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Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site

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FINAL REPORT FOR TIME DOMAIN ELECTROMAGNETIC (TDEM) SURVEYS AT THE WIPP SITE

by

THE EARTH TECHNOLOGY CORPORATION
Golden, Colorado

August 6, 1987

Contract No: 01-6329
Project No: G87105

EXECUTIVE SUMMARY

The Earth Technology Corporation was contracted by Sandia National Laboratories to perform a time domain electromagnetic (TDEM) survey at the WIPP site for the purpose of mapping the depth of occurrence of brine pockets and layers. The impetus for the geophysical survey was that pressurized brine had been encountered in drill holes in the Castile Formation immediately underlying the bedded salts of the Salado Formation in which the waste storage panels are mined. TDEM is a geophysical technique that determines layering in the subsurface from surface resistivity measurements. Because brine layers and pockets have low resistivities compared to the bedded salts of the host rock, they are good targets for electrical exploration.

Most of the measurements (36 out of 38) were located in a 1.5 by 1 km grid directly over the waste storage panels. Two measurements were made next to drill holes WIPP #12 and DOE #1 to validate the interpretation of the geophysical survey. Also, one drill hole (ERDA #9) at the northern boundary of the survey grid was used for calibration.

The results of the survey can be summarized as follows:

- *The geoelectric sections derived from the TDEM measurements compare well with geologic and geophysical data of the the three drill holes. At WIPP #12 the occurrence of brine at a depth of about 800 m (2600 ft.) is clearly seen in the TDEM data.*

- *The results of the TDEM survey over the waste storage panels show the first occurrence of brine at depths corresponding to the Castile Formation in portions of the area and to the Bell Canyon Formation in the rest of the area, some 400 to 600 m below the mined depth of the waste storage panels in the Salado formation. There is no evidence in the data for brine pockets in the Salado or other formations over the waste storage panels.*

Only one sounding was made near drill hole WIPP #12 for the purpose of calibration. Since the center loop TDEM surveys conducted correlate well with drill holes and other geologic data, it is recommended that the areal extent of the brine pocket encountered at WIPP #12 be mapped by surveying a grid centered on WIPP #12.

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FOREWORD

This Final Report is prepared for Sandia National Laboratories in compliance with Contract Number 01-6329. The Report describes The Earth Technology Corporation's time domain electromagnetic (TDEM) survey at the WIPP site near Carlsbad, New Mexico, in compliance with contract requirements and a written quality assurance program.

The document was prepared by Harold Cline and Mark Blohm, and reviewed and approved by Alain A. Sharp and Pieter Hoekstra for Earth Technology. David J. Borns and Charles Stoyer provided the SNL peer reviews.

1.0 INTRODUCTION

This report presents the results of a time domain electromagnetic (TDEM) survey over the location of the waste storage panels of the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. TDEM derives the geoelectric section (electrical resistivity layering) from surface measurements. The objective of the survey was to determine the occurrence and depth of brine in the geologic formations above and below the waste panels. Brine saturated layers and brine pockets have low values of electrical resistivity and, therefore, form good targets for detection by electrical geophysical methods.

A total of 38 TDEM central loop soundings were made during the survey. Thirty-six of these soundings were situated in a grid, 1.5 by 1 km. This grid directly overlays the waste storage panels (Figure 1-1). Two soundings were made outside this grid near two drill holes, WIPP #12 and DOE #1. The purpose of these soundings was to correlate the geoelectric section derived from TDEM soundings with drill hole geological and geophysical data.

The WIPP storage panels are mined in the bedded salts of the Salado Formation at a depth of about 600 m below ground surface. Directly under the Salado Formation is the Castile Formation composed primarily of anhydrite and halite. In the general vicinity of Carlsbad, drill holes encountering pressurized brine reservoirs at depths between 730 and 915 m in the Castile Formation have been documented (Register, 1981). One of these occurrences was in the WIPP #12 drill hole, located about 1.5 km north of the waste storage panels. An important objective of positioning a loop near drill hole WIPP #12 was to calibrate the system at a known depth of brine occurrence.

It is known from oil and gas drilling in the area that the Bell Canyon Formation underlying the Castile Formation acts as an aquifer and that the formation waters have a high TDS. The brines of the Bell Canyon Formation are generally encountered at depths from 1050 to 1400 m.

The interpretation of the geoelectric section in terms of brine occurrences can be summarized as follows:

° The 36 soundings in the 1.5 by 1 km area over the waste storage panels show a continuous brine layer within the Bell Canyon Formation (1200 m depth). Some soundings within the area show brine within the Castile Formation (1050 to 1200 m depth). There is no evidence of brine pockets at the level of the repository. This interpretation is consistent with geologic and geophysical information from drillhole ERDA #9, situated on the northern boundary of the survey area.

° The sounding positioned about 300 m from drill hole WIPP #12 shows the occurrence of brine in the Castile Formation at depths of about 800 m, in excellent agreement with the drilling results.

A Field Operations Plan and a Field Operations Report were submitted at an earlier date. These reports contained detailed information about procedures of data acquisition, processing, and interpretation. The contents of these two reports are not repeated in this

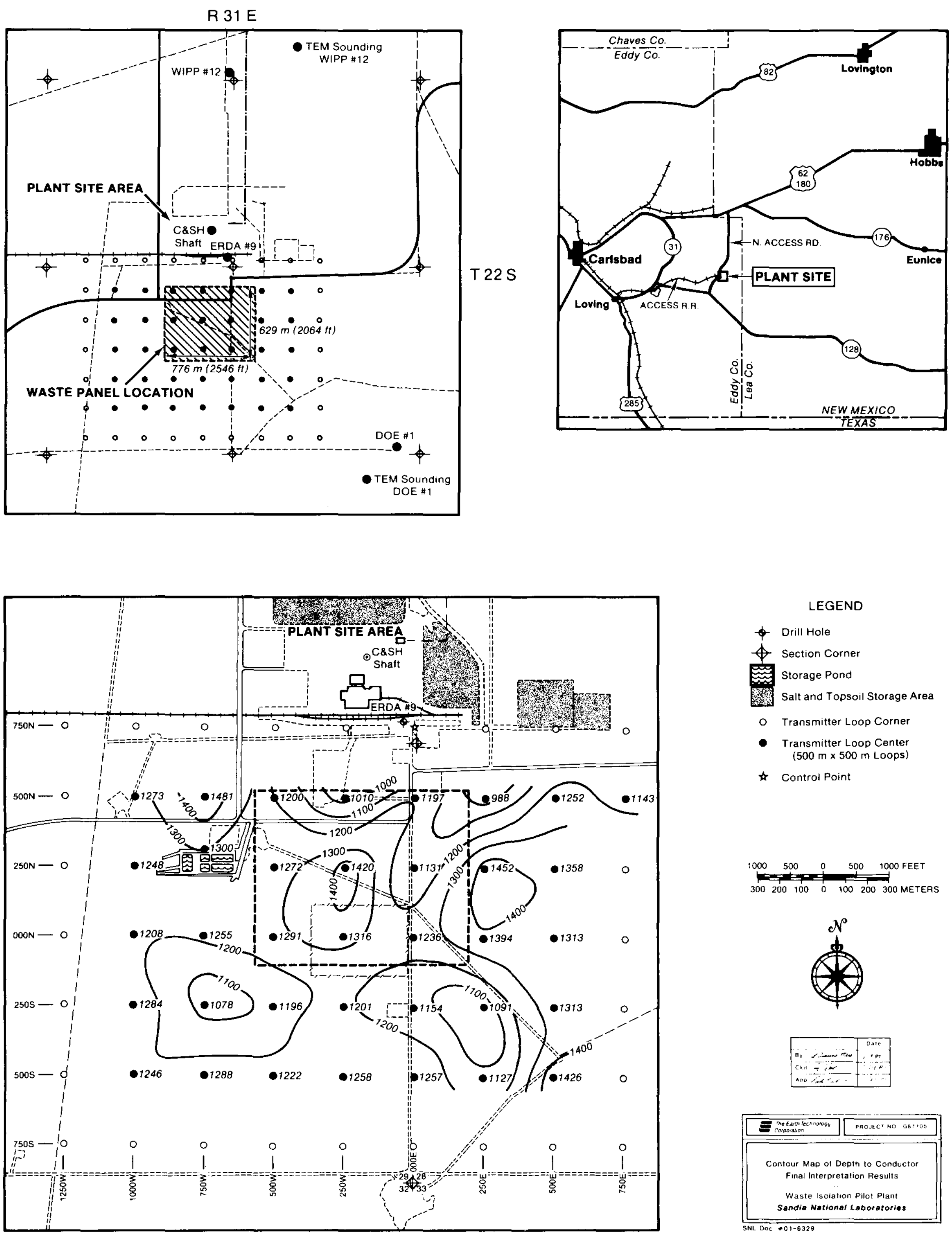


Figure 1-1. TEM Sounding Locations and Waste Panel Location

final report. This final report contains geologic interpretations of geophysical data, comparisons of geophysical interpretations with available geologic and drilling results, comparisons with prior surface electrical surveys, and recommendations for future work.

2.0 BACKGROUND INFORMATION

Several electrical and electromagnetic surveys preceeded the present TDEM survey at the WIPP site (Bartel et al., 1983; Keller et al., 1987). From these surveys the general geoelectric section of the site was known. It was expected to consist of sequences of resistive materials. The presence of brine pockets in such sections was anticipated to represent a highly conductive stratum. It was also known (Bartel et al., 1983) that the Rustler Formation had somewhat lower resistivities (about 10 ohm-m) than the surrounding strata.

To determine optimum survey parameters the geoelectric section at WIPP was simplified as consisting of a thin layer of high conductance (ratio of thickness and resistivity) embedded in a uniform half-space of high resistivity. It was anticipated that variations from this simple model (such as the 10 ohm-m resistivities of the Rustler Formation) would not materially affect the selection of survey parameters.

The models computed prior to the survey are shown in Figure 2-1. In these models a brine layer was positioned at a depth of 1000 m. Based on these model studies, the following survey parameters were selected:

- Use of the Geonics EM-42 TDEM system, because the time range of measurement of the Geonics EM-37 was expected to be insufficient for detection of brine pockets at 1000 m.
- Transmitter loops of 500 by 500 m and measurements with air coil receivers in the center of the loops. The selection of transmitter loop size was dictated by required dipole moment and by the fact that use of smaller loops with the EM-42 sometimes causes noisy data in earlier time channels. The array of center loop soundings was recommended because prior experiences showed it to have better lateral and vertical resolution than grounded line sources.

It is evident from comparing the measured apparent resistivity curves (e.g., Figure 3-1) with the model curves that the behavior of model curves and measured curves is similar, particularly at later times. Model and measured curves have in common maxima and steep right descending branches. They differ at earlier times because in the computed models, run prior to the execution of the survey, the resistivity variation in the upper 200 m was not considered.

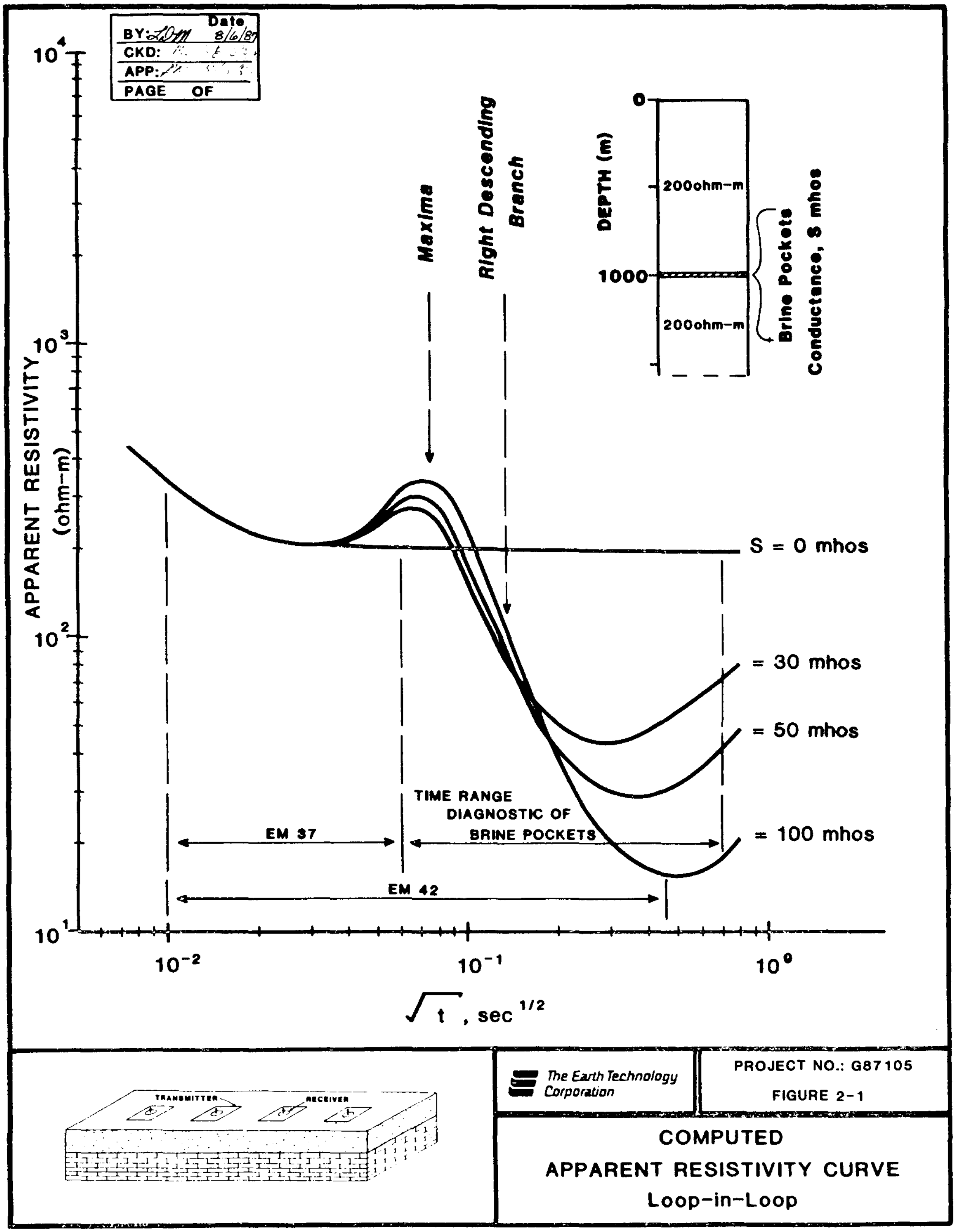


Figure 2-1. Computed Apparent Resistivity Curve

3.0 RESULTS

3.1 GENERAL

The final product of a TDEM sounding is a geoelectric section; i.e., the resistivities and thicknesses of strata encountered within the effective depth of exploration of the measurement. These geoelectric sections are obtained from ridge regression inversions of measured apparent resistivity curves(or EMFs). The inversion process and programs employed were described in the Field Operations Report. Figure 3-1 shows a typical apparent resistivity curve and the geoelectric section derived from the inversion. The inversion consists of four layers of different resistivities.

To interpret this geoelectric section in terms of geologic information and brine occurrences, the geoelectric section is compared in Figure 3-2 with a formation and lithologic log derived from drill holes in the general area, and from published cross-sections (e.g., Barrows et al., 1982). The lithologic log shows the thickness of each formation encountered near the site and the expected variation in their thicknesses in the general vicinity of the WIPP site. Comparison of the geoelectric section, derived from the inversion of TDEM data with the geologic formation log, forms the basis for interpretation. The upper layer, with resistivities between 25 to 30 ohm-m, corresponds with the siltstones and mudstones of the Dewey Lake Redbeds; the relatively thin layer, with resistivities varying between 3 to 12 ohm-m, corresponds with the Rustler Formation, and the low resistivities are most likely caused by aquifers in the dolomites (Powers et al., 1978). The resistive layer of 120 ohm-m corresponds with the bedded salts of the Salado Formation and Castile Formation.

It is often difficult in induction resistivity surveys to determine the absolute value of highly resistive layers sandwiched between two conductive layers. For this reason the resistivity of the bedded salts was fixed in the inversion at 120 ohm-m. This value was determined by digitizing the dual induction log from hole ERDA #9 and subsequently computing an effective longitudinal resistivity. The geoelectric section derived from surface TDEM surveys cannot distinguish between bedded salts in the Salado, Castile, or Bell Canyon Formations.

The layer of very low resistivity represents brine saturated layers. This conclusion is based on the knowledge that in this geologic section there are no other likely causes of resistivities of about 1 ohm-m. Also, the depth of occurrence of the low resistivity layer correlates well with the observed depth of brines in the Bell Canyon Formation in several close oil and gas wells (for instance, Cabin Boy and Pogo #1 Federal).

3.2 SURVEY OVER WASTE STORAGE PANELS

The results of 36 soundings in the 1.5 by 1 km grid directly overlying the waste storage panels all display a similar behavior. The most important observation made from the 36 soundings is that there is no evidence for brine occurrences above 1000 m. The first occurrence of brine is observed over the entire grid at depths between 1050 and 1400 m, or approximately 400 to 600 m below the depth of the mined waste storage panels. The depth of occurrence of low resistivity corresponds with the known depth of the Castile and Bell Canyon Formations.

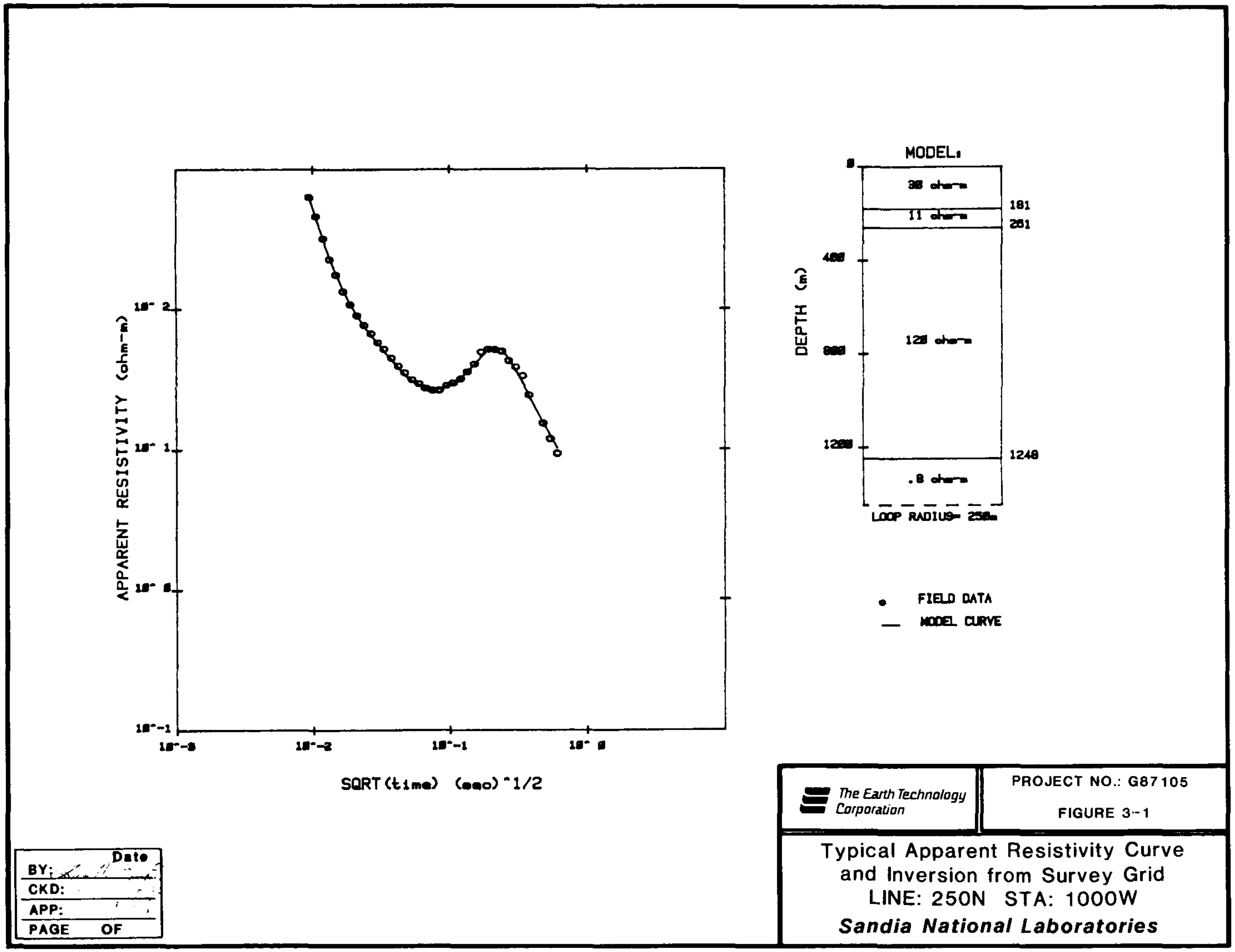


Figure 3-1. Typical Apparent Resistivity Curve and Inversion from Survey Grid

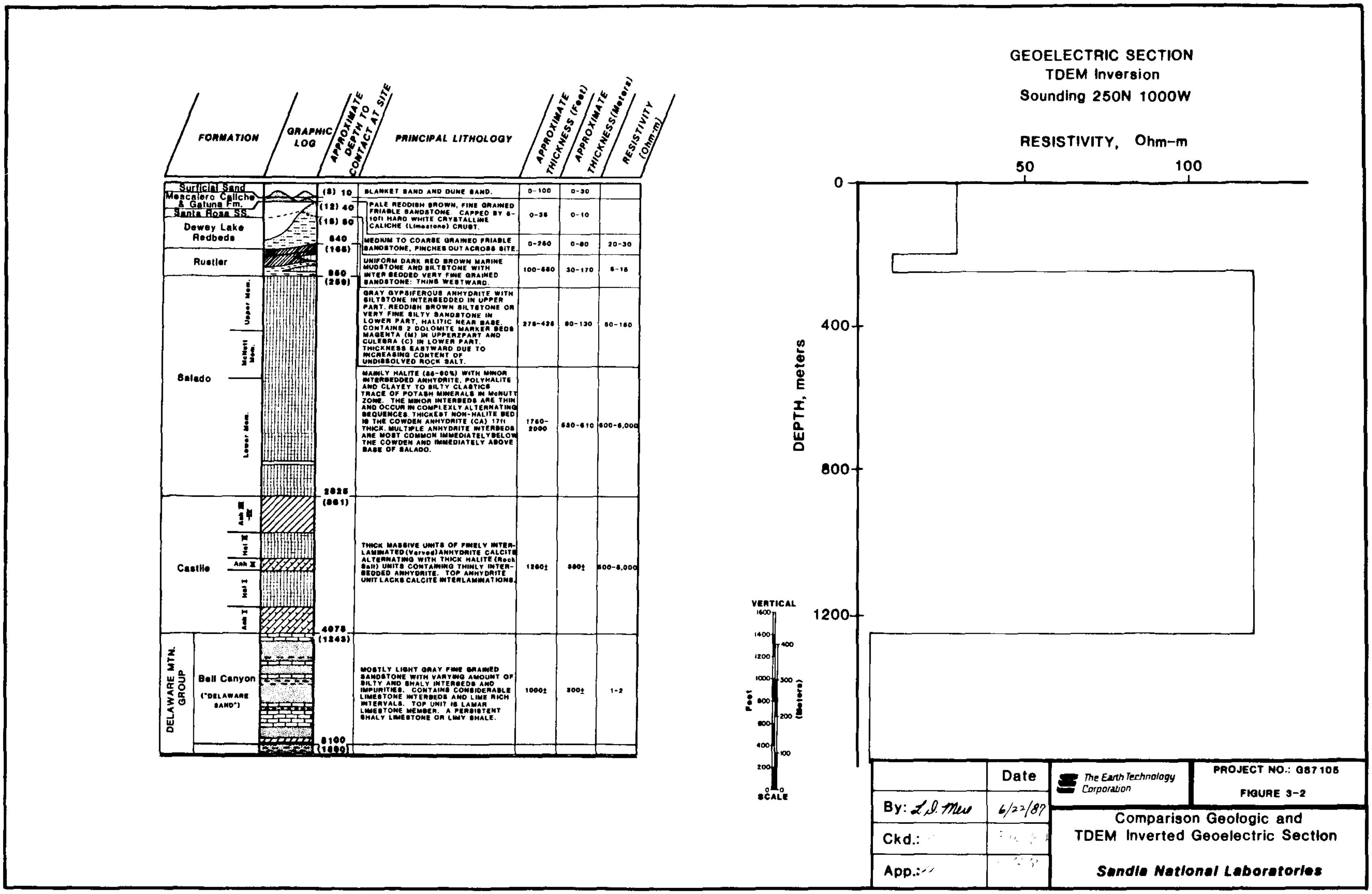


Figure 3-2. Comparison of Geologic and TDEM Inverted Geoelectric Section

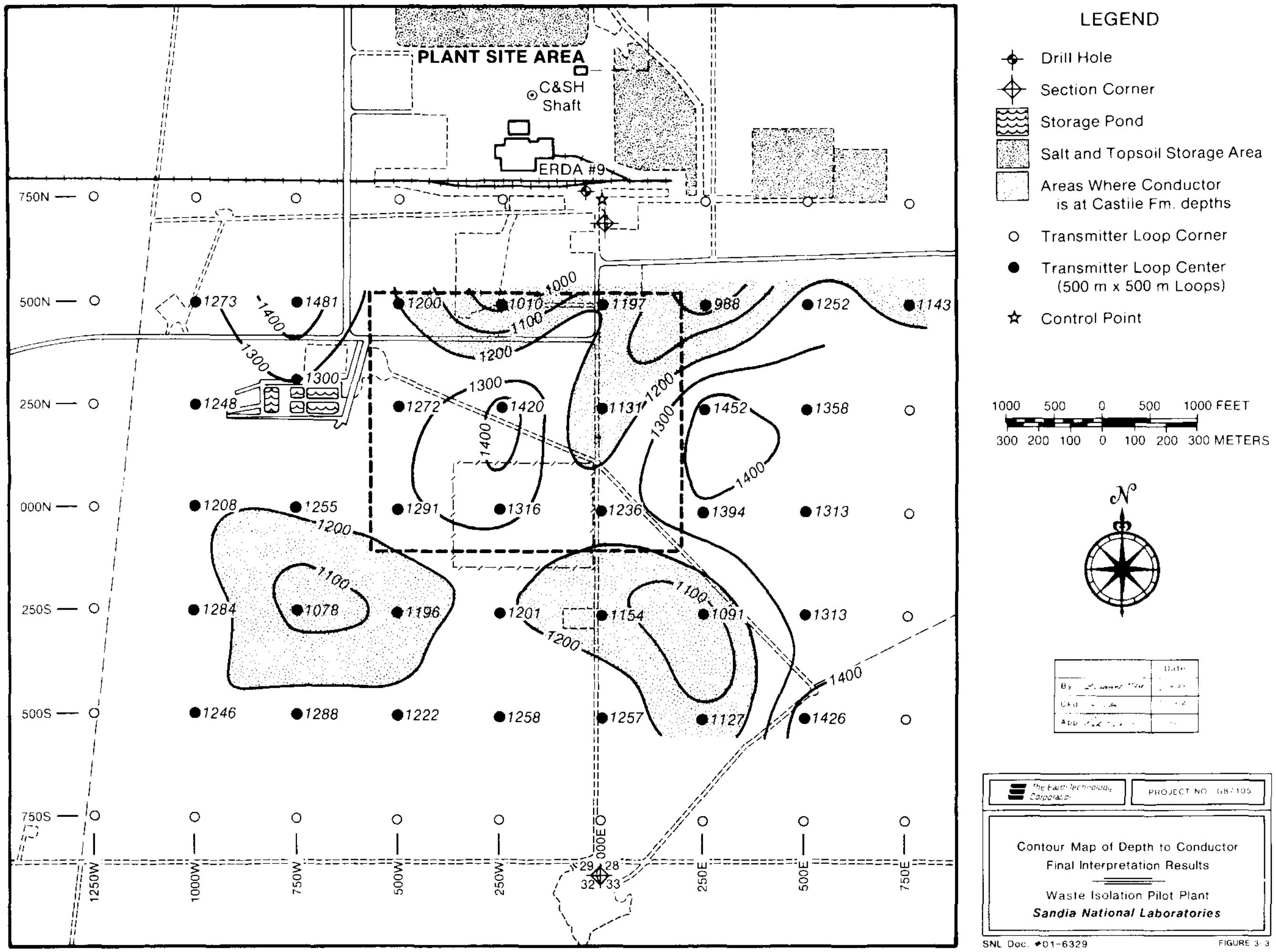


Figure 3-3. Contour Map of Depth to Conductor - Final Interpretation Results

The results of the 38 TDEM soundings are displayed as map contours based on the depth to brine (Figure 3-3) and geolectric cross-sections (Figures 3-4 and 4-11). In Figure 3-5 the TDEM inversion is compared with the dual induction log run in drill hole ERDA #9. The log of ERDA #9 was digitized and mean longitudinal resistivities computed for each strata. The resistivity of the bedded salts was fixed at 120 ohm-m in the inversions, based on the induction log in ERDA #9. All other parameters were allowed to float. The TDEM-derived geoelectric section agrees well with the induction log. The low resistivity values in the upper portion of the derived TDEM geoelectric section correlate with the position of the Rustler Formation in the log.

3.3 TDEM SOUNDING AT WIPP #12 AND DOE #1

The map of Figure 1-1 shows the location of the transmitter loop and receiver station of the sounding near WIPP #12. The receiver station is positioned about 600 m east of the drill hole.

The apparent resistivity curve and the inverted geoelectric section are given in Figure 3-6. A stratum of low resistivity (1.3 ohm-m) is observed at a depth of 802 m. There is evidence for a limited thickness (200 m) of this layer in the data. Figure 3-7 compares the geoelectric section with the well log information at WIPP #12 (Spiegler, 1982). In the drill hole brine was produced from a fracture at the base of an anhydrite unit within the Castile Formation. The range of specific conductances measured on the brines produced in WIPP #12 was 0.42 mho/m to 0.6 mho/m (TDS 310,000 mg/l to 340,000 mg/l). There clearly is excallent agreement between the depth of brine production in the drillhole and the depth of the low resistivity layer derived from the TDEM soundings.

To contrast typical apparent resistivity curves obtained over the waste storage panels and at DOE #1 (about 1.5 km south of WIPP #12) with the apparent resistivity curve measured near WIPP #12, the two data sets are superimposed in Figure 3-8. The differences are readily apparent:

- The maximum in the apparent resistivity curve from WIPP #12 occurs at a substantially earlier time than in sounding DOE #1. The positions of maxima are diagnostic of the depth to the brine layer.
- The right descending branch is steeper for sounding DOE #1 than for the sounding from WIPP #12. At WIPP #12 the right descending branch curves upward, indicating the influence of a resistive layer under the brine.

The two curves are very similar above 800 m. Indeed, little resistivity variation is expected in the Dewey Lake Redbeds, Rustler and Salado Formations between the location of drill hole WIPP #12, and the location of the survey grid and DOE #1.

The fact that the occurrence of brine was clearly detected in the Castile Formation near WIPP #12 gives confidence to the interpretation that no brine pockets exist above 1000 m in the area of the waste storage panels. However, since only one sounding was made near WIPP #12, the extent of the brine pocket has still not been determined.

The TDEM sounding near DOE #1 is given in Figure 3-9. The inversion of this sounding shows no evidence of shallow occurrence of brine, and indeed none was encountered in the drill hole. The

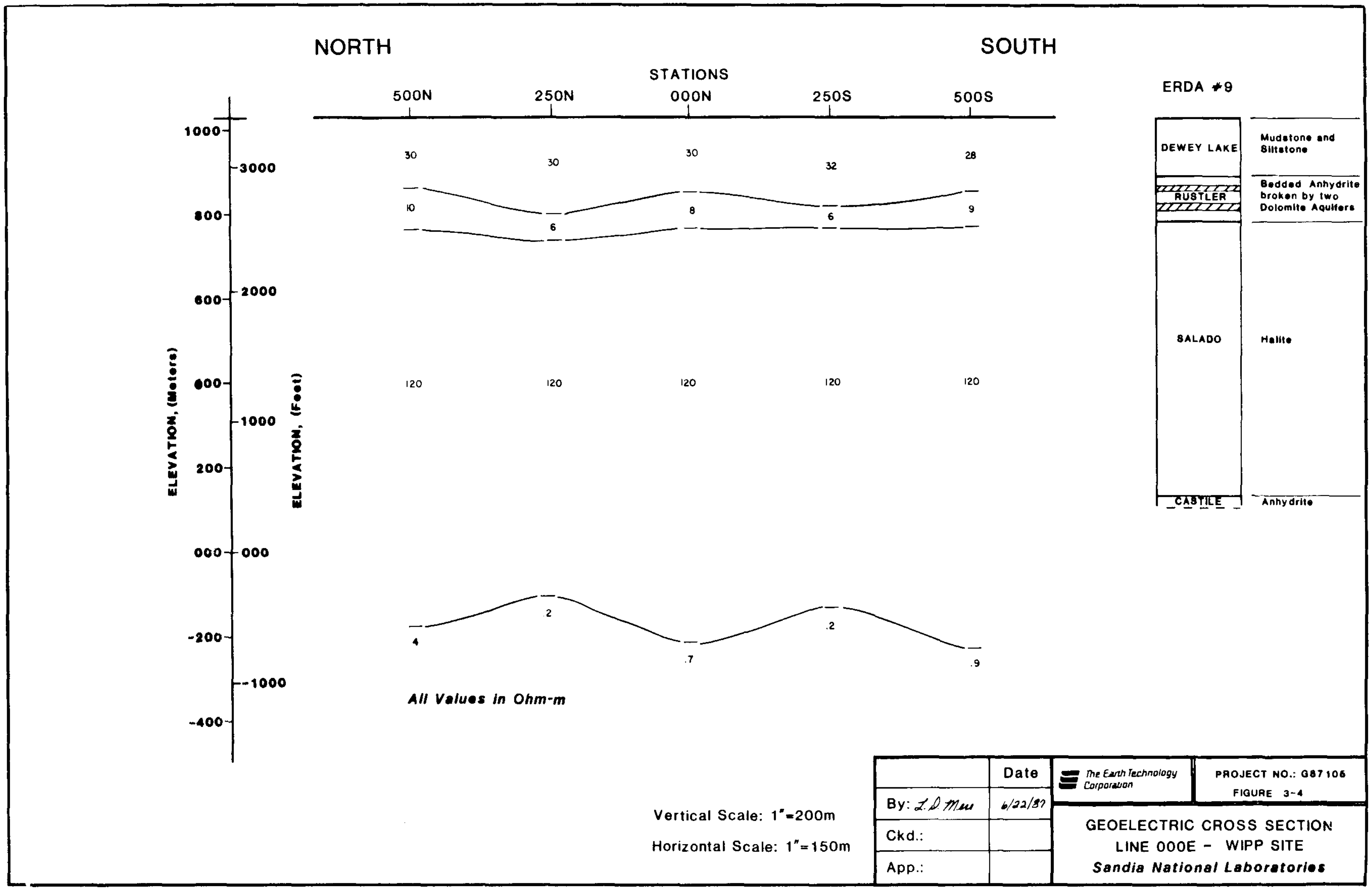


Figure 3-4. Geoelectric Cross-Section - Line OOOE-WIPP Site

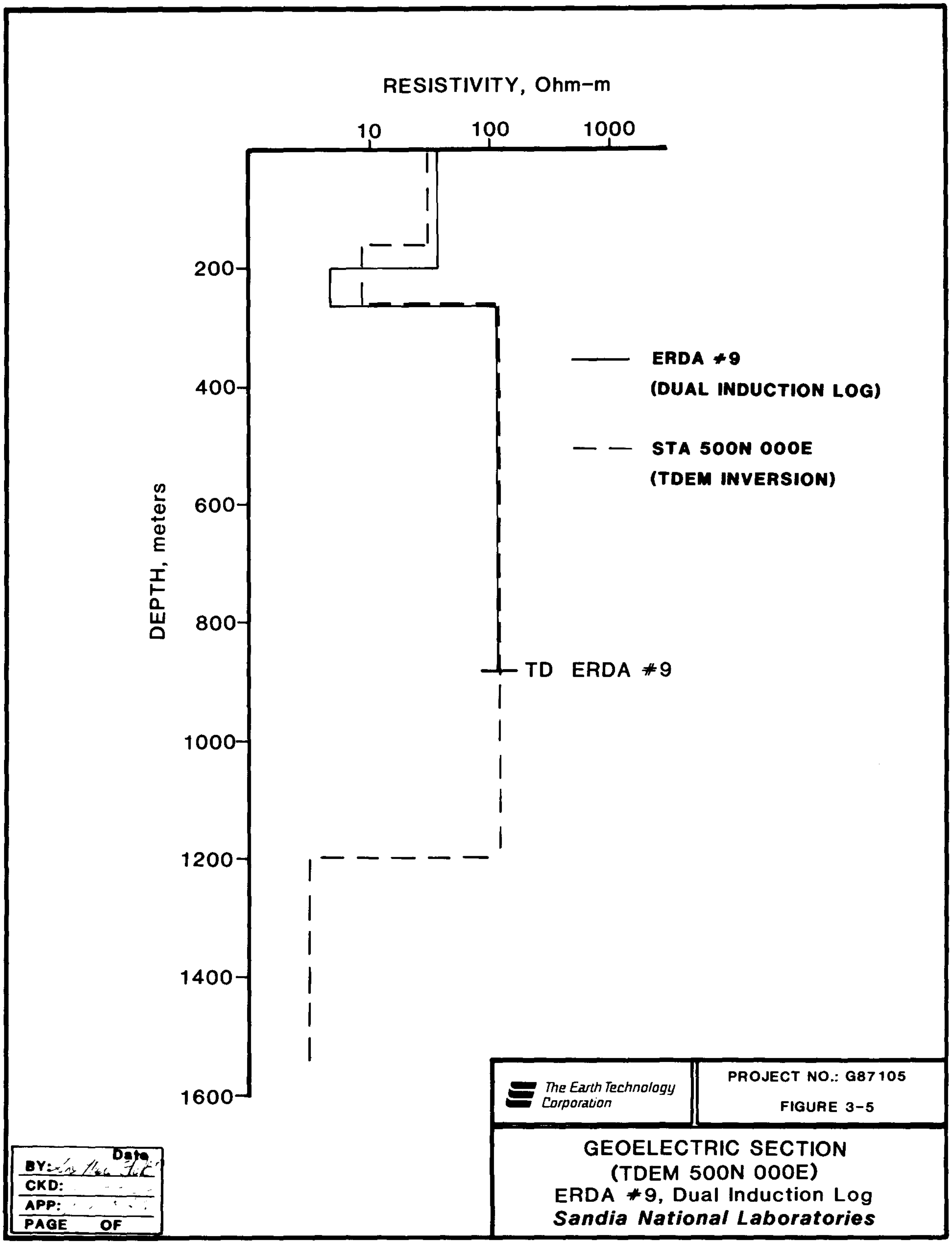


Figure 3-5. Geoelectric Section (TDEM 500N OOOE) ERDA #9 (Dual Induction Log)

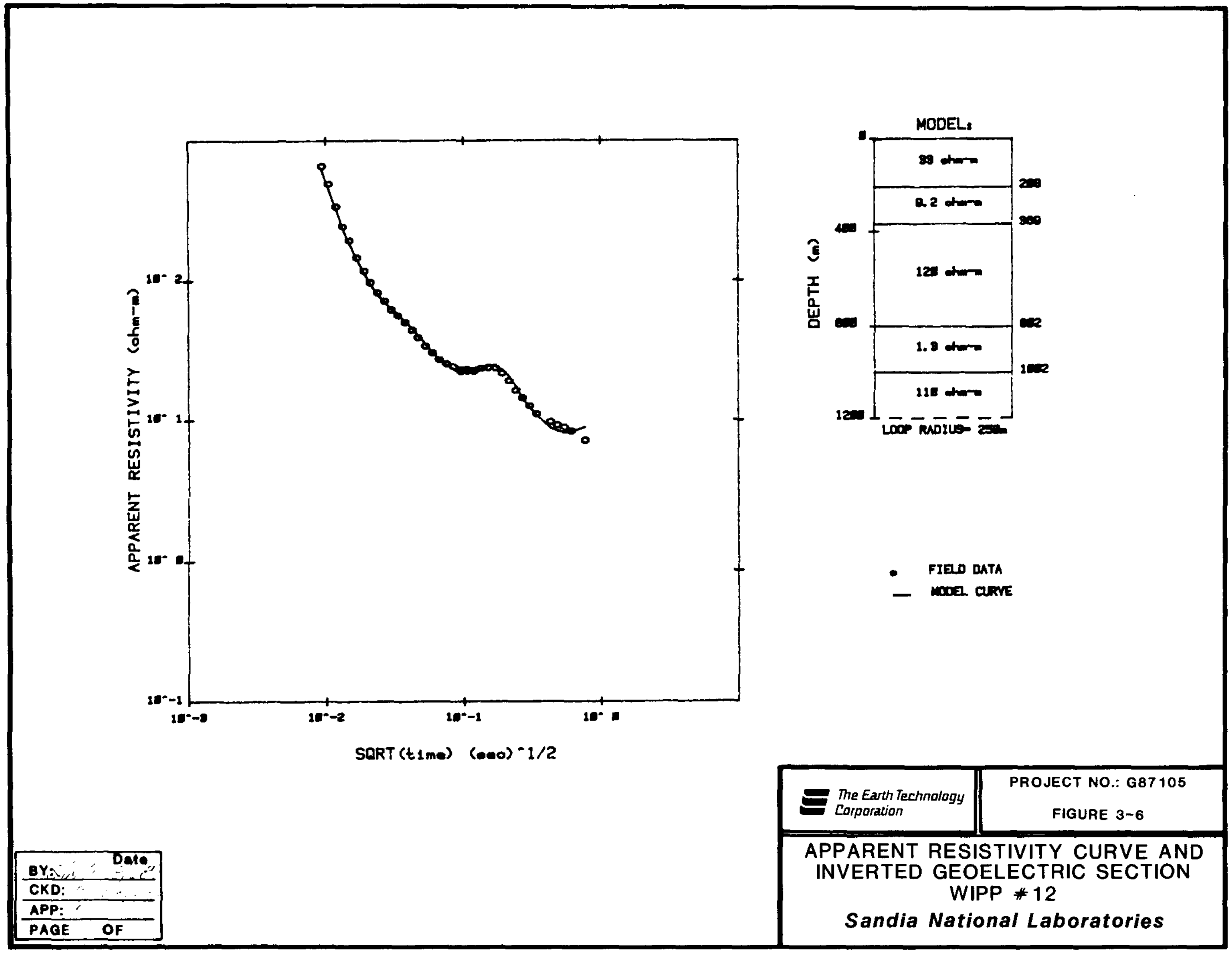


Figure 3-6. Apparent Resistivity Curve and Inverted Geoelectric Section-WIPP #12

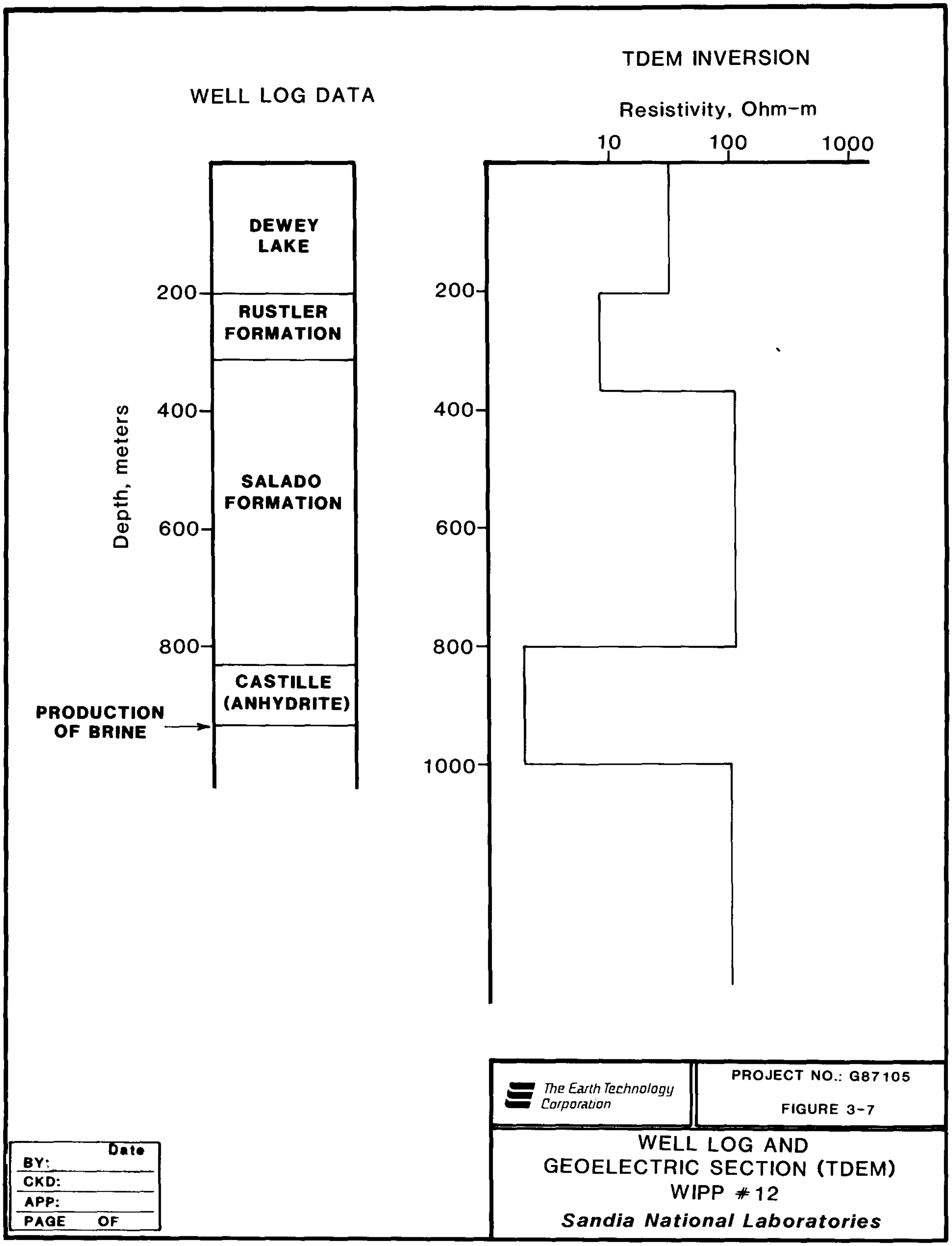
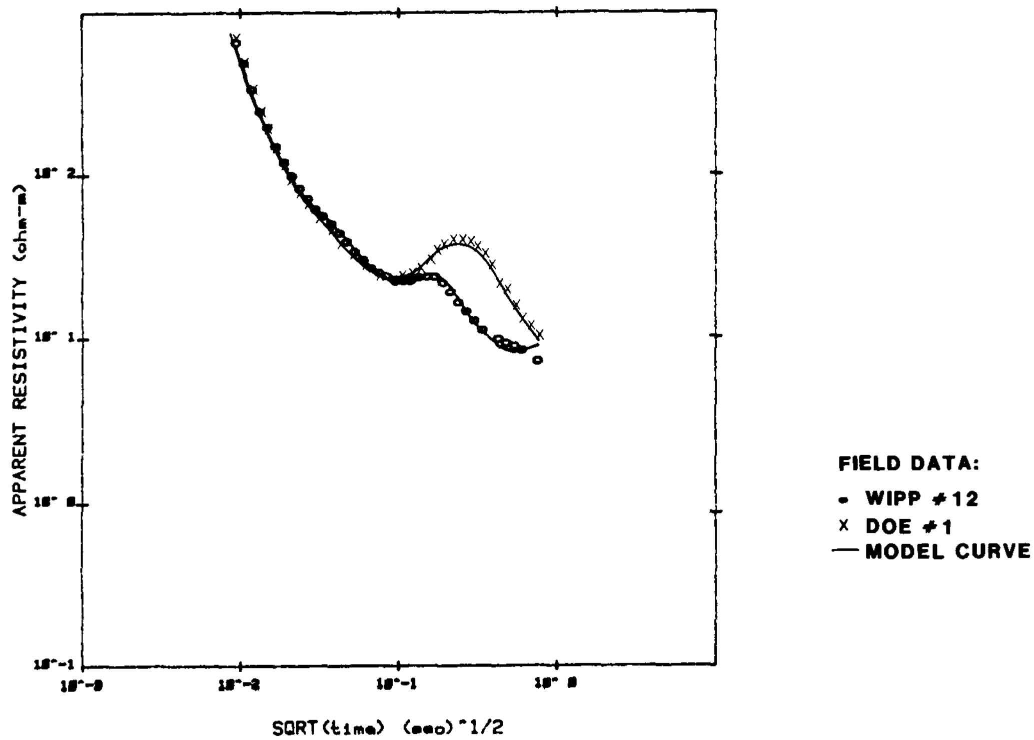


Figure 3-7. Well Log and Geoelectric Section (TDEM)- - WIPP #12



The Earth Technology Corporation	PROJECT NO.: G87105 FIGURE 3-8

Comparison of
Apparent Resistivity Curve
at Drill Holes Wipp #12 and Doe #1
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Figure 3-8. Comparison of Apparent Resistivity Curves at Drill Holes WIPP #12 and DOE #1

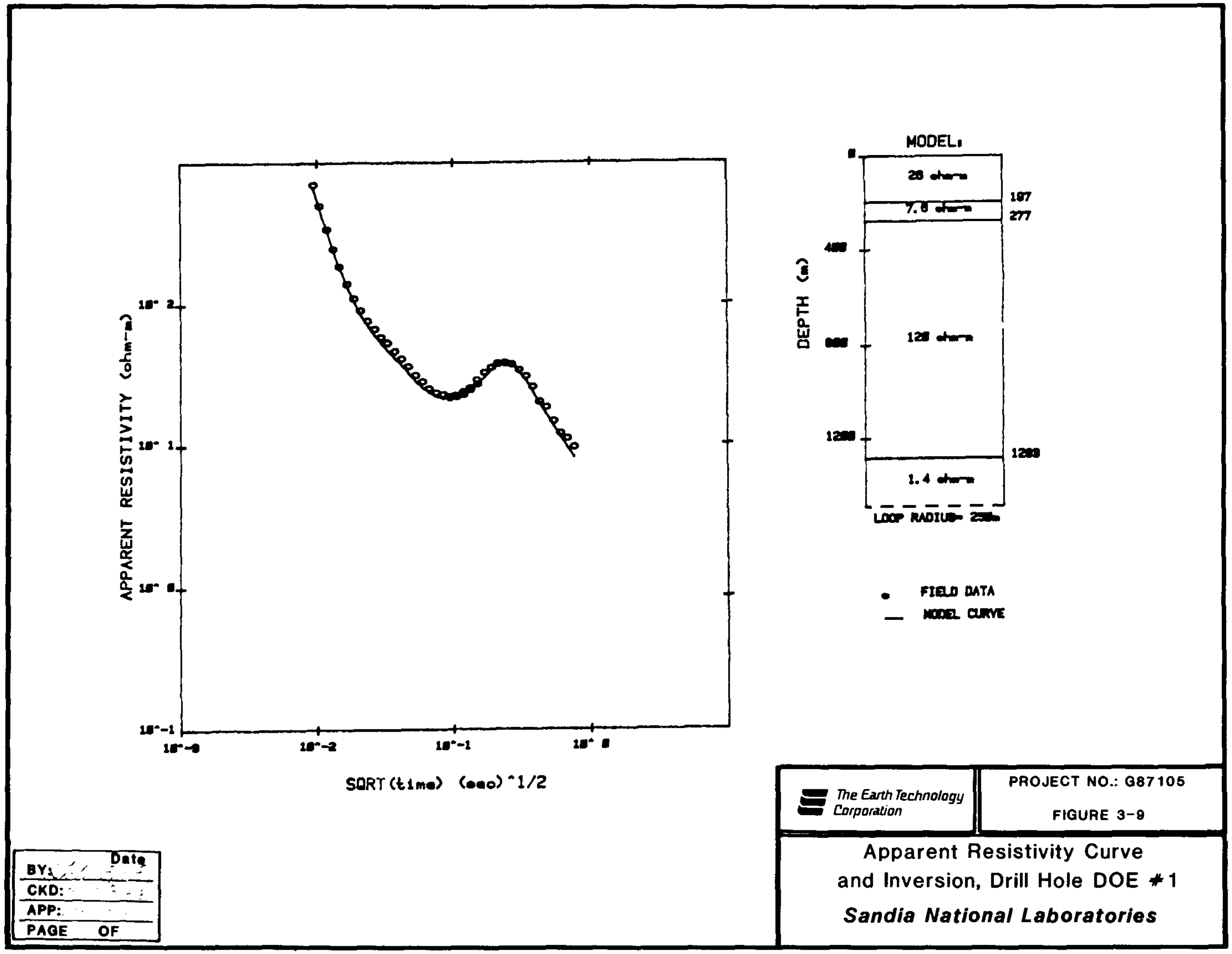

Figure 3-9. Apparent Resistivity Curve and Inversion, Drill Hole DOE #1

geoelectric section of DOE #1, located about 500 m east of the main survey grid, is similar to the section observed over the grid.

3.4 COMPARISON OF PRESENT TDEM SURVEYS WITH PRIOR ELECTRICAL SURVEYS AND INVESTIGATIONS

Several surface electrical surveys were conducted prior to the TDEM survey at the WIPP site. Bartel et al. (1983) conducted several CSAMT surveys near the WIPP #12 area. In Figure 3-10 a typical pseudo-section from the vicinity of WIPP #12 is given. In these sections, apparent resistivities along a profile are plotted versus horizontal distance and frequency of electromagnetic waves. In Figure 3-10, this pseudo-section is compared with a geoelectric section derived from inversion of TDEM data.

There are striking similarities between the two data sets. The resistivity stratification has the same behavior with depth. Resistivities of about 20 to 30 ohm-m are observed in the near surface layers (Dewey Lake Redbeds). This layer is underlain by a layer with resistivities of about 10 ohm-m, corresponding to the Rustler Formation. The Rustler Formation is subsequently underlain by the resistive bedded salts in the Salado Formation. In the TDEM inversions the resistivities of the bedded salts were fixed at 120 ohm-m, based on the induction log in drill hole ERDA #9.

The Rustler Formation is seen in the CSAMT data at frequencies of 512 and 256 hertz. If effective exploration depth is assumed to be about equal to one skin depth, then these frequencies correspond to depths between 121 and 171 m. This is within about 50 m of the depth derived from TDEM inversions and in drill holes. Skin depth, however, is a very approximate measure of effective exploration depth.

Faculty and students from the Department of Geophysics, Colorado School of Mines (Keller et al., 1987), carried out experimental surveys with both electrical (direct current) and electromagnetic methods on the surface over the WIPP site and underground in mine workings.

Magnetic induction conductivity measurements were made with the Geonics EM-31 and EM-34 in the tunnel opening in the bedded salts of the Salado Formation. The range of resistivity values observed on various profiles was between 100 and 200 ohm-m, in good agreement with the values observed in the dual induction log of ERDA #9. The results of these measurements in the drift in the bedded salts also confirms the validity of using a value of 120 ohm-m in the inversion of the TDEM data.

In summary, the geoelectric parameters of the Formations derived from various electrical and electromagnetic techniques at the WIPP site agree.

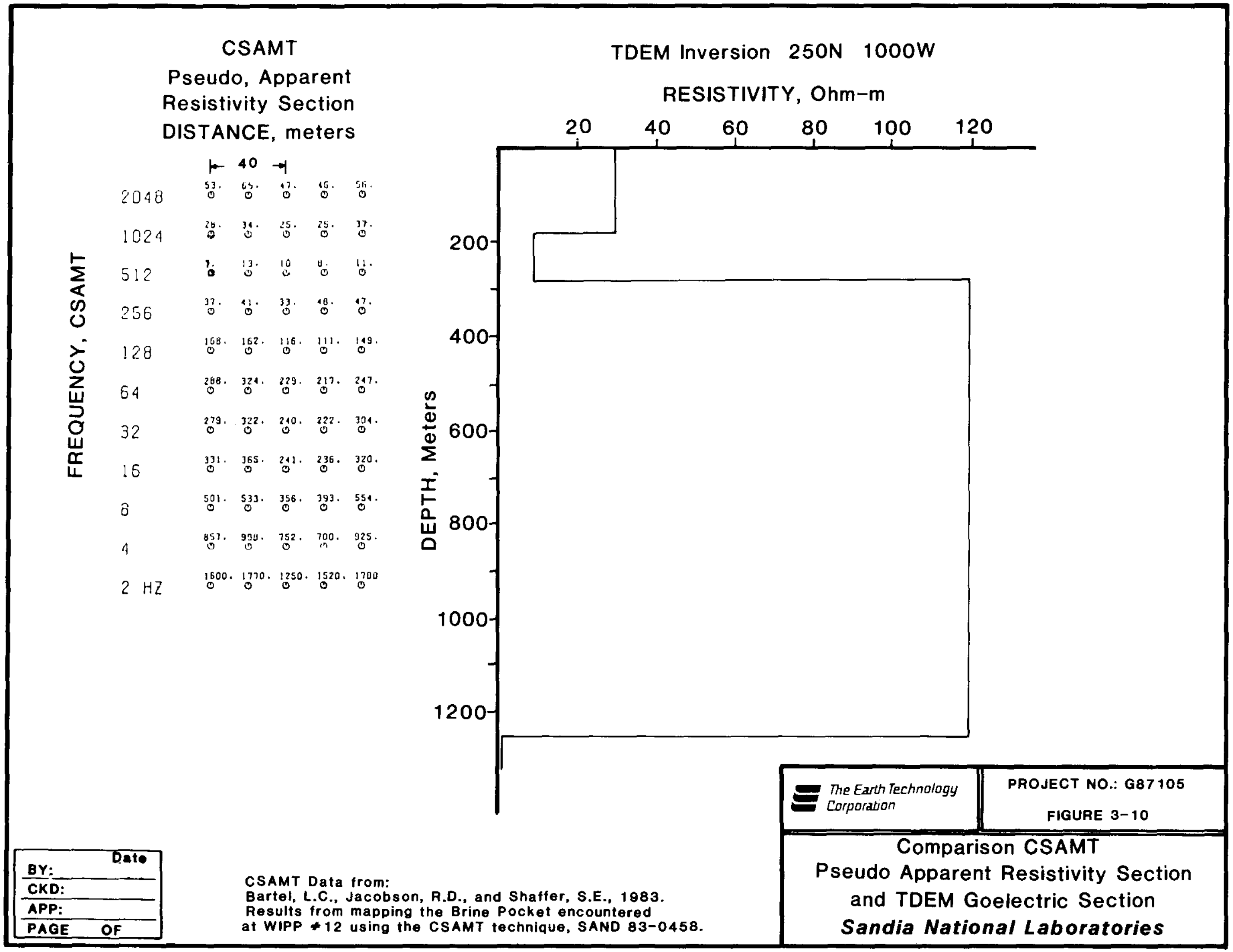

Figure 3-10. Comparison of CSAMT Pseudo Apparent Resistivity Section and TDEM Geoelectric Section

4.0 DATA QUALITY AND ACCURACY OF INVERSIONS

4.1 GENERAL

There are three main factors that affect the vertical resolution of determining depth to brine:

- The accuracy of measuring electromotive forces (EMFs) as a function of time after turn-off
- The non-uniqueness or range of equivalence of inversions of measured EMFs in geoelectric sections
- The validity of one-dimensional interpretations.

4.2 ACCURACY OF MEASURING ELECTROMOTIVE FORCES

In central loop TDEM soundings, the geoelectric section is derived from measuring the EMFs due to the vertical magnetic fields in the center of transmitter loops. The EMFs decay rapidly with time, as is illustrated in Figure 4-1. In fact, at late stage the EMFs decay as time -5/2 (Kaufman and Keller, 1983). For that reason, EMFs are measured to high degrees of accuracy at earlier time gates, but accuracy is less in later time gates, where small EMFs need to be measured.

The Geonics EM-42 system displays for the operator in real time the EMFs as a function of time with error bars. A typical example is given in Figure 4-2. The error bar encloses the 90% confidence limit of the data. The typical data set of Figure 4-2 shows that EMFs could be measured down to a field strength of 10-12 volt/(amp-m2).

The fact that the error in EMFs increases in later gates is not necessarily the main effect in determining the vertical resolution of depth to brine. On the typical apparent resistivity curve in Figure 4-3, the region of time diagnostic of depth to brine is indicated. It is the section of the curve between the maximum and a portion of the right descending branch. As long as there are 3 or 4 points on the right descending branch with small error bars, the vertical resolution will not be significantly influenced by later points with larger error bars. In TDEM, each section of the curve is generally diagnostic of a certain depth in the geoelectric section. If EMF is measured to good accuracy in the diagnostic time range, vertical resolution is mainly determined by non-uniqueness and range of equivalence. This was the case in the majority of TDEM soundings at WIPP. The range of measurement extended well beyond the time range diagnostic of depth to brine.

4.3 NON-UNIQUENESS AND RANGE OF EQUIVALENCE OF INVERSION

Inversions of geophysical data are not unique, but there generally is a range of values for each parameter that matches the observed data with the same error of mismatch. That range of values is called the equivalence of the solution.

Most of the inversions at WIPP required a four layer solution. In a four layer solution there are seven parameters that can be independently varied, five resistivities, and four thicknesses. The only parameter fixed in the inversions at WIPP was the high resistivity layer of the bedded salts in the Salado and Castile Formations. The main objective of the survey was to determine depth to brine and the investigation of equivalence in this section focuses mainly on the vertical resolution in determining that depth.

Equivalence was evaluated on three typical soundings from the survey area (250S 500E, OOON 250W, 250N IOOOW). Forward model computations were performed in which all parameters in a geoelectric section were held constant, except the thickness of the high resistivity bedded salt layer. Since the thickness of the two layers (Dewey Lake Redbeds and Rustler) above the bedded salts was held constant, varying the thickness of bedded salt layers in effect also varies depth to brine. In Figures 4-4, 4-5, and 4-6 the RMS error in the last 15 time gates is plotted versus the thickness of the high resistivity layer. The RMS error can be seen to rapidly increase on both sides of the minima. The overall RMS error of inversions at all WIPP soundings over the important part of the diagnostic time range has been less than 10%. It can be concluded from Figures 4-4, 4-5, and 4-6 that the accuracy of determining depth to brine is better than 75 m.

The range of equivalence in determining the resistivity of the brine layer is evaluated in Figures 4-7, 4-8, and 4-9. The RMS error is derived from forward modeling, holding all parameters of the geoelectric section constant except the resistivity of the brine layer. It is evident from these figures that the equivalence of determining the resistivity of the brine layer is relatively large. The range of equivalence is from about 0.5 to about 2.5 ohm-m.

To determine the influence of the resistivity of the brine layer on determining thickness of the resistive layer, an inversion was made in which all parameters were held constant at various values of brine resistivity, but the thickness of the resistive layer was allowed to float. Figure 4-10 shows the error in thickness of the resistive layer (directly related to depth to brine) at different values of brine resistivity. It can be concluded that the influence of the resistivity of the brine layer on depth to brine is small.

In summary, a limited study of the range of equivalence in depth to brine showed that the accuracy of determining depth to brine on this survey was $\pm$75 m. The range of equivalence of the resistivity of the brine layer is between 0.5 and 2.5 ohm-m. Lack of resolution in determining resistivity of brine has only a small influence on the accuracy of determining depth to brine.

4.3.1 *Variations in Interpreted Depth to Brine*

The interpreted depth to brine in the TDEM soundings over the waste storage panels varies from approximately 1000 to 1500 m. This variation from the expected depth of 1200 m to the Bell Canyon Formation is more than can be accounted for from considering equivalence. This is illustrated in Figure 4-11, which shows the geoelectric cross-section along line 500N with error bars of $\pm$75 m representing the equivalence in determining the depth to the conductor at each sounding location.

The dashed line at 1200 m representing the depth to the Bell Canyon does not pass through all the error bars. Therefore, the variation in depth cannot be accounted for by considering equivalence.

In order to illustrate that the variation is actually present in the data, and not just an error in interpretation, the measured EMF curves at stations 250W, 500W, and 750W were superimposed in Figure 4-12. There is a significant difference between the measured EMFs at the three sounding locations. There is also a significant difference between the apparent resistivity curves as shown in Figure 4-13. Therefore, it is valid to maintain that there is variation in the depth to the conductive layer.

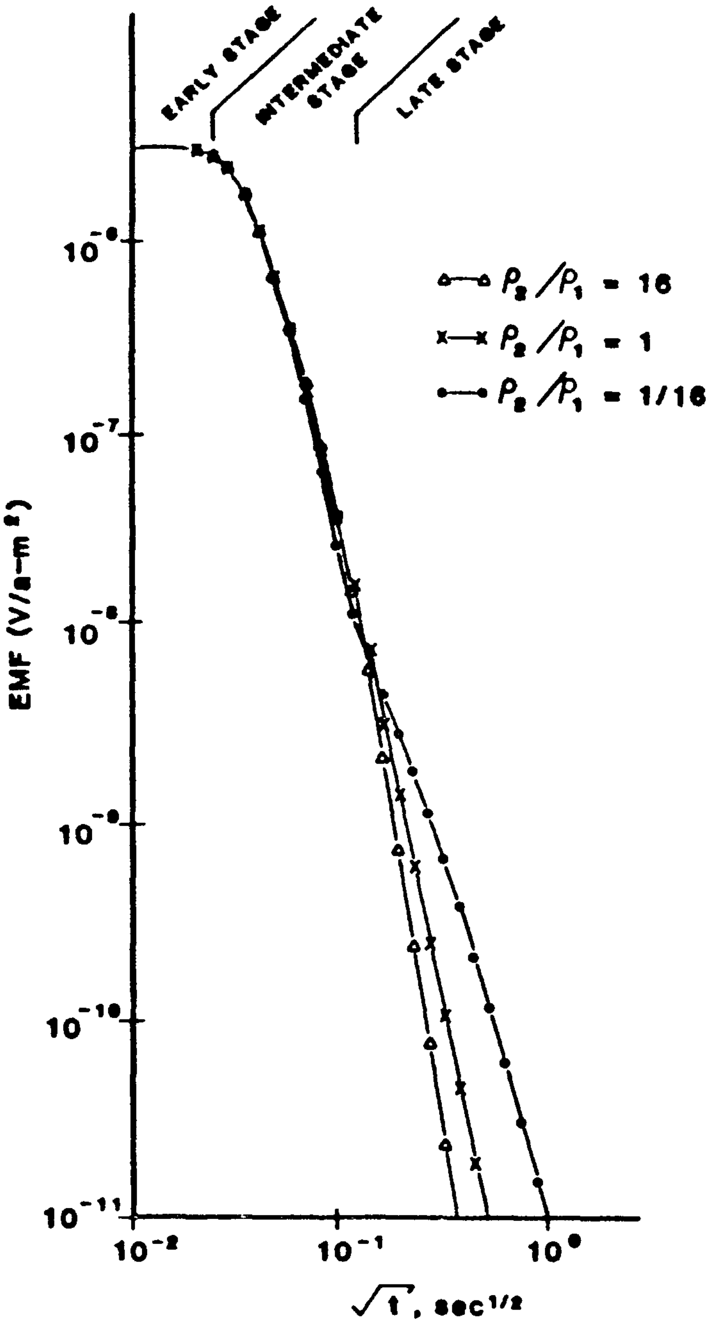

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FIGURE 4-1

BEHAVIOR OF EMF VERSUS TIME FOR TWO-LAYERED SECTIONS

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Figure 4-1. Behavior of EMF versus Time for Two-Layered Sections

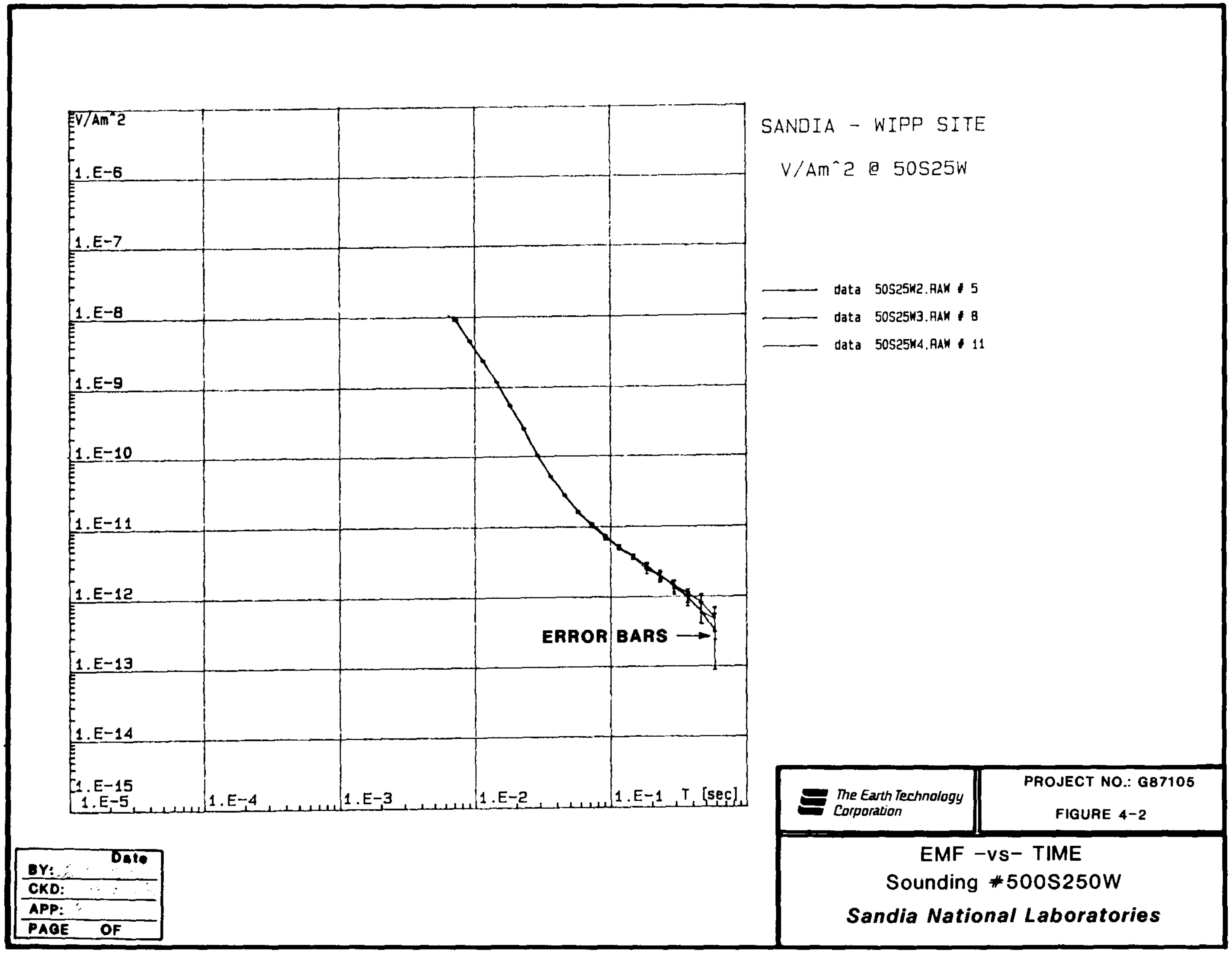

Figure 4-2. EMF versus Time Sounding - Line 500S 250W

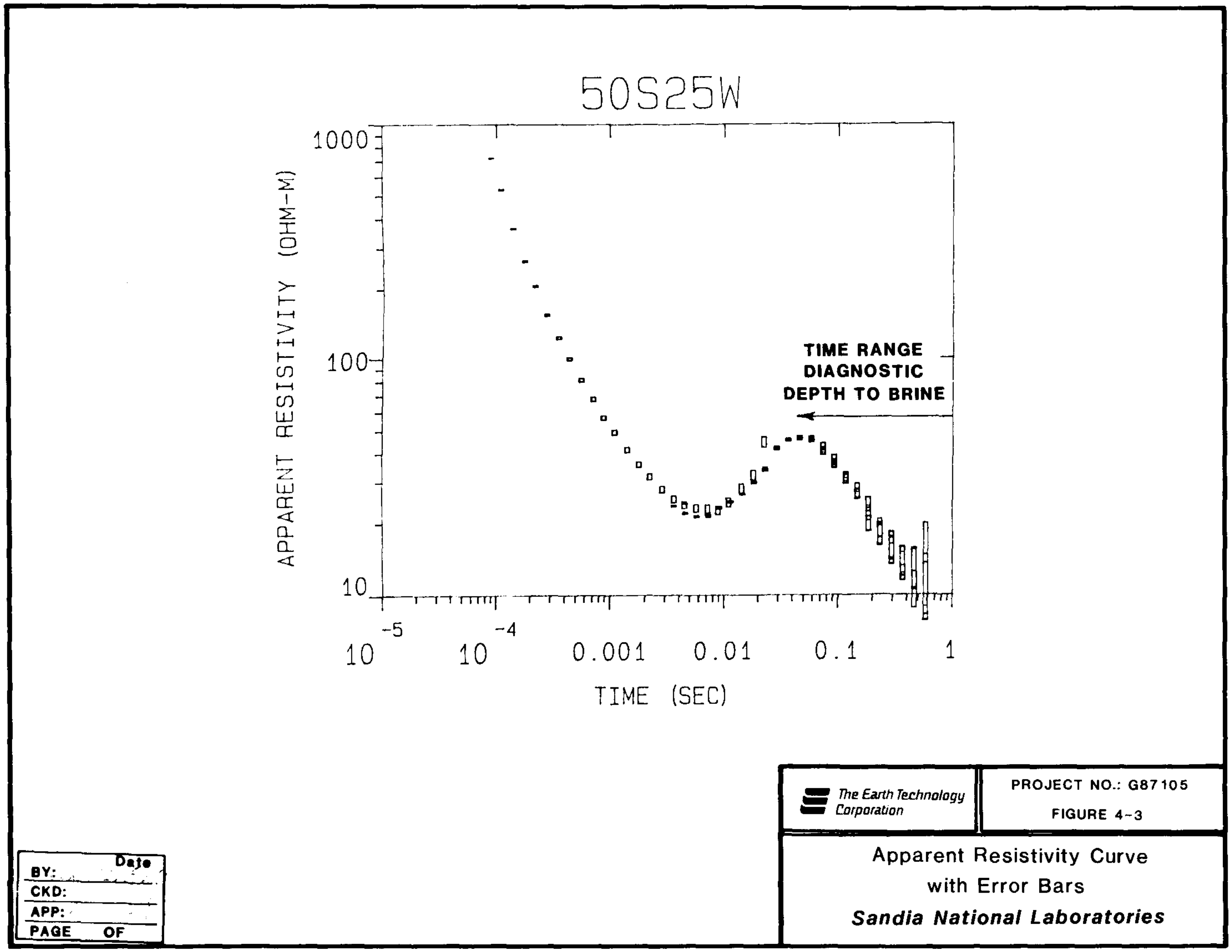

Figure 4-3. Apparent Resistivity Curve with Error Bars

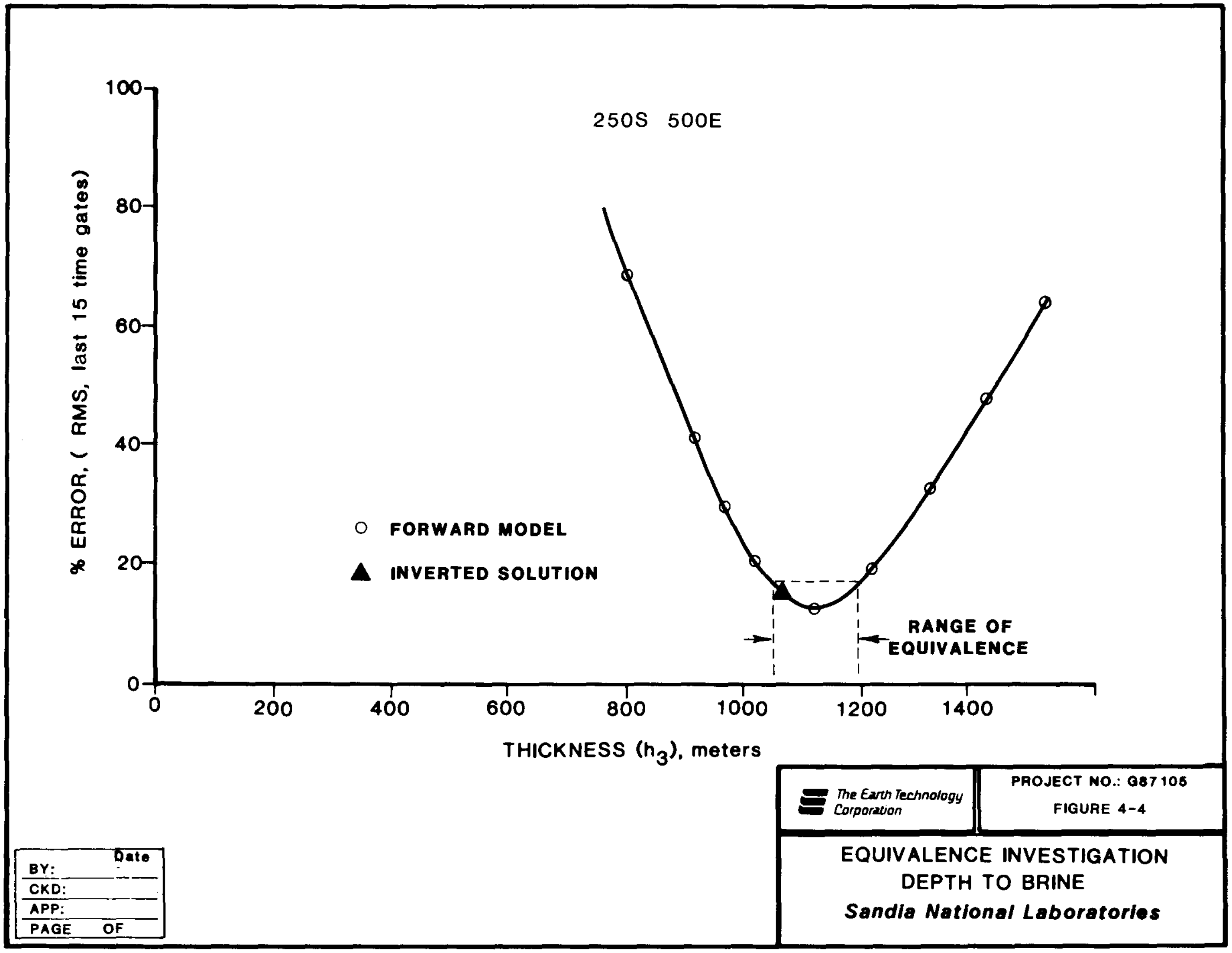

Figure 4-4. Equivalence Investigation - Depth to Brine

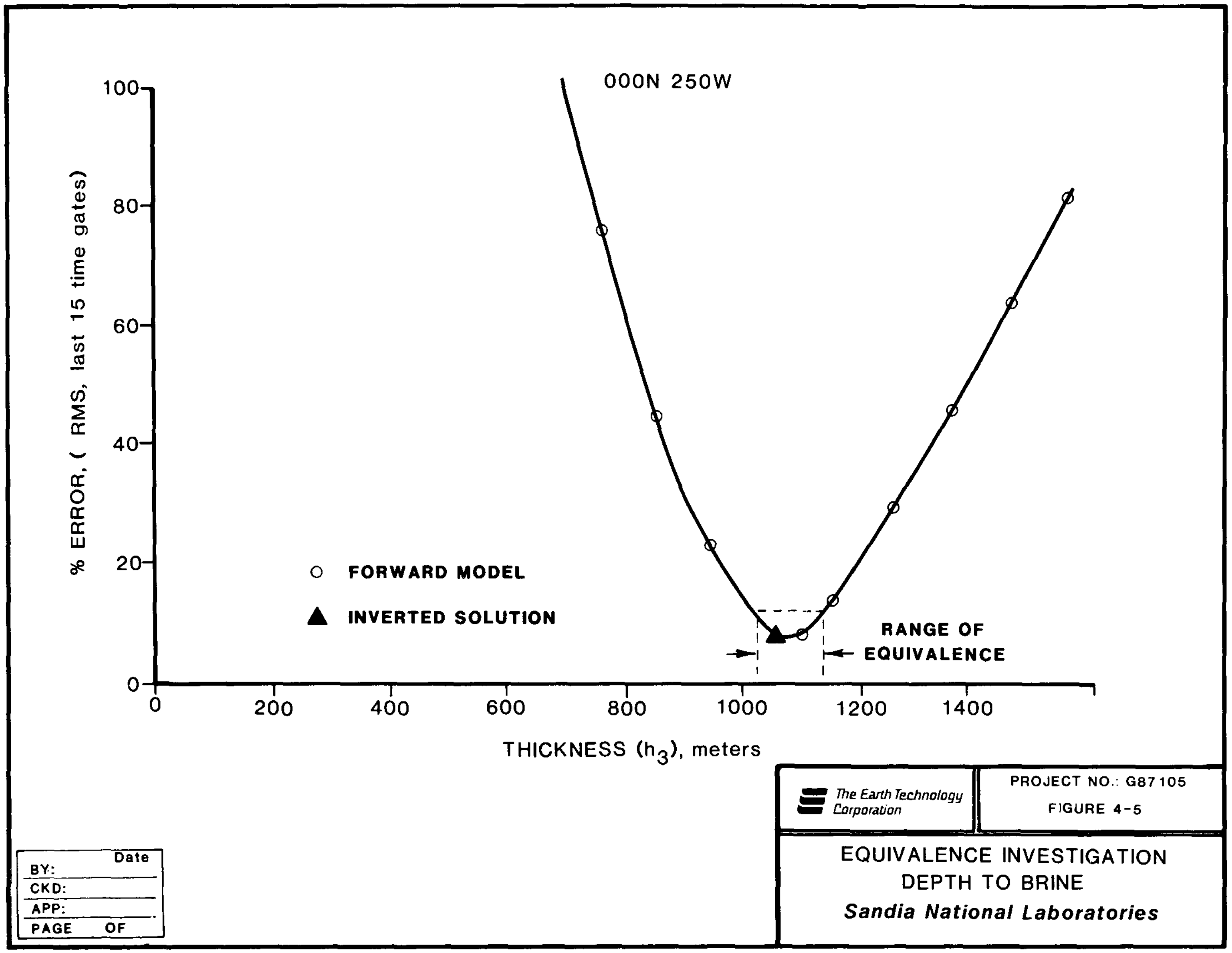

Figure 4-5. Equivalence Investigation - Depth to Brine

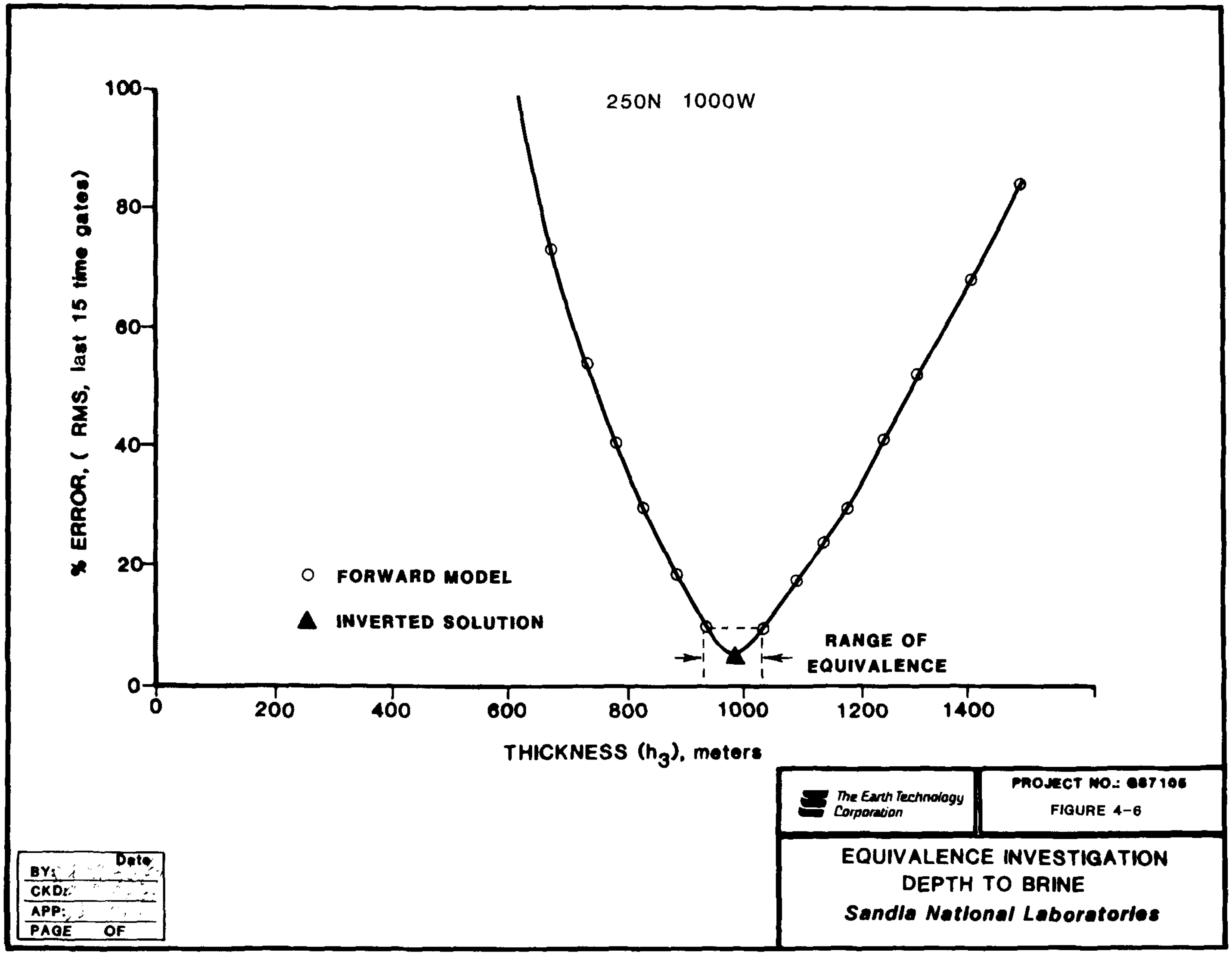

Figure 4-6. Equivalence Investigation - Depth to Brine

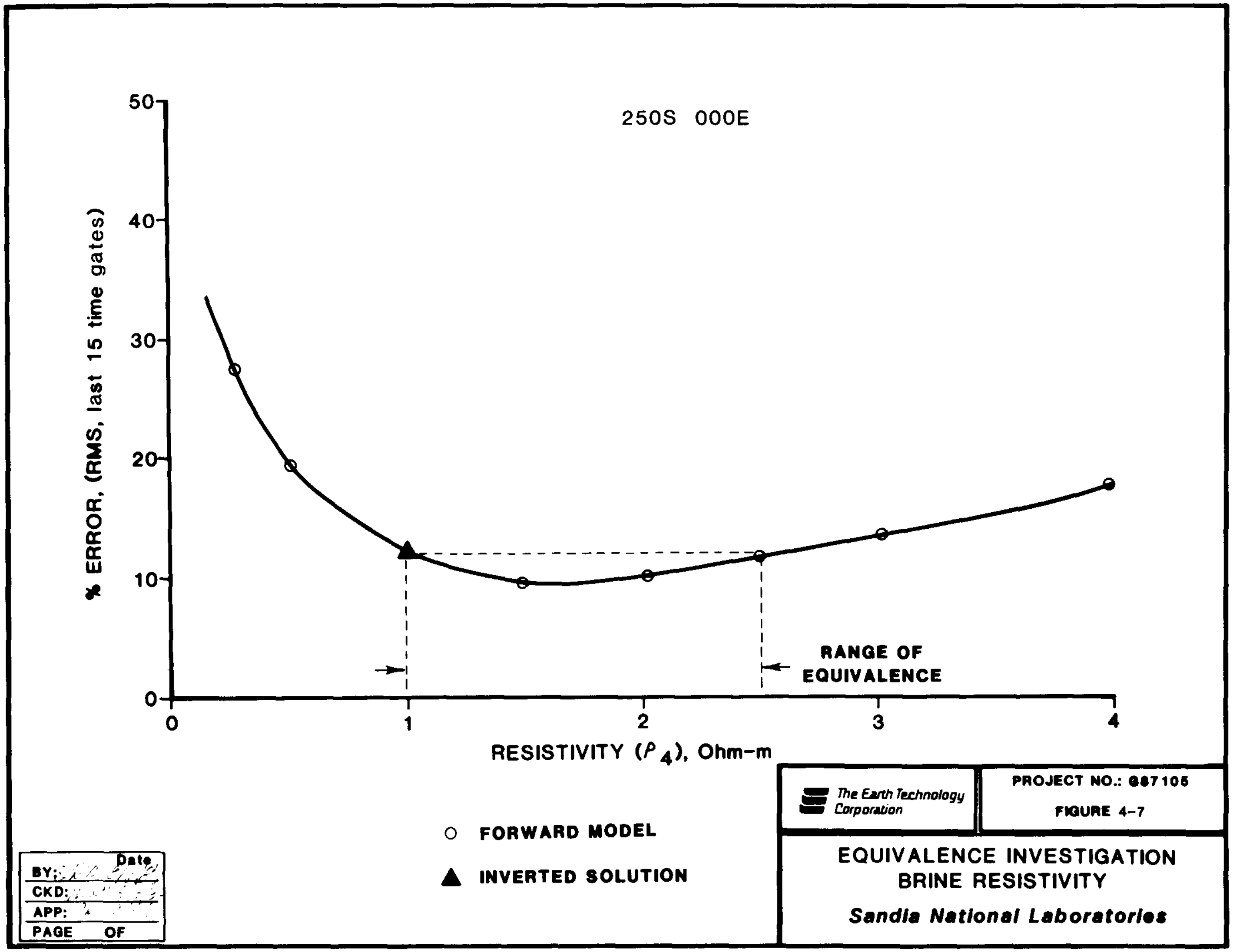

Figure 4-7. Equivalence Investigation - Brine Resistivity

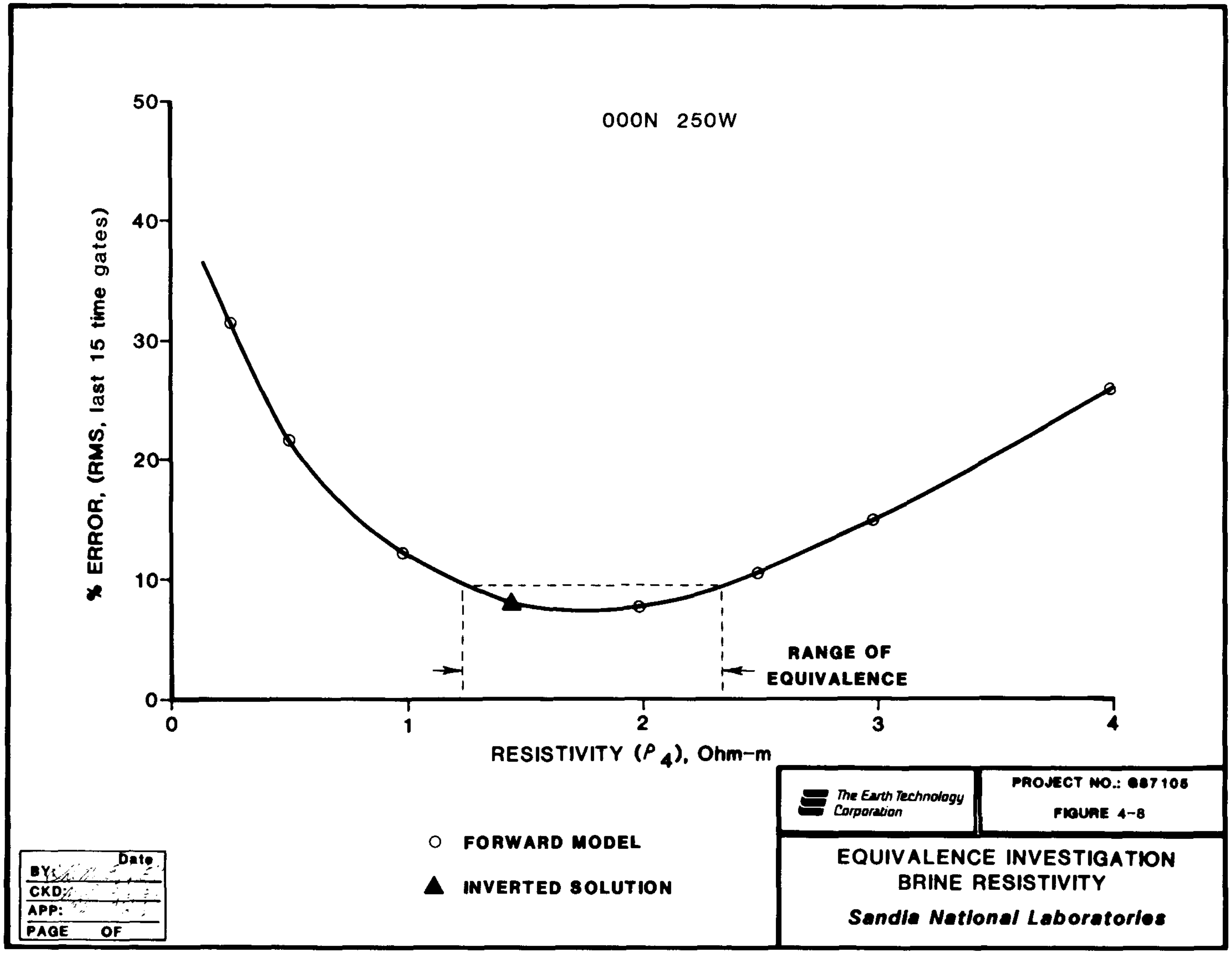

Figure 4-8. Equivalence Investigation - Brine Resistivity

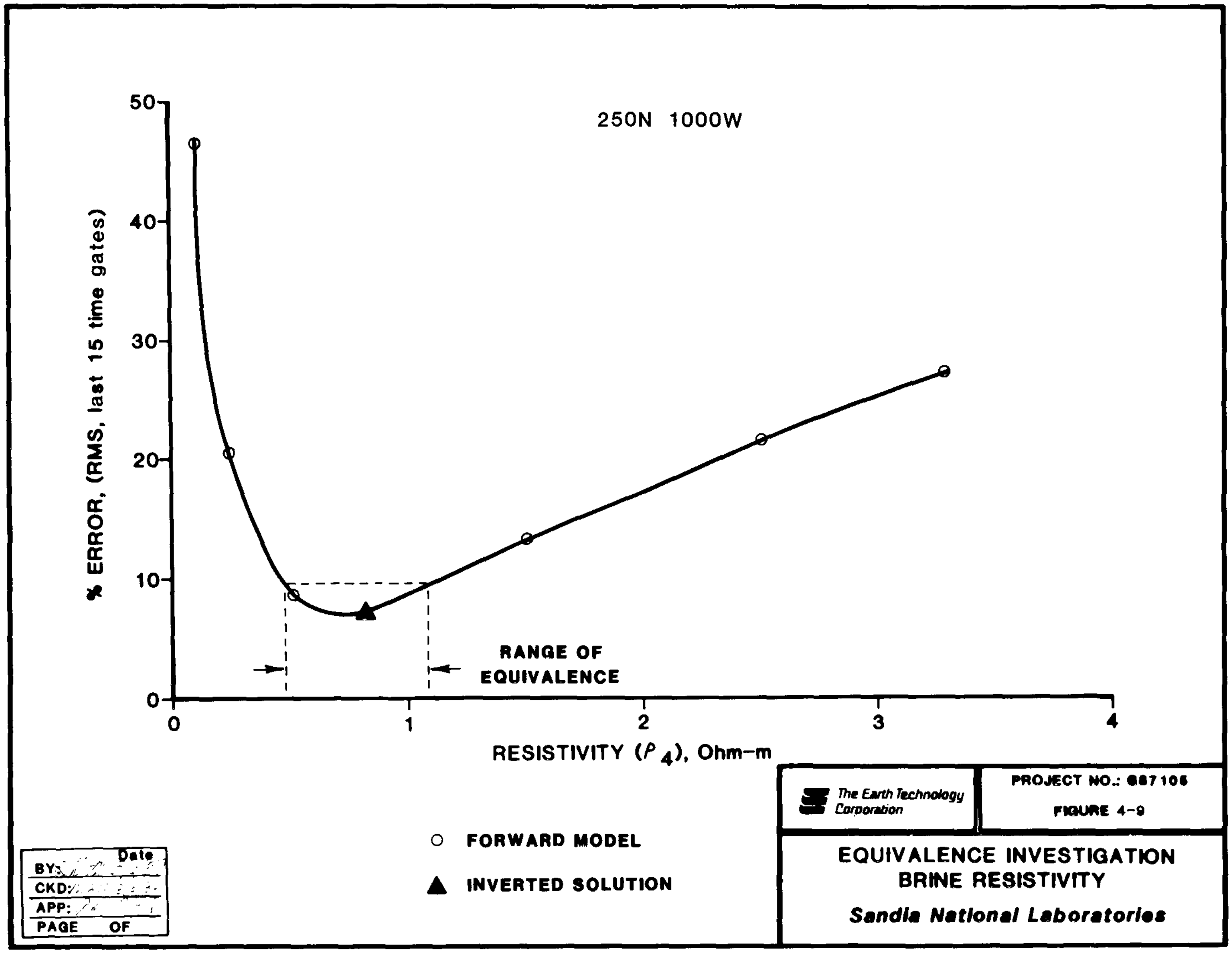

Figure 4-9. Equivalence Investigation - Brine Resistivity

4.4 VALIDITY OF ONE-DIMENSIONAL INTERPRETATIONS

All the soundings at WIPP were interpreted by one-dimensional inversions using an Automatic Ridge Regression Inversion program (ARRTI) created by Interpex Ltd. One-dimensional inversions assume that the geoelectric section consists of near horizontal layers. The available geologic data indicate near horizontal stratification of the formations, and one-dimensional interpretations are expected to be valid. The difficulty of one-dimensional interpretation may, however, arise in mapping localized brine pockets, such as at WIPP #12.

Two-dimensional and three-dimensional modeling of very conductive localized structures in resistive host rock by Anderson and Newman (1985) has shown that one-dimensional interpretations of such structures yield good information about the depth to the conductive target, but has errors in the determination of the resistivity and thickness of the conductive feature.

At the present time, the best argument for the validity of one-dimensional interpretations is the agreement of the geoelectric sections derived from the inversions with three drill holes (WIPP #12, ERDA #9, and DOE #1), as well as consistency with available general geologic and geophysical data.

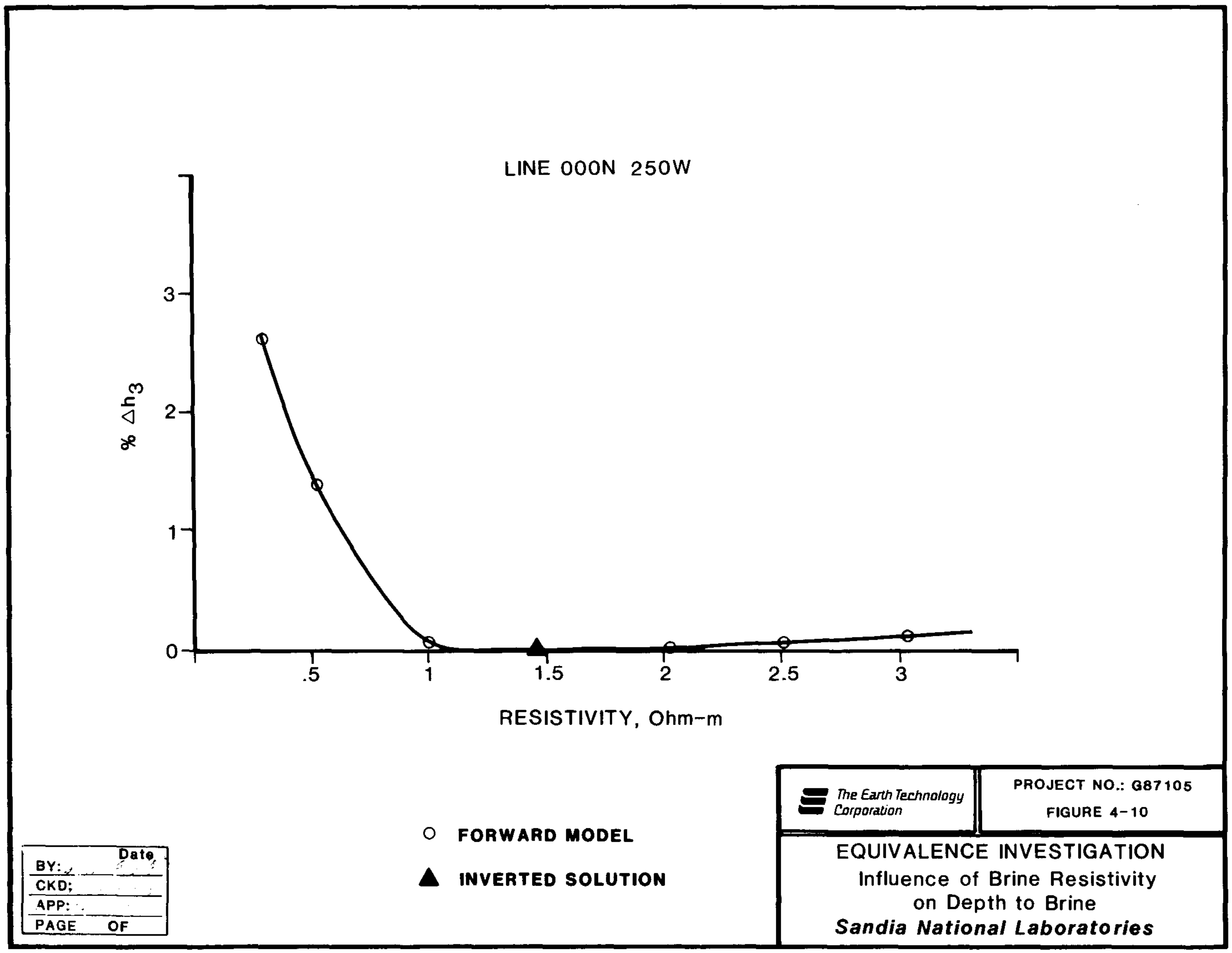

Figure 4-10. Equivalence Investigation - Influence of Brine Resistivity on Depth to Brine

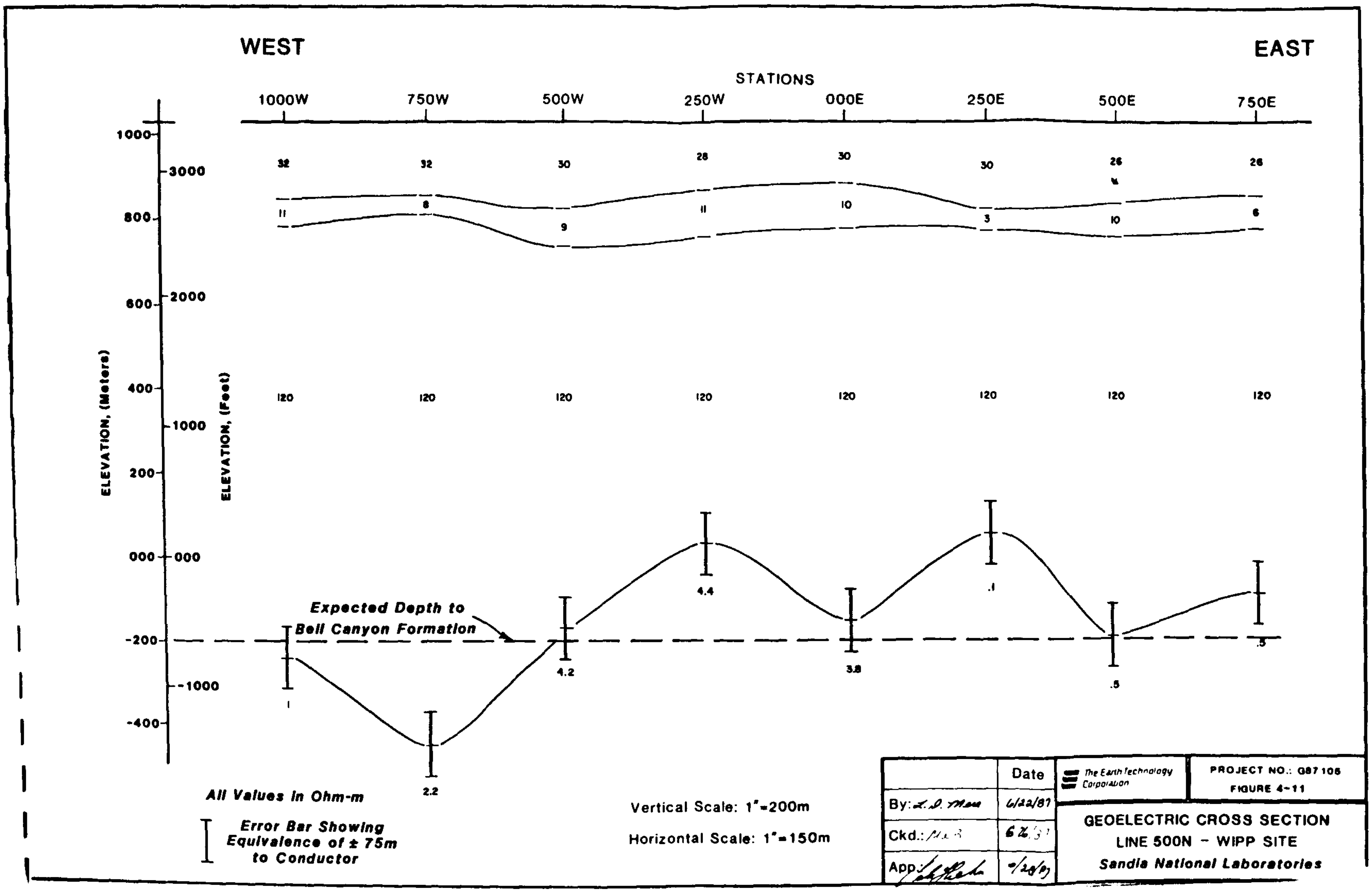

Figure 4-11. Geoelectric Cross-Section - Line 500N --WIPP Site

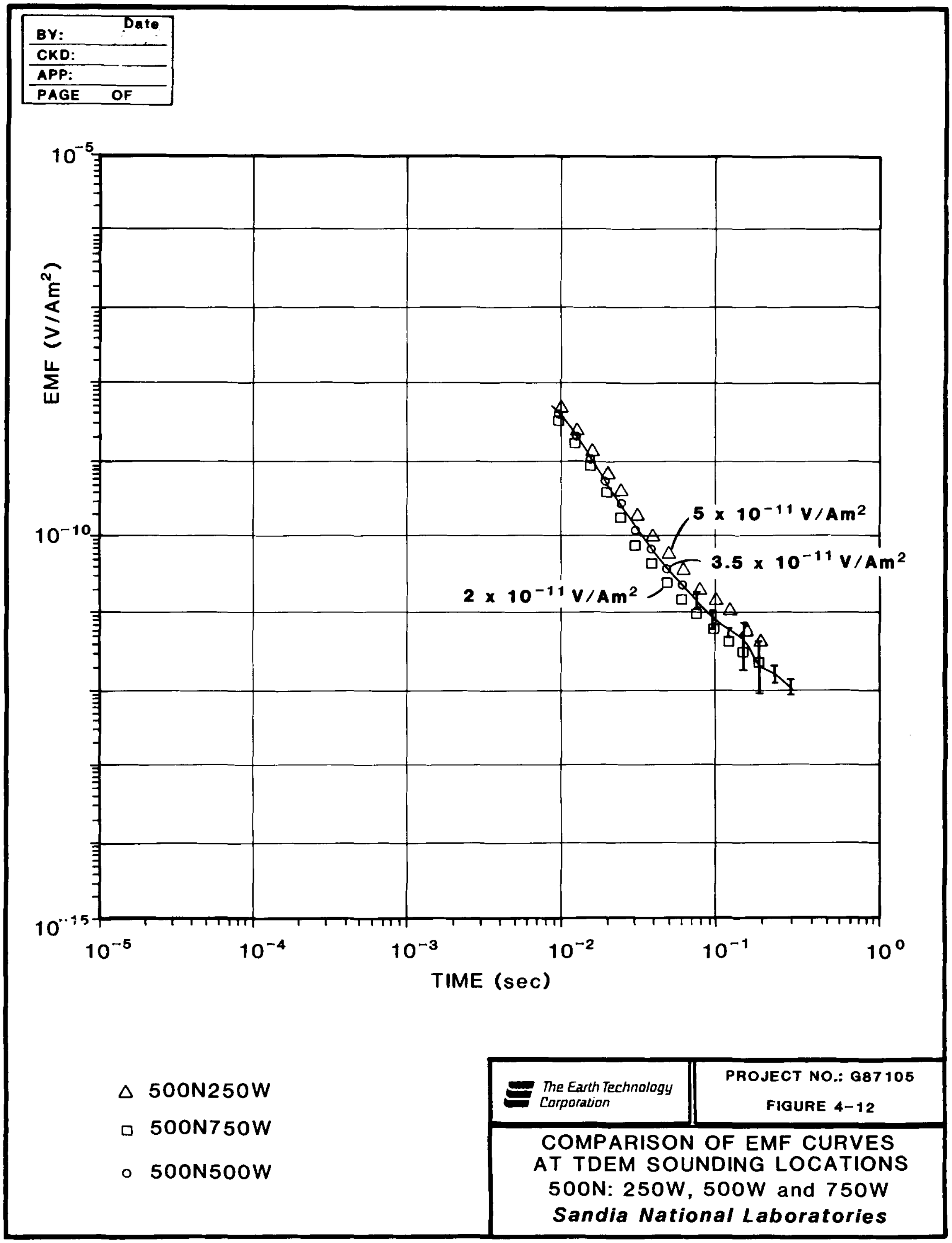

Figure 4-12. Comparison of EMF Curves at TDEM Sounding Locations 500N: 250W, 500W and 750W

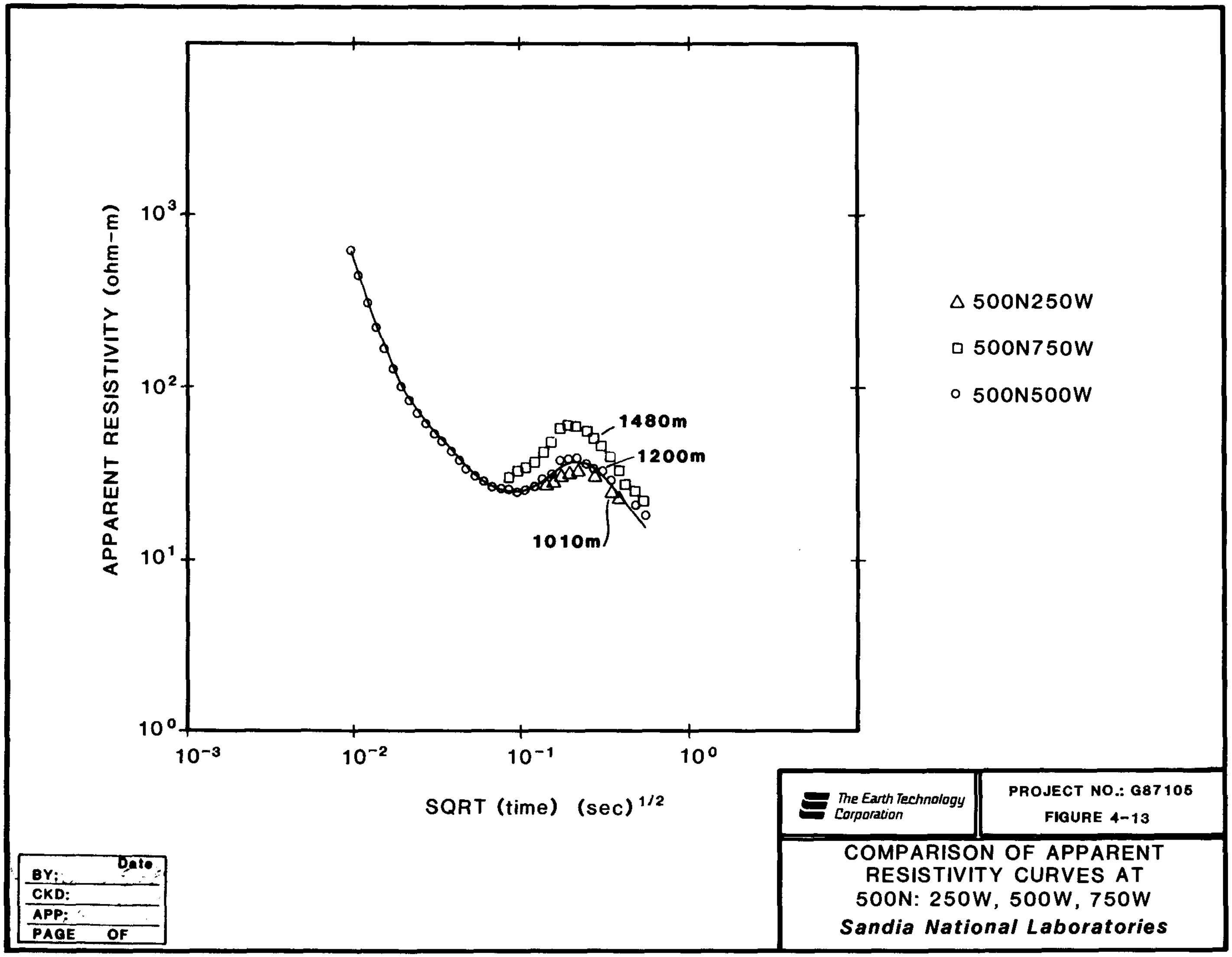

Figure 4-13. Comparison of Apparent Resistivity Curves at 500N: 250W, 500W and 750W

5.0 RECOMMENDATIONS

The results of the TDEM interpretations showed no evidence of brine pockets above 1000 m over the survey grid positioned over the waste storage panels.

A TDEM sounding about 600 m to the east of WIPP #12 showed clear evidence of the presence of a brine pocket at a depth of about 800 m, corresponding closely with drill hole observations. In reviewing previous surface electrical measurements at WIPP, it appears that the interpretations from center loop TDEM surveys correlated better with drill hole information than other electrical techniques. Center loop TDEM soundings appear to offer an opportunity to outline the areal extent of the brine pocket in the Castile Formation intercepted at WIPP #12.

It is, therefore, recommended to conduct a survey on a grid around WIPP #12. The size of the grid would be determined by field results, but would cover sufficient area to map the entire extent of the brine pocket.

Once the general strike of the brine pocket has been determined, it is also recommended to perform a series of measurements in a profiling mode in a manner sketched in Figure 5-1. A rectangular transmitter loop would be used with the long side parallel to the strike. Measurements would be made at receiver positions on lines perpendicular to the strike. Three component measurements would be made at each station. The objectives of these experimental measurements would be to determine if brine pockets at depths up to 1000 m can

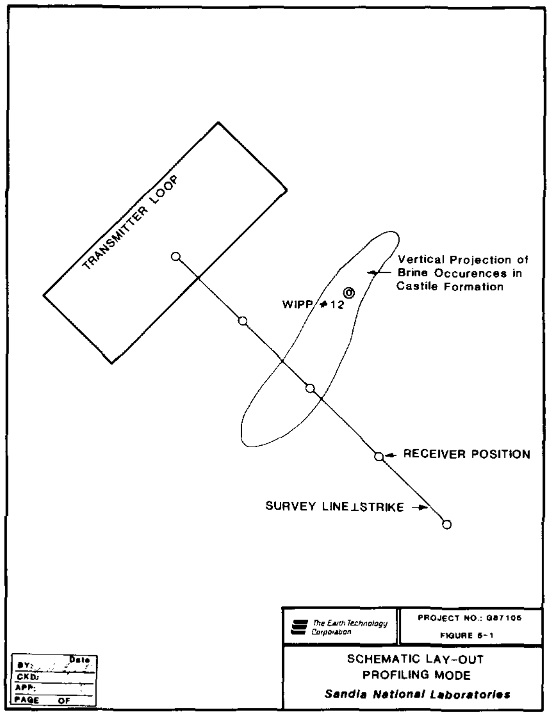

Figure 5-1. Schematic Layout: Profiling Mode

also be detected in a profiling mode, which would have a higher productivity of surveying than center loop soundings.

6.0 REFERENCES

Anderson, W.L. and Newman, G.A., 1985. An album of three-dimensional transient electromagnetic responses for the central induction loop configuration. U.S. Geol. Survey, Open-File Report 85-745.

Bartel, L.C., Jacobson, R.D., and Shaffer, S.E., 1983. Results from Mapping the Brine Pocket Encountered at WIPP #12 Using the CSAMT Geophysical Technique, SAND 83-0458.

Barrows, L.J., Gonzalez, D.D., Weart, W.D., 1982. Geotechnical Field Measurements for Evaluation of the WIPP Site, IEEEE Transactions on Nuclear Science V. NS-29, p. 239.

Kaufman, A.A. and Keller, G.V., 1983. Frequency and Transient Soundings, Elsevier, N.Y.

Keller, G.V., Skokan, C.K., Anderson, H.T., Pfeifer, M.C., Keller, S.D., Kim, K.D., 1987. Studies of Electrical and Electromagnetic Methods for Characterizing salt properties of the WIPP Site, New Mexico, Dept. of Geophysics, CSM, report to Sandia, Contract #: 04-1295.

Powers, D.W., Lambert, S.J., Shaffer, S.E., Hill, L.R., and Weart, W.D., 1978. Geologic Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, SAND78-1596, Vol. 1 and 11.

Register, J.K., 1981. Brine Pocket Ocurrences in the Castile Formation, Southeastern New Mexico, WTSD-TME-3080. U.S. Department of Energy.

Spiegler, P., 1982. Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, Environmental Evaluation Group, State of New Mexico, EEG-17, DOE/AL/10752-17.

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