945 CONTINUE
C
C     ---- COMPUTE AND OUTPUT PROFILES FOR THE VARIOUS
C     ---- ARRAYS
      IPAGE=IPAGE+1
  621 FORMAT(4(2X,E12.6))
      I66=I6
      CALL ARAY3D (AK,BK,IDH,XPD,YPD,XD,YD,ZD,ZDA,ZDB,I66)
      ZPT=1.0
 1000 CONTINUE
      CALL OUTPUT (IDH,IPLOT,XPD,YPD,XD,YD,ZD,ZDA,ZDB)
C
      STOP
      END
C
C
C
C
      SUBROUTINE READ3D
C
```

```
C  THIS SUBROUTINE CALLS BODY3D TO CALCULATE THE COORDINATES OF THE
C  APICES OF THE POLYHEDRON REPRESENTING THE ARBITRARILY SHAPED BODY.
C  IT THEN ASSEMBLES THE INDIVIDUAL TRIANGULAR FACETS IN A LOGICAL
C  ORDER,SO THAT THE OUTWARD-DIRECTED NORMALS TO EACH FACE CAN BE
C   DETERMINED (SEE SUBROUTINE DIRC3D).
C
C     THE POLYHEDRON MUST HAVE A TOP AND A BOTTOM APEX. OTHER APICES
C     MUST BE EVENLY DISTRIBUTED AROUND CONTOURS OF CONSTANT Z.
C     EACH CONTOUR MUST HAVE THE SAME NUMBER OF APICES. OFFSET APICES
C     ON ADJACENT CONTOURS TO OBTAIN MORE EQUILATERAL FACETS.
C
C     INPUT . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C           NC       = NUMBER OF CONTOURS.
C           NV       = NUMBER OF APICES PER CONTOUR.
C           ZT,VZ,ZB = Z-COORDINATES OF TOP, SUCCESSIVE CONTOURS, AND
C                      BOTTOM.
C           XT,YT    = XY-COORDINATES OF TOP APEX.
C           VX,VY    = XY-COORDINATES OF CONTOUR APICES. INPUT THESE
C                      CLOCKWISE (PLAN-VIEW) AROUND EACH CONTOUR IN
C                      DESCENDING ORDER, STARTING ONE POINT FURTHER
C                      CLOCKWISE ON SUCCESSIVE CONTOURS.
C           XB,YB    = XY-COORDINATES OF BOTTOM APEX.
C
C     ---------------C.T.BARNETT-----APRIL 1972---------------
C
C******MODIFIED BY JEFF DANIELS :::MAY 1976 ******
C
      COMMON /BLOK1/ XF(75,3),YF(75,3),ZF(75,3)
      COMMON /BLOK8 / VX(12,12),VY(12,12),VZ(12)
      COMMON /BLOK9 / XT,YT,ZT,XB,YB,ZB
      COMMON /BLOK12/ NC,NV
      COMMON /ISPECS/ IN1,IN2,IOUT1,IOUT2,IOUT3
      COMMON /POLY  / NFACES
C
      COMMON/BODY/VXX(100),VYY(100),VZZ(5)
      CALL BODY3D
      NV2=2*NV
      NFACES=NC*NV2
      ZT=VZZ(1)
      DO 1022 I=2,(NC+1)
 1022 VZ(I-1)=VZZ(I)
      ZB=VZZ(NC+2)
      IST=1
      XT=VXX(1)
      YT=VYY(1)
      DO 100 I=1,NC
      DO 100 J=1,NV
      IST=IST+1
      VX(I,J)=VXX(IST)
  100 VY(I,J)=VYY(IST)
      IST=IST+1
      XB=VXX(IST)
      YB=VYY(IST)
C
      KT1=NFACES-NV
      DO 101 J=1,NV
      KT1=KT1+1
      J1=J+1
      IF (J1.GT.NV) J1=1
      XF(J,1)=VX(1,J)
```

```
      YF(J,1)=VY(1,J)
      ZF(J,1)=VZ(1)
      XF(J,2)=VX(1,J1)
      YF(J,2)=VY(1,J1)
      ZF(J,2)=VZ(1)
      XF(J,3)=XT
      YF(J,3)=YT
      ZF(J,3)=ZT
      XF(KT1,1)=VX(NC,J)
      YF(KT1,1)=VY(NC,J)
      ZF(KT1,1)=VZ(NC)
      XF(KT1,2)=XB
      YF(KT1,2)=YB
      ZF(KT1,2)=ZB
      XF(KT1,3)=VX(NC,J1)
      YF(KT1,3)=VY(NC,J1)
  101 ZF(KT1,3)=VZ(NC)
C
      IF (NC.EQ.1) RETURN
      ND=NC-1
C
      DO 102 I=1,ND
      I1=I+1
      KT2=I*NV2
      KT1=KT2-NV
      DO 102 J=1,NV
      J1=J+1
      IF (J1.GT.NV) J1=1
      KT1=KT1+1
      XF(KT1,1)=VX(I,J)
      YF(KT1,1)=VY(I,J)
      ZF(KT1,1)=VZ(I)
      XF(KT1,2)=VX(I1,J)
      YF(KT1,2)=VY(I1,J)
      ZF(KT1,2)=VZ(I1)
      XF(KT1,3)=VX(I,J1)
      YF(KT1,3)=VY(I,J1)
      ZF(KT1,3)=VZ(I)
C
      KT2=KT2+1
      XF(KT2,1)=VX(I,J1)
      YF(KT2,1)=VY(I,J1)
      ZF(KT2,1)=VZ(I)
      XF(KT2,2)=VX(I1,J)
      YF(KT2,2)=VY(I1,J)
      ZF(KT2,2)=VZ(I1)
      XF(KT2,3)=VX(I1,J1)
      YF(KT2,3)=VY(I1,J1)
  102 ZF(KT2,3)=VZ(I1)
C
      RETURN
      END
C
C
C
C
      SUBROUTINE IPAG3D
C
C     THIS SUBROUTINE PRINTS OUT PAGE 1 OF THE OUTPUT FOR EACH MODEL.
C     THIS GIVES THE DATE AND TIME OF EXECUTION, THE INPUT CONTROL
```

```
C     PARAMETERS, AND A DESCRIPTION OF THE BODY FOLLOWED BY A PRINT-OUT
C     OF THE BODY COORDINATES.
C
C
C     ---------------C.T.BARNETT-----APRIL 1972---------------
C
      COMMON /BLOK8 / VX(12,12),VY(12,12),VZ(12)
      COMMON /BLOK9 / XT,YT,ZT,XB,YB,ZB
      COMMON /BLOK12/ NC,NV
      COMMON /DATIME/ LABEL(16),IDATE(2),ITIME,NPAGES,IPAGE
      COMMON /ISPECS/ IN1,IN2,IOUT1,IOUT2,IOUT3
      COMMON /PARAM / IARRAY(7),AKVAL(7),DEPTH(7),ANGLE(8),YVAL(8),
     &                NARR,NKV,NDPTH,NDIP,NYV,IPLOT
      COMMON /POLY  / NFACES
C
      WRITE (IOUT2,12) IDATE,ITIME
      WRITE (IOUT2,13)
      WRITE (IOUT2,15) (AKVAL(I),I=1,NKV)
      WRITE (IOUT2,16) (DEPTH(I),I=1,NDPTH)
      WRITE (IOUT2,20)
      WRITE (IOUT2,21) LABEL
      WRITE (IOUT2,22)
      WRITE (IOUT2,23) ZT,XT,YT
      DO 100 I=1,NC
      WRITE (IOUT2,24) (I,VZ(I),(VX(I,J),VY(I,J),J=1,2))
      WRITE(IOUT2,25)(VX(I,J),VY(I,J),J=3,4)
      WRITE(IOUT2,32)(VX(I,J),VY(I,J),J=5,7)
      WRITE(IOUT2,32)(VX(I,J),VY(I,J),J=8,10)
  100 WRITE(IOUT2,32)(VX(I,J),VY(I,J),J=11,12)
      WRITE (IOUT2,26) ZB,XB,YB
      IF (IPLOT.EQ.1) RETURN
      WRITE (IOUT3,27) IDATE,ITIME
      WRITE (IOUT3,28) NPAGES,NFACES
      WRITE (IOUT3,29) LABEL
      WRITE (IOUT3,30) NC,NV
      WRITE (IOUT3,31) ZT,(VZ(I),I=1,NC),ZB
      WRITE (IOUT3,31) XT,YT
      DO 200 I=1,NC
  200 WRITE (IOUT3,31) (VX(I,J),VY(I,J),J=1,NV)
      WRITE (IOUT3,31) XB,YB
C
   12 FORMAT (1H1,//,5X,'3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROG
     &RAM',//5X,'DATE:   '2A5,10X,'TIME:   ',A5,10X,'PAGE:  ',I3,'  OF',I4)
   13 FORMAT (//,5X,'INPUT CONTROL PARAMETERS:',/)
   15 FORMAT (5X,'KVALU' ,8X,7(F8.5,2X))
   16 FORMAT (5X,'DEPTH' ,5X,7(F8.2,2X))
   20 FORMAT (5X,'EXECU' )
   21 FORMAT (///,5X,'DESCRIPTION OF MODEL:',4X,4A5,/30X,4A5,/30X,4A5,
     &/30X,4A5)
   22 FORMAT (//,20X,'Z-COORDINATE',5X,'(X,Y)-COORDINATES IN PAIRS   --
     &----------'//)
   23 FORMAT (5X,'TOP',13X,F10.7,6X,F10.7,1X,F10.7)
   24 FORMAT (5X,'CONTOUR',I2,7X,F10.7,4X,2(2X,F10.7,1X,F10.7))
   25 FORMAT (35X,2(2X,F10.7,1X,F10.7))
   26 FORMAT (5X,'BOTTOM',10X,F10.7,7X,F10.7,1X,F10.7)
   27 FORMAT (3A5)
   28 FORMAT (5X,2I5)
   29 FORMAT (16A5)
   30 FORMAT (2I10)
   31 FORMAT (8F10.7)
```

```
   32 FORMAT(2X,3(2X,F10.7,1X,F10.7))
C
      RETURN
      END
C
C
C
C
      SUBROUTINE DIRC3D
C
C     GIVEN THE COORDINATES (X,Y,Z) OF THE THREE VERTICES OF EACH
C     TRIANGULAR FACE IN TURN, DIRC3D FINDS THE DIRECTION COSINES
C     OF THE FOLLOWING ORTHOGONAL UNIT VECTORS;
C     1). - OUTWARD-DIRECTED NORMAL TO THE FACE        (DNX,DNY,DNZ)
C     2). - VECTOR JOINING VERTEX 1 TO VERTEX 3        (DLX,DLY,DLZ)
C     3). - VECTOR MAKING UP A RIGHT-HANDED TRIAD WITH DN AND DL.
C                                                      (DMX,DMY,DMZ)
C
C     DIRC3D THEN COMPUTES THE COORDINATES (U,V,W) OF THE THREE VERTICES
C     AFTER TRANSFORMATION TO A SYSTEM WITH AXES DEFINED BY THESE THREE
C     SETS OF DIRECTION COSINES. NOTE THAT V3=V1 AND W3=W2=W1.
C
C     DIRC3D ALSO COMPUTES THE XYZ COORDINATES OF THE CENTRE OF GRAVITY
C     (XM,YM,ZM) OF EACH TRIANGULAR FACE.
C
C     NFACES = NO. OF FACES
C
C     ----------------C.T.BARNETT------APRIL 1972---------------
C
      COMMON /BLOK1 / XF(75,3),YF(75,3),ZF(75,3)
      COMMON /BLOK2 / XM(75),YM(75),ZM(75)
      COMMON /BLOK3 / DLX(75),DLY(75),DLZ(75),DMX(75)
     &,DMY(75),DMZ(75)
      COMMON /BLOK4 / DNX(75),DNY(75),DNZ(75)
      COMMON /BLOK5 / U1(75),U2(75),U3(75),V1(75),V2(75),W1(75)
      COMMON /POLY  / NFACES
C
      I=1
  200 CONTINUE
      X1=XF(I,1)
      X2=XF(I,2)
      X3=XF(I,3)
      Y1=YF(I,1)
      Y2=YF(I,2)
      Y3=YF(I,3)
      Z1=ZF(I,1)
      Z2=ZF(I,2)
      Z3=ZF(I,3)
C
      UX=X3-X1
      UY=Y3-Y1
      UZ=Z3-Z1
      HX=X2-X1
      HY=Y2-Y1
      HZ=Z2-Z1
      WX=UY*HZ-HY*UZ
      WY=UZ*HX-HZ*UX
      WZ=UX*HY-HX*UY
C
      WW=1.0/SQRT(WX*WX+WY*WY+WZ*WZ)
```

```
      UU=1.0/SQRT(UX*UX+UY*UY+UZ*UZ)
C
      DNXI=WX*WW
      DNYI=WY*WW
      DNZI=WZ*WW
      DLXI=UX*UU
      DLYI=UY*UU
      DLZI=UZ*UU
      DMXI=DNYI*DLZI-DLYI*DNZI
      DMYI=DNZI*DLXI-DLZI*DNXI
      DMZI=DNXI*DLYI-DLXI*DNYI
C
      DLX(I)=DLXI
      DLY(I)=DLYI
      DLZ(I)=DLZI
      DMX(I)=DMXI
      DMY(I)=DMYI
      DMZ(I)=DMZI
      DNX(I)=DNXI
      DNY(I)=DNYI
      DNZ(I)=DNZI
C
      U1(I)=DLXI*X1+DLYI*Y1+DLZI*Z1
      U2(I)=DLXI*X2+DLYI*Y2+DLZI*Z2
      U3(I)=DLXI*X3+DLYI*Y3+DLZI*Z3
      V1(I)=DMXI*X1+DMYI*Y1+DMZI*Z1
      V2(I)=DMXI*X2+DMYI*Y2+DMZI*Z2
      W1(I)=DNXI*X1+DNYI*Y1+DNZI*Z1
C
      XM(I)=(X1+X2+X3)*0.33333333
      YM(I)=(Y1+Y2+Y3)*0.33333333
      ZM(I)=(Z1+Z2+Z3)*0.33333333
C
  100 I=I+1
      IF (I.LE.NFACES) GO TO 200
C
      RETURN
      END
C
C
C
C
C
      SUBROUTINE GB3D
C
C     GB3D COMPUTES THE INTERACTION TERMS BETWEEN RESPECTIVE FACES
C     OF THE BODY. THESE DEPEND PURELY ON THE BODY GEOMETRY AND ARE
C     INDEPENDENT OF THE BODY'S POSITION W.R.T. THE SURFACE OR THE
C     SOURCE.
C
C     PULSE-TYPE BASIS FUNCTIONS ARE USED.
C
C     AN APPROXIMATE VALUE IS FIRST CALCULATED (GBAPR). IF THE ABSOLUTE
C     VALUE OF THIS IS GREATER THAN 0.001, THEN THE EXACT VALUE IS
C     CALCULATED USING A 10-POINT GAUSS-LEGENDRE INTEGRATION FORMULA.
C
C     SUBROUTINE GAUS10 AND EXTERNAL FUNCTION FX1 ARE REQUIRED.
C
C     NFACES = NO. OF FACES
C
```

```
C     ---------------C.T.BARNETT-----APRIL 1972---------------
C
      COMMON /BLOK2 / XM(75),YM(75),ZM(75)
      COMMON /BLOK3 / DLX(75),DLY(75),DLZ(75),DMX(75),
     &DMY(75),DMZ(75)
      COMMON /BLOK4 / DNX(75),DNY(75),DNZ(75)
      COMMON /BLOK5 / U1(75),U2(75),U3(75),V1(75),V2(75),W1(75)
      COMMON /BLOK13/ GH(75,75)
      COMMON /BFX1  / PB,QB,RBR1,R1SQ,G1,G2,H1,H2
      COMMON /POLY  / NFACES
      EXTERNAL FX1
      DATA TWOPI /6.2831925/
C
      J=1
  500 CONTINUE
      DLXJ=DLX(J)
      DLYJ=DLY(J)
      DLZJ=DLZ(J)
      DMXJ=DMX(J)
      DMYJ=DMY(J)
      DMZJ=DMZ(J)
      DNXJ=DNX(J)
      DNYJ=DNY(J)
      DNZJ=DNZ(J)
      U1J=U1(J)
      U2J=U2(J)
      U3J=U3(J)
      V1J=V1(J)
      V2J=V2(J)
      W1J=W1(J)
C
      I=1
  400 CONTINUE
      IF (I.EQ.J) GO TO 250
      CGXI=XM(I)
      CGYI=YM(I)
      CGZI=ZM(I)
      DNXI= DNX(I)
      DNYI= DNY(I)
      DNZI= DNZ(I)
C
      PB=DNXI*DLXJ+DNYI*DLYJ+DNZI*DLZJ
      QB=DNXI*DMXJ+DNYI*DMYJ+DNZI*DMZJ
      RB=DNXI*DNXJ+DNYI*DNYJ+DNZI*DNZJ
      U =CGXI*DLXJ+CGYI*DLYJ+CGZI*DLZJ
      V =CGXI*DMXJ+CGYI*DMYJ+CGZI*DMZJ
      W =CGXI*DNXJ+CGYI*DNYJ+CGZI*DNZJ
C
      P1=U1J-U
      P2=U2J-U
      P3=U3J-U
      Q1=V1J-V
      Q2=V2J-V
      R1=W1J-W
C
      RBR1=RB*R1
      R1SQ=R1*R1
      PM=(P1+P2+P3)*0.33333333
      QM=(Q1+Q2+Q1)*0.33333333
      AREA=0.5*ABS((P3-P1)*(Q2-Q1))
```

```
      GBAPR=-AREA*(PB*PN+GB*QM+RBR1)/((PM*PM+QM*QM+R1SQ)**1.5)
      IF (ABS(GBAPR).GT.0.1E-02) GO TO 300
      GB(I,J)=GBAPR
      GO TO 200
C
  300 CONTINUE
      QQ1=1.0/(Q2-Q1)
      QQ2=Q1*P2
      G1=(P2-P1)*QQ1
      G2=(P2-P3)*QQ1
      H1=(P1*Q2-QQ2)*QQ1
      H2=(P3*Q2-QQ2)*QQ1
C
      CALL GAUS10 (FX1,Q2,Q1,GB(I,J))
      GO TO 200
C
  250 GB(I,I)=TWOPI
C
  200 I=I+1
      IF (I.LE.NFACES) GO TO 400
  100 J=J+1
      IF (J.LE.NFACES) GO TO 500
      RETURN
      END
C
C
C
C
      SUBROUTINE GI3D (DEPTH)
C
C     GI3D COMPUTES THE INTERACTION TERMS BETWEEN FACES OF THE BODY
C     AND FACES OF ITS IMAGE. THESE DEPEND ON THE BODY GEOMETRY AND ON
C     THE BODY'S ATTITUDE AND POSITION W.R.T. THE SURFACE. THEY ARE
C     INDEPENDENT OF THE SOURCE POSITION.
C
C     PULSE-TYPE BASIS FUNCTIONS ARE USED.
C
C     AN APPROXIMATE VALUE (GIAPR) IS FIRST CALCULATED. IF THE ABSOLUTE
C     VALUE OF THIS IS GREATER THAN 0.001, THEN THE EXACT VALUE IS
C     CALCULATED USING A 10-POINT GAUSS-LEGENDRE INTEGRATION FORMULA.
C
C     SUBROUTINE GAUS10 AND EXTERNAL FUNCTION FX1 ARE REQUIRED.
C
C     NFACES = NO. OF FACES
C     DEPTH = DEPTH TO CENTRE OF BODY COORDINATE SYSTEM.
C
C     ---------------C.T.BARNETT-----APRIL 1972---------------
C
      COMMON /BLOK2 / XM(75),YM(75),ZM(75)
      COMMON /BLOK3 / DLX(75),DLY(75),DLZ(75),DMX(75),
     &DMY(75),DMZ(75)
      COMMON /BLOK4 / DNX(75),DNY(75),DNZ(75)
      COMMON /BLOK5 / U1(75),U2(75),U3(75),V1(75),V2(75),W1(75)
      COMMON /BLOK15/ GI(75,75)
      COMMON /BFX1  / PB,QB,RBR1,R1SQ,G1,G2,H1,H2
      COMMON /POLY  / NFACES
      EXTERNAL FX1
C
      D2=2.0*DEPTH
      J=1
```

```
  500 CONTINUE
      DLXJ= DLX(J)
      DLYJ= DLY(J)
      DLZJ=-DLZ(J)
      DMXJ= DMX(J)
      DMYJ= DMY(J)
      DMZJ=-DMZ(J)
      DNXJ= DNX(J)
      DNYJ= DNY(J)
      DNZJ=-DNZ(J)
      U1J=U1(J)
      U2J=U2(J)
      U3J=U3(J)
      V1J=V1(J)
      V2J=V2(J)
      W1J=W1(J)
C
      I=1
  400 CONTINUE
      CGXI=XM(I)
      CGYI=YM(I)
      CGZI=ZM(I)+D2
      DNXI= DNX(I)
      DNYI= DNY(I)
      DNZI= DNZ(I)
C
      PB=DNXI*DLXJ+DNYI*DLYJ+DNZI*DLZJ
      QB=DNXI*DMXJ+DNYI*DMYJ+DNZI*DMZJ
      RB=DNXI*DNXJ+DNYI*DNYJ+DNZI*DNZJ
      U =CGXI*DLXJ+CGYI*DLYJ+CGZI*DLZJ
      V =CGXI*DMXJ+CGYI*DMYJ+CGZI*DMZJ
      W =CGXI*DNXJ+CGYI*DNYJ+CGZI*DNZJ
C
      P1=U1J-U
      P2=U2J-U
      P3=U3J-U
      Q1=V1J-V
      Q2=V2J-V
      R1=W1J-W
C
      RBR1=RB*R1
      R1SQ=R1*R1
      PM=(P1+P2+P3)*0.33333333
      QM=(Q1+Q2+Q1)*0.33333333
      AREA=0.5*ABS((P3-P1)*(Q2-Q1))
      GIAPR=-AREA*(PB*PM+QB*QM+RBR1)/((PM*PM+QM*QM+R1SQ)**1.5)
      IF (ABS(GIAPR).GT.0.1E-02) GO TO 300
      GI(I,J)=GIAPR
      GO TO 200
C
  300 CONTINUE
      QQ1=1.0/(Q2-Q1)
      QQ2=Q1*P2
      G1=(P2-P1)*QQ1
      G2=(P2-P3)*QQ1
      H1=(P1*Q2-QQ2)*QQ1
      H2=(P3*Q2-QQ2)*QQ1
C
      CALL GAUS10 (FX1,Q2,Q1,GI(I,J))
C
```

```
  200 I=I+1
      IF (I.LE.NFACES) GO TO 400
  100 J=J+1
      IF (J.LE.NFACES) GO TO 500
      RETURN
      END
C
C
C
C
      SUBROUTINE H3D (XO,YO,ZO,IDH)
C
C     H3D COMPUTES THE H ELEMENT FOR EACH FACE OF THE POLYHEDRON
C     FOR A PARTICULAR RECEIVER POSITION (POTENTIAL ELECTRODE).
C
C     PULSE-TYPE BASIS FUNCTIONS ARE USED.
C
C     AN APPROXIMATE VALUE IS FIRST CALCULATED (HAPR). IF THE ABSOLUTE
C     VALUE OF THIS IS GREATER THAN 0.02, THEN THE EXACT VALUE IS
C     CALCULATED USING A 10-POINT GAUSS-LEGENDRE INTEGRATION FORMULA.
C
C     SUBROUTINE GAUS10 AND EXTERNAL FUNCTION FX2 ARE REQUIRED.
C     NFACES = NO. OF FACES
C     (-XO,-YO,-ZO) ARE THE COORDINATES OF THE POTENTIAL ELECTRODE
C     W.R.T. THE CENTRE OF BODY COORDINATE SYSTEM.
C
C     ---------------C.T.BARNETT-----APRIL 1972---------------
C
C***MODIFIED BY JEFF DANIELS::1976************
      COMMON /BLOK3 / DLX(75),DLY(75),DLZ(75),DMX(75),
     &DMY(75),DMZ(75)
      COMMON /BLOK4 / DNX(75),DNY(75),DNZ(75)
      COMMON /BLOK5 / U1(75),U2(75),U3(75),V1(75),V2(75),W1(75)
      COMMON /BLOK17/ H(75)
      COMMON /BFX2  / R1SQ,G1,G2,H11,H2
      COMMON /POLY  / NFACES
       EXTERNAL FX2
  400 CONTINUE
C
      X0=XO
      Y0=YO
      Z0=-ZO
      I=1
  300 CONTINUE
      U =X0*DLX(I)+Y0*DLY(I)+Z0*DLZ(I)
      V =X0*DMX(I)+Y0*DMY(I)+Z0*DMZ(I)
      W =X0*DNX(I)+Y0*DNY(I)+Z0*DNZ(I)
      P1=U1(I)-U
      P2=U2(I)-U
      P3=U3(I)-U
      Q1=V1(I)-V
      Q2=V2(I)-V
      R1=W1(I)-W
C
      R1SQ=R1*R1
      PM=(P1+P2+P3)*0.33333333
      QM=(Q1+Q2+Q1)*0.33333333
      AREA=0.5*ABS((P3-P1)*(Q2-Q1))
      HAPR=AREA/SQRT(PM*PM+QM*QM+R1SQ)
      IF (ABS(HAPR).GT.0.2E-01) GO TO 200
```

```
      H(I)=HAPR
      GO TO 100
C
  200 CONTINUE
      QQ1=1.0/(Q2-Q1)
      QQ2=Q1*P2
      G1=(P2-P1)*QQ1
      G2=(P2-P3)*QQ1
      H11=(P1*Q2-QQ2)*QQ1
      H2=(P3*Q2-QQ2)*QQ1
C
      CALL GAUS10 (FX2,Q1,Q2,H(I))
C
  100 I=I+1
      IF (I.LE.NFACES) GO TO 300
      RETURN
      END
C
C
C
C
      SUBROUTINE F3D (XO,YO,ZO,IDFL,ZD)
C
C     F3D COMPUTES THE F ELEMENT (SOURCE FUNCTION) FOR EACH FACE OF
C     THE POLYHEDRON FOR A PARTICULAR SOURCE POSITION (CURRENT
C     ELECTRODE) ON THE SURFACE.
C
C     NFACES = NO. OF FACES
C     (-XO,-YO,-ZO) ARE THE COORDINATES OF THE CURRENT ELECTRODE
C     W.R.T. THE CENTRE OF BODY COORDINATE SYSTEM.
C
C     ----------------C.T.BARNETT-----APRIL 1972---------------
C***MODIFIED BY JEFF DANIELS::1976*******
C
      COMMON /BLOK2 / XM(75),YM(75),ZM(75)
      COMMON /BLOK4 / DNX(75),DNY(75),DNZ(75)
      COMMON /BLOK7 / F(75)
      COMMON /POLY  / NFACES
      DIMENSION F1(75)
C
      XO=-XO
      YO=-YO
      ZO=ZO
      II=1
      DI=2.0
      IF(IDFL.EQ.1) DI=1.0
  400 I=1
  200 CONTINUE
      XI=XM(I)+XO
      YI=YM(I)+YO
      ZI=ZM(I)+ZO
      IF(IDFL.EQ.1.AND.II.EQ.1) ZI=ZI-ZD
      IF(IDFL.EQ.1.AND.II.NE.1)ZI=ZI+ZD
      F(I)=-DI*(XI*DNX(I)+YI*DNY(I)+ZI*DNZ(I))
     &          /((XI*XI+YI*YI+ZI*ZI)**1.5)
C
  100 I=I+1
      IF(I.LE.NFACES) GO TO 200
      IF(IDFL.EQ.0) GO TO 700
      IF(II.EQ.0) GO TO 500
```

```
      DO 800 IZ=1,NFACES
  800 F1(IZ)=F(IZ)
      II=0
      GO TO 400
  500 DO 600 IZ=1,NFACES
 1002 FORMAT(5X,I5,2(2X,E12.6))
  600 F(IZ)=(F(IZ)+F1(IZ))
  700 CONTINUE
      RETURN
      END
C
C
C
C
      SUBROUTINE GAUS10 (FUNCT,A,B,Y)
C
C     THIS SUBROUTINE USES A 10-POINT GAUSS-LEGENDRE INTEGRATION
C     FORMULA TO COMPUTE  Y = INTEGRAL (FUNCT(X).DX)
C
C     REFERENCES: THEORY AND PROBLEMS OF NUMERICAL ANALYSIS - F. SCHEID
C                 SCHAUM'S OUTLINE SERIES.  PP. 134-137.
C
C                 HANDBOOK OF MATHEMATICAL CONSTANTS - ABRAMOWITZ AND
C                 STEGUN - P.887, #25.4.30, AND P.916, TABLE 25.4
C
C
C     SUBROUTINE PARAMETERS:
C     FUNC    = FUNCTION (EXTERNAL) TO BE INTEGRATED
C     A       = LOWER LIMIT OF INTEGRATION
C     B       = UPPER LIMIT OF INTEGRATION
C     Y       = SOLUTION RETURNED
C
C     ---------------C.T.BARNETT-----APRIL 1972---------------
C
      DIMENSION ZERO(5),COEFF(5)
      DATA  ZERO /.14887434,.43339539,.67940957,.86506337,.97390653/
     &,    COEFF /.29552422,.26926672,.21908636,.14945135,.06667134/
C
      Y=0.0
      C1=(B-A)*0.5
      C2=(A+B)*0.5
C
      DO 100 I=1,5
      C3=C1*ZERO(I)
      Y=Y+C1*COEFF(I)*(FUNCT(C2+C3)+FUNCT(C2-C3))
  100 CONTINUE
C
      RETURN
      END
      FUNCTION FX1(Q)
C
C     FX1 IS THE FUNCTION EXTERNAL TO BOTH GB3D AND GI3D, WHICH IS
C     CALLED BY SUBROUTINE GAUS10 TO COMPUTE THE EXACT VALUE OF THE
C     BODY-BODY OR BODY-IMAGE INTERACTION TERMS.
C
C     ---------------C.T.BARNETT-----APRIL 1972---------------
C
      COMMON /BFX1  / PB,QB,RBR1,R1SQ,G1,G2,H1,H2
C
      FAC1=QB*Q+RBR1
```

```
      FAC2=G2*Q+H2
      FAC3=G1*Q+H1
      FAC4=G*Q+R1SQ
      FAC5=PB*FAC4
C
      FX1=(FAC1*FAC2-FAC5)/(FAC4*SQRT(FAC2*FAC2+FAC4))
     1   -(FAC1*FAC3-FAC5)/(FAC4*SQRT(FAC3*FAC3+FAC4))
C
      RETURN
      END
      FUNCTION FX2 (Q)
C
C     FX2 IS THE FUNCTION EXTERNAL TO H3D, WHICH IS CALLED BY SUBROUTINE
C     GAUS10 TO COMPUTE THE EXACT VALUE OF THE H ELEMENT.
C
C     ---------------C.T.BARNETT-----APRIL 1972---------------
C
      COMMON /BFX2  / R1SQ,G1,G2,H1,H2
C
      FAC2=G2*Q+H2
      FAC3=G1*Q+H1
      FAC4=G*Q+R1SQ
C
      FX2=ALOG((FAC2+SQRT(FAC2*FAC2+FAC4))/(FAC3+SQRT(FAC3*FAC3+FAC4)))
C
      RETURN
      END
C
C
C
C
C
C
C
C
C
C
      SUBROUTINE DECOMP
C
C     THIS SUBROUTINE USES GAUSSIAN ELIMINATION WITH PARTIAL PIVOTING
C     TO DECOMPOSE A SQUARE MATRIX INTO UPPER AND LOWER TRIANGULAR
C     FACTORS, AS A FIRST STEP TO SOLVING A SYSTEM OF LINEAR EQUATIONS.
C
C     REFERENCE -  FORSYTHE,G., AND MOLER,C.B., 1967, COMPUTER SOLUTION
C                  OF LINEAR ALGEBRAIC SYSTEMS; PRENTICE-HALL, P. 68-70.
C
C     A  = THE MATRIX TO BE DECOMPOSED (NOTE: IN COMMON HERE).
C     N  = NO. OF ROWS IN THE MATRIX (ALSO IN COMMON HERE).
C
C     IF A SINGULAR MATRIX IS ENCOUNTERED, ERROR MESSAGES ARE PRINTED
C     OUT, AND THE PROGRAM IS EXITED.
C     DEVICE SPECIFICATIONS -:  OUTPUT (ERROR MESSAGES) -  IOUT1
C
C     ---------------C.T.BARNETT-----APRIL 1972---------------
C
      COMMON /BLOK15/ A(75,75)
      COMMON /DECSOL/ IPS(75),UL(75,75)
      COMMON /ISPECS/ IN1,IN2,IOUT1,IOUT2,IOUT3
      COMMON /POLY  / N
      DIMENSION SCALES(75)
```

```
C
C     INITIALIZE UL,IPS AND SCALES
      DO 102 I=1,N
      IPS(I)=I
      ROWNRM=0.0
      DO 101 J=1,N
      UL(I,J)=A(I,J)
      TEST=ABS(UL(I,J))
      IF (TEST.GT.ROWNRM) ROWNRM=TEST
  101 CONTINUE
C
C     BOX 1  --  CHECK FOR SINGULARITY  . . . . . . . . . . . . . . . .

      IF (ROWNRM.LT.0.1E-30) GO TO 301
C
      SCALES(I)=1.0/ROWNRM
  102 CONTINUE
C
C     GAUSSIAN ELIMINATION WITH PARTIAL PIVOTING
      NM1=N-1
      DO 106 K=1,NM1
      BIG=0.0
      DO 103 I=K,N
      IP=IPS(I)
      SIZE=ABS(UL(IP,K))*SCALES(IP)
      IF (SIZE.LE.BIG) GO TO 103
      BIG=SIZE
      IDXPIV=I
  103 CONTINUE
C
C     BOX 2  --  CHECK FOR SINGULARITY  . . . . . . . . . . . . . . . .

      IF (BIG.LT.0.1E-30) GO TO 302
C
      IF (IDXPIV.EQ.K) GO TO 104
      J=IPS(K)
      IPS(K)=IPS(IDXPIV)
      IPS(IDXPIV)=J
  104 KP=IPS(K)
      APIVOT=1.0/UL(KP,K)
      KP1=K+1
      DO 105 I=KP1,N
      IP=IPS(I)
      EM=-UL(IP,K)*APIVOT
      UL(IP,K)=-EM
      DO 105 J=KP1,N
      UL(IP,J)=UL(IP,J)+EM*UL(KP,J)
  105 CONTINUE
  106 CONTINUE
C
C     BOX 3  --  CHECK FOR SINGULARITY  . . . . . . . . . . . . . . . .

      KP=IPS(N)
      IF (ABS(UL(KP,N)).LT.0.1E-30) GO TO 303
C
      RETURN
C
C     OR, PRINT ERROR MESSAGES AND EXIT
  301 IBOX=1
      GO TO 304
```

```
  302 IBOX=2
      GO TO 304
  303 IBOX=3
  304 WRITE (IOUT1,12) IBOX
   12 FORMAT (1H1,//,5X,'SINGULAR MATRIX DETECTED IN SUBROUTINE DECOMP A
     &T BOX',I2,//,5X,'PROGRAM DISCONTINUED.')
      CALL EXIT
      END
C
C
C
C
C
      SUBROUTINE SOLVE (B,X)
C
C     THIS SUBROUTINE SOLVES A SET OF LINEAR SIMULTANEOUS EQUATIONS
C     AFTER THEIR MATRIX HAS BEEN DECOMPOSED INTO UPPER AND LOWER
C     TRIANGULAR FACTORS (SEE SUBROUTINE DECOMP).
C
C     REFERENCE -  FORSYTHE,G., AND MOLER,C.B., 1967, COMPUTER SOLUTION
C                  OF LINEAR ALGEBRAIC SYSTEMS; PRENTICE-HALL, P. 68-70.
C
C     N   = NO. OF ROWS IN THE MATRIX
C     B   = THE CONSTANT VECTOR
C     X   = THE SOLUTION VECTOR
C
C     ---------------C.T.BARNETT-----APRIL 1972--------------
C
      COMMON /DECSOL/ IPS(75),UL(75,75)
      COMMON /POLY  / N
      DIMENSION B(75),X(75)
C
      NP1=N+1
C
      IP=IPS(1)
      X(1)=B(IP)
      DO 2 I=2,N
      IP=IPS(I)
      IM1=I-1
      SUM=0.0
      DO 1 J=1,IM1
    1 SUM=SUM+UL(IP,J)*X(J)
    2 X(I)=B(IP)-SUM
C
      IP=IPS(N)
      X(N)=X(N)/UL(IP,N)
      DO 4 IBACK=2,N
      I=NP1-IBACK
      IP=IPS(I)
      IP1=I+1
      SUM=0.0
      DO 3 J=IP1,N
    3 SUM=SUM+UL(IP,J)*X(J)
    4 X(I)=(X(I)-SUM)/UL(IP,I)
C
      RETURN
      END
C
C
C
```

```
C
      SUBROUTINE NPAG3D (DIP,ZO,YO,AK,IPLOT,INDEX)
C
C     THIS SUBROUTINE PRINTS OUT THE HEADING INFORMATION ON PAGES
C     SUBSEQUENT TO PAGE 1 (SEE SUBROUTINE IPAG3D FOR PAGE 1 DETAILS).
C
C     DIP    = DIP ANGLE TO WHICH BODY HAS BEEN ROTATED.
C     ZO     = DEPTH TO ORIGIN OF BODY COORDINATE SYSTEM.
C     YO     = Y-COORDINATE OF PROFILE ACROSS BODY.
C     AK     = THE REFLECTION COEFFICIENT.
C
C     ---------------C.T.BARNETT-----APRIL 1972---------------
C
      COMMON /ISPECS/ IN1,IN2,IOUT1,IOUT2,IOUT3
      COMMON /DATIME/ LABEL(16),IDATE(2),ITIME,NPAGES,IPAGE
C
      WRITE (IOUT2,11) IDATE,ITIME
   11 FORMAT (1H1,//,5X,'3-DIMENSIONAL IP AND RESISTIVITY MODELLING PROG
     &RAM',//5X,'DATE:   '2A5,10X,'TIME:   ',A5)
      WRITE (IOUT2,12) LABEL
   12 FORMAT (///,5X,'DESCRIPTION OF MODEL:',4X,4A5,/30X,4A5,/30X,4A5,
     &/30X,4A5)
      WRITE (IOUT2,13) AK,ZO
   13 FORMAT (//,5X,'REFLECTION COEFF. K =',F8.5,/5X,'DEPTH =',F8.2,
     &//)
C
C
      RETURN
      END
C
C
C
C

C
C
C
      SUBROUTINE ARAY3D (AK,BK,IDH,XPD,YPD,XD,YD,ZD,ZDA,ZDB,I6)
C
C     THIS SUBROUTINE COMPUTES THE RESPONSE TO THE VARIOUS 4-ELECTRODE

C     ARRAYS.
C
C     NFACES = NO. OF FACES TO THE POLYHEDRON
C     BK       = FUNCTION OF THE REFLECTION COEFFICIENT REQUIRED TO COMPUT
C                THE IP RESPONSE
C     XD,YD,ZD=SOURCE ELECTRODES
C     XPD,YPD= RECEIVER ELECTRODES
C     M=UPPER RECEIVER ELECTRODE
C     N=LOWER RECEIVER ELECTRODE
C     A=UPPER SOURCE ELECTRODE
C     B=LOWER SOURCE ELECTRODE
C
C*****************JEFF DANIELS,,FEB. 1975*****************
C***************USGS,DENVER********************
C
      COMMON /BLOK14/ HH(55,75),SS(75),TT(75),S(75),T(75)
      COMMON /POLY   / NFACES
      COMMON/RESULT/ APRES(50),APIP(50),AR,PS,IR2,NSPA,ZPT
      DOUBLE PRECISION DSUM,DTUM,RA,RT
```

```
C
      K=IFIX(1./PS)
      Y2=(YPD-YD)*(YPD-YD)
      X2=(XPD-XD)*(XPD-XD)
      IF(AR.GT.2.) GO TO 90
      ZM=0.0
      DO 110 I=1,(IR2-K)
      XM=-11.5+FLOAT(I)*PS
      XN=XM+1.0
      XMM=(XM-XD)*(XM-XD)
      XNN=(XN-XD)*(XN-XD)
      AM=SQRT(XMM+Y2+ZDA*ZDA)
      BM=SQRT(XMM+Y2+ZDB*ZDB)
      AN=SQRT(XNN+Y2+ZDA*ZDA)
      BN=SQRT(XNN+Y2+ZDB*ZDB)
      IF(AR.NE.2) GO TO 81
      AM=1.E+08
      AN=1.E+08
   81 CONTINUE
      DSUM=0.0D 00
      DTUM=0.0D 00
  163 FORMAT(1X,'HH(I,1)',E12.6,'HH(I+1,1)',E12.6,'SS(1)',E12.6,
     &'S(1)',E12.6)
      DO 120 J=1,NFACES
      DSUM=DSUM +(SS(J)-S(J))*(HH(I,J)-HH((I+K),J))
  120 DTUM=DTUM+(TT(J)-T(J))*(HH(I,J)-HH((I+K),J))
      RQ=1./AM-1./BM-1./AN+1./BN
      APRES(I)=1.0+DSUM/((1./AM-1./BM-1./AN+1./BN))
      ApIp(I)=(1.-AK*AK)*DTUM/(2.*(1./AM-1./BM-1./AN+1./BN))/ApRES(I)
  110 CONTINUE
      GO TO 100
   90 CONTINUE
      IF(AR.NE.4) GO TO 70
      DO 140 I=1,(IR2-K)
      ZM=FLOAT(I)*PS
      ZN=ZM+1.0
      AM=1.E+08
      AN=1.E+08
      BM=SQRT(X2+Y2+ZM*ZM)
      BN=SQRT(X2+Y2+ZN*ZN)
      DSUM=0.0D+00
      DTUM=0.0D+00
      DO 150 J=1,NFACES
      DSUM=DSUM+(SS(J)-S(J))*(HH(I,J)-HH((I+K),J))
  150 DTUM=DTUM+(TT(J)-T(J))*(HH(I,J)-HH((I+K),J))
      RQ=1./BN-1./BM
      APRES(I)=1.+DSUM/RQ
  140 ApIp(I)=(1.-AK*AK)*DTUM/(2.*RQ)/ApRES(I)
      GO TO 100
   70 CONTINUE
      IF(AR.EQ.6.) GO TO 92
      IF(AR.EQ.7.) GO TO 93
   91 ZM=0.0
      IS1=1
      IS2=IR2-K
      GO TO 94
   92 ZM=ZDA
      ZN=ZDB
      IS1=1
      IS2=1
```

```
      GO TO 94
   93 X2=0.0
      Y2=0.0
      ZM=FLOAT(NSPA)+ZDB
      ZN=ZM+1
      IS1=IFIX(ZM/PS)
      IS2=IS1
   94 DO 105 I=IS1,IS2
      IF(AR.GE.6) GO TO 95
      I1=I
      ZM=FLOAT(I)*PS
      ZN=ZM+1.
   95 CONTINUE
      IF(AR.NE.7) GO TO 96
      X2=0.0
      Y2=0.0
   96 CONTINUE
      AM=SQRT(X2+Y2+(ZM-ZDA)*(ZM-ZDA))
      ATM=SQRT(X2+Y2+(ZM+ZDA)*(ZM+ZDA))
      BM=SQRT(X2+Y2+(ZM-ZDB)*(ZM-ZDB))
      BTM=SQRT(X2+Y2+(ZM+ZDB)*(ZM+ZDB))
      AN=SQRT(X2+Y2+(ZN-ZDA)*(ZN-ZDA))
      ATN=SQRT(X2+Y2+(ZN+ZDA)*(ZN+ZDA))
      BN=SQRT(X2+Y2+(ZN-ZDB)*(ZN-ZDB))
      BTN=SQRT(X2+Y2+(ZN+ZDB)*(ZN+ZDB))
      IF(AR.NE.3) GO TO 64
      AM=1.0E+08
      ATM=1.0E+08
      AN=1.0E+08
      ATN=1.0E+08
   64 CONTINUE
      RA=DBLE(1./AM) -DBLE(1./BM) -DBLE(1./AN) +DBLE(1./BN)
      RT=DBLE(1./ATM)-DBLE(1./BTM)-DBLE(1./ATN)+DBLE(1./BTN)
      DSUM=0.0D 00
      DTUM=0.0D 00
      IF(AR.EQ.6) I1=I6
      IF(AR.EQ.7) I1=IFIX(ZM/PS)
      DO 130 J=1,NFACES
      DSUM=DSUM+DBLE(SS(J)-S(J))*DBLE(HH(I1,J)-HH((I1+K),J))
  130 DTUM=DTUM+DBLE(TT(J)-T(J))*DBLE(HH(I1,J)-HH((I1+K),J))
      IF(AR.EQ.3.OR.AR.EQ.5) GO TO 107
      APRES(I6)= 1.0 +DSUM/(RA+RT)
      APIP(I6)=(1.0-AK*AK)*DTUM/(2.*(RA+RT))/APRES(I6)
      GO TO 105
  107 APRES(I)=1.+DSUM/(RA+RT)
      APIP(I)=(1.-AK*AK)*DTUM/(2.*(RA+RT))/APRES(I)
  105 CONTINUE
  100 CONTINUE
      RETURN
C
      END
C
C
C
C
      SUBROUTINE OUTPUT (IDH,IPLOT,XPD,YPD,XD,YD,ZD,ZDA,ZDB)
C
C
C     ---------------C.T.BARNETT-----APRIL 1972-------------
C******MODIFIED BY JEFF DANIELS, 1975********************
```

```
C
      COMMON /ISPECS/ IN1,IN2,IOUT1,IOUT2,IOUT3
      COMMON/RESULT/ APRES(50),APIP(50),AR,PS,IR2,NSPA,ZPT
C
   12 FORMAT (4E15.8)
C
C
C
C     THIS SECTION OUTPUTS RESULTS FROM THE DOWNHOLE CONFIGURATION
C
      K=IFIX(1./PS)
      IF(AR.EQ.1.) GO TO 100
      IF(AR.EQ.2.) GO TO 200
      IF(AR.EQ.3.) GO TO 300
      IF(AR.EQ.4.) GO TO 400
      IF(AR.EQ.5.) GO TO 500
      IF(AR.EQ.6.) GO TO 600
      IF(AR.EQ.7.) GO TO 700
C HOLE-BIPOLE SOURCE,SURFACE BIPOLE RECEIVER
  100 WRITE(IOUT2,101)
      WRITE(IOUT2,102) ZDA,ZDB,XD,YD
      WRITE(IOUT2,106)YPD
      WRITE(IOUT2,103)
      DO 104 IX=1,(IR2-K)
      XP=-11.0+FLOAT(IX)*PS
  104 WRITE(IOUT2,105) XP,APRES(IX),APIP(IX)
      GO TO 1000
C****************
C BURIED POLE SOURCE, SURFACE BIPOLE RECEIVER
C*********************
  200 WRITE(IOUT2,201)
      WRITE(IOUT2,102) ZDA,ZDB,XD,YD
      WRITE(IOUT2,106) YPD
      WRITE(IOUT2,103)
      DO 204 IX=1,(IR2-K)
      XP=-11.0+FLOAT(IX)*PS
  204 WRITE(IOUT2,105)XP,APRES(IX),APIP(IX)
      GO TO 1000
C**************
C BURIED POLE SOURCE, BURIED BIPOLE RECEIVER
C**************
  300 WRITE(IOUT2,301)
      WRITE(IOUT2,102)ZDA,ZDB,XD,YD
      WRITE(IOUT2,302) XPD,YPD
      WRITE(IOUT2,303)
      DO 304 IX=1,(IR2-K)
      ZP=0.5+FLOAT(IX)*PS
  304 WRITE(IOUT2,105) ZP,APRES(IX),APIP(IX)
      GO TO 1000
C**************
C SURFACE POLE SOURCE, BURIED BIPOLE RECEIVER
C**************
  400 WRITE(IOUT2,401)
      WRITE(IOUT2,603) XD,YD
      WRITE(IOUT2,302) XPD,YPD
      WRITE(IOUT2,303)
      DO 505 IX=1,(IR2-K)
      ZP=0.5+FLOAT(IX)*PS
  505 WRITE(IOUT2,105) ZP,APRES(IX),APIP(IX)
      GO TO 1000
```

```
C***************
C BURIED BIPOLE FIXED SOURCE, BURIED BIPOLE RECEIVER
C***************
  500 WRITE(IOUT2,501)
      WRITE(IOUT2,102) ZDA,ZDB,XD,YD
      WRITE(IOUT2,302)XPD,YPD
      WRITE(IOUT2,303)
      DO 504 IX=1,(IR2-1)
      ZP=0.5+FLOAT(IX)*PS
  504 WRITE(IOUT2,105) ZP,APRES(IX),APIP(IX)
      GO TO 1000
C***************
C BURIED BIPOLE MOVING SOURCE,BURIED BIPOLE RECEIVER
C***************
  600 WRITE(IOUT2,601)
      WRITE(IOUT2,603)XD,YD
      WRITE(IOUT2,302) XPD,YPD
      WRITE(IOUT2,303)
      DO 602 IQ=1,(IR2-K)
      ZP=0.5+FLOAT(IQ)*PS
  602 WRITE(IOUT2,105) ZP,APRES(IQ),APIP(IQ)
      GO TO 1000
C***************
C SINGLE HOLE BIPOLE-BIPOLE CONFIGURATION
C***************
  700 WRITE(IOUT2,701)
      WRITE(IOUT2,703) XD,YD
      WRITE(IOUT2,303)
      IRP1=IR2-IFIX(1/PS+NSPA/PS)
      DO 702 IQ=1,IRP1
      ZP=FLOAT(NSPA)/2+PS*FLOAT(IQ)+1.
  702 WRITE(IOUT2,105)ZP,APRES(IQ),APIP(IQ)
 1000 CONTINUE
  105 FORMAT(2X,F8.3,2(2X,E12.6))
  101 FORMAT(2X,30('*'),/,2X,'BURIED BIPOLE SOURCE,SURFACE
     &BIPOLE RECEIVER',/,30('*'),/)
  201 FORMAT(2X,30('*'),/,2X,'BURIED POLE SOURCE,SURFACE
     &BIPOLE RECEIVER',/,30('*'),/)
  301 FORMAT(2X,30('*'),/,2X,'BURIED POLE SOURCE, BURIED BIPOLE
     &RECEIVER',/,30('*'),/)
  401 FORMAT(2X,30('*'),/,2X,'SURFACE POLE SOURCE,BURIED BIPOLE
     & RECEIVER',/,30('*'),/)
  501 FORMAT(2X,30('*'),/,2X,'BURIED BIPOLE FIXED SOURCE, BURIED
     &BIPOLE RECEIVER',/,30('*'),/)
  601 FORMAT(2X,30('*'),/,2X,'BURIED BIPOLE MOVING SOURCE,BURIED BIPOLE
     &RECEIVER',/,30('*'),/)
  701 FORMAT(2X,30('*'),/,2X,' SINGLE HOLE,BIPOLE-BIPOLE',/,30('*'),/)
  102 FORMAT(2X,'UPPER SOURCE=',F10.3,/,2X,'LOWER SOURCE=',F10.3,
     &/,2X,'X-SOURCE=',F10.3,/,2X,'Y-SOURCE=',F10.3,/)
  106 FORMAT(2X,'Y-PROFILE=',F10.3,/)
  103 FORMAT(2X,'X-RECEIVER',2X,'APPARENT',5X,'APPARENT',/,2X,
     &'POSITION',4X,'RESISTIVITY',2X,'POLARIZABILITY',/)
  302 FORMAT(2X,'X-RECEIVER=',F10.3,/,2X,'Y-RECEIVER=',F10.3,/)
  303 FORMAT(5X,'RECEIVER',2X,'APPARENT',5X,'APPARENT',/,5X,'DEPTH',
     &6X,'RESISTIVITY',2X,'POLARIZABILITY',/)
  603 FORMAT(2X,'X-SOURCE=',F10.3,/,2X,'Y-SOURCE=',F10.3,/)
  703 FORMAT(2X,'X-POSITION OF HOLE=',F10.3,/,2X,'Y-
     &POSITION OF HOLE=',F10.3,/)
      RETURN
      END
```

```
C***************** SUBROUTINE BODY3D *************
C
C     THIS SUBPROGRAM CALCULATES POINTS FOR 3-DIMENSIONAL BODIES.
C     THE BASIC BODY IS AN ELLIPSOID.  A SPHERE MAY BE
C     GENERATED BY MAKING A=B=C.  OUTPUT IS IN THE FORM OF CONTOURS
C     OF (X,Y) VALUES AT Z VALUES. THE OUTPUT IS DESIGNED TO BE USED
C     WITH IP3DDH,THE CENTER OF THE BODY IS ZERO.

C
C     PARAMETERS:
C     A=MAXIMUM X-DIRECTION OF BODY(HALF-WIDTH)
C     B=MAXIMUM Y-DIRECTION OF BODY (HALF-WIDTH
C     C=MAXIMUM Z-DIRECTION OF BODY (HALF-WIDTH)
C     DEL=SEPERATION OF Z POINTS(SEPERATION OF CONTOURS)
C         =(C*2)/4
C     PARAMETERS A,B,AND C ARE READ FROM DISK,DEL IS COMPUTED
C
C                         JEFF DANIELS
C                         USGS DENVER
C                         MARCH 1,1975
C
      SUBROUTINE BODY3D
      DIMENSION X(100),Y(100),VX(100),VY(100)
     &,VXS(10),VYS(10)
      COMMON/BLOK12/NC1,NV
      COMMON/BODY/VXA(100),VYA(100),Z(5)
      IN=13
      READ(IN,6)A,B,C
      DEL=(C*2.)/4.
      NC=4
      ICA=0
      IC=0
      DO 21 I=1,NC+1
      M=I-1
      Z(I)=-C+M*DEL
      XM=SQRT(A*A*(1.-Z(I)*Z(I)/(C*C)))
      IF(XM.EQ.0.0) MM=1
      IF(XM.EQ.0.0) GO TO 42
      DEL1=XM/3
      MM=3
   42 DO 20 J=1,MM
      L=J-1
      X(J)=XM-L*DEL1
      Y(J)=SQRT(B*B*(1.-Z(I)*Z(I)/(C*C)-X(J)*X(J)/(A*A)))
      IC=IC+1
      VX(IC)=X(J)
      VY(IC)=Y(J)
   20 CONTINUE
      IF(I.EQ.1.OR.I.EQ.(NC+1)) GO TO 24
      IC=IC+1
      VX(IC)=0.0
      VY(IC)=SQRT(B*B*(1.-Z(I)*Z(I)/(C*C)))
      DO 22 K=1,MM
      X(MM+K)=-X(MM-K+1)
      Y(MM+K)=Y(MM+1-K)
      IC=IC+1
      VX(IC)=X(MM+K)
      VY(IC)=Y(MM+K)
   22 CONTINUE
      MMM=MM+MM-1
```

```
      IF(ICA.EQ.0) KG=3
      IF(ICA.GT.0) KG=2
      DO 23 KB=1,MMM+LL
      IC=IC+1
      VX(IC)=VX(MMM+ICA-KB+KG)
      VY(IC)=-VY(MMM+ICA-KB+KG)
   23 CONTINUE
      ICA=IC
   24 IF(MM.EQ.1.OR.MM.EQ.(NC+1)) MMQ=MMP+1
   21 CONTINUE
  30  CONTINUE
      NV=(IC-2)/(NC-1)
      NC1=NC-1
      NCC=NC1*NV+2
      VXA(1)=VX(1)
      VYA(1)=VY(1)
      I6=2
      DO 700 I4=1,NC1
      IQ=I4+1
      IST=I4
      DO 800 I7=1,IST
      VXS(I7)=VX(I6+I7-1)
  800 VYS(I7)=VY(I6+I7-1)
      DO 600 I5=IQ,NV
      VXA(I6)=VX(I6+IST)
      VYA(I6)=VY(I6+IST)
  600 I6=I6+1
      DO 900 I9=1,IST
      VXA(I6)=VXS(I9)
      VYA(I6)=VYS(I9)
  900 I6=I6+1
  700 CONTINUE
      VXA(IC)=VX(IC)
      VYA(IC)=VY(IC)
      WRITE(15,201)(Z(IL),IL=1,5)
      WRITE(15,201)(VXA(IL),VYA(IL),IL=1,IC)
  201 FORMAT(2(2X,E12.6))
    6 FORMAT(3F)
      RETURN
      END
```