UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# Schlumberger electric soundings in the Charleston, S. C., earthquake area

by

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Open-File Report 77-617

1977



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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In June 1976, the U.S. Geological Survey made 22 direct current Schlumberger soundings (VES) in the vicinity of Charleston, S. C. The soundings were designated CSC76-1 through CSC76-22. The data were judged to be of very high quality at all stations except CSC76-19, which was near a high-tension power line, and CSC76-15, where inconsistent data may have been due to a nearby buried telephone cable. Electric basement was detected[1] at all stations but these two.

Plate 1 shows location, azimuth, and designation number for the 22 CSC76 soundings (open circles), as well as for 9 other VES (solid circles) made in 1975 and reported earlier (Campbell, 1977). For completeness, the earlier reported depth-resistivity solutions for the 1975 stations are reproduced in Table 1 (page 6).

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1 A VES field curve which for large electrode spacings AB/2 has an upward slope of (about) 45° is said to have detected electric basement. Such a signature is characteristic of true crystalline basement at depth, but may also be caused by other thick, high-resistivity units. In the Charleston area, any deep, thick unit having resistivity in excess of about 100 ohm-m would be seen as electric basement. Thus some of the "basements" reported herein may just be well-indurated sedimentary units, not crystalline rocks.

The CSC76 sounding curves were processed and interpreted by computer[2] as shown in Figures 1-22. Each figure shows the following:

(1) Field data designated by a segmented solid-line curve connecting observed data, plotted with diamond symbols.

(2) A dashed curve which is a continuous representation of the field data. This continuous "field" curve is obtained by shifting the various segments upwards or downwards, usually with respect to the last segment on the segmented field curve (Zohdy and others, 1973), smoothing it by using a subroutine for bicubic spline functions (Anderson, 1971), and digitizing at the rate of six points per logarithmic cycle. The digitized data were then inverted using a computer interpretation program written by Zohdy (1974a and 1975).

(3) The detailed layering solution found by the computer interpretation program and points, plotted as + or x signs, on a sounding curve calculated from that layering.

(4) The Dar Zarrouk (D.Z.) curve intersection points for the detailed layering, plotted as solid dots. On some of the graphs the ordinate values for the D.Z. points are shifted upward or downward by one logarithmic cycle to avoid cluttering the graphs. The D.Z. curves can be used to obtain

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2 All graphs were originally machine-plotted, but some of the figures have been traced from two such graphs, in order to show an improved layering solution which resulted from changing the fit-tolerance parameters in the computer program.

equivalent and simpler solutions containing fewer number of layers and in which certain constraints are imposed on the layer thickness and resistivities (Zohdy, 1974b).

Table 2 (pages 7-8) lists resistivity-depth solutions for CSC76-1 through CSC76-22. These solutions have 8 layers or less, and were derived using the plotted D.Z. points. They are equivalent to the multi-layer solutions plotted in the figures in the sense that they give equally good fit to the smoothed data curves. Their main advantage is their relative simplicity, and the insight they give into the solution variations which are permitted by the data. The listed depths are judged correct to ±10%, and the listed resistivities are an average in the Dar Zarrouk sense (Zohdy, 1974b) of the true resistivities in the corresponding depth interval. Entries marked with a query (?), however, are not well constrained by the field data, and so may have larger errors.

No layering solutions for the CSC 76 soundings can be constrained by well data at this time. There presently are only three deep coreholes in the area, all near Clubhouse Crossroads, S.C. These coreholes are designated CCC1, CCC2, and CCC3 on Plate 1. All three coreholes encountered basalt flows at about 750 m depth, and CCC3 penetrated through about 260 m of basalt into a sedimentary unit which underlies the basalt unit (D. W. Rankin, written commun., 1977). None of the wells reached crystalline basement. The electrical sounding nearest to these coreholes is VES 1 of 1975, which did not detect a high-resistivity layer corresponding to the basalt, but did detect electric basement at about 1300 m.

The field data do not define resistivity values for electric basement, but only indicate that its resistivity is many times that of the layer above. In some cases, subtle features in the field data indicate a possibility of two high-resistivity units at depth; these soundings are marked "double basement?" on Table 2. The listed solution for CSC76-VES2, for example, shows a resistivity increase from 9 to 47 ohm-m at 560 m (basalt?) and a second increase from 47 ohm-m to a much higher value at 2850 m (crystalline basement?). In all cases marked "double basement", the features in the observed data which give rise to this interpretation could be due instead to lateral geological causes such as high-resistivity dikes or faults, or to cultural causes such as fences or pipelines. I prefer the "double basement" interpretation because these alternative causes appear to be rare in the study area. Finally, some electric basement depths in Table 2 (for example, CSC76-19) are listed with a plus sign to indicate they represent a calculated minimum depth only (see Keller and Frischknecht, 1966, p. 124-5); true electric basement may be much deeper at these sites.

## References

Anderson, W. L., 1971, Application of bicubic spline functions to two dimensional guided data: NTIS (National Technical Information Service), No. PB-203579, Springfield, Va.

Campbell, D. L., 1977, Electric and electromagnetic soundings near Charleston, South Carolina, a preliminary report: U.S. Geol. Survey Prof. Paper 1026-M, (in press).

Keller, G. V., and Frischknecht, F. C., 1966, Electrical methods in geophysical prospecting: New York, Pergamon Press, 517 p.

Zohdy, Adel A. R., 1974a, A computer program for the automatic interpretation of Schlumberger sounding curves over horizontally stratified media: NTIS (National Technical Information Service), No. PB-232703/AS, 25 p. Springfield, Va.

Zohdy, Adel A. R., 1974b, The use of Dar Zarrouk curves in the interpretation of VES data: U.S. Geol. Survey Bull. 1313-D, 41 p.

Zohdy, Adel A. R., 1975, Automatic interpretation of Schlumberger sounding curves using modified Dar Zarrouk functions: U.S. Geol. Survey Bull. 1313-E, 39 p.

Zohdy, Adel A. R., Anderson, L. A., and Muffler, L. J. P., 1973, Resistivity, self potential, and induced polarization surveys of a vapor-dominated geothermal system: Geophysics, v. 38, p. 1130-1144.

Table 1.—Interpreted VES solutions - 1975 soundings. From Campbell, 1977.

($\rho$ = resistivity of layer in ohm-m; d = depth to bottom of layer in meters)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| VES 1 | | | | | | | | | |
| ρ= | 810 | 90 | 313 | 39 | 23 | 71 | 10,8 | 1,63 | 200? |
| d= | 1.5 | 4.9 | 6.6 | 30 | 125 | 166 | 689 | 1319 | ∞ |
| VES 2 | | | | | | | | | |
| ρ= | 1200 | 256 | 75 | 14 | 4.5 | 200? | | | |
| d= | 2,6 | 10,1 | 64 | 310 | 900 | ∞ | | | |
| VES 3 | | | | | | | | | |
| ρ= | 80 | 146 | 63 | 7 | 25 | 8 | 200? | | |
| d= | 2.3 | 4.9 | 27 | 59 | 194 | 1186 | ∞ | | |
| VES 4 | | | | | | | | | |
| ρ= | 120 | 25 | 60 | 16 | 50 | 4 | 200? | | |
| d= | 1.5 | 8 | 26 | 110 | 150 | 900 | ∞ | | |
| VES 5 | | | | | | | | | |
| ρ= | 1200 | 300 | 15 | 40 | 7 | 200? | | | |
| d= | 1,5 | 14 | 64 | 96 | 1350 | ∞ | | | |
| VES 6 | | | | | | | | | |
| ρ= | 45 | 91 | 21 | 40 | 10.6 | 4.2 | 200? | | |
| d= | 1.65 | 5 | 14.5 | 47 | 409 | 1113 | ∞ | | |
| VES 7 | | | | | | | | | |
| ρ= | 320 | 64 | 302 | 20,6 | 52.1 | 4.8 | 200? | | |
| d= | 1.7 | 4.4 | 11.3 | 182 | 320 | 965 | ∞ | | |
| VES 8 | | | | | | | | | |
| ρ= | 1000 | 74.5 | 38.4 | 124 | 23 | 7.6 | 200? | | |
| d= | 2.3 | 25 | 68.4 | 139.2 | 889 | 1475 | ∞ | | |
| VES 9 | | | | | | | | | |
| ρ= | 700 | 72 | 15 | 6 | 200? | | | | |
| d= | 10.6 | 70.5 | 226 | 1300 | ∞ | | | | |

Table 2.--Dar Zarrouk-smoothed computer solutions showing resistivity-depth layering for 1976 d.c. electrical soundings near Charleston, S.C.

(ρ = resistivity, in ohm-m, d = depth to bottom of layer, in meters. and ± indicates minimum depth. Depths have 10% likely error except those marked ? may have larger errors.)

CSC76-VES 1

| | | | | | | |
|---|---|---|---|---|---|---|
| ρ= | 29 | 13 | 118 | 31 | 12.5 | 100? |
| d= | 1.9 | 4.2 | 55 | 216 | 1160 | ∞ |

CSC76-VES 2 (Double basement?)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ρ= | 212 | 70 | 46 | 100 | 9 | 47 | 400? |
| d= | 1.65 | 8.9 | 34 | 120 | 560 | 2850 | ∞ |

CSC76-VES 3

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ρ= | 300 | 61 | 32 | 62 | 21 | 8 | 13.4 | 400? |
| d= | 1.8 | 8.9 | 17 | 40 | 240 | 580 | 1750 | ∞ |

CSC76-VES 4 (Double basement?--This inference based on only one data point.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ρ= | 540 | 16 | 95 | 14 | 42 | 5.8 | 65 | 400? |
| d= | 2.2 | 4.4 | 10.5 | 42 | 270 | 660 | 1420? | ∞ |

CSC76-VES 5

| | | | | | |
|---|---|---|---|---|---|
| ρ= | 170 | 7 | 42 | 10 | 400? |
| d= | 1.3 | 33 | 100 | 1300 | ∞ |

CSC76-VES 6

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ρ= | 150 | 3.7 | 15.7 | 10.5 | 18.7 | 15 | 9 | 400? |
| d= | 1.3 | 4.4 | 8.3 | 41 | 150 | 540 | 1280 | ∞ |

CSC76-VES 7

| | | | | | | |
|---|---|---|---|---|---|---|
| ρ= | 400 | 800 | 50 | 21 | 6.3 | 400? |
| d= | 2.1 | 4.9 | 40 | 285 | 850 | ∞ |

CSC76-VES 8

| | | | | | | |
|---|---|---|---|---|---|---|
| ρ= | 140 | 9.8 | 82 | 16 | 4 | 400? |
| d= | 1.75 | 7.2 | 44 | 360 | 640 | ∞ |

CSC76-VES 9 (Double basement?)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ρ= | 800 | 97 | 42 | 120 | 37 | 6.3 | 22 | 100? |
| d= | 3.2 | 12 | 30 | 60 | 170 | 500 | 2300? | ∞ |

CSC76-VES 10

| | | | | | | |
|---|---|---|---|---|---|---|
| ρ= | 2400 | 1290 | 256 | 18 | 10.5 | 300? |
| d= | 2.3 | 4.6 | 17.5 | 158 | 930 | ∞ |

CSC76-VES 11

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\rho$= | 70 | 10 | 50 | 29 | 60 | 5.6 | 400? |
| d= | 1.8 | 5.6 | 35 | 73 | 170 | 710 | ∞ |

CSC76-VES 12

| | | | | | | |
|---|---|---|---|---|---|---|
| $\rho$= | 500 | 51 | 10 | 74 | 4.9 | 400? |
| d= | 2.2 | 14 | 32 | 165 | 870 | ∞ |

CSC76-VES 13 (Double basement??)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\rho$= | 740 | 300 | 35 | 105 | 22 | 4 | 10 | 100? |
| d= | 5.5 | 12 | 42 | 106 | 212 | 450 | 1535 | ∞ |

CSC76-VES 14

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\rho$= | 650 | 210 | 17 | 102 | 21 | 7.2 | 150? |
| d= | 1.6 | 3.2 | 26 | 122 | 266 | 783 | ∞ |

CSC76-VES 15 (Bad data - buried cables along road.)

| | | | |
|---|---|---|---|
| $\rho$= | 1650 | 160 | 29 |
| d= | 4.8 | 18 | 200? |

CSC76-VES 16 (Questionable data—taken during thunderstorm—determines basement.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\rho$= | 2100 | 1370 | 21 | 82 | 28 | 3.3 | 90? |
| d= | 1.5 | 6.5 | 25 | 98 | 158 | 627? | ∞ |

CSC76-VES 17 (High-resistivity basement not seen.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\rho$= | 140 | 300 | 40 | 21 | 6 | 14 | 40? |
| d= | 1.7 | 5 | 32 | 210 | 500 | 1530 | ∞ |

CSC76-VES 18 (Double basement? This inference based on only one data point.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\rho$= | 46 | 73 | 36 | 15.3 | 5.2 | 24 | 400? |
| d= | 8.5 | 17.6 | 54 | 220 | 860 | 1700+ | ∞ |

CSC76-VES 19 (High-resistivity basement not seen. Highline nearby.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\rho$= | 1600 | 200 | 80 | 14 | 54 | 31 | 13 | 40? |
| d= | 4 | 12 | 22 | 40 | 100 | 284 | 990+ | ∞ |

CSC76-VES 20 (Questionable data determines basement. Possible lateral effects.)

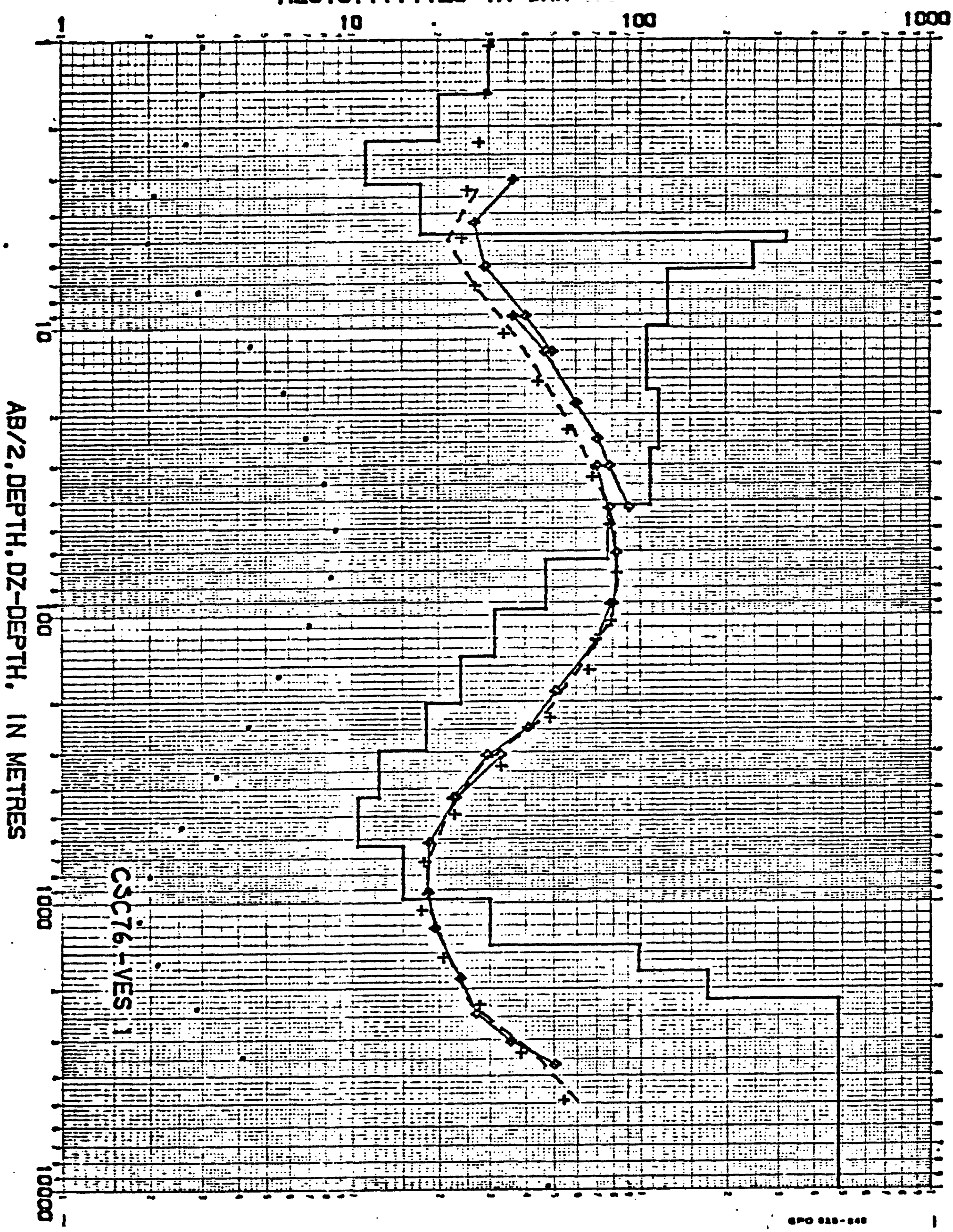
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\rho$= | 1400 | 640 | 57 | 12 | 39 | 20 | 10 | 200? |
| d= | 2.2 | 4.5 | 21 | 43 | 124 | 255 | 1020? | ∞ |

CSC76-VES 21 (Possible double basement or lateral effects.)

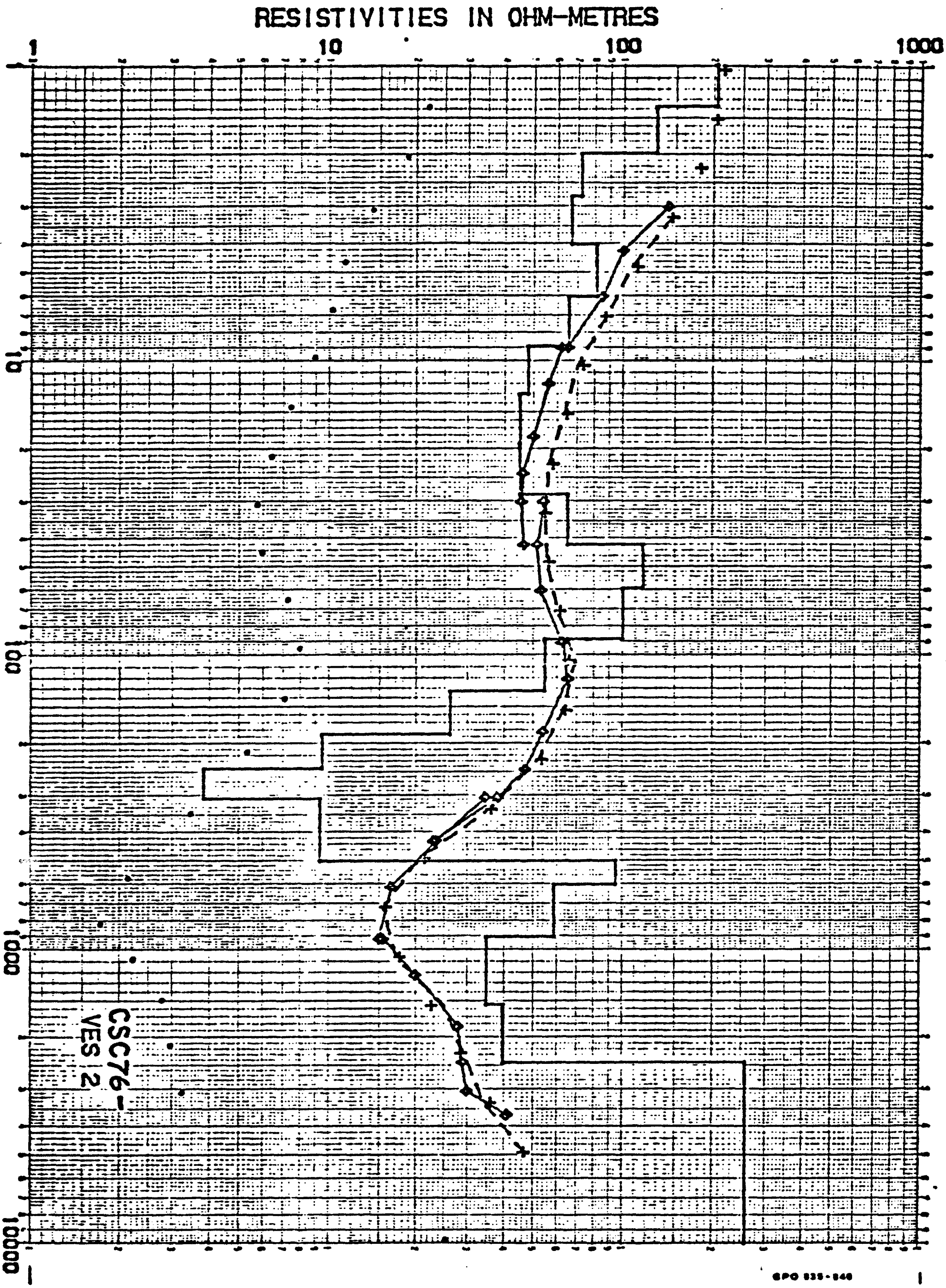
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\rho$= | 700 | 246 | 90 | 15 | 7 | 30? | 100? |
| d= | 3 | 16 | 60 | 300 | 1120 | 2616+ | ∞ |

CSC76-VES 22 (Questionable data determines basement.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\rho$= | 4200 | 1050 | 35 | 66 | 4 | 12 | 3.5 | 400? |
| d= | 2.2 | 8 | 30 | 52 | 120 | 200 | 700 | ∞ |



1
10
100
1000
AB/2,DEPTH,DZ-DEPTH, IN METRES
10
100
1000
10000
C3C76-VES 1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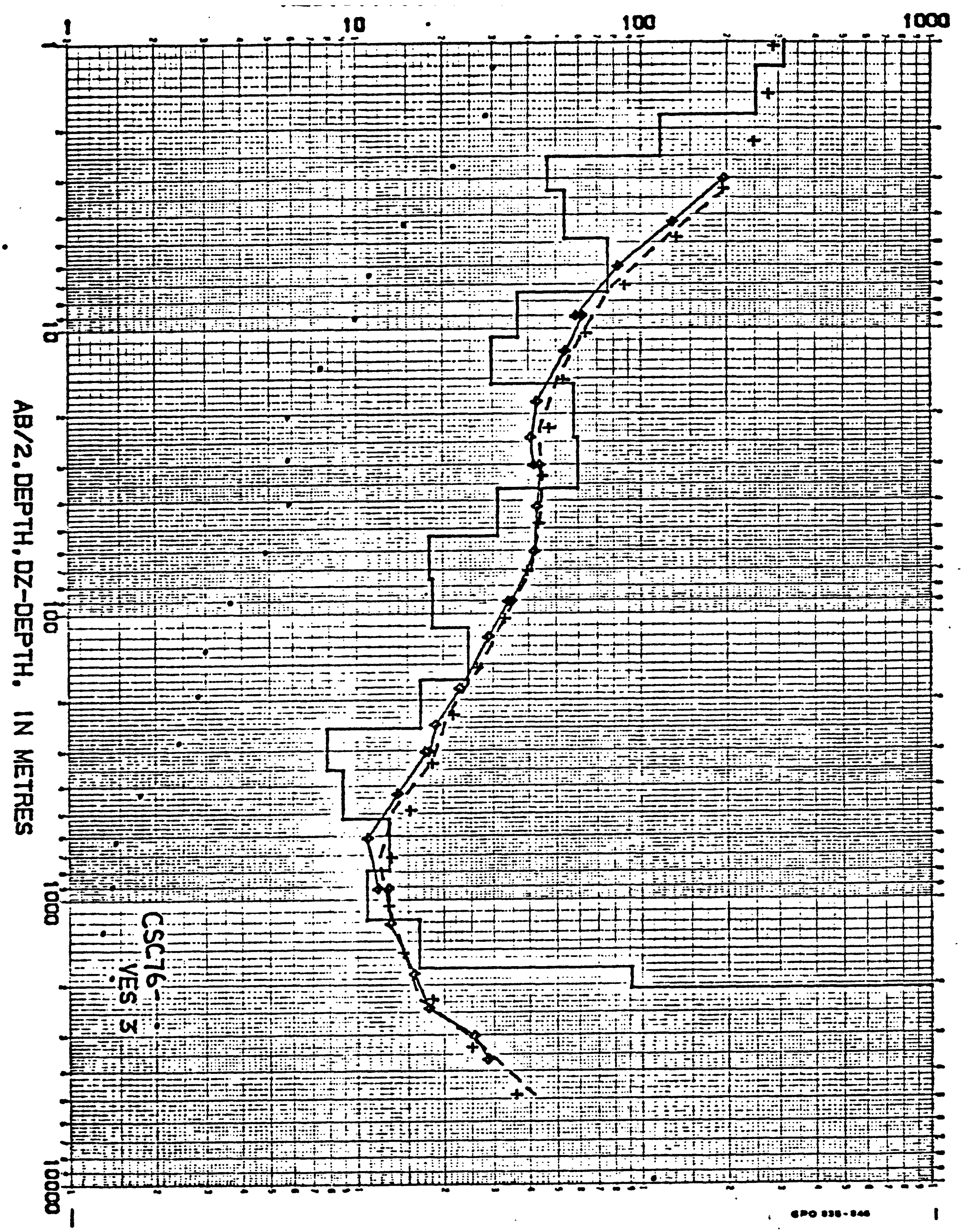
100
1000
10
100
1000
10000
CSC76-
VES 2



1
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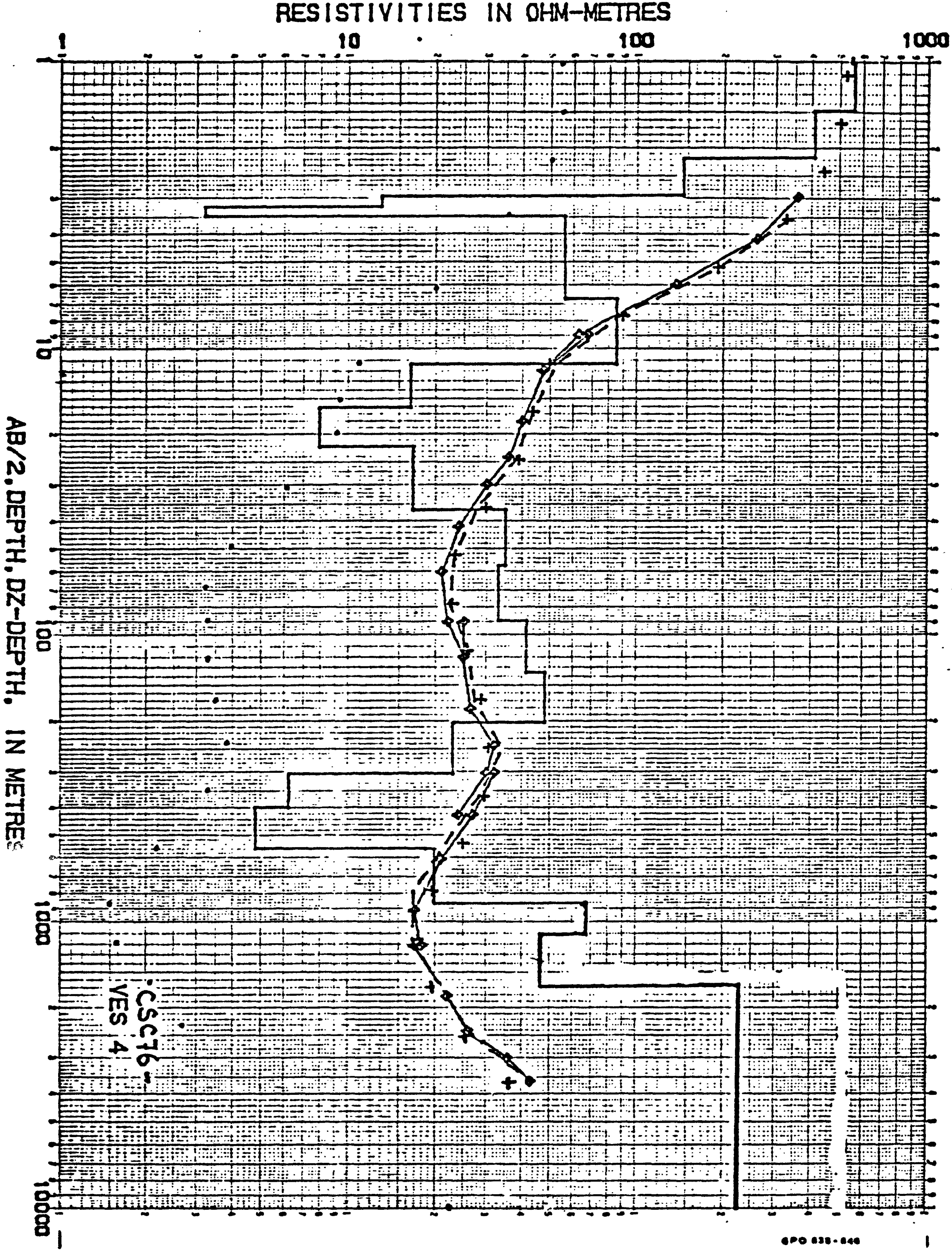
100
1000
AB/2,DEPTH,DZ-DEPTH. IN METRES
CSC76-
VES 3
10000


RESISTIVITIES IN OHM-METRES
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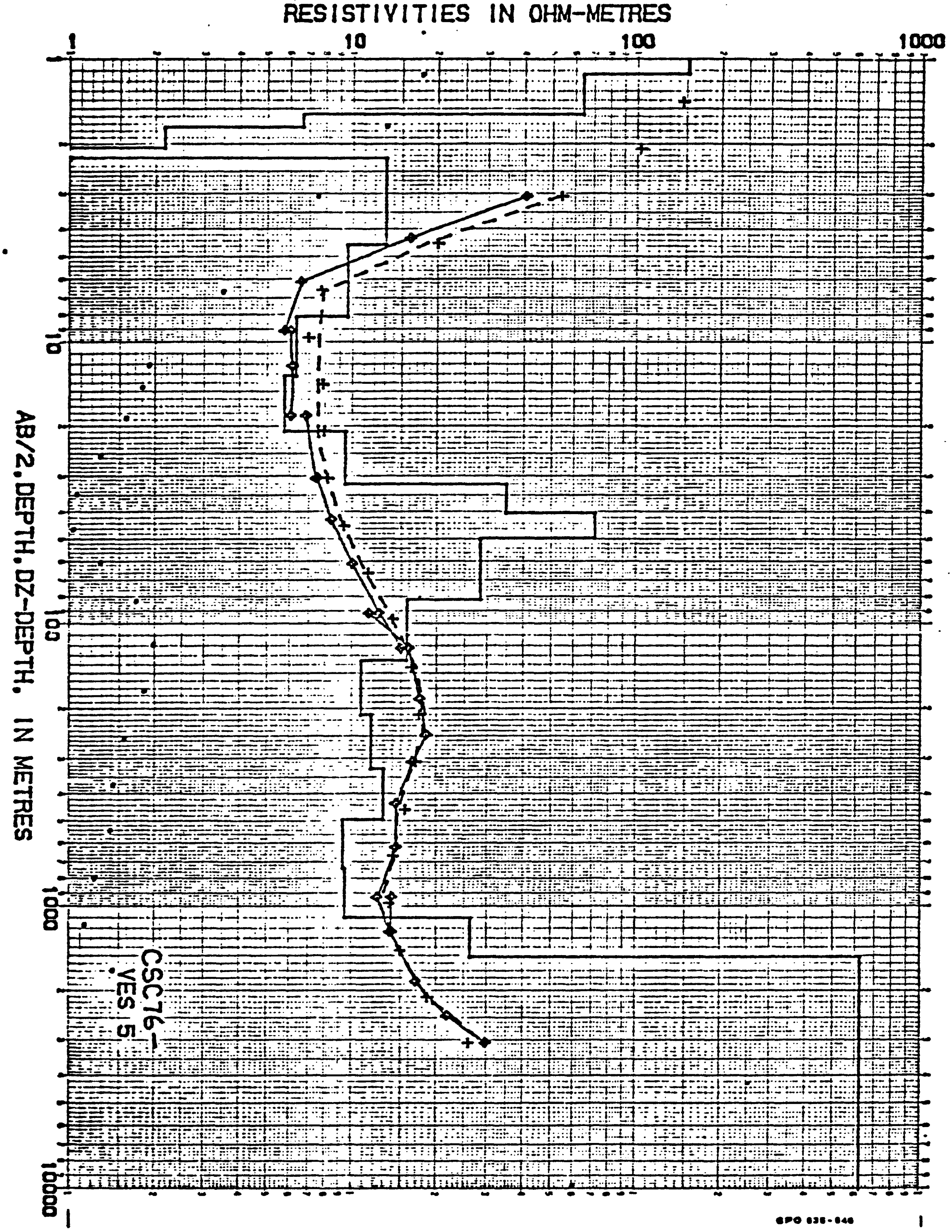
100
1000
AB/2, DEPTH, DZ-DEPTH, IN METRES
10
100
1000
10000
CSC76
VES 4


RESISTIVITIES IN OHM-METRES
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1000
AB/2,DEPTH,DZ-DEPTH, IN METRES
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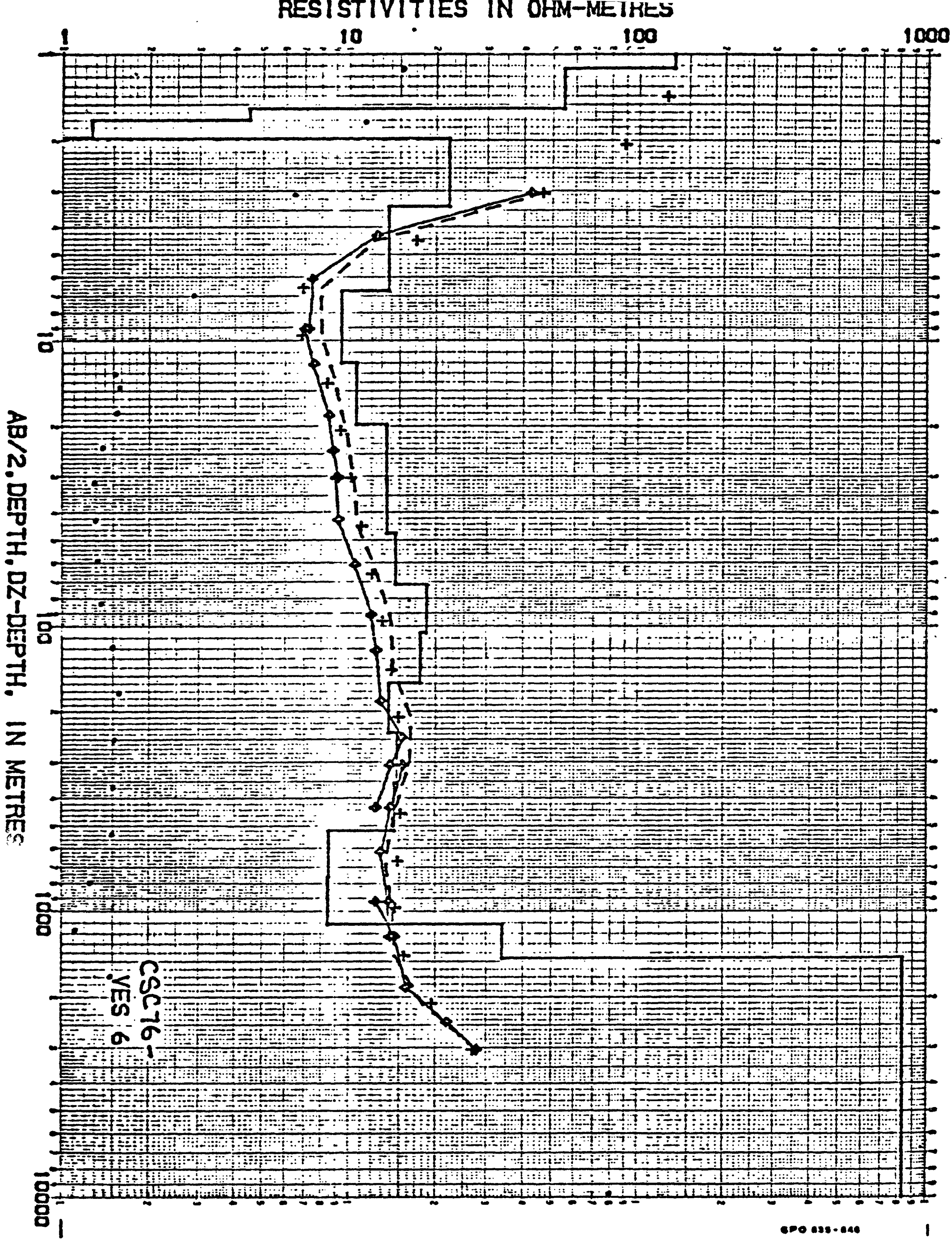
100
1000
10000
CSC76-
VES 5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AB/2, DEPTH, DZ-DEPTH, IN METRES
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1000
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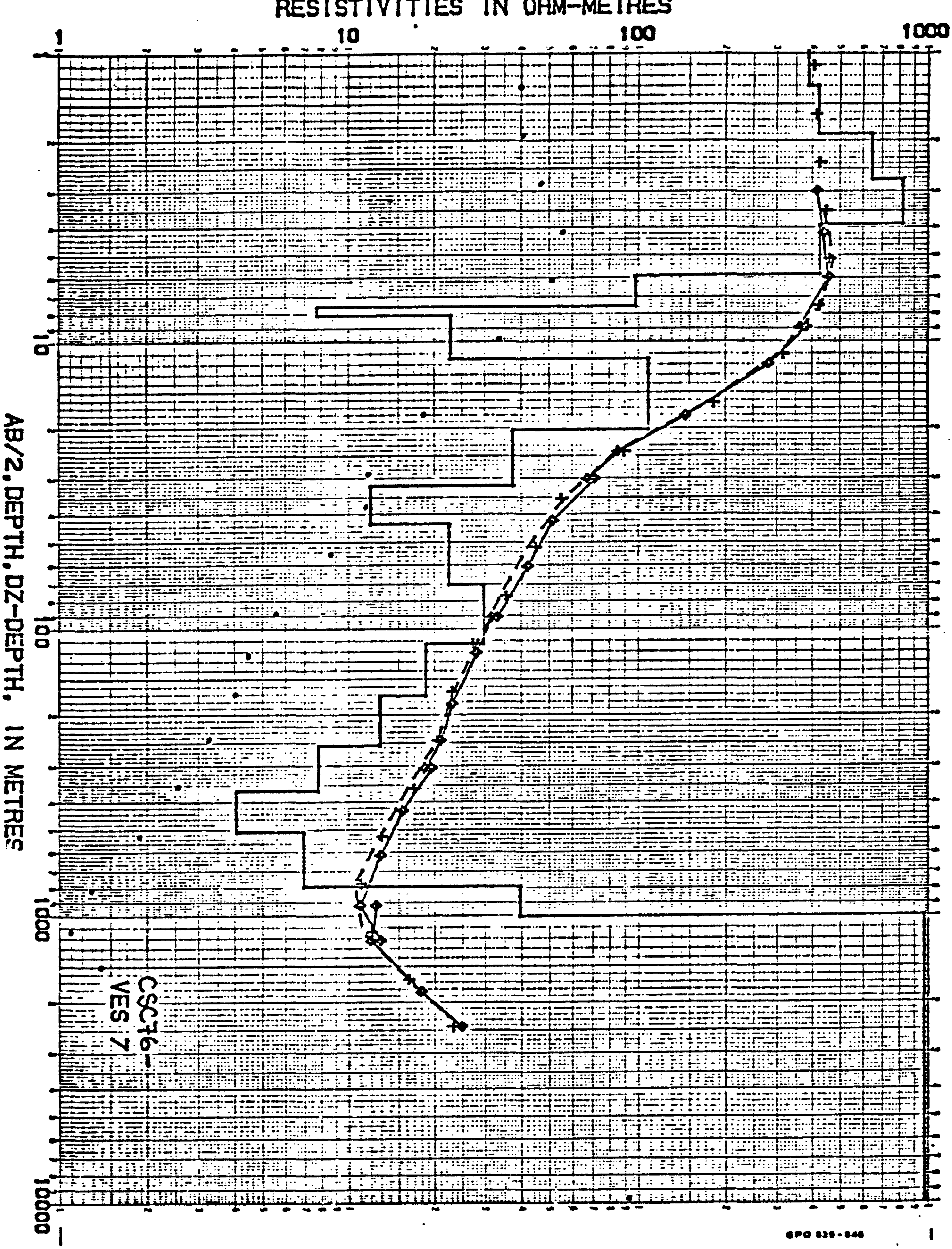
CSC76-
VES 6
GPO 835-846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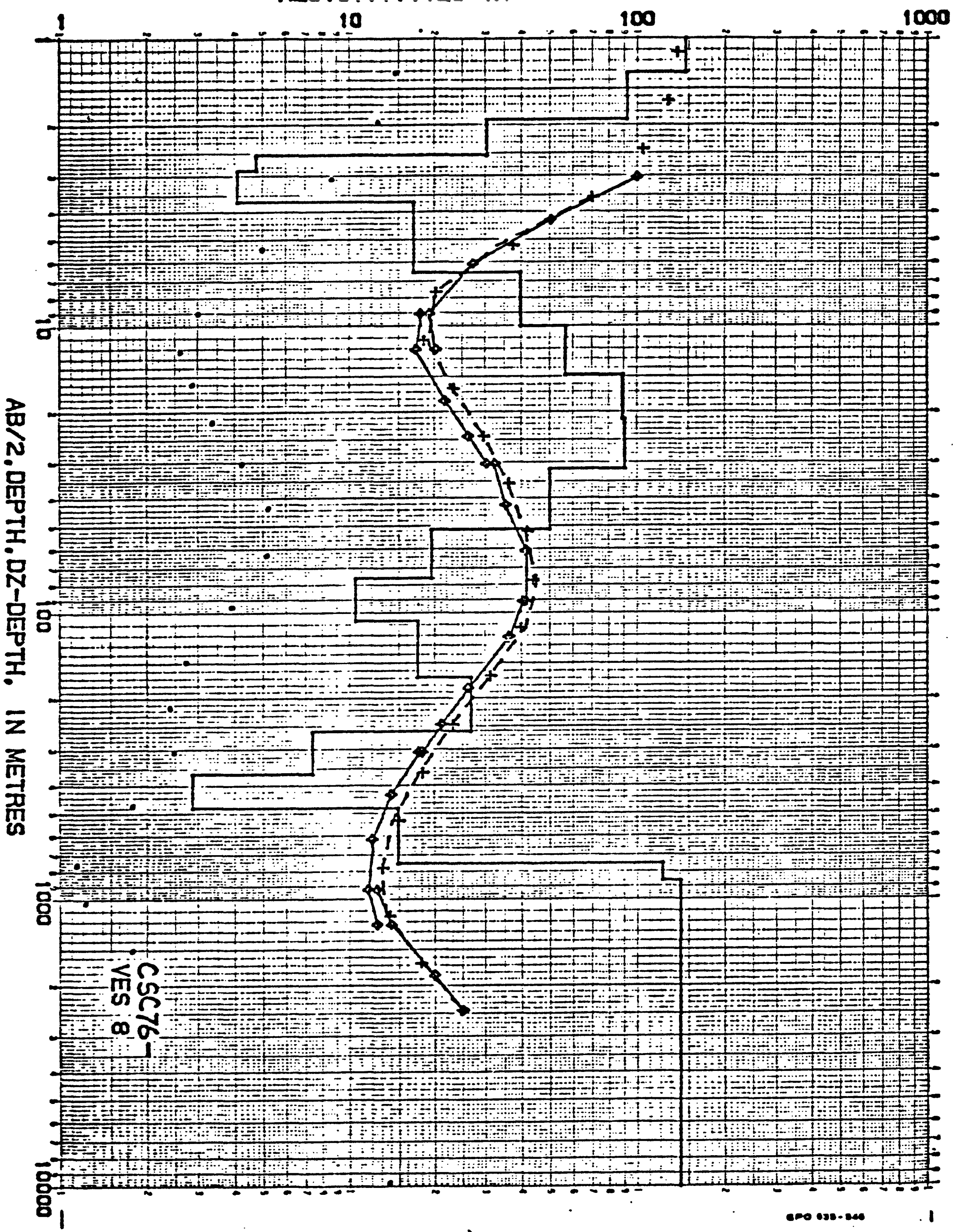
AB/2, DEPTH, DZ-DEPTH, IN METRES
10
100
1000
10000
CSC76-
VES 7
GPO 835-846



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AB/2.DEPTH.DZ-DEPTH, IN METRES
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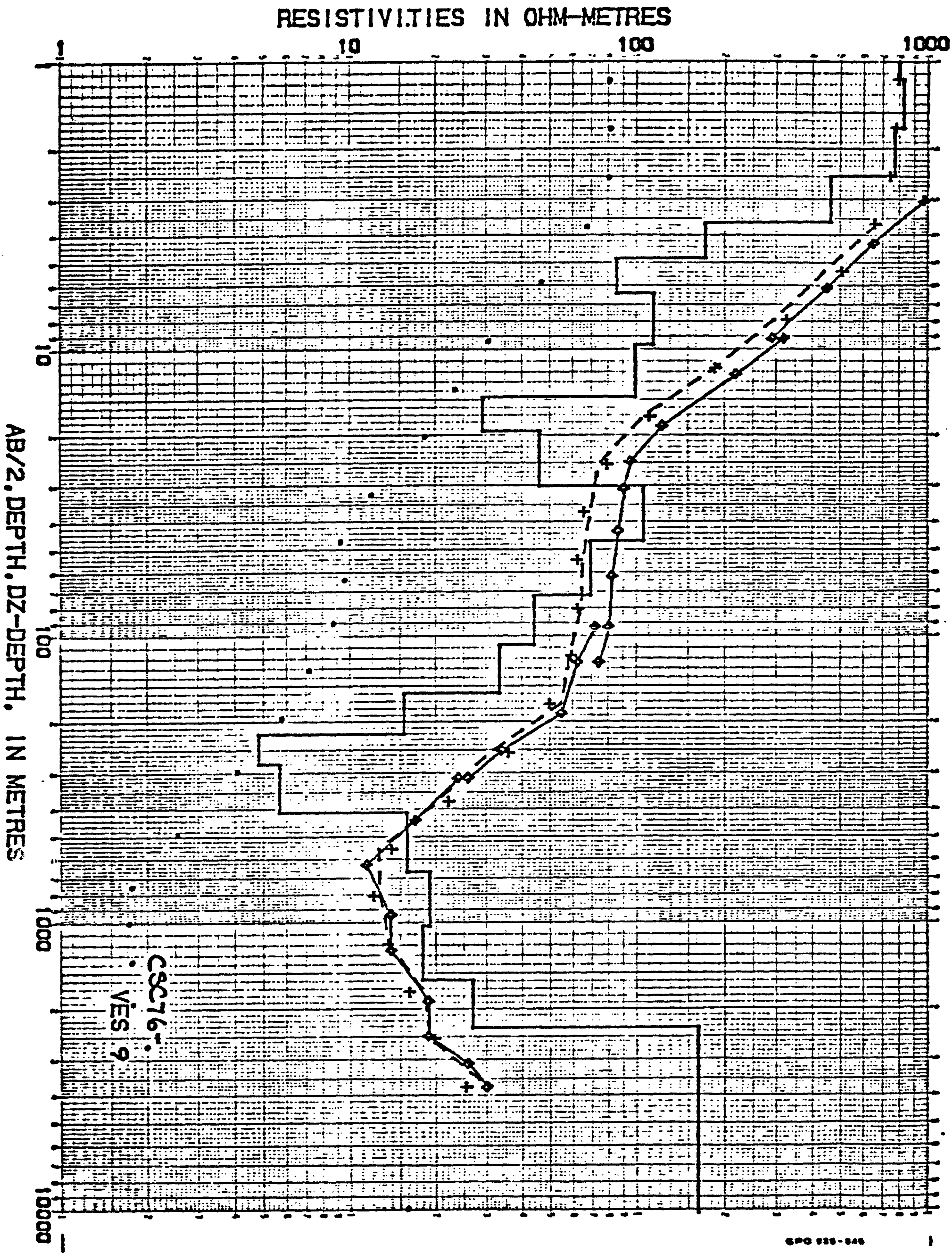
100
1000
10000
CSC76-
VES 8



RESISTIVITIES IN OHM-METRES
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AB/2, DEPTH, DZ-DEPTH, IN METRES
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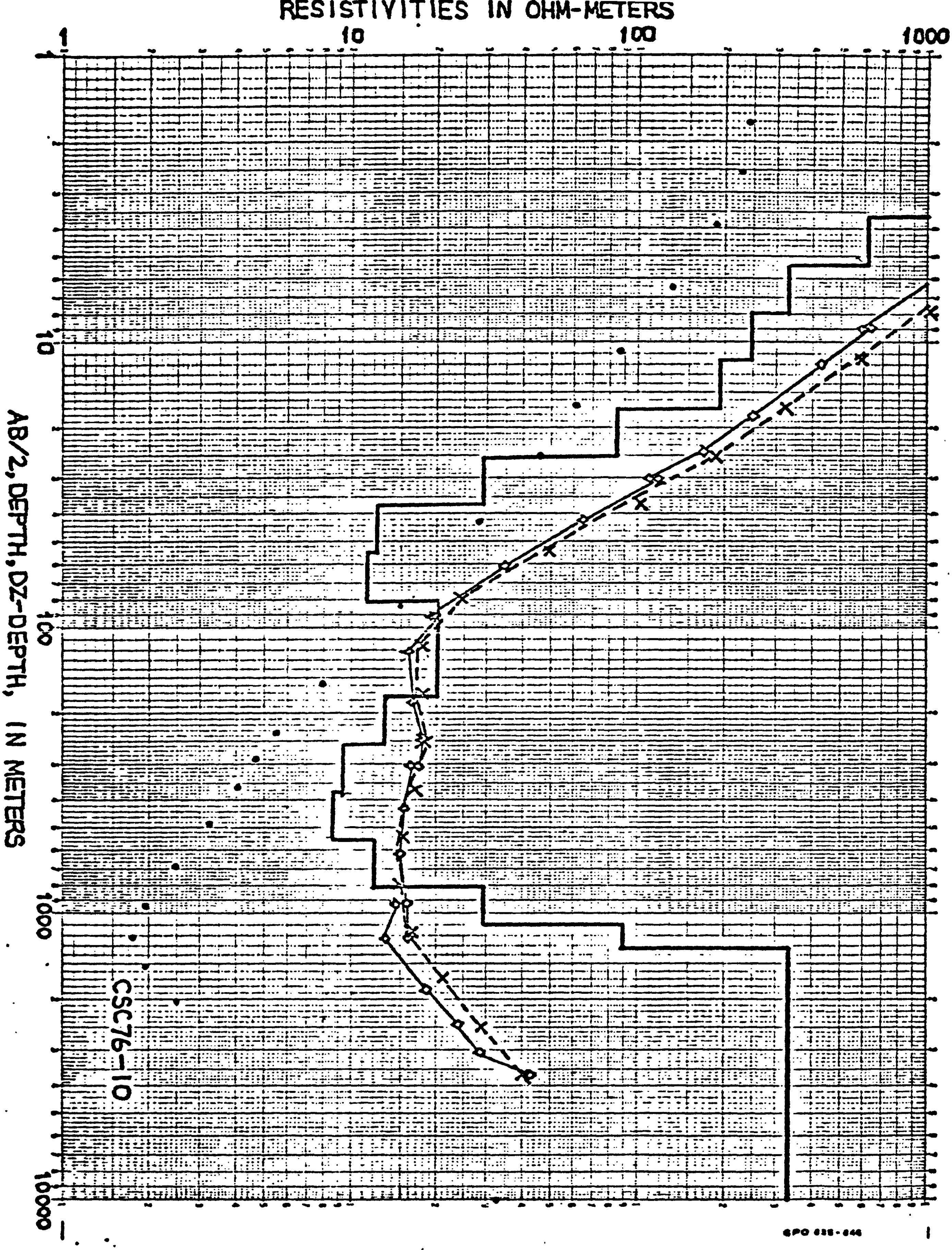
100
1000
10000
CSC76-
VES 9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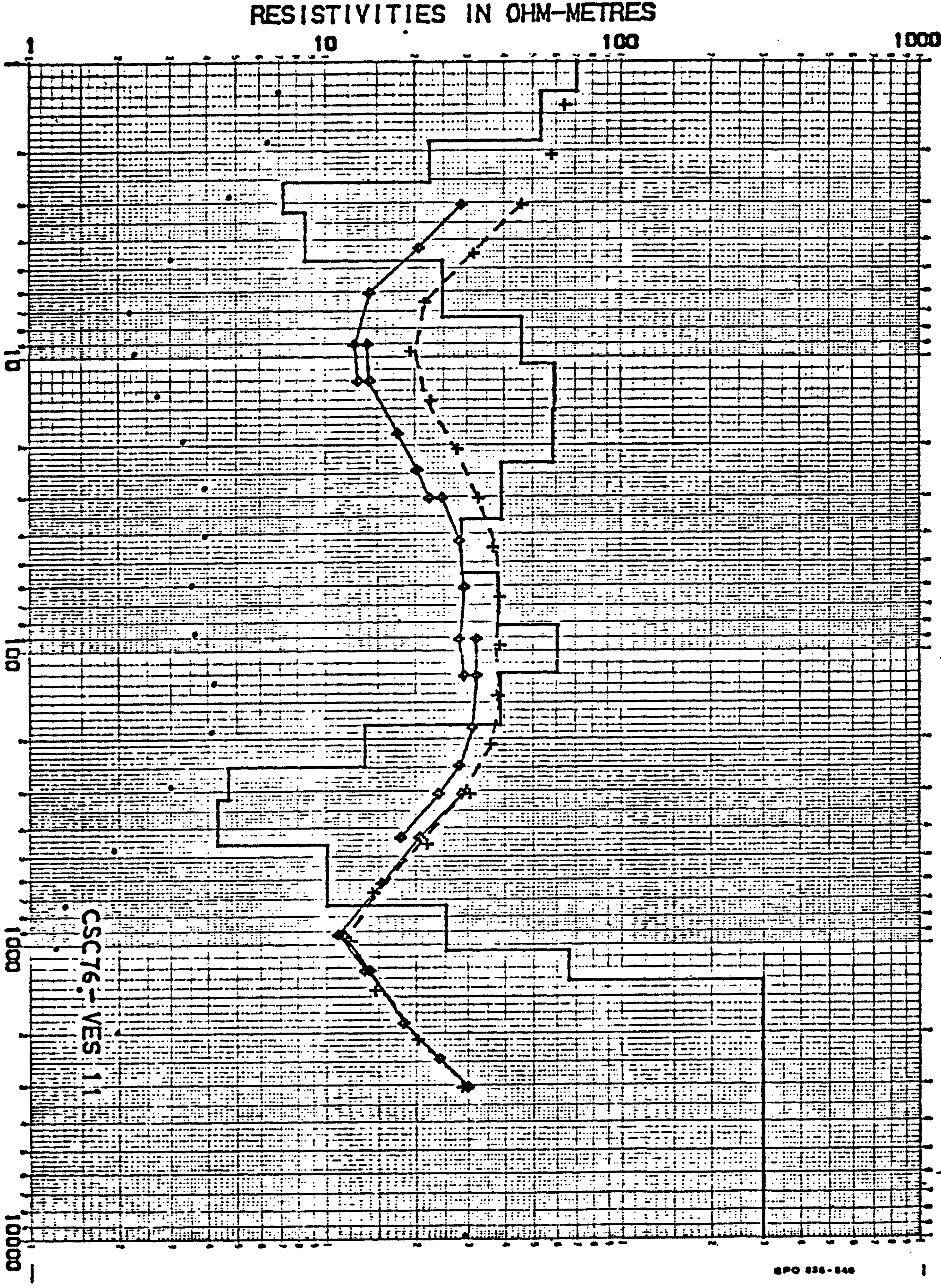
CSC76-10


RESISTIVITIES IN OHM-METRES
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AB/2,DEPTH,DZ-DEPTH, IN METRES
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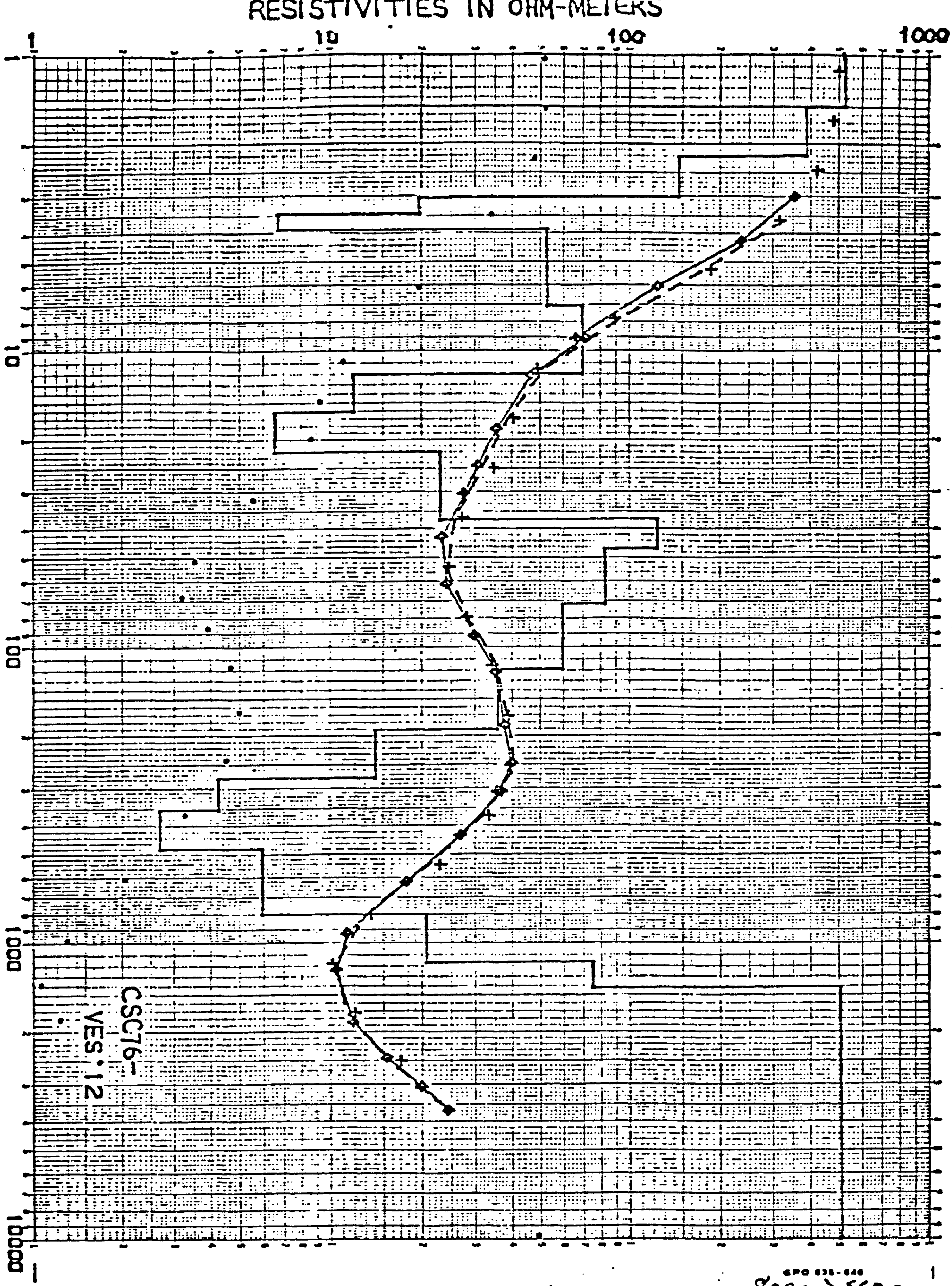
100
1000
10000
CSC76-VES 11


RESISTIVITIES IN OHM-METERS
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AB/2,DEPTH,DZ-DEPTH, IN METRES
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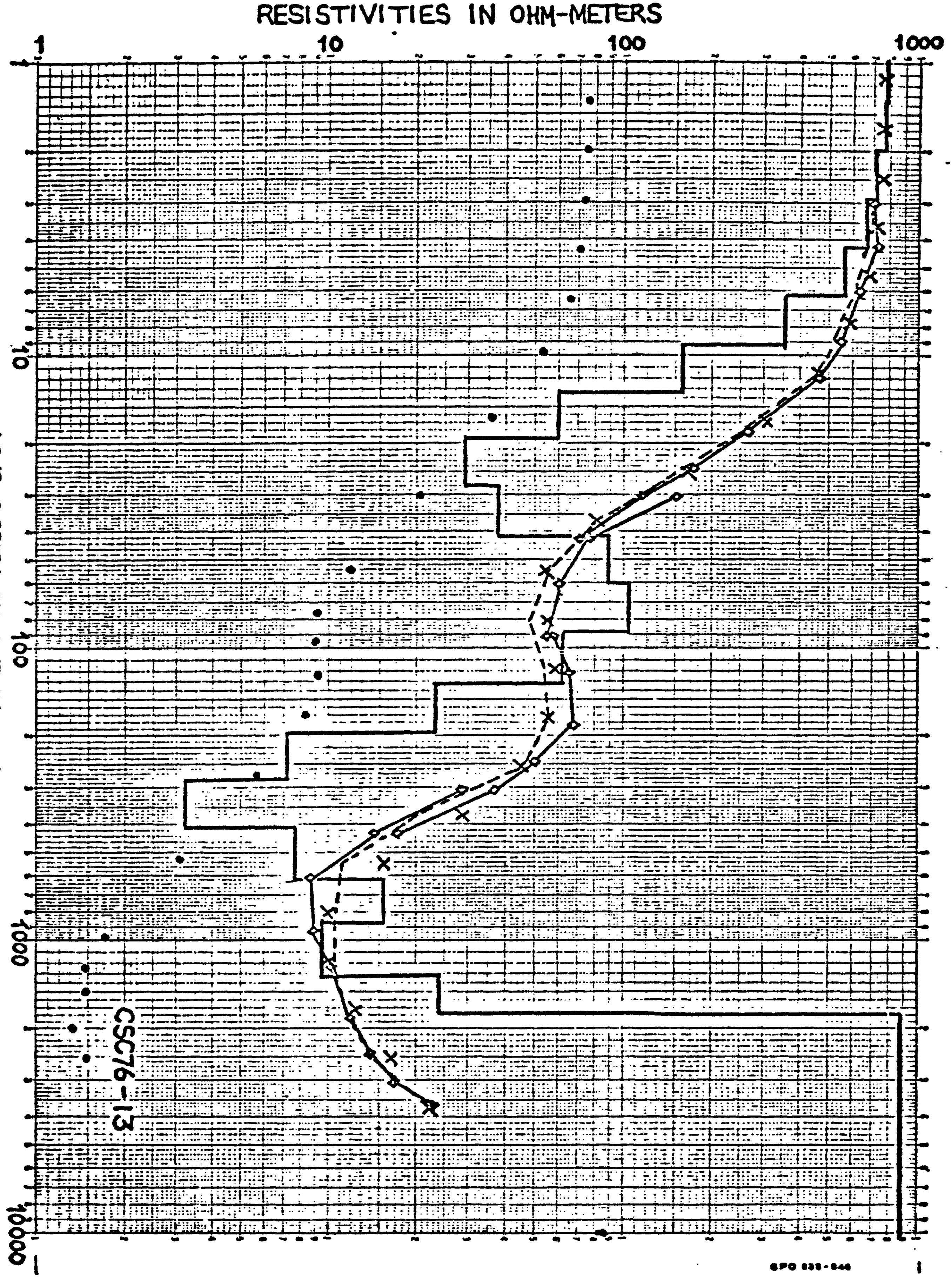
100
1000
CSC76-
VES 12

Slope > 45.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AB/2, DEPTH, DZ-DEPTH, IN METERS
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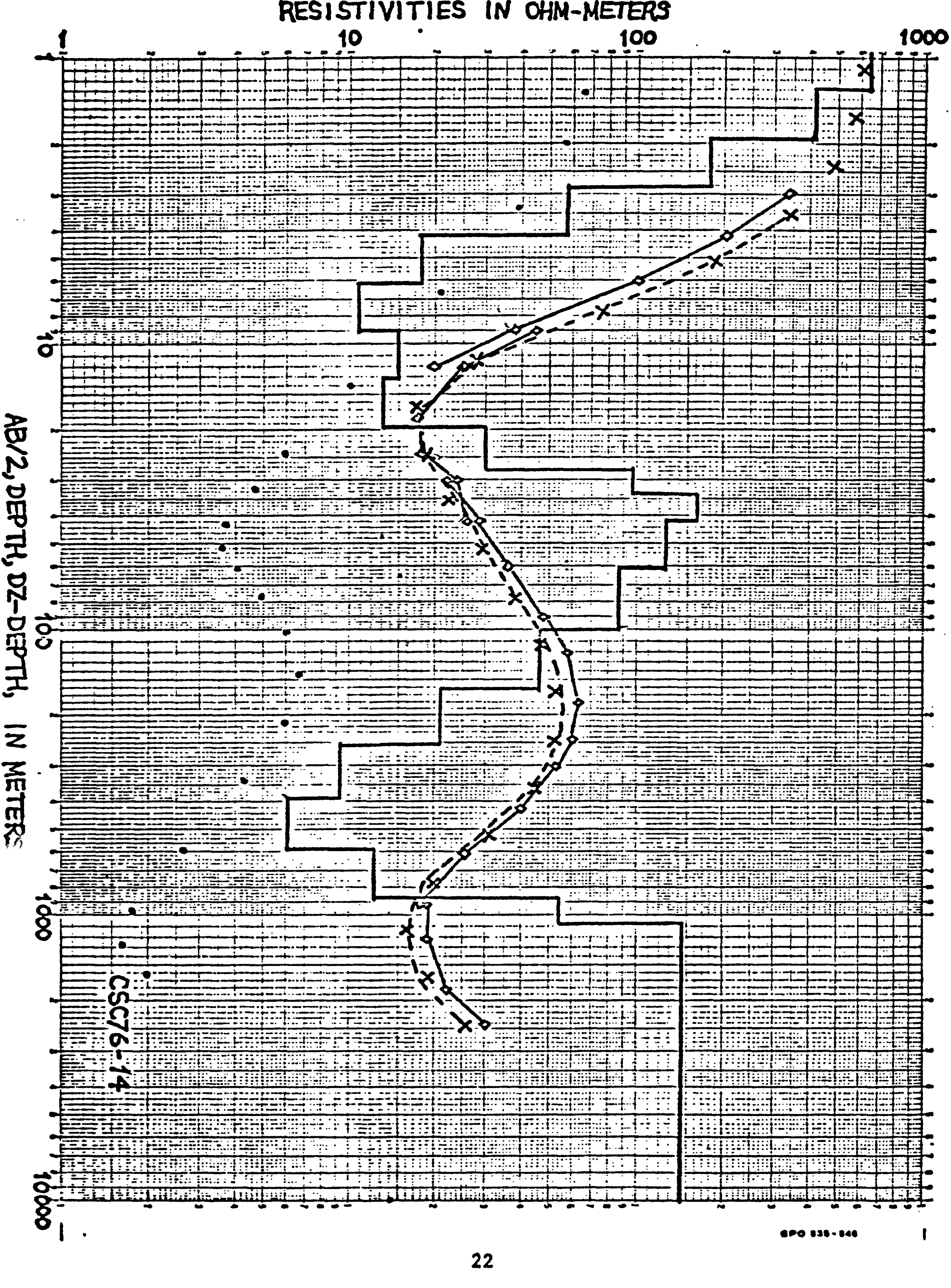
1000
10000
CSC76-13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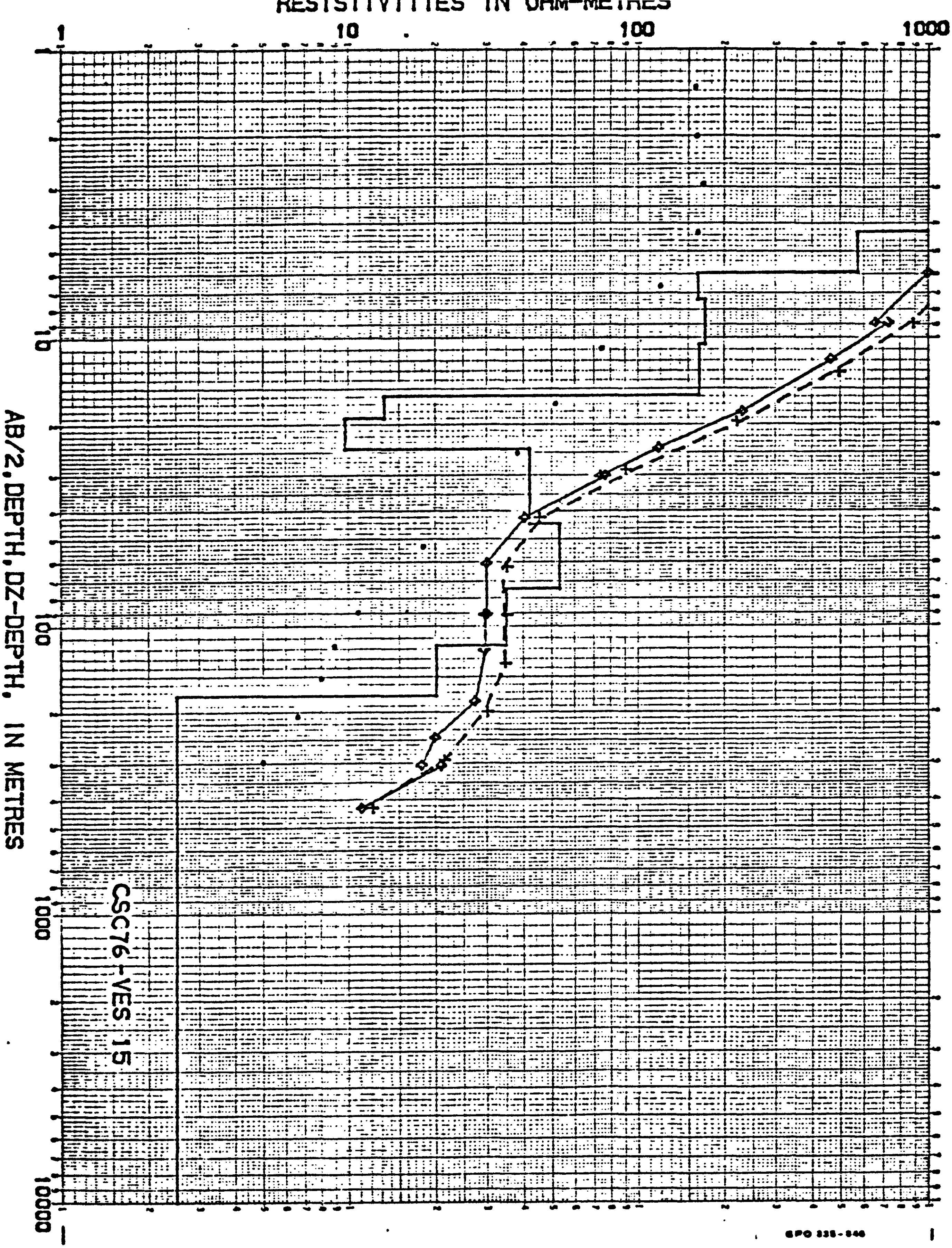
CSC76-14
GPO 835-846


RESISTIVITIES IN OHM-METRES
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AB/2, DEPTH, DZ-DEPTH, IN METRES
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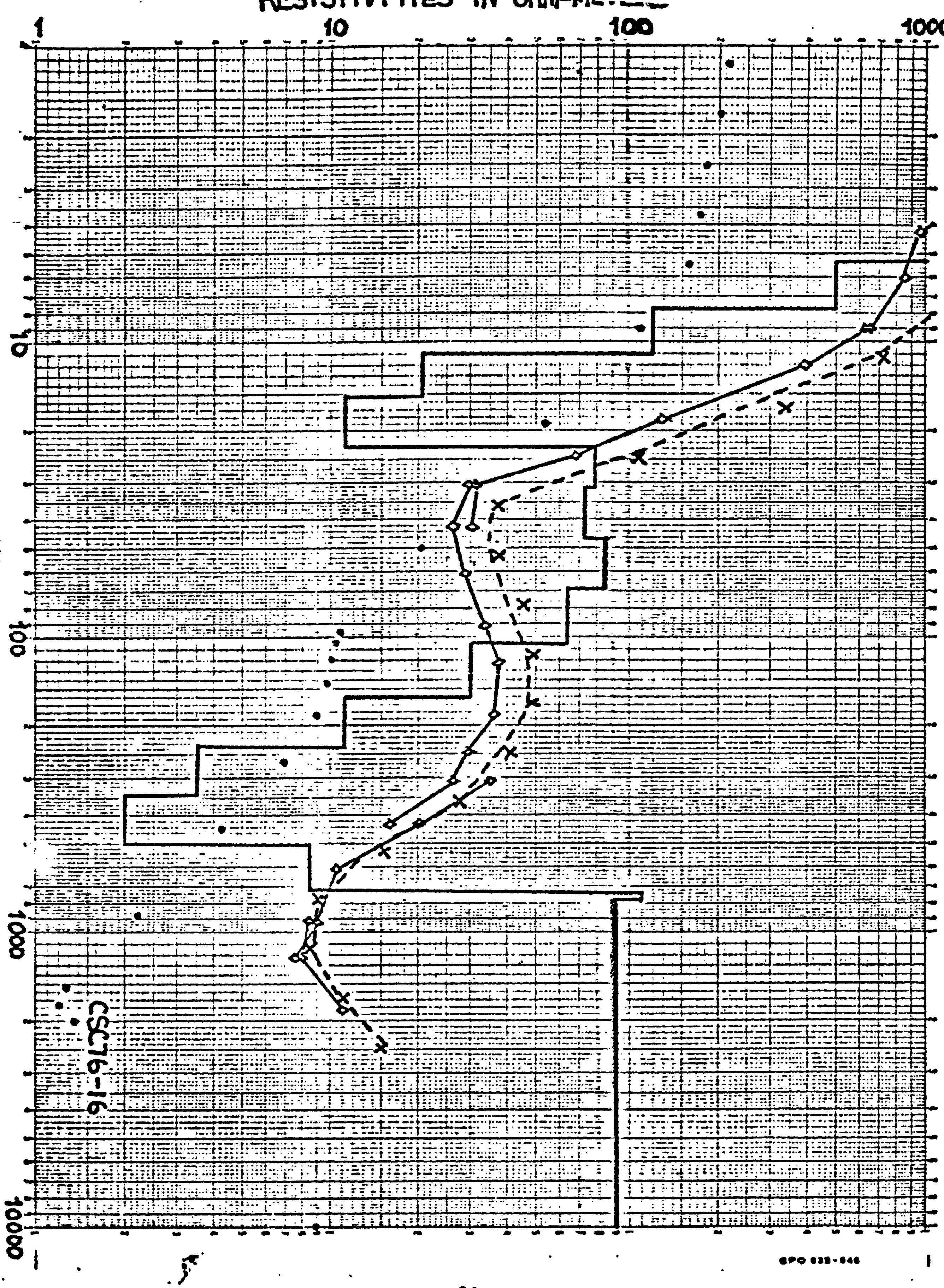
1000
10000
CSC76-VES 15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1000
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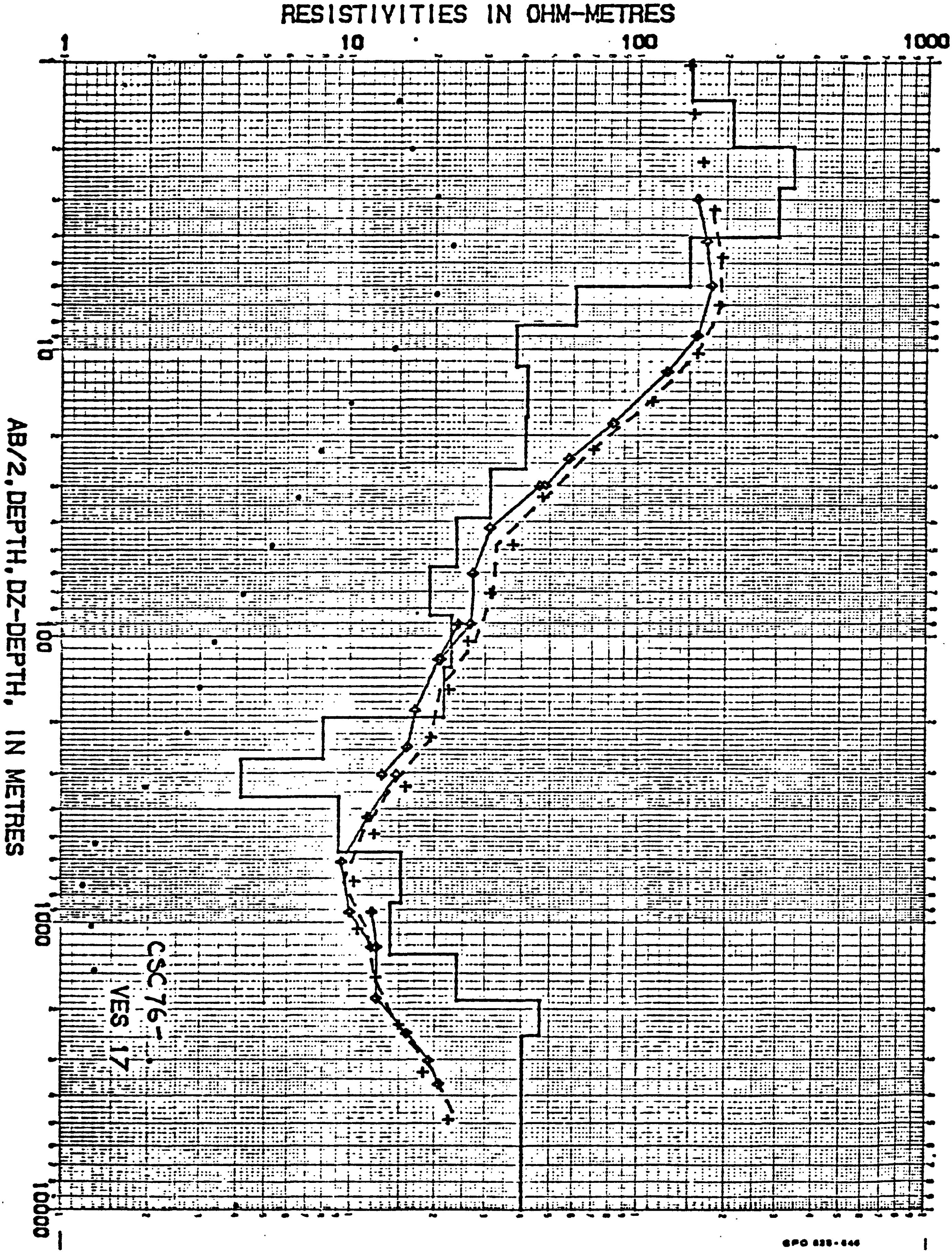
CSC76-16


RESISTIVITIES IN OHM-METRES
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AB/2, DEPTH, DZ-DEPTH, IN METRES
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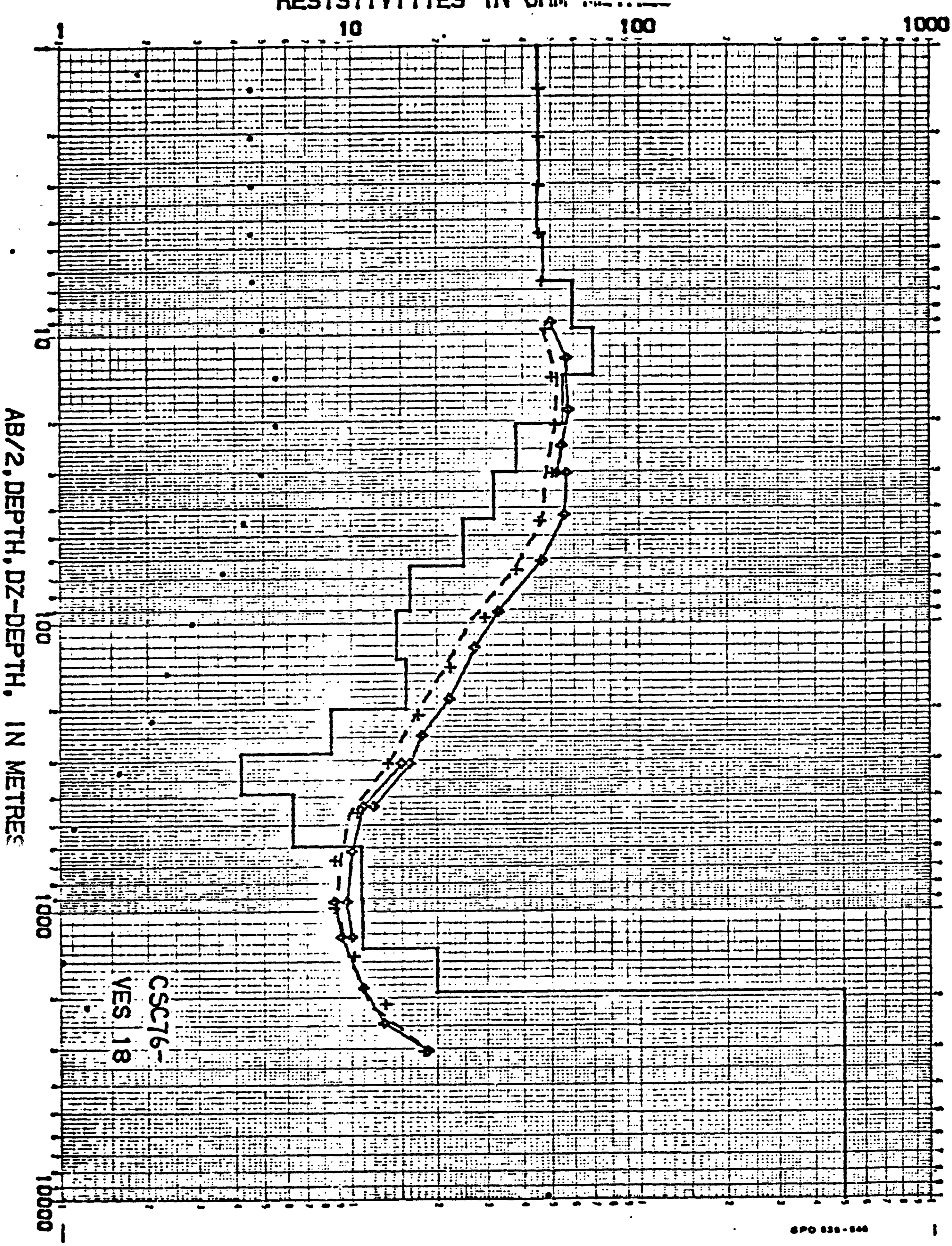
1000
10000
CSC 76-
VES 17



RESISTIVITIES IN
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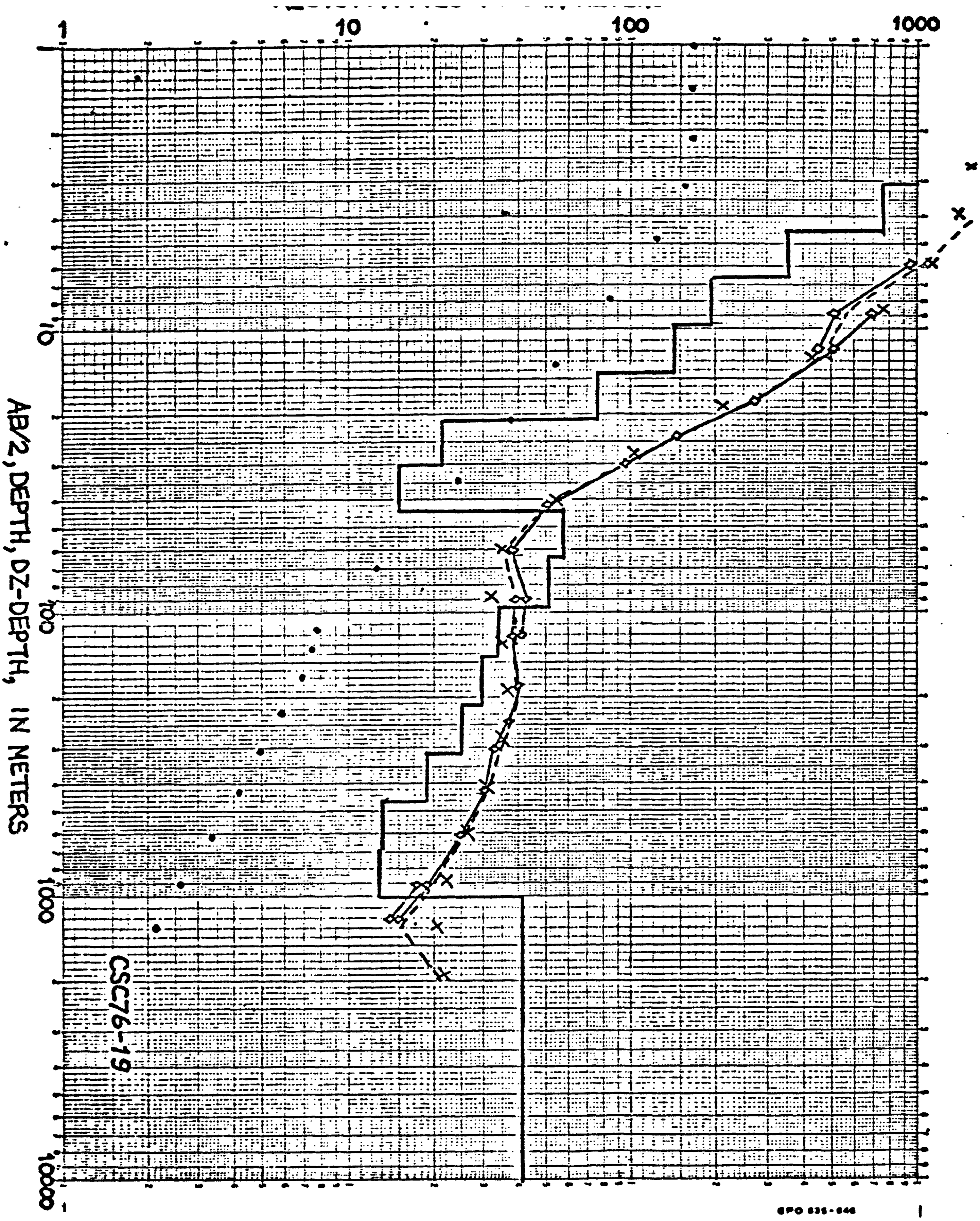
1000
AB/2,DEPTH,DZ-DEPTH, IN METRES
10
100
1000
10000
CSC76-
VES 18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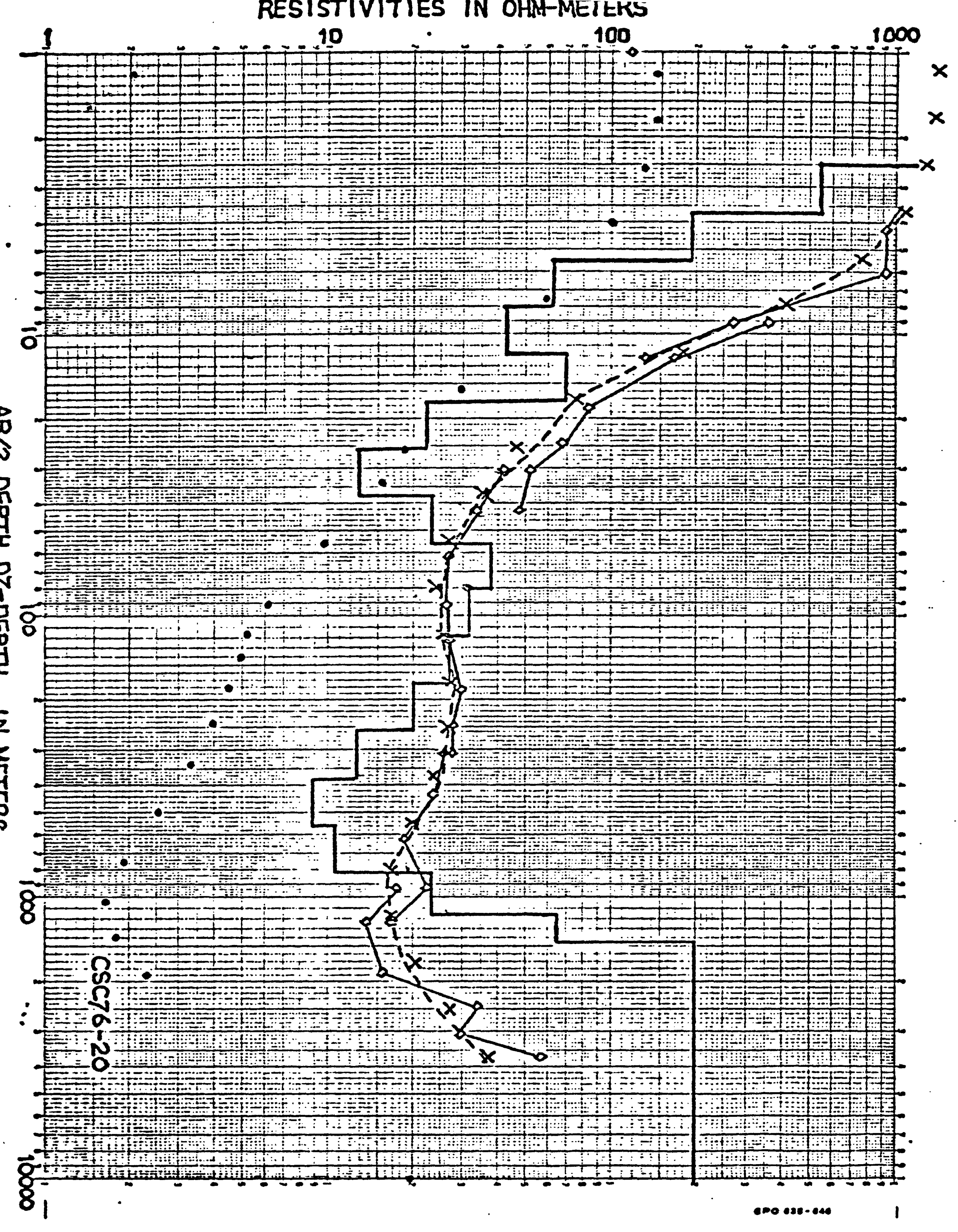
100
1000
AB/2, DEPTH, DZ-DEPTH, IN METERS
CSC76-19


RESISTIVITIES IN OHM-METERS
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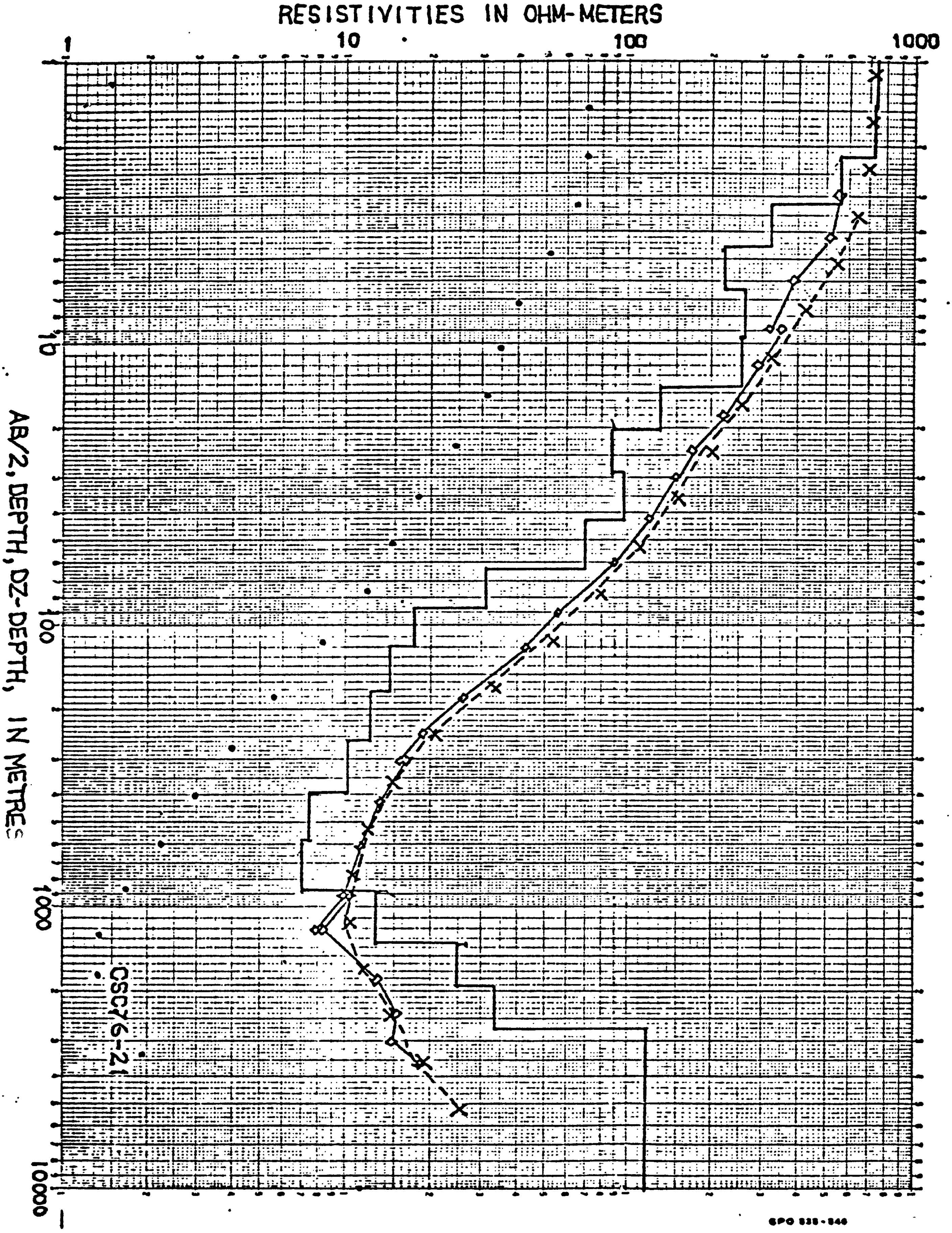
1000
AR/2.DEPTH.DZ-DEPTH, IN METERS
10
100
1000
10000
CSC76-20



RESISTIVITIES IN OHM-METERS
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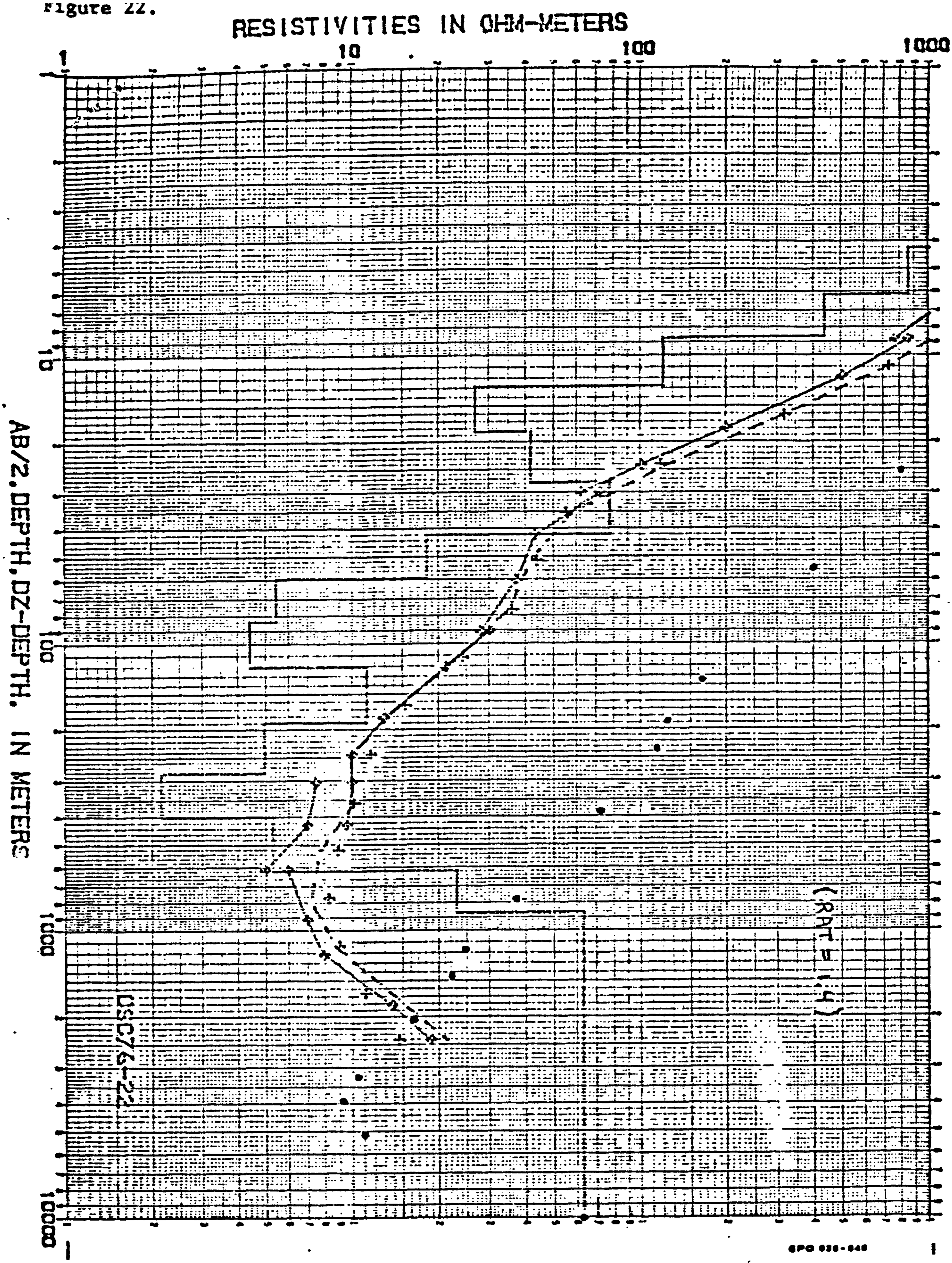
100
1000
AB/2, DEPTH, DZ-DEPTH, IN METRES
10
100
1000
10000
CSC76-21

Figure 22.



RESISTIVITIES IN OHM-METERS
1
10
100
1000
10
100
1000
10000
AB/2.DEPTH.DZ-DEPTH. IN METERS
(RAT = 1.4)
DSC76-22
GPO 836-848