

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOELECTRIC INVESTIGATIONS WITH SCHLUMBERGER SOUNDINGS

NEAR BRUNSWICK, GEORGIA

BY

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Geoelectric Investigations with Schlumberger Soundings near Brunswick, Georgia.

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INTRODUCTION

In 1978 the U. S. Geological Survey made 81 Schlumberger soundings near Brunswick, Georgia. The purpose of this survey was to determine the depth and lateral extent of saltwater encroachment into the carbonate aquifer, and to map the top of the carbonate sequence.

The aquifer in the Brunswick area is composed primarily of limestone, dolomitic limestone, and cavernous dolomitic limestone principally of Eocene age (Wait, 1965). The depth to the top of the carbonates ranges from 150 to 250 m. The principle limestone members of the aquifer are the Ocala Limestone, the Avon Park Limestone, the Lake City Limestone, and the Oldsmar Limestone. Overburden in this area consists of sand, silty-sandy clay, clay, and thin beds of limestone.

In locating the sounding stations consideration had to be given to the location of buried telephone cables, metal fences (especially along interstate 95), pipelines and bridges.

The primary purpose of this report is to release the field data obtained in this survey. However the automatic inversion of the sounding curves and the computer-generated geoelectric cross sections are also given and briefly described.

SCHULMBERGER SOUNDINGS

Figure 1 shows the Schlumberger sounding locations and their direction of expansion. All sounding measurements were made using the symmetric Schlumberger array. The sounding curves are given in the Appendix and are numbered consecutively from Georgia 1 to Georgia 81. All the sounding curves were automatically processed and interpreted (Zohdy, 1973 and 1975) as shown on the graphs in the Appendix. The range of apperant resistivities on several sounding curves (1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 13, 14, 15, 38, 40, 42, 44, 46, 71, and 77) exceeded the range for the accurate application of Ghosh coefficients (Ghosh, 1971). Therefore, for these sounding curves, a larger and more accurate set of coefficients (Anderson, 1975) was used. On many of the graphs (1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 20, 21, 28, 31, 38, 41, 62, 70, 71, 75, and 76) the range of ordinate values exceeded the range afforded by the graph paper. On these graphs the ordinate values in question were shifted upward or downward, as appropriate, by three logarithmic cycles. Each graph shows the following:

1. Field data designated by a segmented, solid-line curve, with diamond symbols for observed data.

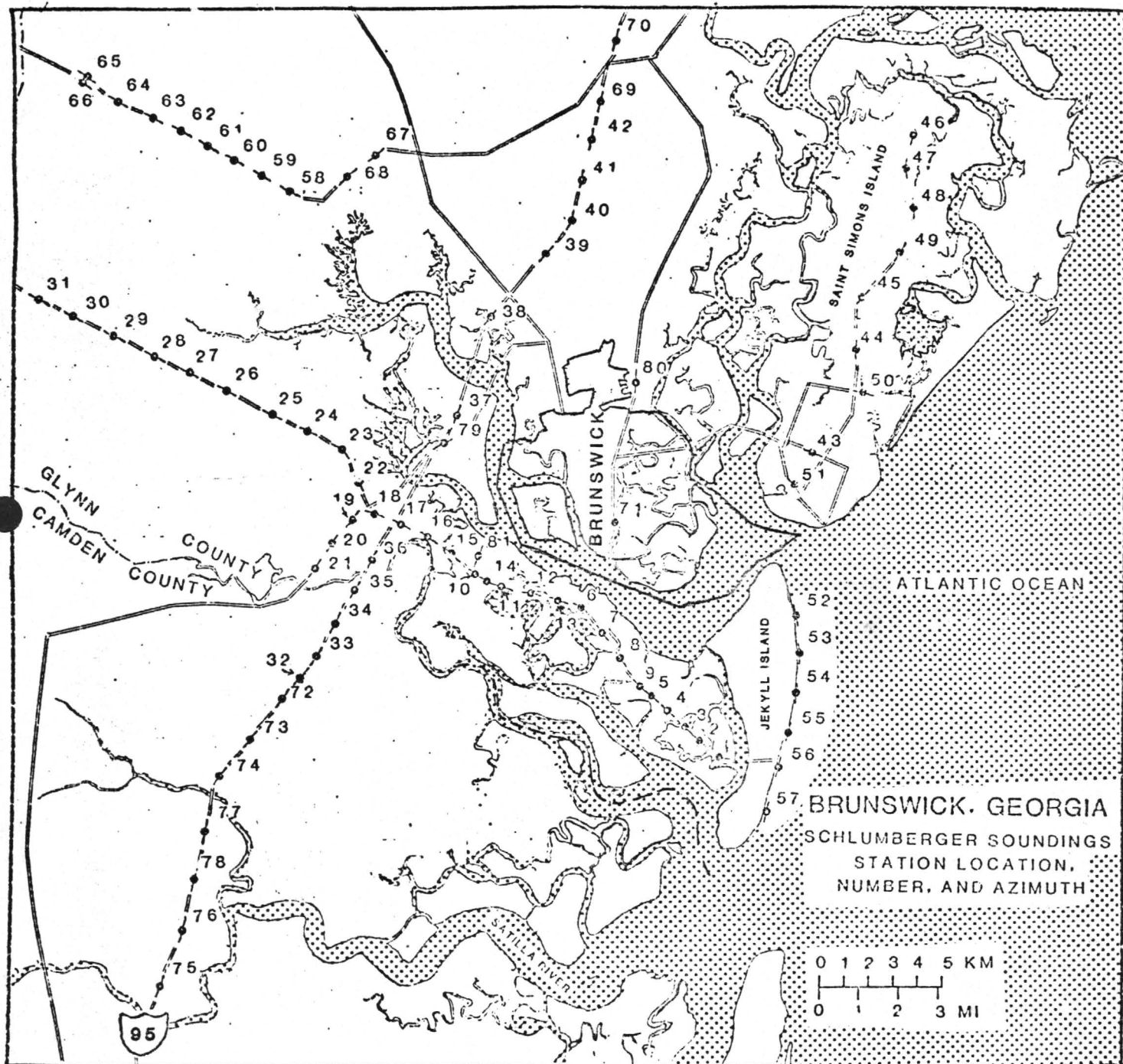


Figure 1.--Map showing Schlumberger sounding locations and directions of expansion.

2. A shifted and digitized field curve designated by square symbols. The shifted field curve is obtained by shifting the various segments upward or downward generally with respect to the last segment on the segmented field curve (Zohdy and others, 1973). This shifted curve is then digitized at the rate of six points per logarithmic cycle. These points were computed using a subroutine in a computer program for bicubic spline functions (Anderson, 1971).
3. The theoretical best fitting sounding curve is designated by plus (+) symbols. This theoretical curve is the output of the automatic interpretation for the digitized curve. The computer program used here is an updated version of the one published by the second author (Zohdy, 1973).
4. The detailed layering (step-function curve of interpreted true resistivity versus depth) for which the theoretical curve is calculated.
5. The D.Z. (Dar Zarrouk) curve for the detailed layering. The ordinate values for the D.Z. curve are shifted upward or downward by one logarithmic cycle or are plotted on a separate page (soundings 1, 2, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 34, 38, 40, 41, 42, 44, 46, 70, 71, 77, and 78) to avoid cluttering the graph. The D.Z. curve can be used to obtain equivalent and simpler solutions containing fewer number of layers and in which certain constraints can be imposed on layer thicknesses and resistivities (Zohdy, 1974).

GEOELECTRIC CROSS SECTIONS

Figures 3 through 7 show computer-generated geoelectric sections of interpreted true resistivity. The cross sections were constructed in the following manner.

For each sounding, the detailed layering (given as a step function) is converted to a smooth curve representing a continuous variation of resistivity with depth. This conversion is made by determining the coordinates of the logarithmic midpoint of each horizontal and vertical segment (figure 2a). The logarithms of these points are splined (Anderson, 1971) to form a continuous curve. Then the computed spline coefficients are used to digitize this continuous curve at the rate of 30 points per decade of depth (figure 2b). After this is done for each sounding interpretation, the digitized resistivity-depth curves generated in this manner are spline-interpolated in the horizontal direction to generate resistivity values at four equally-spaced locations between each pair of soundings. This produces a data set in the form of a mesh suitable for contouring. A computer program based on the work of Evenden (1975) was used for contouring the results. It should be noted that even though the logarithms of the resistivities and depths were used for splining, some significant anomalies may still be generated by interpolation between sounding locations. Thus although the automatic contouring method used here is faithful to the interpreted resistivity values beneath each station, there are other equally acceptable methods of contouring these resistivity values. The reader

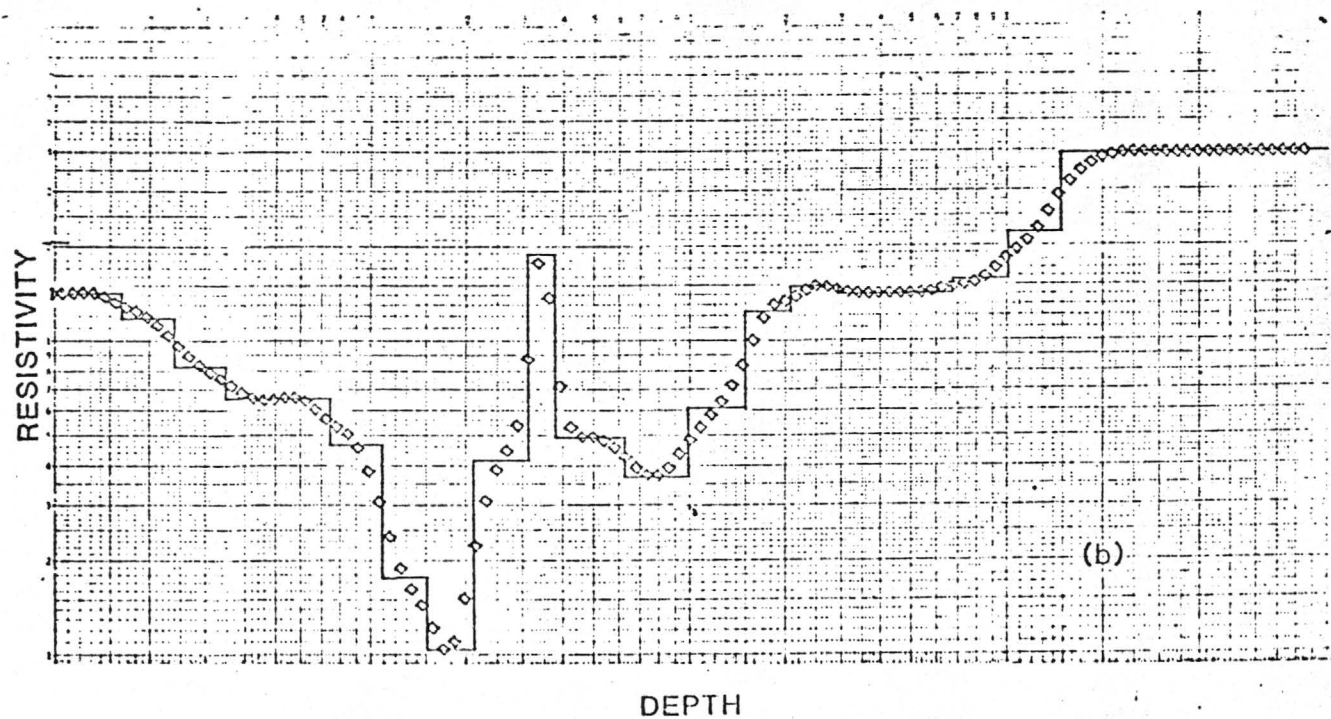
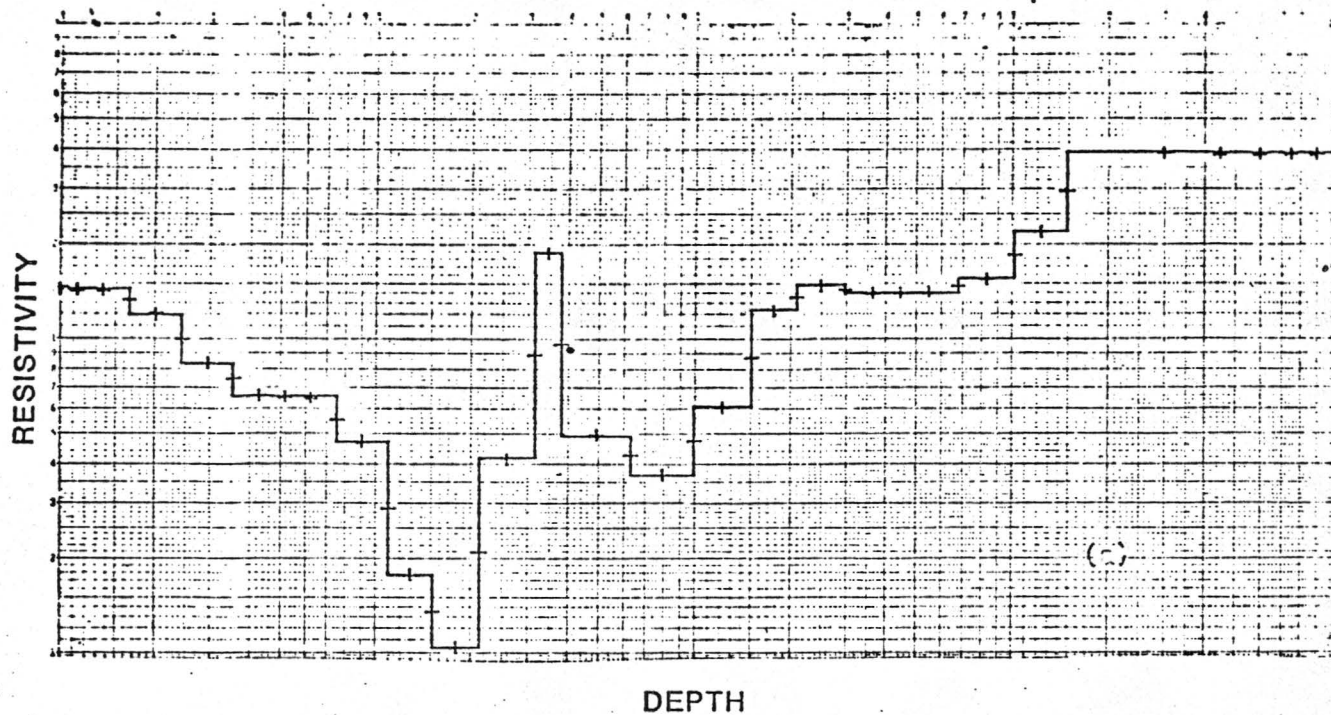


Figure 2.--(a) Detailed layering and coordinates of the logarithmic midpoint of each horizontal and vertical segment (represented by plus symbols);
 (b) Detailed layering and continuous curve digitized at the rate of 30 points per decade (represented by diamond symbols).

is cautioned that anomalies created by interpolation between sounding stations may not be real. The cross sections are contoured at a logarithmically quasi-equal interval of six points per decade, with contours at 1, 1.5, 2, 3, 4.5, 7, 10, 15, 100, 150, 200, 300, and 450, in ohm meters.

Each section is composed of three parts. The top part shows a ten to one vertically exaggerated presentation of the upper 215 m; the middle part, a four to one vertically-exaggerated presentation of the upper 926 m; the lower part, a no vertically-exaggerated presentation of the upper 926 m.

DISCUSSION

Figures 3, 4, 5, 6, and 7 show computer-generated geoelectric cross sections constructed from the sounding data obtained near Brunswick, Georgia. Two of these cross sections are oriented in a northwest-southeast direction and the other three in a southwest-northeast direction. The top of the limestone on all the cross sections is probably represented by the 45 or 70 ohm-m contour. Furthermore, areas at depths of greater than 400 m where the vertical resistivity gradient is distorted and which are characterized by relatively low resistivities of about 150 ohm-m instead of greater than 300 ohm-m are possibly indicative of the presence of saltwater in the limestone.

Figure 3 shows the northernmost northwest-southeast cross section from sounding 66 to 67. On figure 3 the top of the limestone is probably represented by the 70 ohm-m contour. Using this contour as a guide it appears that the limestone is at a depth of about 100 m under sounding 66, in the northwest, then it deepens to about 400 m beneath sounding 67 in the southeast. The most likely places for the possible presence of saltwater at depth (greater than 350 m) are under sounding 63 and under soundings 61, 60, and 59.

Figure 4 shows the southernmost northwest-southeast cross section from sounding 31 to 56. On the left side of figure 4 the top of the limestone may be represented by the 45 ohm-m contour at a depth of about 200 m. This contour can be used for delineating the top of the limestone southeastward to sounding 18. From sounding 18 southeastward to sounding 10 the top of the limestone is not readily detectable. From sounding 10 southeastward to sounding 56 the top of the limestone may be represented once again by the 45 ohm-m contour at a depth of about 210 m under sounding 10.

The central region on the cross section between soundings 22 and 11 (except for sounding 10), is characterized by limestone of lower resistivity (less than 300 ohm-m) to a depth of at least 900 m. This may be used as evidence for the presence of saltwater in the limestone at depths of greater than 400 m. Then to the southeast of sounding 12 the depth to the 300 ohm-m contour becomes gradually shallower until it reaches about 250 m beneath sounding 1. The upper 150 m to the southeast of sounding 15 is generally characterized by very low resistivities (less than 10 ohm-m) which are definitely indicative of an abundance of clay layers and (or) saltwater encroachment.

Figure 5 shows a southeast-northwest cross section from sounding

21 to 79. On figure 5 the top of the limestone may be represented by the 70 ohm-m contour at a depth of about 210 m under sounding 21. This contour deepens to about 400 m under sounding 79. The cross section suggests the possible presence of saltwater-saturated limestone in the area between soundings 18 and 79 at depths greater than 600 m.

Figure 6 shows a southwest-northeast cross section from sounding 75 to 70. On the left side of figure 6 the top of the limestone may be represented by the area between the 45 and 70 ohm-m contours at a depth of about 190 m. From soundings 73 to 36 the top of the limestone appears to gently deepen to about 300 m under sounding 33. Under soundings 17 and 79 the top of the limestone could be as shallow as 100 m deepening to about 200m under sounding 37. Under sounding 38 to about sounding 40 the top of the limestone could be 100 m deep. From sounding 40 the top of the limestone appears to deepen to about 225 m under sounding 70.

There is evidence for the presence of saltwater at depth between soundings 36 and 79 and soundings 38 and 39. The depth to the possible saltwater-saturated zones are greater than 200 m and greater than 400 m respectively.

Figure 7 shows a geoelectric cross section made on Saint Simon and Jekyll islands. Under sounding 57 the top of the limestone may be represented by the 45 ohm-m contour at a depth of about 120 m. Sounding 43 was distorted probably due to water lines and telephone cables in the urban portion of Saint Simons Island. Consequently the low resistivity anomaly shown on the figure beneath sounding 43 is probably unreal, and the depth to the top of the limestone, as interpolated from soundings 51 and 50 should be about 145 m. There is some evidence for the presence of saltwater at depths greater than 300 m under sounding 44, and greater than 600 m under sounding 49.

The hachured areas shown in figure 8 represent areas where the limestone has a relatively low resistivity (less than 300 ohm-m) to depths of greater than 400 m. Indeed the drilling of a deep test well by the USGS in the central region of the map (about 1 km north of soundings 15 and 16) showed the presence of salty water of 5000 mg/l at a depth of about 650 m which then increased in salinity to 18000 mg/l near the bottom of the well at 776 m.

CONCLUSIONS

Detection of the top of the limestone near Brunswick was reasonably evaluated in most parts of the survey area. On the other hand, the detection of saltwater-saturated limestone was not as straightforward as was expected. On the basis of work done in Florida (Bisdorf and Zohdy, 1979), the cavernous dolomitic limestone at depths greater than 400 m containing saltwater was expected to have average resistivities of less than 30 ohm-m. Unfortunately near Brunswick it appears that the effective relative thickness (Zohdy and others, 1974, p. 32) of the deep saltwater-saturated limestone layer must be small and thus could only result in a subtle decrease in the resistivity of the dolomitic limestone from about 450 ohm-m to about 150 ohm-m.

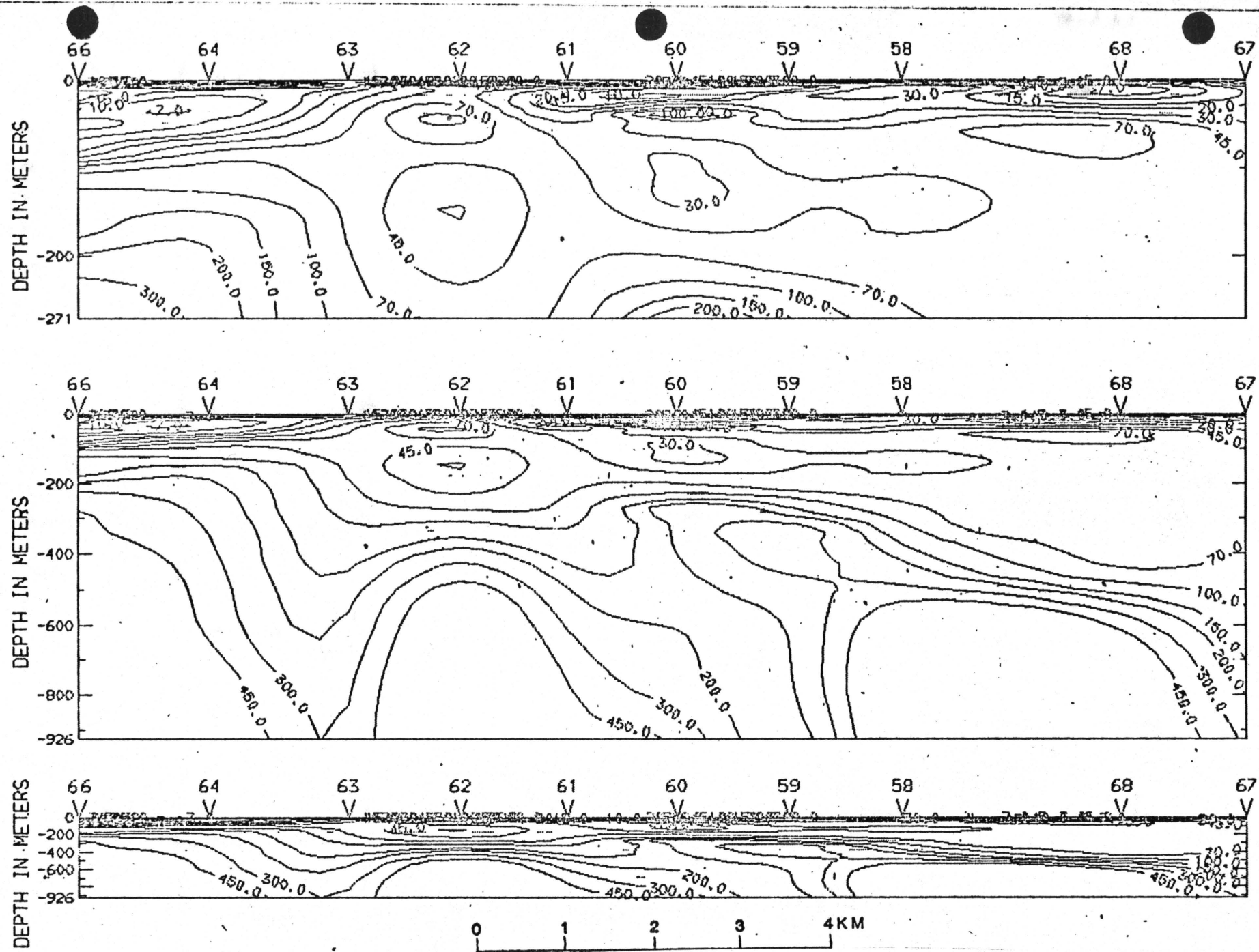


Figure 3.--Computer-generated geoelectric section. See figure 1 for location. Top and middle parts are vertically exaggerated ten and four times, respectively. Bottom part without vertical exaggeration. Contours of interpreted true resistivity in ohm-meters.

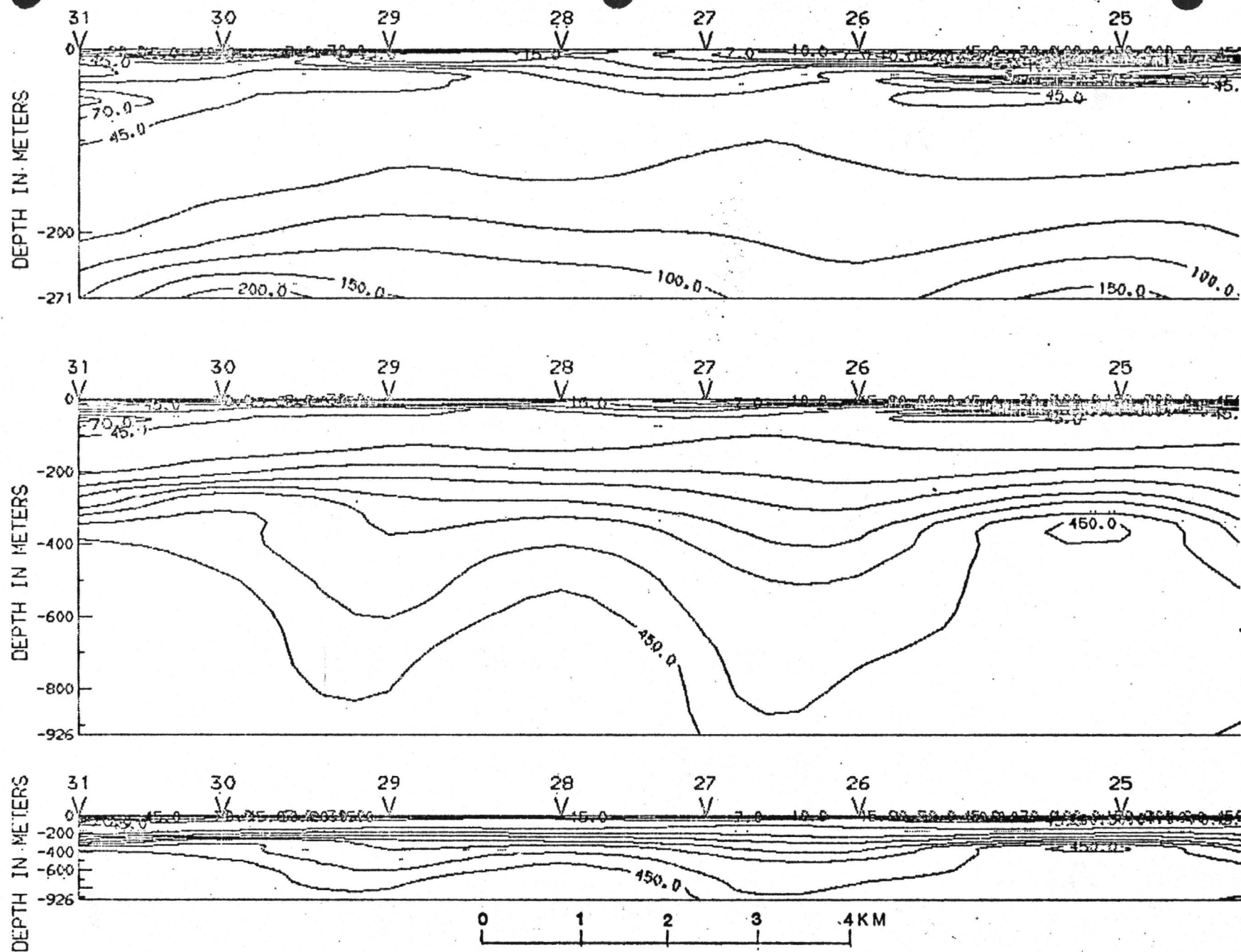


Figure 4a.--Computer-generated geoelectric section. See figure 1 for location. Top and middle parts are vertically exaggerated ten and four times, respectively. Bottom part without vertical exaggeration. Contours of interpreted true resistivity in ohm-meters.

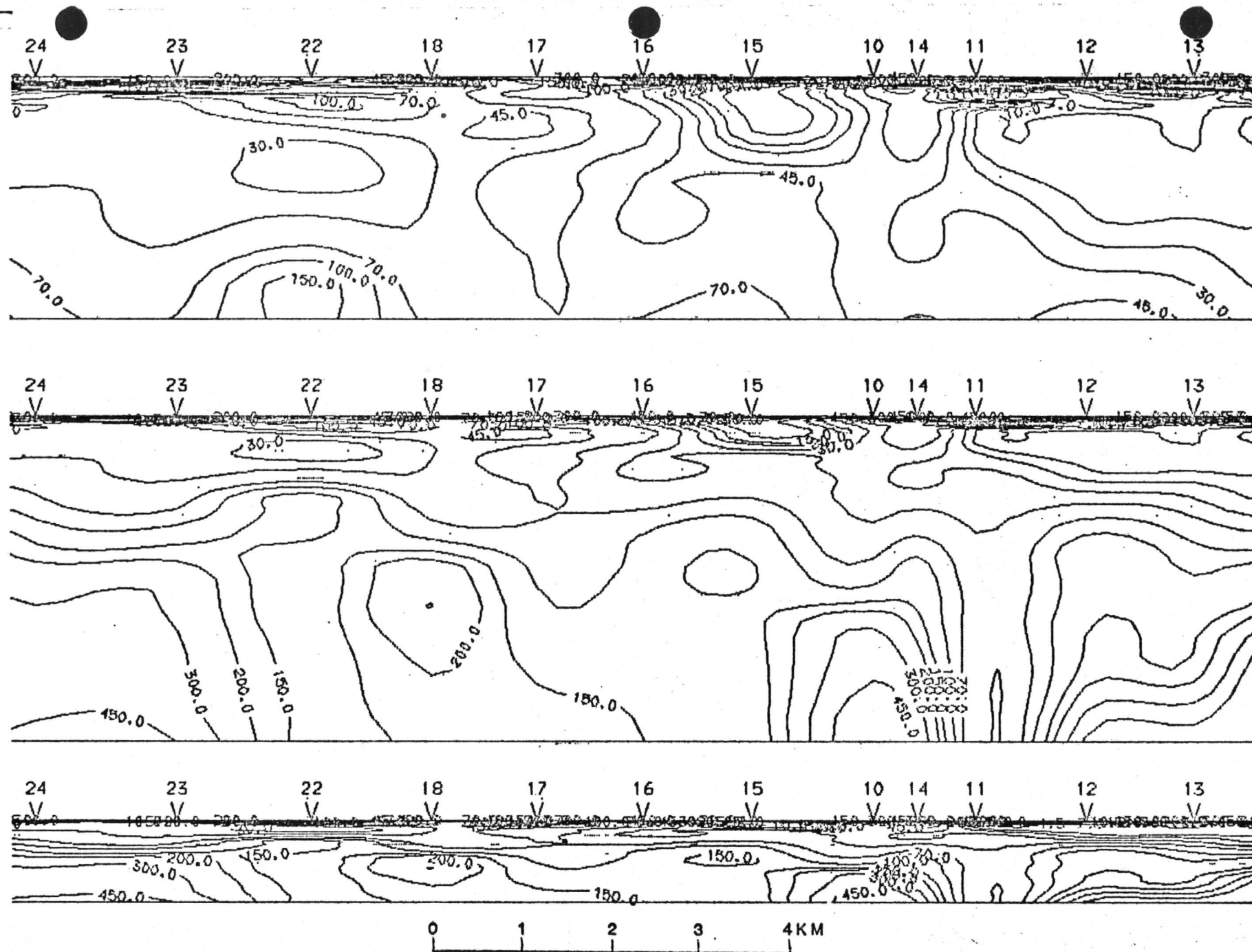


Figure 4b.--Computer-generated geoelectric section continued from figure 4a.

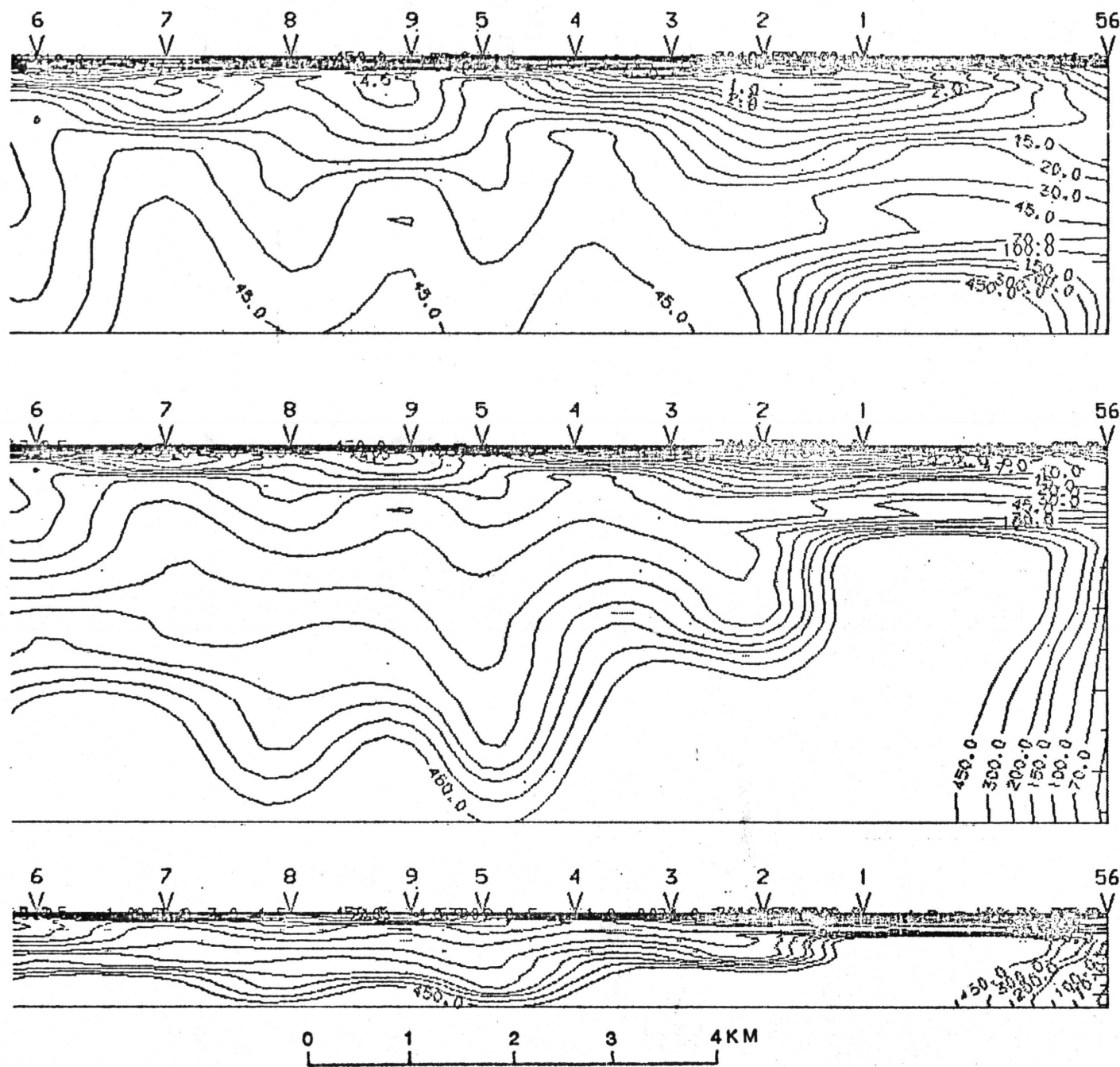


Figure 4 c.--Computer-generated geoelectric section continued from figure 4 b.

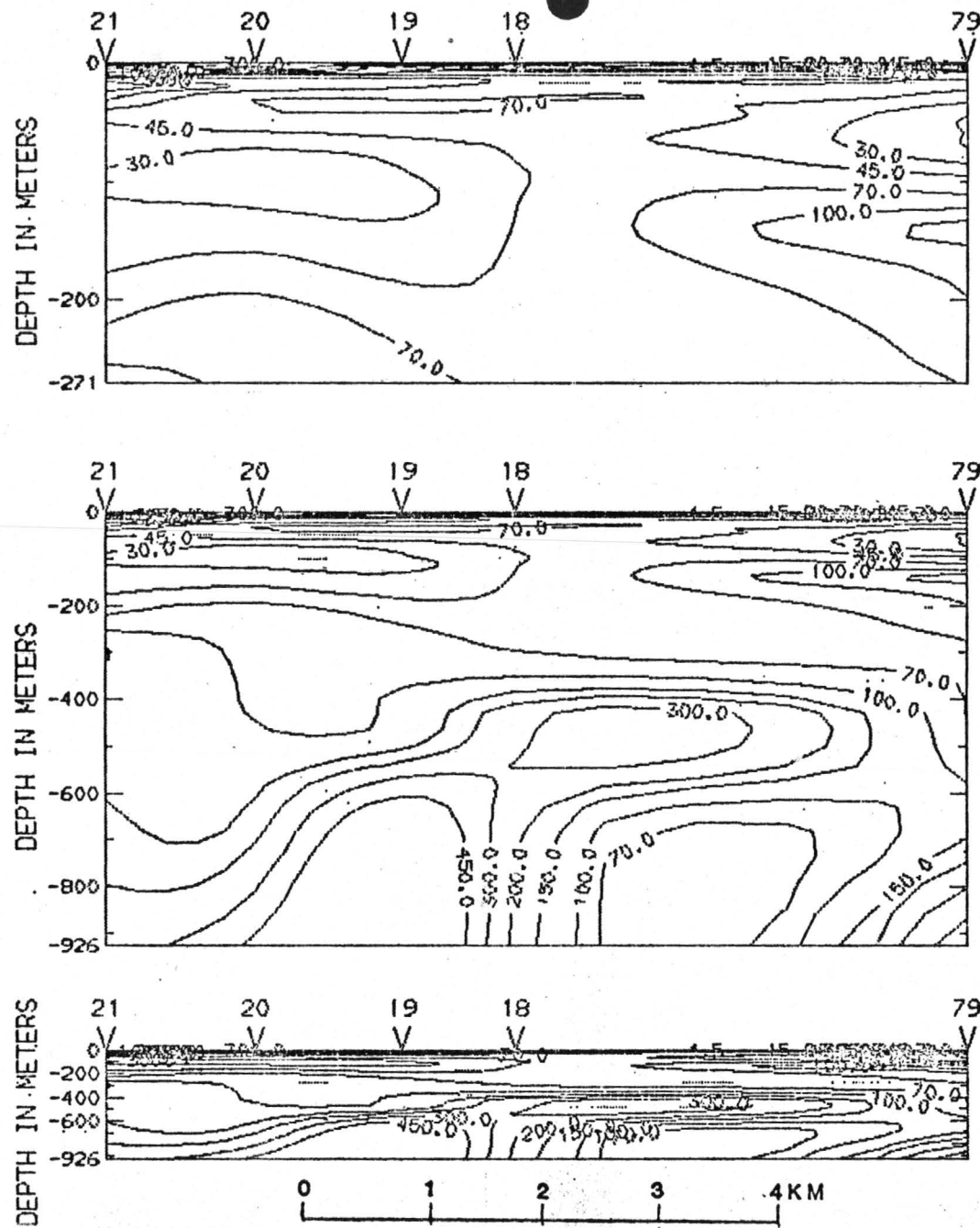


Figure 5. --Computer-generated geoelectric section. See figure 1 for location. Top and middle parts are vertically exaggerated ten and four times, respectively. Bottom part without vertical exaggeration. Contours of interpreted true resistivity in ohm-meters.

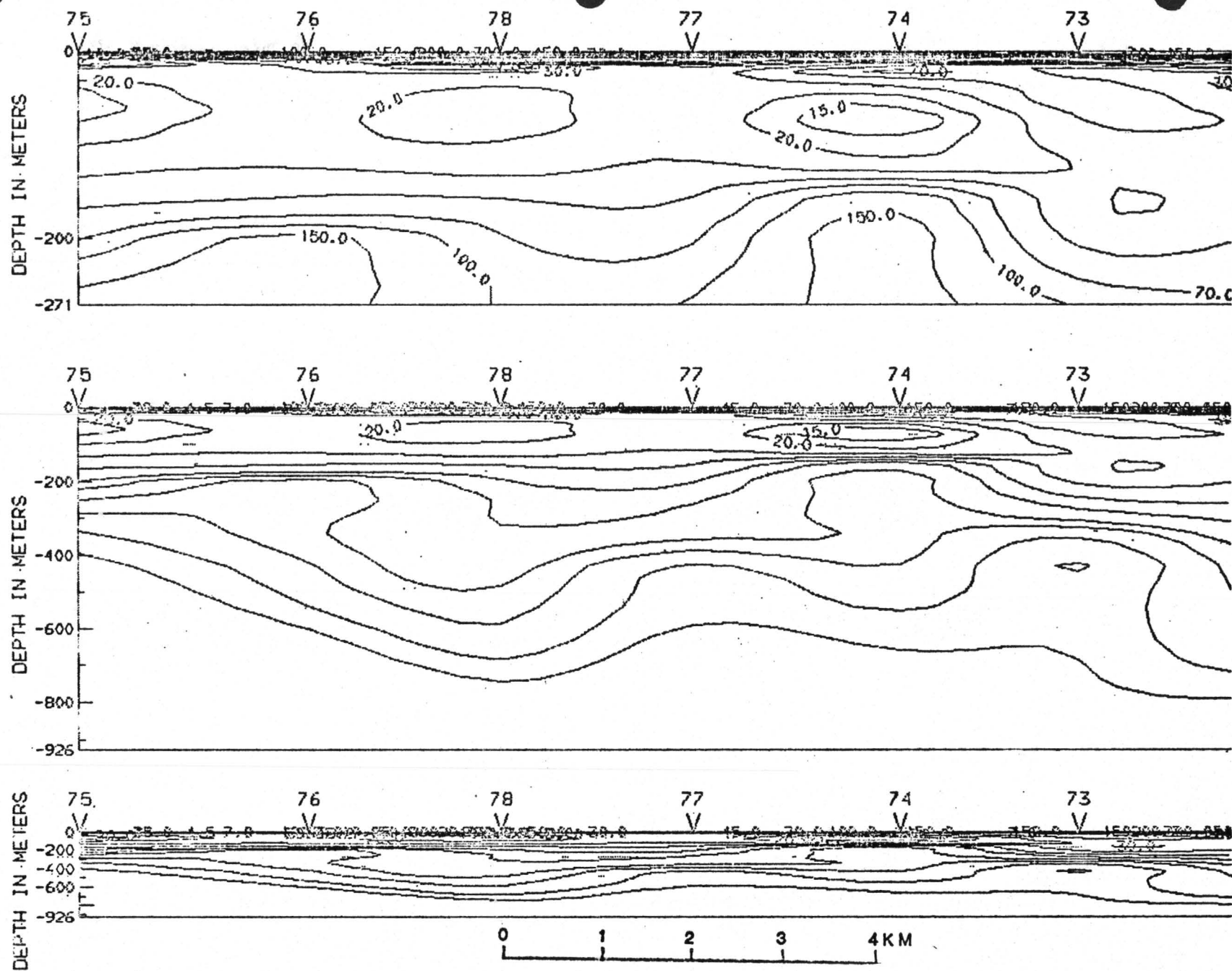


Figure 6a.--Computer-generated geoelectric section. See figure 1 for location. Top and middle parts are vertically exaggerated ten and four times, respectively. Bottom part without vertical exaggeration. Contours of interpreted true resistivity in ohm-meters.

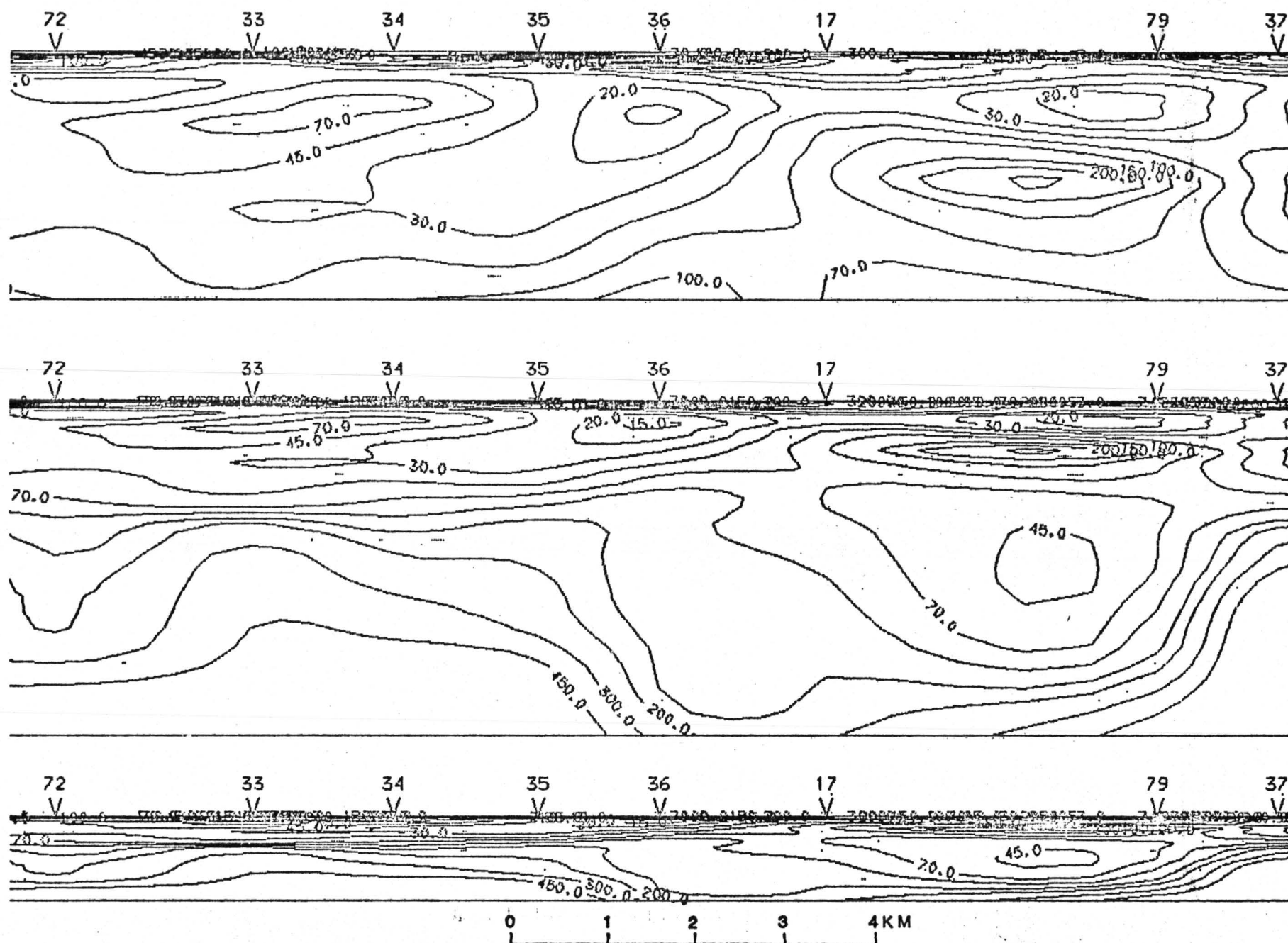


Figure 6b.--Computer-generated geoelectric section continued from figure 6a.

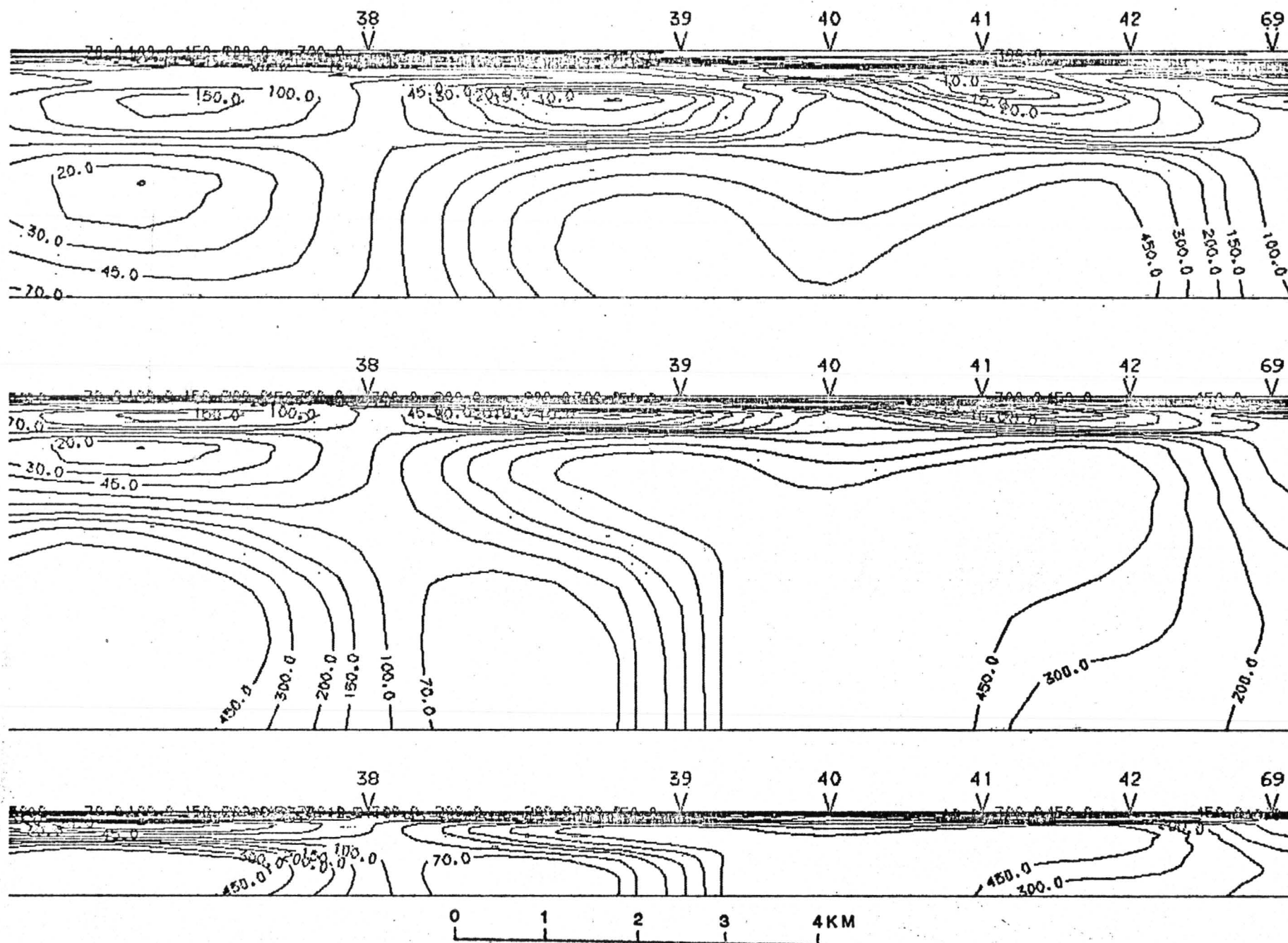


Figure 6c.--Computer-generated geoelectric section continued from figure 6b.

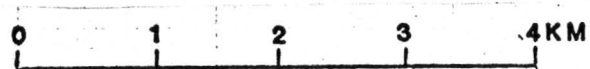
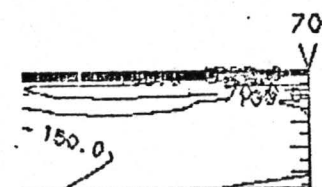
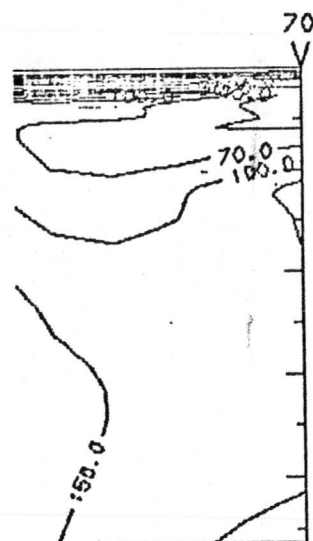
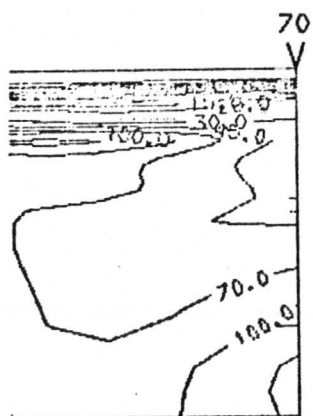


Figure 6d.--Computer-generated geoelectric section continued from figure 6c.

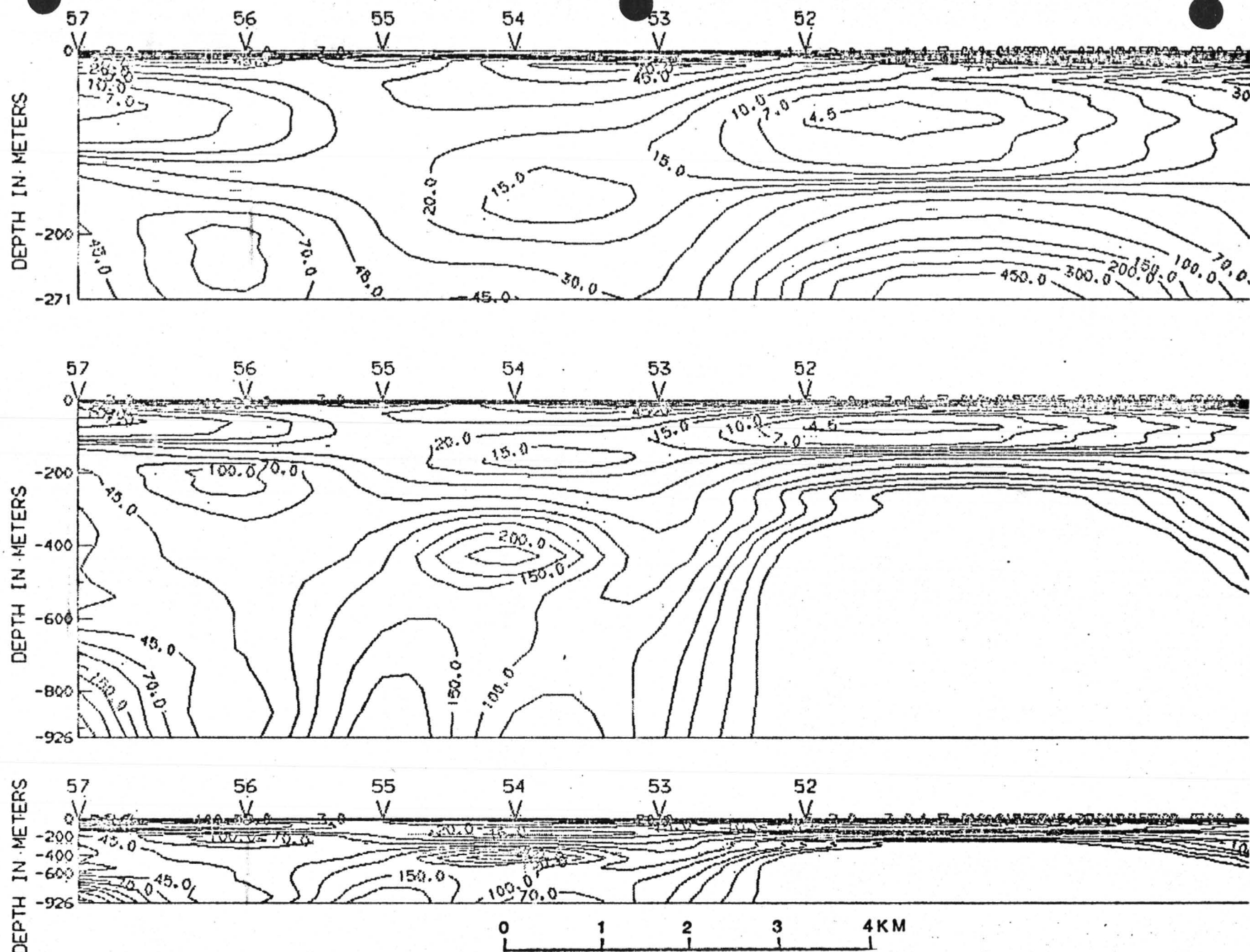


Figure 7a.--Computer-generated geoelectric section. See figure 1 for location. Top and middle parts are vertically exaggerated ten and four times, respectively. Bottom part without vertical exaggeration. Contours of interpreted true resistivity in ohm-meters.

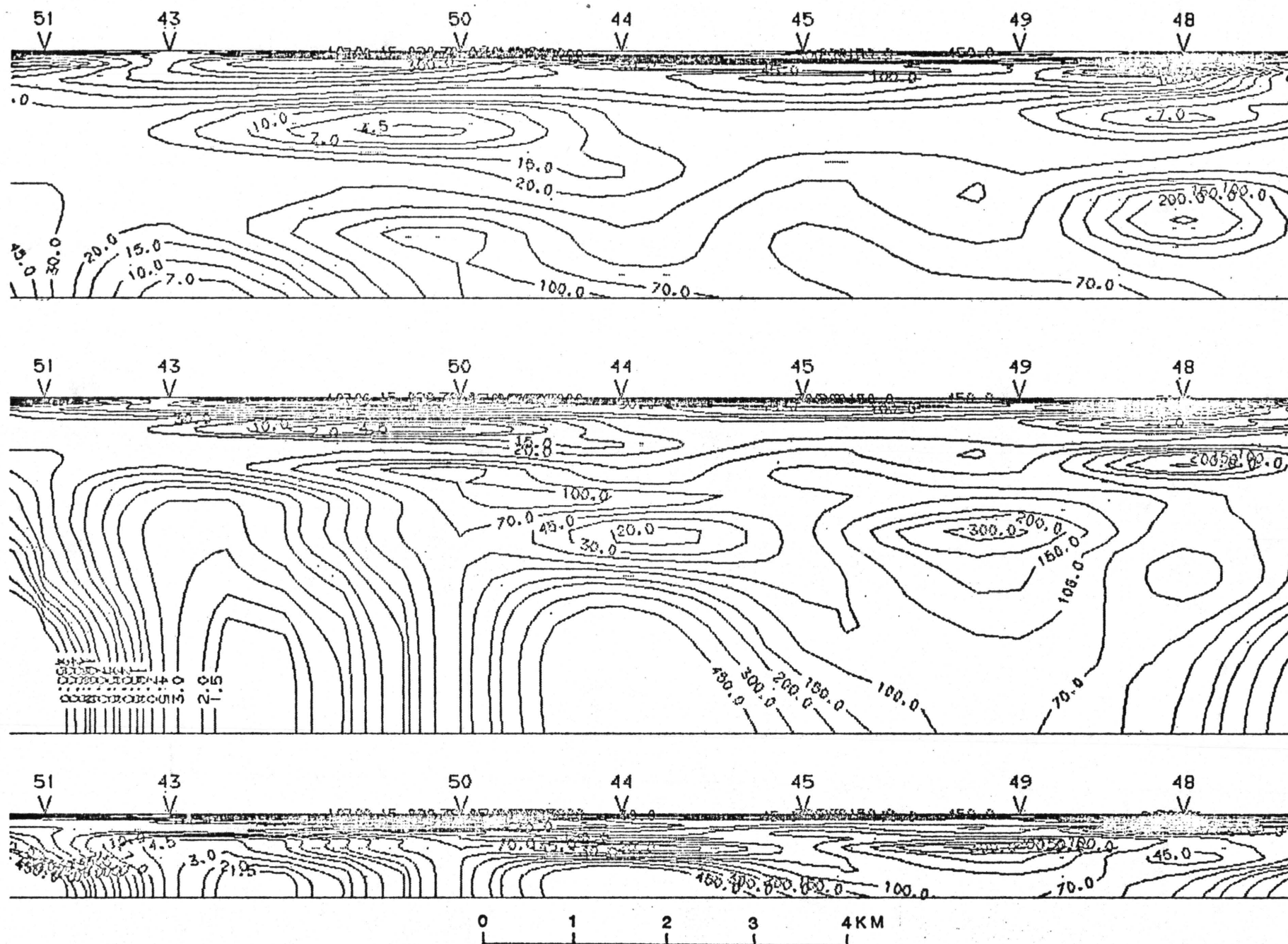


Figure 7b.--Computer-generated geoelectric section continued from figure 7a.

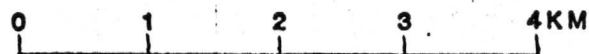
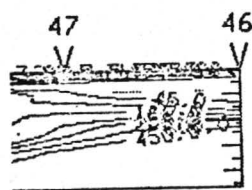
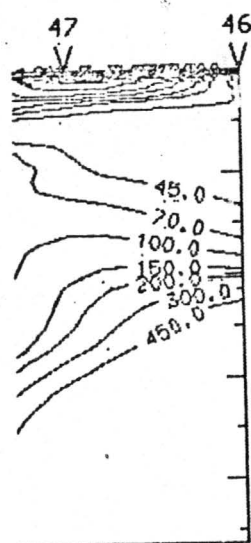
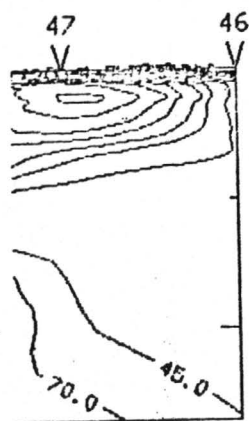


Figure 7c.--Computer-generated geoelectric section continued from figure 7b.

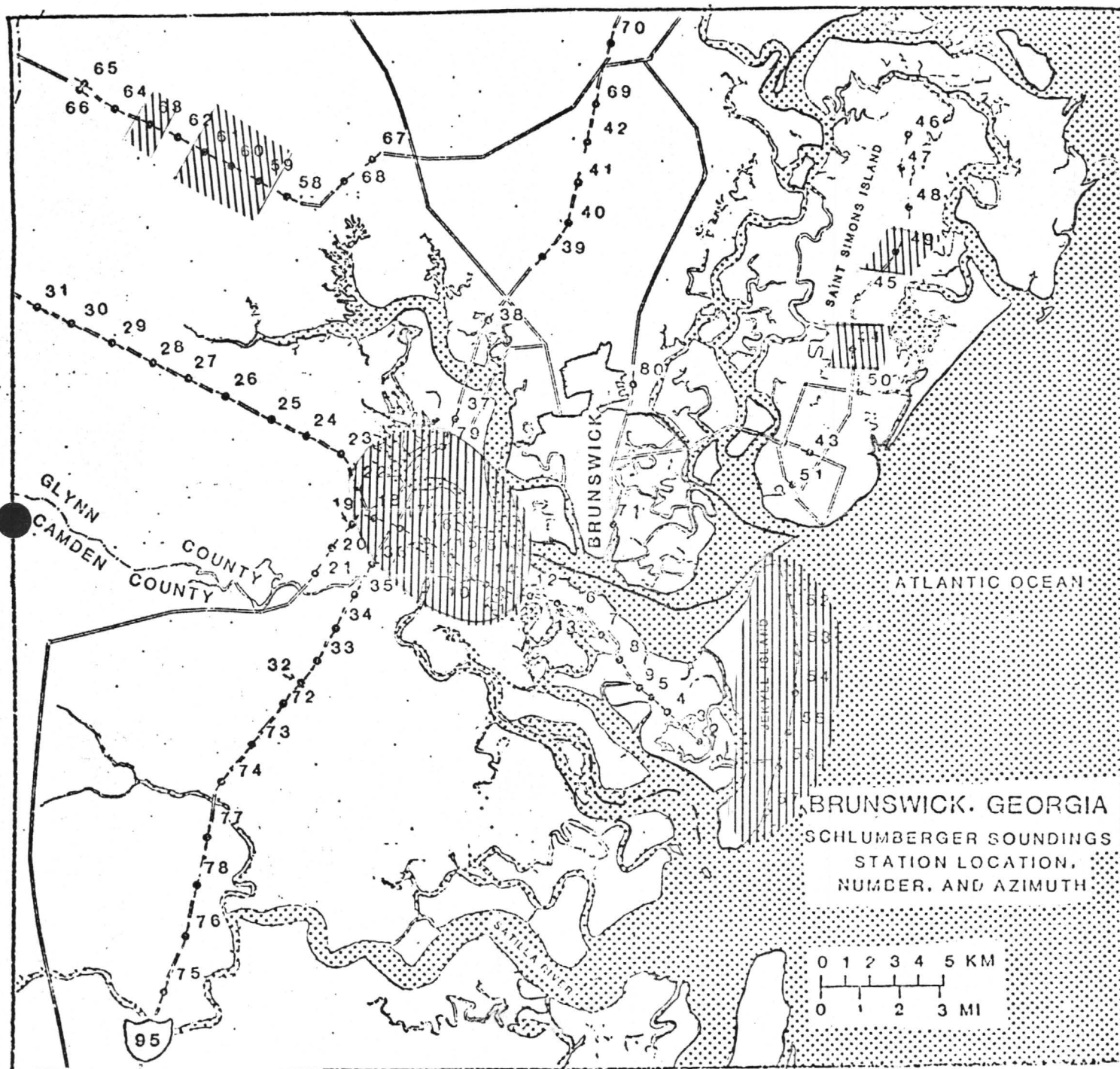
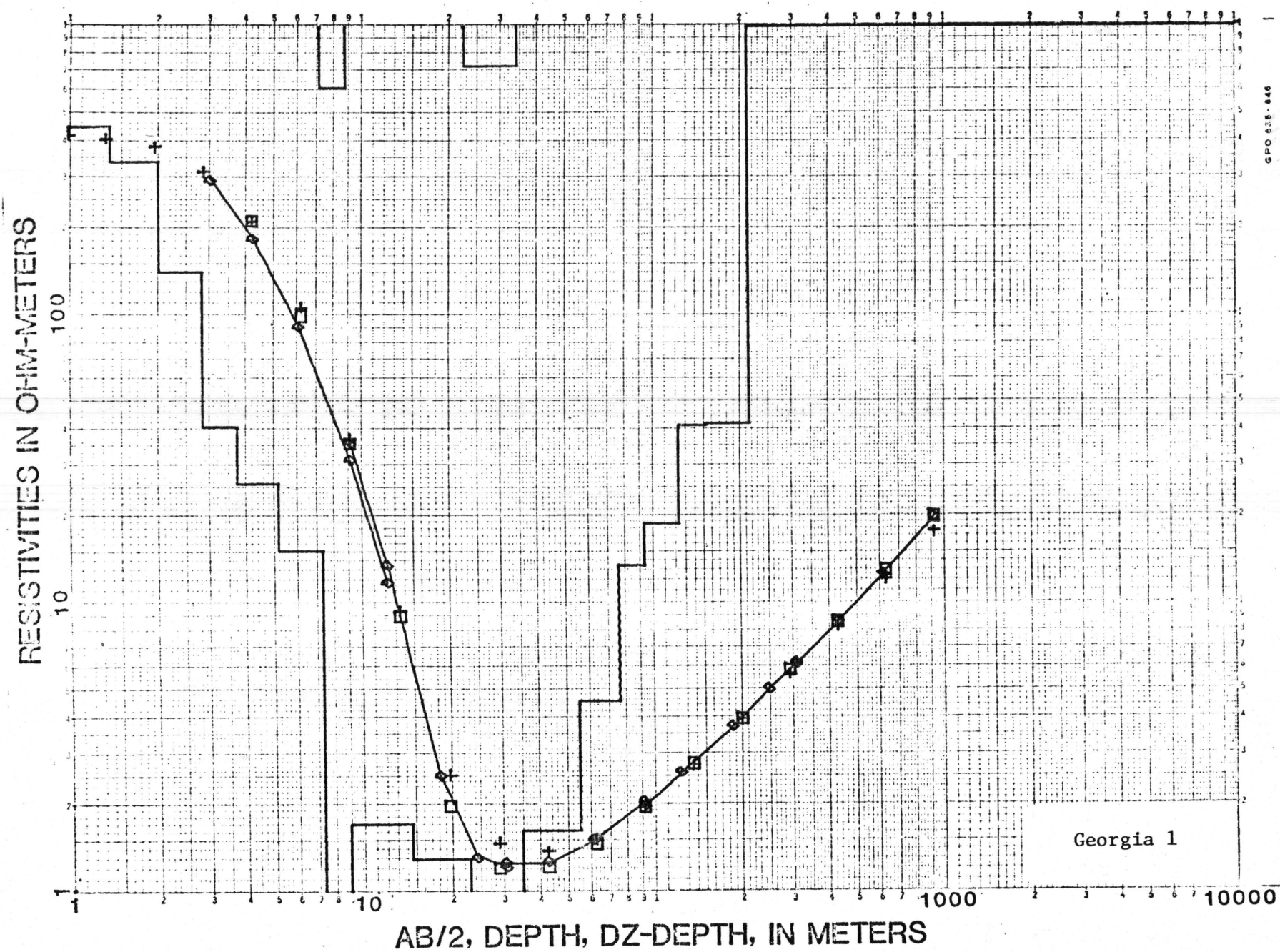


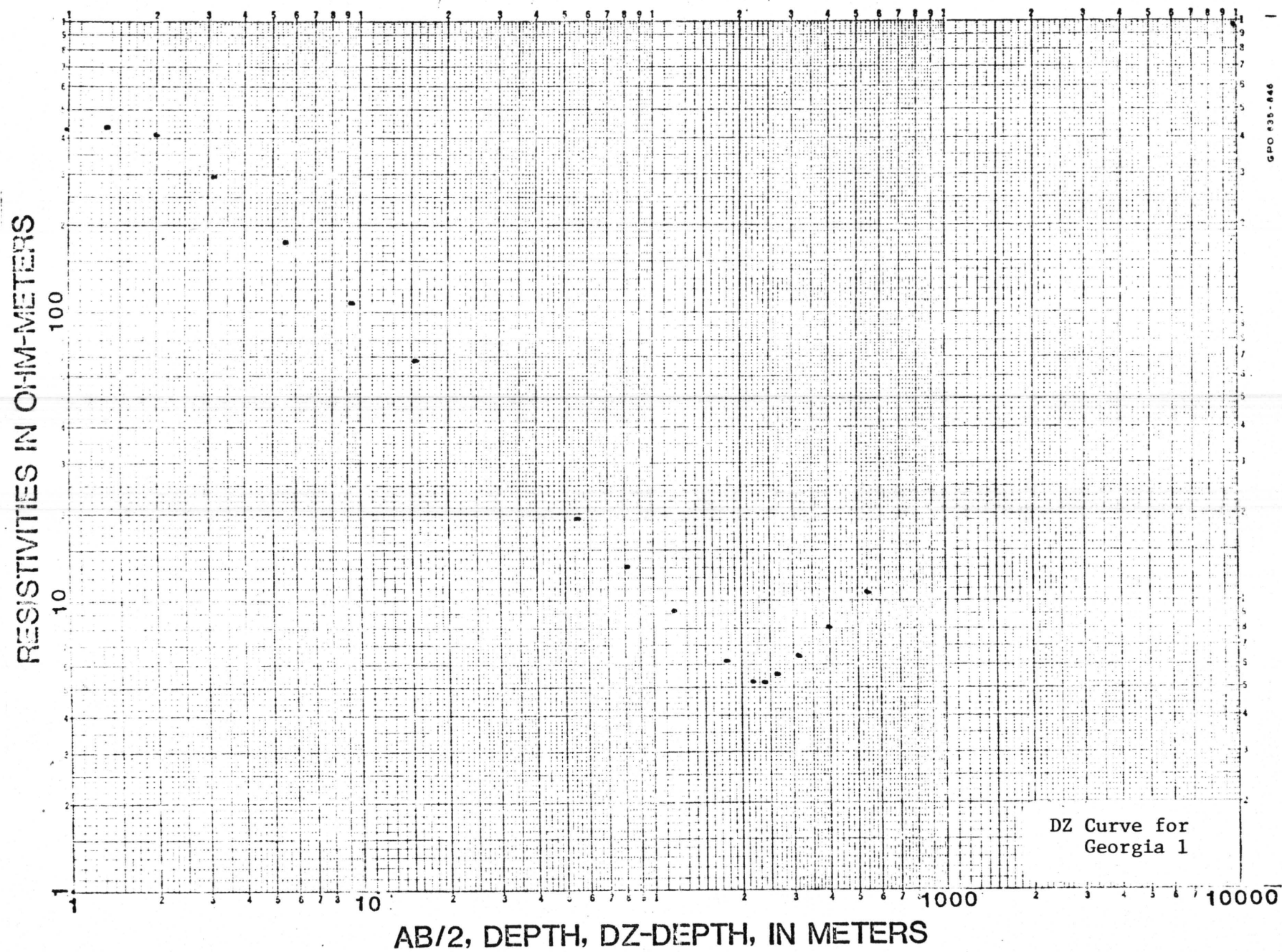
Figure 8.--Map showing the location of areas of possible salt water encroachment (hachured areas) at depths greater than 400 meters.

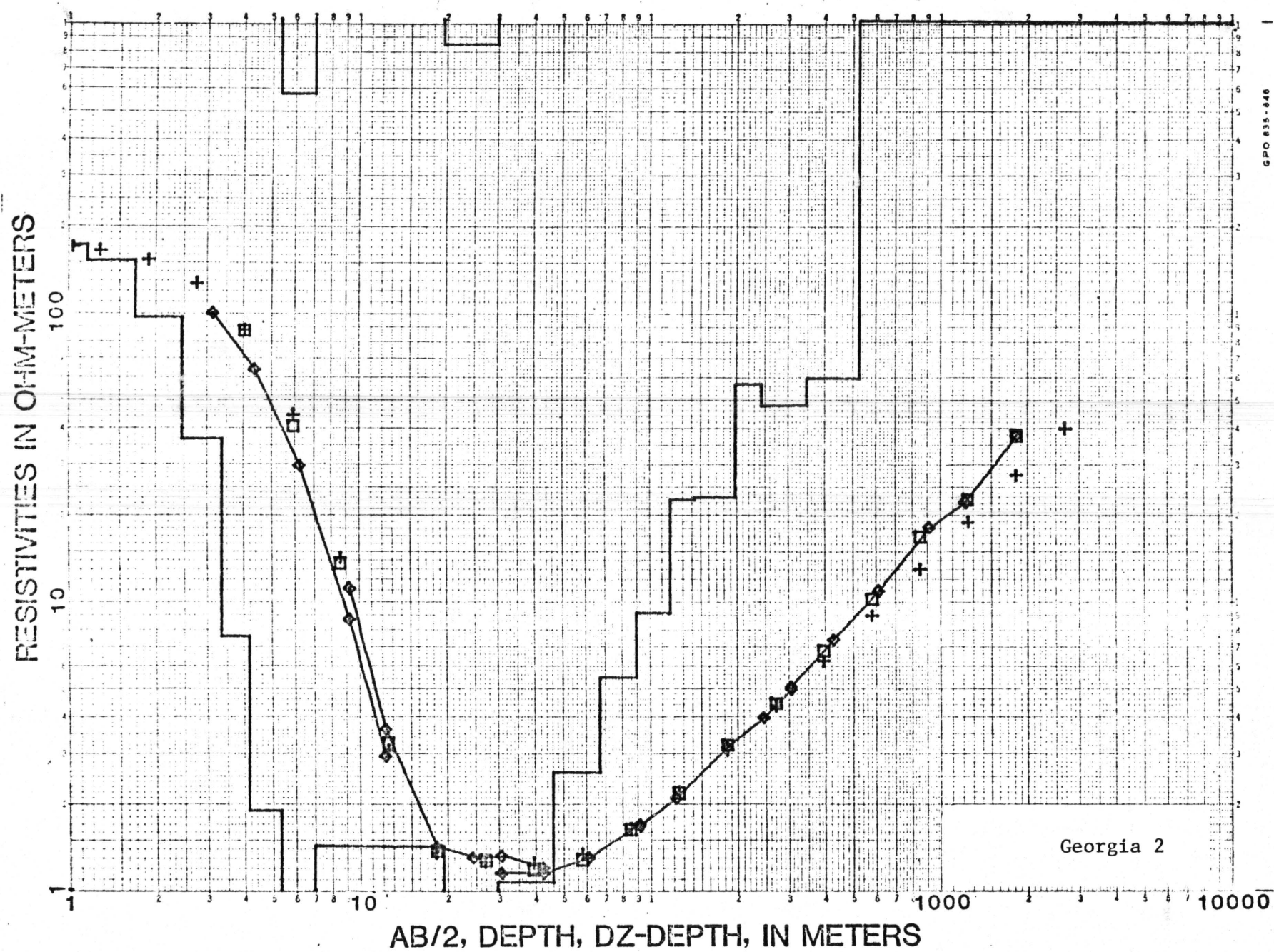
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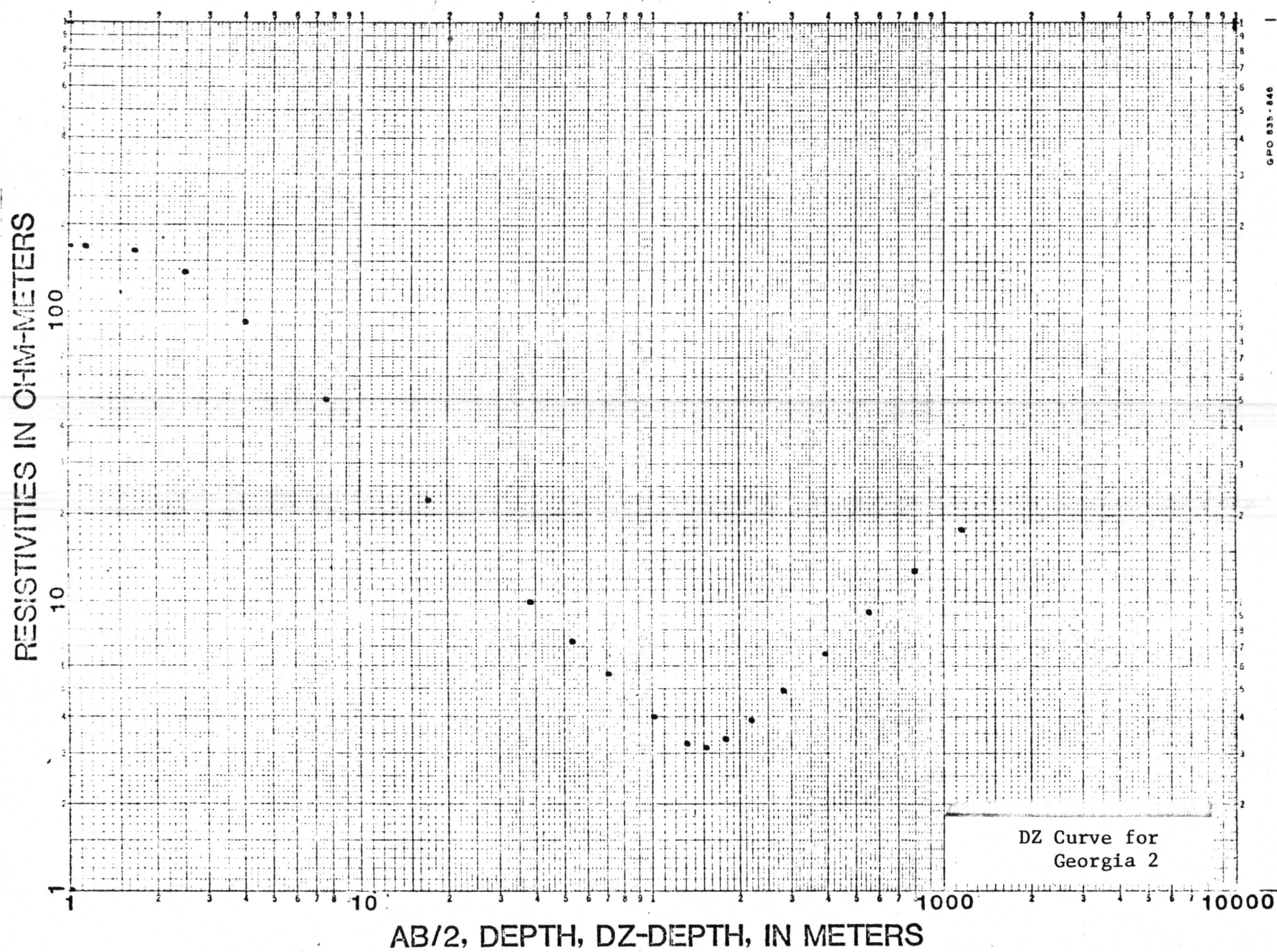
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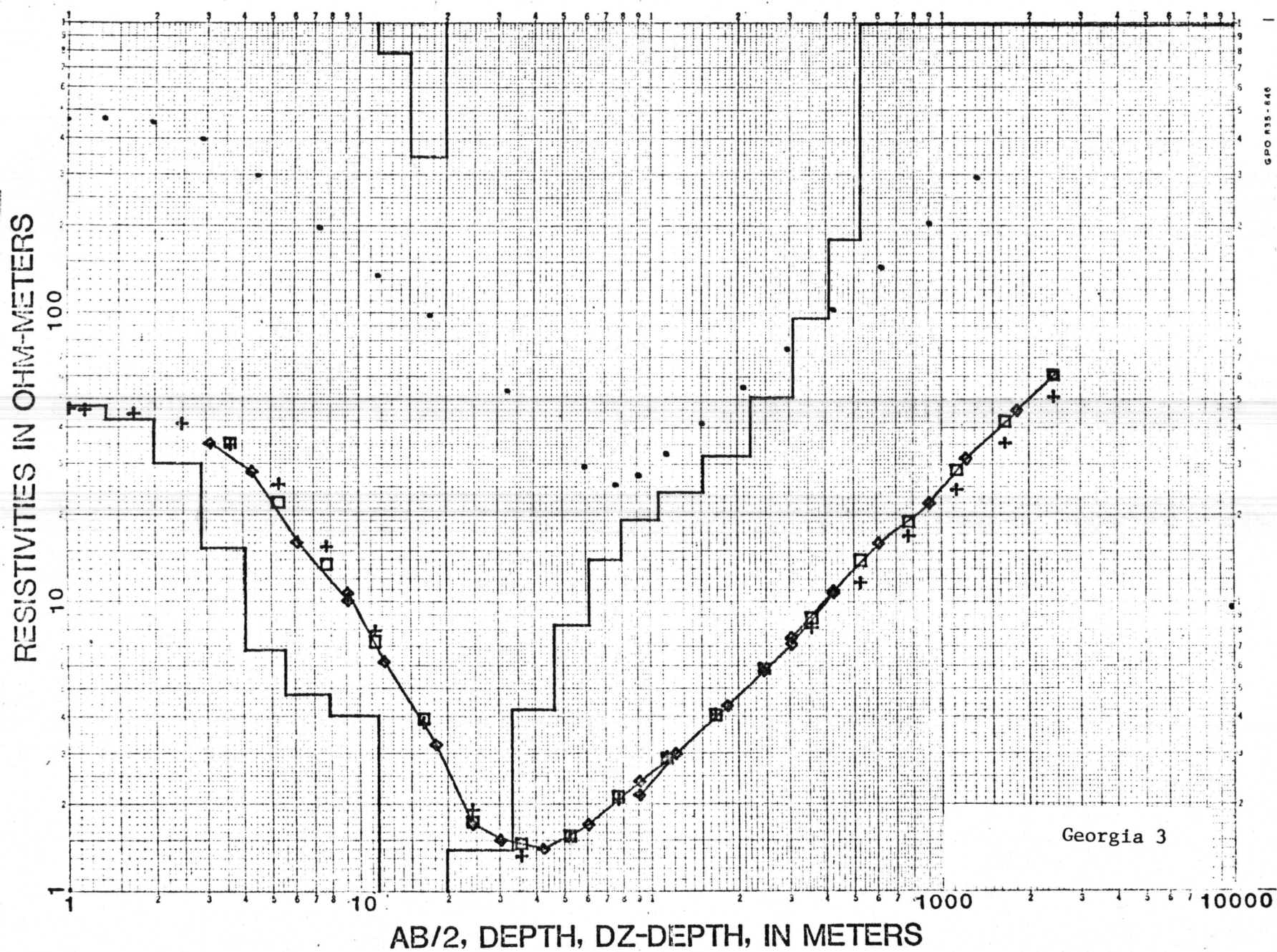
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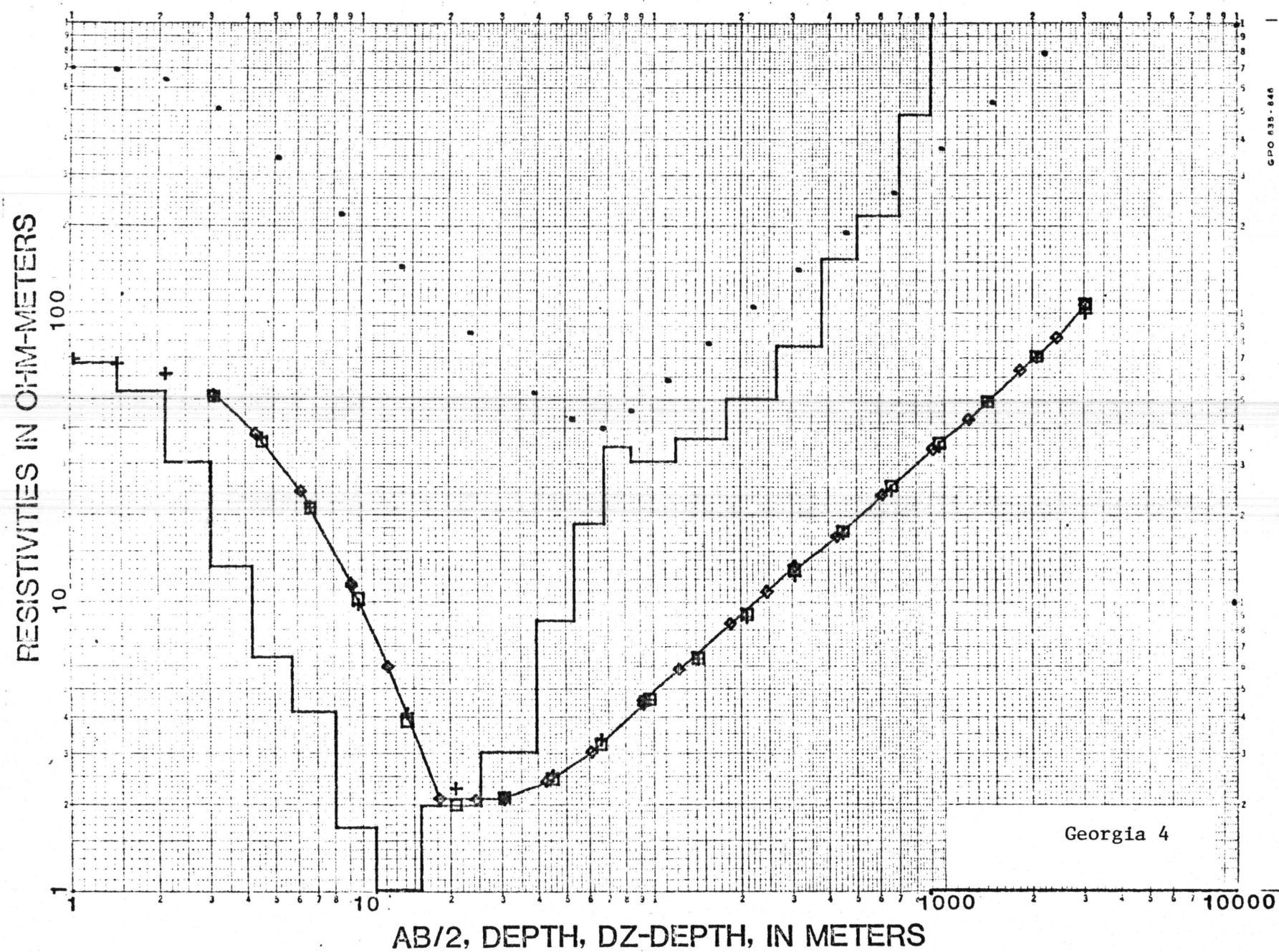


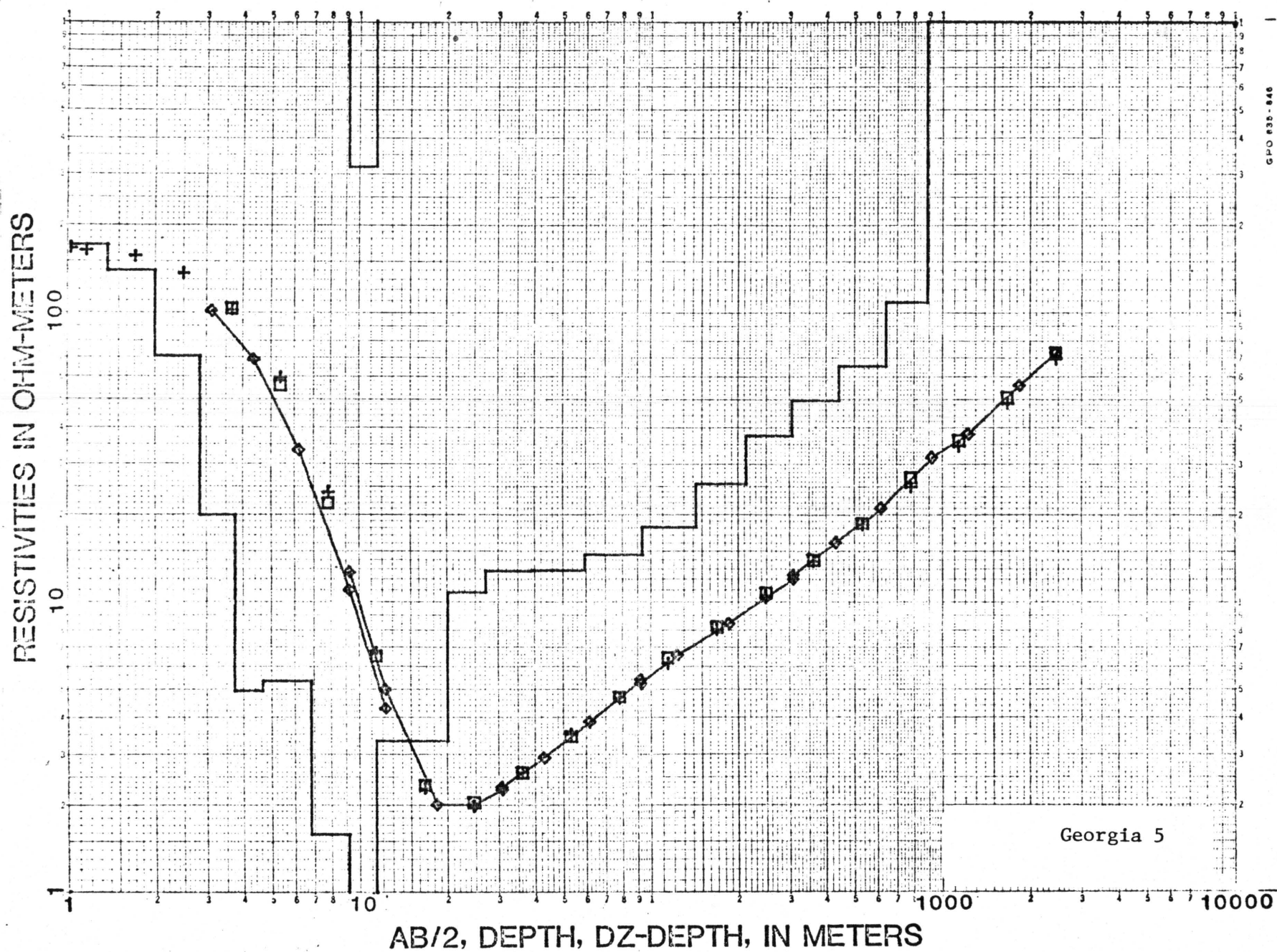




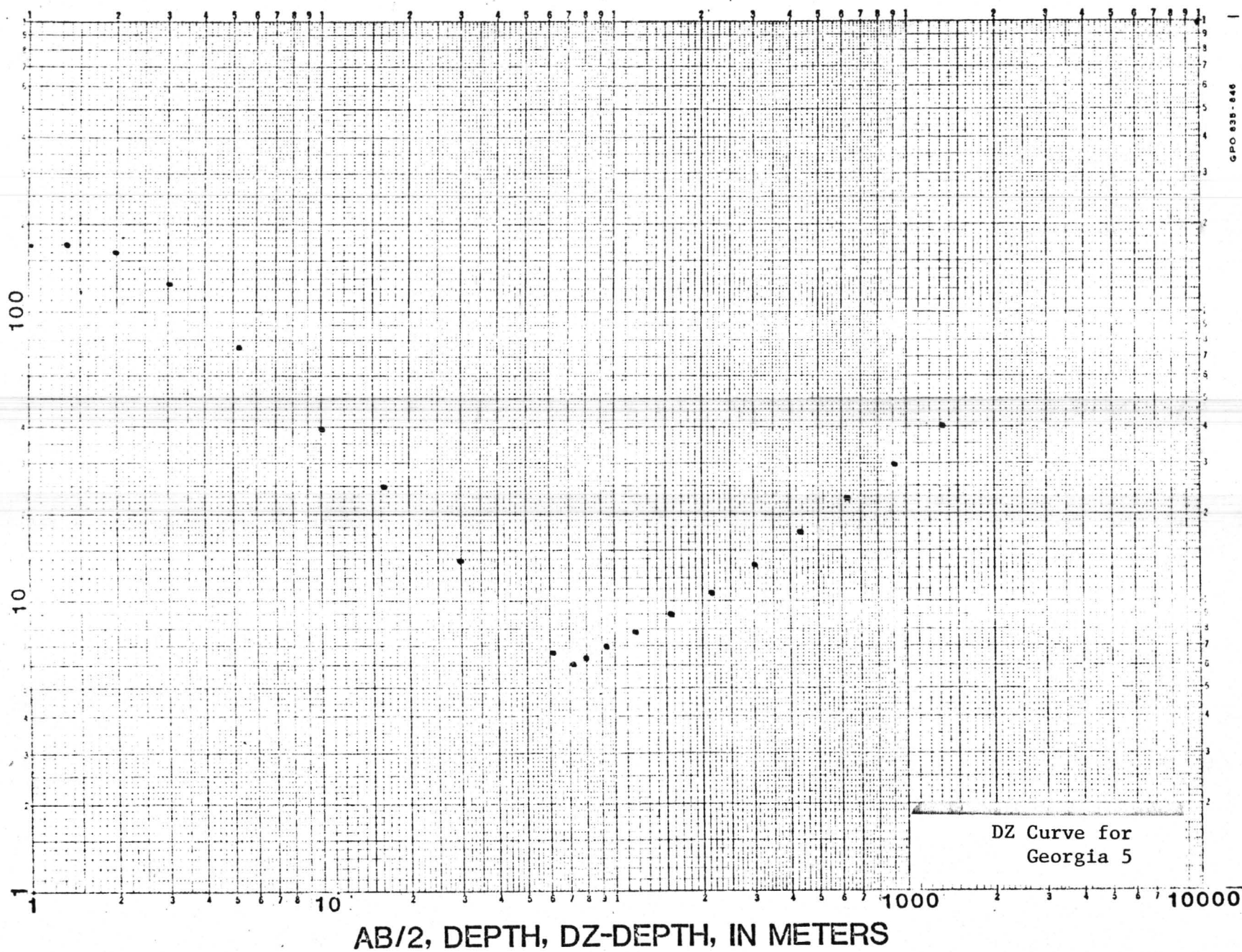




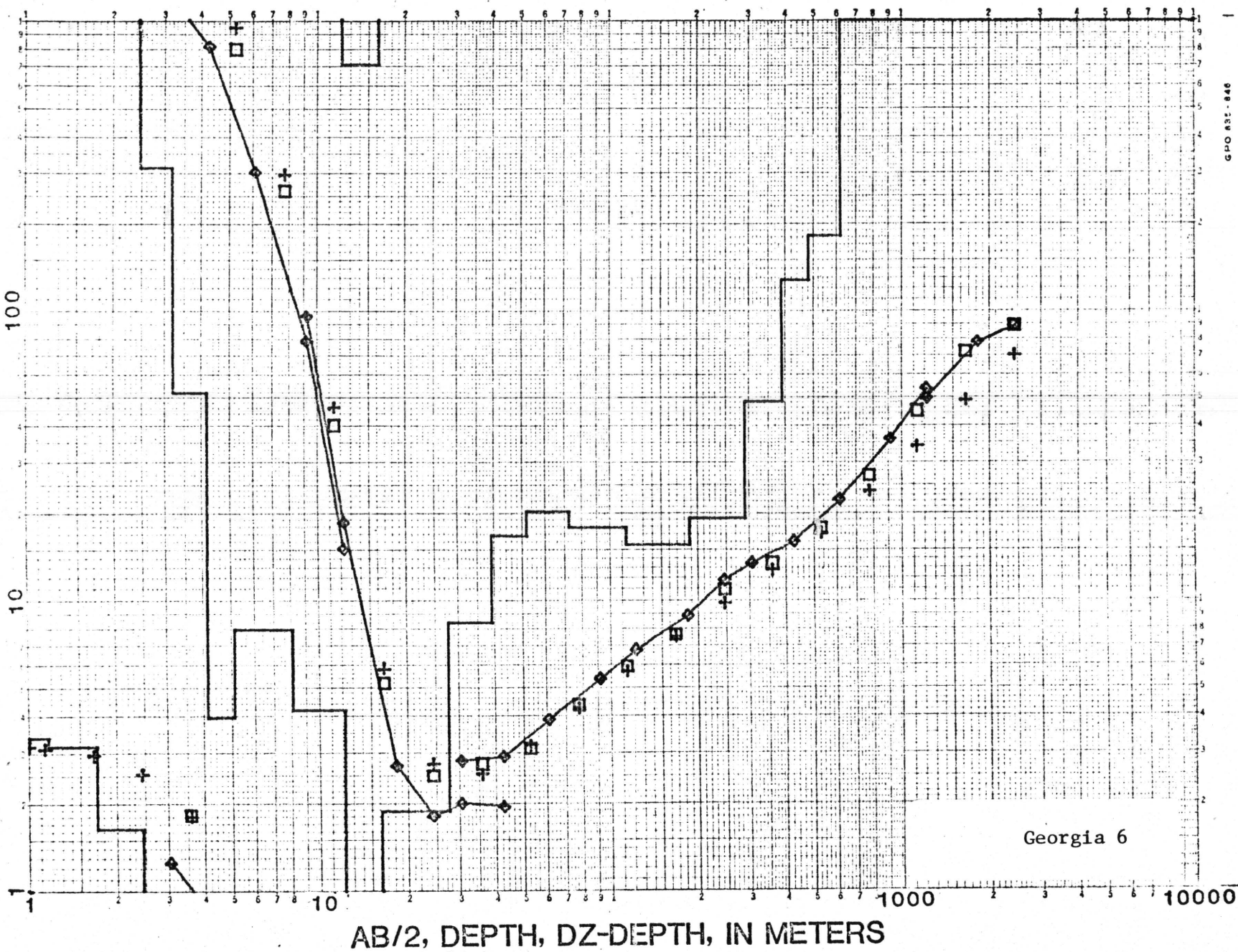




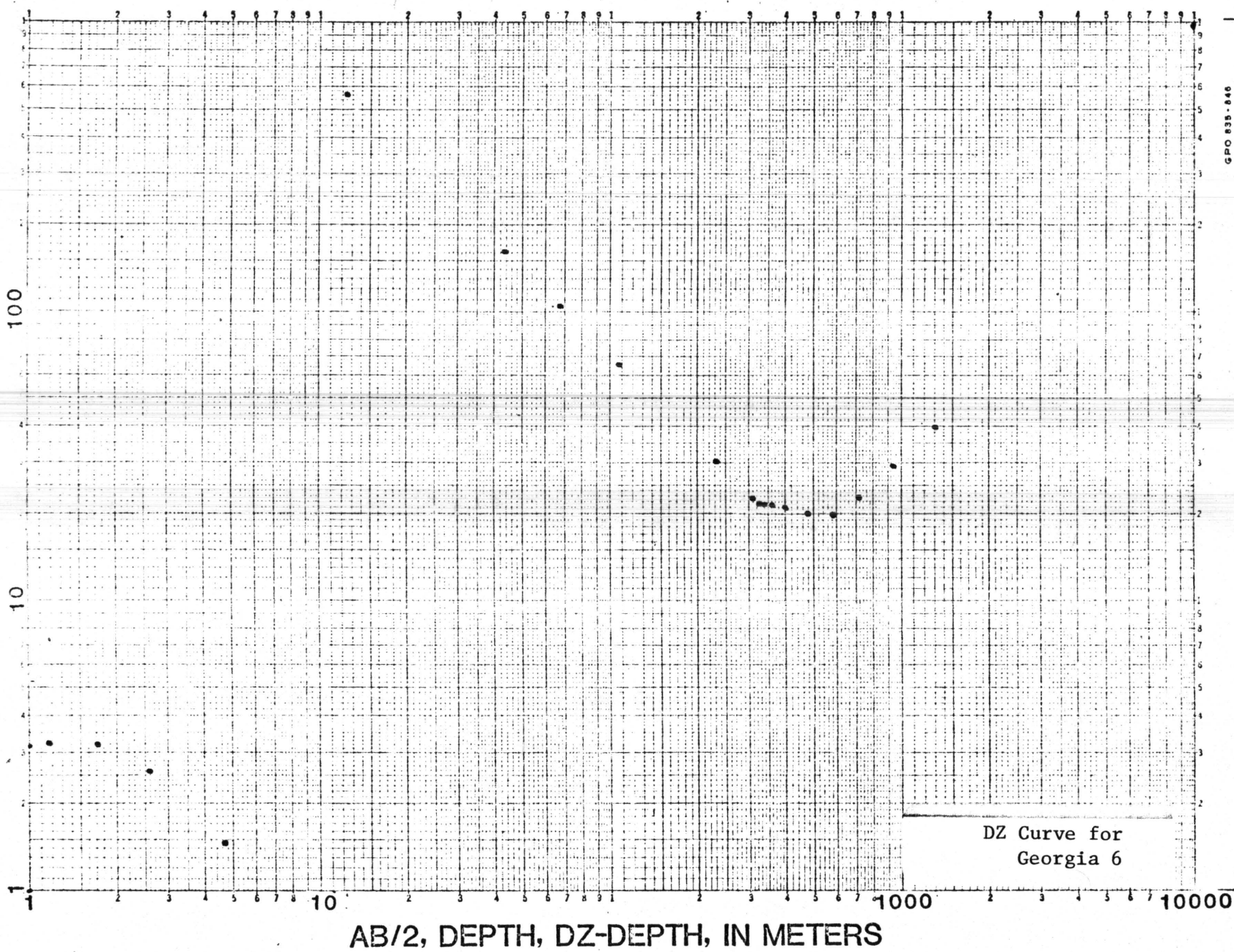
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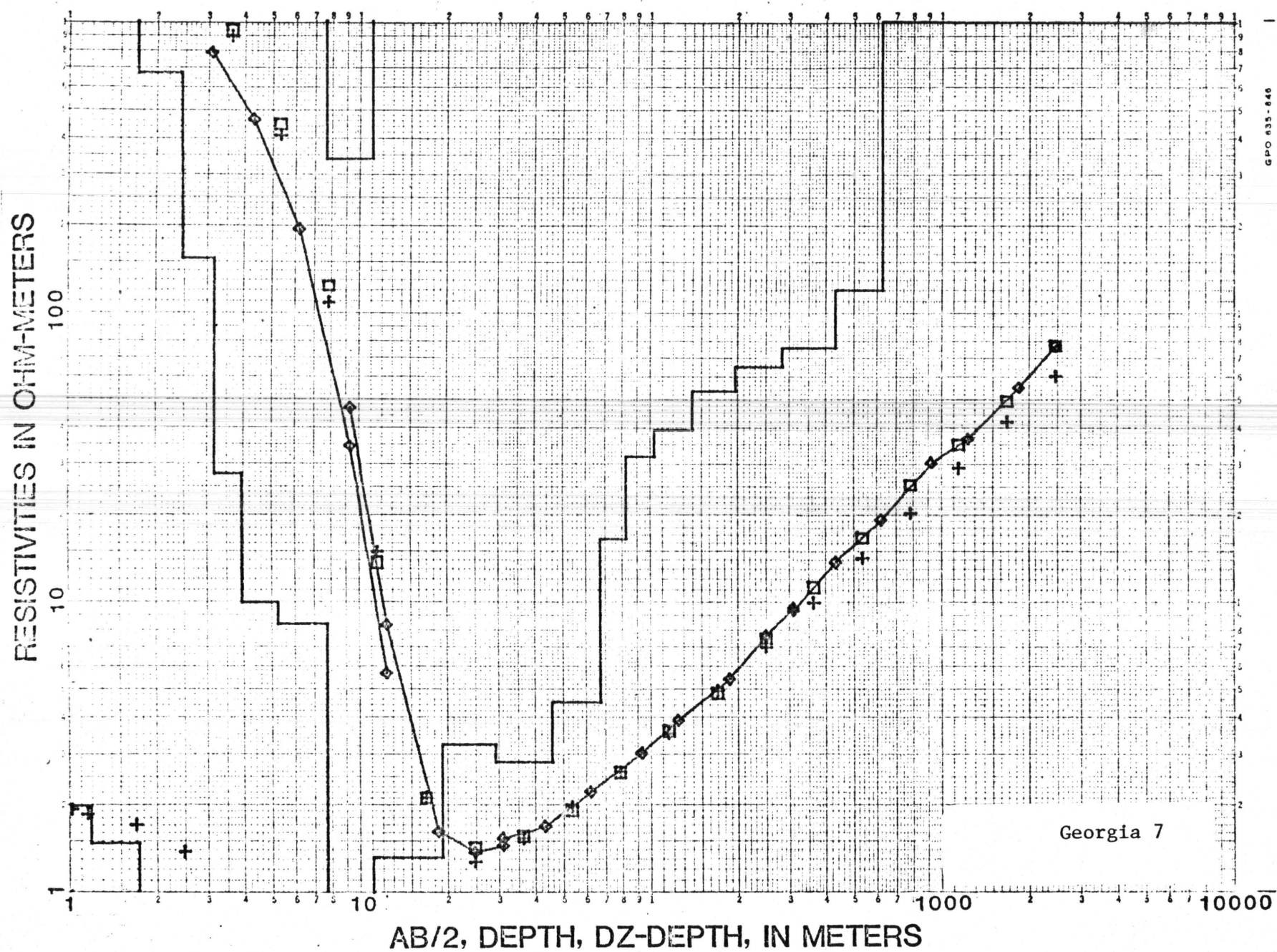


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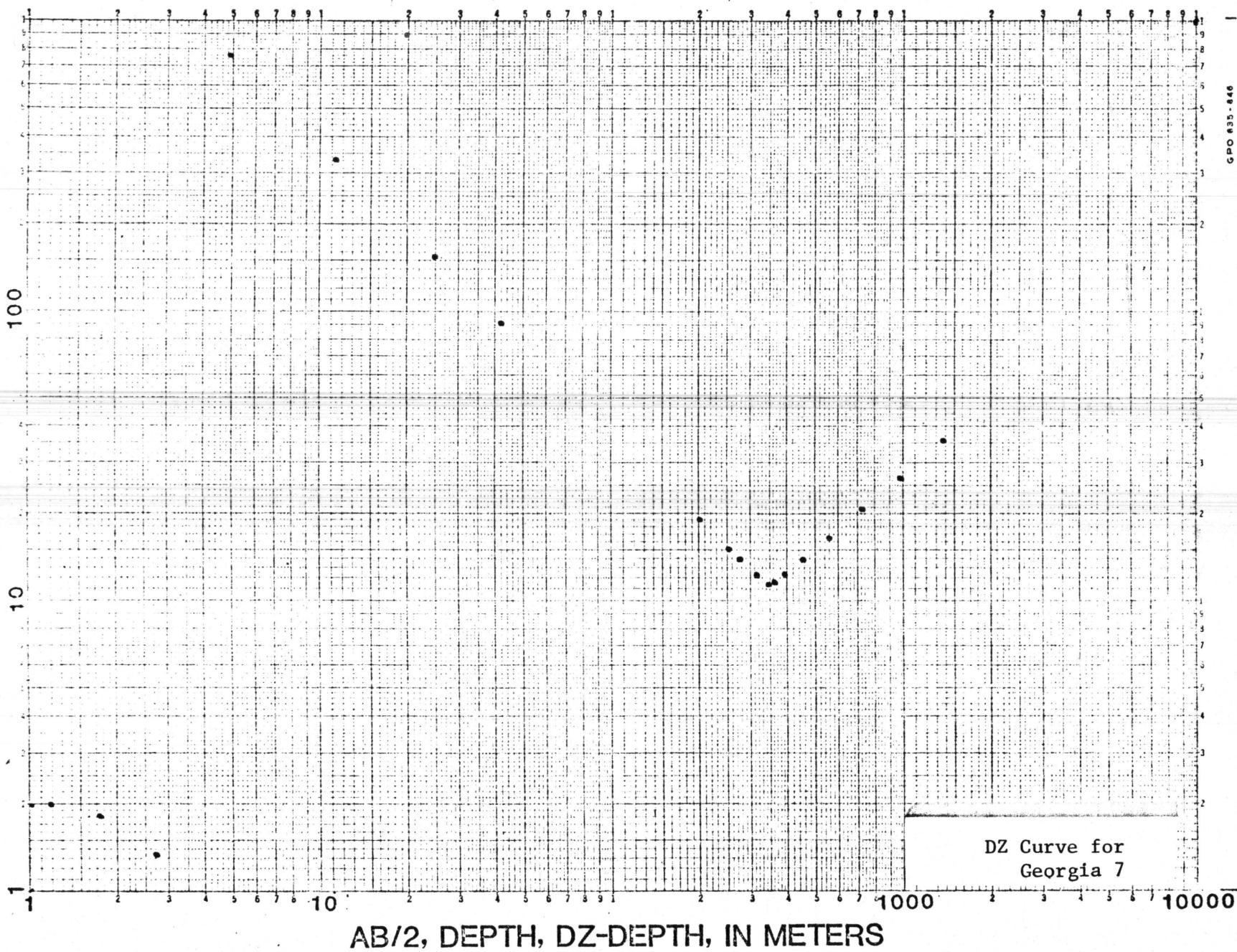


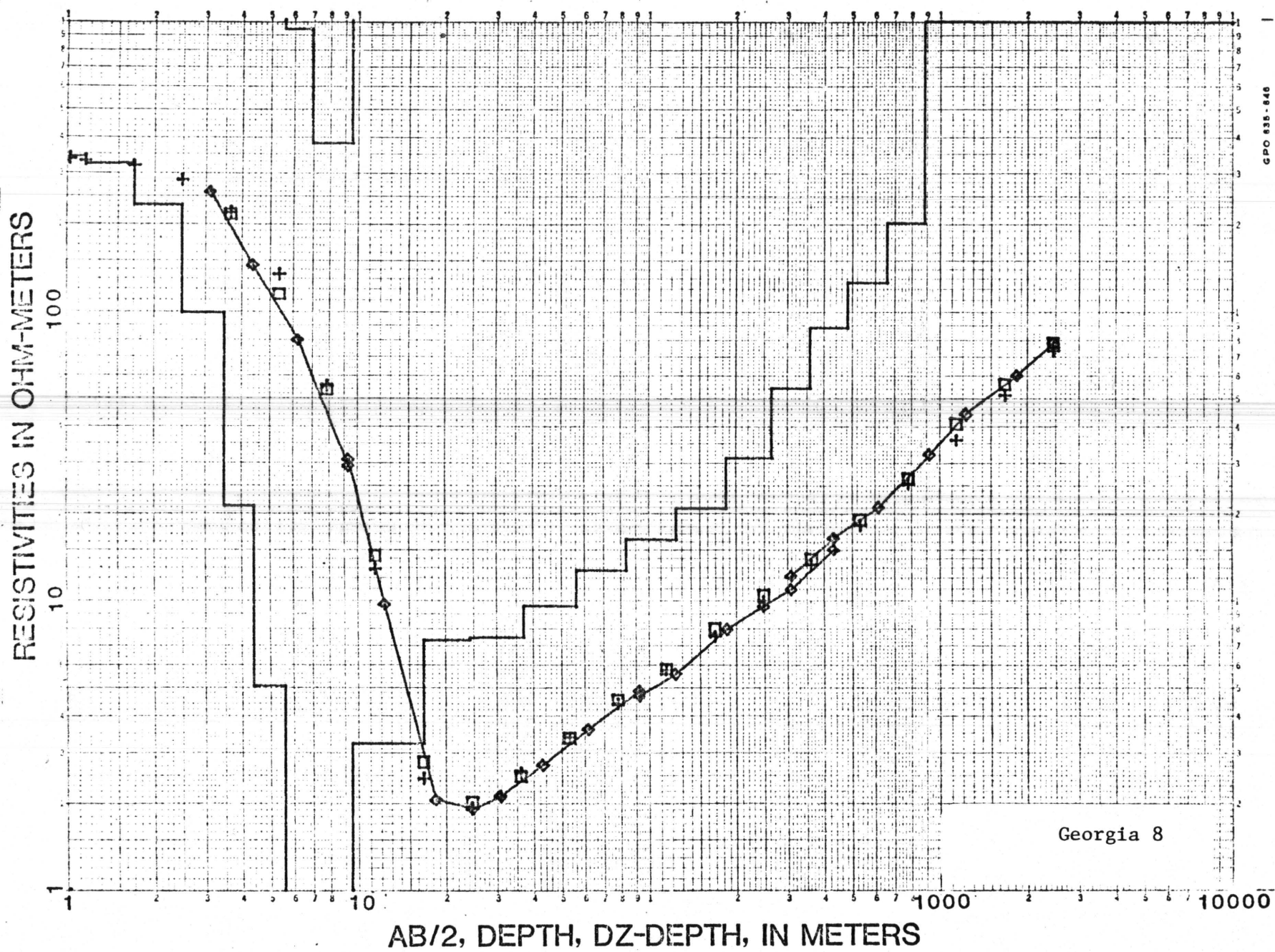
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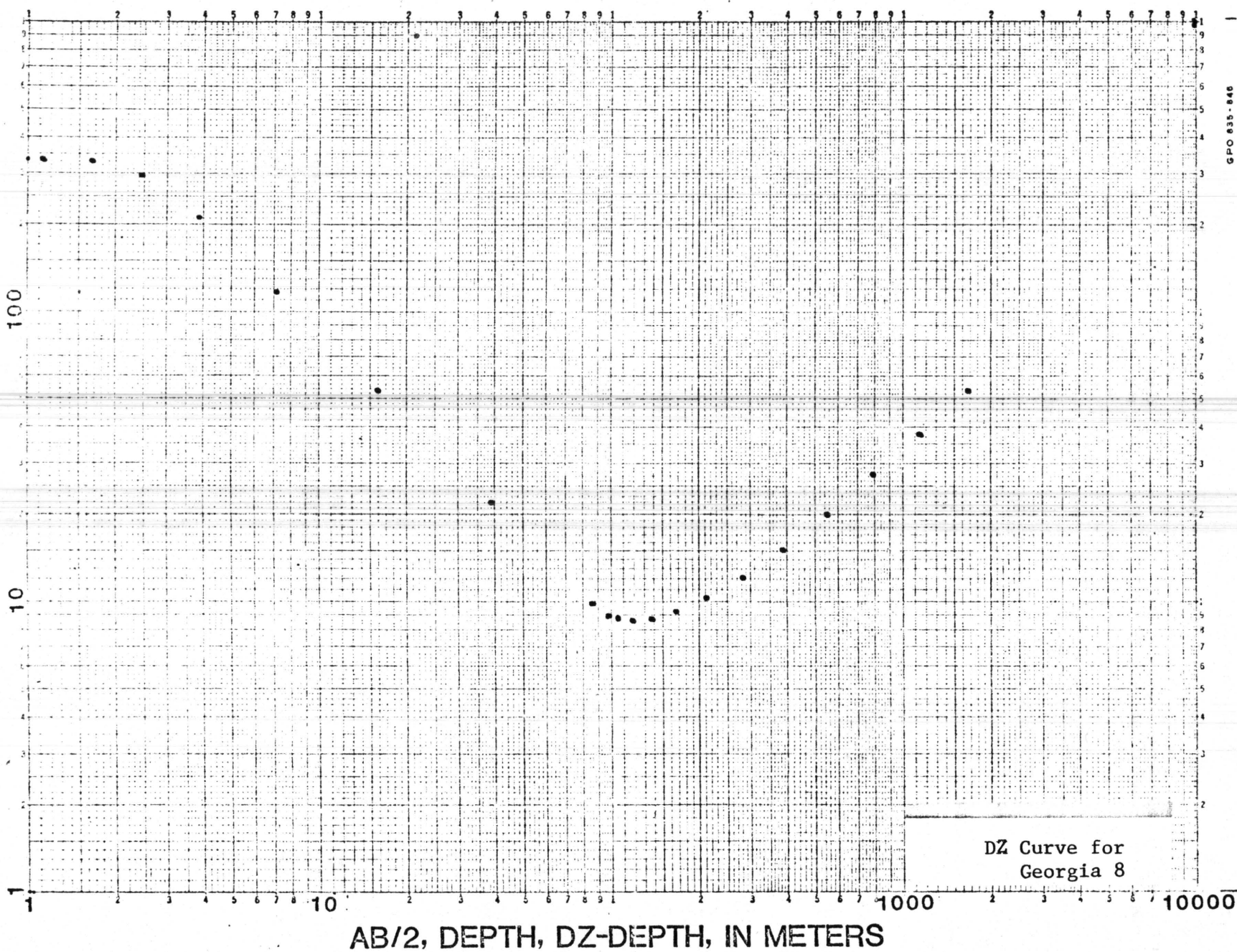


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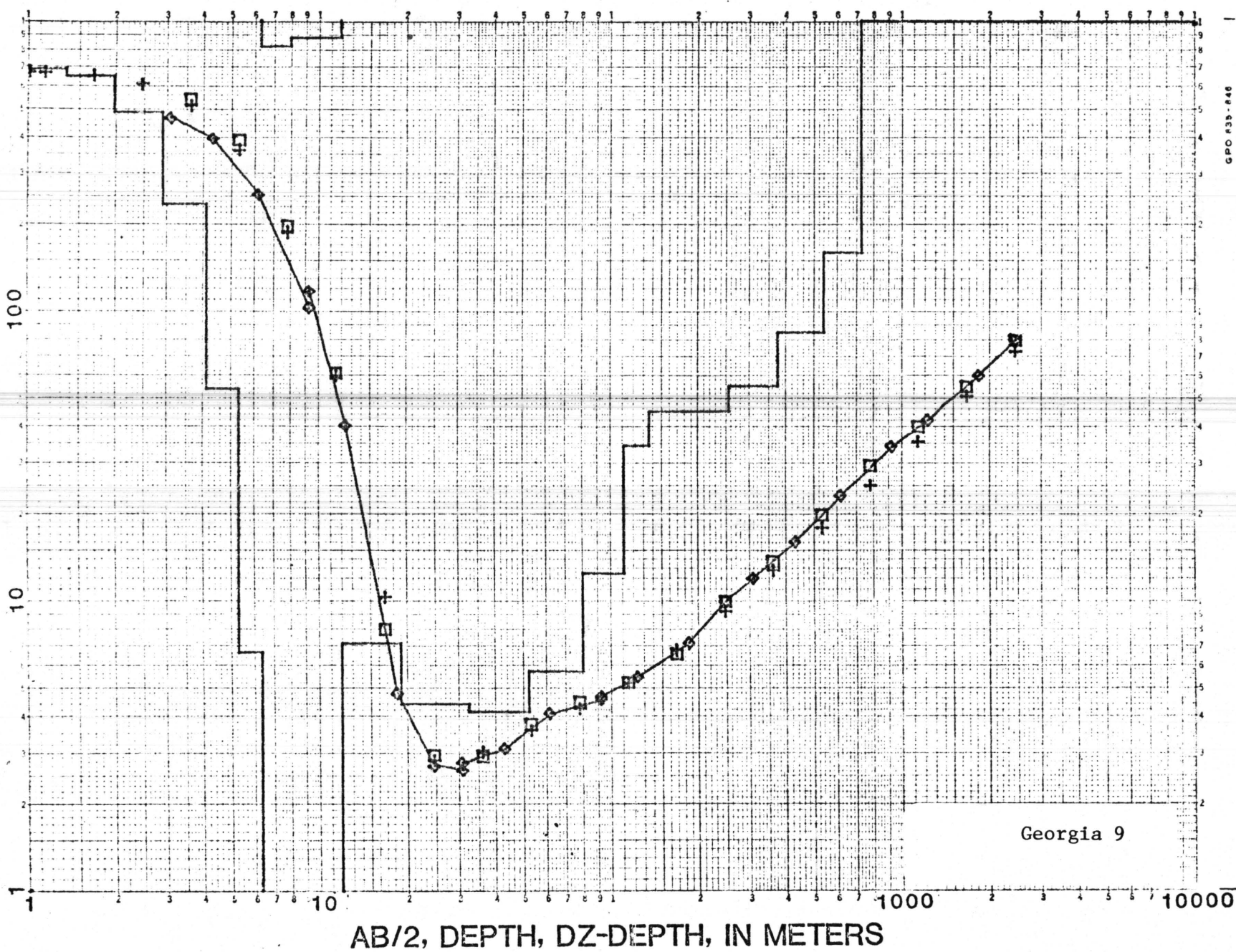


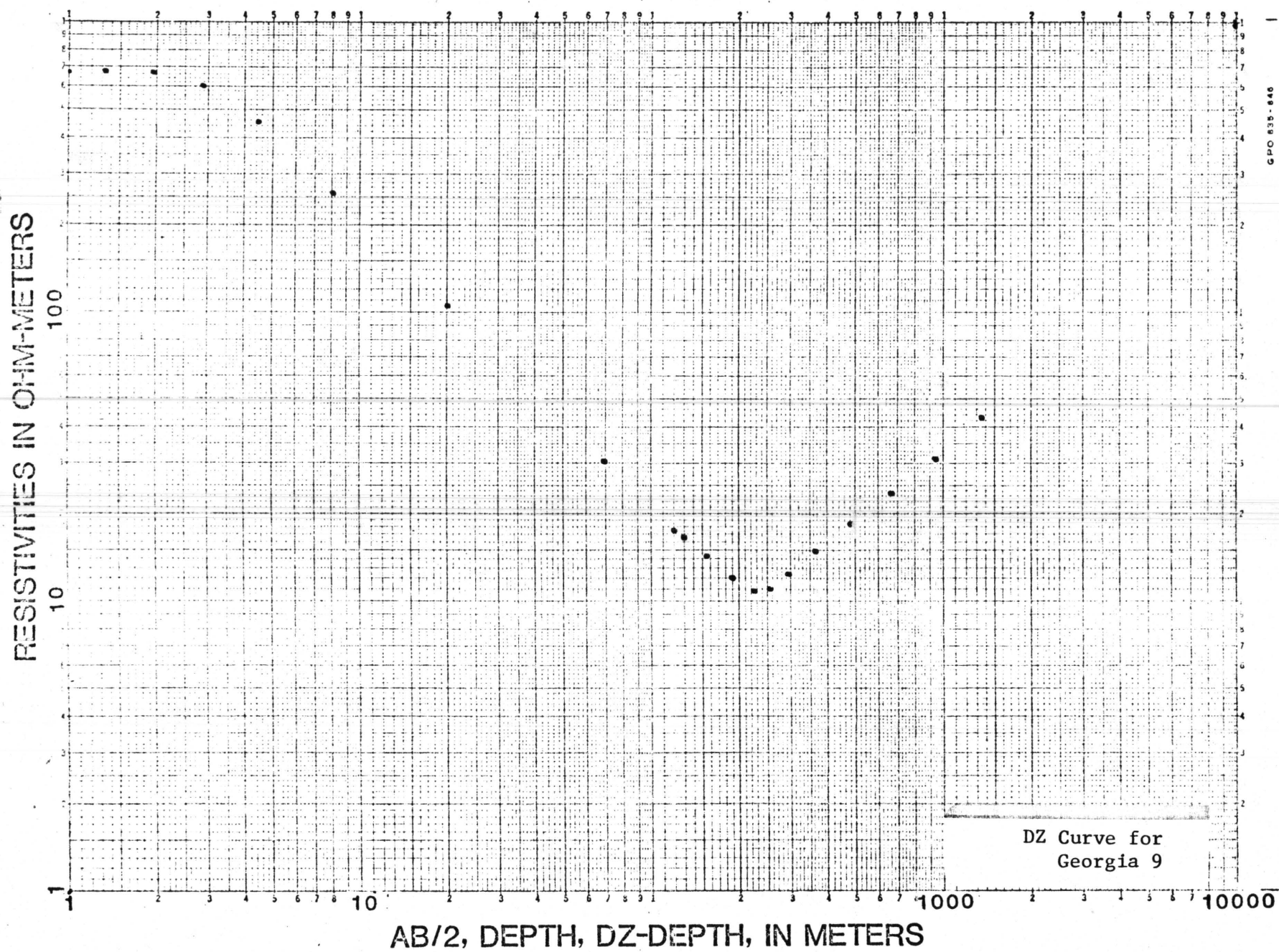


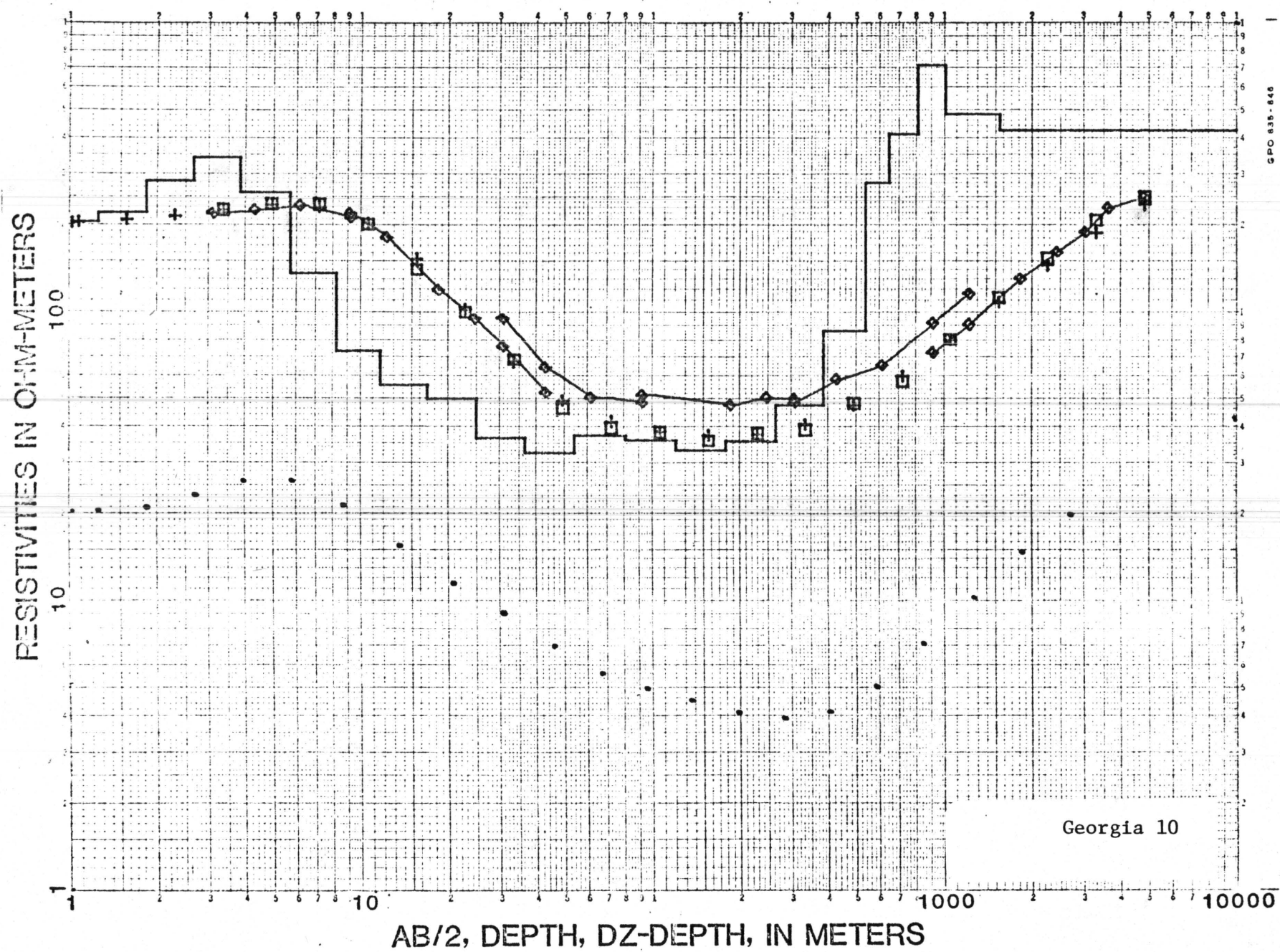
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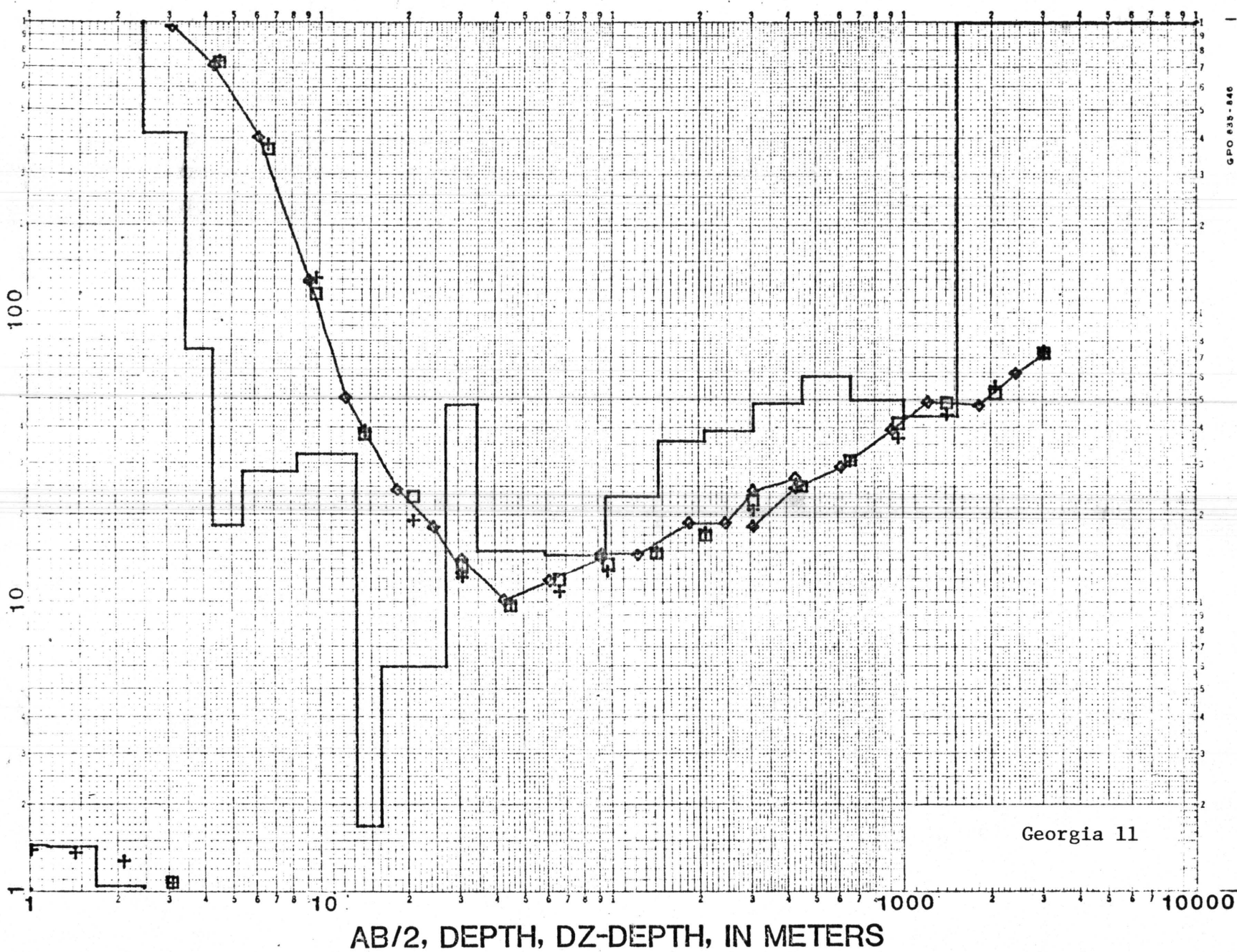
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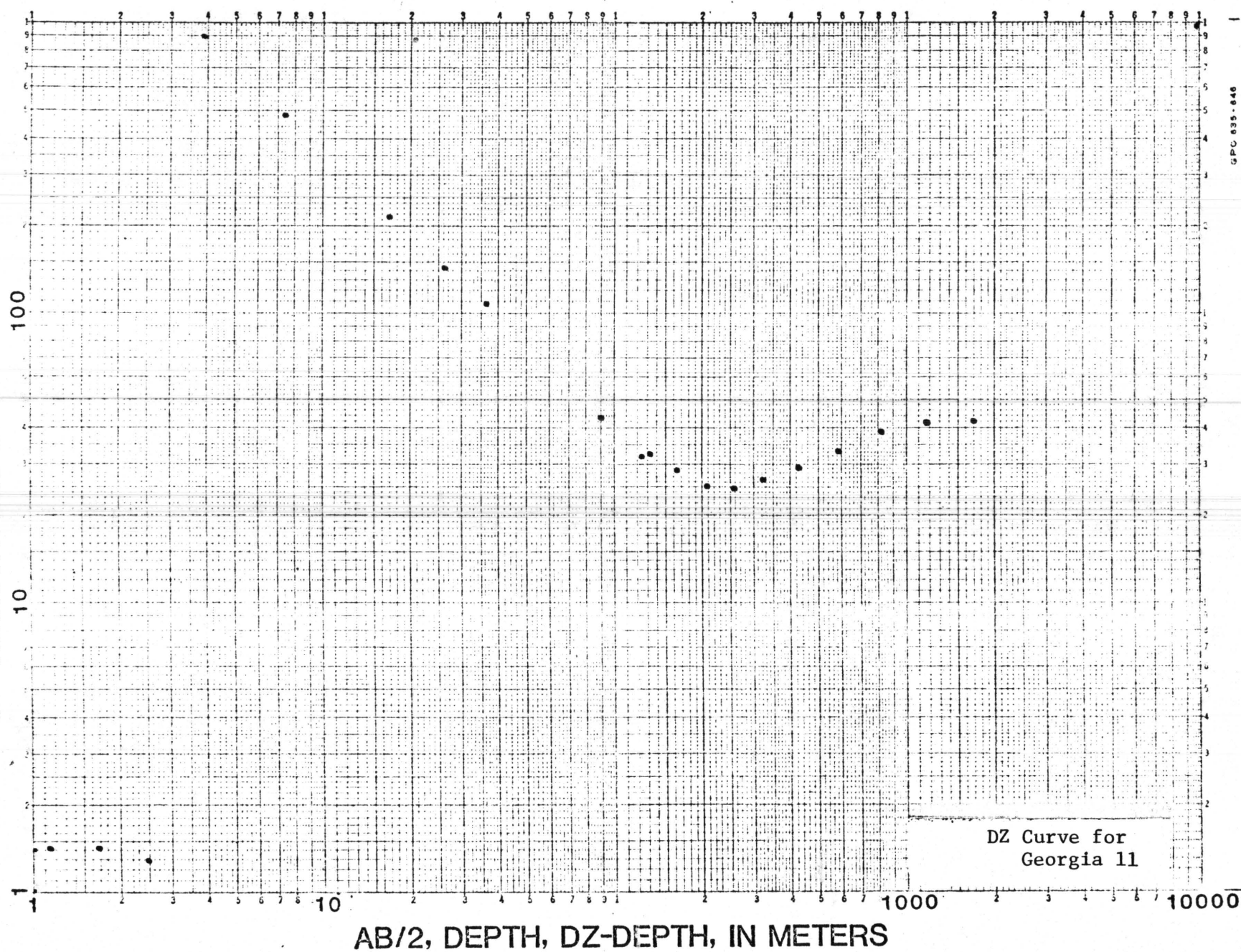


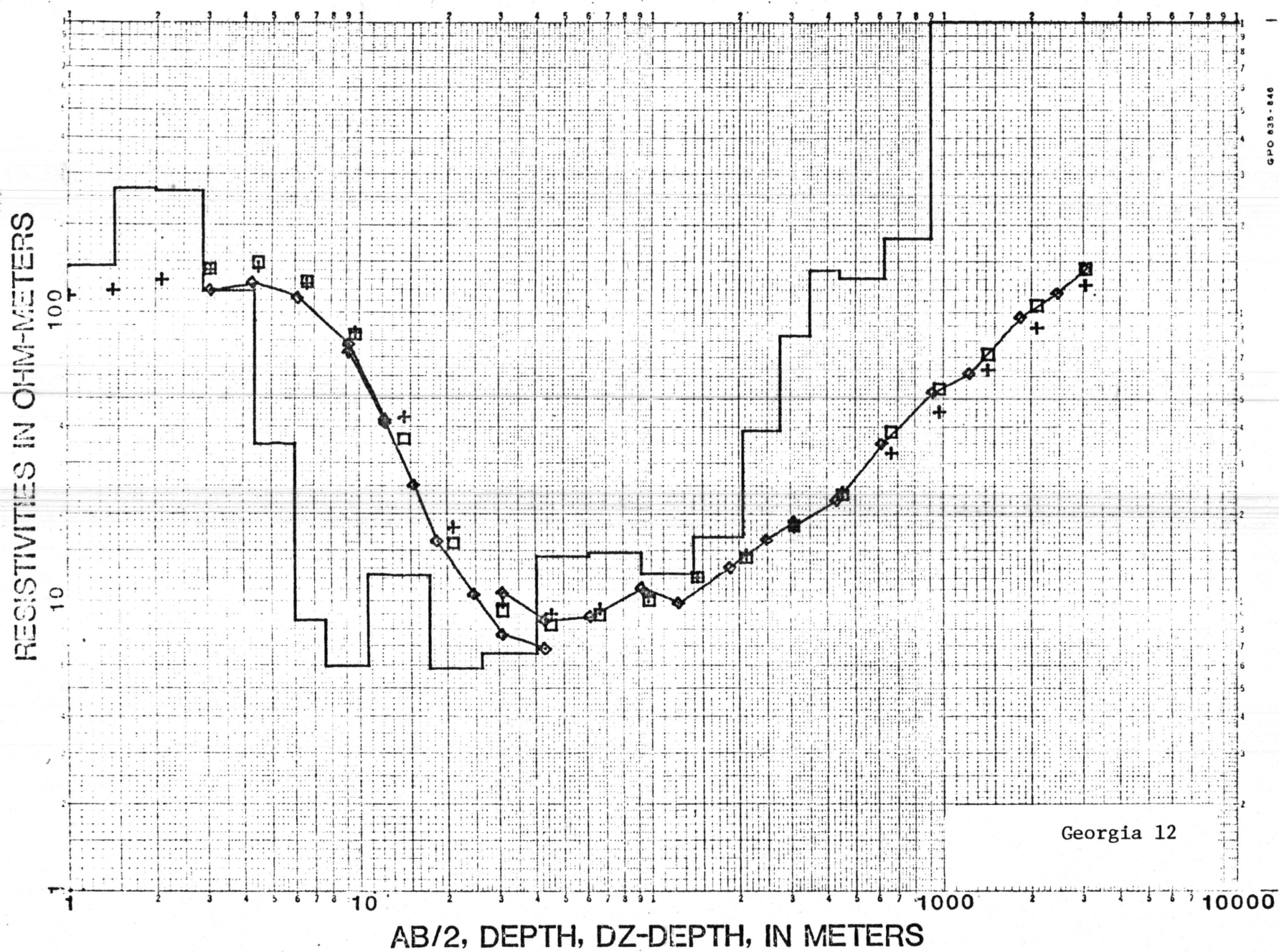


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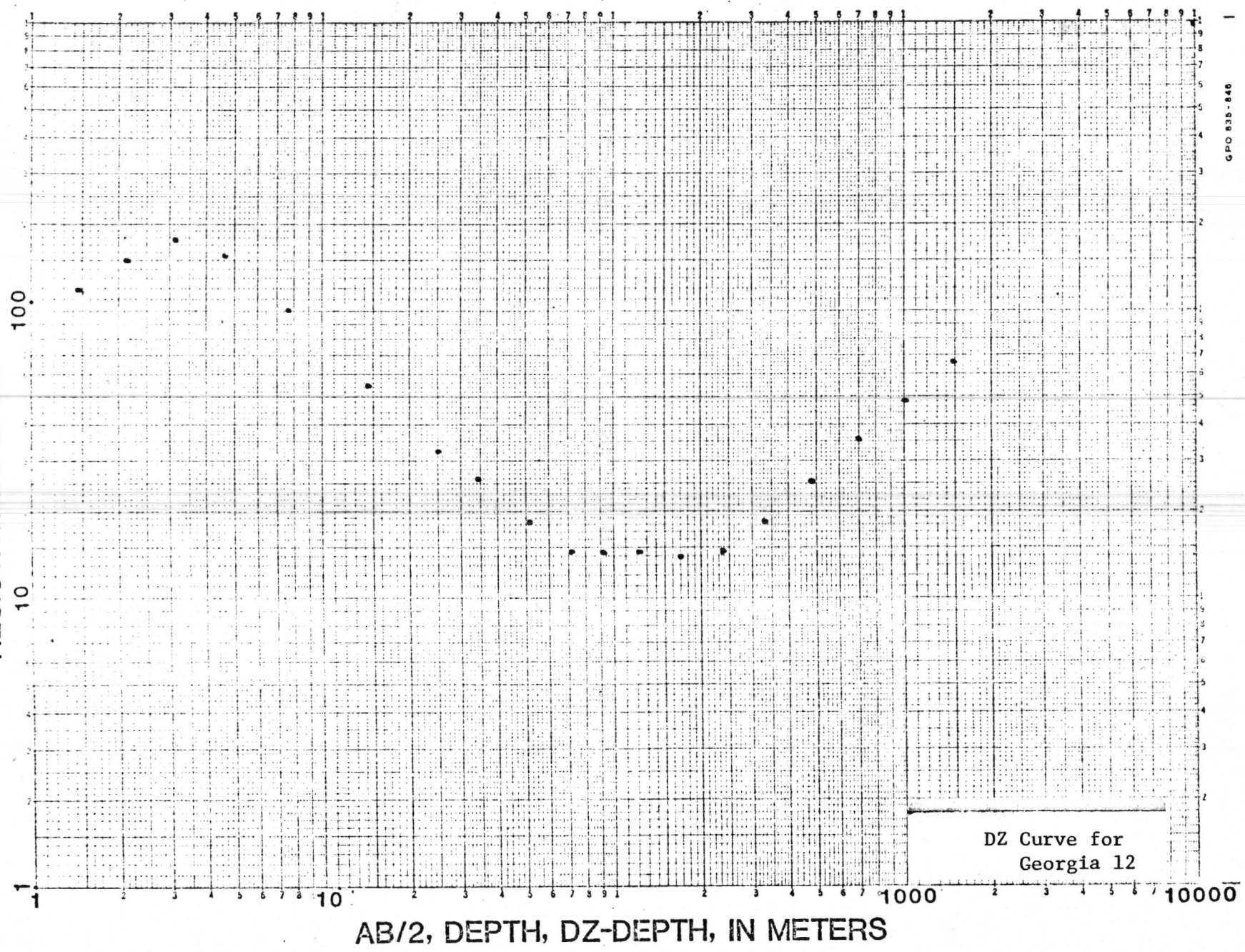




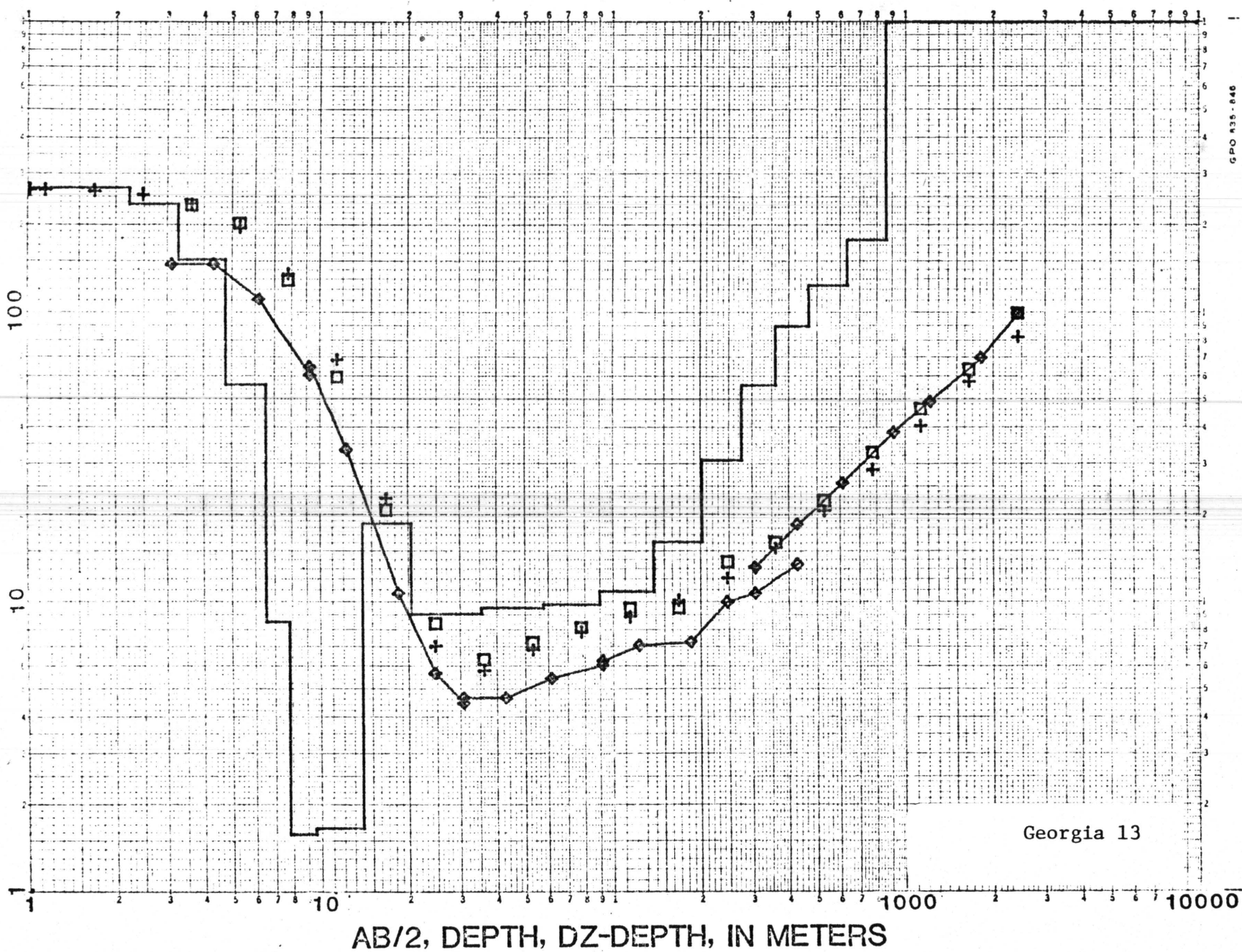
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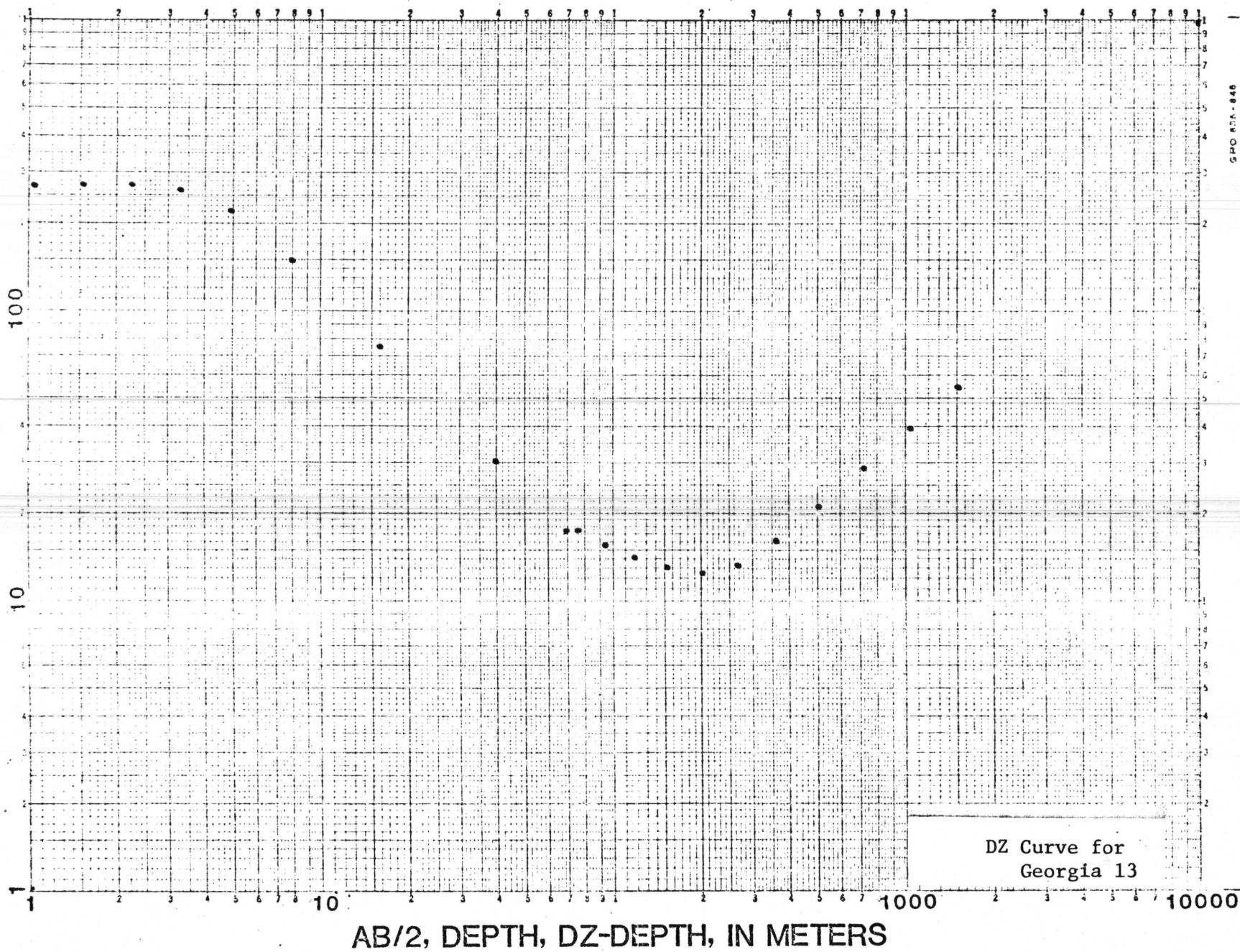
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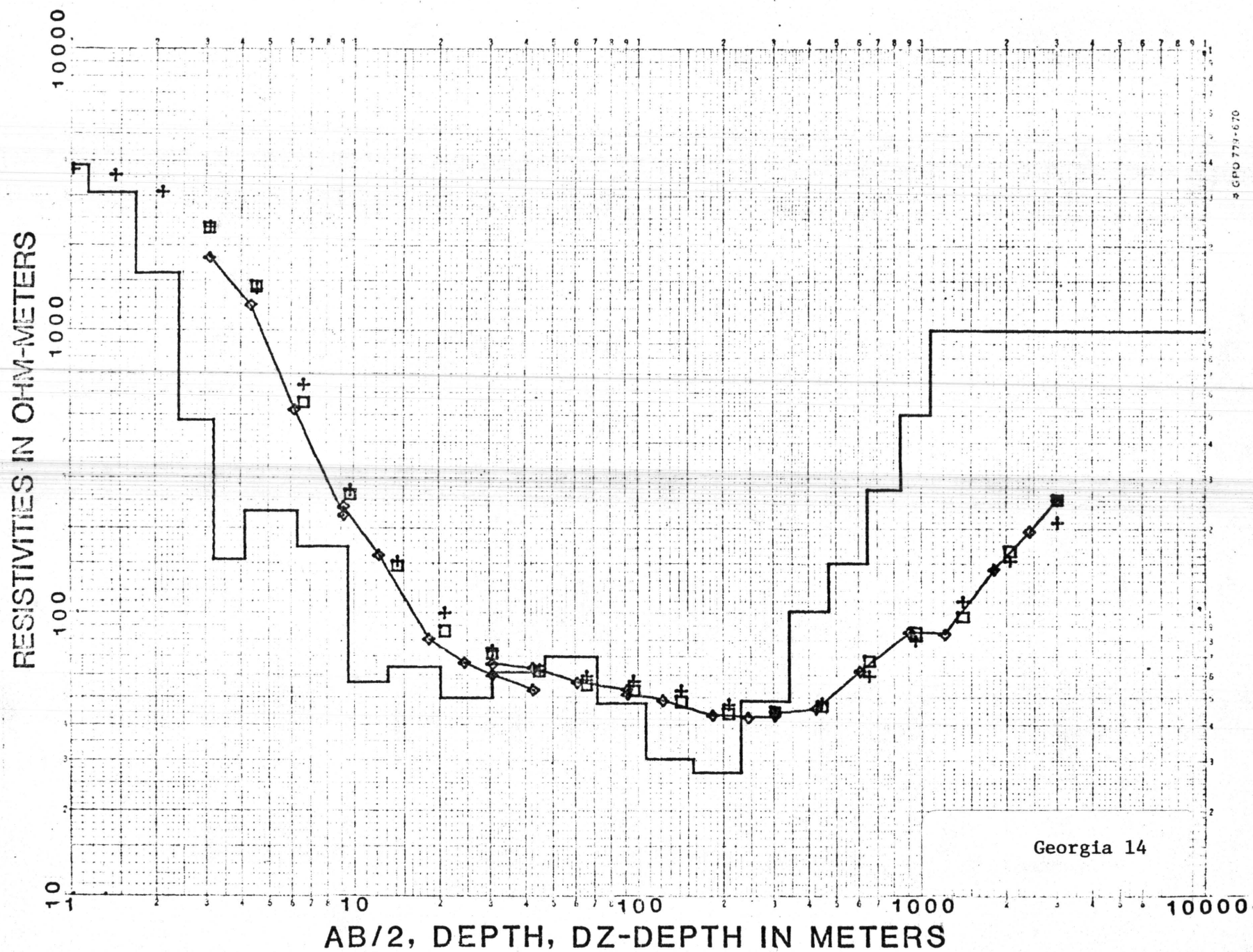


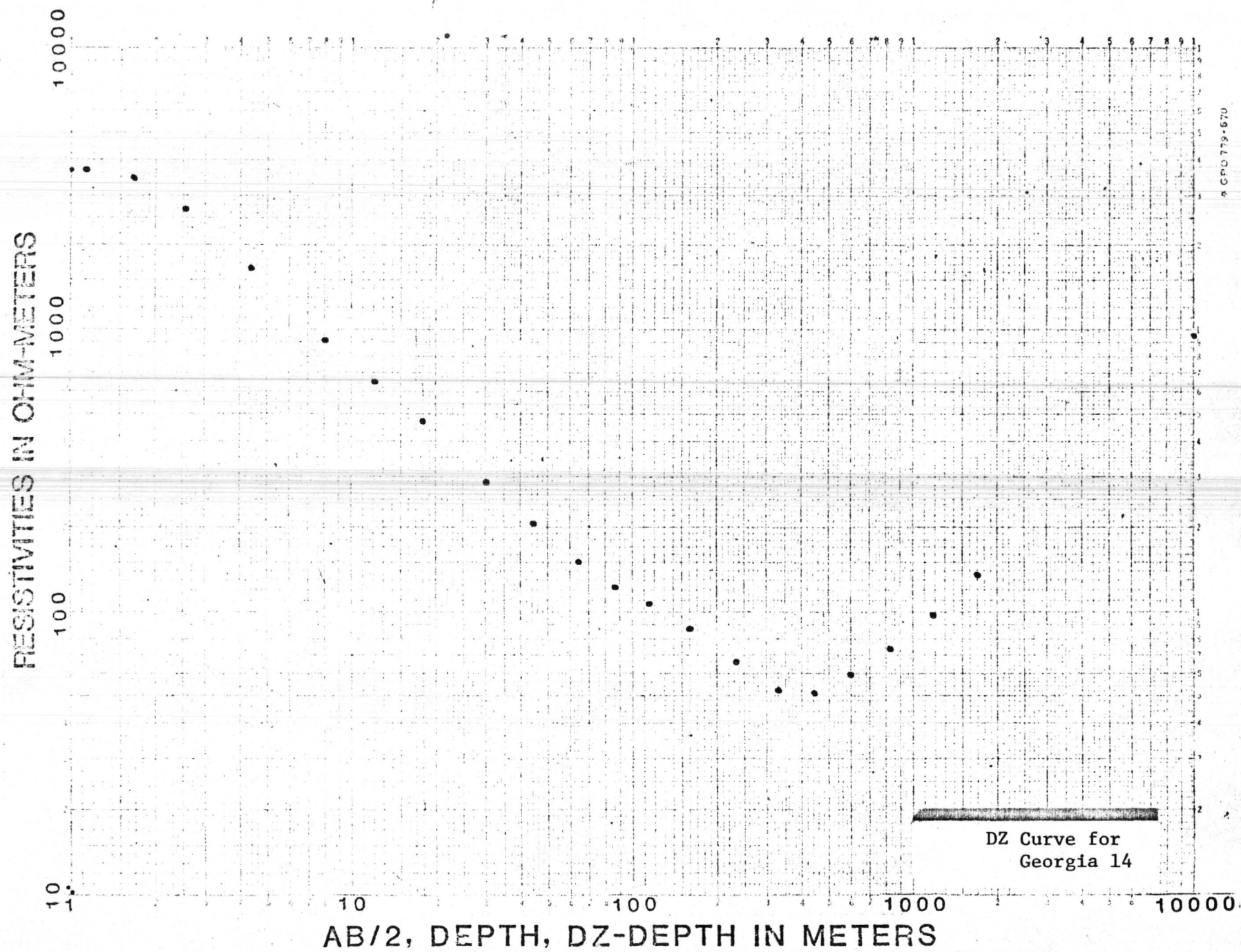
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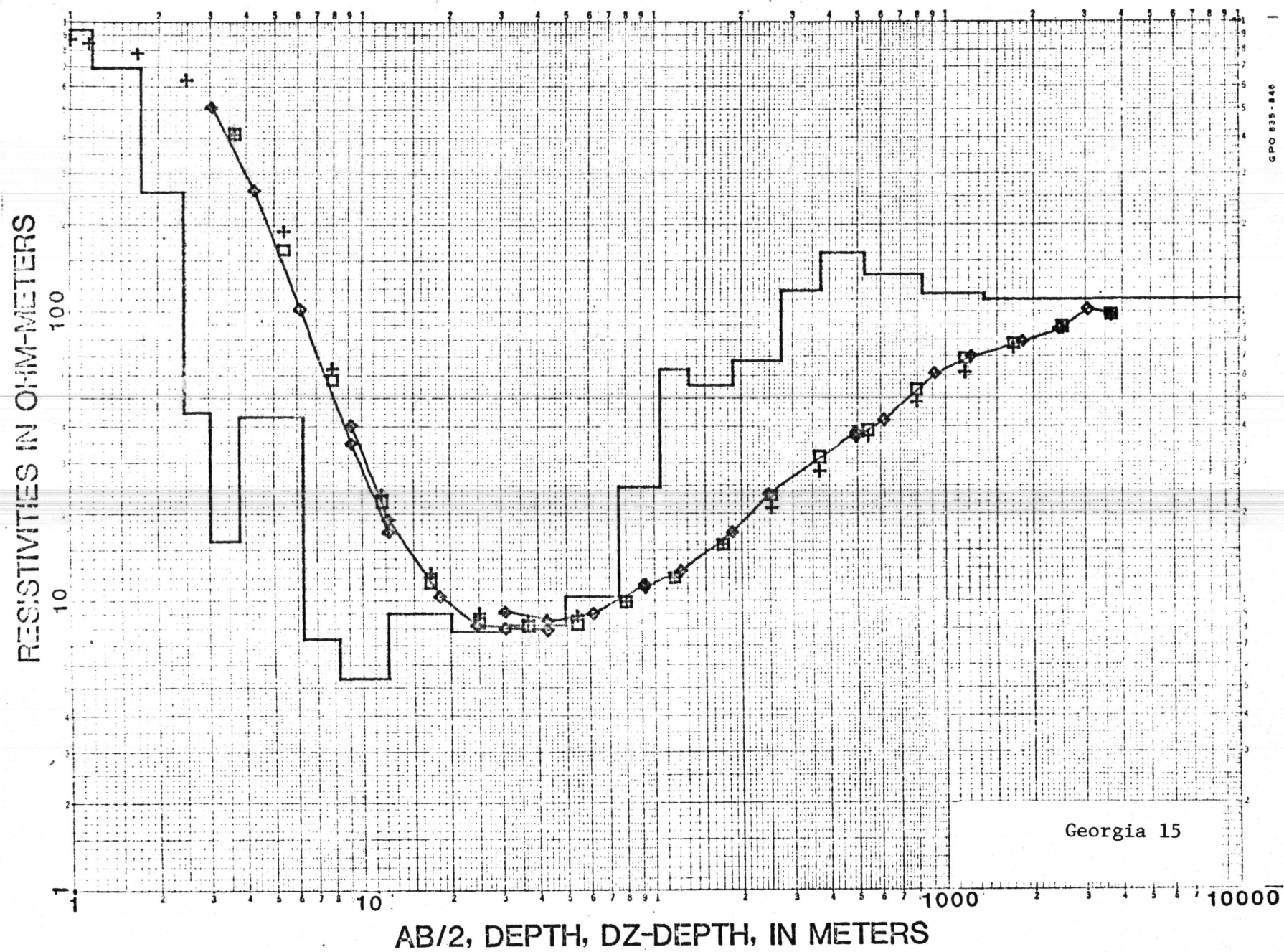


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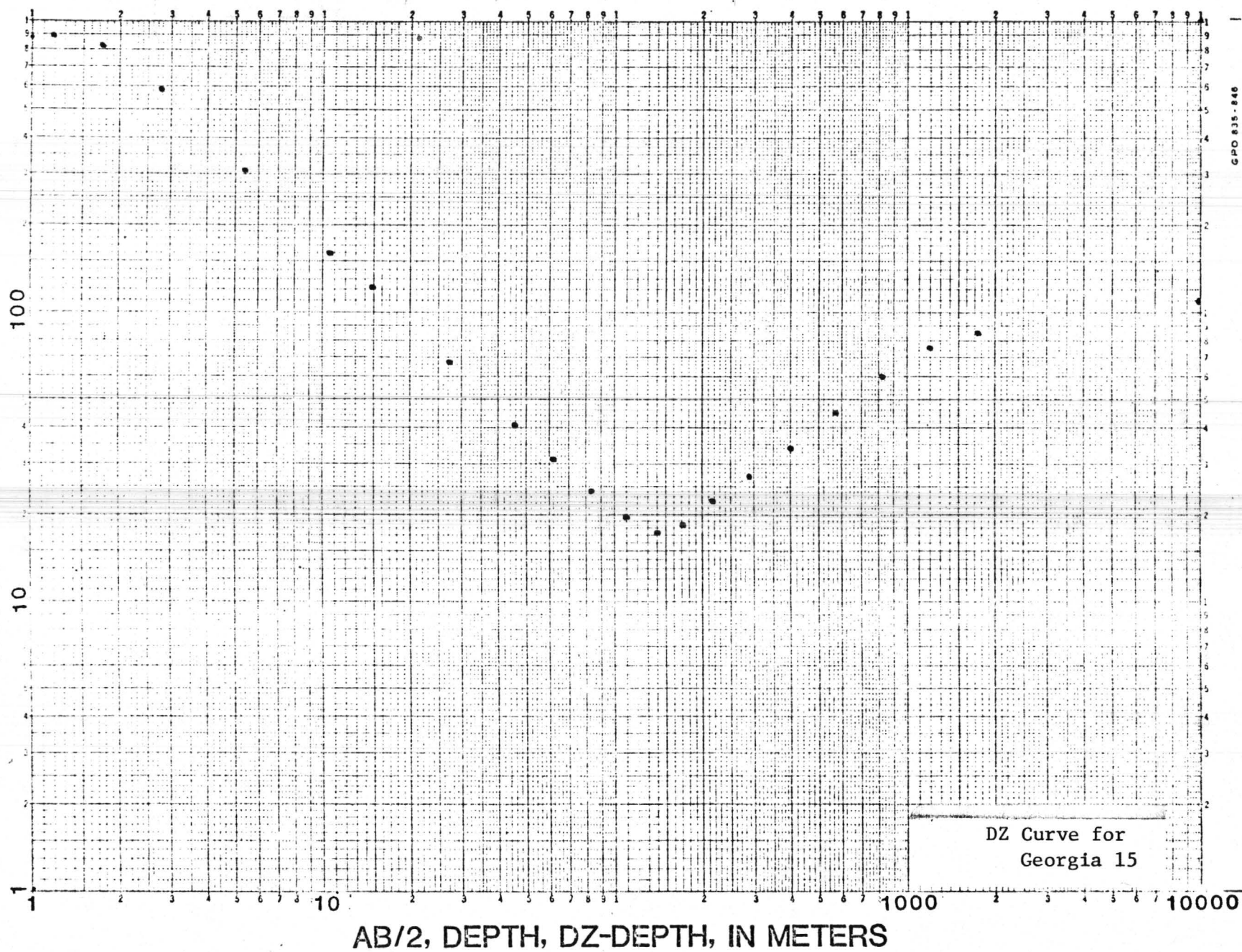


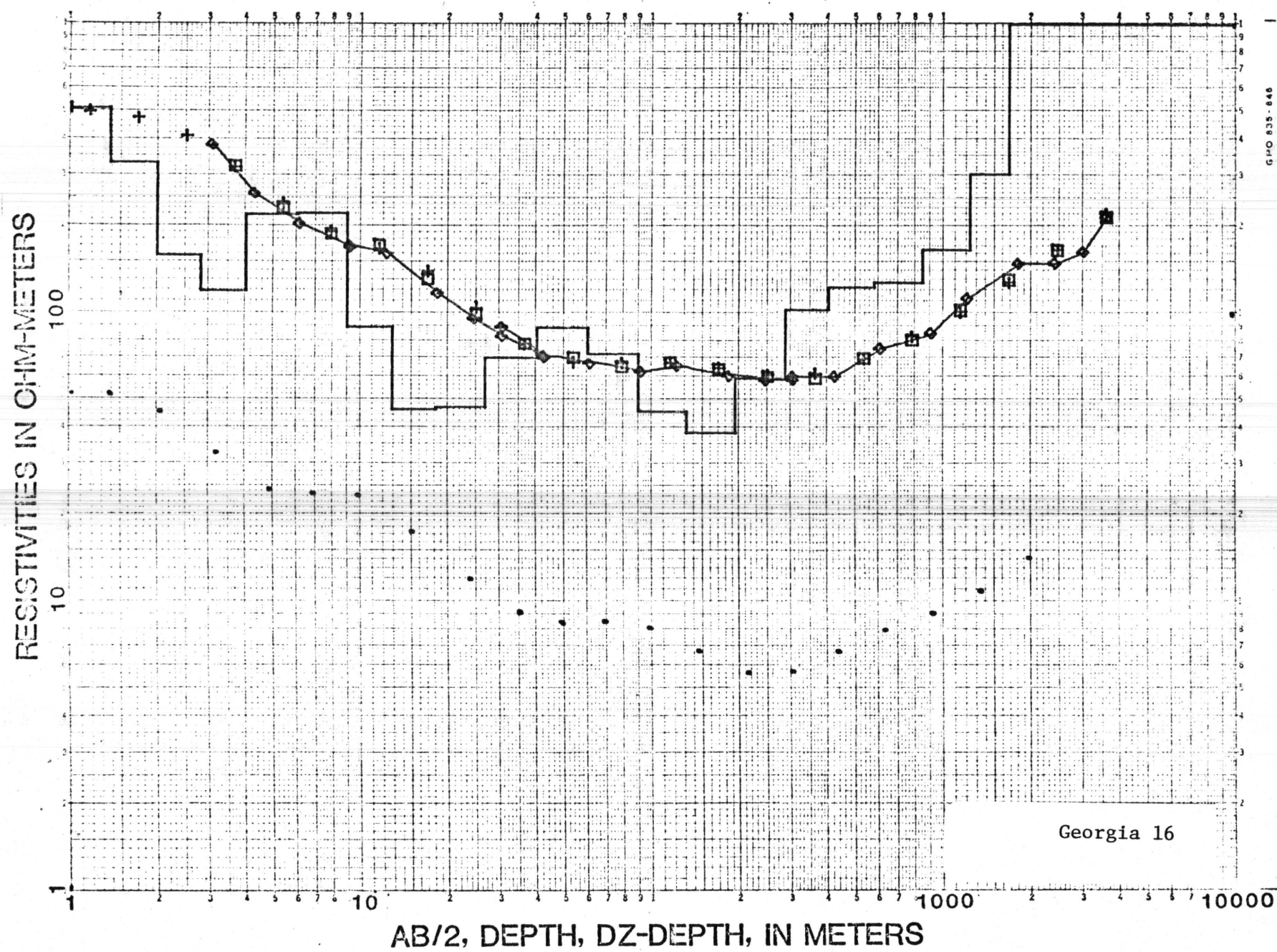




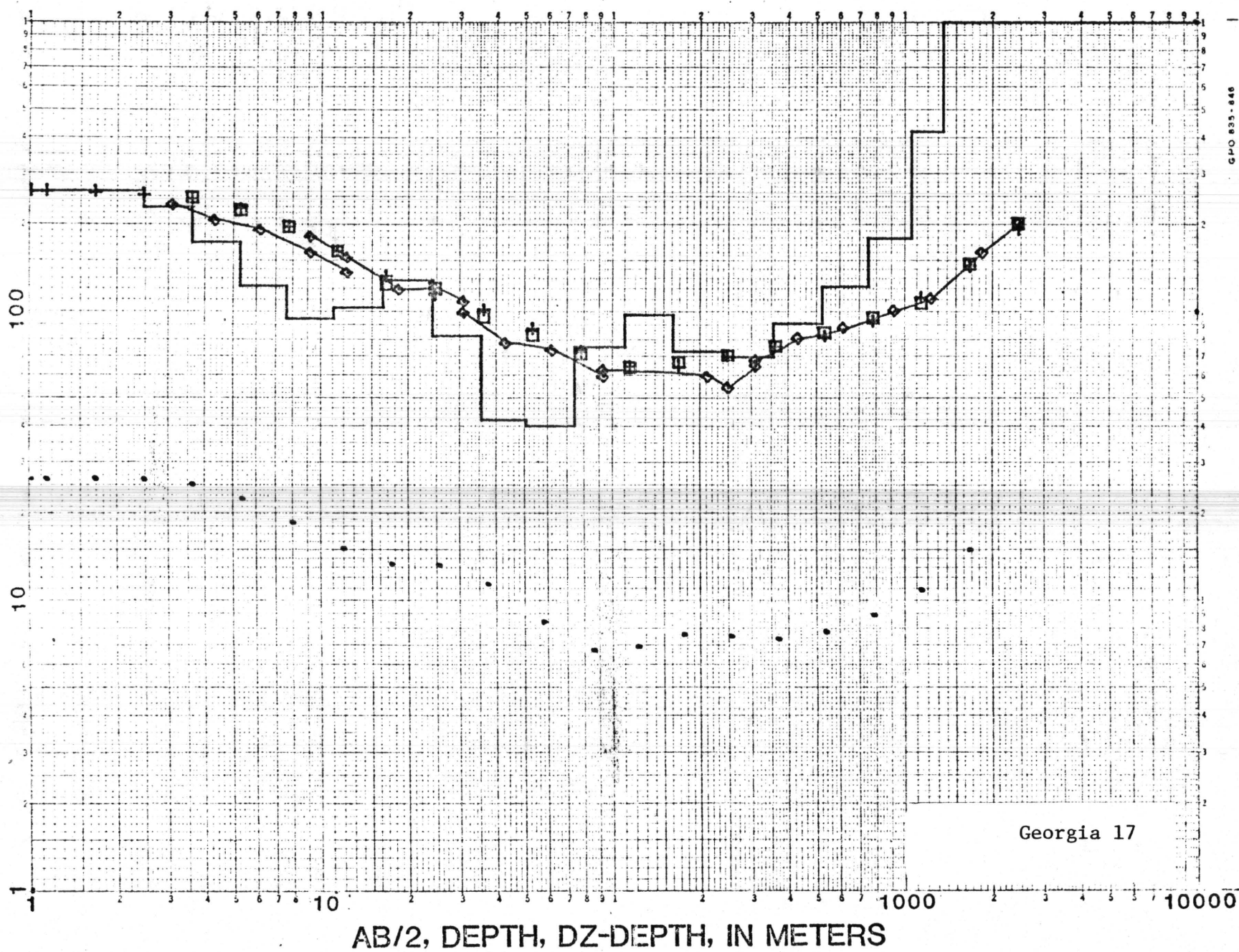


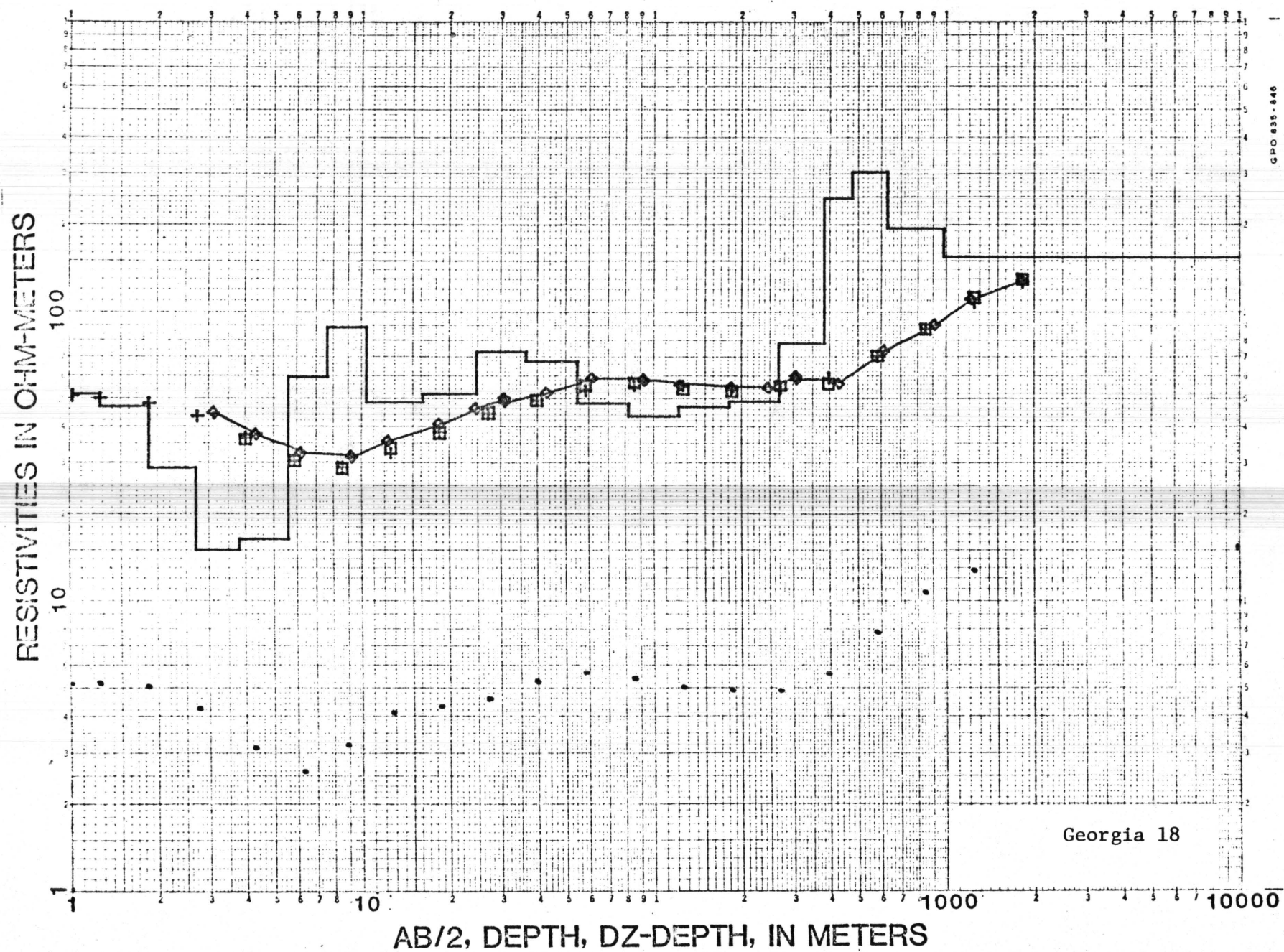
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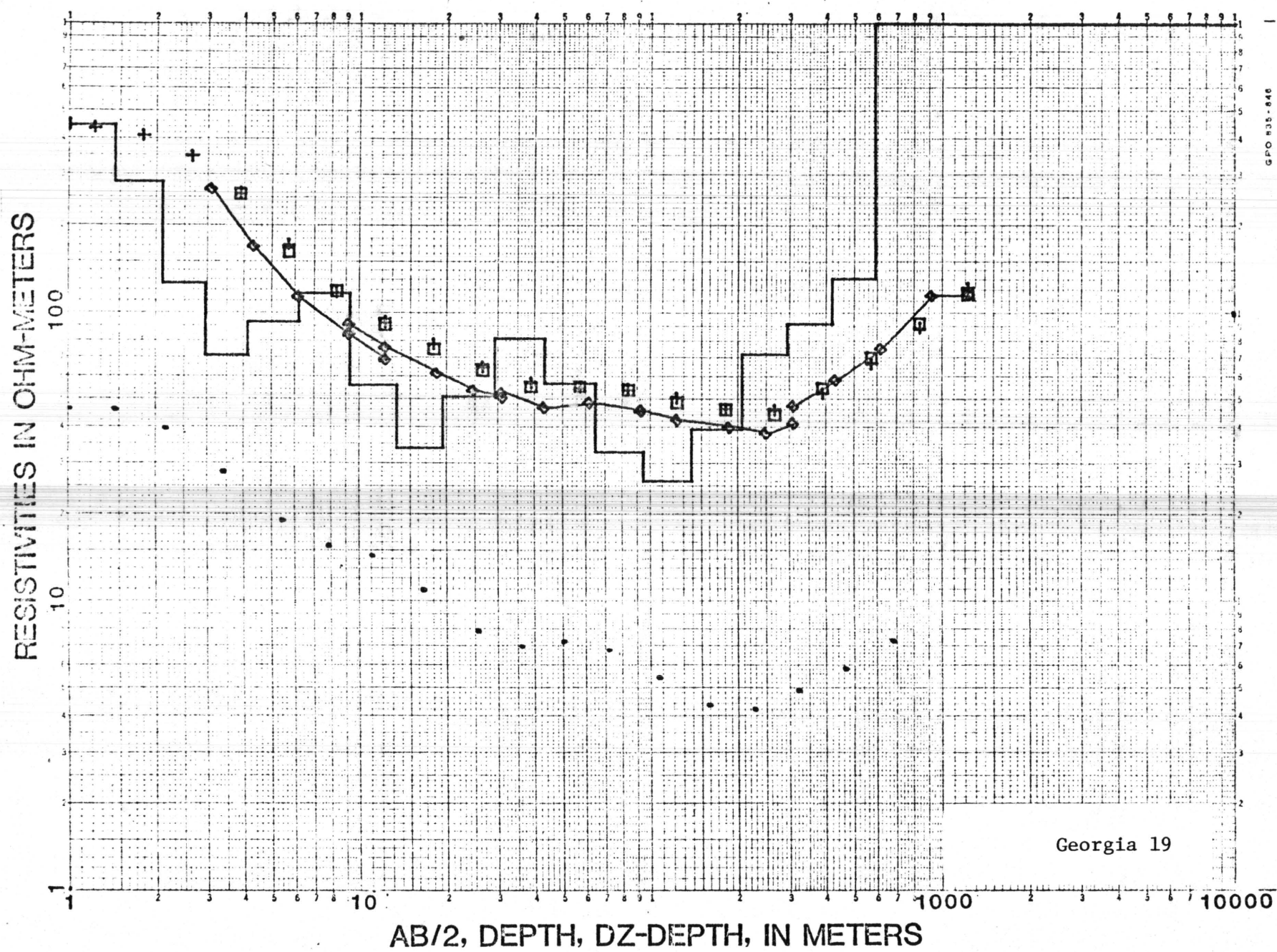


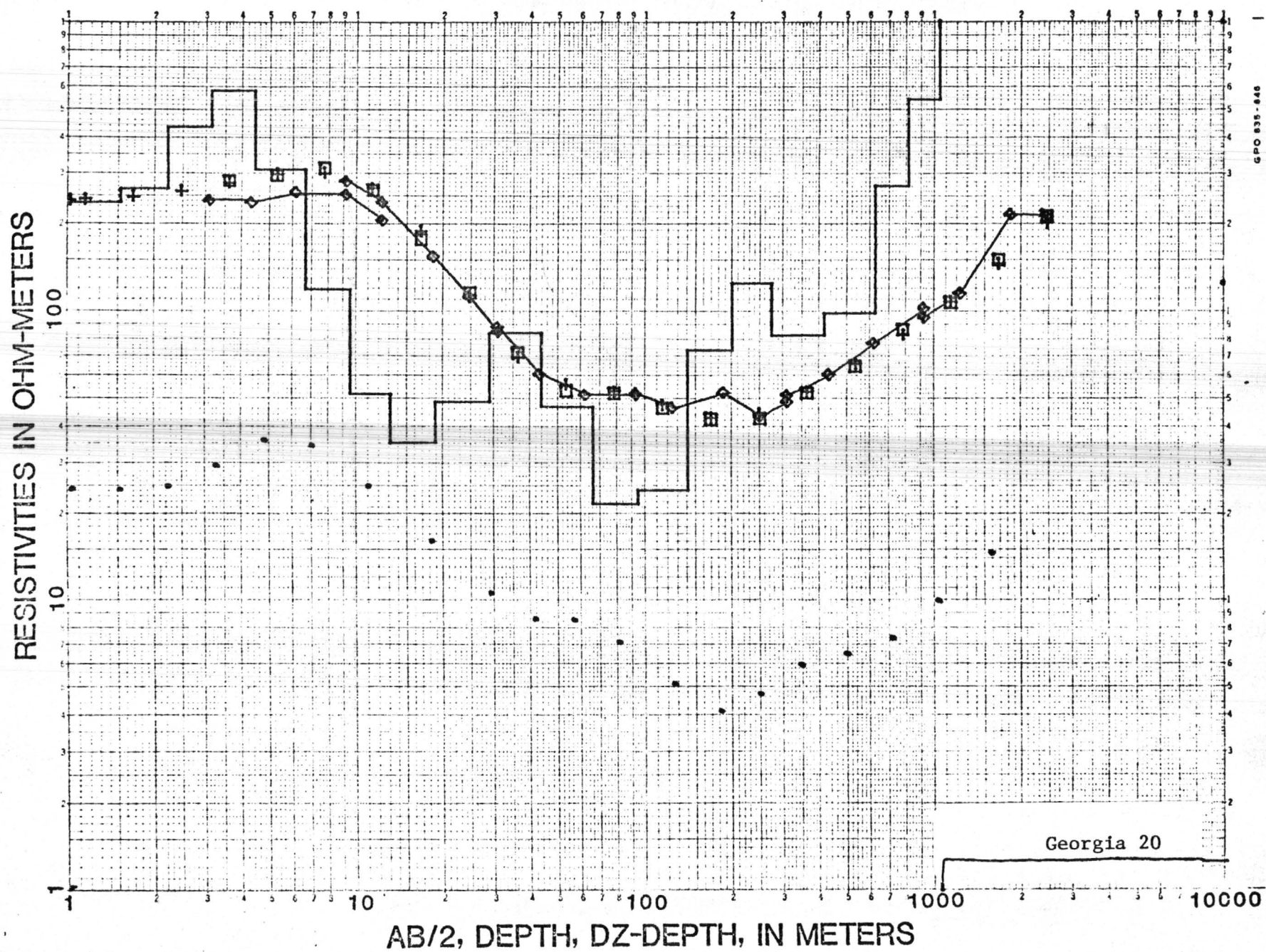


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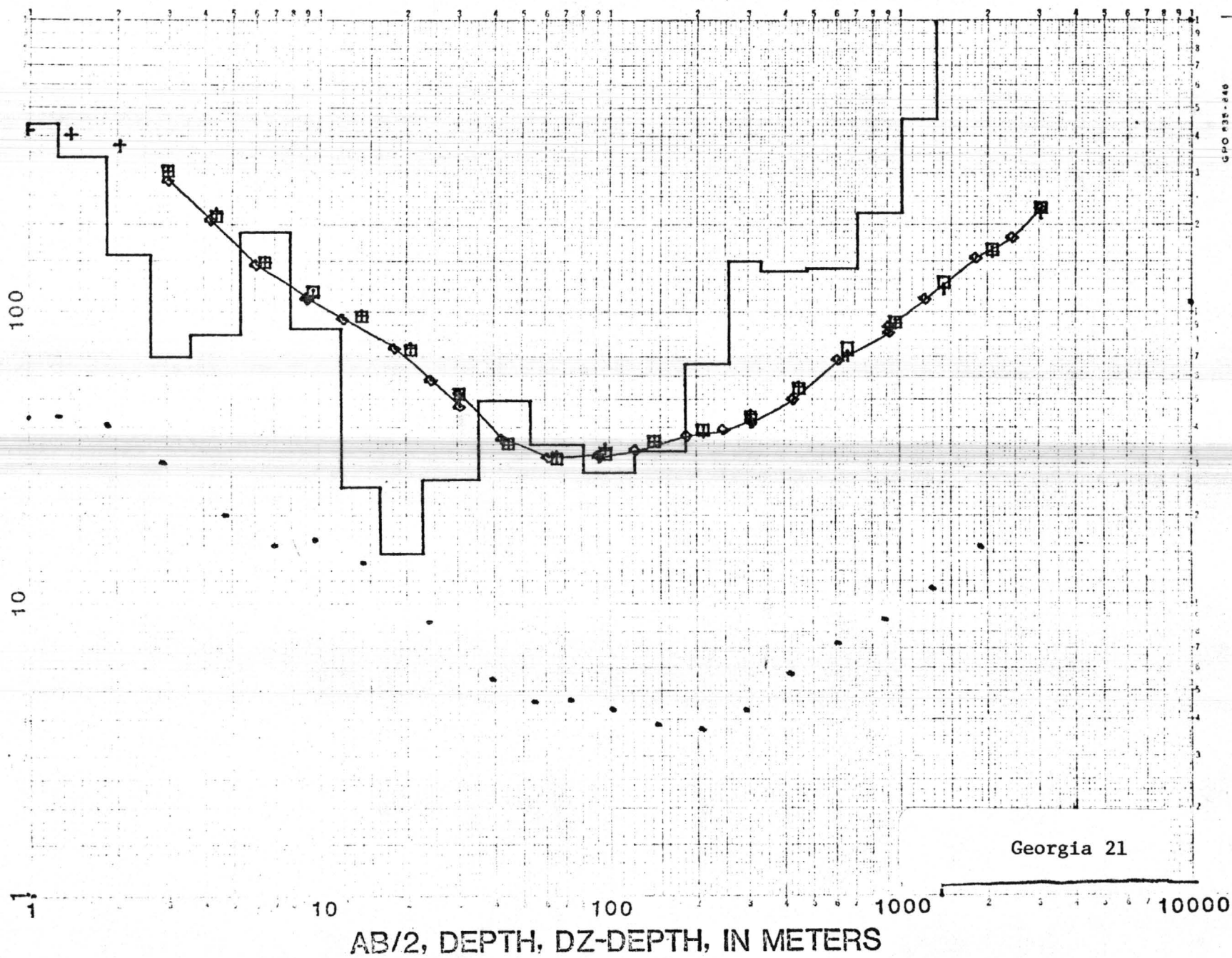






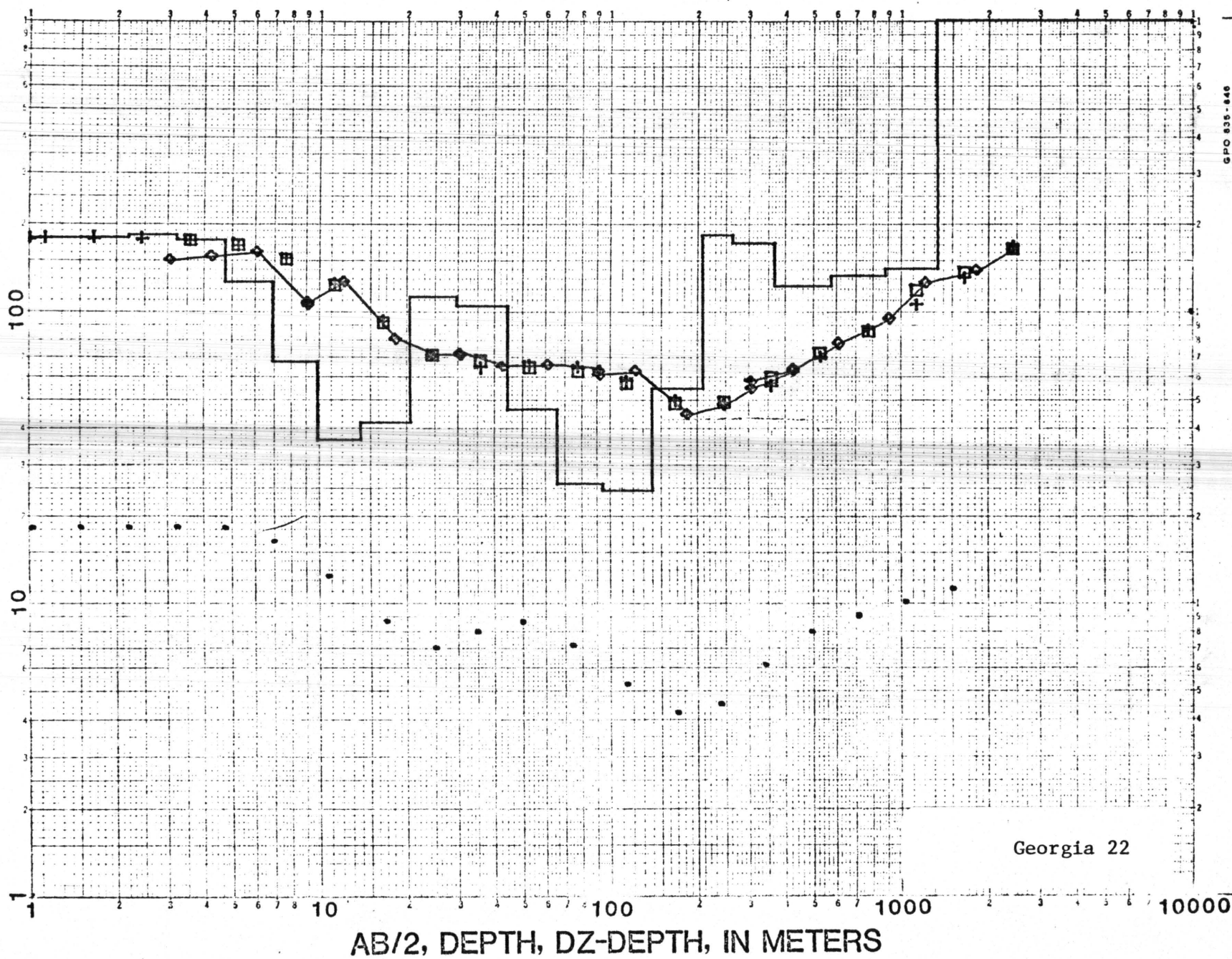


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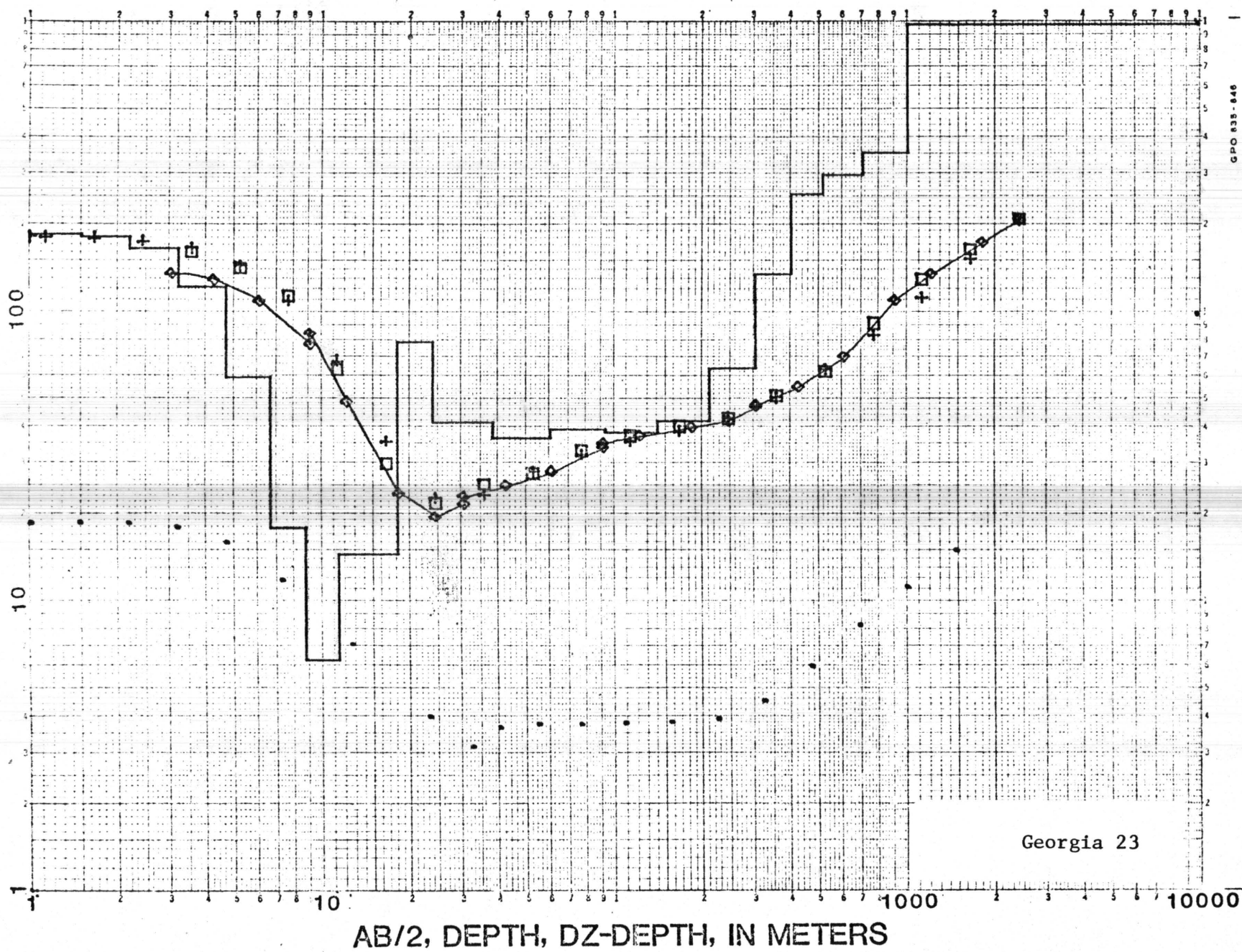
55

RESISTIVITIES IN OHM-METERS

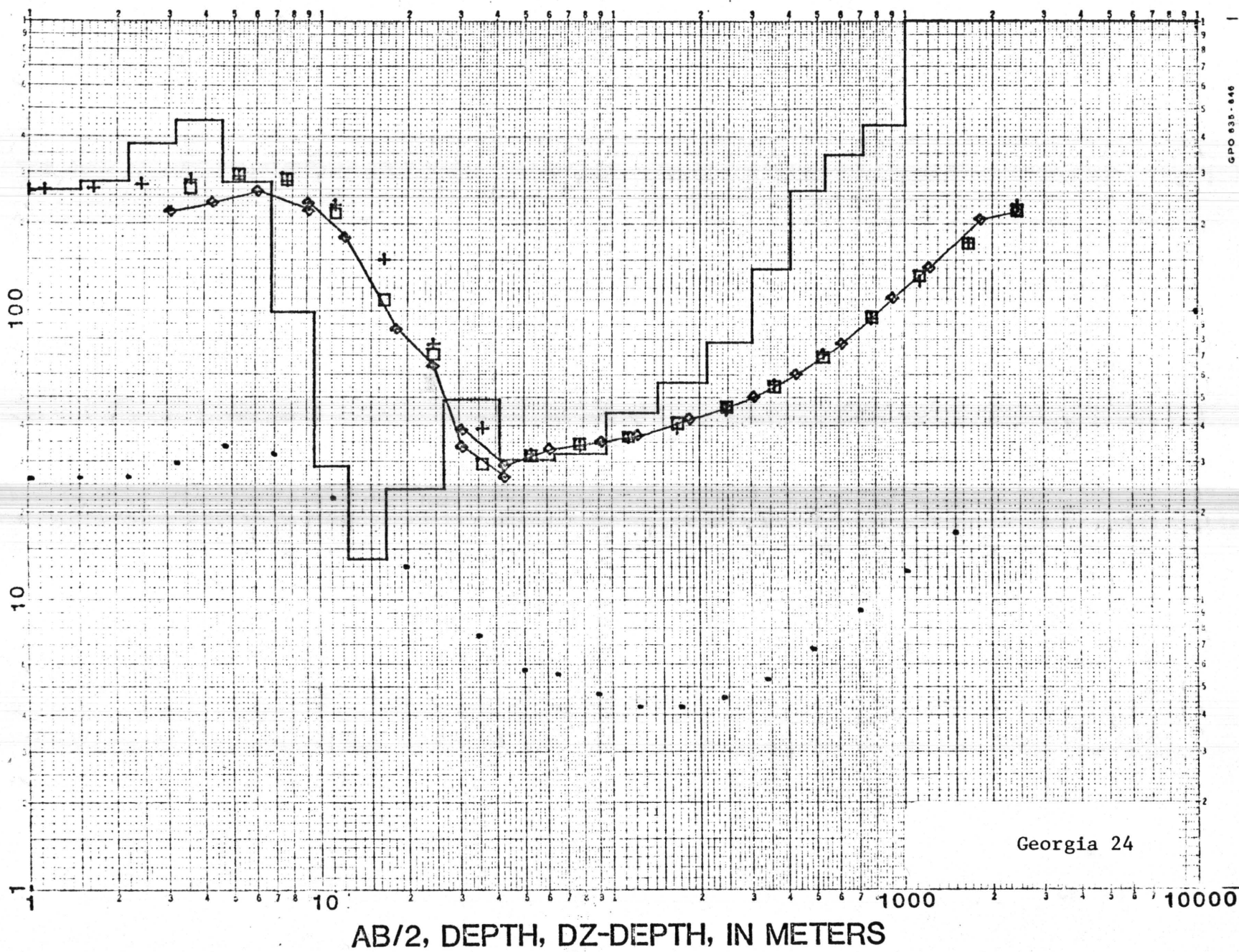


GPO 835-846

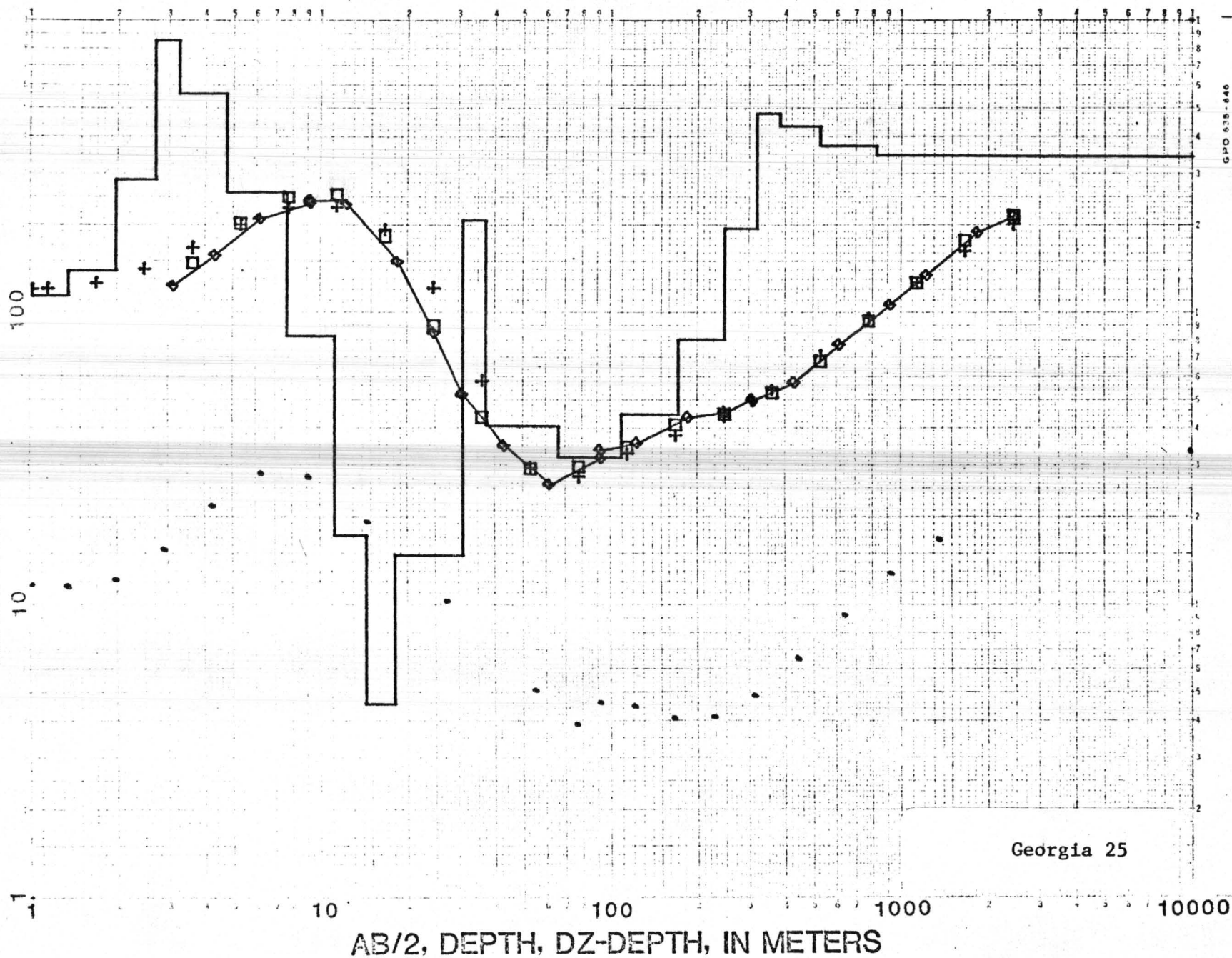
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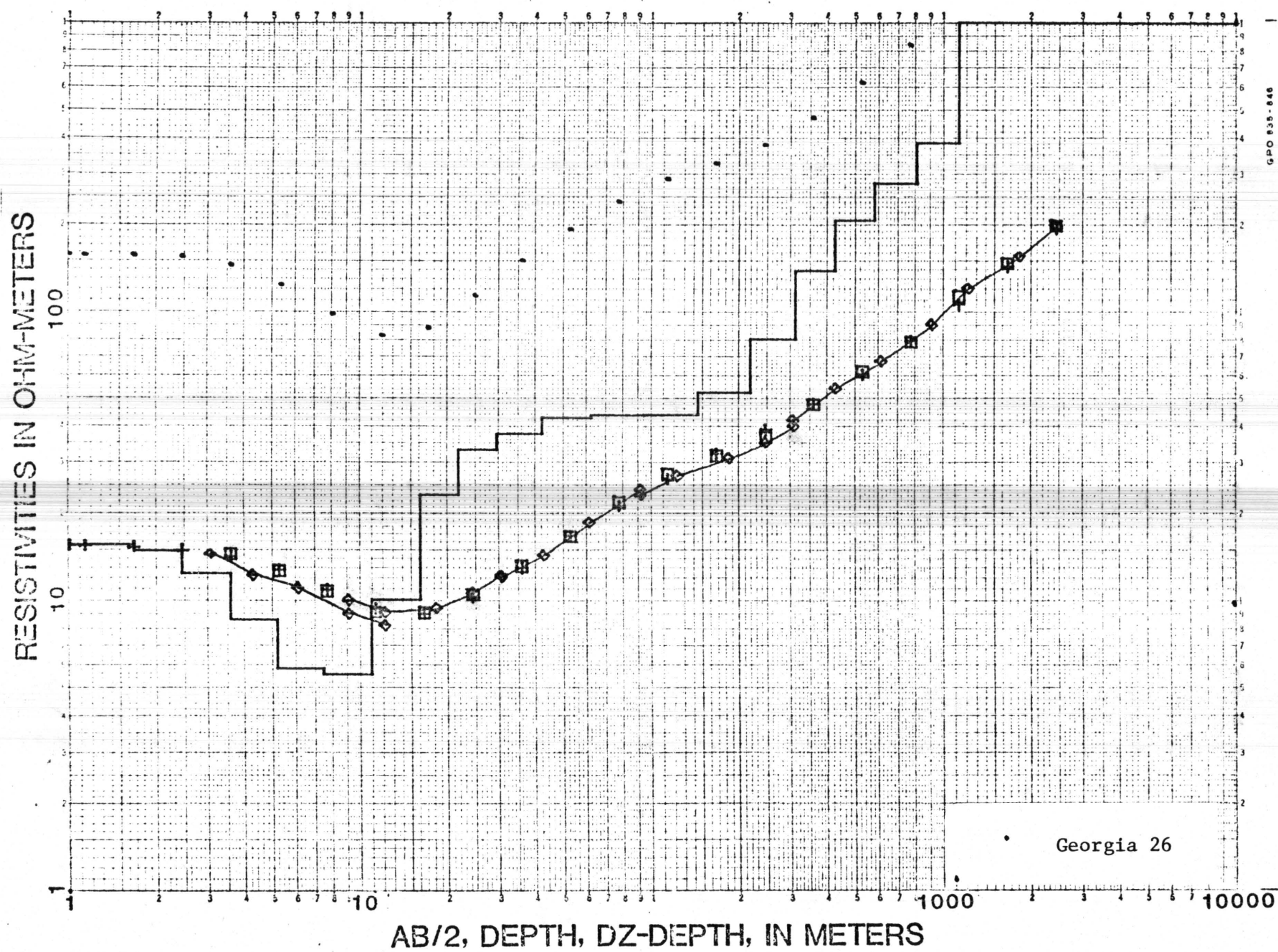
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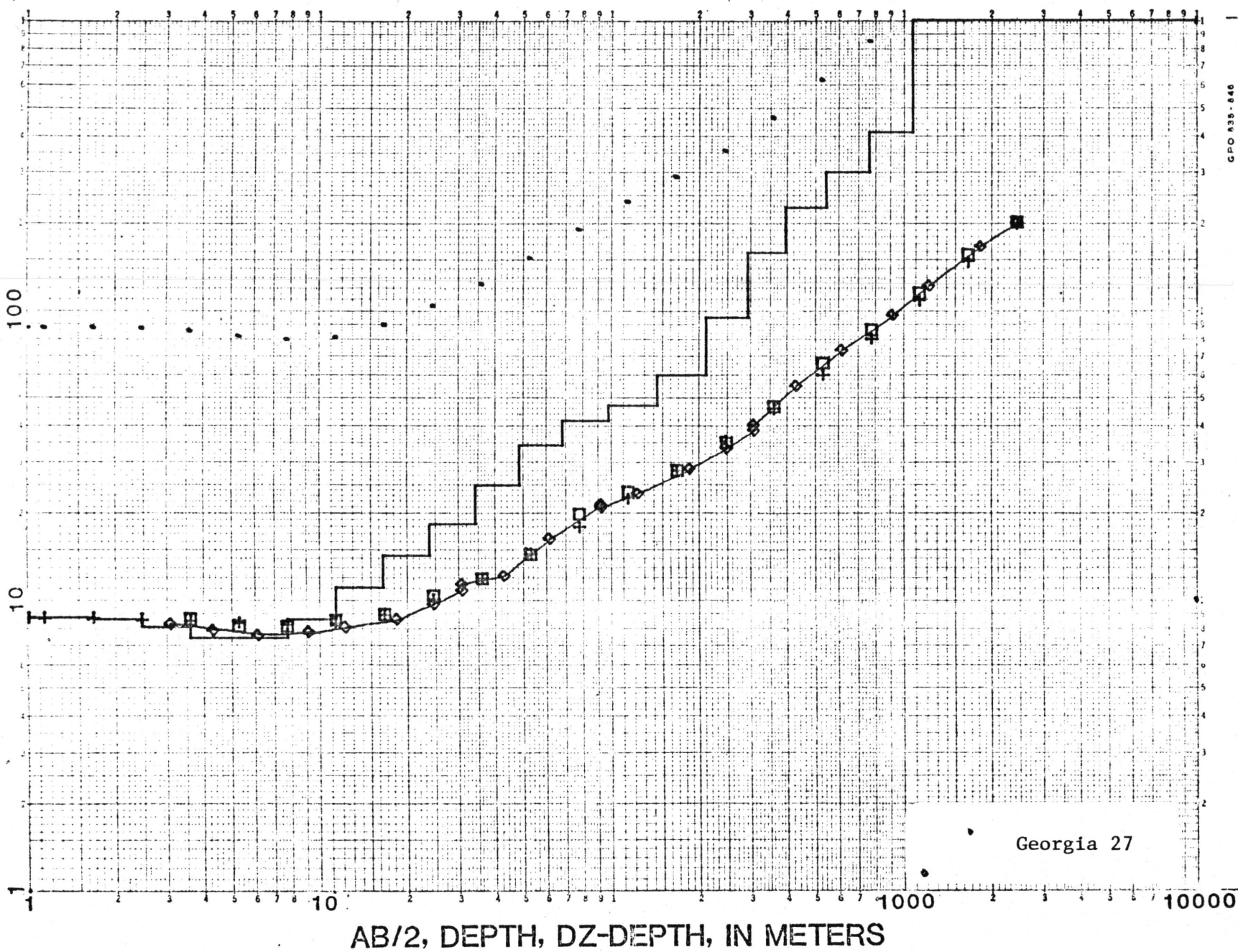
RESISTIVITIES IN OHM-METERS



Georgia 25

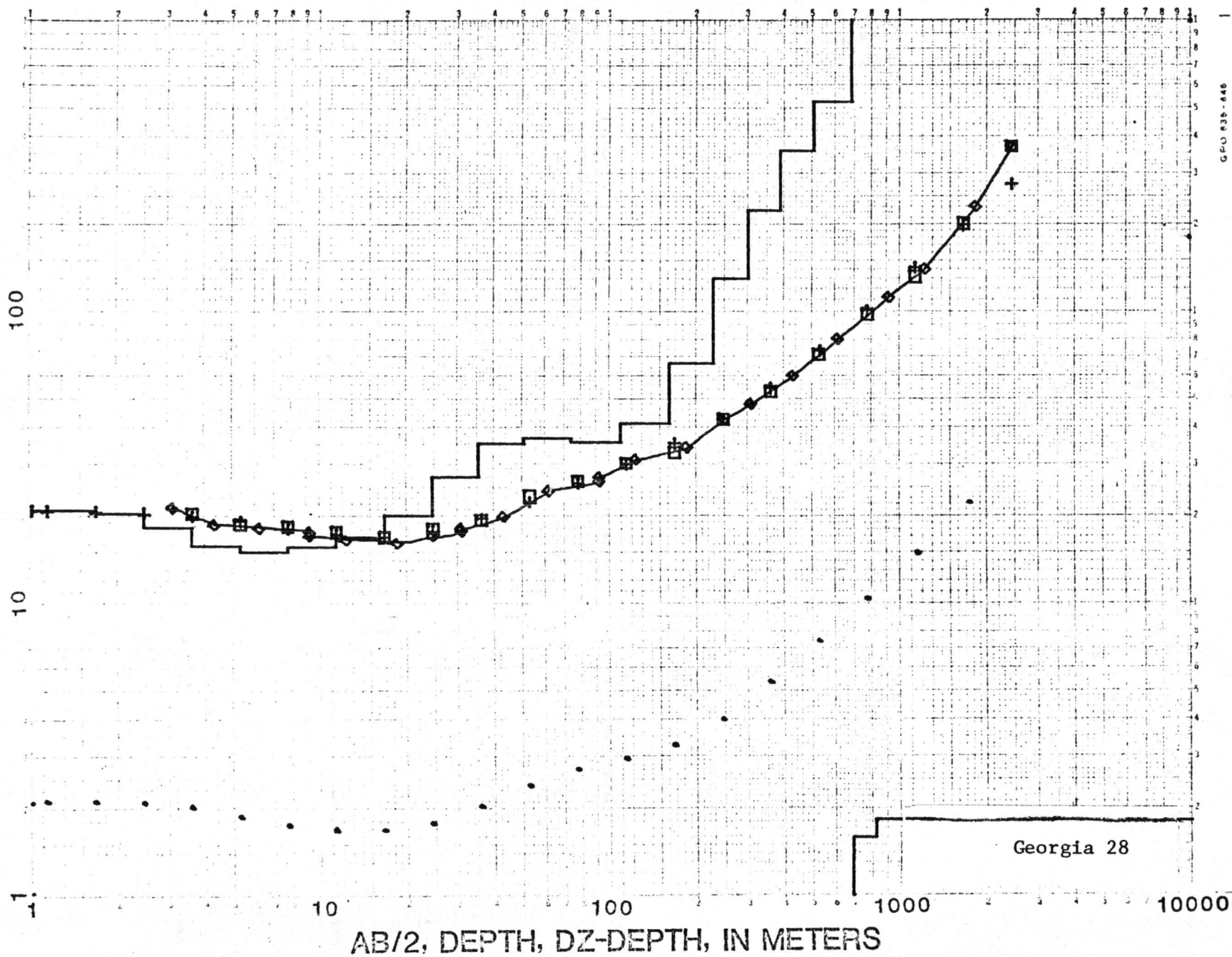


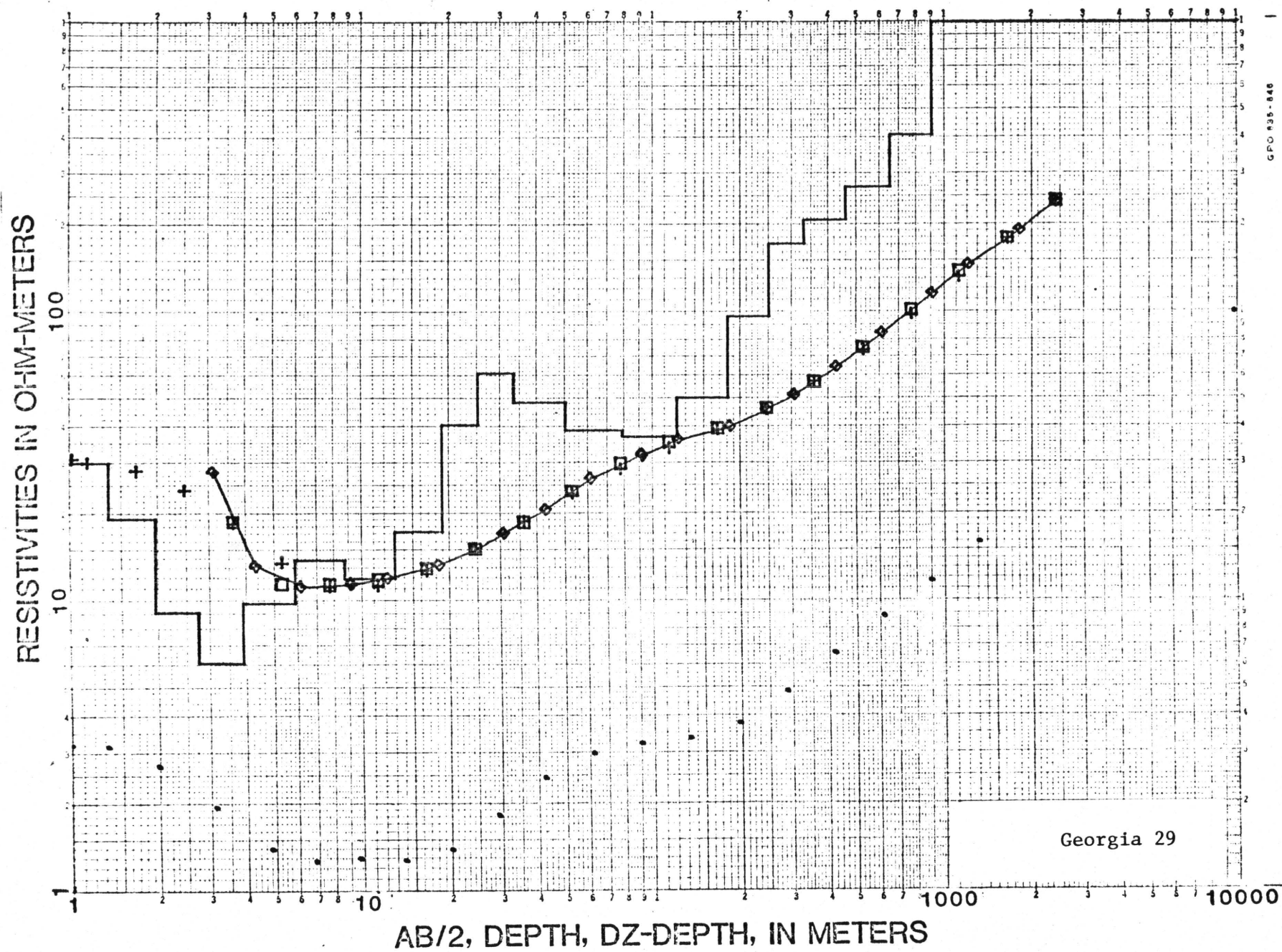
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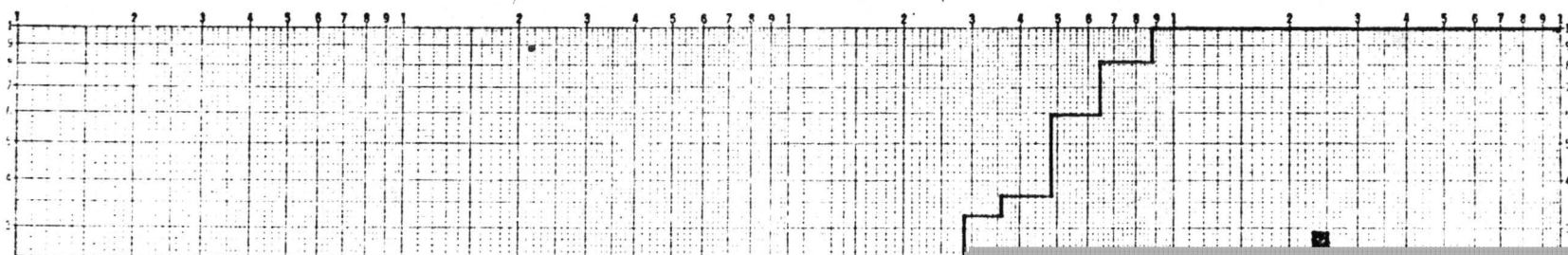


Georgia 27

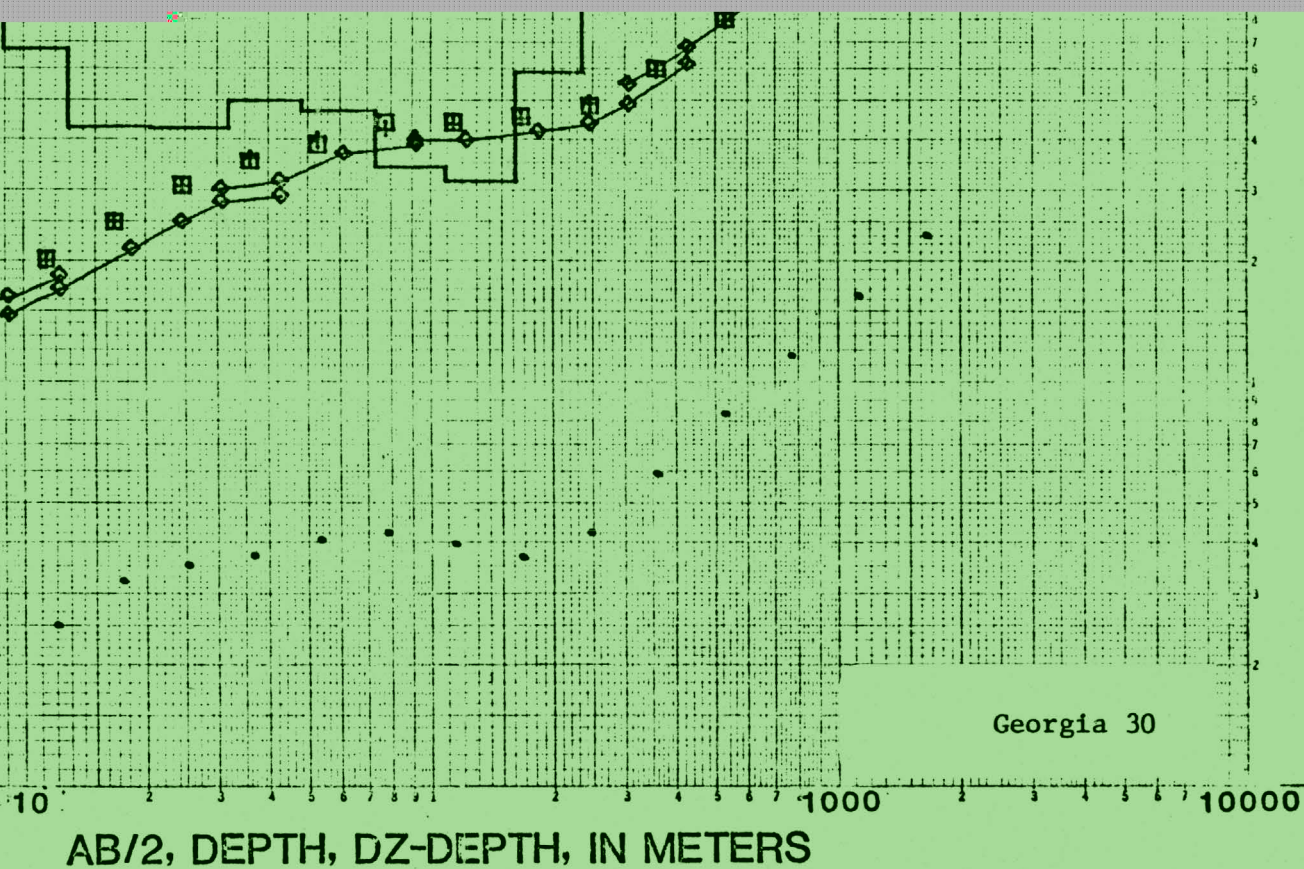
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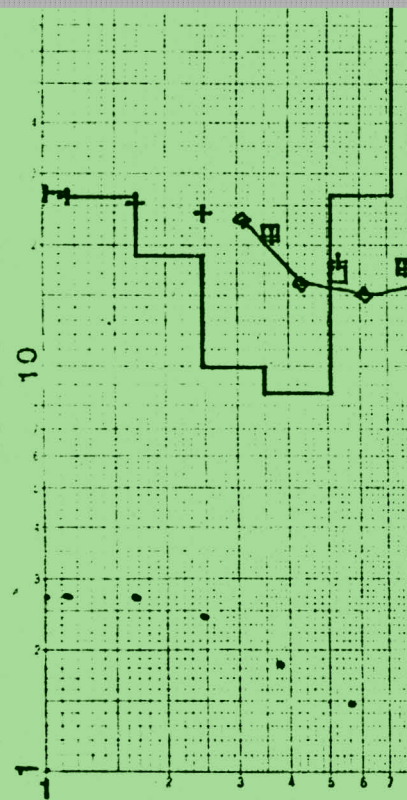


GPO #38-846



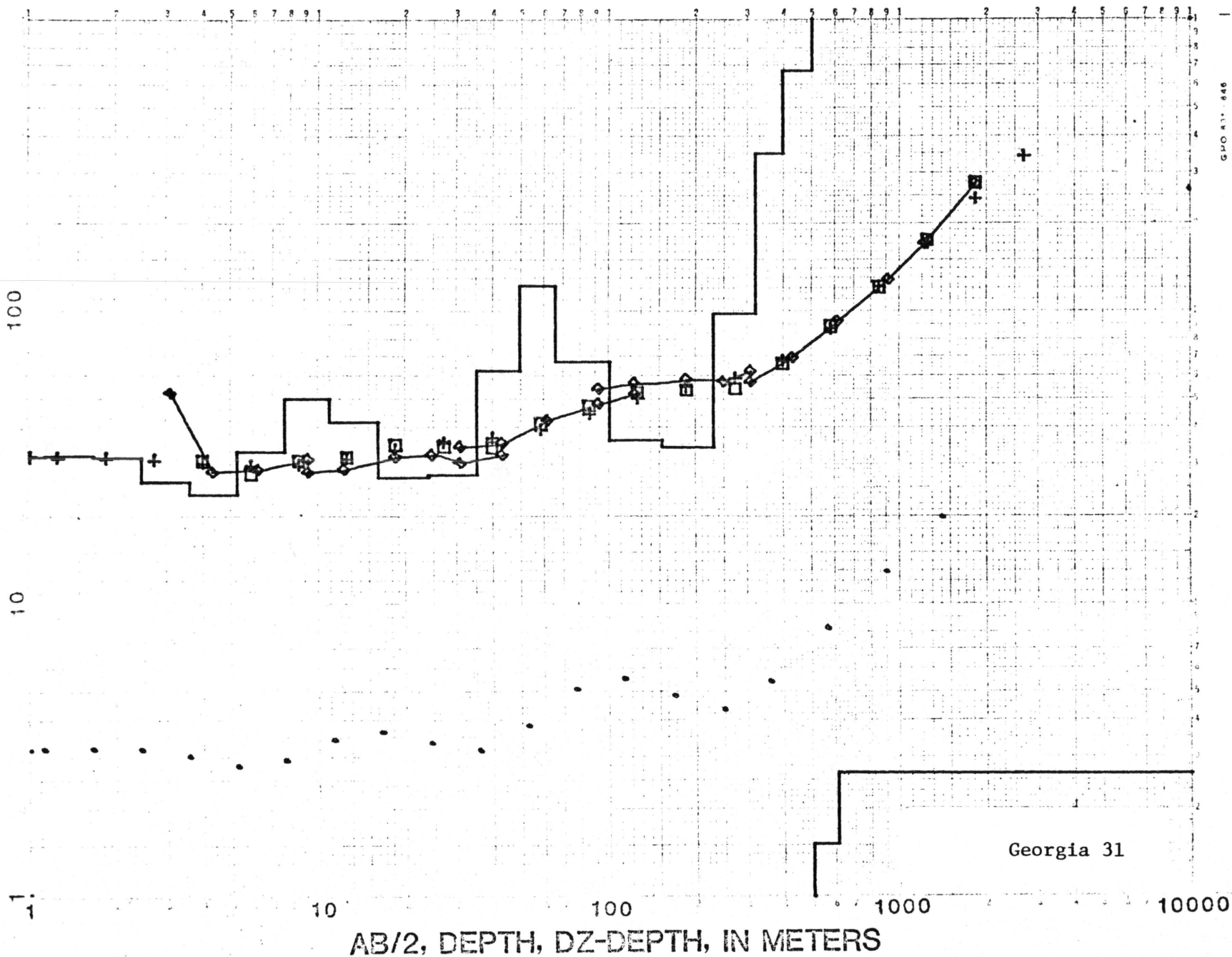
89

RESISTIVITIES IN OHM



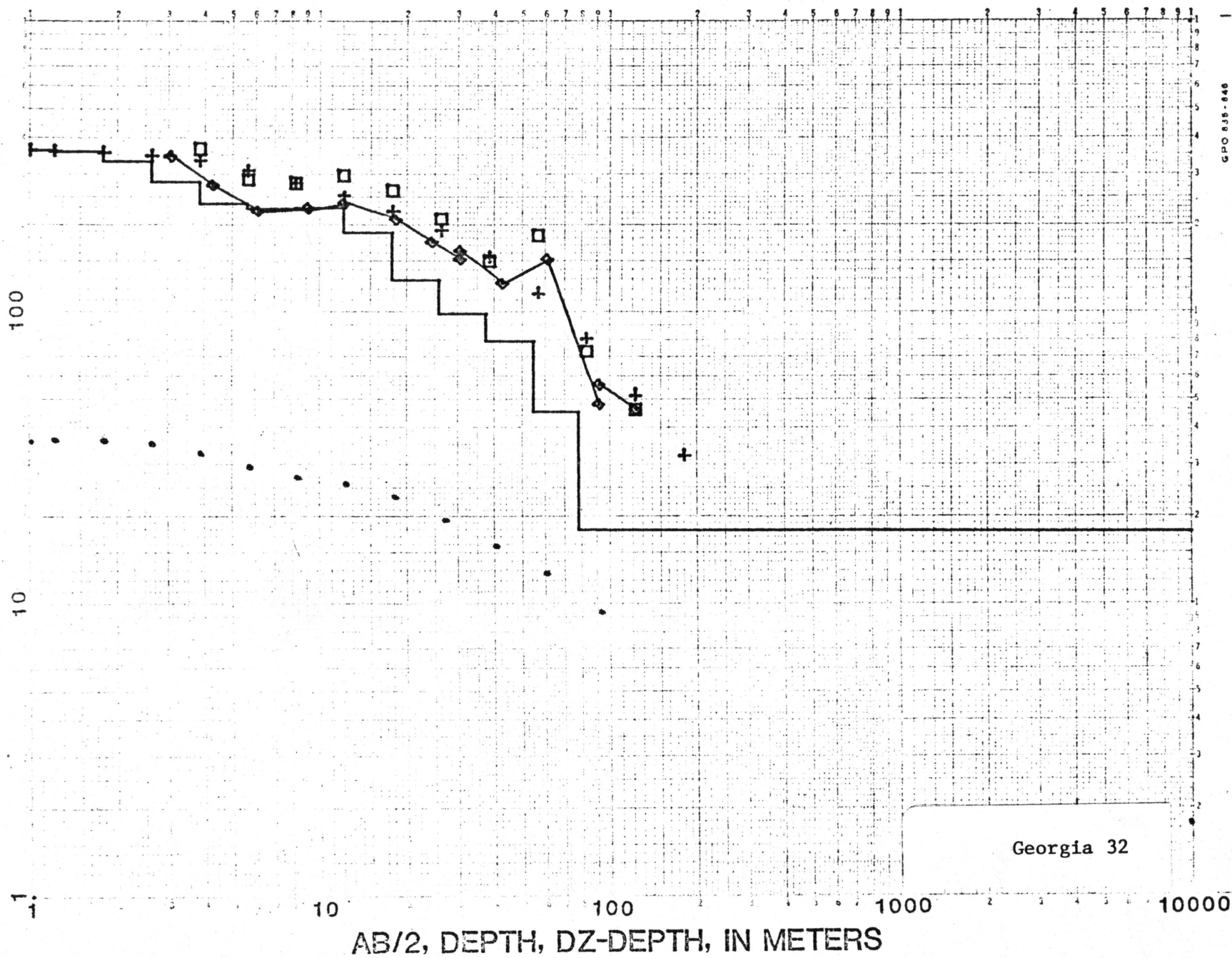
64

RESISTIVITIES IN OHM-METERS

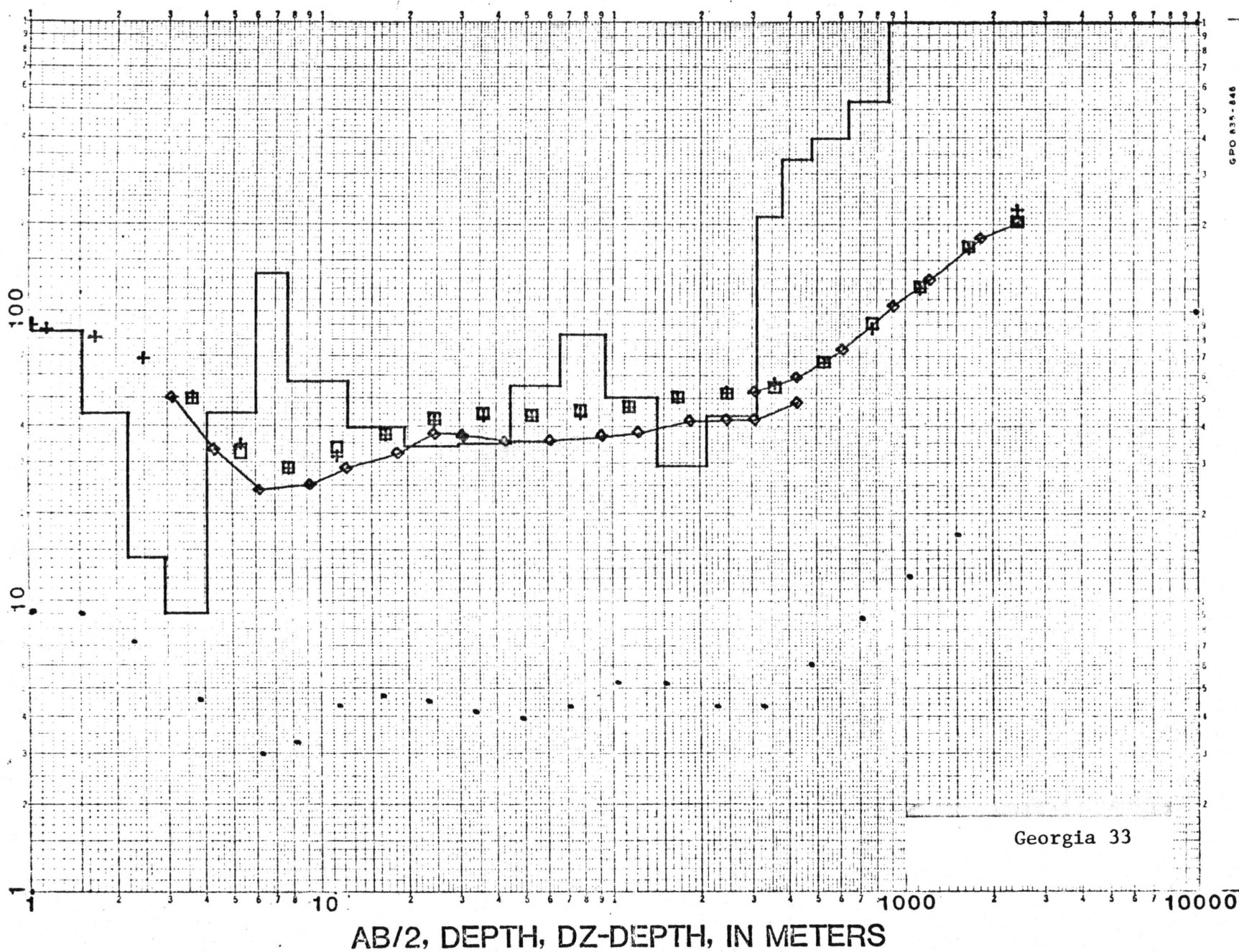


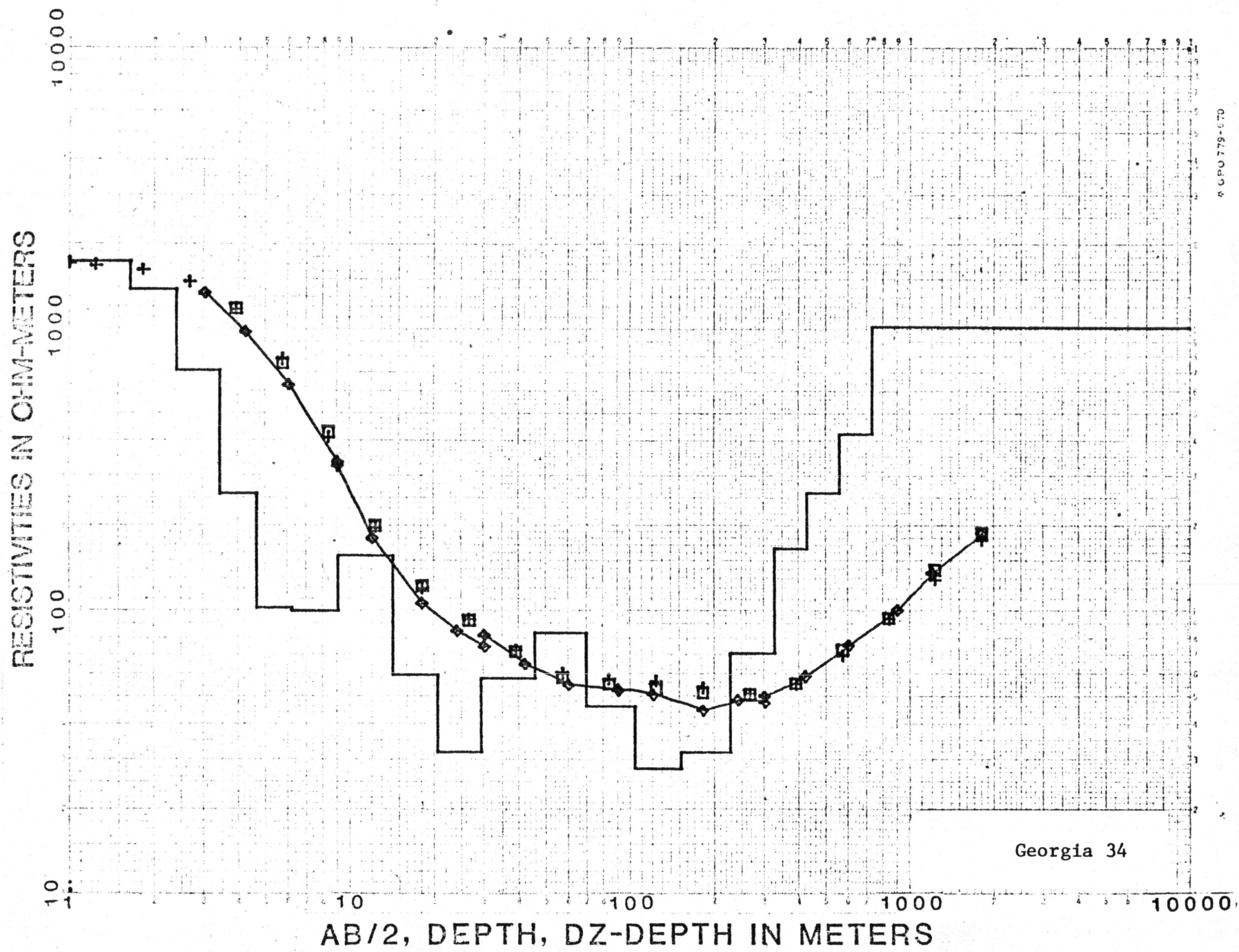
GUO A11-846

RESISTIVITIES IN OHM-METERS

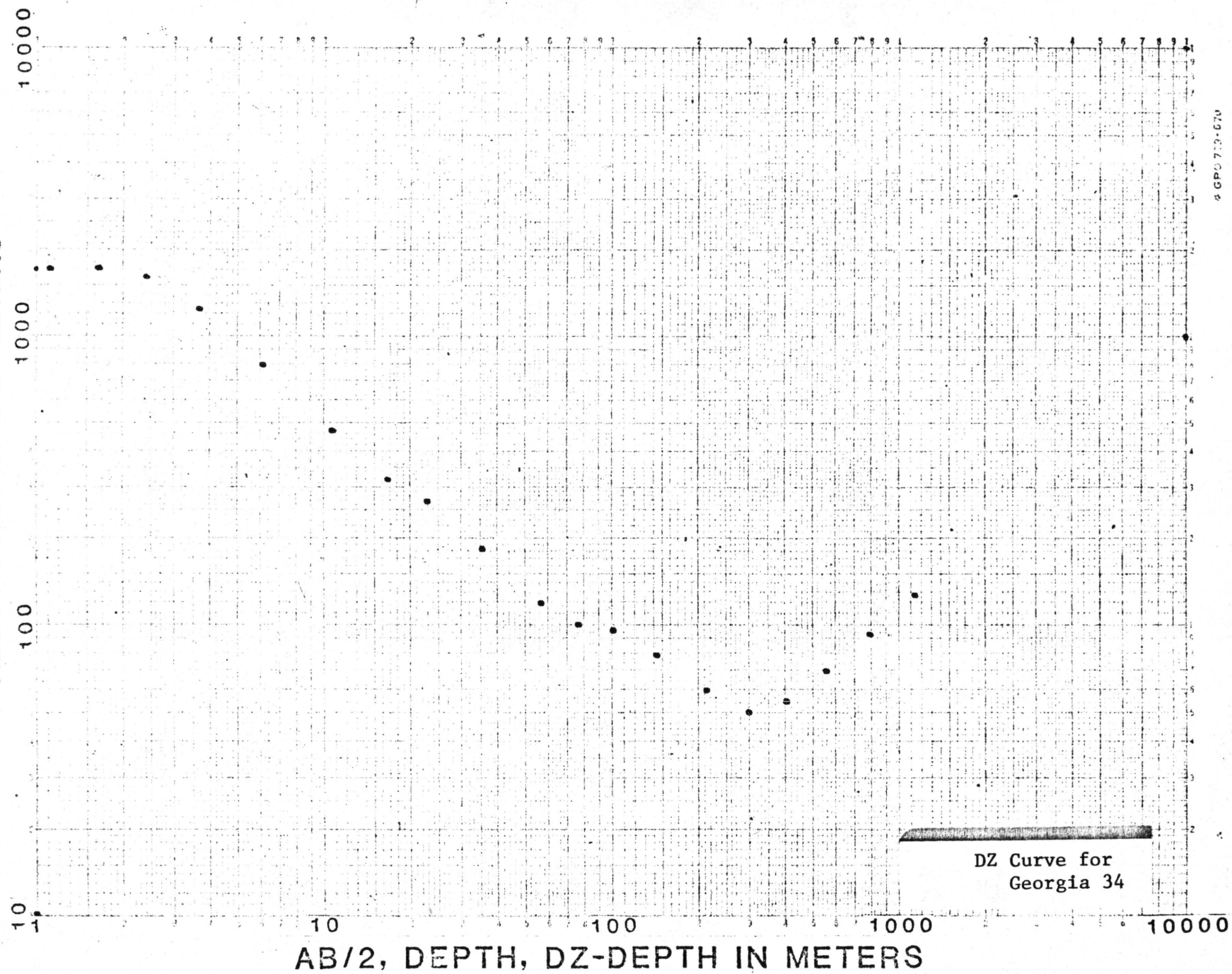


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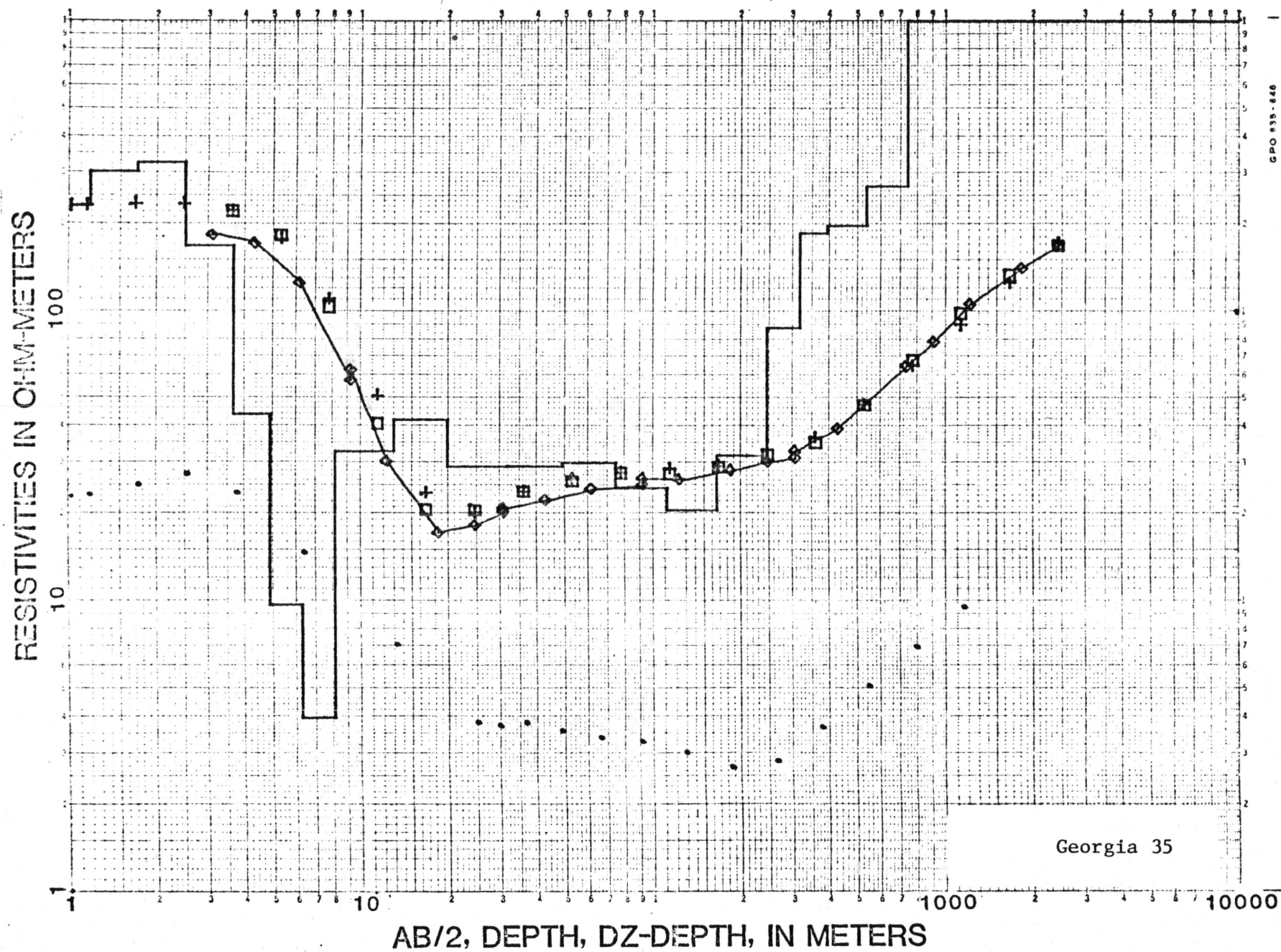


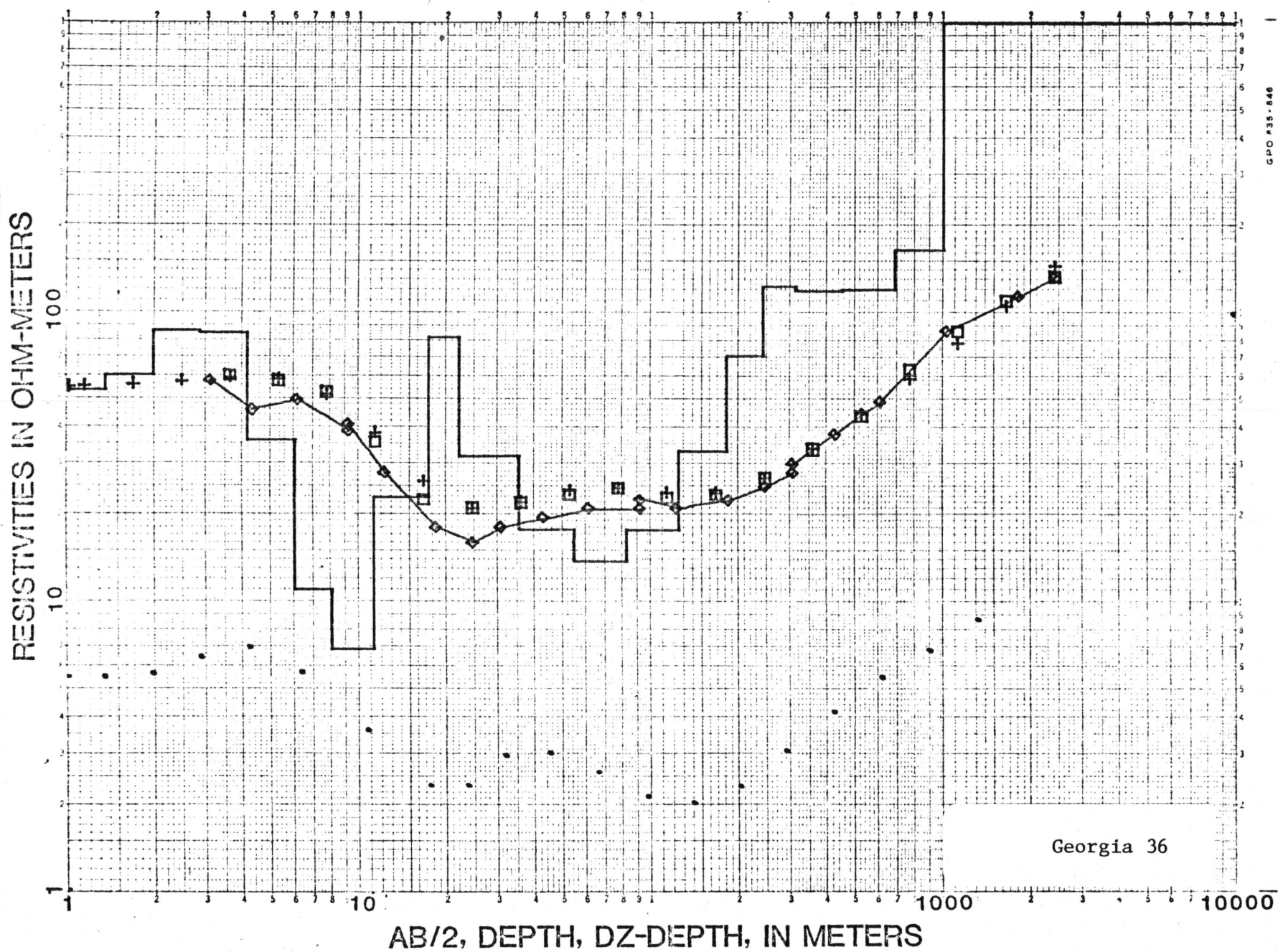


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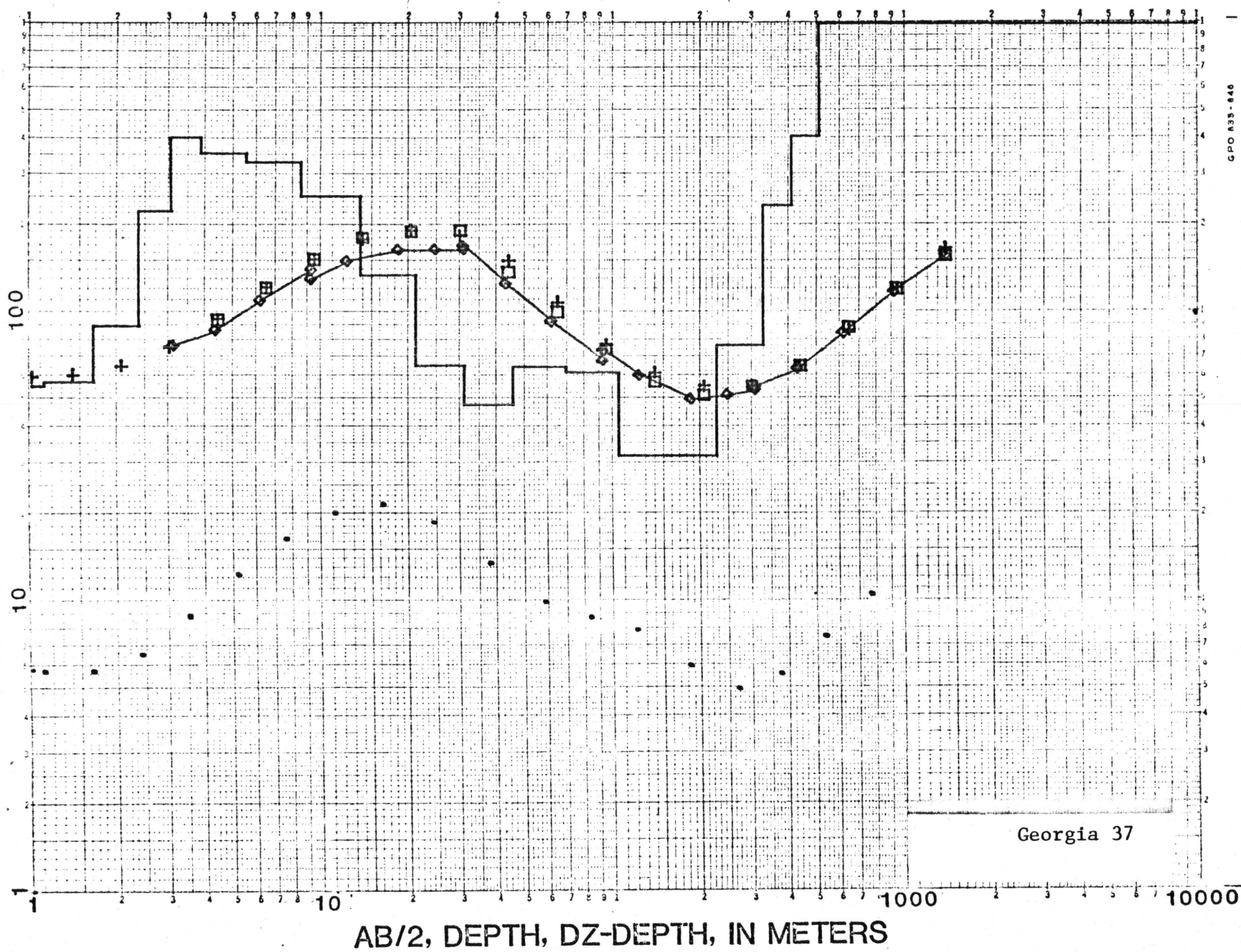


69

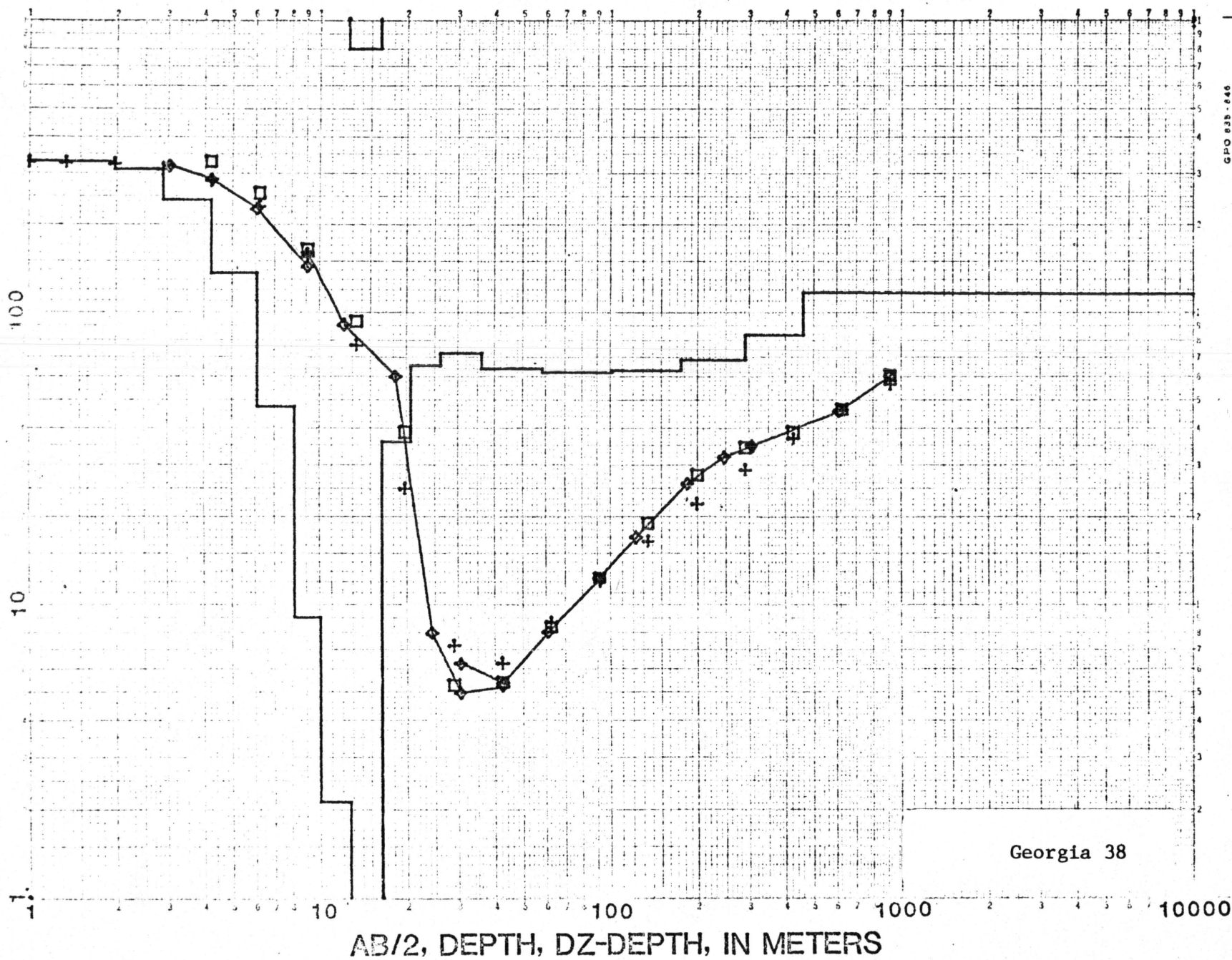




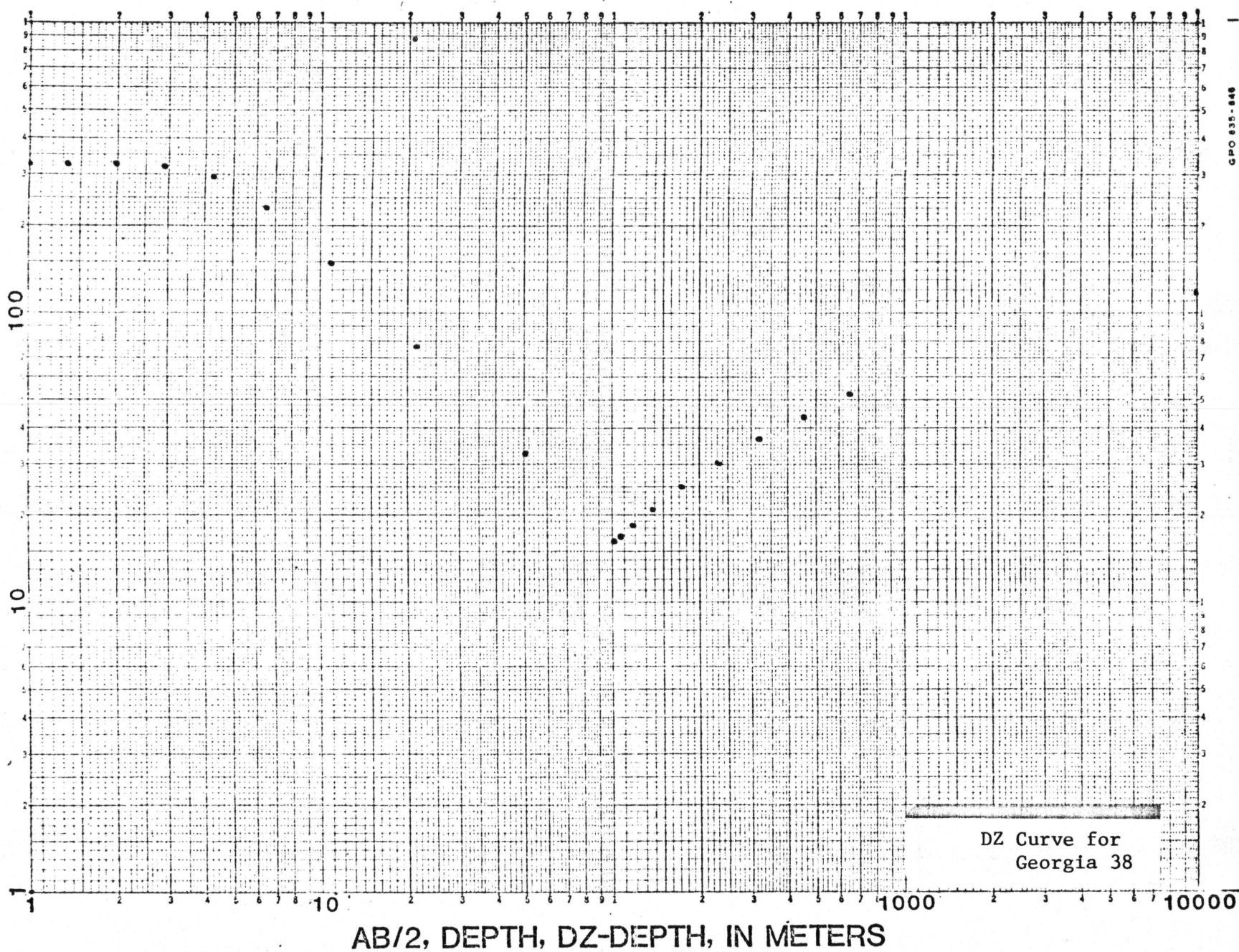
RESISTIVITIES IN OHM-METERS



RESISTIVITIES IN OHM-METERS

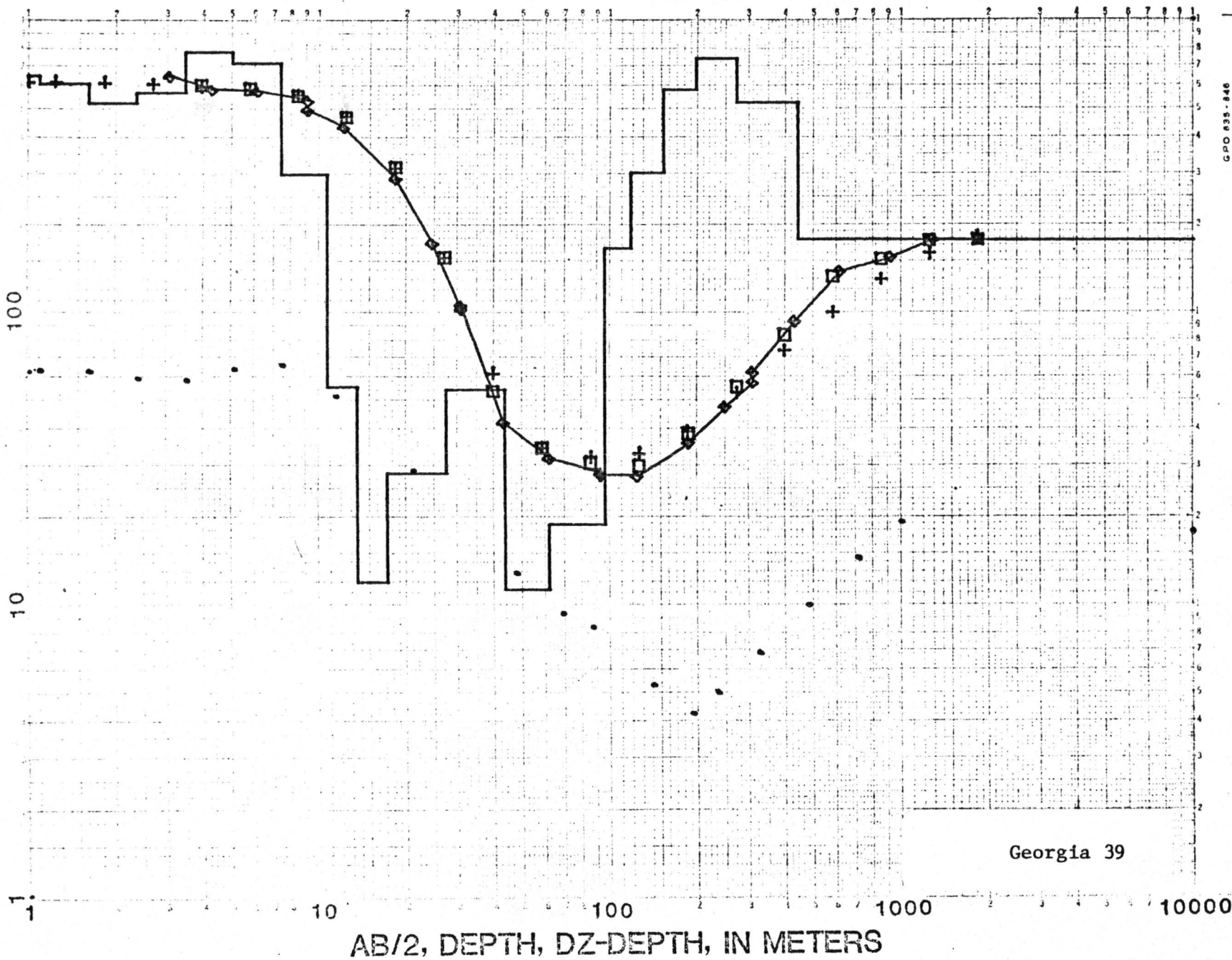


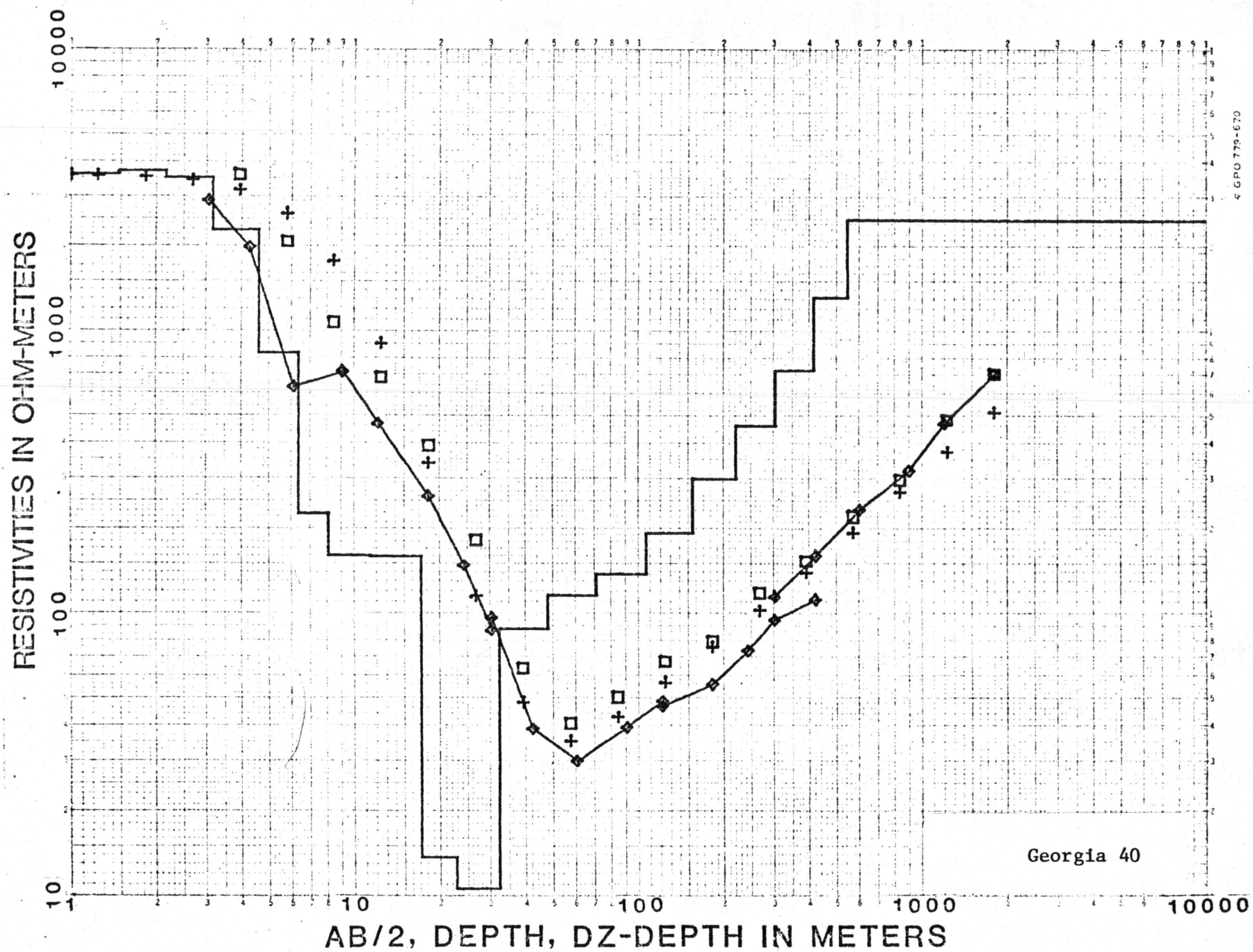
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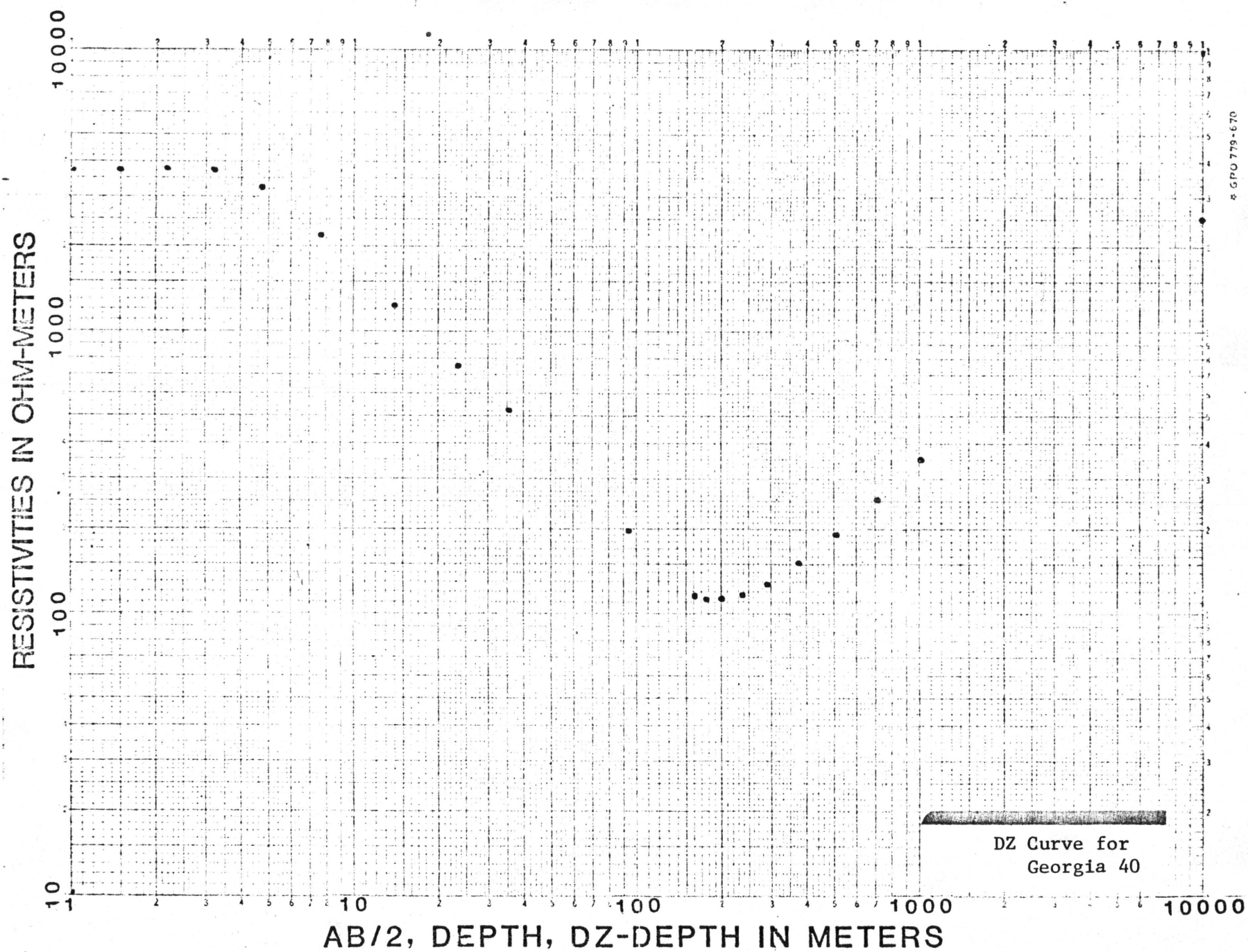


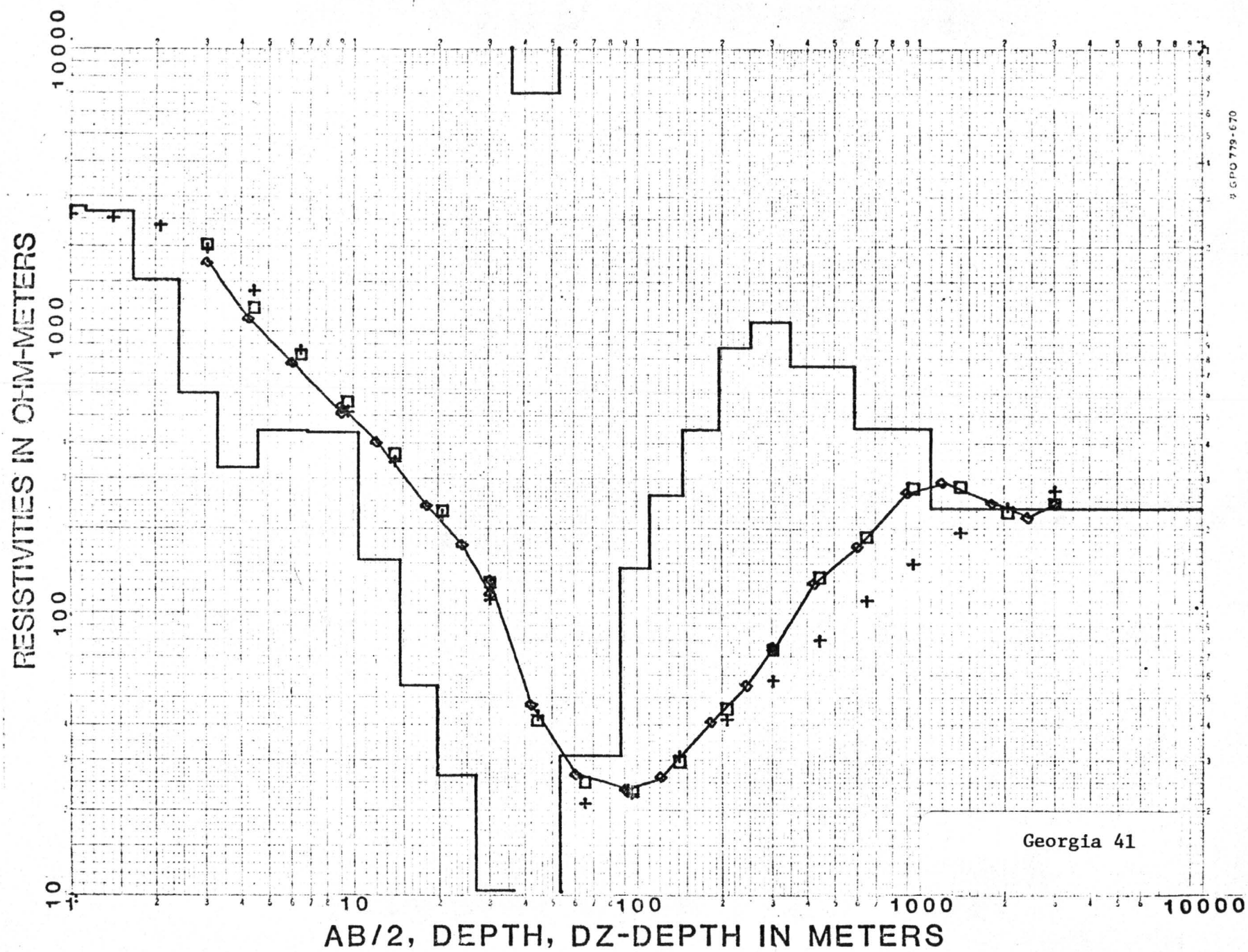
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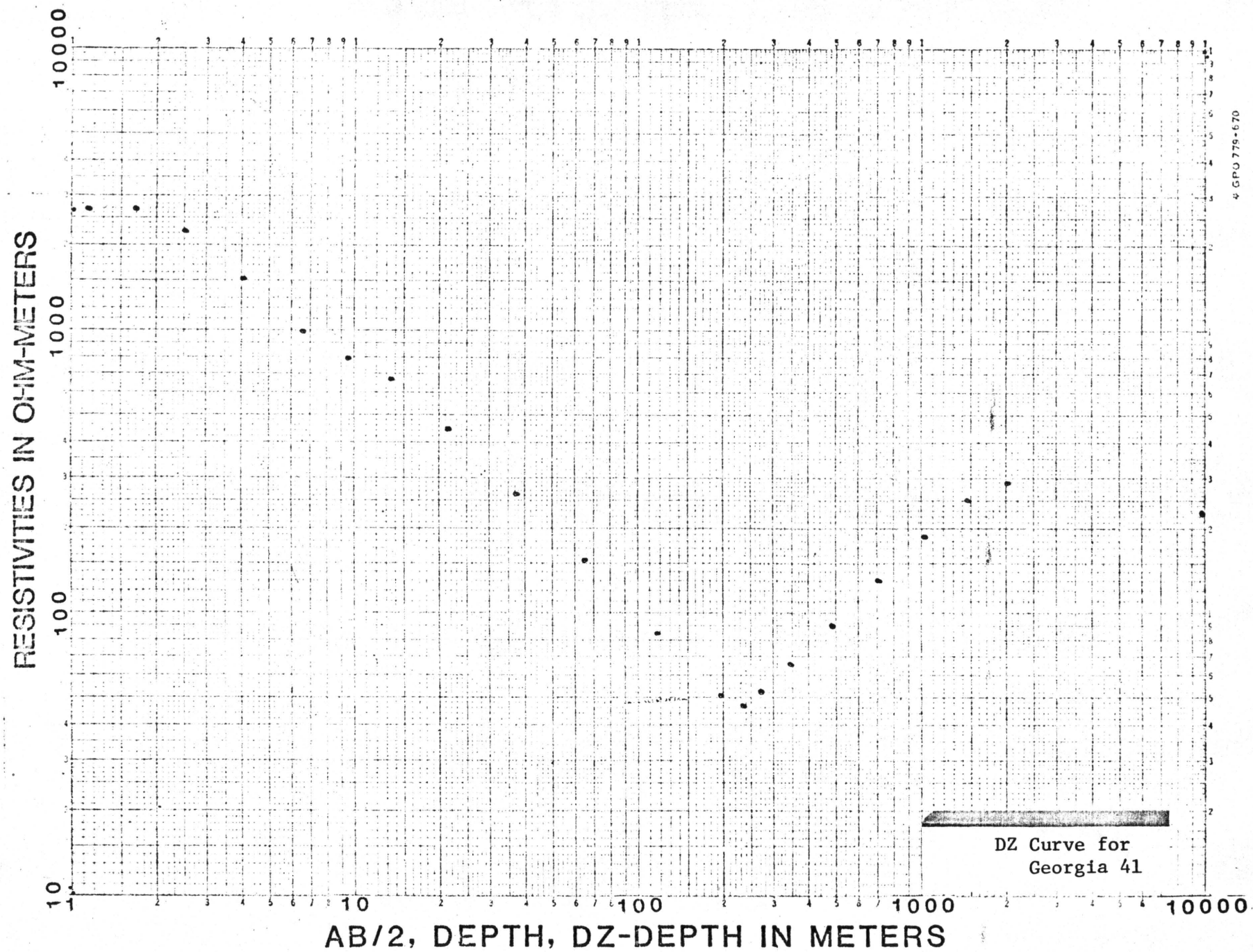
74

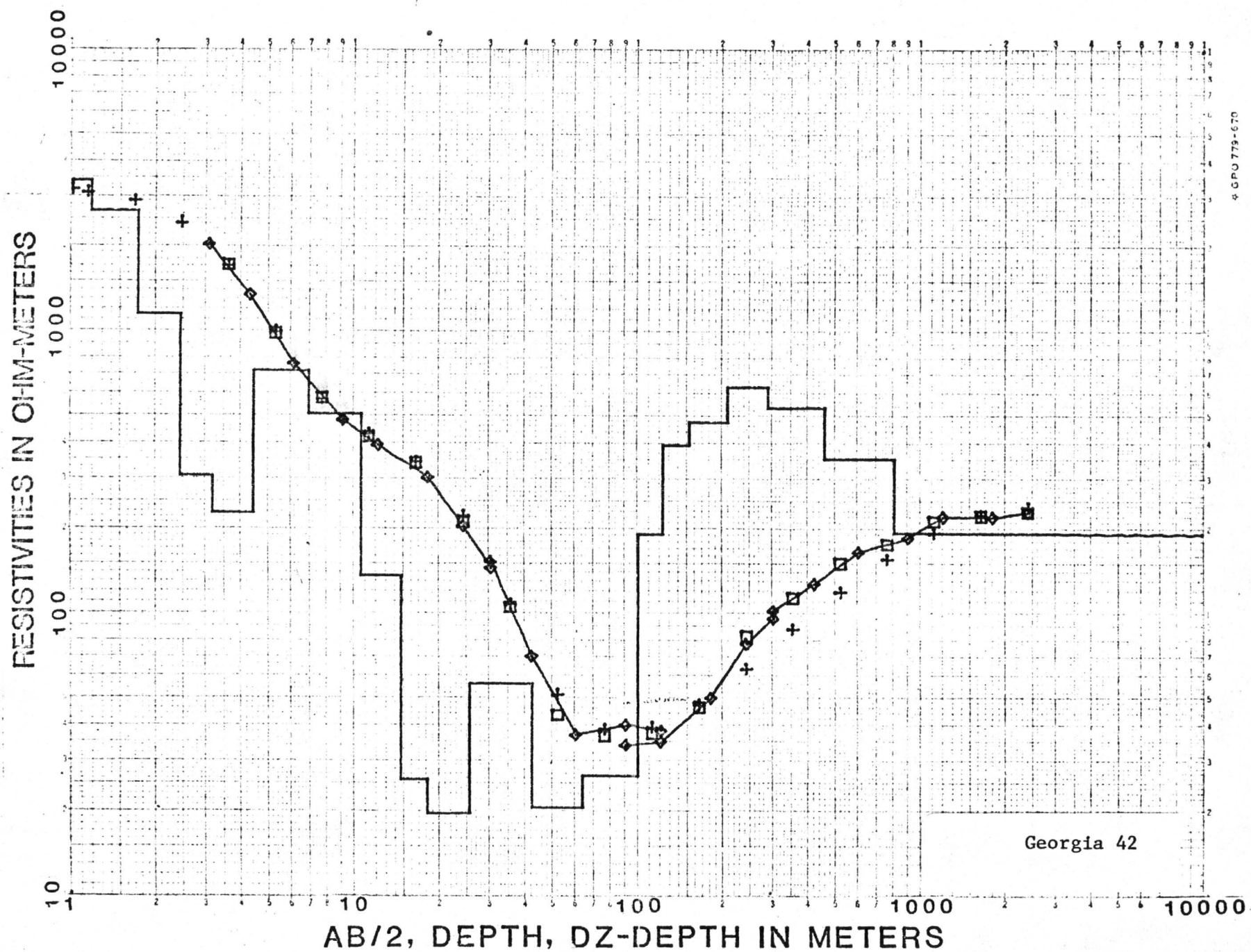




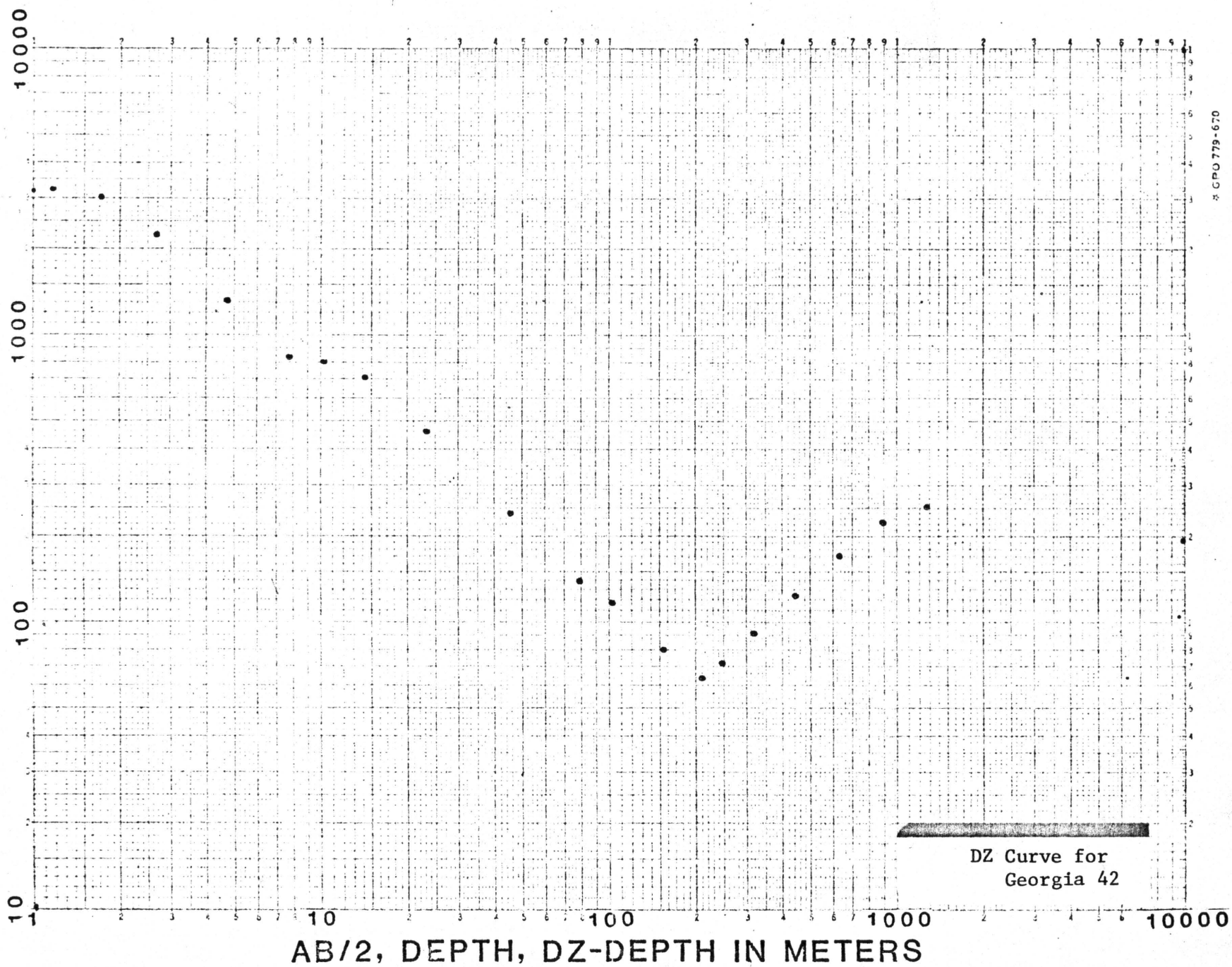


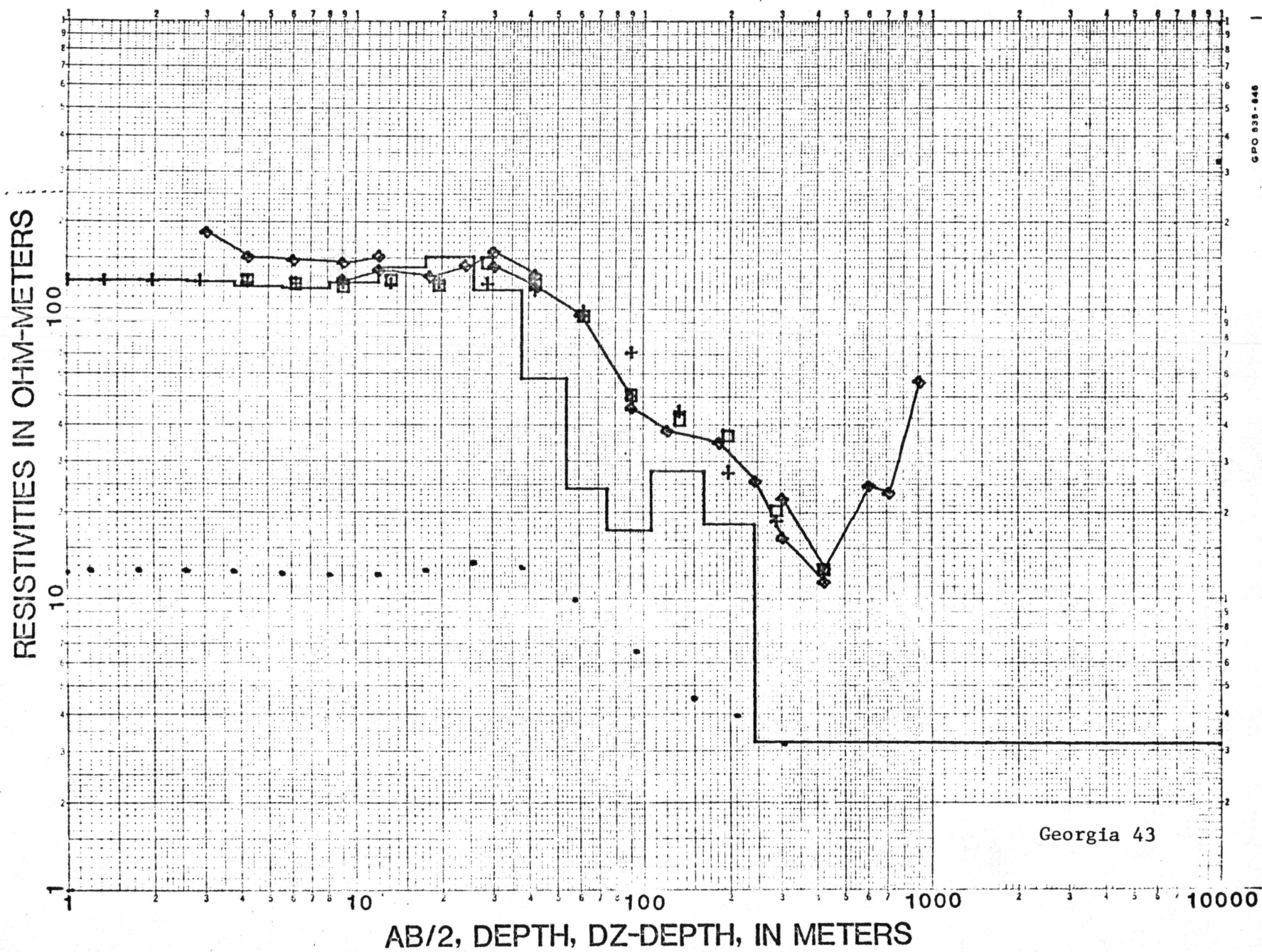


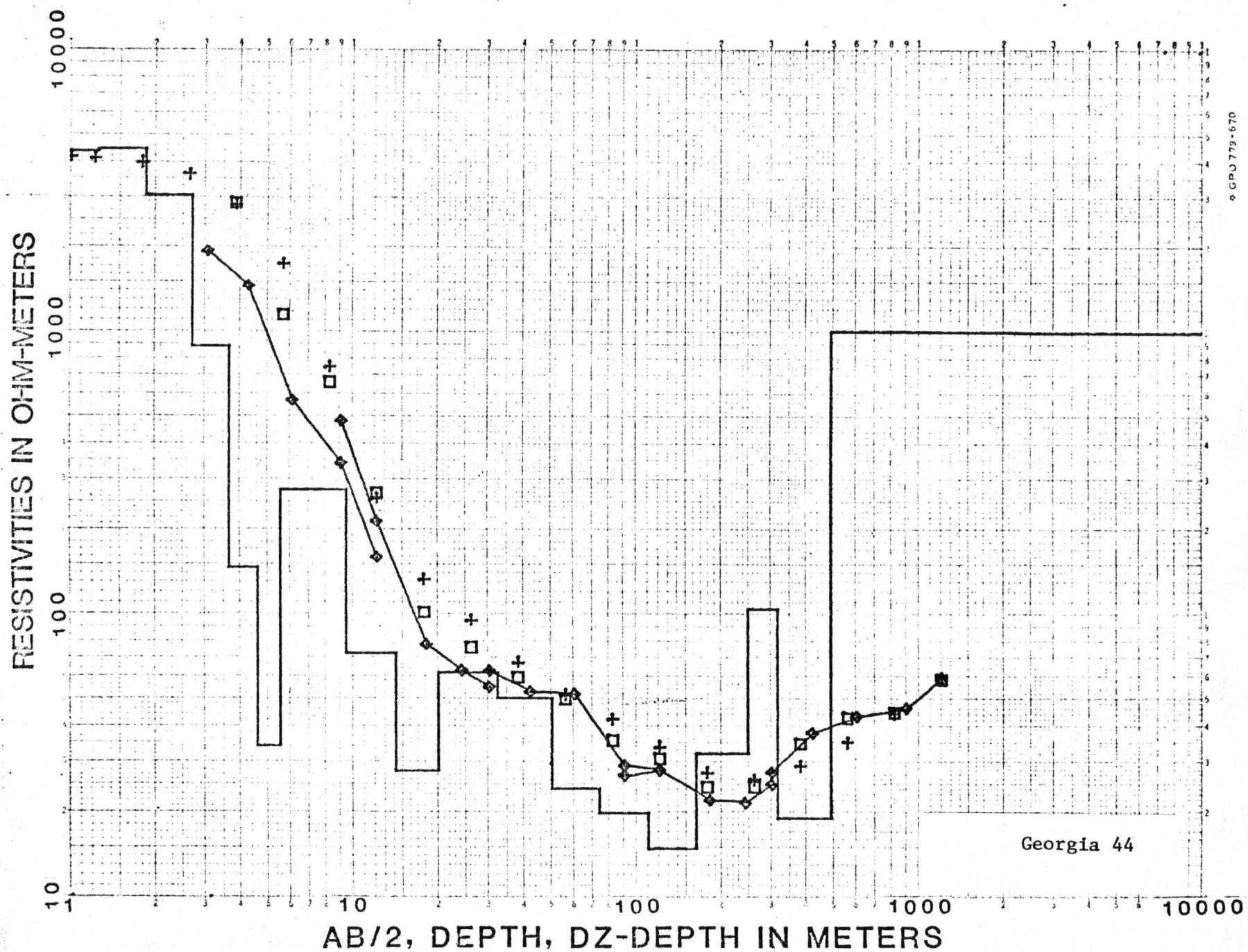


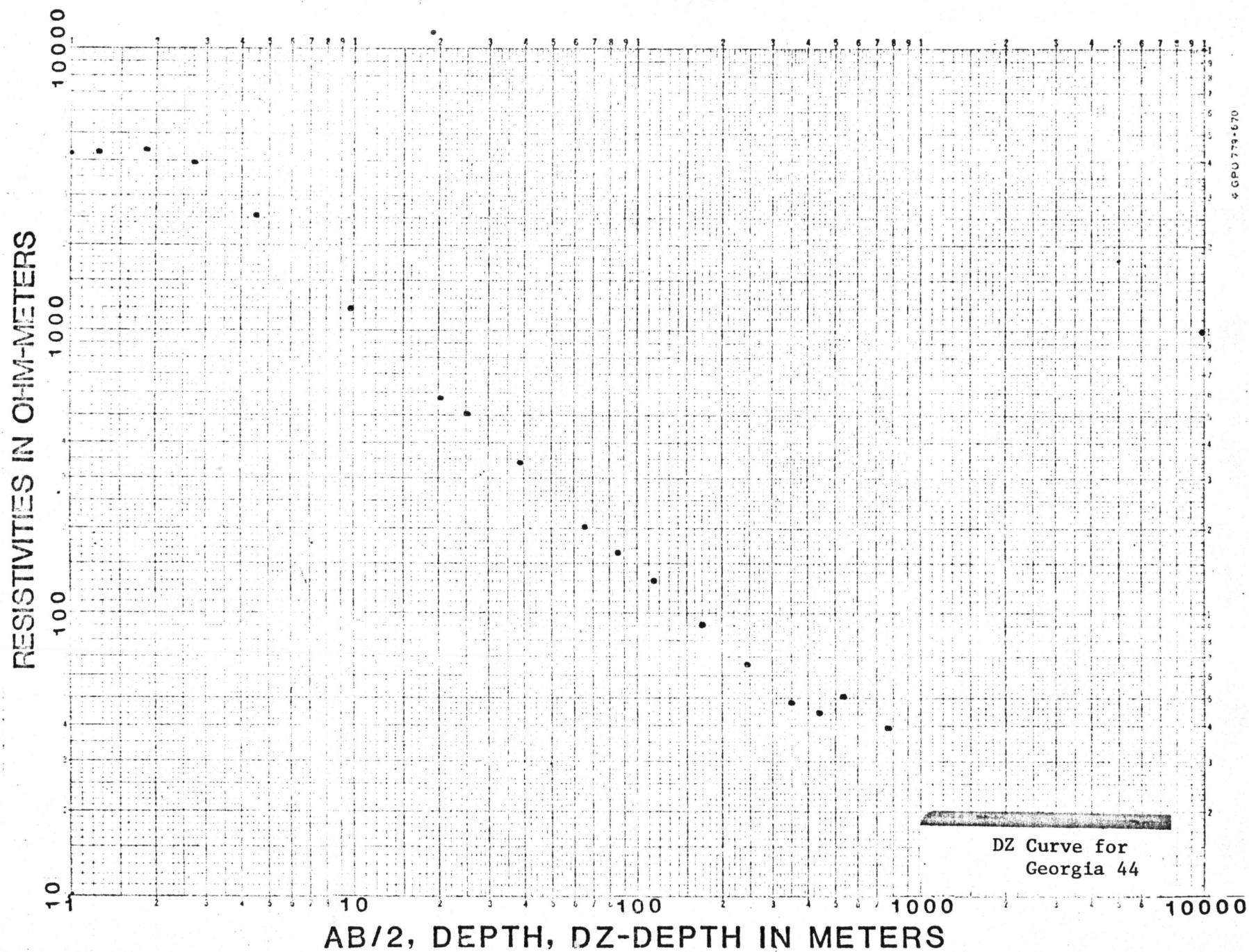


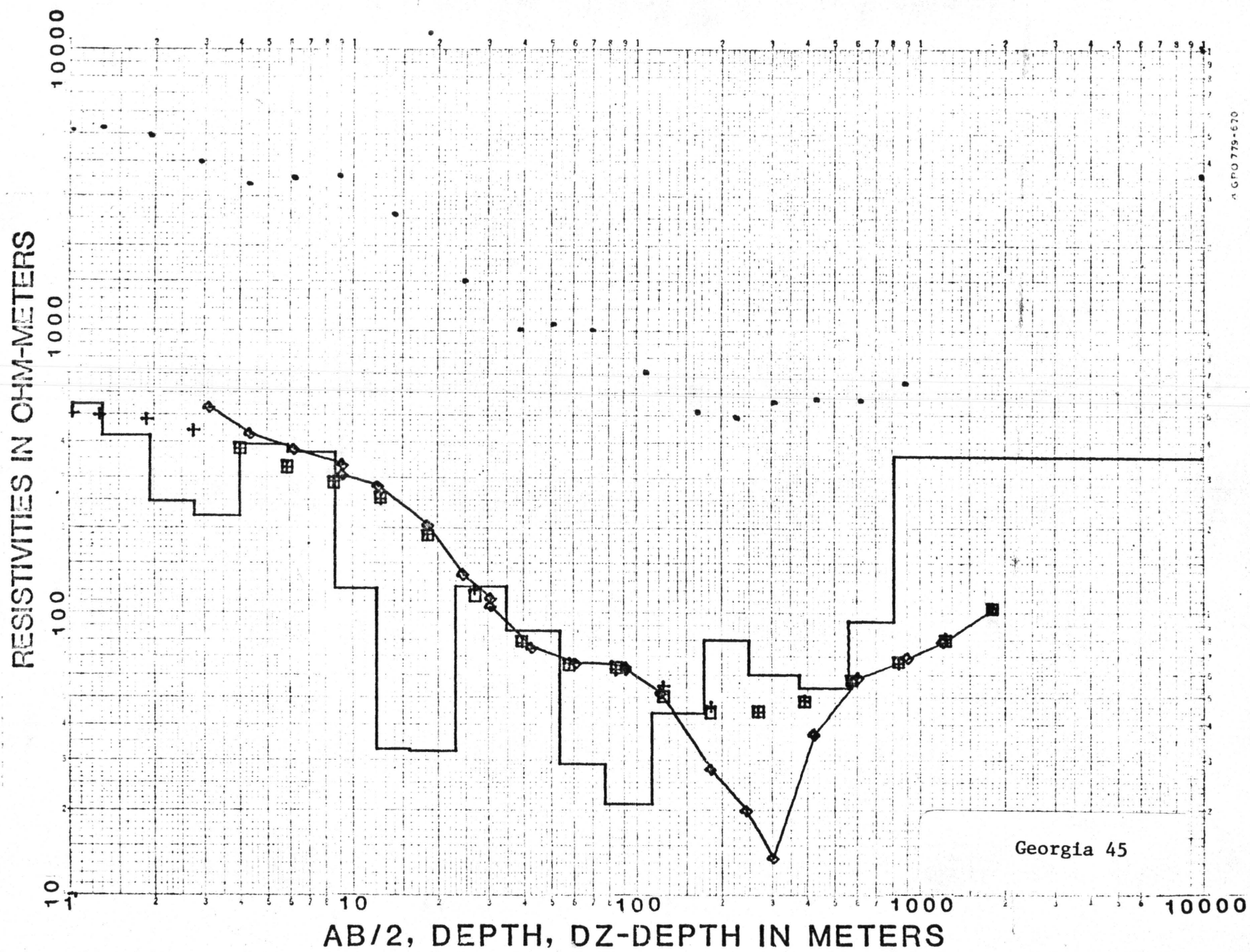
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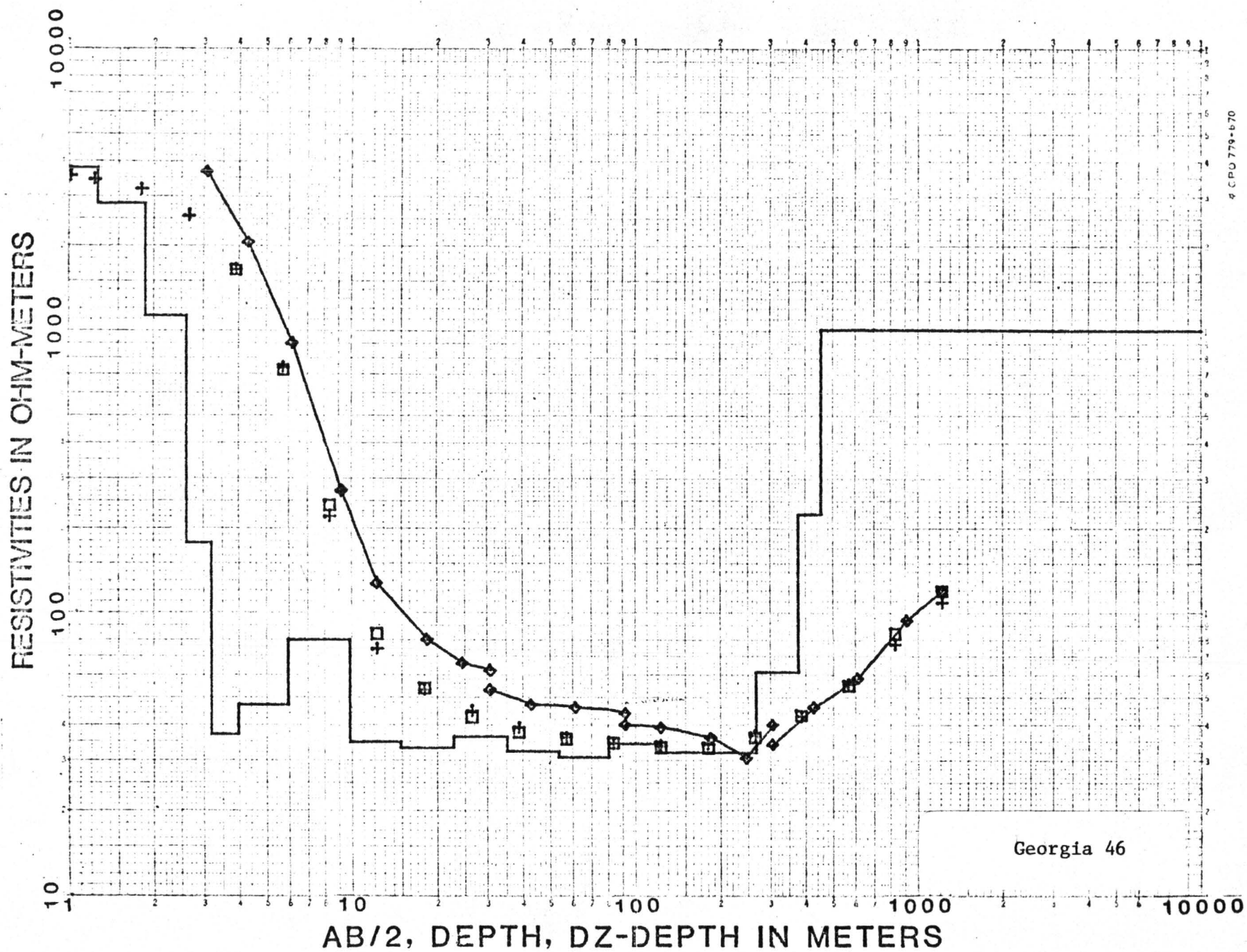




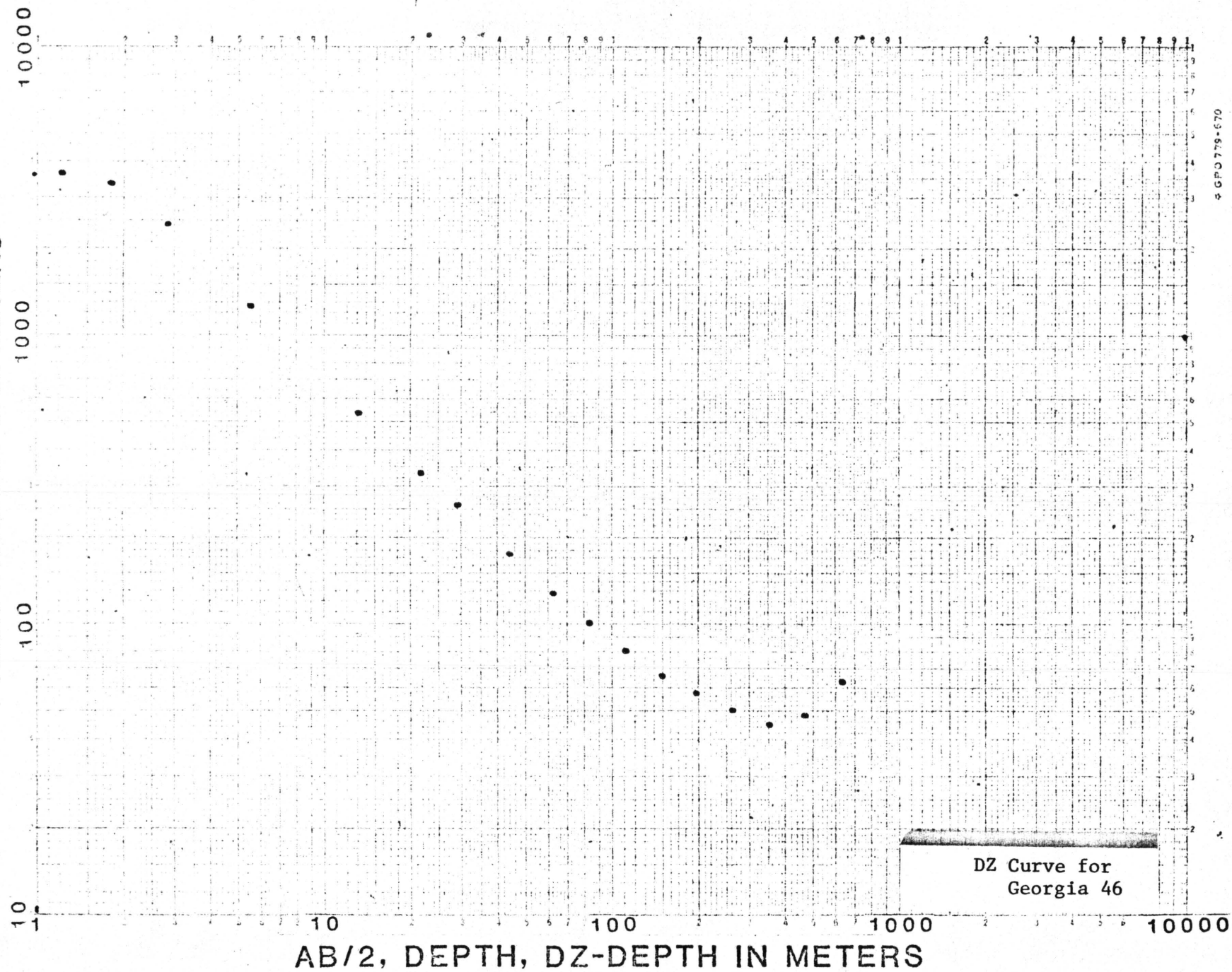


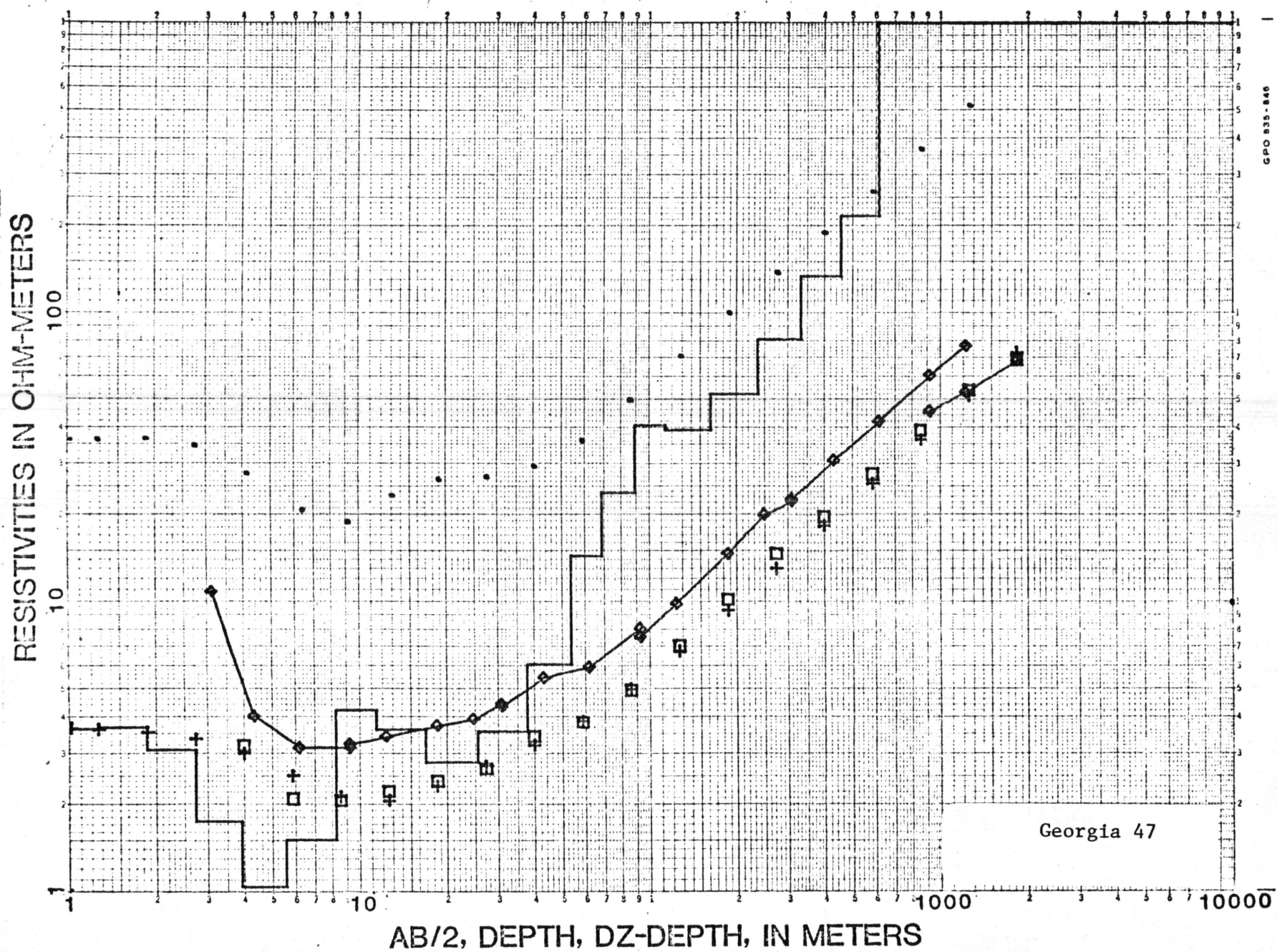




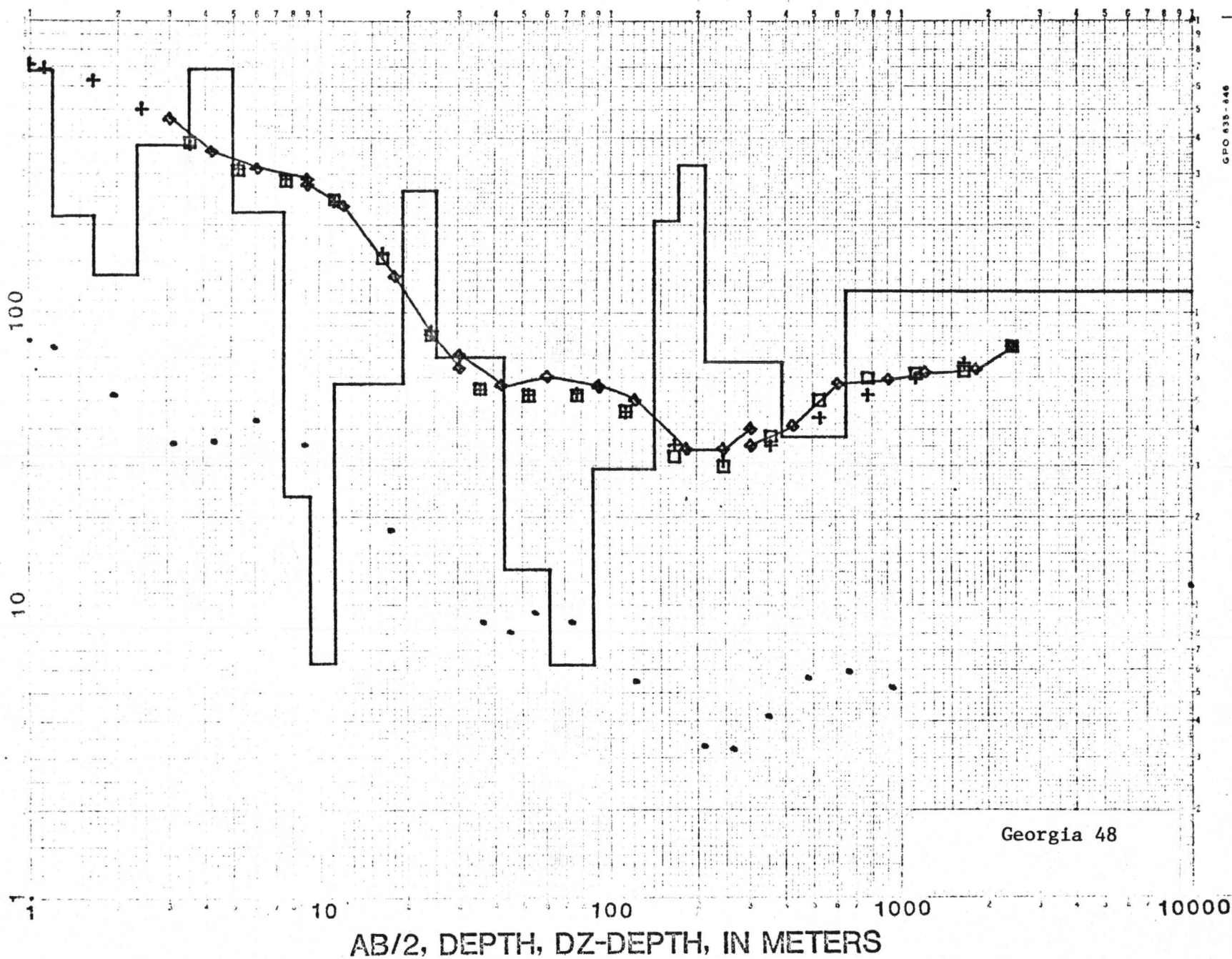


RESISTIVITIES IN OHM-METERS

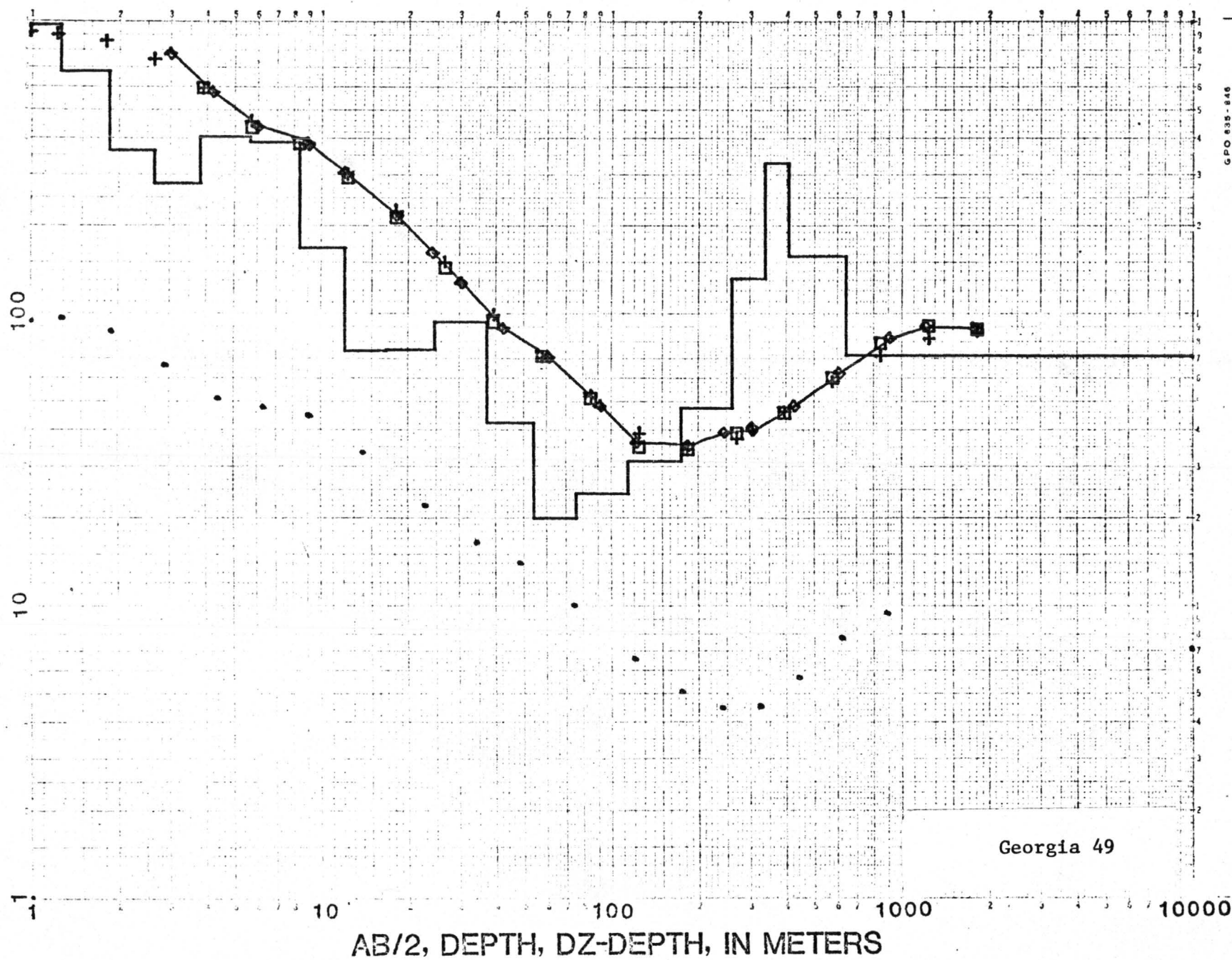




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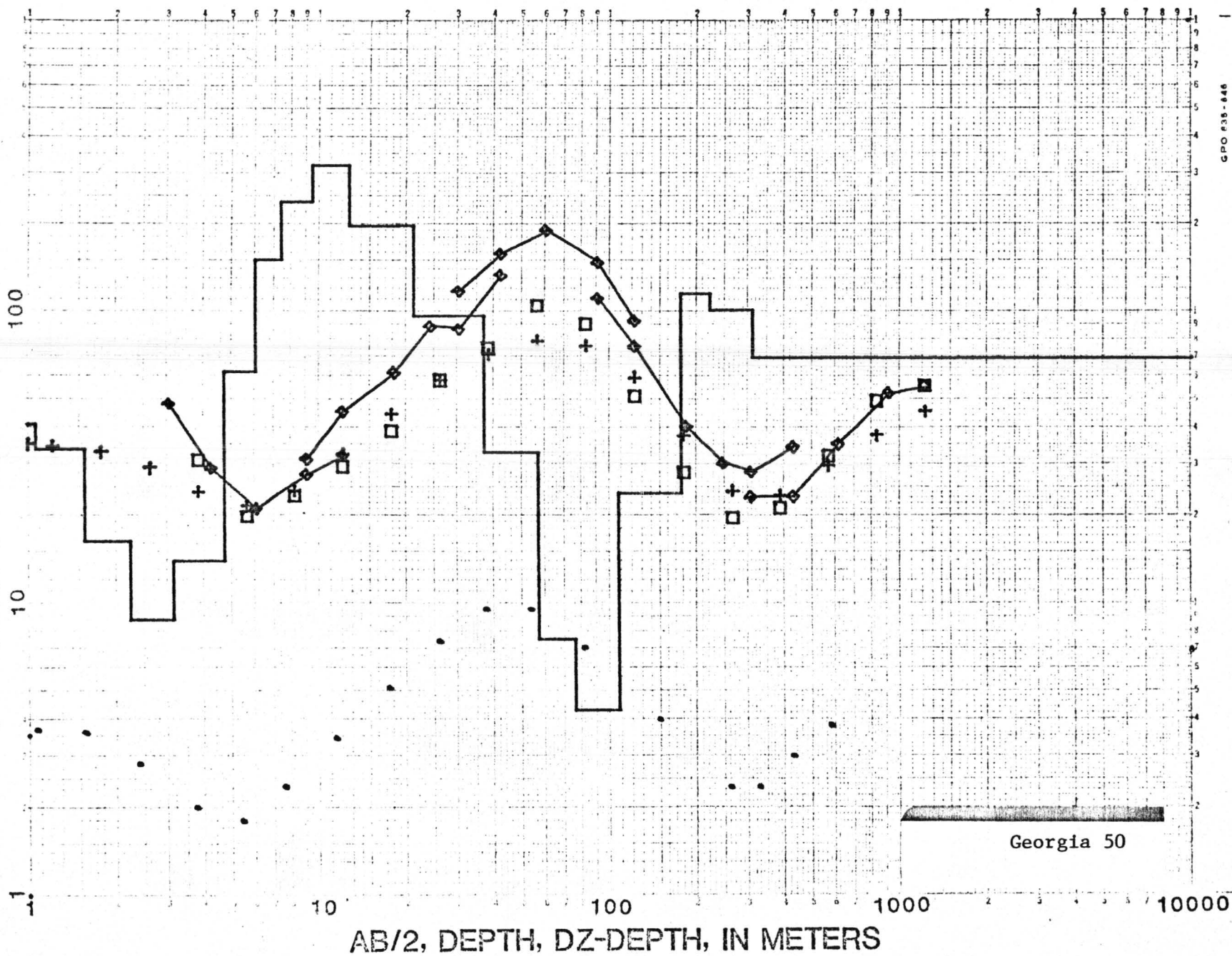


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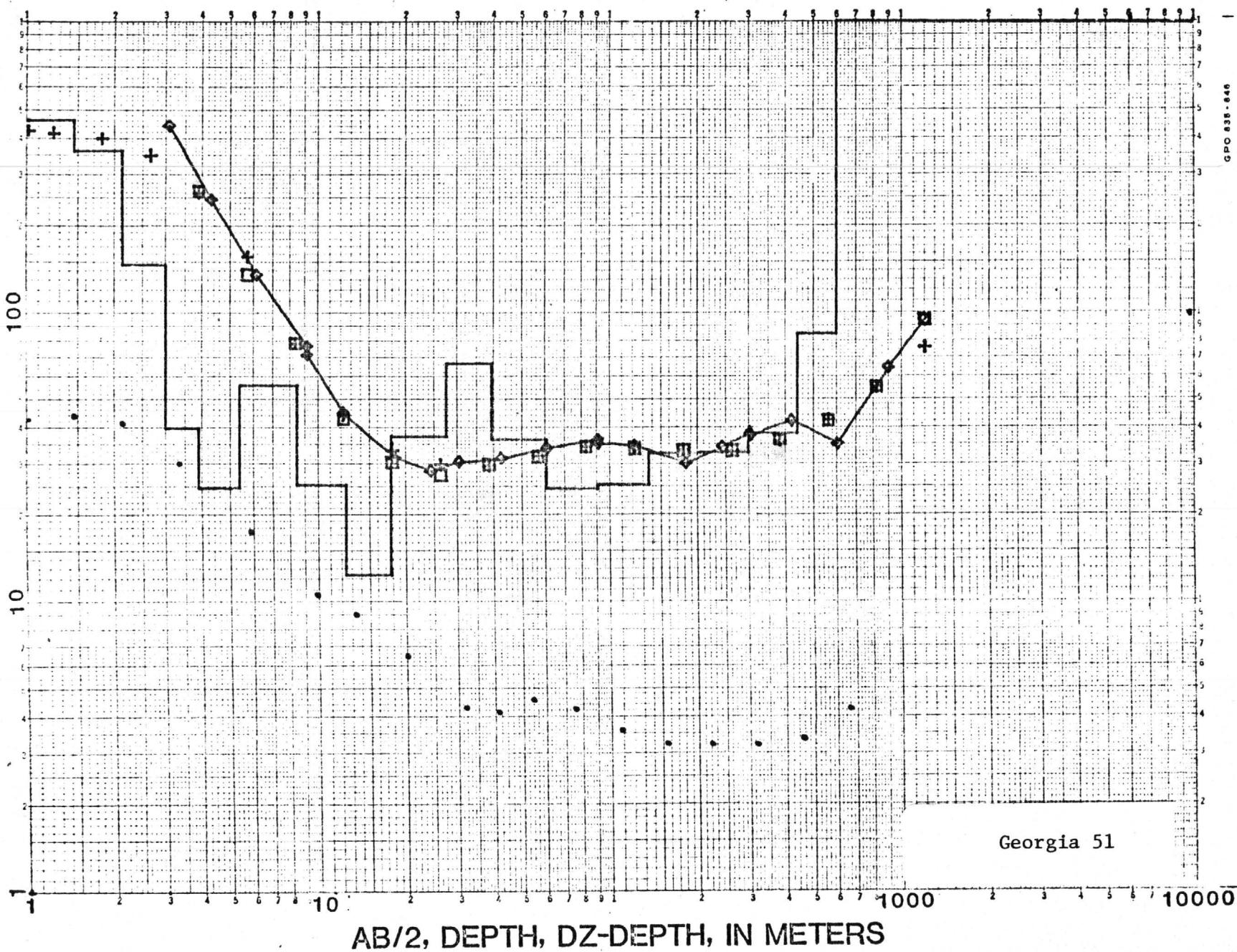
06

RESISTIVITIES IN OHM-METERS

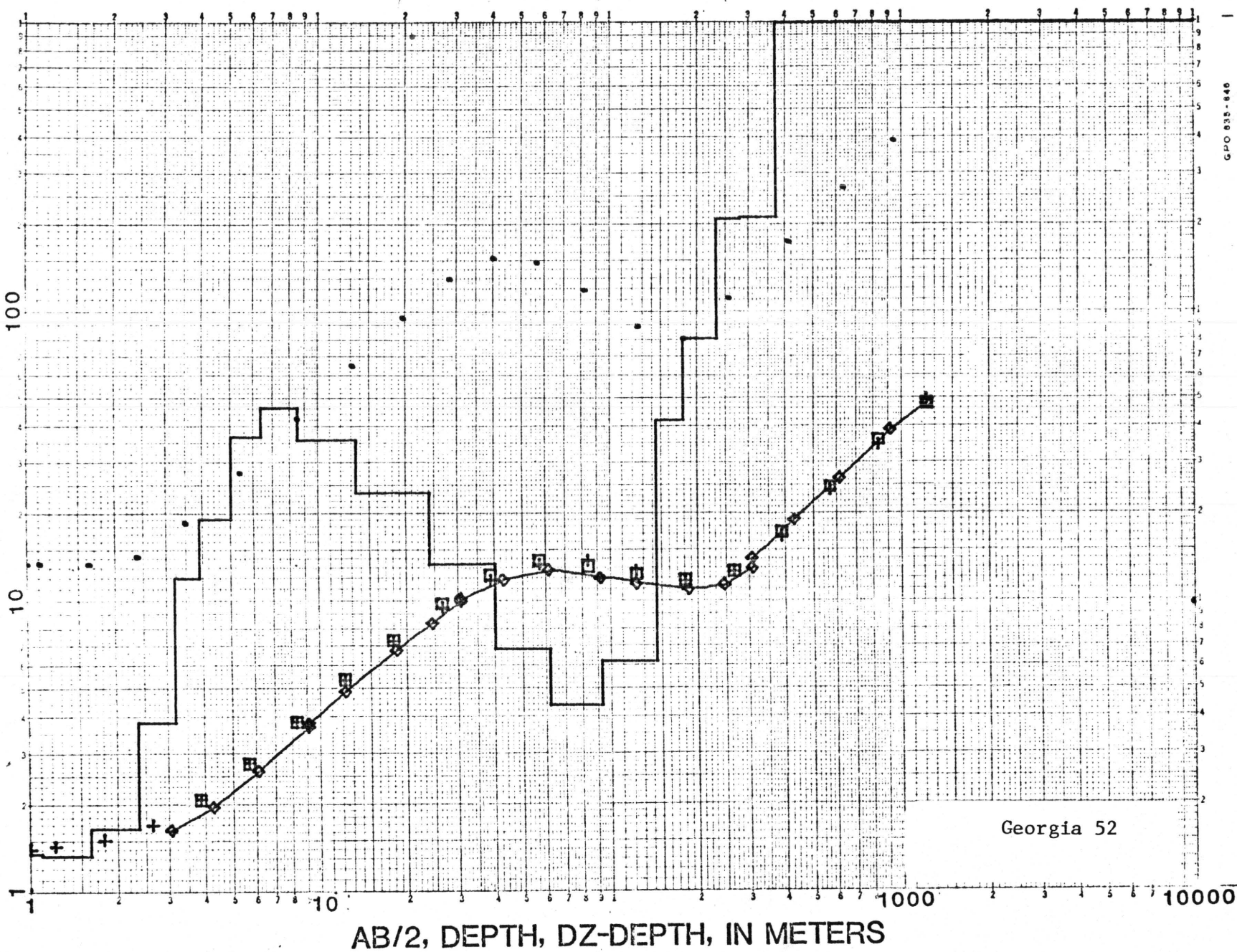


GPO 835-646

RESISTIVITIES IN OHM-METERS

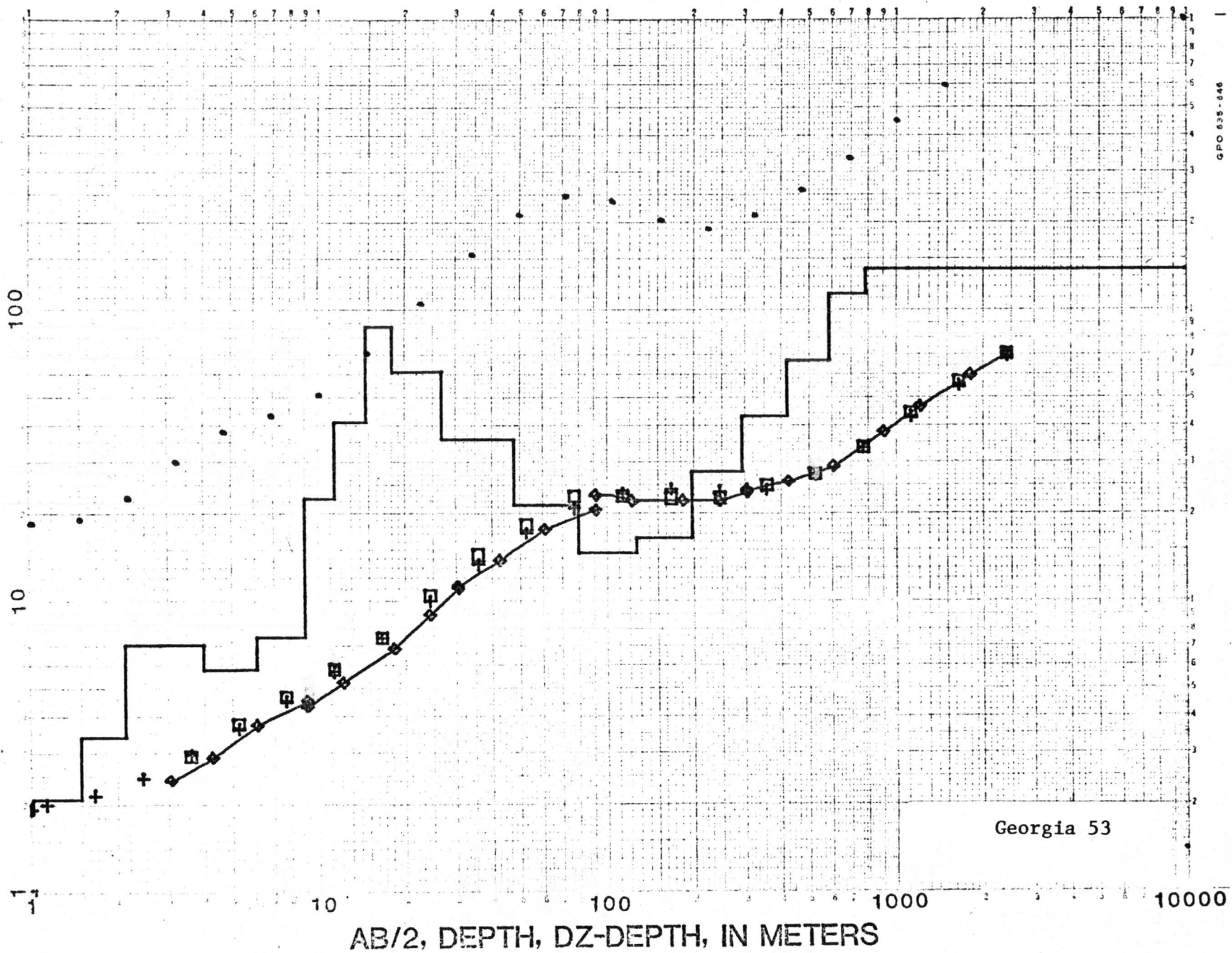


RESISTIVITIES IN OHM-METERS



86

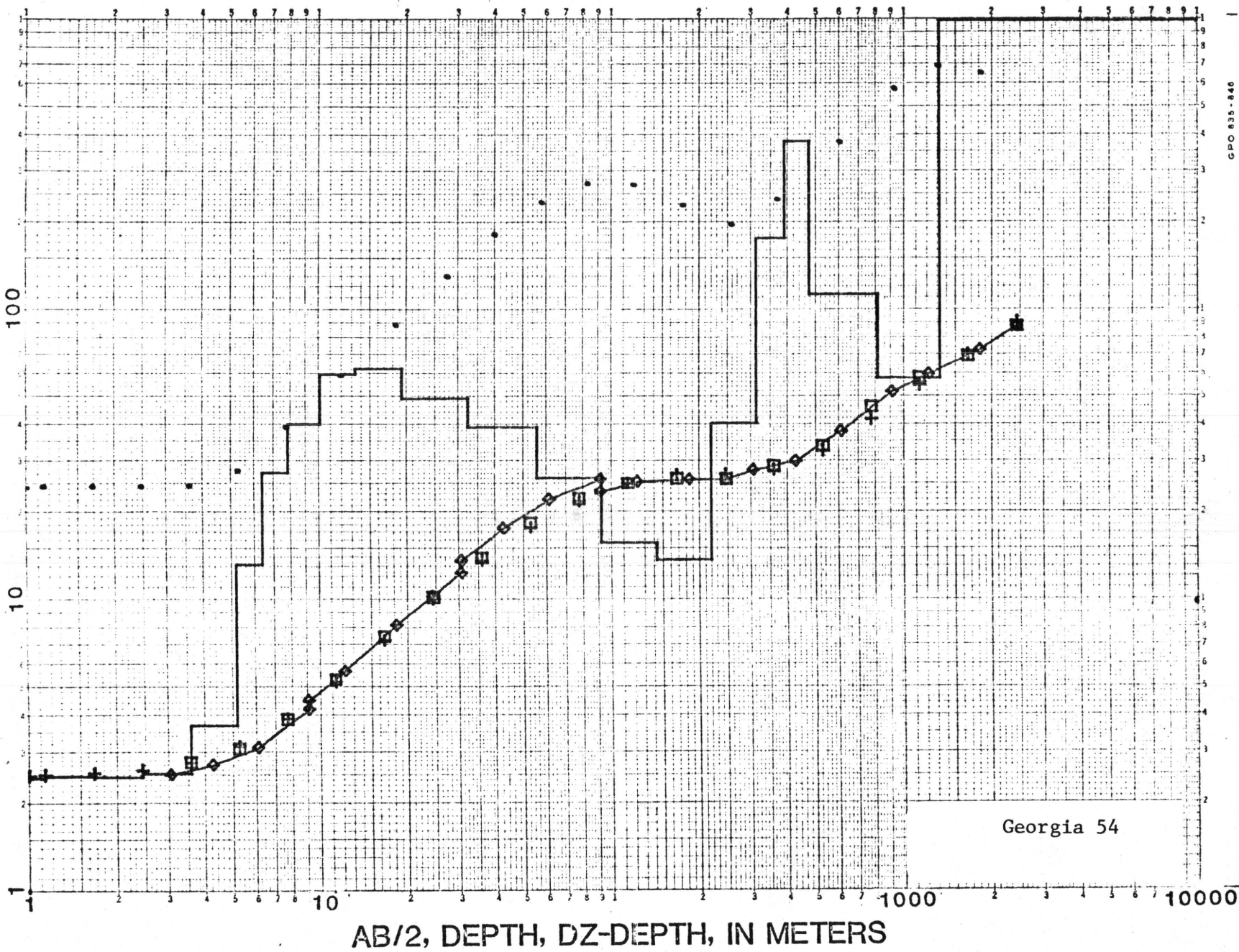
RESISTIVITIES IN OHM-METERS



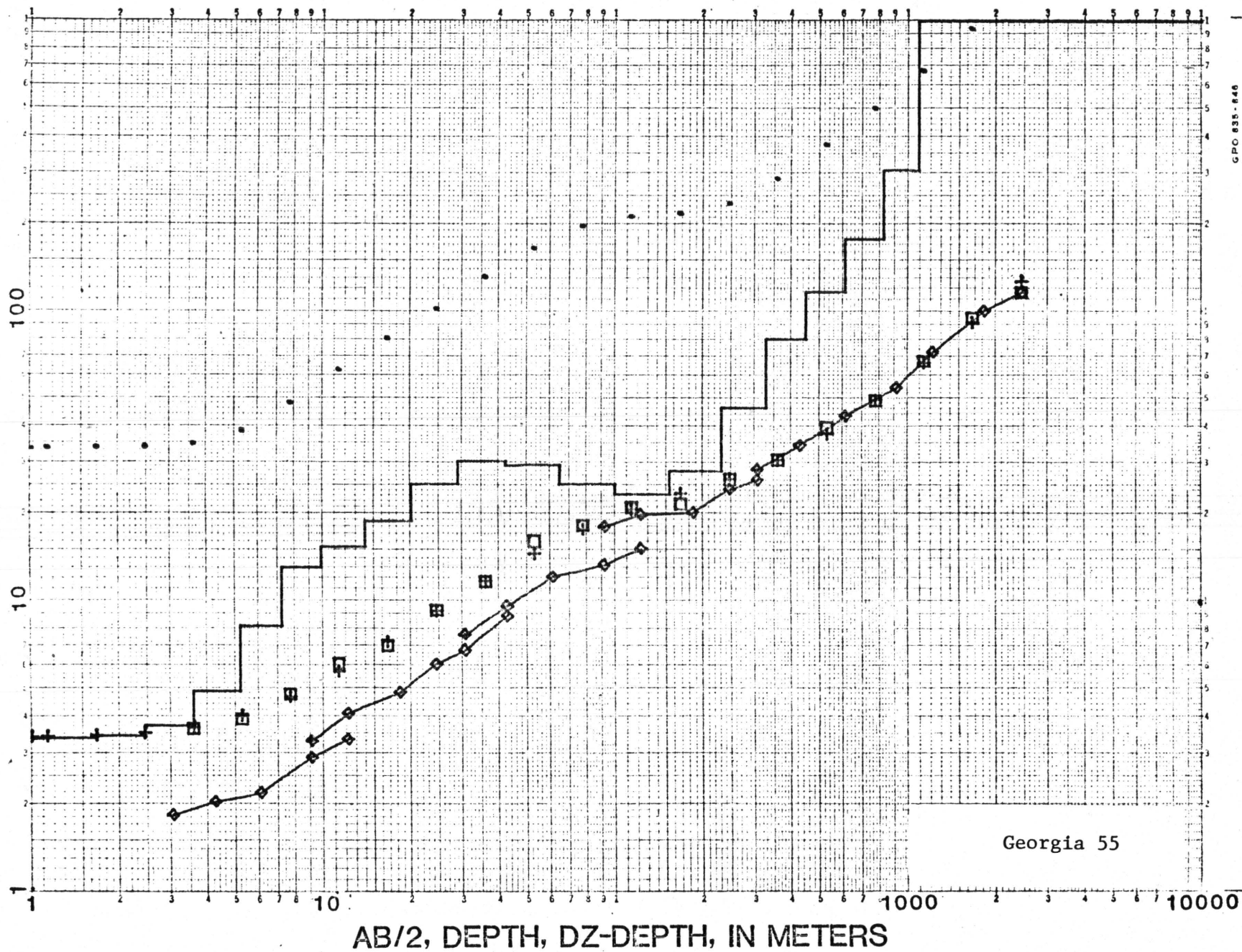
Georgia 53

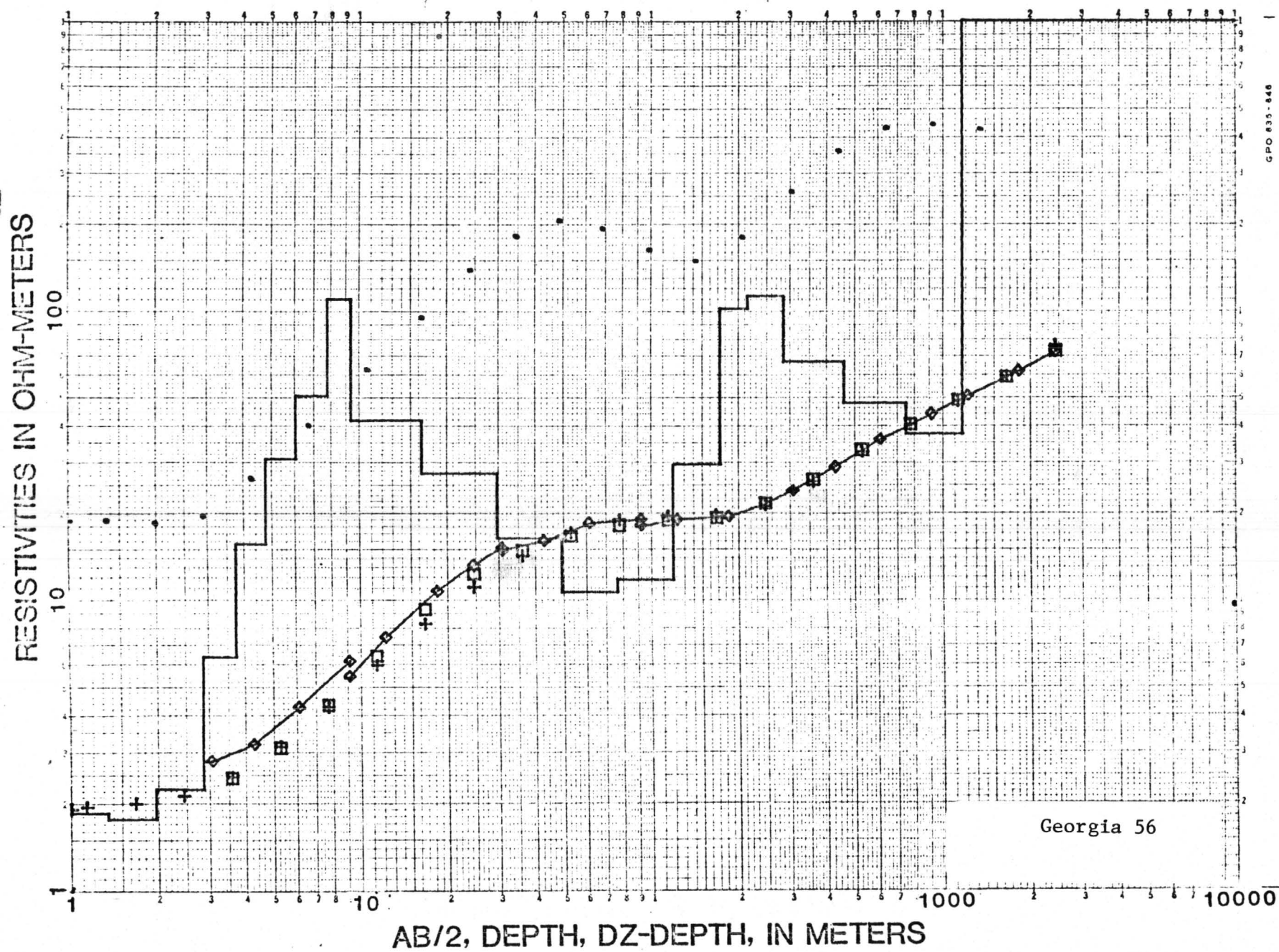
GPO 535-646

RESISTIVITIES IN OHM-METERS

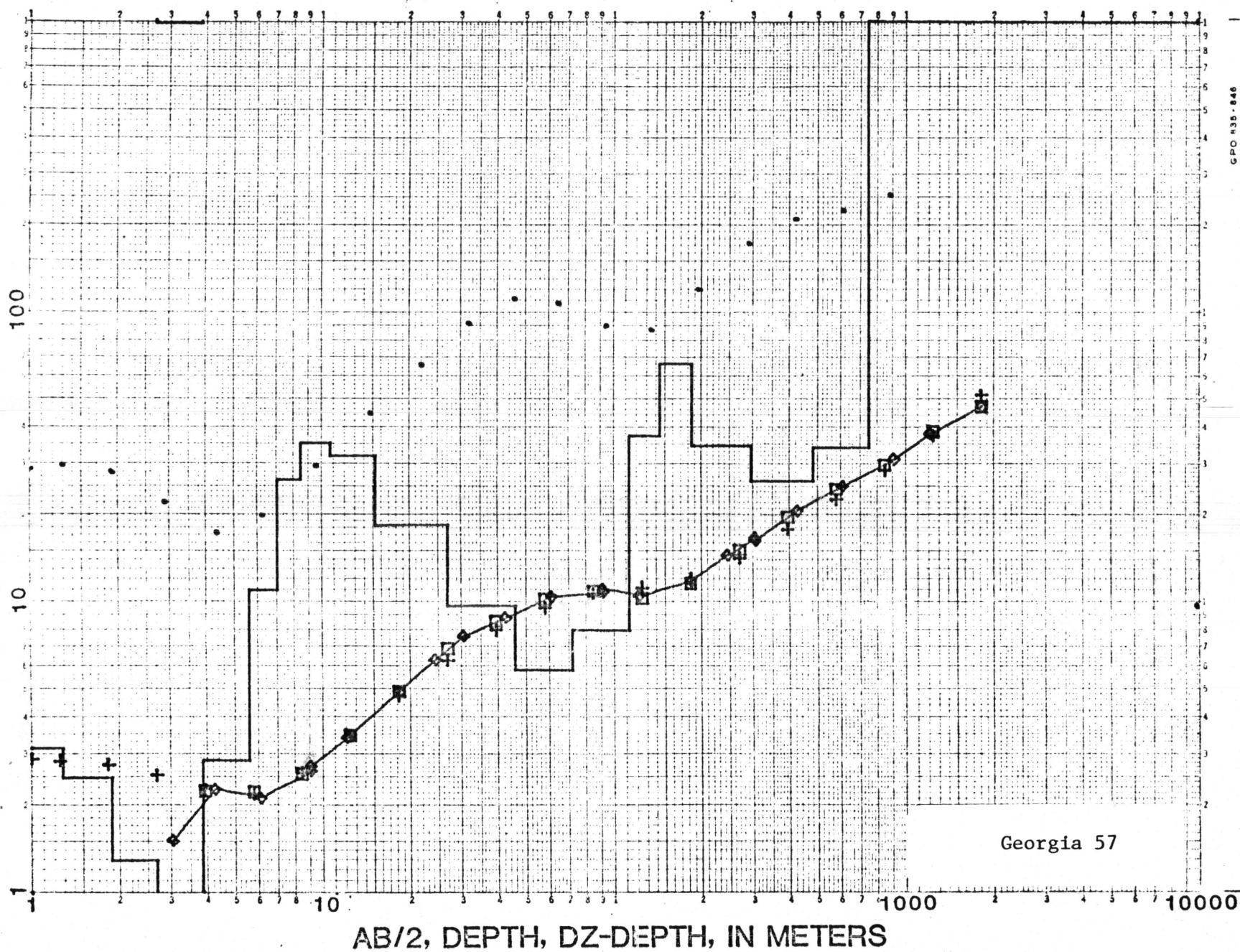


RESISTIVITIES IN OHM-METERS

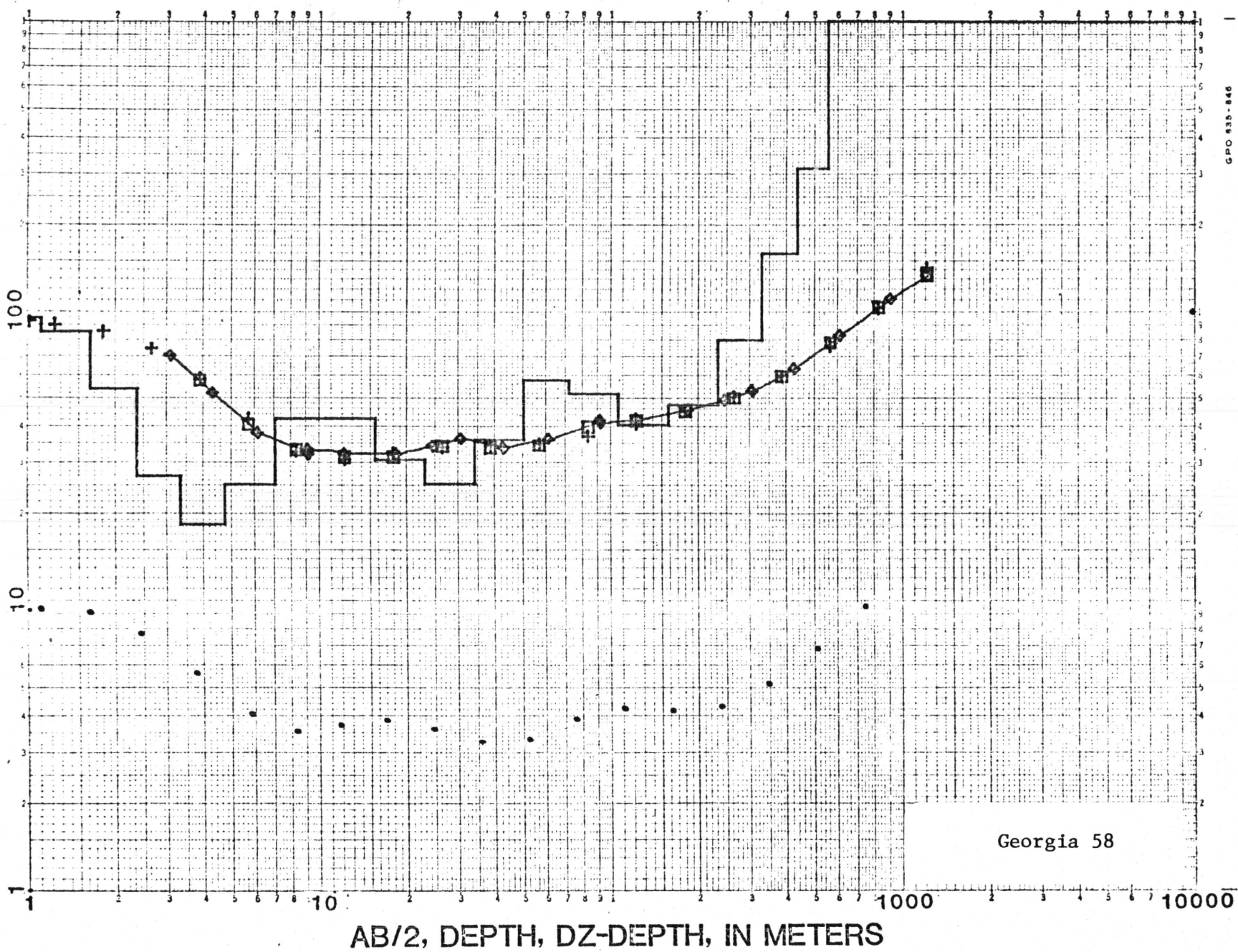




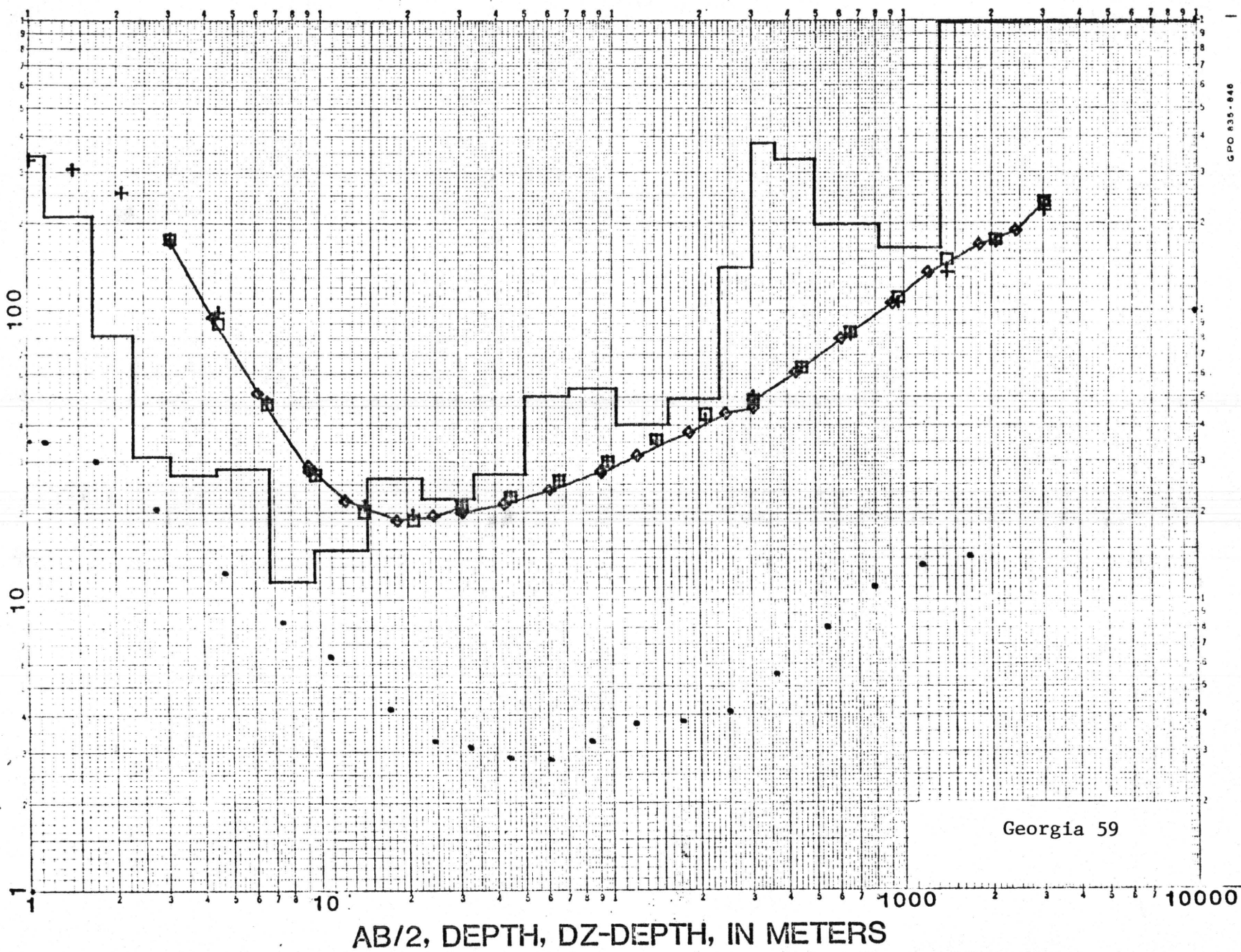
RESISTIVITIES IN OHM-METERS



RESISTIVITIES IN OHM-METERS

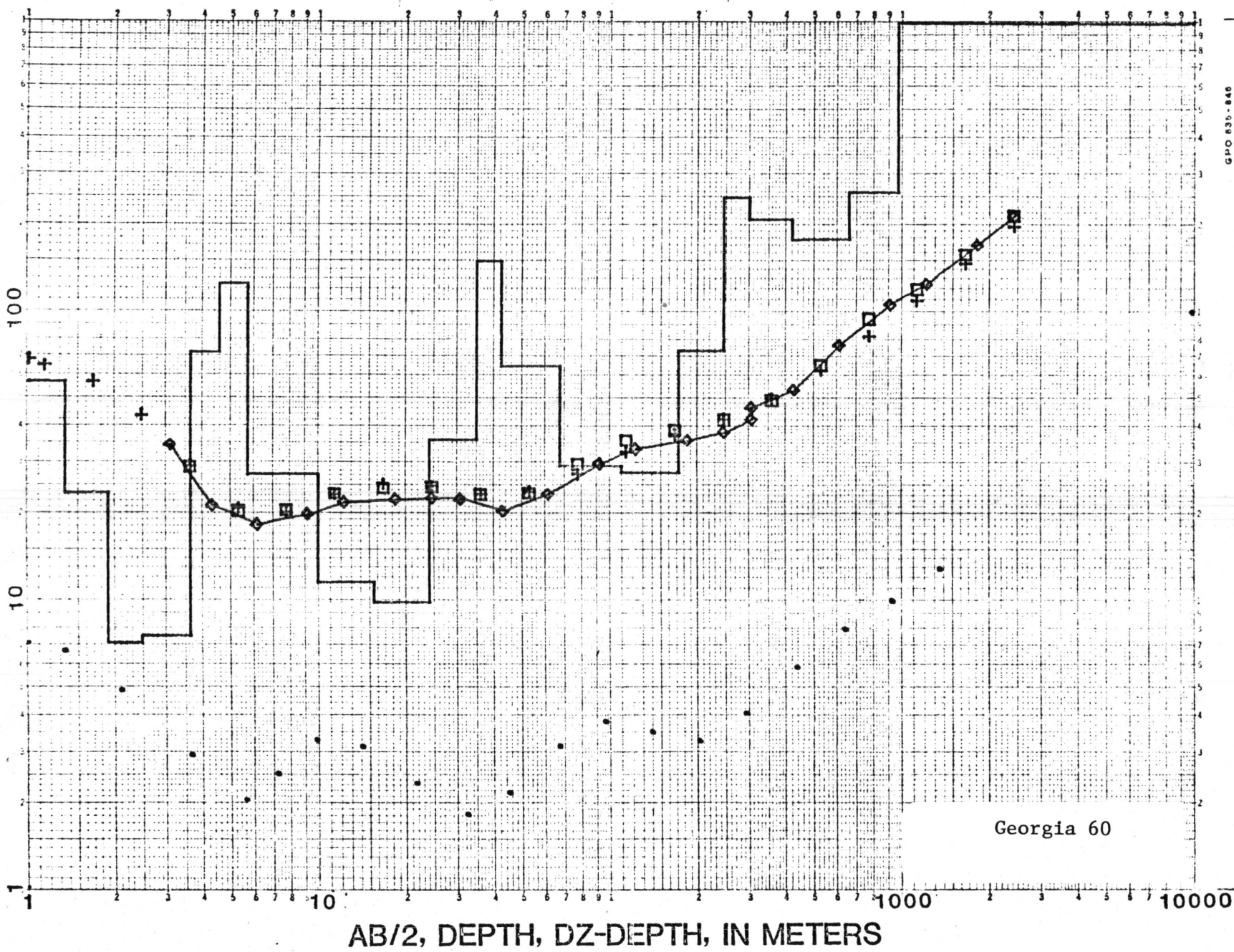


RESISTIVITIES IN OHM-METERS



100

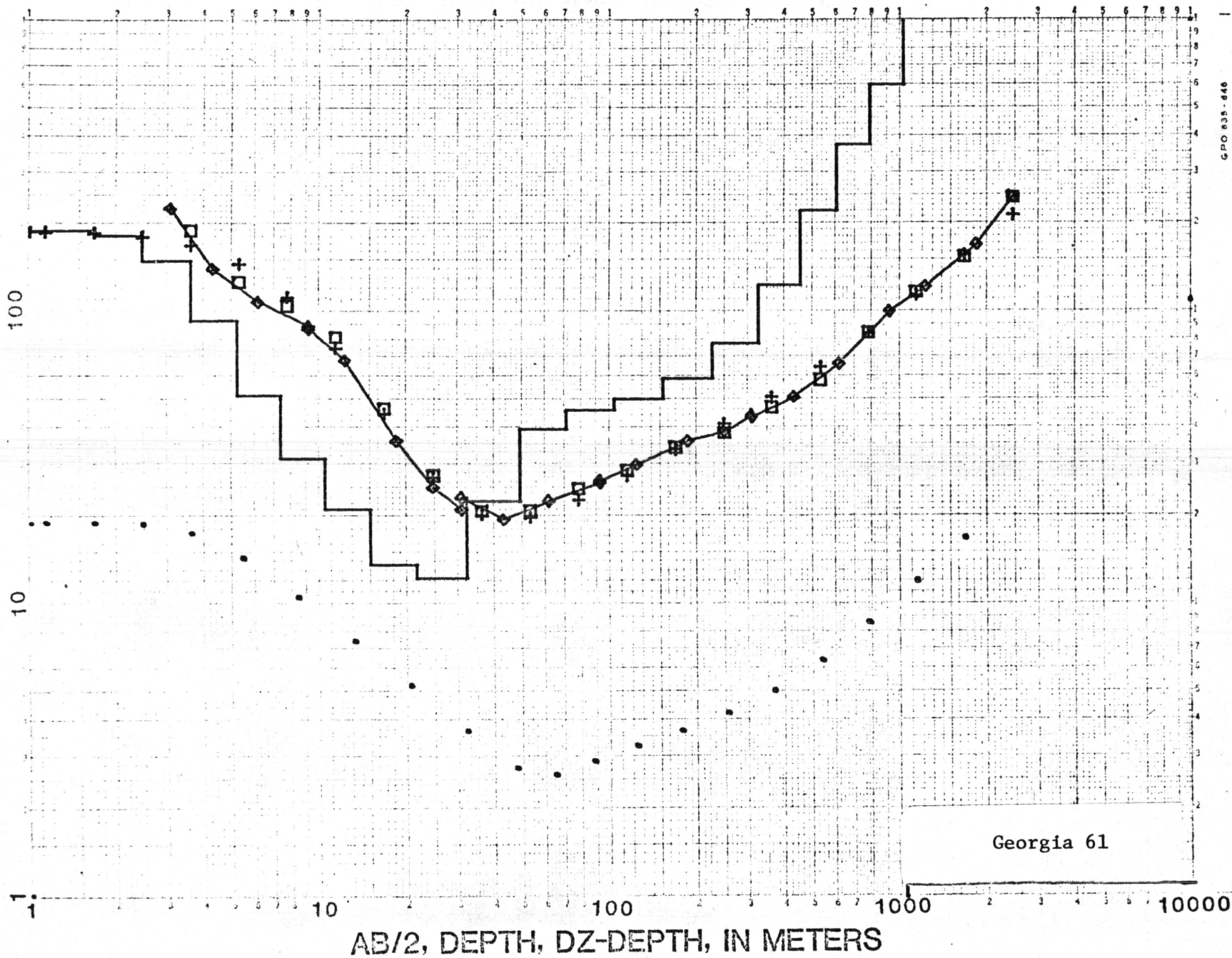
RESISTIVITIES IN OHM-METERS



GPO 635-846

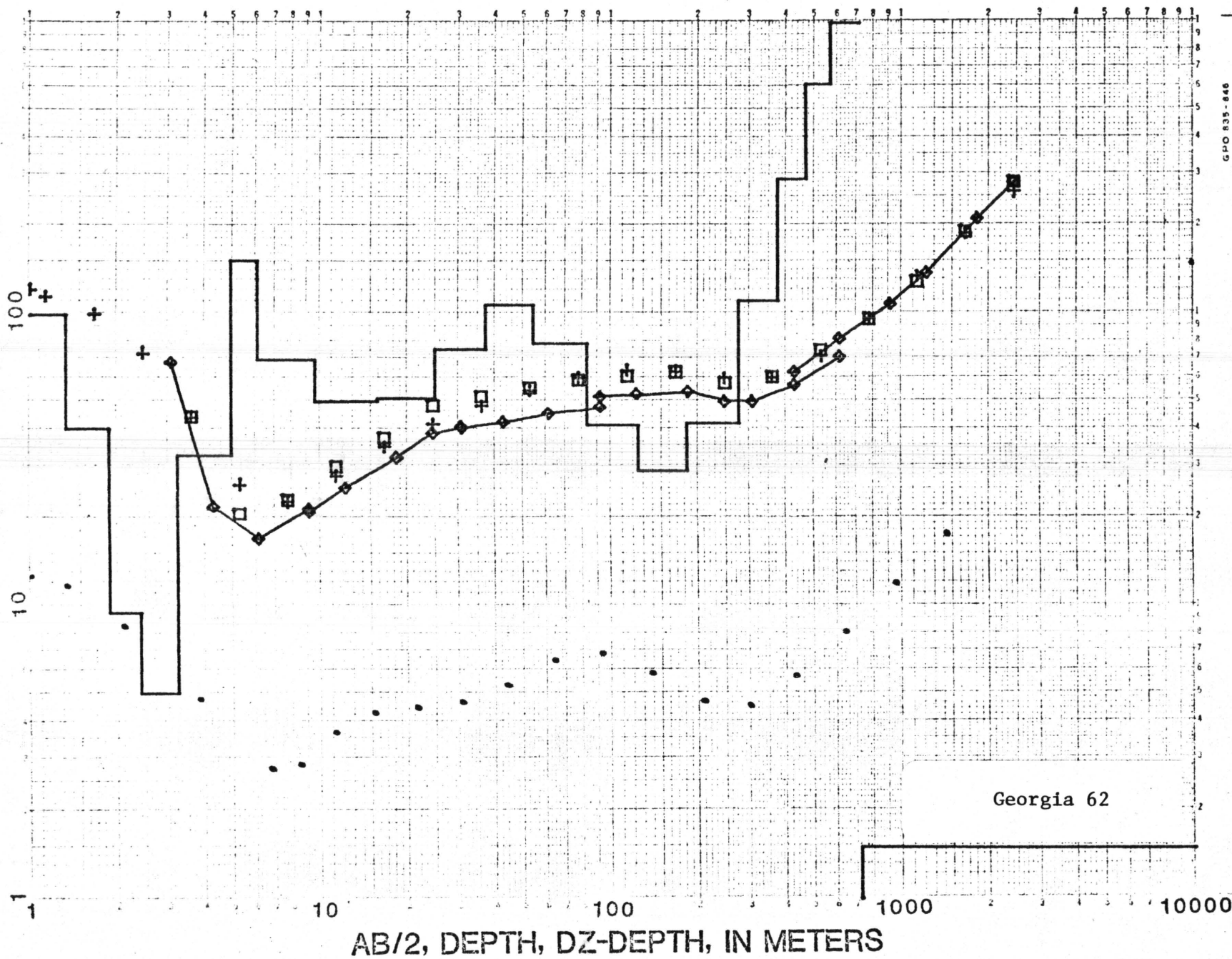
101

RESISTIVITIES IN OHM-METERS



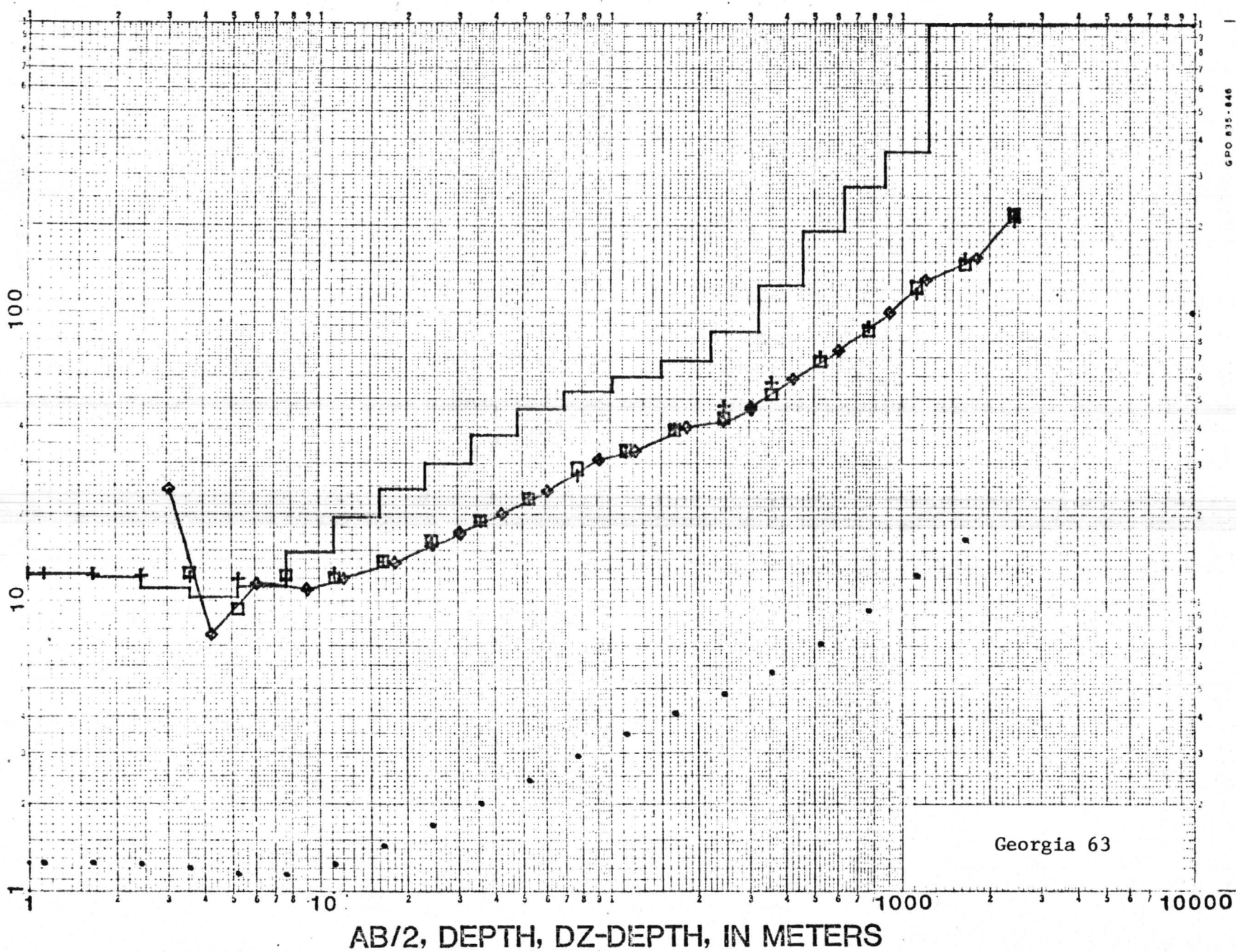
GPO 835-846

RESISTIVITIES IN OHM-METERS

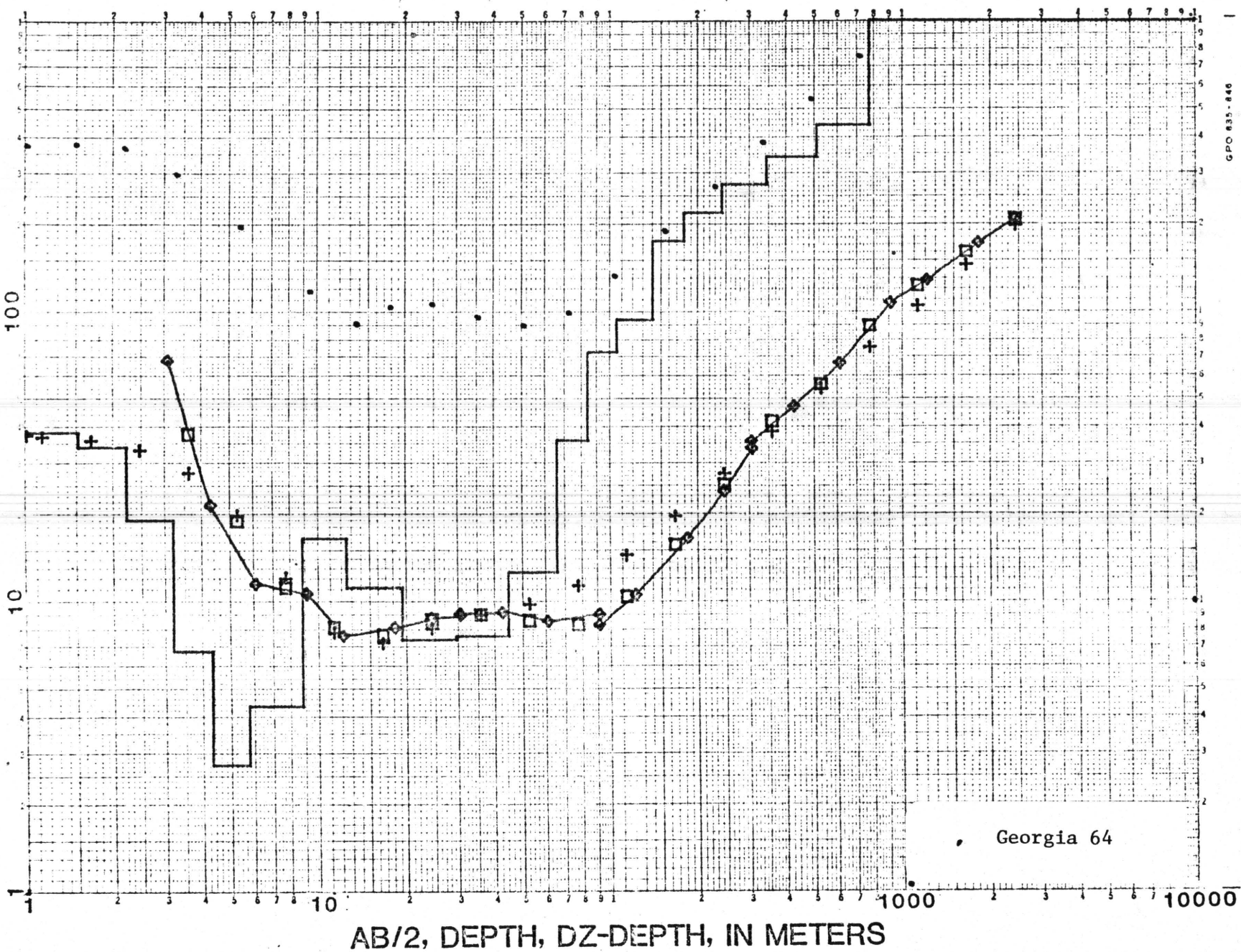


CPO-838-848

RESISTIVITIES IN OHM-METERS



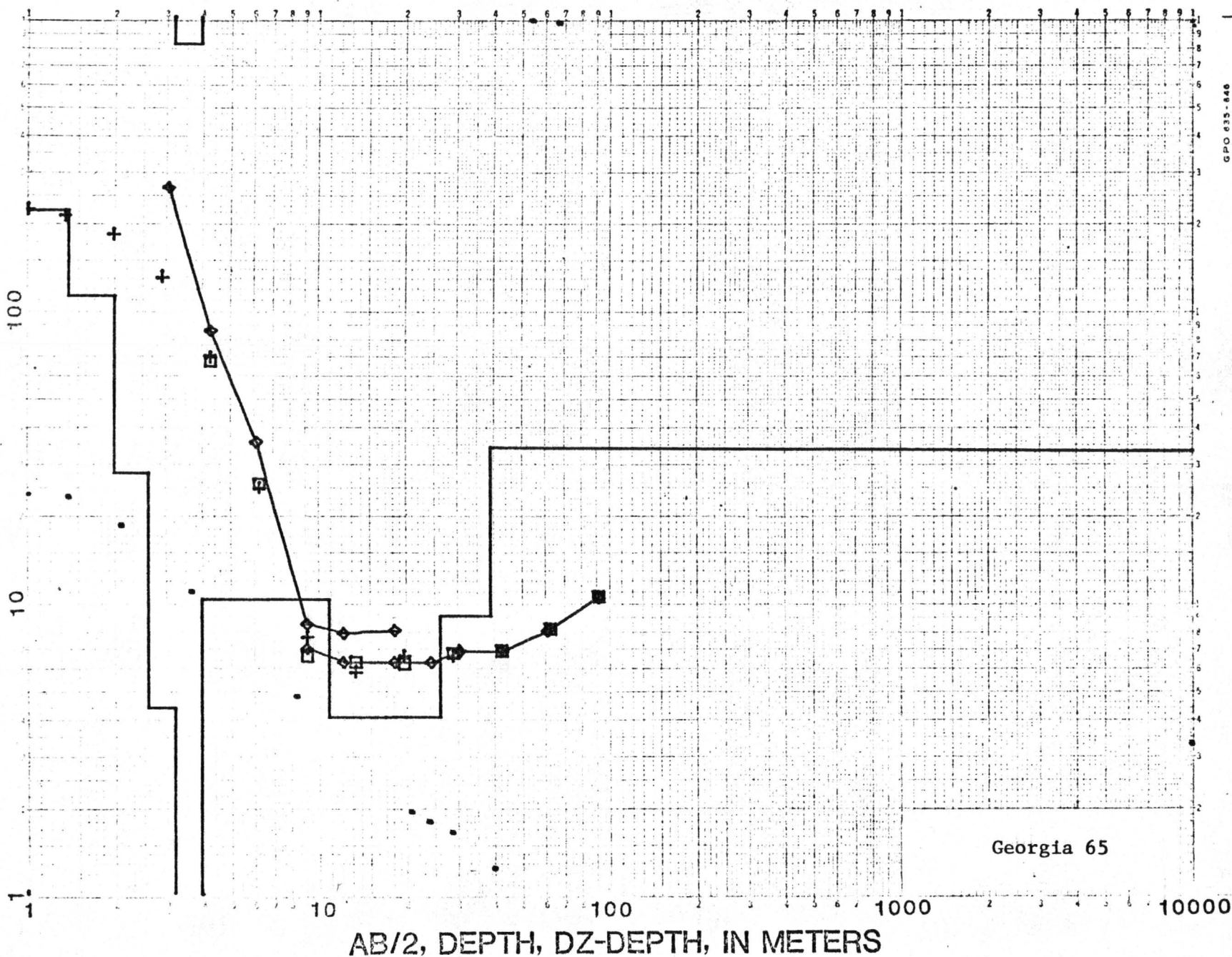
RESISTIVITIES IN OHM-METERS



Georgia 64

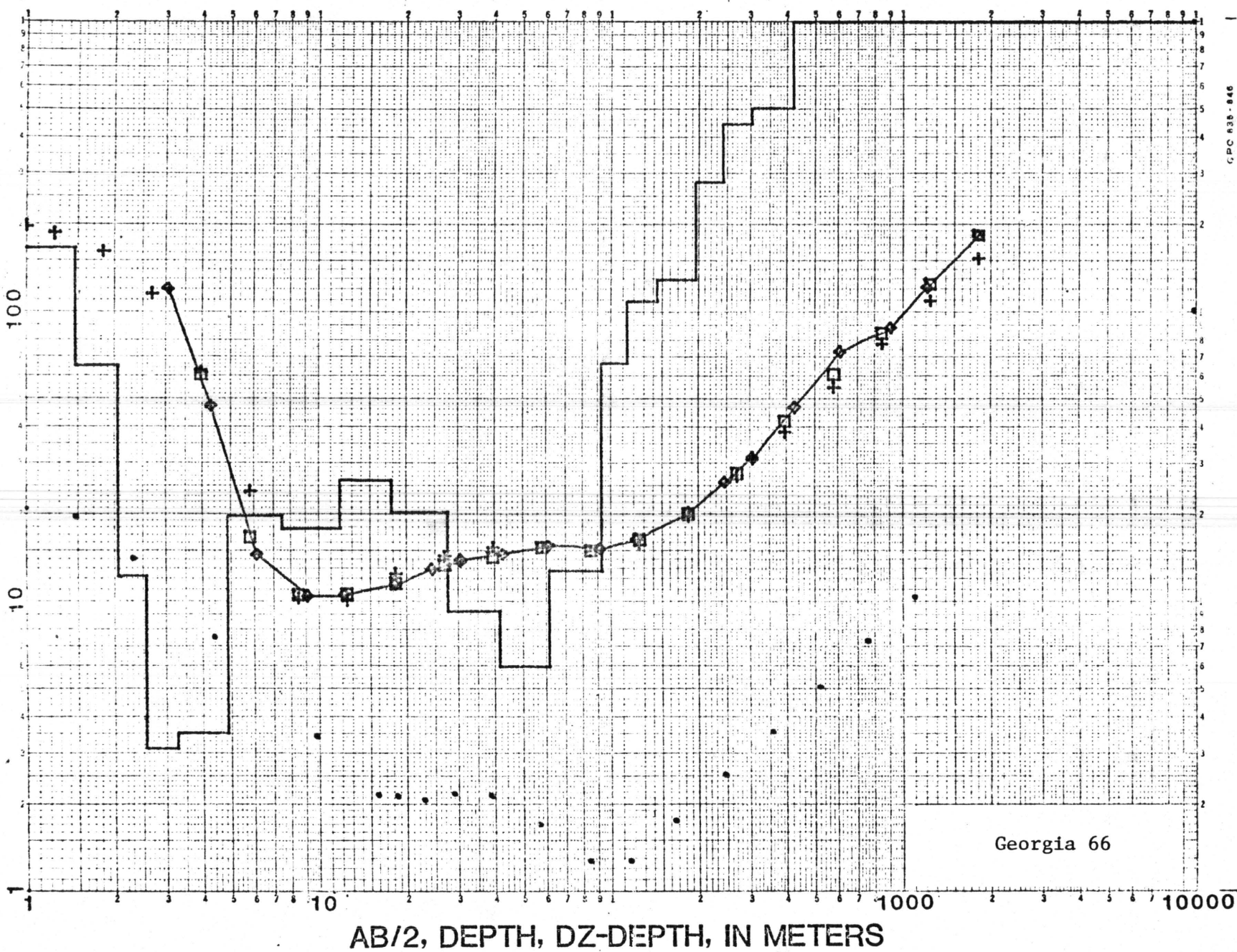
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RESISTIVITIES IN OHM-METERS

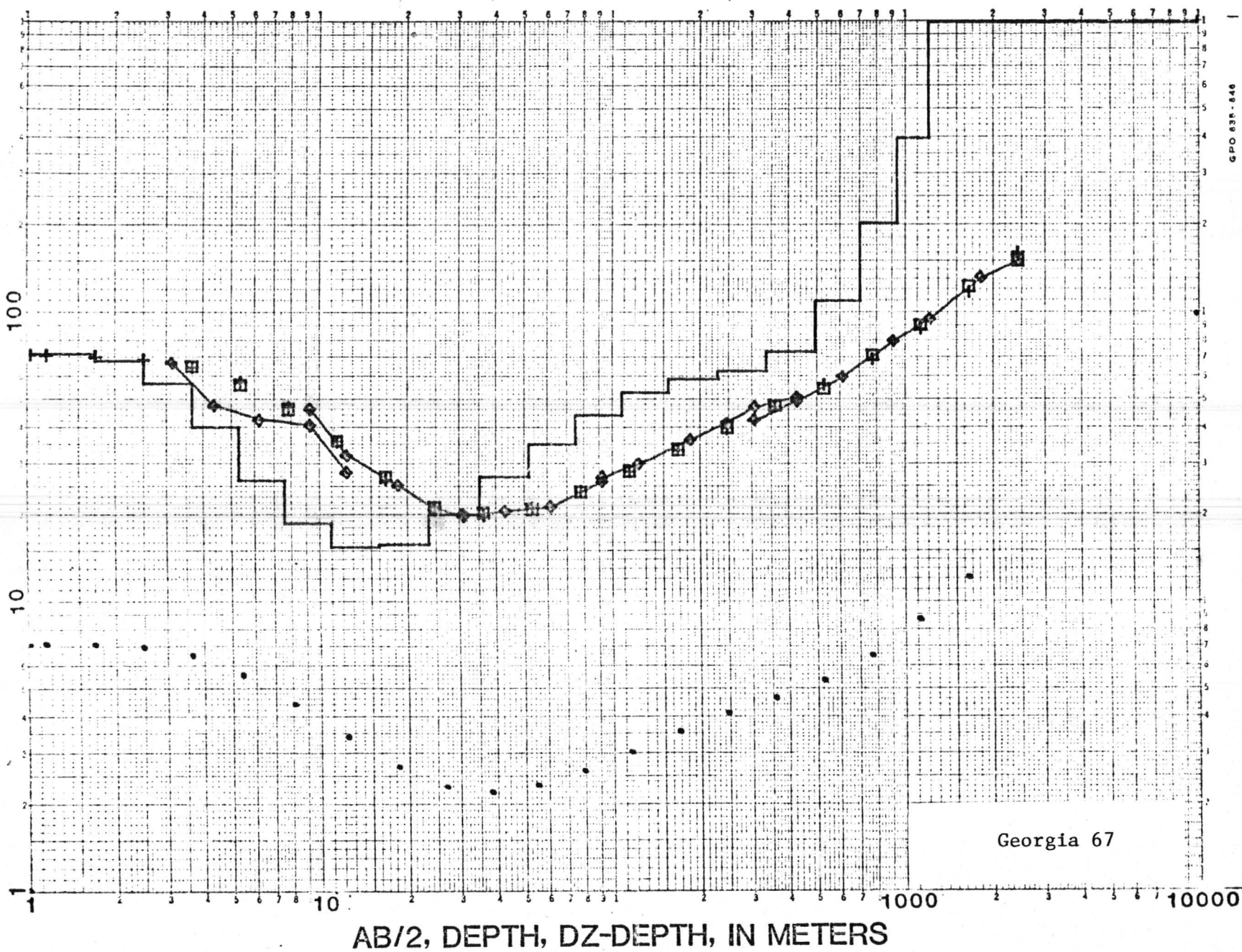


GPO 635-646

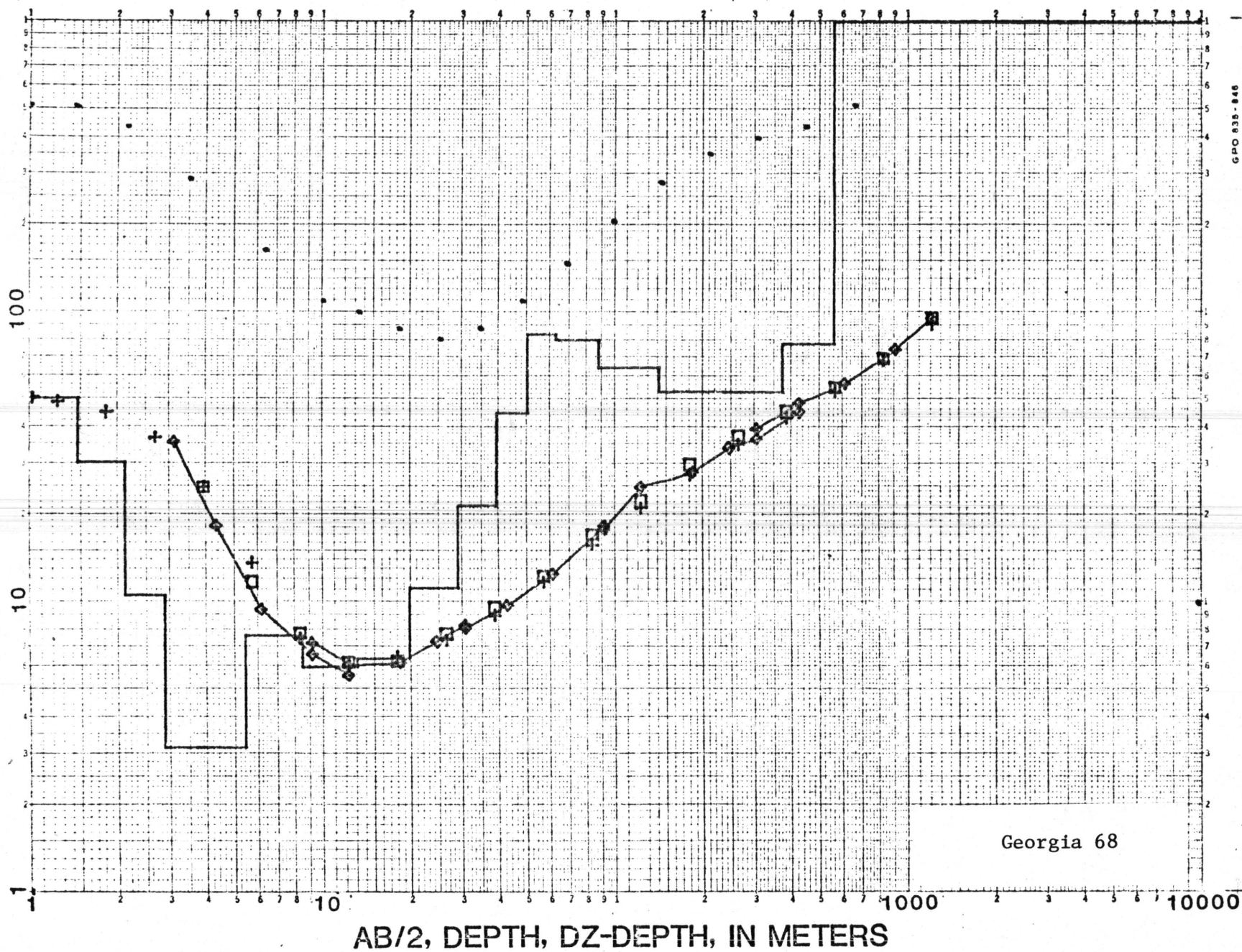
RESISTIVITIES IN OHM-METERS



RESISTIVITIES IN OHM-METERS

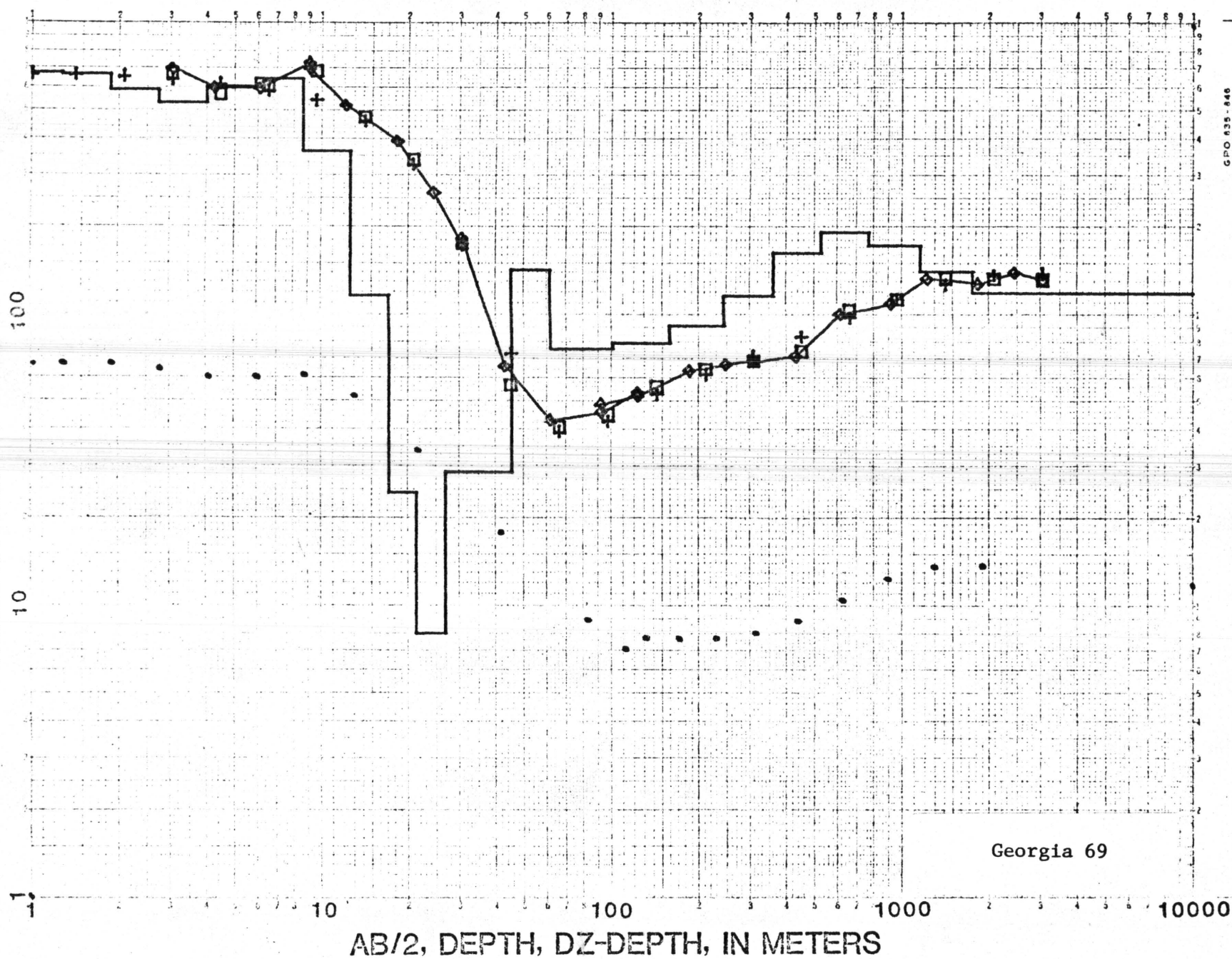


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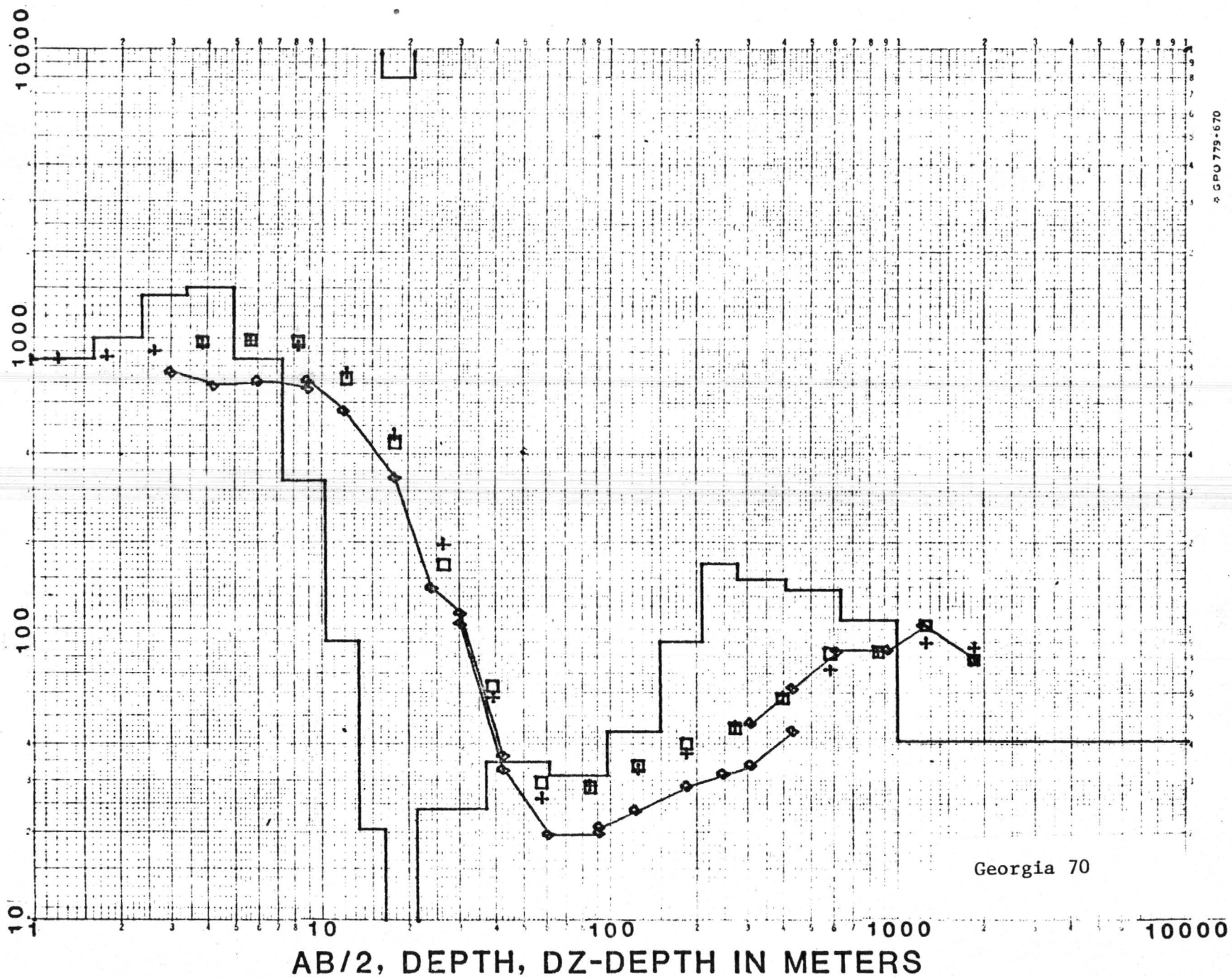


Georgia 68

RESISTIVITIES IN OHM-METERS

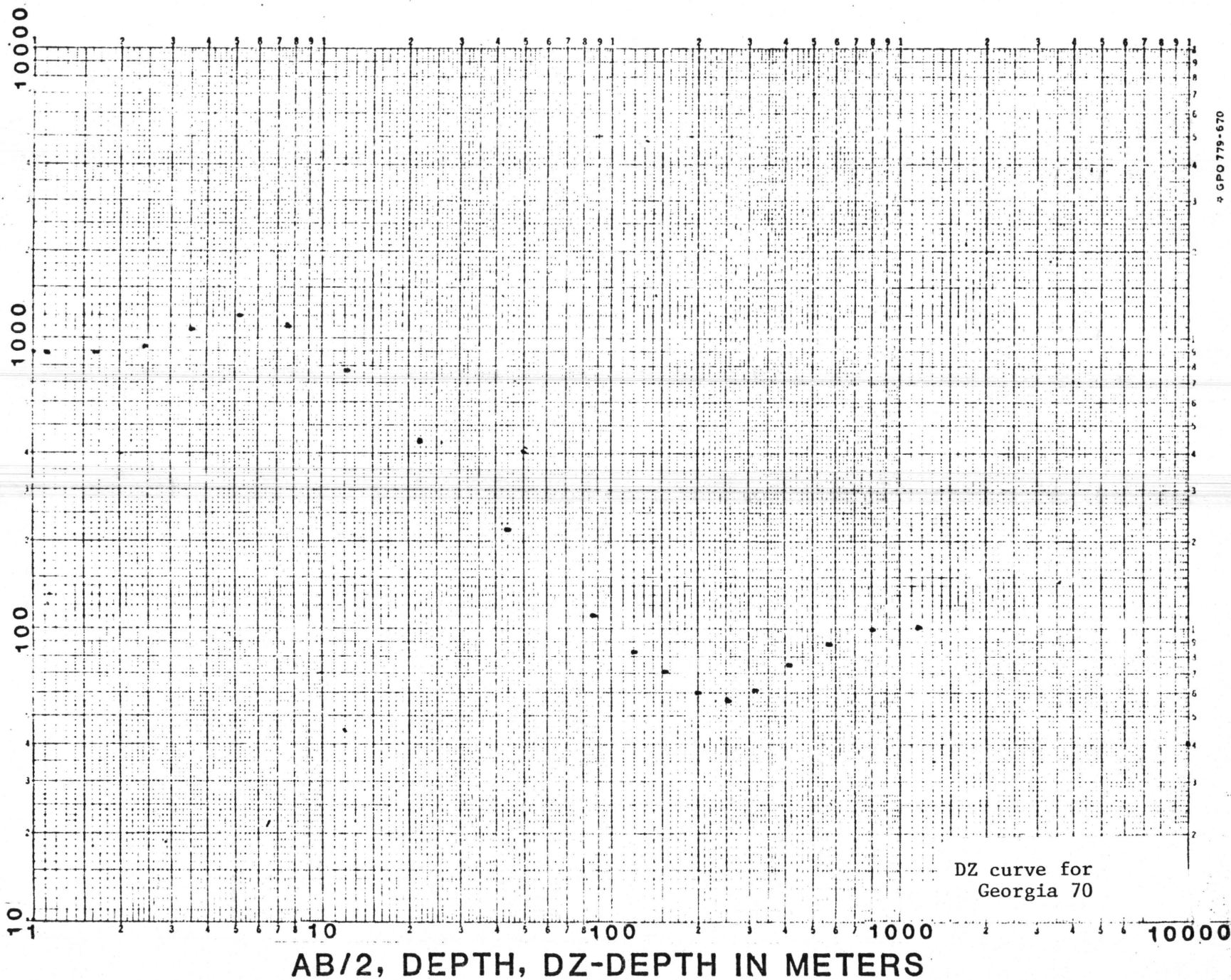


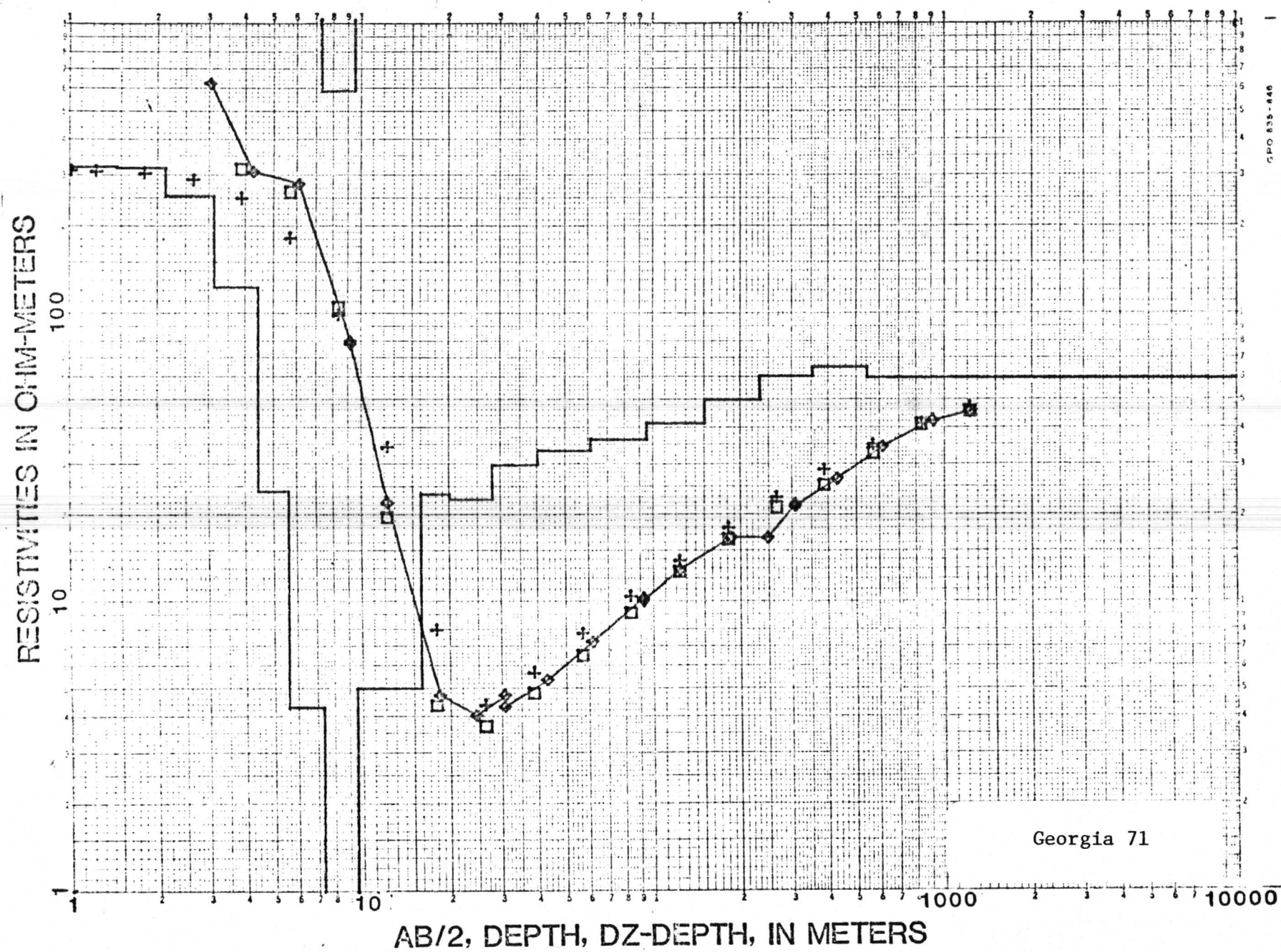
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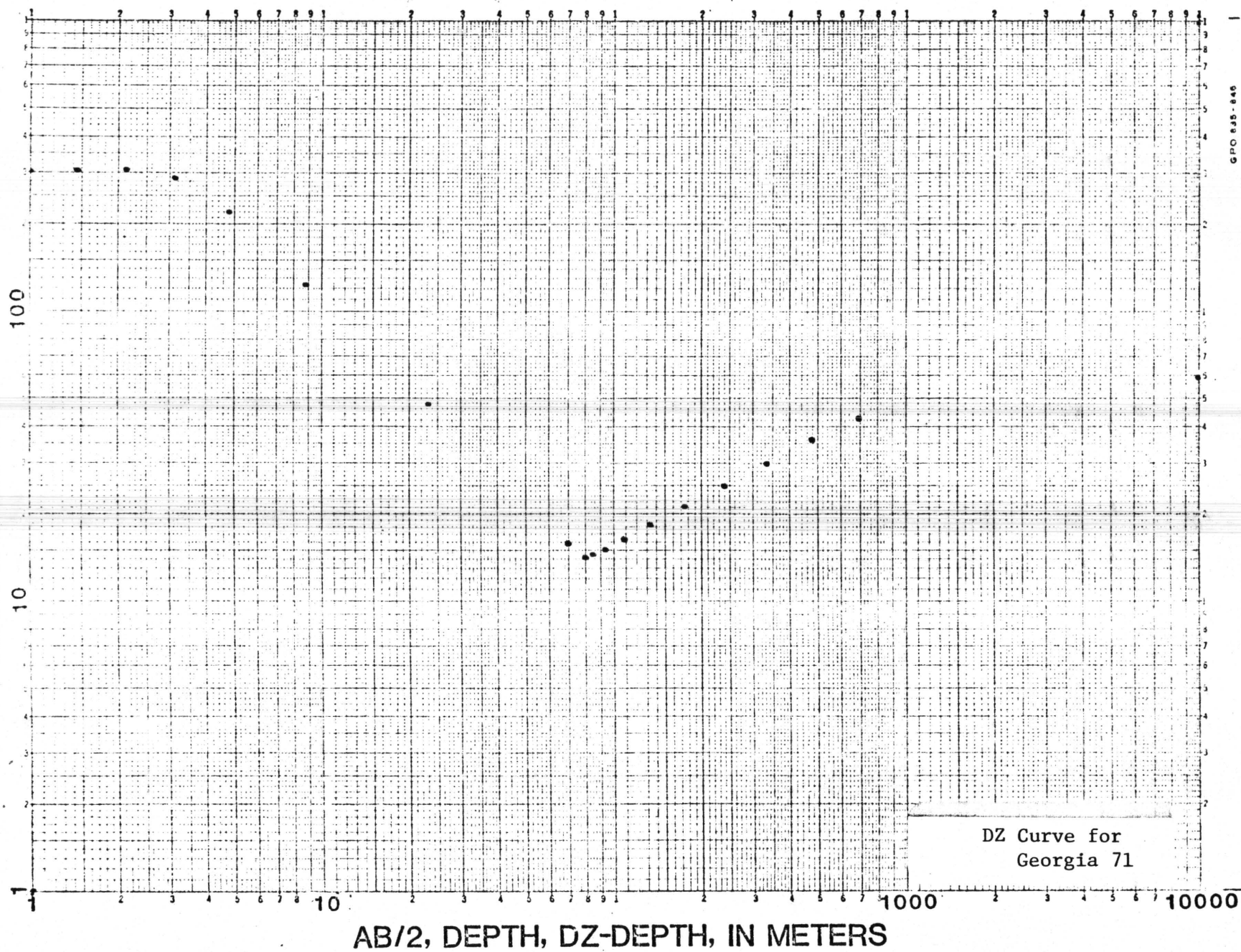
Georgia 70

RESISTIVITIES IN OHM-METERS

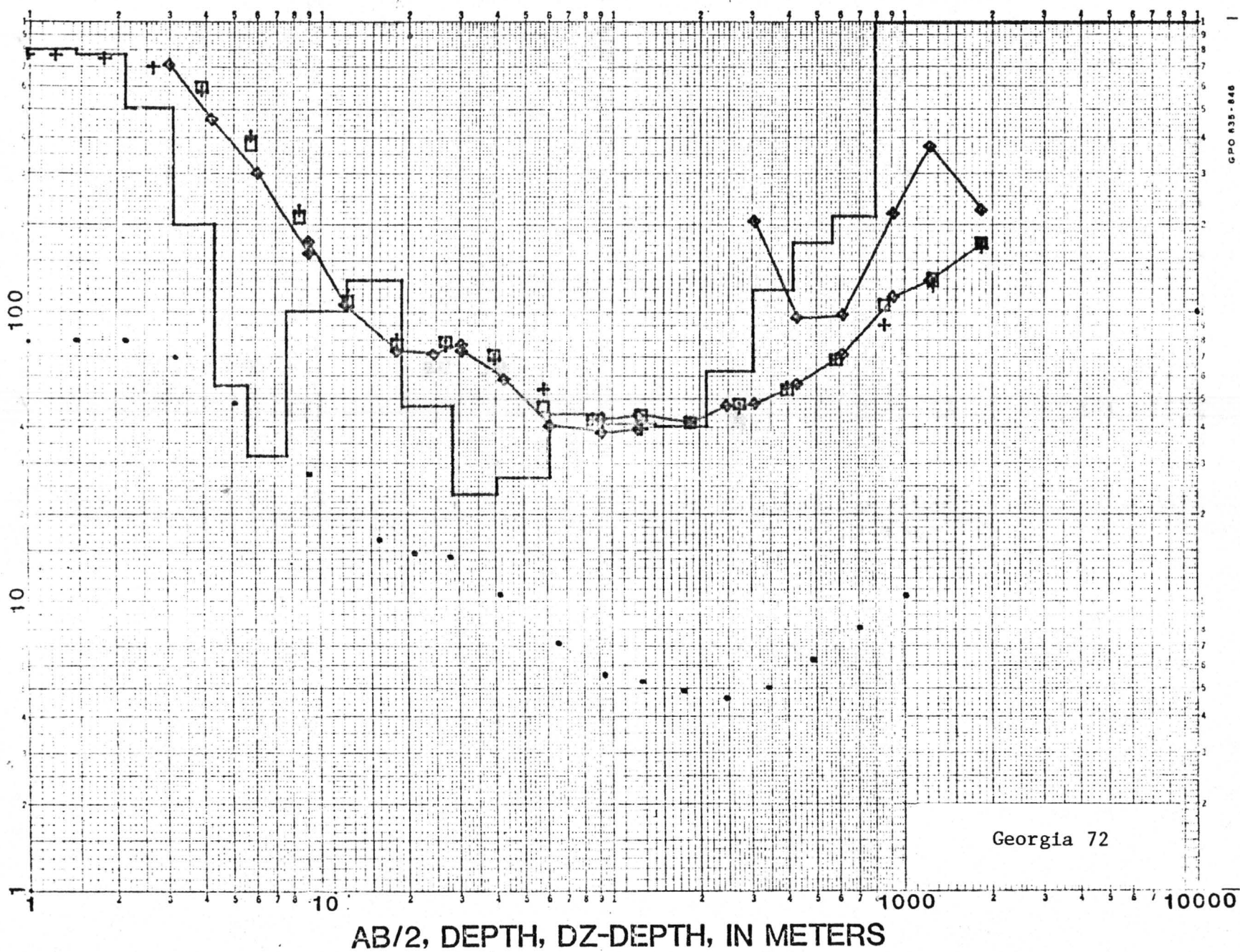




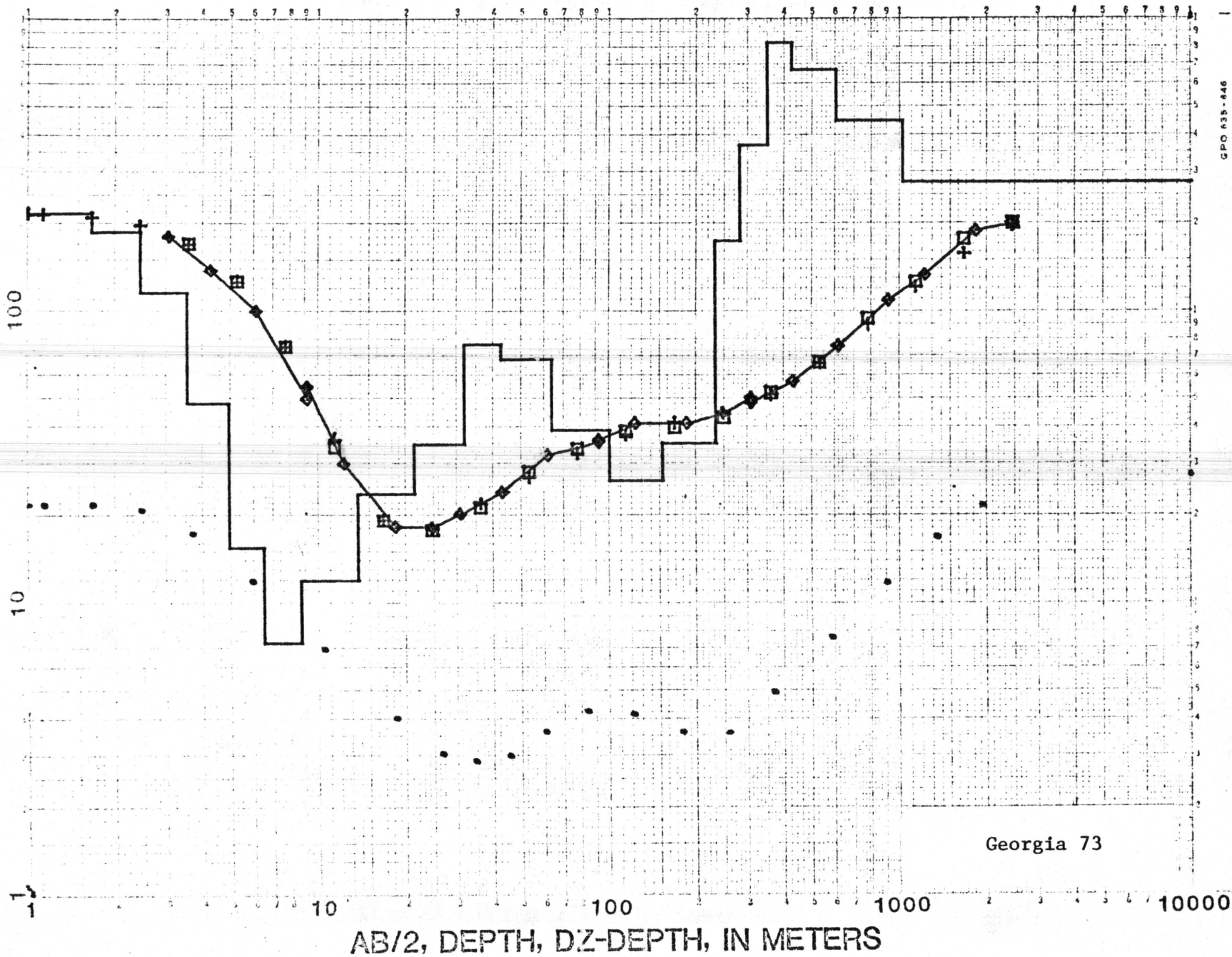
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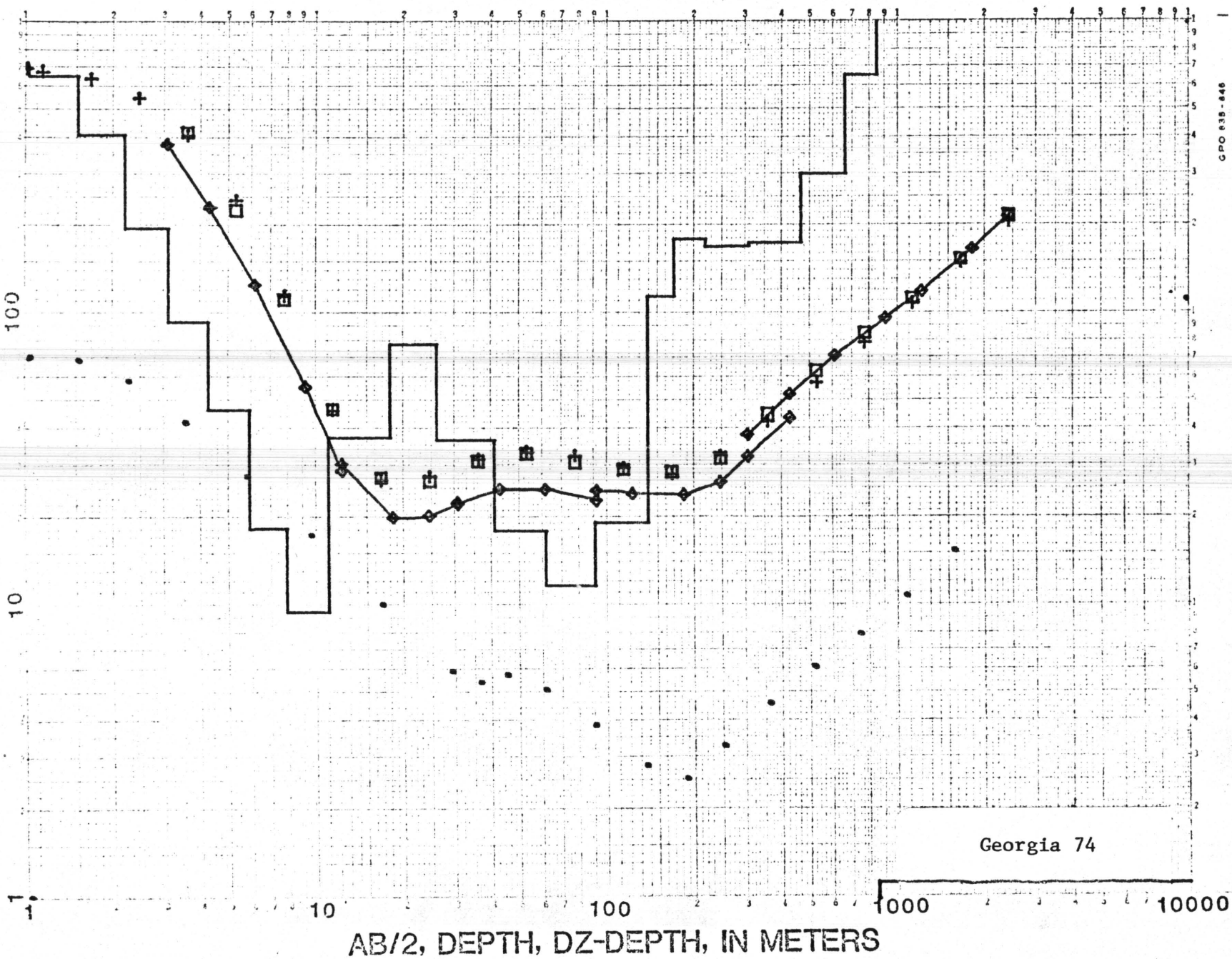
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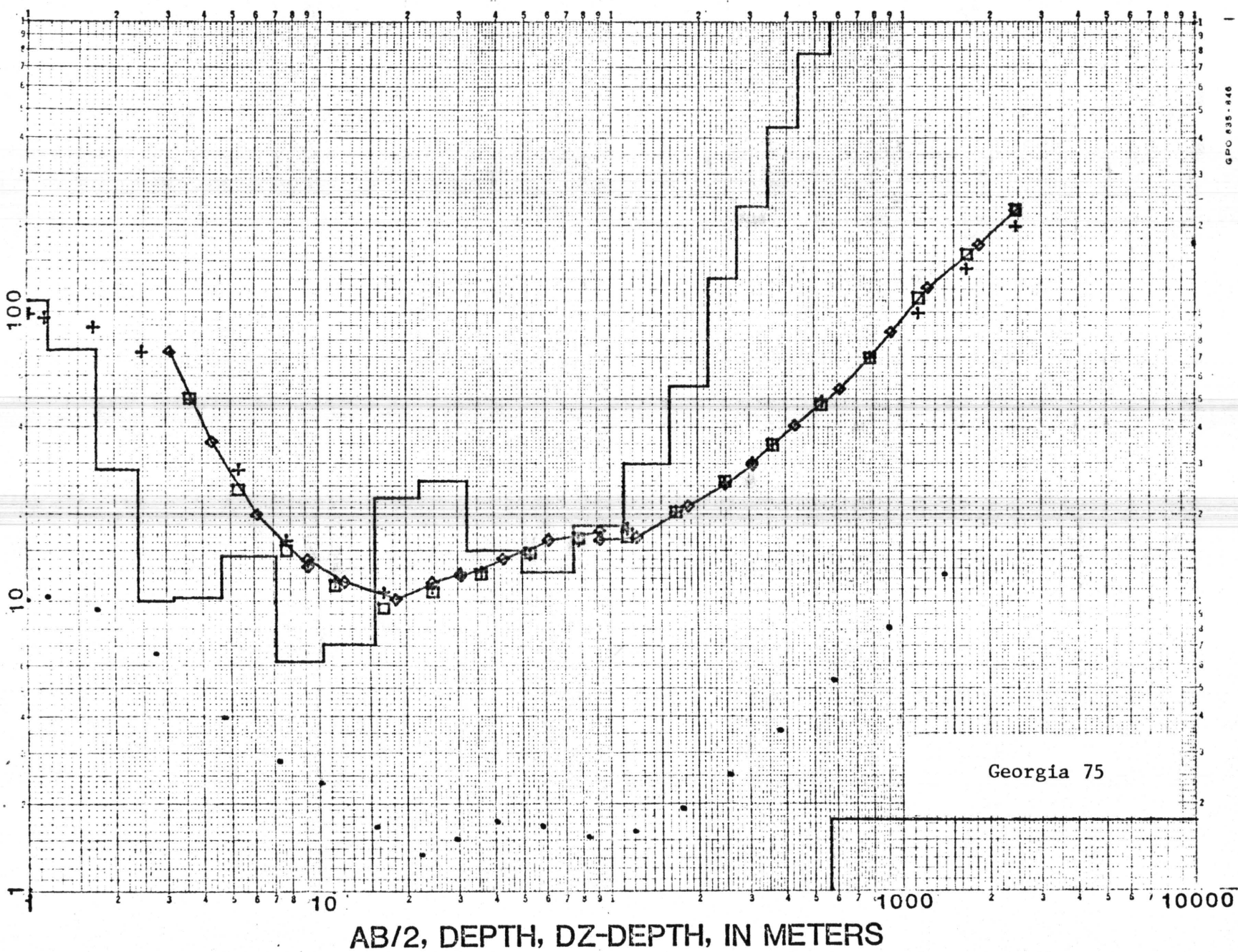
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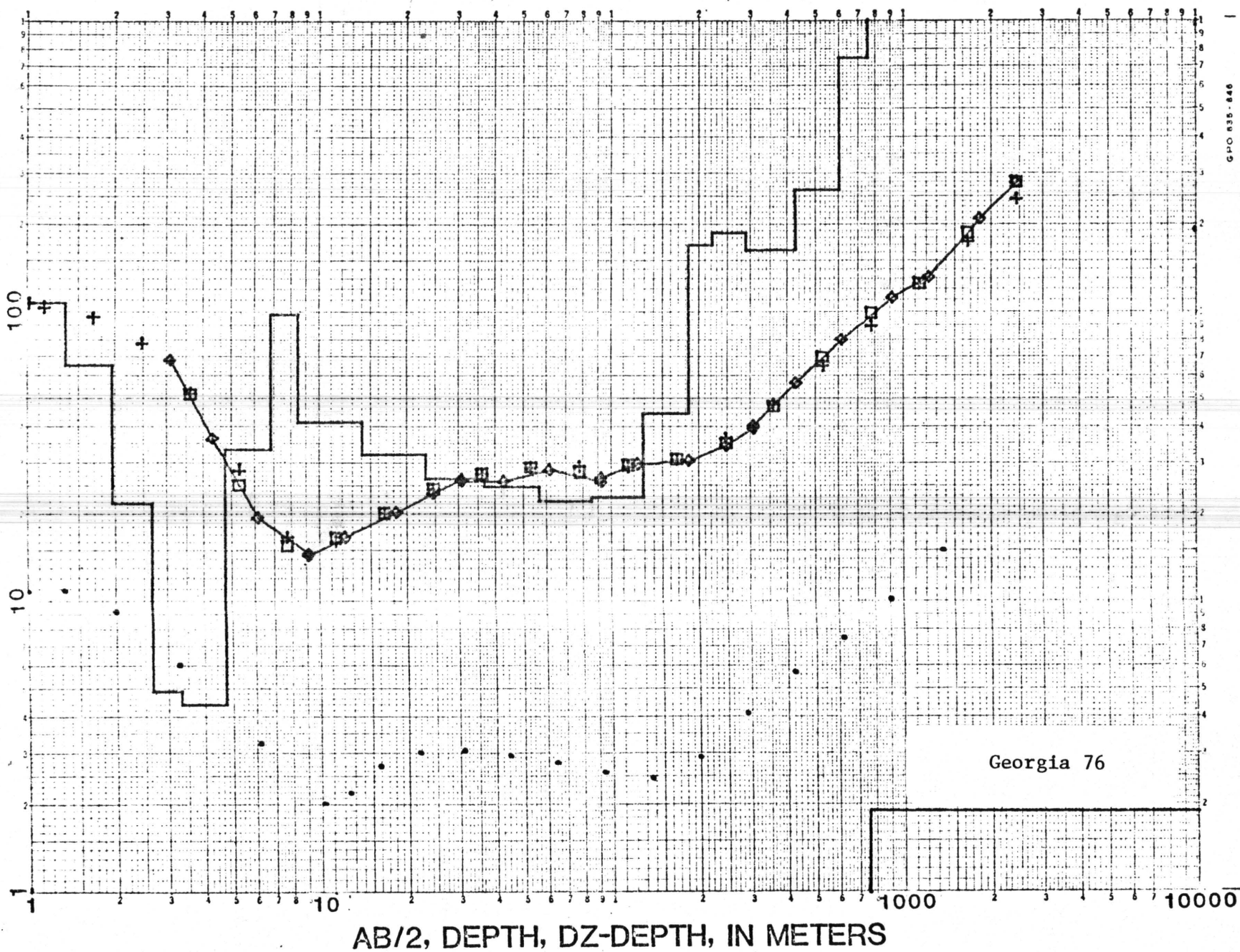
RESISTIVITIES IN OHM-METERS



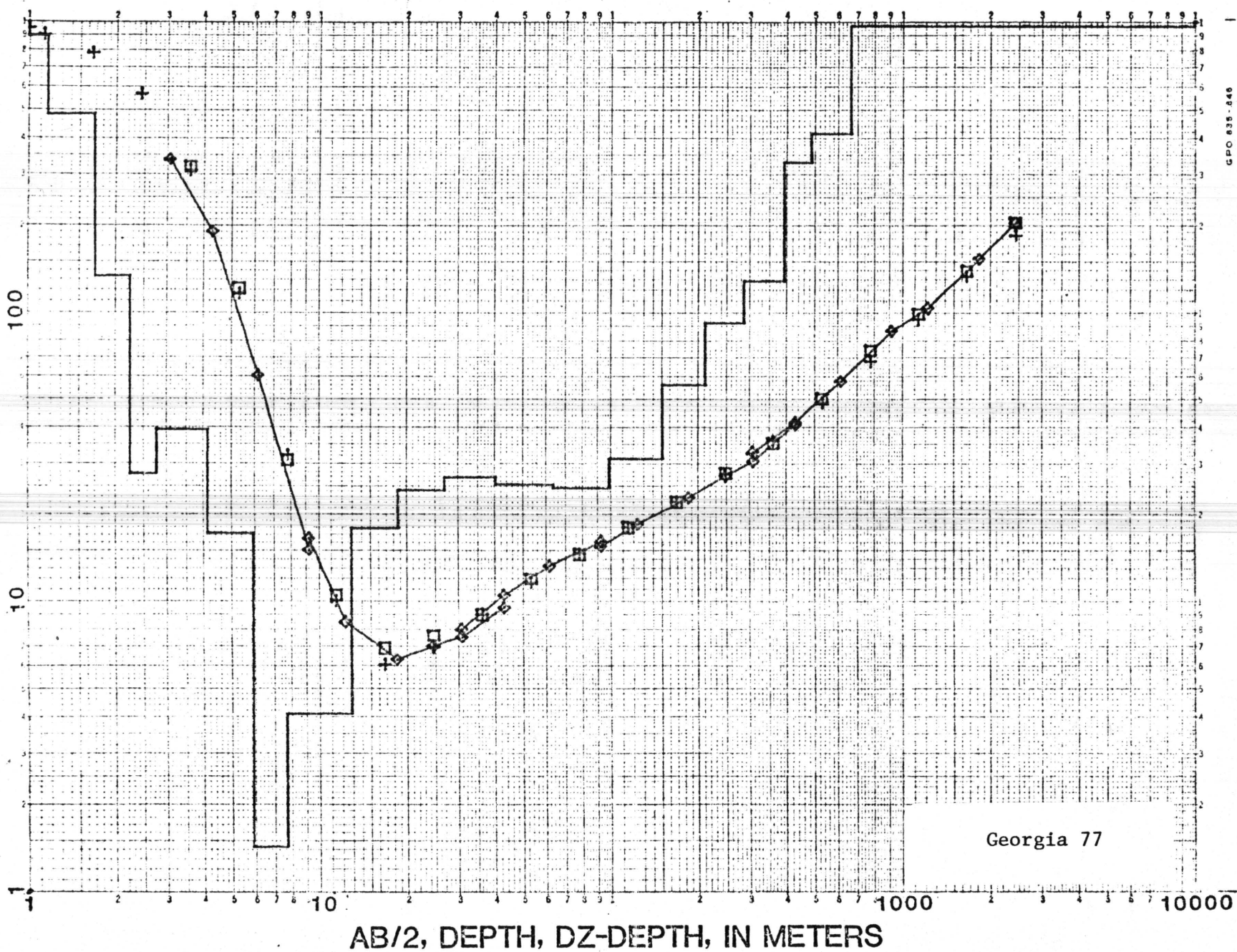
RESISTIVITIES IN OHM-METERS



RESISTIVITIES IN OHM-METERS



RESISTIVITIES IN OHM-METERS

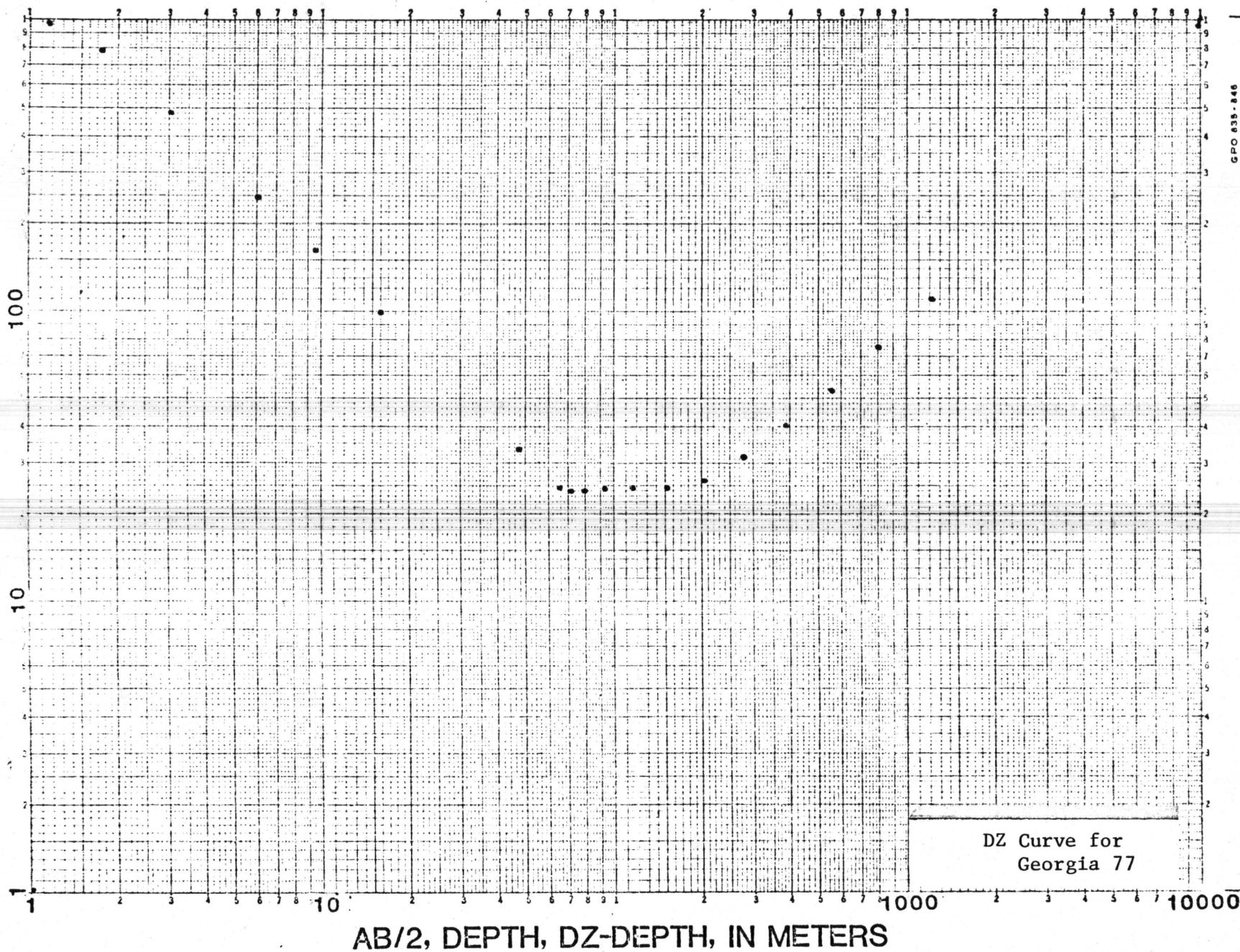


Georgia 77

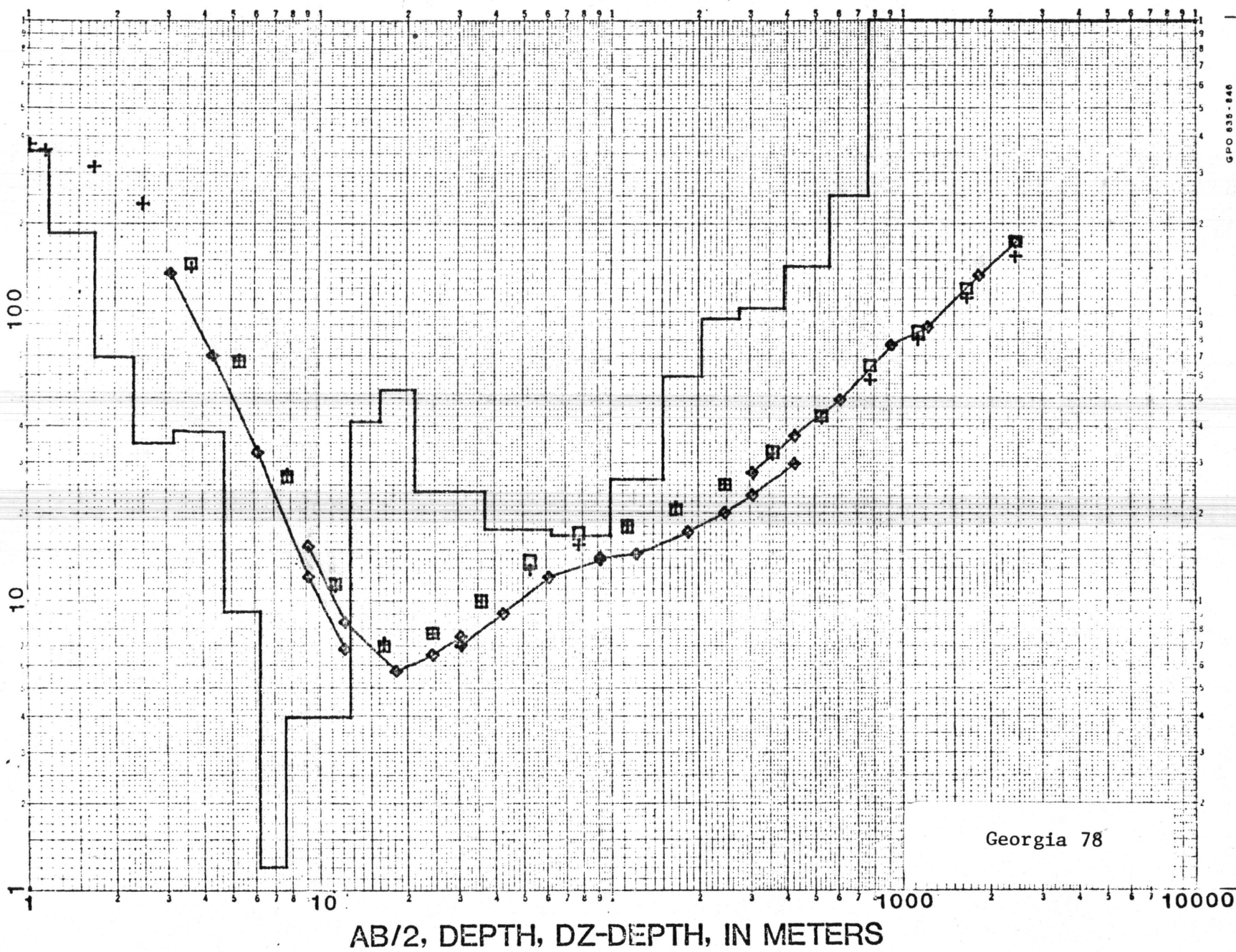
120

RESISTIVITIES IN OHM-METERS

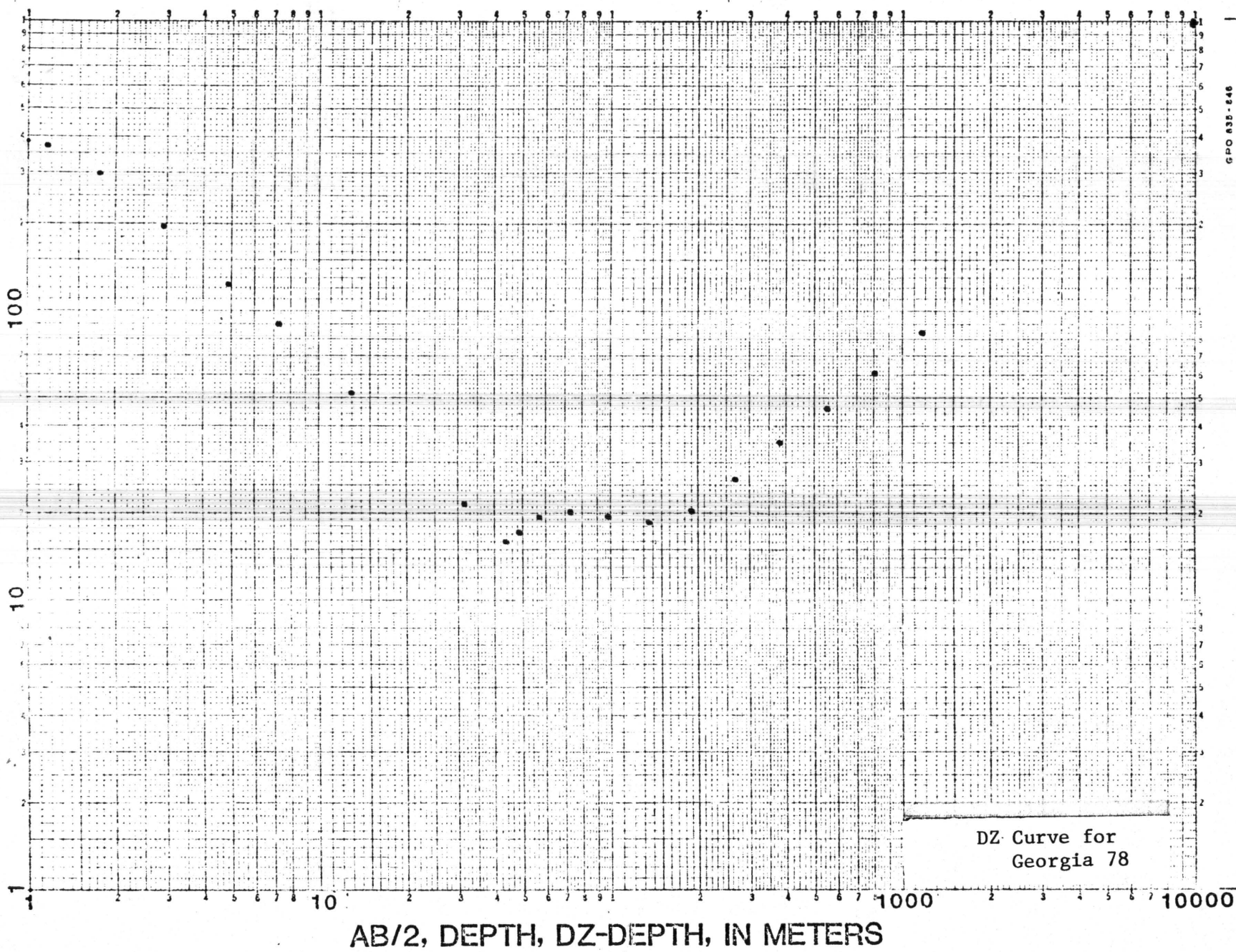
GPO 835-846



RESISTIVITIES IN OHM-METERS

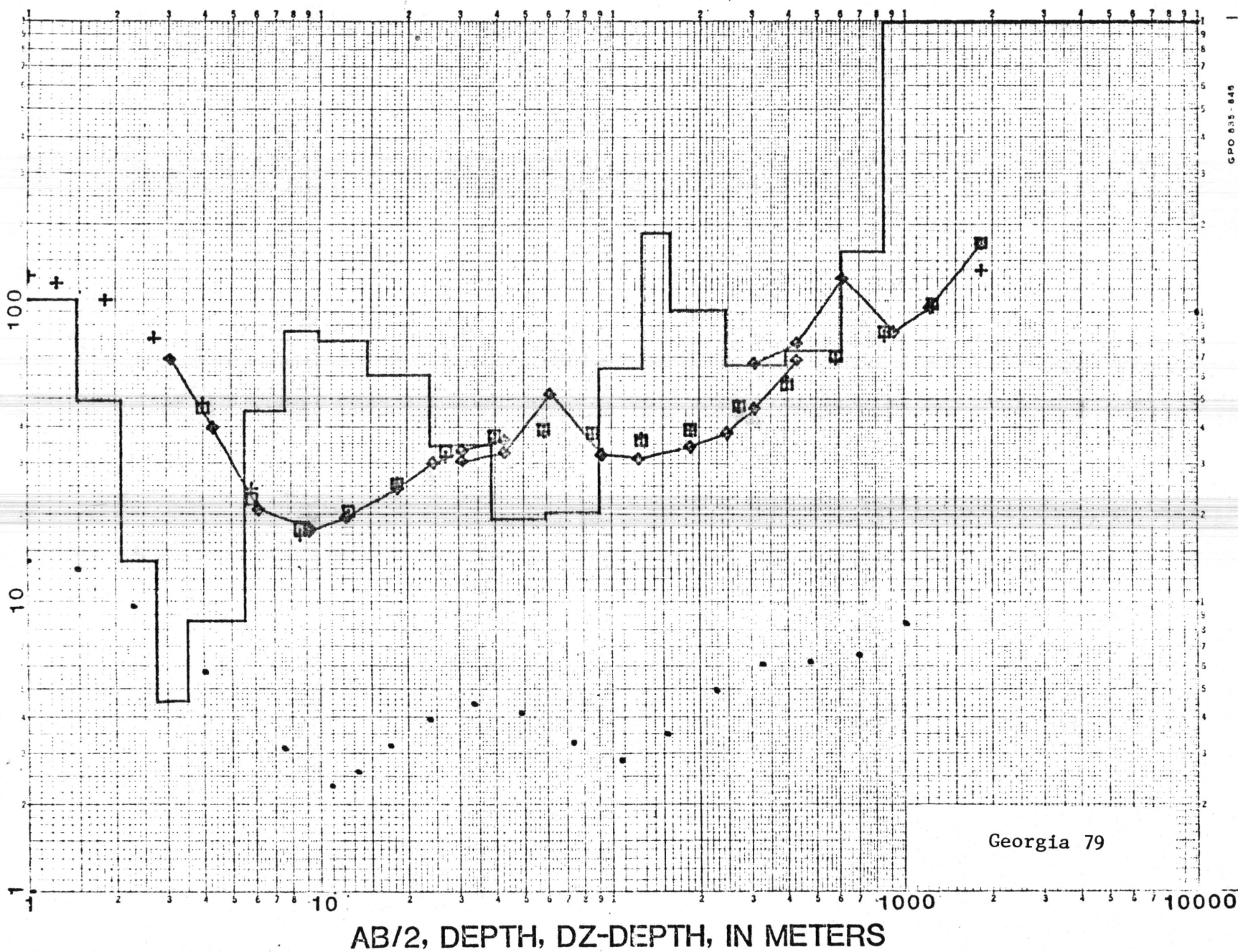


RESISTIVITIES IN OHM-METERS

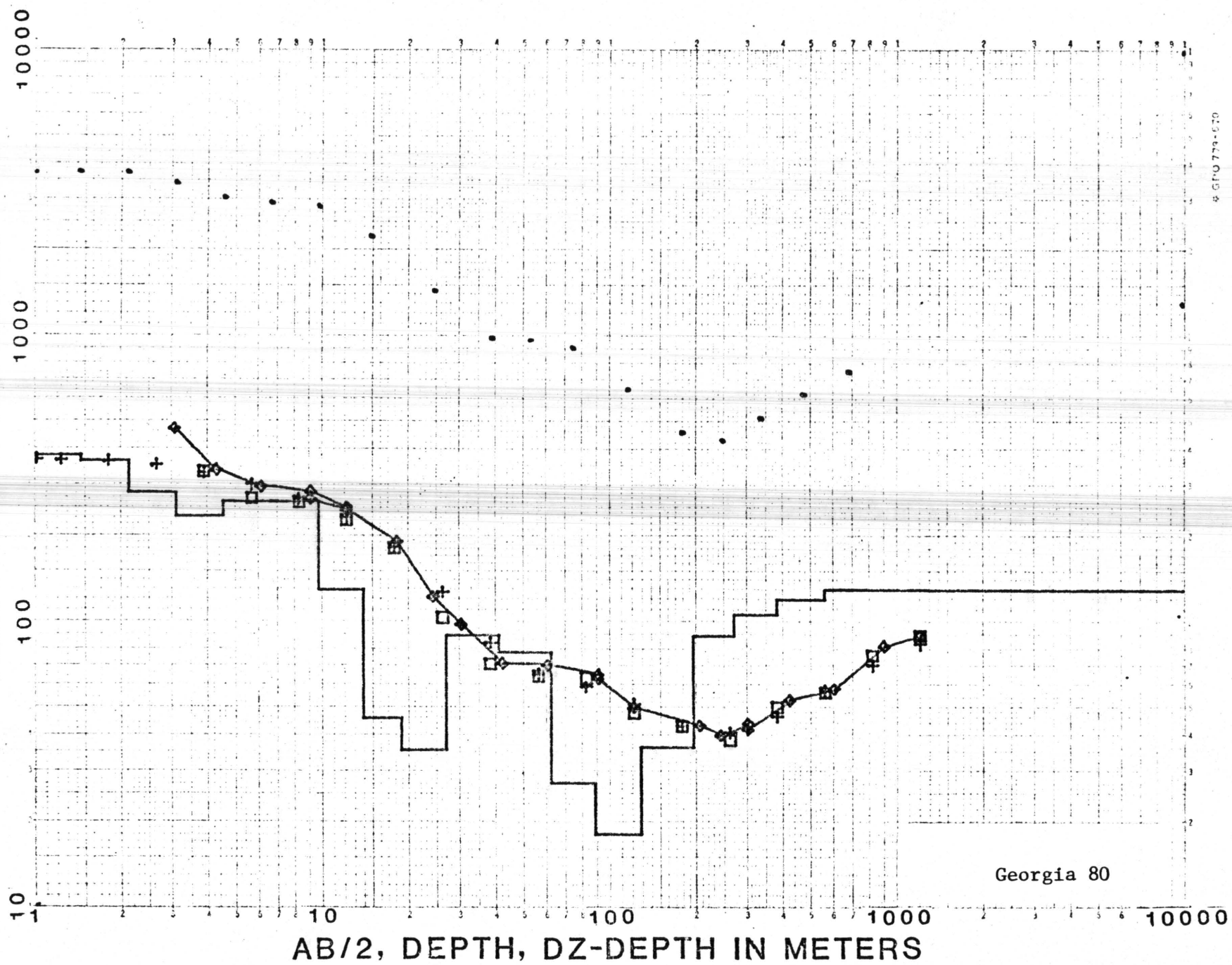
DZ Curve for
Georgia 78

RESISTIVITIES IN OHM-METERS

GPO 515-845

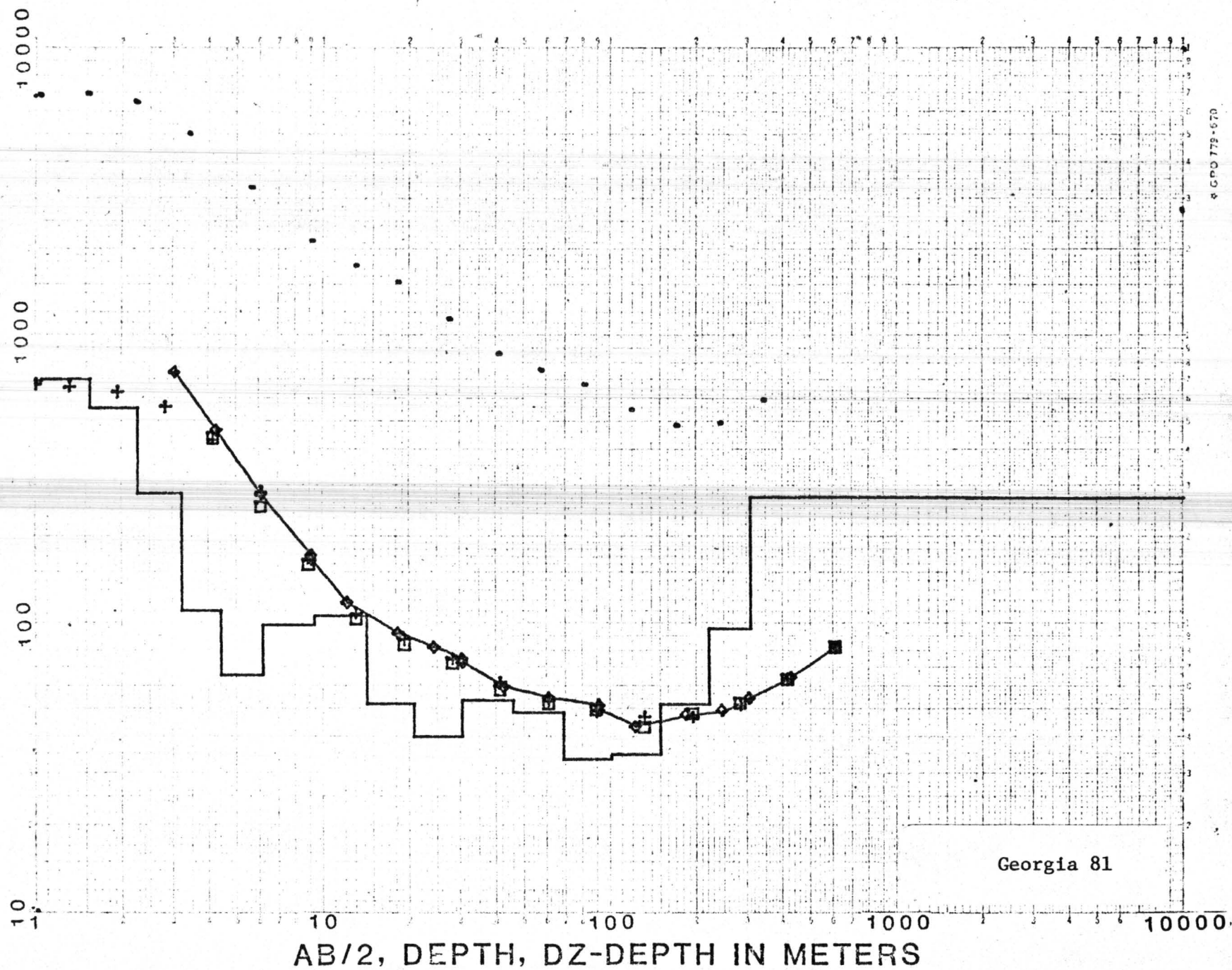


RESISTIVITIES IN OHM-METERS



Georgia 80

RESISTIVITIES IN OHM-METERS



Georgia 81