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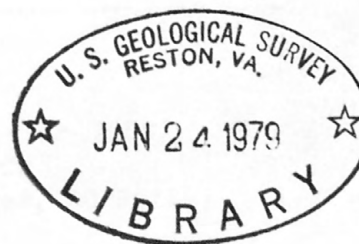
GEOLOGICAL SURVEY.

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Geoelectrical investigation with Schlumberger soundings of
the Buffalo River aquifer, near Moorehead, Minnesota

Adel A. R. Zohdy and R. J. Bisdorf by
Adel A. R. Zohdy 1935-1982



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Reston, VA 22092

Memorandum

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1/10/79

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Publications Division -

From: Chief, Office of Scientific Publications

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AUTHOR(S): *Adel Rahman*
Adel A.R. Zohdy ¹⁹³⁵ and R.J. Bisdorf

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Geoelectrical investigation with Schlumberger soundings of the
Buffalo aquifer, near Moorhead, Minnesota

by

Adel A. R. Zohdy and Robert J. Bisdorf

As early as 1947 the U.S. Geological Survey reported, in two press releases (1947a and b), the presence of a linear deposit of sand and gravel east of Moorhead, Minnesota. The deposit is 37 km long and 1 to 2.5 km wide. It extends north and south through latitudes $46^{\circ}57'30''$ N. to $46^{\circ}37'30''$ N., and its axis lies about 2 km west of longitude $96^{\circ}37'30''$ W. and about 7 km east of the city of Moorhead. Several test wells have been drilled to study this deposit, and several production wells have been drilled in it for irrigation purposes and for the municipal supply of the city of Moorhead (Bingham, 1960).

In November 1976 and March 1977, the U.S. Geological Survey made a resistivity survey to map this sand and gravel deposit south of latitude $46^{\circ}55'$ N., to explore its extension to the south of latitude $46^{\circ}37'30''$ N., and to aid in the study of the Buffalo River aquifer in general. The resistivity survey, which was completed in about three weeks of field work, consisted of 192 Schlumberger soundings (Zohdy and others, 1974) that were located along twelve profiles. Figure 1 is an index map showing the location of the sounding profiles AA' through LL'. The total length of the sounding profiles is about 130 km with an average station spacing of one station per 0.68 km.

Figures 2, 3, 4, 5, 6, 7, and 8 show the locations and numbers of the individual sounding stations and the locations of all the test wells reported by Bingham (1960). With the exception of soundings 13, 18, and 22, which were expanded in a north-south direction, all the other (189) soundings were expanded in an east-west direction. The availability of an excellent road network, the flat terrain, and the near absence of cultural features (fences with metal posts, pipe lines, and so on) made the area an almost ideal place for a resistivity survey and contributed to the efficiency of data collection (average of eight soundings/day).

Figures 9 and 10 show maps of interpreted true resistivity at depths of 10 m and 30 m, respectively. The linear sand and gravel deposit is depicted on these maps by contours of greater than 45 ohm-meter resistivity. The following table (which is based on our practical experience and the comparison of the sounding interpretations with the drill hole information) may be used as a guide for converting resistivities into probable lithologies:

<u>Resistivity</u>	<u>Probable Lithology</u>
10 ohm-meter or less	clay
10-20 ohm-meter	silty clay or glacial till
20-45 ohm-meter	silty sand or glacial till
45-100 ohm-meter	sand
100 ohm-meter or greater	sand and gravel (or electric basement if underlain by rocks of much higher resistivities).

Figures 11 through 22 show computer-generated geoelectric sections of interpreted true resistivity for profiles AA' through LL'. The automatic contouring method used here is faithful to the interpreted resistivity values directly beneath each station. There are, however, other equally acceptable means of contouring these resistivity values. The reader, therefore, is cautioned that some anomalies might have been created by interpolation between sounding stations and may not be real.

Each section is composed of three parts. The top part shows a ten-to-one vertically exaggerated presentation of the upper 68 m; the middle part, a four-to-one vertically exaggerated presentation of the upper 293 m; and the lower part, a one-to-one (no vertical exaggeration) presentation of the upper 293 m (same depth as the middle part). The above table for converting interpreted true resistivities into probable lithologies is also applicable in the study of these geoelectric sections.

In the preparation of the interpreted resistivity maps and cross sections (shown in figures 9 through 22) no attempt was made to utilize information on reported lithologies from available test wells (Bingham, 1960). Nevertheless, good to excellent correlation is obtained upon examining the interpreted resistivities with the reported lithologies. For example, the automatic interpretation of soundings 19 and 20 (see appendix) correlate well with the reported lithologies for the city of Moorhead test wells 56-9 and 56-11 (Bingham, 1960, p. 105 and 106), respectively.

Figure 23 shows a map of the interpreted depth in meters to a high-resistivity (≥ 100 ohm-meters) electric basement which probably corresponds to the Precambrian crystalline bedrock. The map was produced by evaluating the depth, beneath each sounding station, at which the interpreted true resistivity equals 100 ohm-meters and beneath which the interpreted true resistivity continues to increase to more than 100 ohm-meters. For smoothing, a three-point running average using the successive quasi-equal station interval was applied to the depth data obtained along each profile of soundings. The resulting depths then were contoured using a logarithmic contour interval.

The map shows that the basement configuration in the studied area can be divided into three regions: northern (profiles AA' to EE'), middle (profiles FF' to II'), and southern (profiles JJ' to LL'). The northern region is characterized by the presence of a well defined channel which is carved into the basement and whose axis almost coincides with the north-south near-surface sand and gravel deposit. The channel deepens to the south but seems to end abruptly in a large depression near the west end of profile E where the depth to basement is interpreted to exceed 450 m (see sounding 182 in the appendix). A deep test well drilled in the immediate vicinity of sounding 182 should clarify the nature of this extraordinary depression. The middle region is characterized by gentle highs and lows, as might be expected to exist in a glaciated area. In addition, there is weak evidence for the presence of another channel, which deepens to the south, in the eastern section of this region. In the southern region the basement surface seems to deepen monotonically to the south.

The sounding curves are given in the appendix and are numbered consecutively from Moorhead 1 to Moorhead 192. All the sounding curves were automatically processed and interpreted (Zohdy, 1973 and 1975) as shown in the graphs. Each graph shows the following:

1. Field data, designated by a segmented, solid line curve, with diamond symbols for observed data.
2. A shifted and digitized field curve, designated either by a dashed line or 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 sifted curve is then digitized at the rate of six points per logarithmic cycle (square symbols where shown). These points (not specifically shown where dashed curve is used) were computed using a subroutine in a computer program for bicubic spline functions (Anderson, 1971).
3. The theoretical best fitting sounding curve, designated by plus (+) symbols. This theoretical curve is the output of the automatic interpretation for the digitized curve. The computer program used here for the majority of the sounding curves is an updated version of the one published earlier by 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 to avoid cluttering the graphs. A 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 or resistivities (Zohdy, 1974).

All these sounding graphs were generated on a Hewlett Packard^{1/} 7203A graphic plotter. The plotter-driving subroutines were developed by the second author, R. J. Bisdorf.

^{1/}The use of a brand name here is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

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Zohdy, A. A. R., Eaton, G. P., and Mabey, D. R., 1974, Application of surface geophysics to ground-water investigations: Techniques of water resources investigations of the United States Geological Survey, book 2, chapter D1, 116 p.

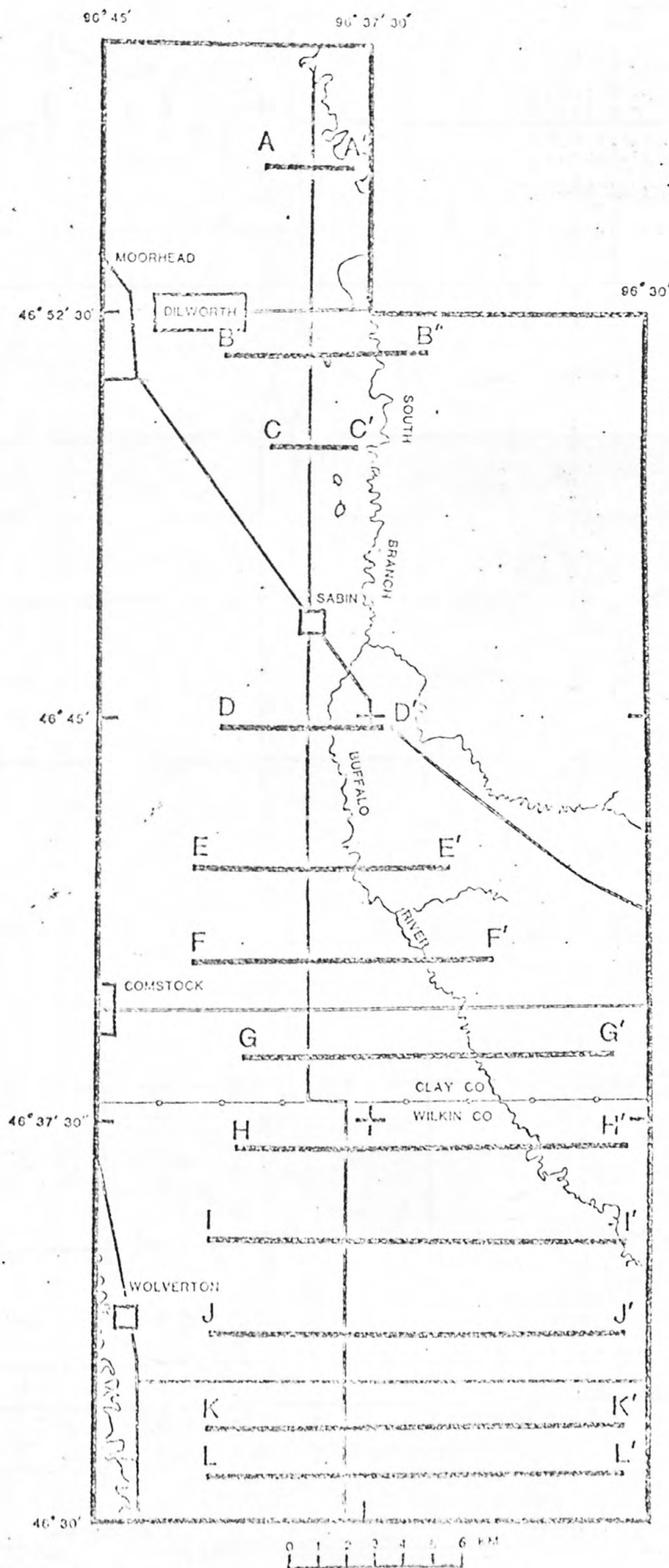


Figure 1.--Index map showing the location of Schlumberger sounding profiles, near Moorhead, Minnesota

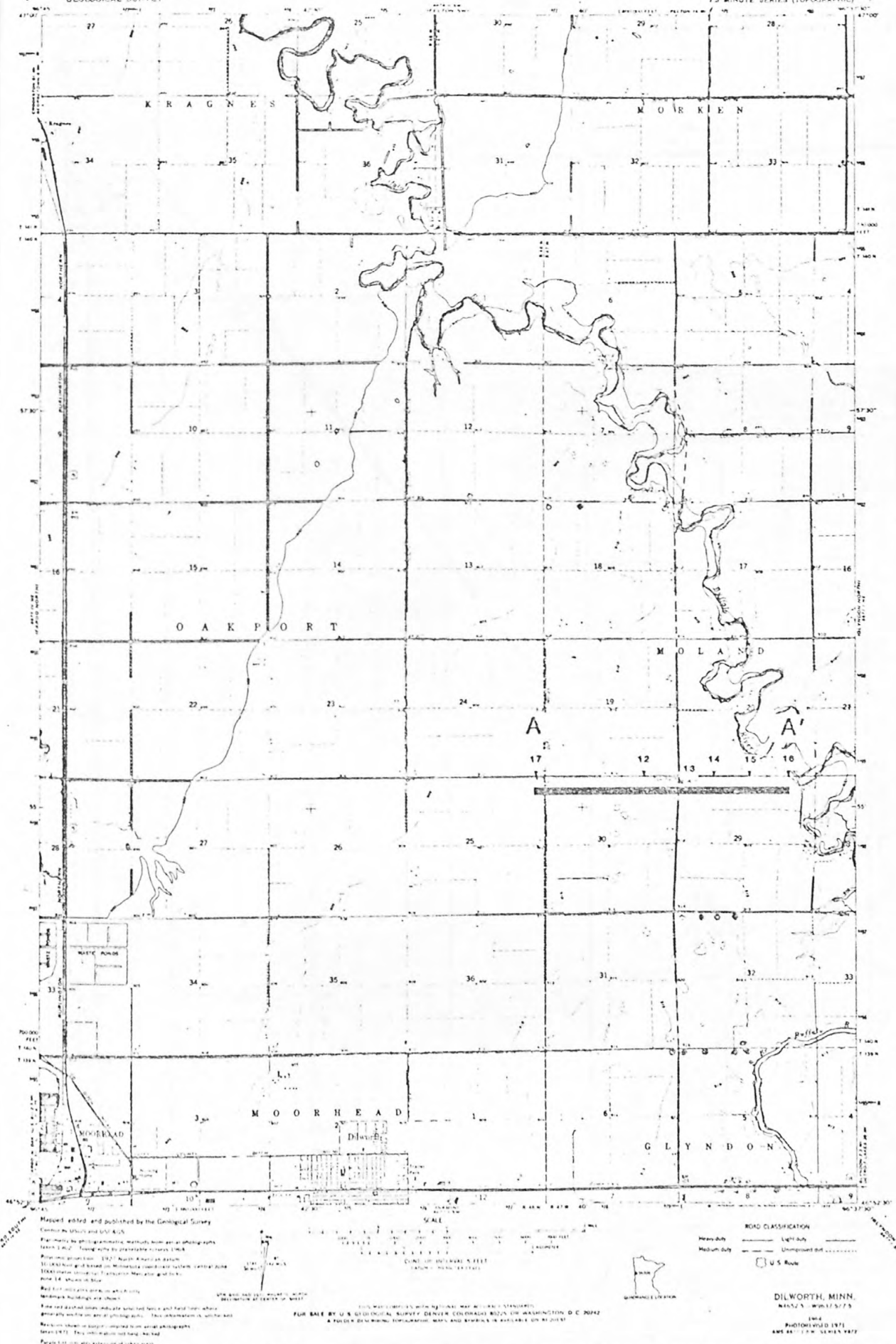


Figure 2.--Map of Dilworth quadrangle, Minnesota, showing location and number of Schlumberger soundings

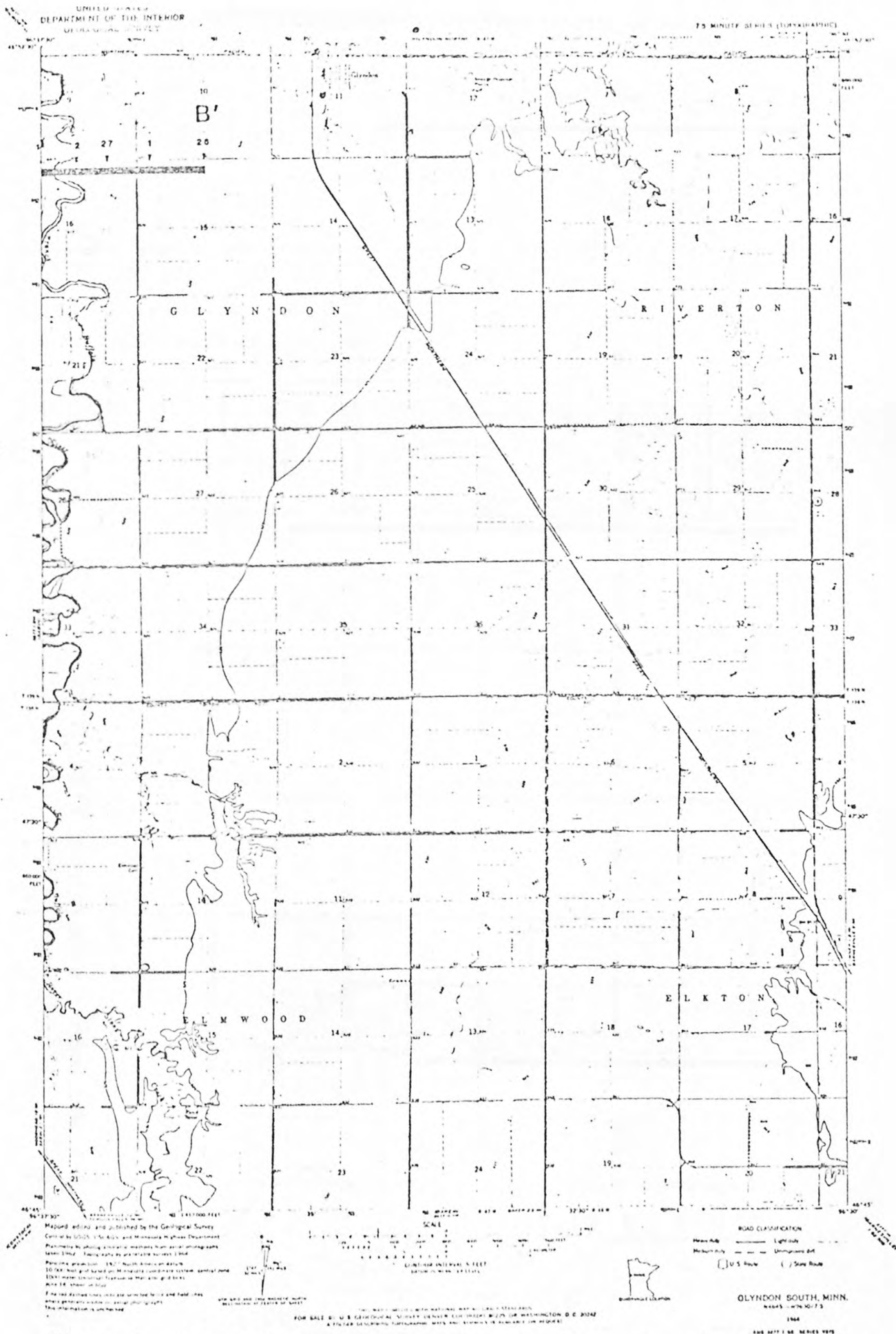
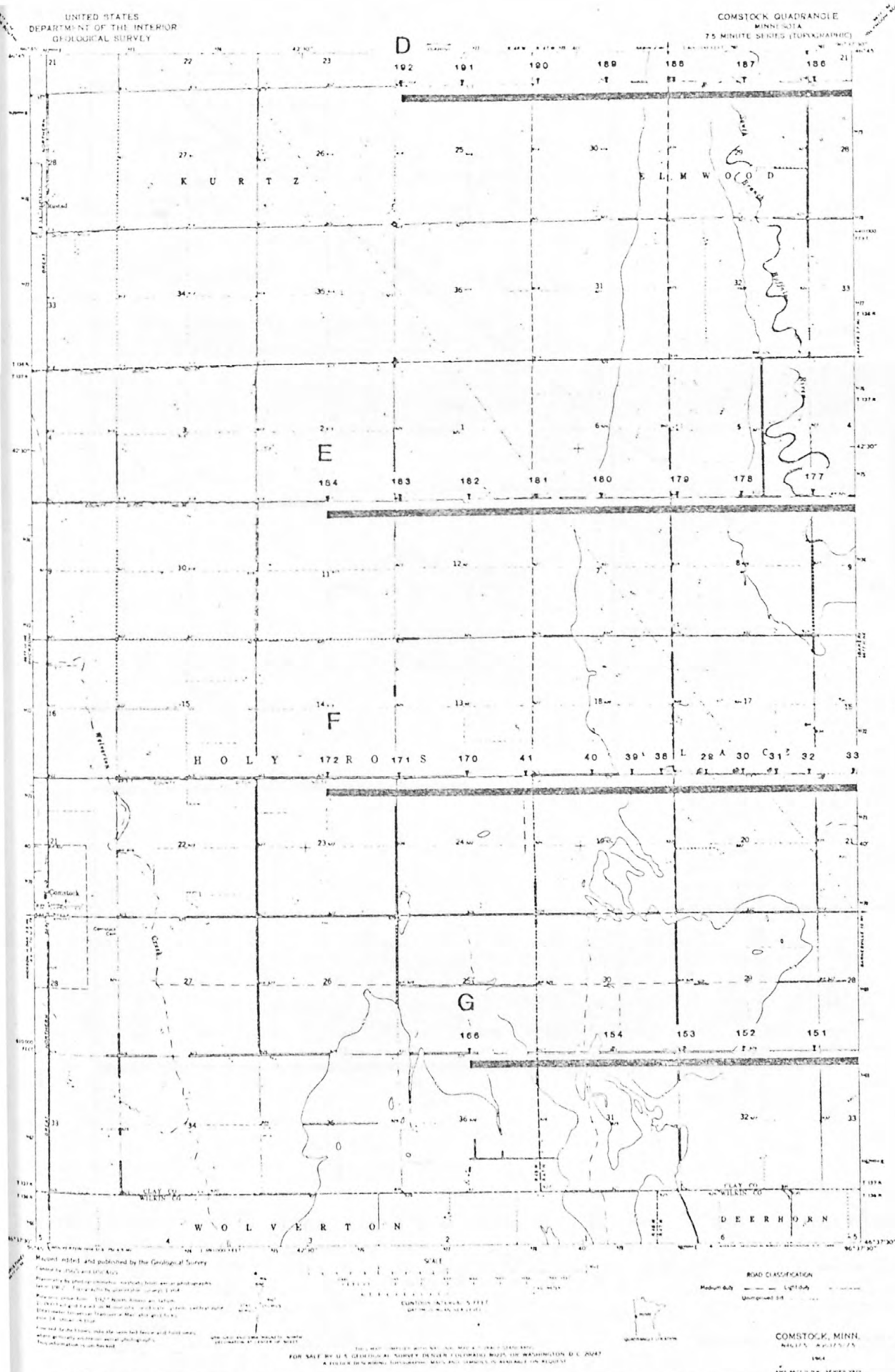


Figure 4.--Map of Glyndon South quadrangle, Minnesota, showing location and number of Schlumberger soundings



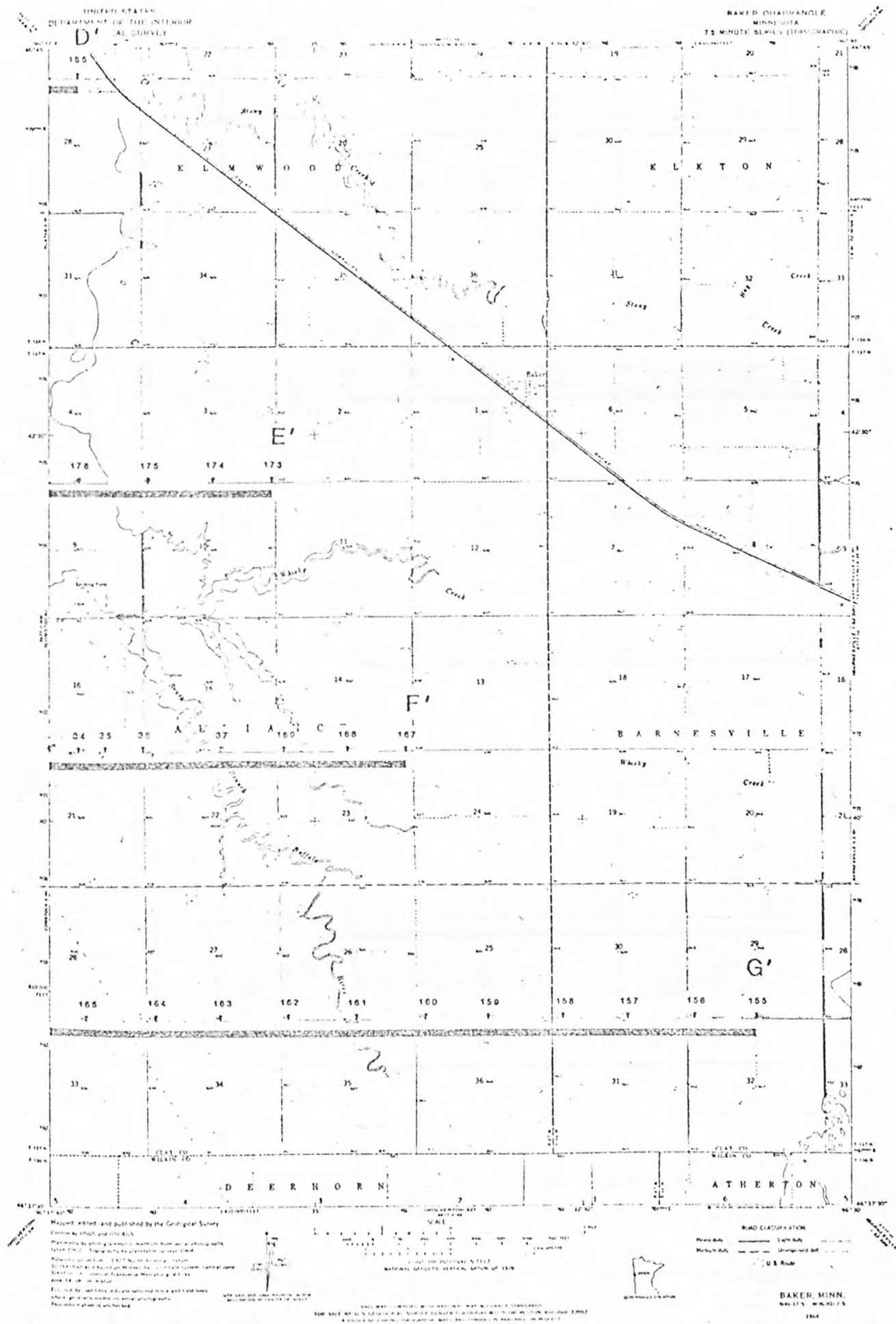
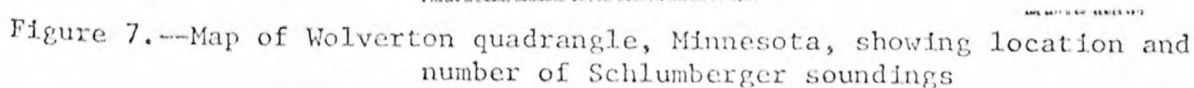
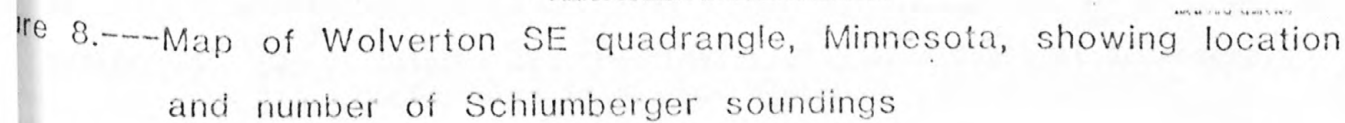


Figure 6.—Map of Baker quadrangle, Minnesota, showing location and number of Schlumberger soundings





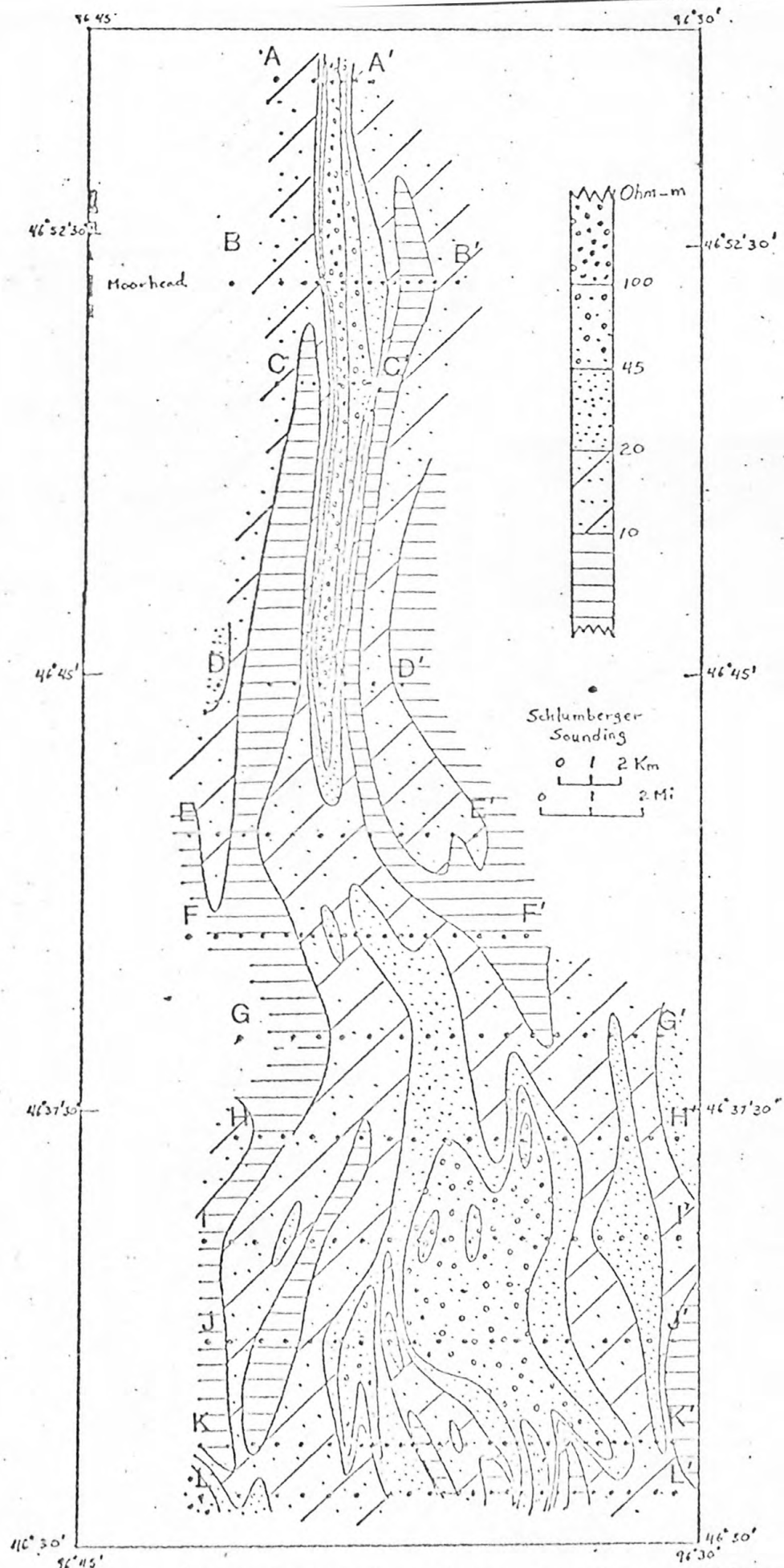


Figure 9.--Map of interpreted true resistivity at a depth of 10 meters. Contours in ohm-m. Near Moorhead, Minnesota.

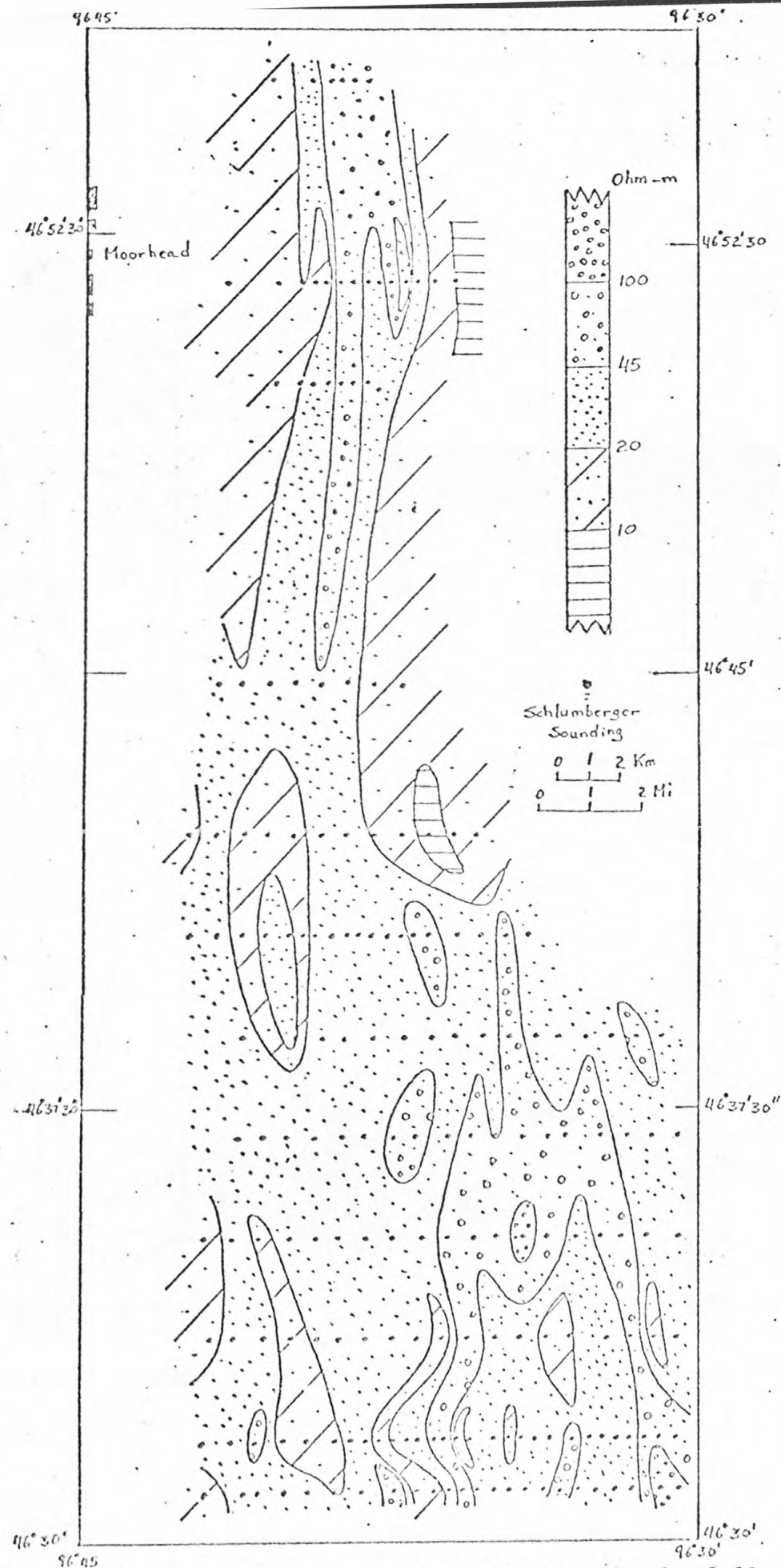


Figure 10.—Map of interpreted true resistivity at a depth of 30 meters. Contours in ohm-meters. Near Moorhead, Minnesota.

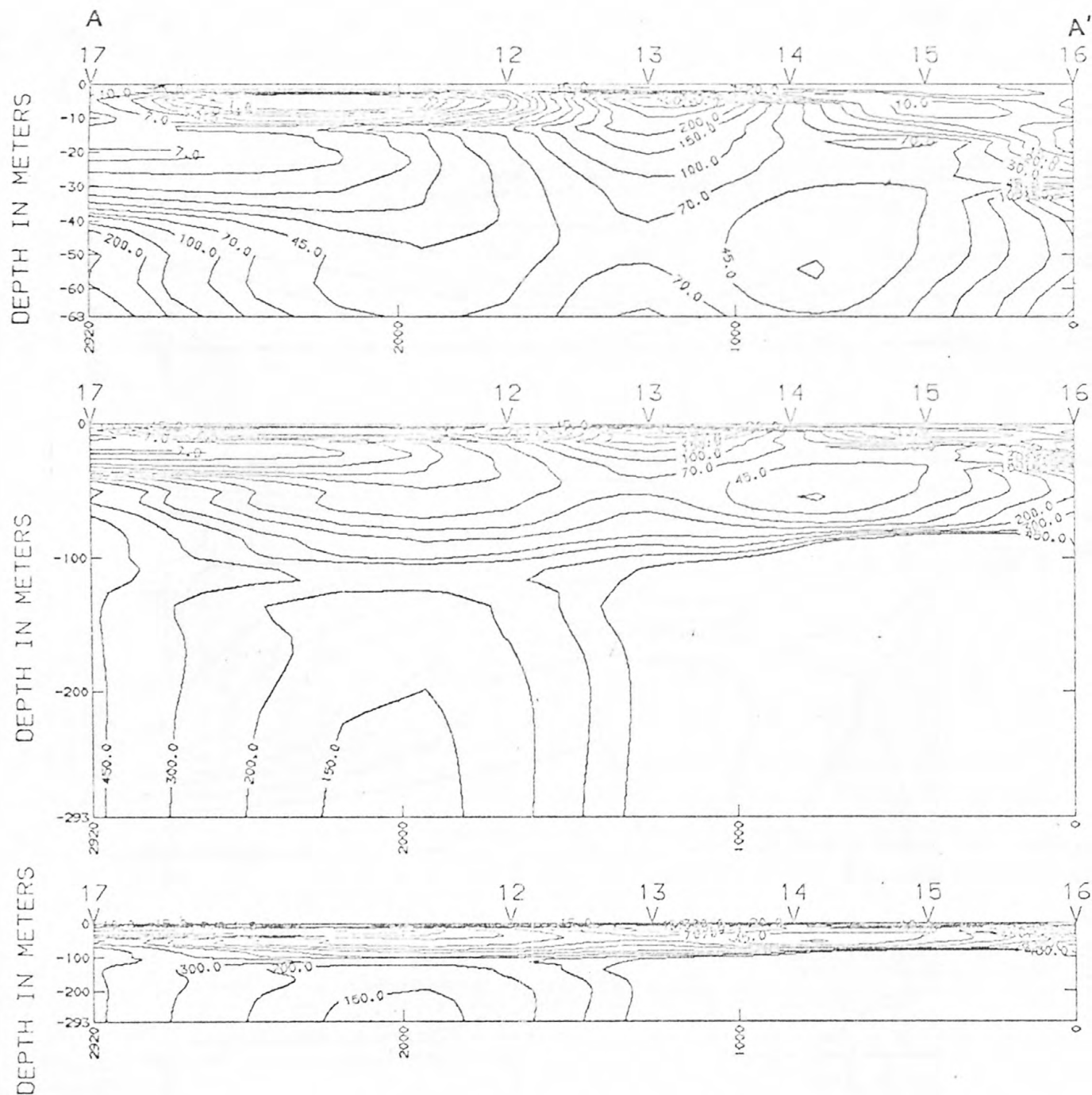


Figure 11.--Computer generated geoelectric section AA'. See figures 1 or 2 for location. Top and middle parts are vertically exaggerated ten and four times, respectively. Bottom part without vertical exaggeration. Horizontal distance in meters. Contours of interpreted true resistivity in ohm-meters.

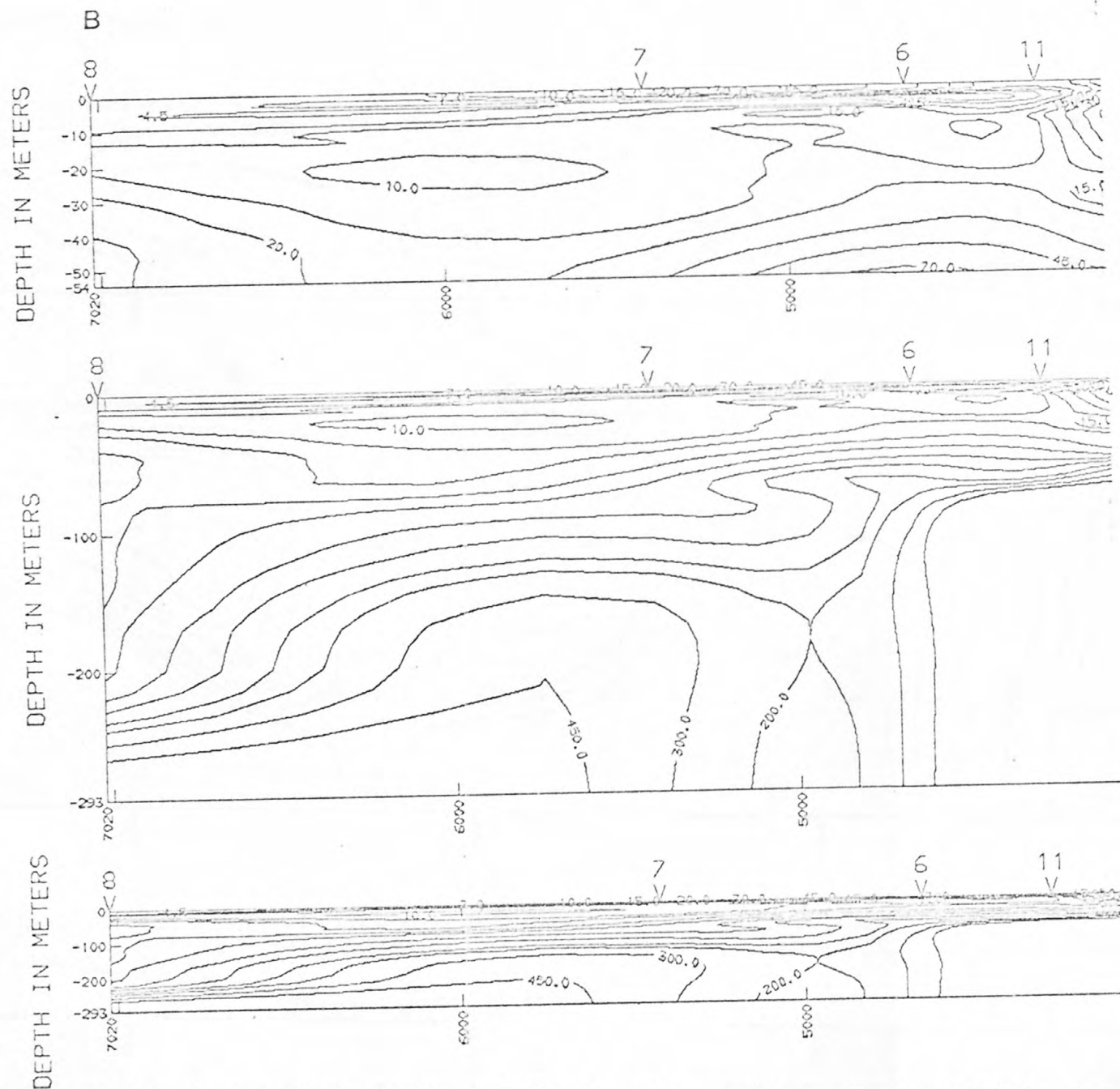


Figure 12a.--Computer generated geoelectric section BB' (continued on next page in figure 12b). See figure 1 or figures 3 and 4 for location. See figure 11 caption for further explanation.

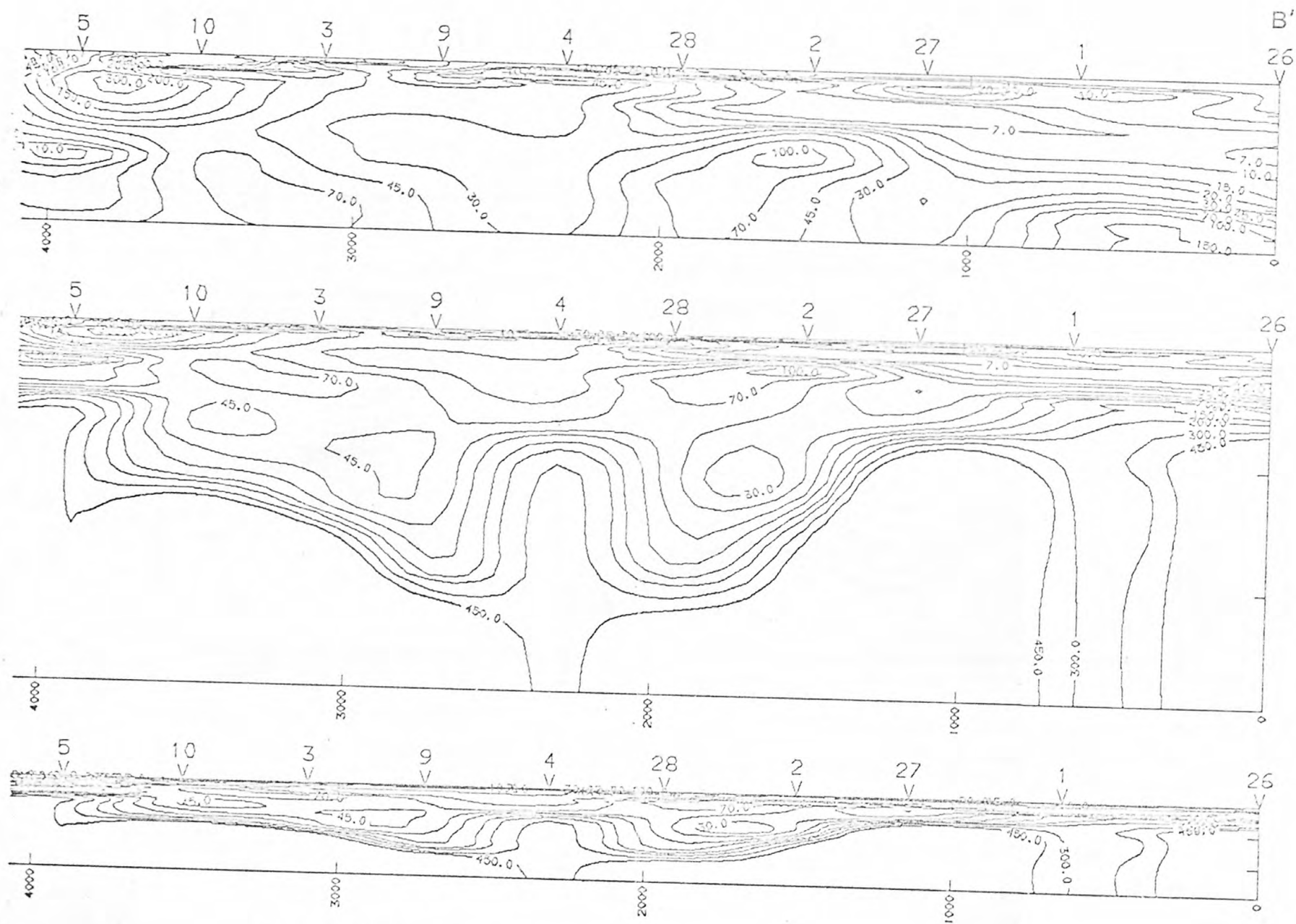


Figure 12b.--Geoelectric section BB' continued from figure 12a.

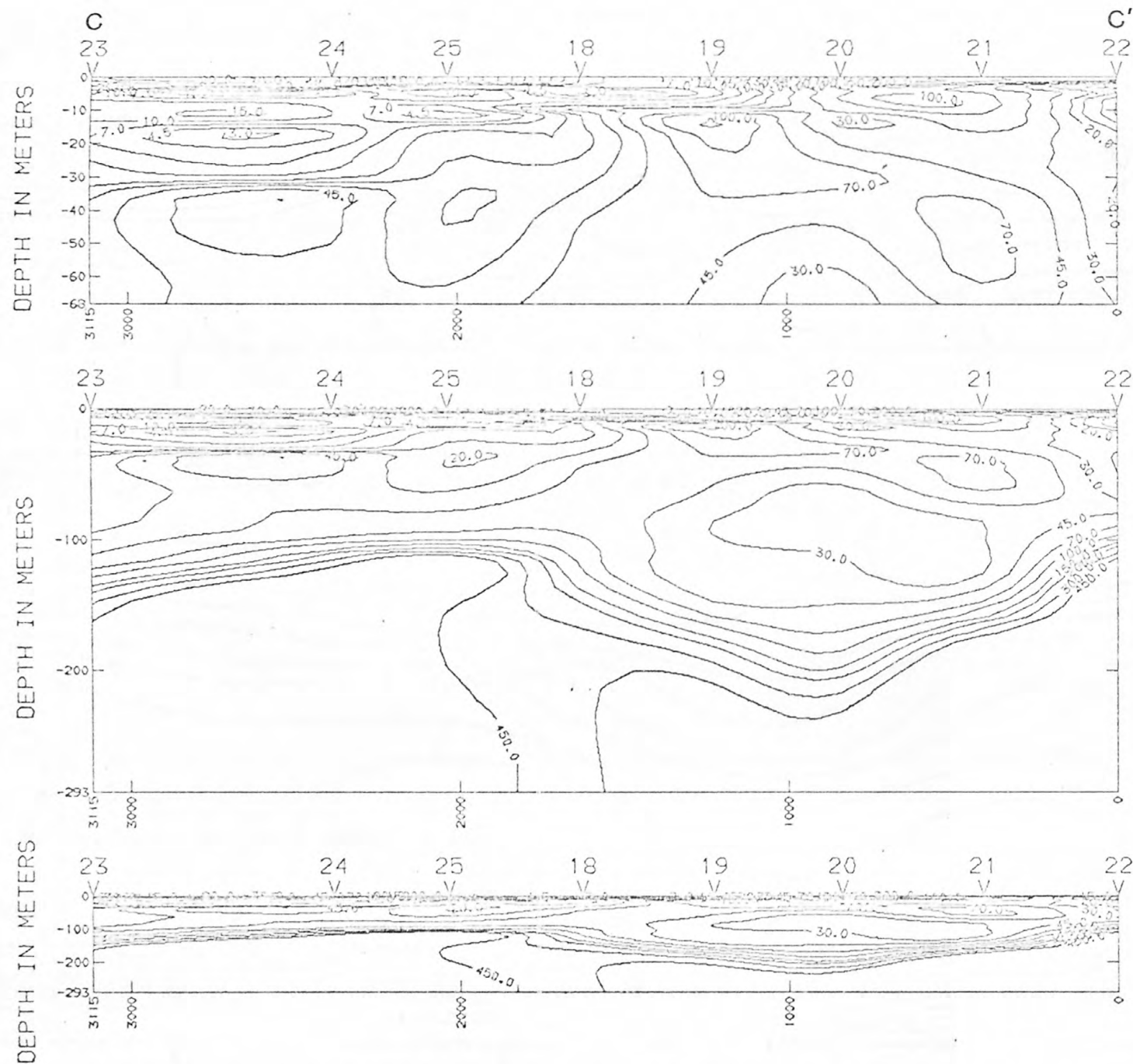


Figure 13.--Computer generated geoelectric section CC'. See figure 1 or figure 3 for location. See figure 11 caption for further explanation.

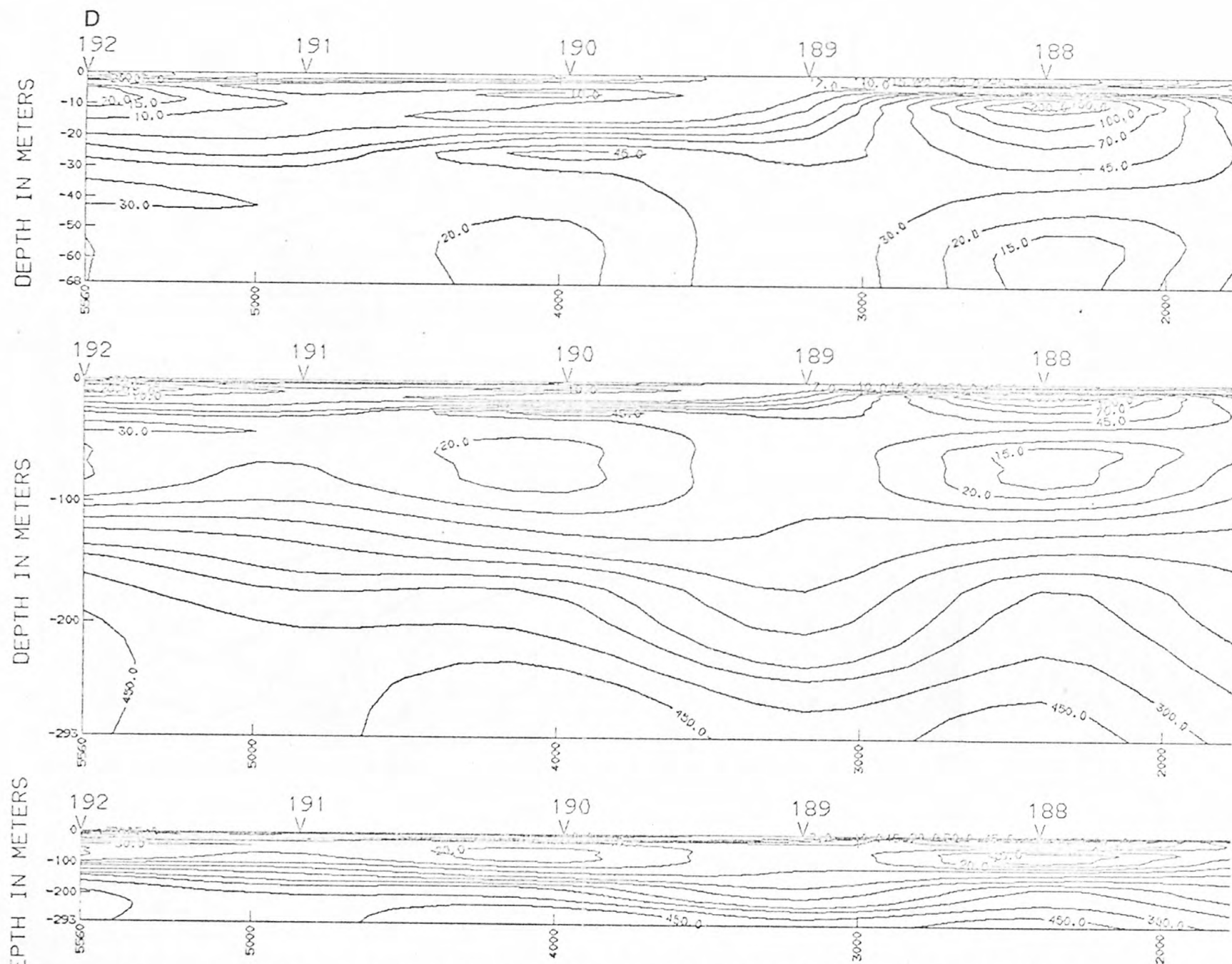


Figure 14a.--Computer generated geoelectric section DD' (continued on next page in figure 14b). See figure or figures 5 and 6 for location. See figure 11 caption for further explanation.

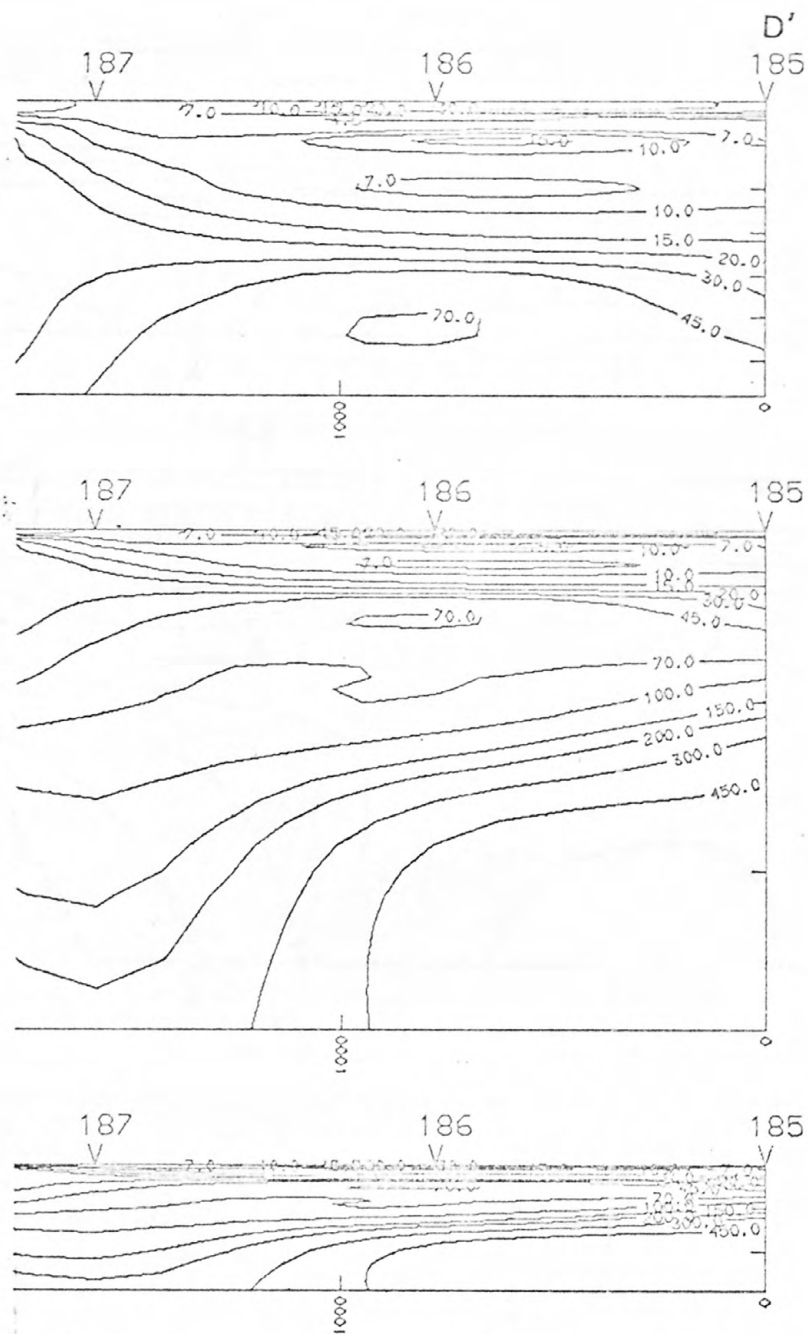


Figure 14b.--Geoelectric section DD' continued from figure 14a.

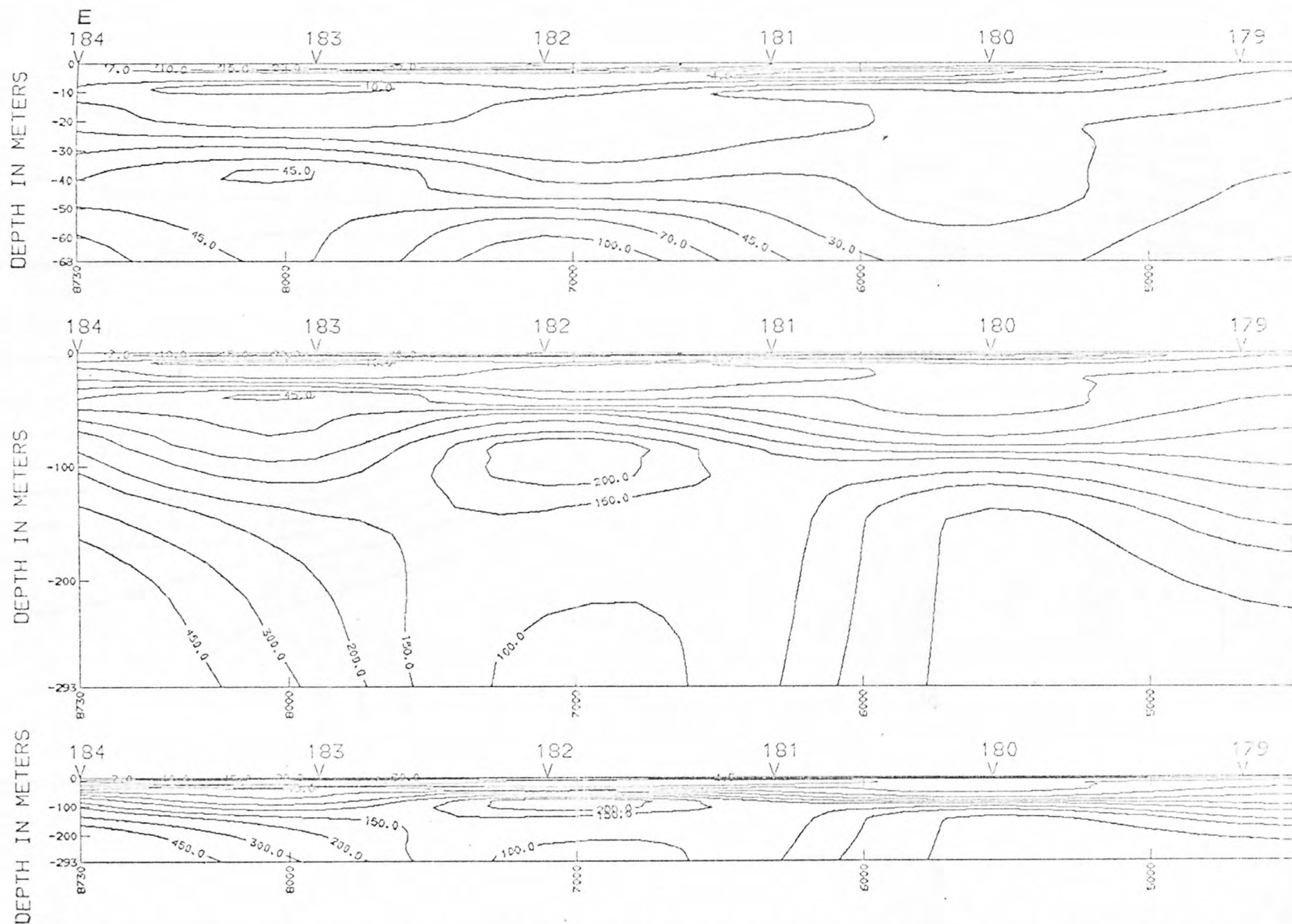
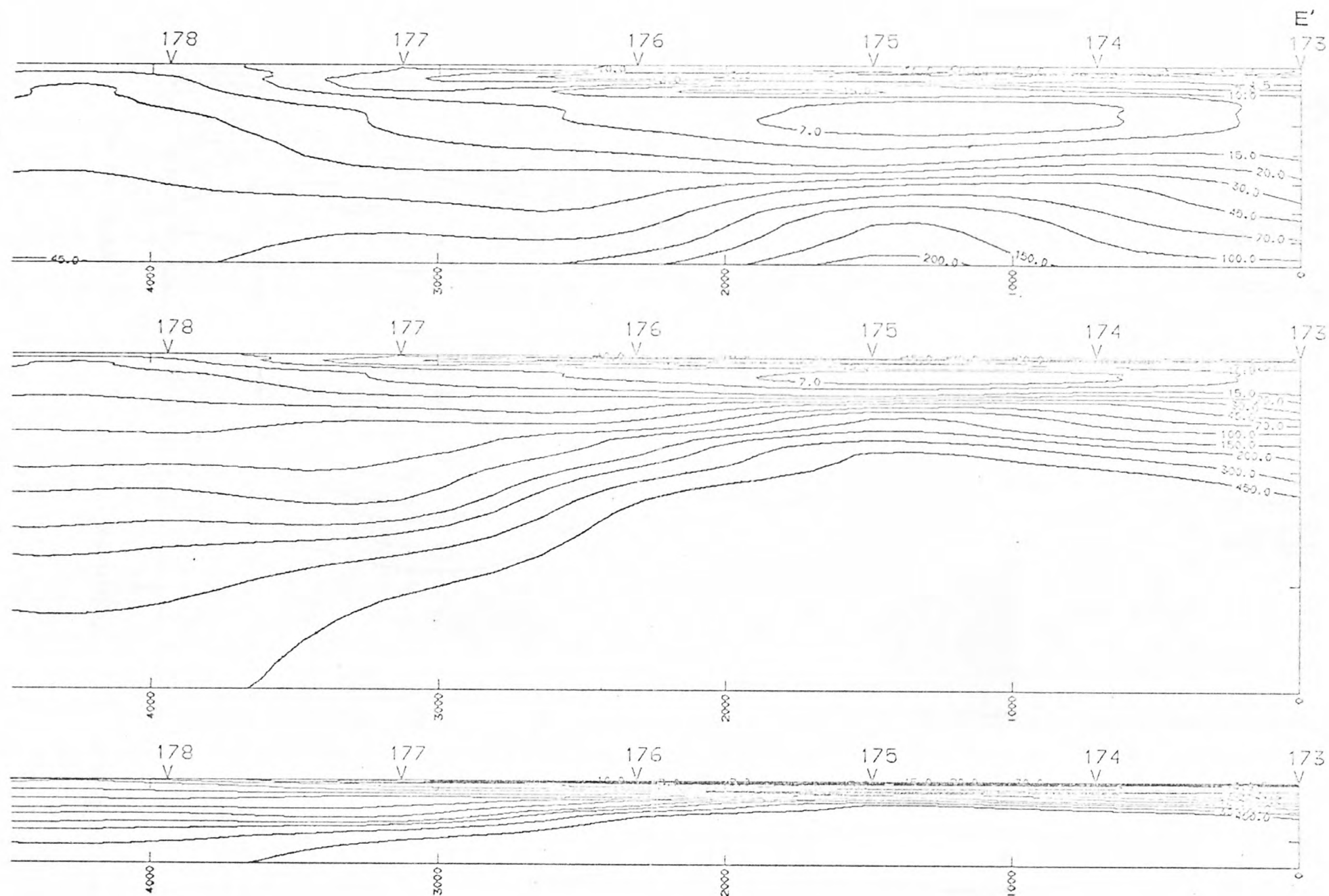


Figure 15a.--Computer generated geoelectric section EE' (continued on next page in figure 15b). See figure 1 or figures 5 and 6 for location. See figure 11 caption for further explanation.



15b.--Geoelectric section EE' continued from figure 15a.

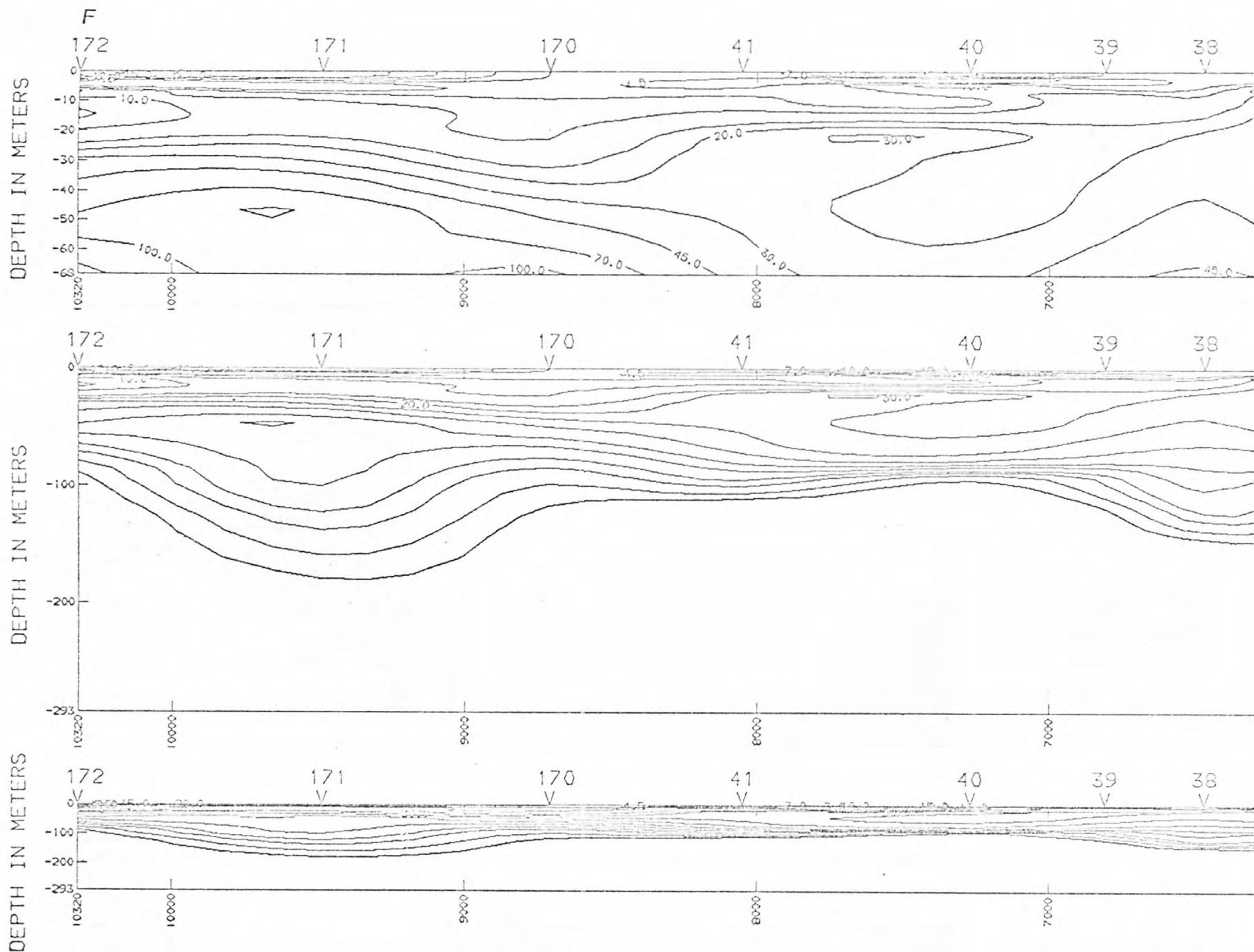


Figure 16a.--Computer generated geoelectric section FF' (continued on next two pages in figures 16b and 16c).
See figure 1 or figures 5 and 6 for location. See figure 11 caption for further explanation.

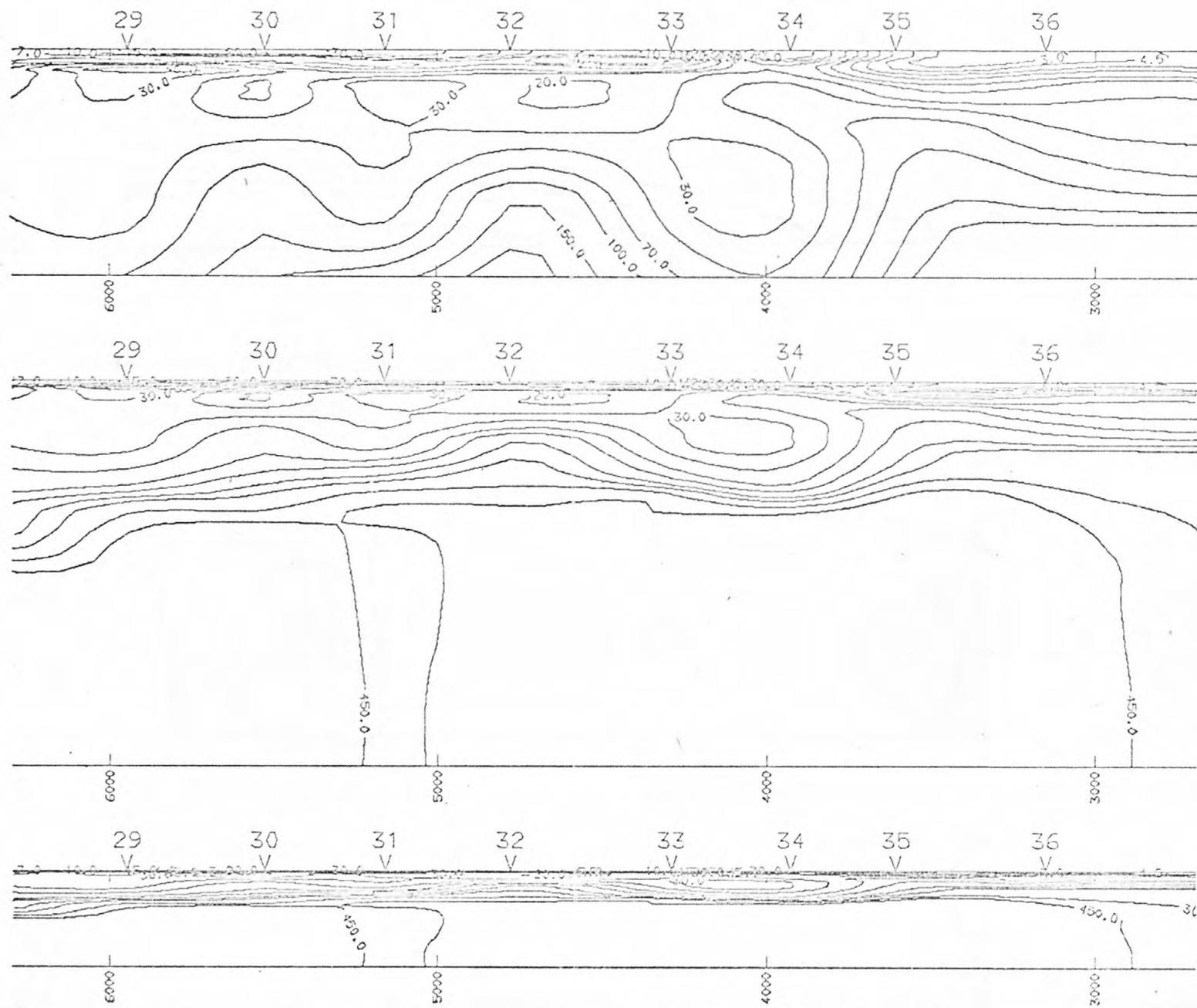


Figure 16b.--Geoelectric section FF' continued from figure 16a.

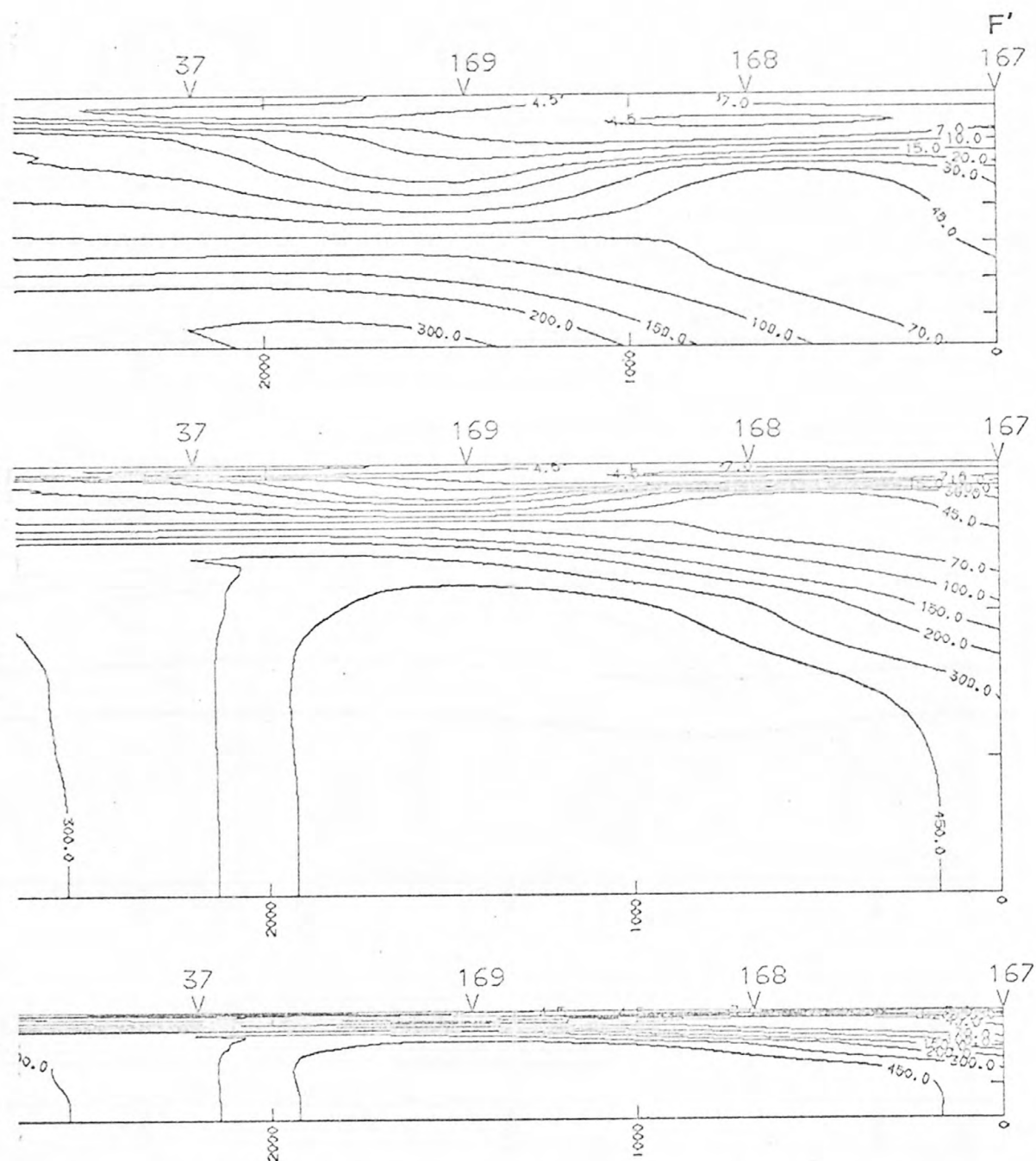


Figure 16c.--Geoelectric section FF' continued from figure 16b.

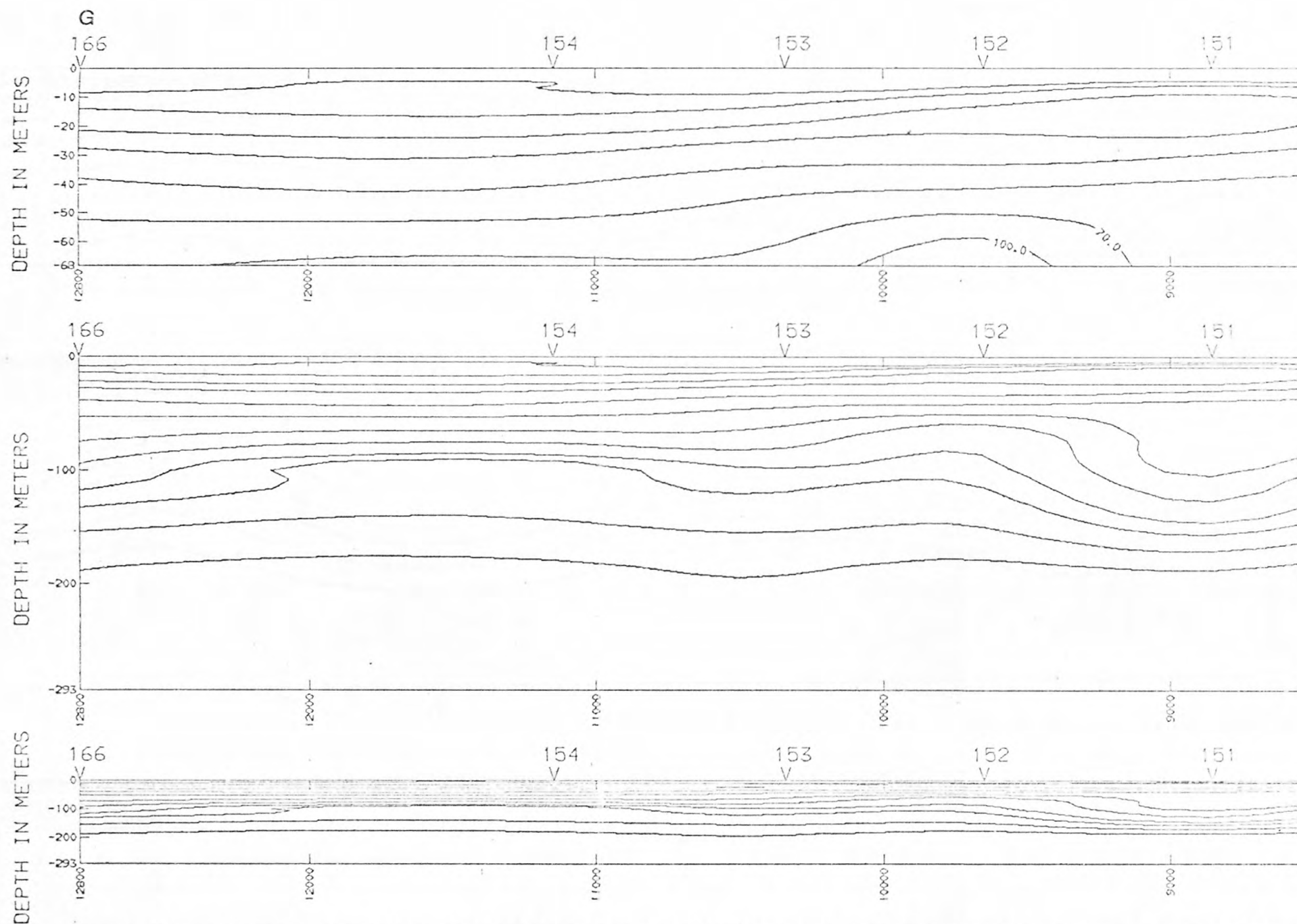


Figure 17a.--Computer generated geoelectric section GG' (continued on next two pages in figures 17b and 17c).
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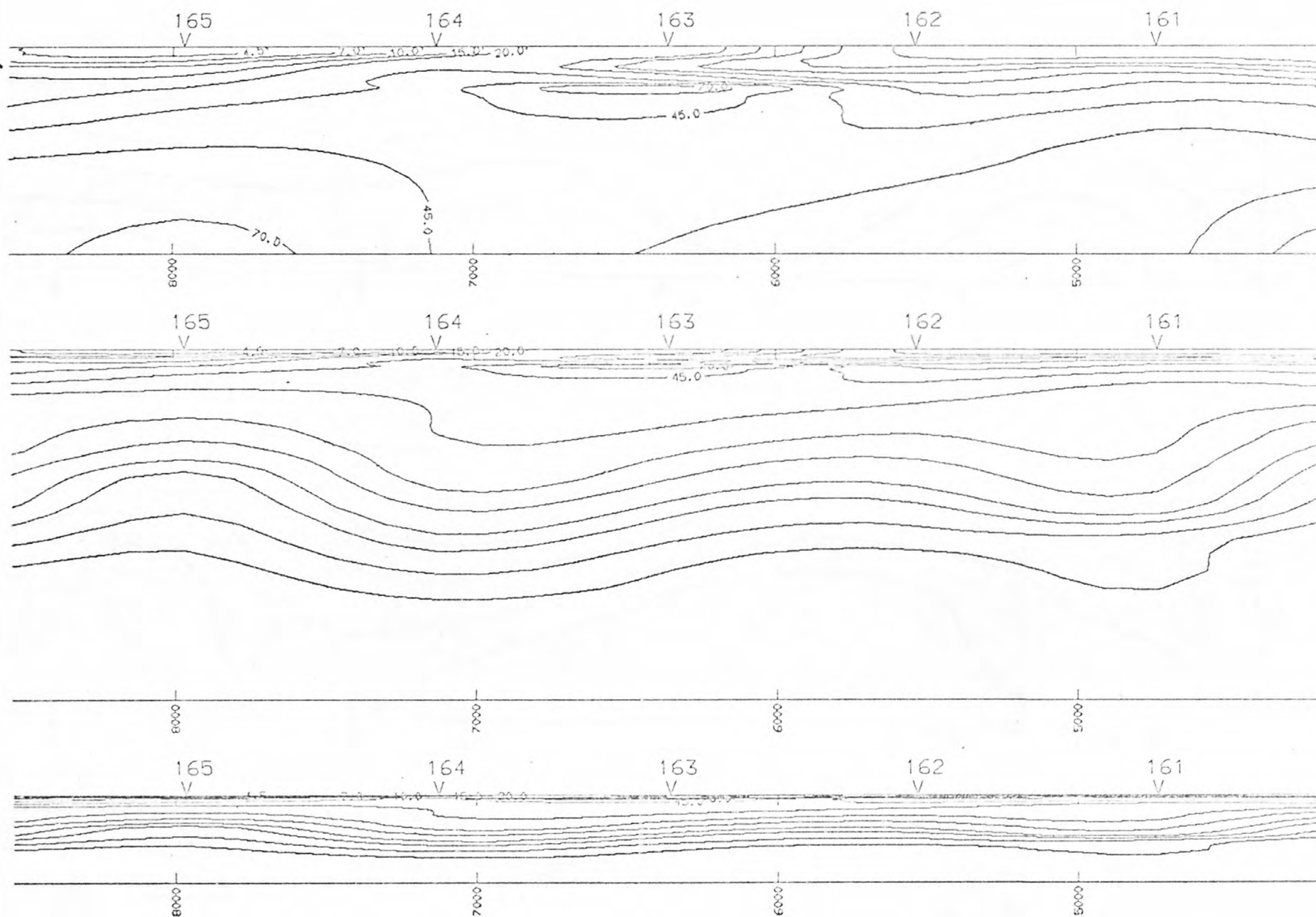


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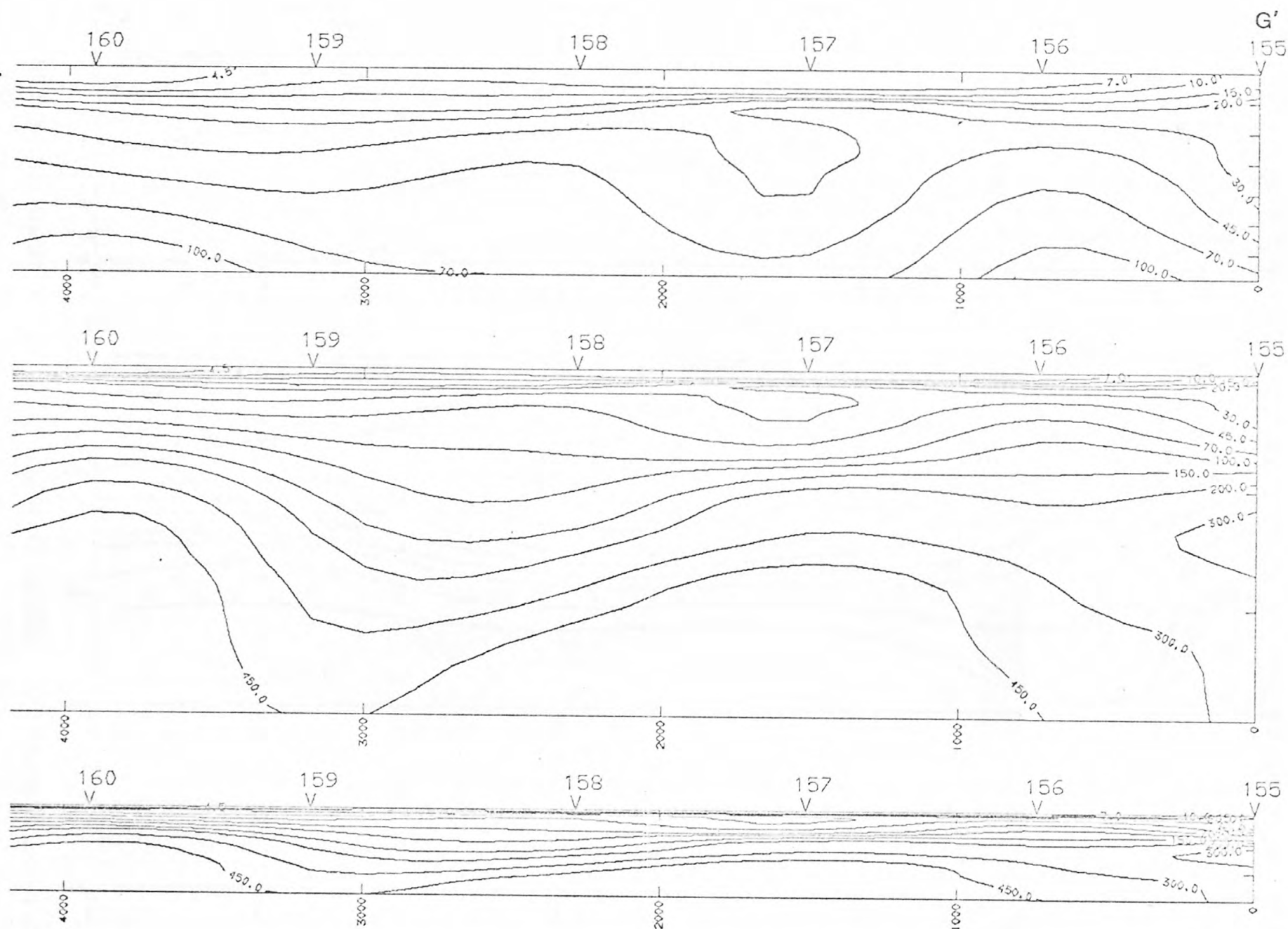


Figure 17c.--Geoelectric section GG' continued from figure 17b.

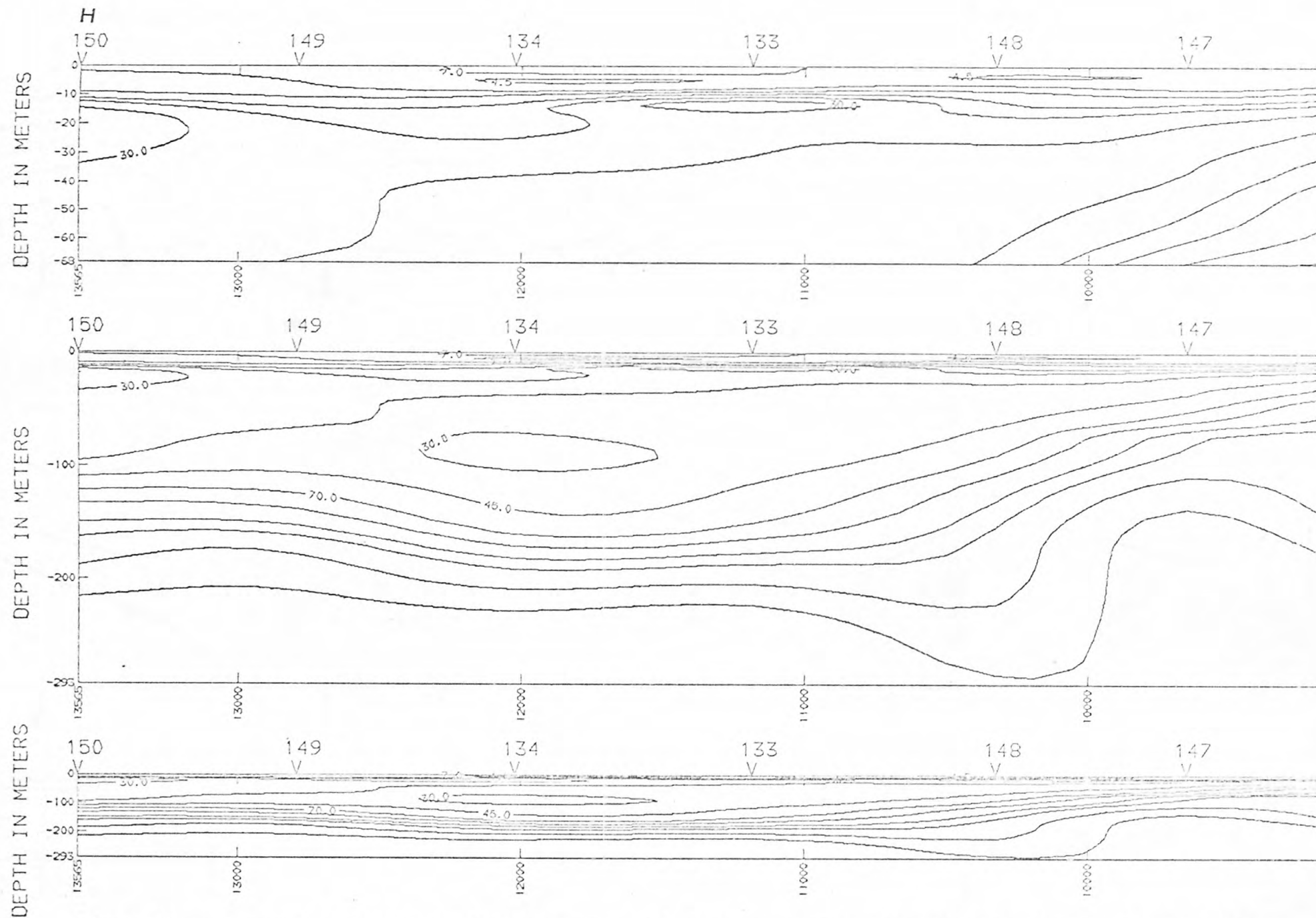


Figure 18a.--Computer generated geoelectric section HH' (continued on next two pages in figures 18b and 18c). See figure 1 or figures 7 and 8 for location. See figure 11 caption for further explanation.

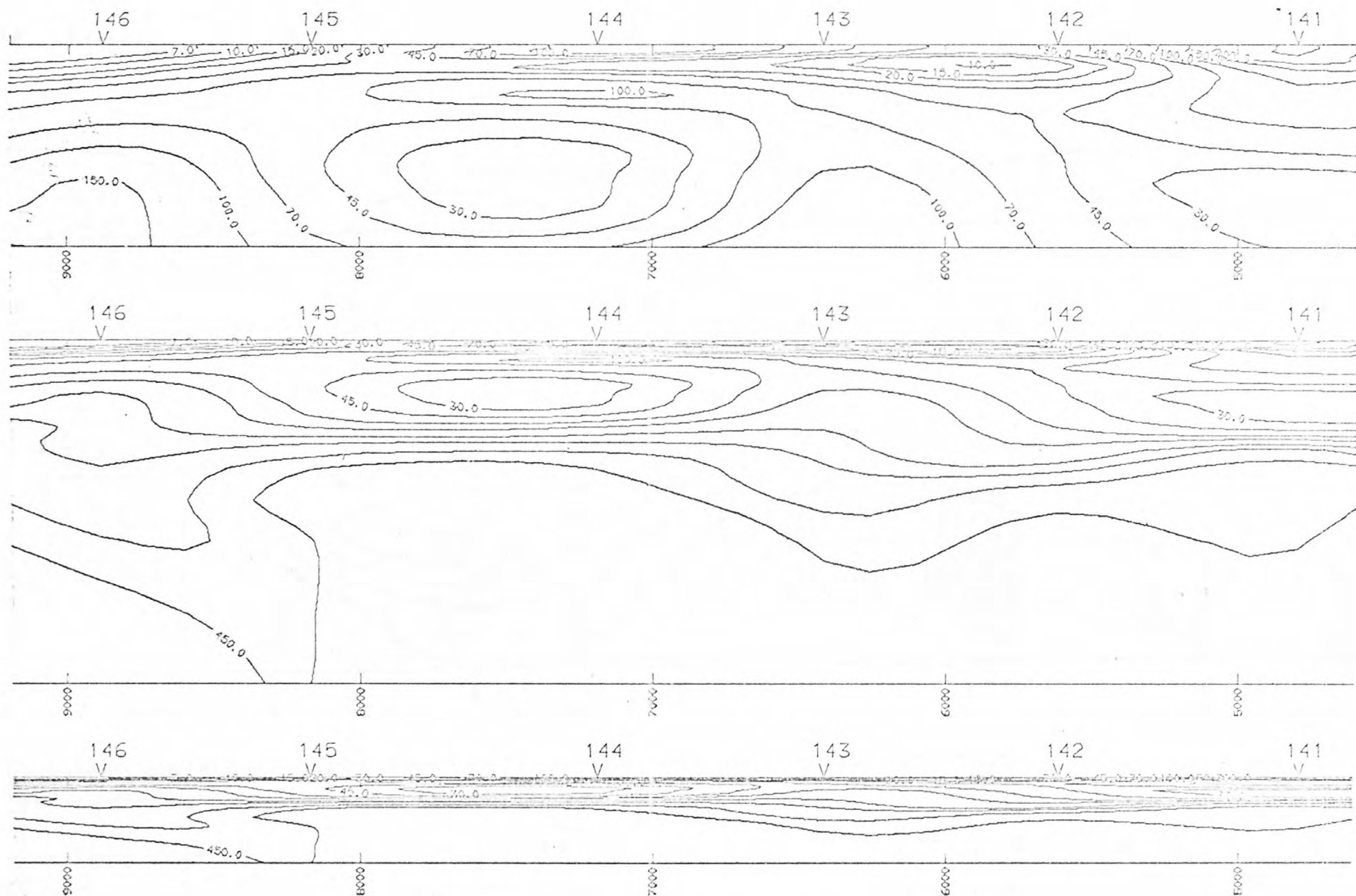


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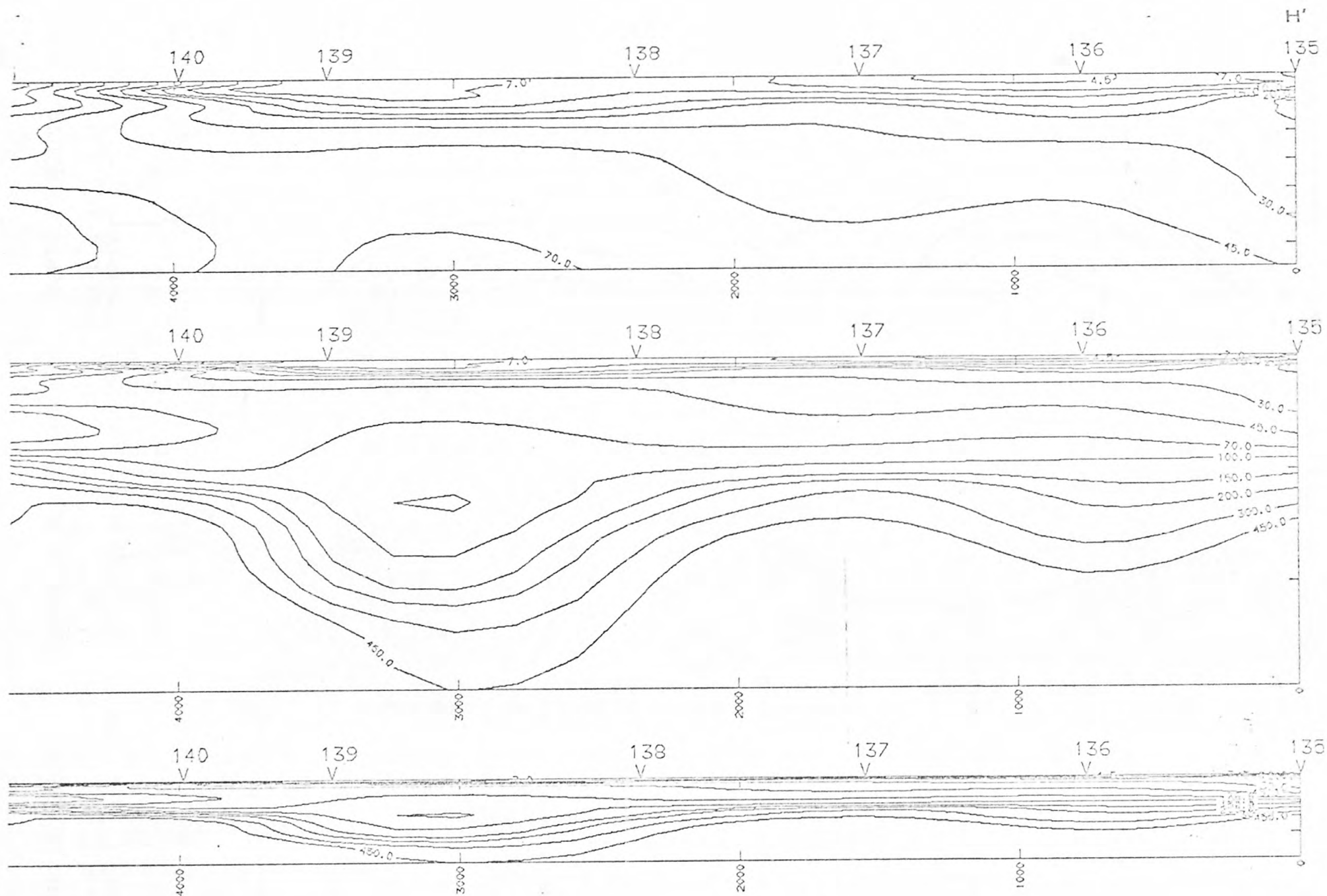


Figure 18c.--Geoelectric section HH' continued from figure 18b.

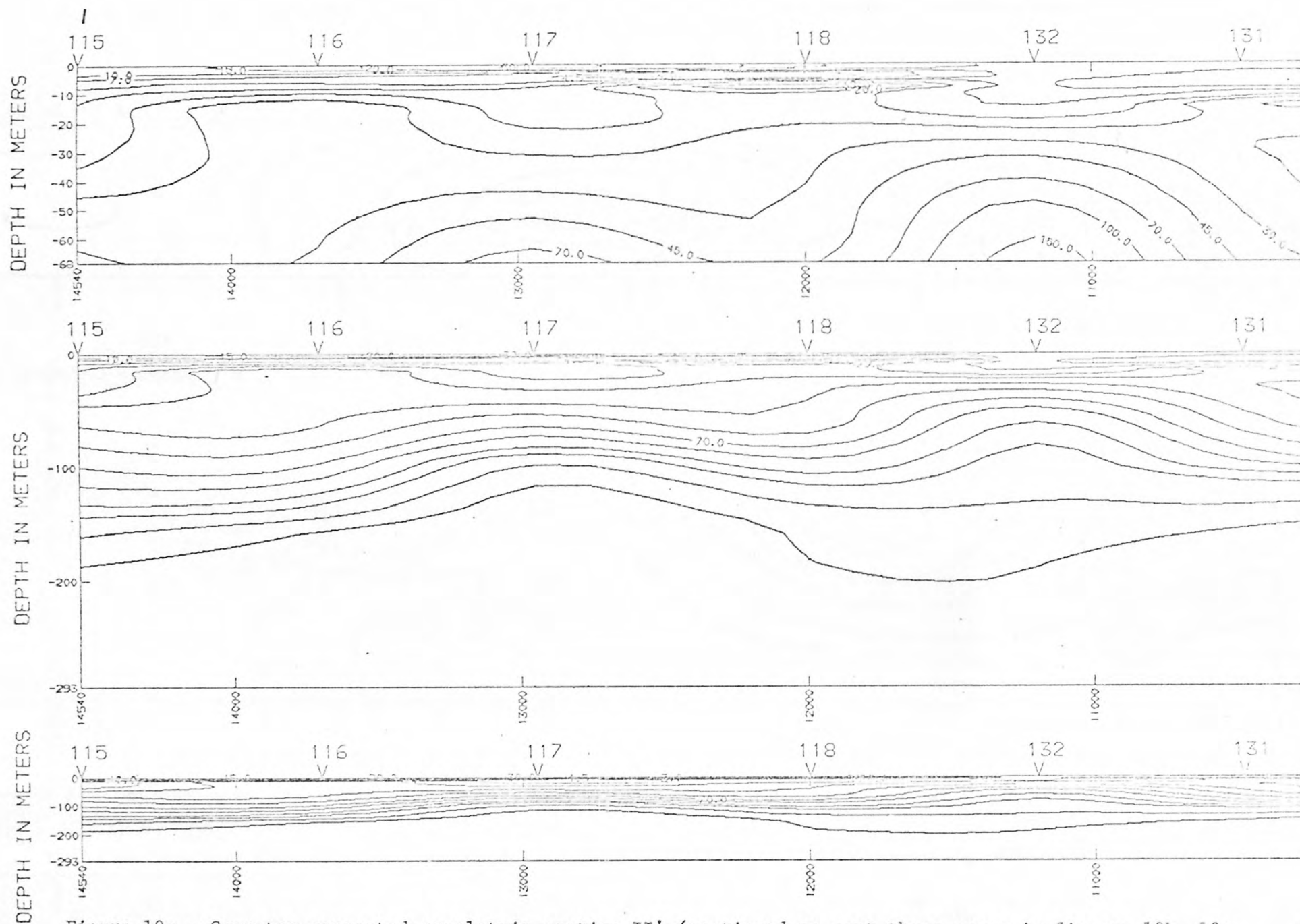


Figure 19a.--Computer generated geoelectric section II' (continued on next three pages in figures 19b, 19c, and 19d). See figure 1 or figures 7 and 8 for location. See figure 11 caption for further explanation.

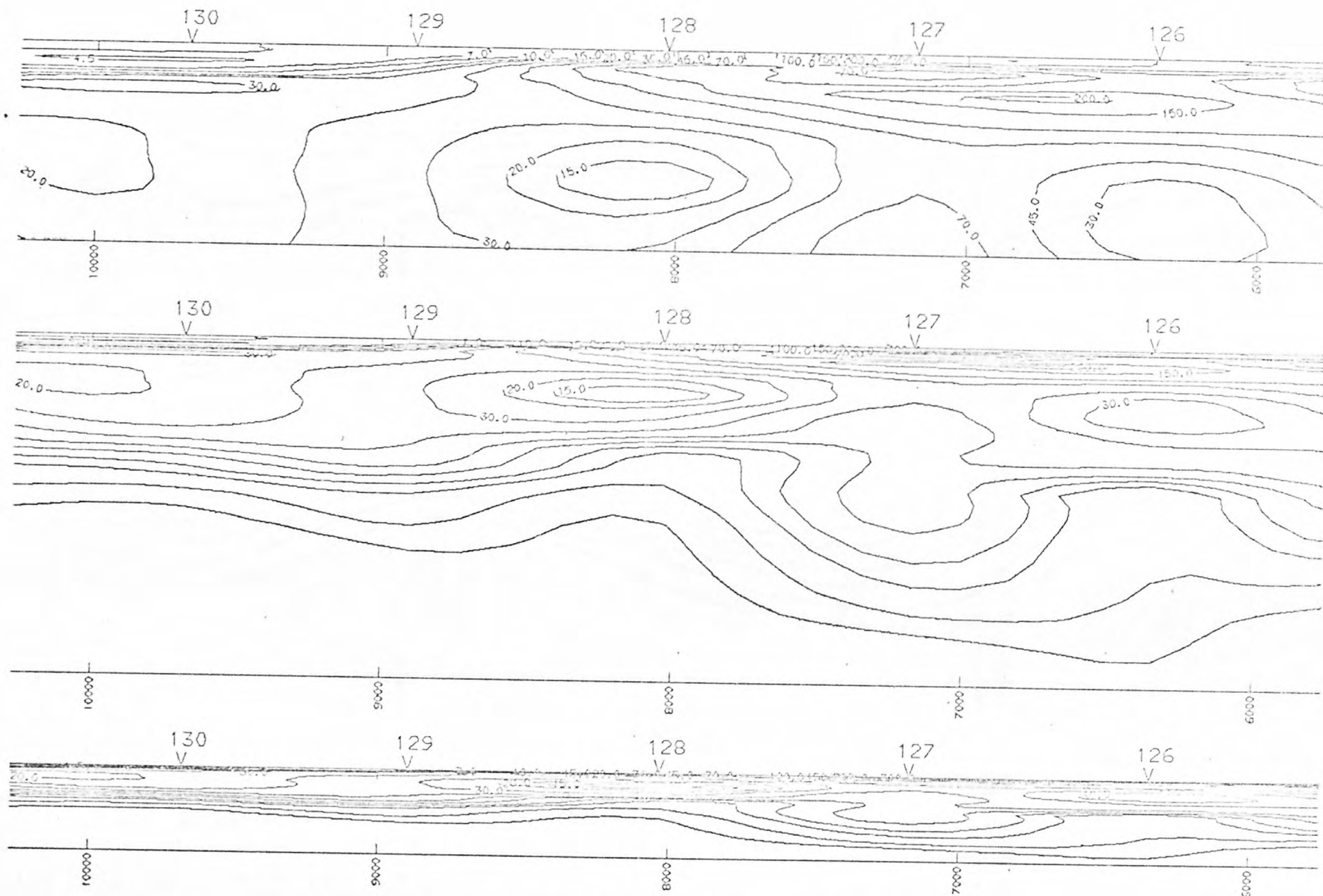


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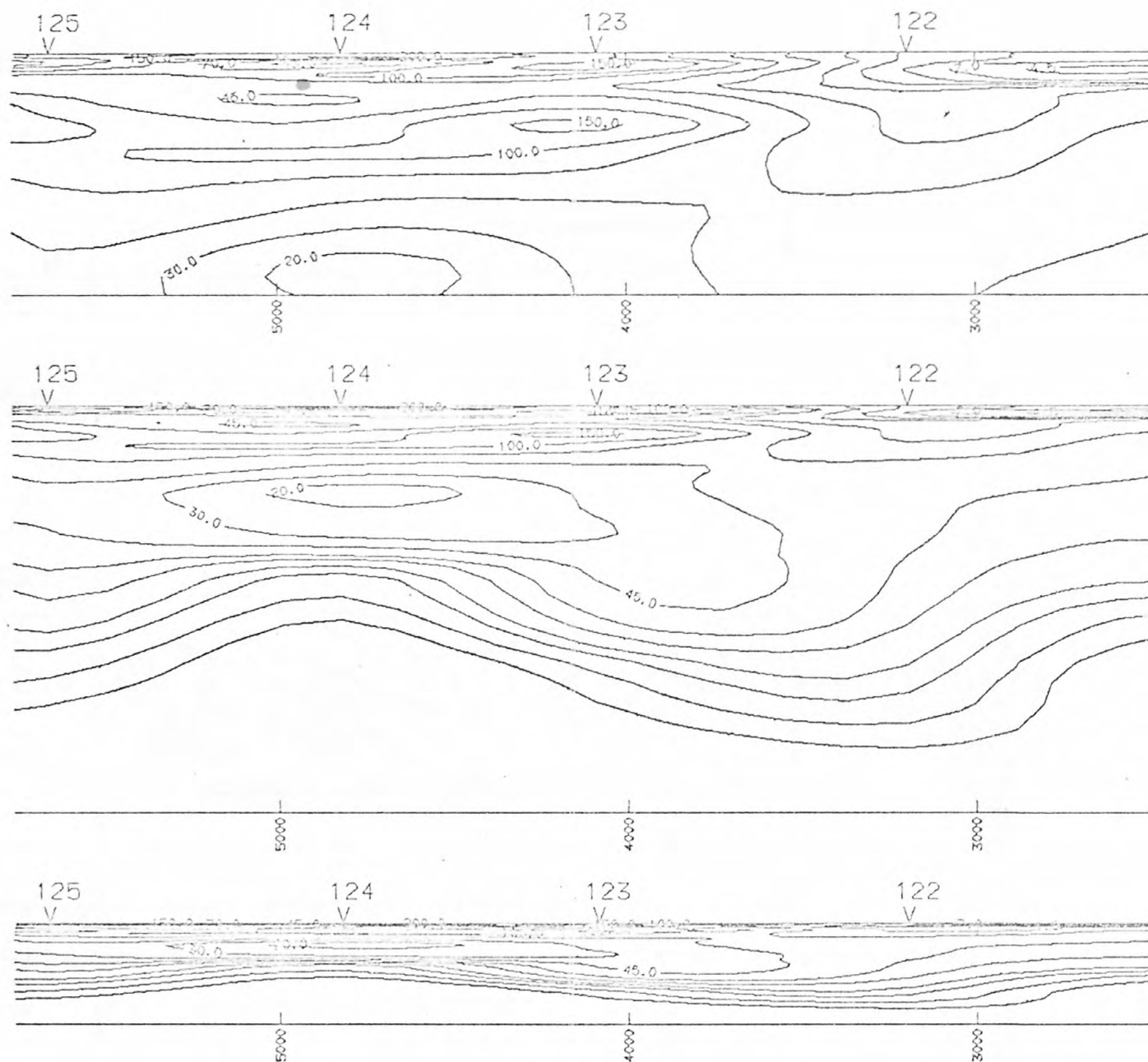


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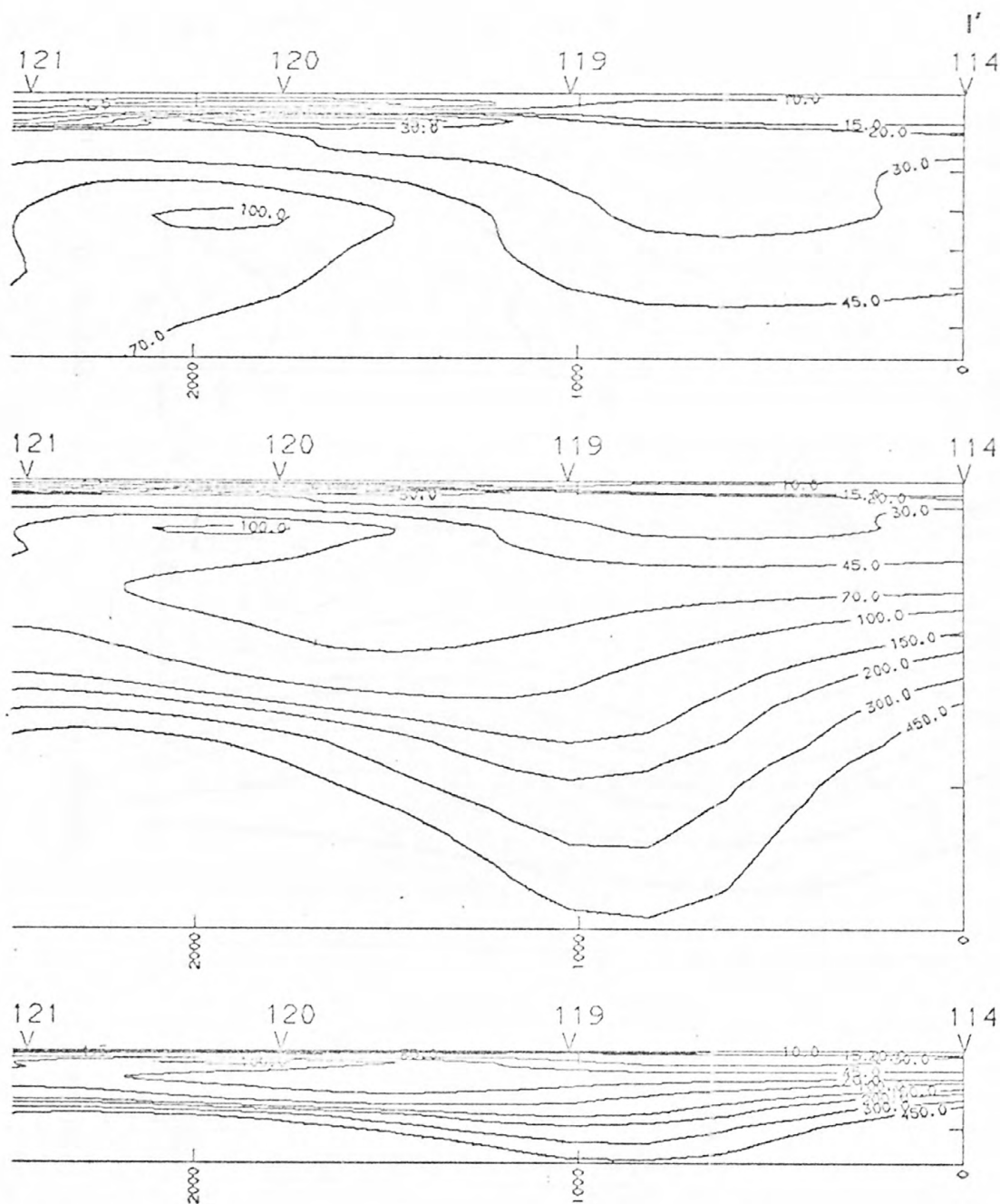


Figure 19d.--Geoelectric section II' continued from figure 19c.

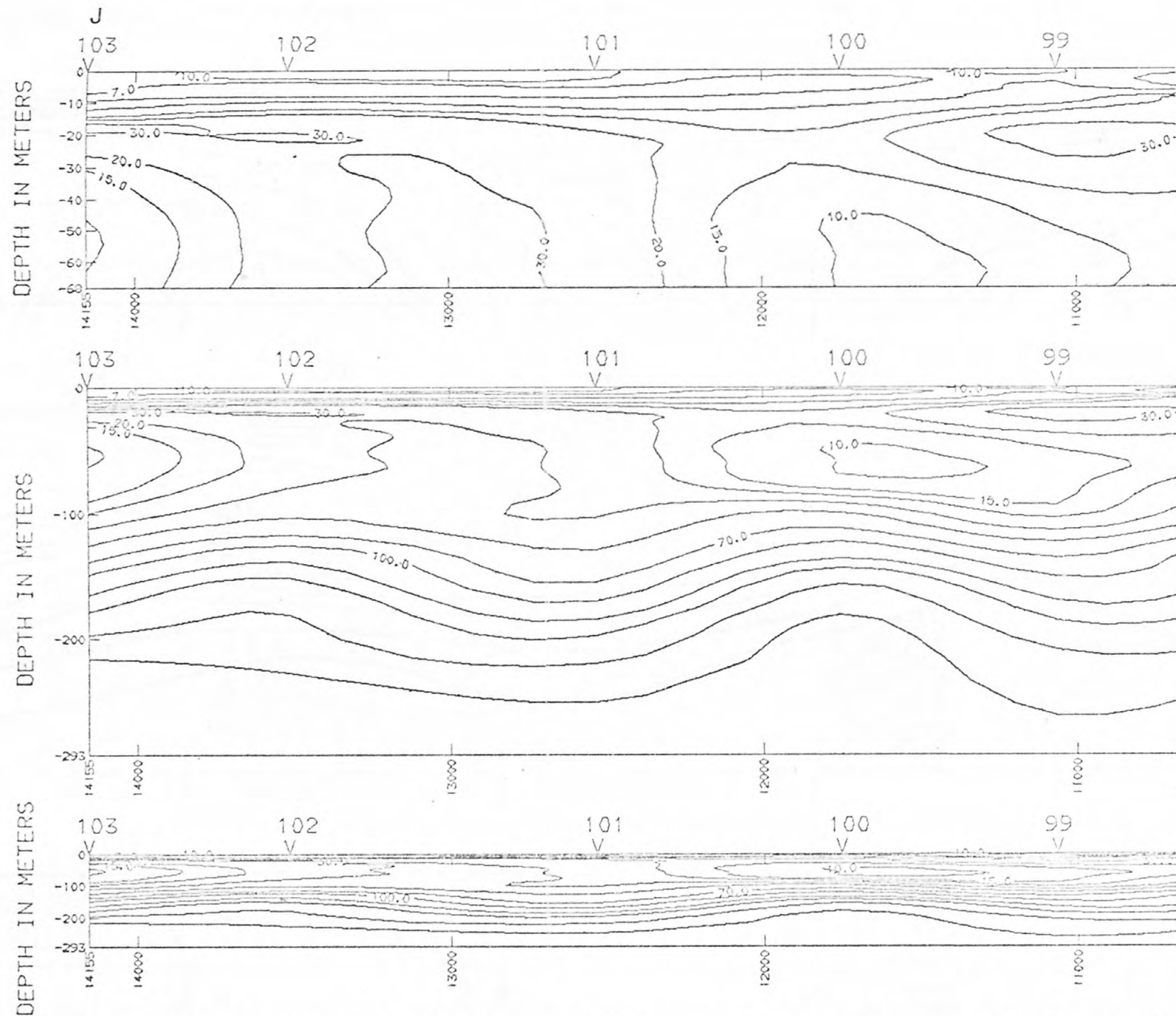


Figure 20a.--Computer generated geoelectric section JJ' (continued on next three pages in figures 20b, 20c, and 20d). See figure 1 or figures 7 and 8 for location. See figure 11 caption for further explanation.

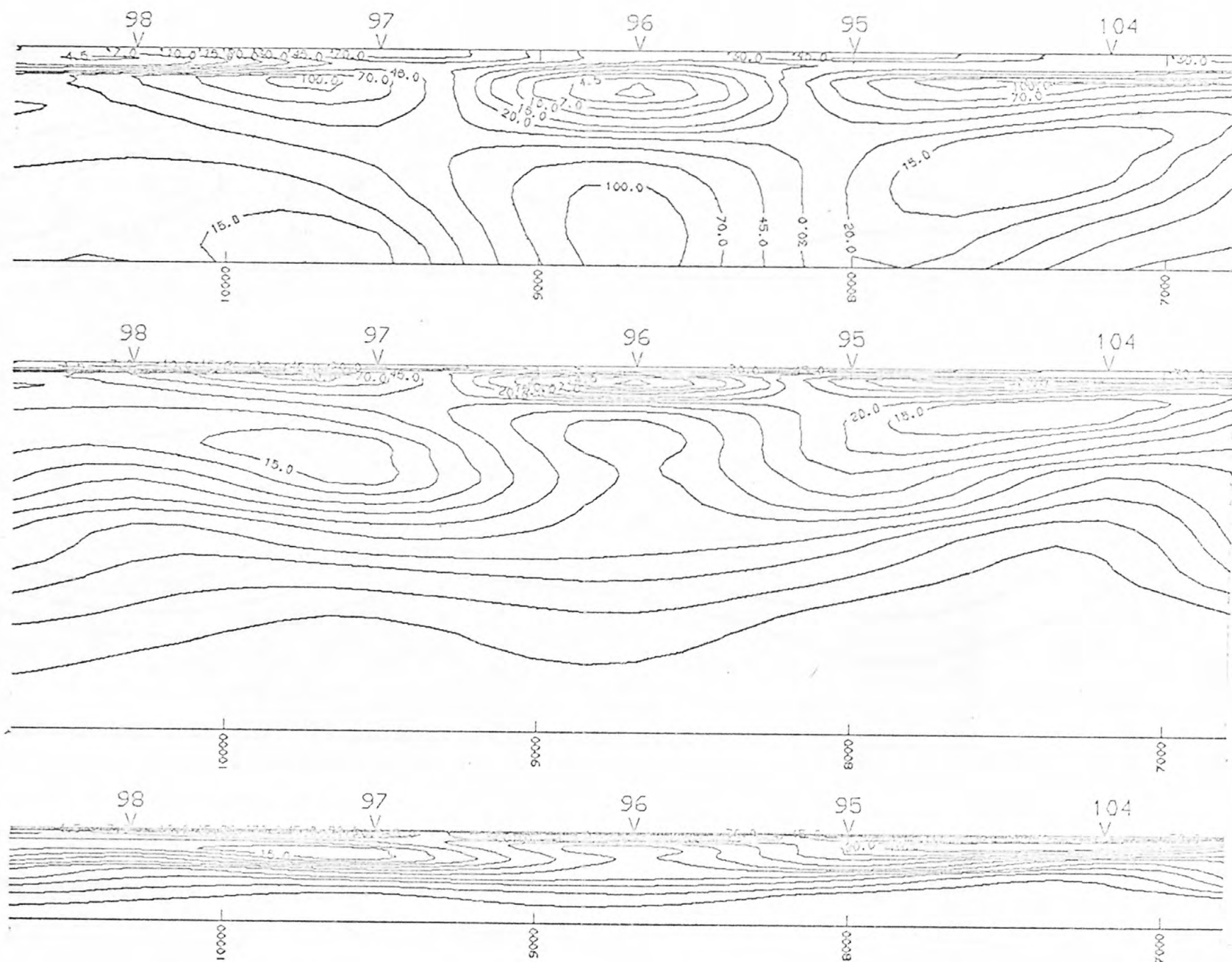


Figure 20b.--Geoelectric section JJ' continued from figure 20a.

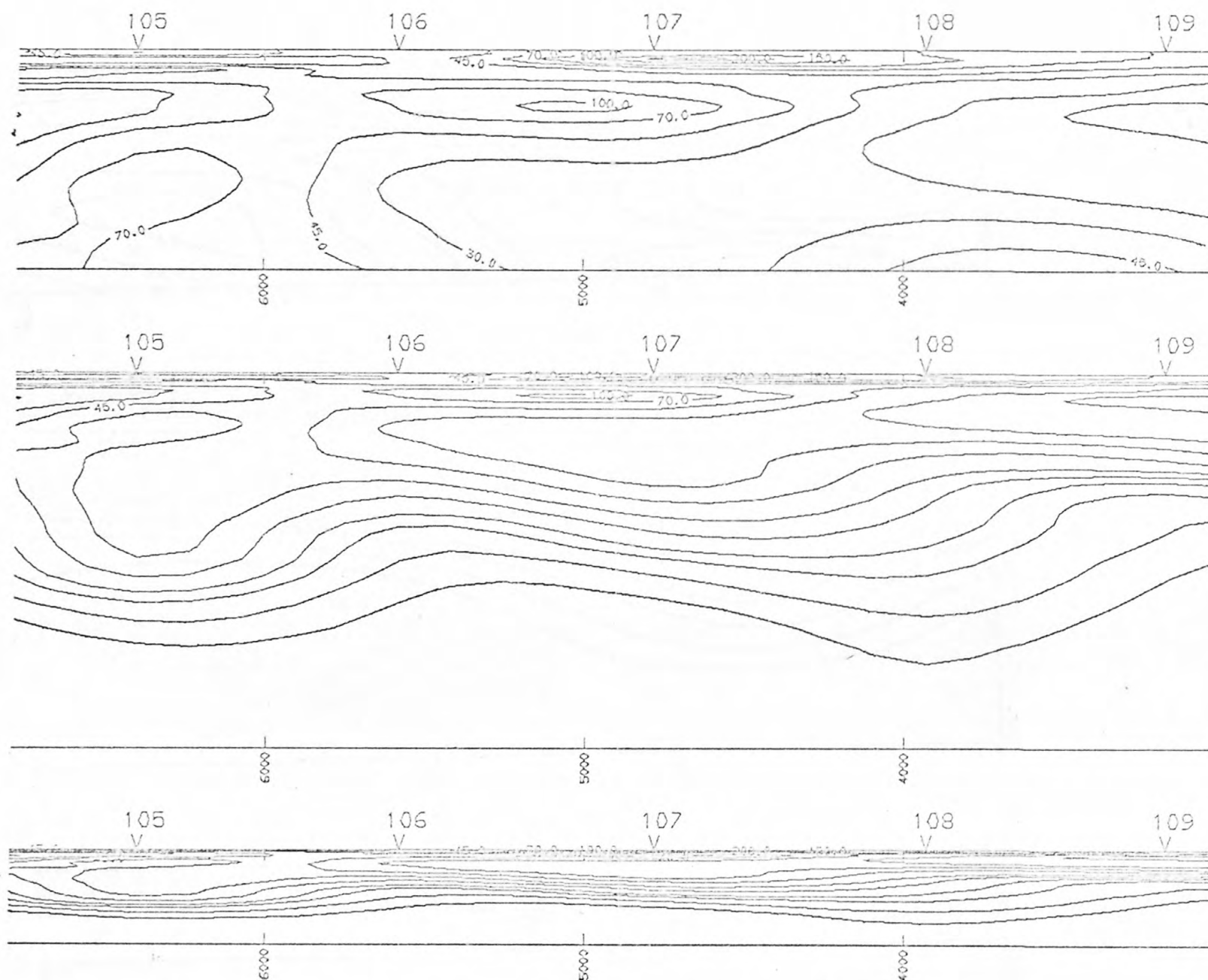


Figure 20c.--Goelectric section JJ¹ continued from figure 20b.

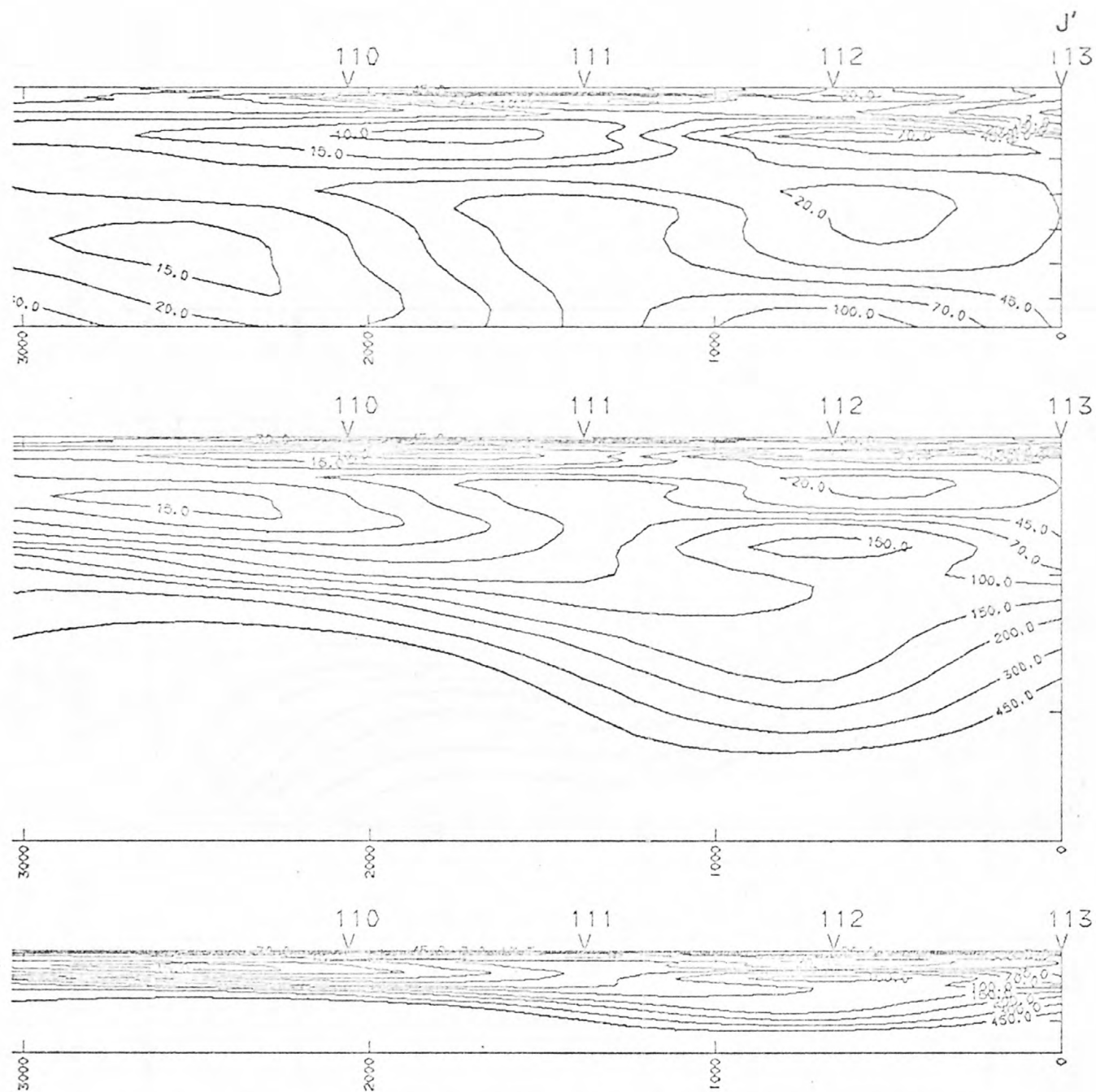


Figure 20d.--Geoelectric section JJ' continued from figure 20c.

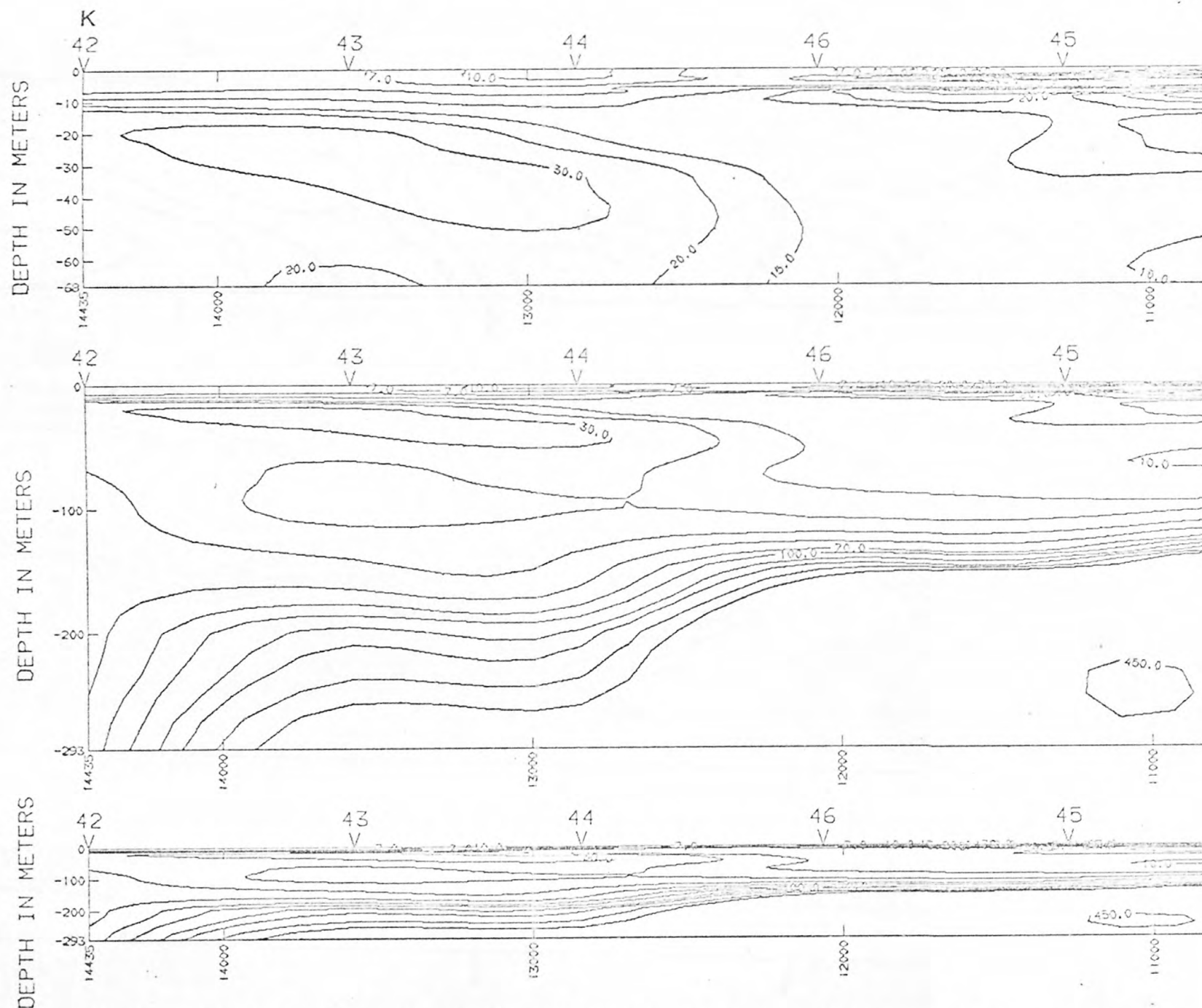


Figure 21a.--Computer generated geoelectric section KK' (continued on next three pages in figures 21b, 21c, and 21d). See figure 1 or figures 7 and 8 for location. See figure 11 caption for further explanation.

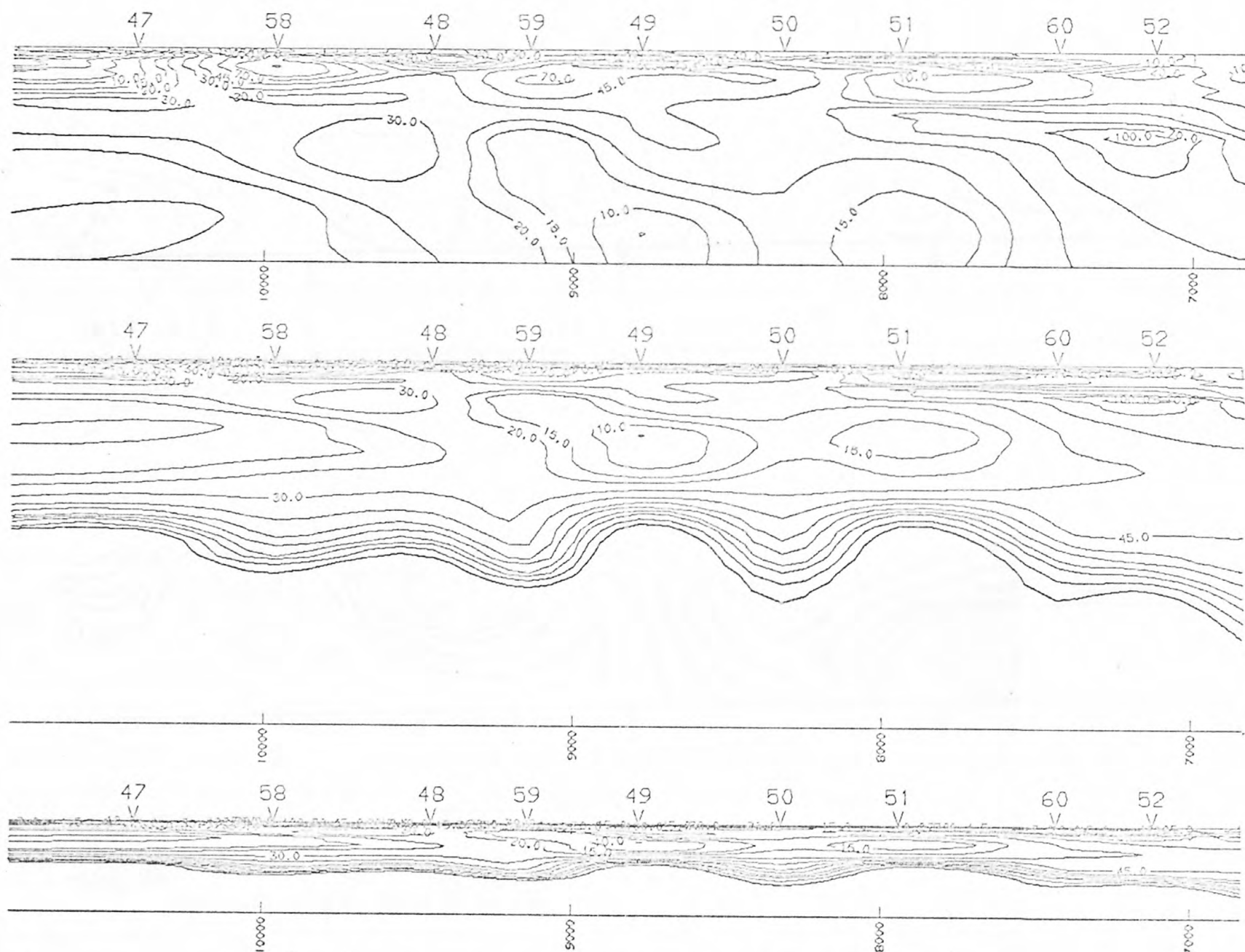


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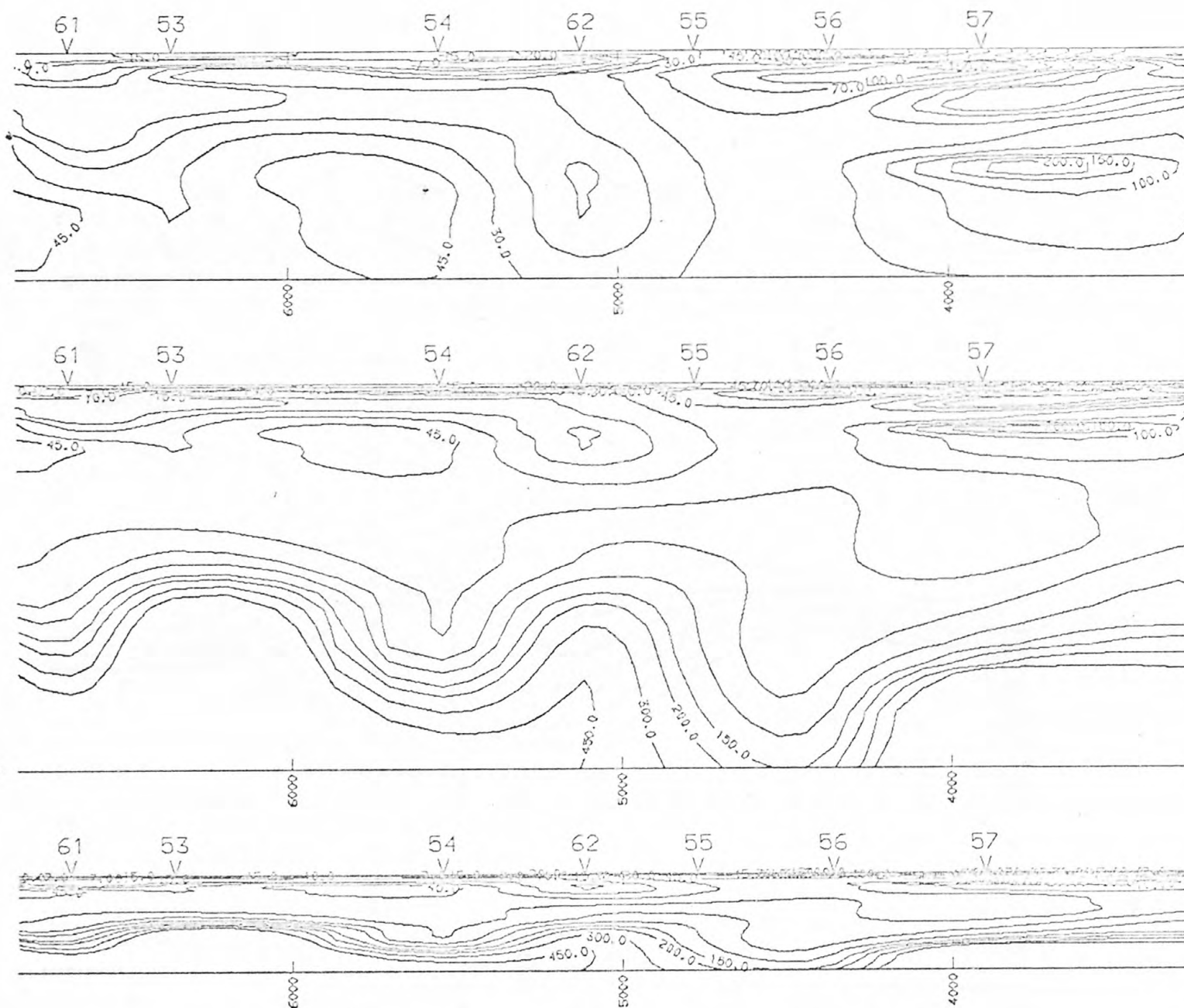


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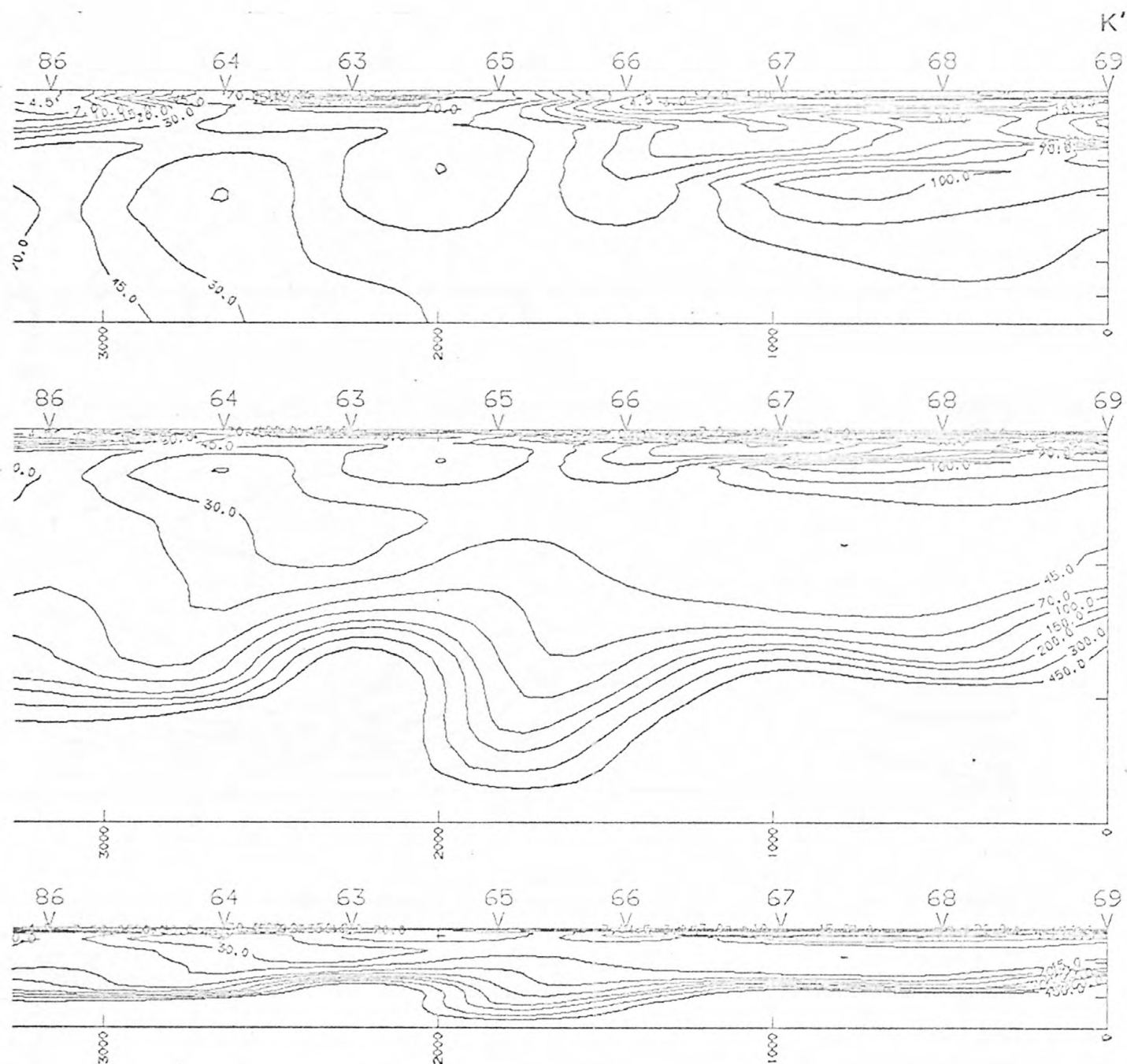


Figure 21d.--Geoelectric section KK' continued from figure 21c.

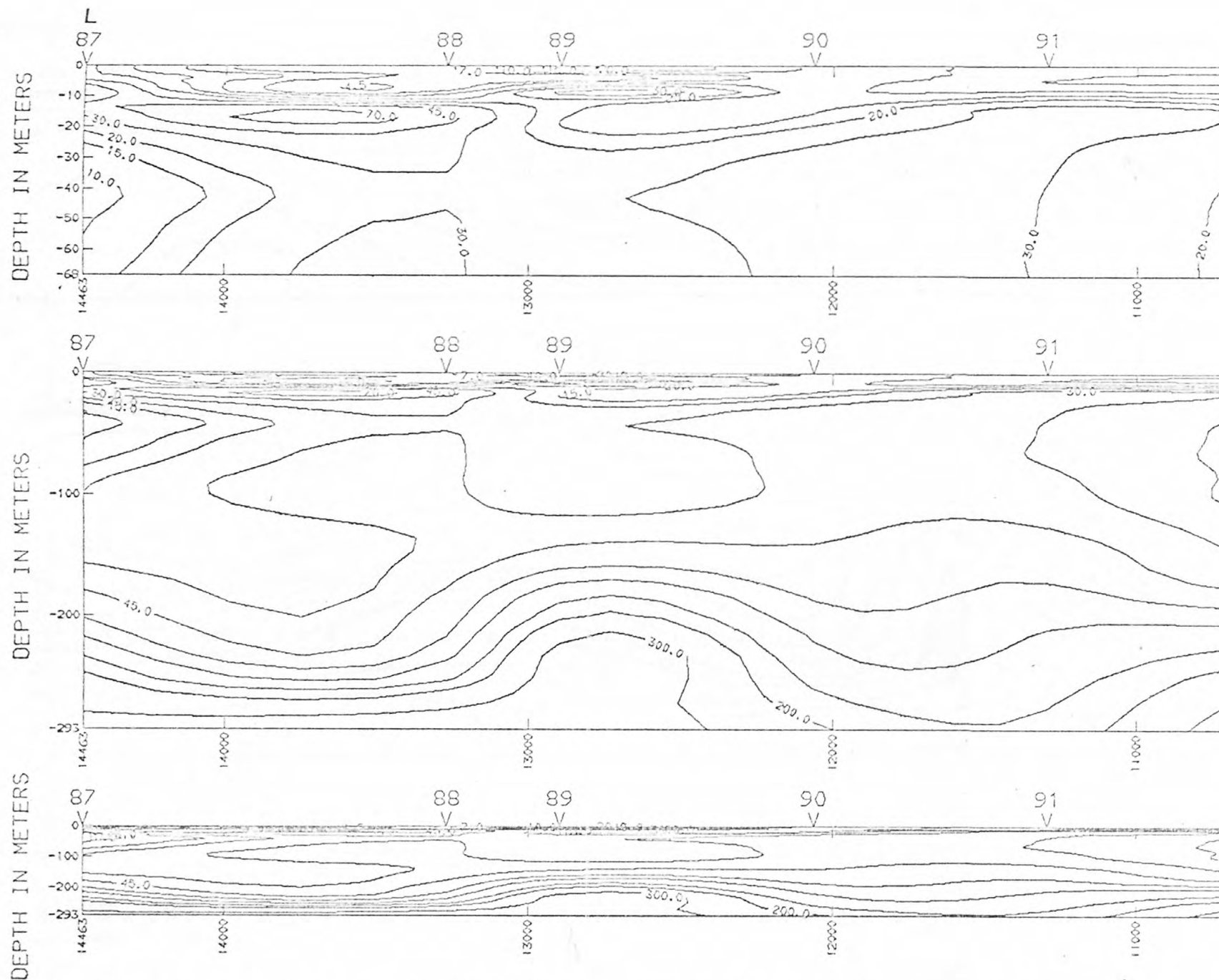


Figure 22a.--Computer generated geoelectric section LL' (continued on next three pages in figures 22b, 22c, and 22d). See figure 1 or figures 7 and 8 for location. See figure 11 caption for further explanation.

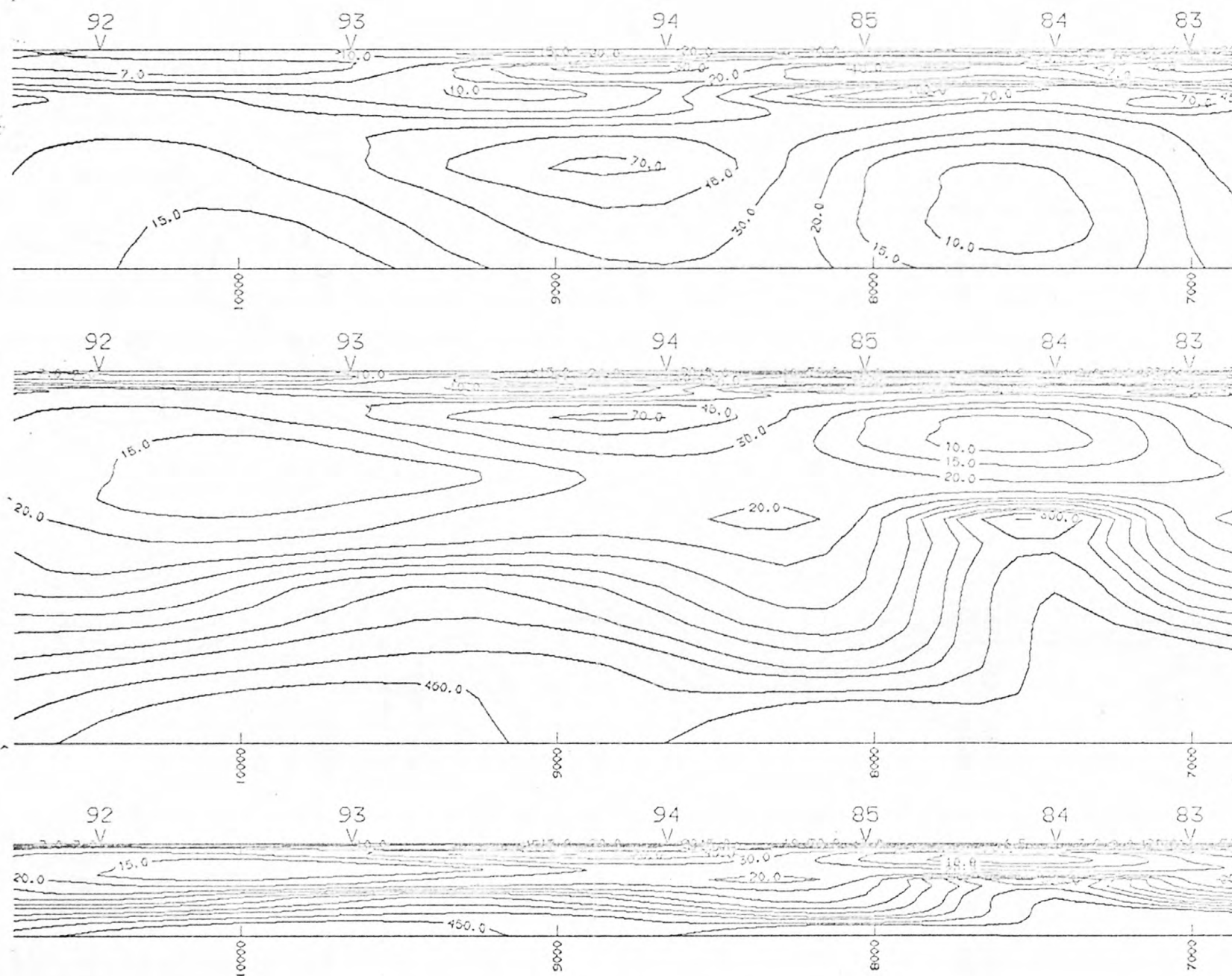


Figure 22b.--Geoelectric section LL' continued from figure 22a.

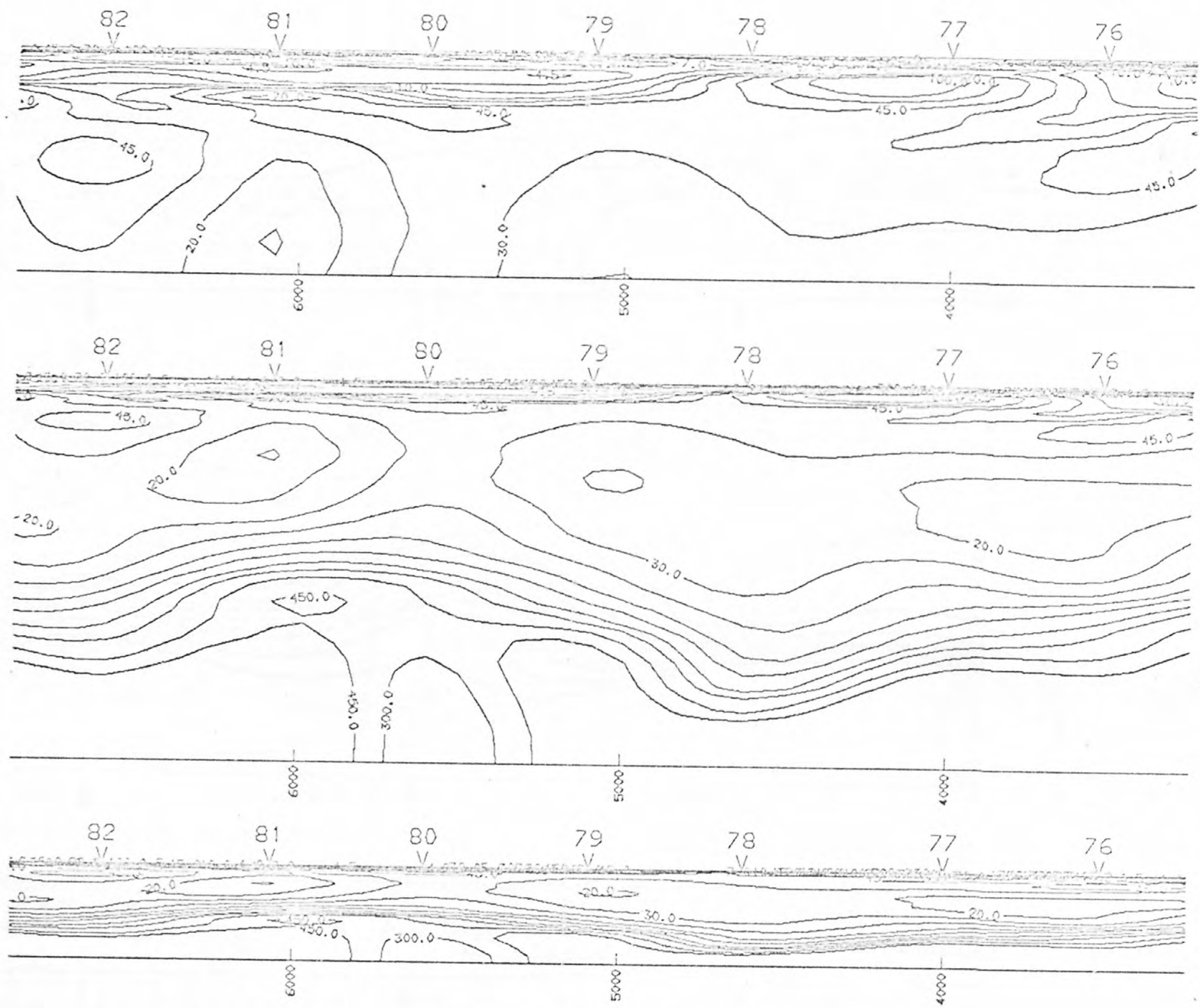


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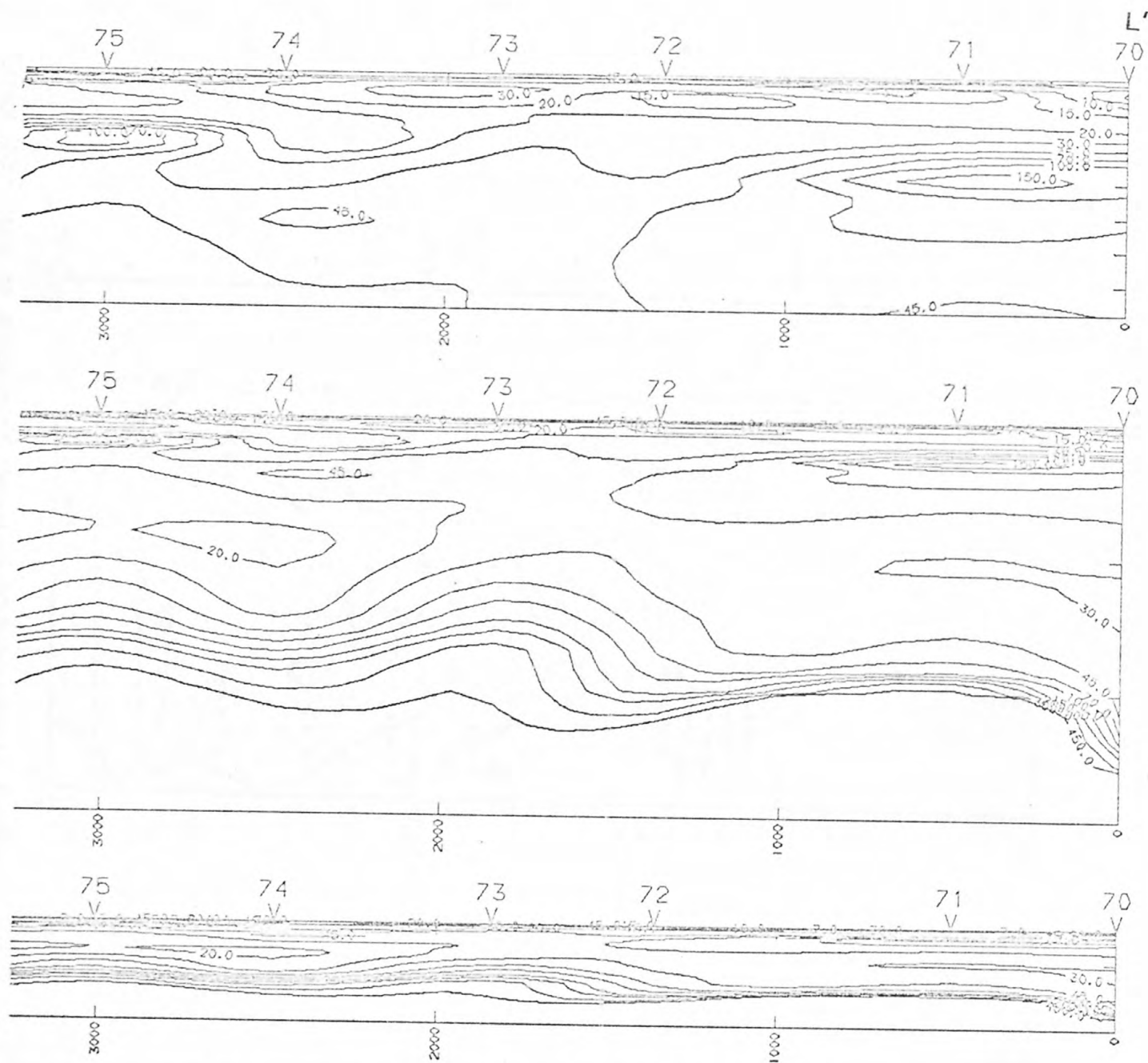


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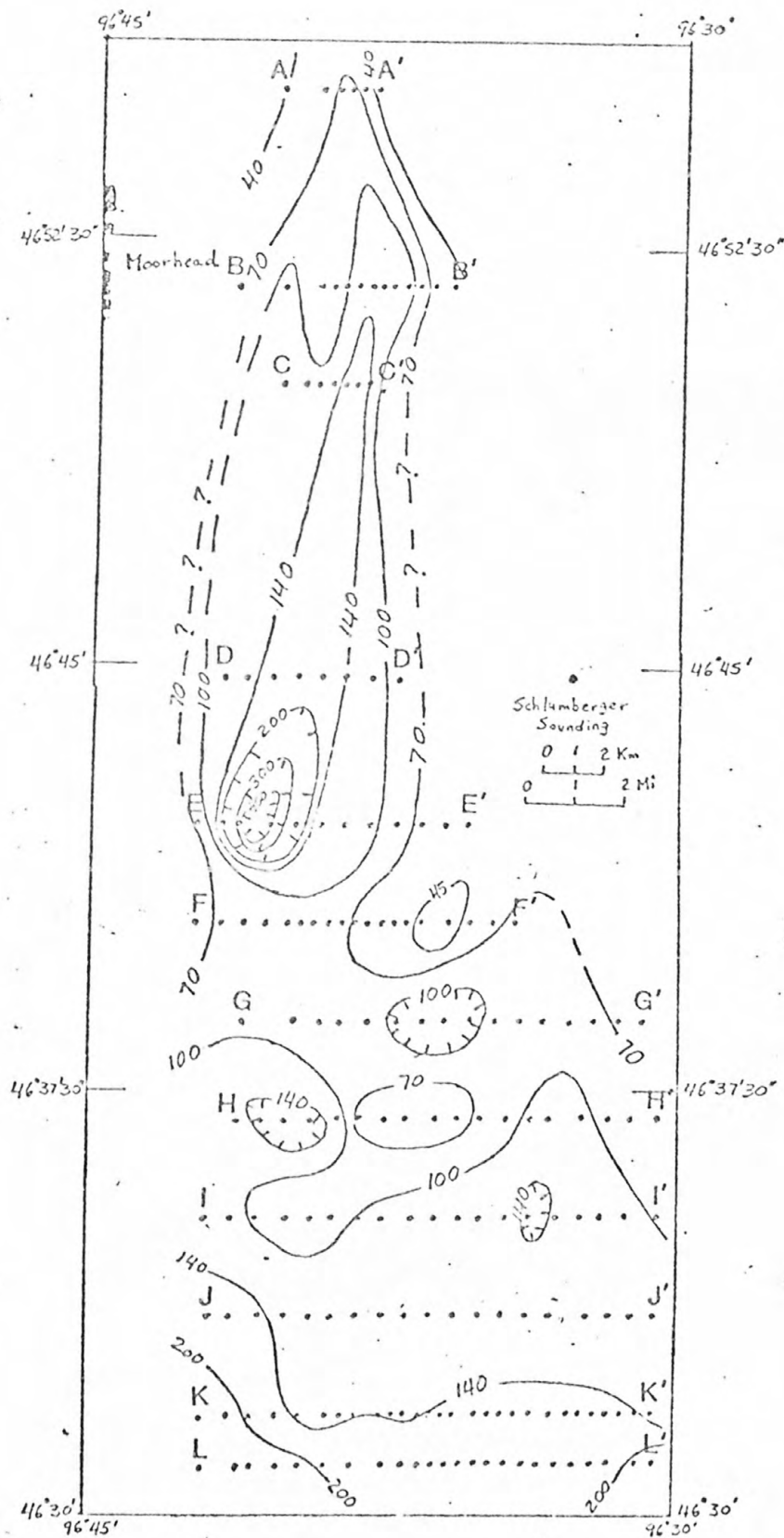
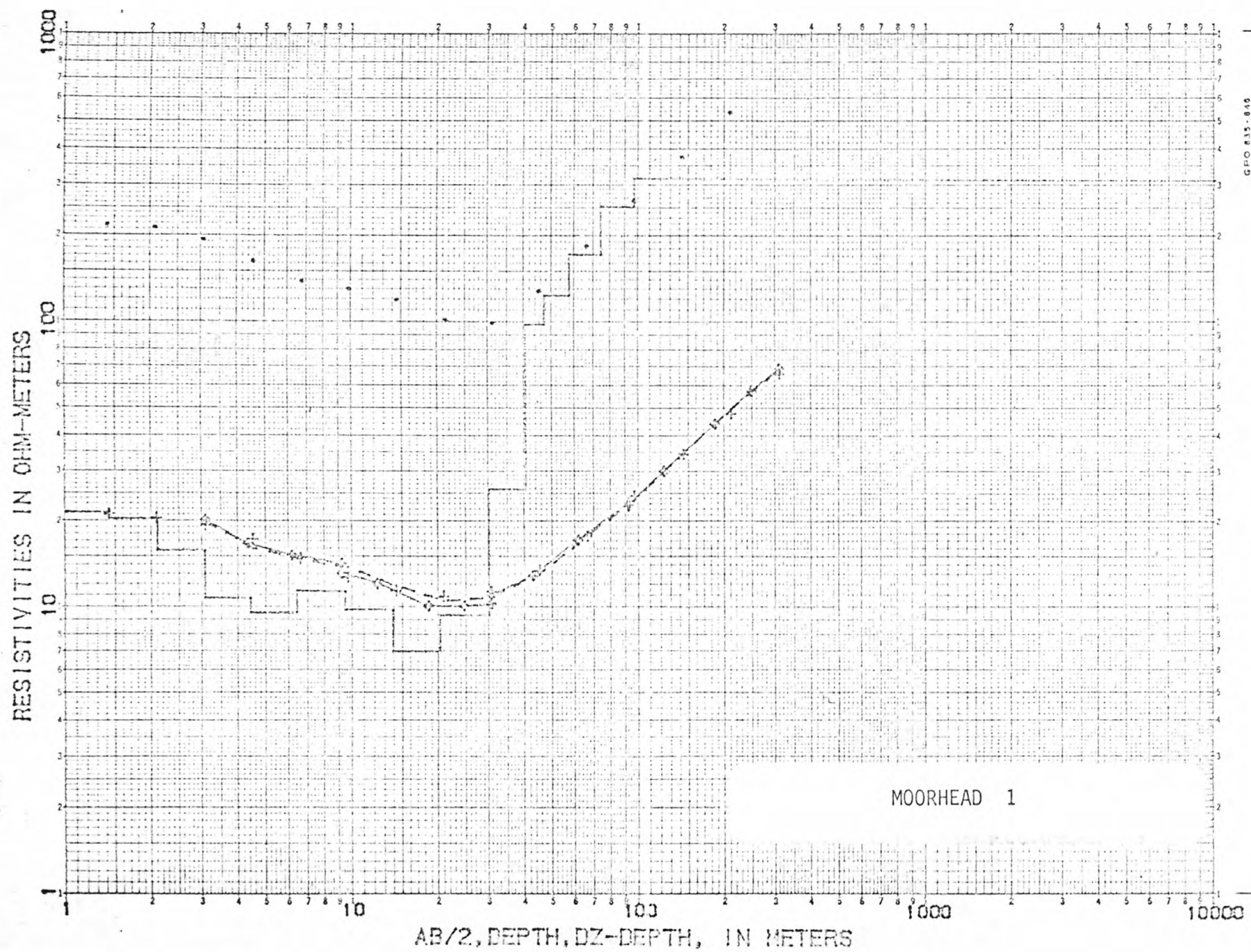
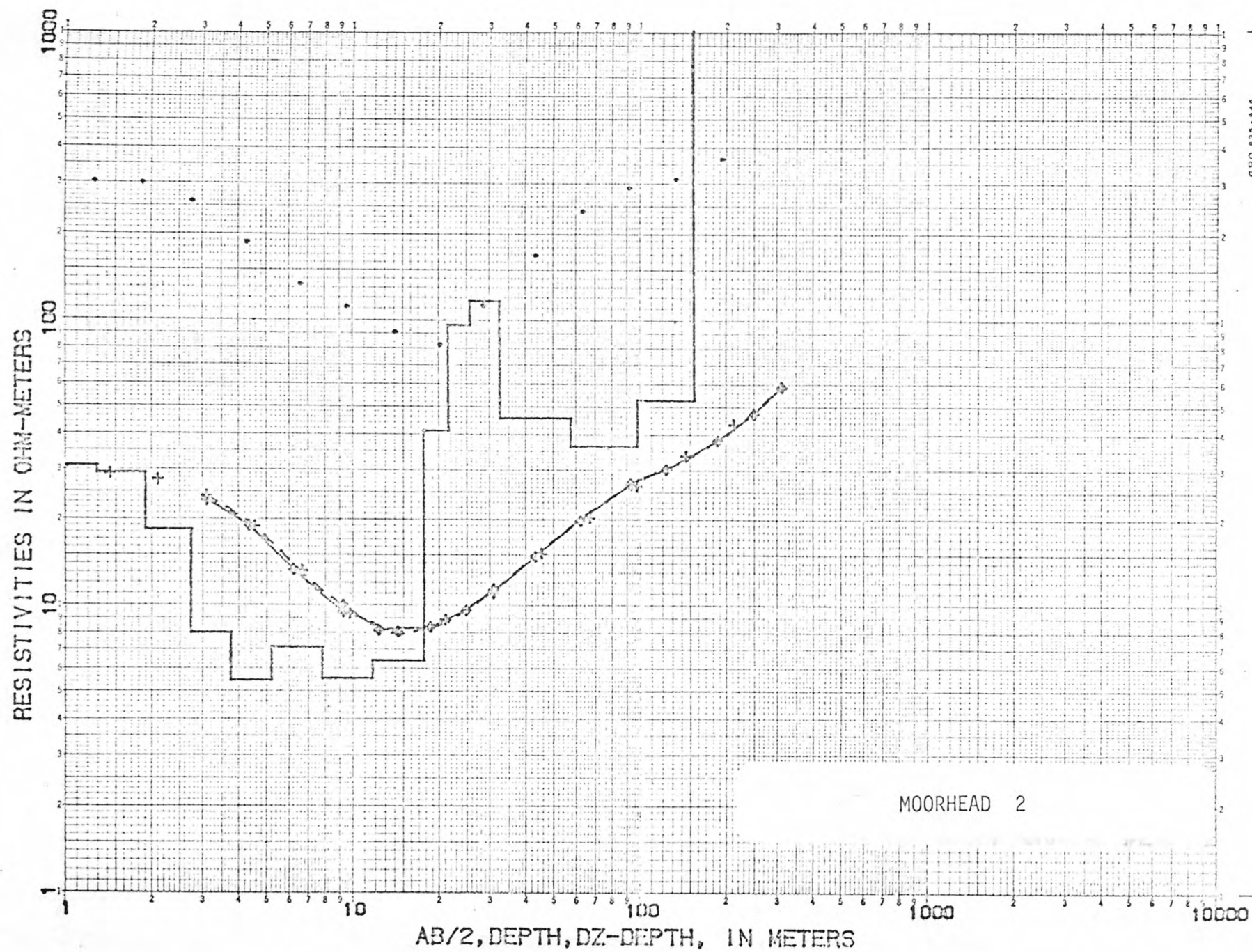
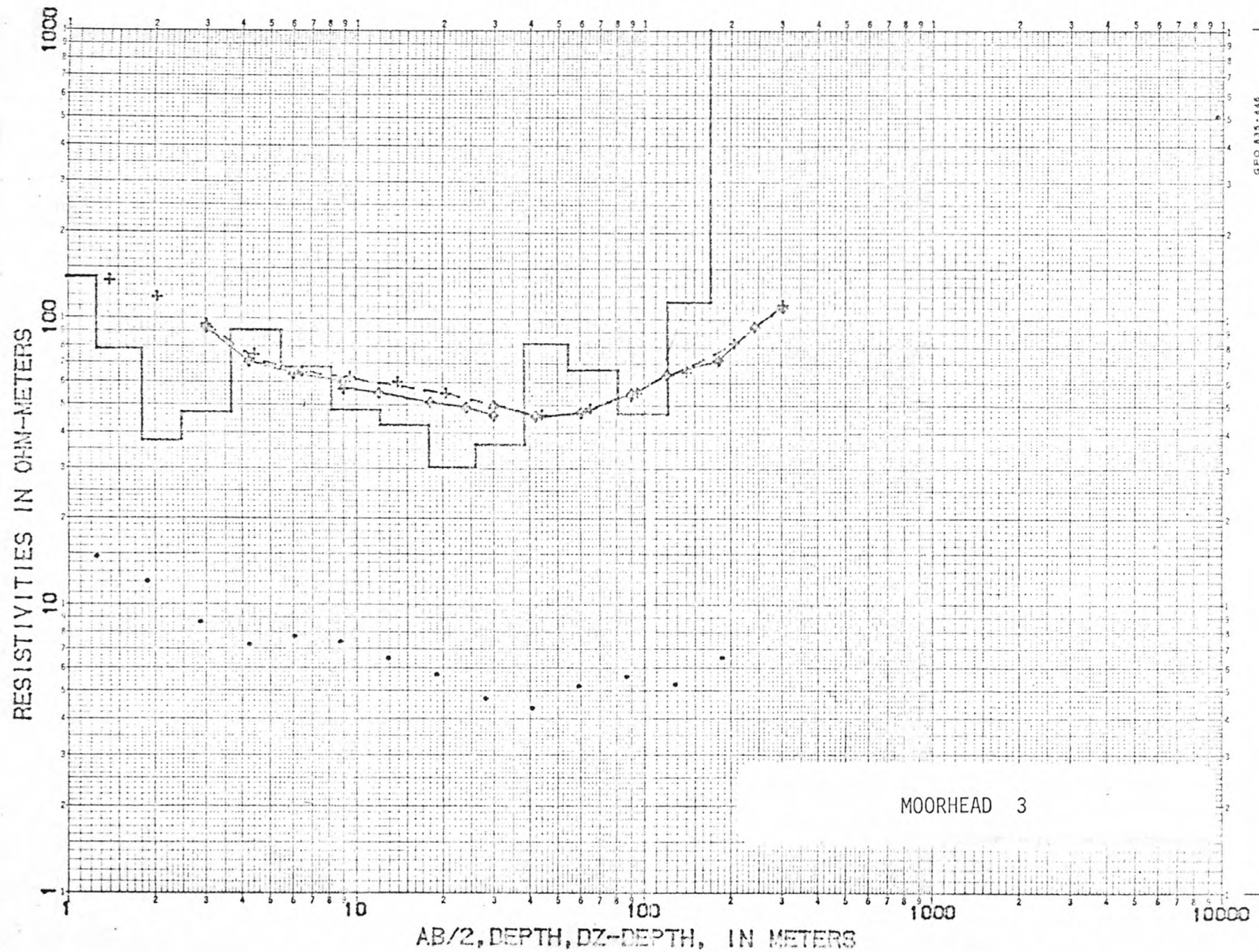


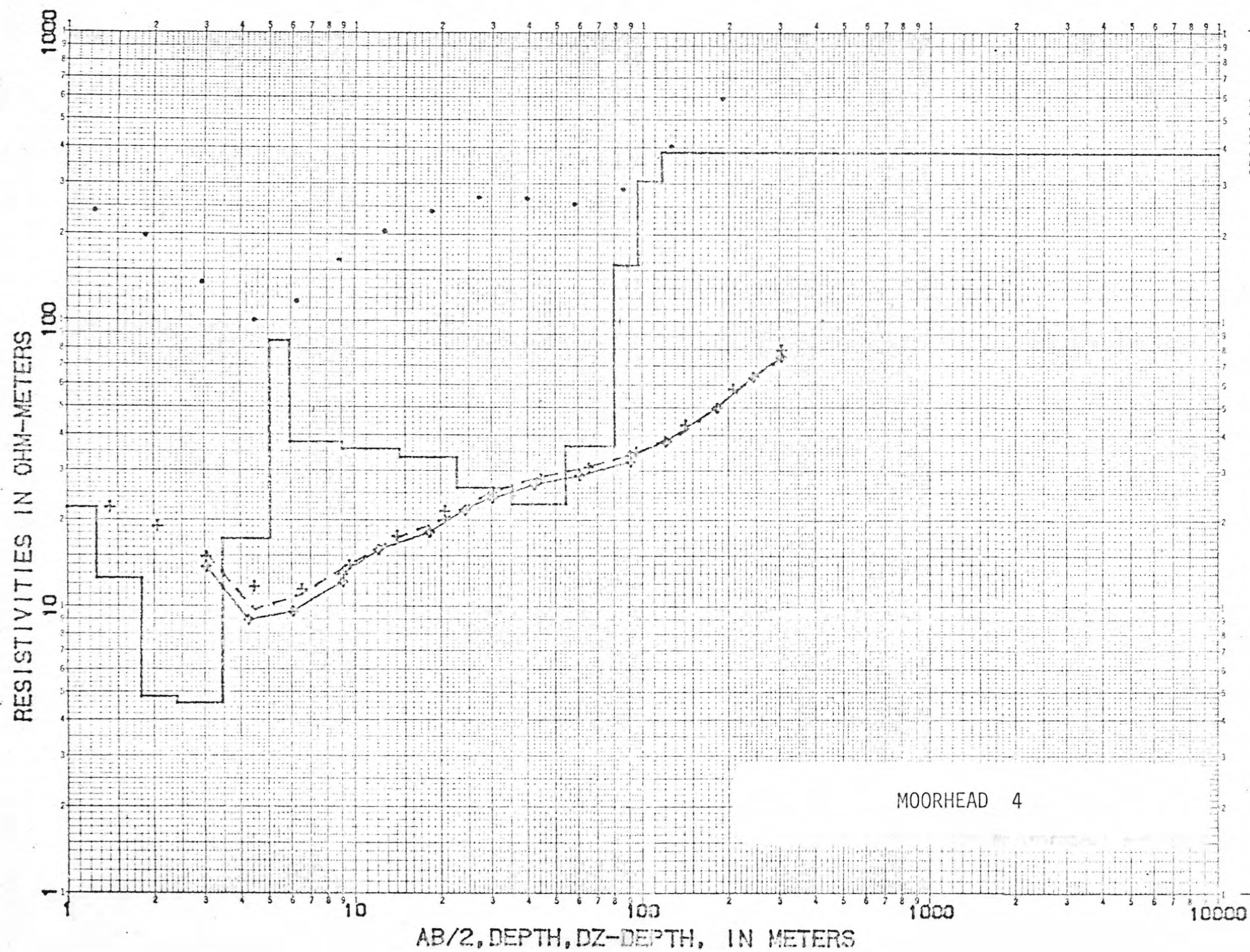
Figure 23.--Map of interpreted depth to high resistivity (≥ 100 ohm-m) electric basement. Contours in meters. Near Moorhead, Minnesota.

APPENDIX

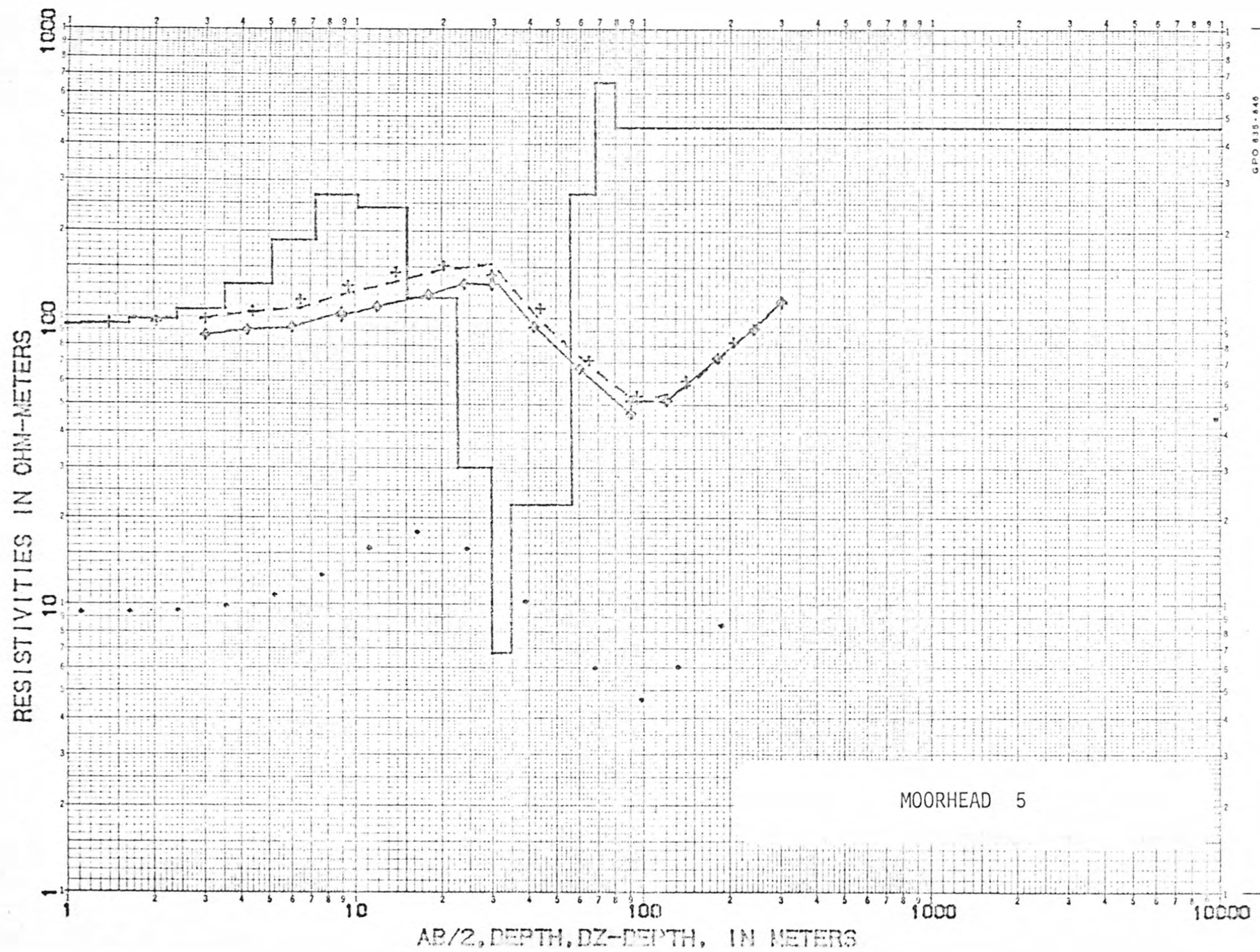


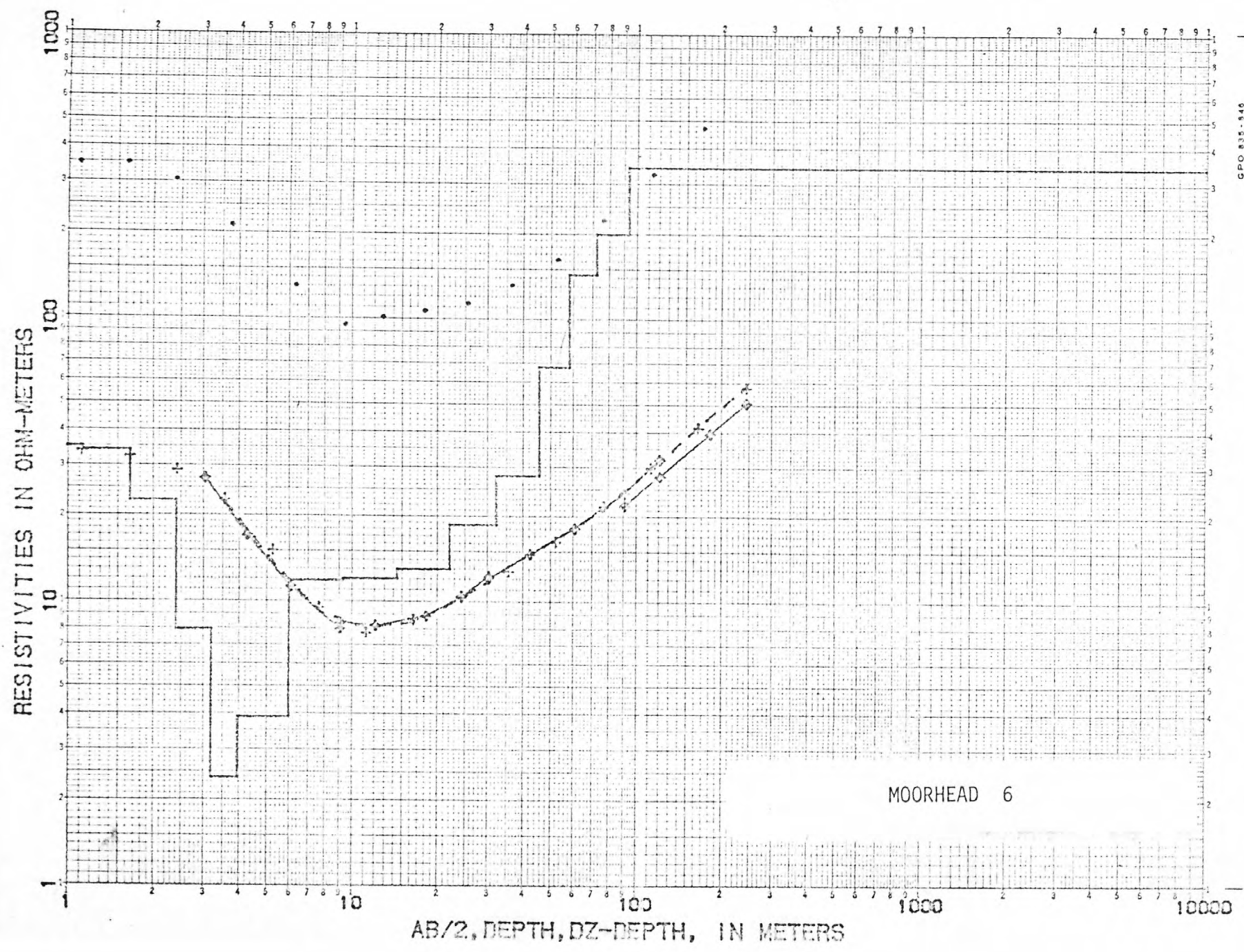


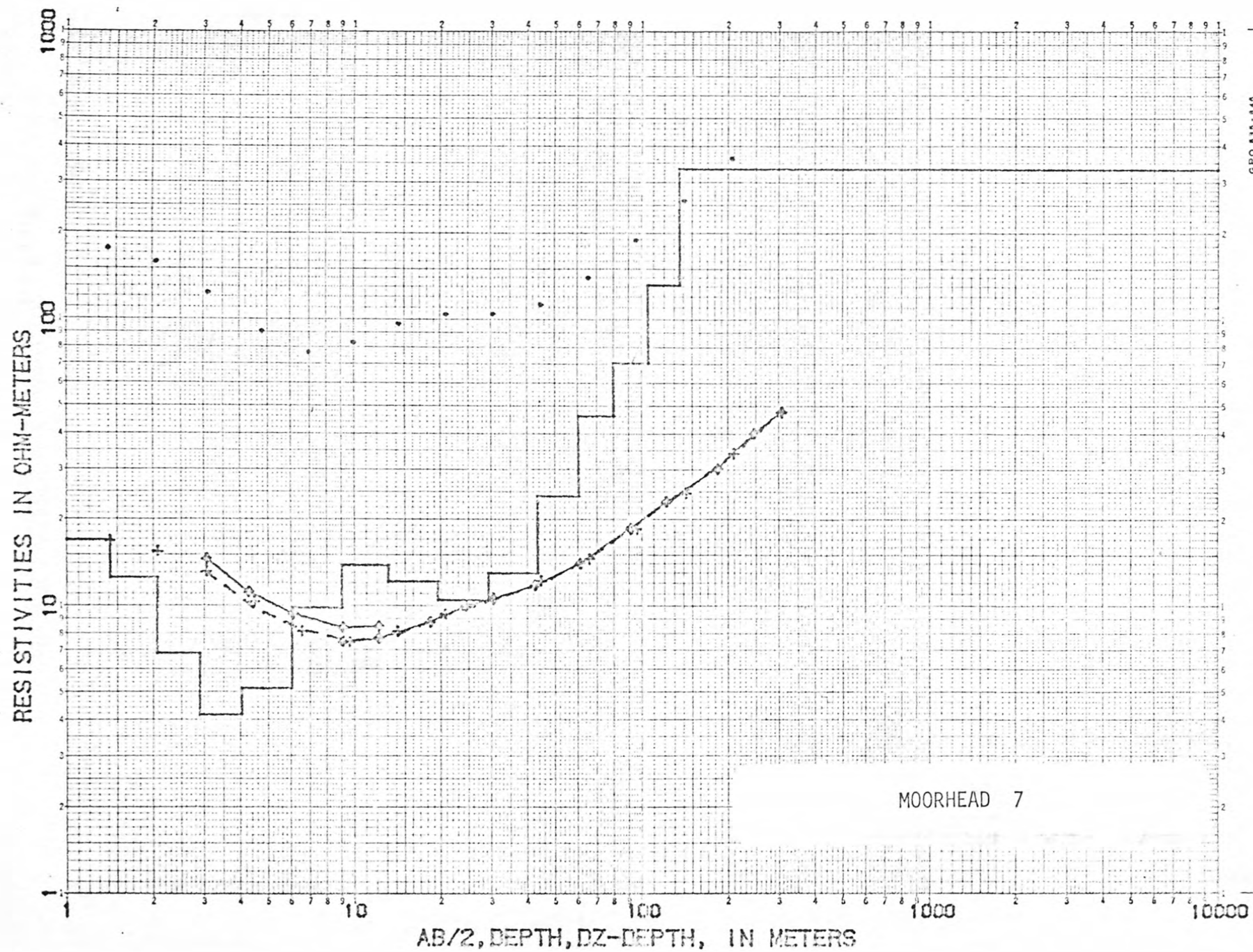


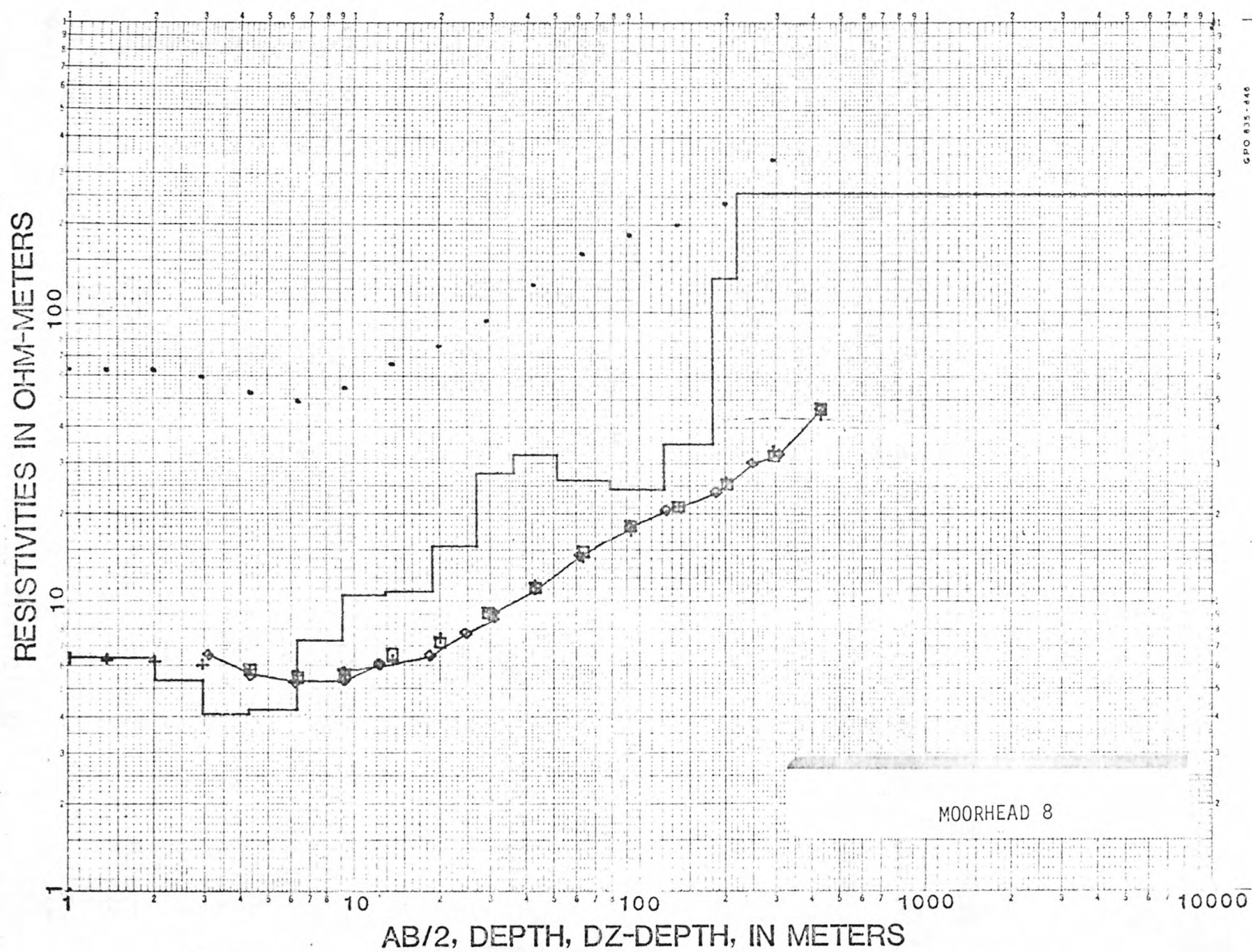


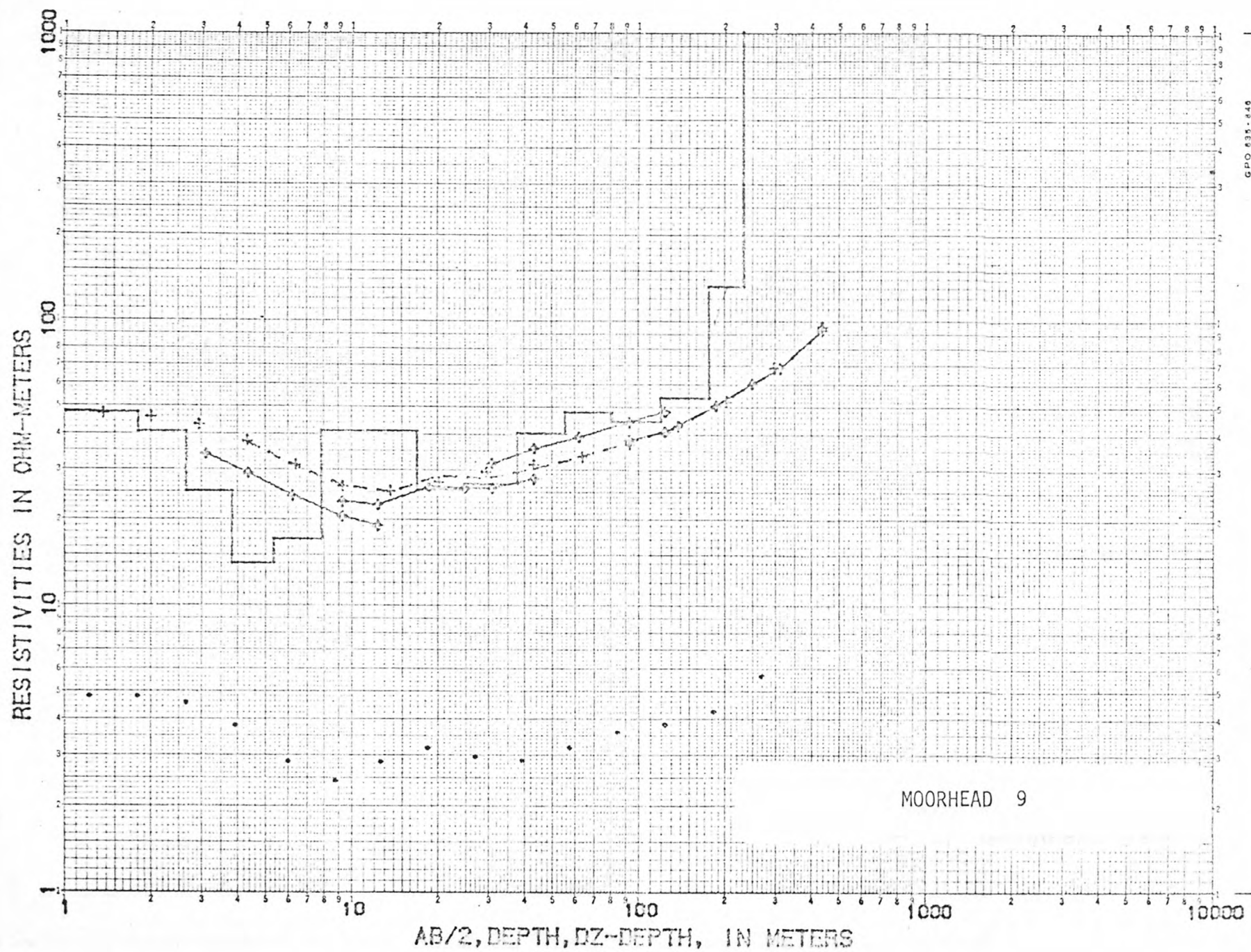
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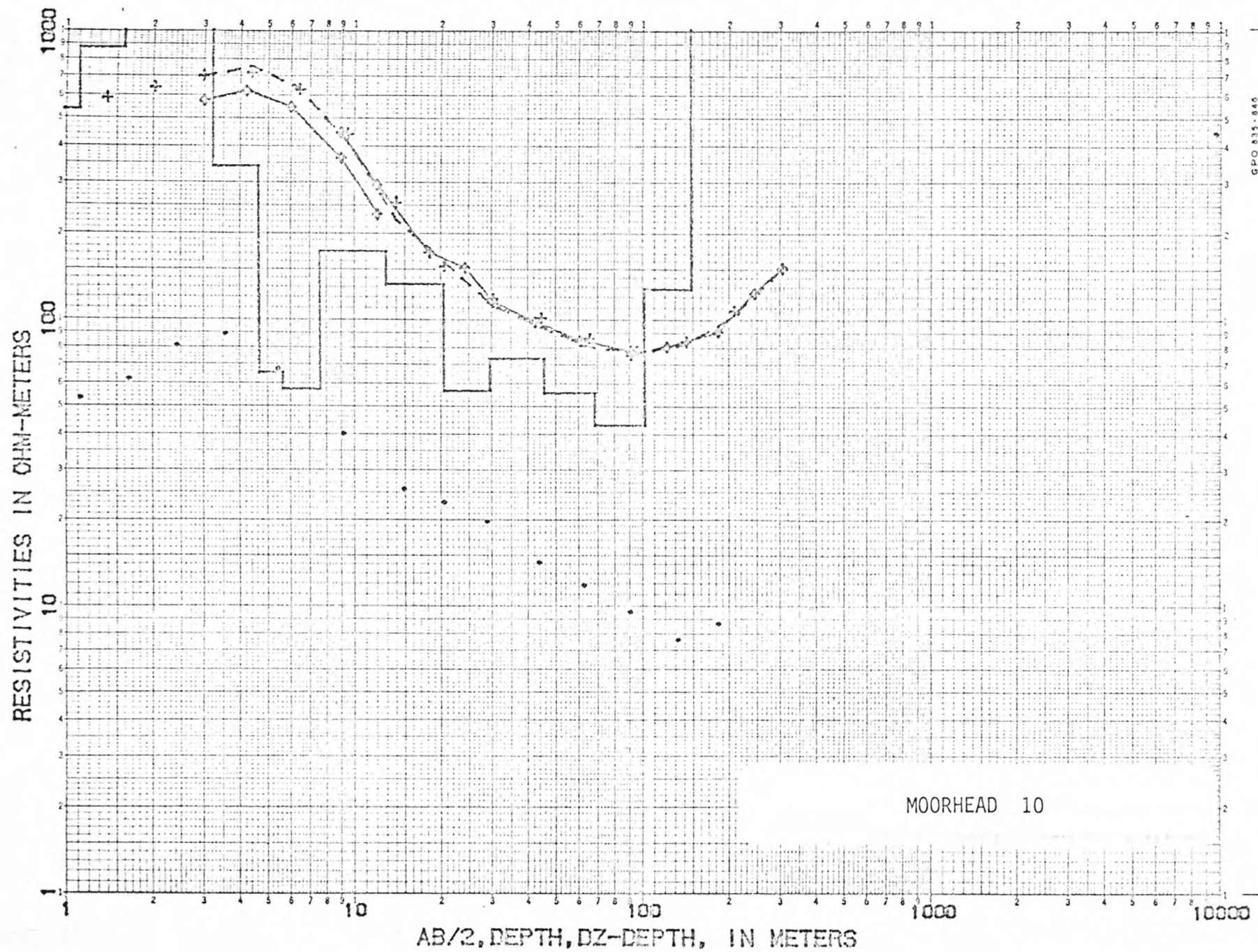


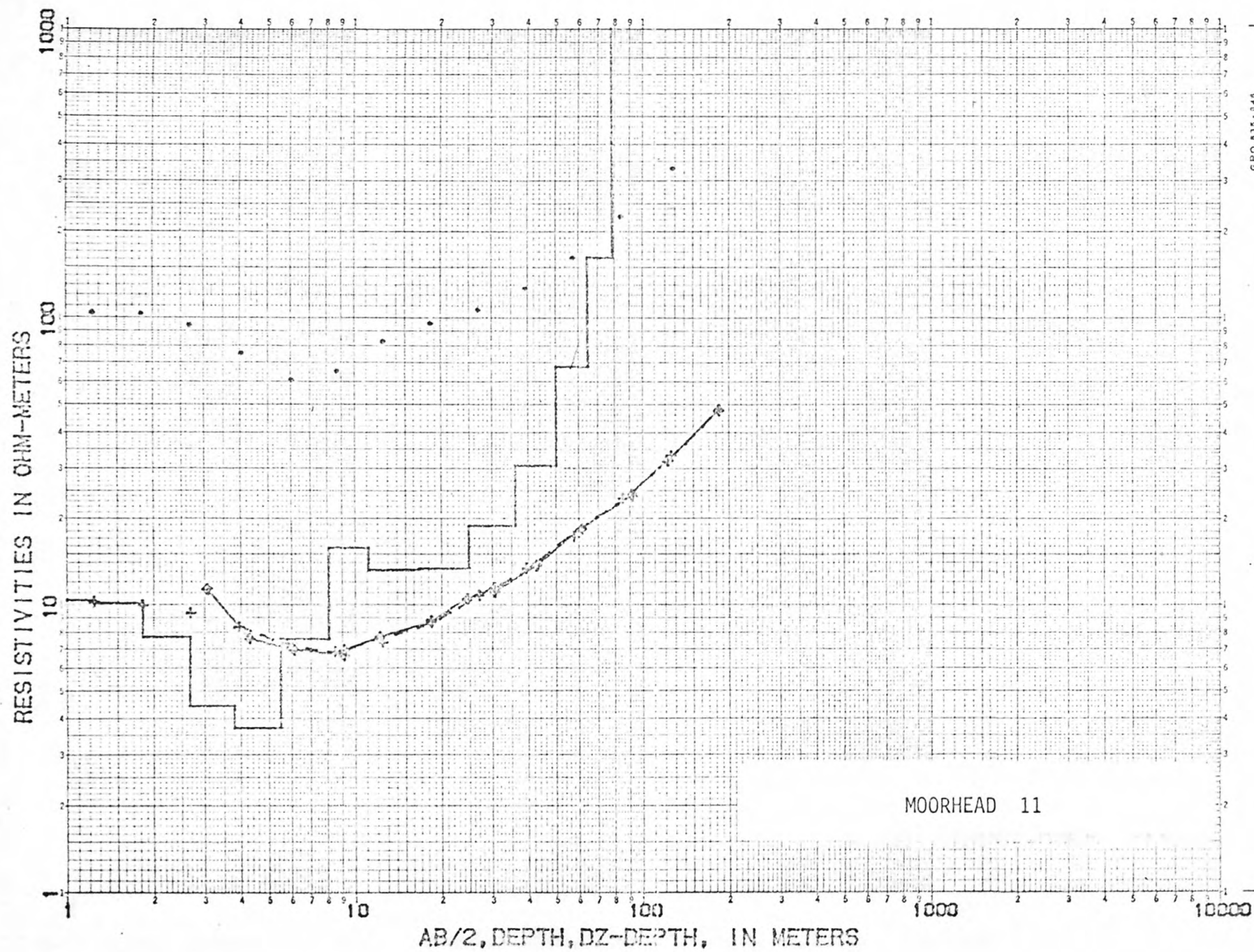


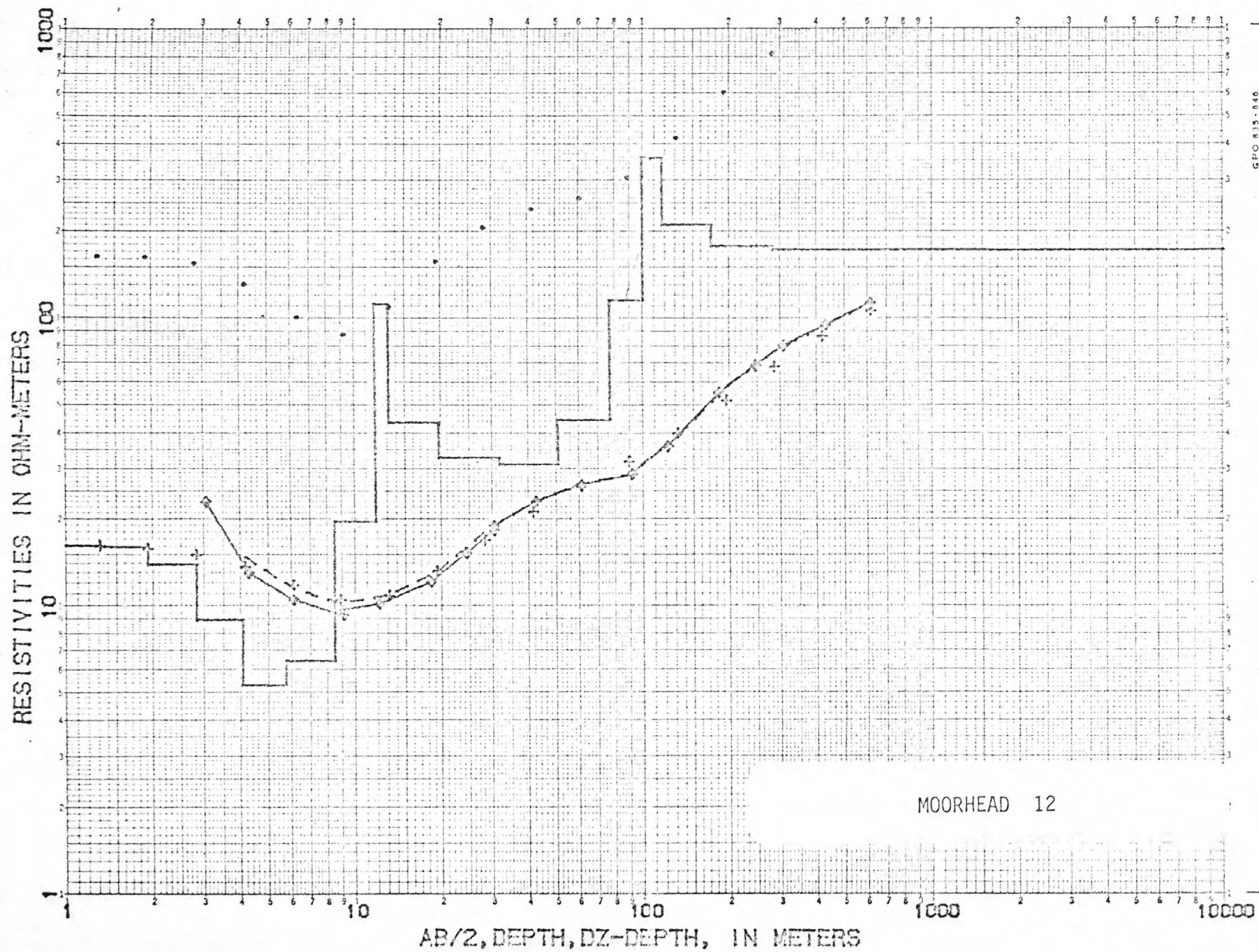


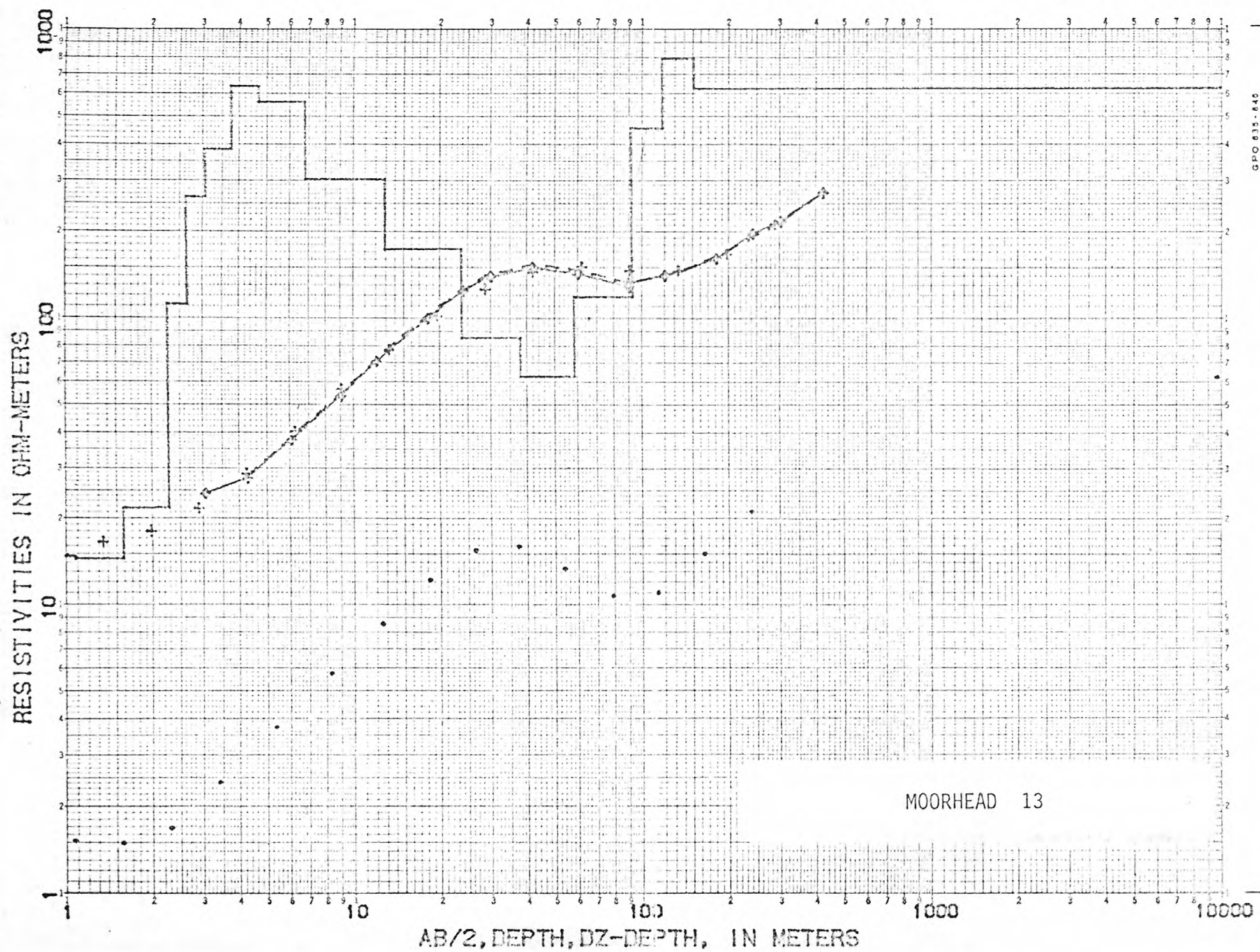




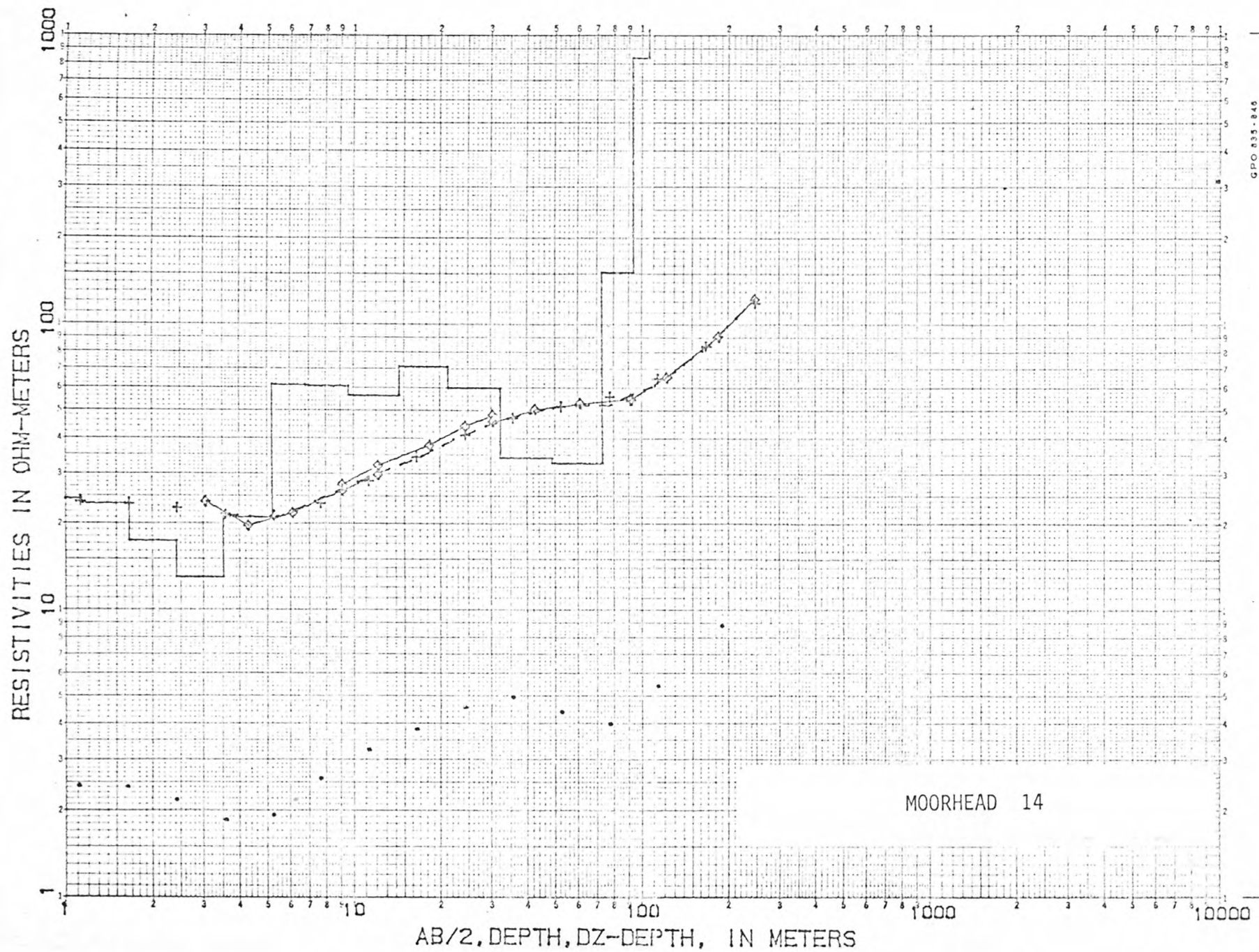


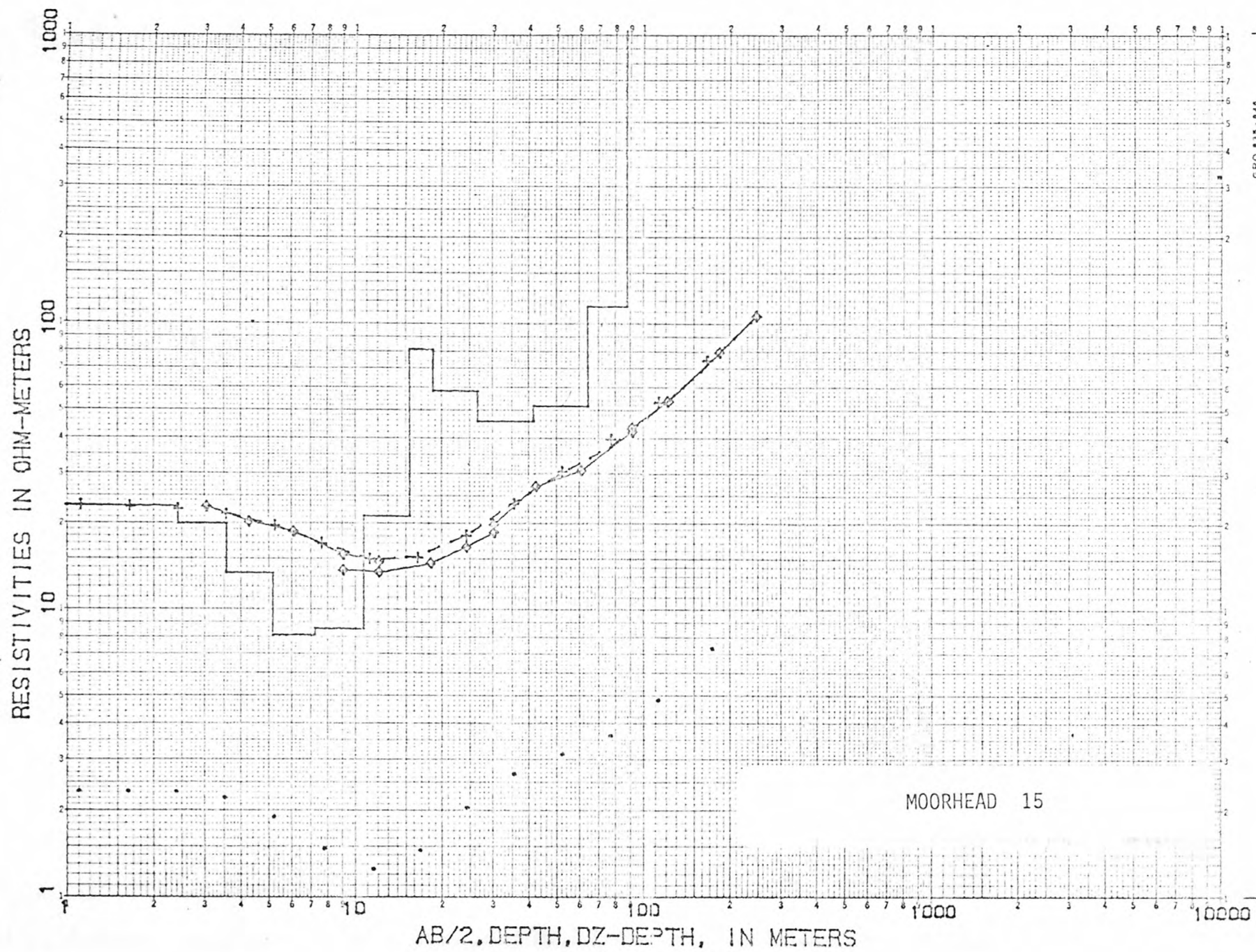


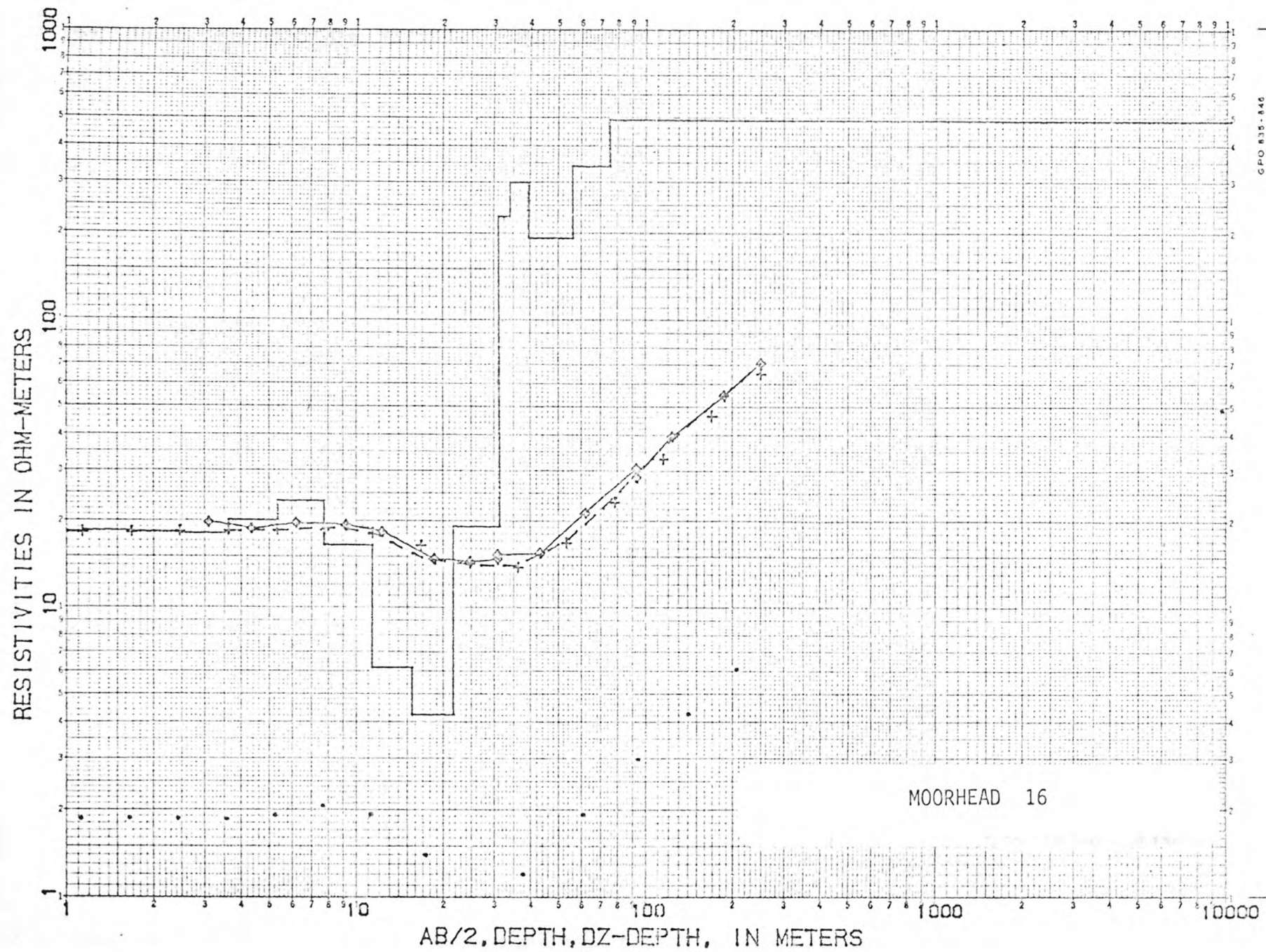


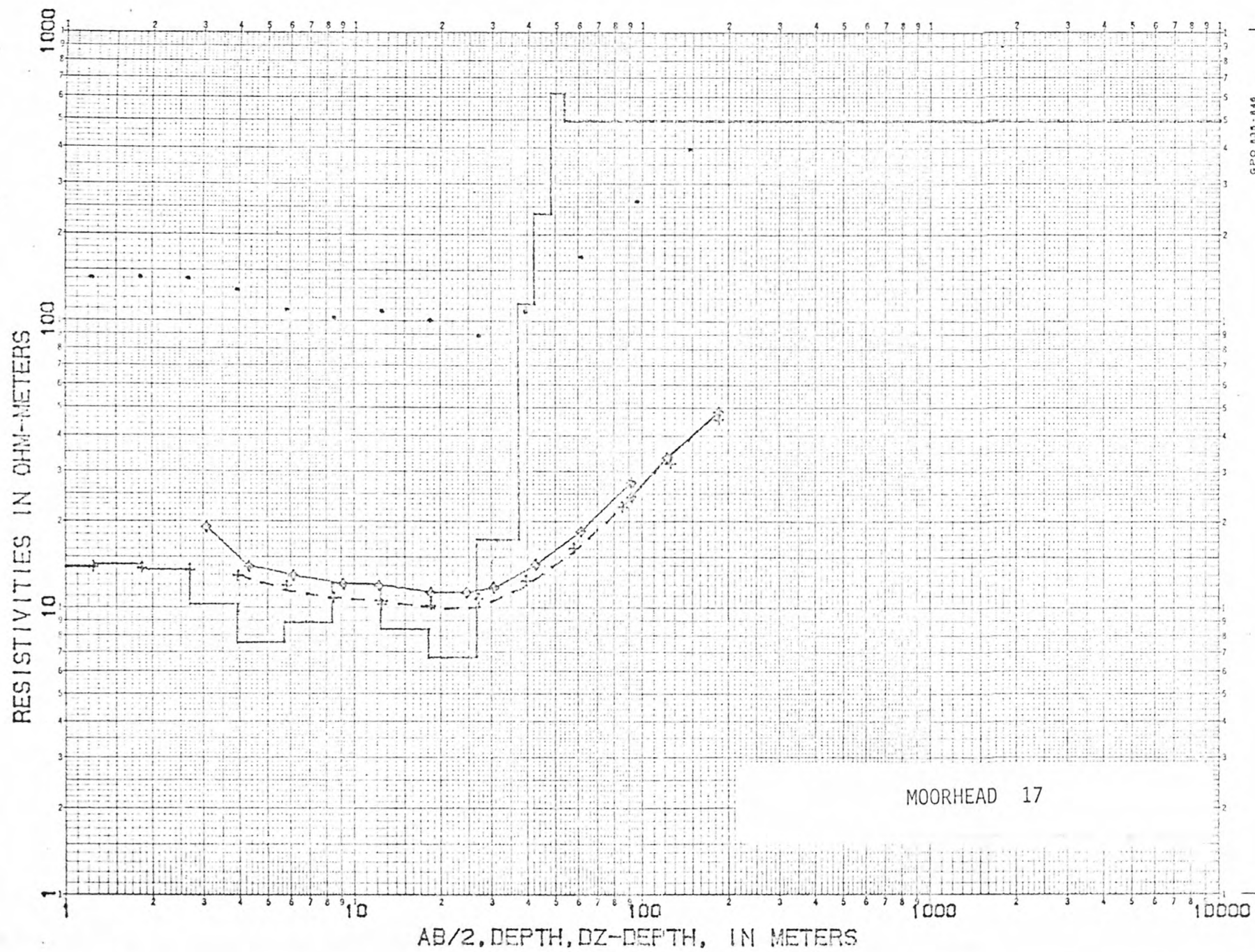


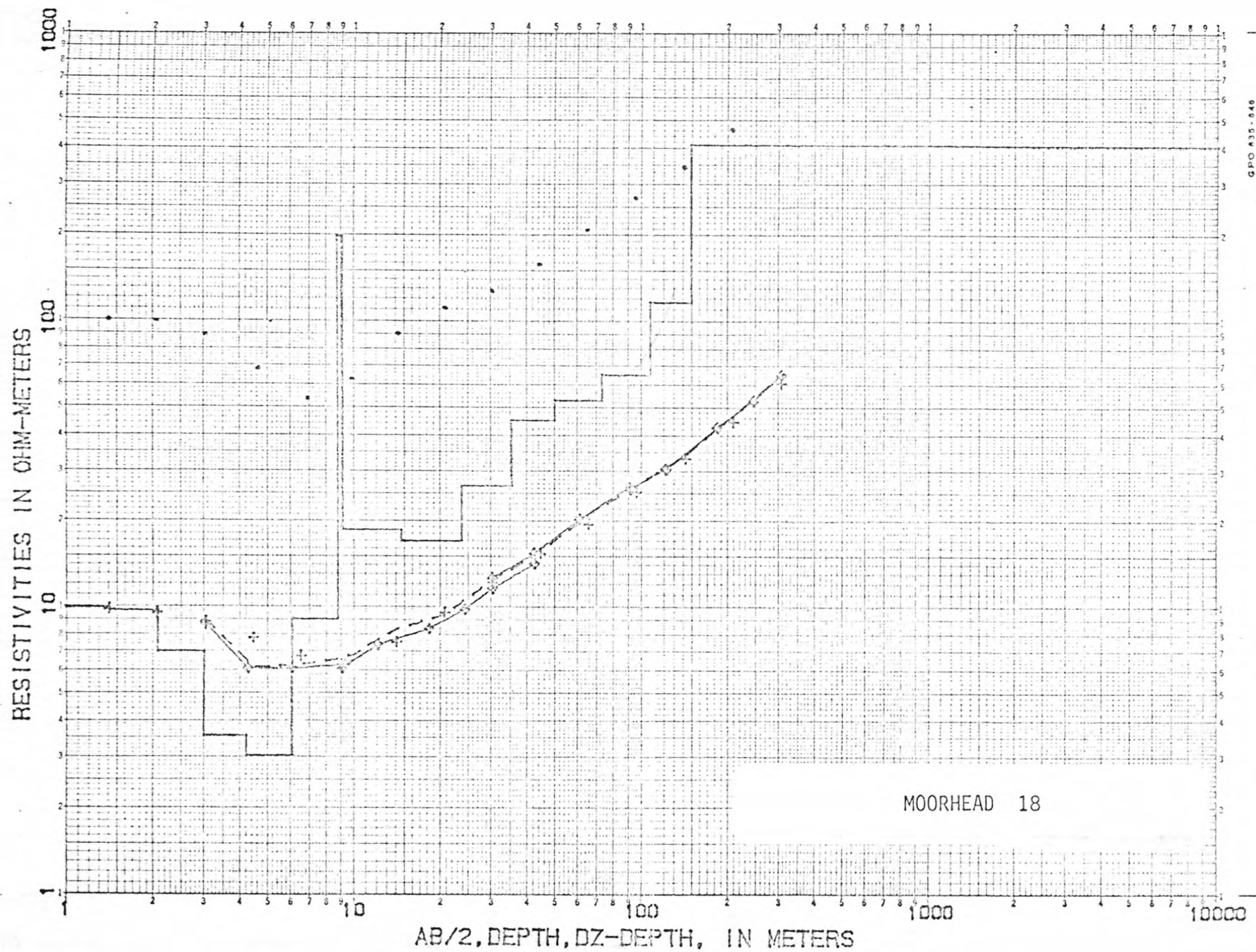
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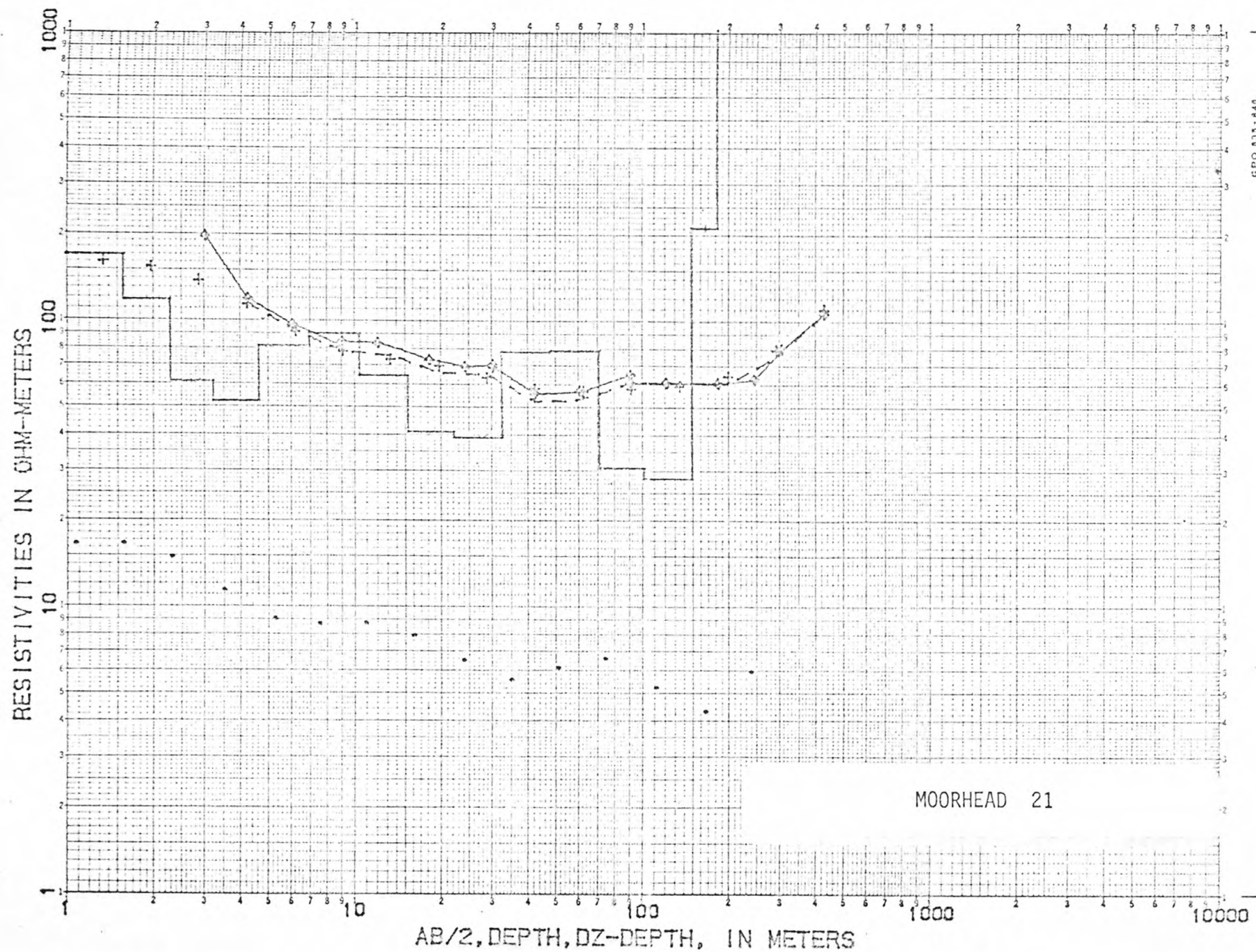


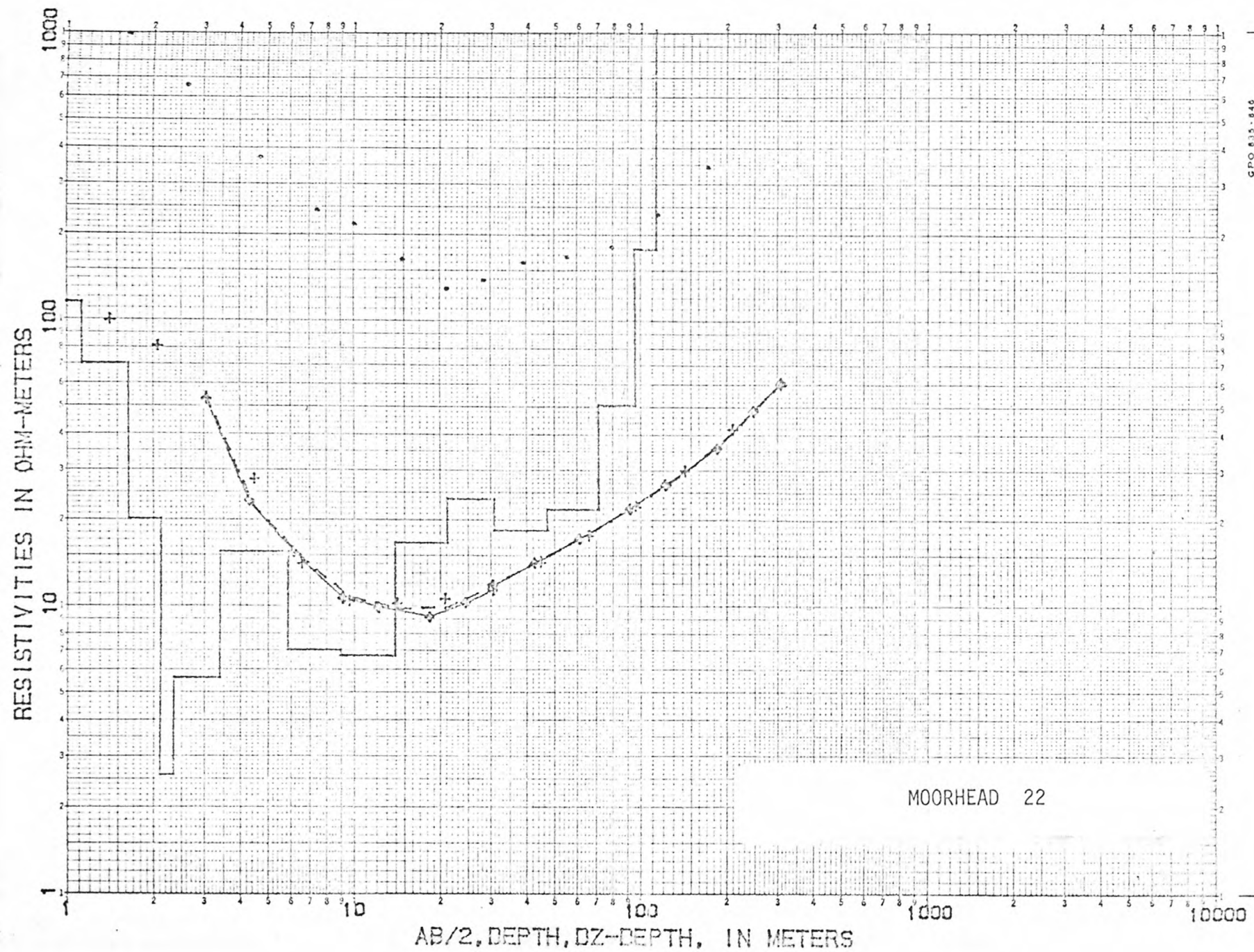


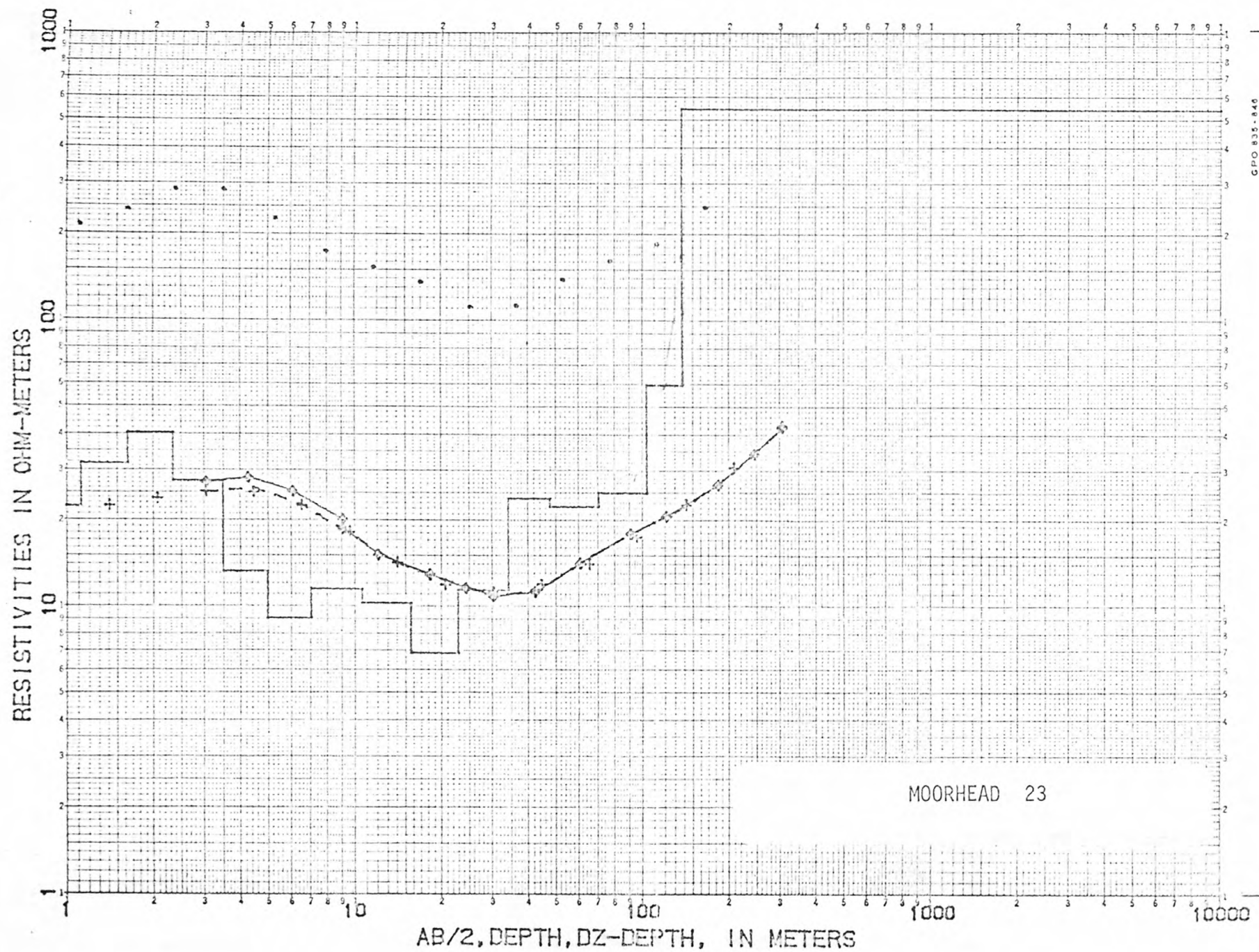




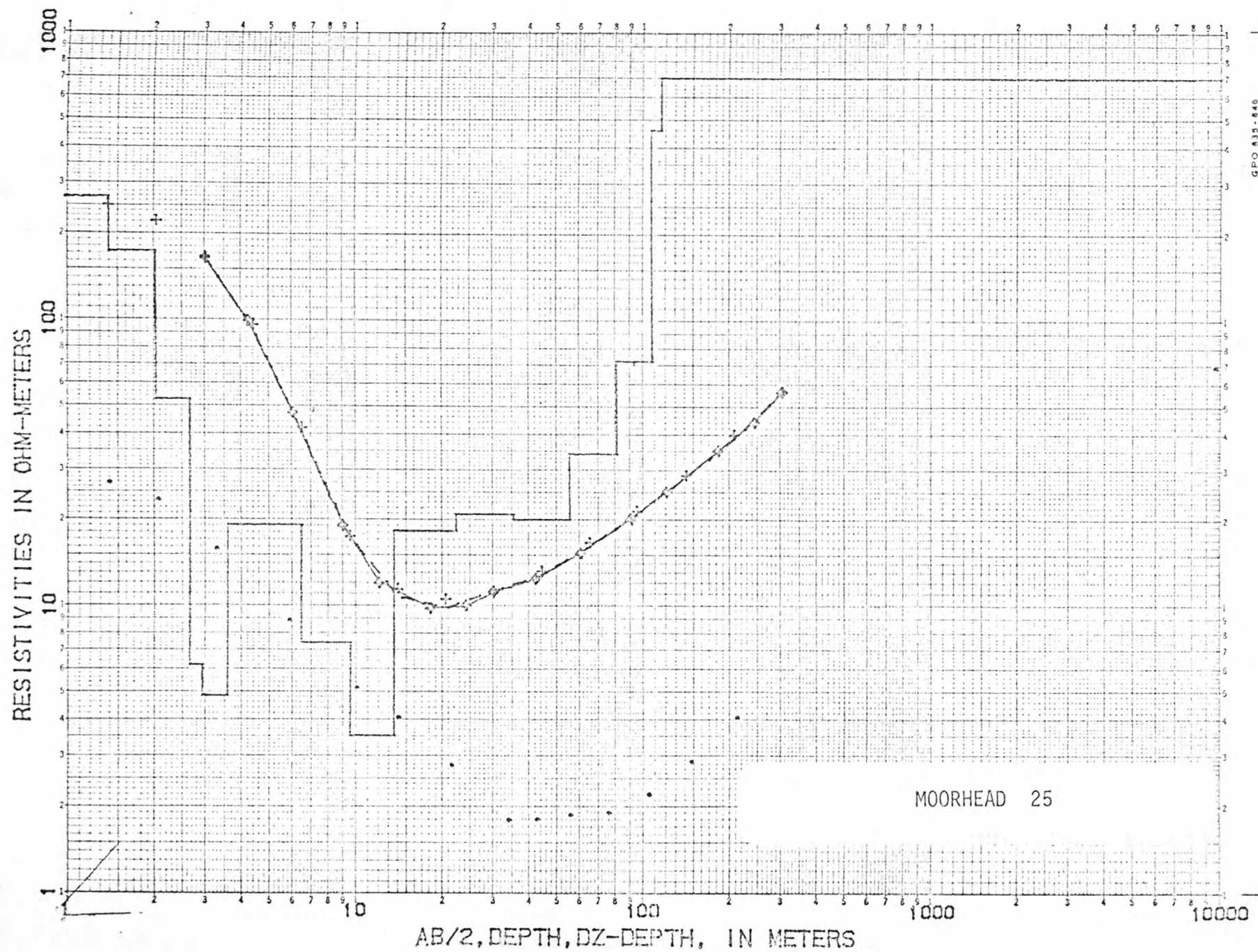


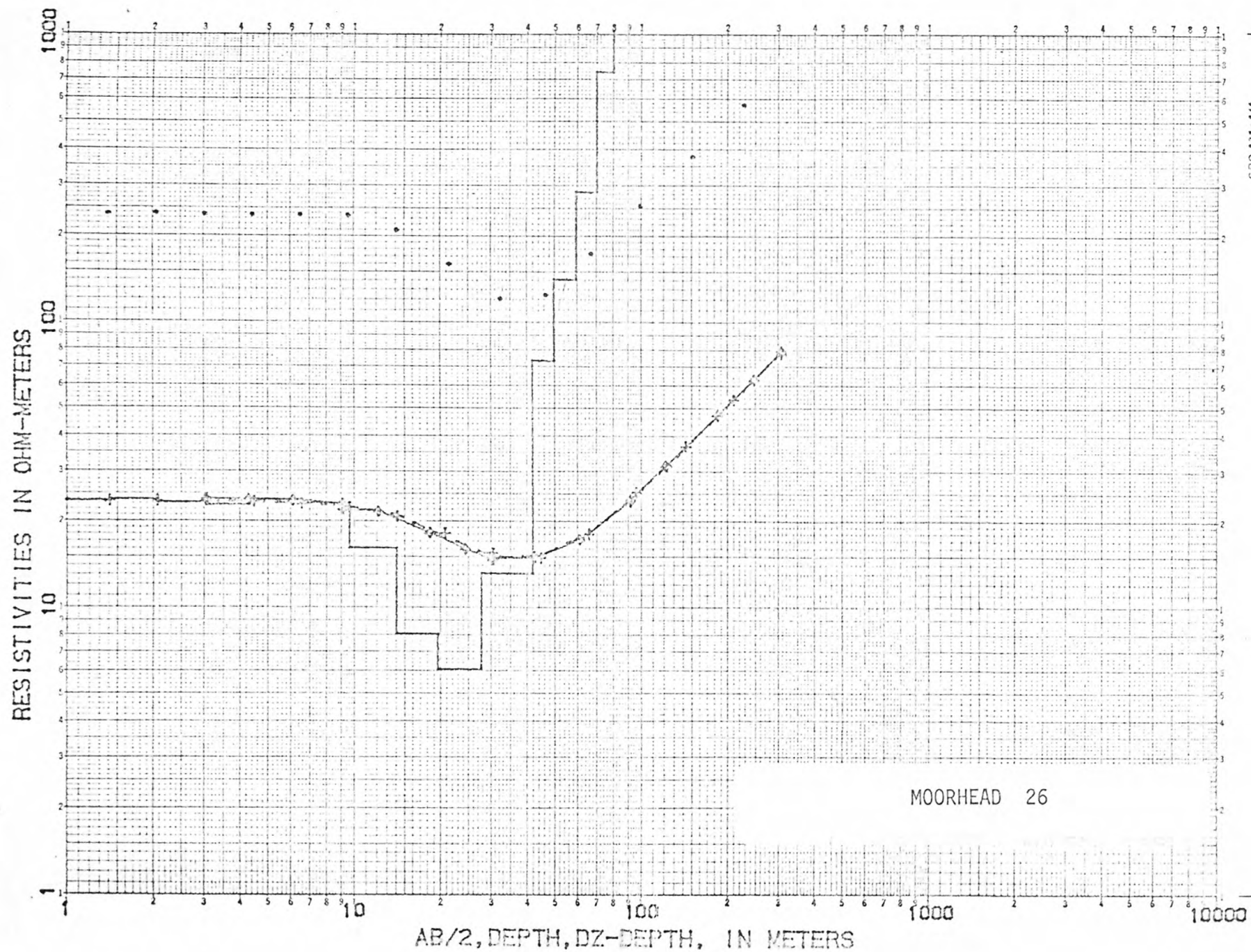


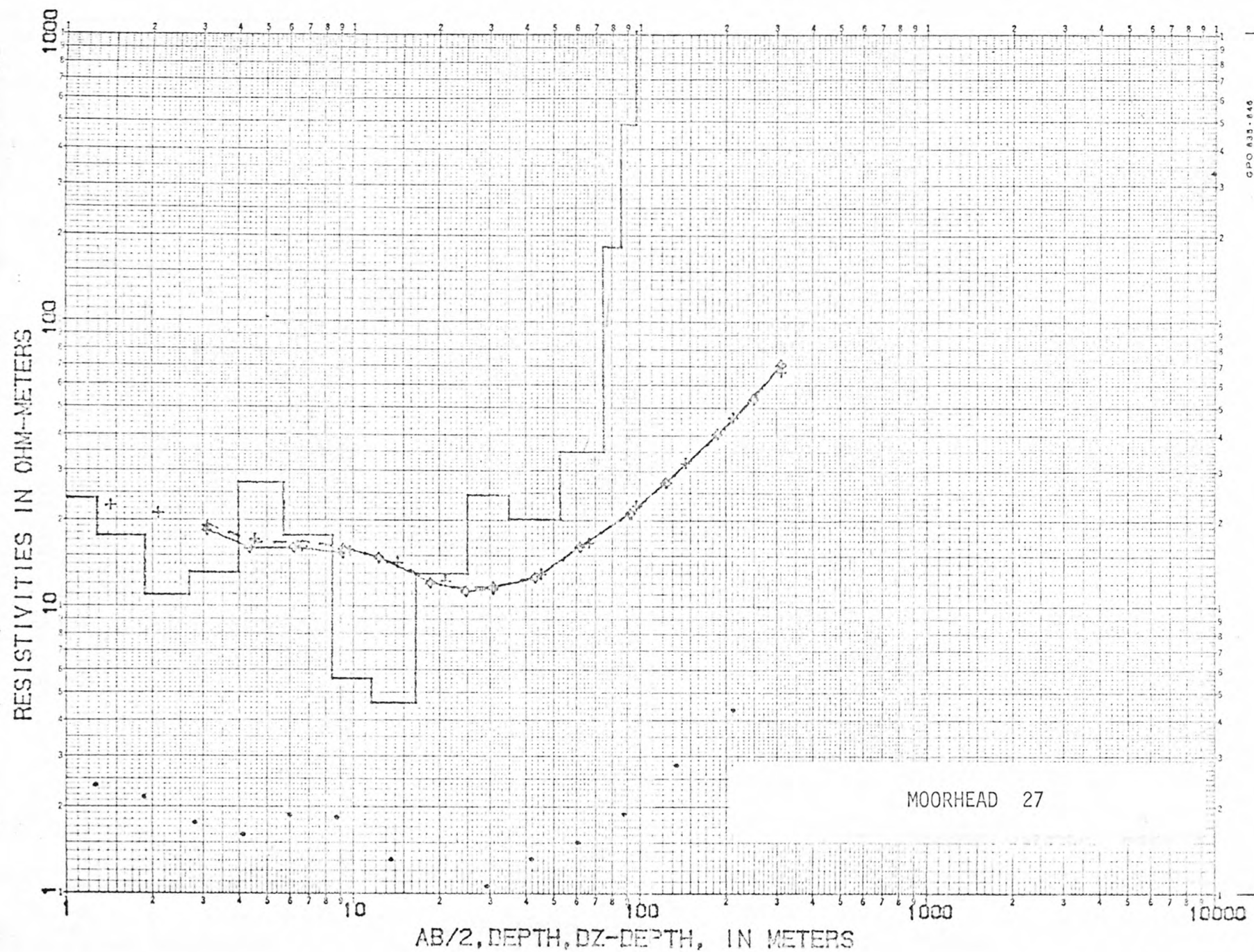


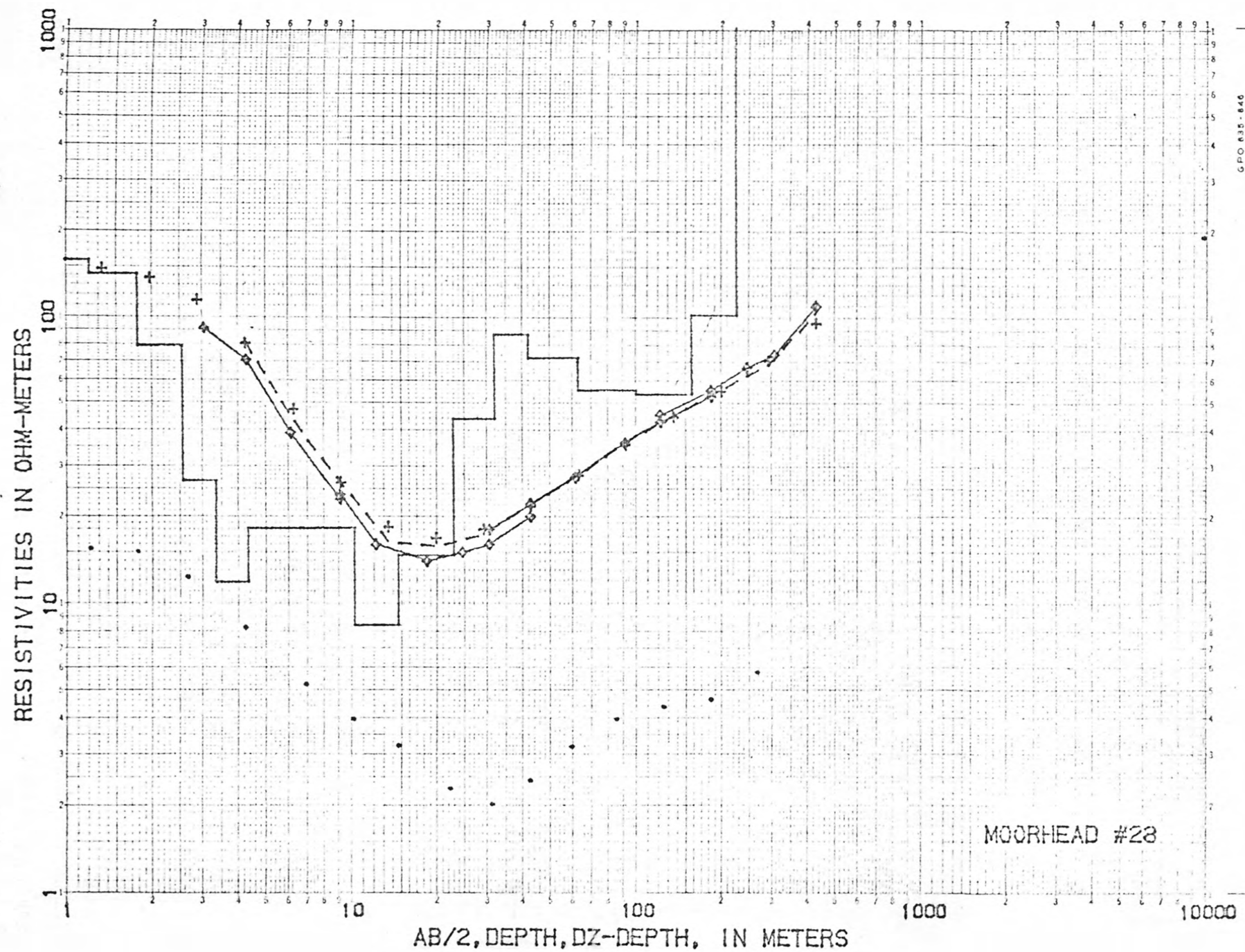


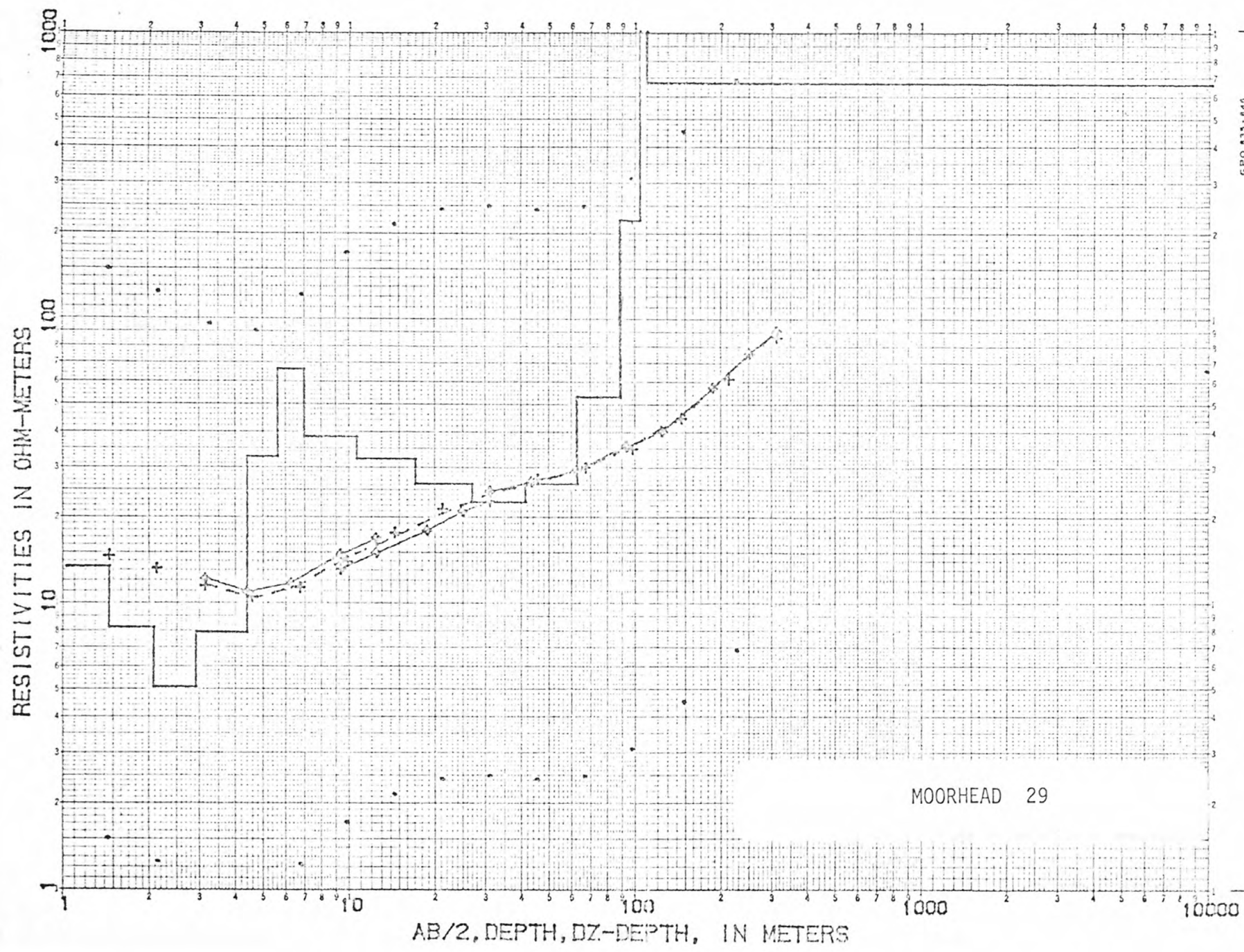


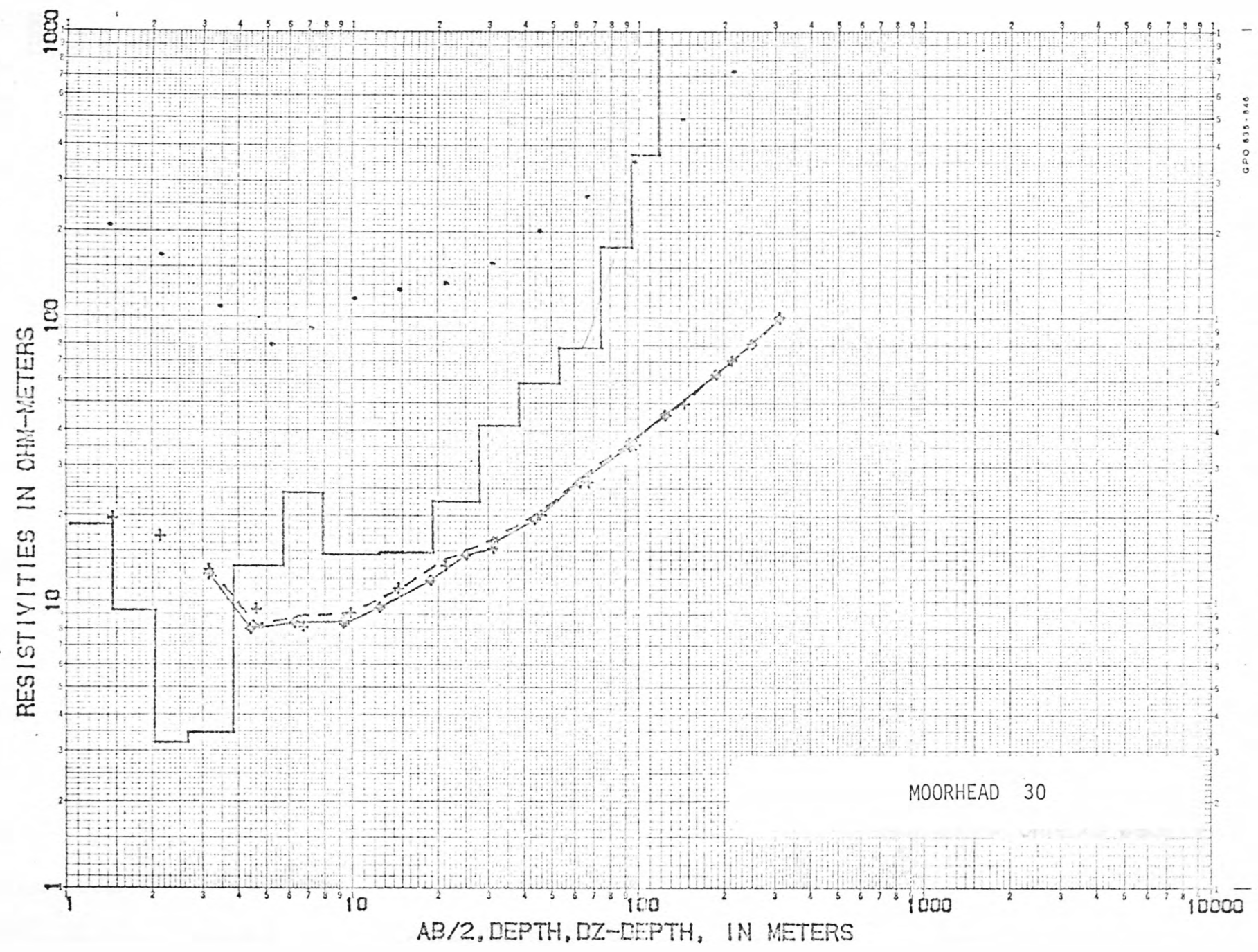


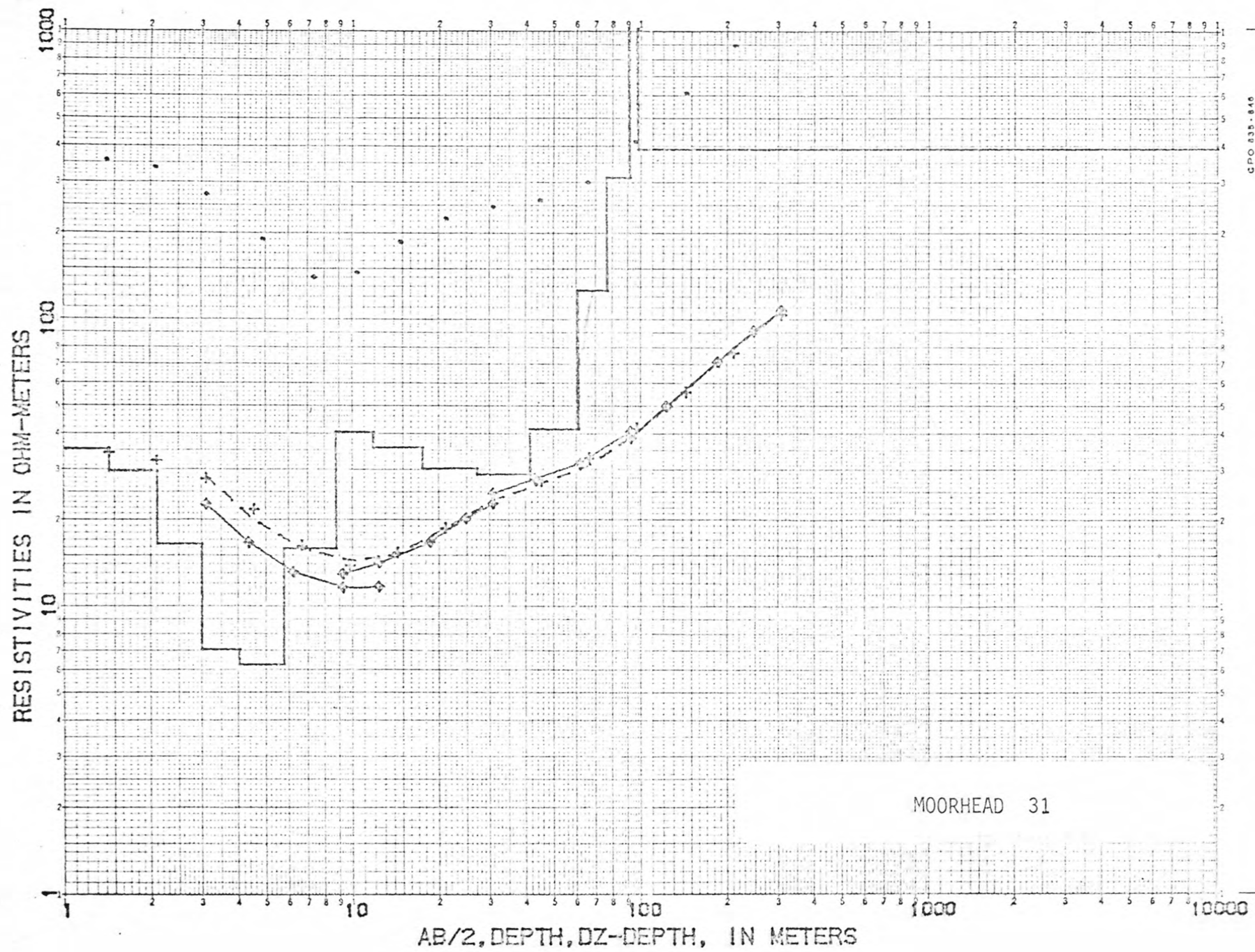


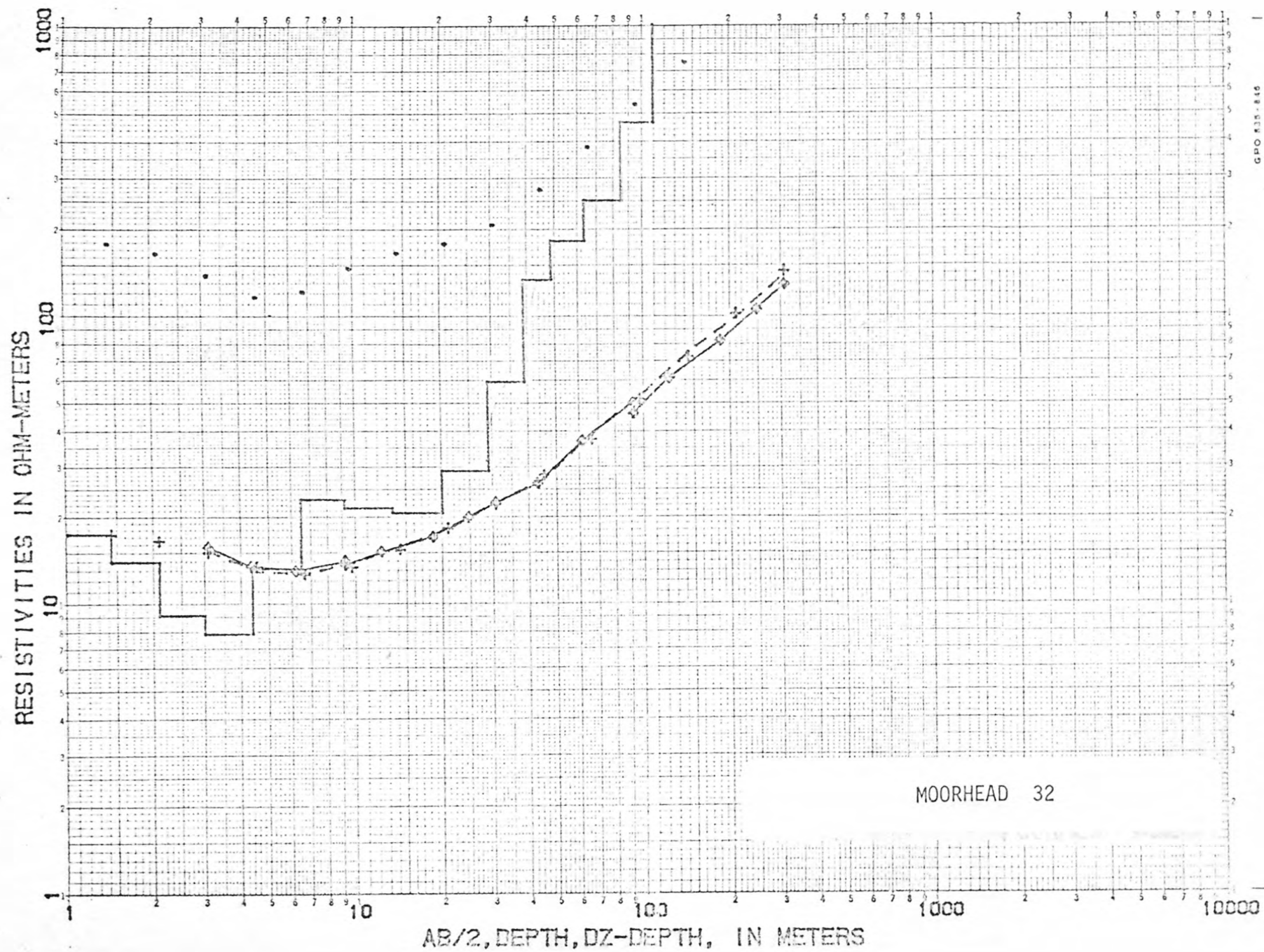


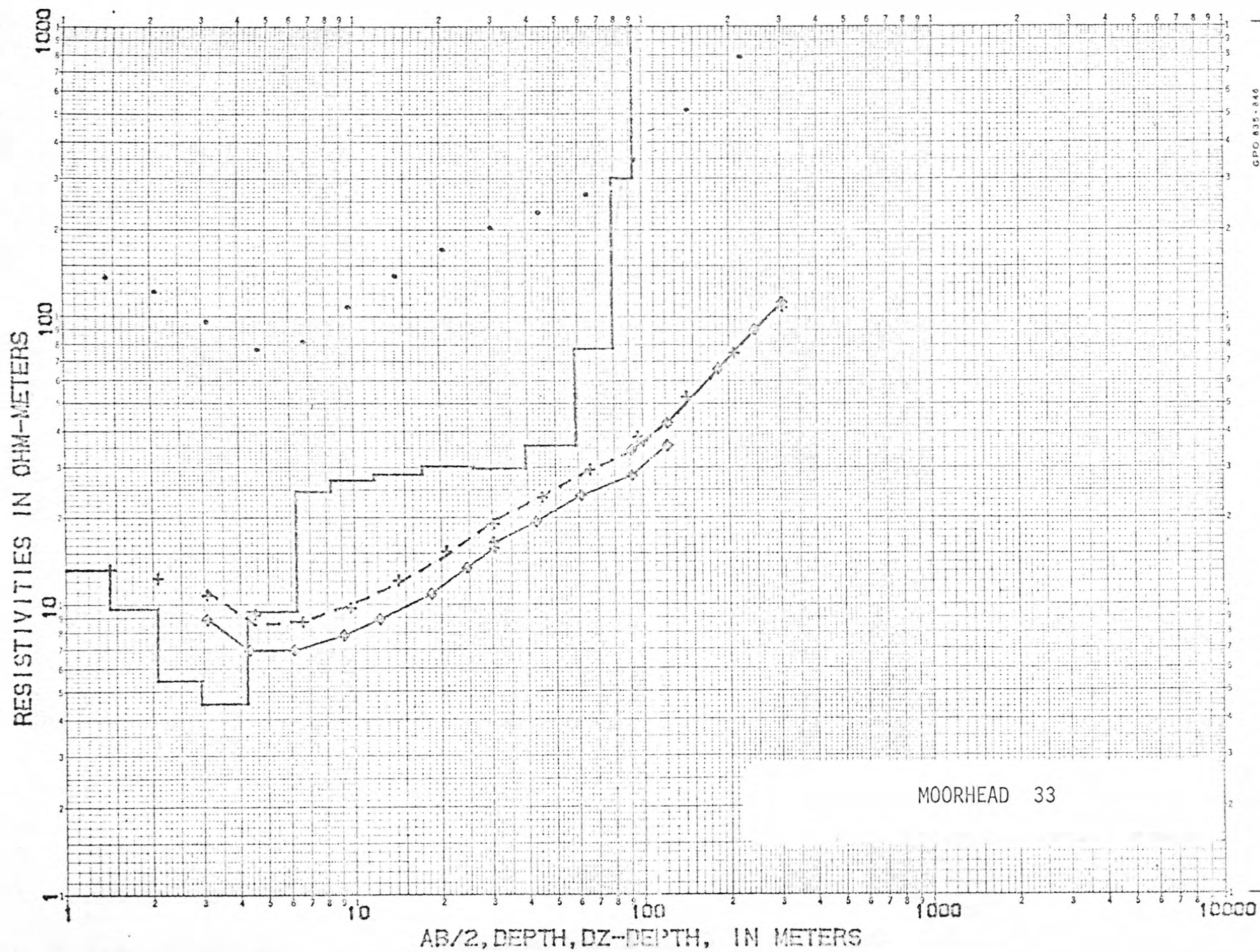


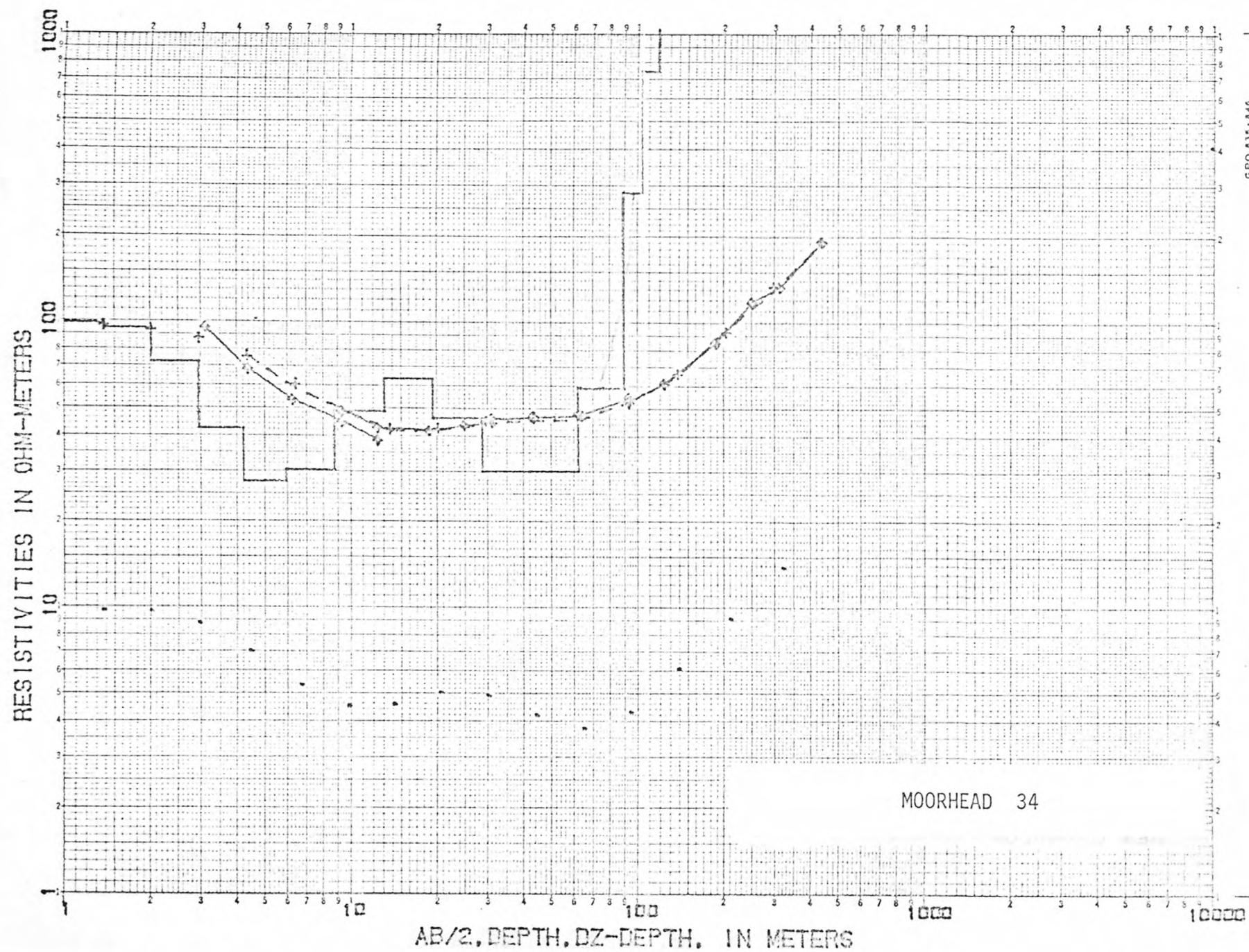


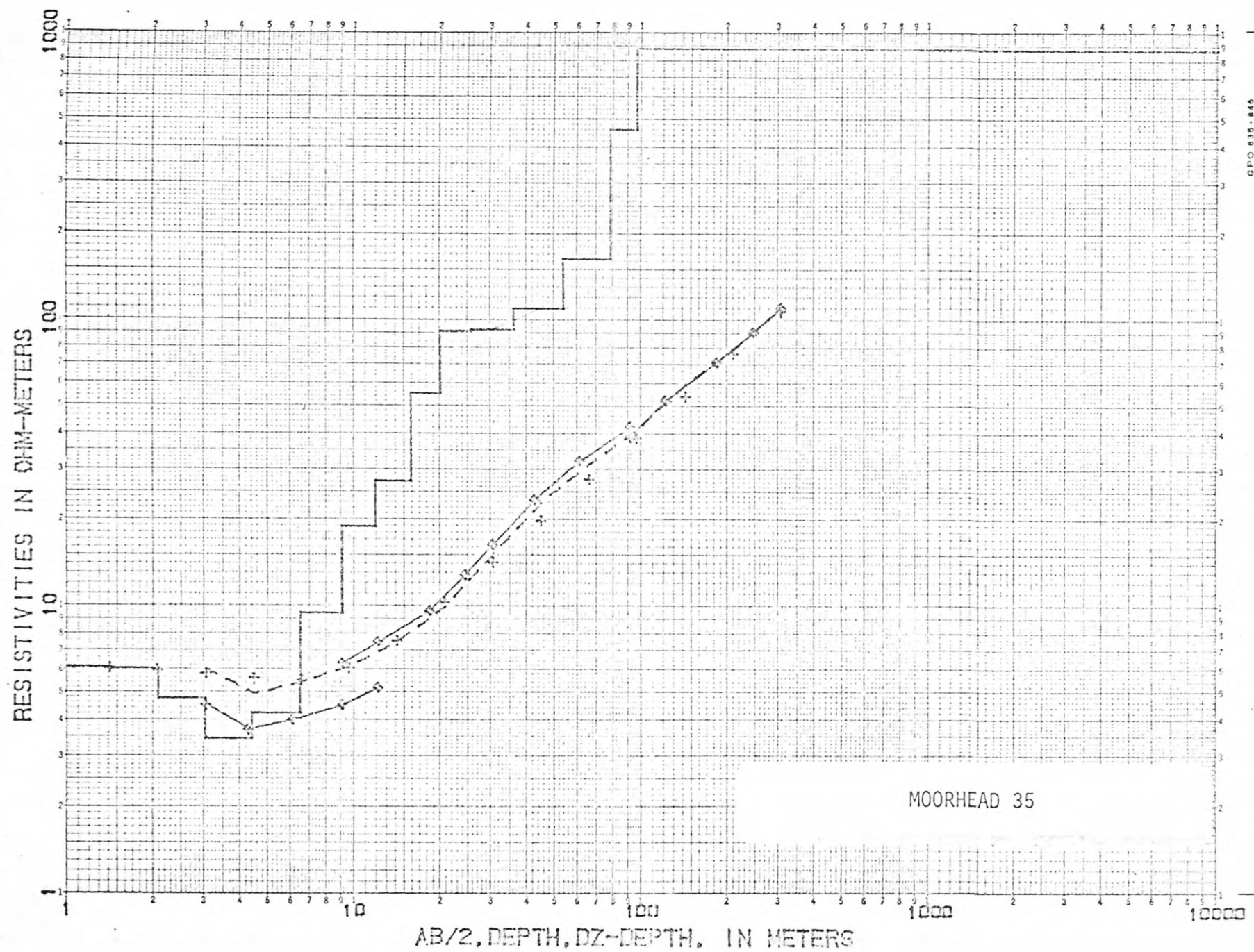


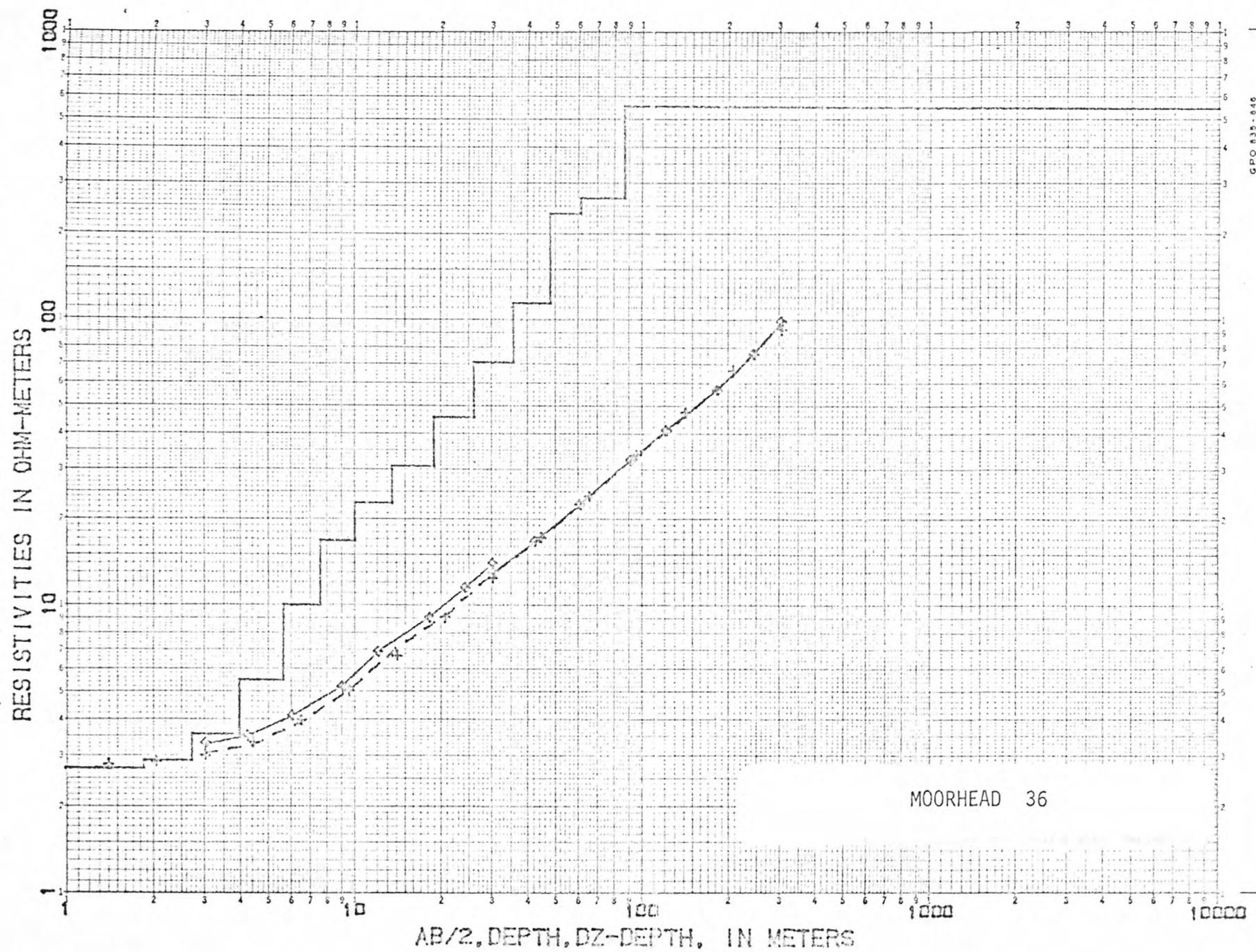


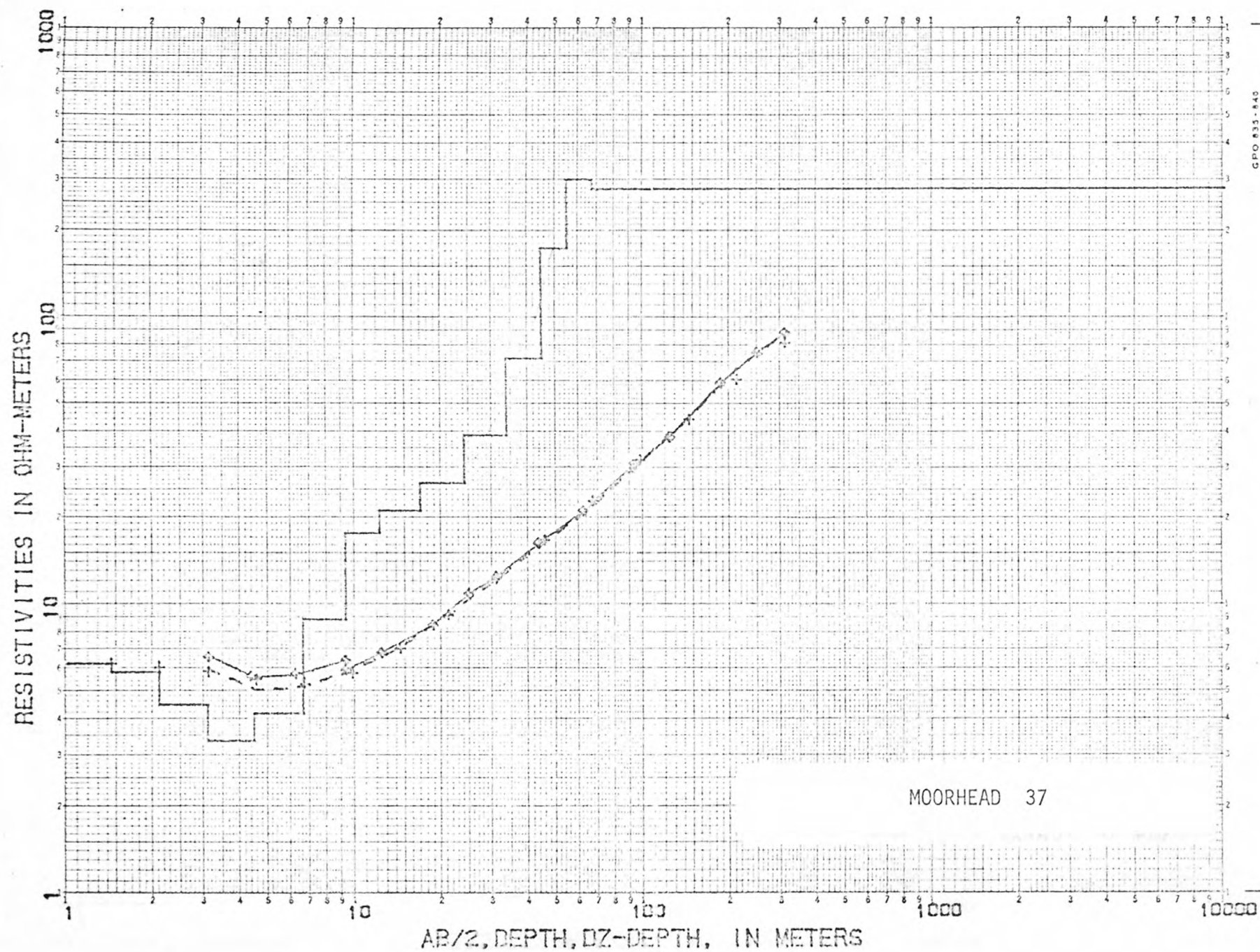




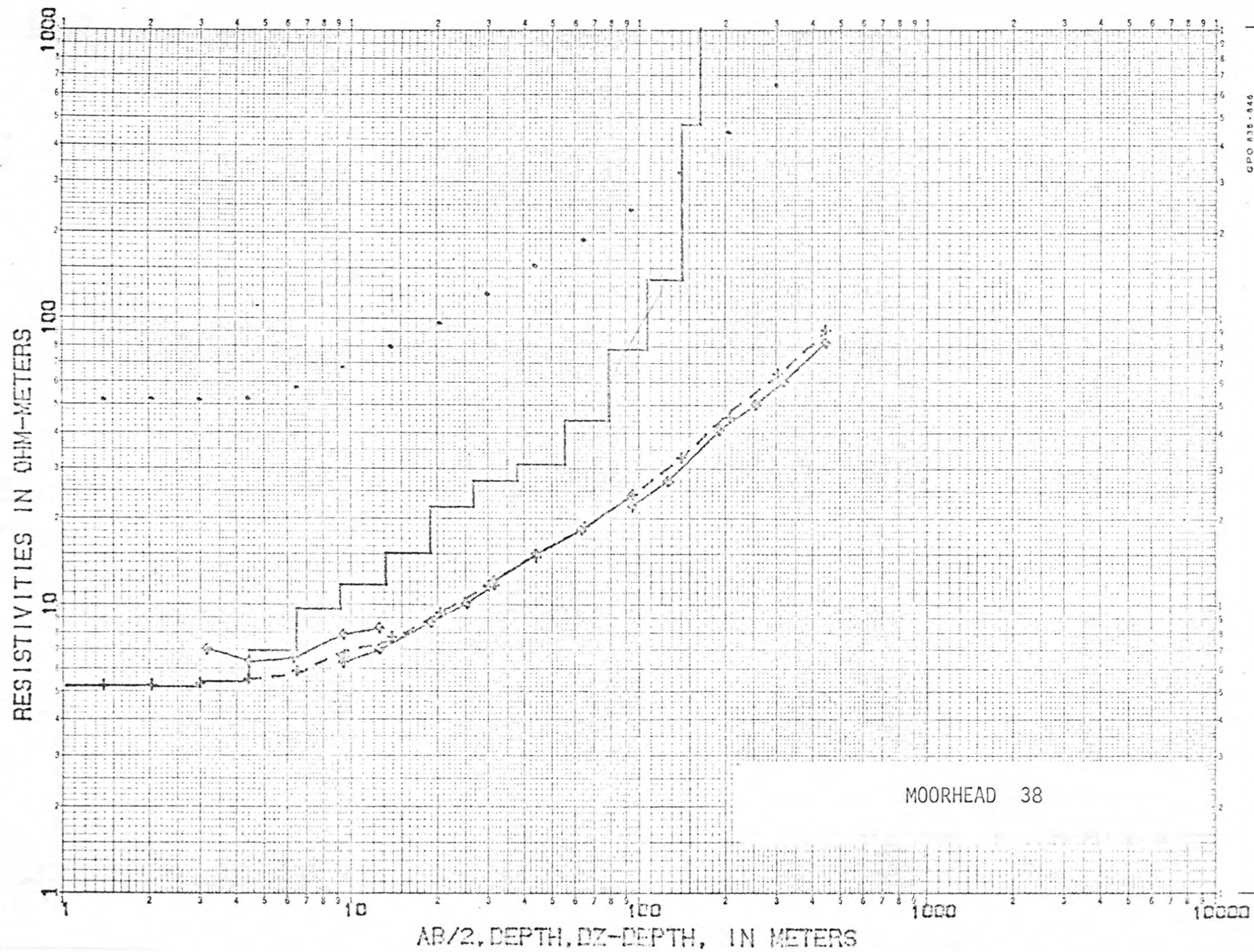




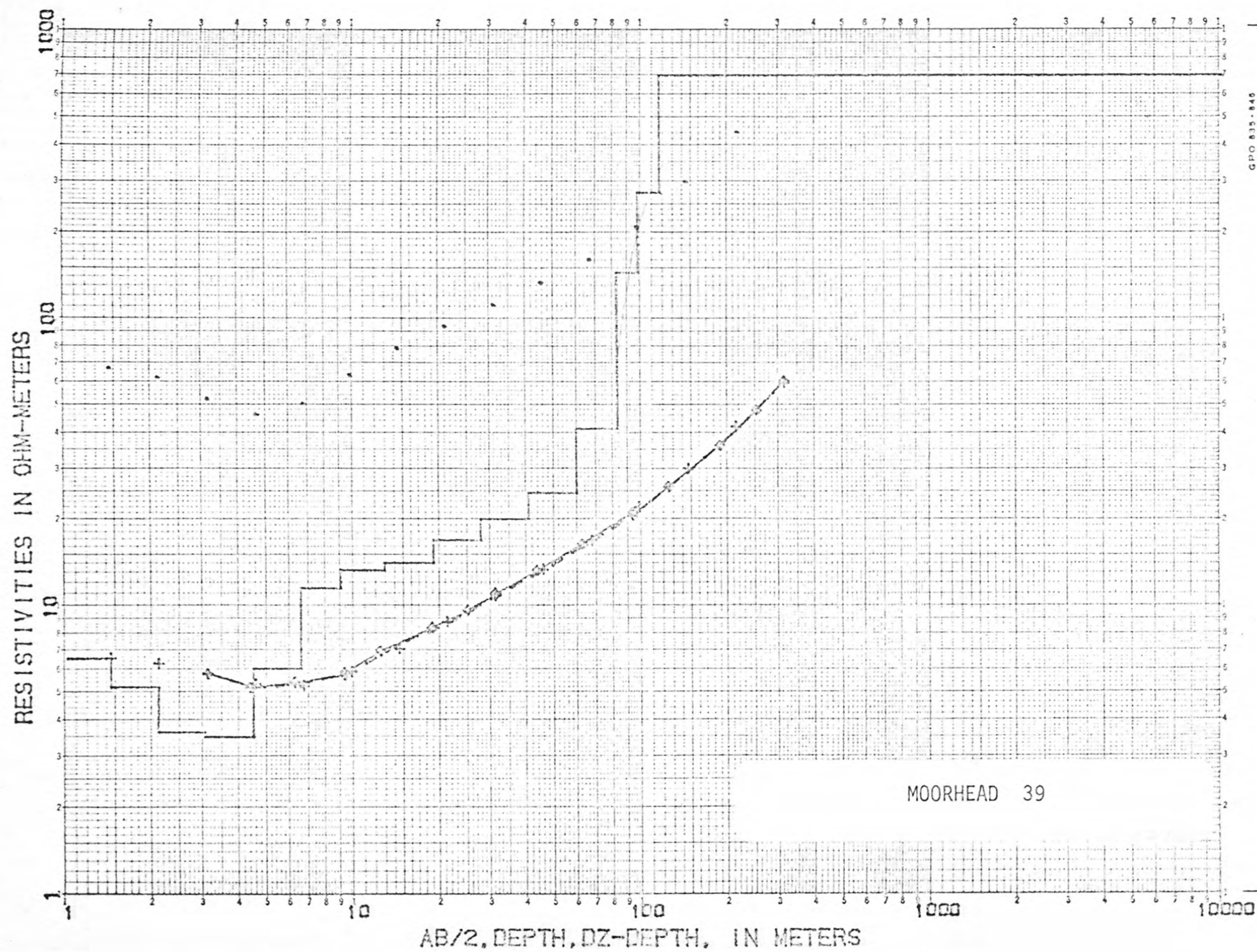


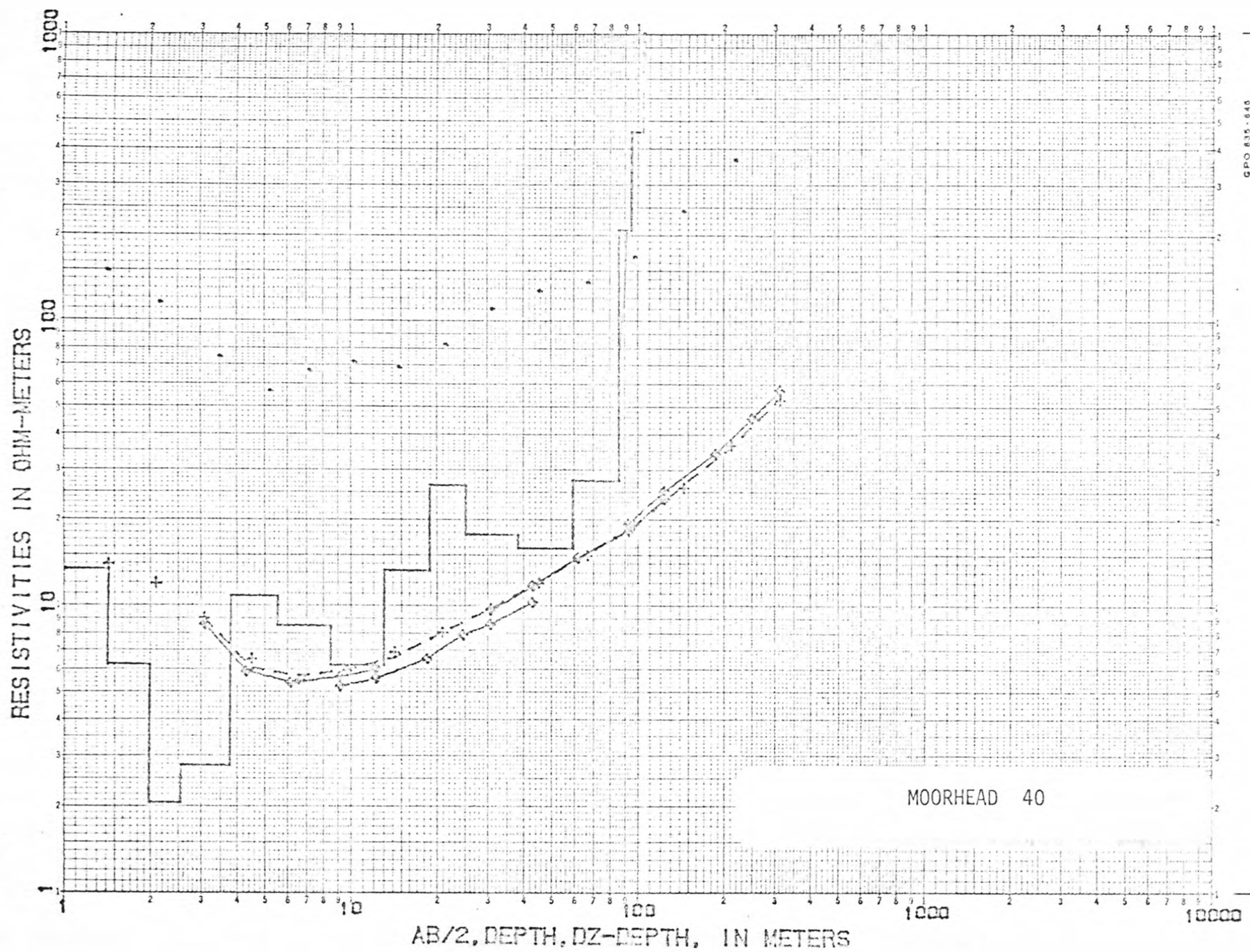


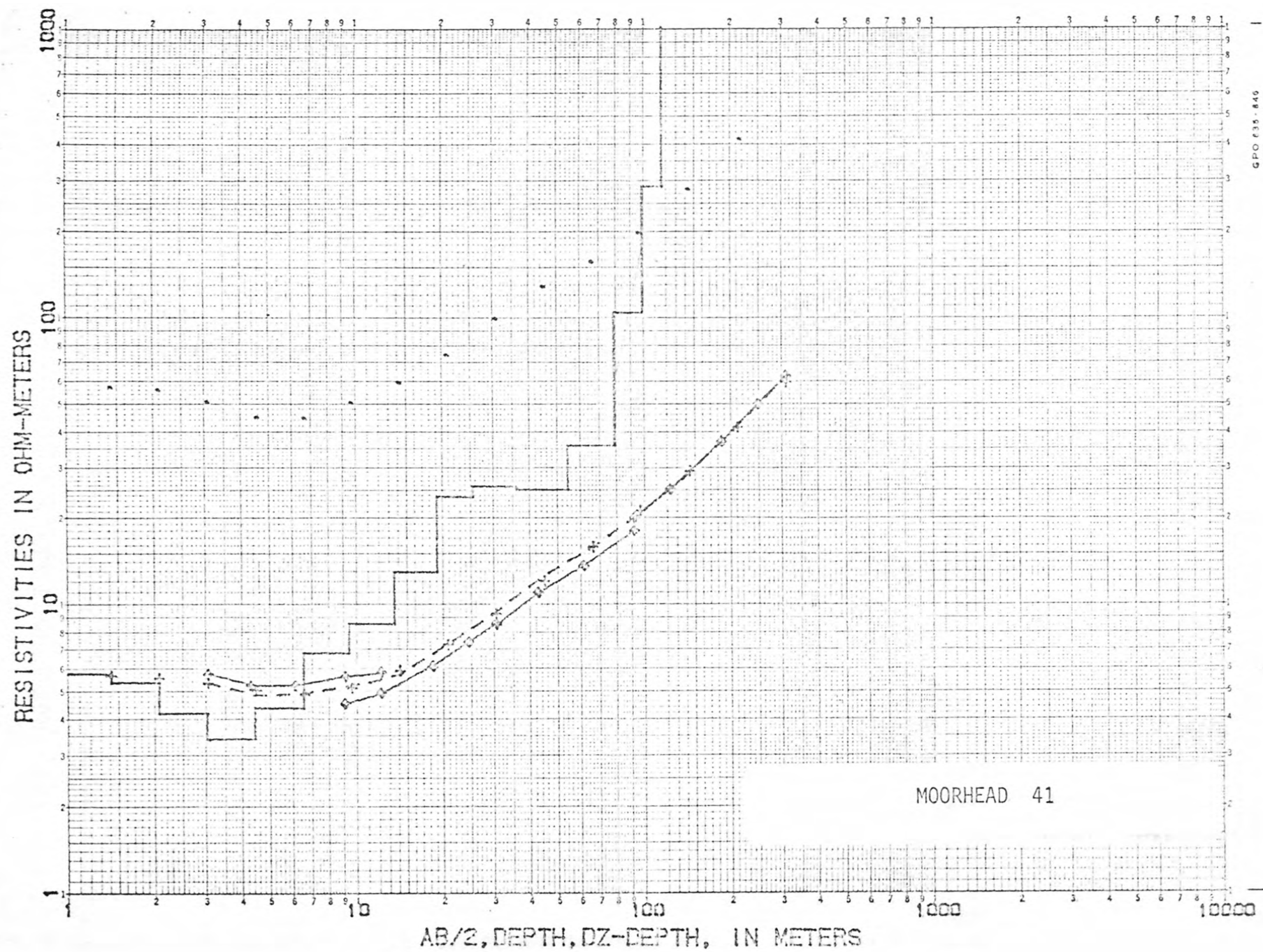
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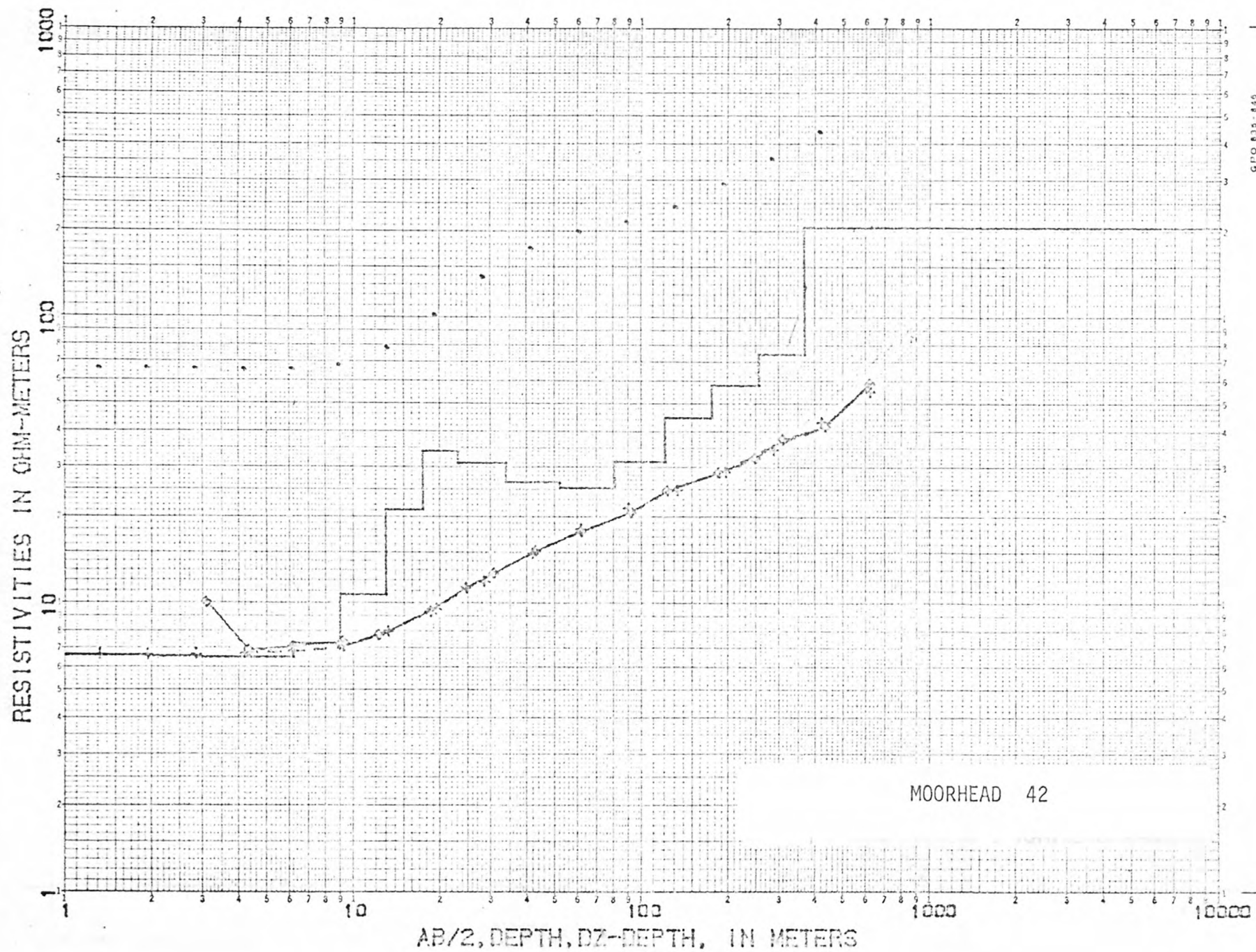


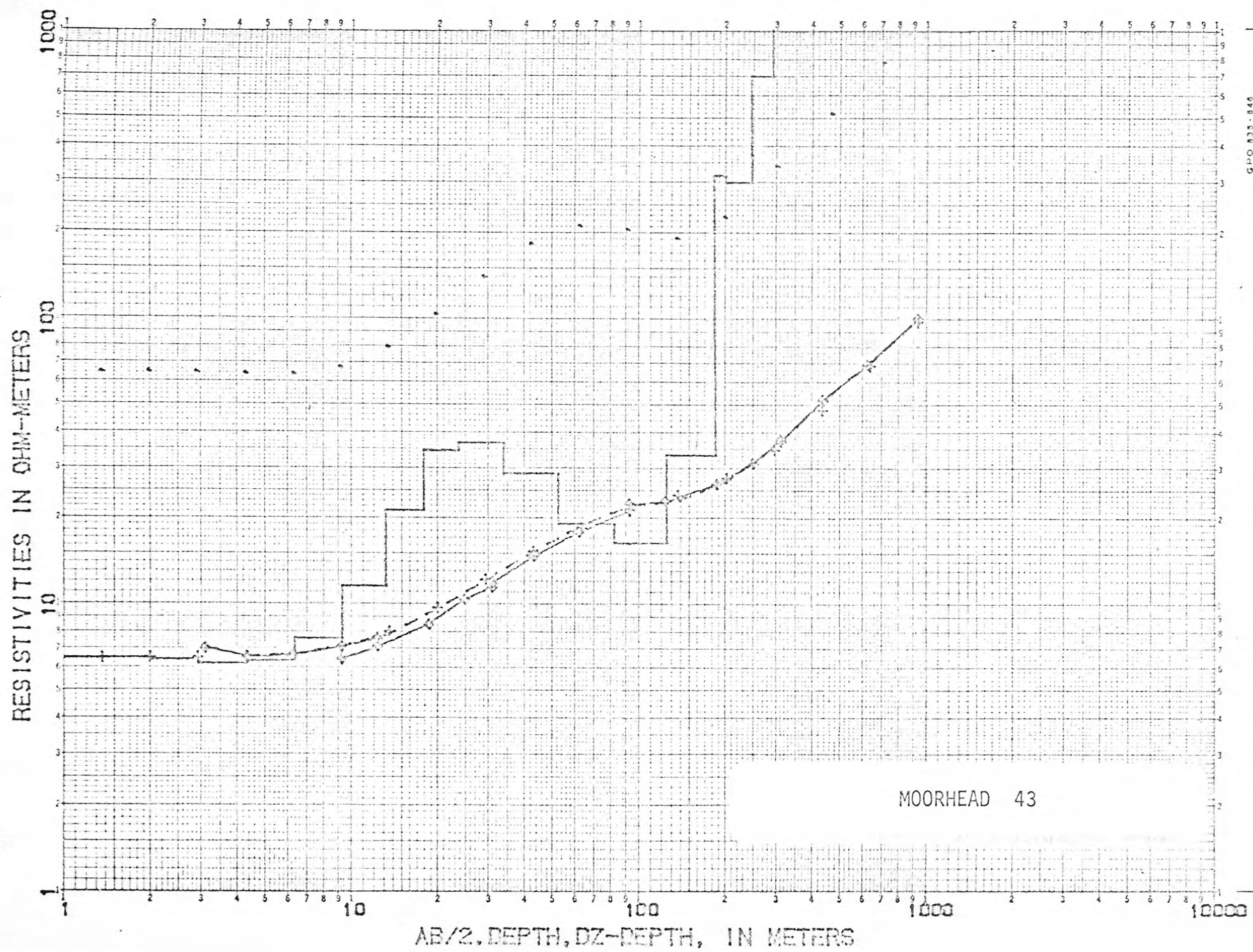
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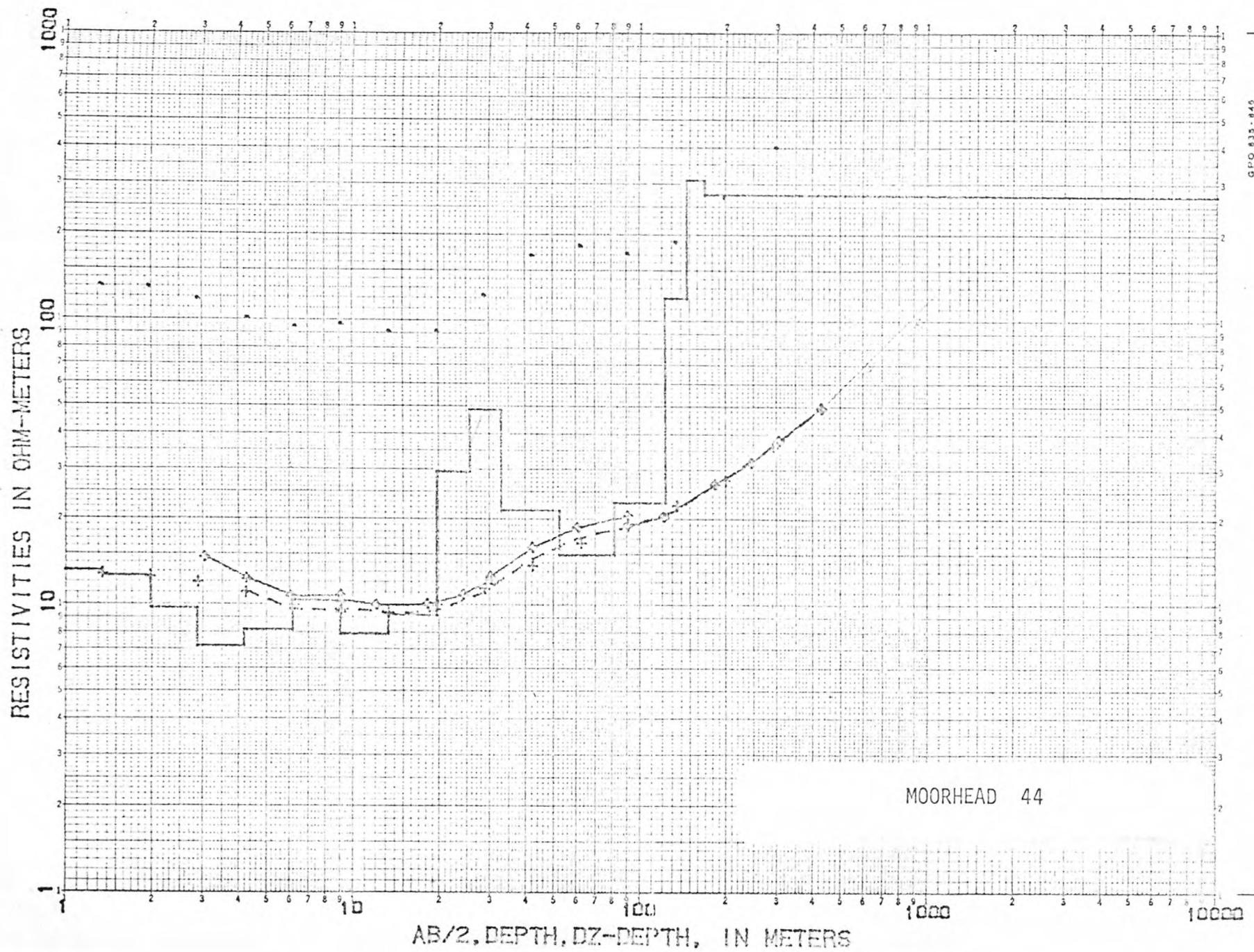


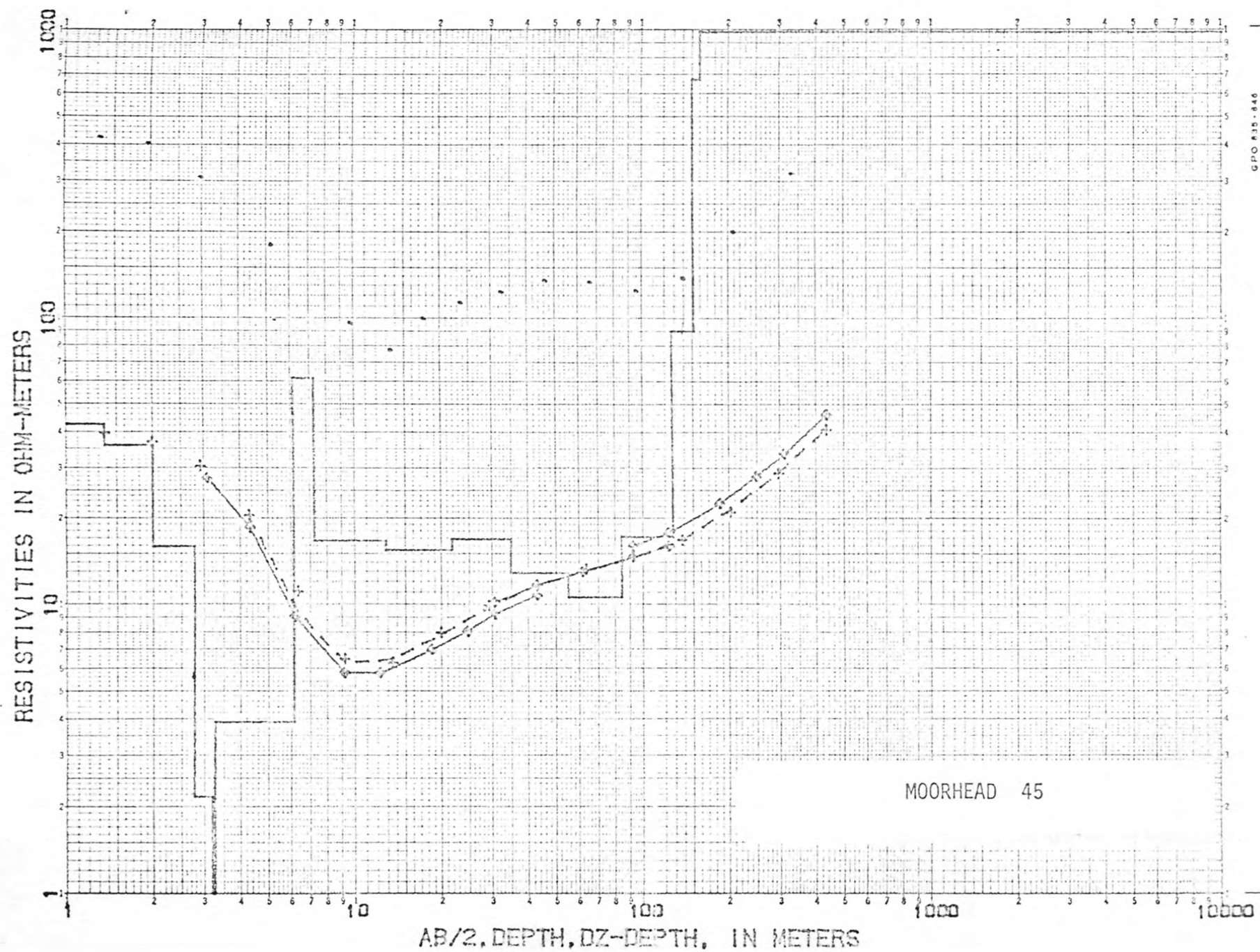


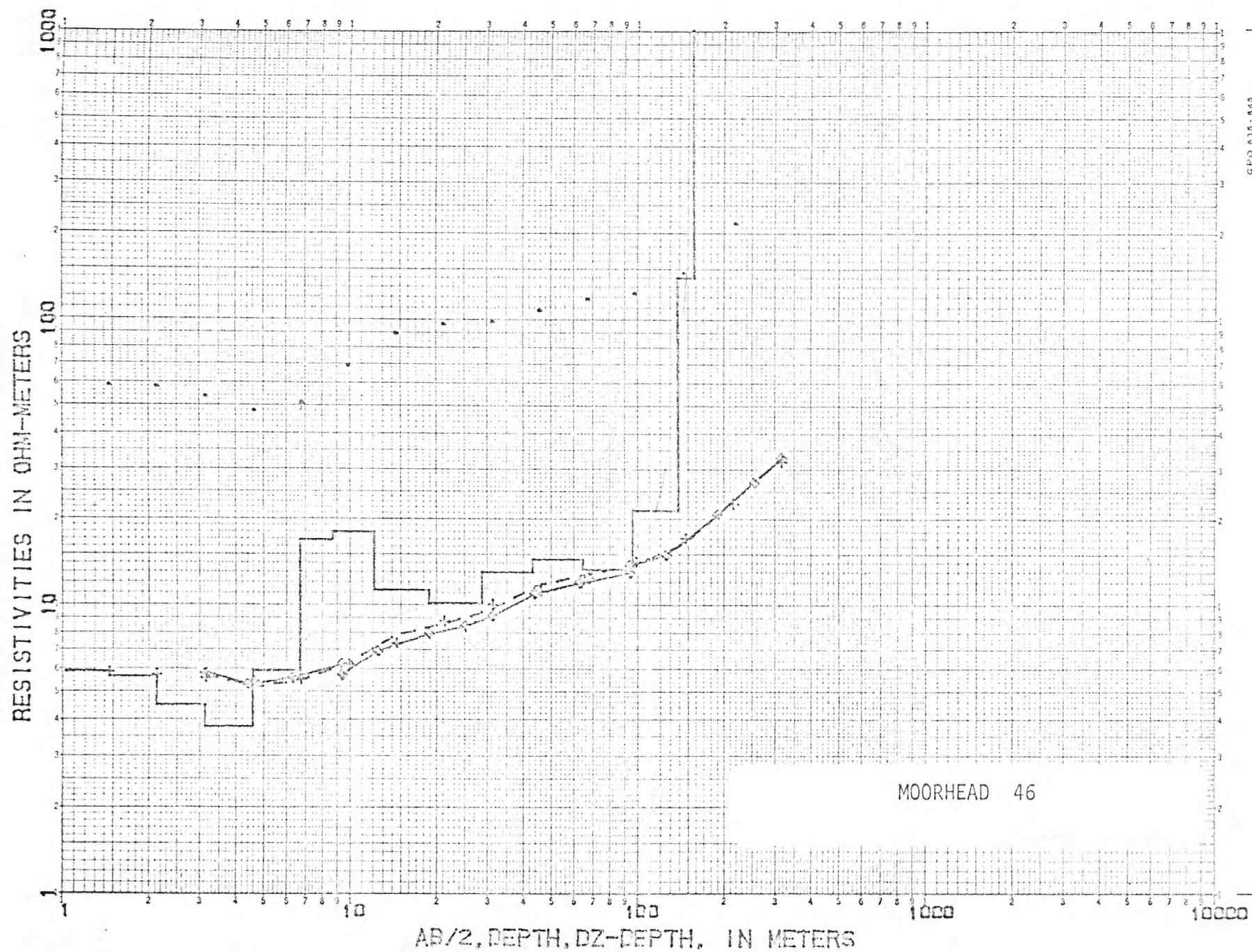


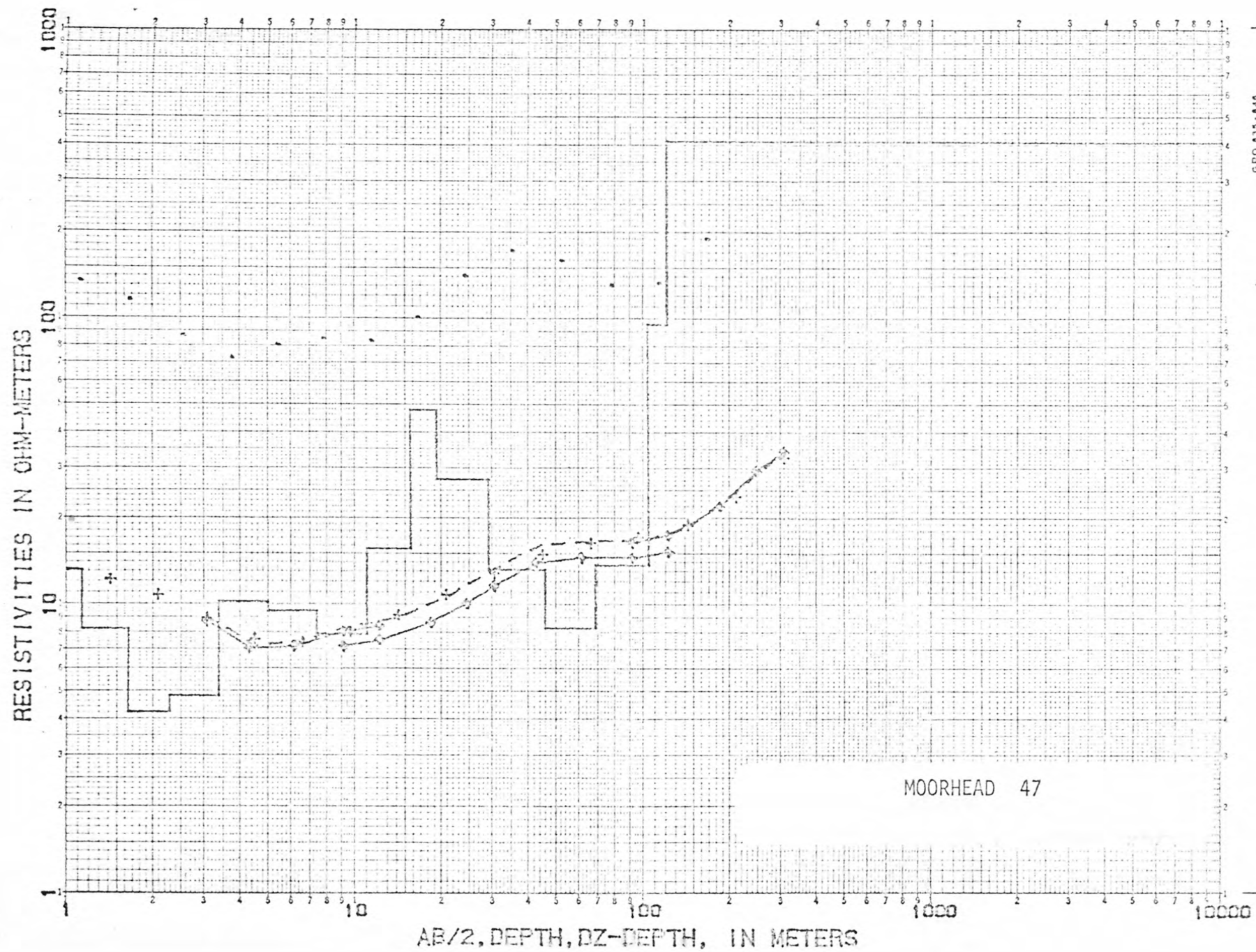


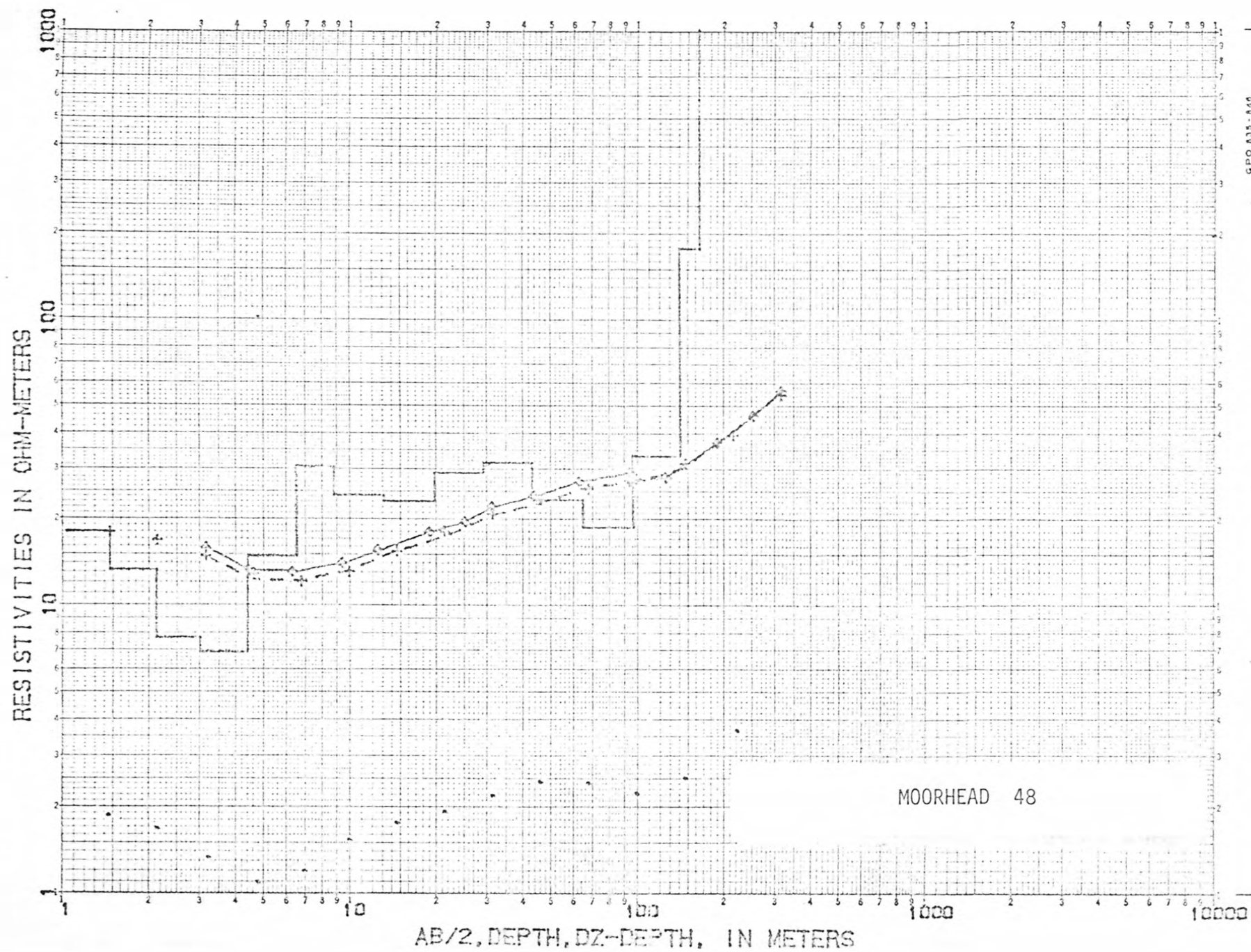


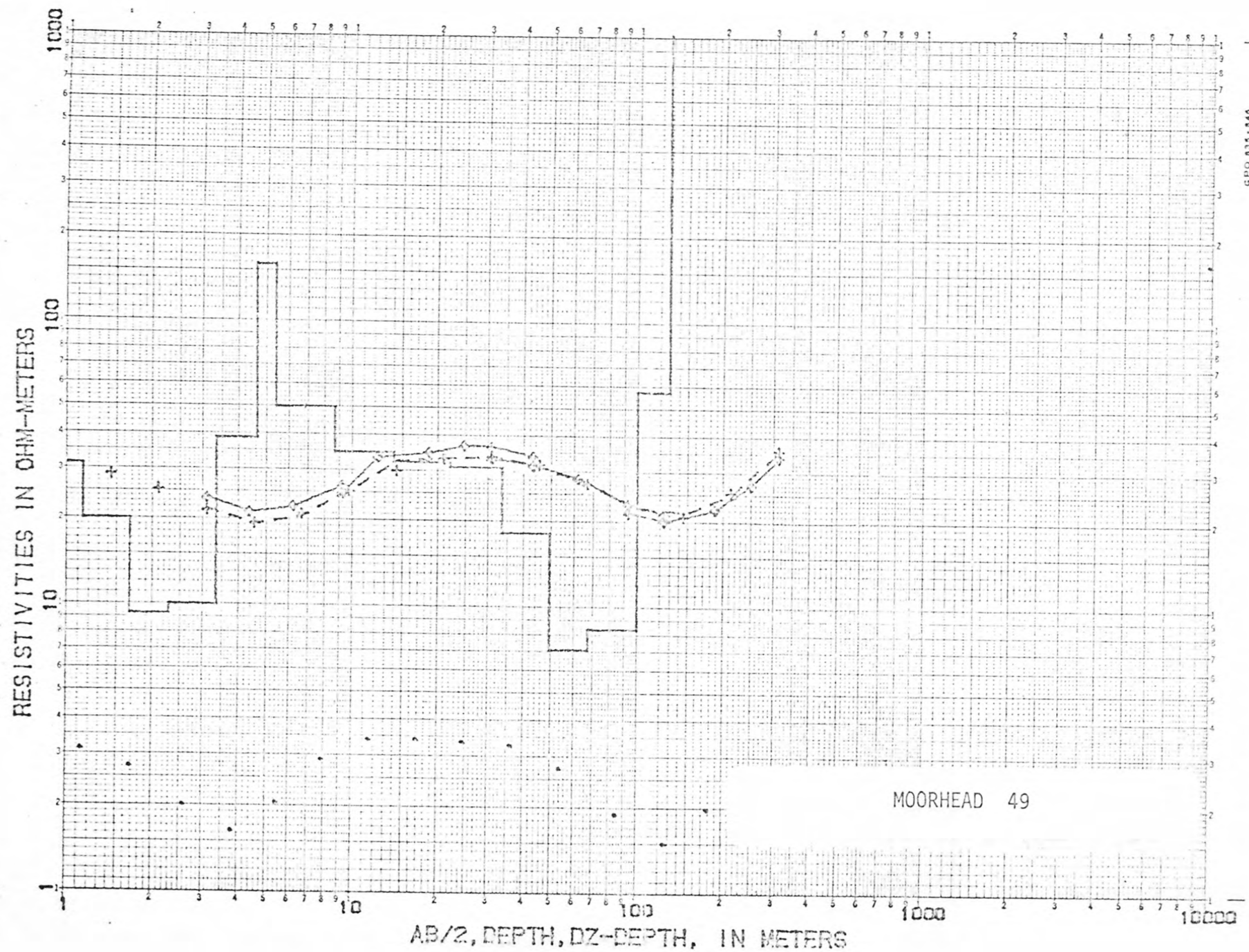


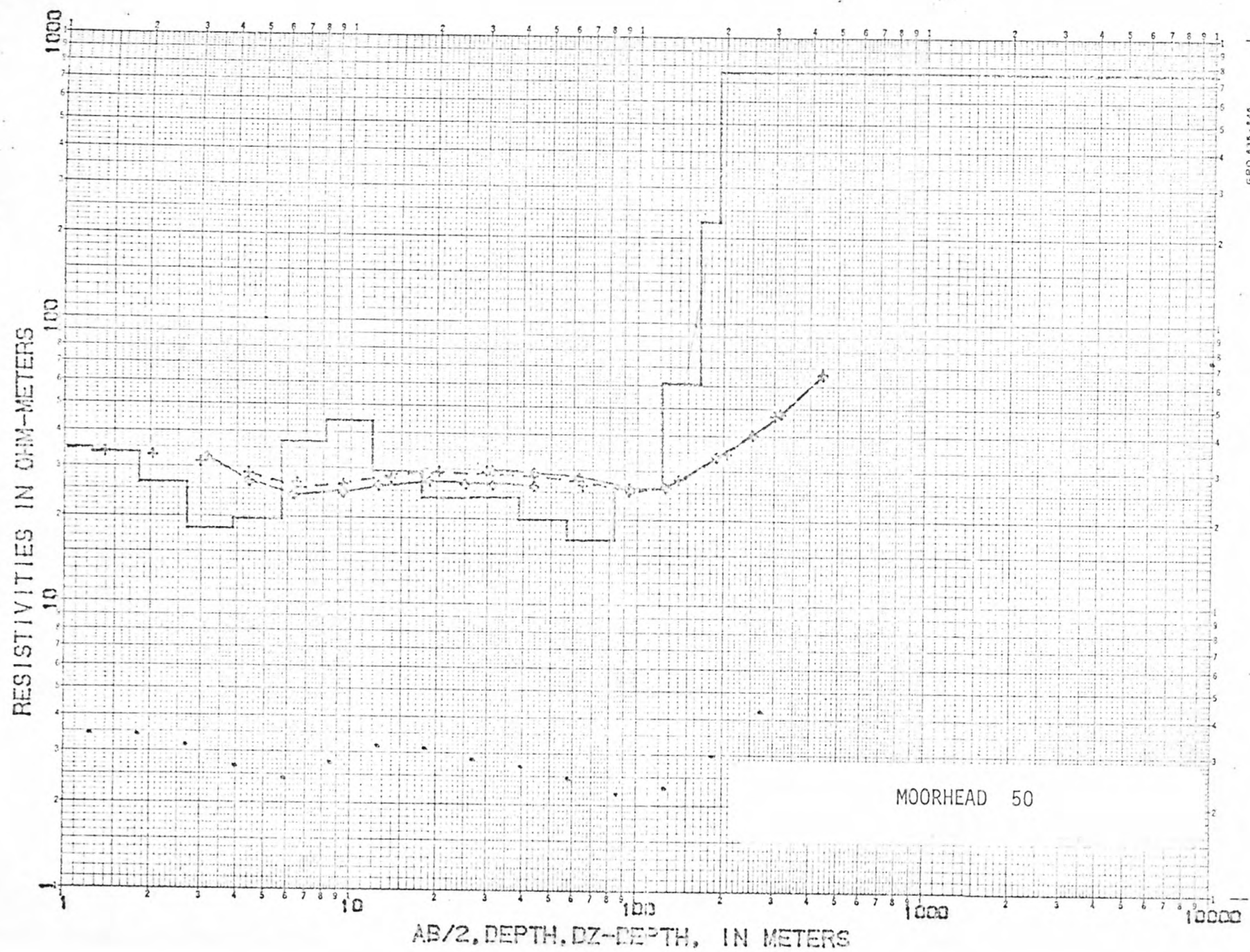


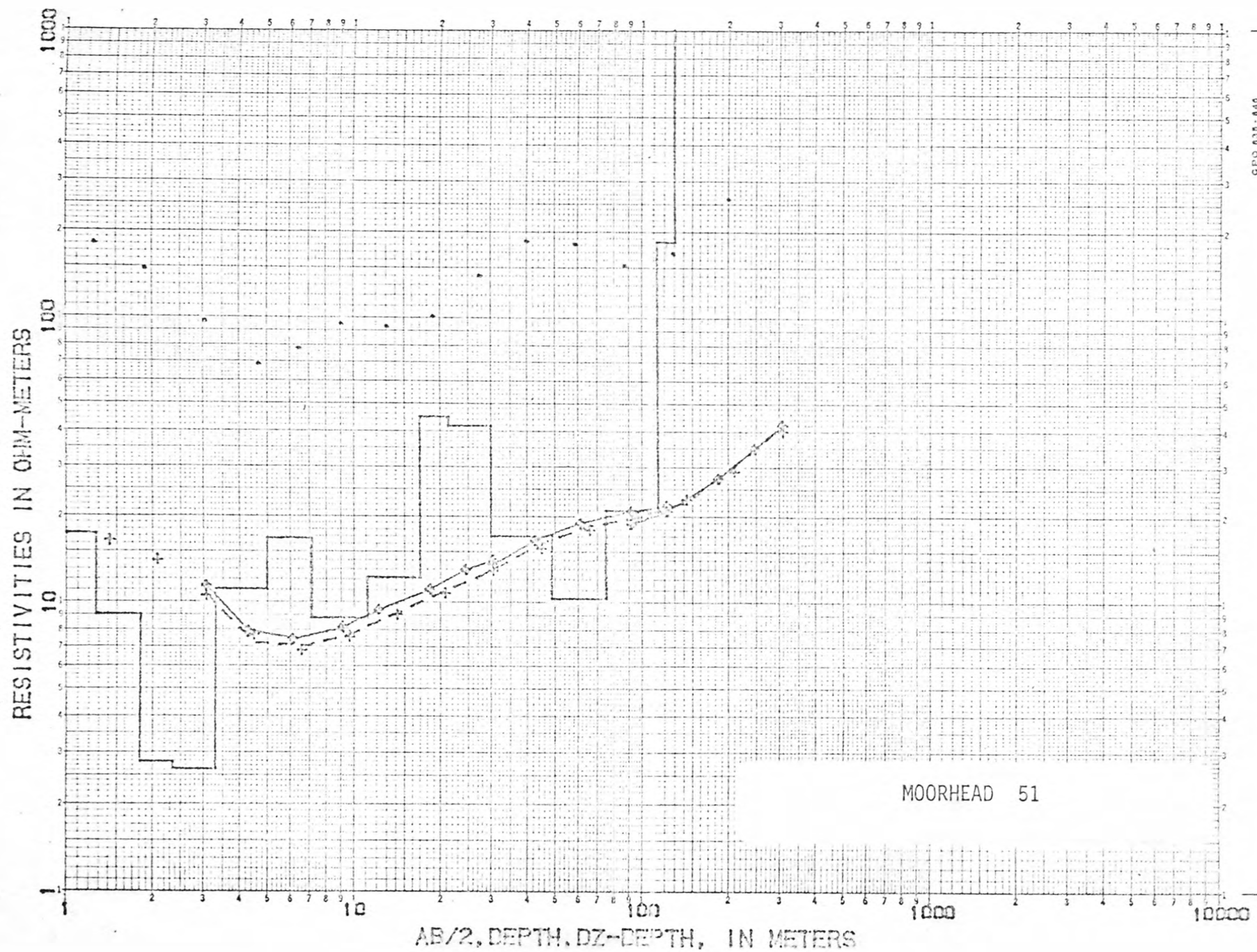


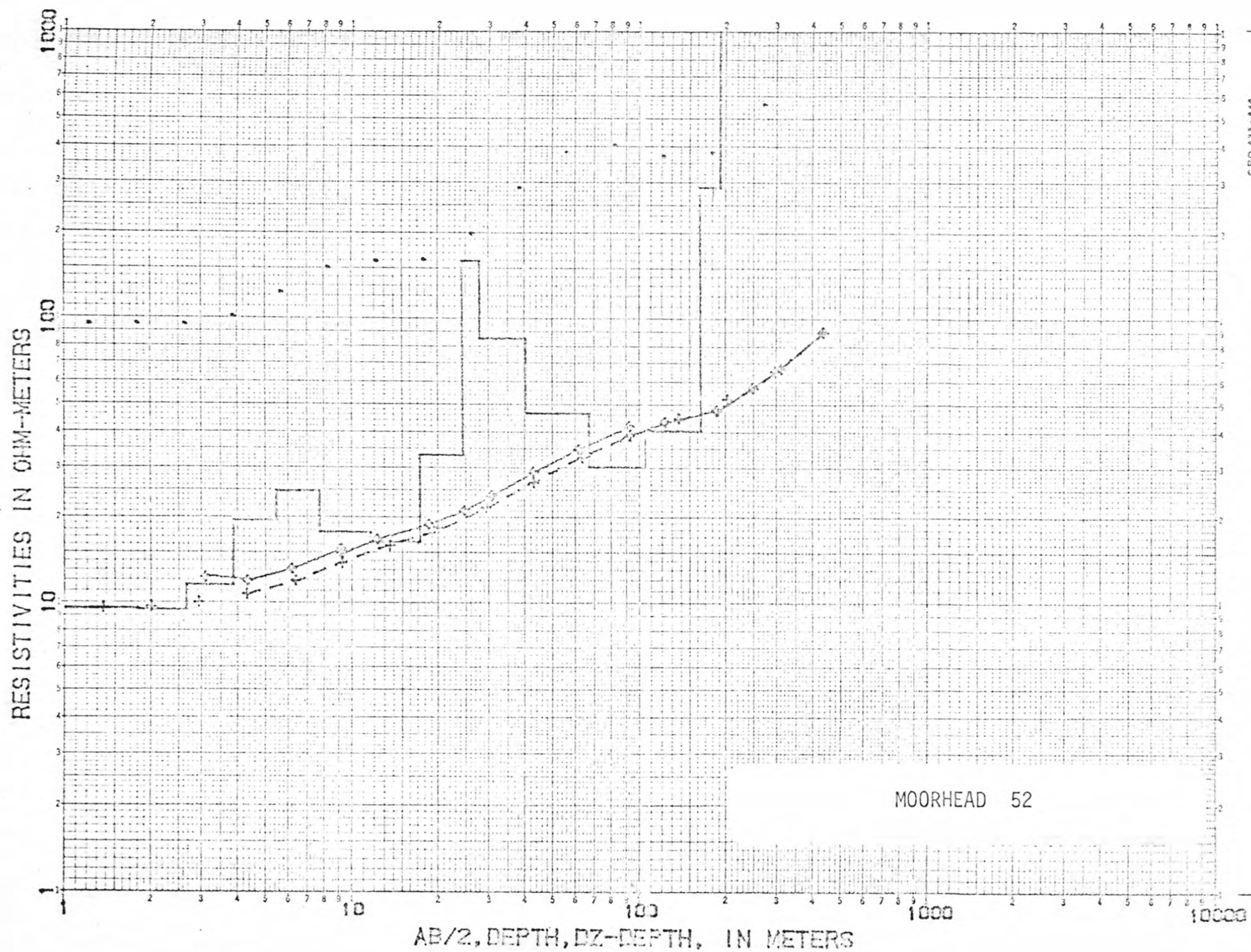


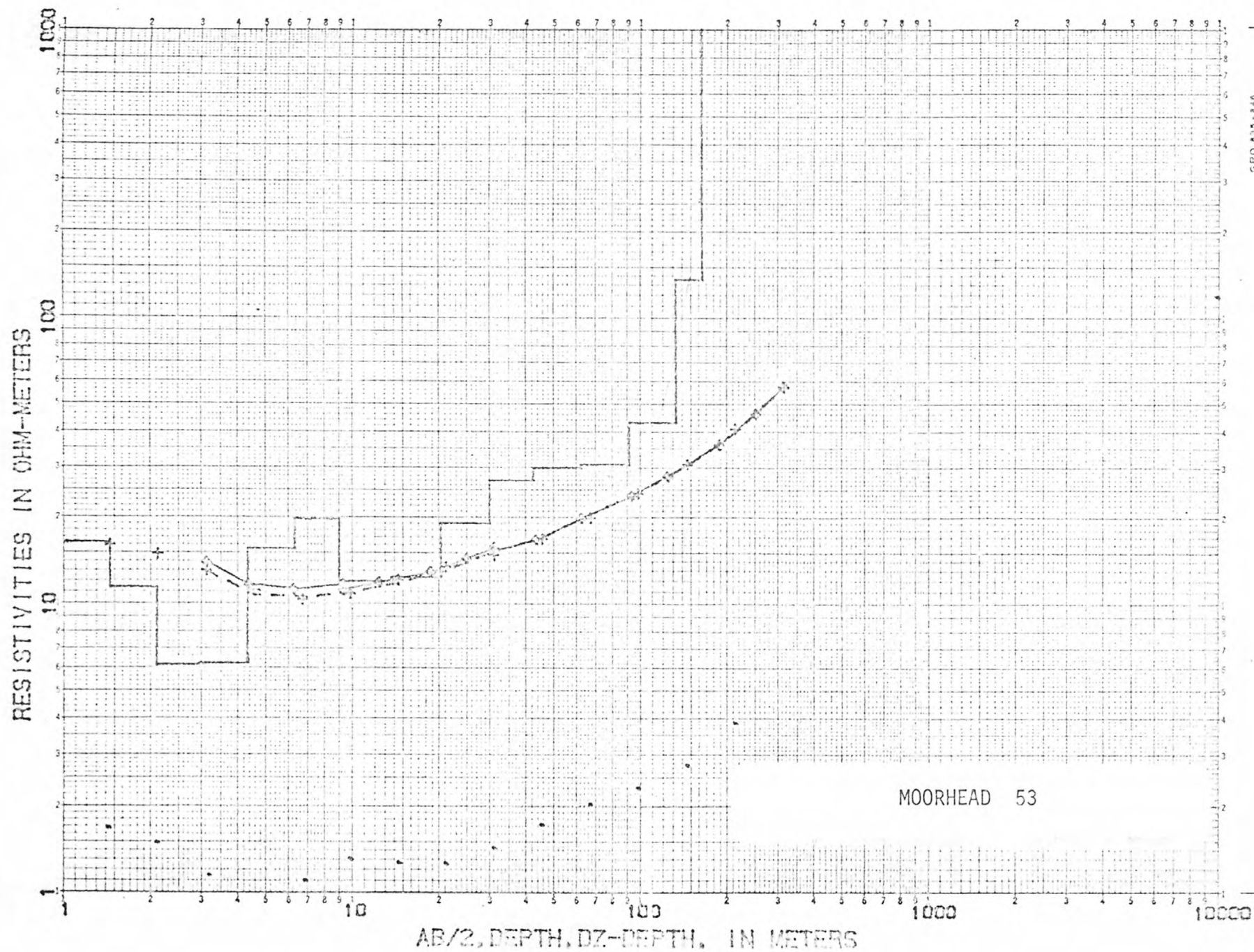


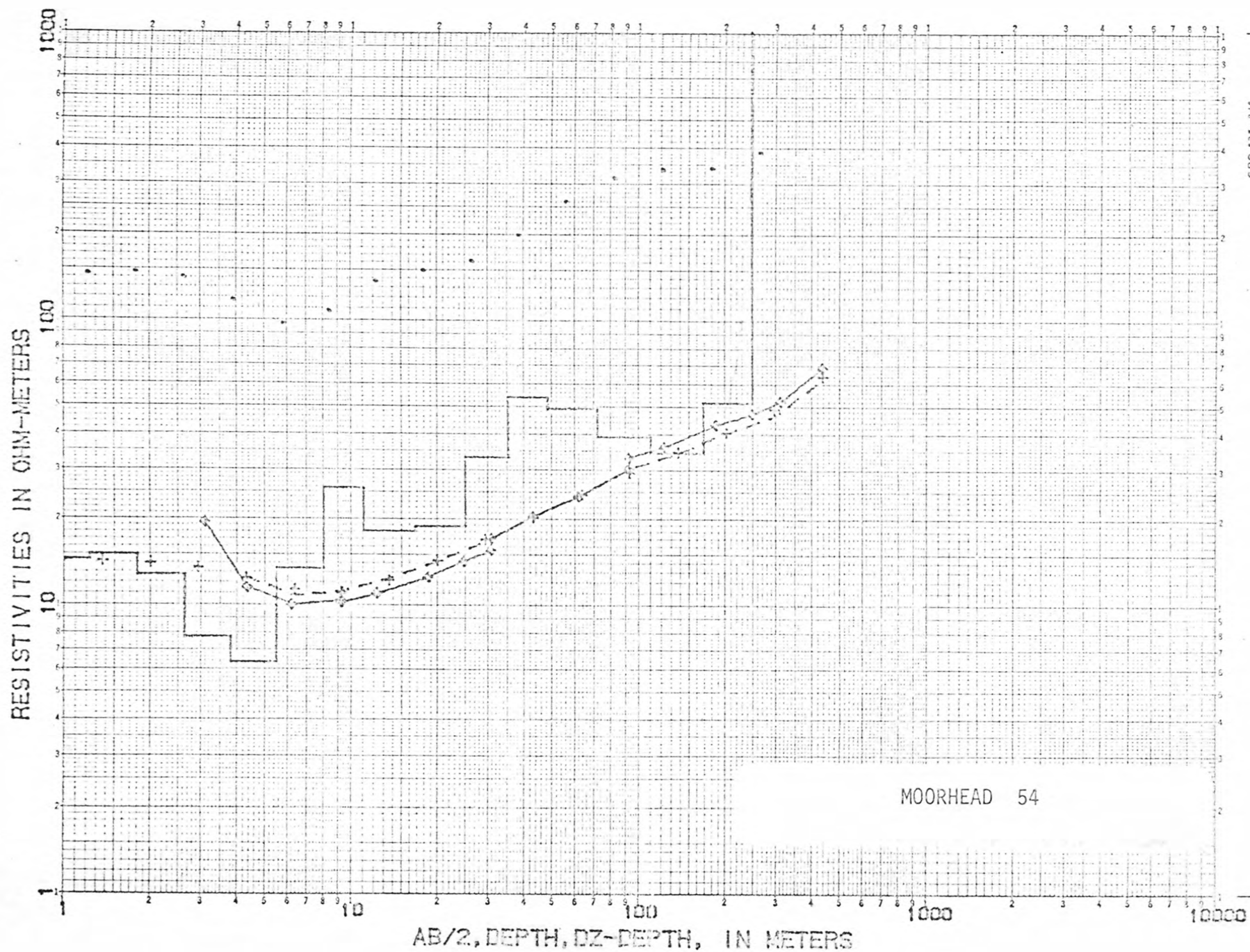


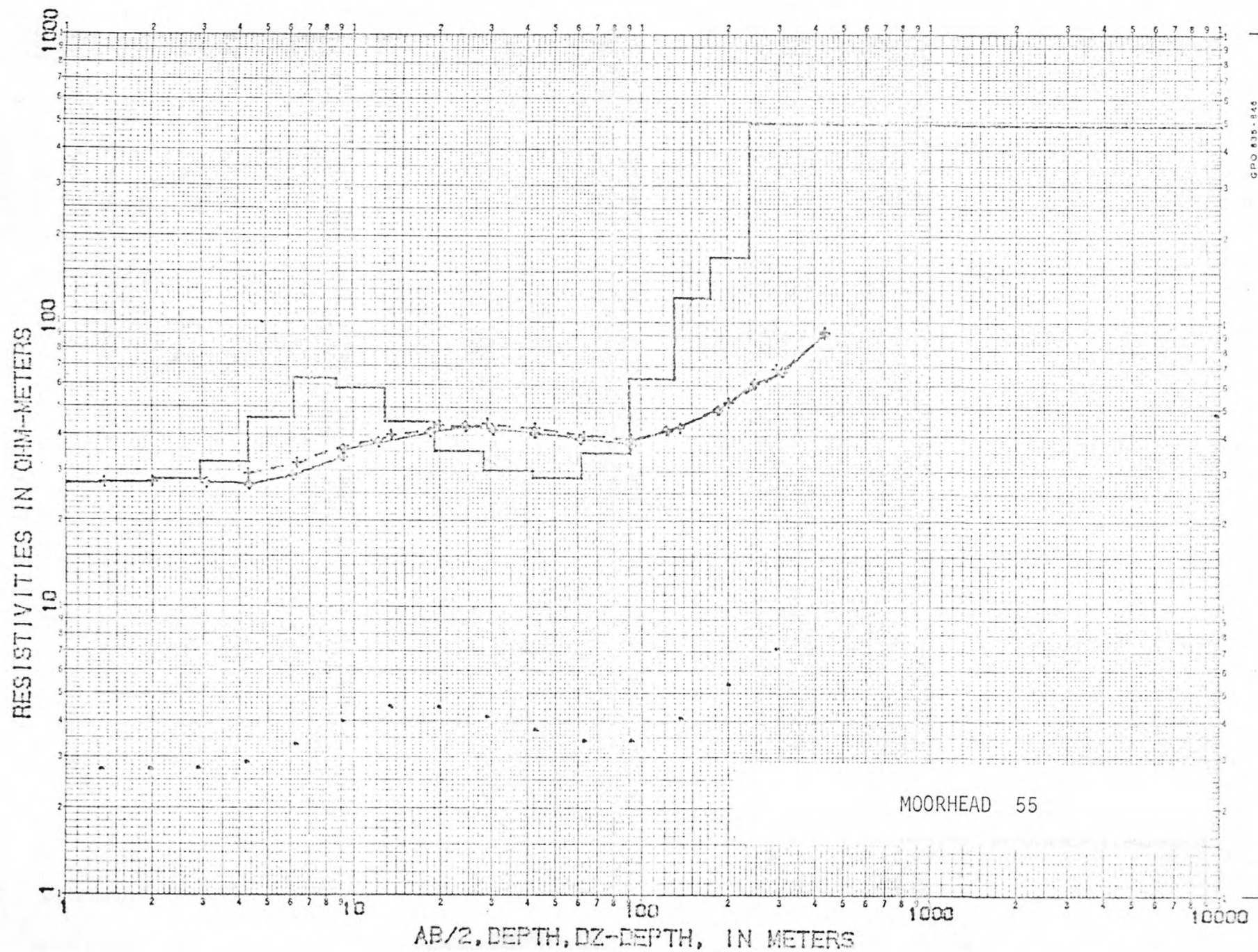


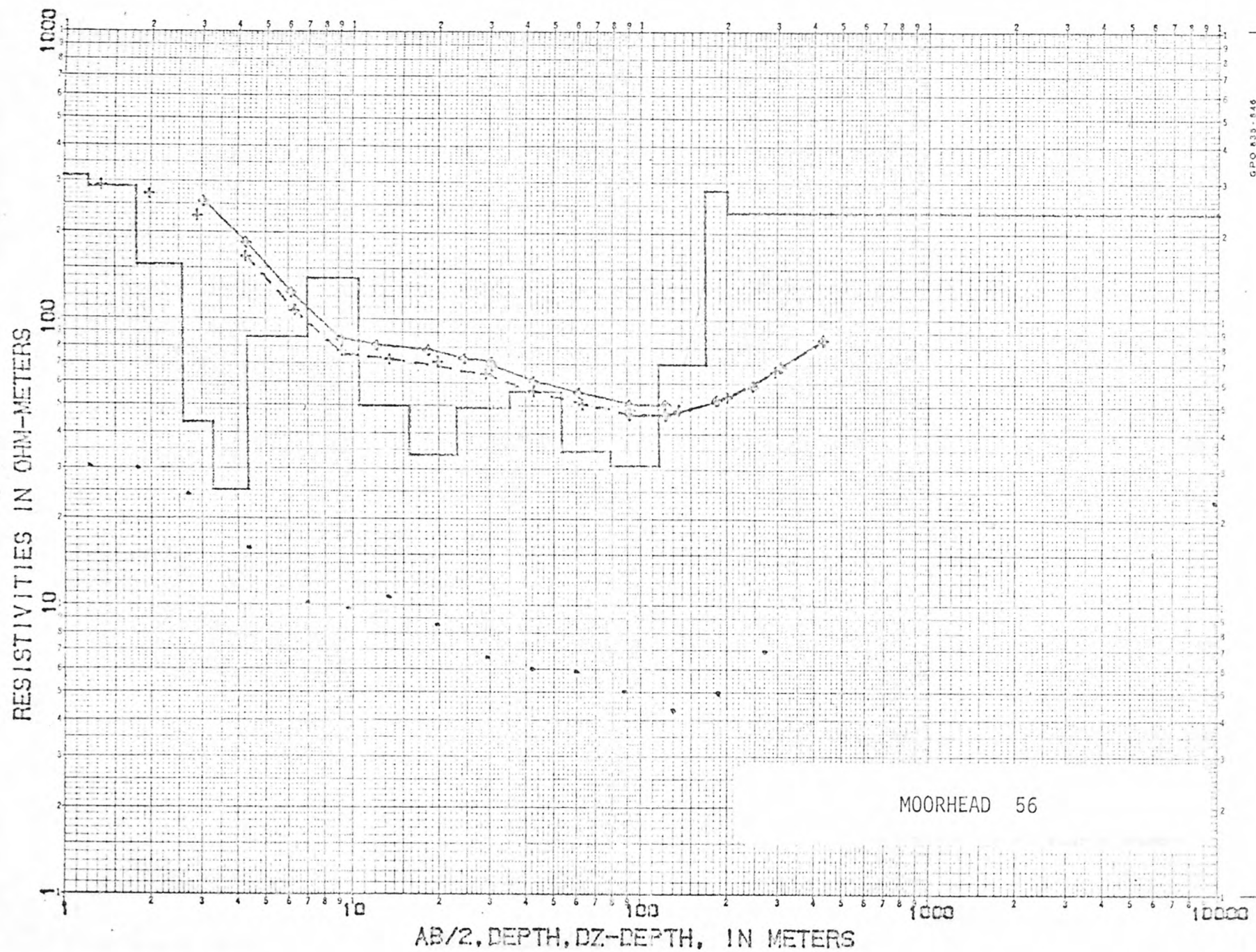




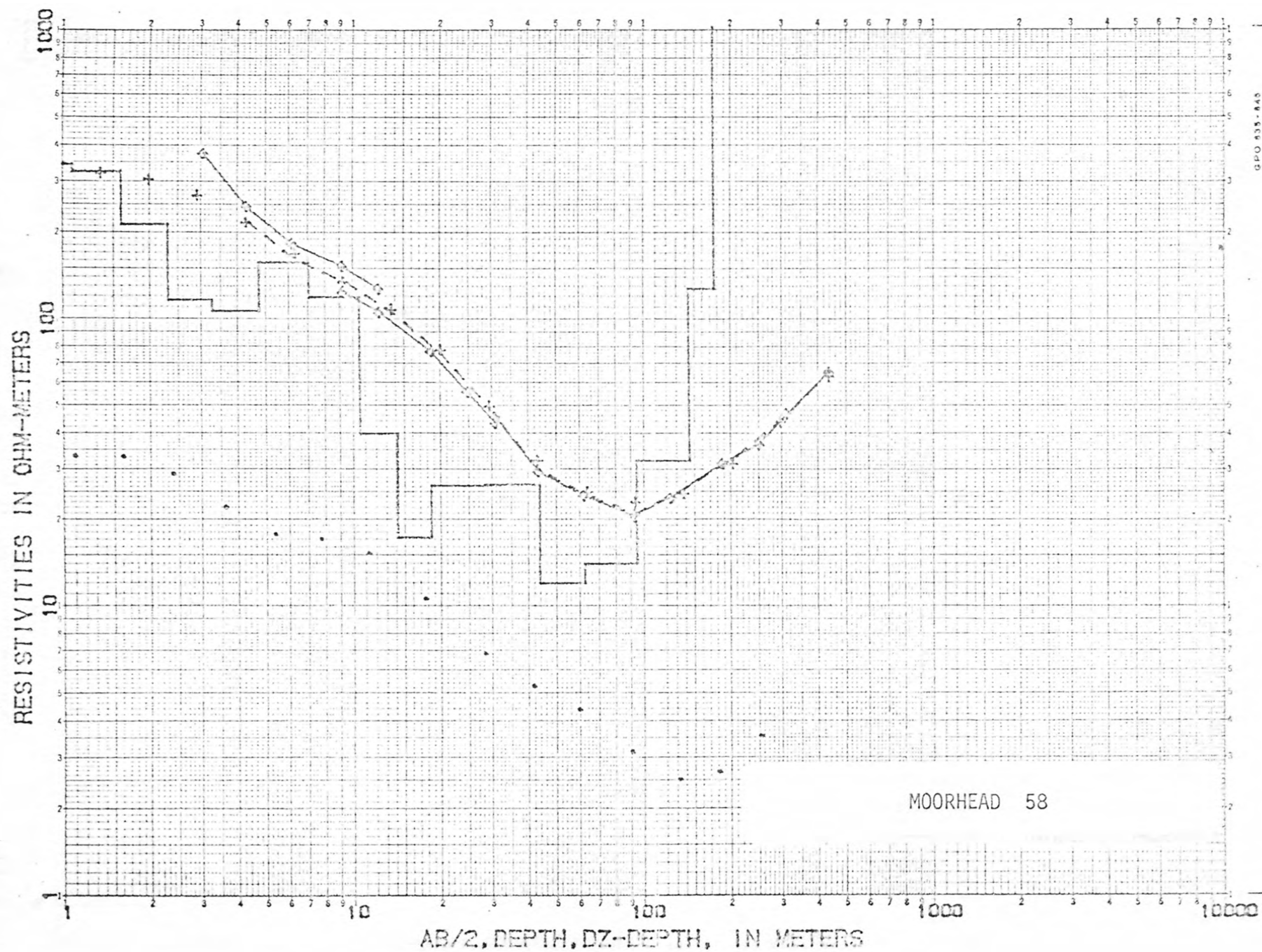


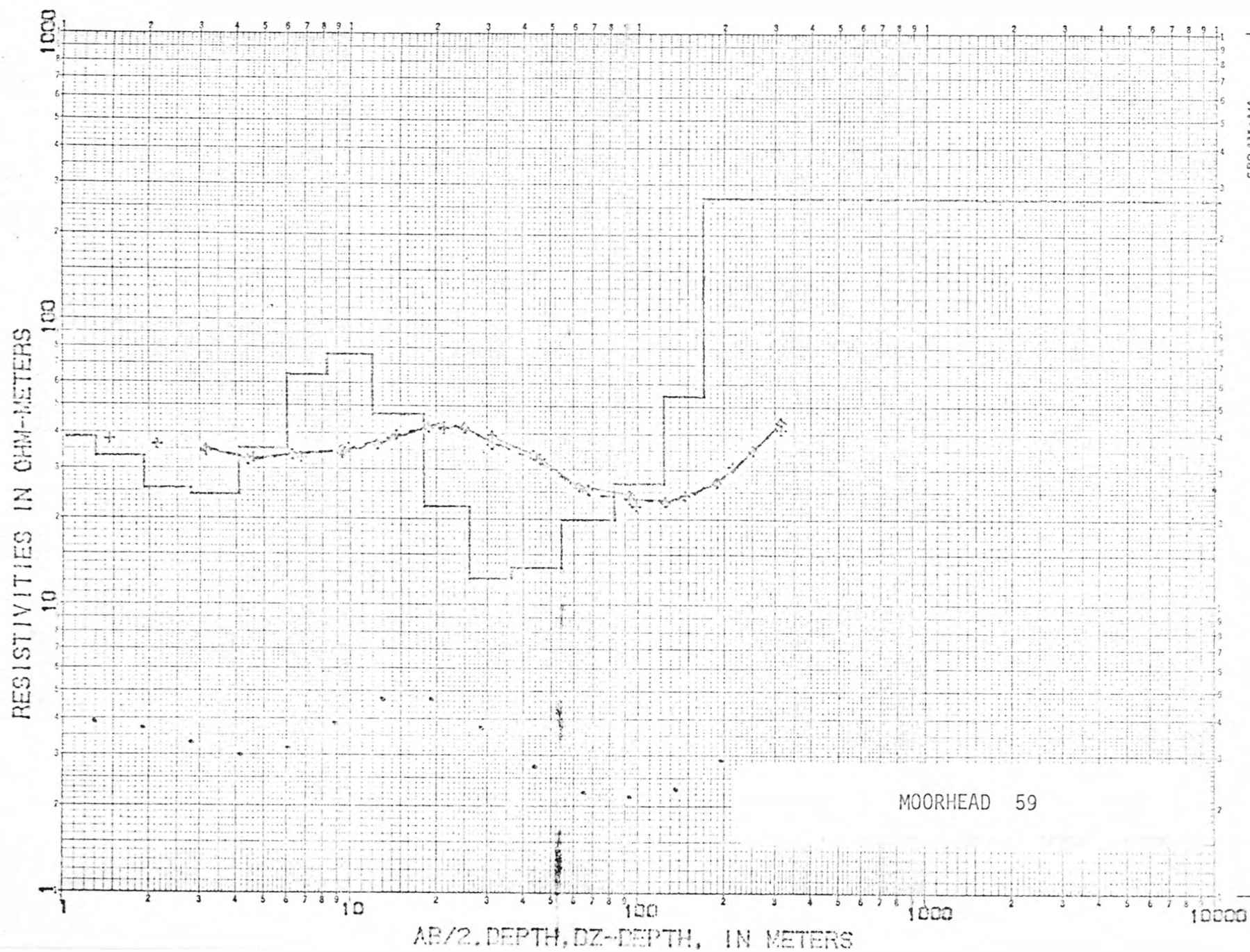


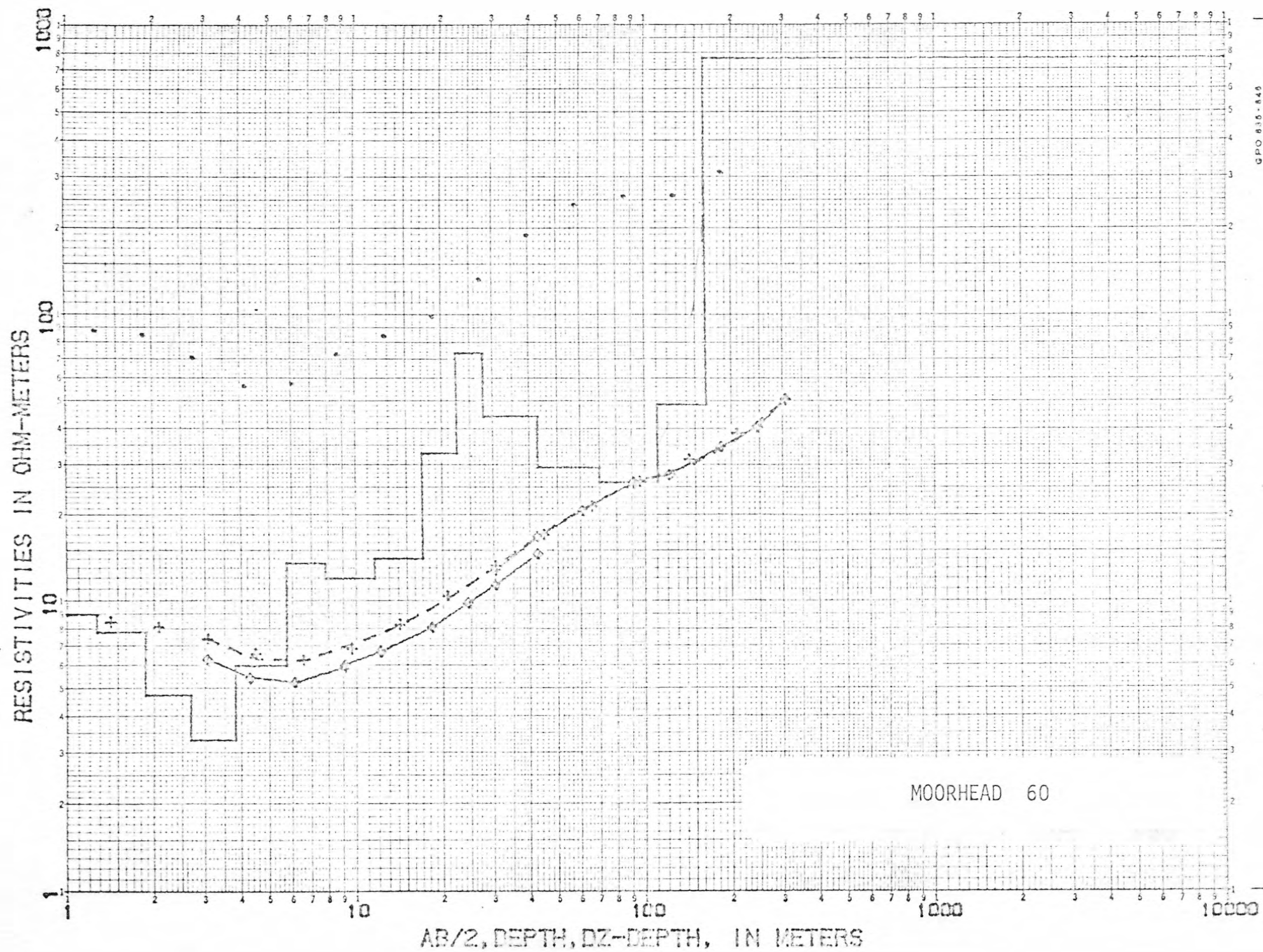


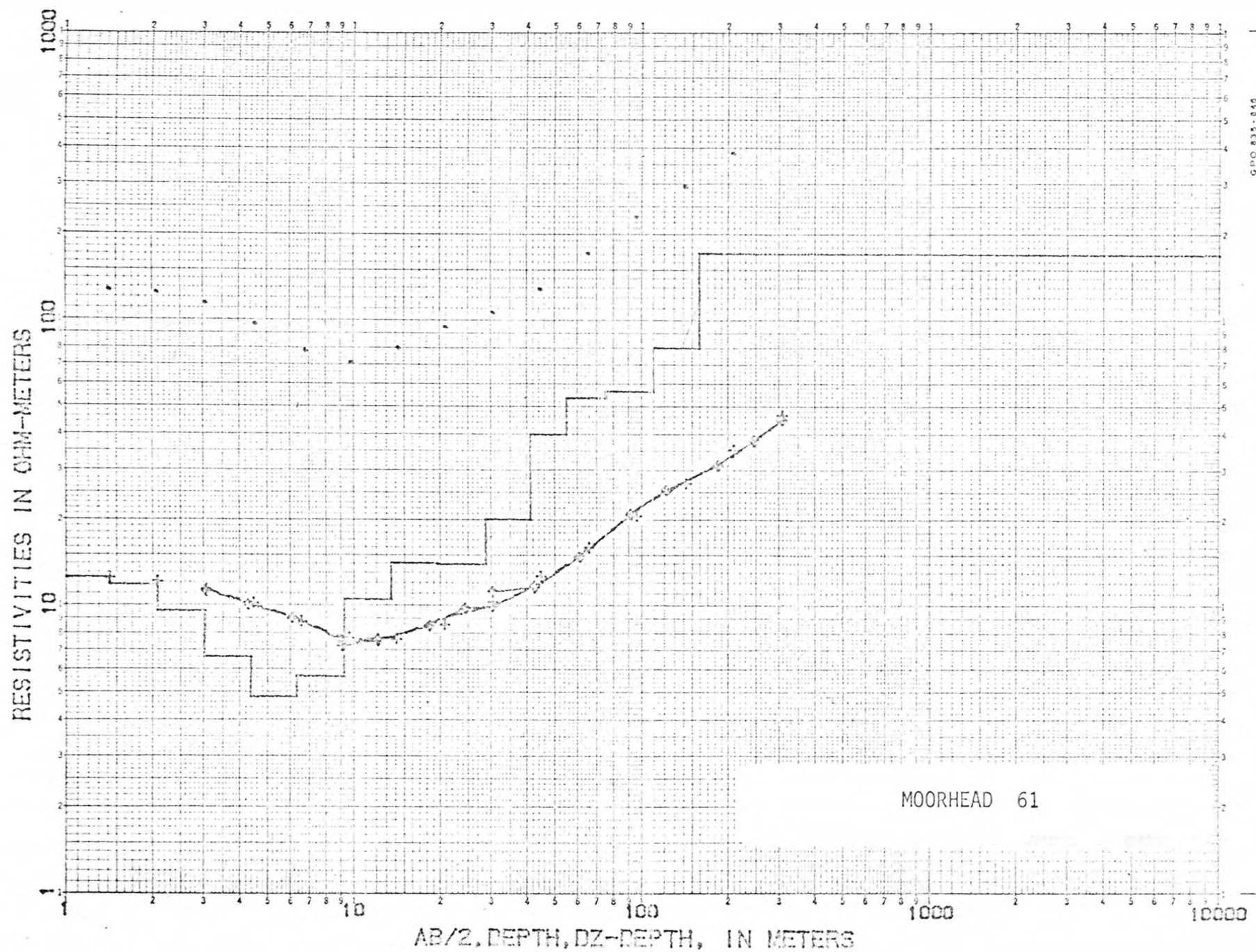


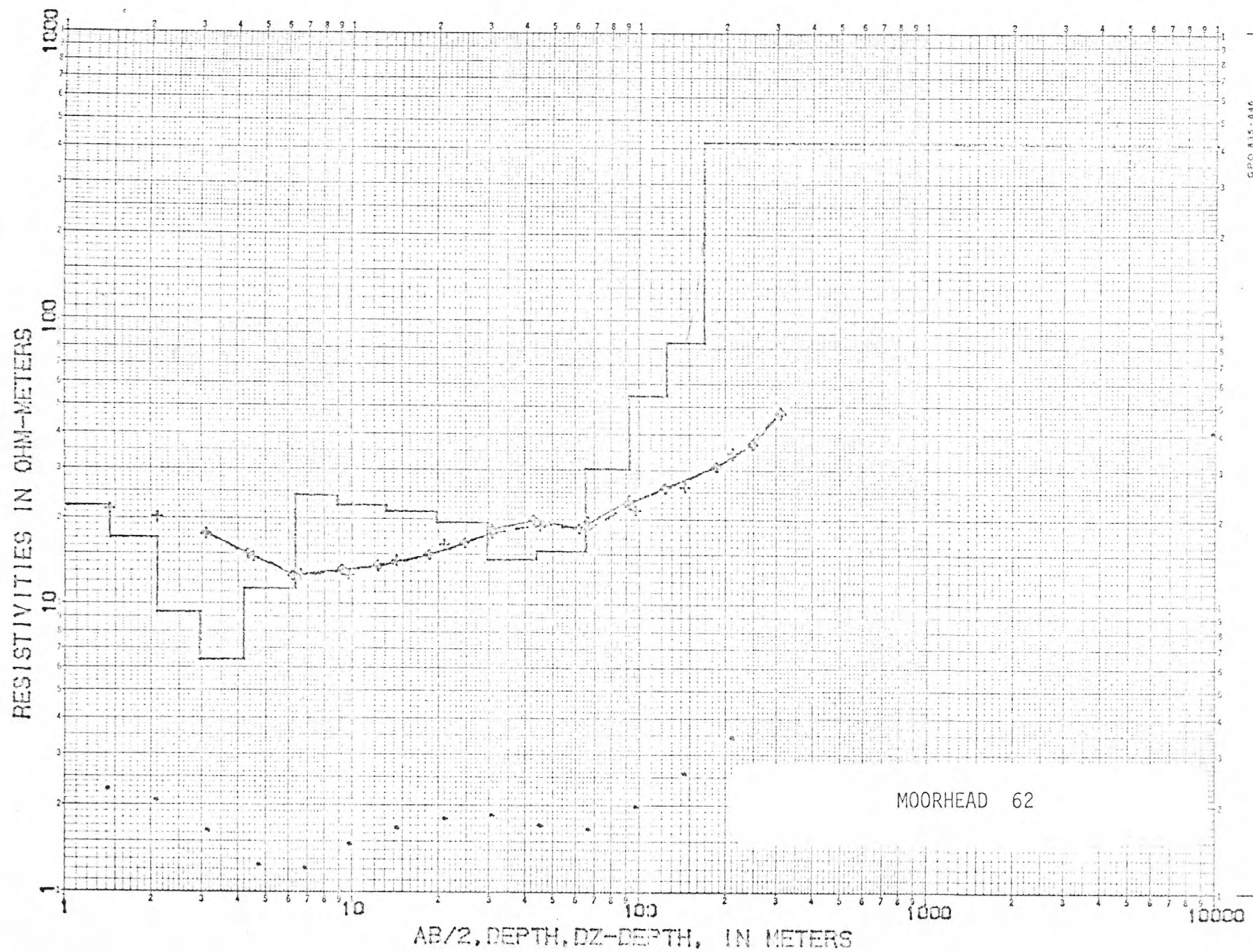


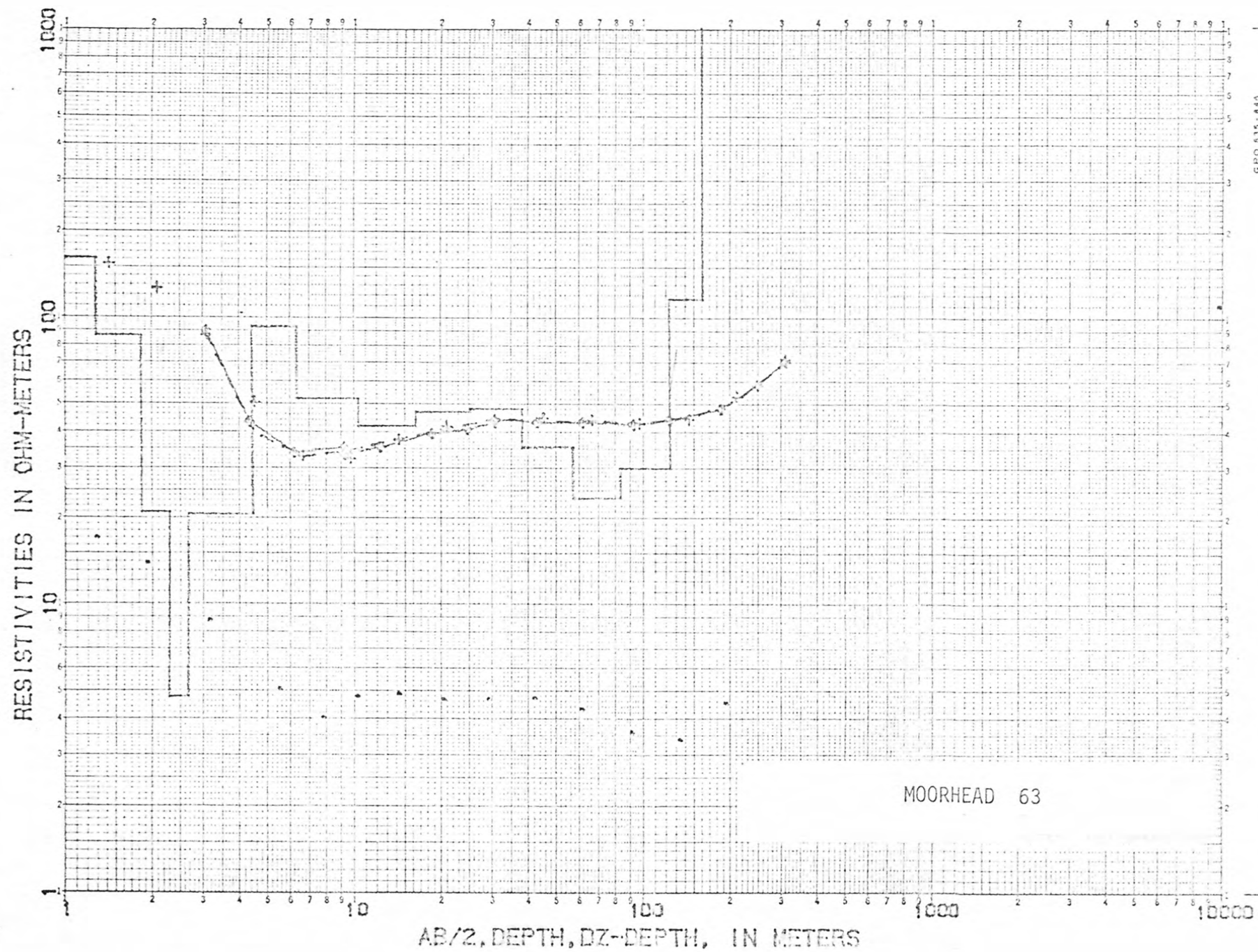


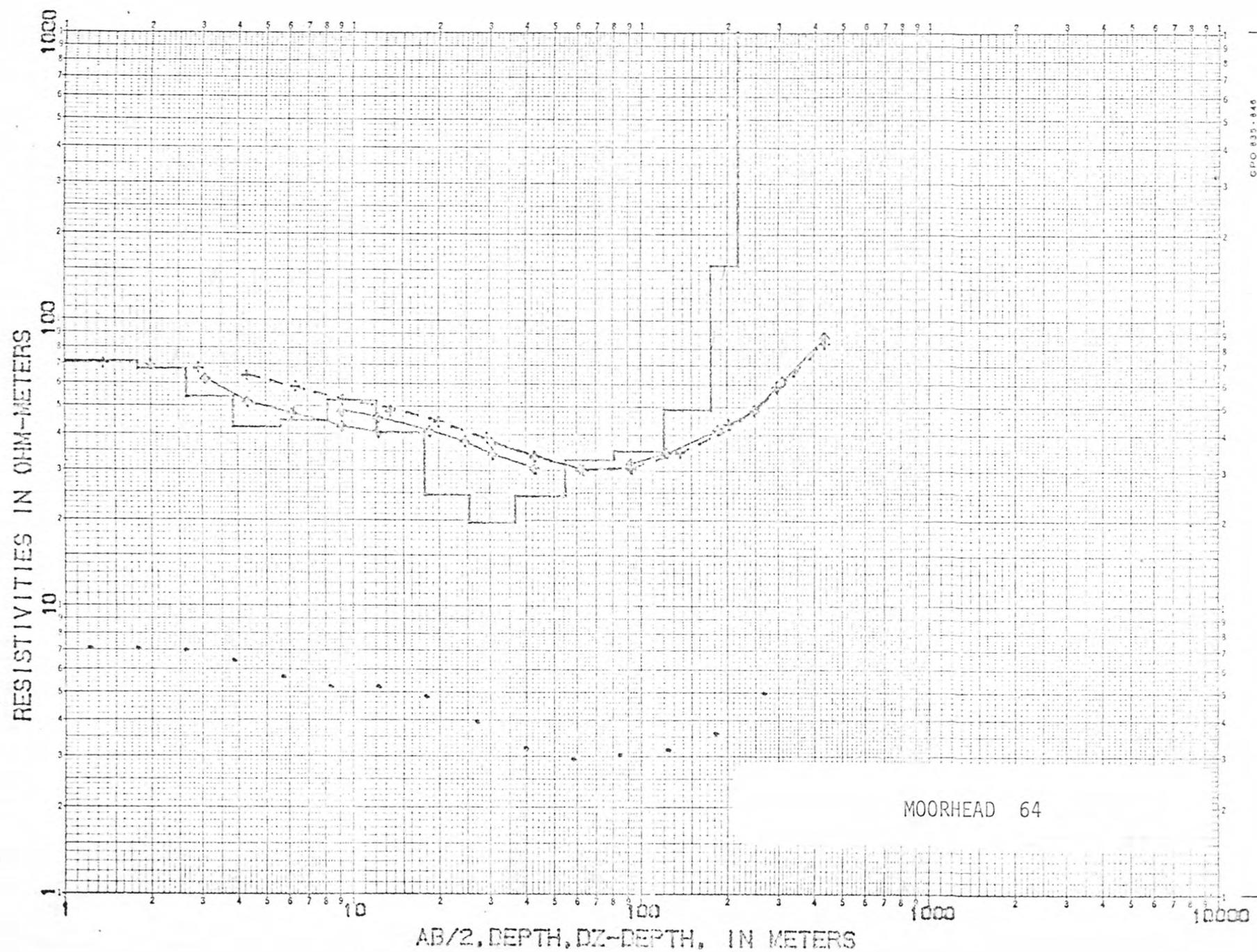


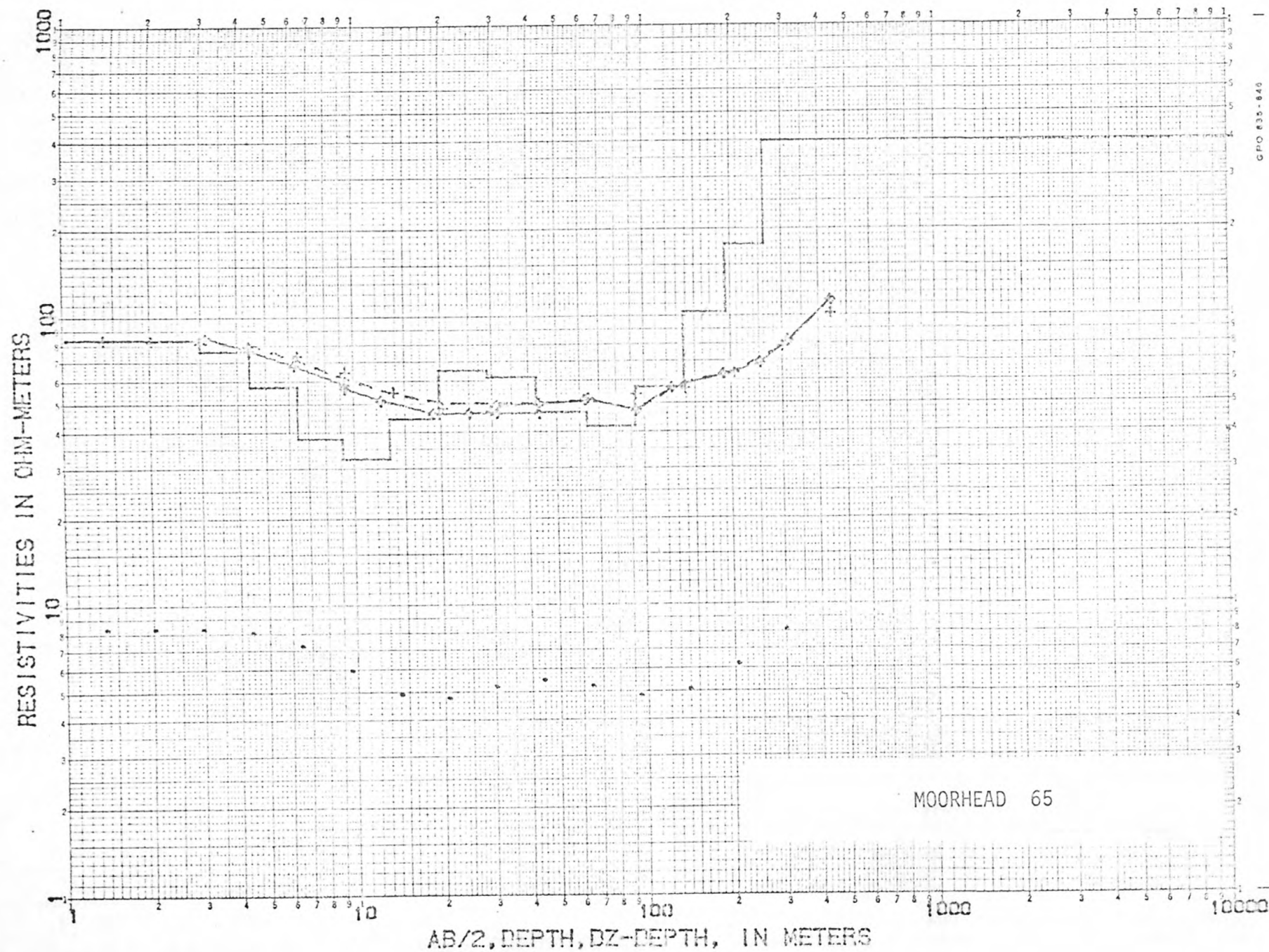


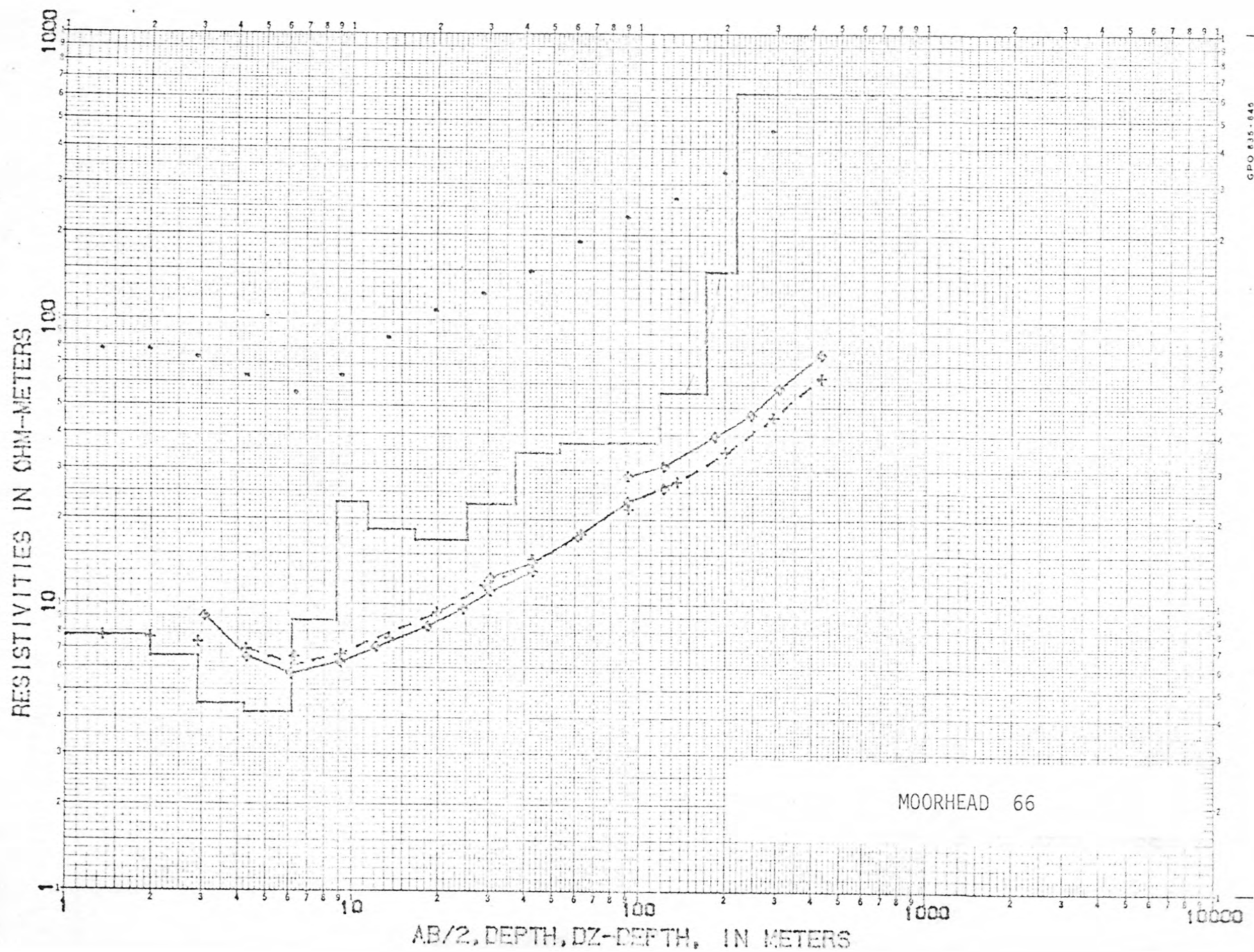




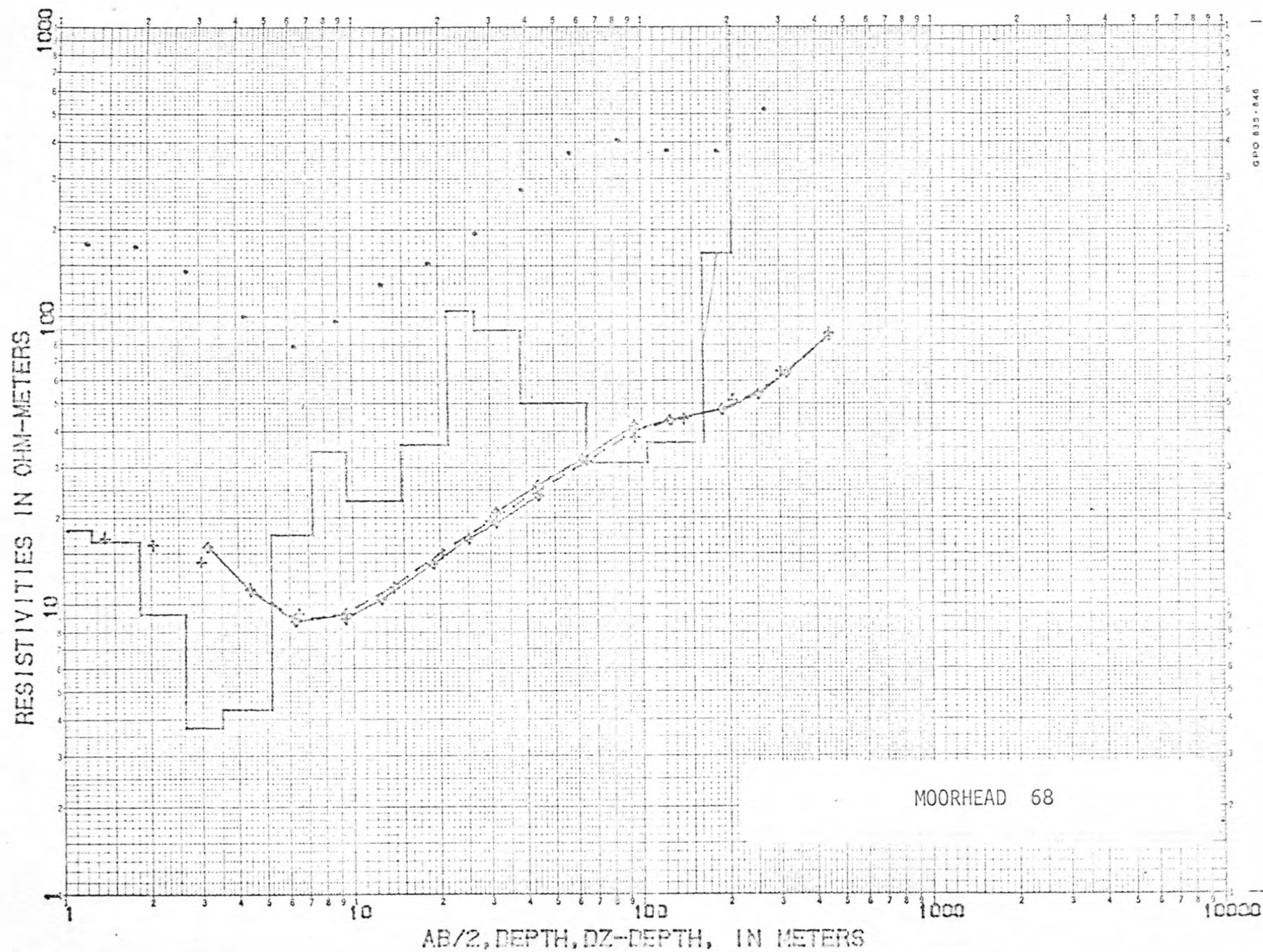


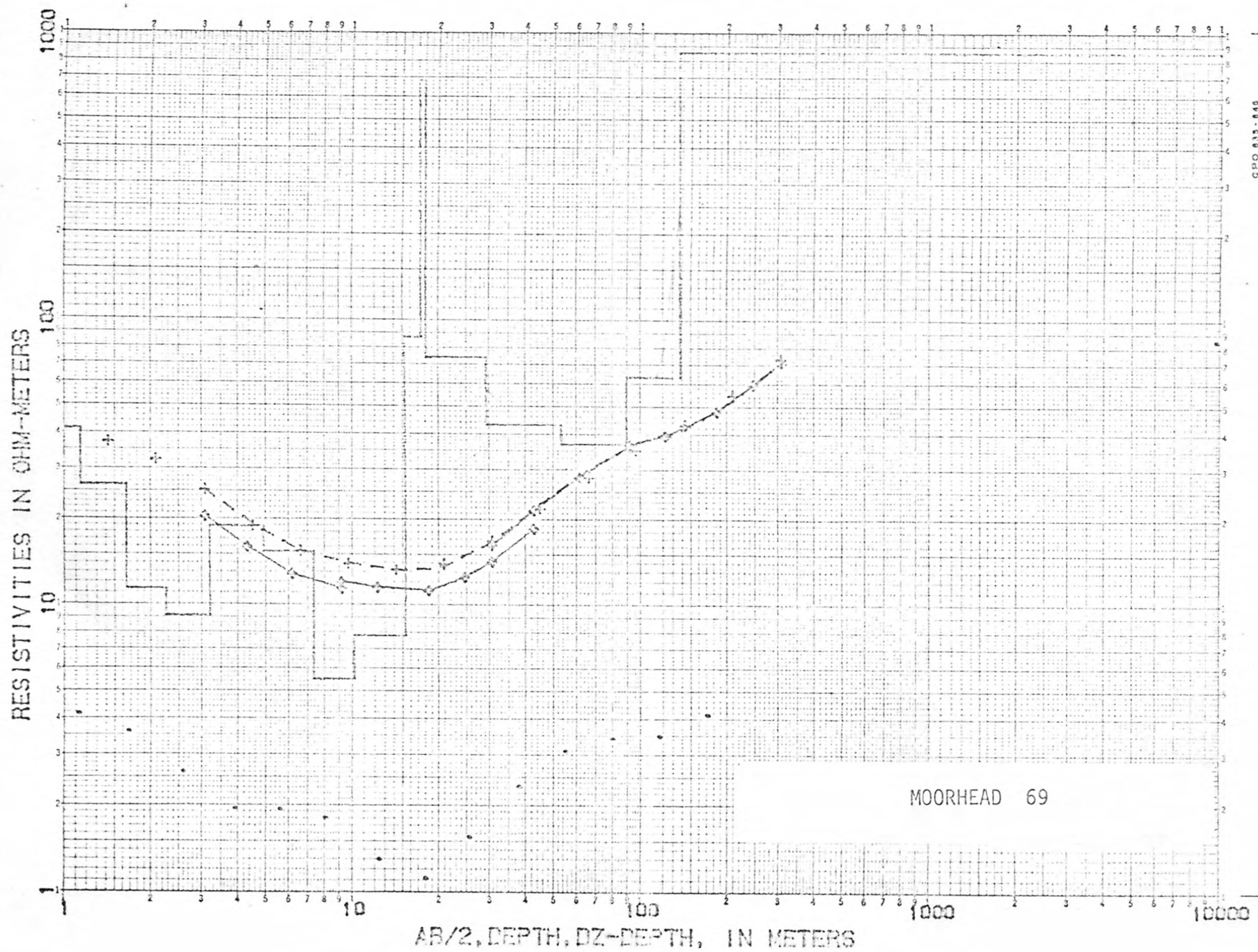


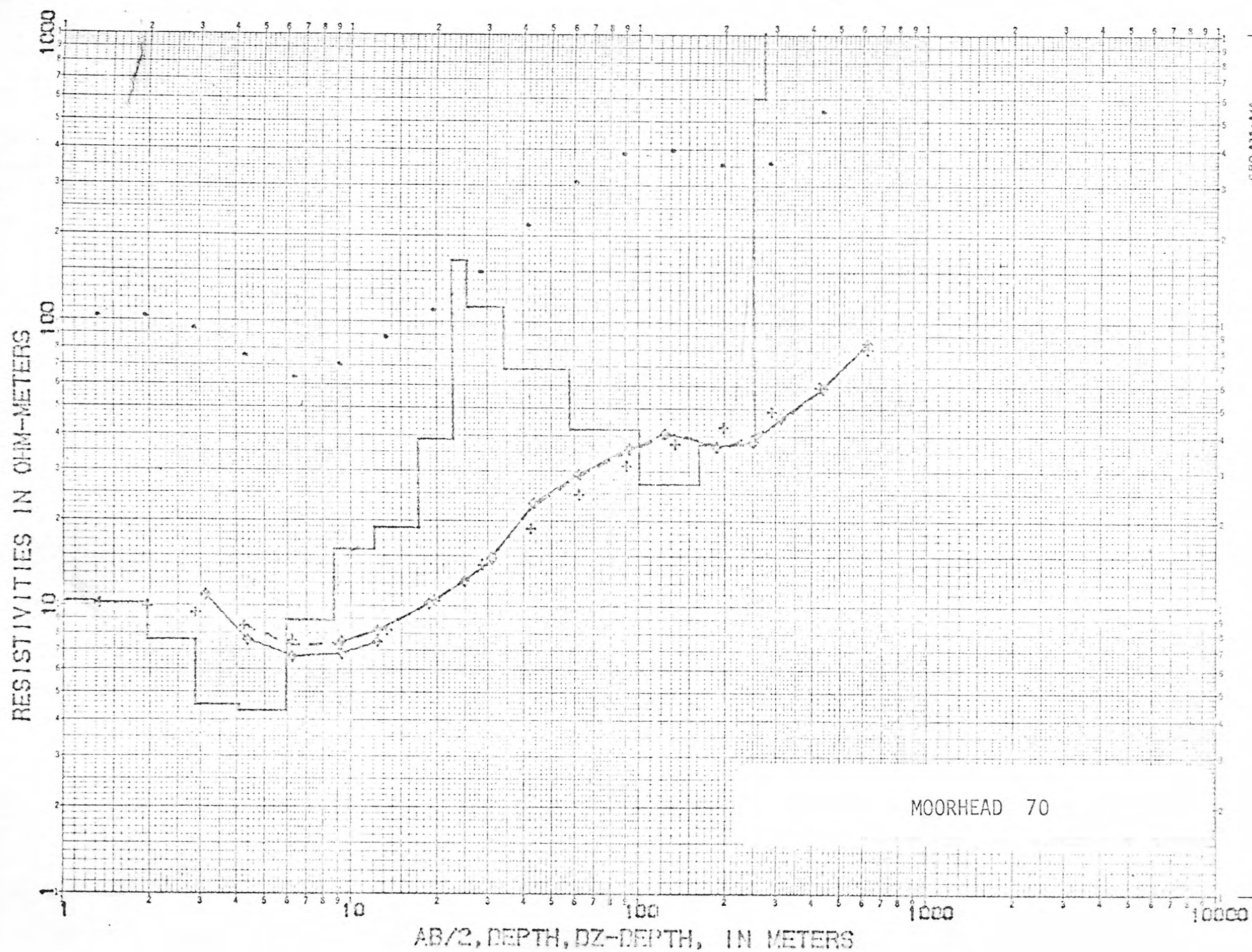




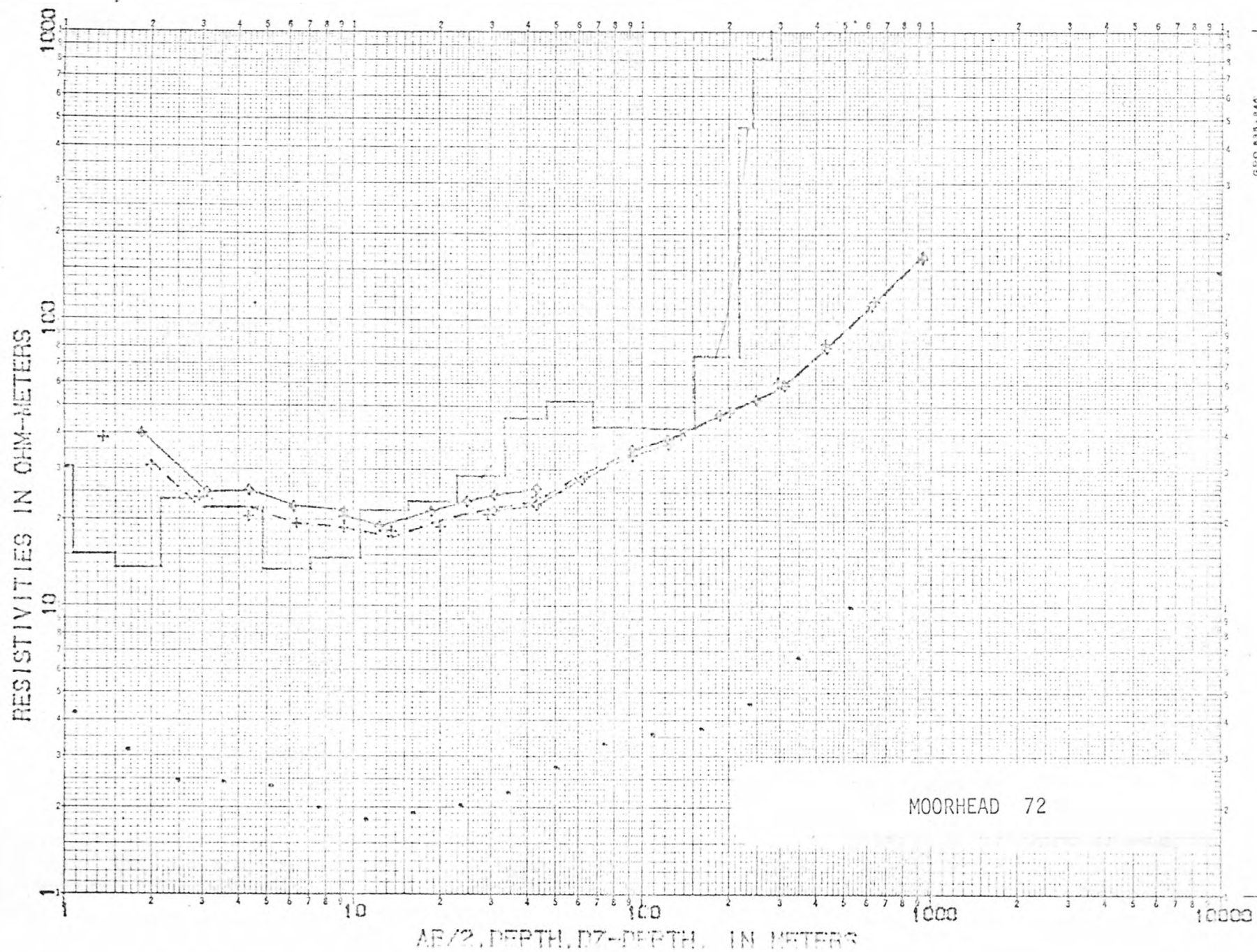


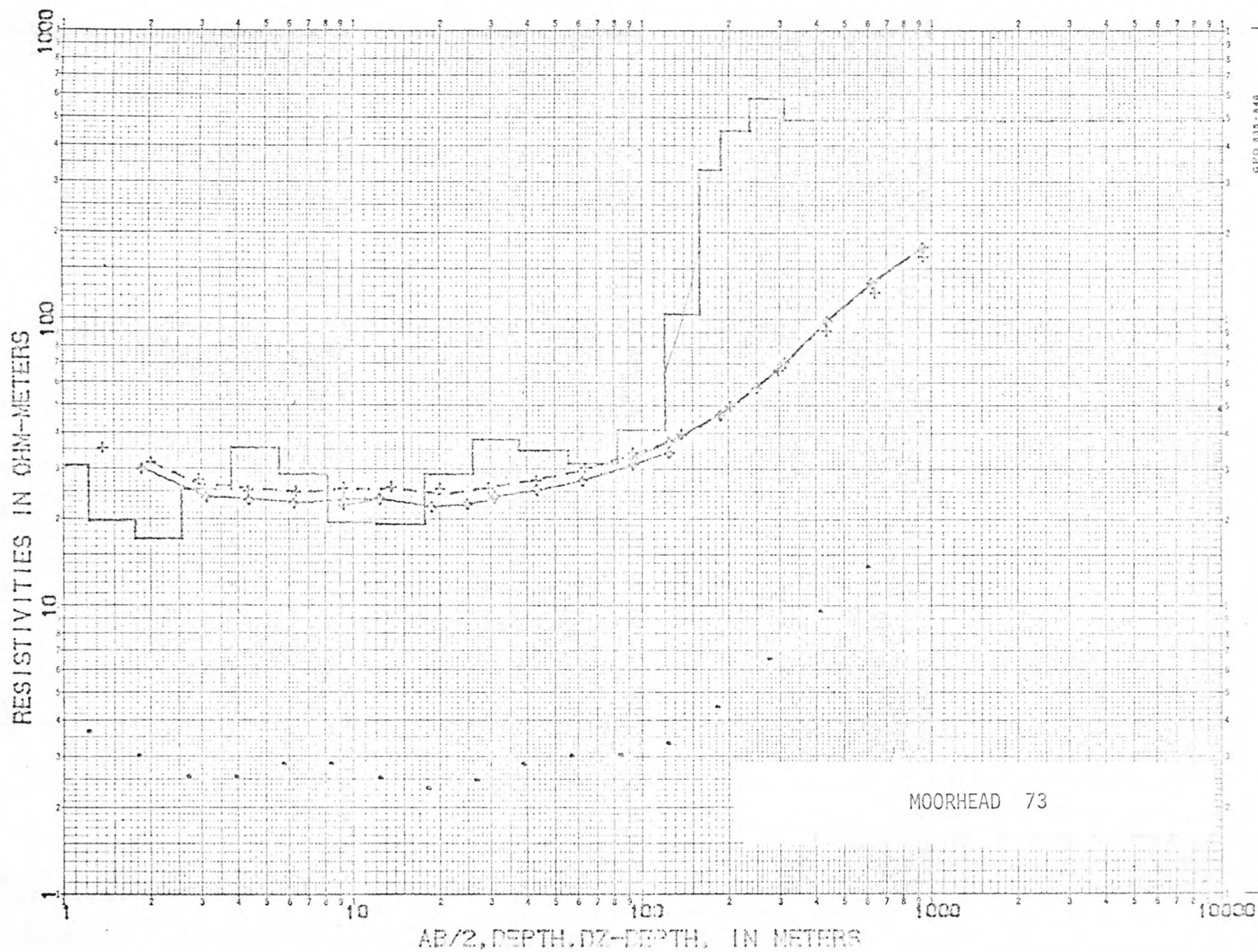


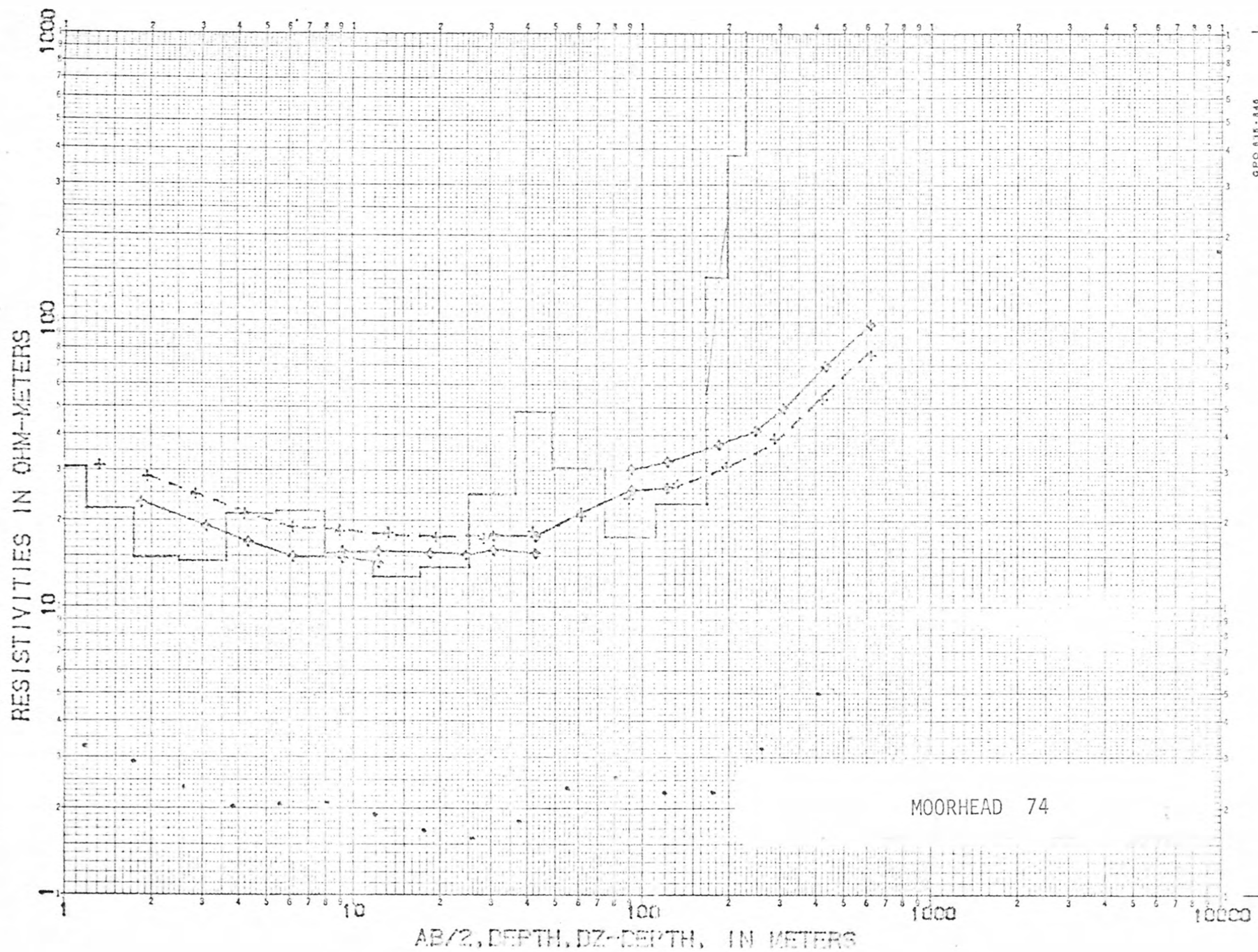


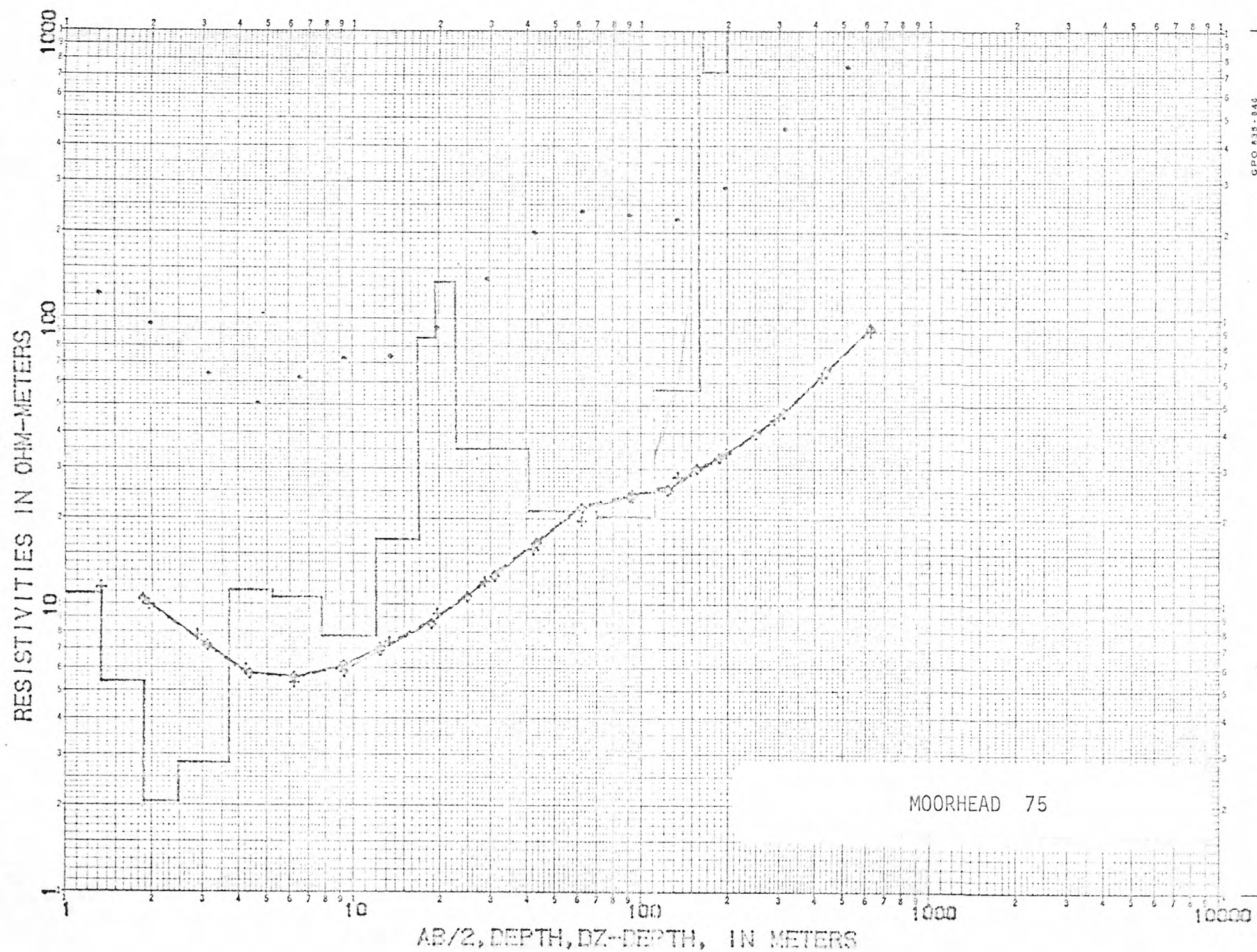


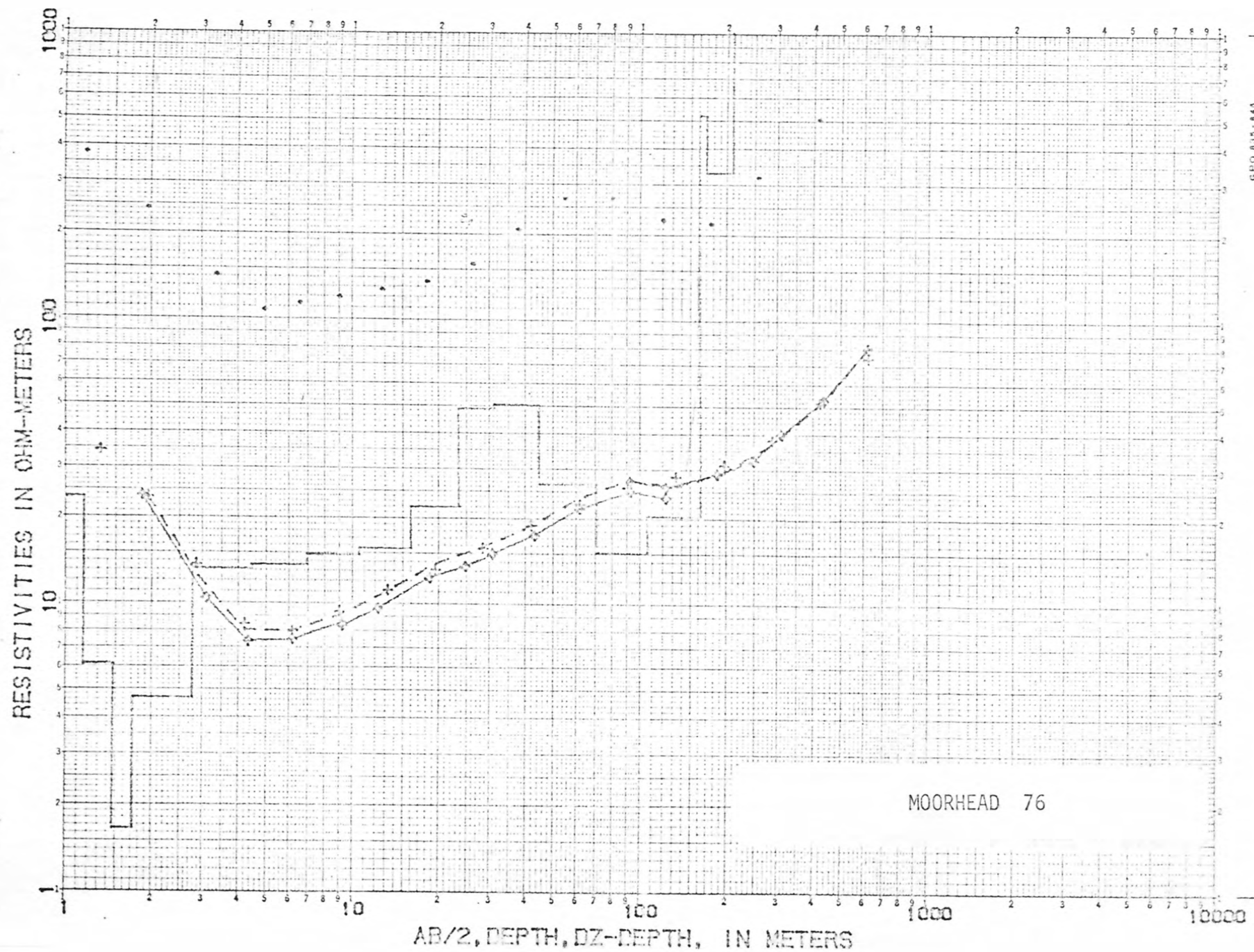


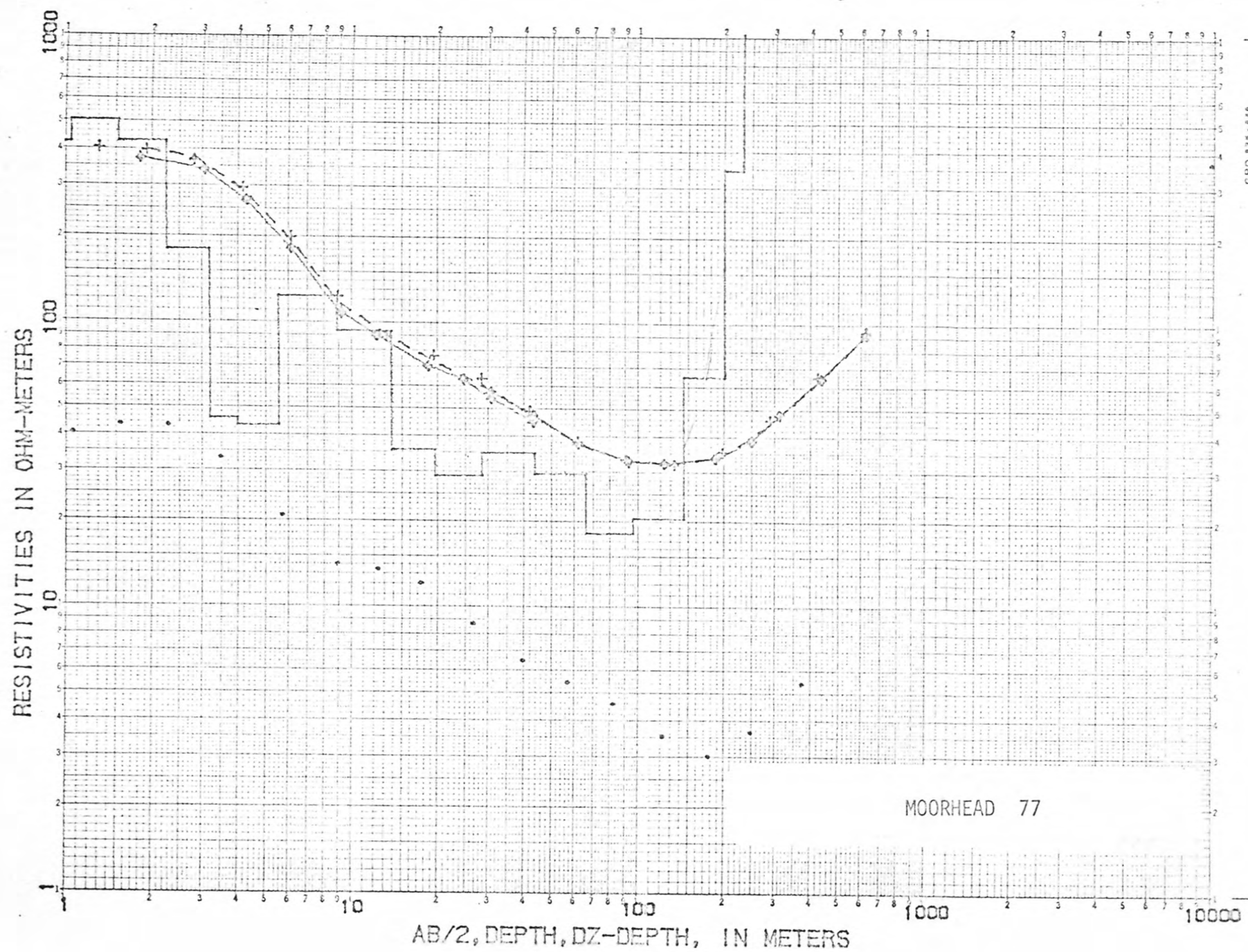


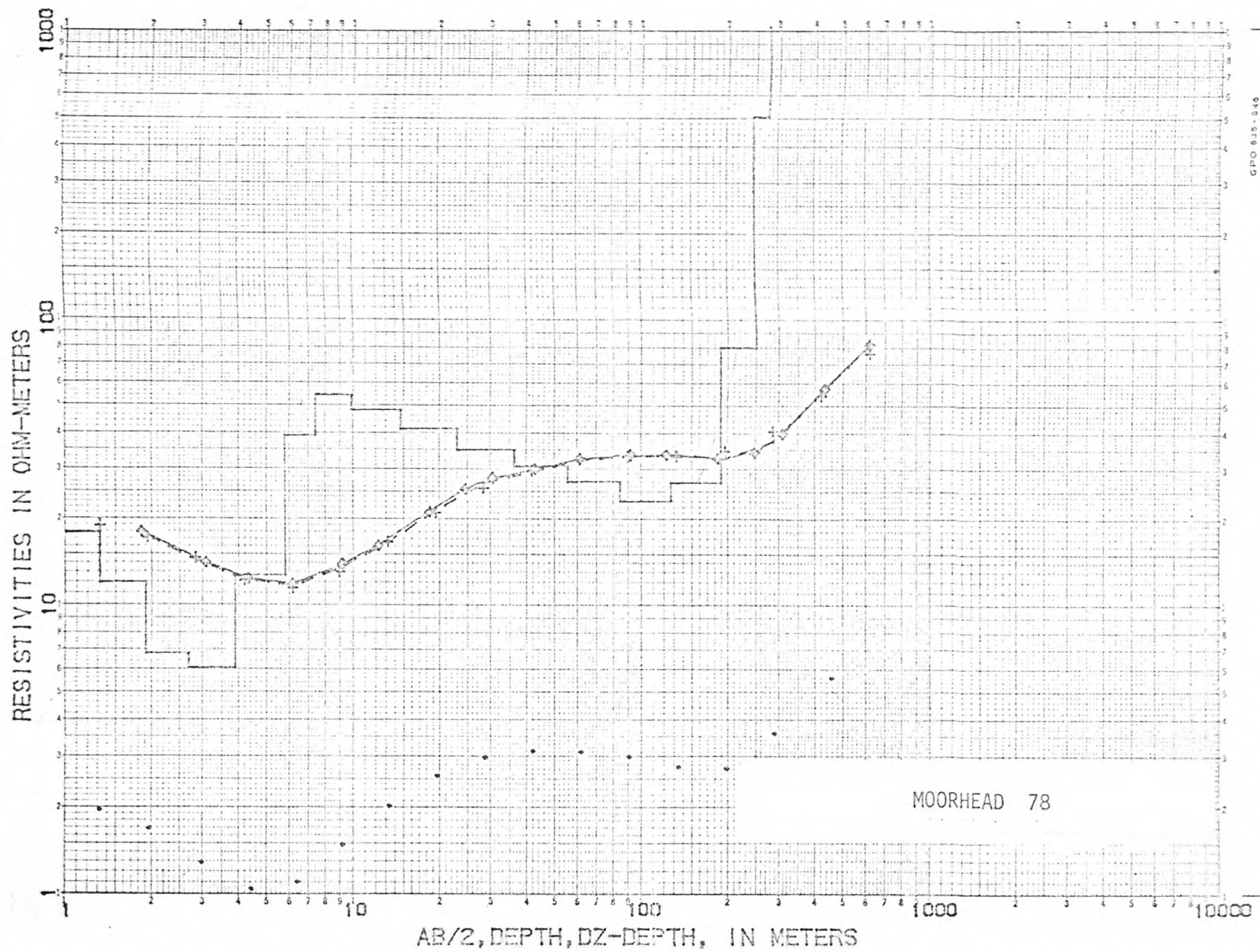


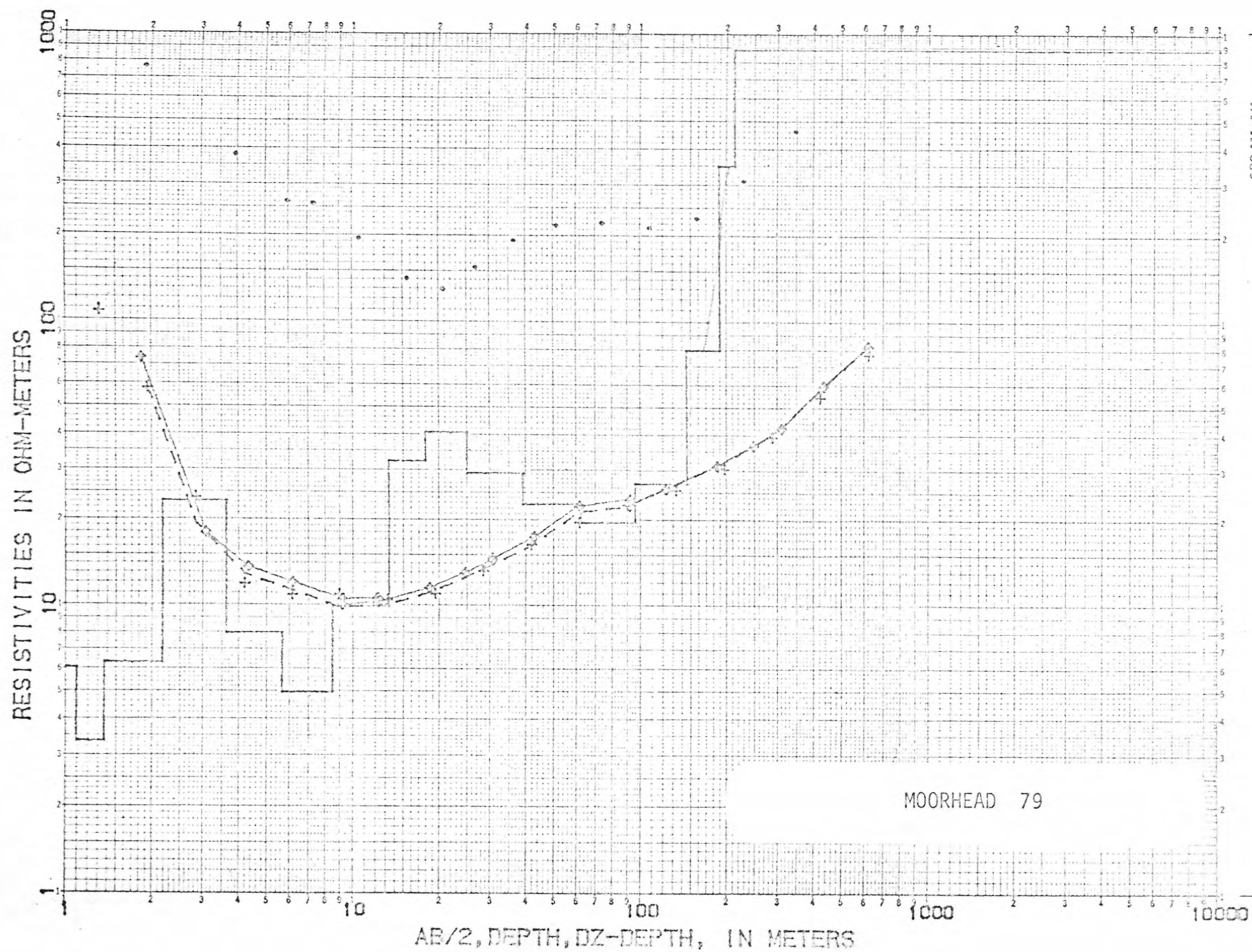




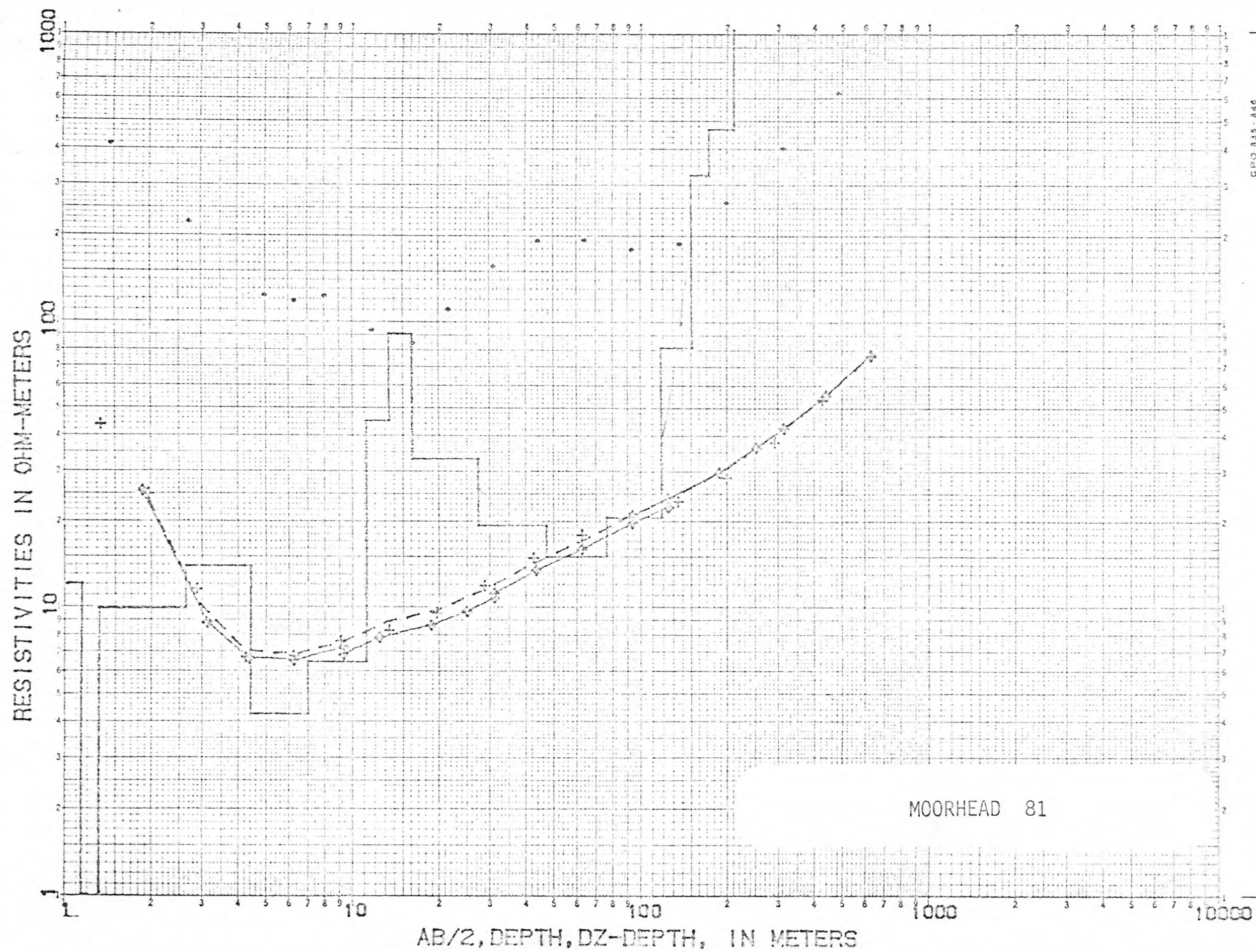


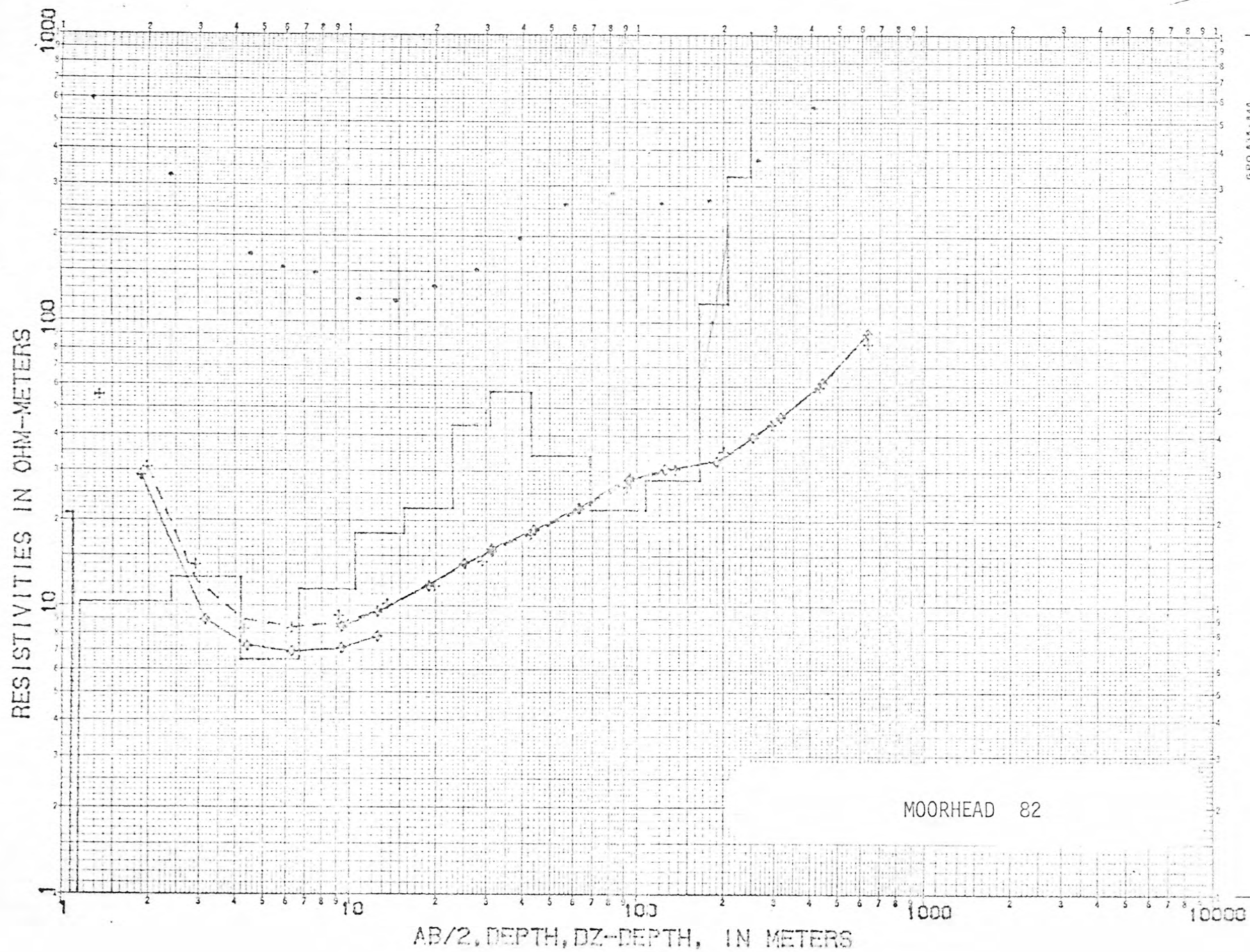


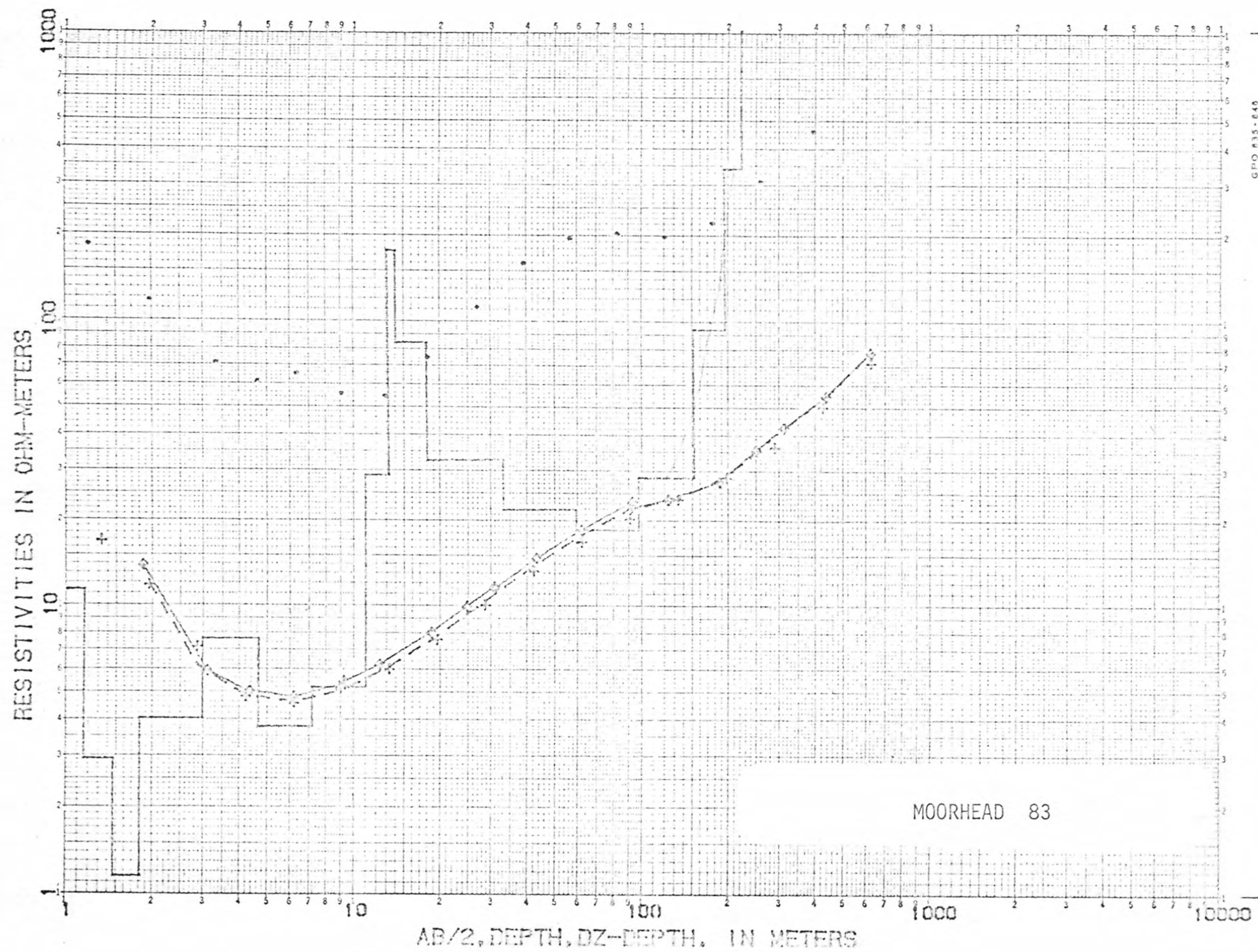


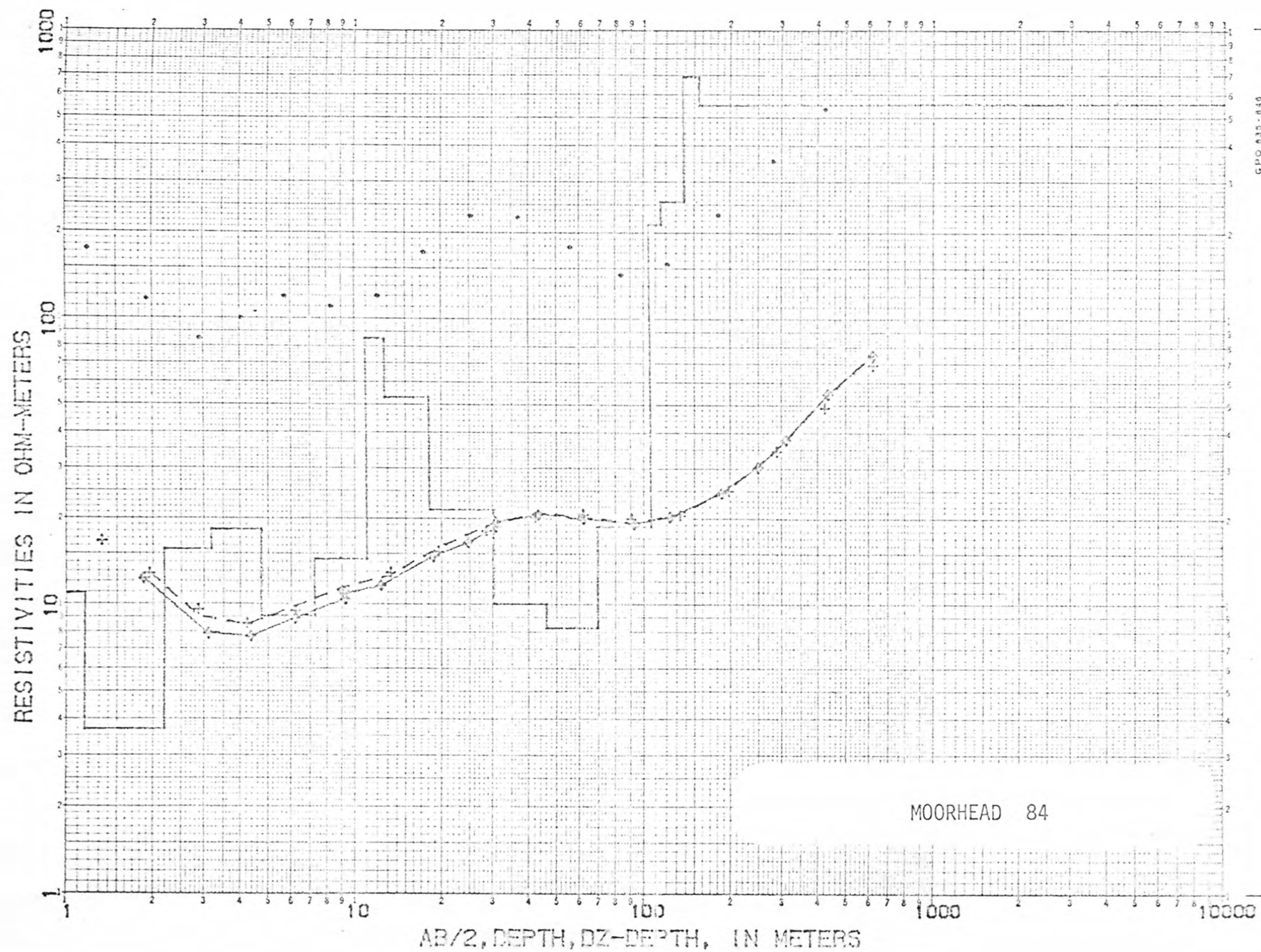


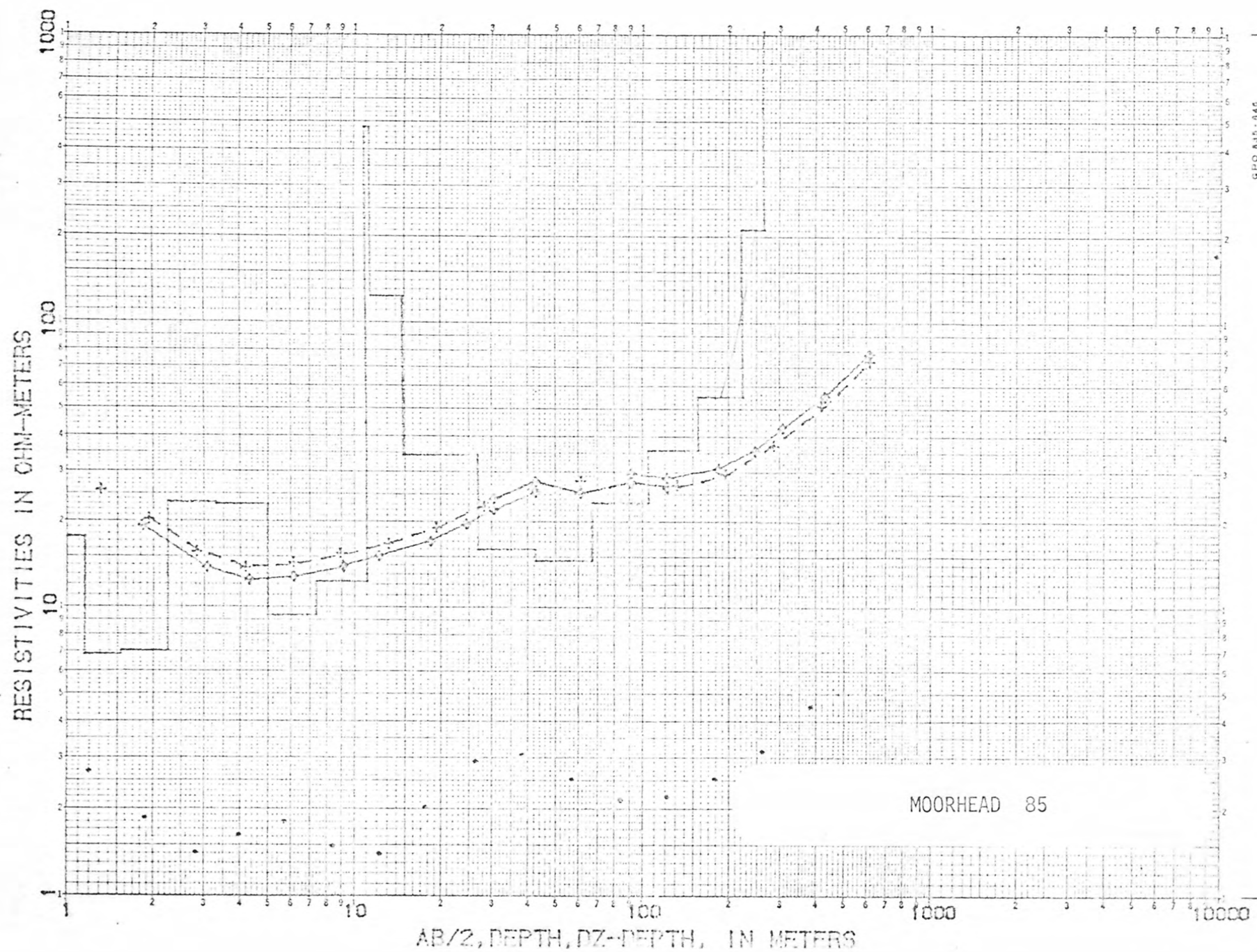


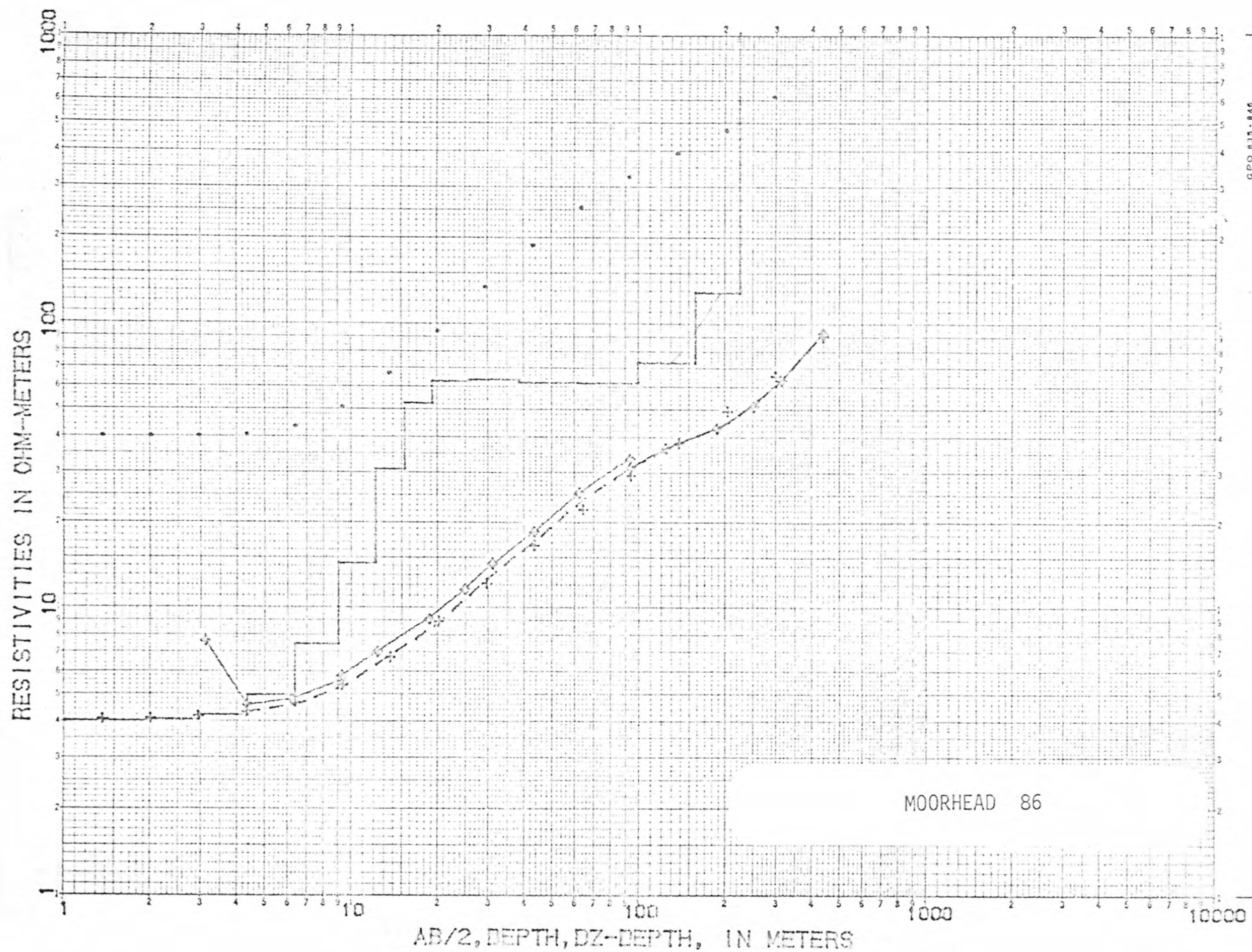




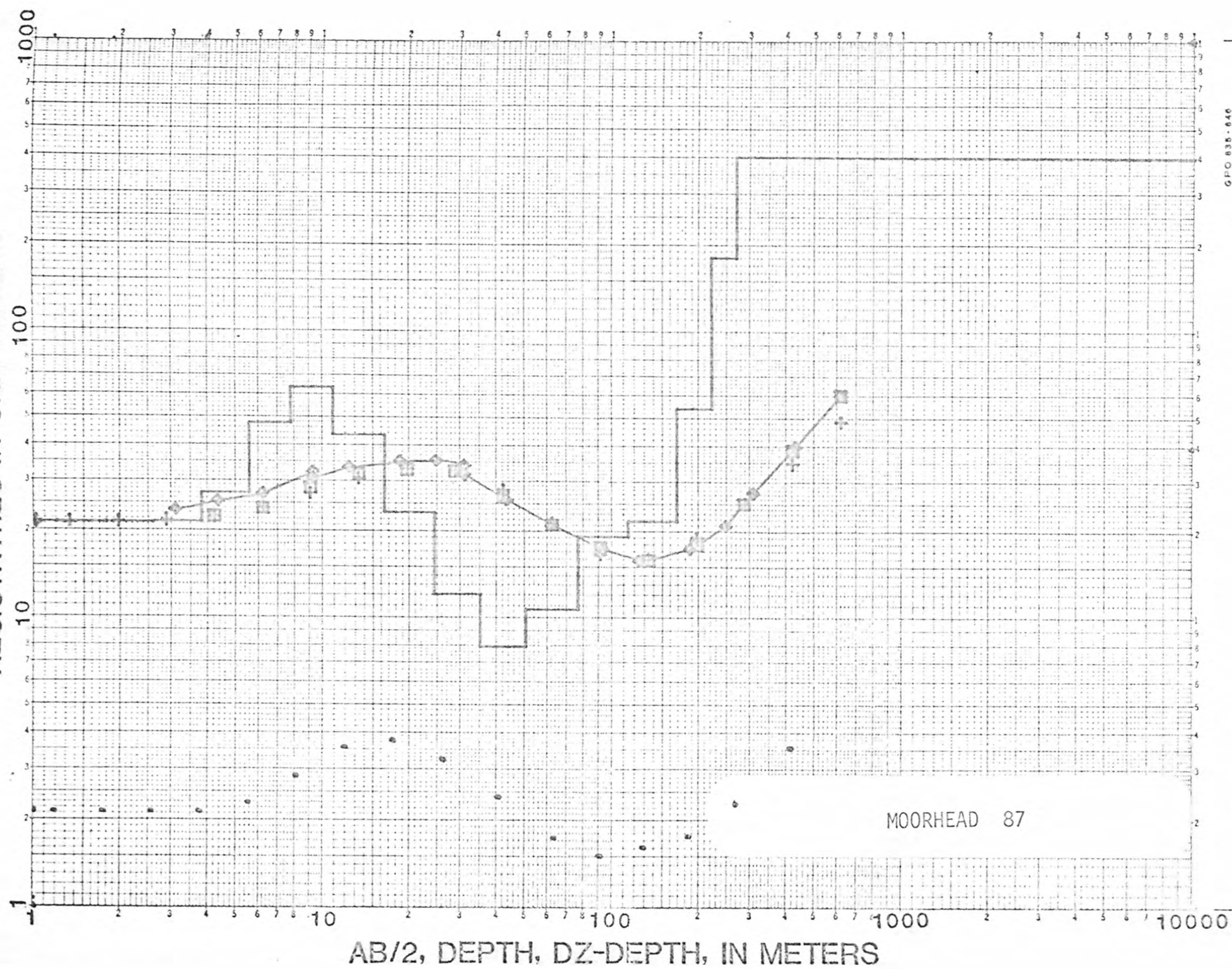


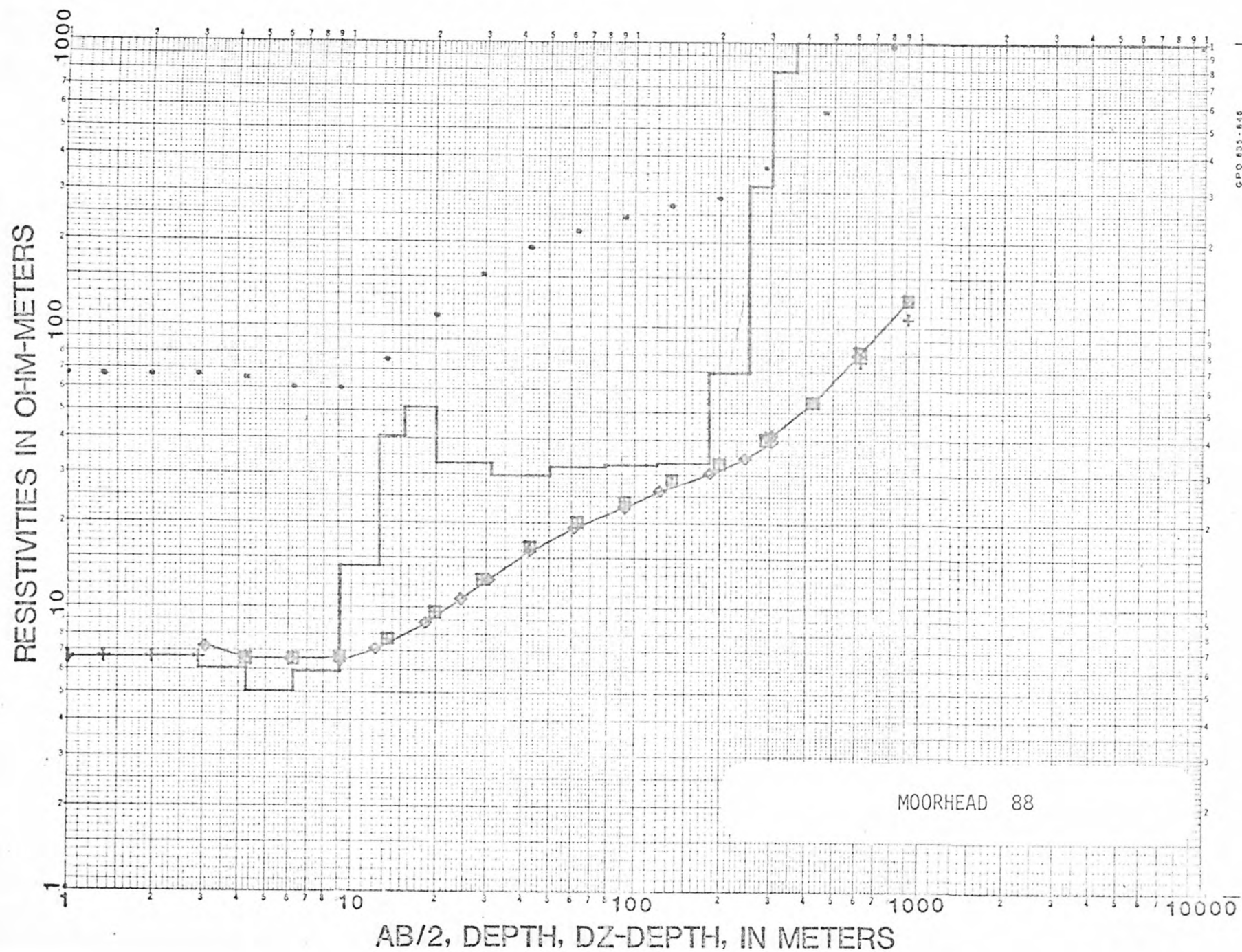


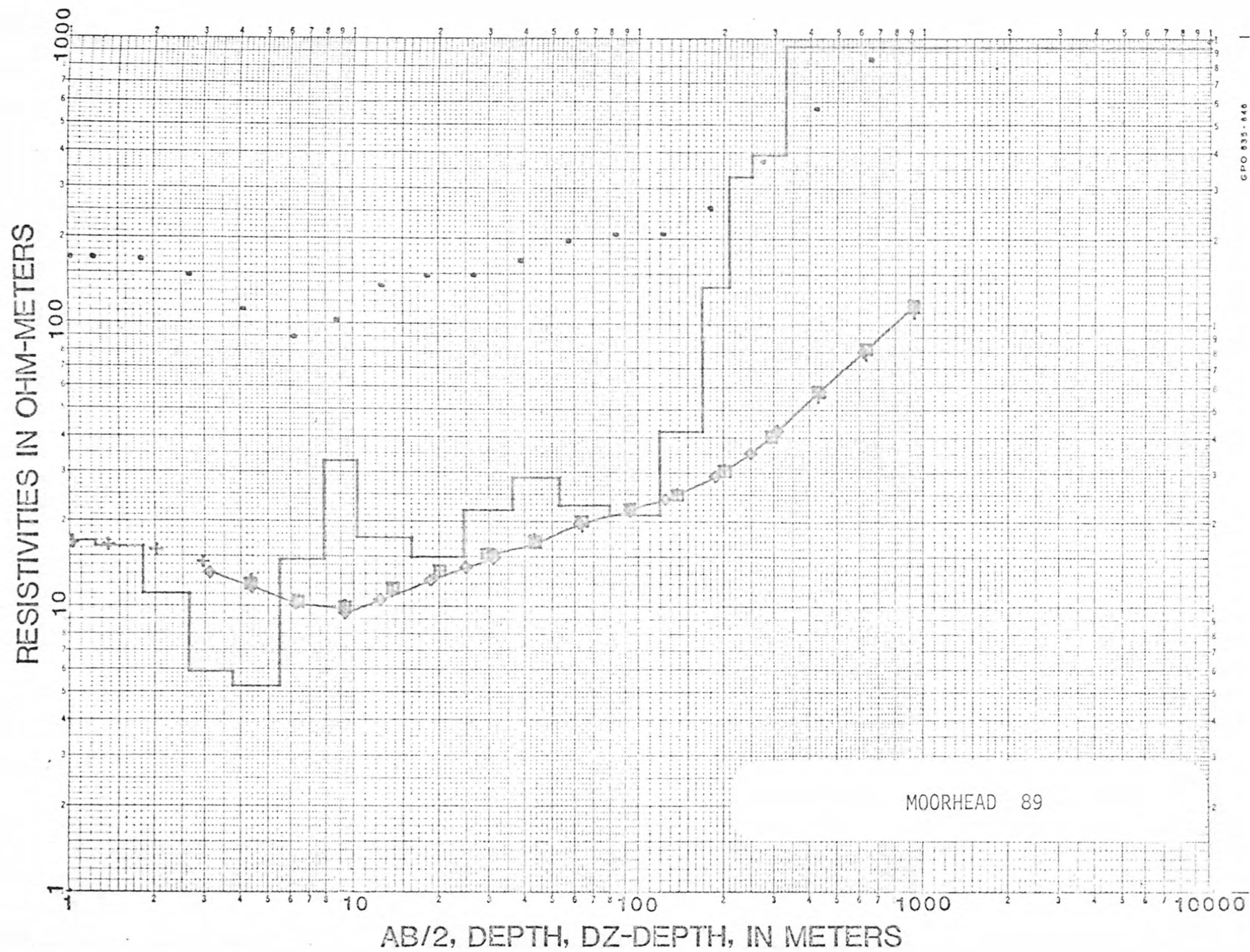


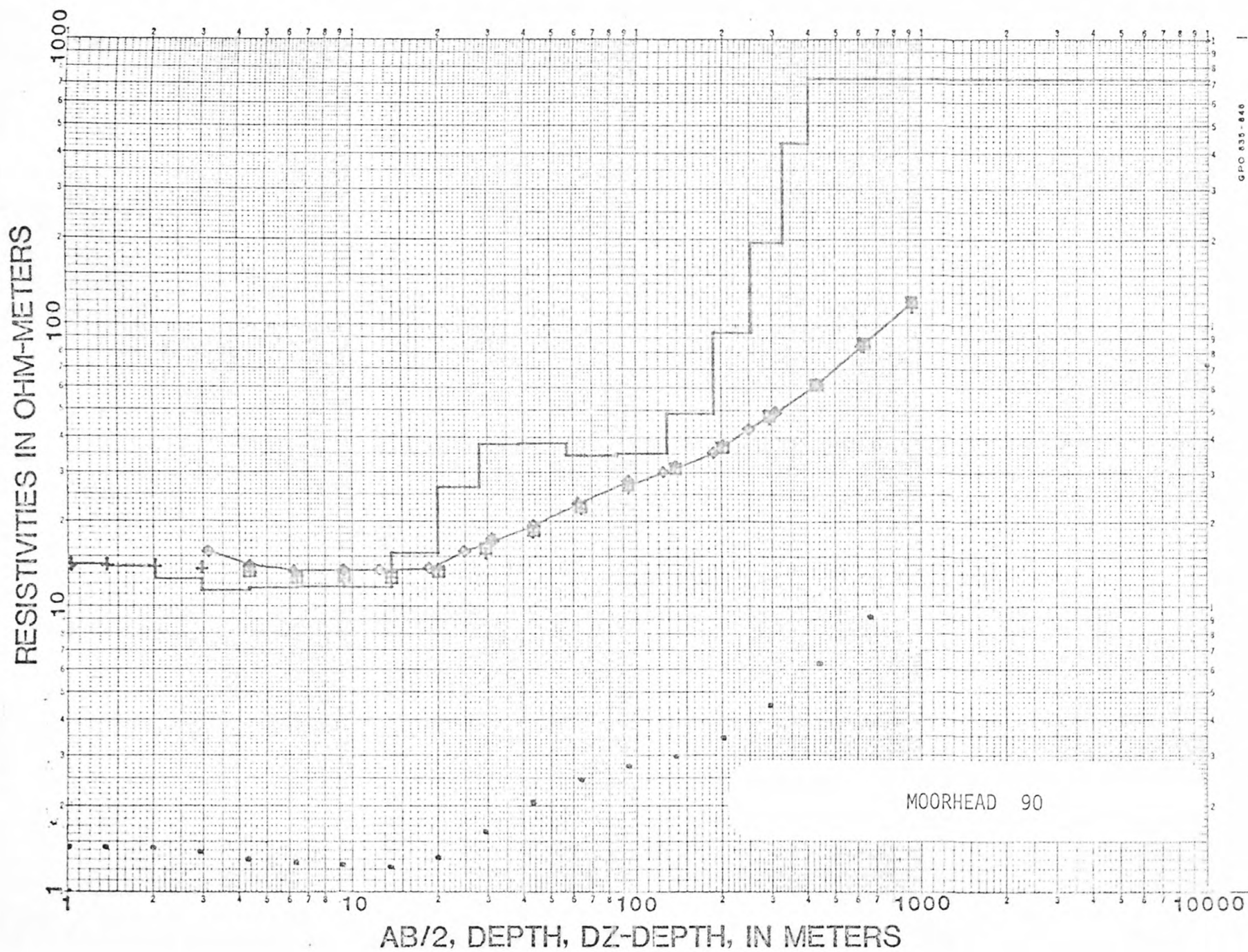


RESISTIVITIES IN OHM-METERS

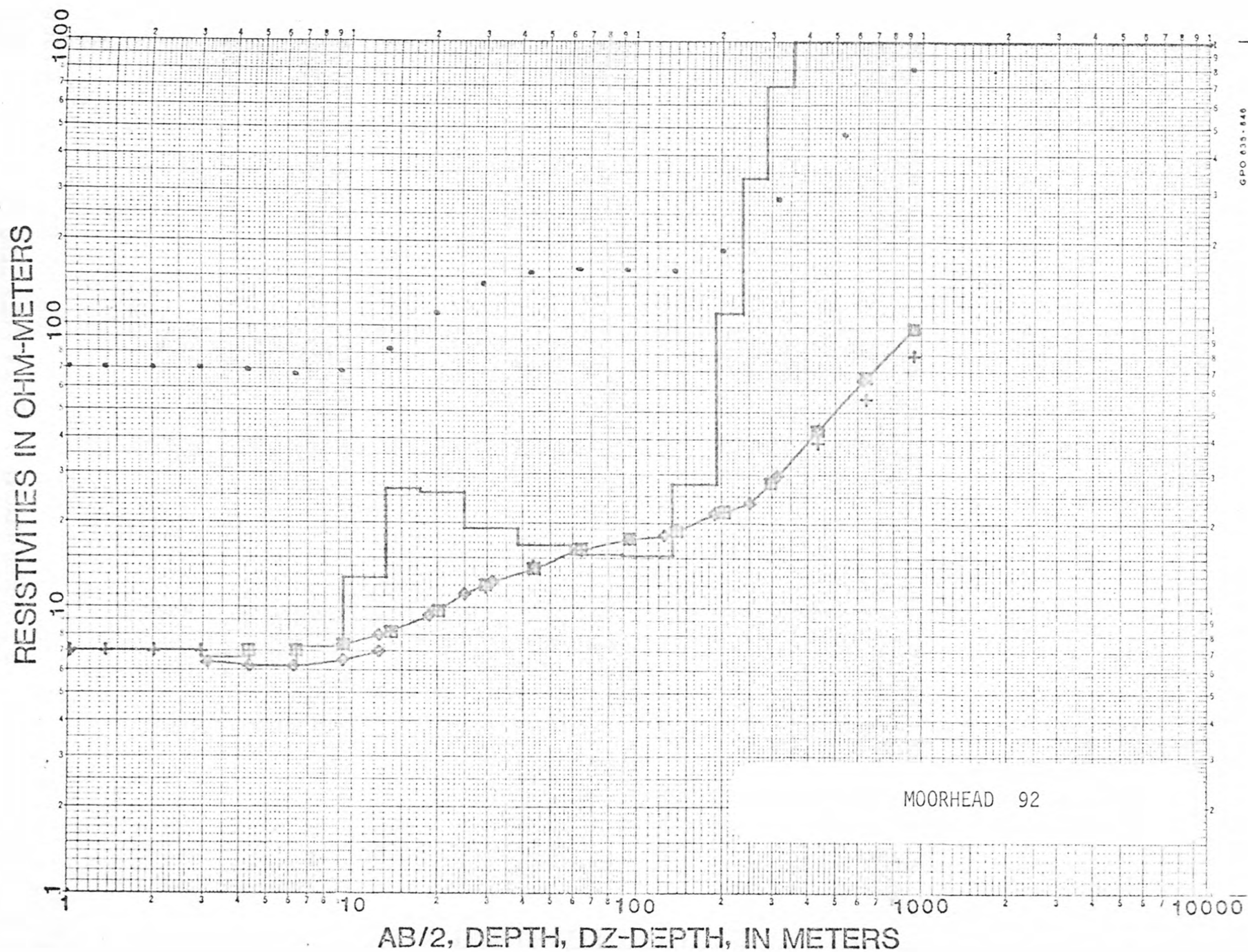


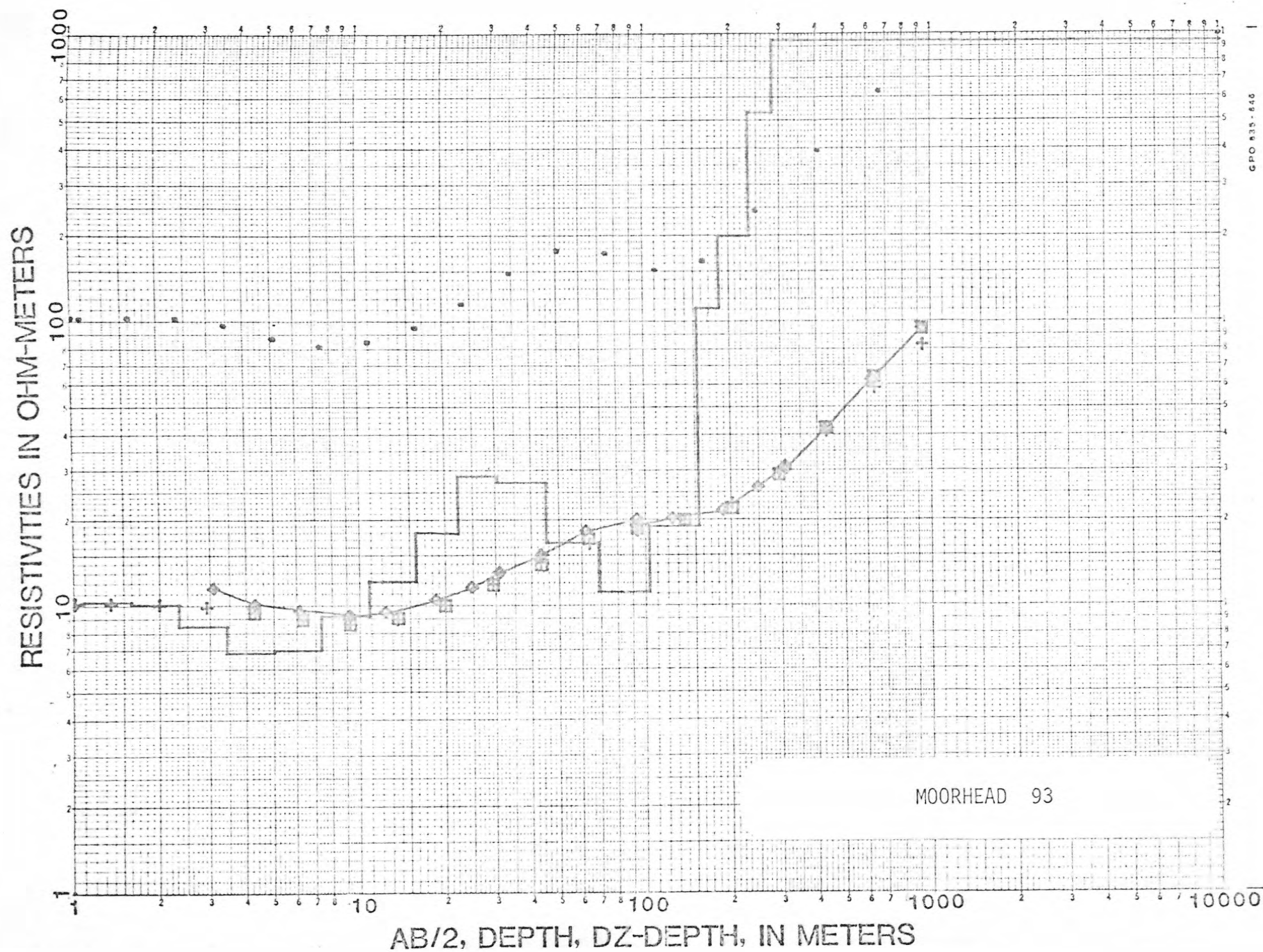


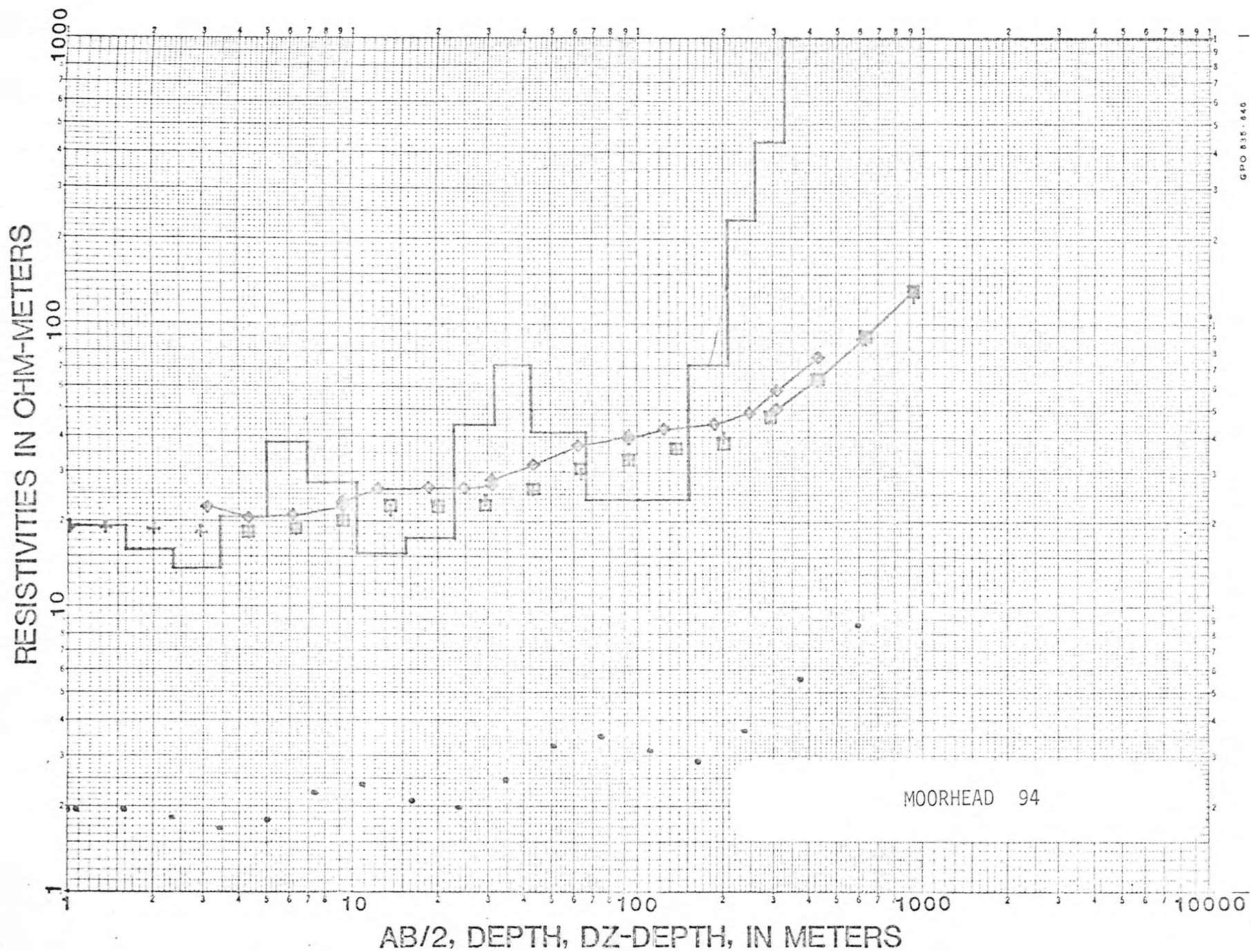






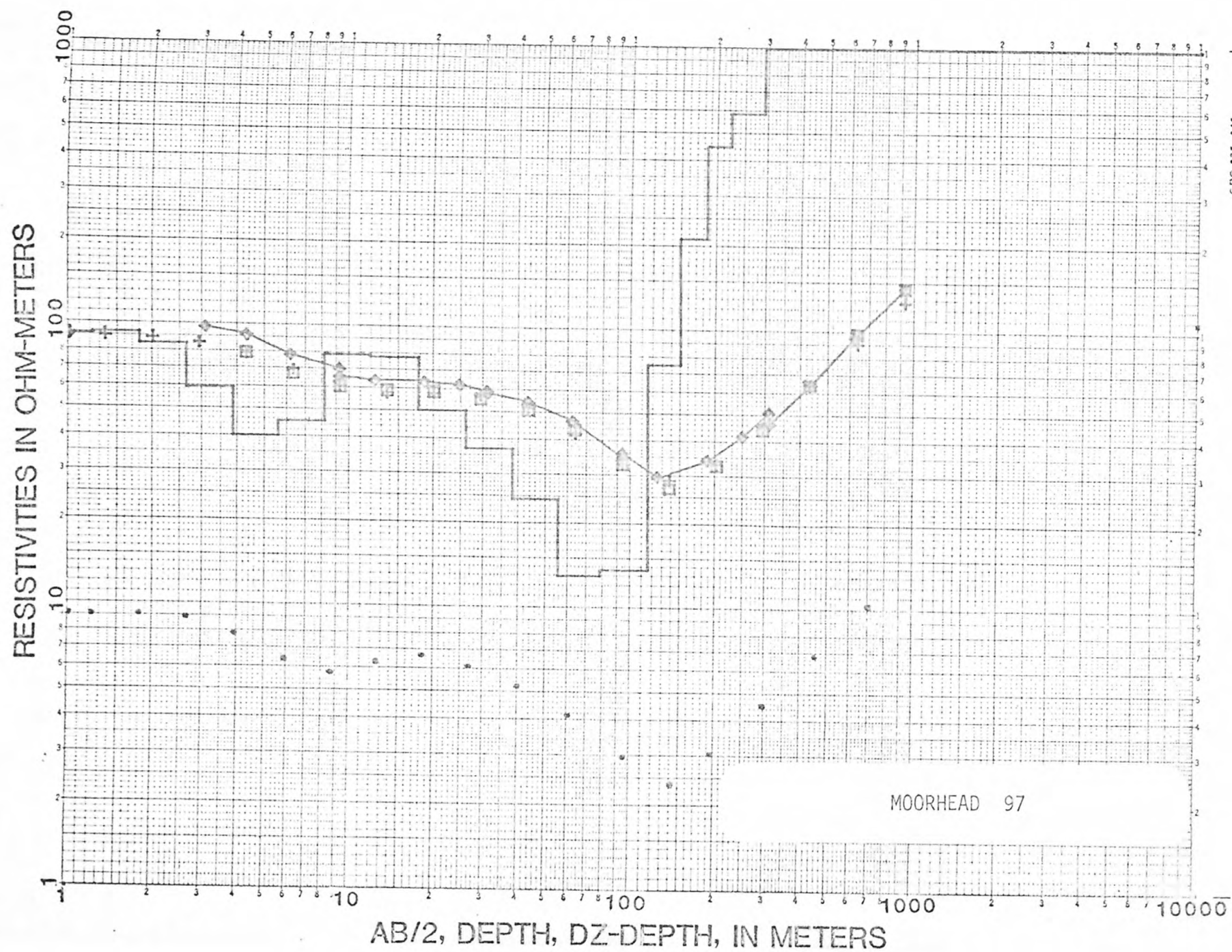


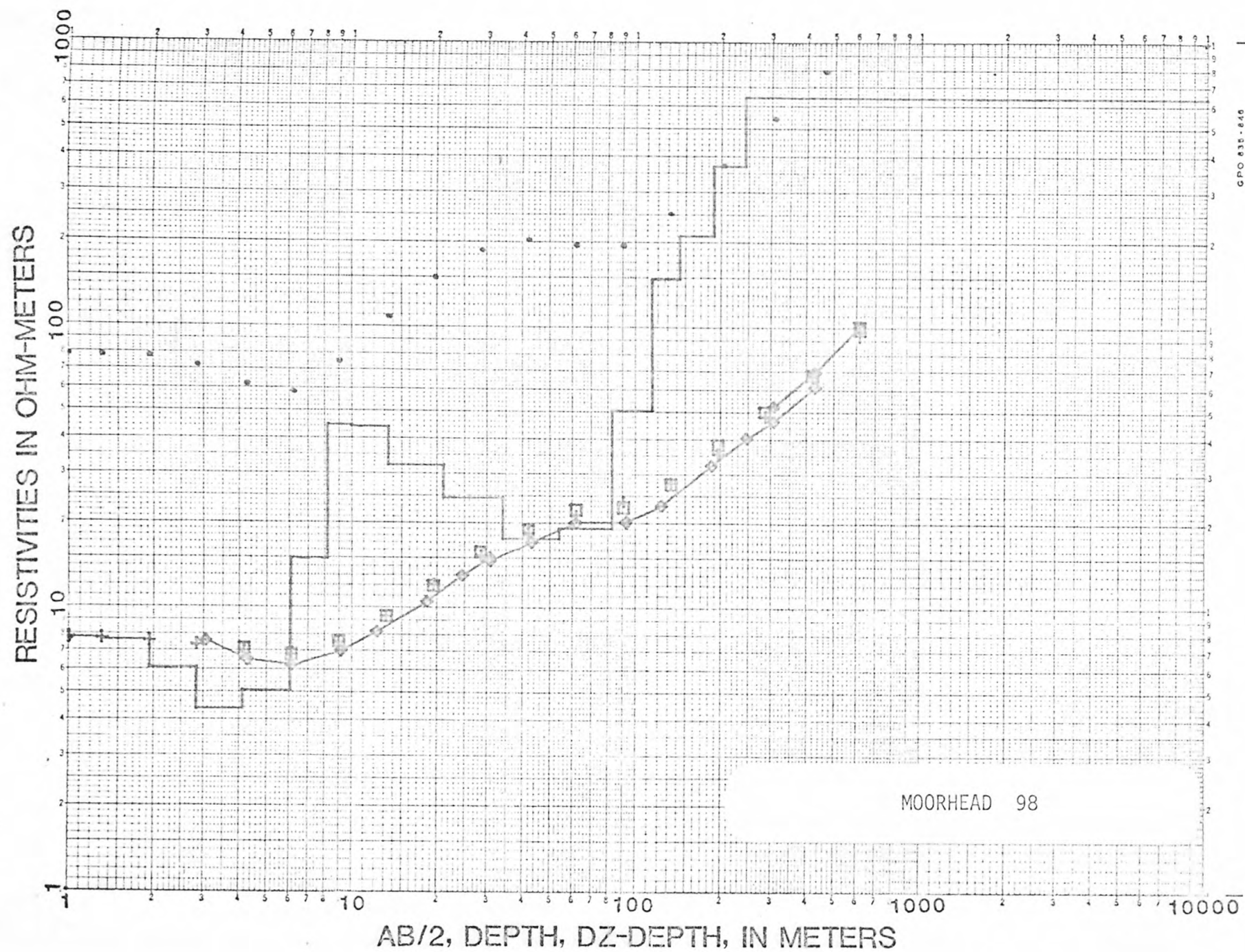


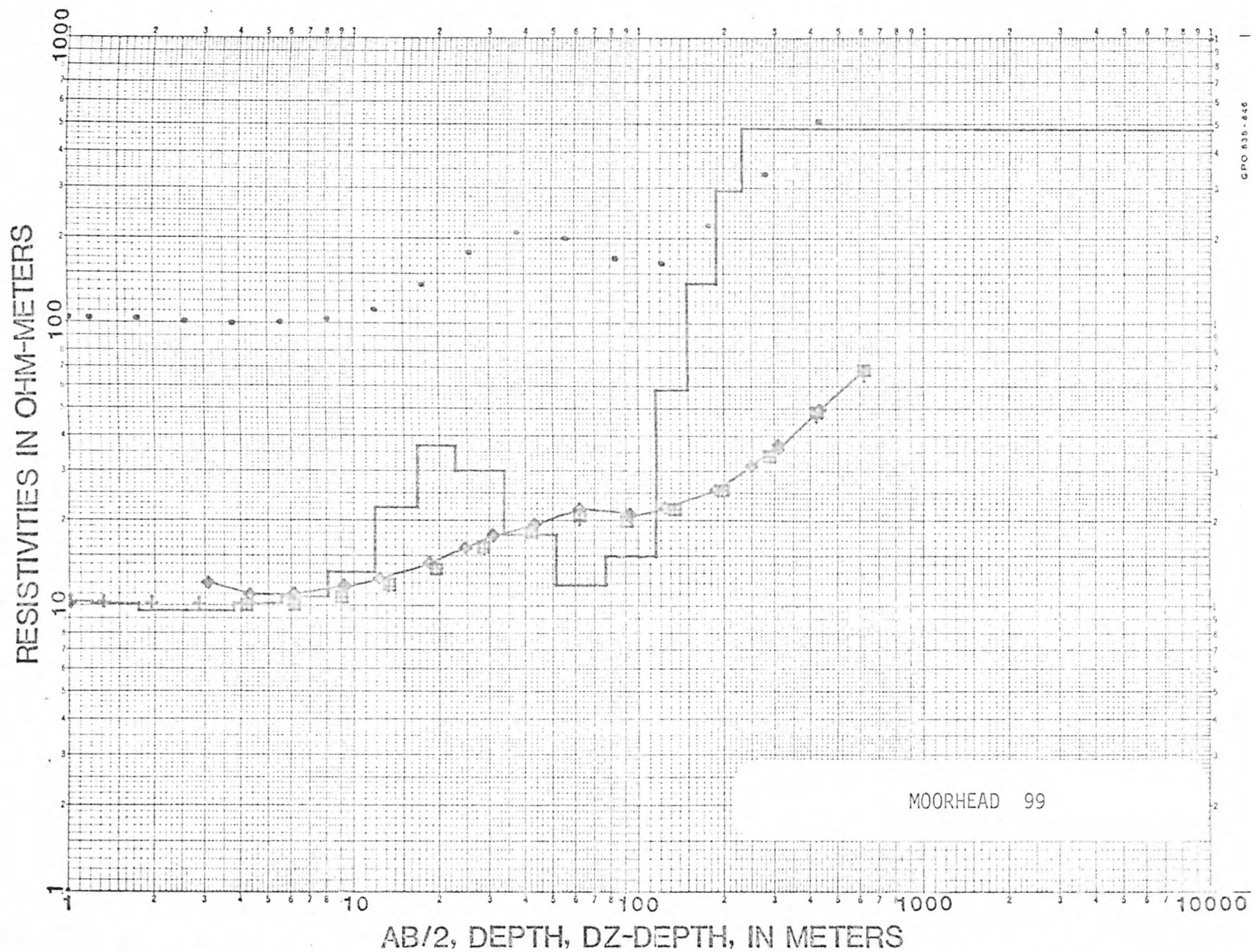




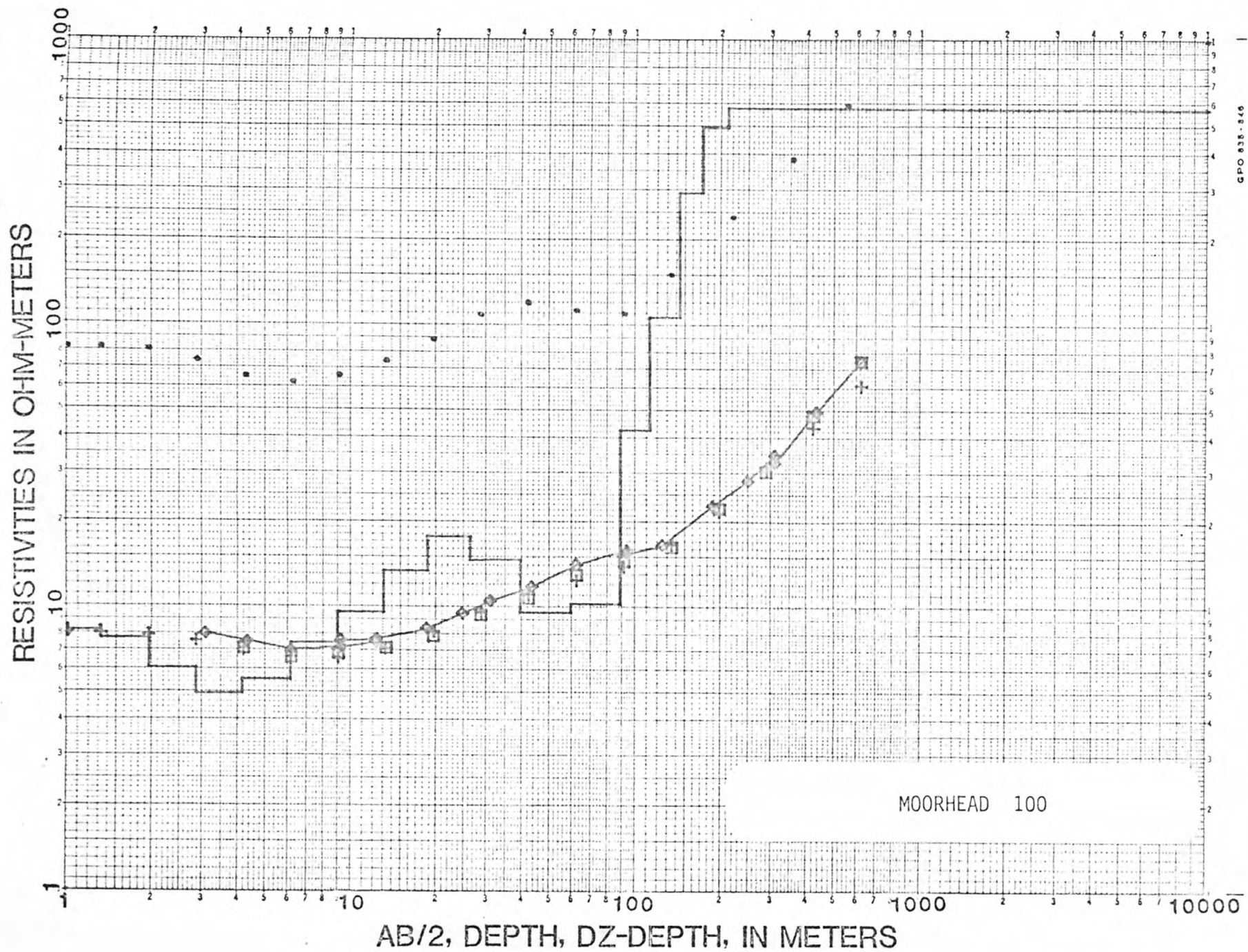


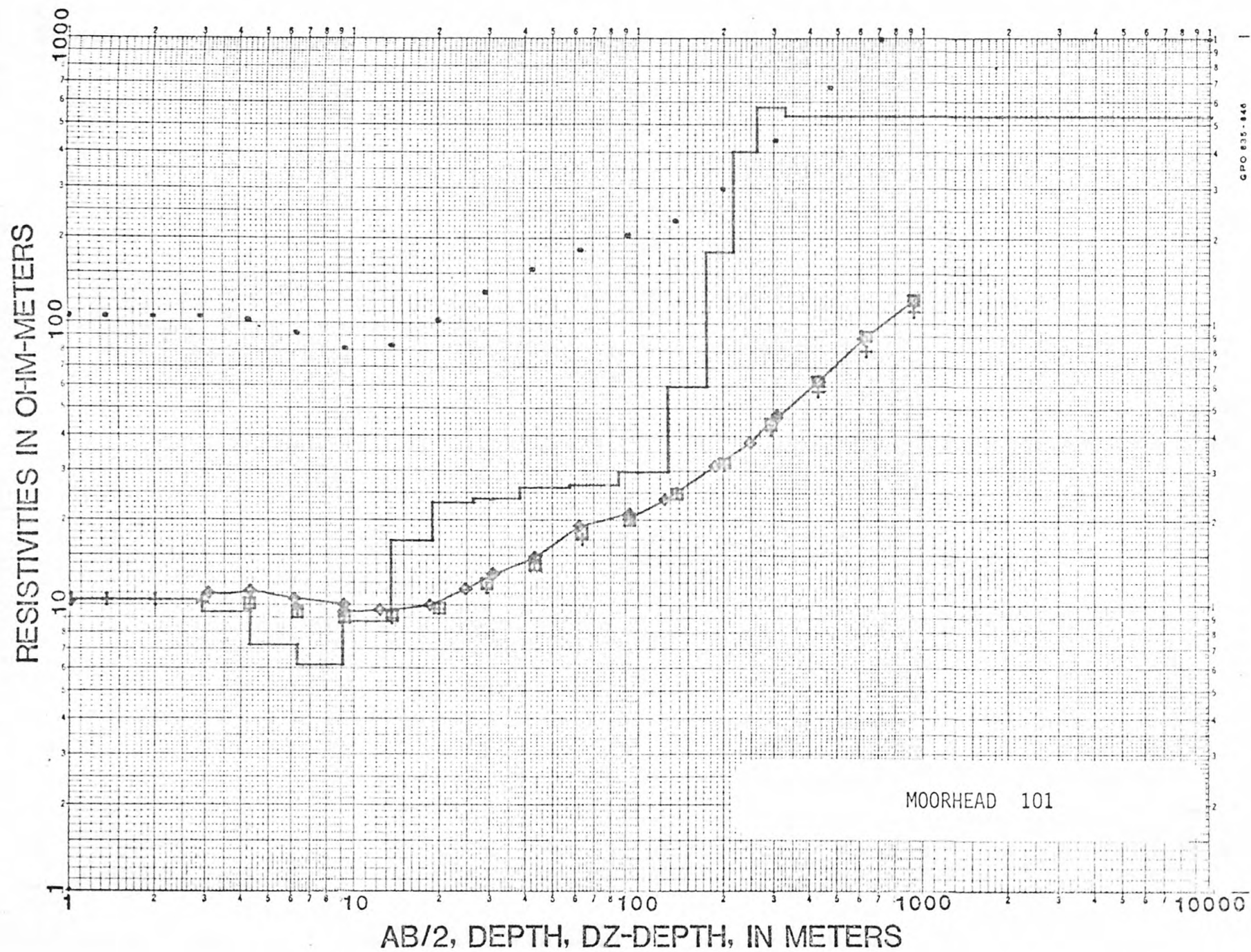


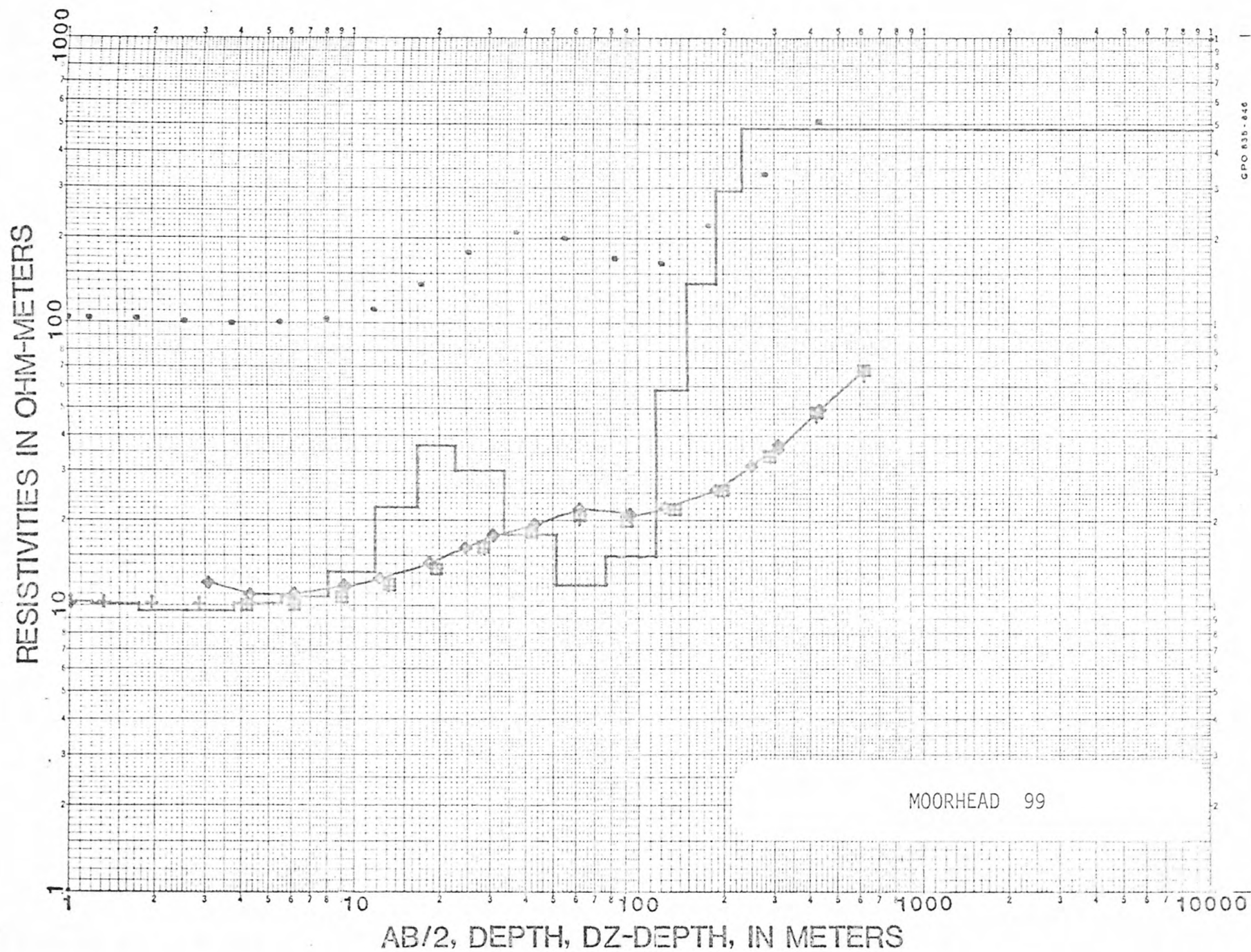


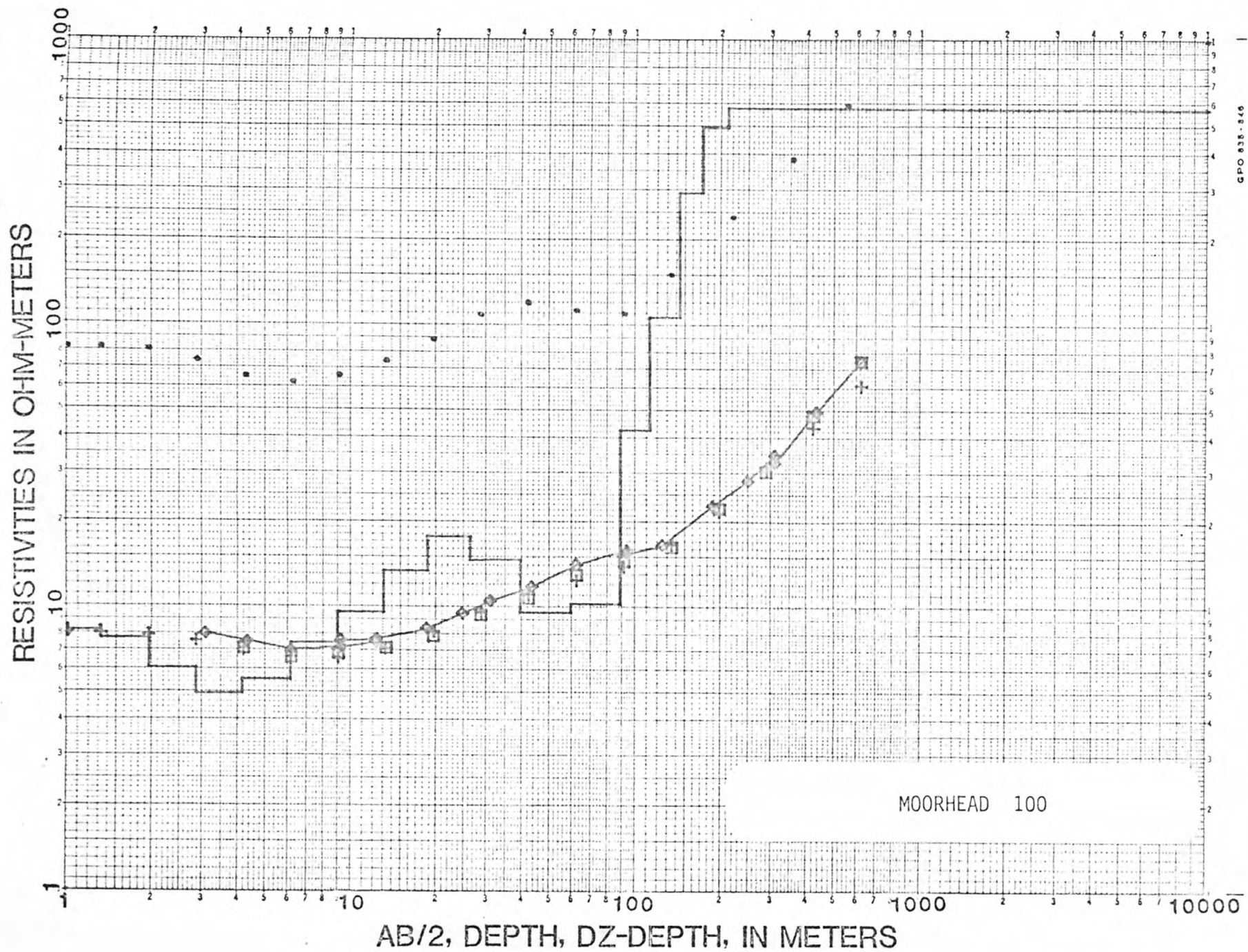




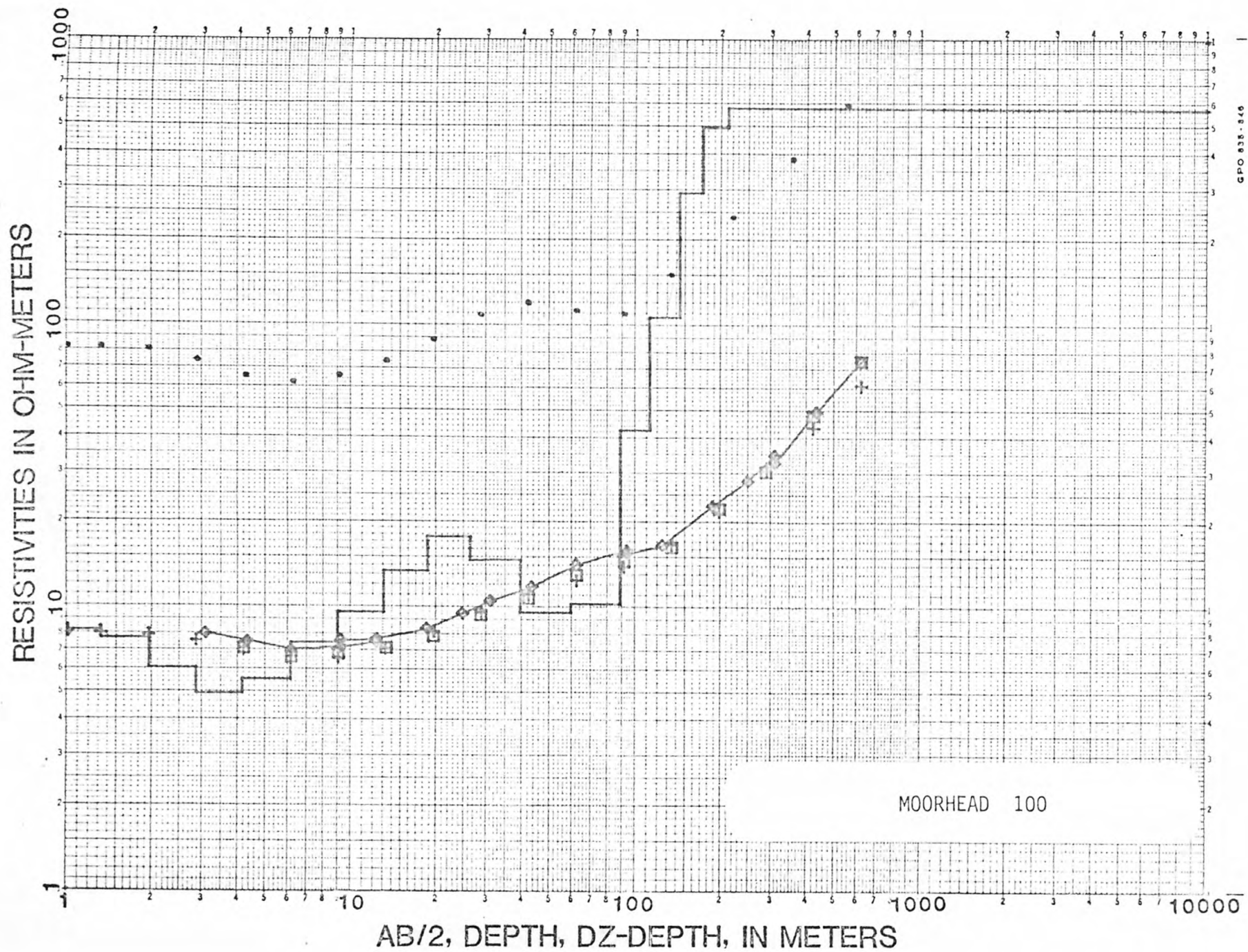


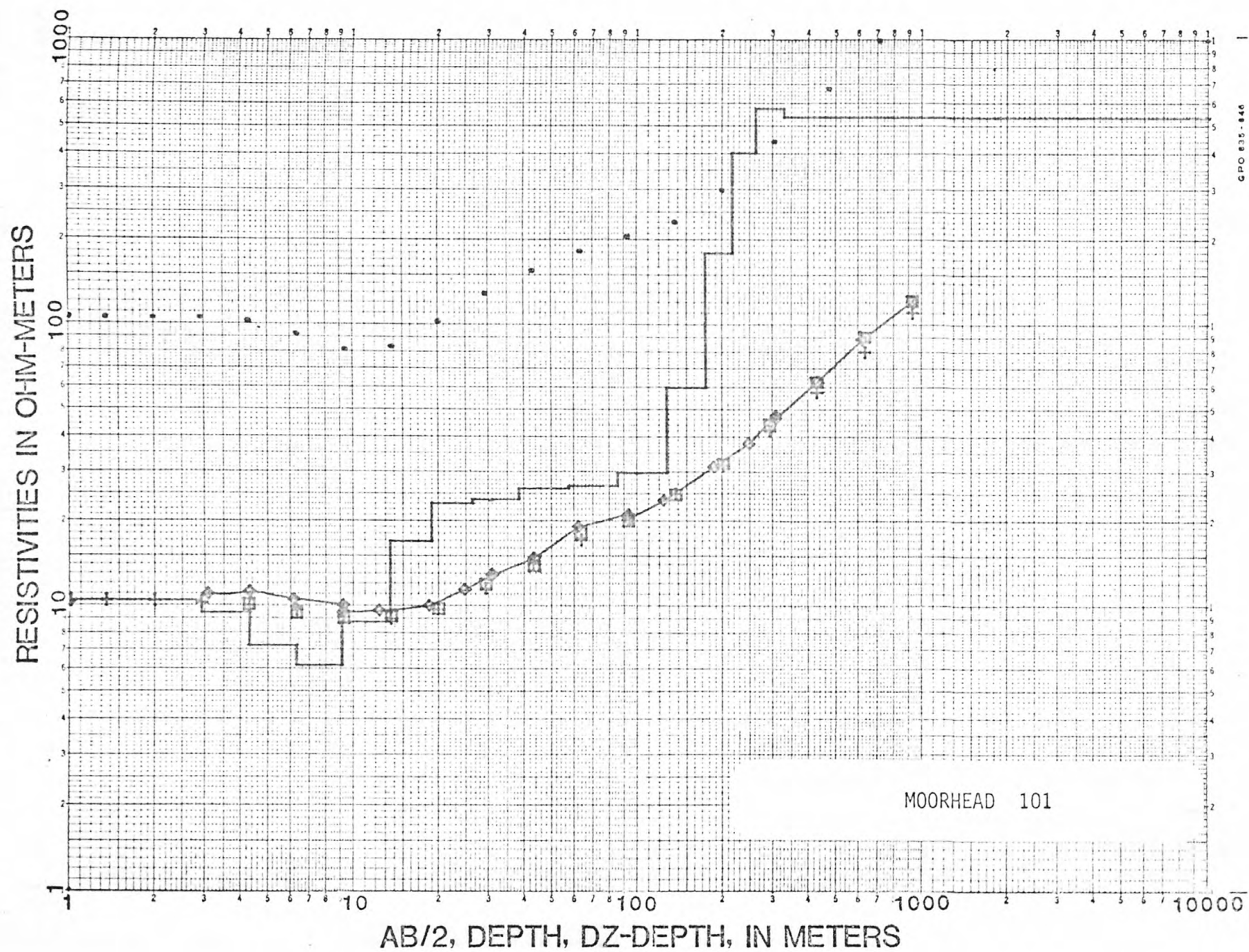


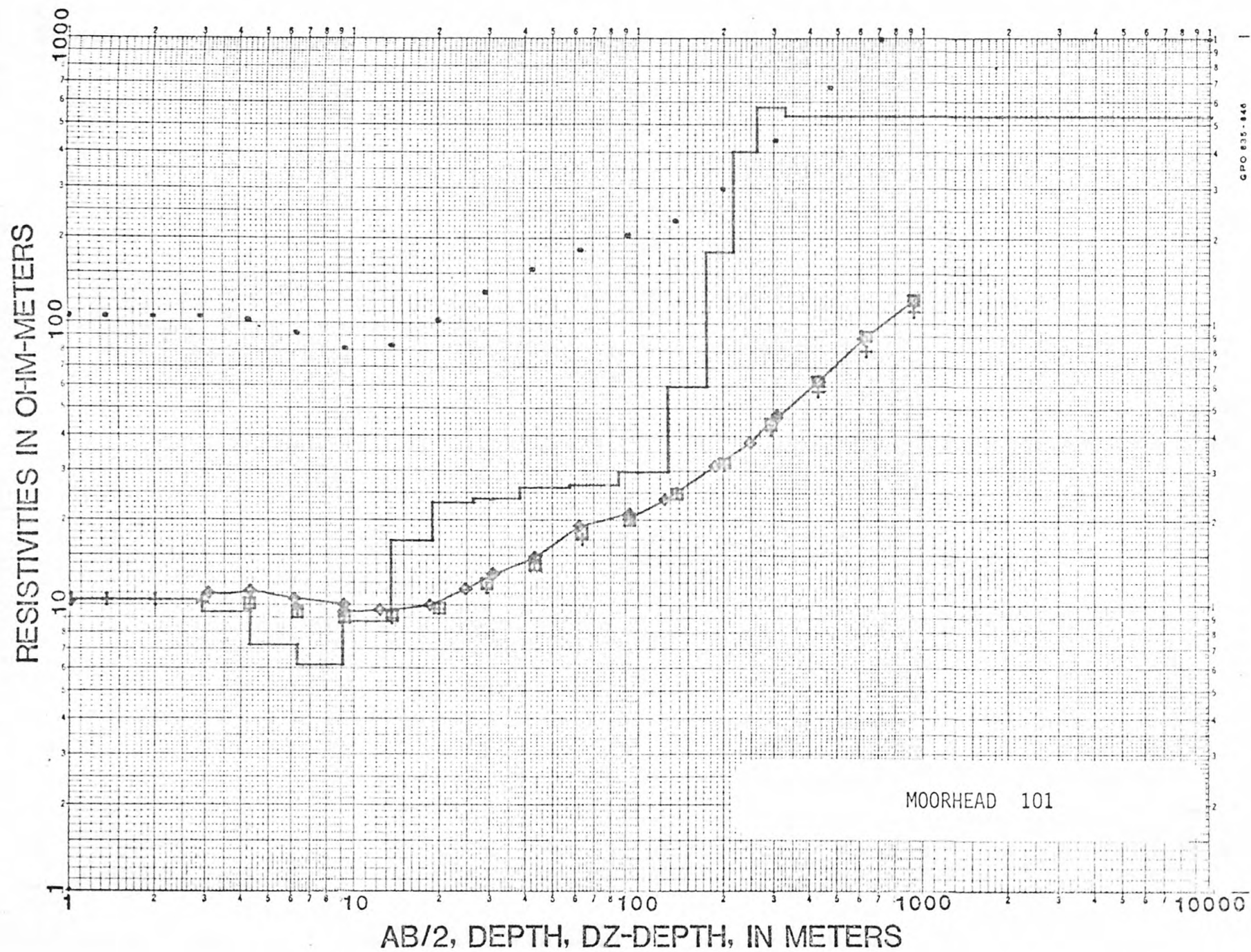


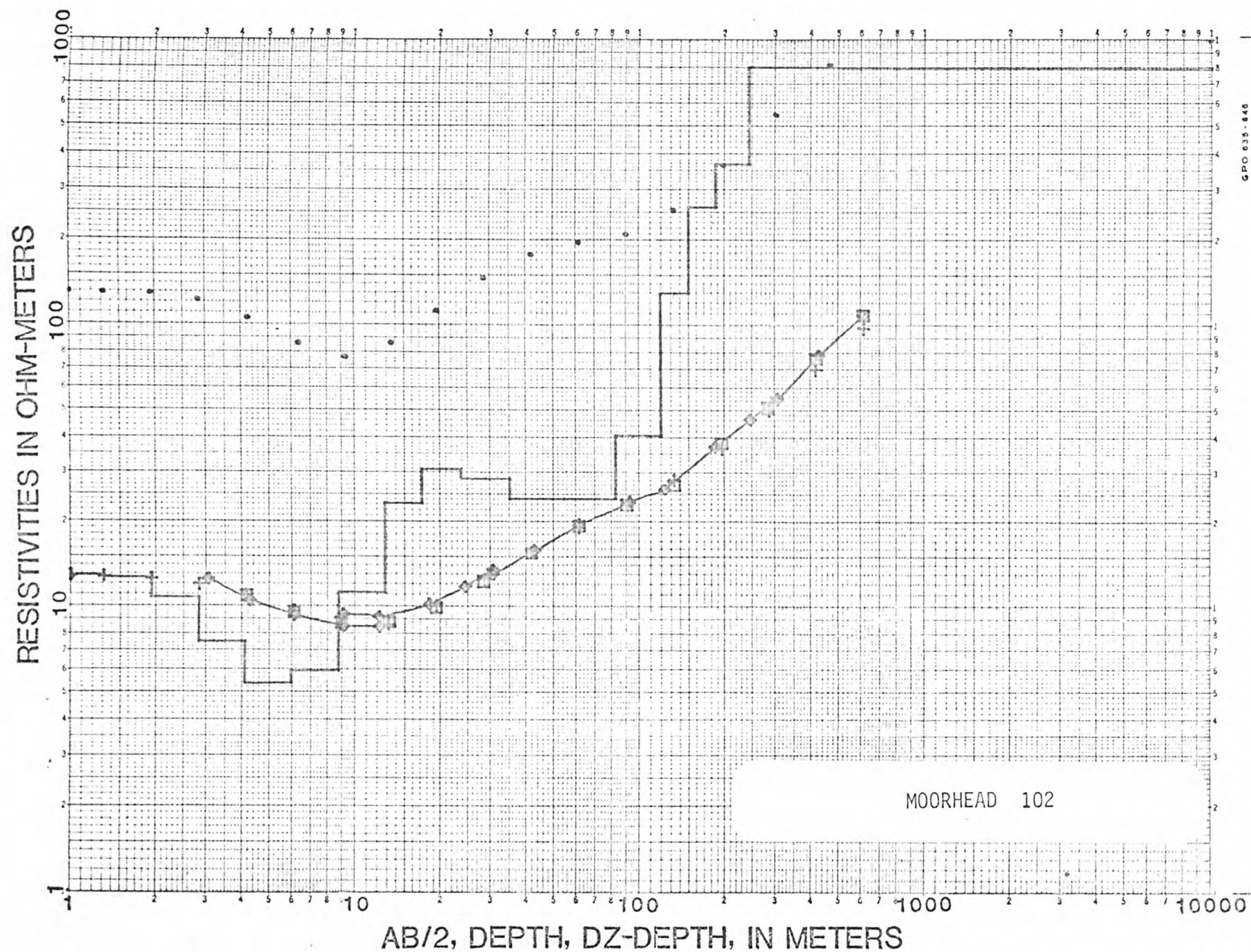


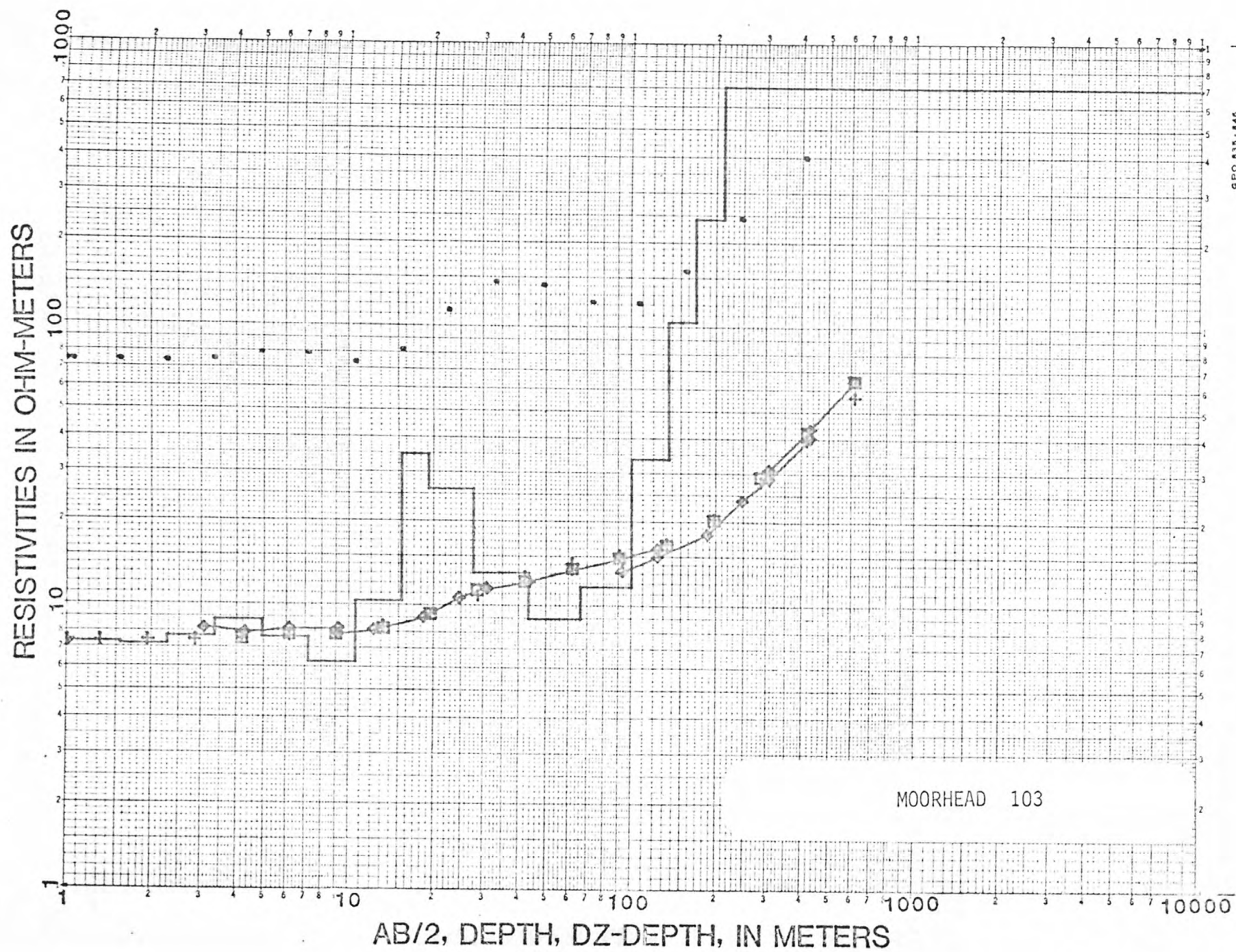


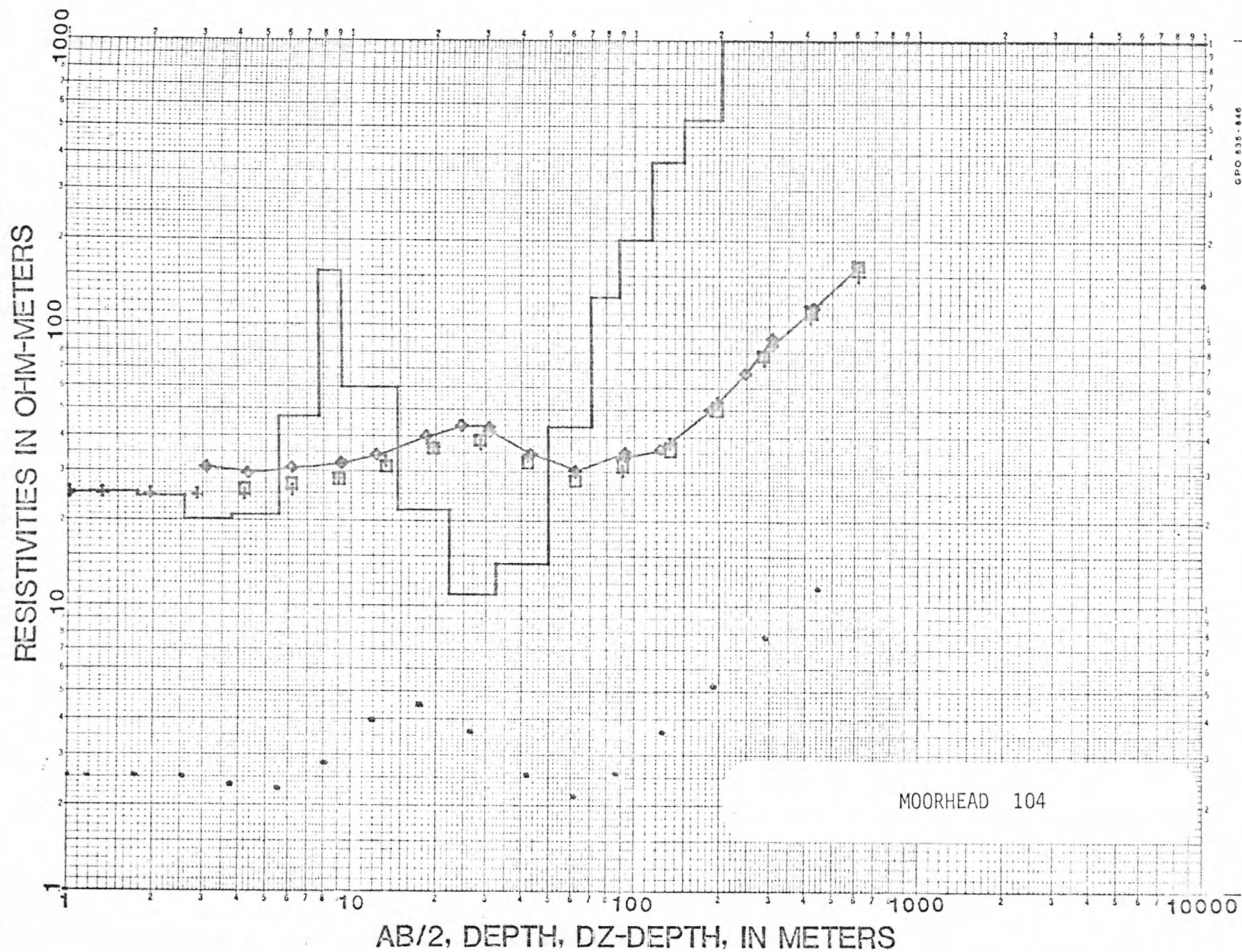


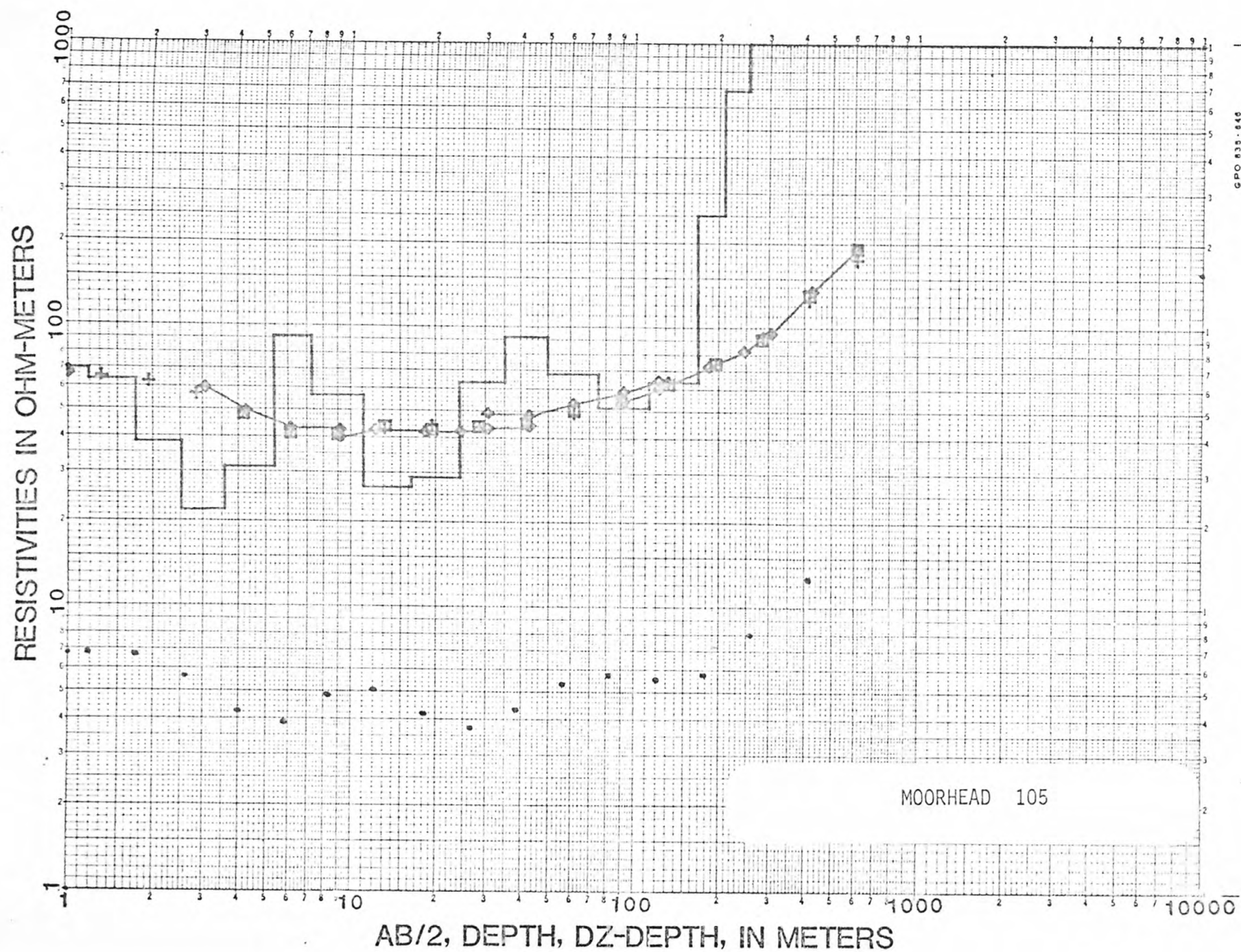


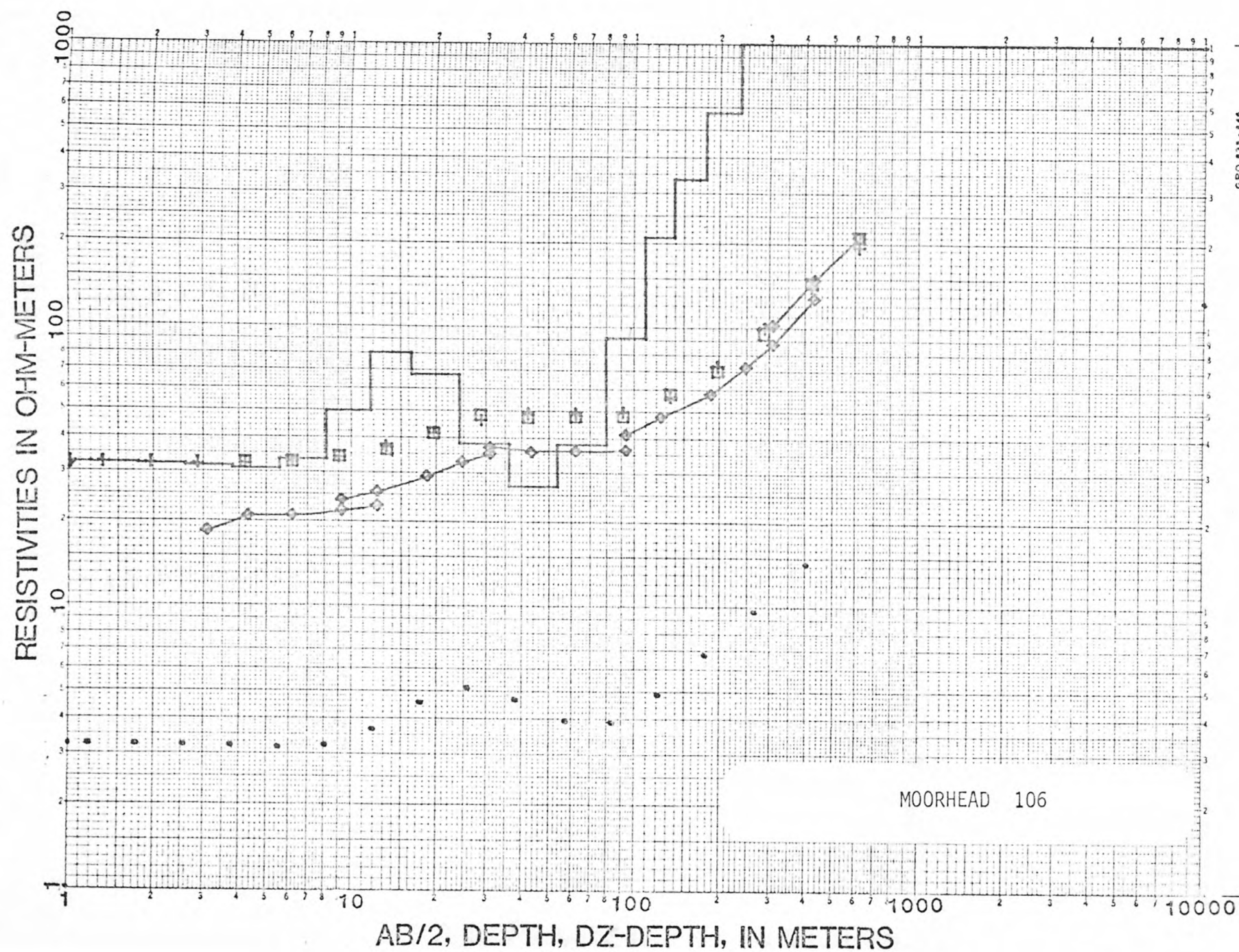


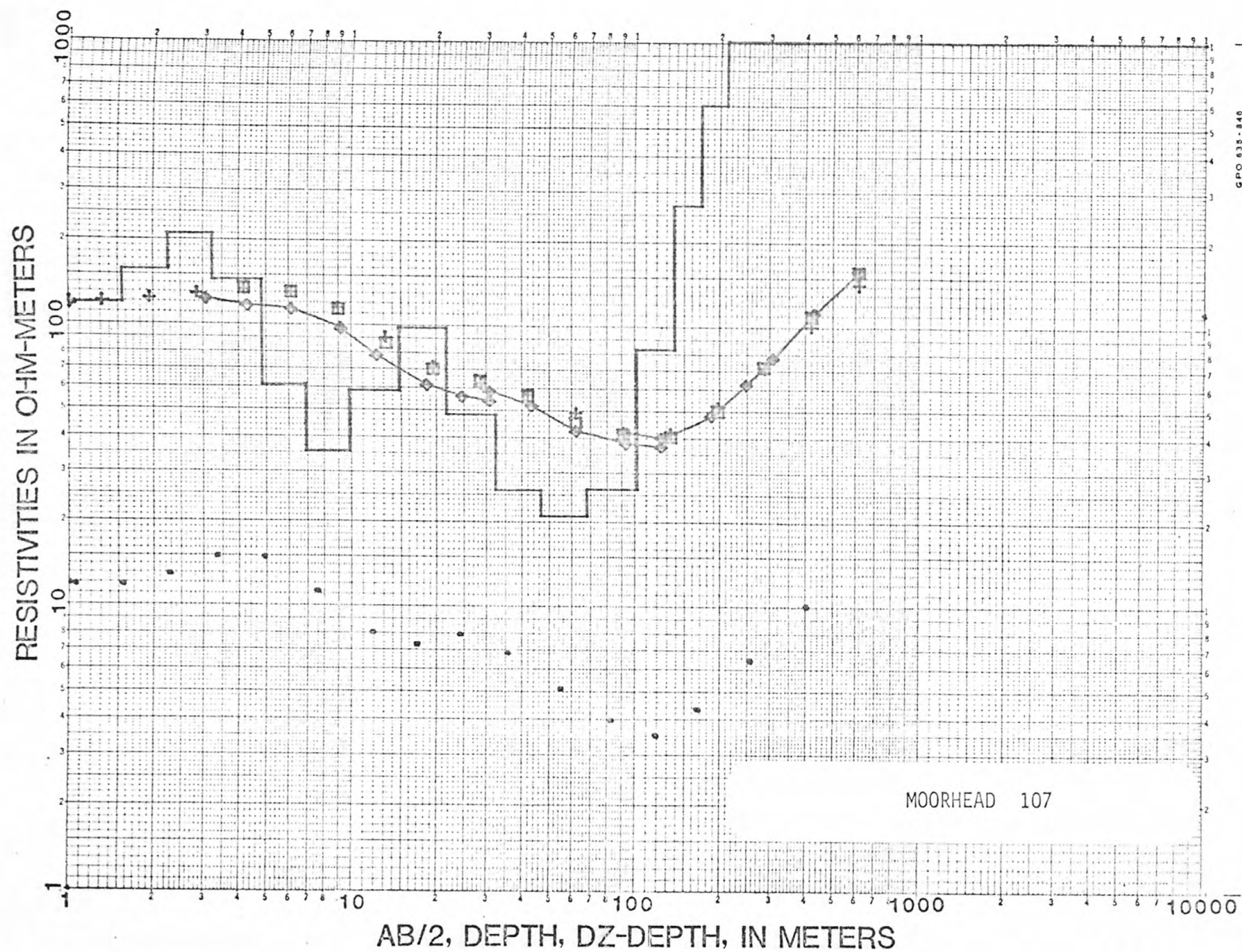


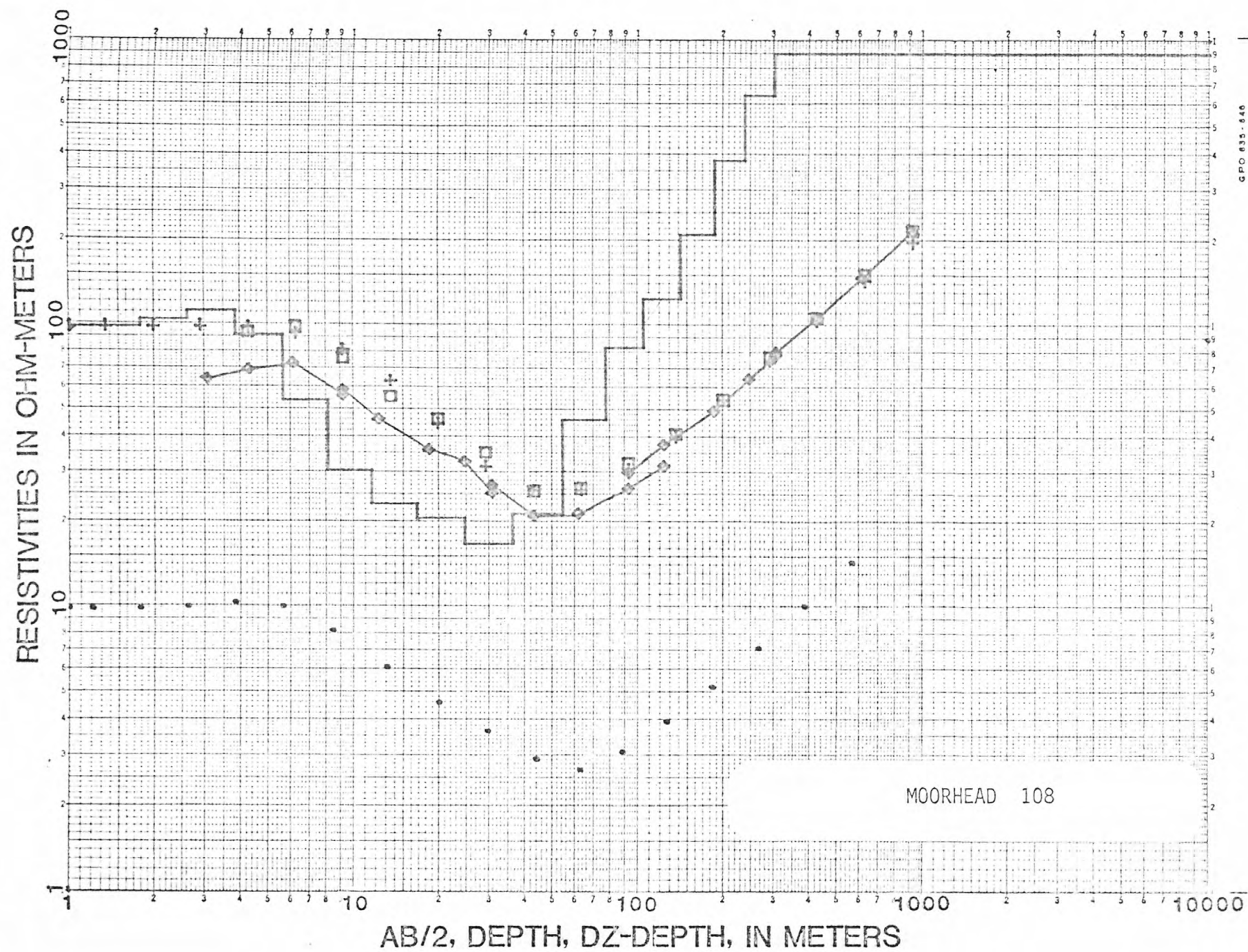


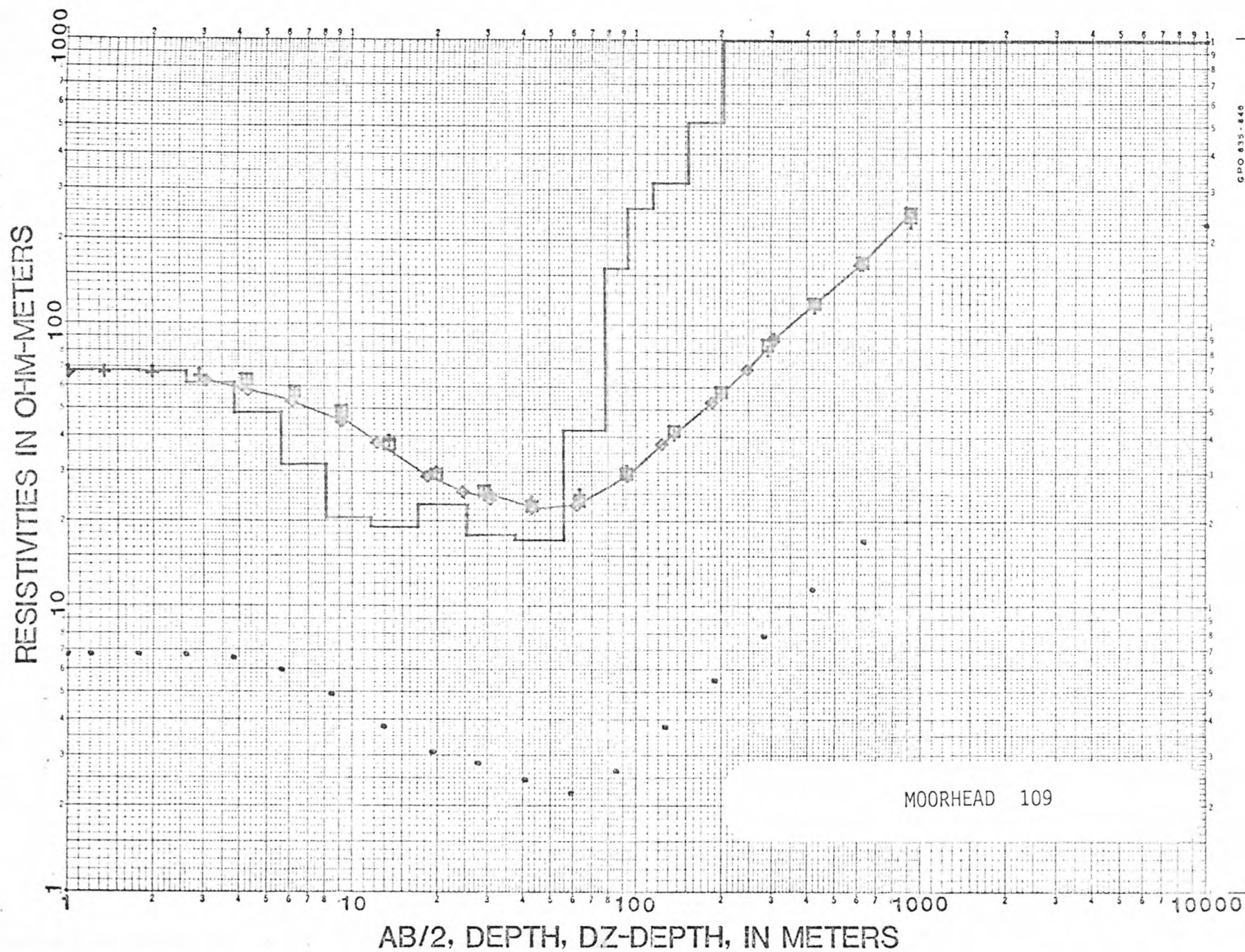


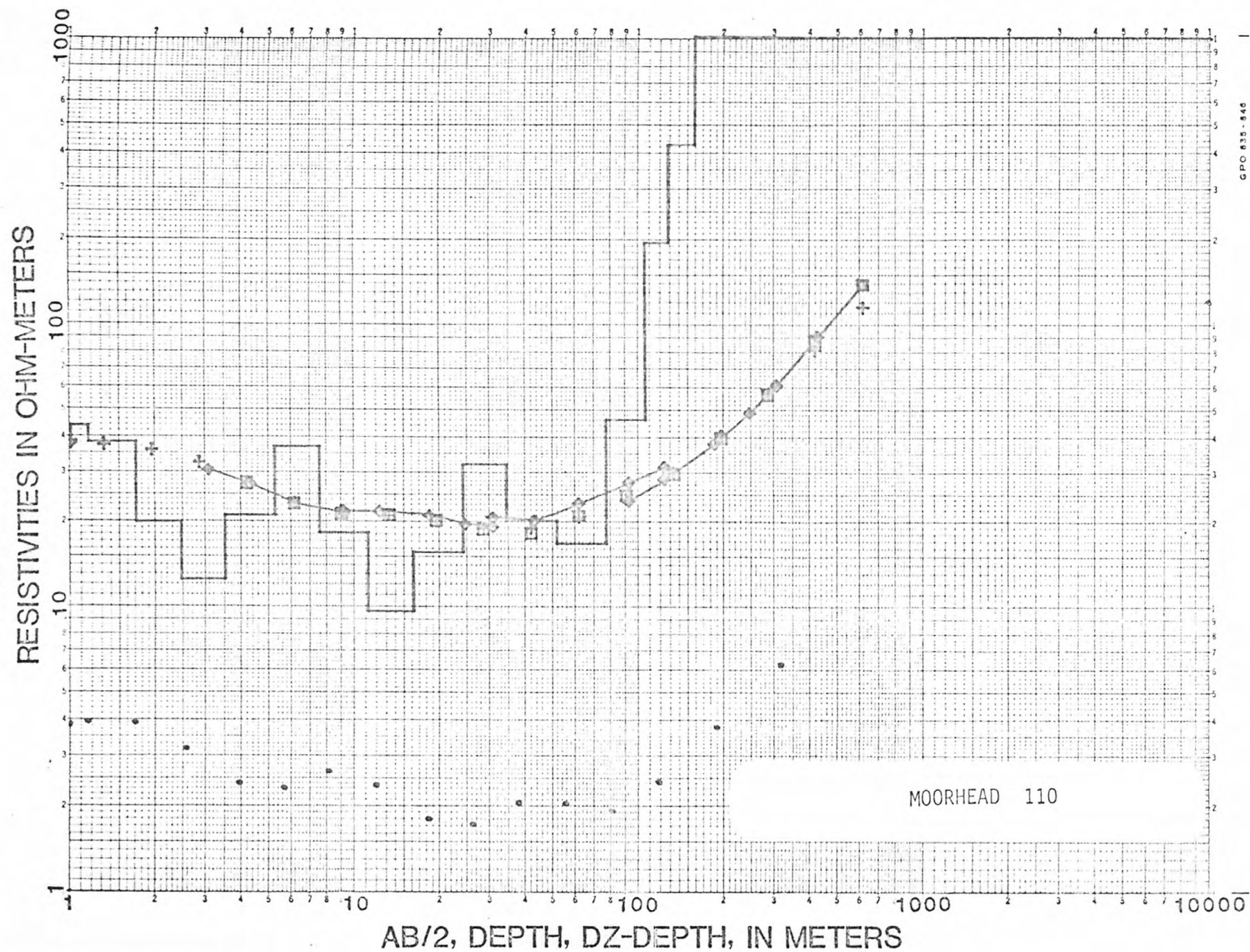


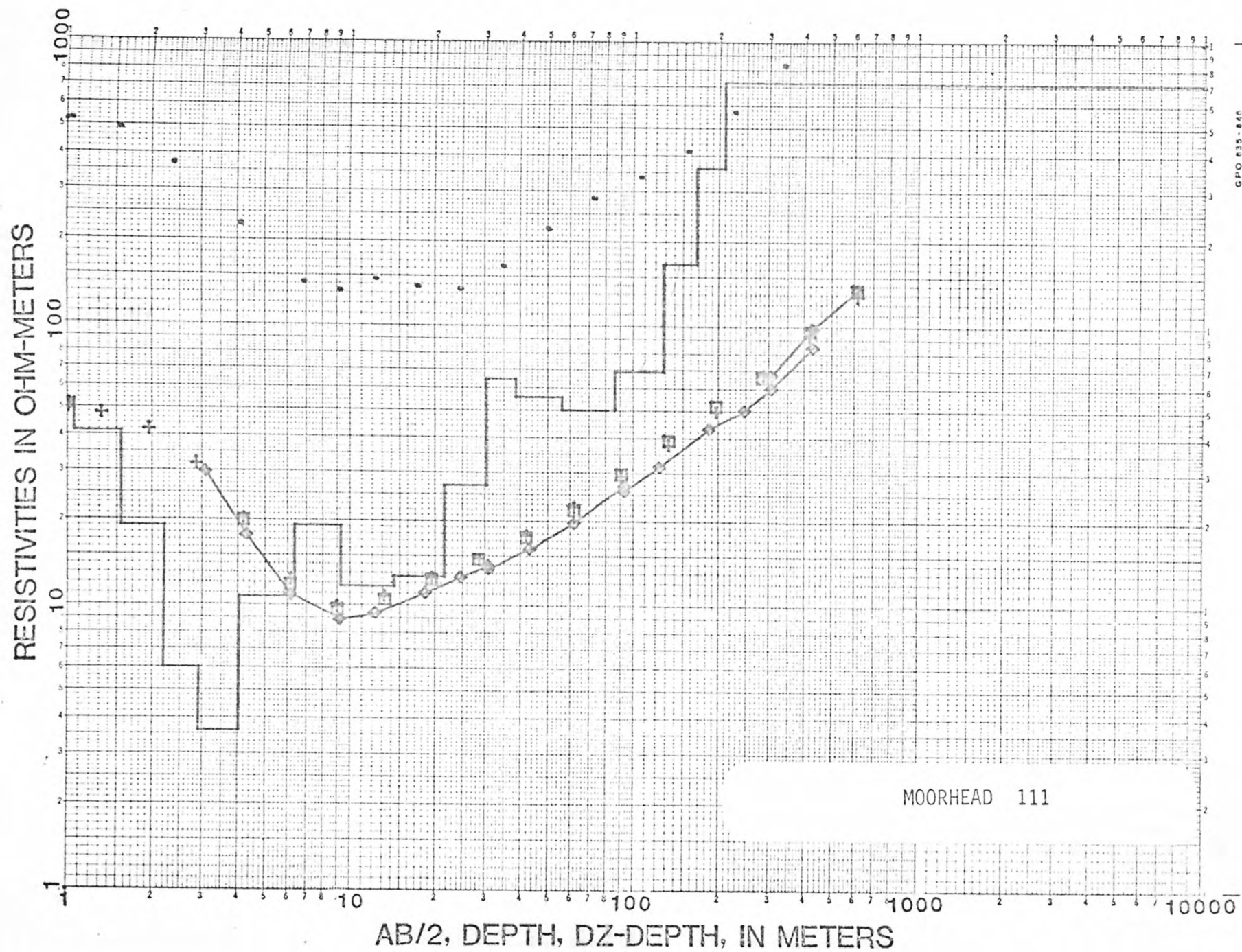


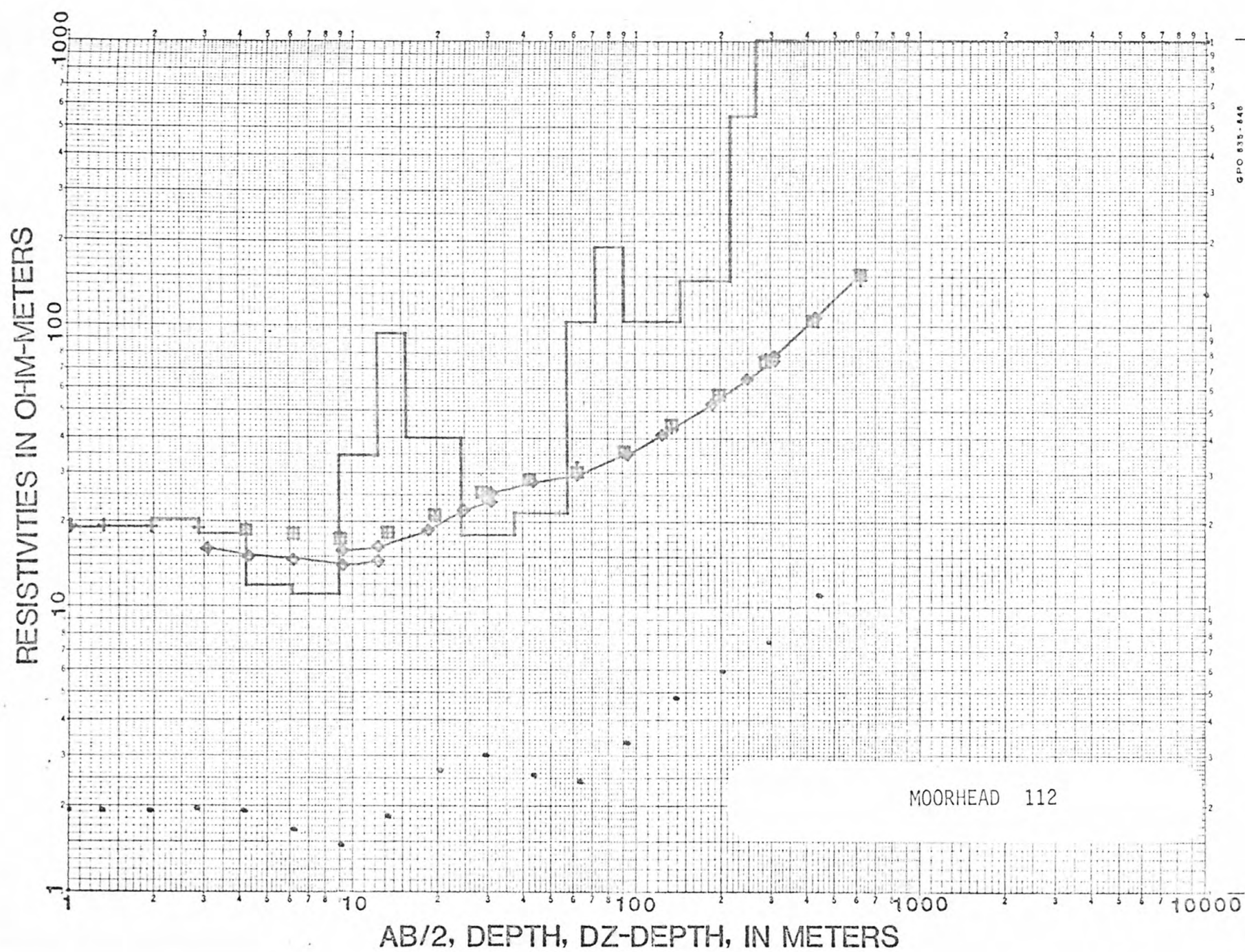


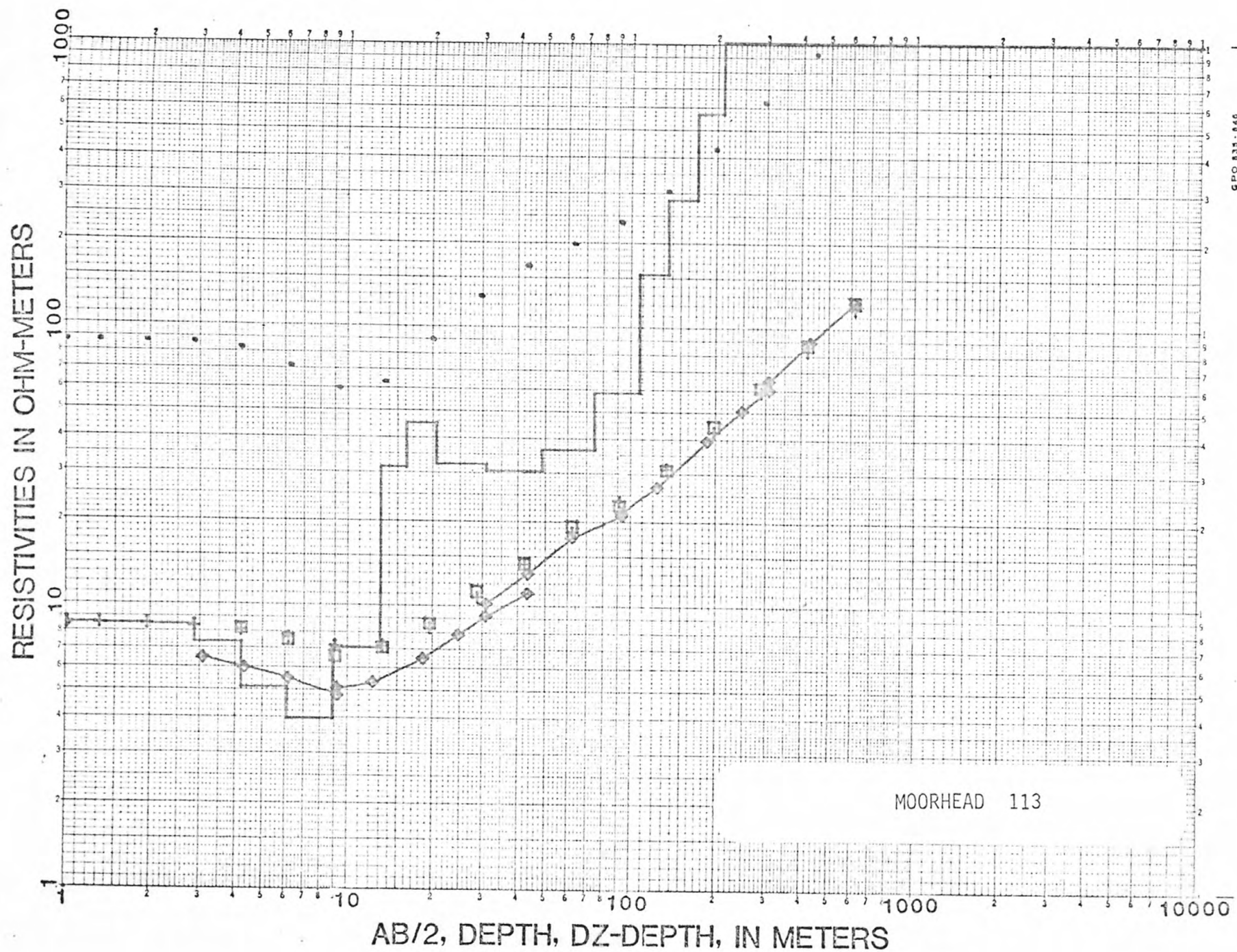


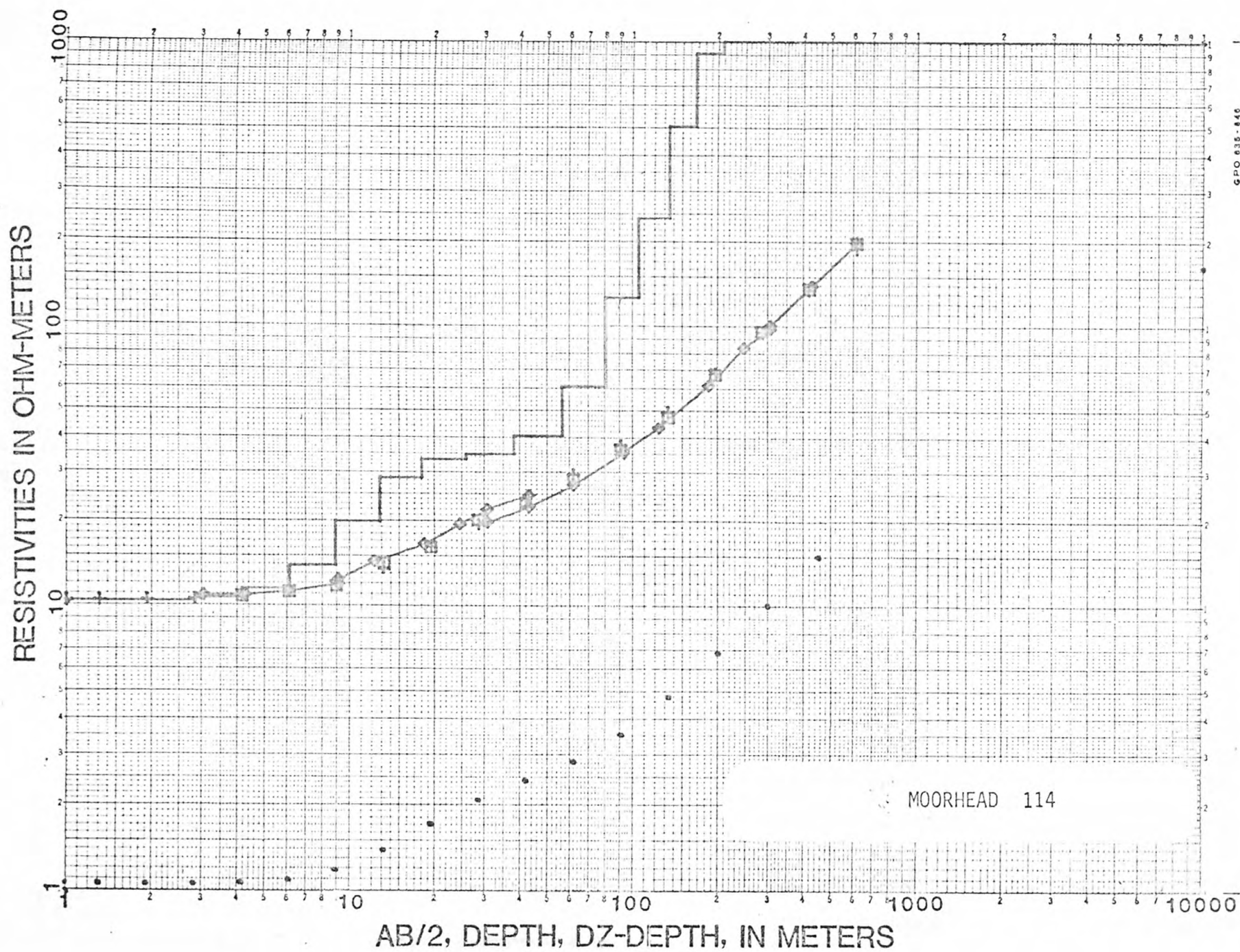


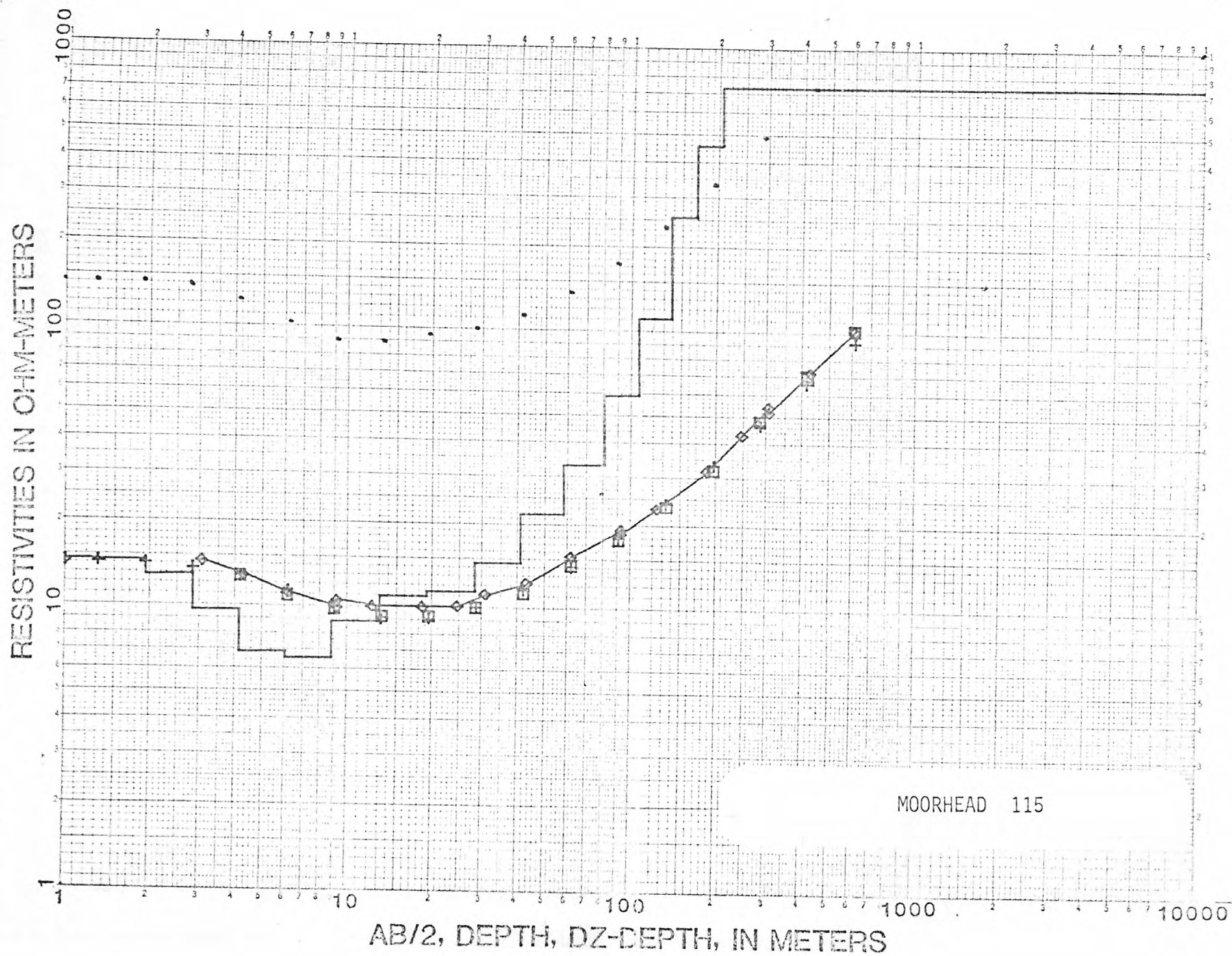


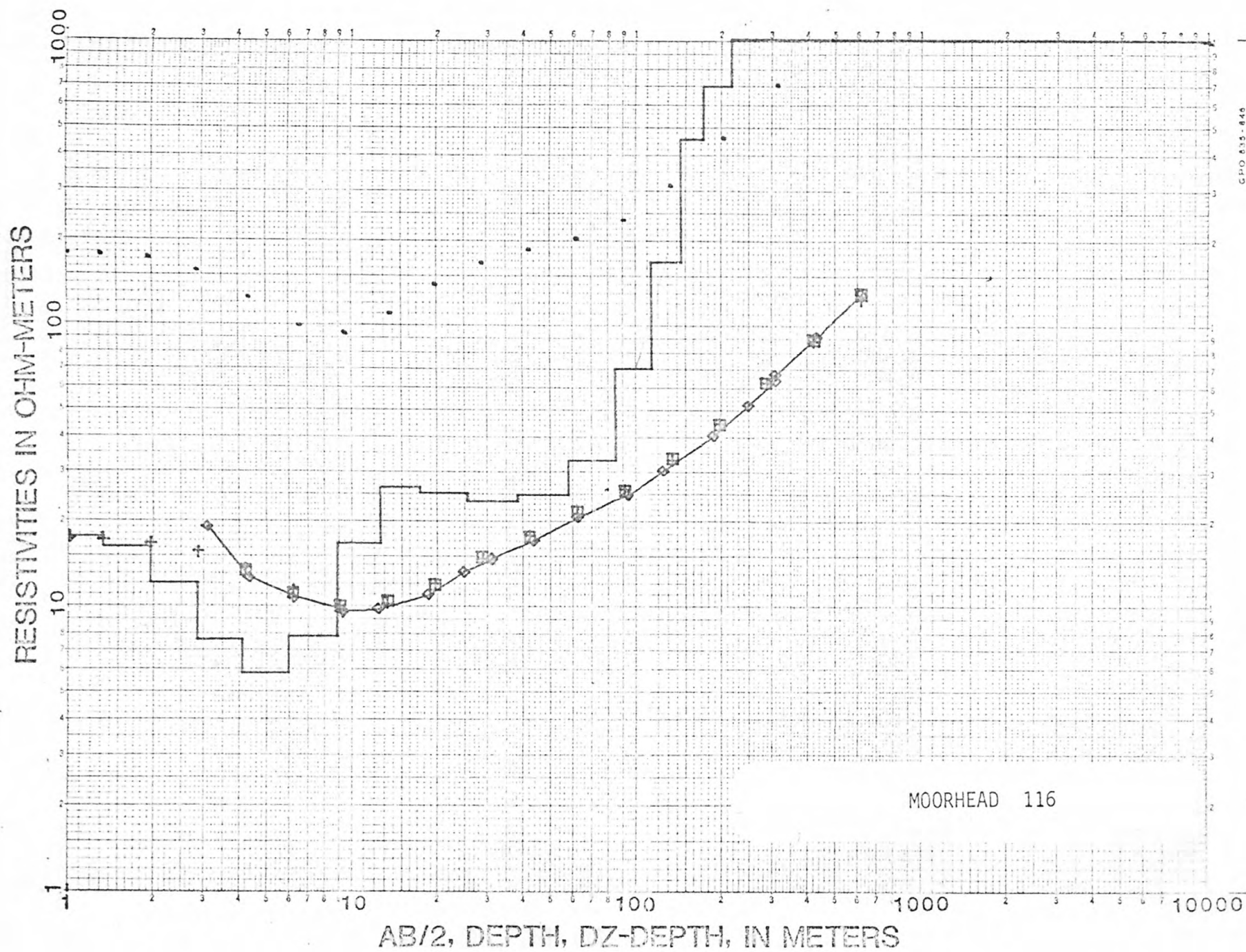


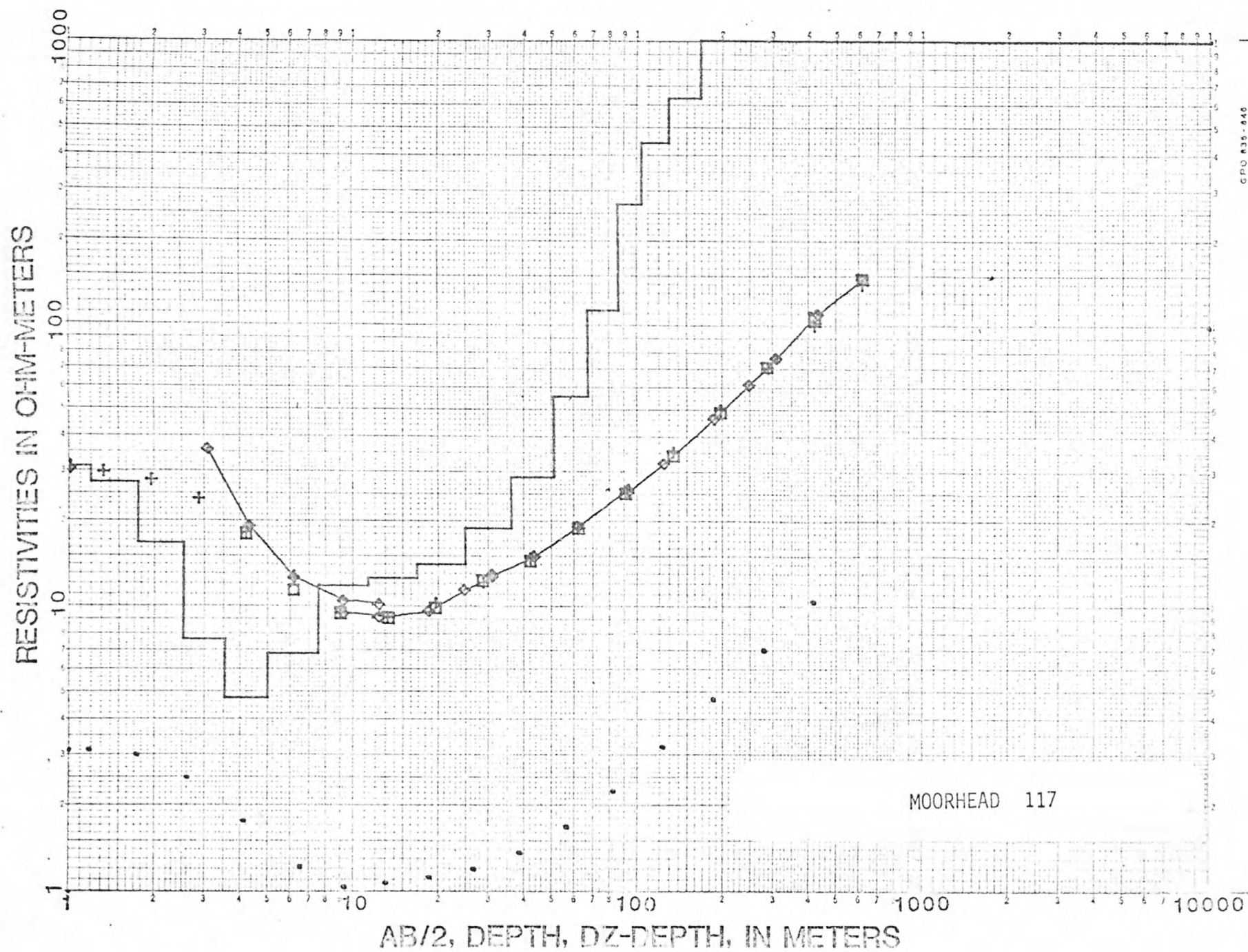


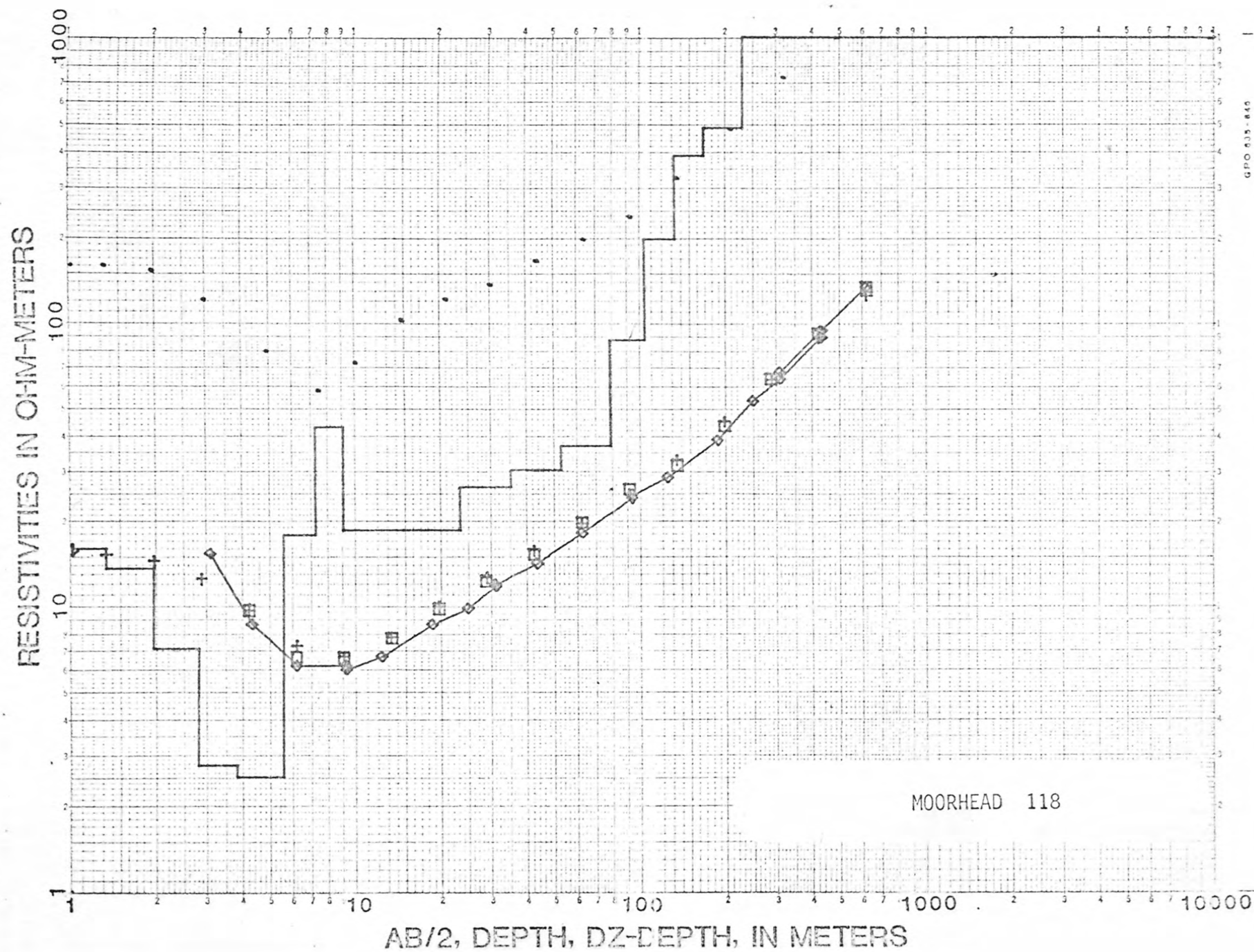


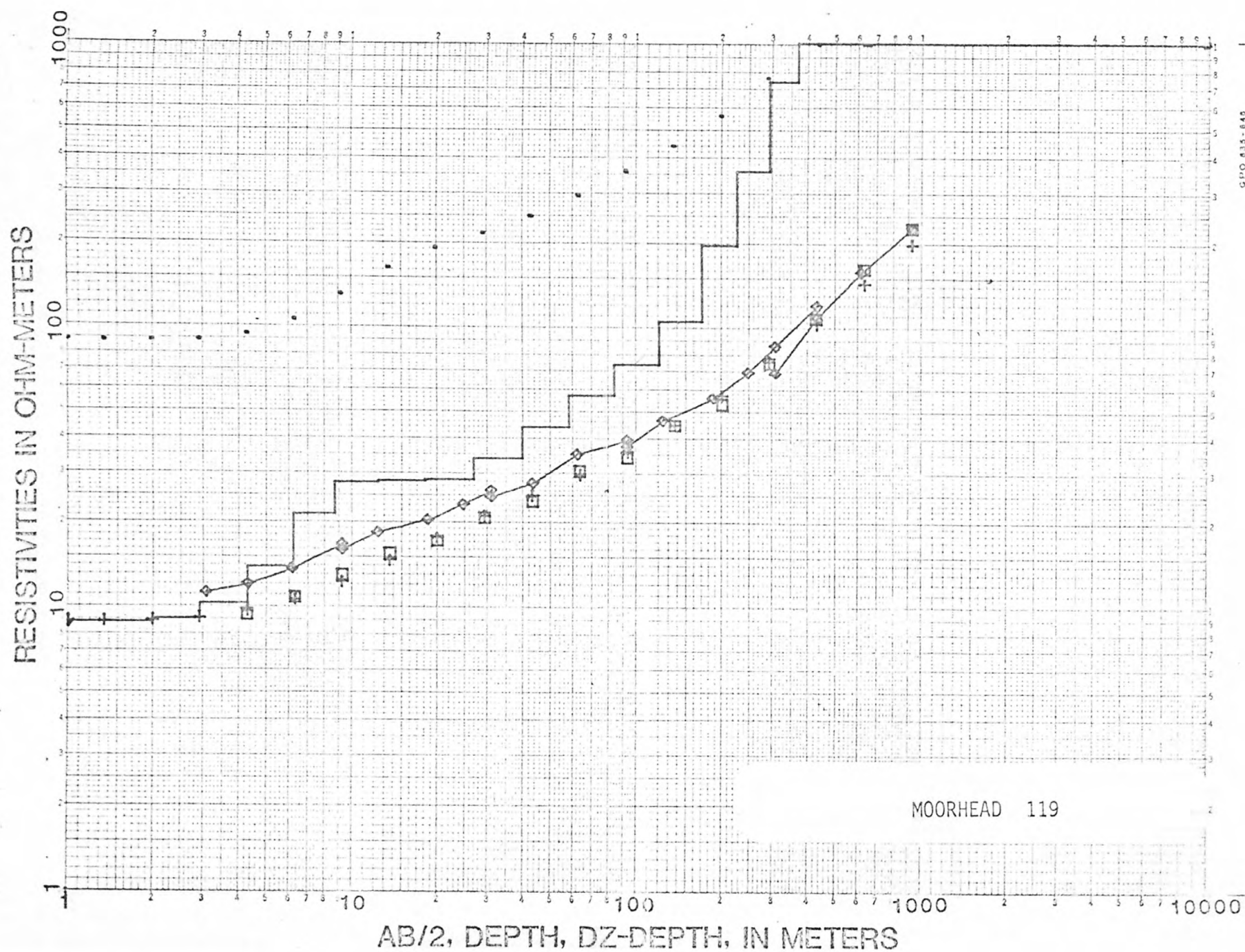


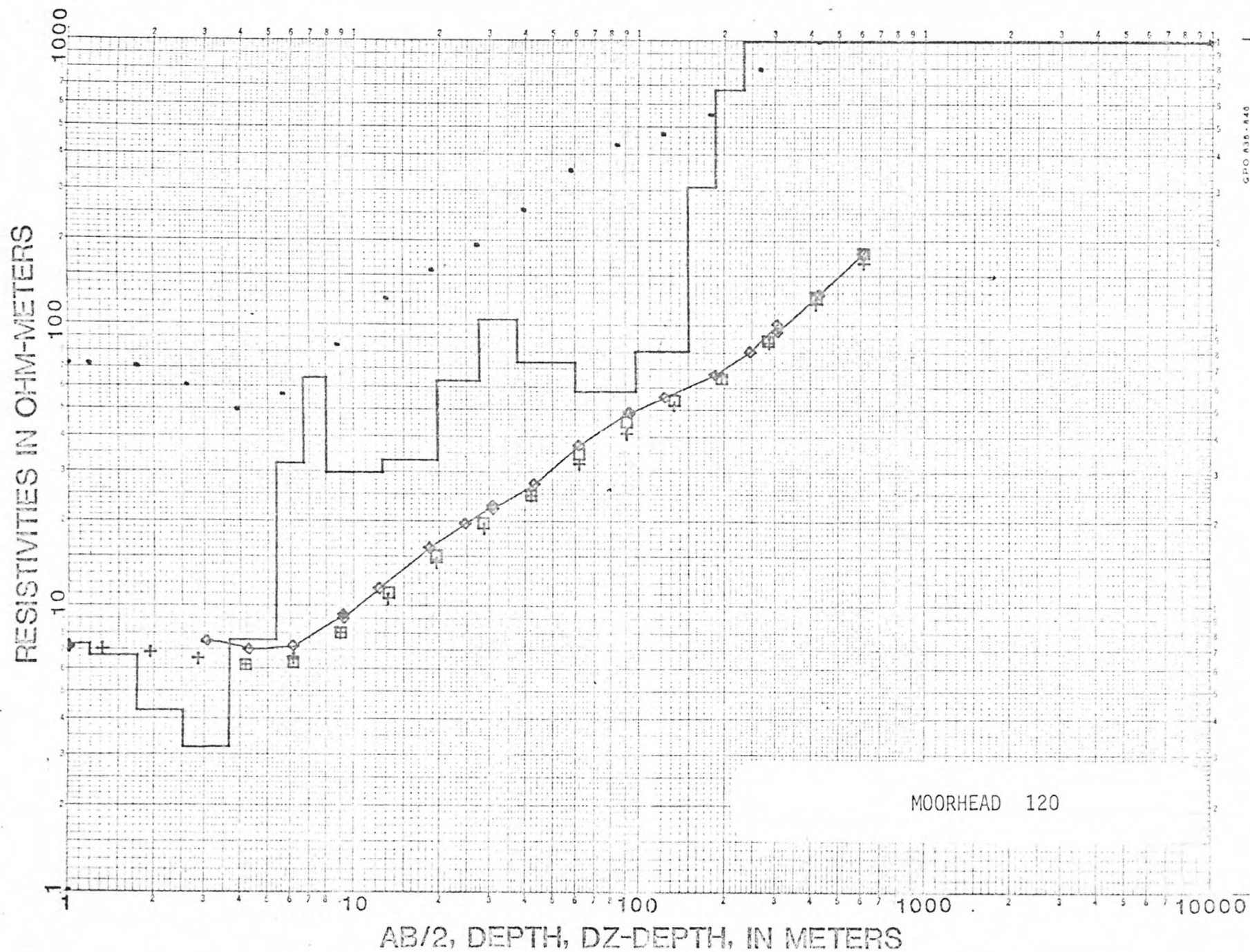


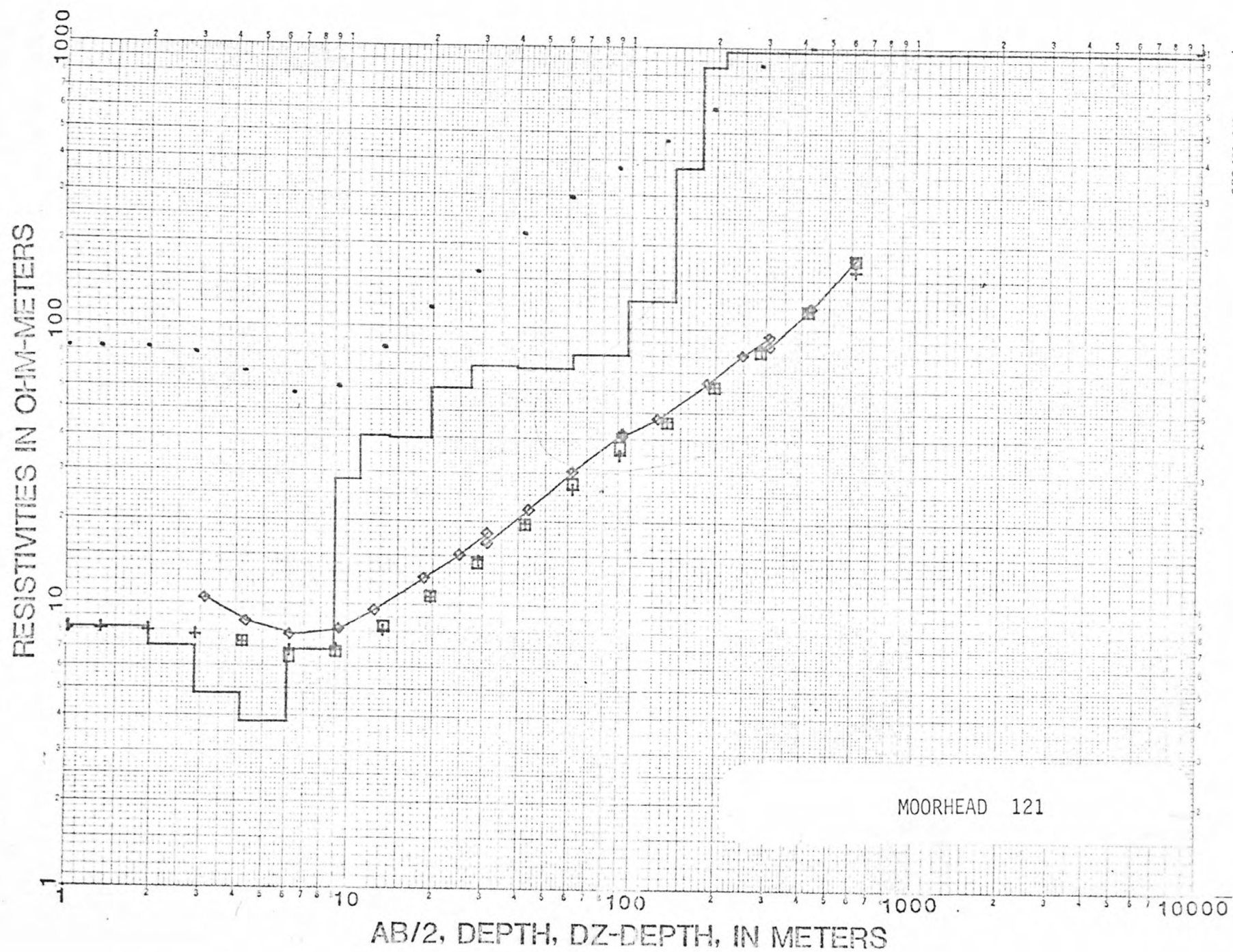


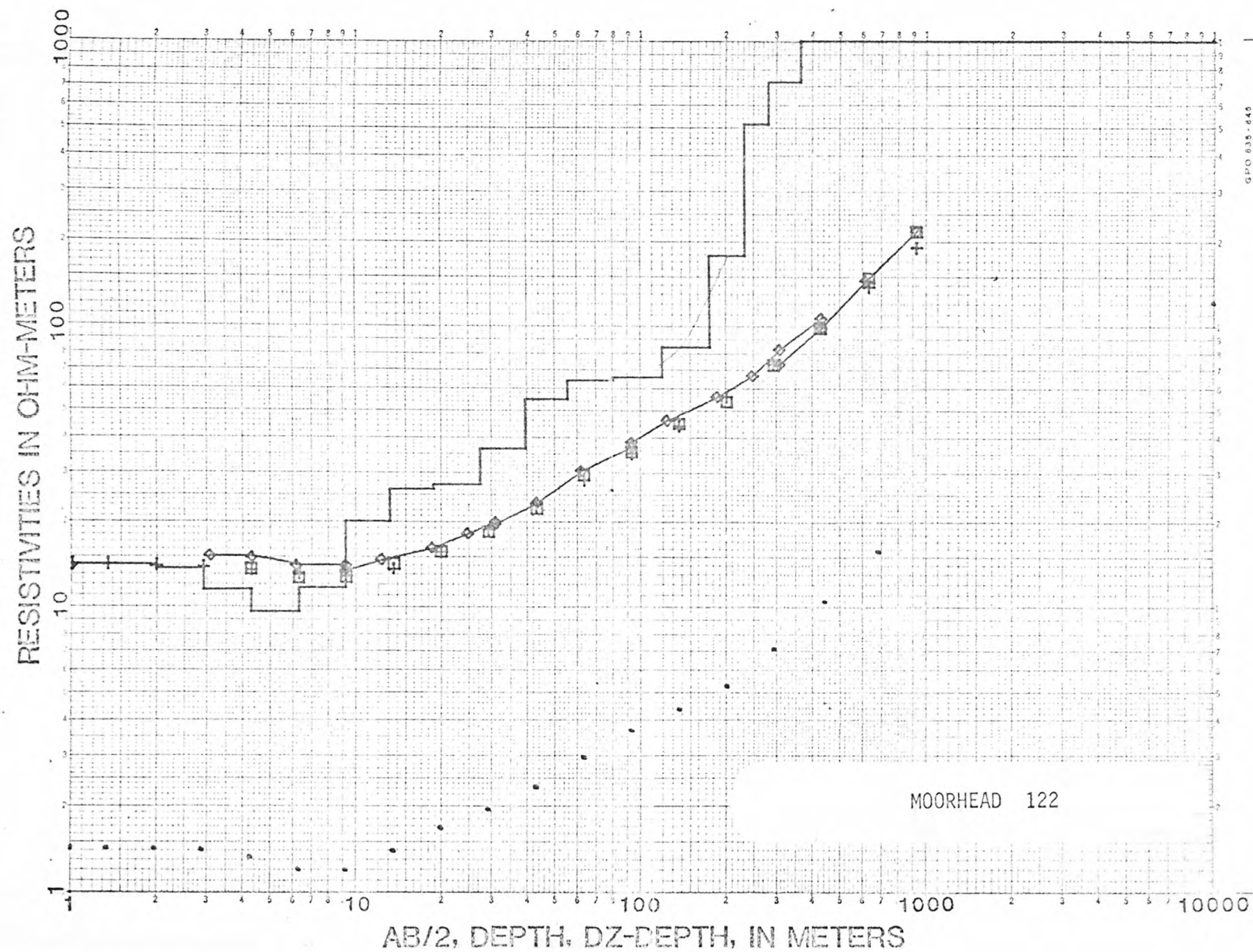


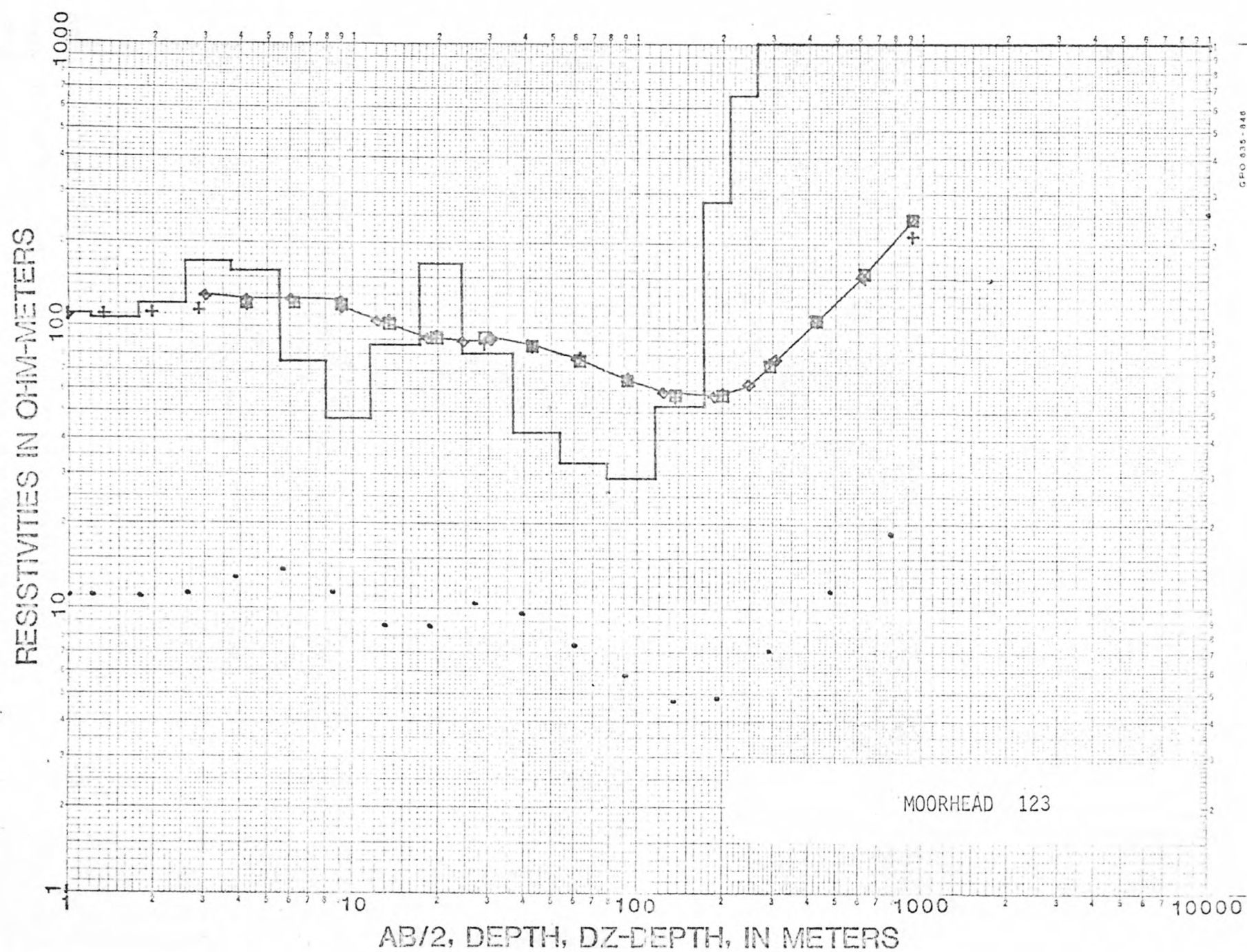


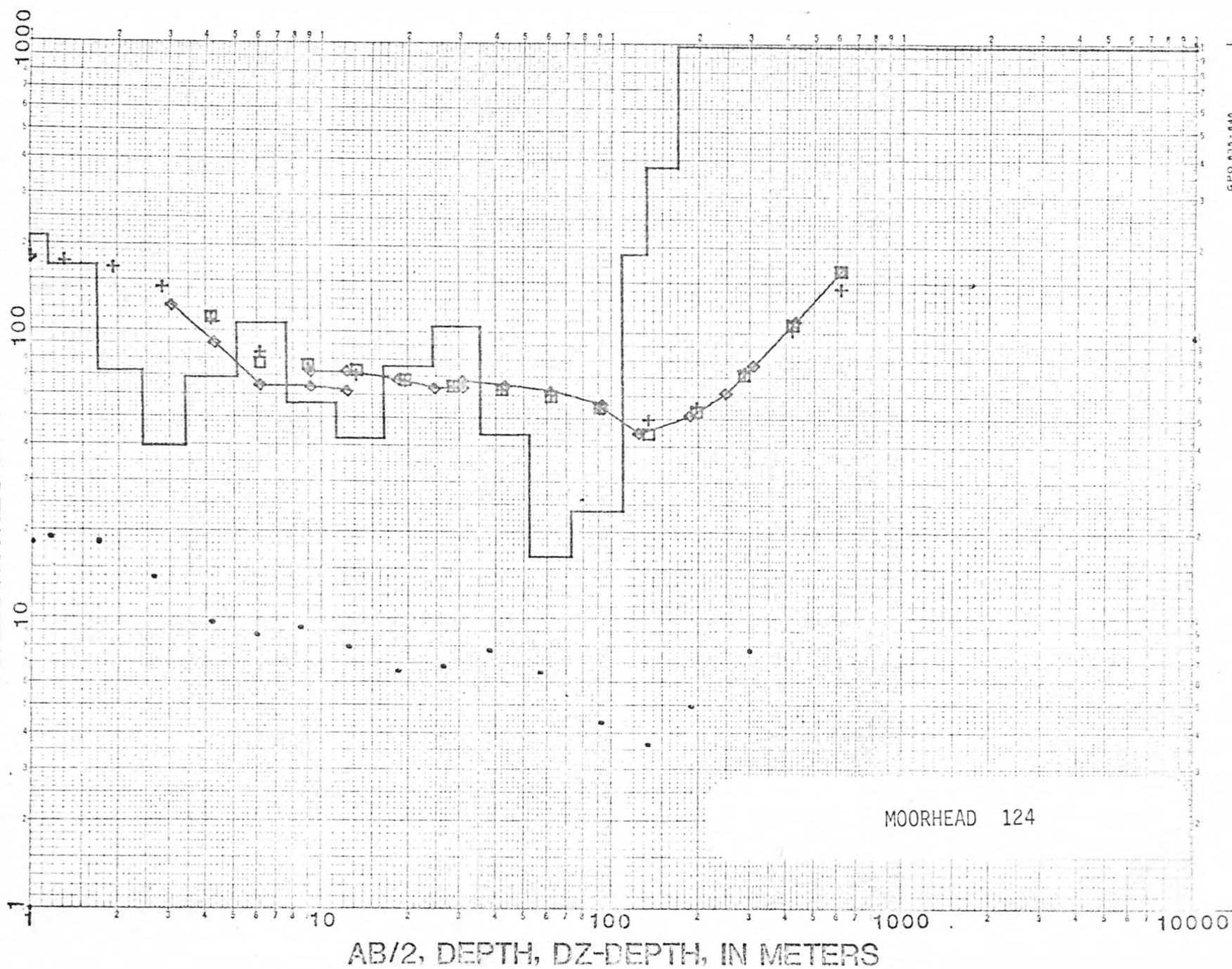


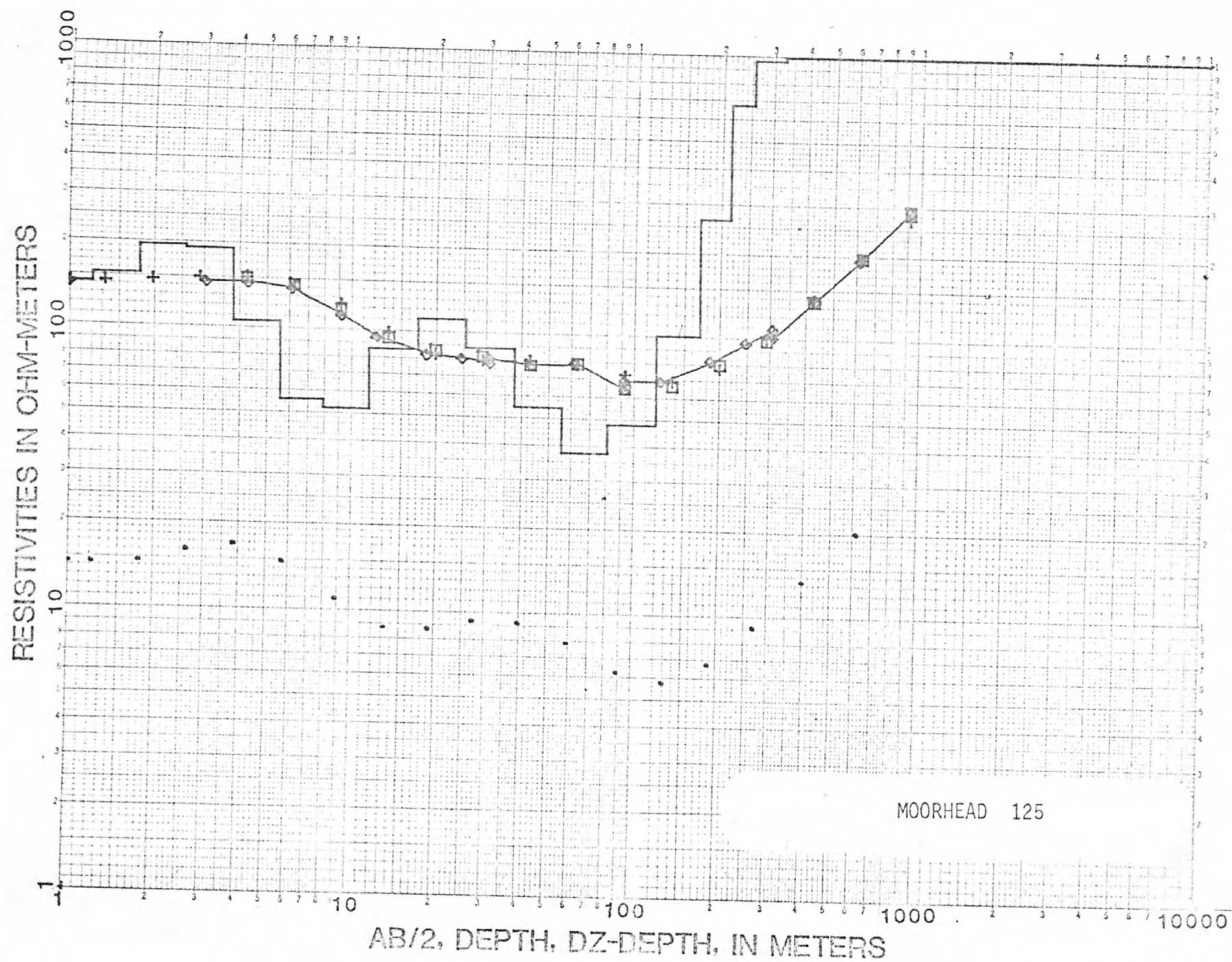


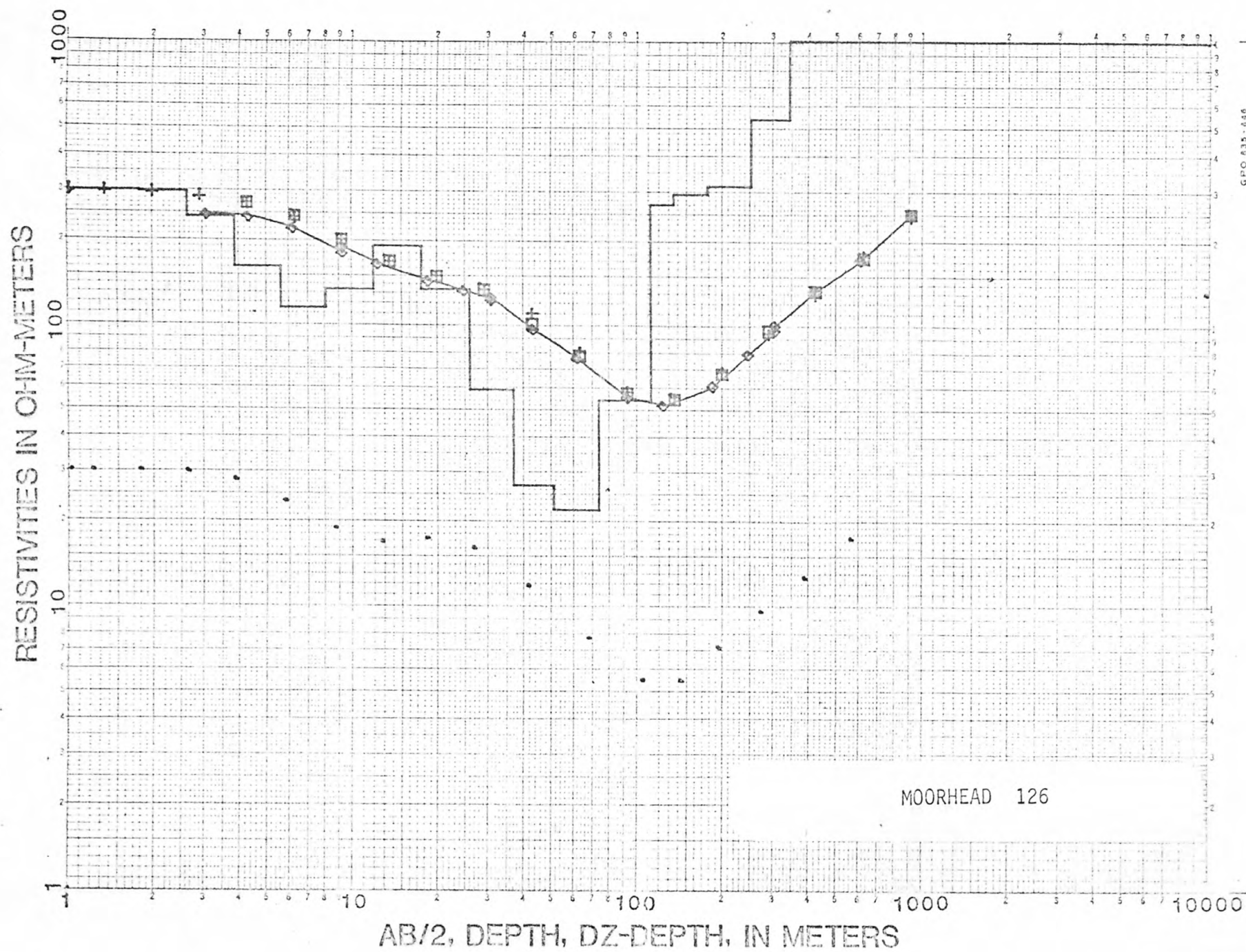


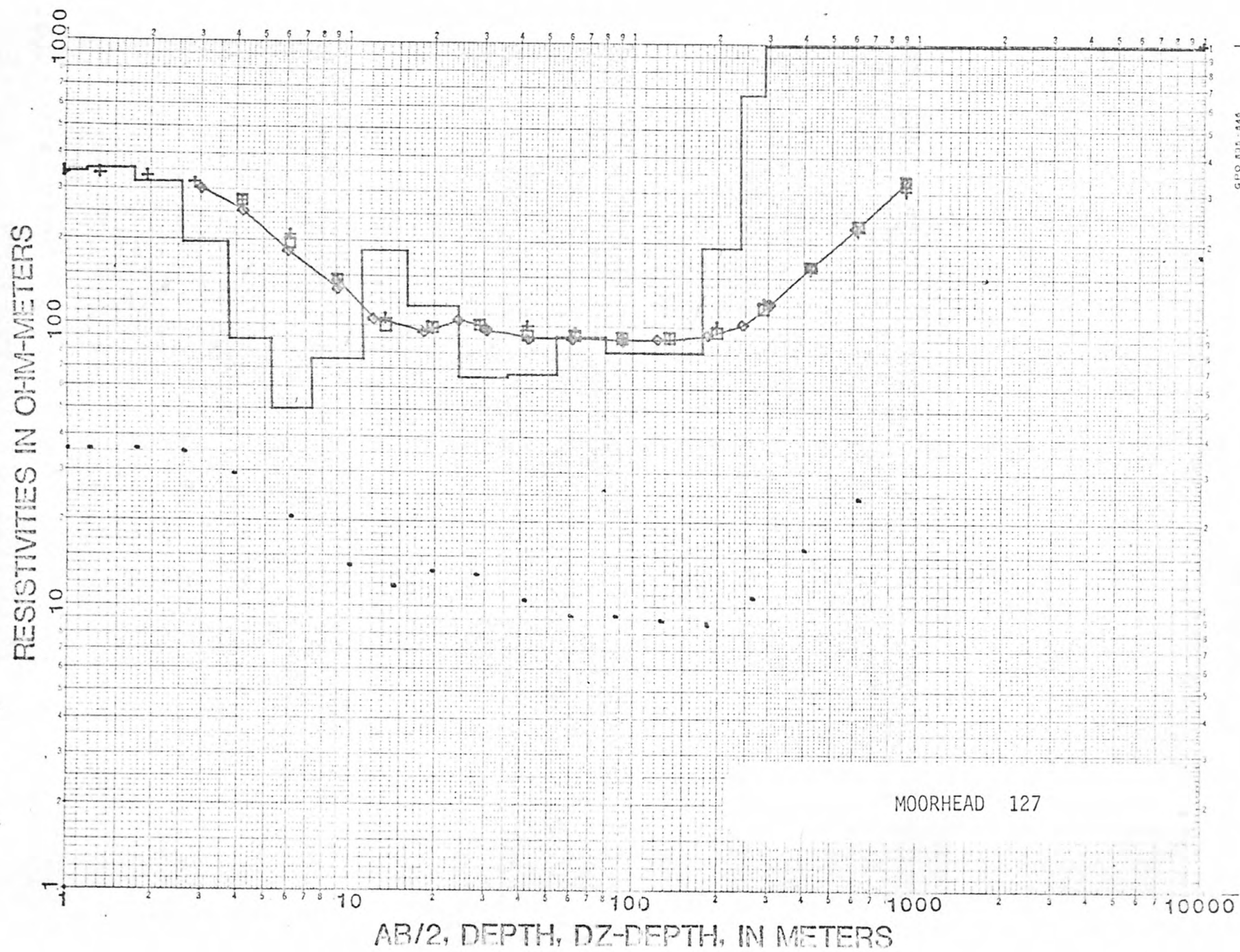


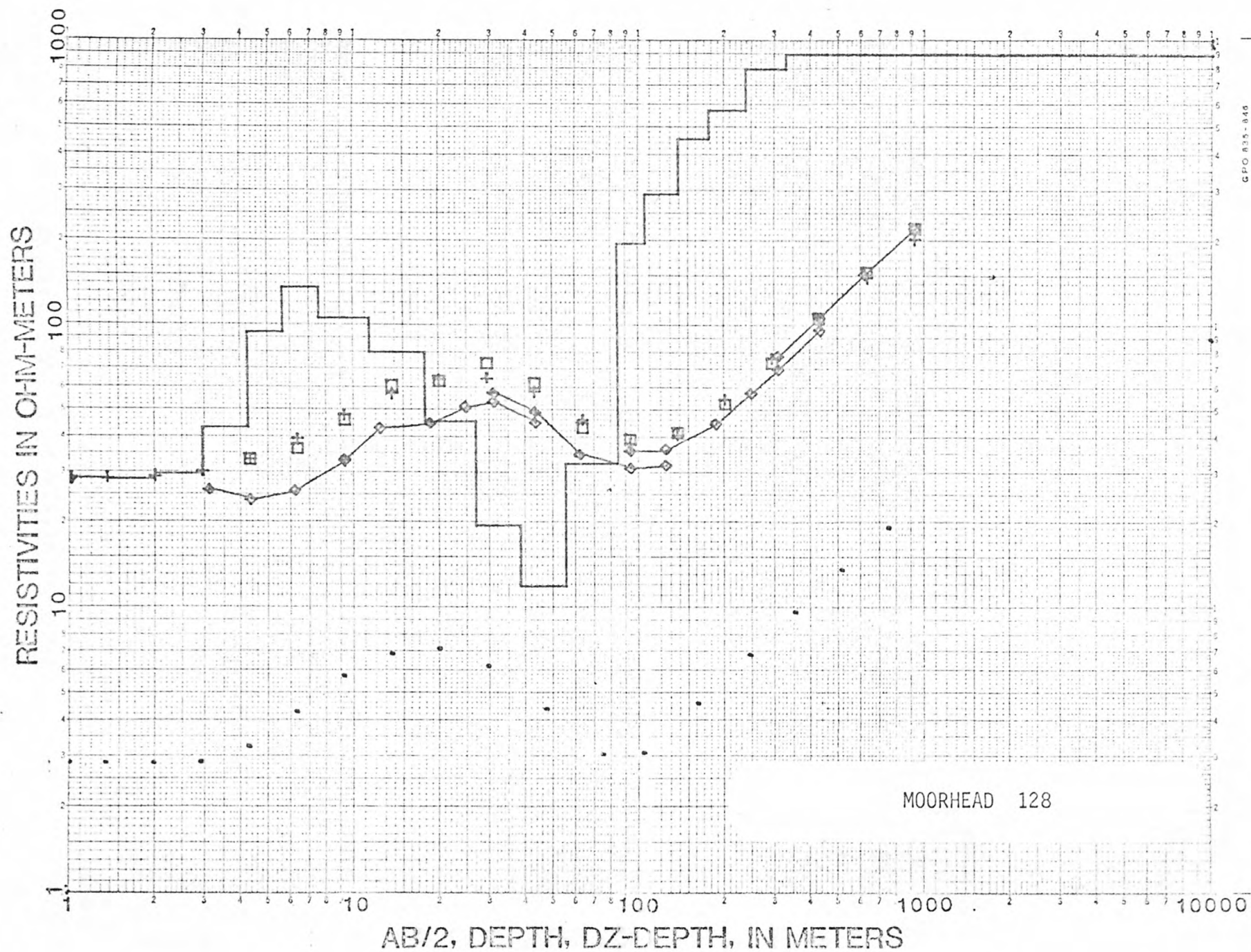


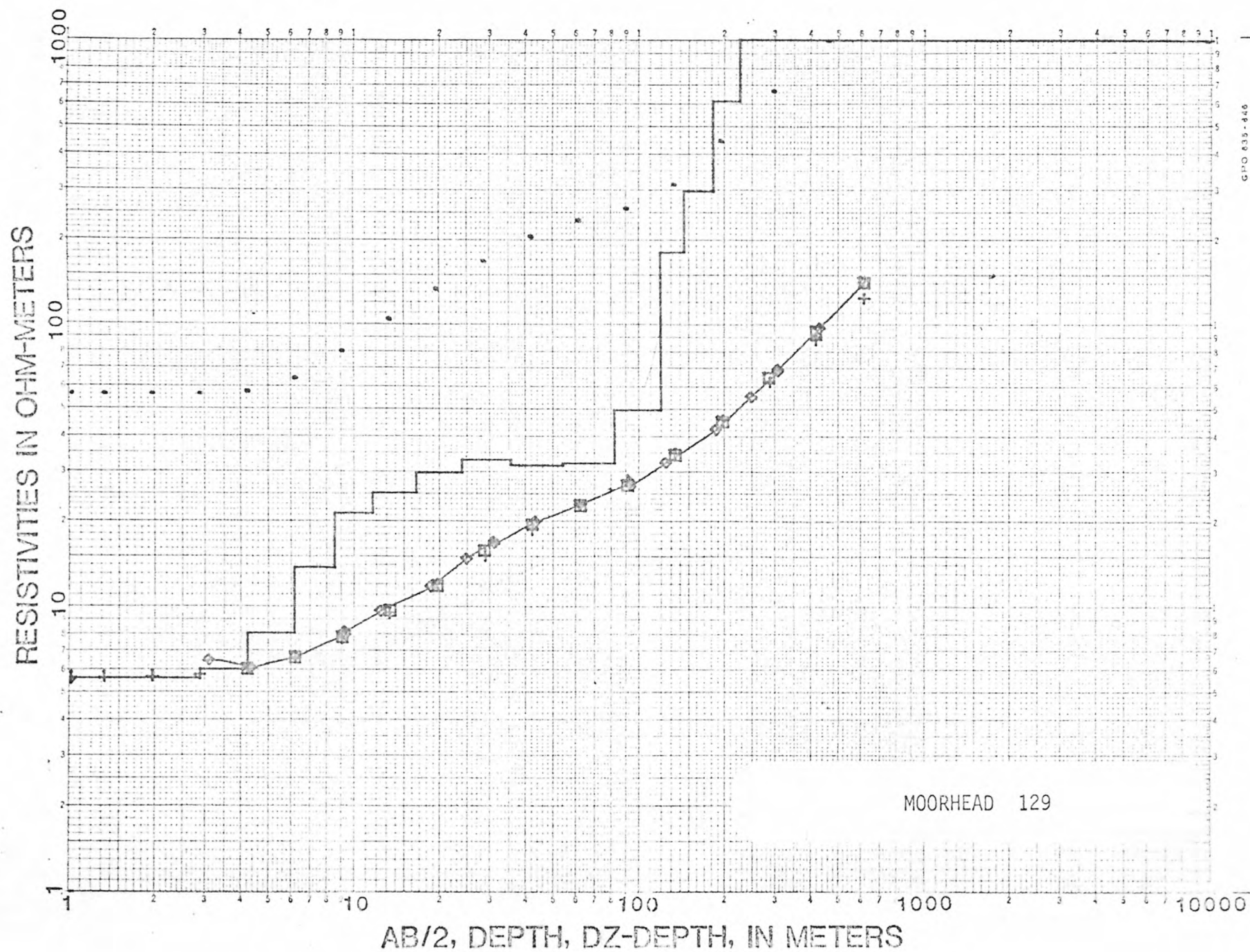


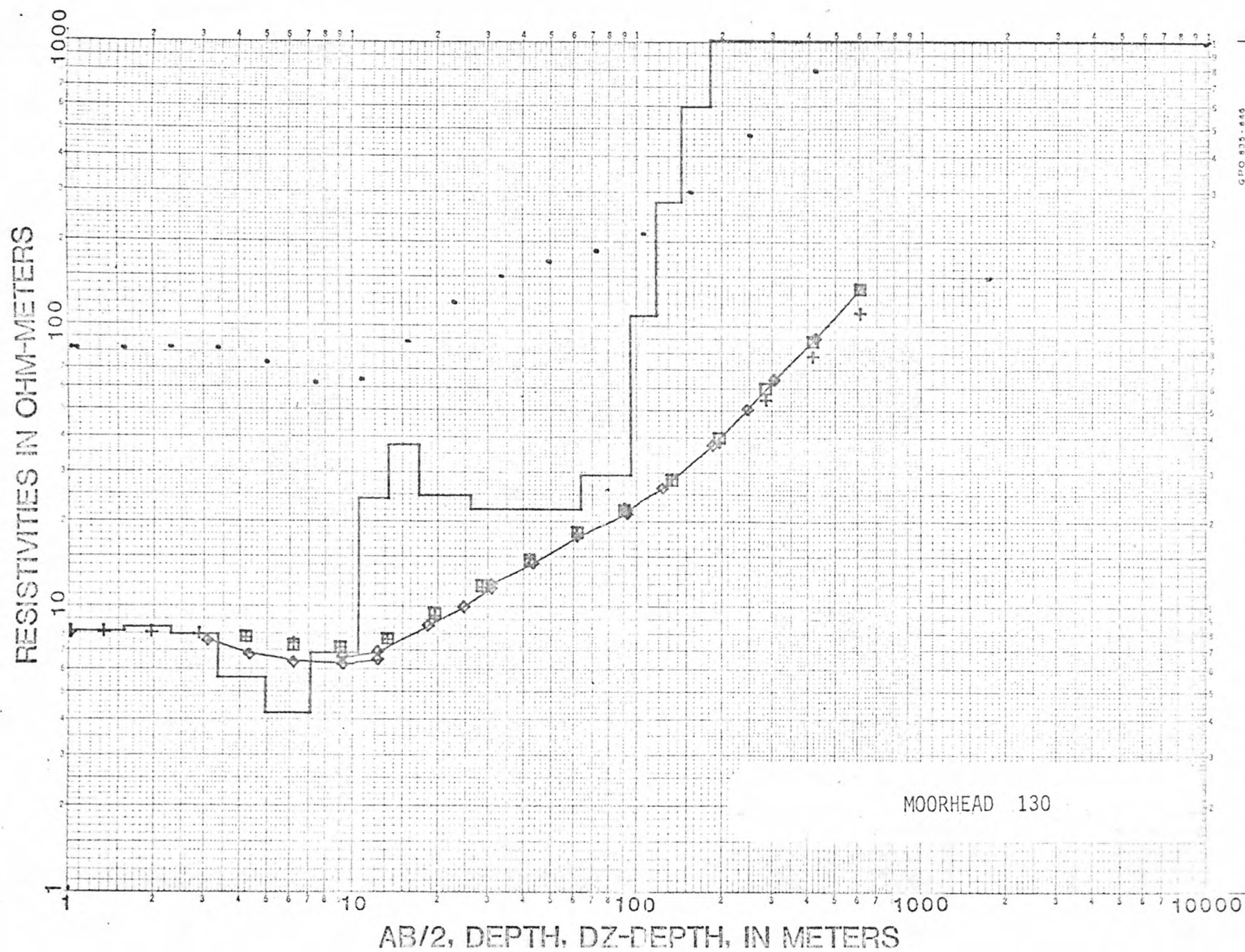




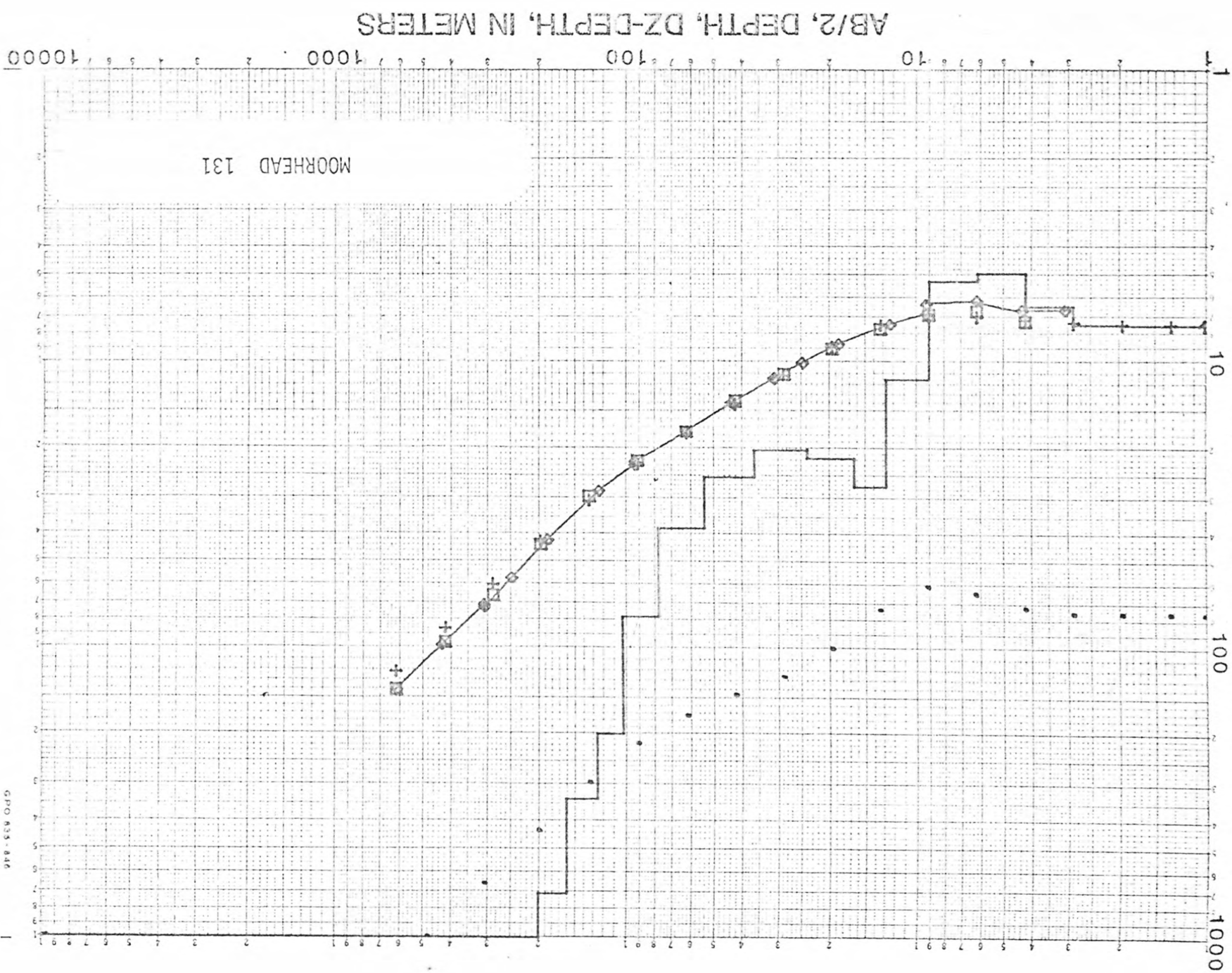


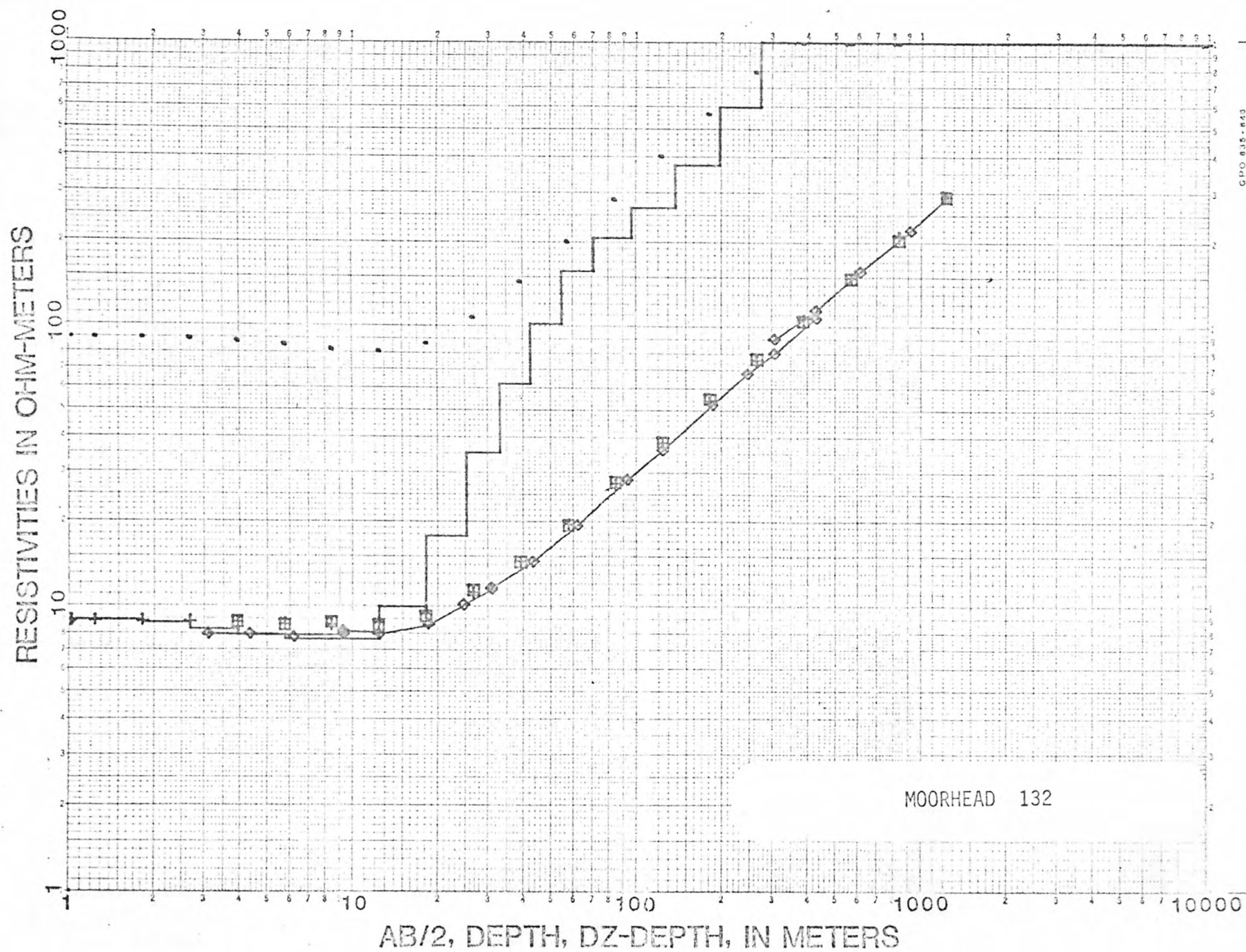


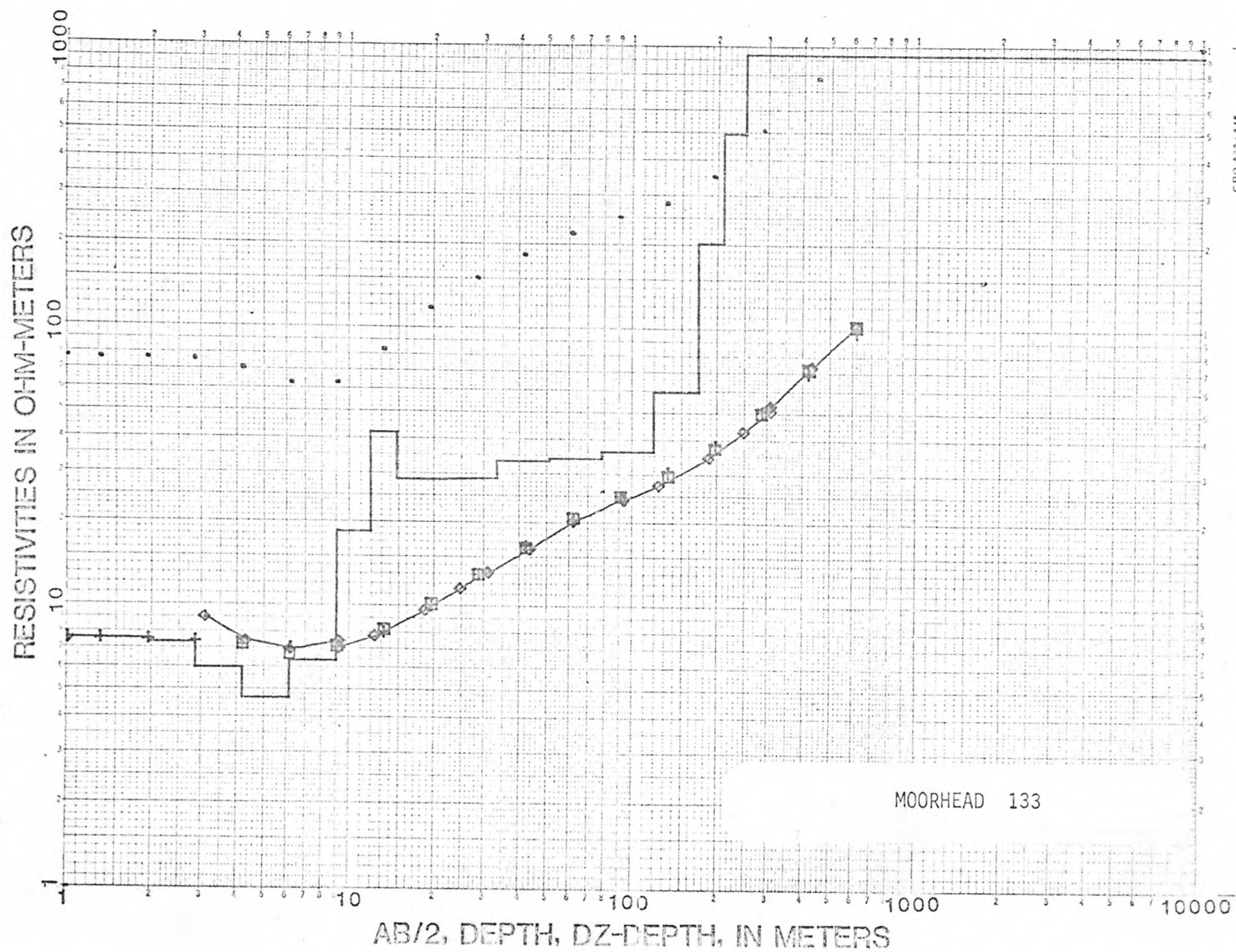


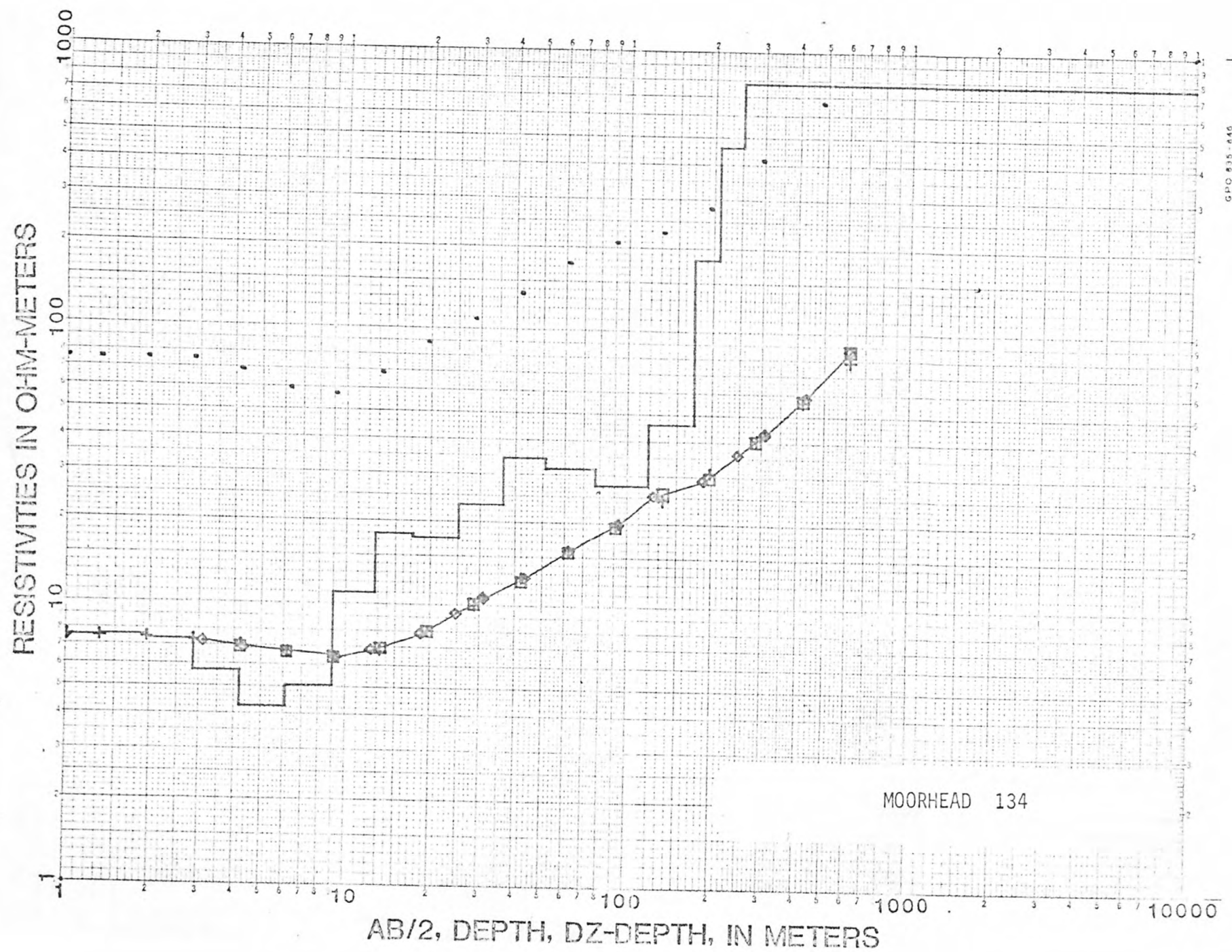


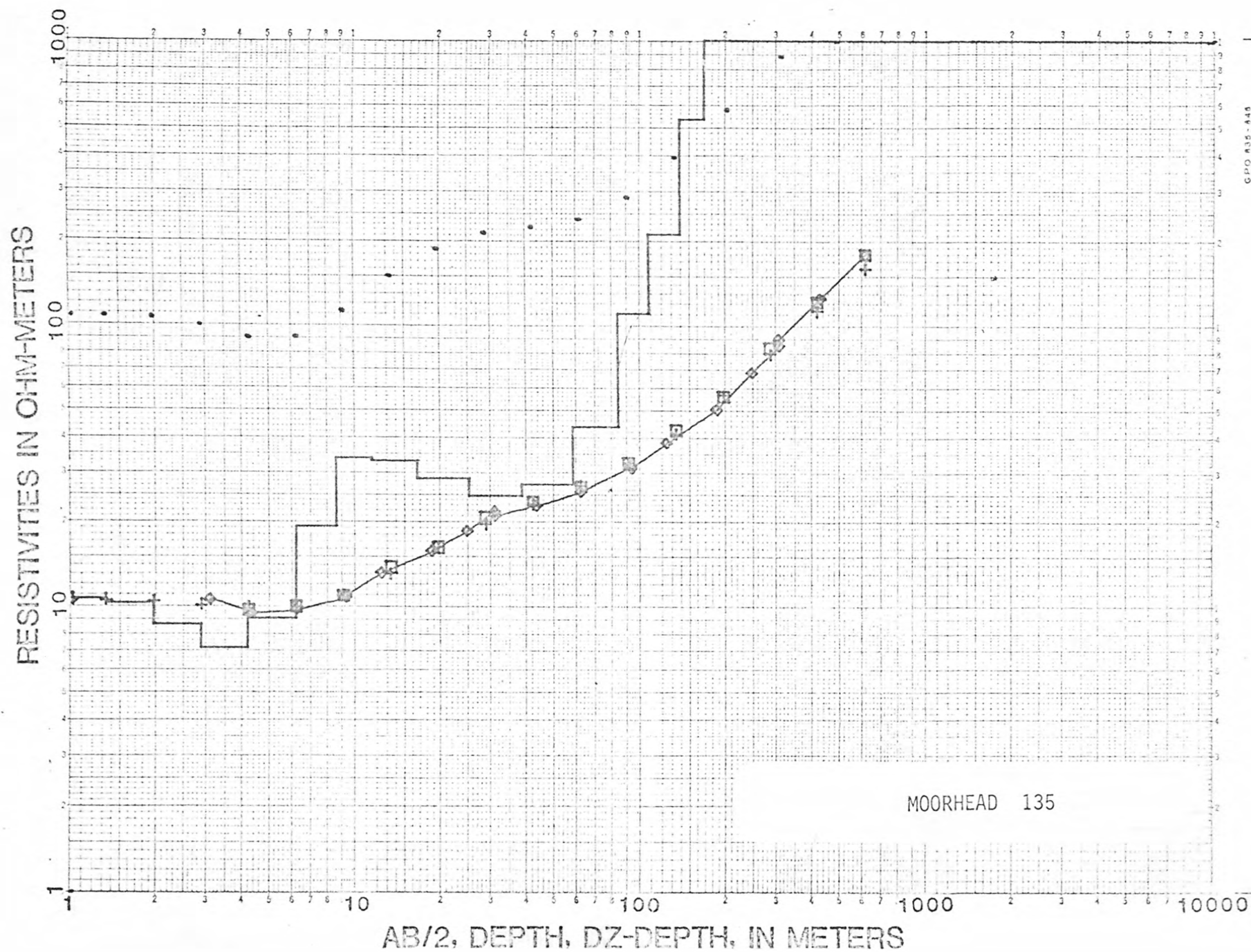
RESISTIVITIES IN OHM-METERS

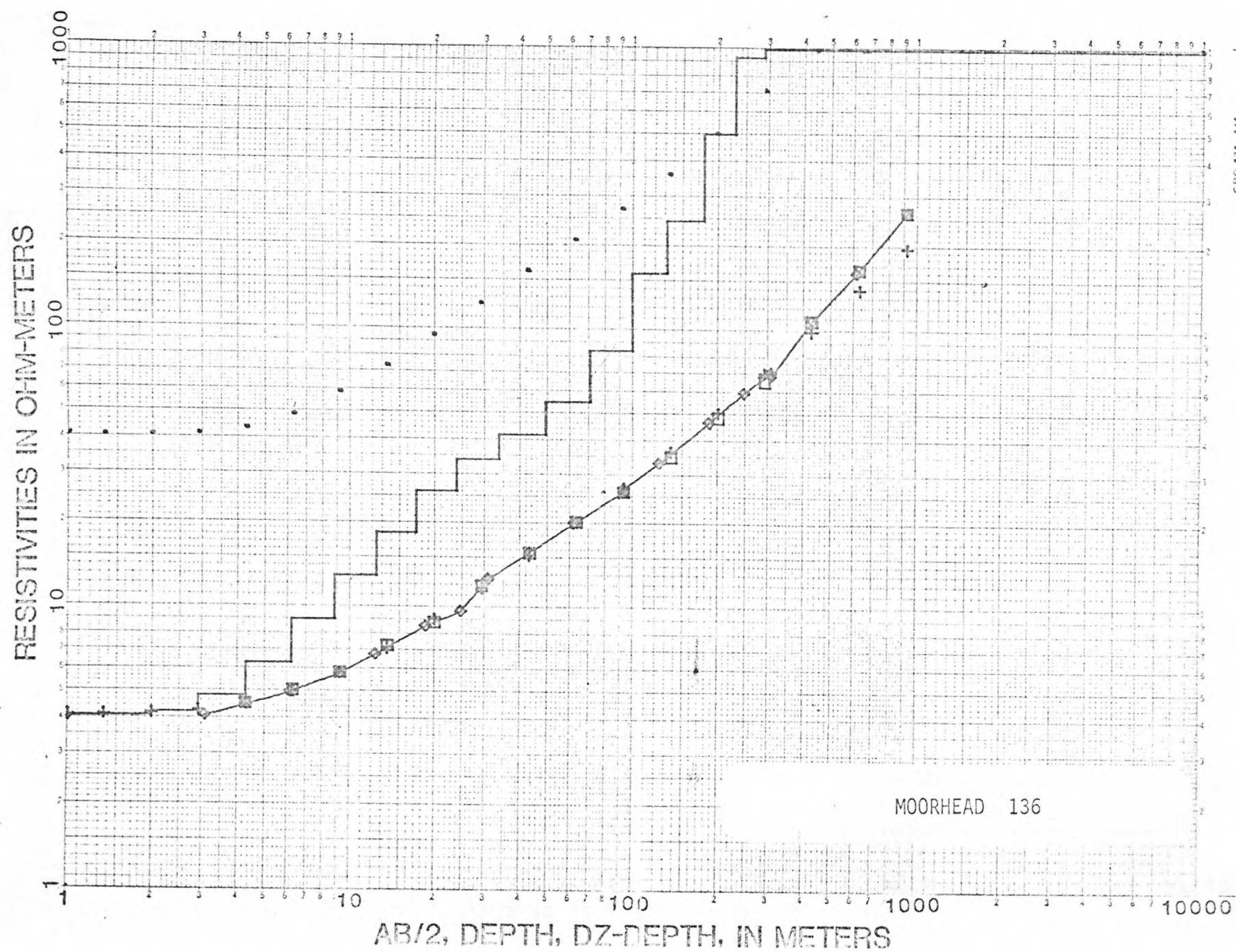


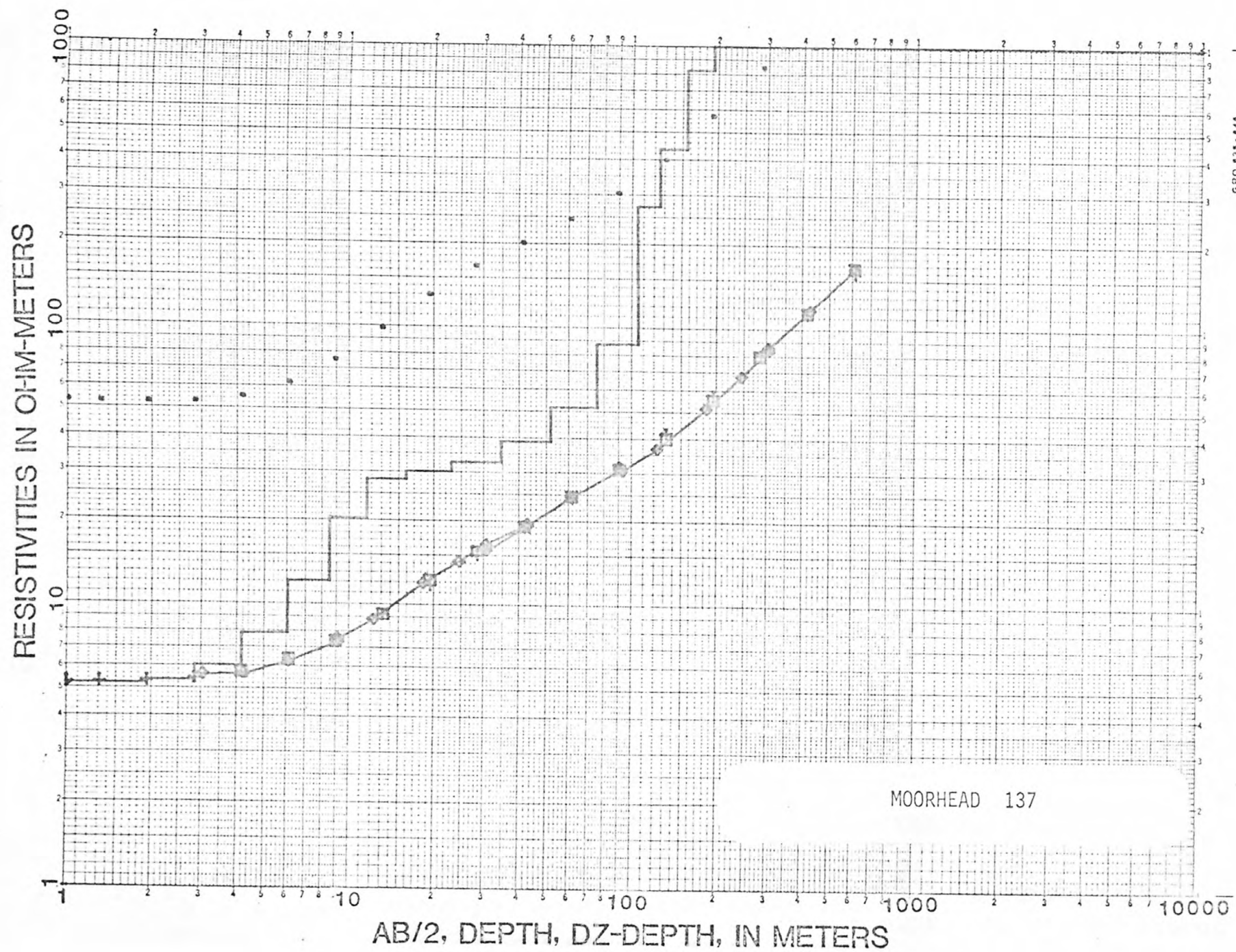


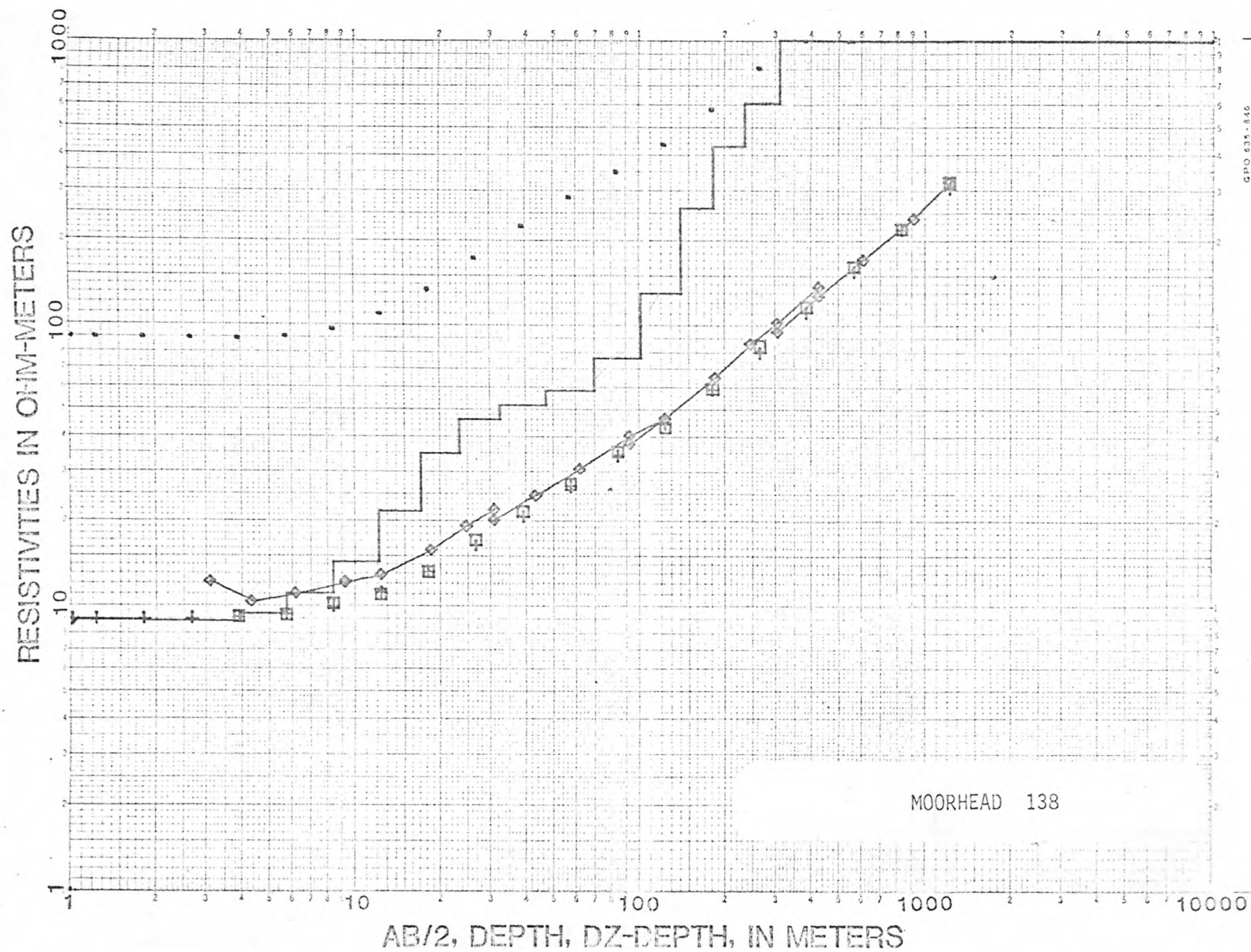


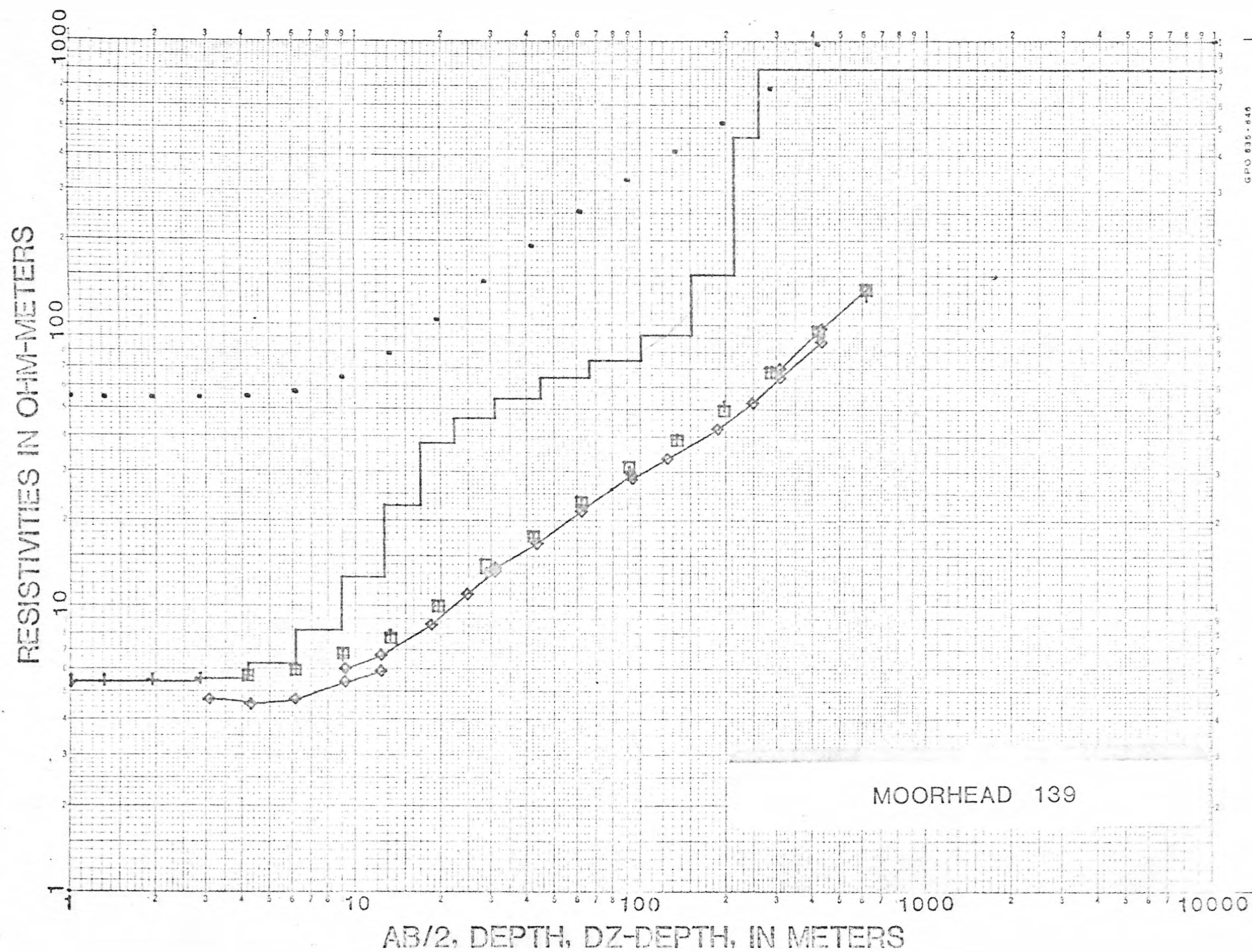


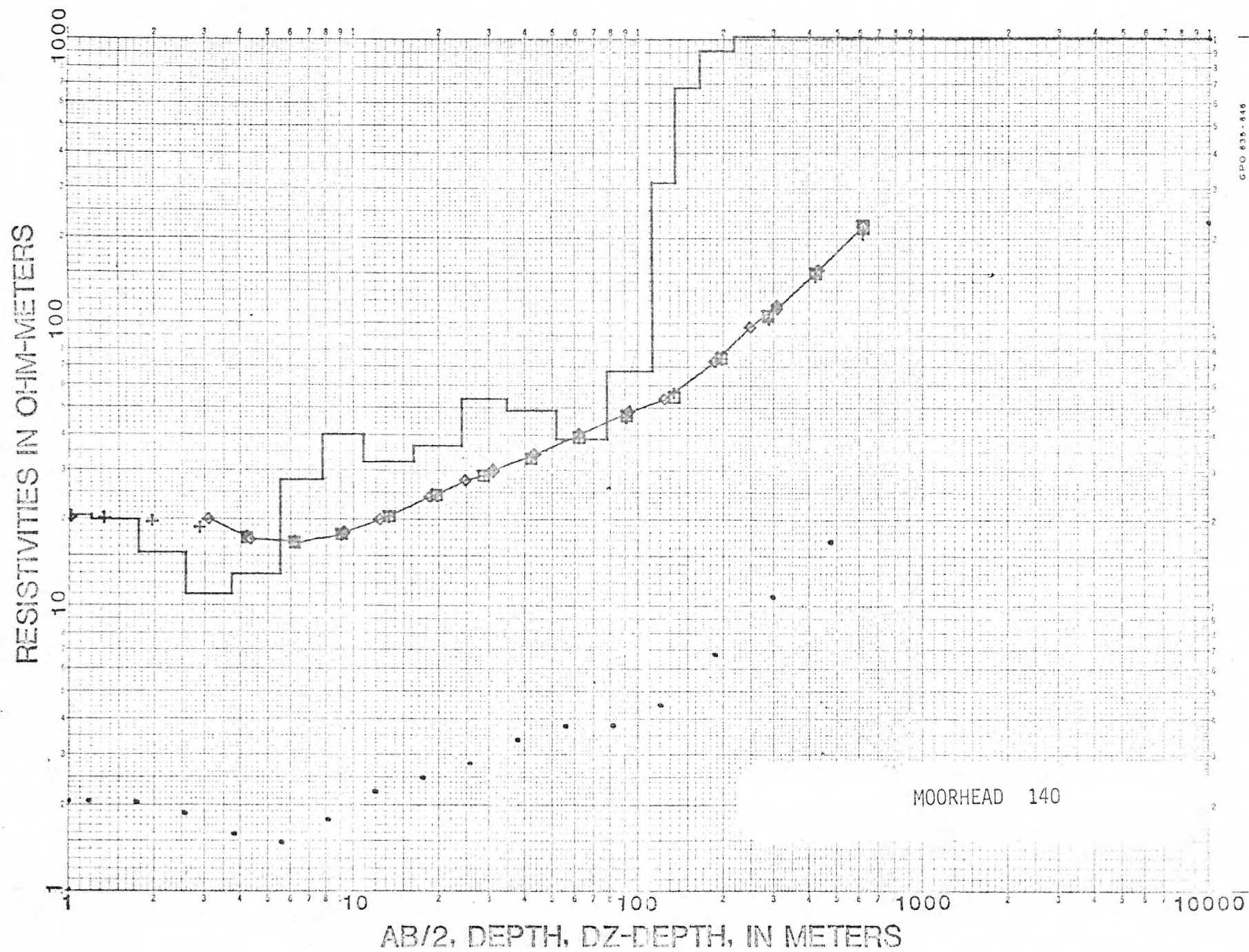




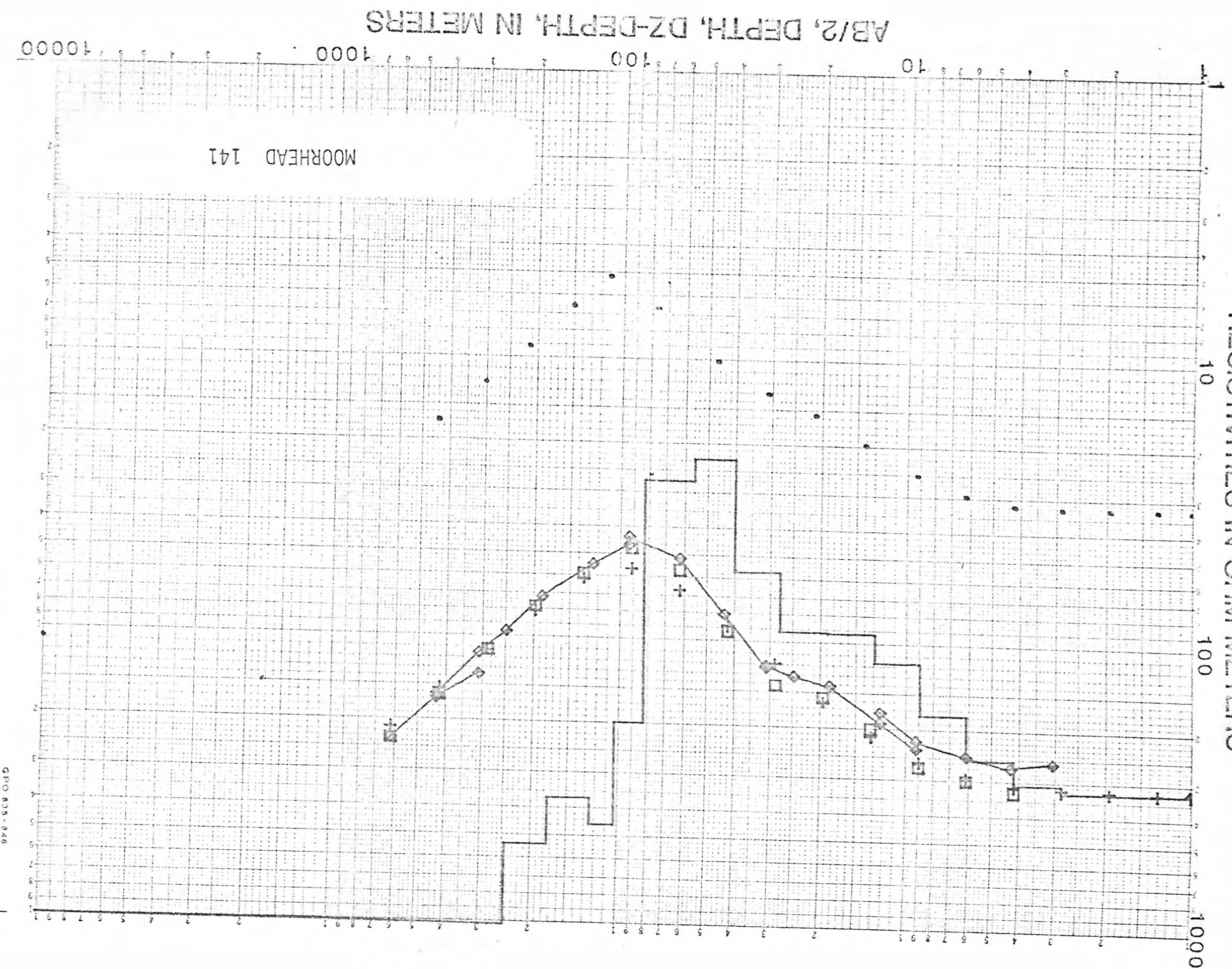


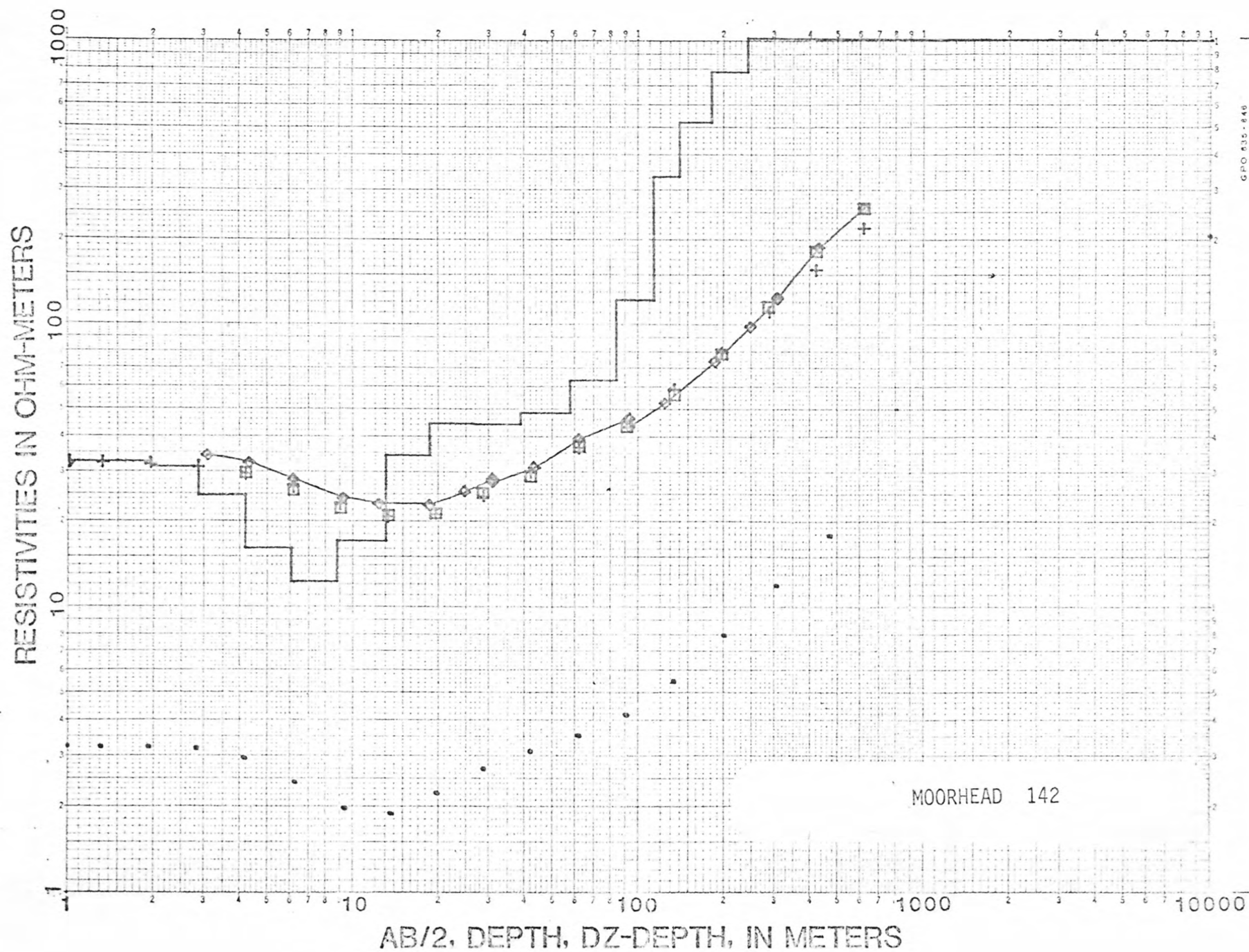


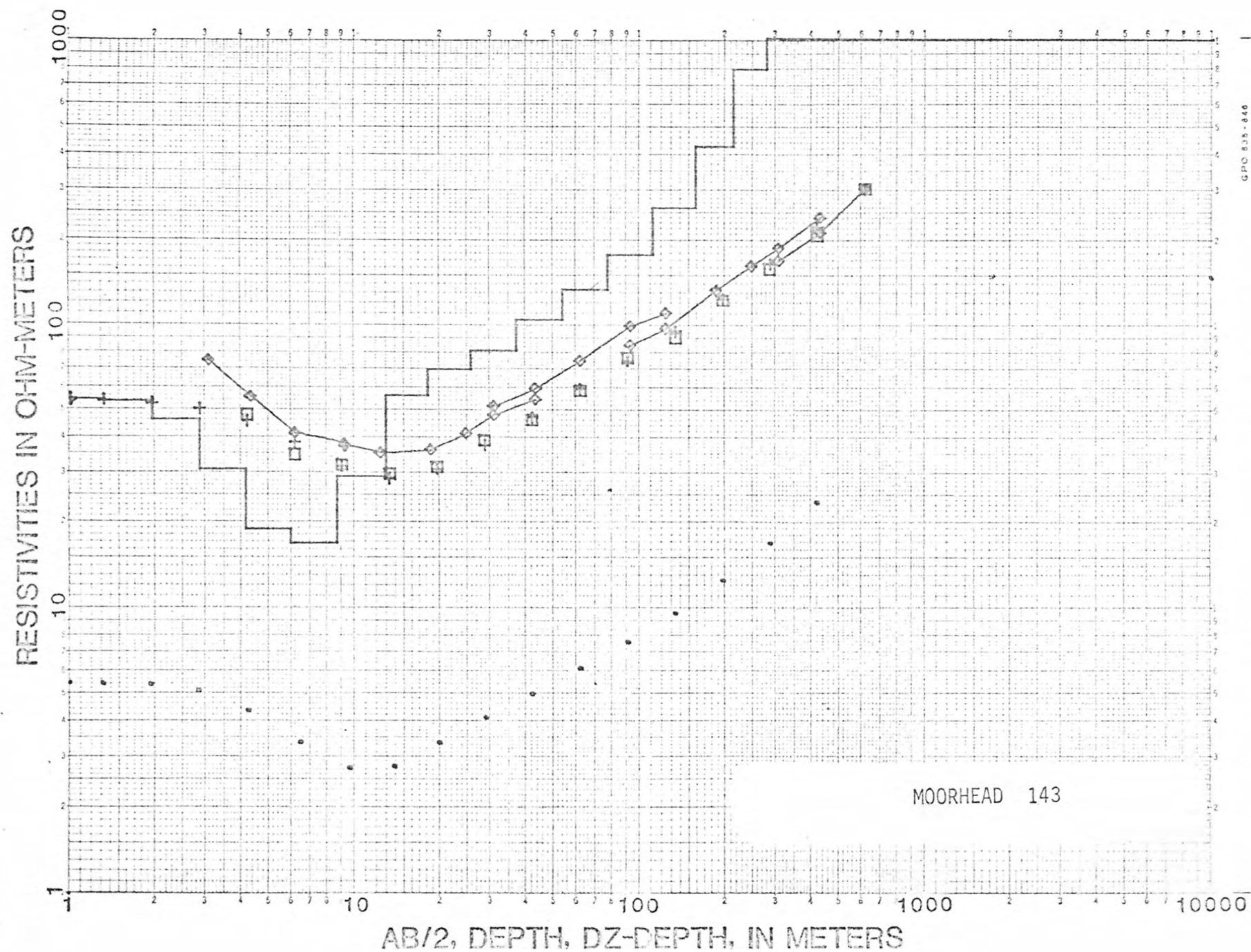




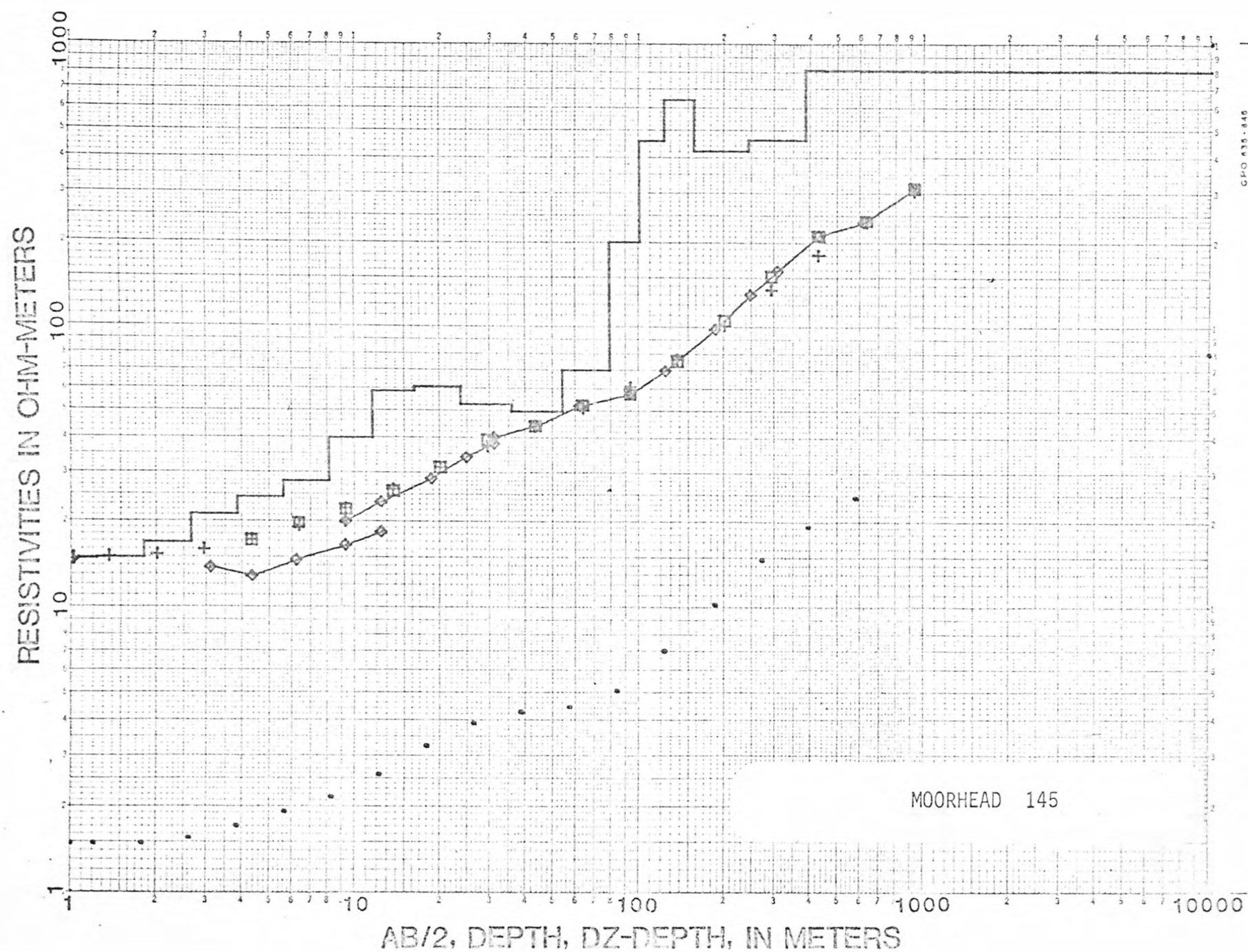
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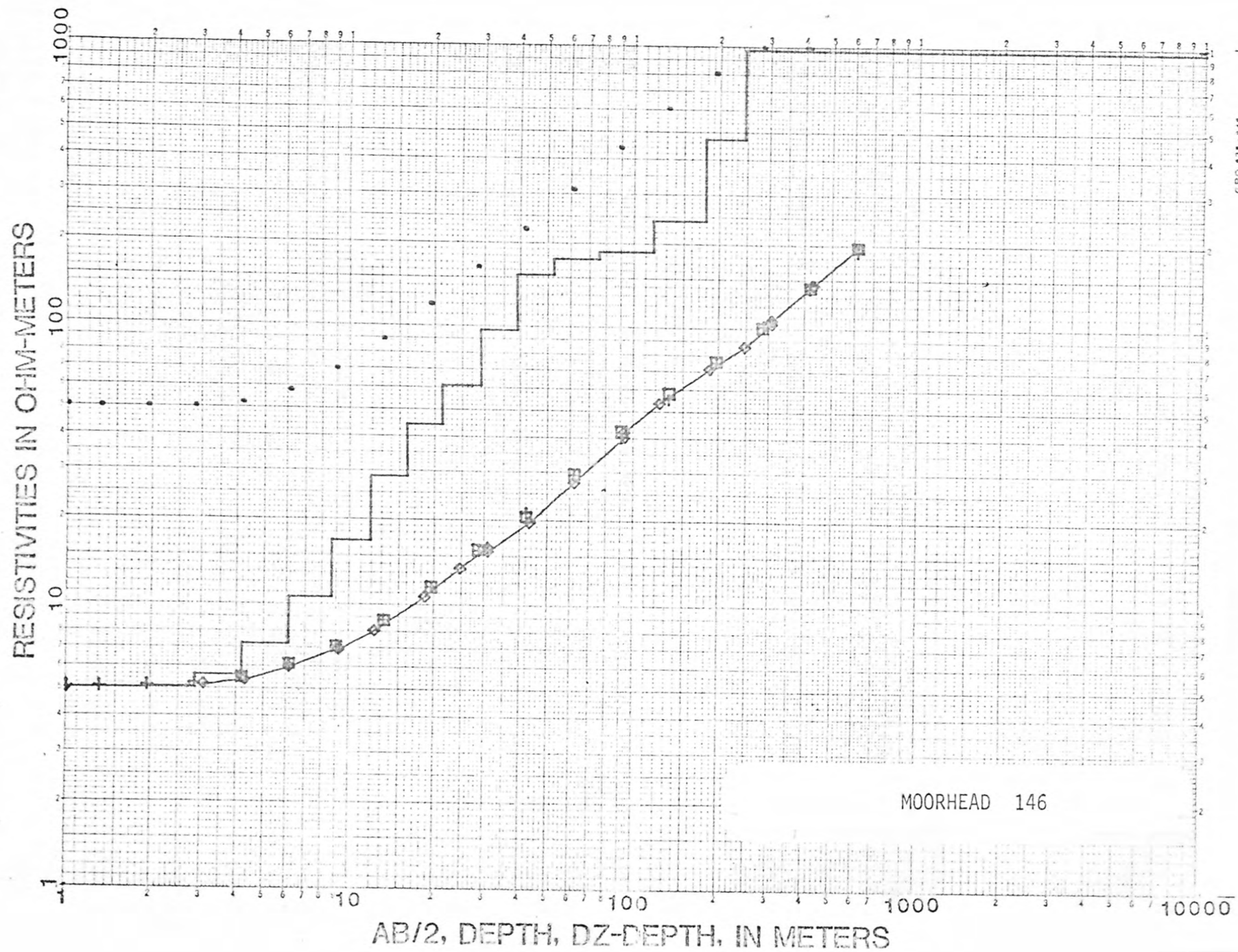


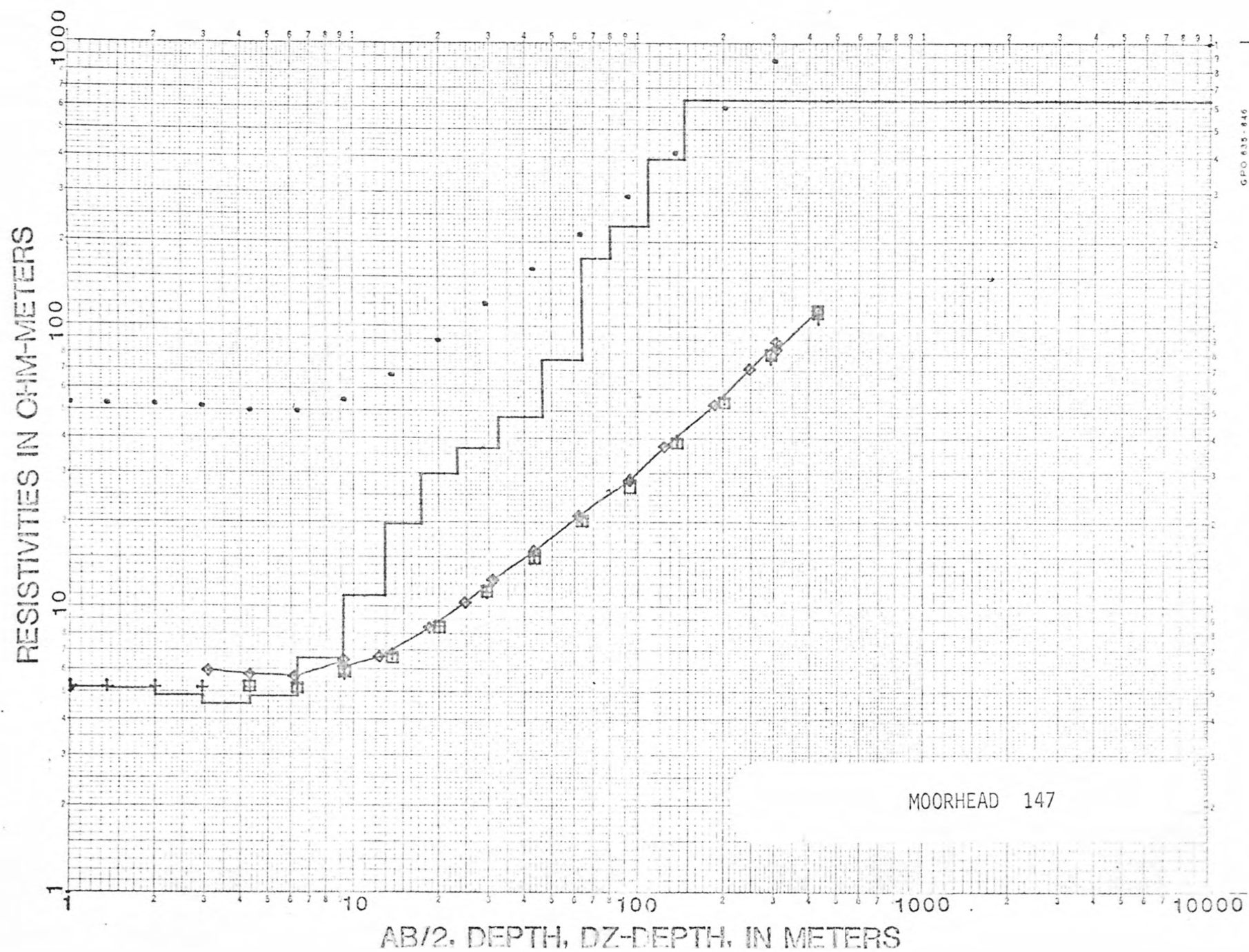




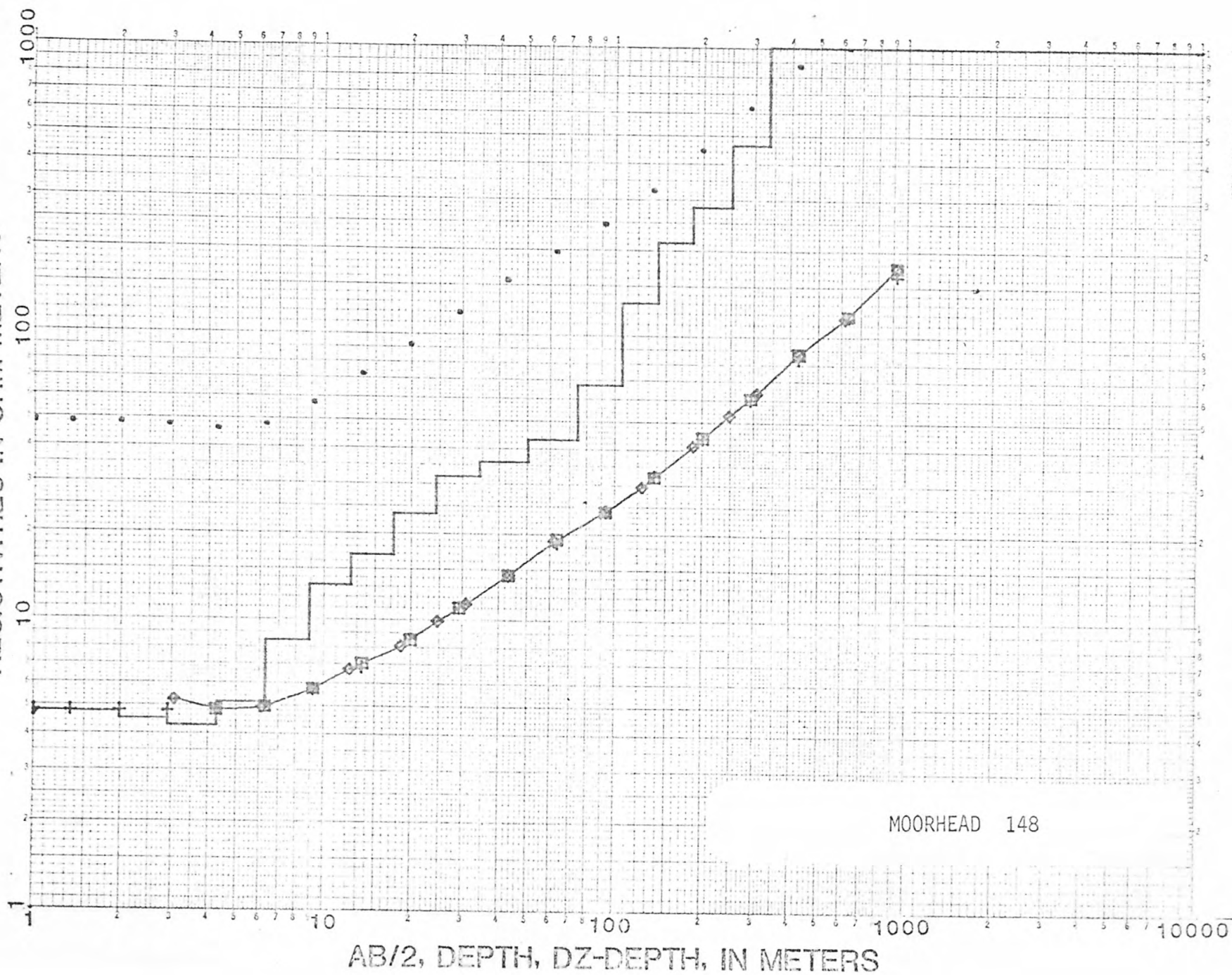


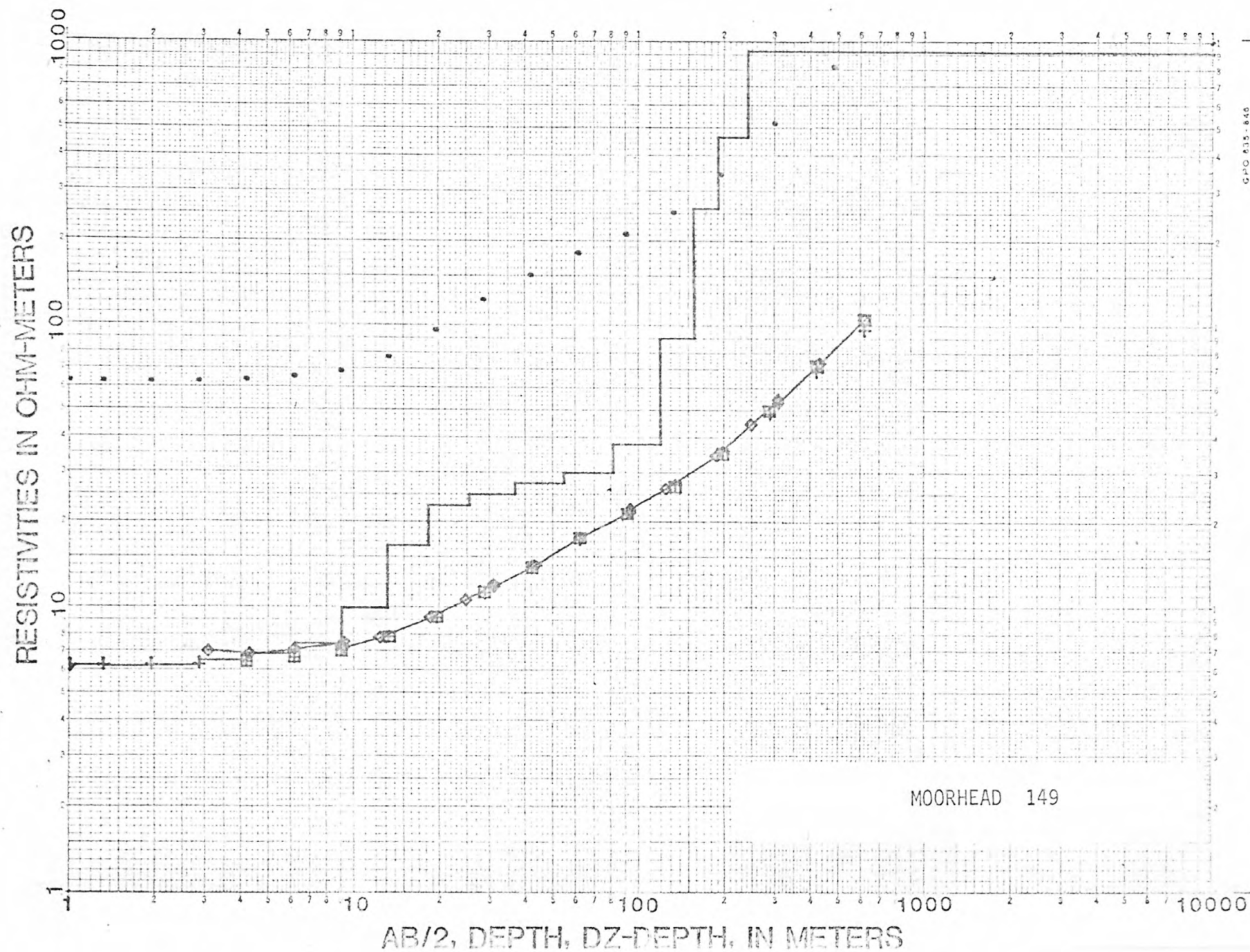


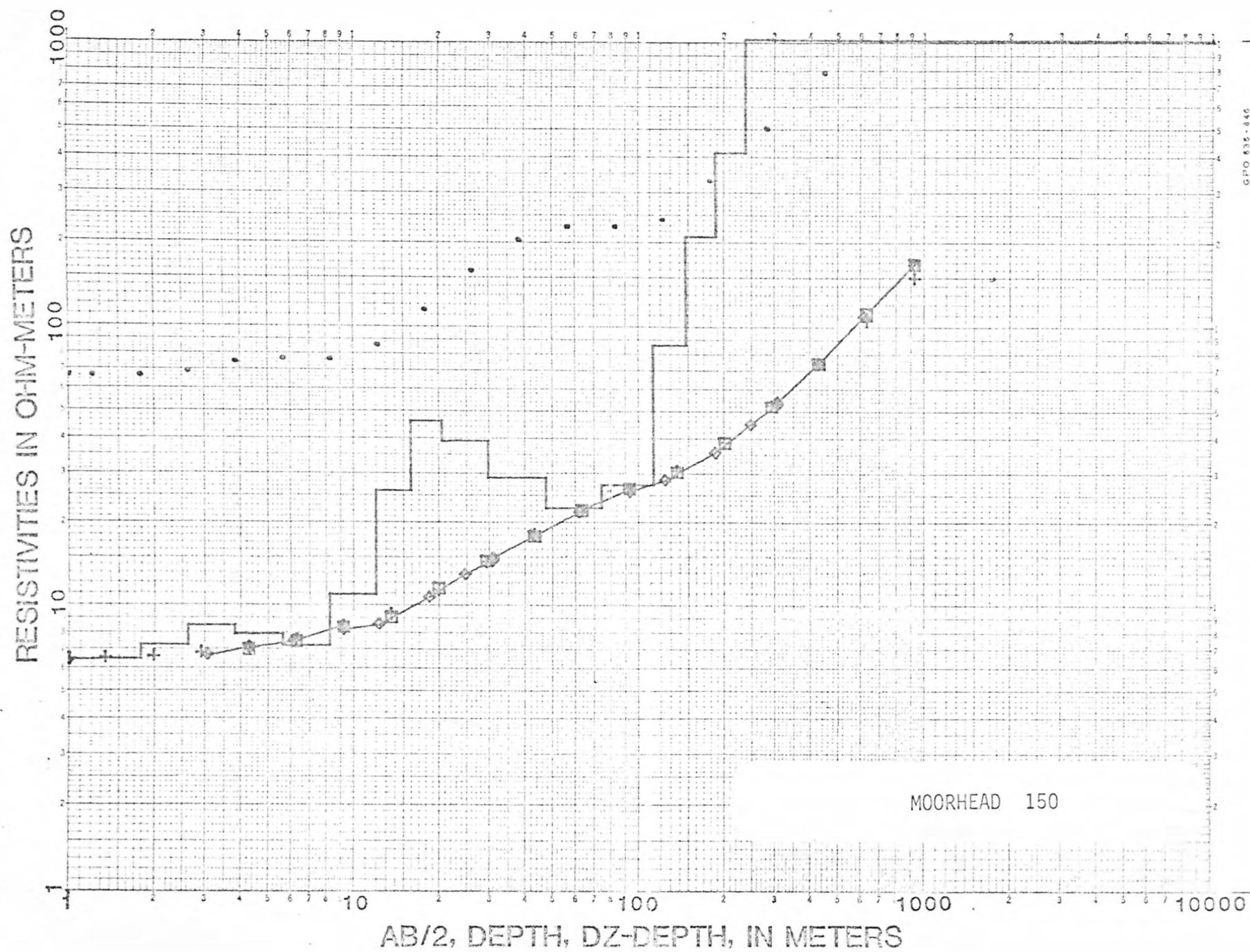


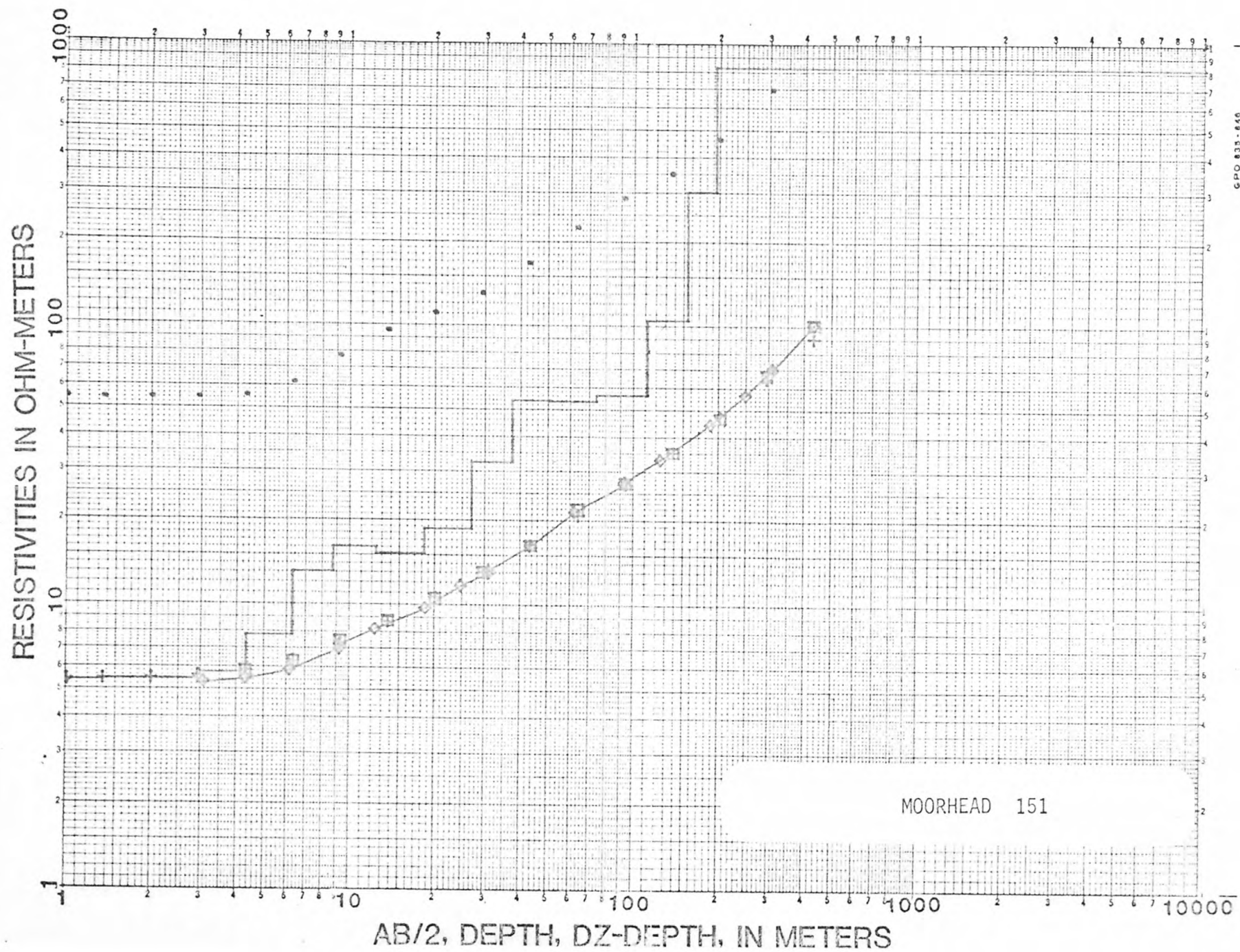


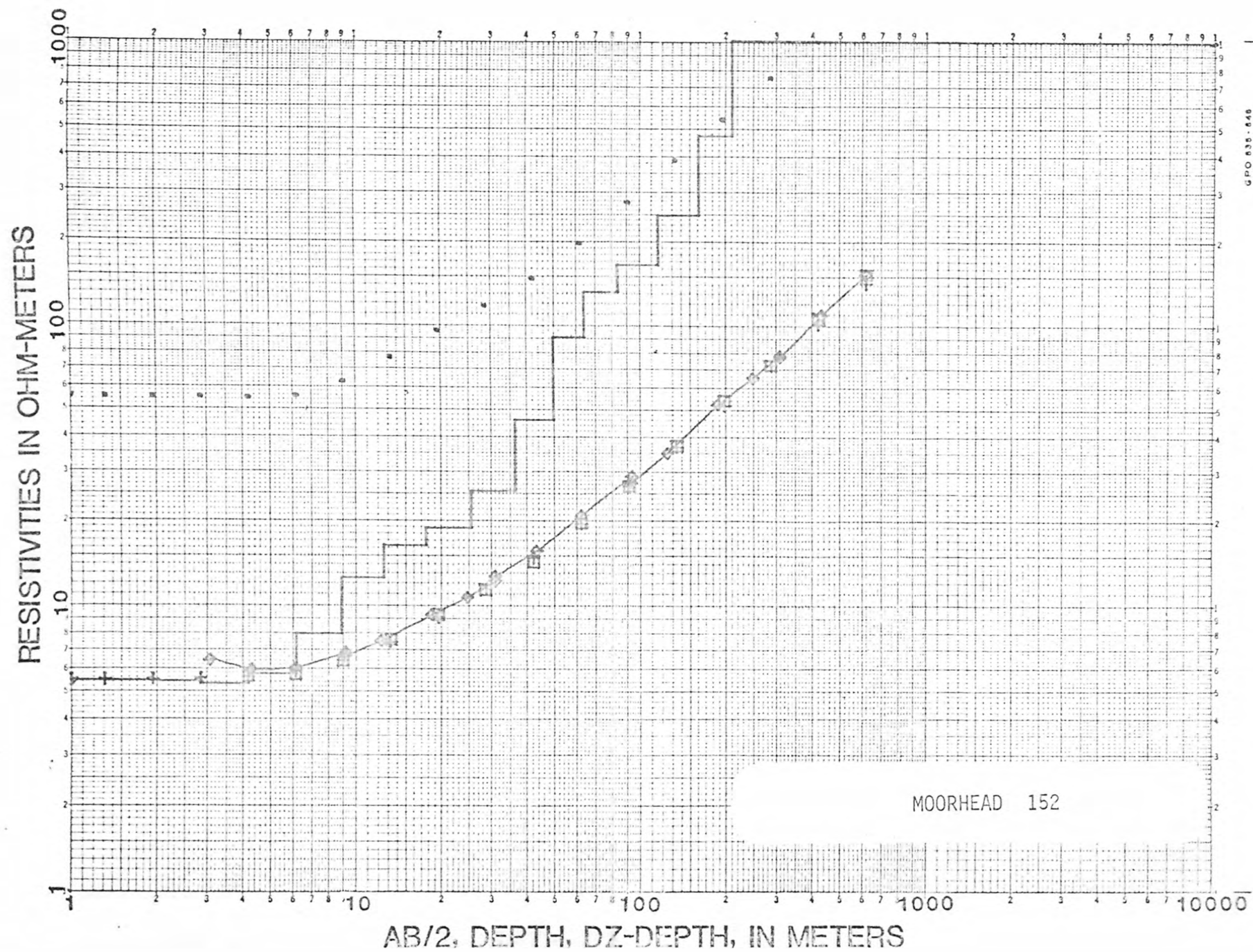
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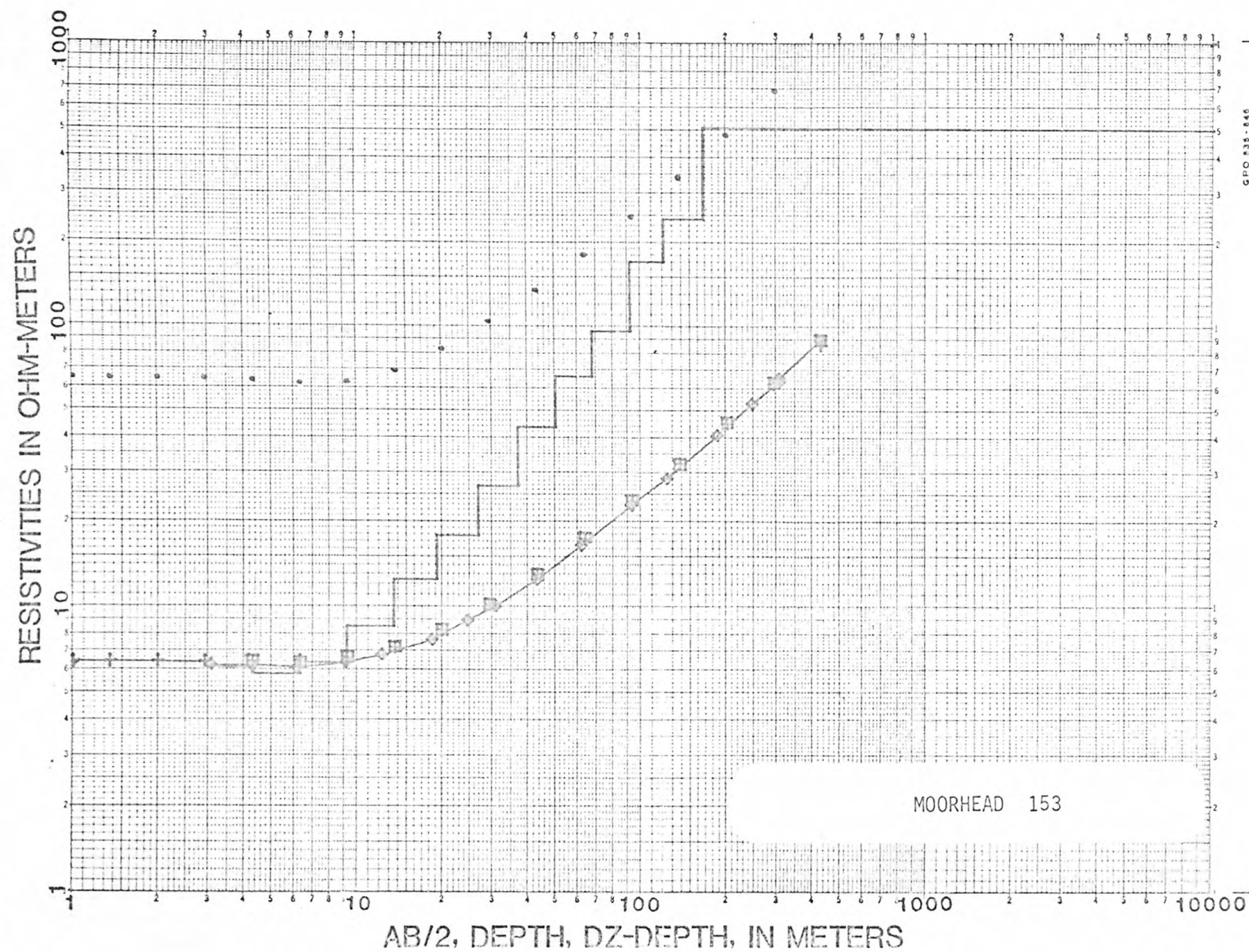


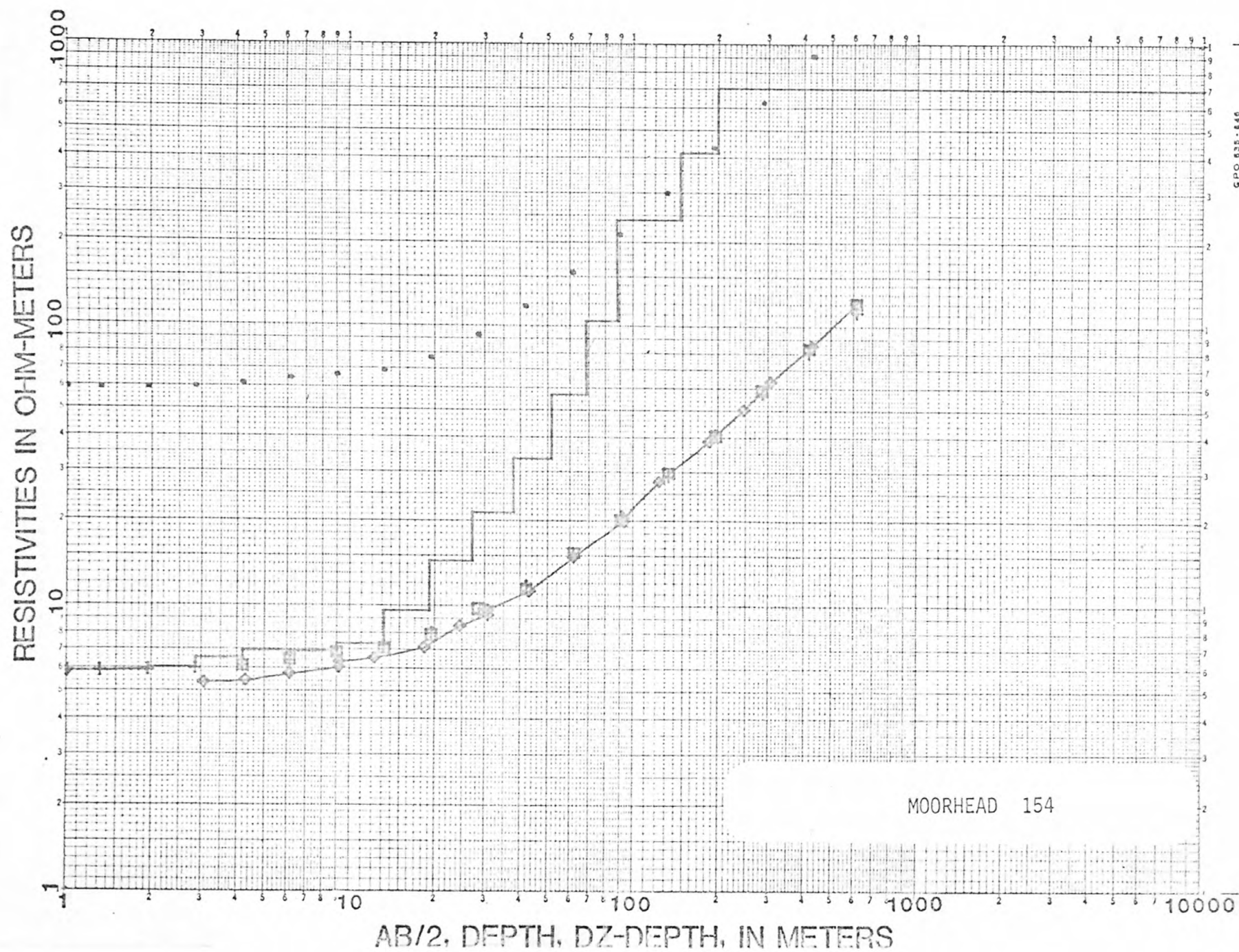


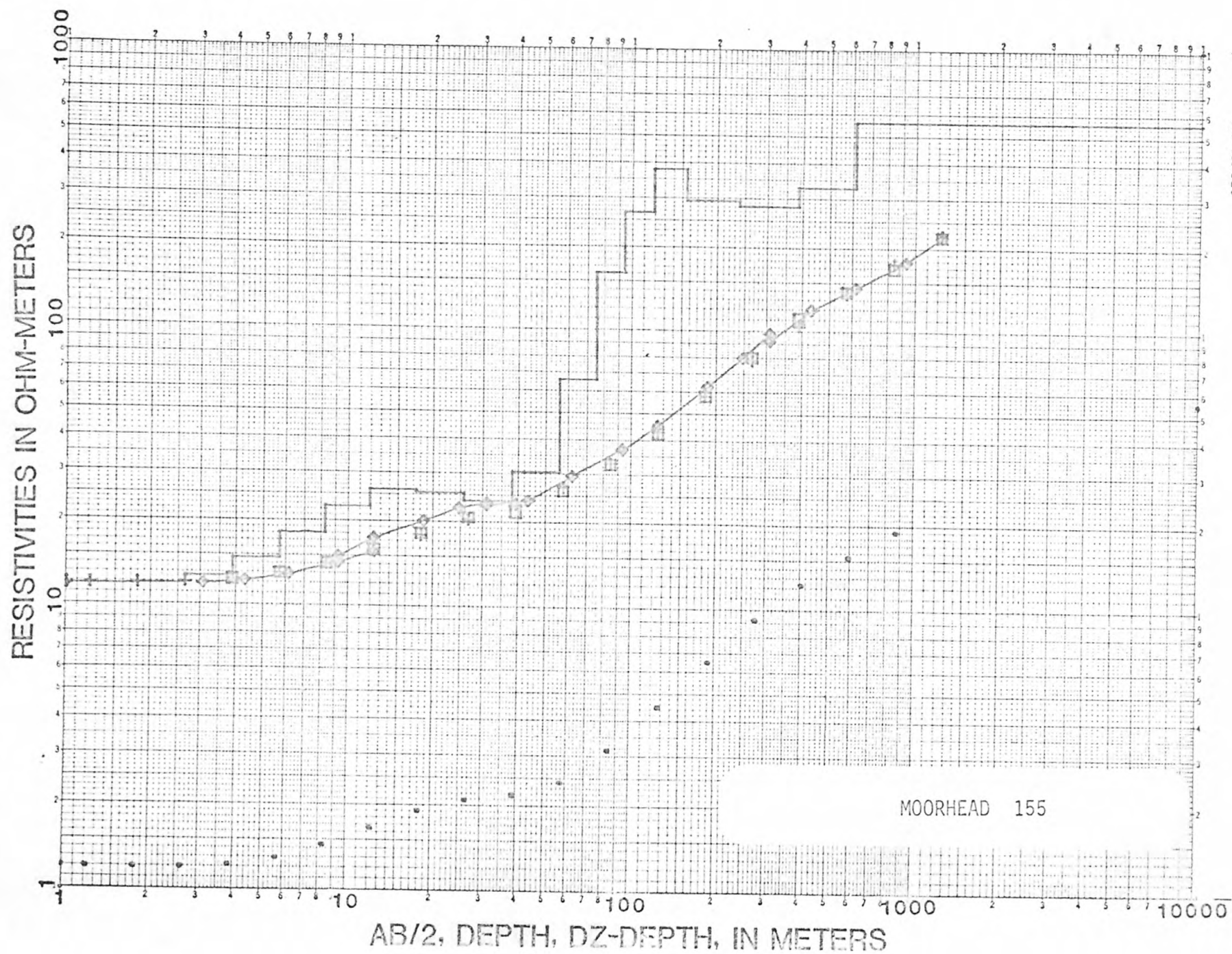


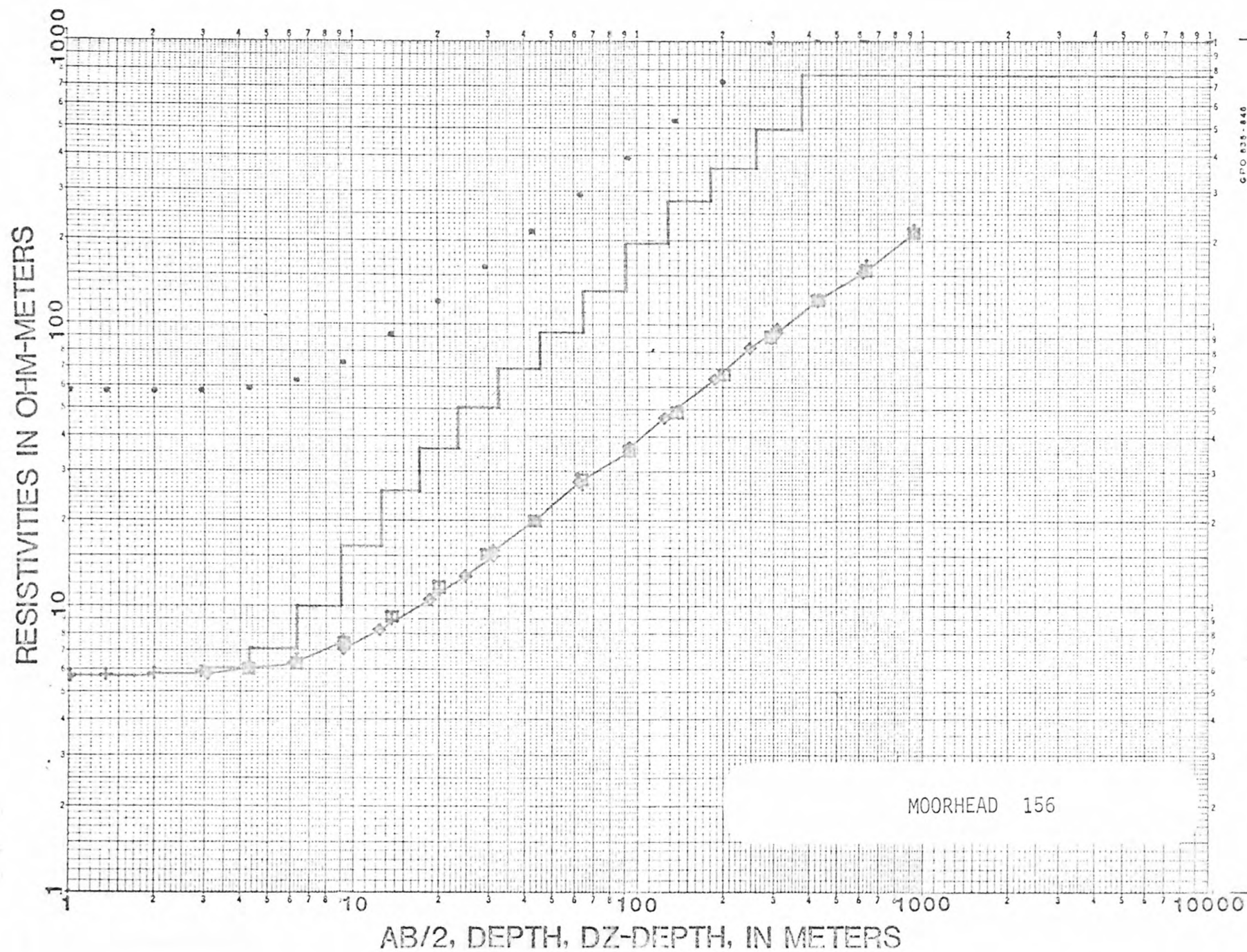


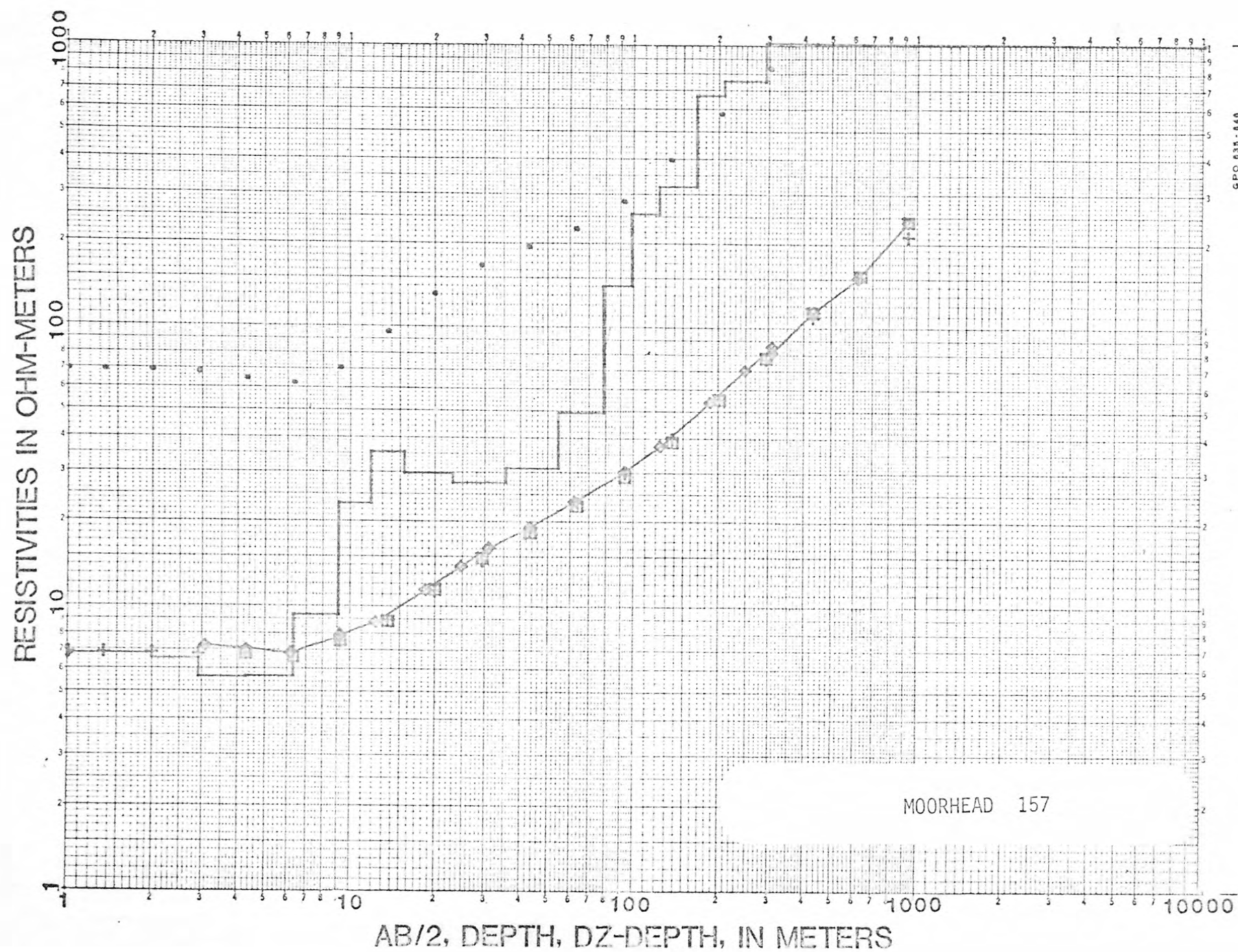


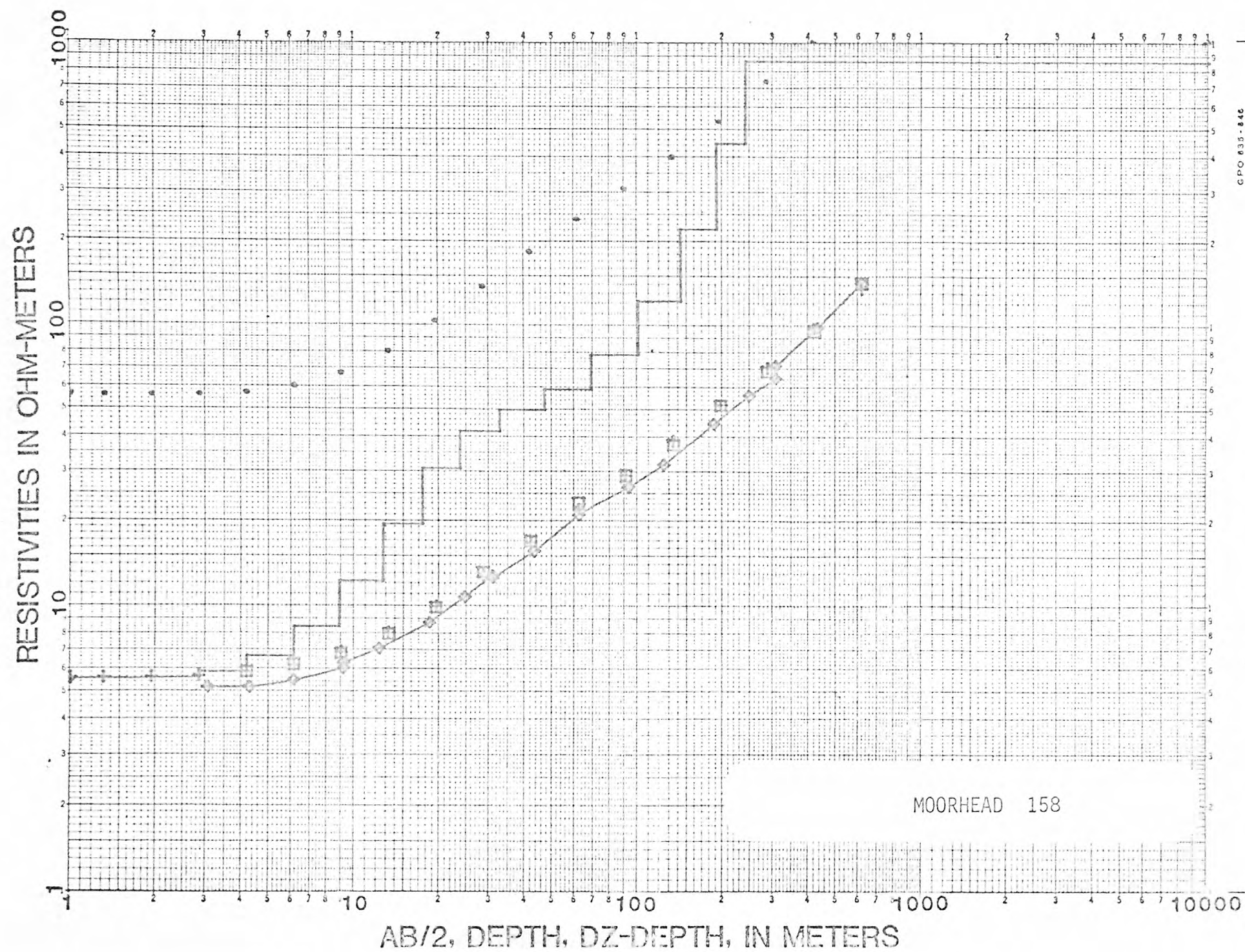




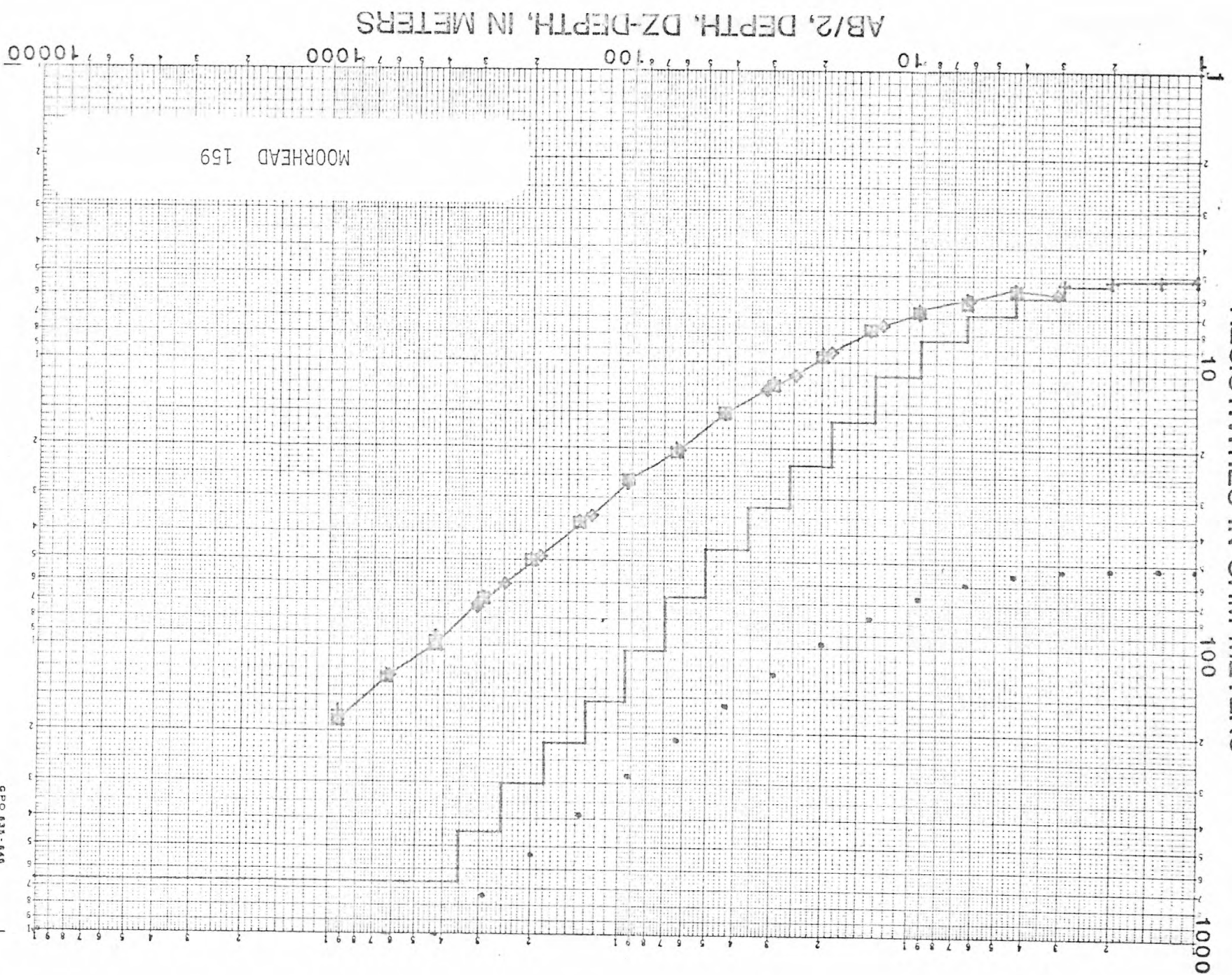


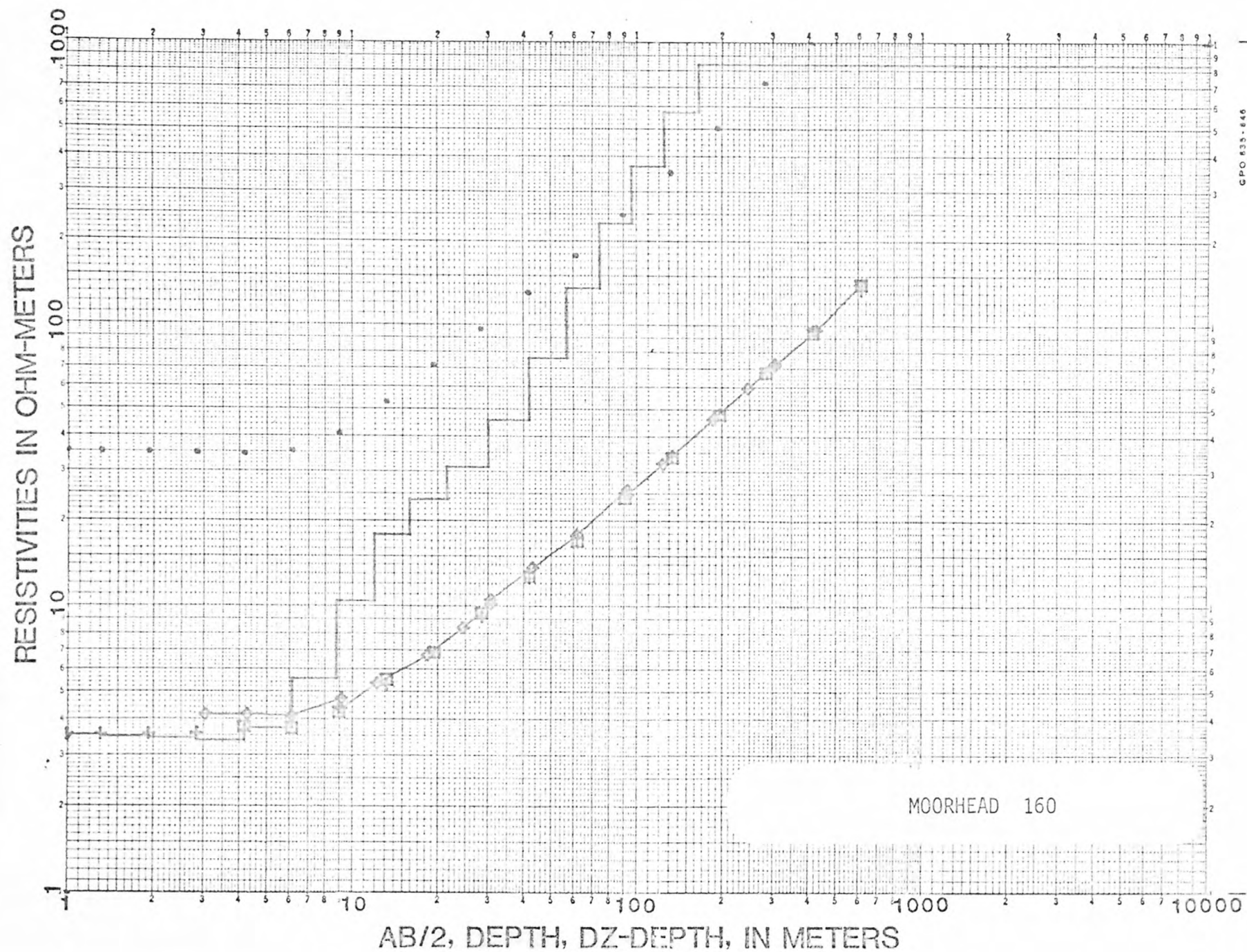


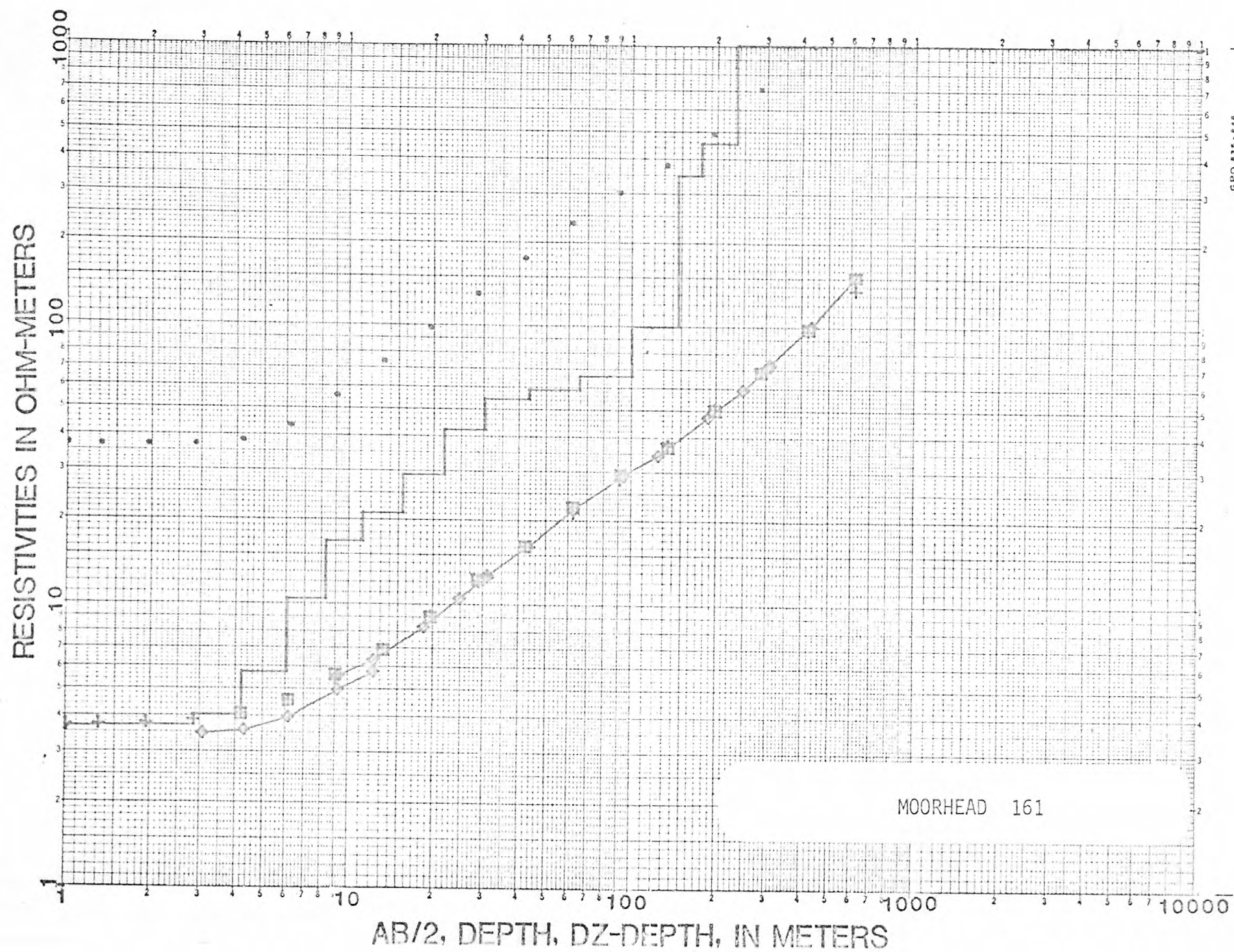


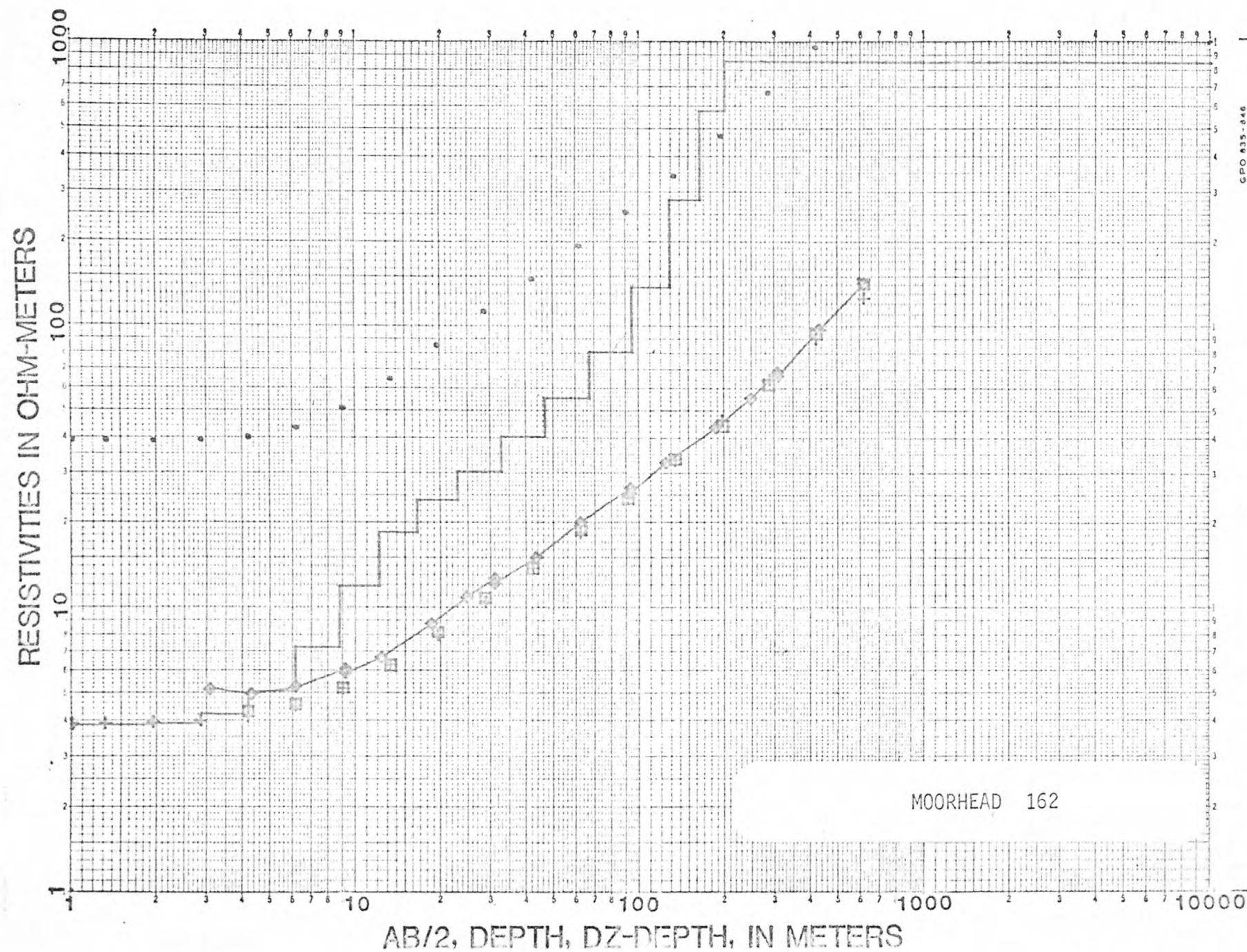


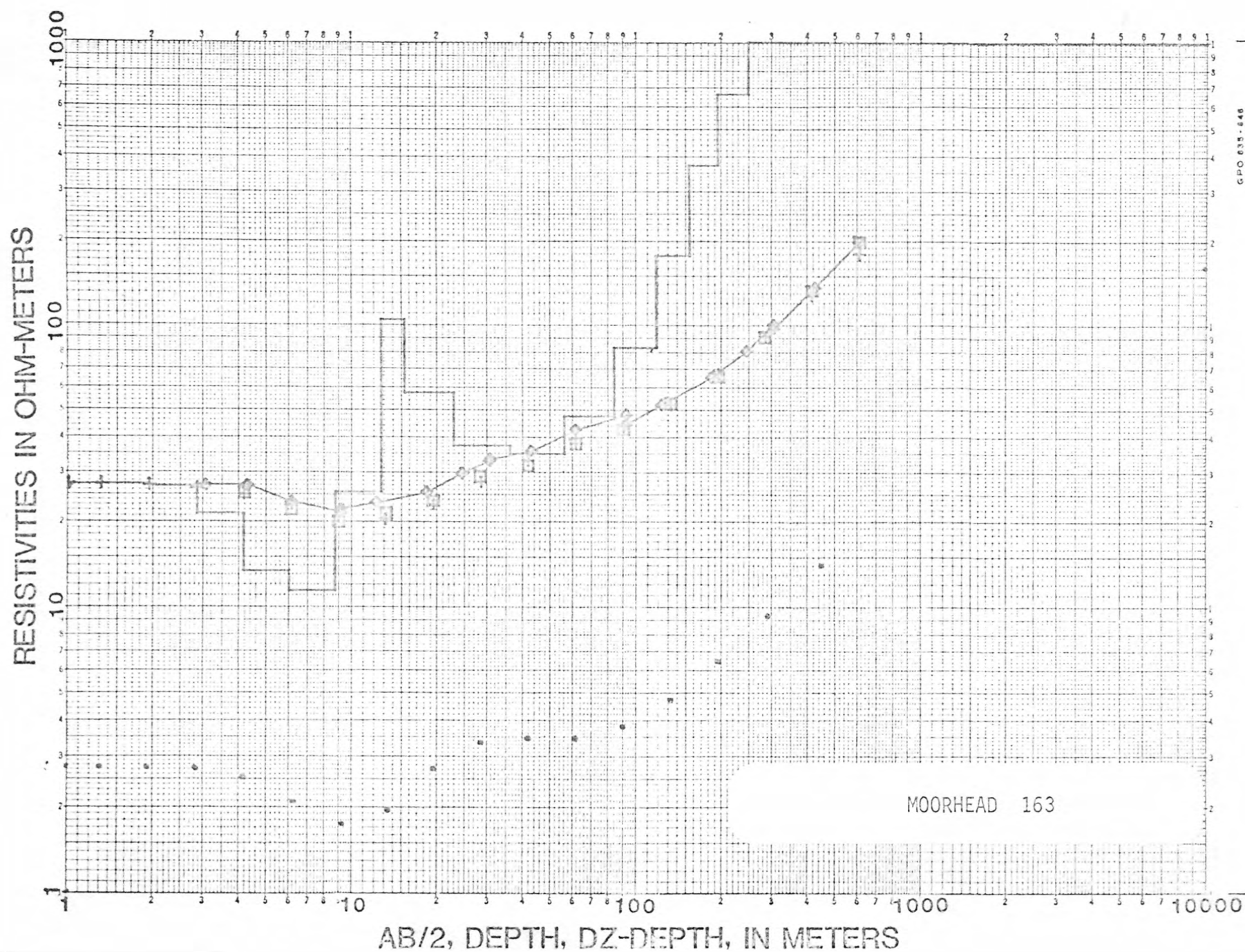
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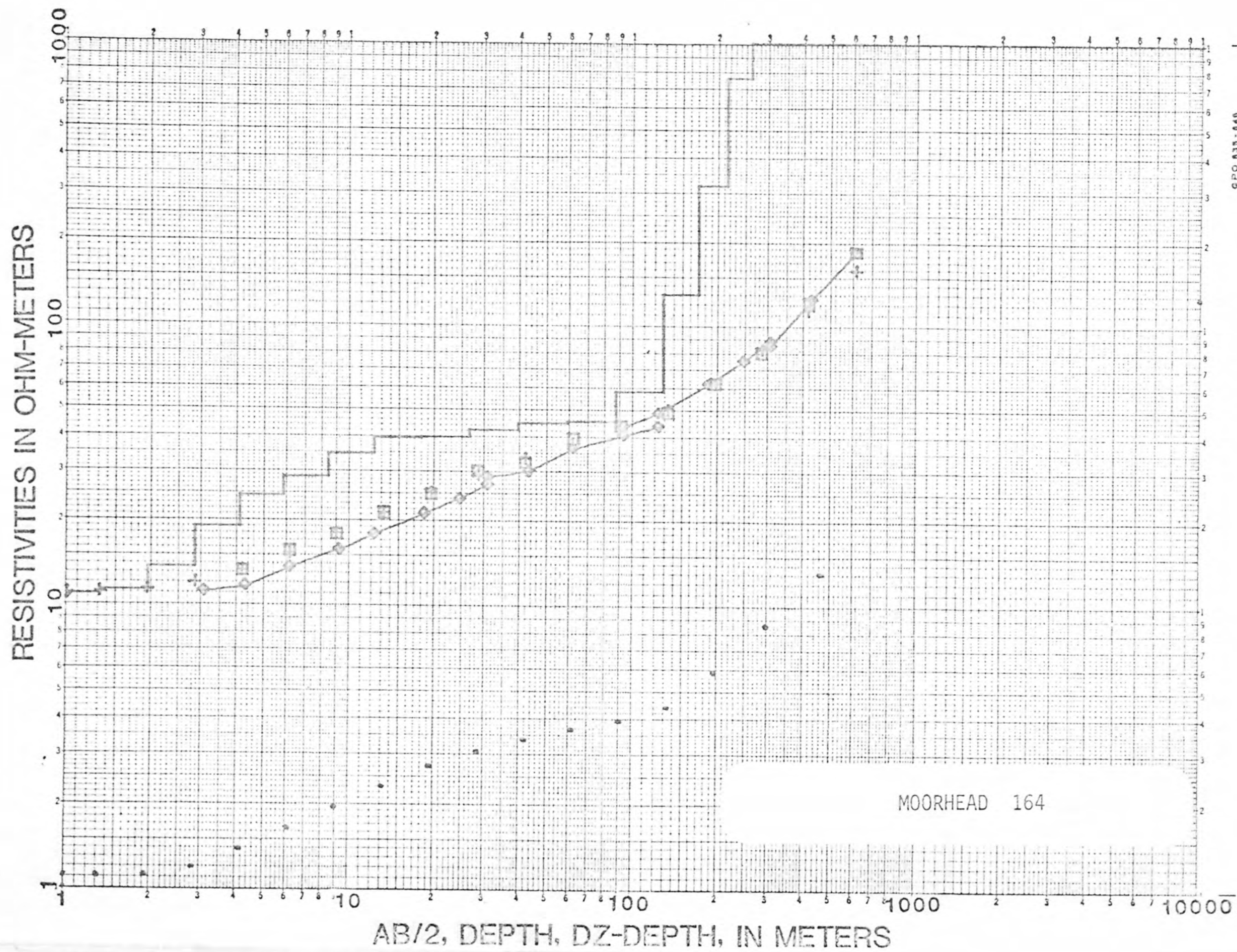


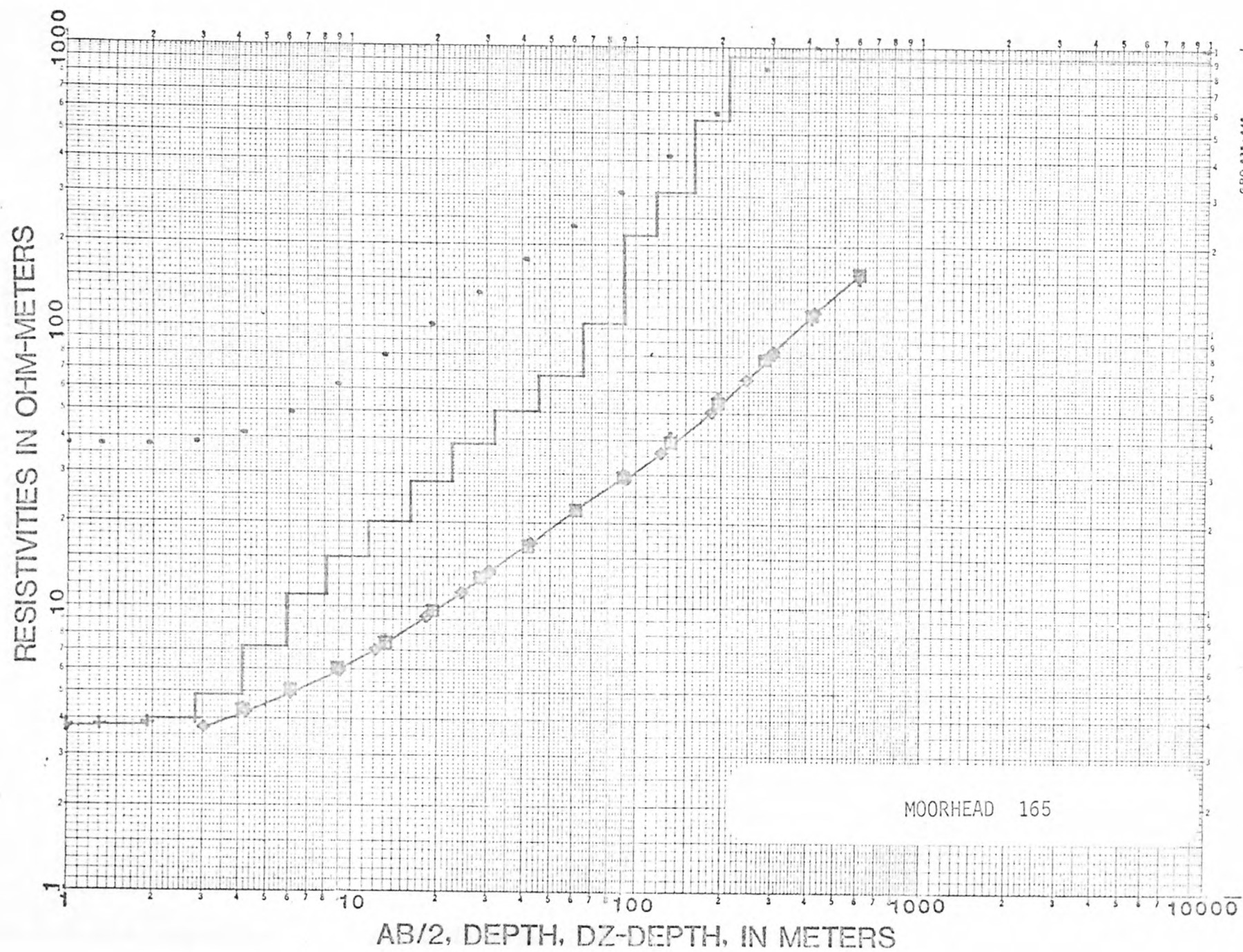


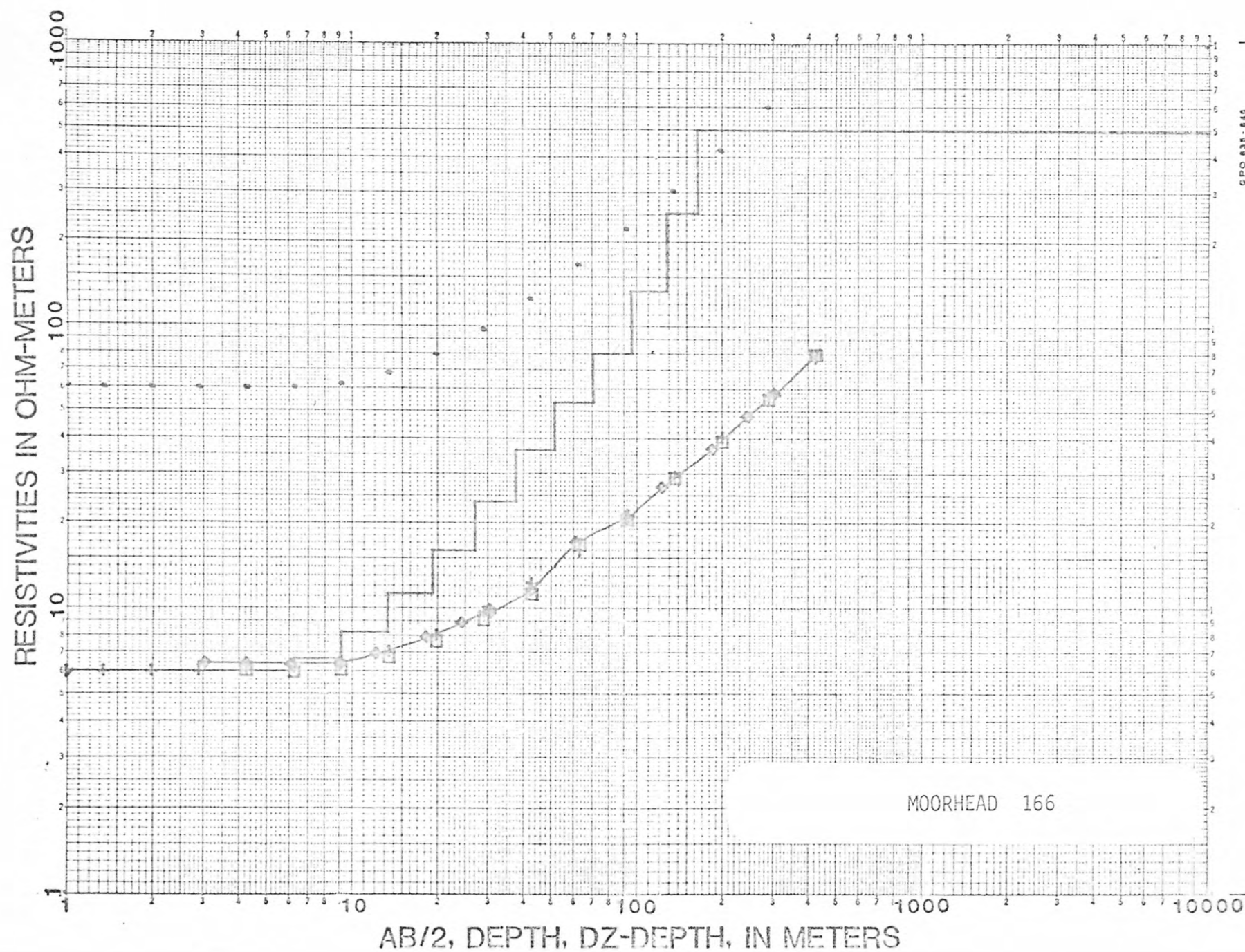


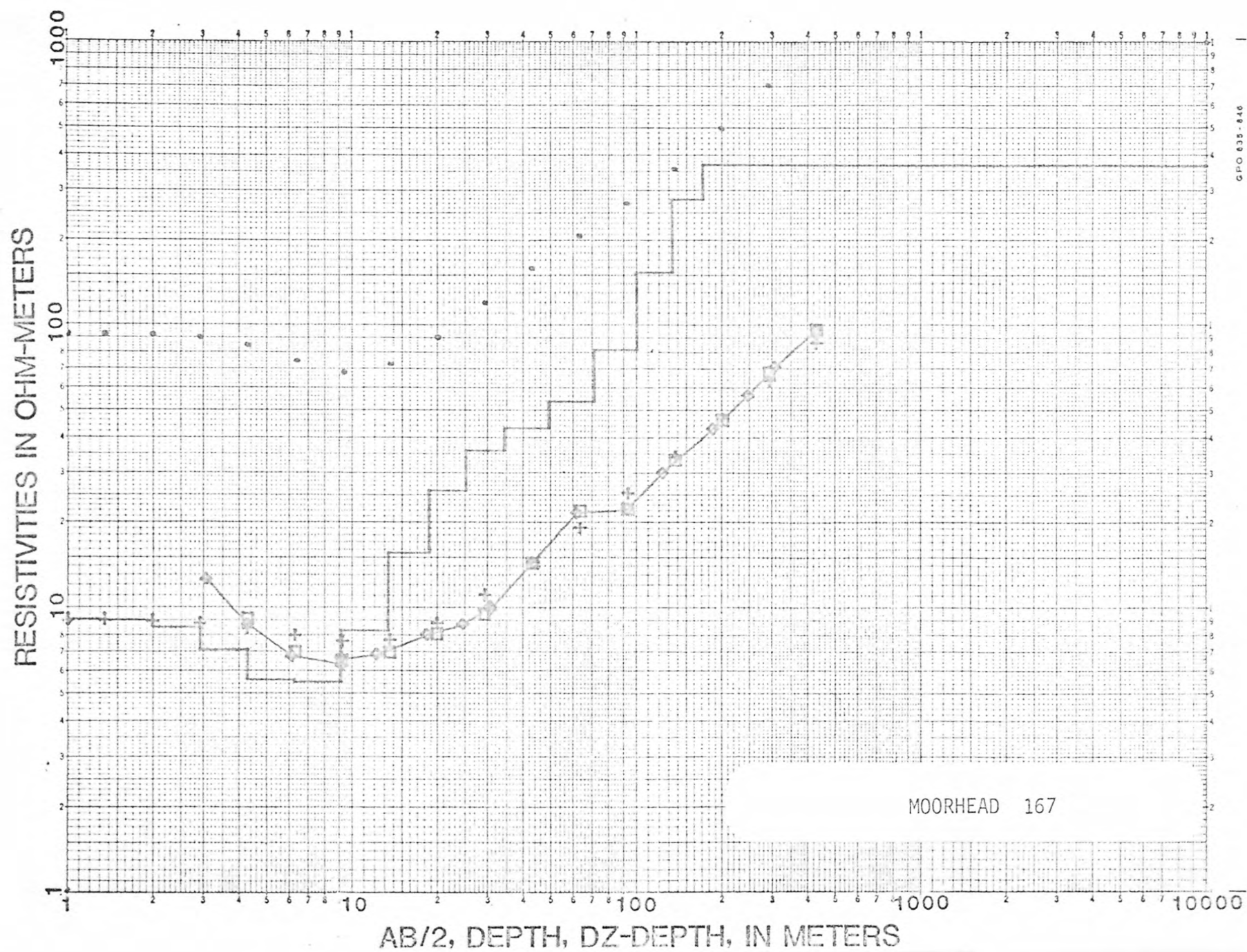


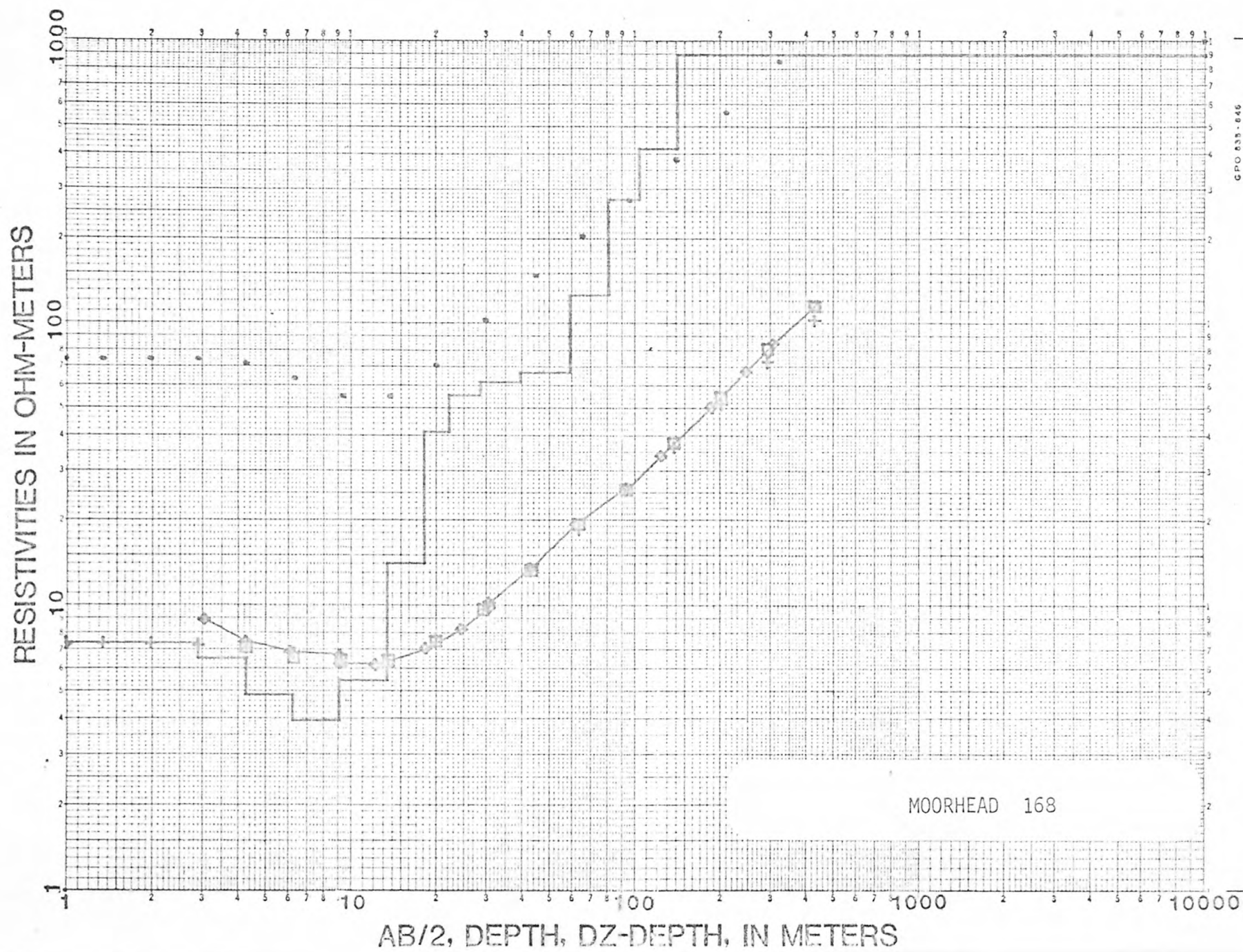


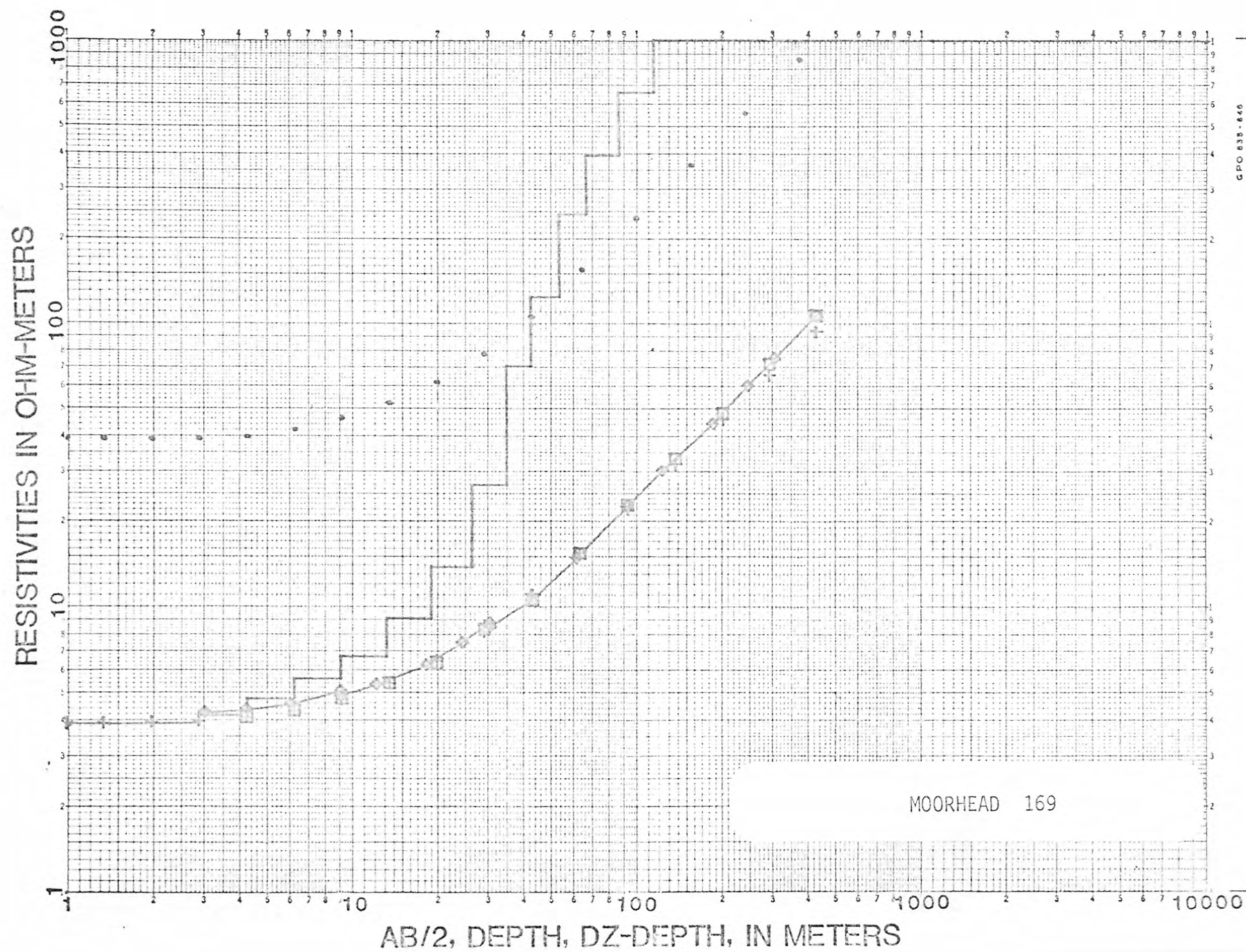


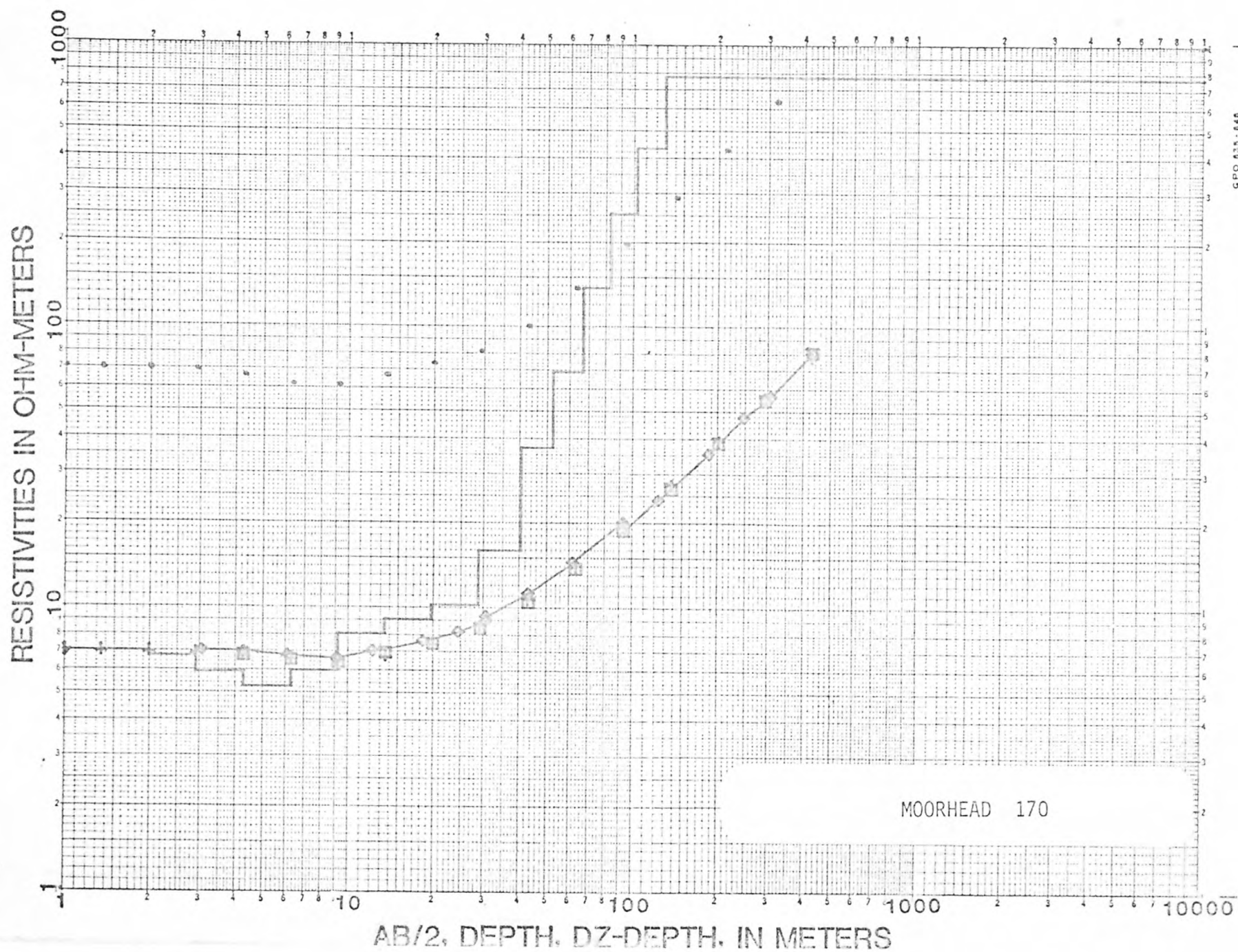




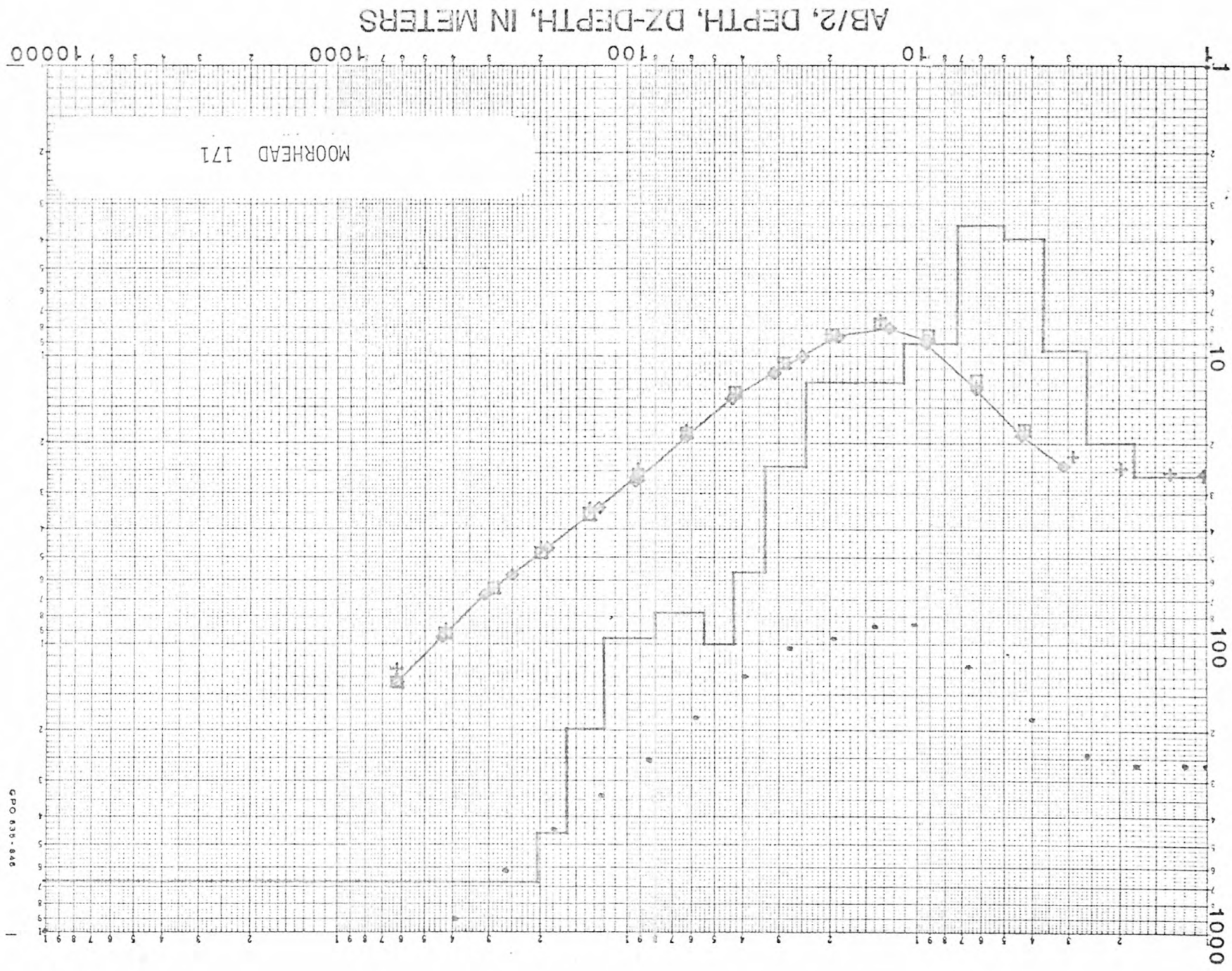


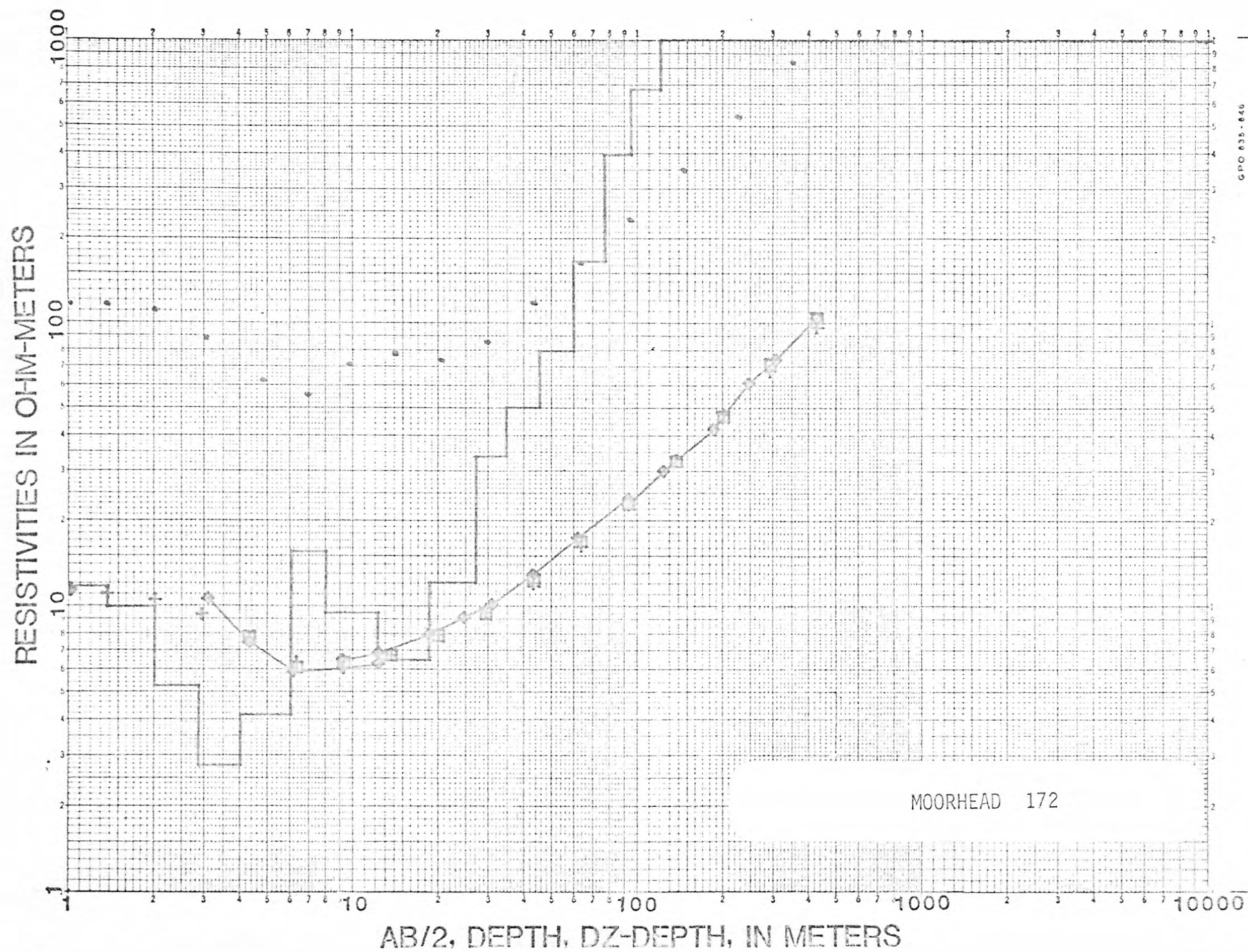


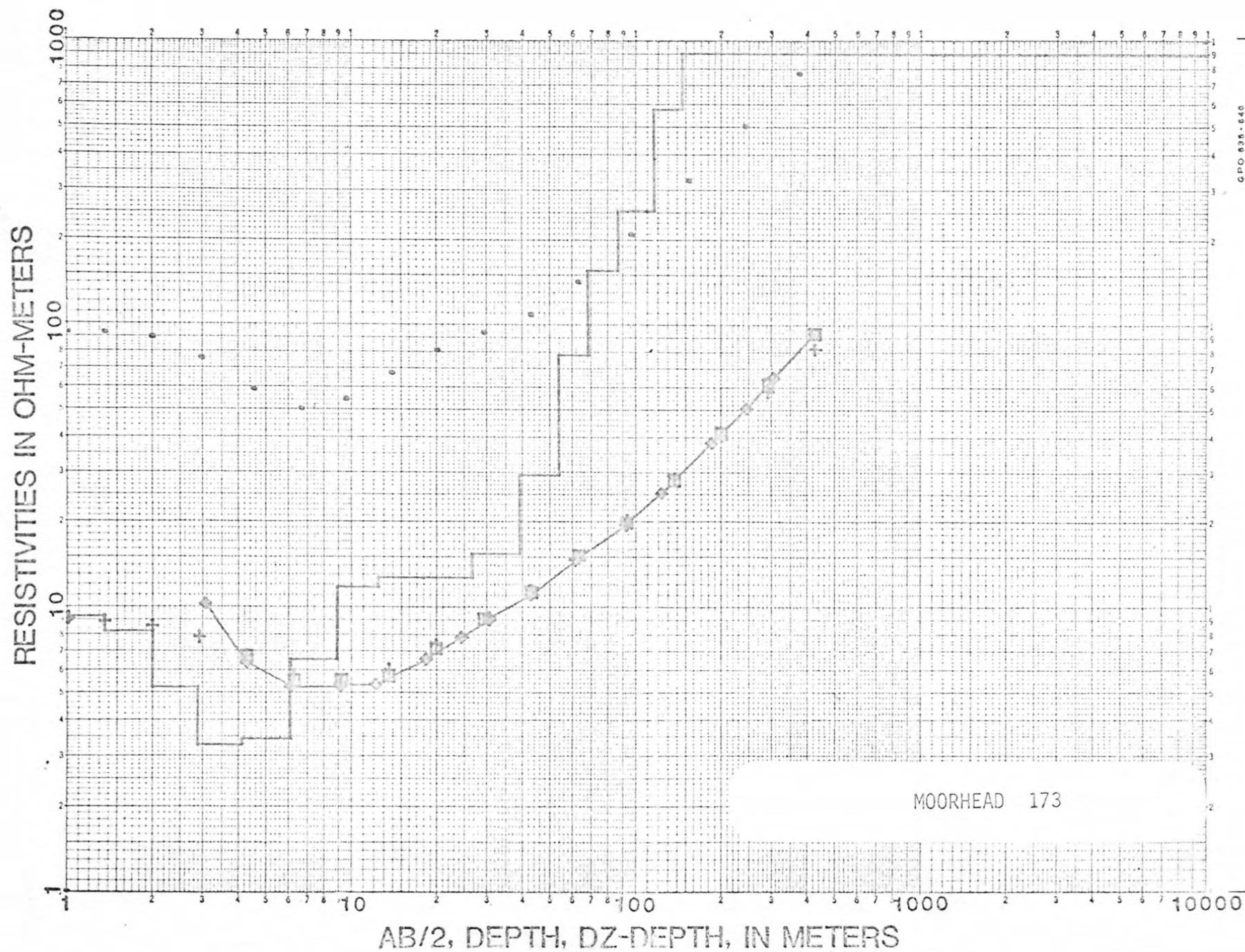


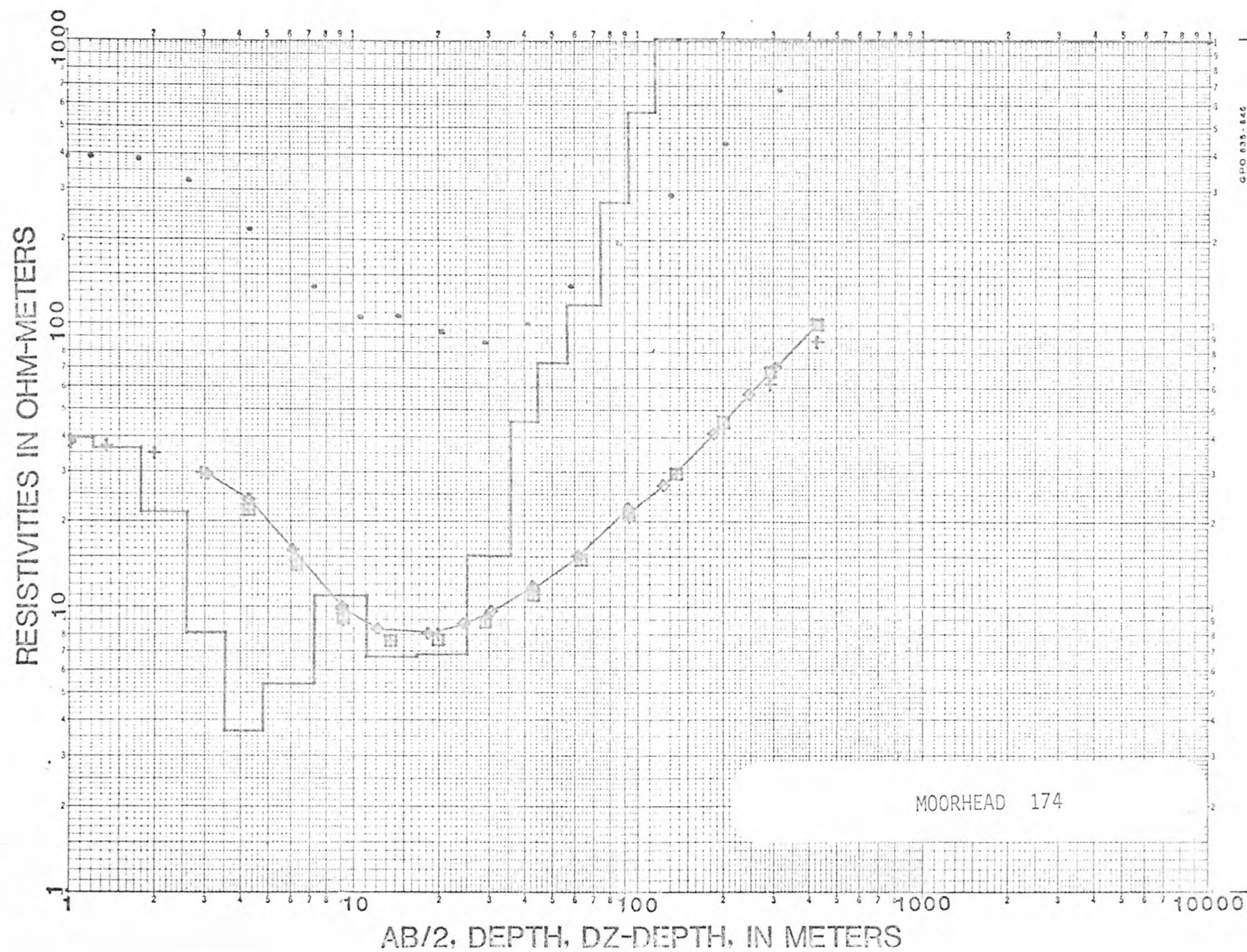


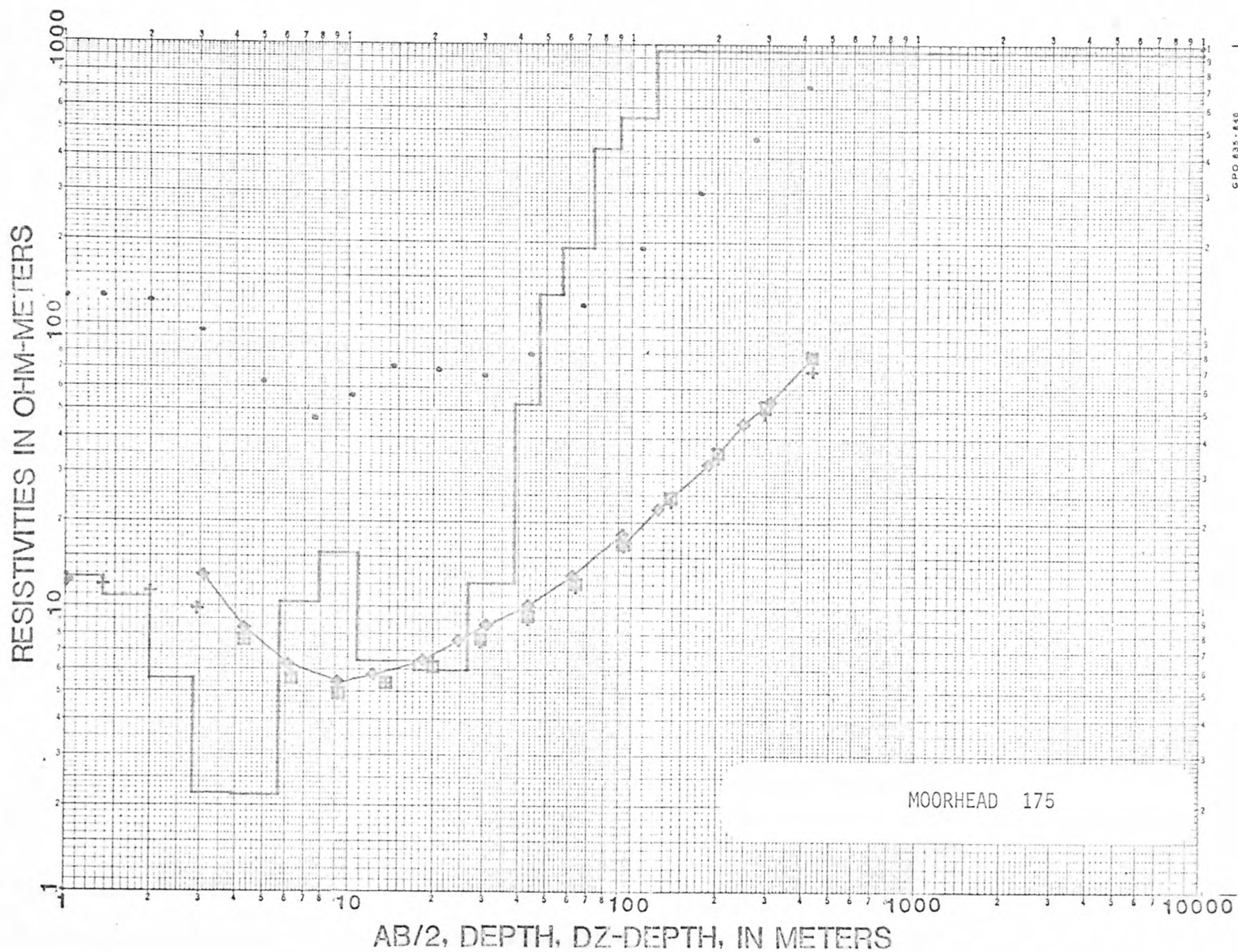
RESISTIVITIES IN OHM-METERS

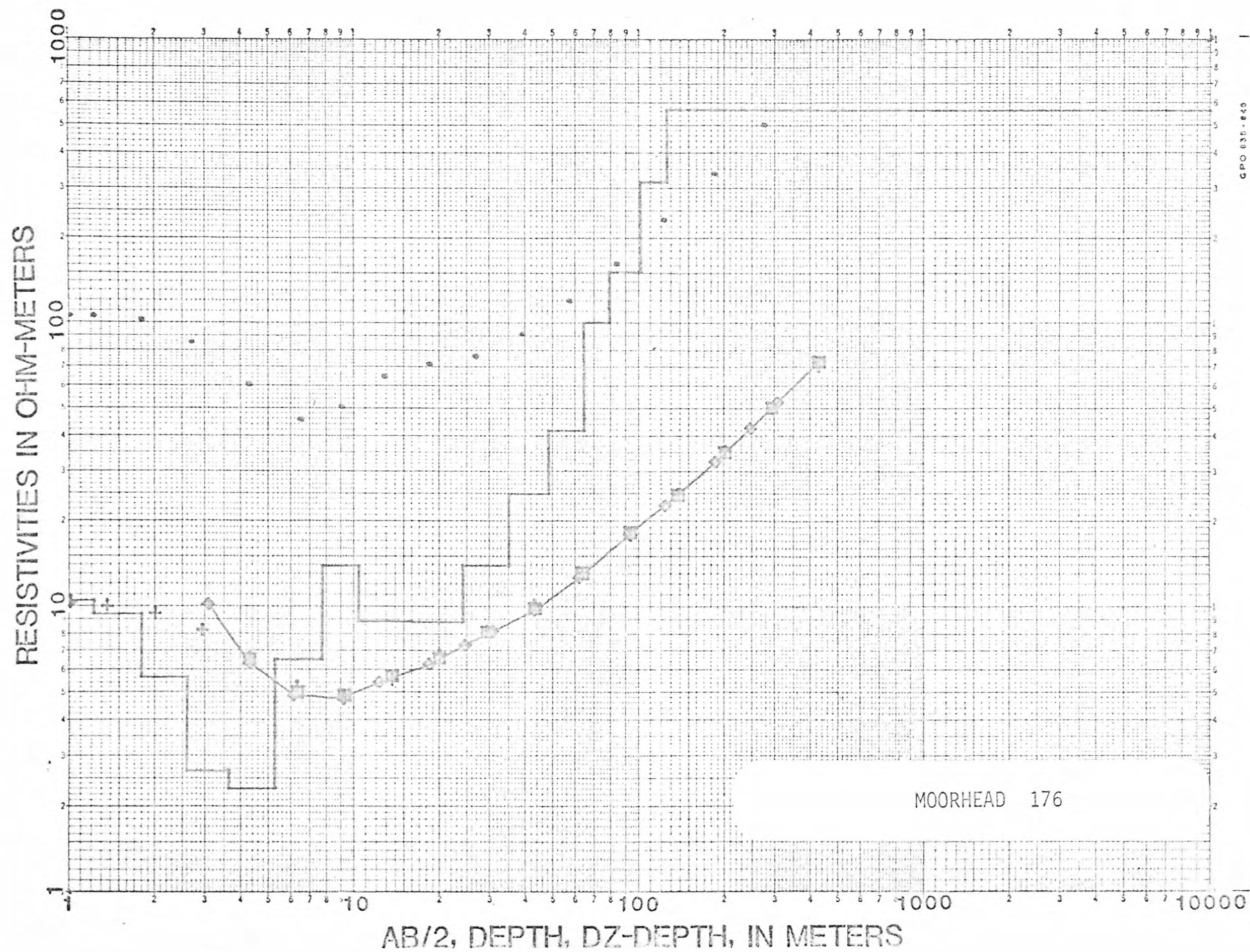


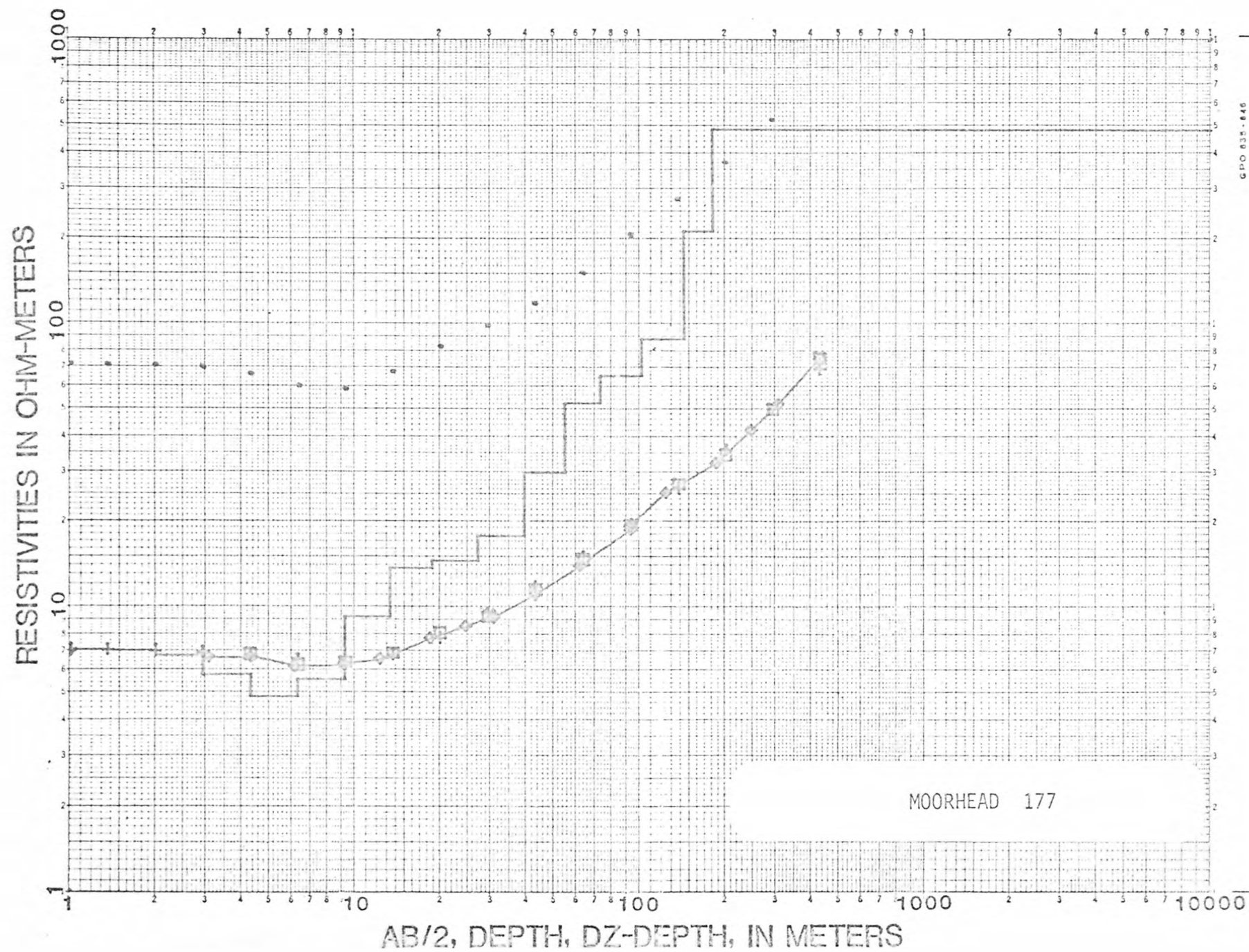


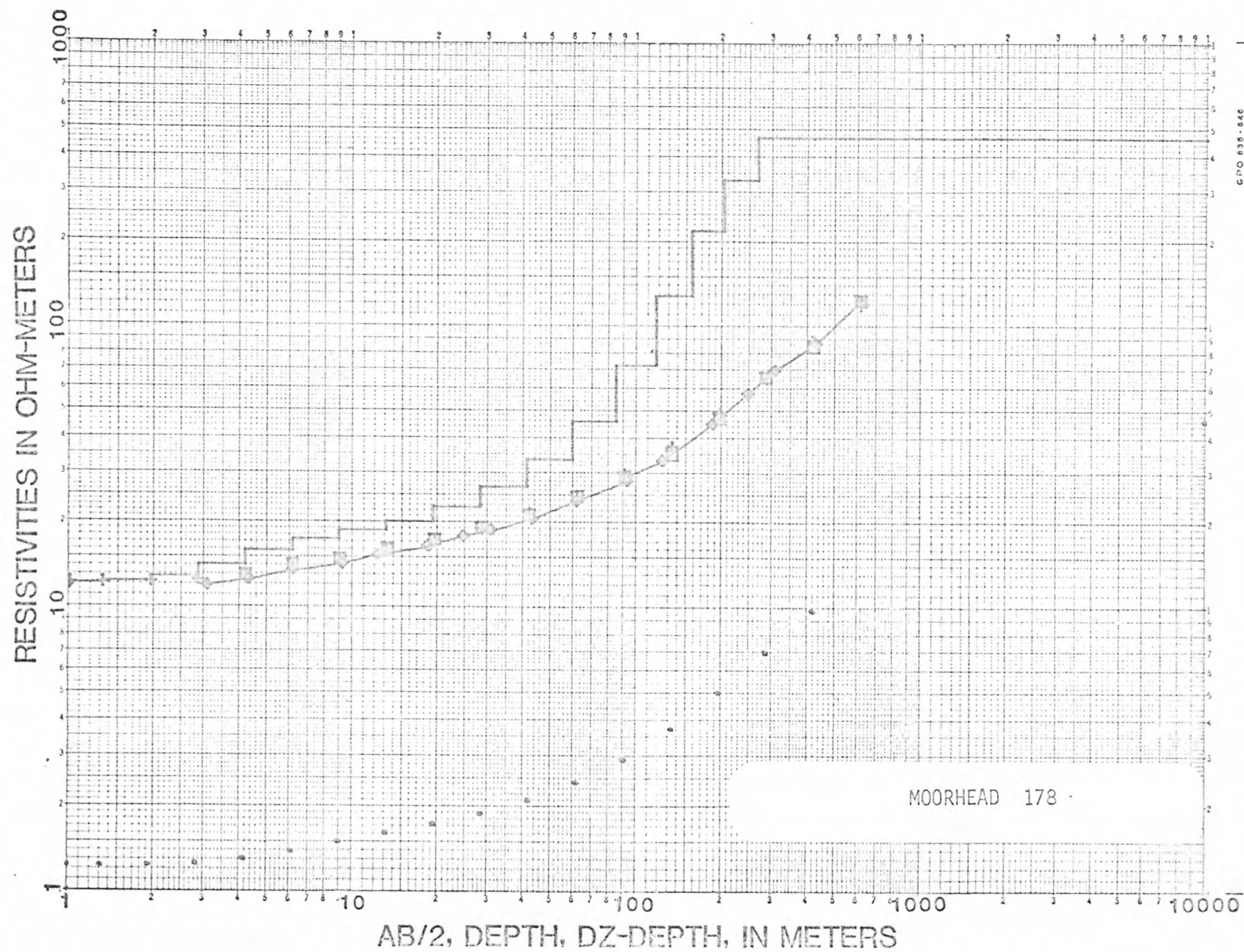


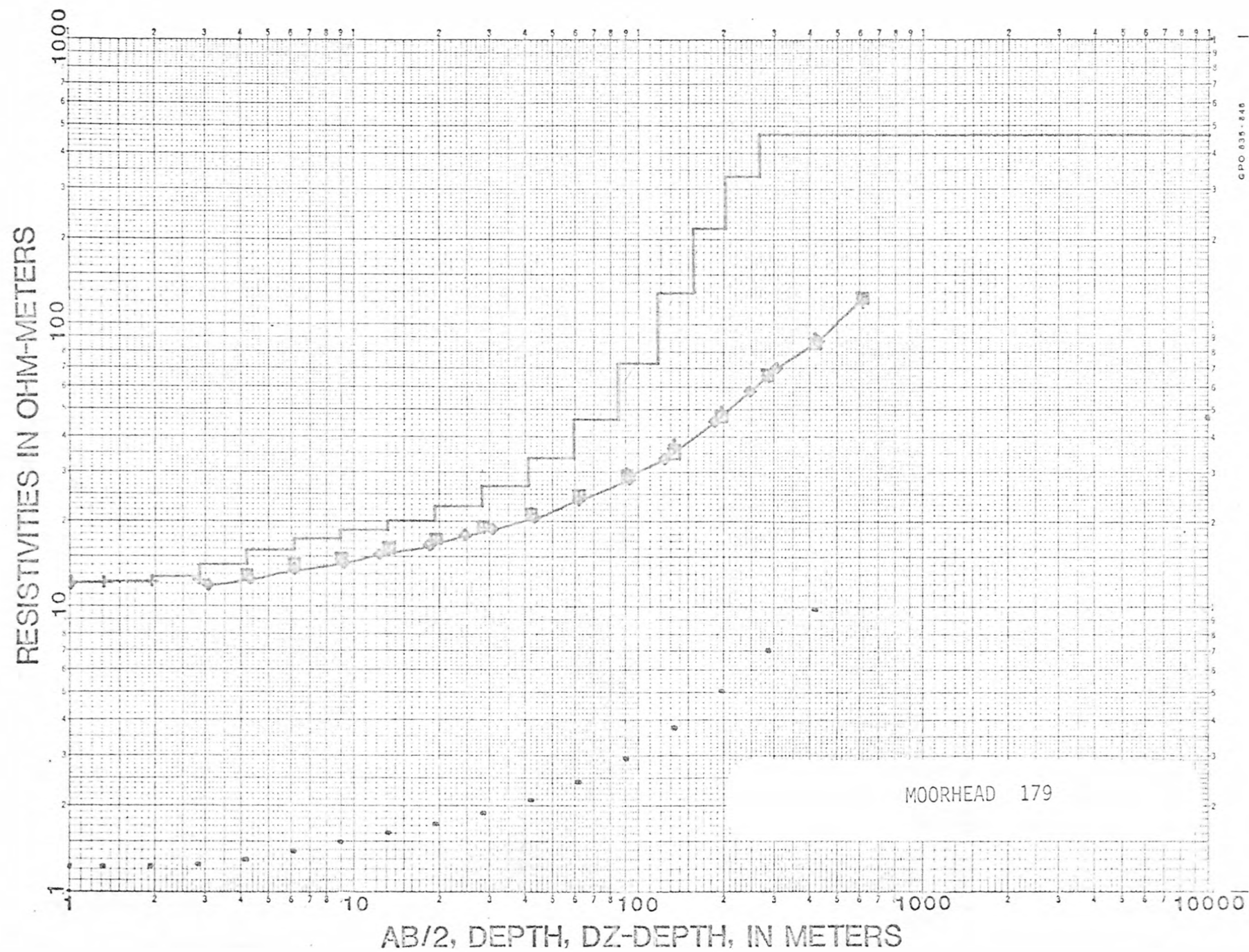


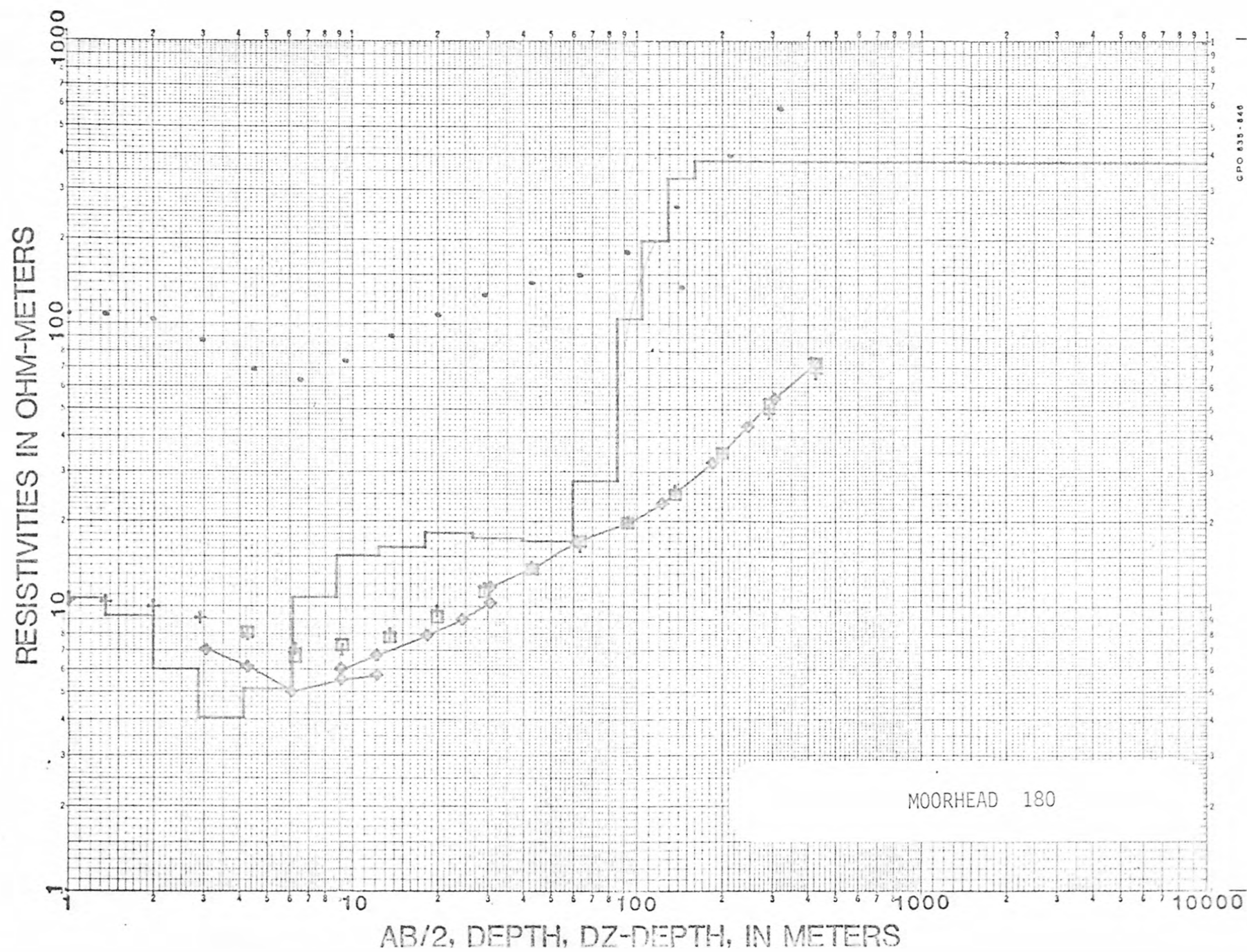


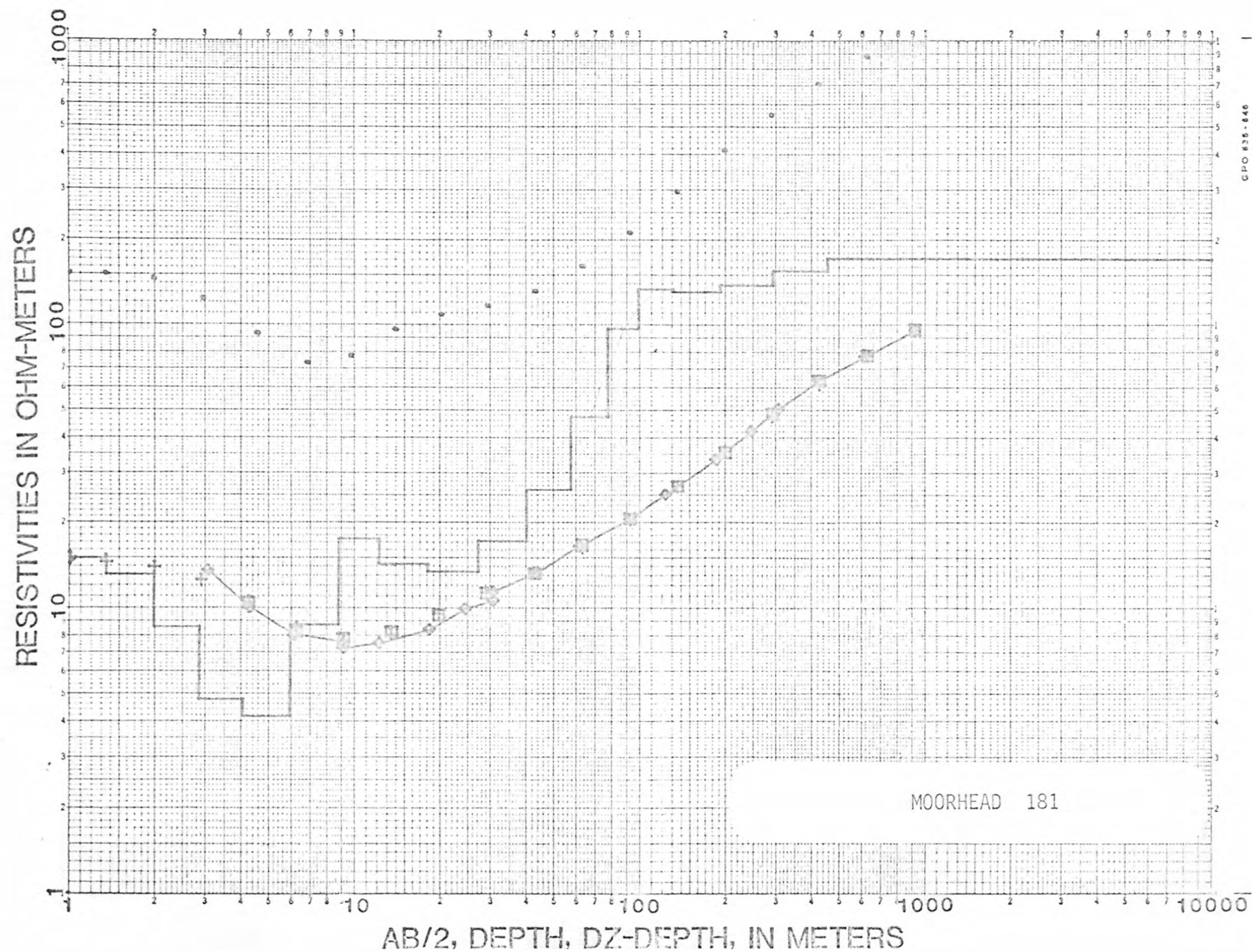


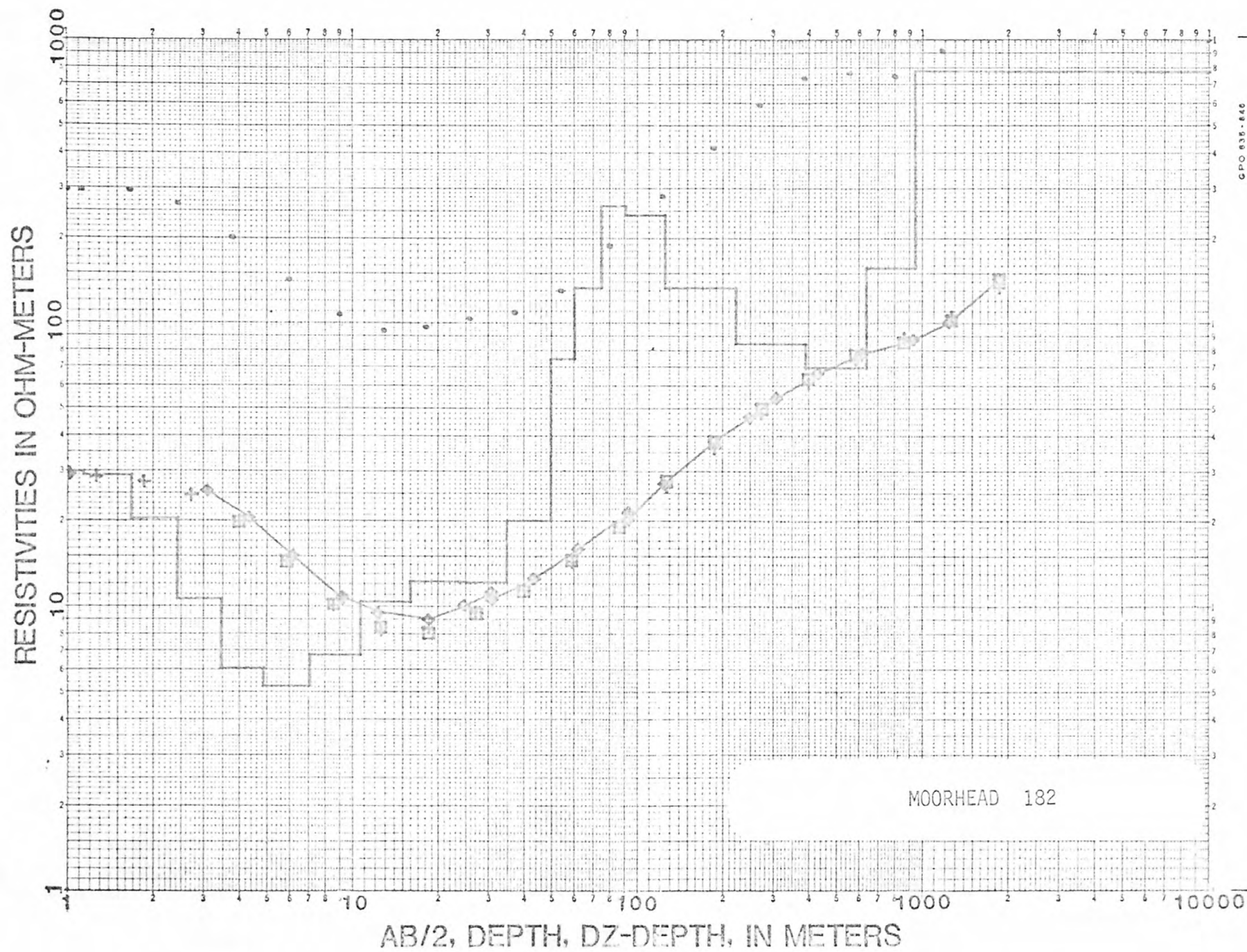


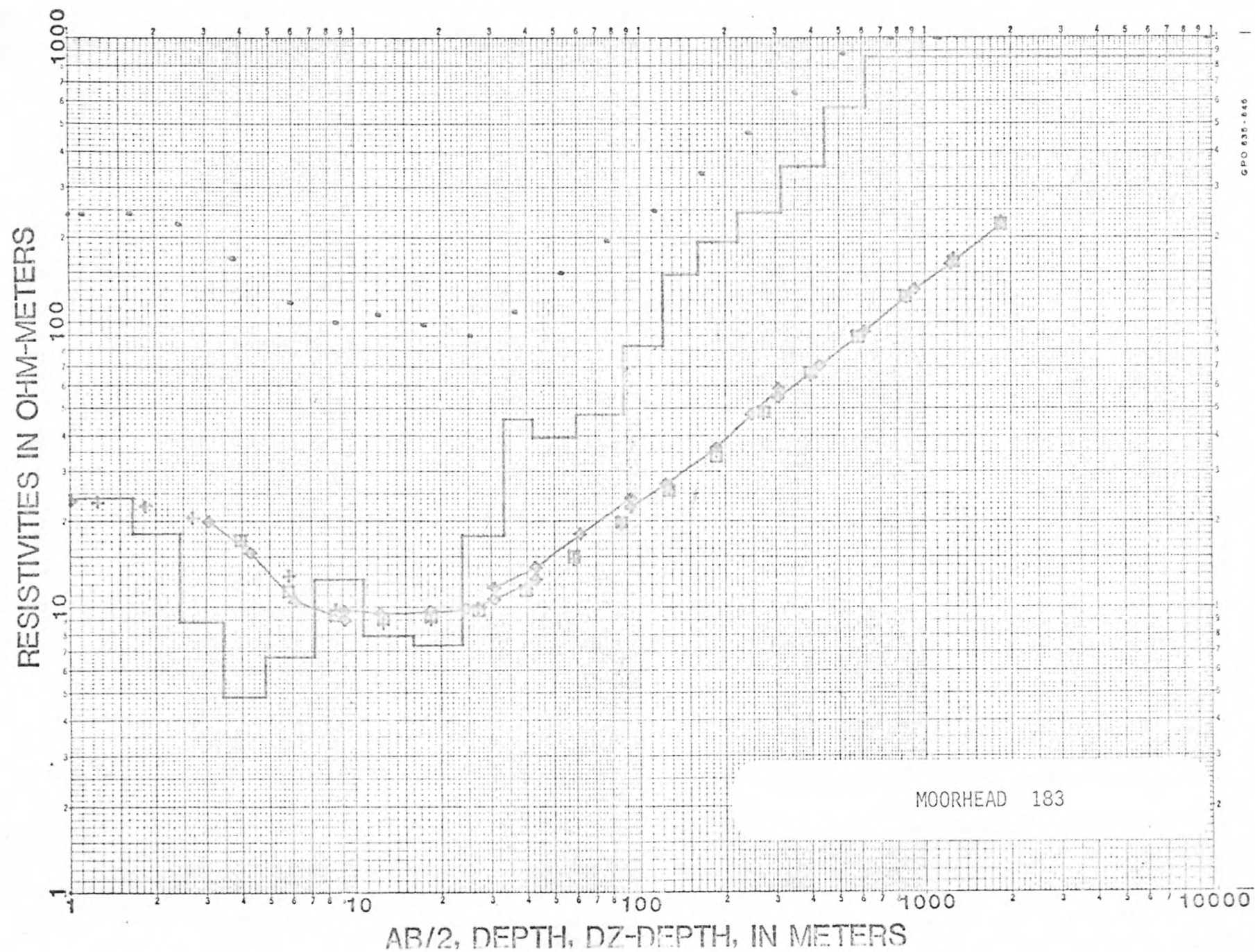


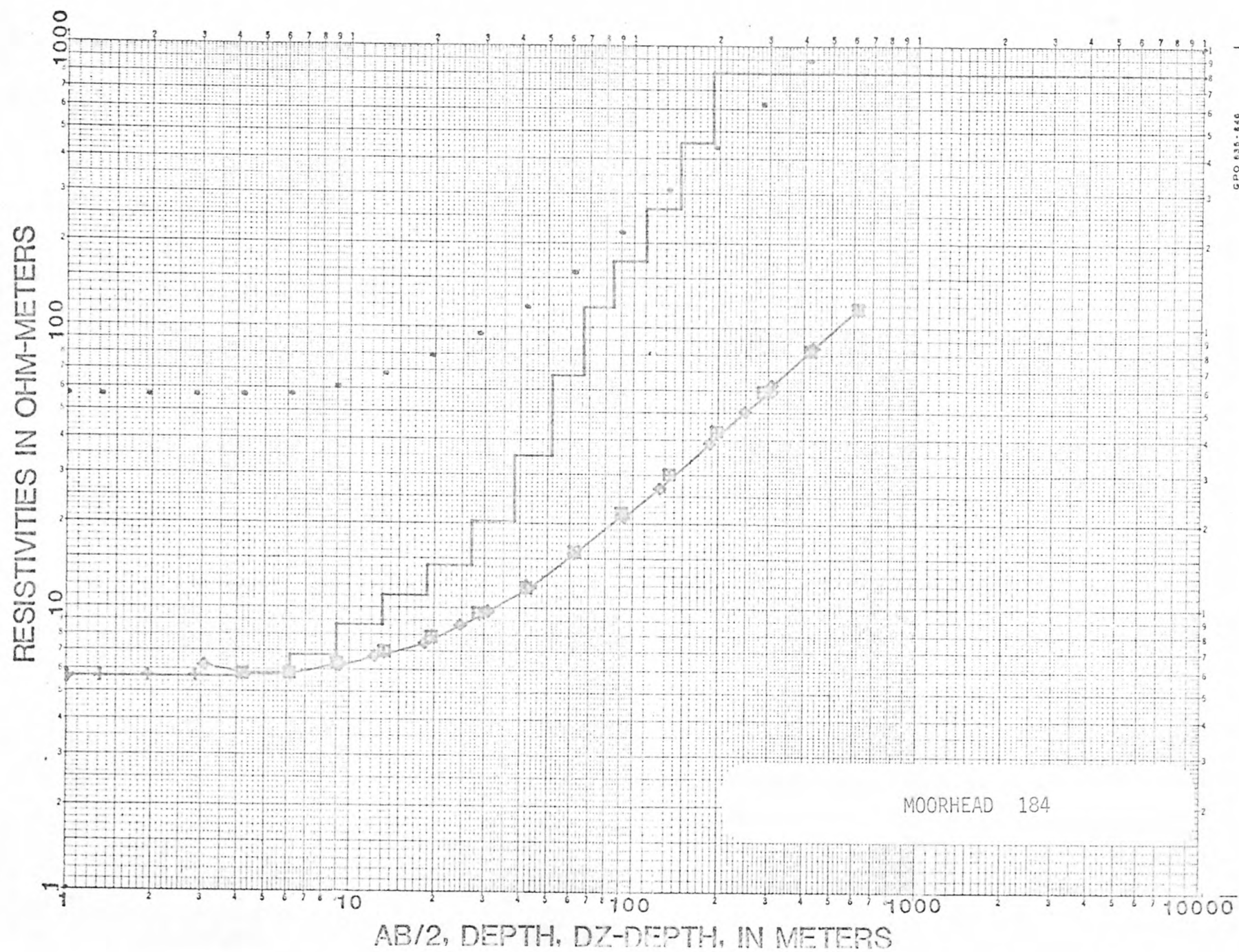


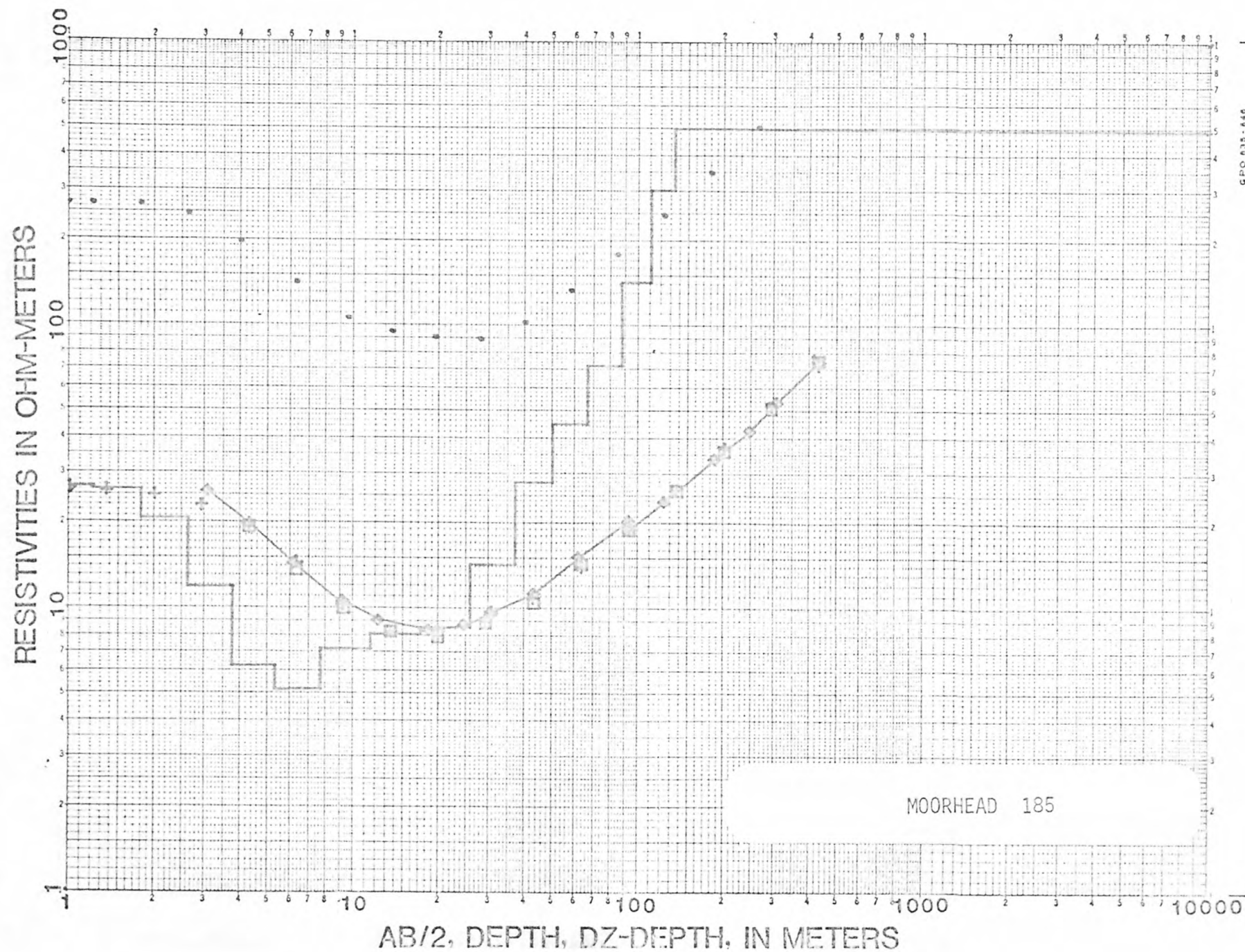


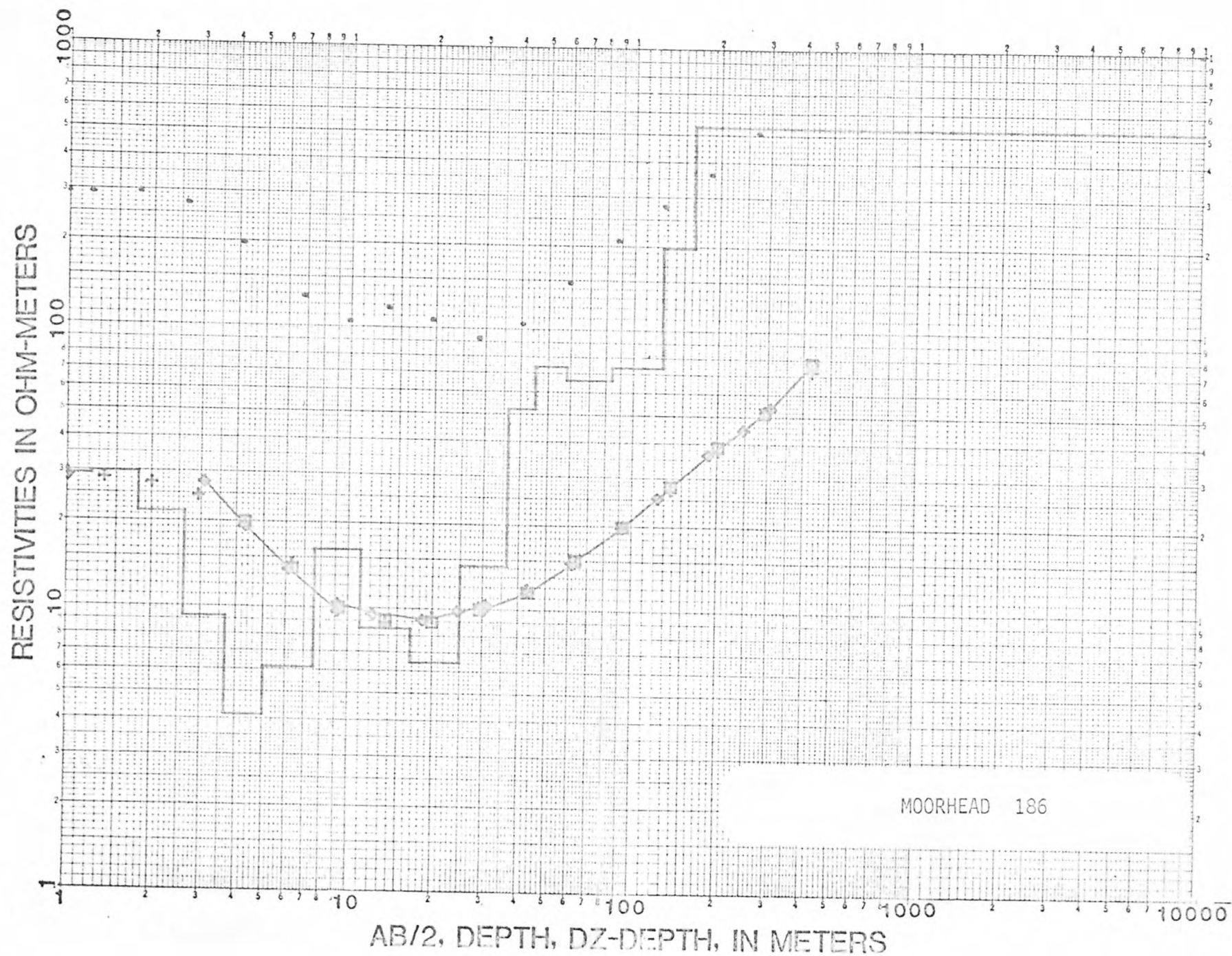


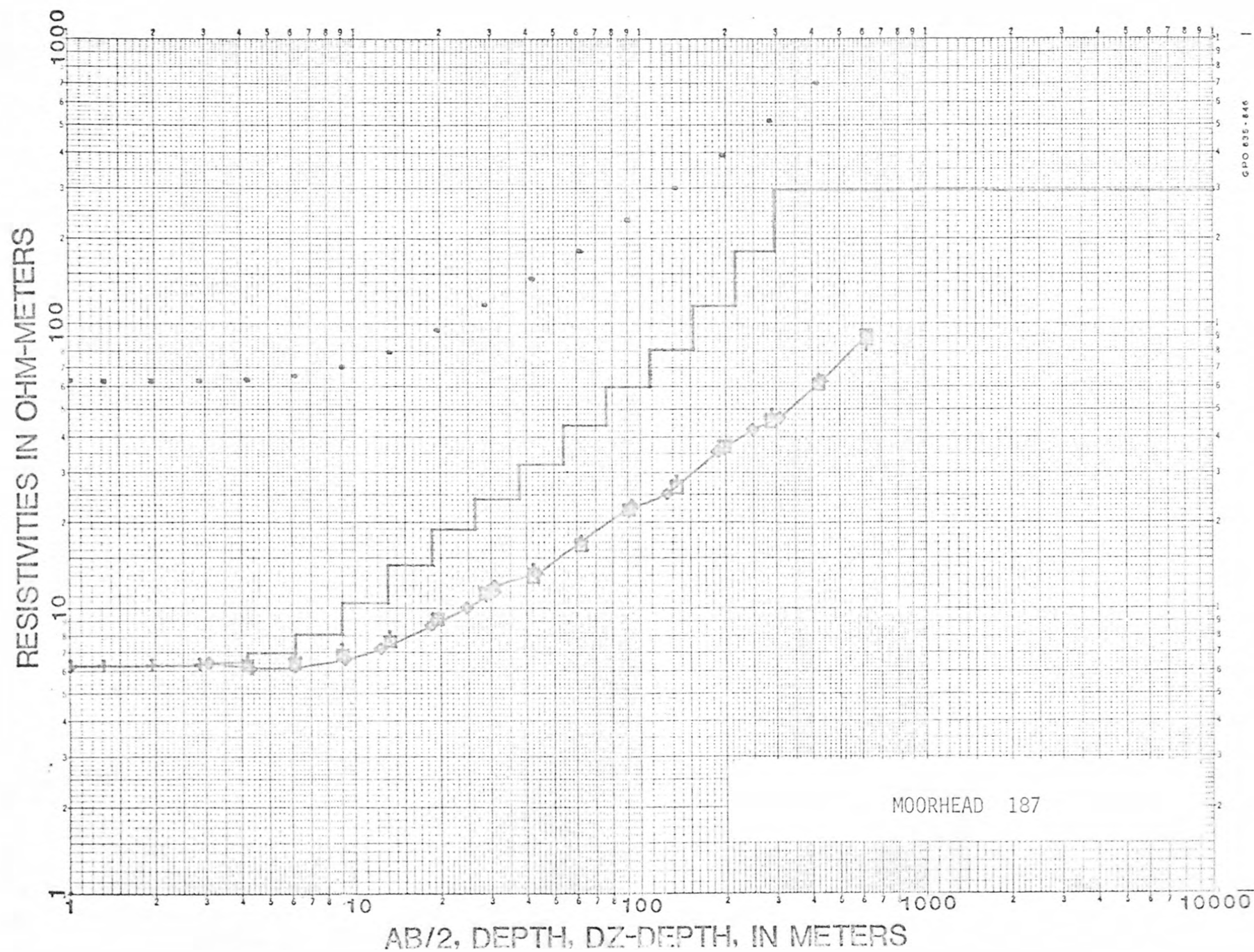




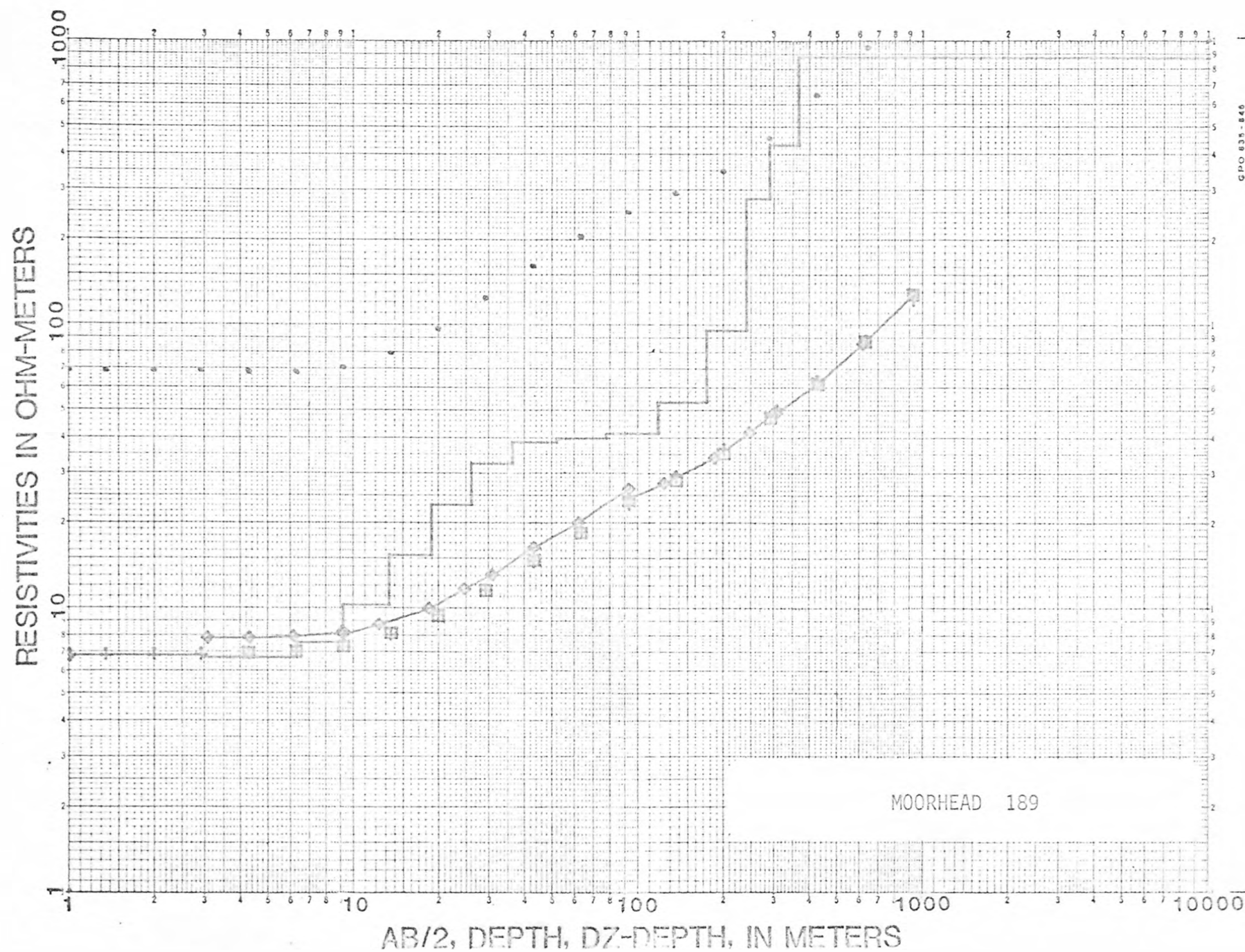


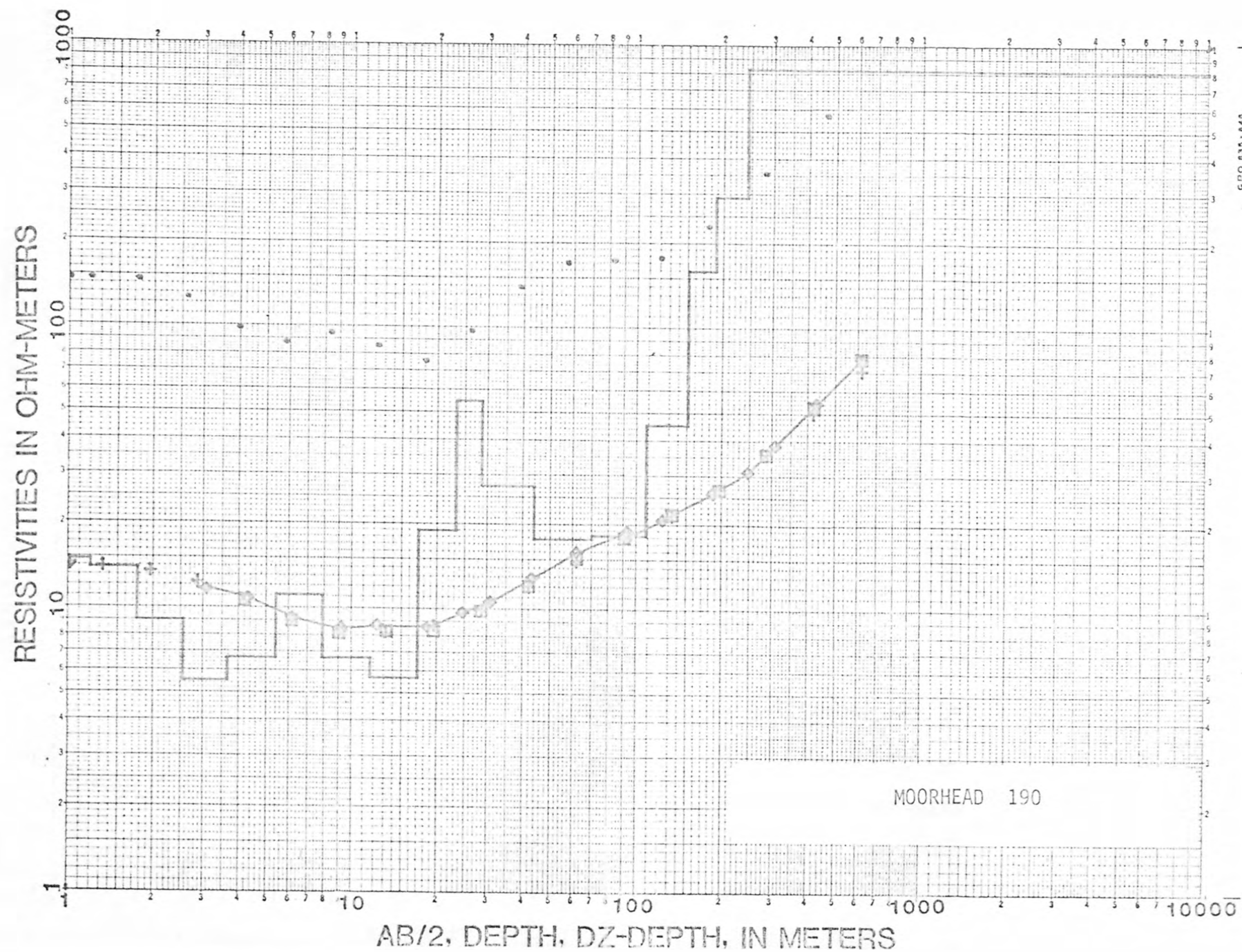


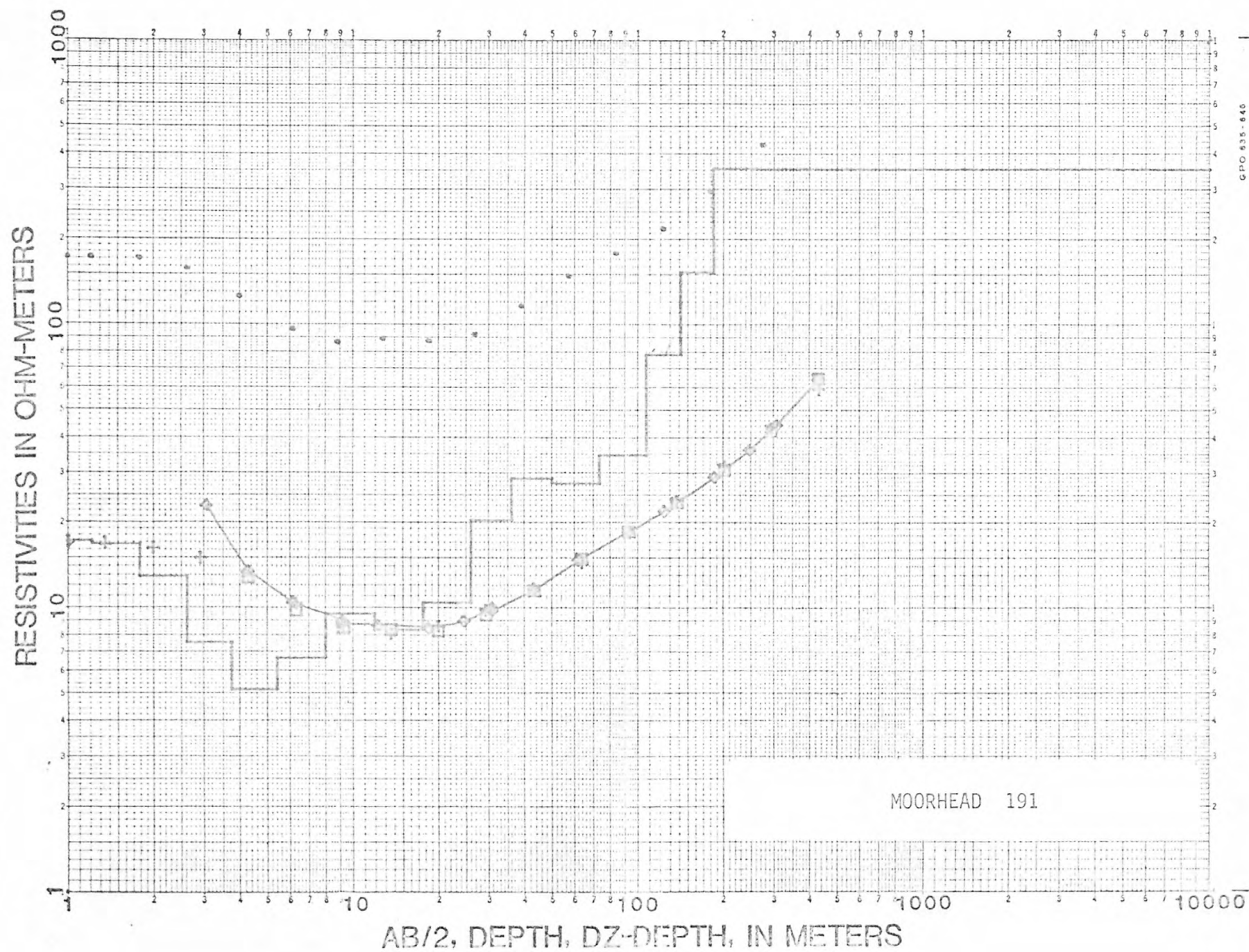


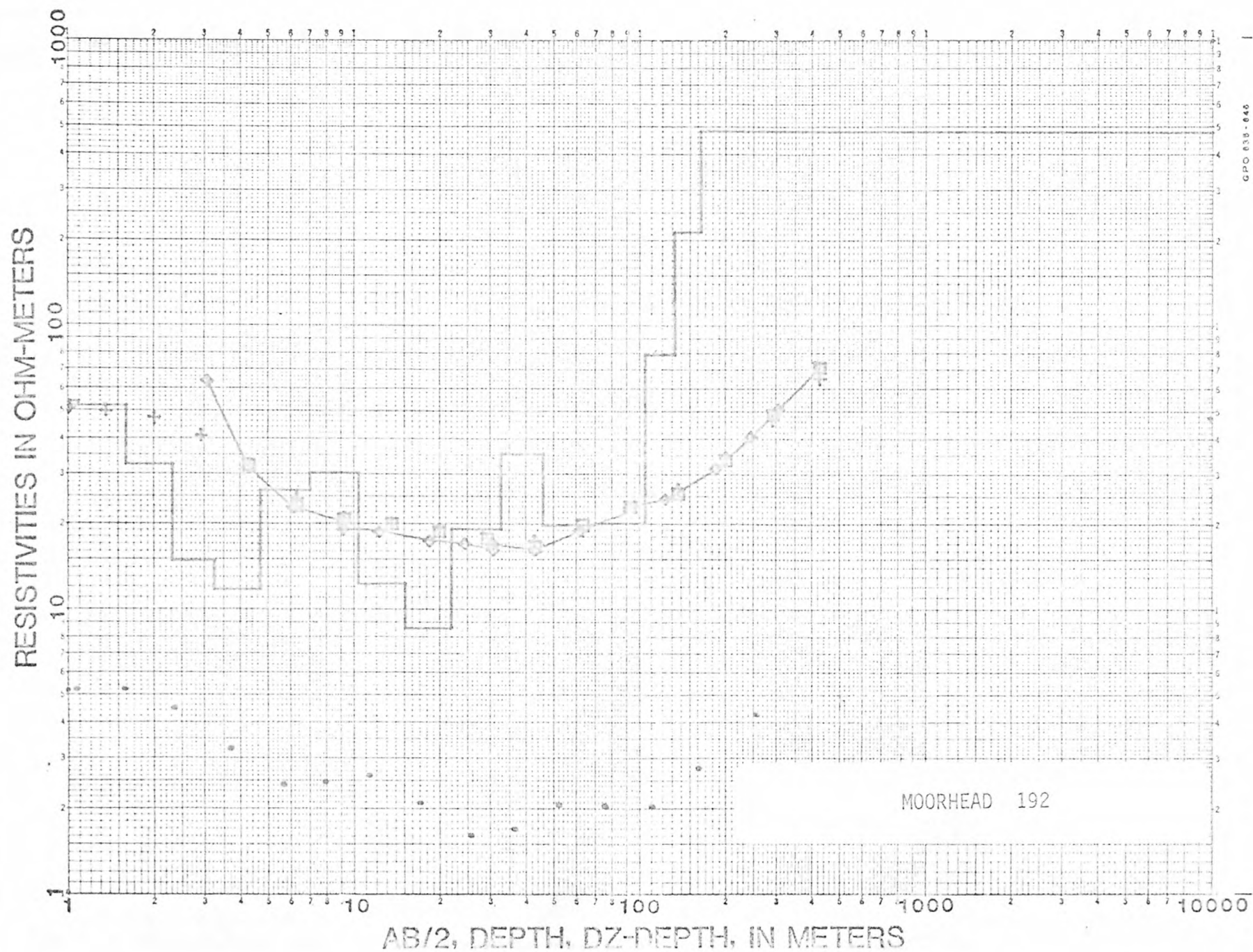














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