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HP-9845 Program for Computing and Plotting Full Schlumberger Sounding Curves and Master Sets Over Three Vertical Layers: Array Expanded at Right Angles to Strike.

by

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HP-9845 Program for Computing and Plotting Full Schlumberger Sounding Curves and Master Sets Over Three Vertical Layers: Array Expanded at Right Angles to Strike.

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INTRODUCTION

The three vertical-layers (or vertical-dike) problem was solved several decades ago by the tedious method of images (Hedstrom, 1932; Van Nostrand and Cook,1966). Logn (1954) derived formulas (in the form of integral equations) for the potential and apparent resistivity of a pole-dipole or half-Schlumberger array. His approach for solving the boundary value problem for vertical layers is similar to that used by Stefanesco and others (1930) for solving the horizontal layer problem. Unfortunately, Logn was unable to evaluate the integral expression he derived without resorting to an infinitesimally thin-dike approximation. Kunetz (1955) also used the infinitesimally thin-dike model for evaluating his integral equation. Thus until now, the infinite-series expressions (image method) have been used for solving the thick-dike problem, and the integral equation evaluation has been used for solving the infinitesimally thin-dike problem.

The computer program presented in this report (see appendix II) is based on a novel method that uses the Gauss-Laguerre numerical integration formula. The integrals are easily evaluated for a dike with any desired width. The neccessary equations for computing the Schlumberger apparent resistivity, using a symmetric (AMNB) and idealized (MN -> 0) array, are given without derivation in appendix I The equations are in a form suitable for the direct use of the Gauss-Laguerre numerical integration formula.

BRIEF PROGRAM DESCRIPTION

This program is named: "VCSCH1"(Vertical Contact SCHlumberger, version 1), and it is written in HP Enhanced BASIC.
The program can be used to compute and plot either a single sounding curve or to generate sets of master curves. Prompting statements diagrams, illustrations, and appropriate error messages are displayed on the screen to assist the user at all steps.

The graphical presentation of any single sounding curve or set of master curves is made on a log-log plot of 4x3 cycles. The length of each log cycle is approximately 4 cm. The axes of each plot are appropriately labeled, and a label designating the distances (d1 and d2) and resistivities (rho-1, rho-2, and rho-3) are given at the top of each plot, and a sketch of the dike and location of the sounding center is drawn in the upper right hand corner of the plot. The computation of any sounding curve is made at the rate 20 points per log cycle. Also the computations always include the points at which the electrode spacing is equal to the distance to a contact.

To compute a single sounding curve the user must type the numerical values (separated by commas) for: (i) the medium on which the sounding center is located (1,2, or 3), (ii) the resistivity values for rho-1, rho-2, and rho-3, (iii) the distances to the contacts d1 and d2, and (iv) the smallest and largest electrode spacing (AB/2) values. The user must type each of these data values after the proper prompting statement appears on the screen and he must press CONT (continue) after each set of values is typed.

To compute a set of master curves, the user must type only the numerical values for: (i) the medium on which the sounding center is located, and (ii) the resistivities (rho-1, rho-2, and rho-3). The resistivity value for the medium where the center is located is taken as unity. The values for d1 and d2 (d1=1, d2= 1,1.5, 2, 4, 8, 20, 40, and infinity) are assigned by the program and are not entered by the user. Similarly the values for the smallest and largest electrode spacings (AB/2) are assigned the values of 0.1 and 1000, and are not entered by the user. Note that for d1=1 and d2= 1, 1.5, 2, 4, 8, 20, 40, and infinity, and with the center on medium 1, the corresponding dike widths are : 0, 0.5, 1, 3, 7, 19, 39, and infinity, respectively; whereas with the center on medium 2 the corresponding dike widths are: 2, 2.5, 3, 5, 9, 21, 41, and infinity, respectively.

INSTRUCTIONS FOR USERS

(1) Turn the machine on and insert the tape cartridge in the T-15 tape drive.

(2) Type GET "VCSCH1", then press EXECUTE.

(3) When the program is loaded in the machine memory (green square light at the bottom right-hand corner of the screen goes out), press RUN.

The following message will appear on the screen:

THIS PROGRAM COMPUTES AND PLOTS FULL SCHLUMBERGER SOUNDING CURVES EXPANDED AT RIGHT ANGLES TO A VERTICAL DIKE, and at the bottom of the screen will appear the first prompting statement:

DO YOU WISH TO HAVE A CURVE SET ? (Y/N) FOR ONE CURVE ONLY TYPE N FOR NO.

Type Y (for YES, meaning you wish to compute a master set) or type N (for NO, meaning you wish to compute only a particular single sounding curve). Then press CONT.

(4) Subsequent prompting statements assisted by illustrations on the screen are self explanatory, and also are shown in the examples section.

(5) To obtain a printed copy of the numerical values for the computed sounding curve wait until the prompting statement INPUT MIN AB/2, MAX AB/2 appears on the screen. Then:

(i) type PRINTER IS 0 and press EXECUTE,

(ii) type the numerical values for the smallest and largest AB/2 values (separated by commas) and press CONT.

To exit from the printer mode, type PRINTER IS 16 and press EXECUTE.

(6) To obtain a hard copy of a single curve, type DUMP GRAPHICS and press EXECUTE.

The graphic display is not cleared after plotting or dumping a single sounding curve. This allows the user to plot other curves with different model parameters on top of of the previous plots. To do this press CONT and enter the new parameters for the new model. To clear the present plot, type GCLEAR and press EXECUTE. Press CONT to start a new problem.

(7) Upon the completion and plotting of a complete set of master curves, four beeps will be heard and a full-screen cross will appear on the screen. The location of the cross on the plot can be moved using the up, down, right, and left arrows on the DISPLAY buttons. The cross is used to indicate to the computer the appropriate position for labeling the different curves with the proper values of d2. This is done as follws: (i) move the cross to the appropriate location on the screen and press CONT. The prompting statement: TYPE VALUE FOR D2, OR TYPE N (WHEN DONE LABELING) will appear. (ii) Type the apprpriate value for d2 (or type appropriate symbols such as vertical or slanted lines to be used for leaders to the curves) and press CONT. (iii) Repeat step (i) as desired to label all the other curves. Note that PEN-1 and PEN 1 commands can be used to correct errors in labeling. (iv) Upon completion of the labeling operation , type N then press CONT. The prompting statement: DUMP GRAPHICS ? (Y/N) will appear on the screen. (v) For a hard copy of the labeled set of master curves type Y and press CONT.

If the user types N and presses CONT, the program will start from the beginning, and the graphics will be deleted.

(8) To exit from the program press STOP.

EXAMPLE OF THE COMPUTATION OF A SINGLE SOUNDING CURVE

Follow steps 1, 2, and 3 in the section on instructions for users.

STEP	PROMPTING STATEMENT	TYPE THEN PRESS CONT
(1)	DO YOU WISH TO HAVE A CURVE SET ? (Y/N)	N
(2)	DESIGNATE MEDIUM WHERE FIXED CENTER IS LOCATED: 1, 2, or 3	1
(3)	INPUT VALUES FOR RHO-1,RHO-2,RHO-3	5,200,25
(4)	INPUT DISTANCES TO CONTACTS:D1,D2	30,60
(5)	INPUT MIN (AB/2), MAX (AB/2)	1,10000
(6)	0:0 COORDINATES ? PRESS CONT FOR AUTO SCALE	(PRESS CONT)

NOTE:

(1) To obtain a printed listing of the computed apparent resistivities for the above example, at step (5) first type PRINTER IS 0, press EXECUTE, then type the minimum and maximum AB/2 values and press CONT.

When the curve is plotted type PRINTER IS 16, press EXECUTE, to exit from printer mode.

(2) In step (6) above, the 0:0 COORDINATES are the values of the smallest AB/2 and smallest apparent resistivity that the user may wish to to assign to the first abscissa and ordinate to shift the plotted curve upward, downward, to the right or to the left. Otherwise by pressing CONT the program will attempt to find the proper coordinate values that will result in a properly located curve.

(3) To obtain a hard copy, type DUMP GRAPHICS and press EXECUTE.

(4) Type GCLEAR and press EXECUTE to clear the screen for the next problem if so desired.

(5) The printer output and the plotted curve for the above example are given in table 1 and in figure 1, respectively.

Table 1 -- Printer output for a single sounding curve.

```
RHO-1;RHO-2;RHO-3                          5.0000   200.0000   25.0000
CENTER IS ON            1.0000
DISTANCES=              30.0000   60.0000

  AB/2                 APPARENT RESISTIVITY

 1.0000                 5.0000
 1.1220                 5.0000
 1.2589                 5.0000
 1.4125                 5.0000
 1.5849                 5.0000
 1.7783                 5.0000
 1.9953                 5.0001
 2.2387                 5.0002
 2.5119                 5.0004
 2.8184                 5.0008
 3.1623                 5.0015
 3.5481                 5.0026
 3.9811                 5.0043
 4.4668                 5.0066
 5.0119                 5.0096
 5.6234                 5.0136
 6.3096                 5.0184
 7.0795                 5.0242
 7.9433                 5.0311
 8.9125                 5.0395
 10.0000                5.0502
 11.2202                5.0653
 12.5893                5.0881
 14.1254                5.1244
 15.8489                5.1824
 17.7828                5.2743
 19.9526                5.4180
 22.3872                5.6432
 25.1189                6.0028
 28.1838                6.5989
 30.0000                7.0882
 33.6606                6.9416
 37.7678                6.7149
 42.3761                6.3628
 47.5468                5.8081
 53.3484                4.9121
 59.8579                3.4083
 60.0000                3.3678
 67.3211                3.3494
 75.5355                3.3324
```

84.7523	3.3174
95.0936	3.3052
106.6968	3.2966
119.7157	3.2923
134.3233	3.2927
150.7132	3.2985
169.1030	3.3100
189.7367	3.3275
212.8880	3.3511
238.8643	3.3807
268.0102	3.4162
300.7123	3.4572
337.4048	3.5034
378.5744	3.5542
424.7675	3.6090
476.5969	3.6672
534.7506	3.7281
600.0000	3.7910
673.2111	3.8552
755.3552	3.9201
847.5225	3.9850
950.9359	4.0494
1066.9676	4.1127
1197.1574	4.1745
1343.2327	4.2343
1507.1319	4.2920
1691.0298	4.3471
1897.3666	4.3996
2128.8803	4.4493
2388.6430	4.4960
2680.1016	4.5398
3007.1234	4.5807
3374.0479	4.6186
3785.7441	4.6538
4247.6747	4.6863
4765.9694	4.7161
5347.5056	4.7435
6000.0000	4.7685
6732.1107	4.7914
7553.5525	4.8121
8475.2253	4.8310
9509.3591	4.8482

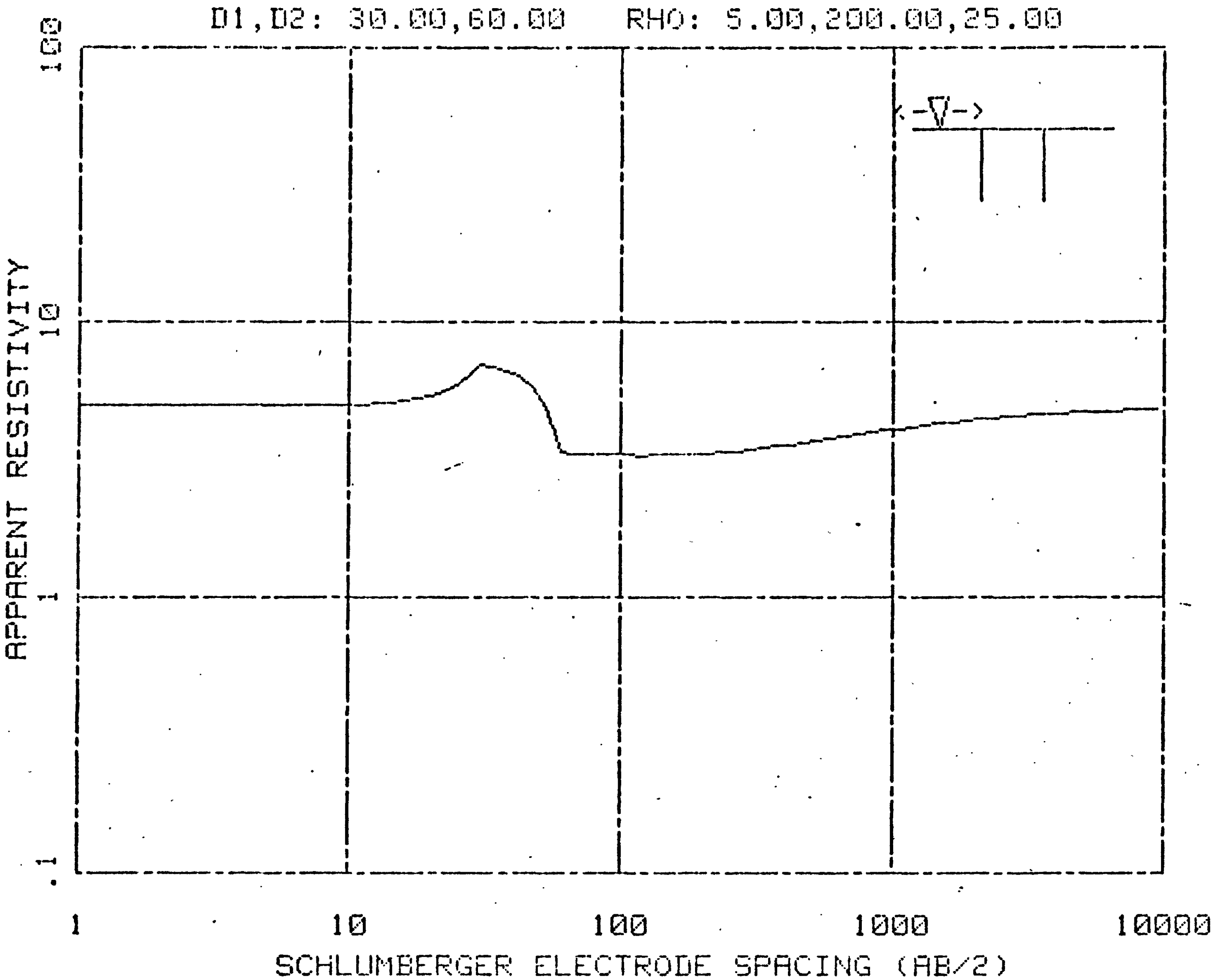

Figure 1: Output example for a single sounding curve.

EXAMPLE OF THE COMPUTATION OF A SET OF MASTER CURVES

Follow steps 1, 2, and 3 given in section on instruction for users.

STEP	PROMPTING STATEMENT	TYPE THEN PRESS CONT
(1)	DO YOU WISH TO HAVE A CURVE SET ? (Y/N)	Y
(2)	DESIGNATE MEDIUM WHERE FIXED CENTER IS LOCATED: 1, 2, OR 3	2
(3)	INPUT VALUES FOR RHO-1,RHO-2,RHO-3	0.1,1,0.1

Figure 2 shows the output to the above example after using the labeling technique described earlier.

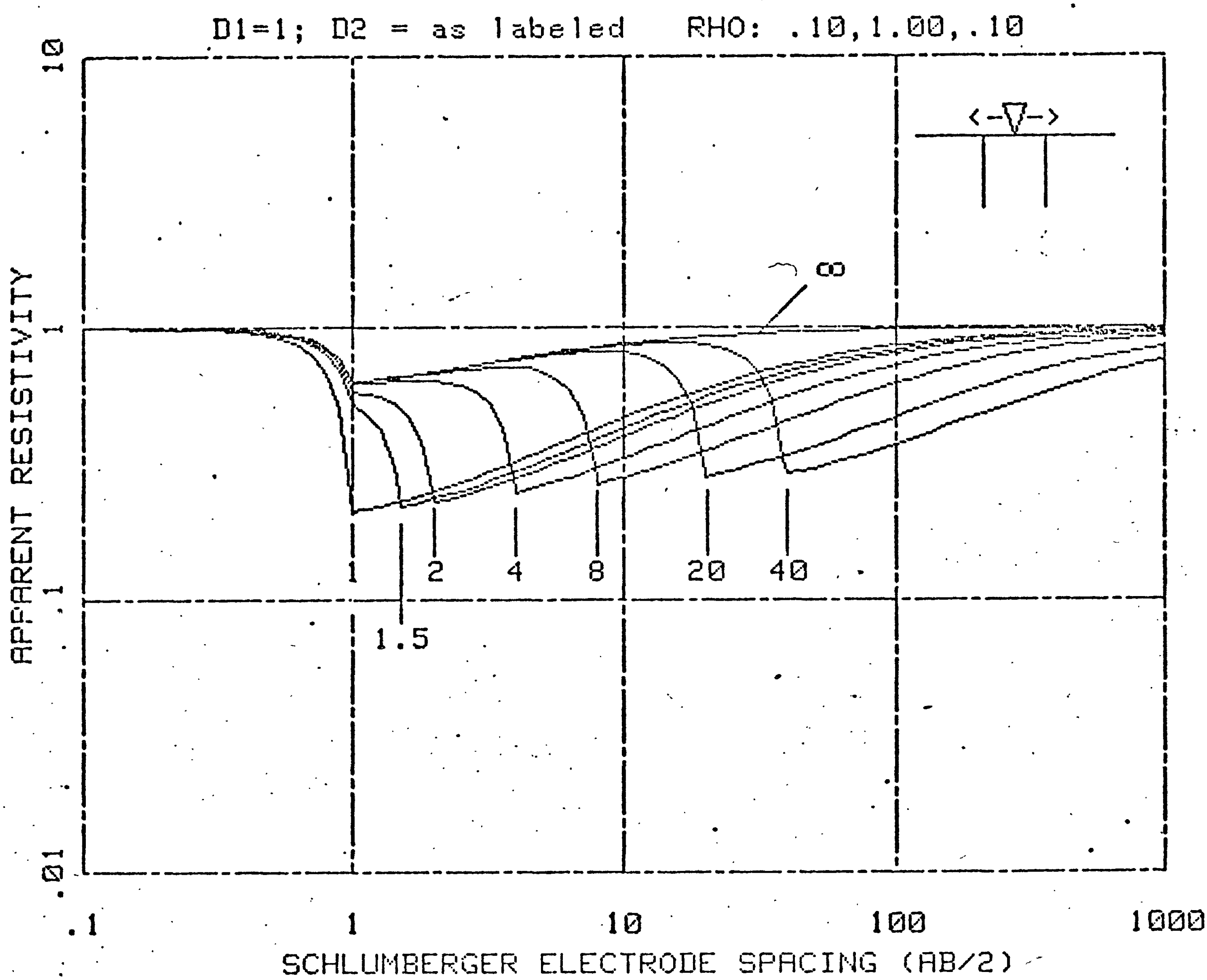

Figure 2: Output example for a set of master curves.

ACKNOWLEDGMENT

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APPENDIX I

MATHEMATICAL FORMULAS

MATHEMATICAL FORMULAS

The Gauss-Laguerre numerical integration formula (Abramowitz and Stegun, 1964, p.923) states that:

$$\int_0^{\infty} e^{-x} f(x)\, dx \approx \sum_{i=1}^{n} W_i f(x_i) ,$$

where W_i = Laguerre weights,

X_i = Laguerre abscissas,

$f(X_i)$ = function to be evaluated at proper X_i values.

By comparing results obtained from the above formula with those obtained from a closed algebraic expression for the limiting case of a vertical fault (Zohdy,1970), and by experimenting with various values of n, I found that the computations are sufficiently accurate with n=5. In fact with values as low as n=1 and Wi=1 the shape of the curve for many models is almost acceptable for practical purposes with errors of about 30 percent in parts of it. The Laguerre abscissas and weights are given in steps 150 to 250 of the program (see appaendix II) and in the above reference.

Two sets of expressions must be derived, one for the sounding center on medium 1 (left layer) , and the other for the sounding center on medium 2 (middle layer). The expressions for the sounding center on medium 3 (right layer) are identical to those with the center on medium 1, but with the resistivities of medium 1 and medium 3 exchanged.

I.SOUNDING CENTER ON MEDIUM 1:

In the following equations, the following definitions apply (also see figure 3):

ρ_1, ρ_2, ρ_3 = resistivities of medium 1, 2, and 3, respectively

k21 = $(\rho_2 - \rho_1)/(\rho_2 + \rho_1)$

k32 = $(\rho_3 - \rho_2)/(\rho_3 + \rho_2)$

d1,d2 = distances from sounding center to first and

y = AB/2 = Schlumberger electrode spacing; that is half distance between current electrodes A and B.

$\bar{\rho}_s(y)$ = Schlumberger apparent resistivity as a function of y=AB/2.

(i) All electrodes on medium 1 (d2>y<d1):

$$\bar{\rho}_s(y) = \frac{\rho_1}{2} \sum_1^5 W_i f(x_i) ,$$

where

$$f(x_i) = x_i \left[2 + \frac{\left[k_{21} + k_{32} e^{-\frac{2x_i}{y}(d_2 - d_1)}\right]\left[e^{-\frac{2x_i}{y}(d_1 - y)} - e^{-\frac{2x_i}{y} d_1}\right]}{1 + k_{21} k_{32} e^{-\frac{2x_i}{y}(d_2 - d_1)}} \right] .$$

(ii) Electrode B on medium 2, all others on medium 1 (d2>y>d1) :

$$\bar{\rho}_s(y) = \frac{\rho_1}{2} \sum_1^5 W_i f(x_i) ,$$

where

$$f(x_i) = x_i \left[\frac{\rho_2}{\rho_1}\left[1 + \frac{k_{32}\left[e^{-\frac{2x_i}{y}(d_2 - y)} - k_{21} e^{-\frac{2x_i}{y}(d_2 - d_1)}\right] - k_{21}\left[1 + k_{32} e^{-\frac{2x_i}{y}(d_2 - y)}\right]}{1 + k_{21} k_{32} e^{-\frac{2x_i}{y}(d_2 - d_1)}}\right]\right.$$

$$\left. + \left[1 - \frac{e^{-\frac{2x_i}{y} d_1}\left[k_{21} + k_{32} e^{-\frac{2x_i}{y}(d_2 - d_1)}\right]}{1 + k_{21} k_{32} e^{-\frac{2x_i}{y}(d_2 - d_1)}}\right] \right] .$$

(iii) Electrode B on medium 3, all others on medium 1 (d2<y>d1):

$$\bar{\rho}_s(y) = \frac{\rho_1}{2} \sum_{1}^{5} w_i \, f(x_i)$$

where

$$f(x_i) = x_i \left[\left[1 - \frac{e^{-\frac{2x_i}{y} d_1} \left[k_{21} + k_{32} \, e^{-\frac{2x_i}{y}(d_2 - d_1)} \right]}{1 + k_{21} k_{32} \, e^{-\frac{2x_i}{y}(d_2 - d_1)}} \right] + \frac{\rho_3}{\rho_1} \left[1 - \frac{k_{32} + k_{21}[1 - k_{32}] + k_{21} k_{32} \, e^{-\frac{2x_i}{y}(d_2 - d_1)}}{1 + k_{21} k_{32} \, e^{-\frac{2x_i}{y}(d_2 - d_1)}} \right] \right]$$

```
                 FIXED CENTER
      A               MN              B
 <- <- !              !!              ! -> ->
----------------------------------------------------------------
                  <---D1---> |//////////////////|
                  <---D2---- |---------------->|
                             |//////////////////|
                             |//////////////////|
                             |//////////////////|
        RHO-1                |//// RHO-2 /////|       RHO-3
                             |//////////////////|
                             |//////////////////|
                             |//////////////////|
```

Figure 3: Electrode array center on medium 1.

II. SOUNDING CENTER ON MEDIUM 2:

In the following equations, the same definitions for the variables apply, except for d1 and d2 (see figure 4) where:

d1 = distance from sounding center to the LEFT contact separating RHO-1 from RHO-2,

d2 = distance from sounding center to the RIGHT contact separating RHO-2 from RHO-3.

(i) All electrodes on medium 2 (d2>y<d1)

$$\bar{\rho}_s(y) = \frac{\rho_2}{2}\sum_{1}^{5} W_i\, f(x_i) \quad ,$$

where

$$f(x_i) = x_i\left[2 + \frac{k_{21}\left[e^{-\frac{2x_i}{y}d_1} + k_{32}\, e^{-\frac{2x_i}{y}(d_1+d_2-y)}\right] + k_{32}\left[e^{-\frac{2x_i}{y}(d_2-y)} - k_{21}\, e^{-\frac{2x_i}{y}(d_2+d_1)}\right]}{1 + k_{21}k_{32}\, e^{-\frac{2x_i}{y}(d_2+d_1)}}\right.$$

$$\left. - \frac{k_{21}\left[e^{-\frac{2x_i}{y}(d_1-y)} + k_{32}\, e^{-\frac{2x_i}{y}(d_2+d_1)}\right] + k_{32}\left[e^{-\frac{2x_i}{y}d_2} - k_{21}\, e^{-\frac{2x_i}{y}(d_1+d_2-y)}\right]}{1 + k_{21}k_{32}\, e^{-\frac{2x_i}{y}(d_2+d_1)}}\right]$$

(ii) Electrode A on medium 1, all others on medium 2 (d1<y<d2)

$$\bar{\rho}_s(y) = \frac{\rho_2}{2}\sum_{1}^{5} W_i\, f(x_i) \quad ,$$

where

$$f(x_i) = x_i\left[\frac{\rho_1}{\rho_2}\left[1 + \frac{k_{21}\left[1 - k_{32}\, e^{-\frac{2x_i}{y}(d_1+d_2)}\right] - k_{32}\left[1+k_{21}\right] e^{-\frac{2x_i}{y}d_2}}{1 + k_{21}k_{32}\, e^{-\frac{2x_i}{y}(d_2+d_1)}}\right]\right.$$

$$+\left[1 + \frac{k_{21}\left[e^{-\frac{2x_i}{y}d_1} + k_{32}\, e^{-\frac{2x_i}{y}(d_1+d_2-y)}\right] + k_{32}\left[e^{-\frac{2x_i}{y}(d_2-y)} - k_{21}\, e^{-\frac{2x_i}{y}(d_1+d_2 \ldots)} \ldots\right.}{1 + k_{21}k_{32}\, e^{-\frac{2x_i}{y}(d_2+d_1)}}\right.$$

(iii) Electrode B on medium 3, all others on medium 2 (d2<y<d1):

$$\bar{\rho}_s(y) = \frac{\rho_2}{2} \sum_{1}^{5} W_i\, f(x_i) \quad ,$$

where

$$f(x_i) = x_i \left[1 - \frac{k_{21}\left[e^{-\frac{2x_i}{y}(d_1-y)} + k_{32}\, e^{-\frac{2x_i}{y}(d_1+d_2)}\right] + k_{32}\left[e^{-\frac{2x_i}{y}d_2} - k_{21}\, e^{-\frac{2x_i}{y}(d_1+d_2-y)}\right]}{1 + k_{21} k_{32}\, e^{-\frac{2x_i}{y}(d_2+d_1)}} \right.$$

$$\left. + \frac{\rho_3}{\rho_2}\left[1 + \frac{k_{21}[1-k_{32}]\, e^{-\frac{2x_i}{y}d_1} - k_{32}\left[1 + k_{21}\, e^{-\frac{2x_i}{y}(d_2+d_1)}\right]}{1 + k_{21} k_{32}\, e^{-\frac{2x_i}{y}(d_1+d_2)}}\right] \right]$$

(iv) Electrode A on medium 1, electrode B on 3, and center on 2 (d2<y>d1):

$$\bar{\rho}_s(y) = \frac{\rho_2}{2} \sum_{1}^{5} W_i\, f(x_i) \quad ,$$

where

$$f(x_i) = x_i \left[\frac{\rho_1}{\rho_2}\left[1 + \frac{k_{21}\left[1 - k_{32}\, e^{-\frac{2x_i}{y}(d_1+d_2)}\right] - k_{32}[1+k_{21}]\, e^{-\frac{2x_i}{y}d_2}}{1 + k_{21} k_{32}\, e^{-\frac{2x_i}{y}(d_1+d_2)}}\right] \right.$$

$$\left. + \frac{\rho_3}{\rho_2}\left[1 + \frac{k_{21}[1-k_{32}]\, e^{-\frac{2x_i}{y}d_1} - k_{32}\left[1 + k_{21}\, e^{-\frac{2x_i}{y}(d_1+d_2)}\right]}{1 + k_{21} k_{32}\, e^{-\frac{2x_i}{y}(d_1+d_2)}}\right] \right]$$

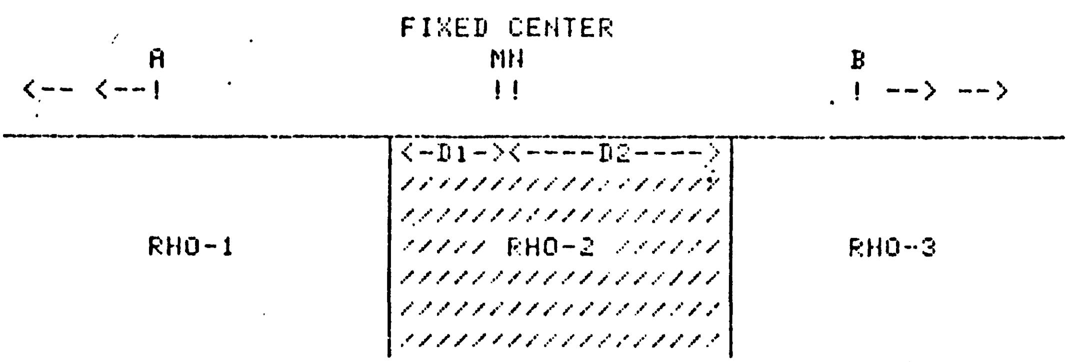

Figure 4: Electrode array center on medium 2.

APPENDIX II

PROGRAM LISTING OF VCSCH1

```
10    ! *****PROGRAM FOR COMPUTING AND PLOTING FULL SCHLUMBERGER***********
20    ! *****SOUNDING CURVES EXPANDED AT RIGHT ANGLES TO A VERTICAL*******
30    ! *****DIKE. BY ADEL A.R. ZOHDY, USGS, DENVER, COLORADO. SEP.13,79***
40    ! **************************************************************
50    ! **************************************************************
60    !
70    !
80    !
90    !
100   OVERLAP
110   OPTION BASE 1
120   FIXED 4
130   DIM Ki(5),Wt(5),Fi(5),Rhobar(100),Rad(100)
140   MAT READ Ki                     ! LA GUERRE ABSCISSAS FOR N=5
150    DATA 0.263560319718
160    DATA 1.413403059107
170    DATA 3.596425771041
180    DATA 7.085810005859
190    DATA 12.640800844276
200   MAT READ Wt                     ! LA GUERRE WEIGHTS FOR N=5
210    DATA 5.21755610583E-01
220    DATA 3.98666811083E-01
230    DATA 7.59424496817E-02
240    DATA 3.61175867992E-03
250    DATA 2.33699723858E-05
260    EXIT GRAPHICS
270    PRINT PAGE
280   PRINT "THIS PROGRAM COMPUTES AND PLOTS FULL SCHLUMBERGER SOUNDING CURVES
EXPANDED   AT RIGHT ANGLES TO A VERTICAL DIKE"
290   PRINT
300   INPUT "DO YOU WISH TO HAVE A CURVE SET ? (Y/N). FOR ONE CURVE ONLY TYPE N
FOR NO.",Curve_set$
310   IF (Curve_set$="Y") OR (Curve_set$="N") THEN 360
320   DISP "PLEACE TYPE:  Y  OR  N .. (FOR YES OR NO)"
330   BEEP
340   WAIT 2000
350   GOTO 300
360   PRINT PAGE
370   CALL Plot
380   INPUT "DESIGNATE MEDIUM WHERE FIXED CENTER IS LOCATED: 1,2,OR 3",Center
390   IF (Center=1) OR (Center=2) OR (Center=3) THEN 440
400   DISP "ERROR: CENTER MUST BE ON MEDIUM 1,2,OR 3"
410   BEEP
420   WAIT 3000
430   GOTO 380
440   IF Center=1 THEN CALL Plot1
450   IF Center=2 THEN CALL Plot2
460   IF Center=3 THEN CALL Plot3
470   INPUT "INPUT VALUES FOR RHO-1,RHO-2,RHO-3",R1,R2,R3
480   IF (R1=0) AND (Center=1) THEN 520
490   IF (R2=0) AND (Center=2) THEN 520
500   IF (R3=0) AND (Center=3) THEN 520
510   GOTO 590
520   DISP "TRIVIAL CASE, WITH CENTER ON ZERO RESISTIVITY ...."
530   BEEP
540   WAIT 3000
550   DISP "ALL APPARENT RESISTIVITIES WILL BE ZERO !!!"
560   WAIT 3000
570   BEEP
580   GOTO 470
590   IF Curve_set$="N" THEN 660
600   D1=1
610   READ D2
620   DATA 40,20,8,4,2,1.5,1,1000000
630   Ymin=.1
```

```
640   Ymax=1000
650   GOTO 1020
660   IF (Center=1) OR (Center=3) THEN 750
670   INPUT "INPUT DISTANCES TO THE LEFT, AND TO THE RIGHT: D1,D2",D1,D2
680   IF (D1<>0) AND (D2<>0) THEN 860
690   DISP "ERROR: D1 OR D2 CANNOT BE ZERO"
700   BEEP
710   WAIT 2000
720   DISP "BECAUSE OF DISCONTINUITY IN APPARENT RESISTIVITY"
730   WAIT 3000
740   GOTO 670
750   INPUT "INPUT DISTANCES TO CONTACTS: D1,D2 ",D1,D2
760   IF D1<>0 THEN 810
770   DISP "ERROR: D1 CANNOT BE ZERO BECAUSE OF DISCONTINUITY IN APPARENT RESI
STIVITY"
780   BEEP
790   WAIT 3000
800   GOTO 750
810   IF D2>=D1 THEN 860
820   DISP " ERROR: D2 MUST BE LARGER THAN OR EQUAL TO D1"
830   BEEP
840   WAIT 3000
850   GOTO 750
860   INPUT "INPUT MINIMUM AB/2,MAXIMUM AB/2",Ymin,Ymax
870   IF Ymax>Ymin THEN 920
880   DISP "ERROR: MIN AB/2 MUST BE SMALLER THAN MAX AB/2"
890   BEEP
900   WAIT 3000
910   GOTO 860
920   PRINT "RHO-1;RHO-2;RHO-3",R1;R2;R3
930   PRINT "CENTER IS ON",Center
940   IF (Center=1) OR (Center=3) THEN 980
950   PRINT "DISTANCE TO THE LEFT=";D1
960   PRINT "DISTANCE TO THE RIGHT=";D2
970   GOTO 990
980   PRINT "DISTANCES=",D1;D2
990   PRINT
1000  PRINT "  AB/2","APPARENT RESISTIVITY"
1010  PRINT
1020  Y=Ymin                          ! SMALLEST VALUE FOR AB/2
1030  Ncy=3                           ! #OF LOG CYCLES ON Y-AXIS
1040  Ncx=4                           ! #OF LOG CYCLES ON X-AXIS
1050  P=20                            ! #OF POINTS PER LOG CYCLE
1060  K=0
1070  Kk=0
1080  R=EXP(LOG(10)/P)                !ABSCISSA RATIO FOR SUCCESSIVE POINTS
1090  J=1
1100  FOR I=1 TO 5
1110  Fi(I)=-2*Ki(I)
1120  NEXT I
1130  IF (R1=0) AND (R2=0) THEN GOTO 1160
1140  K21=(R2-R1)/(R2+R1)
1150  GOTO 1170
1160  K21=0
1170  IF (R2=0) AND (R3=0) THEN 1200
1180  K32=(R3-R2)/(R3+R2)
1190  GOTO 1210
1200  K32=0
1210  IF Center=1 THEN C1
1220  IF Center=2 THEN C2
1230  IF Center=3 THEN C3
1240 C2: Total=0
1250  FOR I=1 TO 5
1260  E1=EXP(Fi(I)*D1/Y)
1270  E2=EXP(Fi(I)*D2/Y)
```

```
1280  E3=EXP(Fi(I)*(D1+D2)/Y)
1290  E4=EXP(Fi(I)*(D1-Y)/Y)
1300  E5=EXP(Fi(I)*(D2-Y)/Y)
1310  E6=EXP(Fi(I)*(D1+D2-Y)/Y)
1320  D=1+K21*K32*E3
1330  IF Y>D2 THEN D
1340 A:  A=(K21*(E1+K32*E6)+K32*(E5-K21*E3))/D
1350  A=1+A
1360  IF Y>D1 THEN C
1370 B:  B=(K21*(E4+K32*E3)+K32*(E2-K21*E6))/D
1380  B=1-B
1390  IF Y>D2 THEN L3
1400  GOTO L1
1410 C:  C=(K21*(1-K32*E3)-K32*(1+K21)*E2)/D
1420  C=1+C
1430  C=R1*C/R2
1440  IF Y>D2 THEN L4
1450  GOTO L2
1460 D: F=(K21*(1-K32)*E1-K32*(1+K21*E3))/D
1470  F=1+F
1480  F=R3*F/R2
1490  IF Y>D1 THEN C
1500  GOTO B
1510 L1: Total=Total+Wt(I)*Ki(I)*(A+B)
1520  GOTO L5
1530 L2: Total=Total+Wt(I)*Ki(I)*(A+C)
1540  GOTO L5
1550 L3:  Total=Total+Wt(I)*Ki(I)*(B+F)
1560  GOTO L5
1570 L4:  Total=Total+Wt(I)*Ki(I)*(C+F)
1580 L5: NEXT I
1590  Rad(J)=Y
1600  Rhobar(J)=R2*Total/2
1610  PRINT Rad(J),Rhobar(J)
1620  J=J+1
1630  IF Y>Ymax THEN GOTO G1
1640  Y=Y*R
1650  IF Y<D1 THEN 1700
1660  K=K+1
1670  IF K>1 THEN 1700
1680  Y=D1
1690  GOTO C2
1700  IF Y<D2 THEN C2
1710  Kk=Kk+1
1720  IF Kk>1 THEN C2
1730  Y=D2
1740  GOTO C2
1750 C1: IF Y>D1 THEN C12
1760  Total=0
1770  FOR I=1 TO 5
1780  E1=EXP(Fi(I)*(D2-D1)/Y)
1790  E2=EXP(Fi(I)*(D1-Y)/Y)
1800  E3=EXP(Fi(I)*D1/Y)
1810  D=1+K21*K32*E1
1820  A=2+(K21+K32*E1)*(E2-E3)/D
1830  Total=Total+Wt(I)*Ki(I)*A
1840  NEXT I
1850  Rhobar(J)=R1*Total/2
1860  Rad(J)=Y
1870  PRINT Rad(J),Rhobar(J)
1880  J=J+1
1890  Y=Y*R
1900  IF Y>Ymax THEN Reset
1910  GOTO C1
1920 C12:  K=K+1
```

```
1930  IF K=1 THEN Y=D1
1940  IF Y>D2 THEN C13
1950  Total=0
1960  FOR I=1 TO 5
1970  E1=EXP(Fi(I)*(D2-D1)/Y)
1980  E2=EXP(Fi(I)*D1/Y)
1990  D=1+K21+K32*E1
2000  A=(K21+K32*E1)/D
2010  A=A*E2
2020  A=1-A
2030  E3=EXP(Fi(I)*(D2-D1)/Y)
2040  E4=EXP(Fi(I)*(D2-Y)/Y)
2050  B=(K21+K32*(K21*(E3+E4)-E4))/D
2060  B=R2*(1-B)/R1
2070  Total=Total+Wt(I)*Ki(I)*(A+B)
2080  NEXT I
2090  Rad(J)=Y
2100  Rhobar(J)=R1*Total/2
2110  PRINT Rad(J),Rhobar(J)
2120  J=J+1
2130  Y=Y*R
2140  IF Y>Ymax THEN Reset
2150  GOTO C12
2160 C13:  Kk=Kk+1
2170  IF Kk=1 THEN Y=D2
2180  Total=0
2190  FOR I=1 TO 5
2200  E1=EXP(Fi(I)*(D2-D1)/Y)
2210  E2=EXP(Fi(I)*D1/Y)
2220  D=1+K21*K32*E1
2230  A=1-E2*(K21+K32*E1)/D
2240  B=R3*(1-(K32+K21*(1-K32)+K32*K21*E1)/D)/R1
2250  Total=Total+Wt(I)*Ki(I)*(A+B)
2260  NEXT I
2270  Rhobar(J)=R1*Total/2
2280  Rad(J)=Y
2290  PRINT Rad(J),Rhobar(J)
2300  J=J+1
2310  Y=Y*R
2320  IF Y>Ymax THEN Reset
2330  GOTO C13
2340 C3: H=R1                            ! EXCHANGE VALUES OF R1 AND R3
2350  R1=R3                              ! AND MAKE Center =1 INSTEAD OF 3
2360  R3=H
2370  Center=1
2380  Z=1
2390  GOTO 1140
2400 Reset:                              ! RE-SET VALUES OF R1,R3,AND Center
2410  IF Z<>1 THEN GOTO G1
2420  H=R1
2430  R1=R3
2440  R3=H
2450  Center=3
2460  Z=0
2470 G1: CALL G1(Ncx,Ncy,Rad(*),Rhobar(*),J,R1,R2,R3,Center,D1,D2,Curve_set$)
2480  IF Curve_set$="N" THEN 2720
2490  Curve_set$="Y+1"
2500  IF D2=1000000 THEN 2520
2510  GOTO 610
2520  BEEP
2530  WAIT 200
2540  BEEP
2550  WAIT 200
2560  BEEP
2570  DIGITIZE X,Y
```

```
2580  INPUT "TYPE VALUE FOR D2,  OR TYPE  N  (WHEN DONE LABELING)",D2$
2590  IF D2$="N" THEN 2640
2600  LORG 5
2610  MOVE X,Y
2620  LABEL D2$
2630  GOTO 2570
2640  INPUT "DUMP GRAPHICS ? (Y/N)",Dump_graphics$
2650  IF Dump_graphics$="N" THEN 2670
2660  DUMP GRAPHICS
2670  GCLEAR
2680  PRINT PAGE
2690  RESTORE 620
2700  EXIT GRAPHICS
2710  GOTO 300
2720  END
2730  SUB Plot2
2740  PRINT PAGE
2750  PRINT LIN(3)
2760  PRINT "                            FIXED CENTER                          "
2770  PRINT "            A                   MN                  B             "
2780  PRINT "   <-- <--!                     !!                  ! --> -->     "
2790  PRINT "  ----------------------------------------------------------------"
2800  PRINT "                      |<-D1-><----D2---->|                         "
2810  PRINT "                      |//////////////////|                         "
2820  PRINT "                      |//////////////////|                         "
2830  PRINT "            RHO-1     |///// RHO-2 //////|         RHO-3           "
2840  PRINT "                      |//////////////////|                         "
2850  PRINT "                      |//////////////////|                         "
2860  PRINT "                      |//////////////////|                         "
2870  SUBEND
2880  SUB Plot
2890  PRINT
2900  PRINT
2910  PRINT "  ----------------------------------------------------------------"
2920  PRINT "                      |               |                           "
2930  PRINT "                      |               |                           "
2940  PRINT "            1         |       2       |         3                 "
2950  PRINT "                      |               |                           "
2960  PRINT "                      |               |                           "
2970  PRINT "                      |               |                           "
2980  PRINT "                      |               |                           "
2990  SUBEND
3000  SUB Plot1
3010  PRINT PAGE
3020  PRINT LIN(3)
3030  PRINT "                  FIXED CENTER                          "
3040  PRINT "         A             MN             B                 "
3050  PRINT "  <- <- !              !!             ! -> ->           "
3060  PRINT "  ----------------------------------------------------------------"
3070  PRINT "                       <---D1--->|////////////////|              "
3080  PRINT "                       <---D2----|--------------->|              "
3090  PRINT "                                 |////////////////|              "
3100  PRINT "                                 |////////////////|              "
3110  PRINT "                                 |////////////////|              "
3120  PRINT "              RHO-1              |//// RHO-2 /////|    RHO-3     "
3130  PRINT "                                 |////////////////|              "
3140  PRINT "                                 |////////////////|              "
3150  PRINT "                                 |////////////////|              "
3160  SUBEND
3170  SUB Plot3
3180  PRINT PAGE
3190  PRINT LIN(3)
3200  PRINT "                                     FIXED CENTER            "
3210  PRINT "                       A                  MN             B  "
3220  PRINT "                       !                  !!             !  "
```

```
3230  PRINT "_____________________________________________________________________________________"
3240  PRINT "                       |//////////////////|                              "
3250  PRINT "                       |//////////////////|<---D1--->                    "
3260  PRINT "                       <------------------|-----D2--->                   "
3270  PRINT "                       |//////////////////|                              "
3280  PRINT "                       |//////////////////|                              "
3290  PRINT "     RHO-1             |///// RHO-2 /////|          RHO-3                "
3300  PRINT "                       |//////////////////|                              "
3310  PRINT "                       |//////////////////|                              "
3320  PRINT "                       |//////////////////|                              "
3330  SUBEND
3340  SUB G1(Ncx,Ncy,Rad(*),Rhobar(*),J,R1,R2,R3,Center,D1,D2,Curve_set$) ! GRAP
HICS
3350  ! Ncx=NUMBER OF LOG CYCLES ON X-AXIS=4
3360  ! Ncy=NUMBER OF LOG CYCLES ON Y-AXIS=3
3370  ! Rad=ELECTRODE SPACINGS (AB/2)
3380  ! Rhobar=APPARENT RESISTIVITIES
3390  ! J=NUMBER OF POINTS ON THE CURVE
3400  ! R1,R2,R3= TRUE RESISTIVITIES
3410  ! Center=1,2,OR 3=LOCATION OF FIXED CENTER ON MEDIUM 1,2,OR 3
3420  ! D1,D2= DISTANCES TO CONTACTS
3430  DIM Ax(5),Ay(4)
3440  GRAPHICS
3450  IF Curve_set$="Y+1" THEN 4580
3460  Ax(1)=0
3470  Ay(1)=0
3480  IF Curve_set$="Y" THEN 3540
3490  INPUT "0:0 COORDINATES ? PRESS CONT FOR AUTO SCALE",Ax(1),Ay(1)
3500  IF Ax(1)=0 THEN 3540
3510  Ax(1)=10^INT(LGT(Ax(1)))
3520  GCLEAR
3530  GOTO 3550
3540  Ax(1)=10^INT(LGT(Rad(1)))
3550  FOR I=2 TO 5
3560  Ax(I)=Ax(I-1)*10
3570  NEXT I
3580  Minrho=Rhobar(1)
3590  Maxrho=Rhobar(1)
3600  FOR I=1 TO J-1                        !COMPUTE MINIMUM AND MAXIMUM Rhobar.
3610  IF Rhobar(I)<Minrho THEN Minrho=Rhobar(I)
3620  IF Rhobar(I)>Maxrho THEN Maxrho=Rhobar(I)
3630  NEXT I
3640  Average_rho=EXP((LOG(Rhobar(1))+LOG(Minrho)+LOG(Maxrho))/3)
3650  GOTO 3680
3660  Ay(1)=10^INT(LGT(Ay(1)))
3670  GOTO 3690
3680  Ay(1)=10^INT(LGT(Average_rho))/10
3690  FOR I=2 TO 4
3700  Ay(I)=Ay(I-1)*10
3710  NEXT I
3720  A1=10^(LGT(Ax(1))+Ncx)
3730  A2=10^(LGT(Ay(1))+Ncy)
3740  GRAPHICS
3750  LOCATE 7,115,5,100
3760  CALL Log_cycle(LGT(Ax(1)),LGT(A1),LGT(Ay(1)),LGT(A2),Ncx,Ncy)
3770  SETGU
3780  LORG 1
3790  X=90                            !DRAW DIKE SKETCH
3800  Y=85
3810  MOVE X,Y
3820  DRAW X+20,Y
3830  MOVE X+7,Y
3840  DRAW X+7,Y-7
3850  MOVE X+13,Y
3860  DRAW X+13,Y-7
```

```
3870  IF Center=2 THEN 3960
3880  IF Center=3 THEN 4030
3890  MOVE X+2.7,Y                              !DRAW SOUNDING TRIANGLE ON MEDIUM 1
3900  DRAW X+3.7,Y+3
3910  DRAW X+1.7,Y+3
3920  DRAW X+2.7,Y
3930  MOVE X-1.8,Y+1                            !DRAW ARROWS TO THE RIGHT AND LEFT
3940  LABEL "<- ->"
3950  GOTO Label1
3960  MOVE X+10,Y                               !DRAW SOUNDING TRIANGLE ON MEDIUM 2
3970  DRAW X+11,Y+3
3980  DRAW X+9,Y+3
3990  DRAW X+10,Y
4000  MOVE X+5.3,Y+1                            !DRAW ARROWS TO THE RIGHT AND LEFT
4010  LABEL "<- ->"
4020  GOTO Label1
4030  MOVE X+15,Y                               !DRAW SOUNDING TRIANGLE ON MEDIUM 3
4040  DRAW X+16,Y+3
4050  DRAW X+14,Y+3
4060  DRAW X+15,Y
4070  MOVE X+10.5,Y+1                           !DRAW ARROWS TO THE RIGHT AND LEFT
4080  LABEL "<- ->"
4090 Label1: !                                  !LABEL VALUES FOR RHO AND D
4100  X=20
4110  Y=95
4120  FIXED 2
4130  MOVE X,Y
4140  IF Curve_set$="N" THEN 4170
4150  LABEL "D1=1; D2 = as labeled"&"   RHO: "&VAL$(R1)&","&VAL$(R2)&","&VAL$(R3
)
4160  GOTO 4180
4170  LABEL "D1,D2: "&VAL$(D1)&","&VAL$(D2)&"   RHO: "&VAL$(R1)&","&VAL$(R2)&","
&VAL$(R3)
4180  X=7                                       !LABEL AXES
4190  Y=6
4200  MOVE X,Y
4210  FOR I=1 TO 5
4220  N=0                                       !FIXED ORDER (0,1,2,3,..etc)
4230  K=1
4240  IF Ax(I)>=K THEN Label2
4250  K=K/10
4260  N=N+1
4270  GOTO 4240
4280 Label2:  FIXED N
4290  LORG 4
4300 LABEL VAL$(Ax(I))
4310  X=X+27
4320  MOVE X,Y
4330  NEXT I
4340  MOVE 25,2
4350  LORG 1
4360  LABEL " SCHLUMBERGER ELECTRODE SPACING (AB/2)"
4370  MOVE 0,33
4380  DEG
4390  LORG 3
4400  LDIR 90
4410  LABEL "APPARENT RESISTIVITY"
4420  X=3
4430  Y=12
4440  MOVE X,Y
4450  FOR I=1 TO 4
4460  K=1
4470  N=0                                       !FIXED ORDER (0,1,2,3,...etc)
4480  IF Ay(I)>=K THEN Label3
4490  K=K/10
```

```
4500  N=N+1
4510  GOTO 4480
4520 Labels:  FIXED N
4530  LORG 6
4540  LABEL VAL$(Ay(I))
4550  Y=Y+27
4560  MOVE X,Y
4570  NEXT I
4580  LDIR 0
4590  LORG 1
4600  FIXED 4
4610  SETUU
4620  MOVE LGT(Rad(1)),LGT(Rhobar(1))
4630  FOR I=1 TO J-1
4640  PLOT LGT(Rad(I)),LGT(Rhobar(I))
4650  NEXT I
4660  BEEP
4670  WAIT 100
4680  BEEP
4690  SUBEND
4700  SUB Log_cycle(Lxmin,Lxmax,Lymin,Lymax,Ncx,Ncy)
4710  LINE TYPE 7
4720  SHOW Lxmin,Lxmax,Lymin,Lymax
4730  MOVE Lxmin,Lymin
4740  FOR I=1 TO Ncx+1
4750  X=Lxmin+I-1
4760  PLOT X,Lymin,1
4770  PLOT X,Lymax,2
4780  NEXT I
4790  FOR I=1 TO Ncy+1
4800  Y=Lymin+I-1
4810  PLOT Lxmin,Y,1
4820  PLOT Lxmax,Y,2
4830  NEXT I
4840  LINE TYPE 1
4850  SUBEND
```