UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Hole-to-surface resistivity measurements at Salt Valley, Utah

by

Jeffrey J. Daniels and James H. Scott

Open-File Report 80-981

1980

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Abstract

Evaporites are an important potential medium for the storage of radioactive wastes. In order to ascertain the viability of a proposed waste isolation site, it is necessary to study its geology without extensive drilling that might destroy its structural integrity. Hole-to-surface and hole-to-hole geophysical measurements can be useful in supplementing geologic data obtained from a few drill holes and can be used to aid the interpretation of surface geophysical measurements. The study presented in this paper was conducted at Salt Valley, Utah to test the feasibility of using hole-to-surface direct-current resistivity measurements to detect geologic inhomogeneities in evaporites. These measurements show the following:

(1) It is feasible to make hole-to-surface resistivity measurements over evaporites. However, near-surface steel casing can make it difficult to quantitatively analyze the field data with present interpretation techniques. Future investigations should include theoretical studies to solve interpretation problems when steel casing is in the hole and the mud is a high-conductivity brine.

(2) A comparison of measurements made from the three different source drill holes shows that the halite acts as an electrical insulator and most of the current emitted from the source is contained in the caprock.

(3) A comparison of measurements made parallel and perpendicular to the valley walls shows that there are more variations in the halite-caprock interface perpendicular than parallel to the axis of the Salt Valley anticline.

(4) Structurally complex interbeds within the salt may cause differences in the current distribution measured at the surface from current sources buried at different depths.

(5) Total field mapping would be more useful than the single-component data that were collected in this study.

Introduction

Hole-to-surface direct-current resistivity measurements are made by placing a pole or bipole source down a borehole and measuring the resulting distribution of the electrical potential on the surface. Theoretical studies of surface potentials due to in-hole current sources have been described by Alfano (1962), Merkel (1971), Merkel and Alexander (1971), Snyder and Merkel (1973), and Daniels (1977, 1978).

The hole-to-surface electrode configuration is shown in figure 1. Current was input through the in-hole electrodes ("A" and "B"). The current source consisted of a square-wave transmitter that was driven by a 45 kilowatt, 400 hz, generator. The level of the input current for each of the drill-hole sources was approximately 10 amperes. Steel casing in each of the three drill holes causes a distribution of current for the upper electrode ("A"), rather than an ideal point source of current. This factor makes it

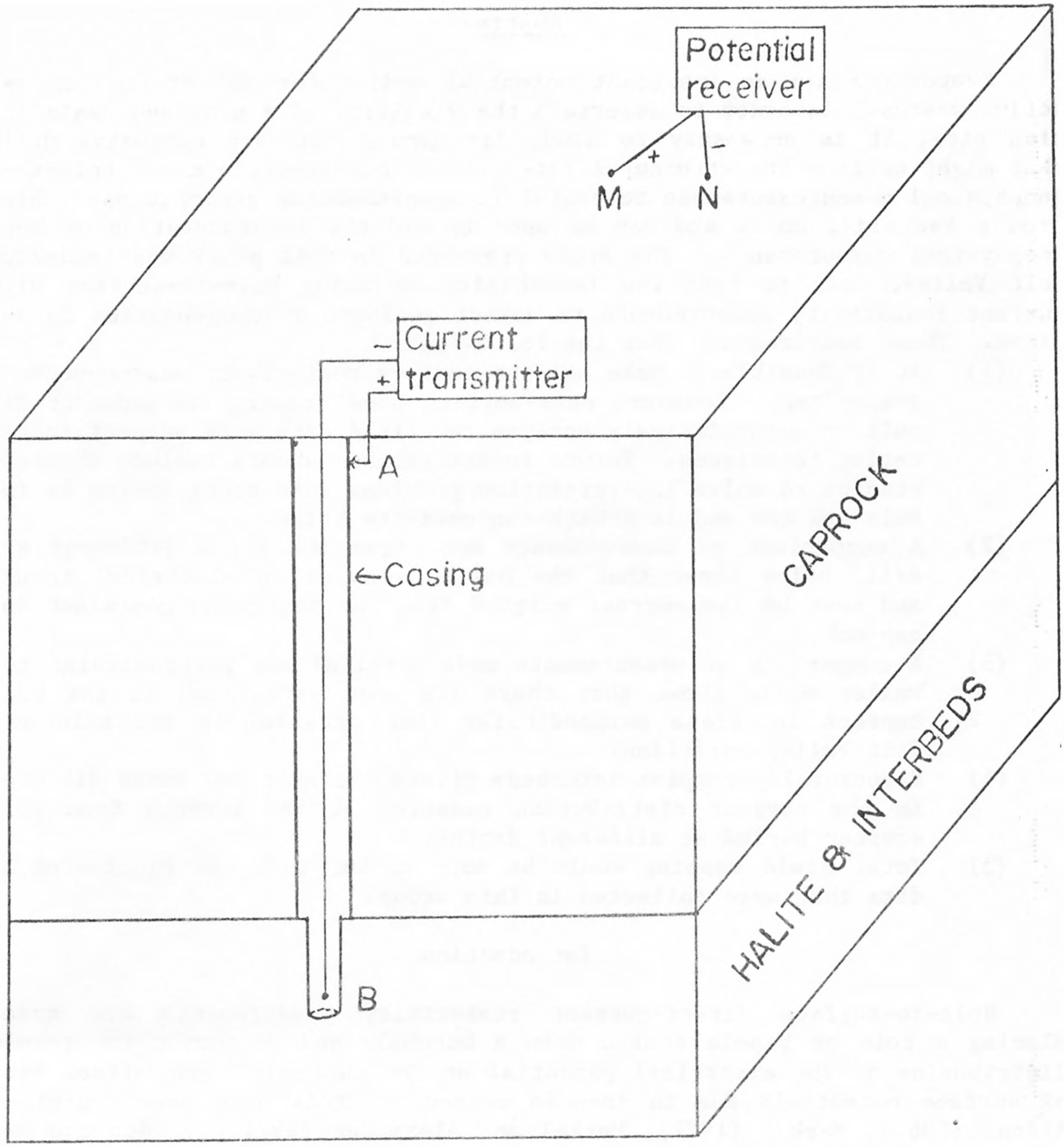

Figure 1.--Hole-to-surface electroconfiguration used at Salt Valley.

difficult to calculate theoretical models for the Salt Valley data. Also, the low-resistivity brine probably causes most of the current to be confined to the mud column. Potential-difference measurements were made on the surface between the "M" and "N" electrodes, using an analog chart recorder. These surface measurements were made along profiles (shown in figure 2) at 15.24 m intervals using an "M"-"N" electrode spacing of 15.24 m. The apparent resistivity was calculated from the field data, using the following equation:

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

where

ρ_a is the apparent resistivity (in ohm-m),
AM is the distance between the A-current electrode and the M-potential electrode,
AN is the distance between the A-current electrode and the N-potential electrode,
BM is the distance between the B-current electrode and the M-potential electrode,
BN is the distance between the B-current electrode and the N-potential electrode,
I is the input current (in amperes),
and U_M-U_N is the potential difference (in volts) measured by the receiver between the M and N electrodes.

The apparent-resistivity profiles with the current source in drill holes SV1, SV2, and SV3 are shown in appendices A, B, and C, respectively.

Qualitative Interpretation of Salt Valley Hole-to-Surface Resistivity Data

The length of the casing in each of the three drill holes (approximately 200 m) and the low-resistivity brine in the hole makes it impossible to accurately model the field data with theoretical models that are presently available. Therefore, the goals of this study are: (a) to test the feasibility of making hole-to-surface resistivity measurements in evaporites, (b) to compare measurements made from the three different source drill holes, and (c) to compare measurements made at two different source depths in drill hole SV3. The results of this qualitative analysis can be used to design survey parameters for future hole-to-surface resistivity studies.

Figures 3 through 6 show data from several profiles whose positions are indicated in figure 2. Normally, in DC resistivity surveys the depth of investigation increases as the source-receiver separation is increased. However, this is not strictly true in the case of Salt Valley where a conductive caprock overlies high-resistivity halite that contains conductive interbeds. The halite acts as an electrical insulator and most of the current emitted from the source is contained in the caprock. It is possible that electrical current could be conducted through the interbeds as well as through the caprock. This will occur if one of the source-current electrodes is in proximity to one of the conductive interbed sequences. Conduction through the brine and the interbed will be increased as the electrode is placed closer to the interbed.

Figure 3 shows the measurements for profile line 2S for each of the source drill holes. Except for a few points for the profile with the source

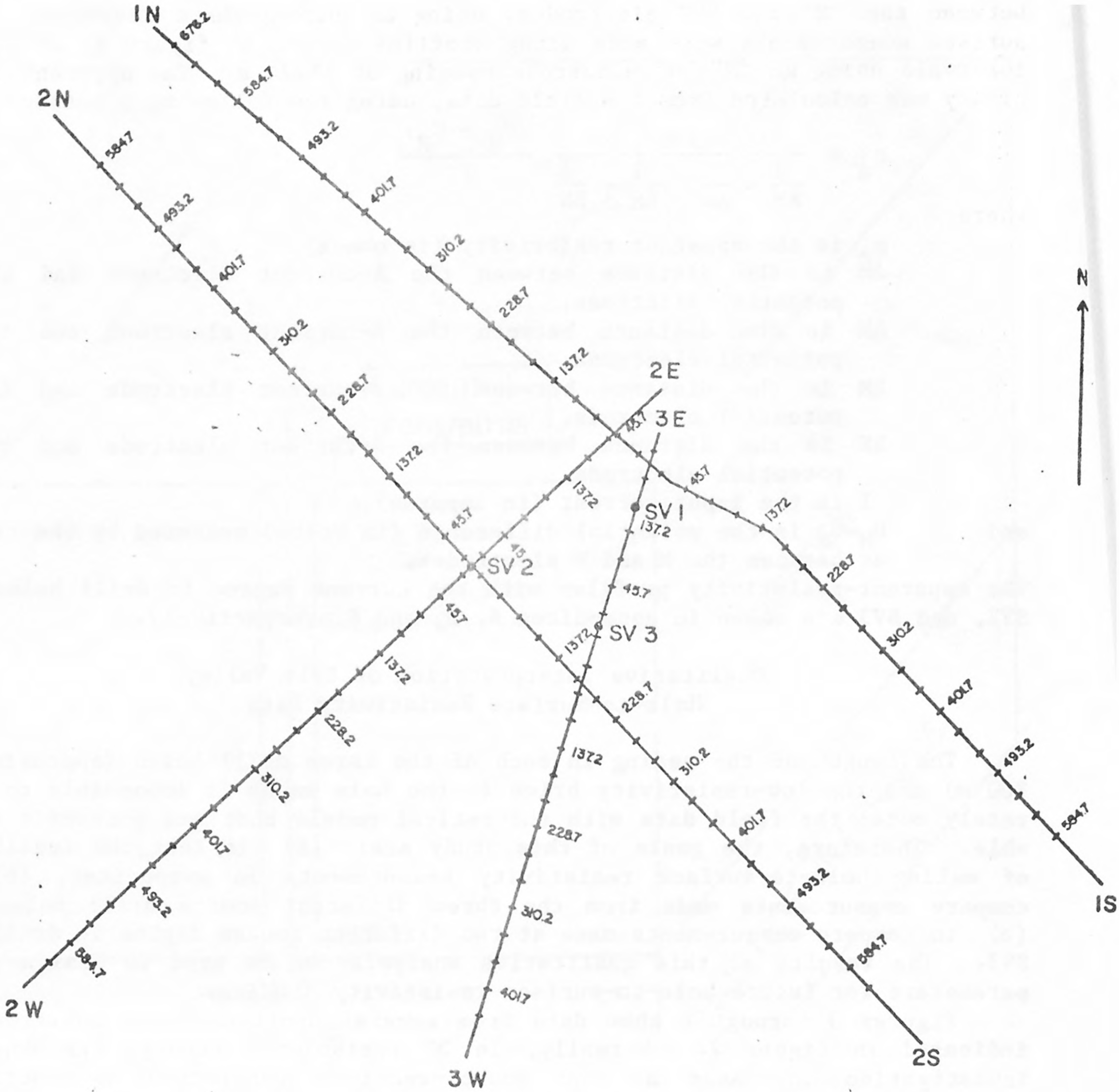

Figure 2.--Location of the receiver lines (1S, 2S, 2E, 3E, 2W, 3W, 1N, and 2N) with respect to the source holes SV1, SV2, and SV3.

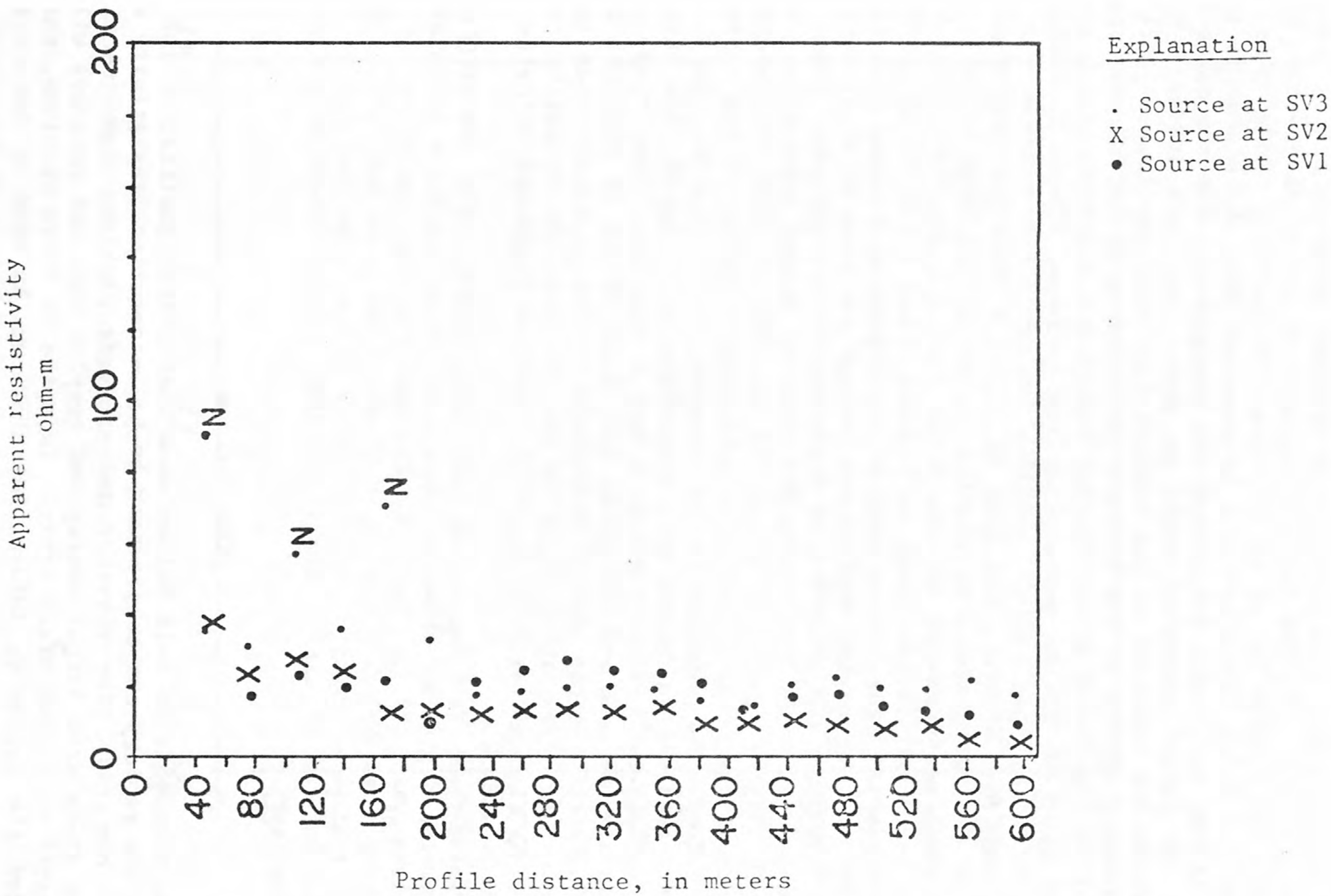

Figure 3.--Comparison of hole-to-surface data (receiver line 2S) with source in drill holes SV1, SV2, and SV3. The current electrodes were at the surface, next to the casing, (A-electrode), and at a depth of 305 m (B-electrode). Measurements marked with a "z" probably are affected by surface interference.

in drill hole SV3, there is only a small difference in the apparent resistivity values for the three sources. The large deviation, for small profile distances, in the profile for source SV3 can be attributed to near-surface cultural noise around drill hole SV3. Other possible reasons for the differences between the three profiles include the following: (1) The distance between the source drill hole and a given distance value on line 2S is different for each profile. (2) The radial component of the total electric field is measured when the source is in drill holes SV2 and SV3, while a non-radial component of the total electric-field is measured when the source is in drill hole SV1. If the earth near the source was homogeneous, the component perpendicular to the radial component would be zero. The data indicate that the electric fields are confined to the caprock (for this particular profile) and the heterogeneous nature of the caprock (combined with the line-source electric current excitation from the casing) causes a multi-directional distribution of the electric fields measured at the surface. These conclusions are further supported by the "radial" profiles for drill-hole sources SV1 and SV2 shown in figure 4. However, the data in figure 4 show the effect of directionality for the measurements at profile distances less than 160 m.

The profile measurements for the lines that are perpendicular (line 2W) and oblique (line 3W) to the lines in figures 3 and 4 are shown in figure 5. The two profiles in figure 5 are similar for distances greater than 140 m and less than 400 m. The higher resistivity values for line 2W at distances less than 140 m indicates the presence of high-resistivity material (such as consolidated dolomite) near drill hole SV2 that is absent near drill hole SV3. Similarly, the high-resistivity values for line 3W, at distances greater than 400 m, indicates the presence of high-resistivity material in the caprock. An outcrop of dolomite is adjacent to the termination of line 3W, and the higher resistivity values may be caused by a subsurface extension of this outcrop. A comparison of figure 5 with figures 3 and 4 indicates that there is more variation in the caprock resistivities for lines 2W and 3W than for lines 1S and 2S. These differences may be attributed to the presence of an irregular halite-caprock interface along lines 2W and 3W, and (or) it may be caused by an increase in high-resistivity material (such as foundered dolomite blocks) along lines 2W and 3W.

The measurement response along the same profile for two different B-electrode source depths is shown in figure 6. These profiles are similar for distances less than 280 m. However, the two profiles are different at distances greater than 280 m. Two interbed sequences were intersected in drill hole SV3 in the depth interval from 305 m to 518 m. The differences in these profiles may be the result of changes in the current distribution caused by these interbeds.

Conclusions

The measurements at Salt Valley show that useful qualitative information concerning the geology can be provided by hole-to-surface resistivity measurements in evaporites. The physical and geologic problems encountered in the Salt Valley study area (steel casing and complex interbed geology) will probably be absent in future study areas. In spite of these problems, this study has provided the following information that can be used in future studies: (1) the heterogeneous nature of the caprock, combined with line-source electric field excitation from the casing causes a multi-directional distribution

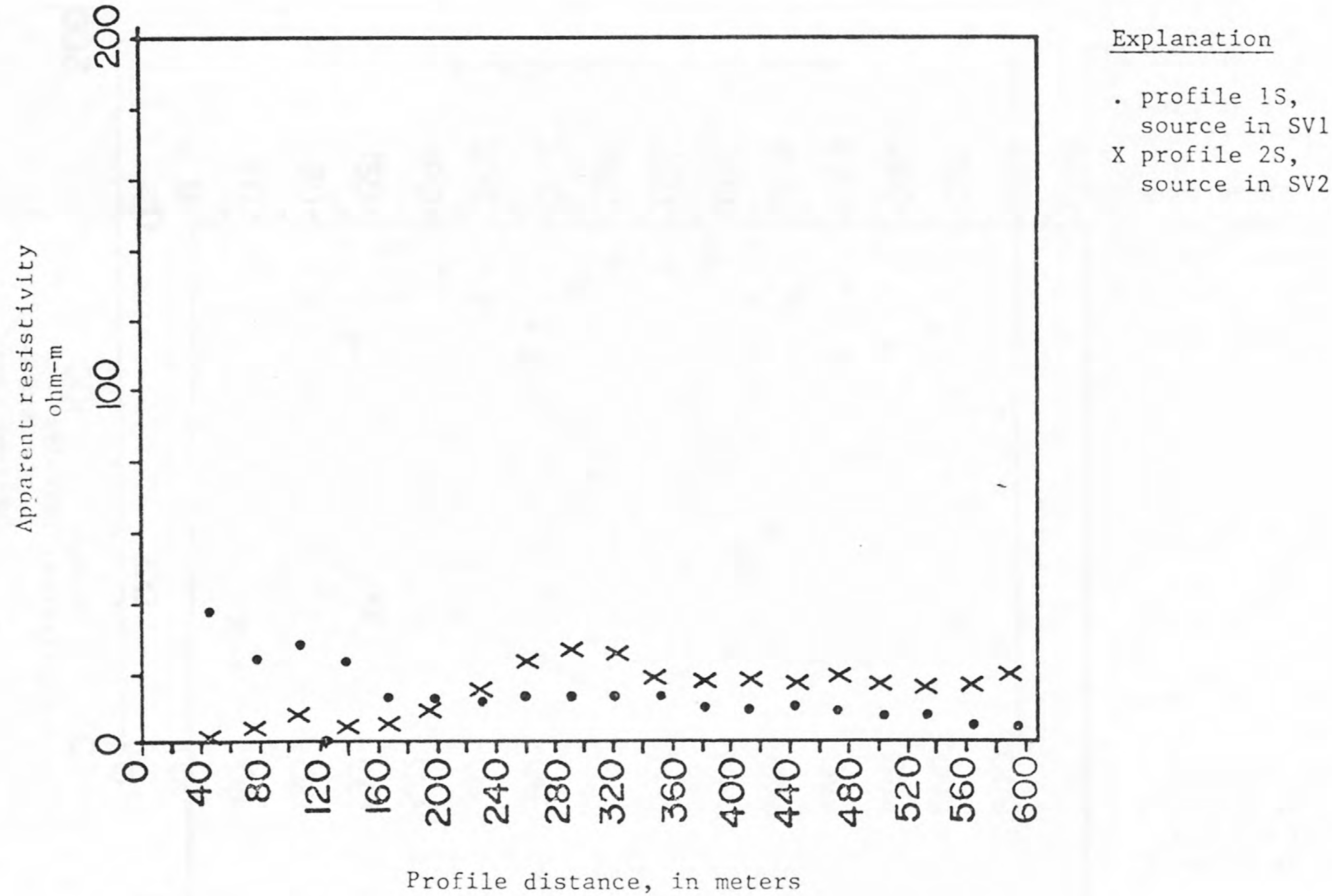

Figure 4.--Comparison of hole-to-surface resistivity profiles for line 1S (source in drill hole SV1) with the profiles for line 2S (source in drill hole SV2).

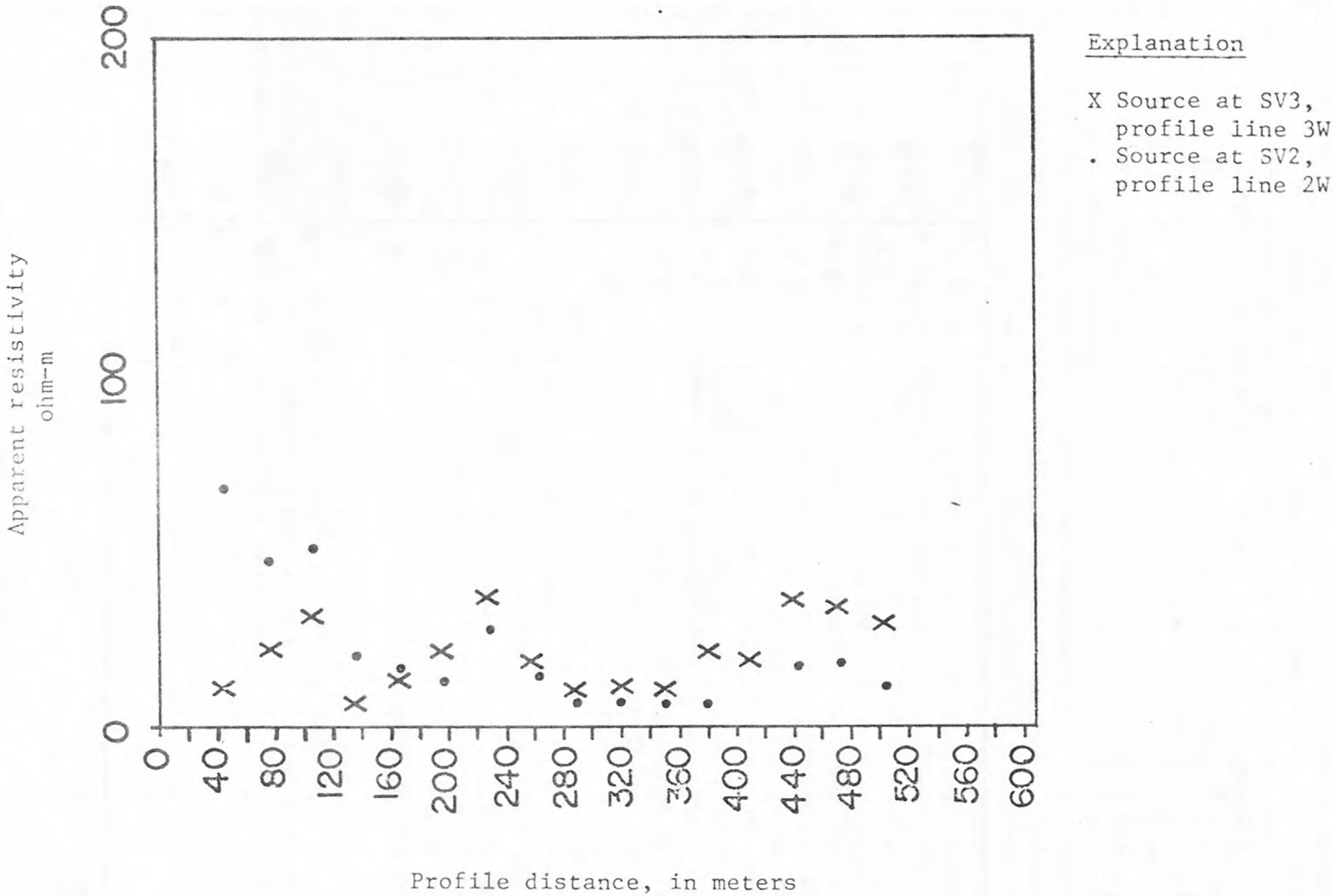

Figure 5.--Comparison of hole-to-surface resistivity profiles for line 2W (source in drill hole SV2) and for line 3W (source in drill hole SV3).

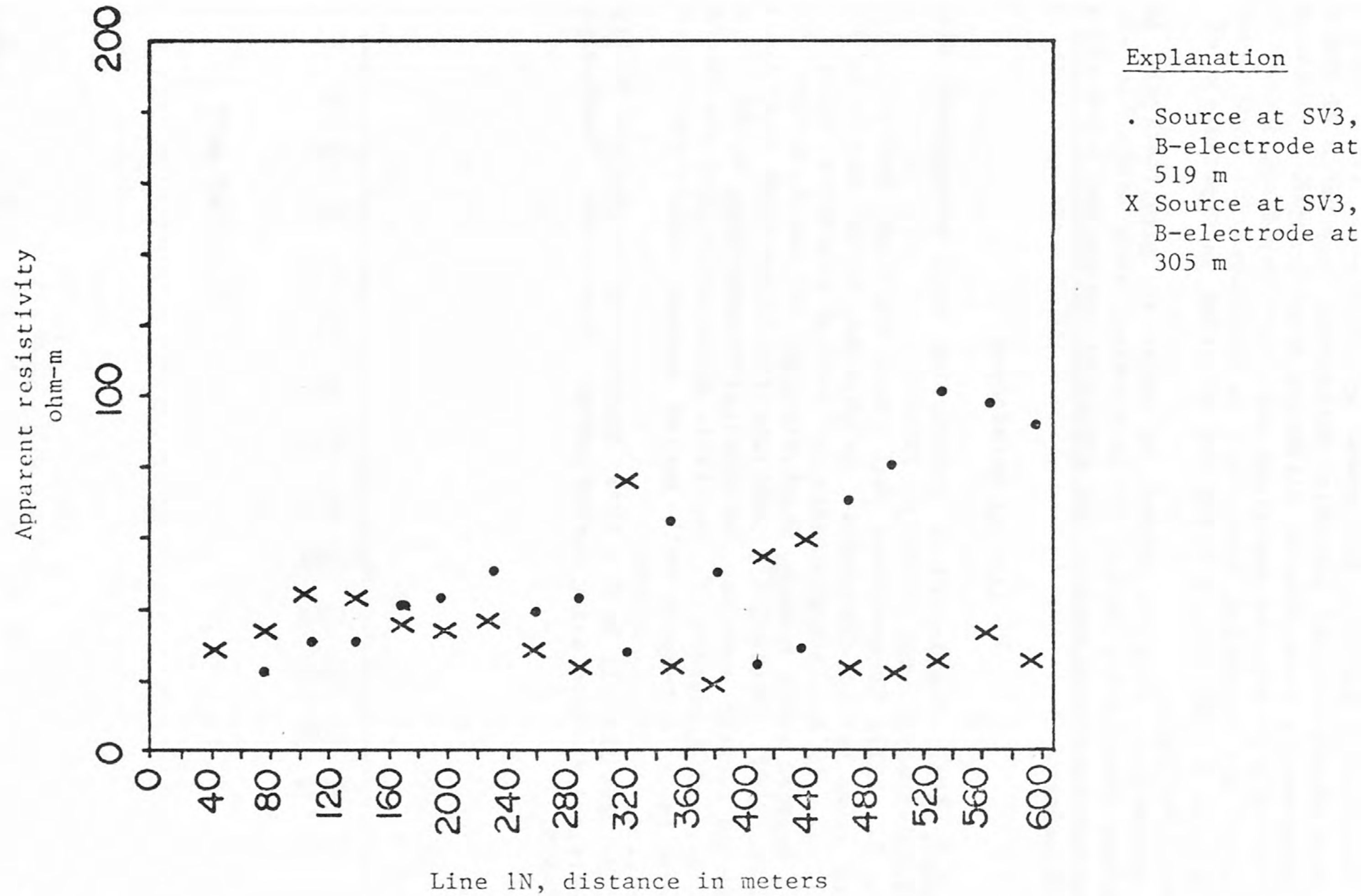

Figure 6.--Comparison of hole-to-surface resistivity profiles for line 1N with the lower source pole (electrode "B") at depths of 305 m and 519 m.

of the electric fields measured at the surface. (2) Differences in the response along the same profile for different source depths may be the result of changes in the current distribution caused by the interbeds. Future hole-to-surface surveys should include measuring orthogonal components of the electric field and measurements from several different source depths. These measurements could be used to map the magnitude and azimuthal direction of the total electric field. The resulting data could be contoured for each source depth and would provide a much better basis for detailed interpretation of caprock and interbed lithology.

More theoretical work is needed in order to quantitatively interpret hole-to-surface resistivity data. In particular, this study has shown that theoretical studies should include the effect of casing and brine-filled holes on the measurements.

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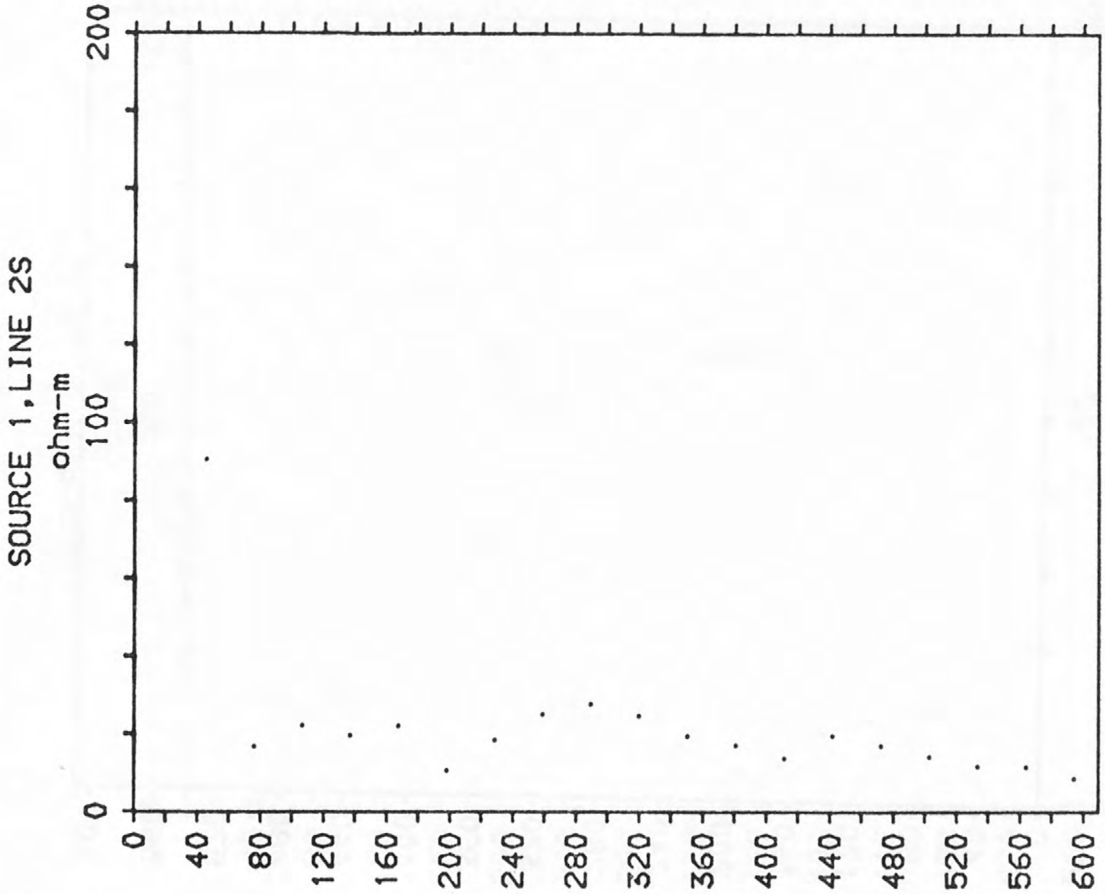


Profile distance, in meters

Figure A1.--Source in drill hole SV1 at a depth of 305 m. Receiver profile line 2S.

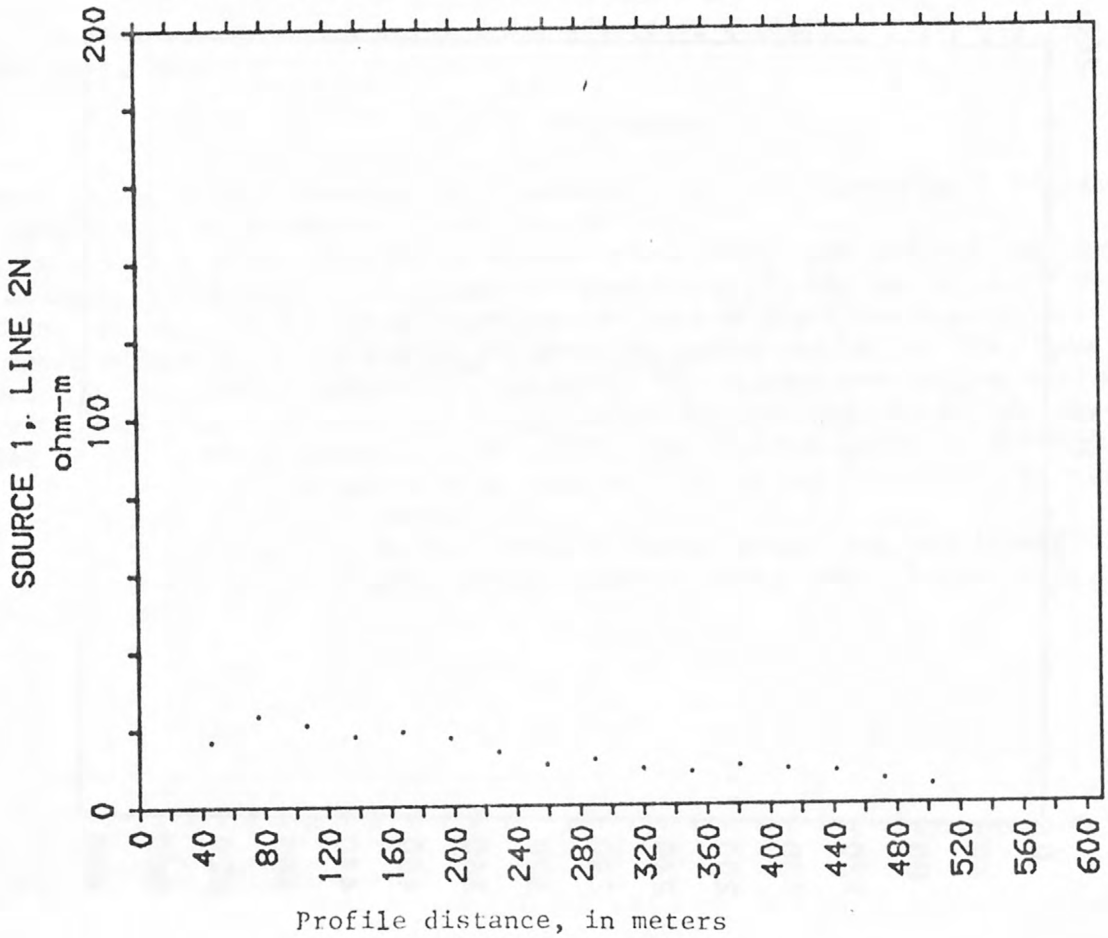


Figure A2.--Source in drill hole SV1 at a depth of 305 m. Receiver profile line 2N.

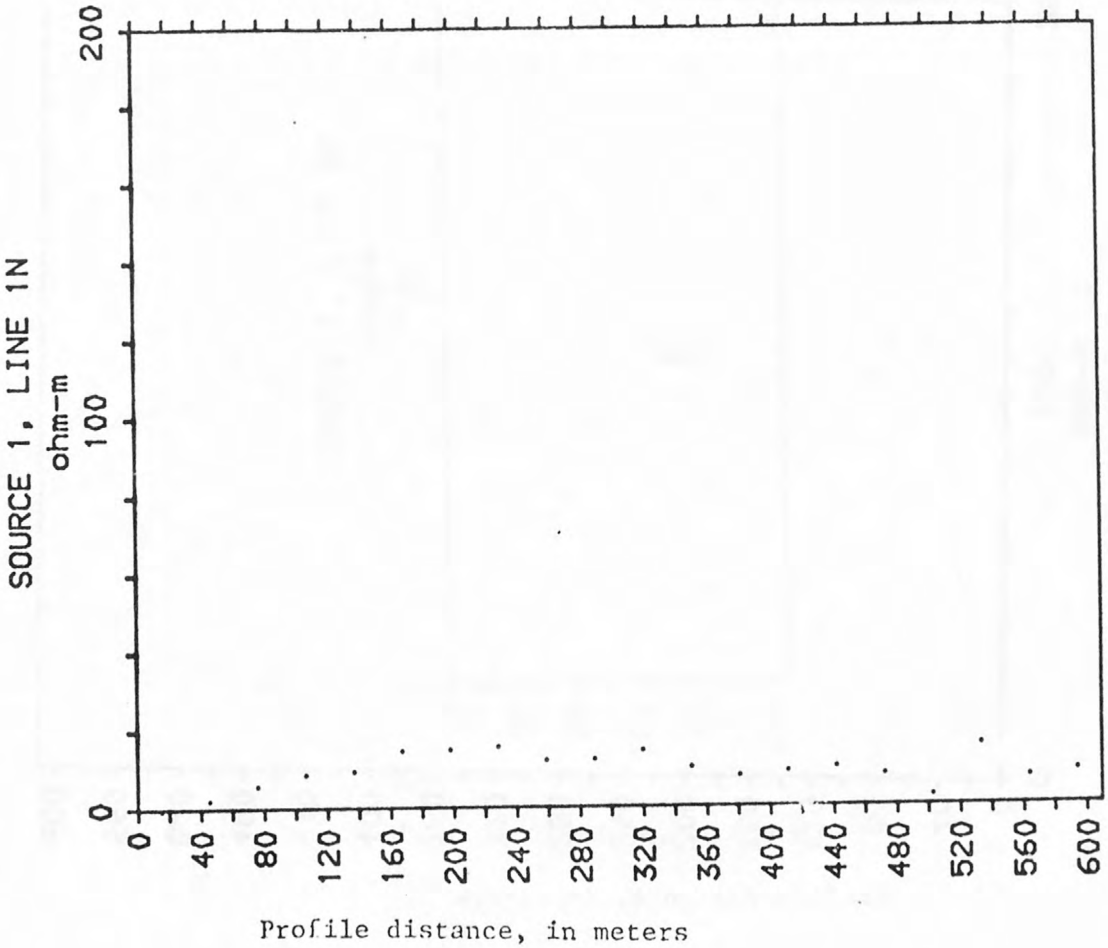


Figure A3.--Source in drill hole SV1 at a depth of 305 m. Receiver profile line 1N.

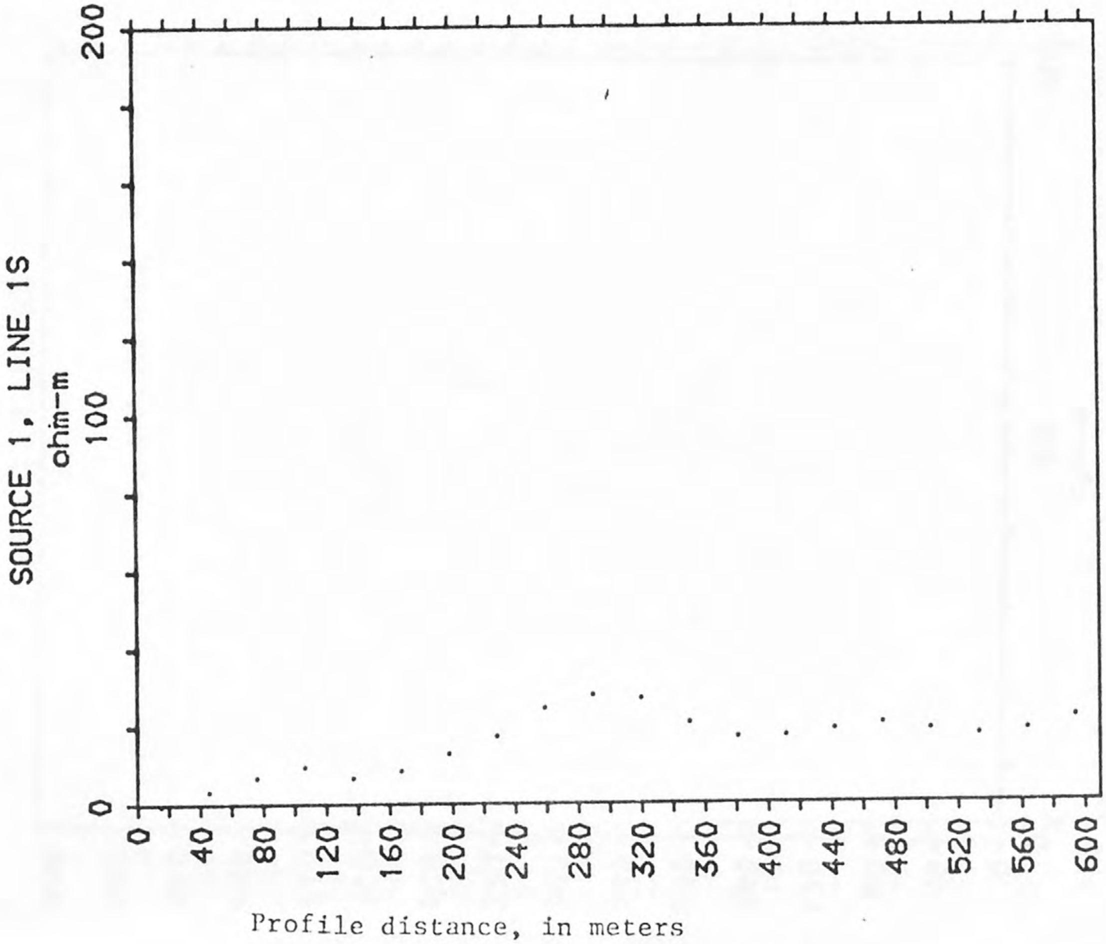


Figure A4.--Source in drill hole SV1 at a depth of 305 m. Receiver profile line 1S.

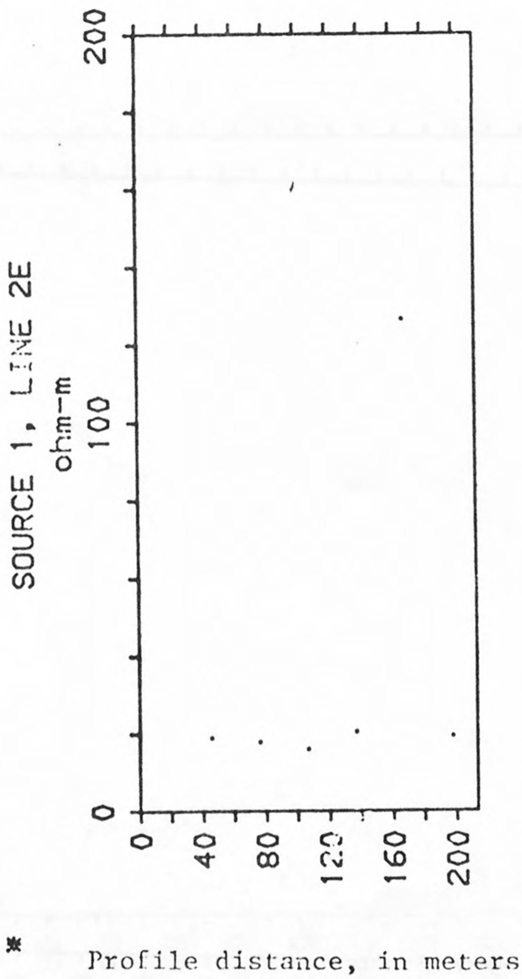


Figure A5.--Source in drill hole SV1 at a depth of 305 m. Receiver profile line 2E.

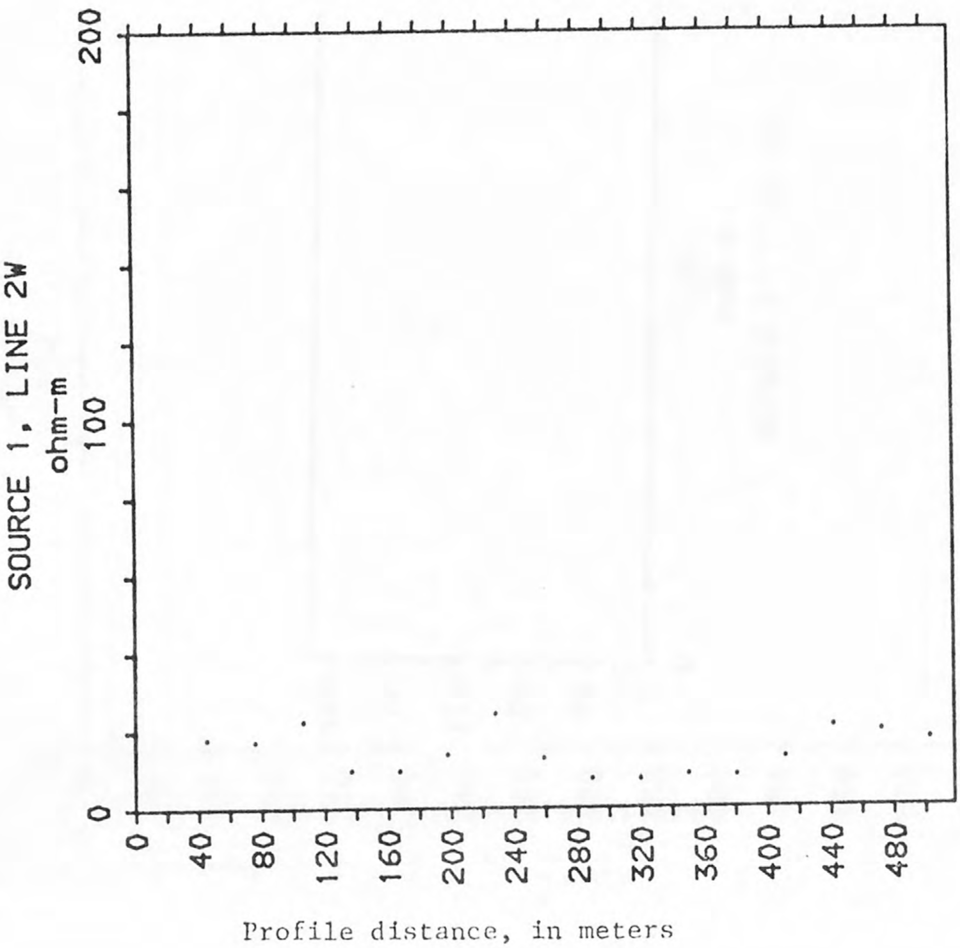


Figure A6.--Source in drill hole SV1 at a depth of 305 m. Receiver profile line 2W.

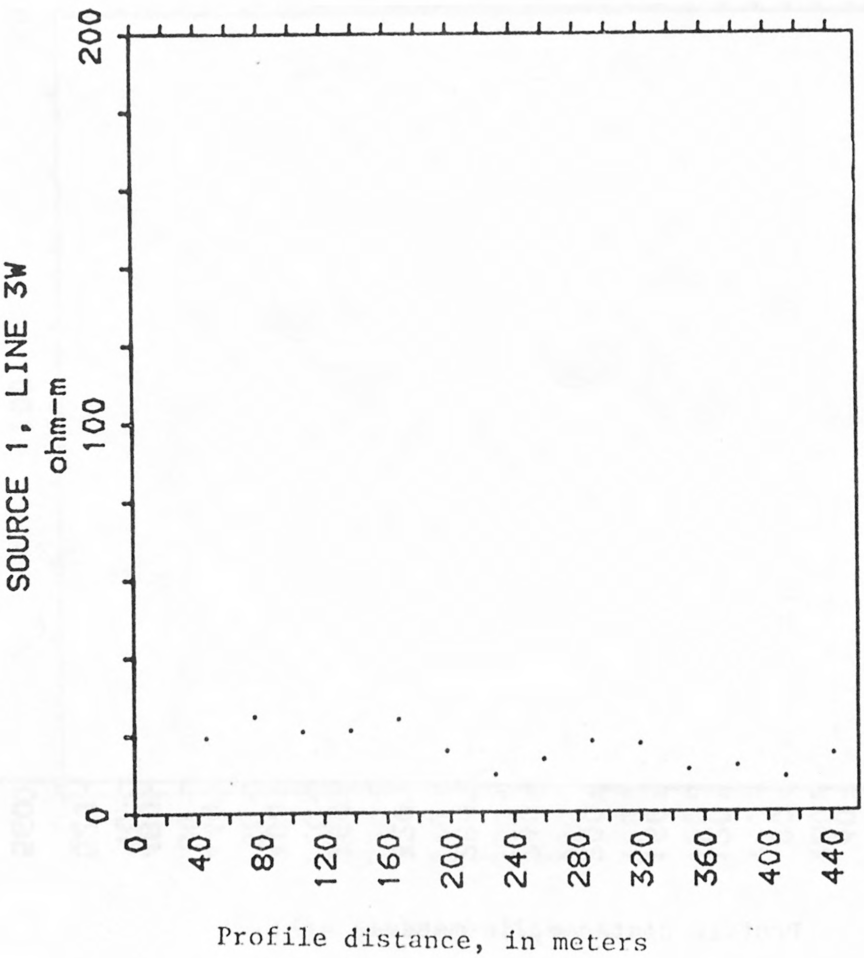


Figure A7.--Source in drill hole SV1 at a depth of 305 m. Receiver profile line 3W.

APPENDIX B - Hole-to-surface data for drill hole SV2.

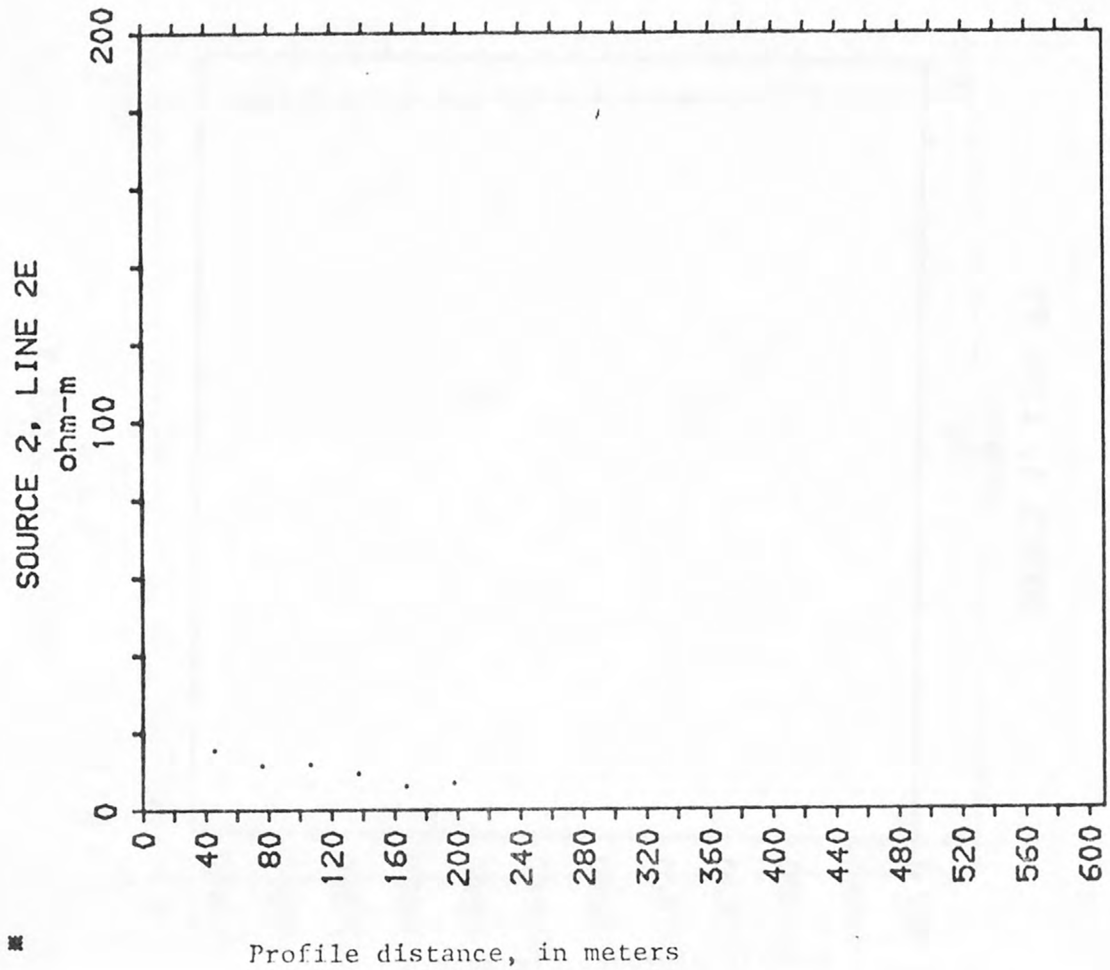


Figure B1.--Hole-to-surface resistivity data for source drill hole SV2. Source depth is 305 m. Receiver profile line 2E.

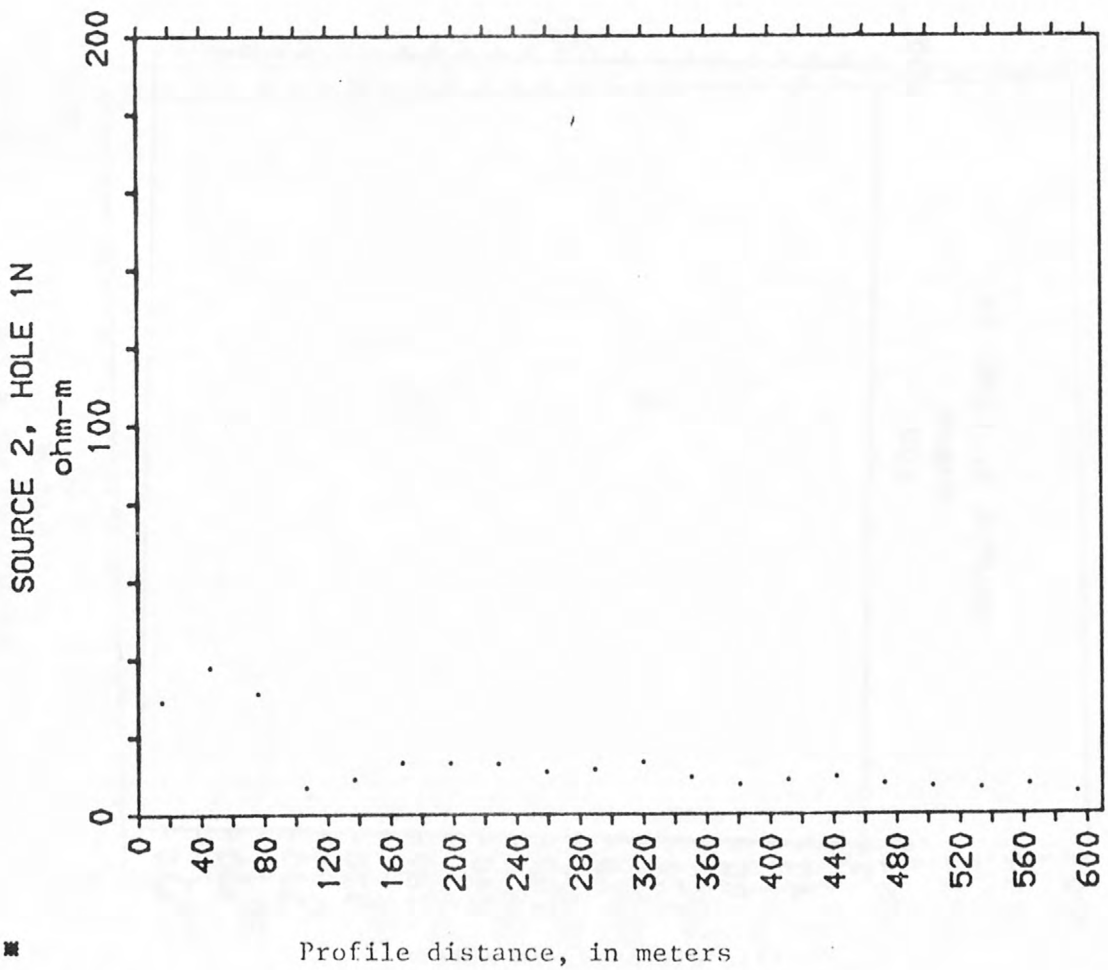
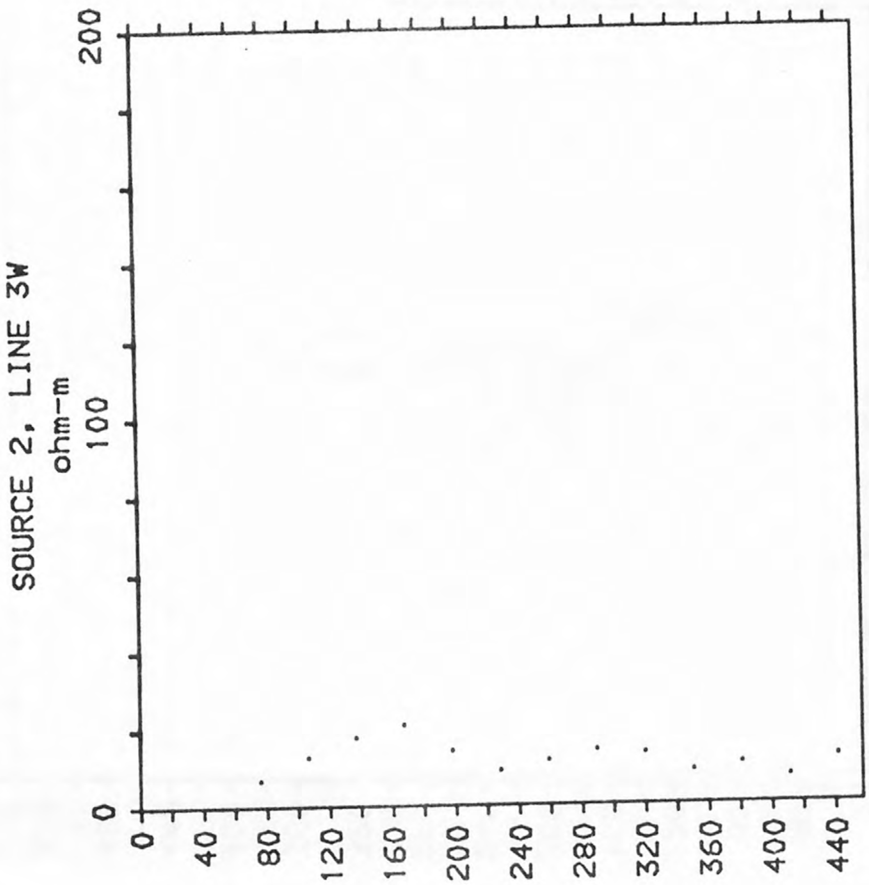


Figure B2.--Hole-to-surface resistivity data for source drill hole SV2. Source depth is 305 m. Receiver profile line 1N.



Profile distance, in meters

Figure B3.--Hole-to-surface resistivity data for source drill hole SV2. Source depth is 305 m. Receiver profile line 3W.

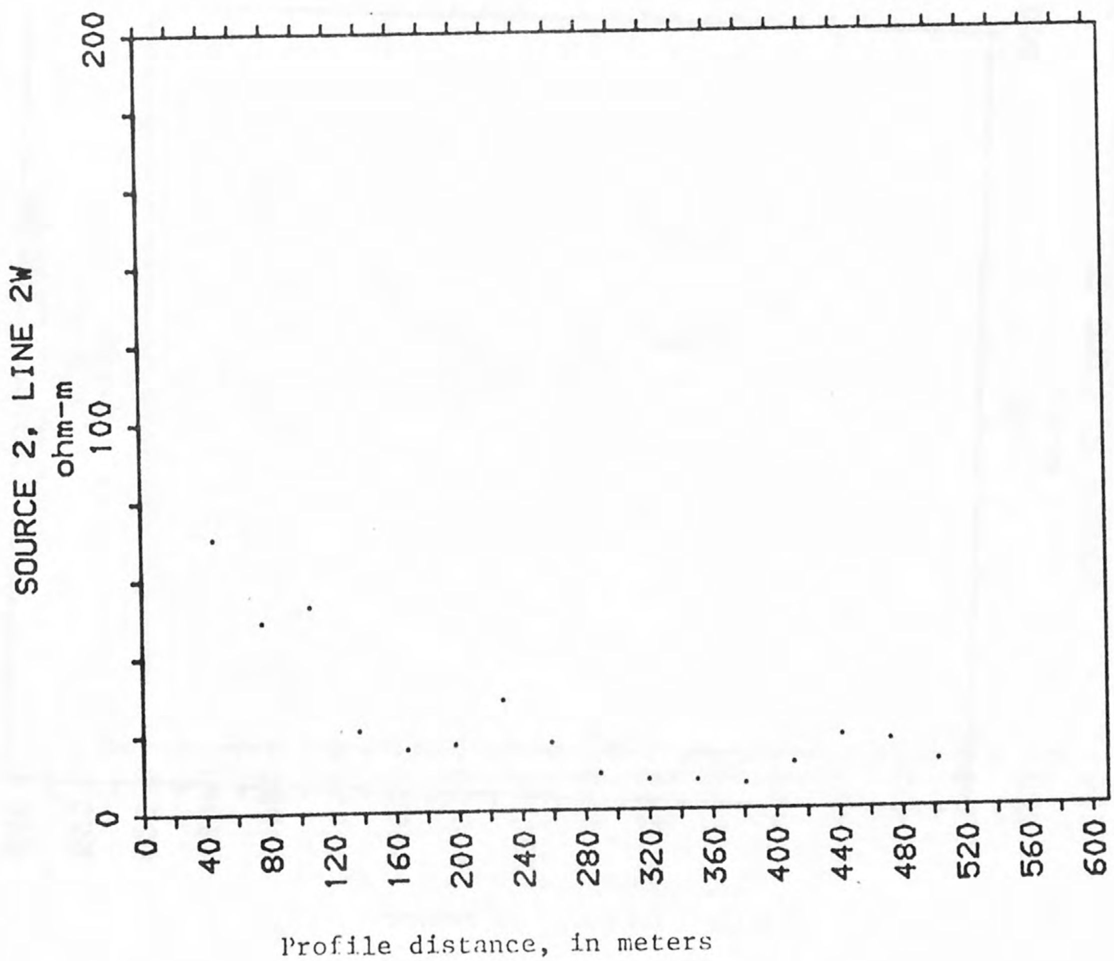


Figure B4.--Hole-to-surface resistivity data for source drill hole SV2. Source depth is 305 m. Receiver profile line 2W.

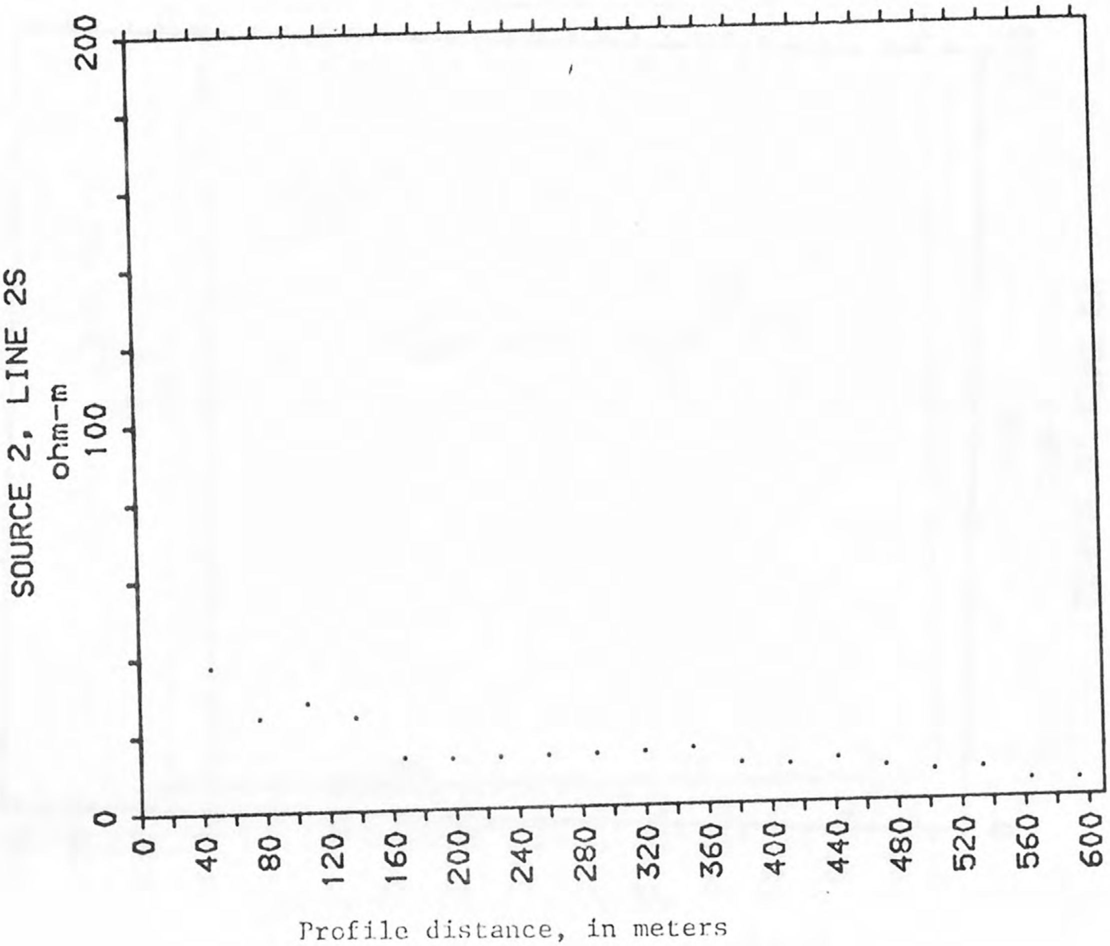


Figure B5.--Hole-to-surface resistivity data for source drill hole SV2. Source depth is 305 m. Receiver profile line 2S.

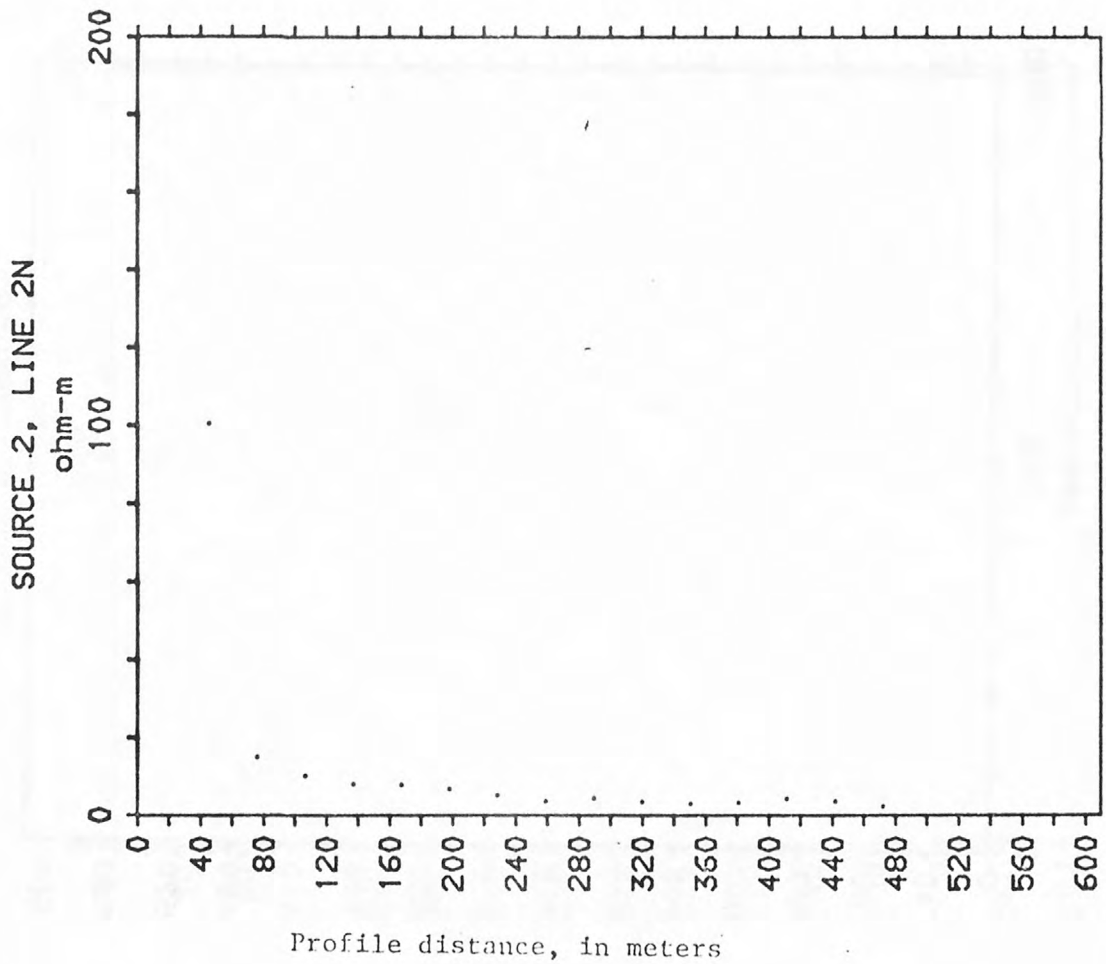
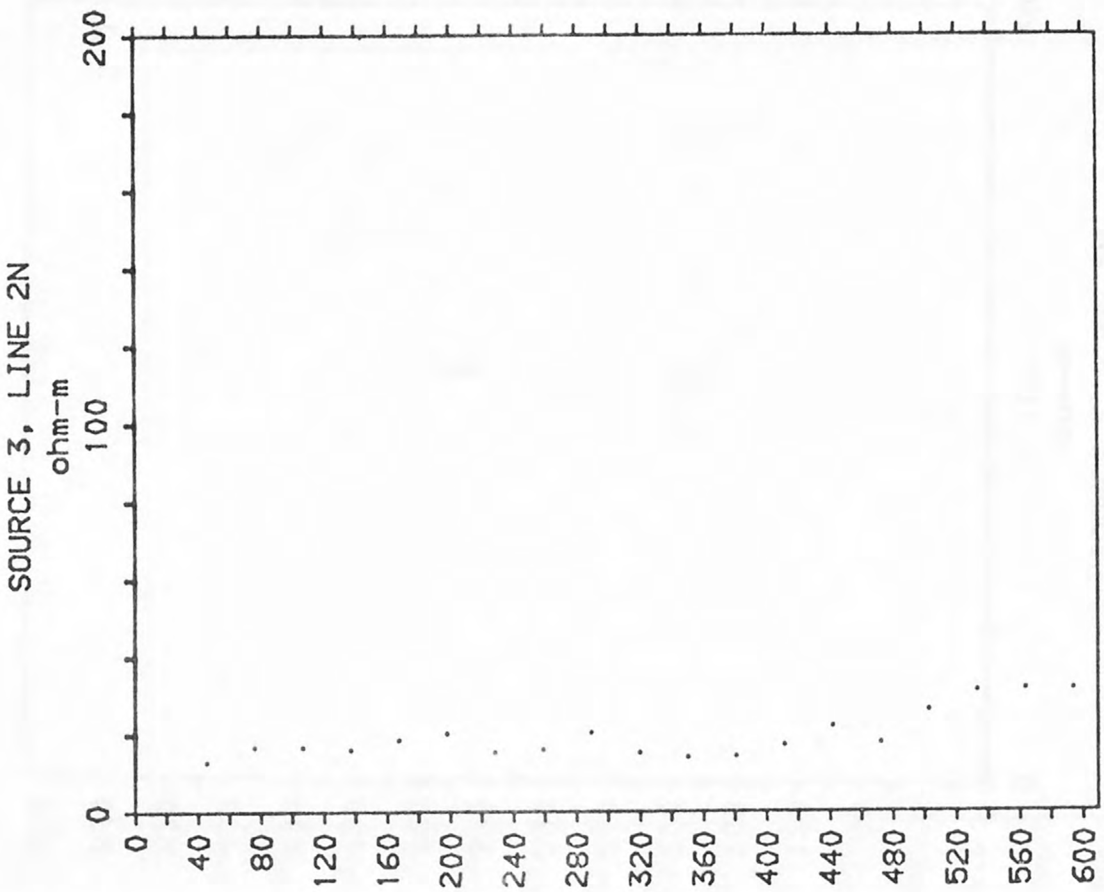


Figure B6.--Hole-to-surface resistivity data for source drill hole SV2. Source depth is 305 m. Receiver profile line 2N.

APPENDIX C - Hole-to-surface data for drill hole SV3.



Profile distance, in meters

Figure C1.--Hole-to-surface resistivity data for source drill hole SV3. Depth of source electrode is 305 m. Receiver profile line 2N.

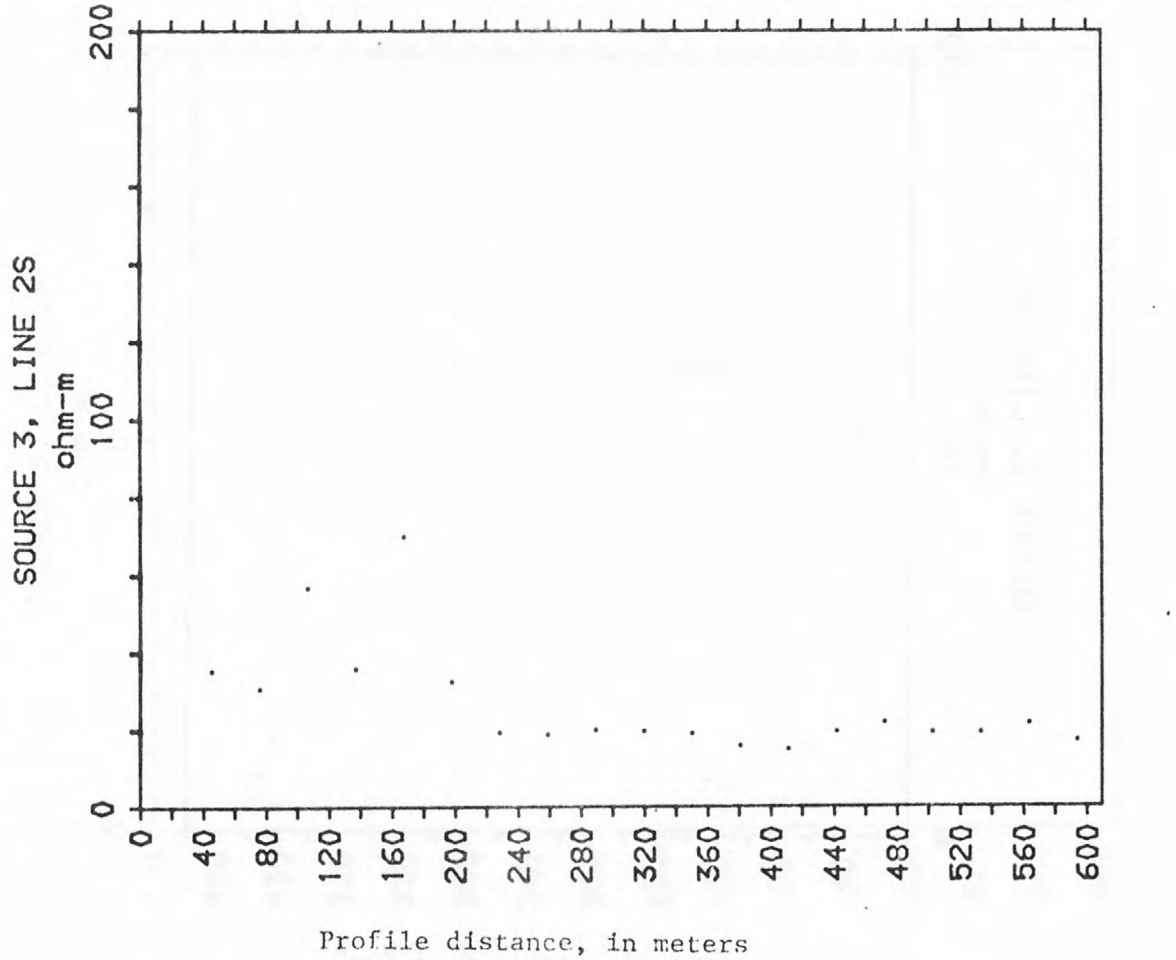


Figure C2.--Hole-to-surface resistivity data for source drill hole SV3. Depth of source electrode is 305 m. Receiver profile line 2S.

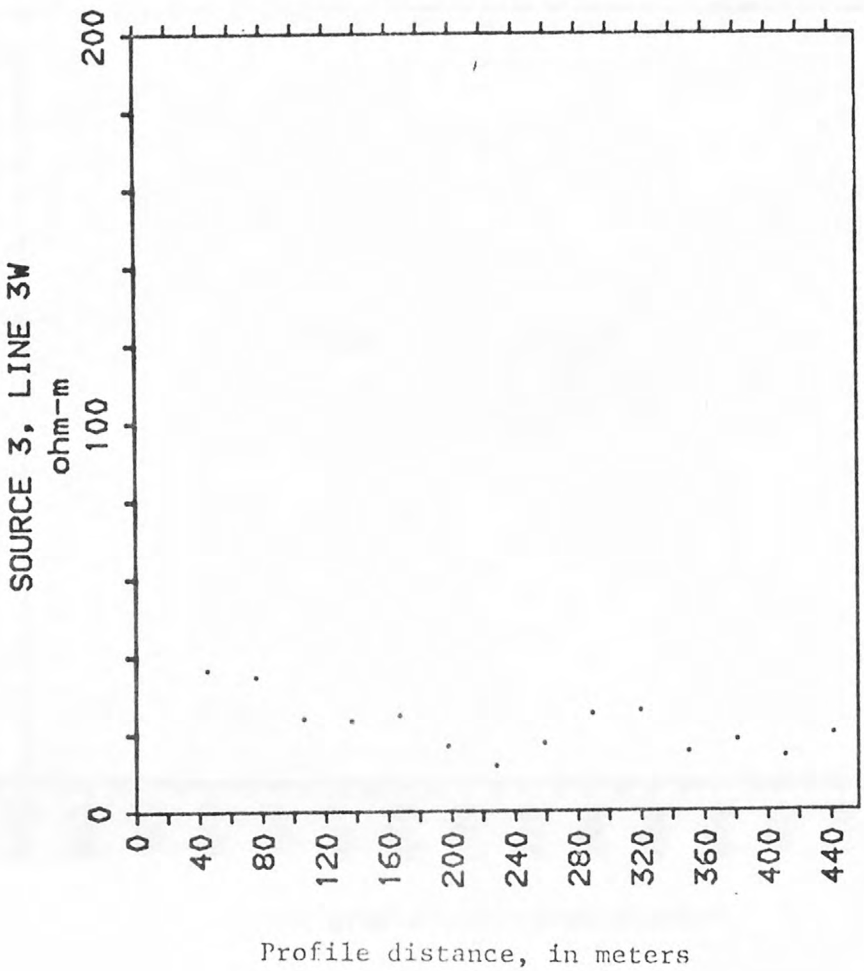


Figure C3.--Hole-to-surface resistivity data for source drill hole SV3. Depth of source electrode is 305 m. Receiver profile line 3W.

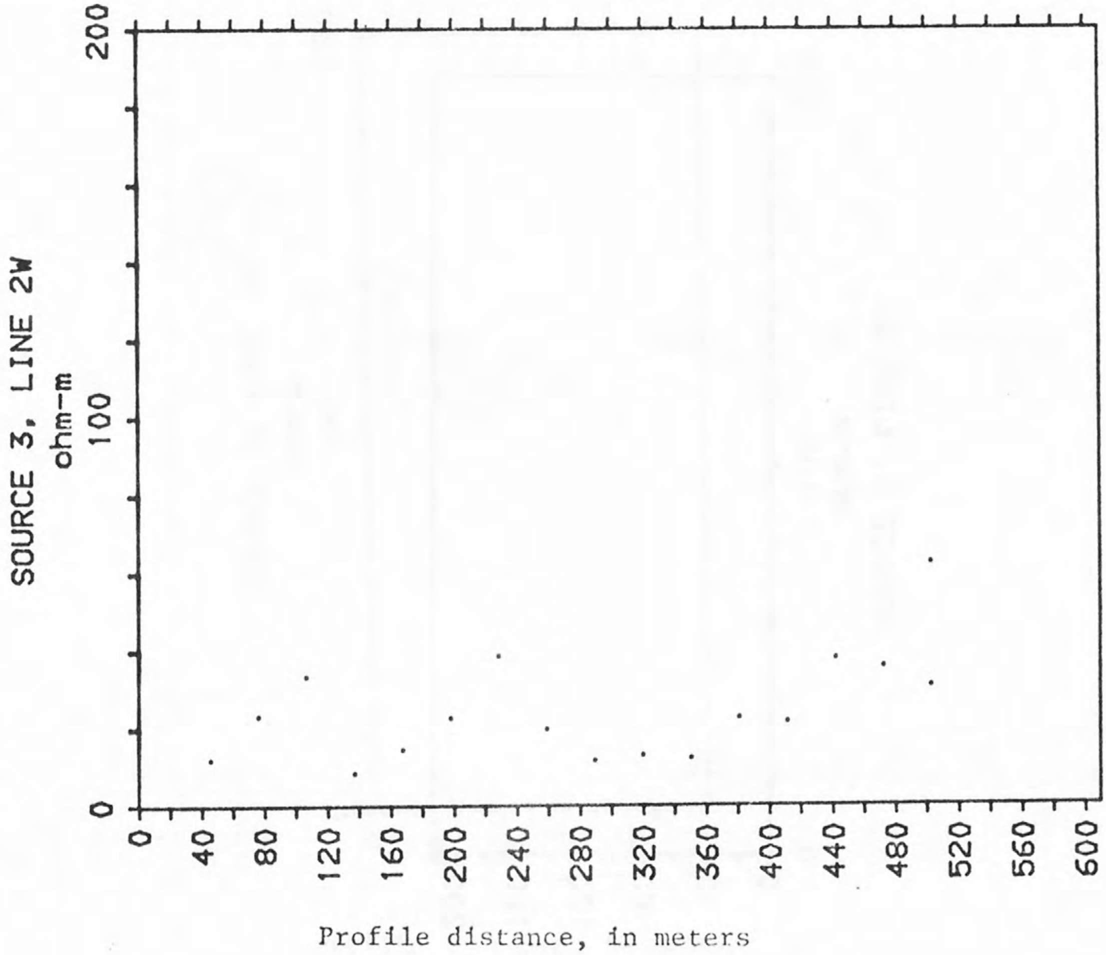


Figure C4.--Hole-to-surface resistivity data for source drill hole SV3. Depth of source electrode is 305 m. Receiver profile line 2W.

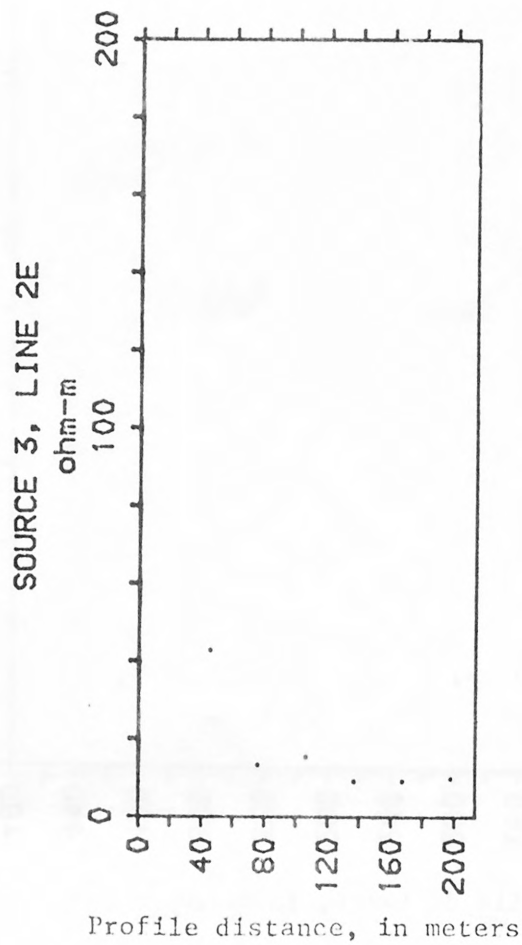
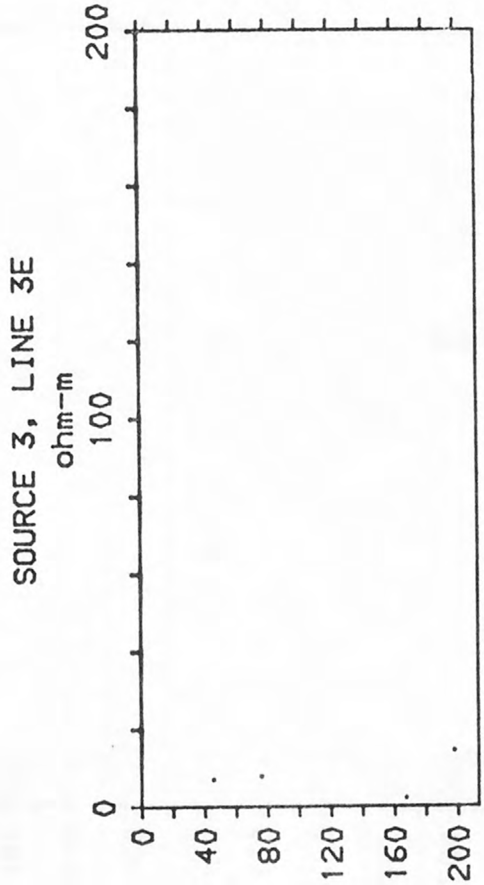


Figure C5.--Hole-to-surface resistivity data for source drill hole SV3. Depth of source electrode is 305 m. Receiver profile line 2E.



Profile distance, in meters

Figure C6.--Hole-to-surface resistivity data for source drill hole SV3. Depth of source electrode is 305 m. Receiver profile line 3E.

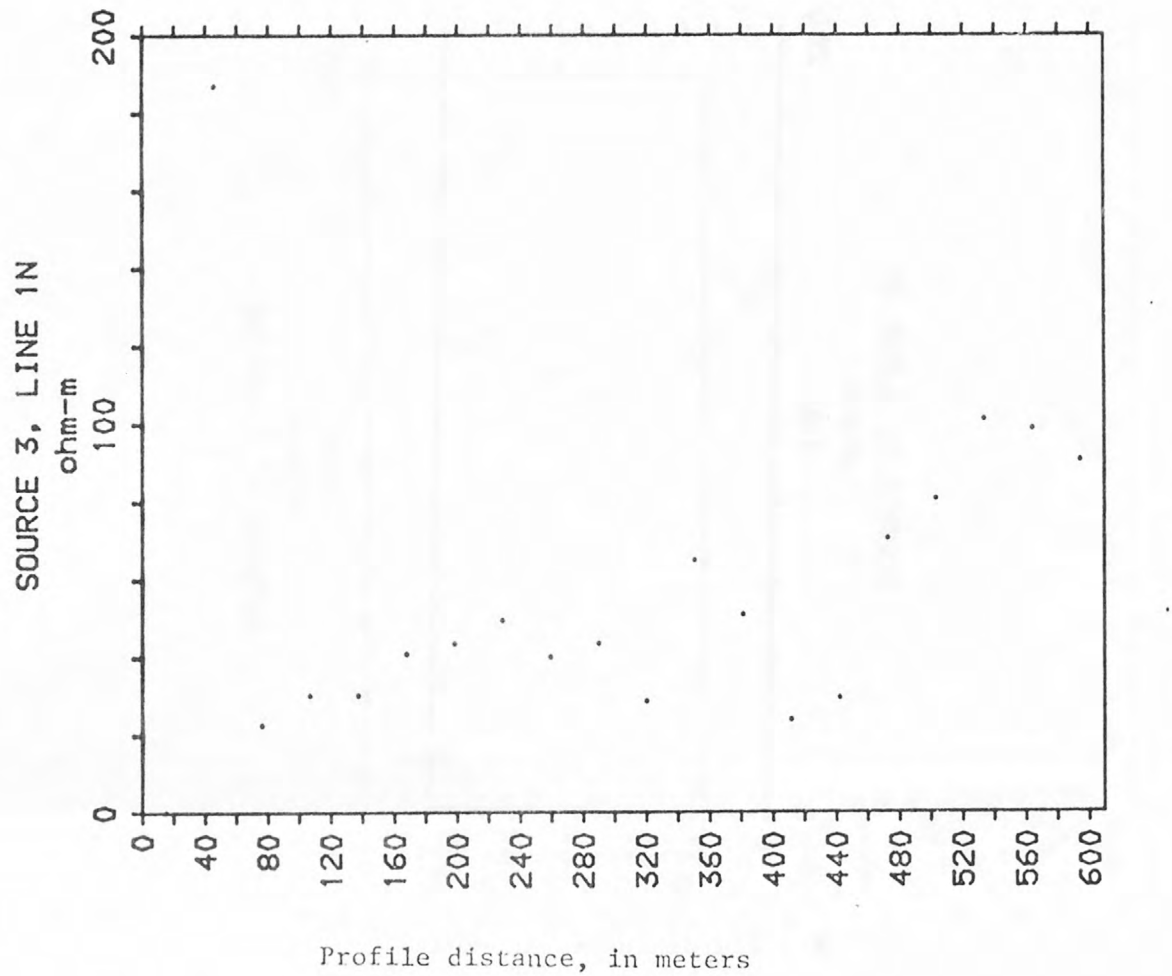


Figure C7.--Hole-to-surface resistivity data for source drill hole SV3. Depth of source electrode is 305 m. Receiver profile line 1N.

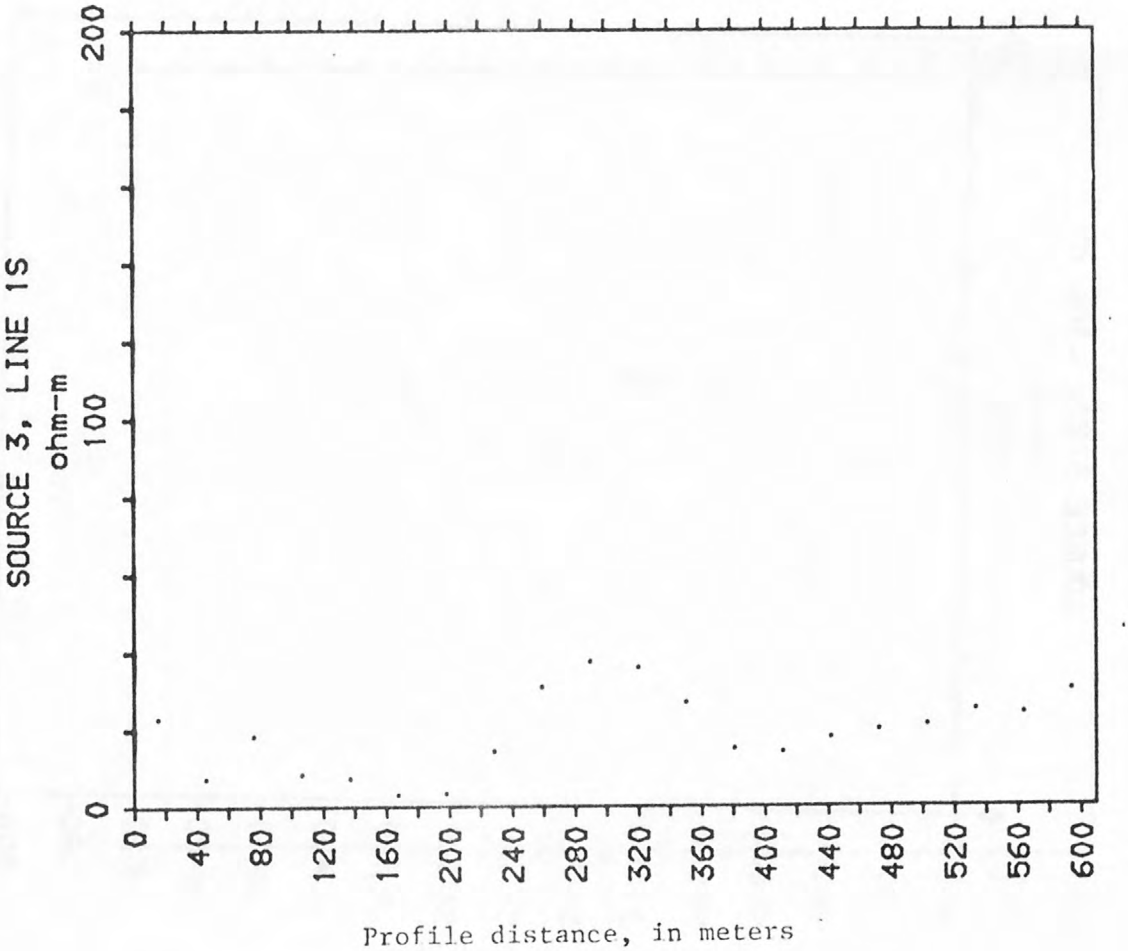
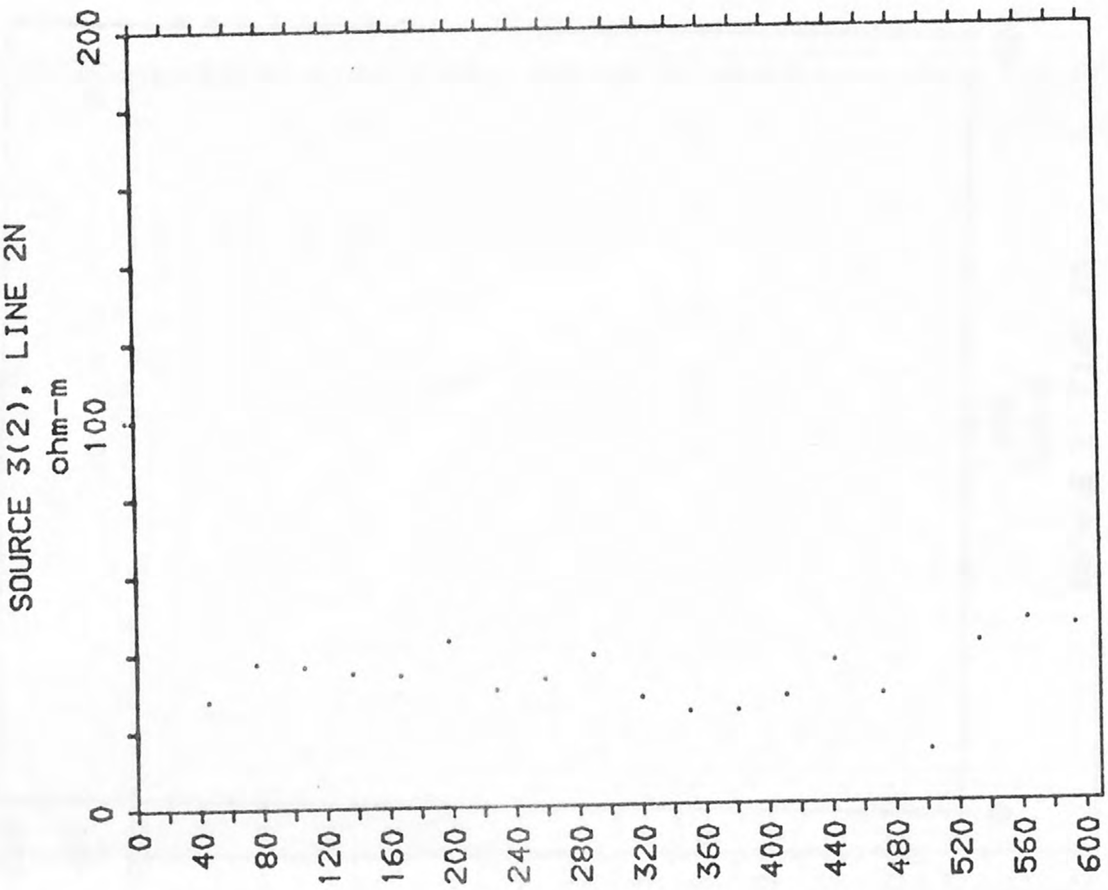
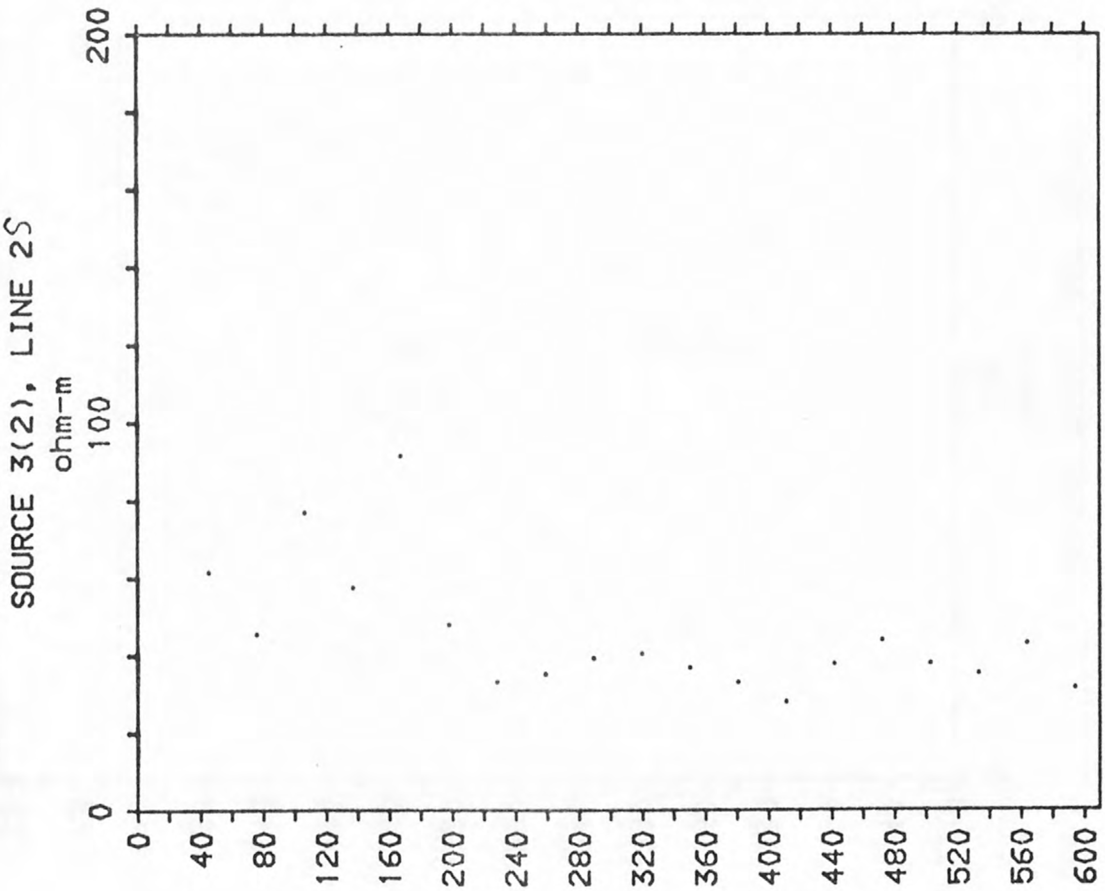


Figure C8.--Hole-to-surface resistivity data for source drill hole SV3. Depth of source electrode is 305 m. Receiver profile line 1S.



Profile distance, in meters

Figure C9.--Hole-to-surface resistivity data for drill hole SV3. The source is at a depth of 519 m. Receiver is profile line 2N.



Profile distance, in meters

Figure C10.--Hole-to-surface resistivity data for drill hole SV3. The source is at a depth of 519 m. Receiver is profile line 2S.

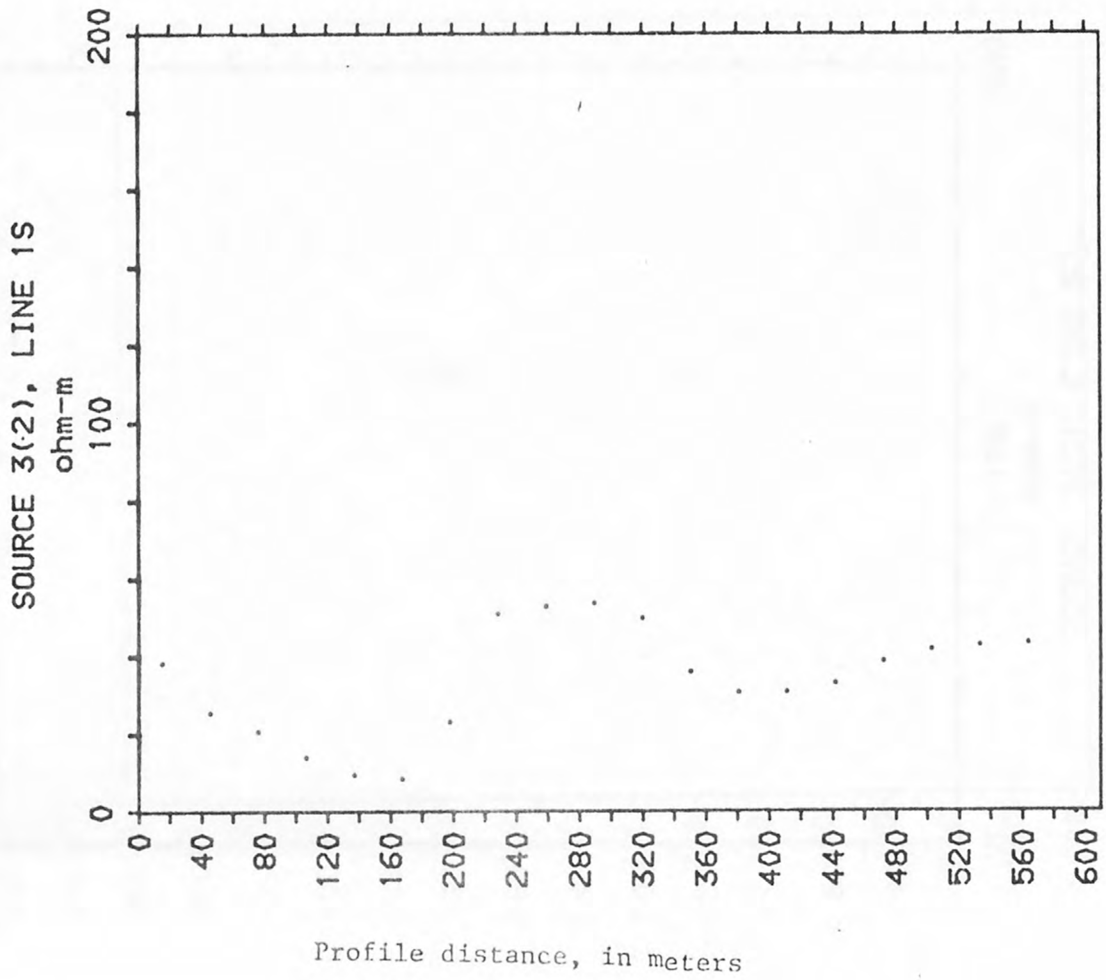


Figure C11.--Hole-to-surface resistivity data for drill hole SV3. The source is at a depth of 519 m. Receiver is profile line 1S.

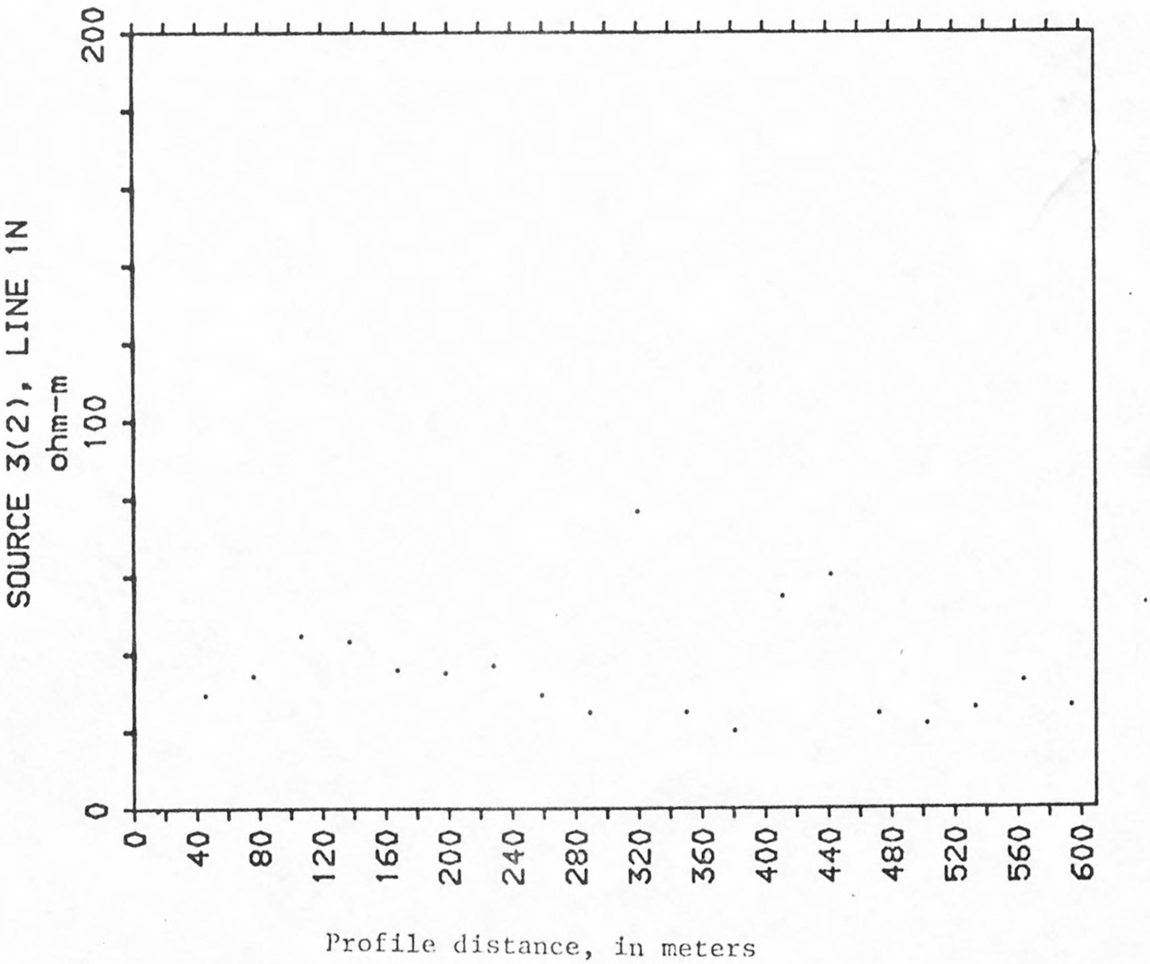


Figure C12.--Hole-to-surface resistivity data for drill hole SV3. The source is at a depth of 519 m. Receiver is profile line 1N.