GL02448

MAGNETO-TELLURIC SURVEY

SODA LAKE AREA
Churchill County, Nevada

1975 for 3-9-NV9 SL3A

CHEVRON OIL COMPANY

(MAP OPPOSITE ABSTRACT)

by

GEOTRONICS CORPORATION
Austin, Texas

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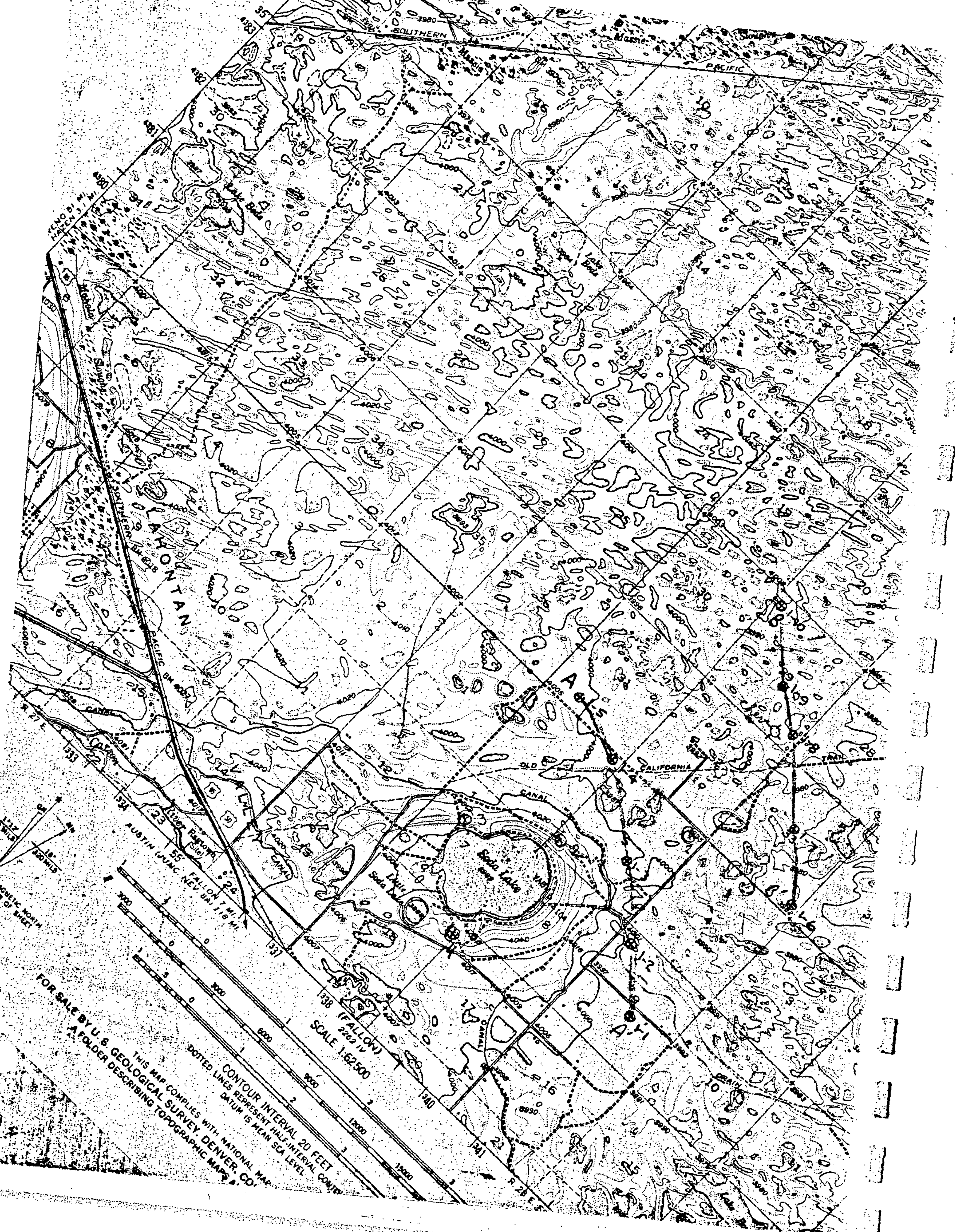


SOUTHERN
PACIFIC
Lake Beds
Slough
LAHONTAN
VALLEY
Soda Lake
Little Soda Lake
OLD
CALIFORNIA
TRAIL
CANAL
River
FALLON 7 MI.
AUSTIN (JUNC. NEV 84) 116 MI.
R. 27 E.
R. 28 E.
(FALLON)
2262 IV
SCALE 1:62500
CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT HALF-INTERVAL CONT
DATUM IS MEAN SEA LEVEL
THIS MAP COMPLIES WITH NATIONAL MAP
FOR SALE BY U S GEOLOGICAL SURVEY, DENVER, CO
A FOLDER DESCRIBING TOPOGRAPHIC MAPS
A-1
A-5
L-6
DRAIN

Abstract

This field report presents the results and conclusions of a magneto-tellurics survey in a suspected geothermal area. Two definite conductive zones are evident in the data. A third is postulated primarily on the basis of modeling studies performed on the data. All are of possible geothermal interest.

The zones are:

1) A low resistivity zone (approximately 1.5 to 2.5 ohm-meters) ranging from a few hundred feet to about 4000 feet in depth and approximately 1000 feet to 3000 feet in thickness under the two lines is readily evident in the data. This zone is likely a (hot?) saturated aquifer and may also be considerably altered.

2) A possible conductive zone centered under Site 1-2. Very little can be said about this zone, except that it might exist. Its size, conductivity, and depth are postulated primarily on the basis of geological reasonability -- they cannot be uniquely assigned from the data. The low conductivity might be due either to alteration or an isolated aquifer. The latter possibility is much the less likely of the two, but would be of more geothermal interest.

3) A deep conductive zone, the top of which varies from approximately 16,000 to 30,000 feet under the survey area. This zone is very conductive (averaging approximately 0.3 ohm-meters) and is quite likely a magma chamber.

List of Figures

I. Introduction

At the request of Mr. William E. Mero of the Chevron Oil Company, Minerals Staff, Geotronics Corporation conducted a magneto-tellurics survey near Soda Lake, Nevada, in March of 1975. The purpose of the survey was to attempt to detect, and if possible delineate, electrically conductive zones of geothermal interest in the subsurface of the area. The survey consisted of ten sites situated in two parallel lines just northeast of Soda Lake. Site locations are shown on the enclosed map.

The theory of magneto-telluric interpretation is presented in considerable detail in reference 2 of this report, along with the analysis and interpretation of a sample survey. For the sake of brevity, this theory has not been repeated extensively in this report, although it is the basis of most of the reasoning used in the interpretation.

Brief descriptions of the field operation, data processing procedure, and computer programs used in the interpretation are presented in the appendices.

II. Results

Figures II-1 through II-10 are plots of resistivity and phase, tensor rotation angles, and 3-D indices for sites 1-1 through 1-10. Final OPTMOD models are plotted over the data. The significance of these quantities, along with their acceptance criteria will be discussed in section III. Figures II-11 through II-20 are composite plots of the final layered models and the final INVERT models for each site. These models will also be discussed in more detail in section III.

The Chevron-Phillips 1-29 well log model is plotted along with the data from Site 1-8, which is only 400 feet away. The well log was modeled by inputting the resistivities and thicknesses on the log to the bottom of the drill hole (4310 feet). The bottom resistivity in the hole (28 ohm-meters) was then continued to a depth of approximately 32,000 feet, the point where the top of the lower conductor should be under this site. A resistivity of 1 ohm-meter was assumed for the lower conductor.

There is some discrepancy between the measured MT data and the modeled well log data at shallow depths. This is likely a real difference due to a difference in geology between MT Site 1-8 and the well site. It may also be partly attributable to the difference in measuring scale of the two methods and the fact that the local effects seen in the well log must be assumed to extend in infinite horizontal layers in order to compute the well log model.

Primarily, the well log appears to not be seeing as much of the shallow conductive zone as MT is. At greater depths, the two models begin to track each other somewhat better, indicating that the lower parts of the model are likely realistic.

III. Geoelectrical Interpretation

A. General Comments

The computed results used in the interpretation for this survey are contained in Section II, Figures II-1 through II-10. Refer to Appendices A, B, and C for more details regarding the measurements and data processing and for some description of the terminology used herein. The results used include the apparent resistivity (RTE and RTM) and associated phase functions, the tensor rotation angles for maximum impedance direction (A(Z)) and for maximum H_z admittance direction (A(YZ)), and the 3-D indices (ALPHA and BETA).

On the average, two or more recording runs were processed for each frequency band (except for B2) for each site. Data point acceptance criteria were based primarily on the levels of phasor coherency associated with the data points of each frequency. RTE and RTM data was passed for coherencies above 0.8. Rotation angle data and 3-D indices were passed only if both RTM and RTE values passed at a given frequency. For a coherency pass level of 0.8, the theoretical bands of $\pm$ 20% of mean value should enclose about 90% of the data points for RTM and RTE from all individual data sets applying at a given frequency. The scatter in the computed results does appear to be about $\pm$ 20% for most sites except for some cases where special noise influences came to bear in certain frequency regions (e.g., Site 1-8 between 0.1 and 1.0 H_z).

The results for each site tend to show a fairly low degree of apparent anisotropy. This applies generally over the entire survey area. The low apparent anisotropy (low degree of RTE-RTM separation) implies a low influence of lateral changes on the results for a given sounding and consequently favors an interpretation based upon 1-D inversions of the results for each site. The apparent anisotropy present at the lower frequency range appears to be due to anomalies in the resistive basement and the deep conductive zone. A discussion of this will follow. It should be noted at this point that the rotation angle results are well defined only for frequencies where the apparent anisotropy is significant compared to the measurement noise. The rotation angle data are consequently very scattered and essentially meaningless for most of the sites of this survey for frequencies above 0.1 to 1.0 Hz. The angles are reasonably well defined for lower frequencies where the RTE-RTM split begins to appear.

III. (continued...)

B. One-Dimensional Models

One dimensional models for each site were generated from the RTE and associated phase functions using both programs INVERT and OPTMOD (see Appendix C) and the resulting resistivity-depth functions are plotted in Section II, Figures II-11 - II-20, with both models for a given site plotted together for comparison. Both models reflect the same gross features of the resistivity profile and show essentially all of the detail that is warranted by the resolution for these results. The layered model provides a better means for estimating the bounds on the average resistivity for a given zone or layer, but the layered model does not imply that the resistivity values change abruptly at the interface shown. A given layer interface might fall near the center of a continuous transition between two values of resistivity at different depths. The INVERT model tends to smooth any abrupt changes that might actually exist. In a sense the two models tend to bracket the true model.

The estimated resistivity bounds or confidence limits are indicated on the model plots. These apply to the inverse of the average conductivity across a given zone indicated by a layer. Where no bounds are specified, the probable error in the parameter can be considered approximately ± 10 percent.

The ± 10 percent tolerance can be applied to layer interface depths while remembering that the interface might represent the mean depth for a smooth transition in the resistivity profile. It should be noted, too, that the specified parameter bounds are not meant to include all possibilities of error due to two- and three-dimensional anomalies. It can only be said that such effects are not apt to be large for these results.

The transition into the deep (lower) conductive zone of the model appears to be quite abrupt as evidence by the rapid decrease in resistivity shown by the INVERT model at most sites. This zone is quite probably a magma chamber, since it is too shallow to be to upper mantle, and molten rock is the only material that deep in the earth likely to have such a high conductivity. It is very unlikely that any three-dimensional effects could cause more than 10 to 20 percent error in this depth determination.

The deep resistive zone (overlying the deep conductor) is electrically thin enough at sites 1-3, 1-4, 1-5, 1-6, 1-7, and 1-10 that

III. (continued...)

essentially only its thickness is defined by the sounding. The minimum values of resistivity allowed by the results are specified. For sites 1-1, 1-2, 1-8, and 1-9, the corresponding resistive zone is electrically thick enough (i.e. its conductivity-thickness product is great enough) that upper and lower limits on resistivity are indicated by the results. It is important to note that for sites 1-1 and 1-2 the deep resistive zone need only have an average conductivity across the zone of the range indicated. Another acceptable model for this zone would be to divide the layer (say resistivity ρ_0 and thickness T_0) into three zones with resistivities ρ_1, ρ_2, and ρ_3 and thicknesses T_1, T_2, and T_3, where zone 2 is in the middle and situated in the mid to upper region of the original layer, and where ρ_2 is less than ρ_0 (say 1 to 2 ohm-m), and the condition $(T_1/\rho_1 + T_2/\rho_2 + T_3/\rho_3) = T_0/\rho_0$ is met. An alternate model is indicated in the model plot for Site 1-2. see Fig III-3B

C. Cross Sections from 1-D Models

Figures III-1 and III-2 show vertical geoelectric cross sections for the two traverse lines (A and B) produced from the INVERT models by contouring on constant resistivity. These models represent a smoothed version of the resistivity structure.

Figures III-3A and III-4 show vertical geoelectric cross sections for the two traverse lines (A and B) produced by a correlation of the OPTMOD models across the traverse. Resistivity bounds are indicated on the sections. Figure III-3B shows an alternate solution at sites 1-1 and 1-2 for traverse A.

The effects of lateral smoothing should be considered when interpreting the sections. For example, the transition in the surface depth of the deep conductive zone, in going from Site 1-8 to Site 1-6 might actually occur more abruptly near Site 1-7. Actual determination of this is beyond the resolution of the results.

The layers 3 and 4 at sites 1-6 and 1-7 possibly indicate a more gradual increase in resistivity with depth than at sites 1-8, 1-9, and 1-10, and do not necessarily imply a definite interface between layers 3 and 4.

D. Apparent Anisotropy and Rotation Angles

For the sake of discussion, it is convenient to define an anisotropy factor as

III. (continued...)

$$AF(f) = RTM/RTE \quad (1)$$

where f is frequency. Let $AF^1(f)$ be the first derivative of AF with respect to f. For one-dimensional results $AF(f) = 1$ and $AF^1(f) = 0$ for all f. For frequencies where a lateral anomaly (or apparent anisotropy) is sensed, the RTE and RTM functions separate and $AF(f) \neq 1$ and $AF^1(f) \neq 0$. It can be shown that the conductive or resistive nature of the anomaly is indicated by the polarity of $AF^1(f)$ as follows:

for $AF^1(f) < 0$, anomaly is conductive;
$AF^1(f) > 0$, anomaly is resistive.

For the results of this survey, examination of the RTE and RTM functions shows that for sites 1-1 through 1-5 (traverse A) and 1-6 of the traverse B, as frequency is decreased, the first significant anomaly is a conductive one, as evidence by RTM rising above RTE for decreasing frequency ($AF^1(f) < 0$). For sites 1-7 through 1-10 the first significant anomaly is resistive and a deeper, conductive anomaly appears as it is further decreased.

This behavior is probably explained by the following two considerations:

1) For sites 1-3 through 1-6, the deep resistive zones are electrically thin and effects of the deep conductor surface appear for the same frequencies for which the resistor surface becomes effective. Consequently, anomalies in the conductor surface (perhaps the slope) dominate the effect. For sites 1-1 and 1-2, which are not considered electrically thin, the conductive anomaly might be an embeded conductor in the resistive zone, supporting the alternate model discussed in Section III-B.

2) For sites 1-7 through 1-10, the much thicker deep resistive zone (especially at sites 1-8 and 1-9) presents a resistive anomaly (perhaps its irregular surface) before the frequency is low enough to sense the effect of the deep conductor anomaly.

The foregoing is very speculative, but does seem to produce a rational agreement with the model structure. Figures III-5 and III-6

III. (continued...)

are plan views of the upper surfaces (obtained from OPTMOD models) of the deep resistor and deep conductor models, respectively. Rotation angles A(YZ) corresponding to the two zones are plotted, indicating the apparent "dip axis" directions (direction of maximum change) which point normal to the apparent strike. The angles corresponding to the deep conductor were chosen as the values for the lowest frequency values computed. The A(YZ) functions for all sites except 1-5 are still changing in the CCW direction at the lowest frequency value, implying that they have not reached final value and would swing further to the north with further decrease in frequency. This would perhaps cause better agreement with the average deep conductor surface contours. It is interesting to note that for the shallower rotation angles (which correspond to about 2 to 3 km depth, and consequently to the resistive zone) the directions tend to agree reasonably well with the surface contours for sites 1-7 through 1-10, showing a NE-SW strike, and the angles for sites 1-3 through 1-5 are close to the deep conductor angles for those sites. This behavior is in agreement with the earlier speculation regarding the anisotropy.

IV. Geologic Models of Soda Lake

The geologic models of Soda Lake are derived by correlating the magneto-telluric data with the published geology (Morrison, 1964), the well log of Chevron-Phillips 1-29, and a preliminary cross section provided by Chevron Oil.

Two possible models are herein proposed. The first one will be called the Alteration Model, and is the more likely of the two. The second will be called the Buried Reservoir Model, and although it is the more interesting geothermal model, it is not as easily justifiable geologically as is the Alteration Model.

The Alteration Model is shown by figures IV-1A and IV-2 for Lines A and B respectively. The Buried Reservoir Model is shown by figures I V-1B and IV- 2, for lines A and B. Note that the single model for Line B is common to both the Alteration Model and the Buried Reservoir Model.

It should be kept in mind that these models are quite speculative. Lithologic units are proposed on the basis of the range of resistivities that they are likely to have. The models are subject to the error limits for both the depths to interfaces and resistivity ranges which were set down in Section III.

The Alteration Model assumes that unaltered Tertiary rocks, primarily rhyolites, have an average resistivity of about 40 to 70 ohm-meters, and that altered Tertiary rocks range in resistivity from possibly as low as one ohm-meter to about 25 ohm-meters -- the more intense the alteration, the lower the resistivity. If this assumption is valid, then the MT data is likely detecting alteration zones of the approximate dimensions and intensities shown on the model cross sections.

A low resistivity zone (approximately 1.5 to 2.5 ohm-meters) ranging from a few hundred feet to about 4000 feet in depth and approximately 1000 feet to 3000 feet in thickness under the two lines, is readily evident in the data. This zone likely lies in the Lower Lahontan Valley group (Wyemaha?). Since the Wyemaha apparently has fair potential as a reservoir (Morrison, 1964), and since 1.5 to 2.0 ohm-meters is a reasonable resistivity range for a saturated aquifier (especially if the

IV. (continued)

water is hot), one possibility is that this conductive zone is a saturated aquifer overlying the impermeable Tertiary basement. The other possibility is that this zone is not saturated, but that the alteration extends into it. A combination of saturation and alteration is also quite likely.

Above this is a thin layer (varying from approximately 300 to 1000 feet thick) of more resistive material (ranging from approximately 5 to 15 ohm-meters). This is likely unsaturated Sehoo or Wyemaha formation, with some interbeded volcanics. During the modeling phase, it was noted that the models for some sites required thin high resistivity layers in order to produce a good fit to the high frequency data.

The probable depth to the lower magma chamber varies from an average of about 20,000 feet under Line A to about 25 to 30,000 feet under Line B. Although these depths appear to be changing somewhat rapidly, they are probably quite representative, since 3-D effects would be relatively small, as per the discussion in section III.

The resistivity of the deep magma chamber cannot be precisely defined, but is likely in the range of 0.1 to 1.0 ohm meters, and appears to average about .30 ohm-meters.

The Buried Reservoir Model is similar to the Alteration Model in most respects. The major difference is the proposed cause of the conductive anomaly under Site 1-2. Modeling studies on the data show that a layer of approximately 1.23 ohm-meter resistivity and 1 kilometer thickness sandwiched within a layer of approximately 40 ohm-meters and 4.5 kilometers thick fits the data for Site 1-2 quite well. It should be noted that because of the restraints necessary in adjusting conductivity-thickness products for the model, we cannot unambiguously assign an exact depth to the layer, if it exists. Neither can we assign an exact resistivity or thickness to the layer -- only a conductivity-thickness product. For example, a layer twice as conductive, but only half as thick would produce the same results. Similarly, the conductive layer could lie anywhere between the upper and lower boundaries of the assumed 40 ohm-meter block, and the same data curve would result.

Geologically, this model is somewhat reasonable, if we assume that the conductive layer is possibly a saturated block of Truckee formation

IV. (continued)

overlain by younger volcanics. It is very speculative in that the exact sequence of geological events necessary for its existence are not immediately obvious, and open to more than one interpretation.

Finally, it should be noted that all faulting in the models is proposed primarily on the basis of geologic necessity, and is not necessarily indicated by MT data. The MT data shows little or no evidence of faulting. Any faulting in the area is probably on a scale too small to be within the resolution limits of the MT method.

Bibliography

1. Morrison, R. B.; "Lake Lahontan: Geology of the Southern Carson Desert, Nevada," United States Geological Survey Professional Paper 401, 1964.

2. Word, D.R., H. W. Smith, and F.X. Bostick, Jr., "An Investigation of the Magnetotelluric Tensor Impedance Method," The University of Texas at Austin, Electrical Geophysics Research Lab., Report No. 82, 1970.

Appendix A - Field Operation

Five orthogonal component, surface EM field measurements (E_x, E_y, H_x, H_y, H_z) were made of the micropulsation fields of each site in the overall frequency range of approximately 0.002 to 100 Hz. This range was covered by four overlapping bands as described in Table B-1.

Figure A-1 shows the field sensor configuration used. The positive x axis is directed to magnetic north, which has an average declination of 18°E. The E-field sensors are electrode lines using 100 square inch lead electrodes with a spacing of 600 feet. The H-field sensors are Geotronics induction magnetometers - model MTC-4SS for H_x and H_y, and model MTC-6SS for H_z.

The instrument van contains the recording system of Geotronics manufacture, consisting of the MTE-4 three-channel E-field preamplifier, the MTH-4 three-channel H-field preamplifier, the MTC-2 calibrator, the MTF-16 filter-post amplifier, and the MTDR-2 digital recorder. A 6-channel Brush chart recorder is used for field monitoring of the signals.

A five-man field crew is used, consisting of the crew chief and instrument man, alternate instrument man, and a three-man site layout team including a surveyor.

Proper field technique, which is of extreme importance in MT recording, has been developed by Geotronics personnel through 15 years of MT experience and is stressed throughout the survey. System noise and data quality checks are made routinely. All sensors are buried about 12 inches or more deep and all cables buried or weighted to reduce wind noise and improve thermal stability. While one site is being recorded, an alternate set of sensors is installed at the next site, and an adequate time (a few hours) is allowed for stabilization, including thermal and magnetic stabilization of the magnetometers and contact potential stabilization of the electrodes.

Field tapes are sent back to Geotronics daily (when conditions permit) so that preliminary analysis can be done to assess signal quality while the field crew is still in the survey area.

The Soda Lake survey consists of 2 traverse lines containing a total of 10 sites. Data bands B6, B5, B4, and B3 were recorded at sites 1-2, 1-3, 1-4, 1-7, 1-8, and 1-9. Bands B6, B5, B4, and B2 were recorded at sites 1-1, 1 5, 1-6, and 1-7 (end sites of each line). Multiple recordings of bands B3 through B6 were made to assure data quality; multiple recordings were not routinely made of band B2 because of the recording time involved.

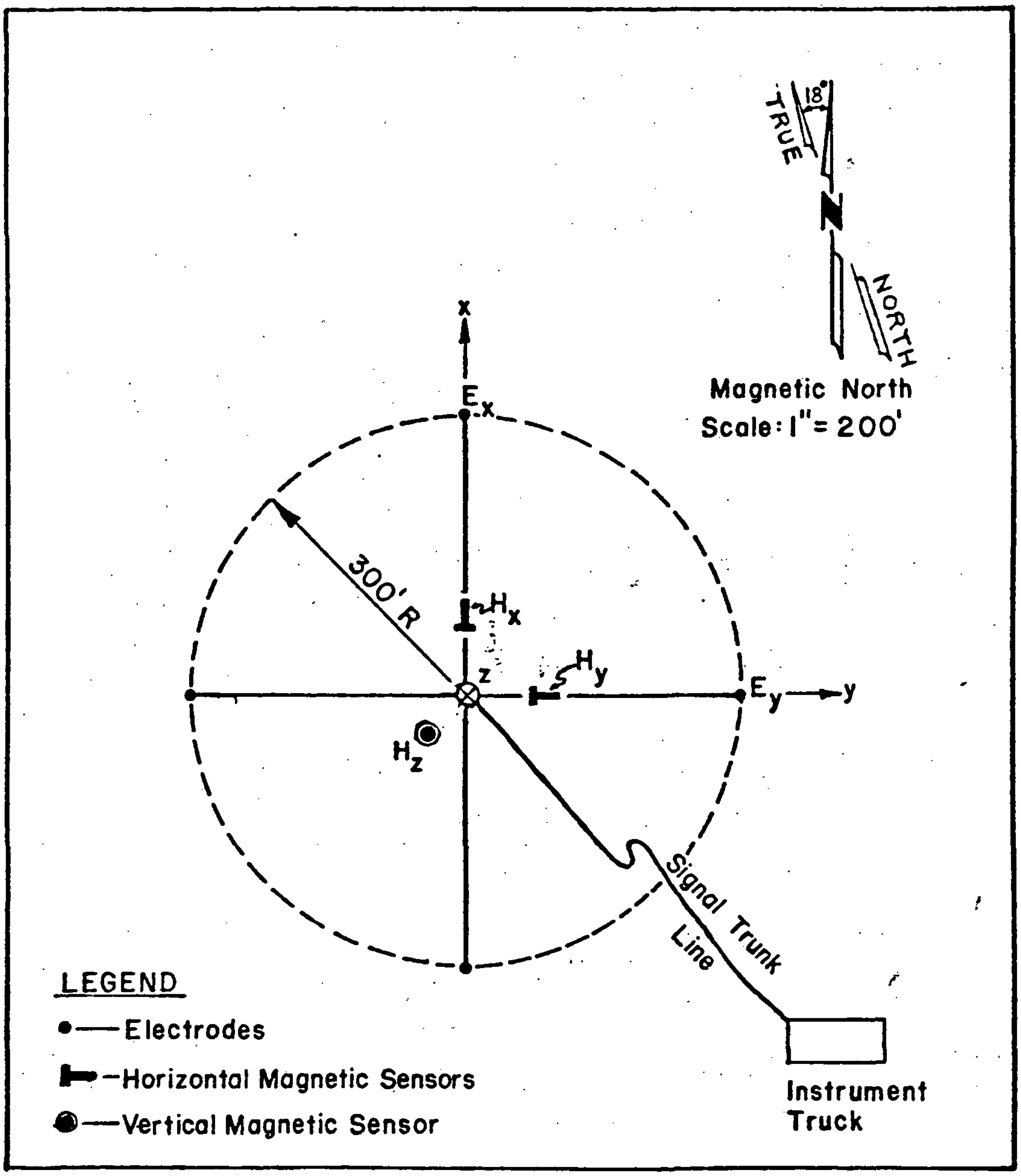


FIGURE #1. Magneto-Telluric Field Sensor Layout.

Appendix B - Data Processing Procedure

Computer processing was done on the Control Data Corporation Cybernet System. The Houston based CDC 6600 was used and accessed through the CDC-Austin 200 series user terminal. Field tapes were sent to Houston and stored in the CDC tape library in read-only mode for the duration of the survey and analysis.

The analysis phase of the processing was done by program MAGTAN2, which performs a tensor MT analysis. A description of the program functions and output results is given in Appendix C. The frequency domain results used in the interpretation of this survey are:

(1) Rotated apparent resistivity and phase functions (RTE and RTM and related phase functions) for E-parallel to strike and E-perpendicular to strike respectively.

(2) Rotation angle (A(YZ)) for the apparent "dip-axis" direction determined from H_z, the vertical magnetic field, and is the direction of maximum gradient.

(3) Rotation angle (A(Z)) for maximum impedance.

(4) Three-dimensionality indices (ALPHA and BETA) which are the "skew" and "ellipticity" of the impedance tensor. Zero value for both of these quantities constitutes the necessary and sufficient condition for two-dimensionality.

The frequency bands used in the analysis are given in Table B-1, which includes the sampling parameters and the frequency range of results used for each band. The upper limit on the frequency range used is near the alias filter cut-off frequency, which is set to approximately half the Nyquist frequency. The lower three frequency points of the analysis results are omitted to avoid truncation aliasing error that is apt to be present. The analysis frequency bands overlap for redundancy.

Strip chart records and field logs were checked to select the best data recording runs for analysis. Initially, one run of each band for each site was processed and the results checked for several acceptance criteria. Additional runs were processed where needed to produce the best definition of the computed functions. Finally, all runs of the frequency domain results to be used were plotted for use in the subsequent interpretation. Averaged and smoothed functions were produced from the raw results for use in modeling and other interpretation.

One-dimensional models were fit to the RTE and phase functions at each site using two different methods and employing computer programs described briefly in Appendix C. In the first method, 1-D inversions were made by program INVERT, which analytically produces a continuous smoothed function of intrinsic resistivity vs. depth. In the second method, best fit 1-D N-layered models were produced by program OPTMOD. These 1-D models were correlated or contoured to produce laterally and vertically smoothed versions of the vertical cross-sections along the survey traverses.

The 1-D models are considered as estimates of the resistivity-depth, vertical profile under a given site. The 1-D inversion of the RTE function produces the best estimate of the 1-D vertical profile, but it must be kept in mind, when interpreting the model, that any neighboring lateral variations in the conductivity structure have some degree of influence on the profile, depending upon the distance to and magnitude of the anomaly. Normally, the influence is such as to produce a lateral smoothing effect on the cross section. Consequently, it must be considered that a change in any direction in the structure may, in reality, be more abrupt than reflected in the interpreted cross section. When a low degree of two- and three-dimensionality is indicated in the MT results the lateral structural variations (electrical parameters) are usually gradual enough to yield a reasonably faithful interpreted cross section.

Two-dimensional modeling is often useful for verifying the response to an anomaly in a particular region of the structure, but, because of the large number of degrees of freedom in the model, it is not usually practical to attempt a precise fit to the measured results. Two-dimensional modeling was not applied in the interpretation of this survey, primarily because of lack of time to produce a meaningful test. In any case, it was considred of lesser importance because of the fairly low degree of two- and three-dimensionality present.

Appendix B, Data Processing Procedure, continued...

After producing 1-D models, model parameter-tests were made using program LAYERPXY, which solves the forward MT solution, to estimate parameter tolerances or confidence limits.

Finally, a study was made to correlate the two- and three-dimensional properties of some of the computed MT results with the interpreted geoelectric cross sections. This includes the apparent anisotropy evidenced in the RTE and RTM functions, the rotation angles, A(YZ), and the 3-D indicators ALPHA and BETA.

Table B-1 - Recording Frequency Bands

Band	Post Filter (Hz)	Sampling Rate (Hz)	Number Samples	Frequency Range Used (Hz)	No. Runs Recorded (Nominal)
B6	10-256	1000	4096	2.08-256	8
B5	1-25	100	4096	0.208-25.6	4
B4	.1-5	20	4096	0.0415-5.12	4
B3	.01-.5	2	4096	0.00415-0.512	2
B2	.002-.125	.5	2048	0.00208-0.128	1

Appendix C - Computer Programs

This section gives a brief description of programs:

(1) MAGTAN2

(2) INVERT

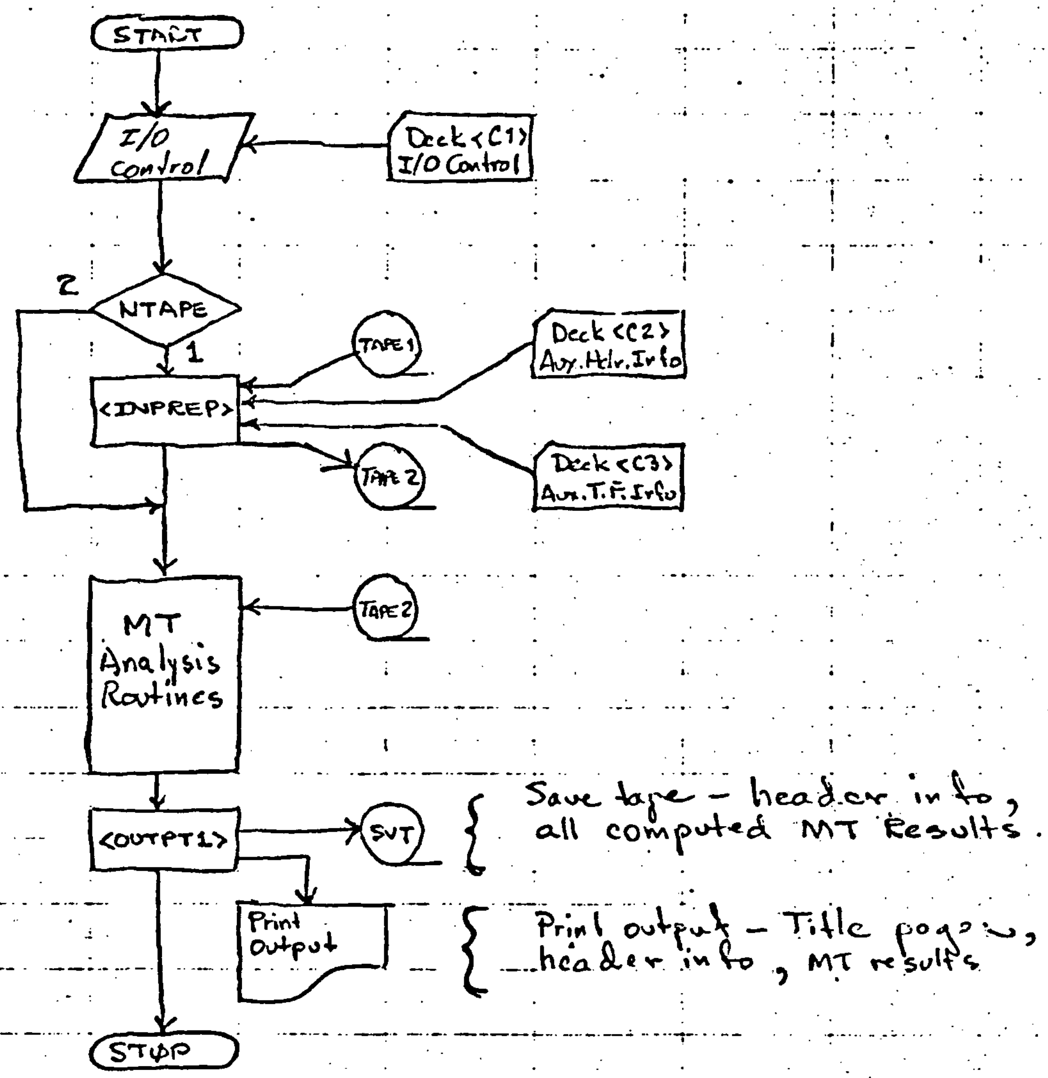
(3) OPTMOD

(4) LAYERPXY

Additional information on program functions, data tape formats, etc., are available on request.

(II) MAGTAN MT ANALYSIS
Program Introduction
& Description of Transfer
function form used to
represent System

MAGTAN2 (Simplified Flow Diagram)



Notes: 1) TAPE 1 – Packed binary field tape – Header – Site, system, sampling params.
Data – N channels, time multiplexed

2) TAPE 2 – Unpacked BCD tape – Header – TAPE1 Header info & system polynomial coefficients
Data – N channels demultiplexed

3) Card Deck C1 – Input / Output control parameters –

4) Card Deck C2 – Auxilliary Header information –

5) Card Deck C3 – Auxilliary Transfer function info. –

6) Subroutine INPREP – controls unpacking of TAPE1 & generation of TAPE 2.
Info. from Decks C2 and C3 is included in TAPE

28 May 74

```
      PROGRAM MAGTAN1 (INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4,TAPE5,
     * TAPE6,TAPE7,PUNCH)
*****************************************************************************
*                 ** GEOTRONICS CORP - AUSTIN, TEXAS USA **                 *
*                                                                           *
*   *** PROGRAM <MAGTAN1> *** - FORTRAN IV    ***  DR=5001X001              *
*                                                                           *
*     * MAGNETOTELLURIC (MT) ANALYSIS PROGRAM  *  GEOTRONICS CORPORATION    *
*     * FOR TENSOR SURFACE IMPEDANCE METHOD    *  AUSTIN, TEXAS - U.S.A.    *
*                                                                           *
*****************************************************************************
*                                                                           *
*   PURPOSE:    <MAGTAN1> COMPUTES TENSOR IMPEDANCE METHOD MT RESULTS       *
*               FOR 5-COMPONENT E AND H FIELD MEASUREMENTS IN RECTANGULAR   *
*               COORDINATES.                                                *
*                                                                           *
*   COMPUTER ADAPTATION: CDC-6600                                           *
*                                                                           *
*   SOURCE LANGUAGE: FORTRAN IV                                             *
*                    COMPASS                                                *
*                                                                           *
*   NO. OF SUBROUTINES: 43                                                  *
*                                                                           *
*   CORE STORAGE REQMT:  LOAD-155000 BASE-8                                 *
*                        RUN -145000 BASE-8                                 *
*                                                                           *
*   PERIPHERAL STORAGE AND I/O:                                             *
*                                                                           *
*                    TAPE UNITS- 1 , FILE <TAPE1> (INPUT DATA - PACKED BINARY) *
*                    DISK UNITS- 6 , FILE <TAPE2-7> (2-UNPKD DATA, 3-7-SCRATCH) *
*                    CARD READER                                            *
*                    LINE PRINTER                                           *
*               OPTIONAL I/O -                                              *
*                    TAPE UNITS- 2 , FILE <TAPE2,8> (2-UNPKD DATA, 8-OUTPUT) *
*                    CARD PUNCH     (SEE NOTE)                              *
*                    PLOTTER        (SEE NOTE)                              *
*                                                                           *
*                  NOTE- DUMMY SUBROUTINES ARE INCLUDED FOR USER IMPLEMENTATION *
*                        OF TAPE, PUNCH, AND PLOT OUTPUT. ALL OUTPUT IS     *
*                        CONTROLLED BY SUBR<OUTPT1>, COMPUTED RESULTS ARE   *
*                        AVAILABLE TO OUTPUT ROUTINES VIA COMMON BLOCK <SPEC>. *
*                                                                           *
*   SPECIAL CORE STORAGE AREAS:                                             *
*          COMMON BLOCK <SPEC> - 25000 WORDS                                *
*                                                                           *
*   ROUTINES CALLED BY <MAGTAN1>: <TITLE1>                                  *
*                                 <INPREP>                                  *
*                                 <POSIT2>                                  *
*                                 <XFORMX>                                  *
*                                 <IPSPEC>                                  *
*                                 <APSPEC>                                  *
*                                 <TITLE2>                                  *
*                                 <MAGTEL>                                  *
*                                 <SPECAV>                                  *
*                                 <OUTPT1>                                  *
*                                                                           *
*                                                                           *
*   SPECIAL PROGRAM VARIABLES :                                             *
```

6/3

```
<TAPEID>   -   INPUT TAPE ID - FOR <TAPE1> AND/OR <TAPE2>.
<TITLE>    -   TAPE FILE (DATA SET) TITLE.
<TITLEA>   -   TITLE FOR AVERAGED RESULTS.
<A,B,C,D,E,H> - SRATCH ARRAYS
<NFREQ>    -   NO. OF OUTPUT FREQUENCIES.
<FR(I)>    -   OUTPUT FREQ ARRAY- FREQ OF I TH WORD IN OUTPUT ARRAYS.
<P(K,I)>   -   SIGNAL POWER SPECTRA ARRAY- K TH COMPONENT, I TH FREQ.
<NSP(I)>   -   NO. OF INCREMENTAL SPECTRAL HARMONICS AVERAGED
               IN EACH P(K,I).


GENERAL!  MOST PROGRAM VARIABLES AND PARAMETERS ARE DEFINED IN THE
          SECTIONS THAT DESCRIBE THEIR USE.

          INDIVIDUAL SUBROUTINE HEADERS DESCRIBE THE PROGRAM FUNCTIONS
          AND THE ASSOCIATED PARAMETERS.
```

I. --- SCOPE ---

A. MT MODEL AND BASIC RELATIONSHIPS!

THE TOTAL ELECTRIC AND MAGNETIC FIELDS <E> AND <H> (FREQ (F) DOMAIN) AT POINT <O> ON THE EARTH SURFACE ARE CONSIDERED TO BE RELATED BY

(I-1,2)   <E> = <Z><H>   OR   <H> = <Y><E>   (EXCLUDING F=0),

WHERE <E>,<H> ARE VECTORS AND <Z>,<Y> ARE DYADIC TENSORS REPRESENTING THE SURFACE IMPEDANCE AND ADMITTANCE RESPECTIVELY. <Z> AND <Y> ARE FUNCTIONS OF FREQ, THE FIELD SOURCE AND THE EARTH PARAMETERS.

COORDINATE SYSTEM ---

STANDARD RIGHT HAND RECTANGULAR COORD SYSTEM (X,Y,Z-AXES) WITH +Z-DOWN (VERTICAL AXIS) AND THE ORIGIN AT POINT <O>. THE X-AXIS IS IN GENERAL ROTATED CLOCKWISE (LOOKING IN +Z-DIRECTION) BY AN ANGLE (A) FROM THE REFERENCE XR-AXIS, WHERE +XR-NORTH, +YR-EAST. IN THE ROTATED COORD SYSTEM <E(A)>=<Z(A)><H(A)>, ETC.

MODEL ---

Z ≥ 0 - SEMI-INFINITE CONDUCTIVE HALF-SPACE (SOLID EARTH) WITH
        GENERALLY 3-DIMENSIONAL INTRINSIC PROPERTIES.
Z < 0 - FREE SPACE

FIELD SOURCE ---

EM PLANE WAVE PROPAGATING IN +Z-DIRECTION (DOWN) AND INCIDENT ON Z=0 SURFACE. ANY POLARIZATION IS ALLOWABLE EXCEPT AT LEAST SOME DEGREE OF RANDOM POLARIZATION IS REQUIRED BY THE COMPUTATION PROCESS.

```
<Z> AND <Y> ARE INDEPENDENT OF PLANE WAVE SOURCE CONDITIONS.

FIELD RELATIONS IN RECTANGULAR COORD SYSTEM ---

FOR THE (X,Y,Z-AXES) EQUATIONS  (I-1) AND (I-2) BECOME

(I-3)       EX(A) = ZXX(A) HX(A) + ZXY(A) HY(A)
(I-4)       EY(A) = ZYX(A) HX(A) + ZYY(A) HY(A)

(I-5)       HX(A) = YXX(A) EX(A) + YXY(A) EY(A)
(I-6)       HY(A) = YYX(A) EX(A) + YYY(A) EY(A)
(I-7)       HZ(A) = YZX(A) EX(A) + YZY(A) EY(A)

ANOTHER MT RELATIONSHIP TO CONSIDER IS OBTAINED BY SUBSTITUTING
(I-3),(I-4) INTO (I-7)

(I-8)       HZ(A) = KZX(A) HX(A) + KZY(A) HY(A)

REFERENCE INFO ---

WORD,D.R.,H.W.SMITH,F.X.BOSTICK,JR., =AN INVESTIGATION OF
     THE MAGNETOTELLURIC TENSOR IMPEDANCE METHOD=, ELECTRICAL
     GEOPHICS RESEARCH LAB., TECH REPT NO. 82, UNIV. OF TEXAS,
     AUSTIN,TEX.,1970.

B. PROGRAM FUNCTION:

<MAGTAN1> PERFORMS THE FOLLOWING FUNCTIONS (IN ORDER SHOWN)---
-0-      INPUT I/O CONTROL PARAMETERS AND DATA ACQUISITION SYS. INFO.
-1-      INPUT TIME DOMAIN SAMPLED DATA REPRESENTING ALL RECTANGULAR
COMPONENTS OF <E> AND <H> FOR THE REF COORD DIRECTIONS XR,YR, AND Z.
-2-      FOURIER TRANSFORM ALL SIGNAL COMPONENTS.
-3-      MODIFY SPECTRAL WINDOW TO REDUCE SIGNAL TRUNCATION ALIASING.
-4-      SCALE  DATA WITH GENERALIZED FREQ FUNCTIONS - TO CORRECT
FOR DATA ACQUISITION TRANSFER FUNCTIONS, ETC.
-5-      COMPUTE INCREMENTAL AUTO- AND CROSS-POWER SPECTRA
FOR ALL FIELD COMPONENTS.
-6-      COMPUTE FREQ BAND AVERAGE OF INCR AUTO- AND CROSS-POWER
SPECTRA AND ASSOCIATED FREQ ARRAY FOR AVERAGED SPECTRA.
-7-      COMPUTE <E> AND <H> POLARIZATION PROPERTIES.
-8-      COMPUTE <Z(A)> AND <Y(A)> ELEMENTS (AMPL AND PHASE) FOR
A=0 AND FOR THE VARIOUS PRINCIPAL VALUES OF (A). COHERENCIES,
DIMENSIONAL PROPERTIES (SKEW AND ELLIPTICITY), AND INDICATORS OF
COMPUTATIONAL STABILITY ARE ALSO COMPUTED. <Z(F,A)> IS ALSO
COMPUTED FOR 10 DEGREE INCREMENTS IN (A).
-9-      OUTPUT RESULTS PER OUTPUT OPTION SELECT ARRAY (I/O CONTROL).

NOTE - THE FREQ RANGE OF COMPUTATION FOR ITEMS 2-8 IS THE ENTIRE
       RANGE ALLOWED BY SAMPLING CONDX.

II.--- PROGRAM OPERATION ---

 A. INPUT :

  1- I/O CONTROL   - <C1> DATA CARD DECK
```

(A)

```
2- DATA              - <TAPE1>  PACKED BINARY TAPE (BMR FORMAT);(1 5-CH DATA
                  OR  <TAPE2>  UNPACKED BCD  TAPE (GC  FORMAT); SET/FILE)

3- AUX TAPE1
   HEADER INFO     - <C2> DATA CARD DECK  (OPTIONAL)

4- AUX SYSTEM
   TRANSFER FN     - <C3> DATA CARD DECK  (OPTIONAL)


<MAGTAN1> HAS A NUMBER OF BASIC INPUT OPTIONS. A PRECISE DEFINITION
OF THE OPTIONS AND THE VARIOUS CONTROLLING PARAMETERS IS PROVIDED IN
THE DESCRIPTION OF CARD DECK <C1>. THE MAIN OPTIONS ARE:
   (1)  <TAPE1> OR <TAPE2> MAY BE USED AS INPUT.
   (2)  <TAPE1> MAY BE UNPACKED WITH OR WITHOUT FULL EXEC OF <MAGTAN1>
   (3)  <TAPE1> HEADER INFO MAY BE INPUT FROM <TAPE1>,<C2>,OR A MIXTURE.
   (4)  AUXILLIARY TRANSFER FUNCTION INFO MAY BE INPUT FROM <C3> FOR
         ANY FREQ DOMAIN SCALING OF THE DATA.
   (5)  <TAPE1> FILES MAY BE SELECTED IN ANY ORDER. DATA RECORDS
         WITHIN A FILE MAY BE SKIPPED PRIOR TO READ. THIS FILE AND
         RECORD SELECT DETERMINES THE ORDER IN WHICH DATA IS PLACED
         ON <TAPE2> (WHICH MAY BE EITHER A DISK OR TAPE UNIT).
   (6)  <TAPE2> FILES MAY BE SELECTED IN ANY ORDER.
   (7)  DATA SETS ARE PROCESSED INDIVIDUALLY. THE POWER SPECTRAL AVERAGE
         OF SPECIFIED GROUPS OF COMPATIBLE DATA SETS MAY BE COMPUTED
         AND  PROCESSED.

DATA CARD DECK STRUCTURE:

          READ ORDER -- 1- DECK <C1>      I/O CONTROL      ,READ BY <MAGTAN1>
                        2- DECK <C2(N)>  (FOR DATA SET N),READ BY <HDHCROS>
                        3- DECK <C3(N)>  (FOR DATA SET N),READ BY <AUXMOD>

                      - REPEAT THE <C2>,<C3> GROUP FOR EACH DATA FILE
                        READ AND PROCESSED FROM <TAPE1> IN THE ORDER (N)
                        SELECTED FROM <TAPE1>. EITHER OR BOTH <C2> AND
                        <C3> MUST BE OMITTED IF THE CORRESPONDING AUX
                        INPUT IS NOT OPTED BY <C1>. FOR <TAPE2> DATA
                        INPUT ONLY <C1> IS REQUIRED.
```

SYSTEM FUNCTION ---

A STANDARDIZED FUNCTIONAL FORM IS USED TO REPRESENT SYSTEM CHANNELS AND THE NOS. OF POLES AND ZEROS ARE FIXED. A FIXED NO. OF ZEROS IS PLACED AT THE ORIGIN AND CERTAIN POLE ALLOCATIONS ARE COMMITTED TO LO-CUT USE WITH THE ORIGIN ZEROS. LO-CUT POLES NOT USED ARE TO BE PLACED AT THE ORIGIN. OTHER POLES AND ZEROS ARE TO BE PLACED AT A HIGH ENOUGH FREQ TO BE INEFFECTIVE IN THE PASS BAND.
THE FOLLOWING NOTATION WILL USE: <J> - SYSTEM CHAN NO.
<I> - POLE OR ZERO INDEX.

<AP(J)> - PREAMP GAIN - CHAN J.
<AFO(J)>- POSTAMP GAIN - CHAN J.
<KX(J)> - SENSOR GAIN FACTOR.
<KP(J)> - POLE-ZERO NORMALIZING FACTOR - PREAMP.
<KI(J)> - POLE-ZERO NORMALIZING FACTOR - PLUG-IN FILTER.
<KF(J)> - POLE-ZERO NORMALIZING FACTOR - POST FILTER.
<S> - COMPLEX FREQ.
<P(I,J)>- SYSTEM POLE.
<Z(I,J)>- SYSTEM ZERO.

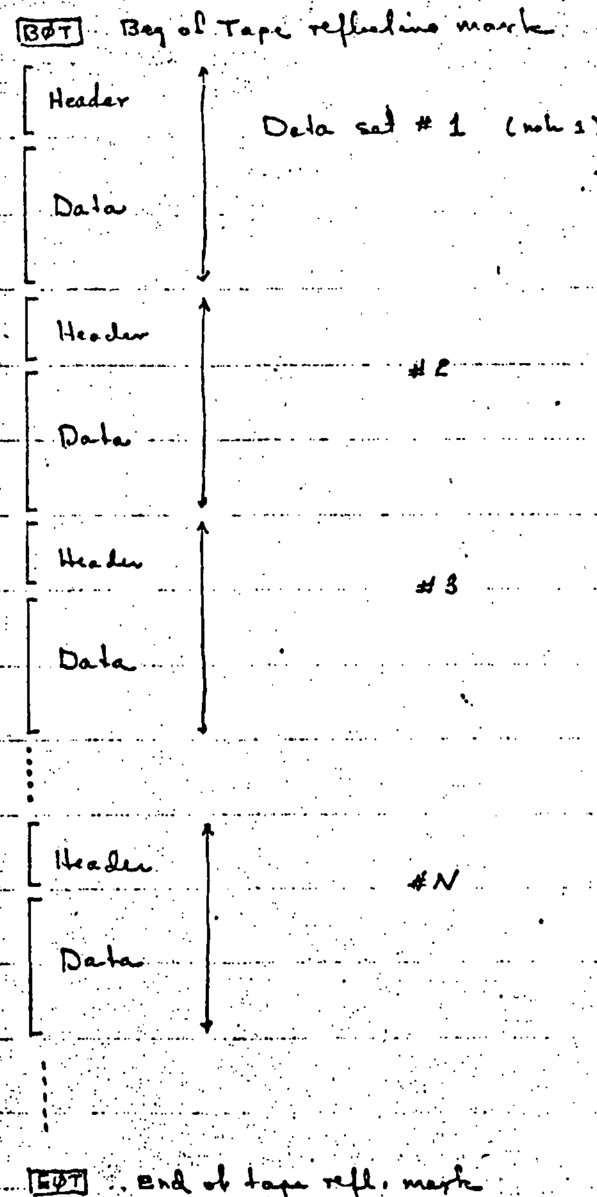
```
      <DF(J)> - E-LINE LENGTH (METERS)
      <GA(J)> - AUX TRANSFER FN GAIN FACTOR.
     <PA(I,J)>- AUX TRANSFER FN POLE.
     <ZA(I,J)>- AUX TRANSFER FN ZERO.
      <NPA(J)>- NO. AUX TF POLES - CH J
      <NZA(J)>- NO. AUX TF ZEROS - CH J

          PRD <X(I)>,I=1,N = X(1)*X(2)*...X(N)


 SENSOR-PREAMP FN -

                AP(J)*KX(J)*KP(J)*(S)       ,KX(J)=(1.E-6)*DE(J),J=1,2
      GP(J) =  ------------------------ ,          = 1.0          ,J=3,5
                PRD <(S-P(I,J))>,I=1,6

            WHERE  KP(J)= CABS(PRD <P(I,J)>,I=2,6)

                   P(1,J) - LO-CUT POLE.

 PLUG-IN FILTER FN -

                       PRD <S-Z(I,J)>,I=1,4
      G1(J) =   K1(J)*----------------------
                       PRD <S-P(I,J)>,I=7,10

      WHERE K1(J)= CABS((PRD <P(I,J)>,I=7,10)/(PRD <Z(I,J)>,I=1,4))

 POST AMP-FILTER FN -

                AFO(J)*KF(J)*(S**3)
      GF(J) =  ----------------------
                PRD <S-P(I,J)>,I=11,19

      WHERE  KF(J)= CABS(PRD <P(I,J)>,I=14,19)

                P(I,J),I=11,13 - LO-CUT POLES.

 SYSTEM TRANSFER FN -

      GO(J) = GP(J)*G1(J)*GF(J)

 AUXILLIARY TRANSFER FN --- SEE <AUXMOD> FOR INPUT DETAILS.

                         PRD <S-ZA(I,J)>,I=1,NZA(J)
      G(J) = GA(J) * --------------------------
                         PRD <S-PA(I,J)>,I=1,NPA(J)

 TOTAL TRANSFER FUNCTION REMOVED FROM DATA ---

      GOX(J) = GO(J)*G(J)

      SEE <POLYCO> FOR THE POLYNOMIAL REPRESENTATION OF <GOX> AS
      IT IS USED FOR RESPONSE CORRECTION IN <FILTER>.


C. OUTPUT :
```

```
OTHER SPECIAL OUTPUT ROUTINES. THE OUTPUT OPTION SELECT ARRAY <IOS>
(READ IN VIA DECK <C1>) IS CHECKED TO DETERMINE THE OUTPUT STATUS.
ALL COMPUTED RESULTS ARE MADE AVAILABLE TO <    1> W/ COMMON <SPEC>.

SUBROUTINE <OUTPRNT> FOR LINE PRINTER OUTPUT IS PRESENTLY INCLUDED.
SUBR<OUTCARD>,<OUTTAPE>,<OUTPLOT> ARE INSERTED AS BLANK ROUTINES FOR
THE USER TO IMPLEMENT WITH HIS DESIRED FORMAT.

SEE  SUBROUTINES <MAGTEL>,<ZFIT>,<OUTPT1> FOR OUTPUT PARAM DETAILS.
```

6/9

re: MAGTAN 2 MT Analysis

Save Tape (Merge Tape) Format



Notes:

1.) See SAVE TAPE FØRMAT enclosed for detailed format of individual data sets on tape.

2.) Each data set corresponds to a recording run, and thus the results for a particular freq. band.

3.) The data set recording run no. for each set is contained in the Header information.

```
      SUBROUTINE OUTTAPE (TITLE,IOS,I1,I2,I3)
C
C   SAVE TAPE FORMAT
C
C  ---HEADER RECORD---
C
C   VARIABLE OR ARRAY                  WORD NUMBER
C        FLAG1                         1
C        NFREQ                         2
C        IOS                           3--82
C        I1                            83
C        I2                            84
C        I3                            85
C        DATE                          86
C        HOUR                          87
C        MIN                           88
C        SEC                           89
C        HEAD2(1-500)                  90--589
C
C
C  ---DATA RECORD---
C
C   VARIABLE OR ARRAY                  WORD NUMBER
C        FLAG2                         1
C        NFREQ                         2
C        PASSLVLS                      3--22
C        FR                            23--22+NFREQ
C        NSP                           23+NFREQ--22+2*NFREQ
C        PP                            23+2*NFREQ--22+27*NFREQ
C        DEPC                          23+27*NFREQ--22+29*NFREQ
C        ELIPC                         23+29*NFREQ--22+31*NFREQ
C        IANC                          23+31*NFREQ--22+33*NFREQ
C        RHOC                          23+33*NFREQ--22+35*NFREQ
C        IAC                           23+35*NFREQ--22+37*NFREQ
C        COR                           23+37*NFREQ--22+4 *N6R58
C        RC                            23+41*NFREQ--22+45*NFREQ
C        IPC                           23+45*NFREQ--22+49*NFREQ
C        COC                           23+49*NFREQ--22+53*NFREQ
C        PRC                           23+53*NFREQ--22+58*NFREQ
C        ANC                           23+58*NFREQ--22+63*NFREQ
C        COHC                          23+63*NFREQ--22+68*NFREQ
C        ANGC                          23+68*NFREQ--I1+71*NFREQ
C        KMMC                          23+71*NFREQ--22+73*NFREQ
C        ALPC                          23+73*NFREQ--22+75*NFREQ
C        BTAC                          23+75*NFREQ--22+78*NFREQ
C        DELC                          23+78*NFREQ--22+80*NFREQ
C        KZE                           23+80*NFREQ--22+82*NFREQ
C        AKZ                           23+82*NFREQ--22+84*NFREQ
C        COK                           23+84*NFREQ--22+85*NFREQ
C        ANK                           23+85*NFREQ--22+86*NFREQ
C        BTAK                          23+86*NFREQ--22+87*NFREQ
C        IXXC                          23+87*NFREQ--22+105*NFREQ
C        IXYC                          23+105*NFR50--22+123*NFR58
C        IEXXC                         23+123*NFREQ--22+124*NFREQ
```

Notes:

- Header Record flag, FLAG1 = 1
- NFREQ = 27 (for all runs up through ~~Apr 1975~~ May 1975.)
- TAPE 2 Header words in order — see TAPE 2 specs.
- Data Record flag, FLAG2 = 0
- not currently used (PASSLVLS)

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```
      C        IEXYC                                23+124*NFREQ--22+125*NFREQ       OUTTAPE   56
      C        EPDCOH                               23+125*NFREQ--22+126*NFREQ       OUTTAPE   57
      C        HPDCOH                               23+126*NFREQ--22+127*NFREQ       OUTTAPE   58
      C                                                                              OUTTAPE   59
      C                                                                              OUTTAPE   60
10          COMMON /SPEC/SP(8193),       FR(100),RNSP(100),P(25,140),PP(100,25)      OUTTAPE   61
           1,DEPC(100,2),ELIPC(100,2),RIANC(100,2),RHOC(100,2),RIAC(100,2),          OUTTAPE   62
           2COR(100,2),RC(100,4),RIPC(100,4),COC(100,4),RRC(100,5),ANC(100,5),       OUTTAPE   63
           3 COHC(100,5),ANGC(100,3),RKMMC(100,2),ALPC(100,2),BTAC(100,3),DELC        OUTTAPE   64
           4(100,2),RKZE(100,2),AKZ(100,2),COK(100),ANK(100),BTAK(100),              OUTTAPE   65
           5PIXXC(100,18),RIXYC(100,18),RIEXXC(100),RIEXYC(100),EPDCOH(100),         OUTTAPE   66
           6HPDCOH(100)                                                              OUTTAPE   67
)10         COMMON /HEADER/ HEAD2(500)                                               OUTTAPE   68
)10         COMMON /PASSLVL/ ARRAY(20)                                               OUTTAPE   69
)10         DIMENSION TITLE(8),RIOS(80),IOS(1)                                       OUTTAPE   70
)10         INTEGER DATE,CLOCK                                                       OUTTAPE   71
```

} E & H predicted coherency – not currently computed

(Handwritten mark * beside COMMON /SPEC/.)

* See subsequent description of variable names in the enclosed documentation section for subroutine MAGTEL.

Header and Data records each written by FORTRAN IV WRITE statement of form:

WRITE (i) l , where i – unit number

l – variable list

```
      SUBROUTINE MAGTEL(P,F,NSP,TITLE,NFREQ,NBIAS)
C*********************************************************************
C*                          ** GEOTRONICS CORP - AUSTIN, TEXAS USA **
C*                                                                   *
C*   SUBROUTINE +MAGTEL> - FORTRAN IV                DRW5022X001     *
C*                                                                   *
C*   USED CALL MAGTEL (P,F,NSP,TITLE,NFREQ,NBIAS)                    *
C*                                                                   *
C*             MAGTEL COMPUTES MAGNETOTELLURIC (MT) RESULTS          *
C*             FROM THE POWER SPECTRA MATRIX +P>. QUANTITIES         *
C*             COMPUTED ARE DESCRIBED BELOW IN THE NOTATION          *
C*             GIVEN IN THE +MAGTAN1> HEADER.                        *
C*             ALL OUTPUT QUANTITIES ARE STORED IN COMMON +SPEC>     *
C*             FOR FURTHER ACCESS BY OUTPUT ROUTINES.                *
C*                                                                   *
C*   PARAMETERS0                                                     *
C*      +P(J,I)> - AUTO- AND CROSS-POWER SPECTRA MATRIX FOR          *
C*                 FIELD COMPONENTS +EX,EY,HX,HY,HZ>.                *
C*                       I- FREQ INDEX                               *
C*                       J- COMPONENT INDEX                          *
C*                 SPEC COMPONENT LOCATIONS -                        *
C*                 J=     1-PEXEX    10-PEYEY 18,19-PHXHY            *
C*                    2,3-PEXEY 11,12-PEYHX 20,21-PHXHZ              *
C*                    4,5-PEXHX 13,14-PEYHY    22-PHYHY              *
C*                    6,7-PEXHY 15,16-PEYHZ 23,24-PHYHZ              *
C*                    8,9-PEXHZ    17-PHXHX    25-PHZHZ              *
C*                 (CROSS-POWERS ARE STORED WITH REAL AND IMAG       *
C*                  PARTS ADJACENT WORDS IN ORDER)                   *
C*                NOTE 1-E-POWER       UNITS - (MV/KM)**2/HZ         *
C*                       H-POWER       UNITS -    GAMMA**2/HZ        *
C*                       E-H-POWER     UNITS - (MV/KM)*GAMMA/HZ      *
C*                NOTE 2-THE COMPONENT ORDER GIVEN IS FOR +P>        *
C*                       UPON INPUT TO +MAGTEL>. THE +P> ORDER       *
C*                       IS MODIFIED IN +MAGTEL> AFTER CALL OF       *
C*                       +ZFIT> AND SOME INFO IS DISCARDED. THE      *
C*                       UNMODIFIED +P(J,I)> INFO IS SAVED IN        *
C*                       +PP(I,J)>. BOTH ARE STORED IN +SPEC>.       *
C*        +F(I)> - FREQ OF ITH WORD IN ALL OUTPUT ARRAYS (HZ).       *
C*      +NSP(I)> - NO. OF INCREMENTAL HARM ASSOC WITH +FR(I)>.       *
C*       +TITLE> - TITLE OF DATA SET.                                *
C*       +NFREQ> - NO. OF WORDS IN +FR(I)> (I=1,NFREQ).              *
C*       +NBIAS> - NO. OF COMPONENTS IN +P(J,I)> (J=1,NBIAS)         *
C*                                                                   *
C*   ROUTINES CALLED0 +ZFIT>                                         *
C*                    +IDATAN>                                       *
C*                                                                   *
C*   SPECIAL STORAGE AREAS0                                          *
C*         COMMON BLOCK +SPEC> - 25000 WORDS                         *
C*                                                                   *
C*                                                                   *
C*    MT RESULTS COMPUTED0 (ARRAYS IN COMMON +SPEC>)                 *
C*              NOTE 1-SEE +MAGTAN1> FOR NOTATION.                   *
C*              NOTE 2-I - FREQ INDEX (I=1,NFREQ)                    *
C*                     J - CONTENTS INDEX                            *
```

```
*                                                                 *    MAGTEL
*        +NFREQ> - NO. OF FREQS.                                  *    MAGTEL
*        +FR(I)> - FREQ - I=1,NFREQ - (HZ)                        *    MAGTEL
*       +NSP(I)> - NO. INCREMENTAL HARM AVGD FOR +FR(I)>.         *    MAGTEL
*                                                                 *    MAGTEL
*       +P(J,I)> - POWER SPECTRA MATRIX - SEE ABOVE DESCR.        *    MAGTEL
*      +PP(I,J)> -  = +P(J,I)> PRIOR TO ANY MOD OF +P> .          *    MAGTEL
*                                                                 *    MAGTEL
*    +DEPC(I,J)> - J=1,2 - RATIO OF UNPOLARIZED POWER TO TOTAL    *    MAGTEL
*                  POWER OF E AND H FIELDS RESPECTIVELY.          *    MAGTEL
*                                                                 *    MAGTEL
*   +ELIPC(I,J)> - J=1,2 - RATIO OF MINOR TO MAJOR AXIS OF        *    MAGTEL
*                  POLARIZATION ELLIPSE FOR POLARIZED COMPONENTS  *    MAGTEL
*                  OF E AND H(HORIZ) FIELDS RESPECTIVELY.         *    MAGTEL
*                  (+ FOR RT HAND POLARIZ - CLOCKWISE WHEN        *    MAGTEL
*                  LOOKING IN +Z-AXIS DIRECTION)                  *    MAGTEL
*                                                                 *    MAGTEL
*    +IANC(I,J)> - AZIMUTH ANGLE (DEGREES) OF MAJOR AXIS OF       *    MAGTEL
*                  POLARIZ ELLIPSE FOR E AND H(HORIZ) FIELDS.     *    MAGTEL
*                                                                 *    MAGTEL
*   0+RHOC(I,J)> - J=1,2- APPARENT RESISTIVITY (APP RES) FOR      *    MAGTEL
*   0              ZX AND ZY RESPECTIVELY (OHM-METERS).           *    MAGTEL
*   0 +IAC(I,J)> - J=1,2- PHASE OF ZX AND ZY (DEGREES).           *    MAGTEL
*   0 +COR(I,J)> - COHERENCY FOR (EX-HY) AND (EY-HX).             *    MAGTEL
*   0                                                             *    MAGTEL
*   0 WHERE  ZX = EX/HY AND ZY = EY/HX  (UNROTATED CAGNIARD Z).   *    MAGTEL
*                                                                 *    MAGTEL
*      +RC(I,J)> - J=1,4- APP RES FOR TENSOR +Z> ELEMENTS         *    MAGTEL
*                  ZXX,ZYY,ZXY,ZYX IN ORDER (OHM-METERS).         *    MAGTEL
*     +IPC(I,J)> - J=1,4- PHASE OF ZXX,ZYY,ZXY,ZYX  (DEGREES)     *    MAGTEL
*     +COC(I,J)> - J=1,4- PHASOR COHERENCY FOR ZXX,ZYY,ZXY,ZYX.   *    MAGTEL
*                                                                 *    MAGTEL
*    NOTE--ROTATED +Z> AND +Y> RESULTS --- IN THE FOLLOWING THE   *    MAGTEL
*          XY-AXES ARE ROTATED AT EACH FREQ TO ANGLE +A>=+A(Z)>   *    MAGTEL
*          FOR +Z> AND INVERTED +Y> TENSORS SO THAT               *    MAGTEL
*          CABS+ZXY(A)+ZYX(A)> IS MAX FOR +A>=+A(Z)>. THE XY-AXES*    MAGTEL
*          ARE ROTATED FOR +YZ> (EQUATION I-7 OF +MAGTAN1>) TO    *    MAGTEL
*          ANGLE +A>=+A(YZ)> SO THAT CABS+YZY(A)> IS MAX (HZ IS   *    MAGTEL
*          MOST COHERENT WITH EY). THE XY-AXES ARE ROTATED FOR    *    MAGTEL
*          +KZ> (EQUATION I-8 OF +MAGTAN1> TO +A>=+A(KZ)> SO THAT*    MAGTEL
*          CABS+KZX(A)> IS MAX (HZ IS MOST COHERENT WITH HX).     *    MAGTEL
*          FINALLY THE  IMPEDANCES   +ZTE> (E PARALLEL TO STRIKE)*    MAGTEL
*          AND +ZTM> (H PARALLEL TO STRIKE) ARE SELECTED FROM     *    MAGTEL
*          +ZXY(A(Z))> AND +ZYX(A(Z))> ON THE BASISO FOR THE      *    MAGTEL
*          1ST AN 4TH QUADRANT PRINCIPLE VALUES OF +A(Z)> AND     *    MAGTEL
*          +A(YZ)> -                                              *    MAGTEL
*             IF(ABS+A(Z)-A(YZ)>.LE.45 DEGR) --+ZTE>=+ZYX(A(Z))>  *    MAGTEL
*                                              +ZTM>=+ZXY(A(Z))>  *    MAGTEL
*             IF(ABS+A(Z)-A(YZ)>.GT.45 DEGR) --+ZTE>=+ZXY(A(Z))>  *    MAGTEL
*                                              +ZTM>=+ZYX(A(Z))>  *    MAGTEL
*                                                                 *    MAGTEL
*     +RRC(I,J)> - J=1,2- APP RES - +ZTE>,+ZTM> - +Z> TENSOR      *    MAGTEL
*                      3,4- APP RES - +ZTE>,+ZTM> - +Y> TENSOR    *    MAGTEL
*                        5- APP RES - +YZY(A(YZ))>- +Y> TENSOR    *    MAGTEL
*                           (I.E.- APP RES FOR EY/HZ AT +A(YZ)>.) *    MAGTEL
```

```
*   +ANC(I,J)> - J=1,2- PHASE - +ZTE>,+ZTM>    - +Z> TENSOR        *          MAGTEL
*                3,4- PHASE - +ZTE>,+ZTM>    - +Y> TENSOR        *          MAGTEL
*                  5- PHASE - +YZY(A(YZ))>   - +Y> TENSOR        *          MAGTEL
*  +COHC(I,J)> - J=1,2- PHASOR COH - +ZTE>,+ZTM> - +Z> TENSOR     *          MAGTEL
*                3,4- PHASOR COH - +ZTE>,+ZTM> - +Y> TENSOR     *          MAGTEL
*                  5- PHASOR COH - +YZY(A(YZ))>- +Y> TENSOR     *          MAGTEL
*  +ANGC(I,J)> - J=1,2- +A(Z)>-+Z> TENSOR, +A(Z)>-+Y> TENSOR      *          MAGTEL
*                  3- +A(YZ)> - +Y> TENSOR                        *          MAGTEL
*  +DELC(I,J)> - J=1,2- NORMALIZED DENOMINATOR TERMS ASSOC        *          MAGTEL
*                     WITH SOLUTIONS FOR +Z> AND +Y> RESP.       *          MAGTEL
*                     (USED TO ASSESS COMPUTATIONAL              *          MAGTEL
*                     STABILITY. +Z> OR +Y> ESTIMATE IS          *          MAGTEL
*                     ACCEPTED IF +DELC>.GE.+0.1>).              *          MAGTEL
*  +ALPC(I,J)> - J=1,2- TENSOR SKEW FOR +Z> AND +Y> RESP.         *          MAGTEL
*                     DEFO                                       *          MAGTEL
*                       +ALPC>=+ZXX+ZYY>/+ZXY-ZYX>               *          MAGTEL
*                       (INDEPENDENT OF +A>).                    *          MAGTEL
*  +BTAC(I,J)> - J=1,3- TENSOR ELLIPTICITY FOR +Z>,+Y>,+YZ>,      *          MAGTEL
*                     RESP. DEFO                                 *          MAGTEL
*                       +BTAC>=+YZX(A)>/+YZY(A)>,+A>=+A(YZ)>     *          MAGTEL
*  +KMMC(I,J)> - J=1,2- NO.OF INDEPENDENT SOLUTIONS OF            *          MAGTEL
*                     +Z> AND +Y> RESP ACCEPTED AND AVGD         *          MAGTEL
*                     TOGETHER - USING +DELC> ACCEPTANCE TEST*          MAGTEL
*   +KZE(I,J)> - J=1,2- +KZX(A)>,+KZY(A)> RESP FOR +A>=+A(KZ)>  *          MAGTEL
*                     (EQUATION I-8 OF +MAGTAN1>)                *          MAGTEL
*   +AKE(I,J)> - J=1,2- PHASE FOR +KZX(A)>,+KZY(A)>,+A>=+A(KZ)>*          MAGTEL
*     +COK(I)> -        (HZ-HX) COHERENCY FOR +A>=+A(KZ)>        *          MAGTEL
*     +ANK(I)> -        +A(KZ)> FOR +KZ> TENSOR                  *          MAGTEL
*    +BTAK(I)> -        +KZ> TENSOR ELLIPTICITY.                 *          MAGTEL
*                       DEFO +BTAK> = +KZY(A)>/+KZX(A)>,         *          MAGTEL
*                                     +A>=+A(KZ)>                *          MAGTEL
*                                                                *          MAGTEL
*                                                                *          MAGTEL
*  NOTE--THE FOLLOWING ARRAYS PERTAIN TO ROTATION OF +ZXX>       *          MAGTEL
*        AND +ZXY> BY 10 DEGREE INCREMENTS FROM +A>=-80 DEG      *          MAGTEL
*        TO +A>=+90 DEG FOR EACH FREQ VALUE.                     *          MAGTEL
*                                                                *          MAGTEL
*  +IXXC(I,J)> - J=1,18- APP RES FOR +ZXX(A)>, -80≠A≠+90 DEGR     *          MAGTEL
*                        IN 10 DEGR INCR. (DIVIDED BY 10**IXXC)*          MAGTEL
*  +IXYC(I,J)> - J=1,18- APP RES FOR +ZXY(A)>, -80≠A≠+90 DEGR     *          MAGTEL
*                        IN 10 DEGR INCR. (DIVIDED BY 10**IXYC)*          MAGTEL
*   +IEXXC(I)> - DECIMAL EXPONENT FOR +IXXC>.                    *          MAGTEL
*   +IEXYC(I)> - DECIMAL EXPONENT FOR +IXYC>.                    *          MAGTEL
*                                                                *          MAGTEL
*  NOTE--REFER TO REFERENCE(S) GIVEN IN +MAGTAN1> FOR MORE       *          MAGTEL
*        DETAILED DESCRIPTION OF THE MT THEORY AND COMPUTATIONS*          MAGTEL
*                                                                *          MAGTEL
*                                                                *          MAGTEL
******************************************************************          MAGTEL
```

MAGTAN 2 - Line Printer Output Specification

```
      SUBROUTINE OUTPT1 (TITLE,IOS,I1,I2,I3)
*****************************************************************
*                  ** GEOTRONICS CORP - AUSTIN, TEXAS USA **     *
*                                                                *
*  SUBROUTINE +OUTPT1> - FORTRAN IV              DRW5014X001     *
*                                                                *
*  USED  CALL OUTPUT1 (TITLE,IOS,I1,I2,I3)                       *
*                                                                *
*        OUTPT1 CONTROLS THE OUTPUT OF +MAGTAN1>. ARRAYS TO BE   *
*        OUTPUT ARE TAKEN FROM COMMON BLOCK +SPEC>. OUTPUT       *
*        OPTIONS ARE CONTROLLED BY THE I/O SELECT ARRAY +IOS>.   *
*        +IOS> ALLOWS SELECTION OF ANY OR ALL OF A NUMBER        *
*        OF PRINTED OUTPUT SUBSETS PER SUBR+OUTPRNT>. PUNCH      *
*        CARD OUTPUT PER SUBR+OUTCARD>, AND MAG TAPE OUTPUT      *
*        PER SUBR+OUTTAPE>. THE FLAG PARAMETERS +I1>,+I2>,+I3>   *
*        ARE PASSED TO INDICATE THE IDENTITY AND STATUS OF       *
*        THE DATA SET BEING PROCESSED. THESE MAY BE USED WITH    *
*        +IOS> IN SELECTION OF THE OUTPUT OPTIONS WITH LOGIC     *
*        ADDED BY THE USER.                                      *
*        (PLOT OUTPUT BY SUBR+OUTPLOT> MAY BE EASILY INCLUDED    *
*        BY ADDING THE PROPER CALLING LOGIC TO +OUTPT1>, USING   *
*        BLANK ELEMENTS OF +IOS>.)                               *
*                                                                *
*  PARAMETERS0                                                   *
*     +TITLE> - DATA SET TITLE.                                  *
*     +IOS(N)> - I/O SELECT ARRAY - (80 SINGLE CHAR ELEMENTS).   *
*              IOS(N)=1 -  ENABLE CONDX FOR ITEM N               *
*                    =0 - DISABLE CONDX FOR ITEM N               *
*     ---TABLE OF PRESENT IMPLEMENTATION OI +IOS> OPTIONS.       *
*        N=1 - TITLE PAGE 1 - PER SUBR+TITLE1>.                  *
*          2 - TITLE PAGE 2 - PER SUBR+TITLE2>.                  *
*          3 - DECODED TAPE1 HEADER INFO - PER SUBR+TEOUT>.      *
*          4 - BLANK                                             *
*          5 - ENABLE CALL SUBR+OUTPRNT> - CK IOS(N),N= 6,19.    *
*          6 - E-H FIELD AUTO-POWER SPECTRA.       -+OUTPRNT>.   *
*          7 - E-H FIELD POLARIZATION PROPERTIES.  -+OUTPRNT>.   *
*          8 - Z-SCALAR RESULTS    - UNROTATED.    -+OUTPRNT>.   *
*          9 - Z-TENSOR RESULTS    - UNROTATED.    -+OUTPRNT>.   *
*         10 - Z-TENSOR RESULTS    -   ROTATED.    -+OUTPRNT>.   *
*         11 - Y-TENSOR RESULTS    -   ROTATED.    -+OUTPRNT>.   *
*         12 - HZ-RELATIONS        -   ROTATED.    -+OUTPRNT>.   *
*         13 - Z-TENSOR AXIS ROTATION - FREQ  MAP.-+OUTPRNT>.    *
*         14 - PRINT SETS 5,13 FOR AVG RESULTS ONLY.             *
*      15-19 - BLANK                                             *
*         20 - ENABLE CALL SUBR+OUTCARD> - CK IOS(N),N=21,29.    *
*      21-29 - BLANK                                             *
*         30 - ENABLE CALL SUBR+OUTTAPE> - CK IOS(N),N=31,39.    *
*      31-39 - BLANK                                             *
*      40-80 - BLANK   (MAY BE USED FOR ADDED OPTIONS).          *
*      NOTE- IN PRESENT USE +IOS> ELEMENTS HAVE ONLY 2 STATES    *
*            +0> AND +1>. THE USER MAY INTRODUCE STILL MORE      *
*            FLEXIBILITY BY IMPLEMENTING THE USE OF MORE         *
*            STATES. ANY OR ALL OF THE ALPHANUMERIC CHARACTER    *
*            SET MAY BE USED.                                    *
```

Note: Punch code incompatibility causes some special symbol to print incorrectly:

< → +

: → 0

≤ → ≠

and a few others

Note: 1) IØS(N) is printed in upper right corner of each standard output page

2) For non-standard, special printouts, example output pages are provided marked to identify the output

```
*          +I1> - OUTPUT DATA SET STATUS -+0>-SINGLE DATA SET.      *
*                                           +1>-GROUP AVERAGE.      *
*          +I2> - DATA SET GROUP INDEX (+J> IN +MAGTAN1>).          *
*          +I3> - DATA SET INDEX IN GROUP+I2> (+I> IN +MAGTAN1>.    *
*                                                                   *
*    ROUTINES CALLEDO +OUTPRNT>                                     *
*                     +OUTCARD>                                     *
*                     +OUTTAPE>                                     *
*                                                                   *
*    SPECIAL STORAGE AREASO                                         *
*          COMMON BLOCK +SPEC> - 24828 WORDS                        *
*            NOTE - SEE SUBR+MAGTEL> AND SUBR+ZFIT> FOR             *
*                   DEFINITION OF OUTPUT ARRAYS IN +SPEC>.          *
*                                                                   *
*********************************************************************
```

```
      SUBROUTINE OUTPRNT(TITLE,IOS,I1,I2,I3)
C*********************************************************************
C*                     ** GEOTRONICS CORP - AUSTIN, TEXAS USA **     *
C*                                                                   *
C* SUBROUTINE +OUTPRNT> - FORTRAN IV                     DSR1025X001 *
C*                                                                   *
C* USED  CALL OUTPRNT(TITLE,IOS,I1,I2,I3)                            *
C*                                                                   *
C*       THIS ROUTINE PRODUCES LINE PRINTER OUTPUT FOR RESULTS       *
C*       FROM +MAGTEL> AND +ZFIT>, WITH APPROPRIATE TITLES AND       *
C*       COLUMN HEADINGS.                                            *
C*                                                                   *
C* PARAMETERS0                                                       *
C*     +TITLE> - TITLE OF DATA SET - FORMAT(8A10).                   *
C*       +IOS> - OUTPUT OPTION SELECT ARRAY.                         *
C*               (SEE HEADER FOR +MAGTAN1> OR +OUTPT1> FOR           *
C*                CURRENT IMPLEMENTATION OF OPTIONS)                 *
C*        +I1> - TYPE OF DATA BEING CURRENTLY PROCESSED              *
C*                      0-SINGLE DATA SET                            *
C*                      1-AVERAGED RESULTS                           *
C*        +I2> - NOT USED.                                           *
C*        +I3> - NOT USED.                                           *
C*                                                                   *
C* ROUTINES CALLED0  NONE                                            *
C*                                                                   *
C* SPECIAL STORAGE AREAS0                                            *
C*       COMMON BLOCK +SPEC> - 22993 WORDS                           *
C*                                                                   *
C* DESCRIPTION OF OUTPUT, BY HEADINGS0                               *
C*                                                                   *
C*  ALL PRINTER OUTPUT0                                              *
C*       NO. - THE LINE NUMBER, CORRESPONDING TO THE ITH FREQ.       *
C*       FREQ - FR(I) - FREQUENCY (HZ).                              *
C*       NHARM - NSP(I) -    INCREMENTAL HARMONICS AVERAGED.         *
C*                                                                   *
C*  E-H FIELD AUTO-POWER SPECTRA0                                    *
C*       PEXEX - PP(I,1)  -   EX - AUTO-POWER-(MV/KM)**2/HZ.         *
C*       PEYEY - PP(I,10) -   EY - AUTO-POWER-(MV/KM)**2/HZ.         *
C*       PHXHX - PP(I,17) -   HX - AUTO-POWER- GAMMA**2/HZ.          *
C*       PHYHY - PP(I,22) -   HY - AUTO-POWER- GAMMA**2/HZ.          *
C*       PHZHZ - PP(I,25) -   HZ - AUTO-POWER- GAMMA**2/HZ.          *
C*                                                                   *
C*  E-H FIELD POLARIZATION PROPERTIES0                               *
C*       EDEP - DEPC(I,1) -  E-FIELD DEPOLARIZATION - RATIO OF       *
C*                           UNPOLARIZED TO TOTAL POWER              *
C*       EELIP - ELIPC(I,1) -E-FIELD ELLIPTICITY OF                  *
C*                           POLARIZED POWER COMPONENT               *
C*       EA - IANC(I,1) -    E-FIELD POLARIZATION ANGLE (DEGR)       *
C*       HDEP - DEPC(I,2) -  H-FIELD DEPOLARIZATION - RATIO OF       *
C*                           UNPOLARIZED TO TOTAL POWER              *
C*       HELIP - ELIPC(I,2) -H-FIELD ELLIPTICITY OF                  *
C*                           POLARIZED POWER COMPONENT               *
C*       HA - IANC(I,2) -    H-FIELD POLARIZATION ANGLE (DEGR)       *
C*                                                                   *
```

```
*     --SCALAR RESULTS - UNROTATEDO                                 *   OUTPRNT
*          RX(PH)COH - RHOC(I,1),IAC(I,1),COR(I,1) - APP RES ,      *   OUTPRNT
*                      PHASE, AND COHERENCY FOR ZX = EX/HY.         *   OUTPRNT
*                      (CAGNIARD SOLUTION)                          *   OUTPRNT
*          RY(PH)COH - RHOC(I,2),IAC(I,2),COR(I,2) - APP RES ,      *   OUTPRNT
*                      PHASE, AND COHERENCY FOR ZY = EY/HX.         *   OUTPRNT
*                      (CAGNIARD SOLUTION)                          *   OUTPRNT
*                                                                   *   OUTPRNT
*     Z-TENSOR RESULTS - UNROTATEDO                                 *   OUTPRNT
*          RXX(PH)COZ - RC(I,1),IPC(I,1),COC(I,1) -  APP RES ,      *   OUTPRNT
*                      PHASE, AND PHASOR COH FOR  ZXX  ELEMENT      *   OUTPRNT
*                      OF +Z> TENSOR (UNROTATED)                    *   OUTPRNT
*          RYY(PH)COZ - RC(I,2),IPC(I,2),COC(I,2) -  APP RES ,      *   OUTPRNT
*                      PHASE, AND PHASOR COH FOR  ZYY  ELEMENT      *   OUTPRNT
*                      OF +Z> TENSOR (UNROTATED)                    *   OUTPRNT
*          RXY(PH)COZ - RC(I,3),IPC(I,2),COC(I,2) -  APP RES ,      *   OUTPRNT
*                      PHASE, AND PHASOR COH FOR  ZXY ELEMENT       *   OUTPRNT
*                      OF +Z> TENSOR (UNROTATED)                    *   OUTPRNT
*          RYX(PH)COZ - RC(I,4),IPC(I,4),COC(I,4) -  APP RES ,      *   OUTPRNT
*                      PHASE, AND PHASOR COH FOR  ZYX ELEMENT       *   OUTPRNT
*                      OF +Z> TENSOR (UNROTATED)                    *   OUTPRNT
*                                                                   *   OUTPRNT
*     Z-TENSOR RESULTS - ROTATEDO                                   *   OUTPRNT
*          RTM(PH)COZ - RRC(I,1),ANC(I,1),COHC(I,1) -   APP RES ,   *   OUTPRNT
*                      PHASE, PHASOR COH - E PERP TO STRIKE         *   OUTPRNT
*          RTE(PH)COZ - RRC(I,2),ANC(I,2),COHC(I,2) -   APP RES ,   *   OUTPRNT
*                      PHASE, PHASOR COH - E PARAL TO STRIKE        *   OUTPRNT
*          A(Z) - ANGC(I,1) - ROTATION ANGLE FOR PRINCIPLE AXES     *   OUTPRNT
*                      OF +Z> TENSOR  (DEGREES)                     *   OUTPRNT
*          N - KMMC(I,1)     - NO. OF INDEPENDENT +Z> SOLUTIONS     *   OUTPRNT
*                             AVERAGED                              *   OUTPRNT
*          ALPHA - ALPC(I,1)- +Z> TENSOR SKEW                       *   OUTPRNT
*          BETA - BTAC(I,1) - +Z> TENSOR ELLIPTICITY                *   OUTPRNT
*          DEN - DELC(I,1) - NORM DENOM DETERMINANT FOR             *   OUTPRNT
*                            +Z> SOLUTIONS                          *   OUTPRNT
*                                                                   *   OUTPRNT
*     Y-TENSOR RESULTS - ROTATEDO                                   *   OUTPRNT
*          RTM(PH)COZ - RRC(I,3),ANC(I,3),COHC(I,3) -   APP RES ,   *   OUTPRNT
*                      PHASE, PHASOR COH - E PERP TO STRIKE         *   OUTPRNT
*          RTE(PH)COZ - RRC(I,4),ANC(I,4),COHC(I,4) -   APP RES ,   *   OUTPRNT
*                      PHASE, PHASOR COH - E PARAL TO STRIPE        *   OUTPRNT
*          A(Z) - ANGC(I,2) - ROTATION ANGLE FOR PRINCIPLE AXES     *   OUTPRNT
*                      OF +Y> TENSOR  (DEGREES)                     *   OUTPRNT
*          N - KMMC(I,2) -     NO. OF INDEPENDENT +Y> SOLUTIONS     *   OUTPRNT
*                             AVERAGED                              *   OUTPRNT
*          ALPHA - ALPC(I,2) -+Y> TENSOR SKEW                       *   OUTPRNT
*          BETA - BTAC(I,2) - +Y> TENSOR ELLIPTICITY                *   OUTPRNT
*          DEN - DELC(I,2) - NORM DENOM DETERMINANT FOR             *   OUTPRNT
*                            +Y> SOLUTIONS                          *   OUTPRNT
*                                                                   *   OUTPRNT
*     HZ-RELATIONS - ROTATEDO                                       *   OUTPRNT
*          RZTE(PH)COY - RRC(I,5),ANC(I,5),COHC(I,5) - APP RES ,    *   OUTPRNT
*                        PHASE, PHASOR COH FOR  YZY(A(YZ)).         *   OUTPRNT
*          A(YZ) - ANGC(I,3) - PRINCIPLE ROTATION ANGLE FOR +YZ>    *   OUTPRNT
*          BETA - BTAC(I,3) -  ELLIPTICITY OF +YZ>                  *   OUTPRNT
```

```
*         KZTE(PH)COK - KZE(I,1),AKZ(I,1),COK(I)- KZX(A(KZ)),       *
*                        PHASE, AND (HZ-HX) COH FOR +KZ> TENSOR     *
*         A(KZ) - ANK(I) - PRINCIPLE ROTATION ANGLE FOR +KZ>        *
*         BETA - BTAK(I) -     ELLIPTICITY OF +KZ>                  *
*                                                                   *
*    Z-TENSOR  AXIS ROTATION-FREQ  MAPO  PLOT OF  RXX (TOP LINE)*
*              AND RXY (BOT LINE) VS. A (DEGR) AND FREQ (HZ).       *
*              DECIMAL ASSUMED AT LEFT OF 3 DIGITS (LEADING         *
*              ZEROS OMITTED) FOR EACH R VALUE . MULTIPLY EACH      *
*              VALUE BY 10 TO EXPONENT AT END OF ROW.               *
*                                                                   *
*********************************************************************
```

Appendix C, Computer Programs, continued...

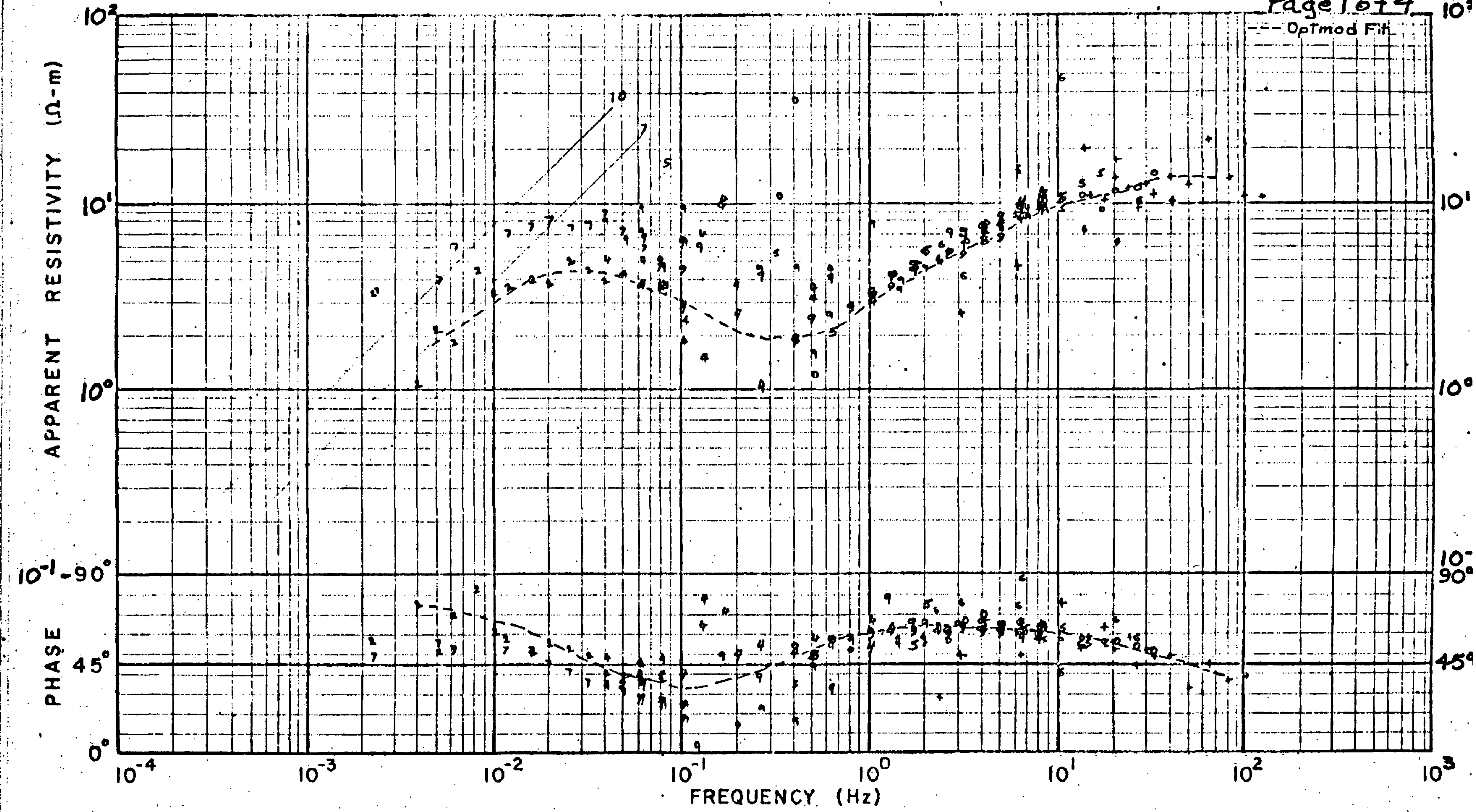
(2) INVERT - produces an approximate one-dimensional inversion of an apparent resistivity and associated phase function, using an analytical approach. The output is a continuous function of intrinsic resistivity vs. depth and represents a vertically smoothed version of the real vertical profile. This, like any MT inversion is more sensitive to conductive zones and will tend to underestimate or ignore electrically thin resistive zones.

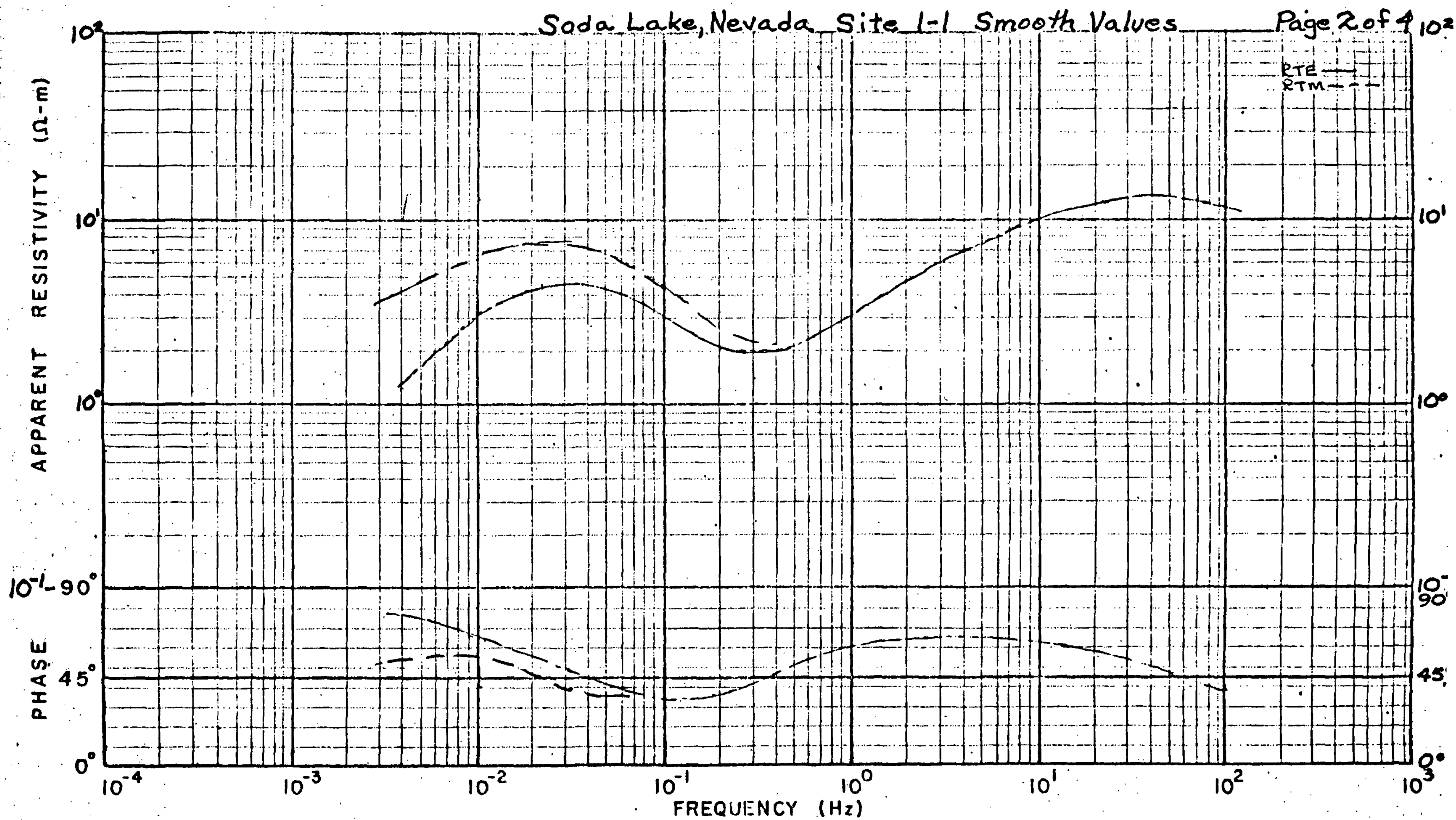
(3) OPTMOD - produces a one-dimensional N-layered model by least squares fitting the complex impedance functions for the model and the measured data, with respect to all model parameters, for up to N = 10 layers.

(4) LAYERPXY - produces the forward MT solution for a one-dimensional layered model and plots the model apparent resistivity and phase with the like measured functions for comparison. Results for permutations of a number of values for one or two model parameters can be produced to examine the effect of a parameter change.

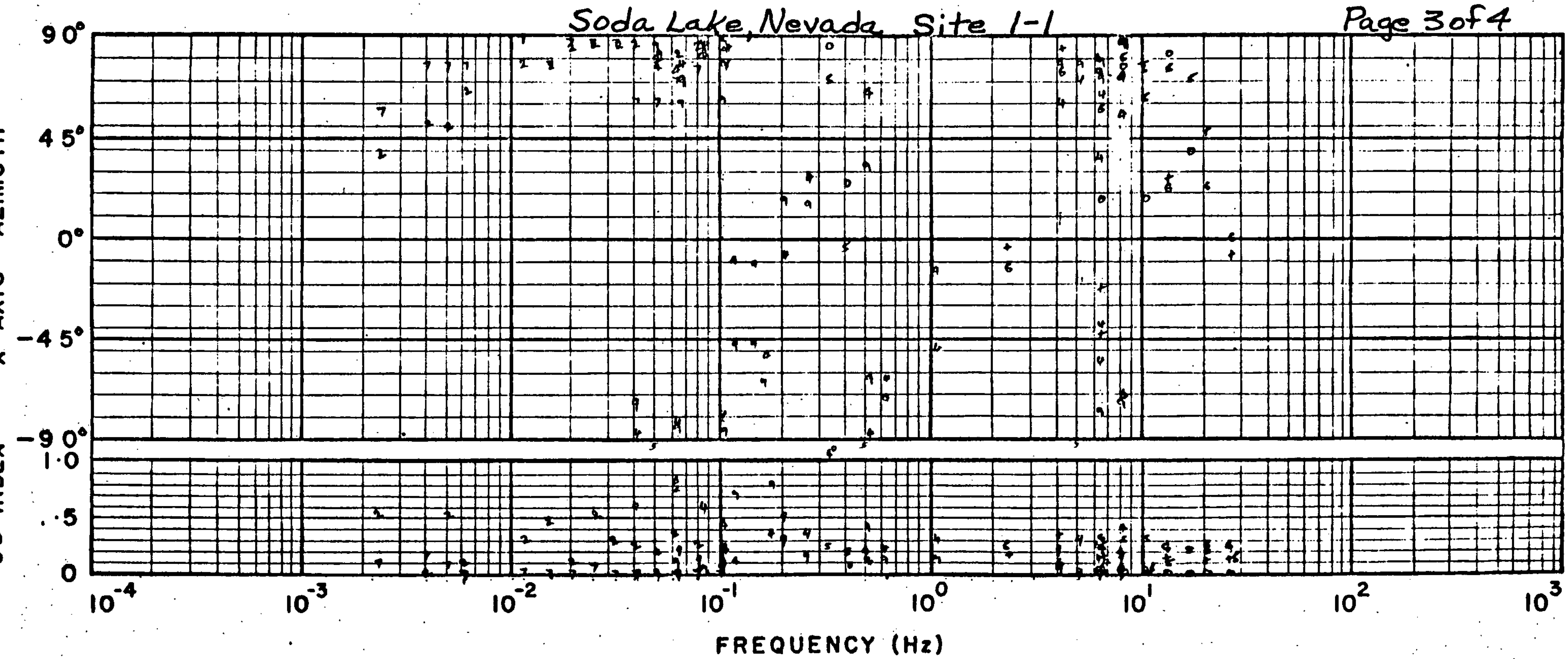
Soda Lake, Nevada Site 1-1

Figure II-1
Page 1 of 4

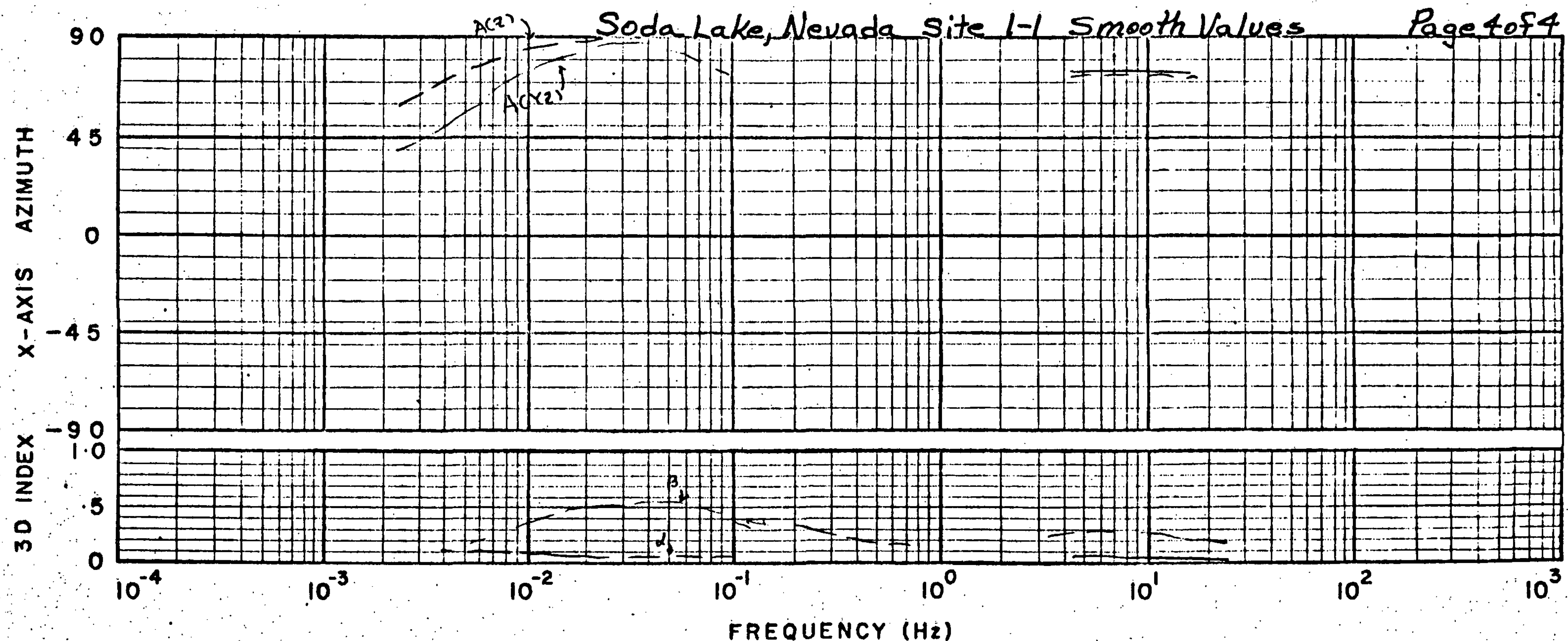




Soda Lake, Nevada Site 1-1 Smooth Values
Page 2 of 4
ρTE ——
ρTM - - -
APPARENT RESISTIVITY (Ω-m)
PHASE
10²
10¹
10⁰
10⁻¹-90°
45°
0°
10⁻⁴
10⁻³
10⁻²
10⁻¹
10⁰
10¹
10²
10³
FREQUENCY (Hz)

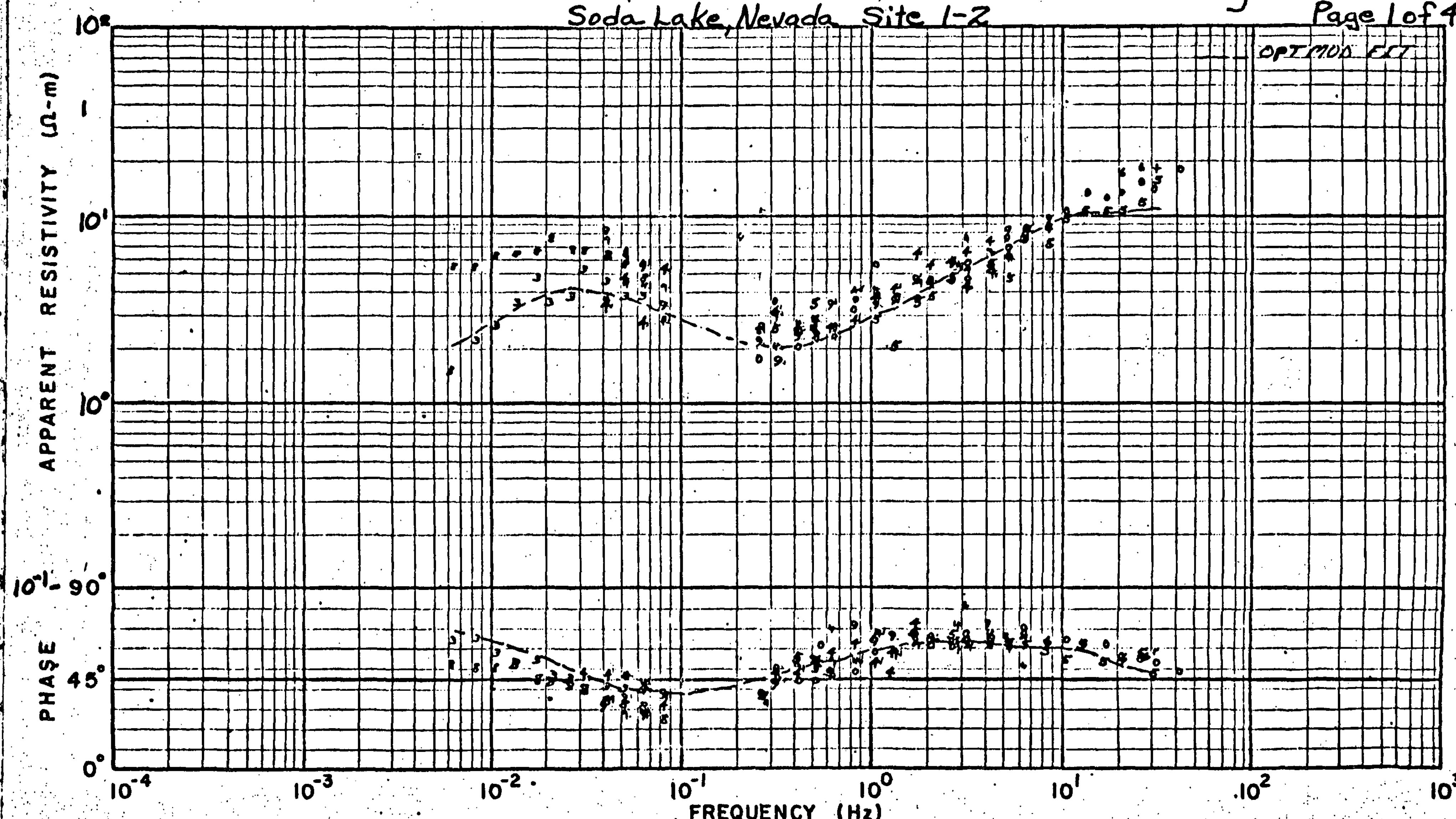


Soda Lake, Nevada Site 1-1
Page 3 of 4
X-AXIS AZIMUTH
90°
45°
0°
-45°
-90°
3D INDEX
1.0
.5
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)

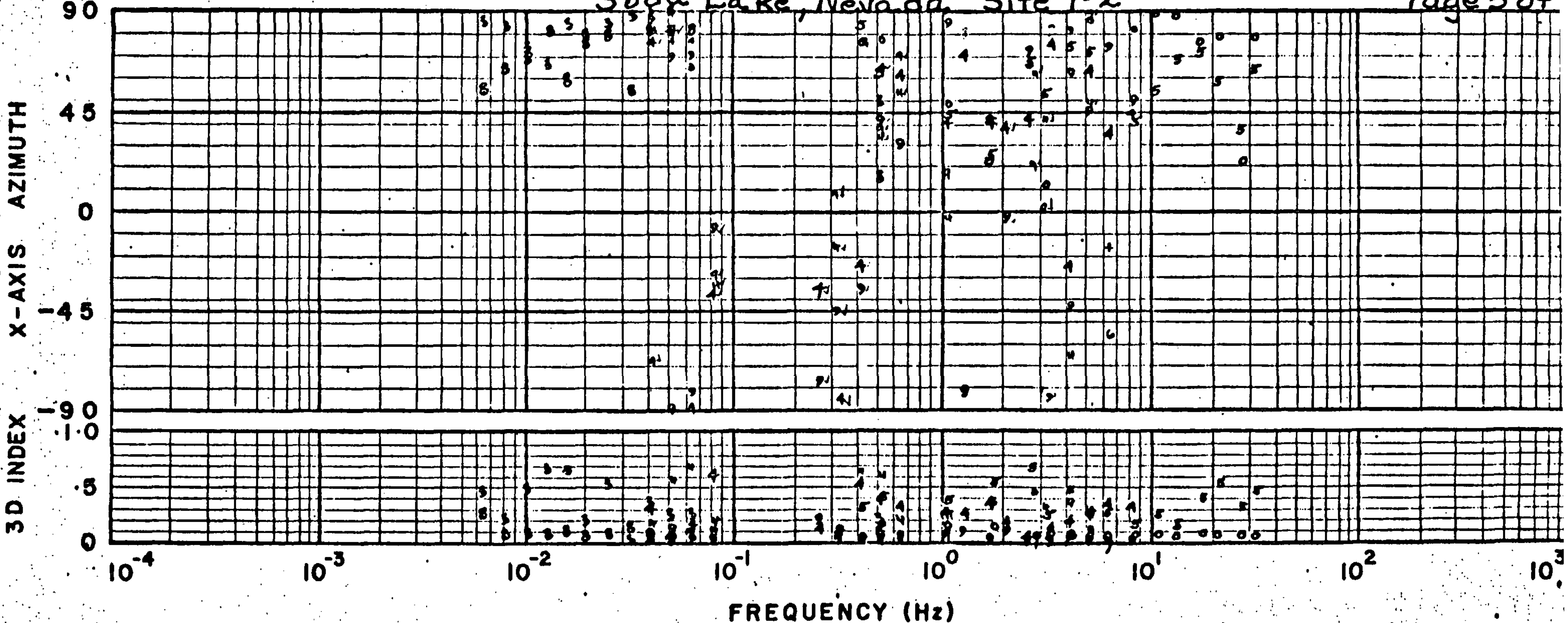


Soda Lake, Nevada Site 1-1 Smooth Values
Page 4 of 4
90
45
0
-45
-90
X-AXIS AZIMUTH
1.0
.5
0
3D INDEX
A(Z)
A(YZ)
B
α
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)

FIGURE II-2


Soda Lake, Nevada Site 1-Z
OPTMOD FIT
APPARENT RESISTIVITY (Ω-m)
PHASE
FREQUENCY (Hz)
10²
1
10¹
10⁰
10⁻¹ - 90°
45°
0°
10⁻⁴
10⁻³
10⁻²
10⁻¹
10⁰
10¹
10²
10³

Soda Lake, Nevada Site 1-2 Page 3 of



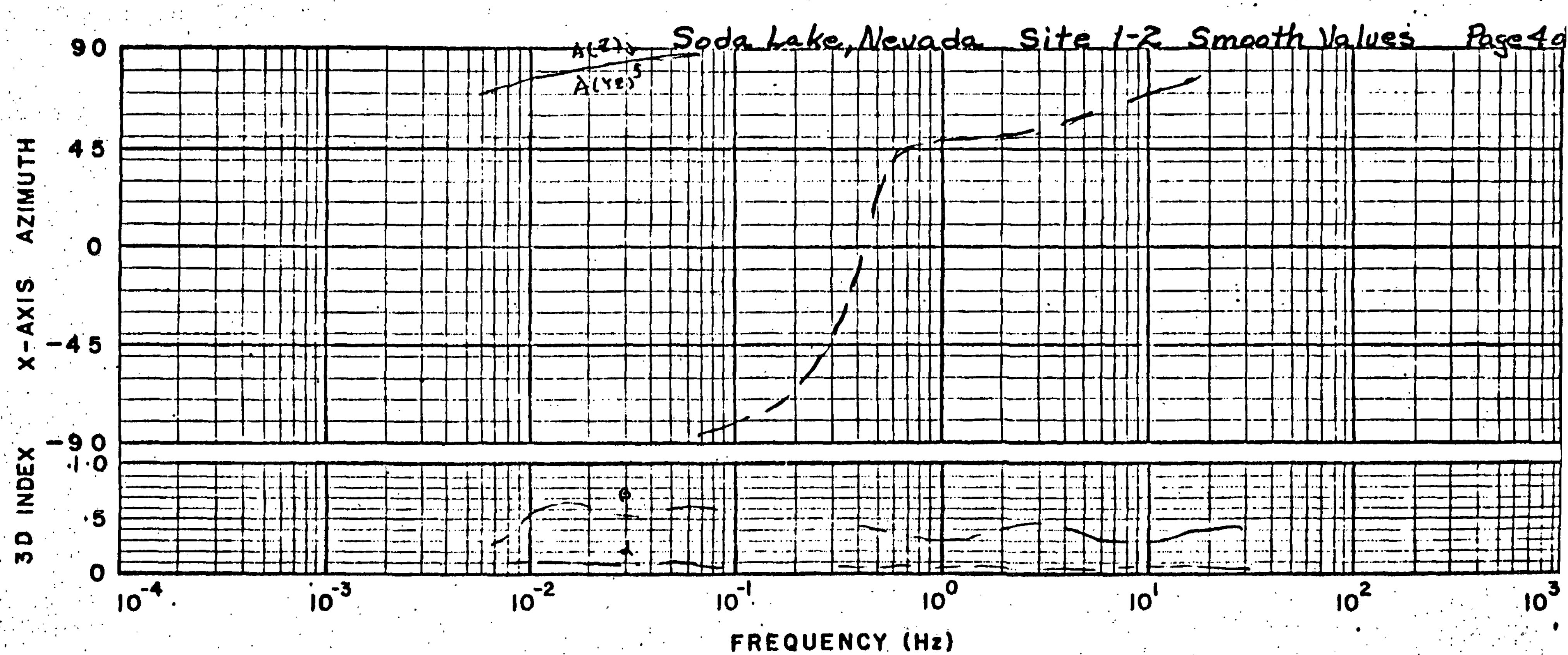
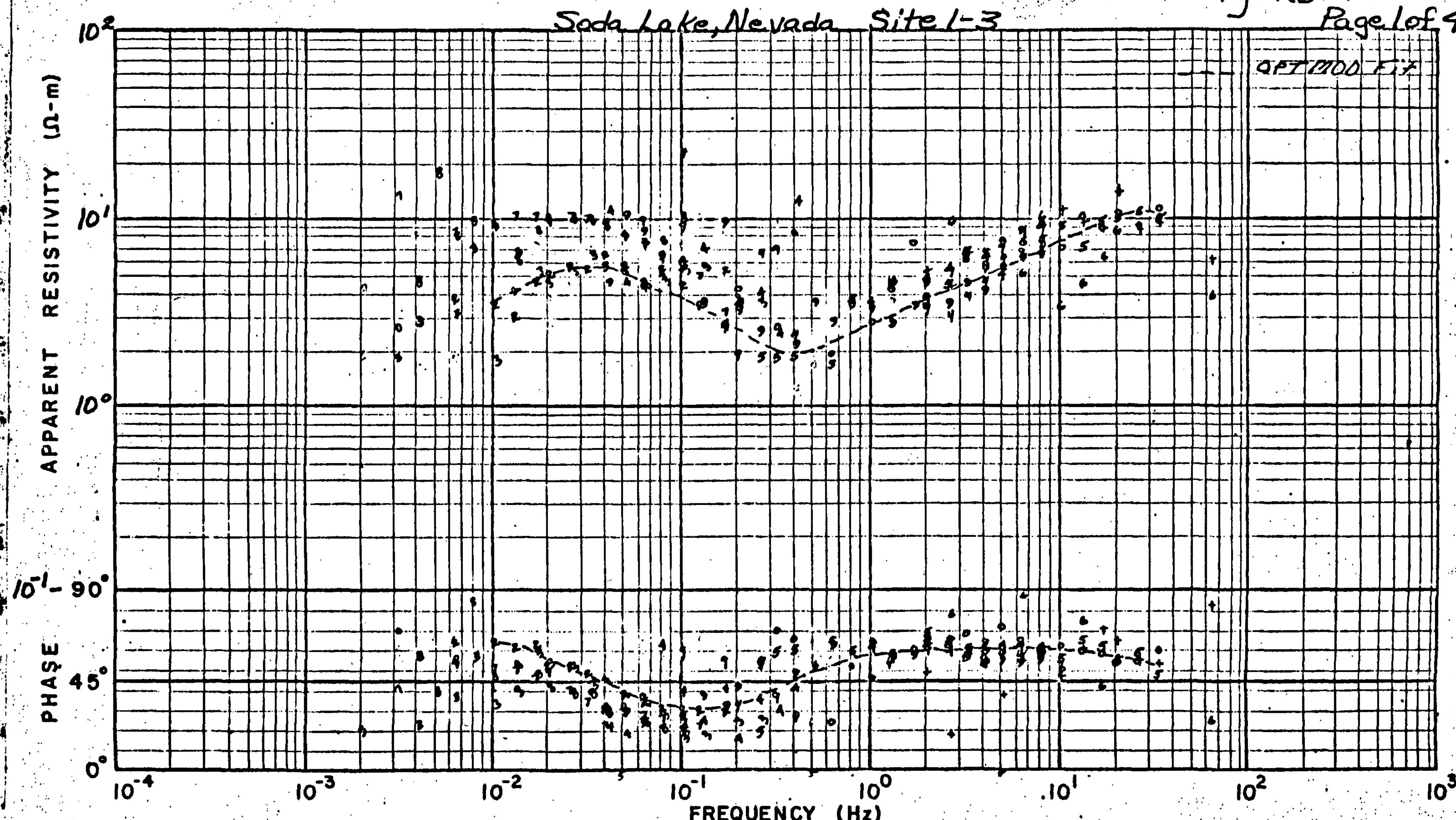
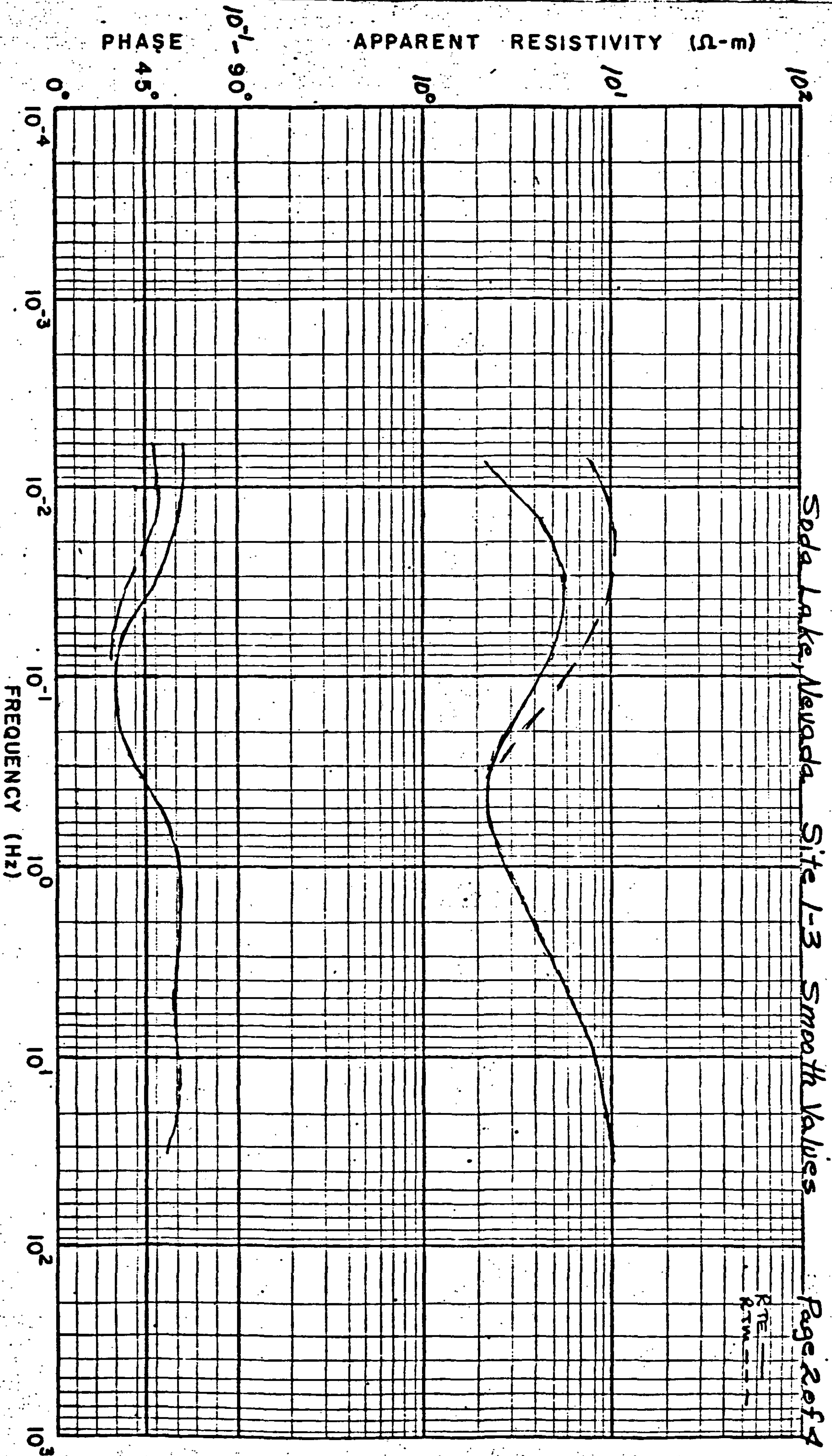
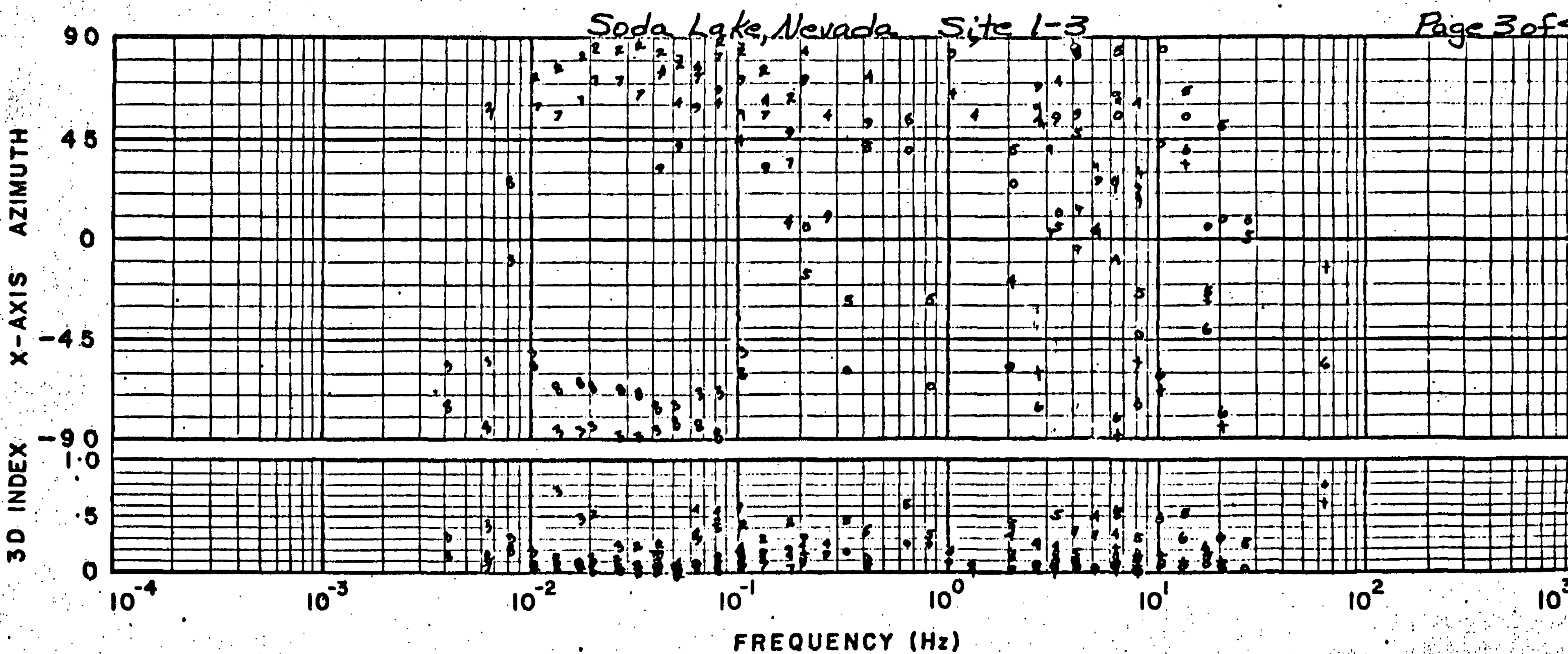

Soda Lake, Nevada Site 1-2 Smooth Values Page 40
90
45
0
-45
-90
X-AXIS AZIMUTH
1.0
.5
0
3D INDEX
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)

FIGURE II-3
Page 1 of 4





Soda Lake, Nevada Site 1-3 Smooth Values
Page 2 of 4
PHASE
APPARENT RESISTIVITY (Ω-m)
0°
45°
10^{-1} 90°
10^0
10^1
10^2
FREQUENCY (Hz)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
RTE —
RTM - - -



Soda Lake, Nevada Site 1-3
Page 3 of 4
90
45
0
-45
-90
1.0
.5
0
X-AXIS AZIMUTH
3D INDEX
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)

Soda Lake, Nevada Site 1-3 Smooth Values Page 4 of

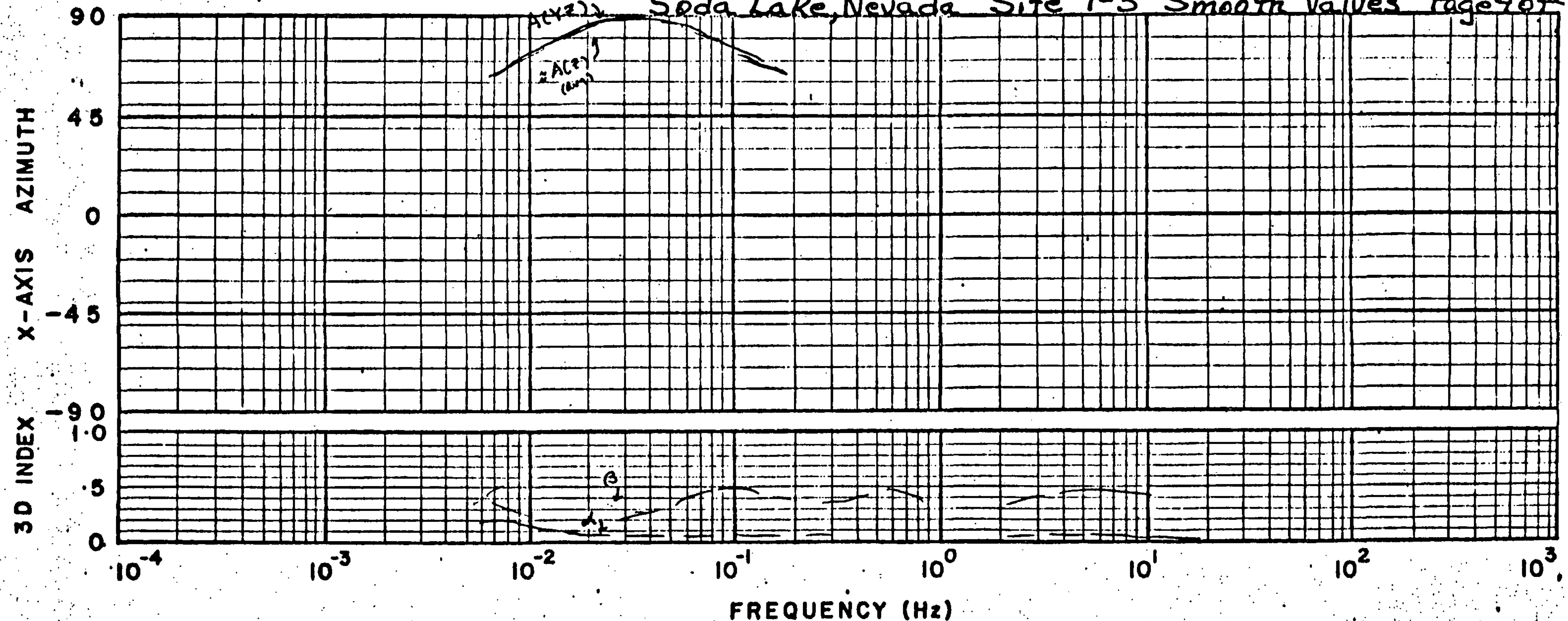
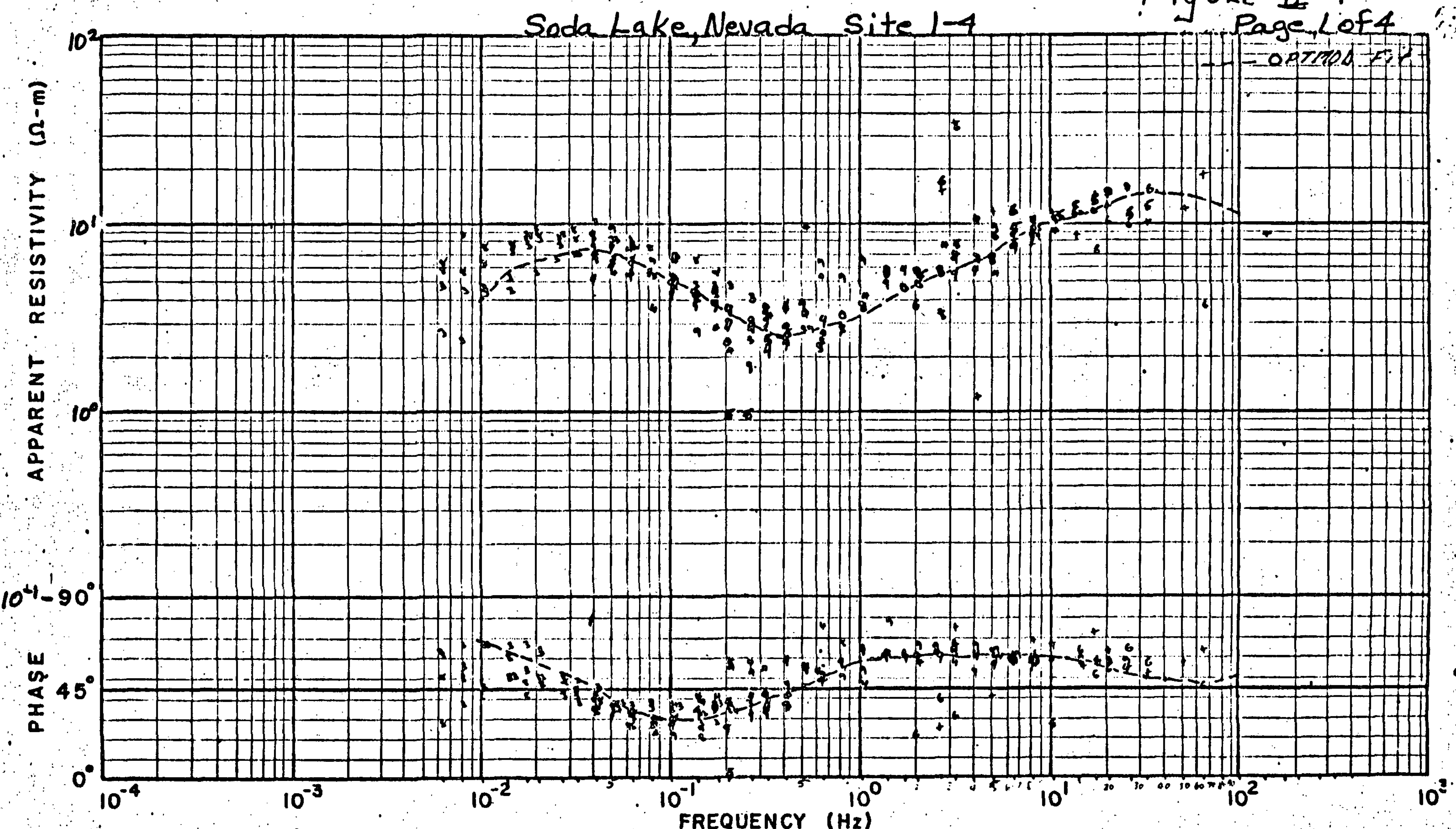
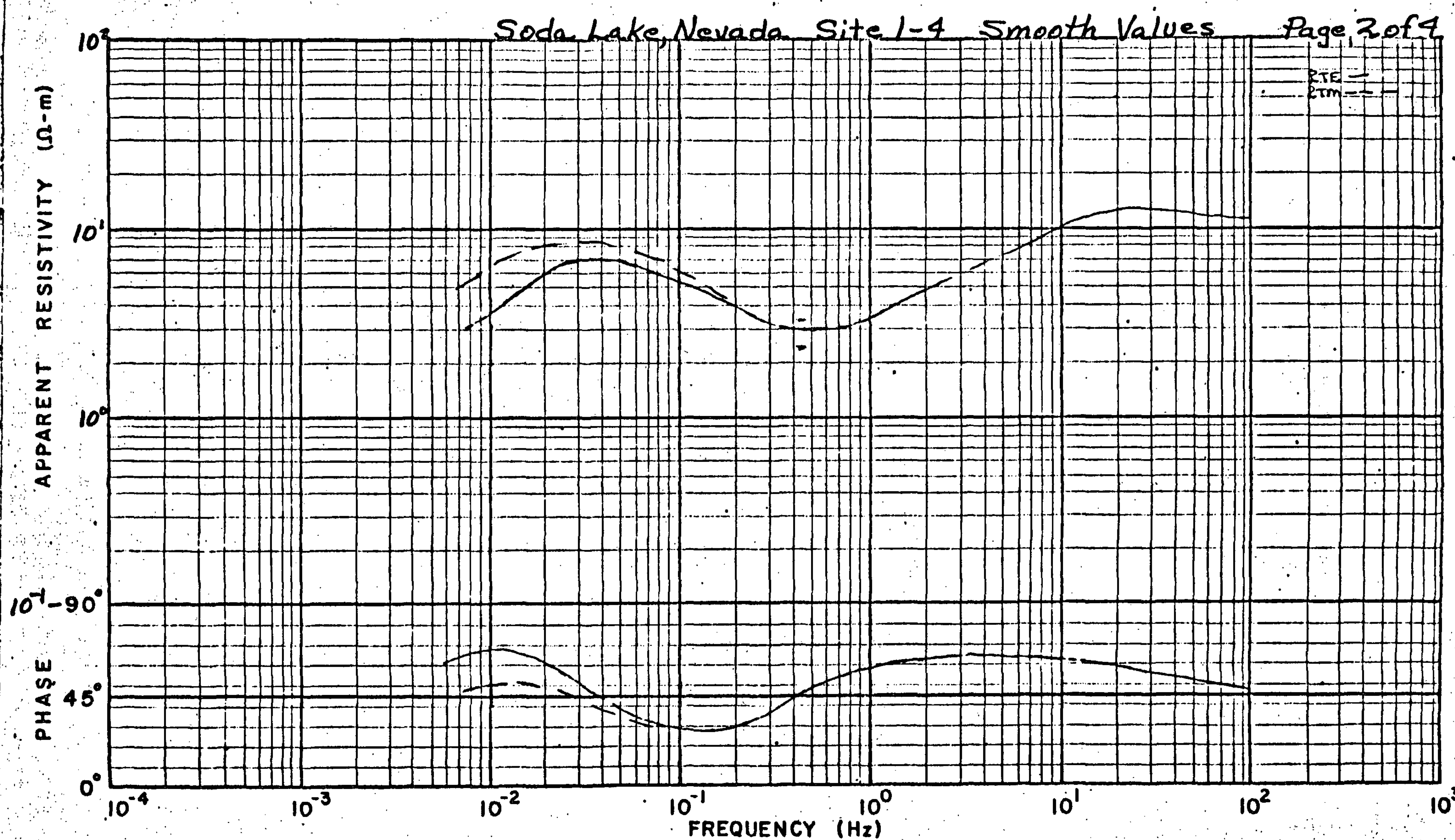
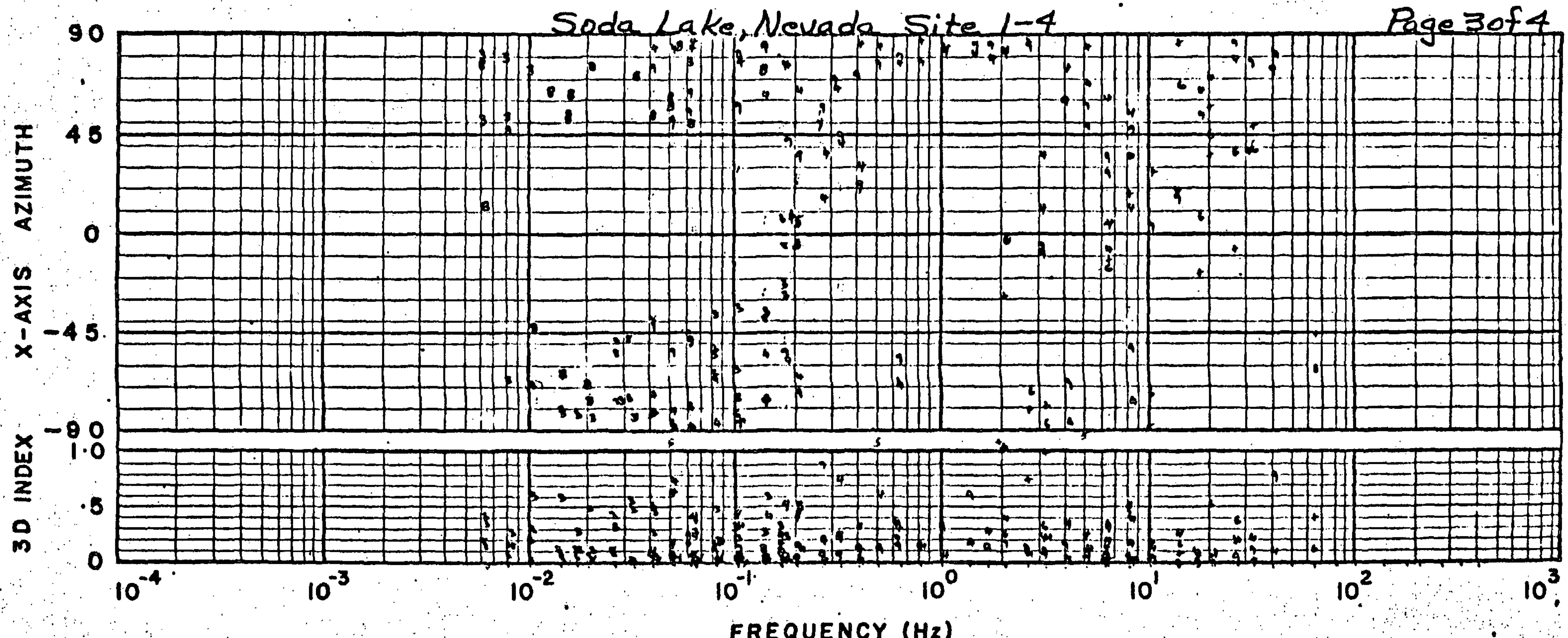


Figure II-4
Page 1 of 4




Soda Lake, Nevada Site 1-4 Smooth Values
Page 2 of 4
ρTE —
ρTM — —
APPARENT RESISTIVITY (Ω-m)
PHASE
10^2
10^1
10^0
10^{-1}-90°
45°
0°
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
FREQUENCY (Hz)


Soda Lake, Nevada Site 1-4
Page 3 of 4
X-AXIS AZIMUTH
3D INDEX
90
45
0
-45
-90
1.0
.5
0
10^-4
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3
FREQUENCY (Hz)

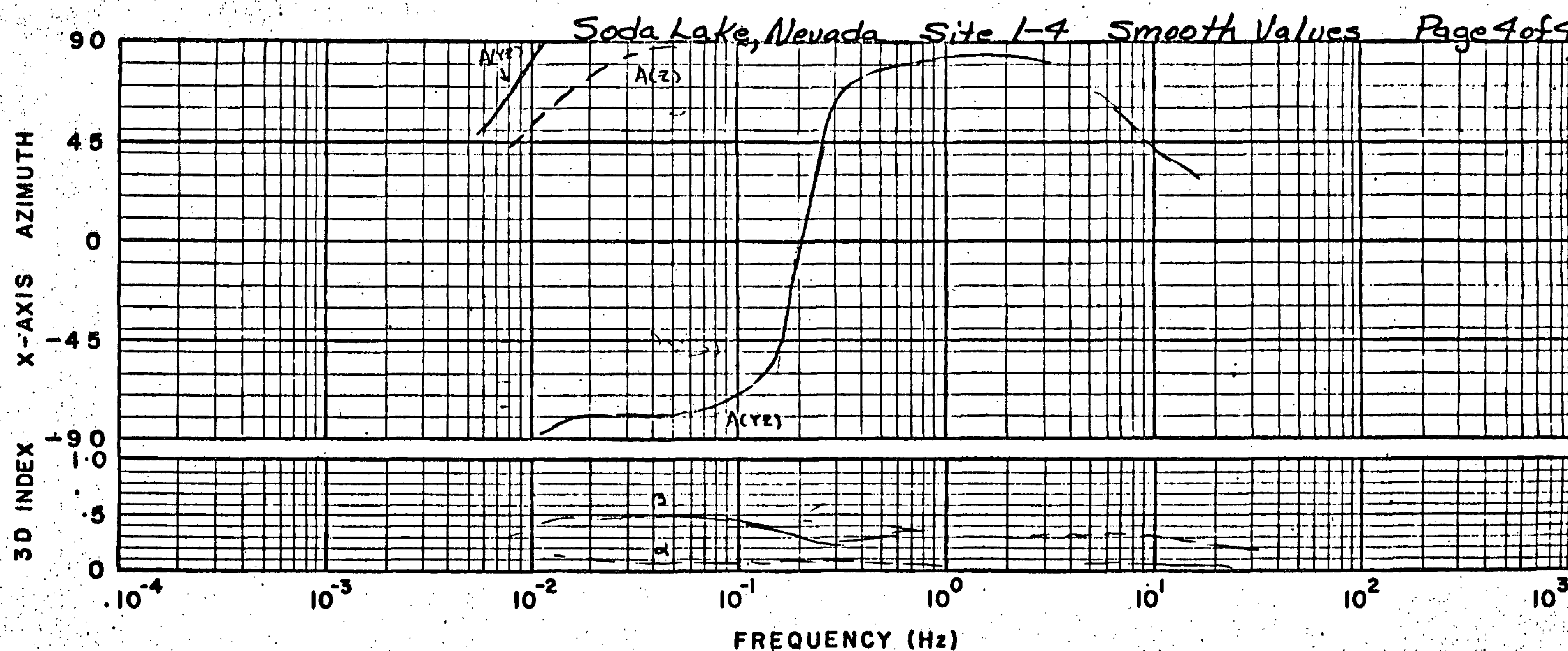
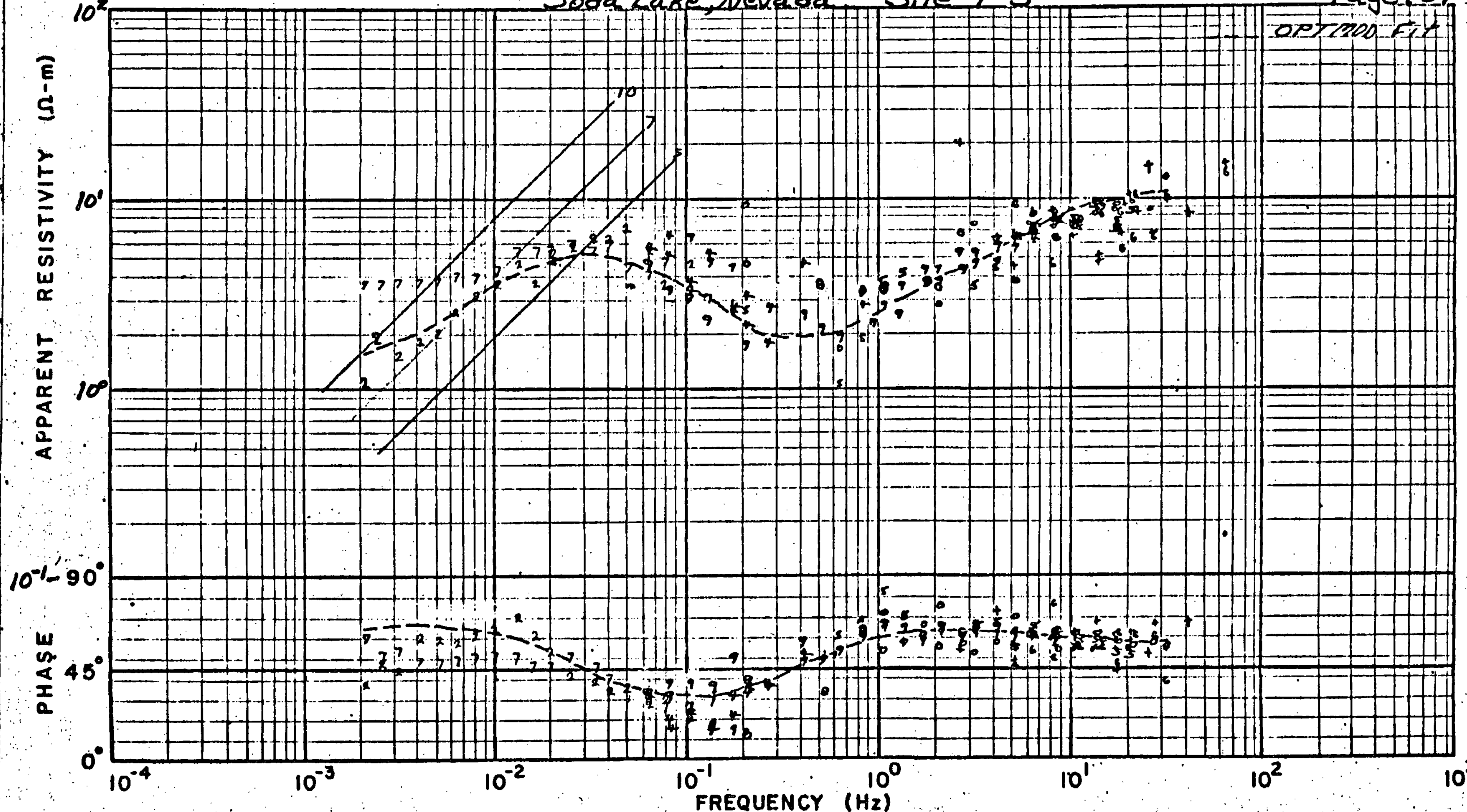
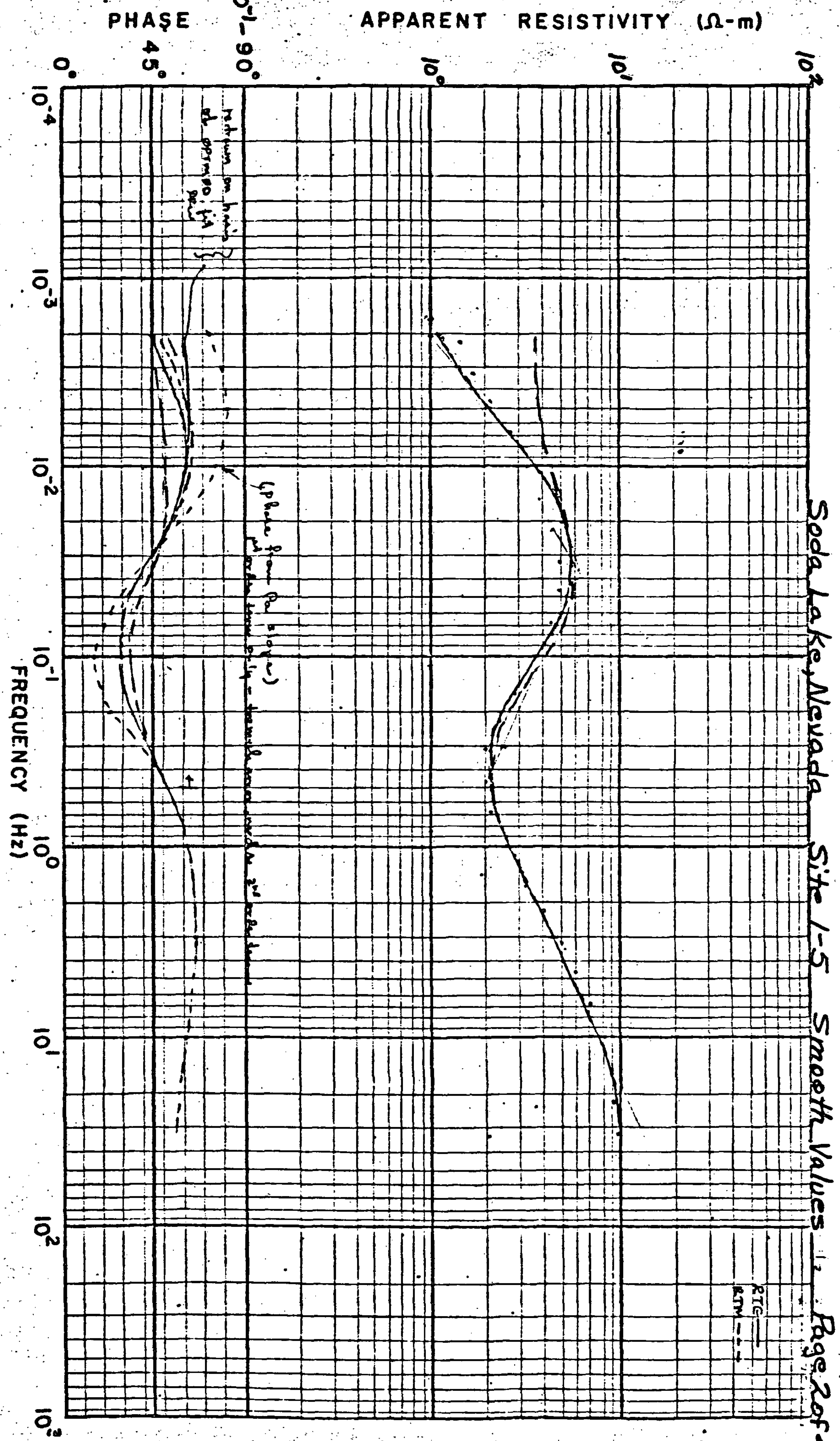

Soda Lake, Nevada Site 1-4 Smooth Values Page 4 of 4
90
45
0
-45
-90
X-AXIS AZIMUTH
A(YZ)
A(Z)
A(YZ)
1.0
.5
0
3D INDEX
β
α
10-4
10-3
10-2
10-1
10^0
10^1
10^2
10^3
FREQUENCY (Hz)

Figure II-5
Page 1 of 4

Soda Lake, Nevada Site 1-5

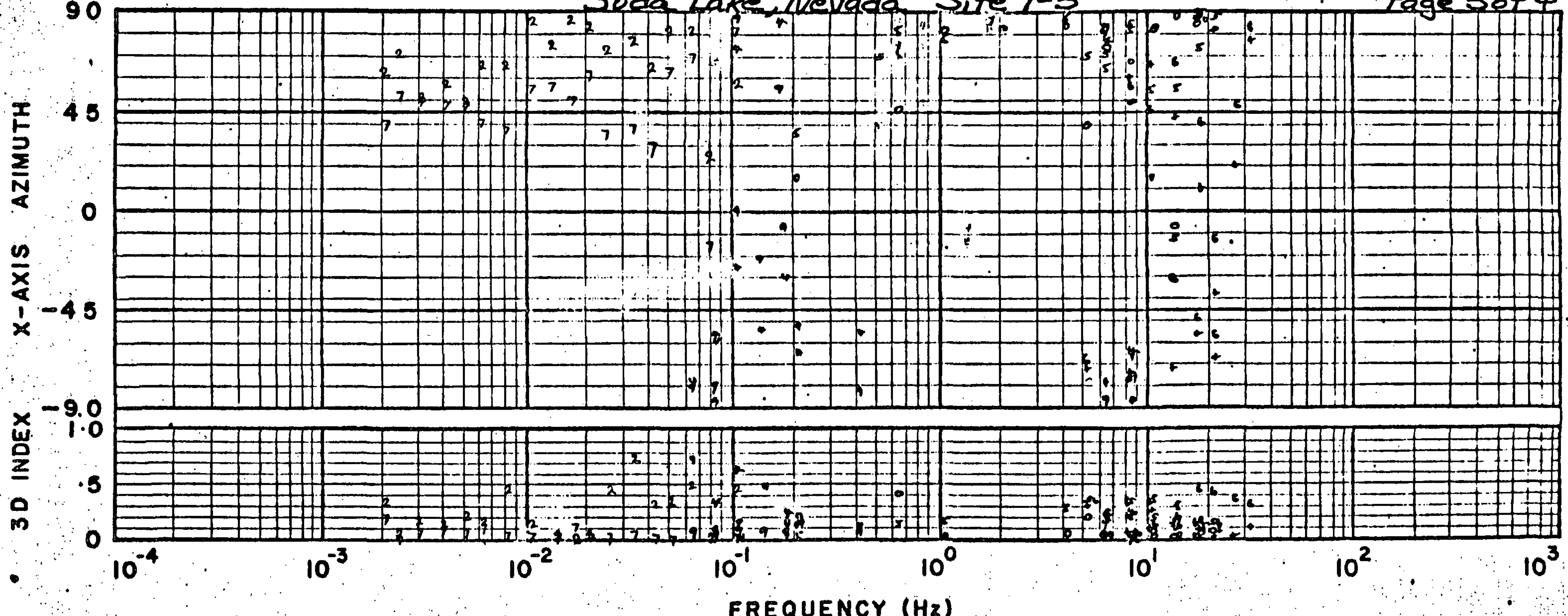




PHASE
APPARENT RESISTIVITY (Ω-m)
0°
45°
10^{-1}–90°
10^{0}
10^{1}
10^{2}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)
Soda Lake, Nevada Site 1-5 Smooth Values Page 2 of 4
RTE —
RTM - - -

Lo hz – β, A(YZ)
Hi hz – α, A(Z)

Soda Lake, Nevada Site 1-5



Soda Lake, Nevada Site 1-5 Smooth Values Page 4 of

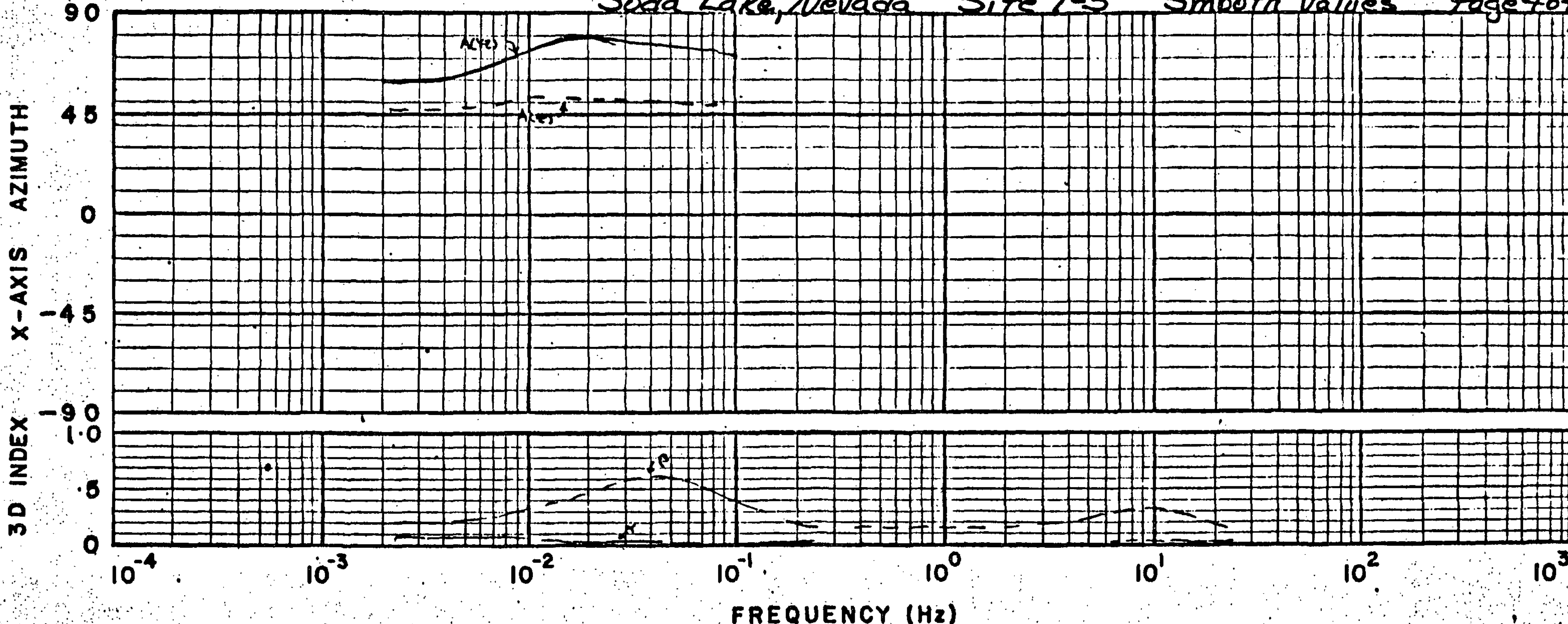
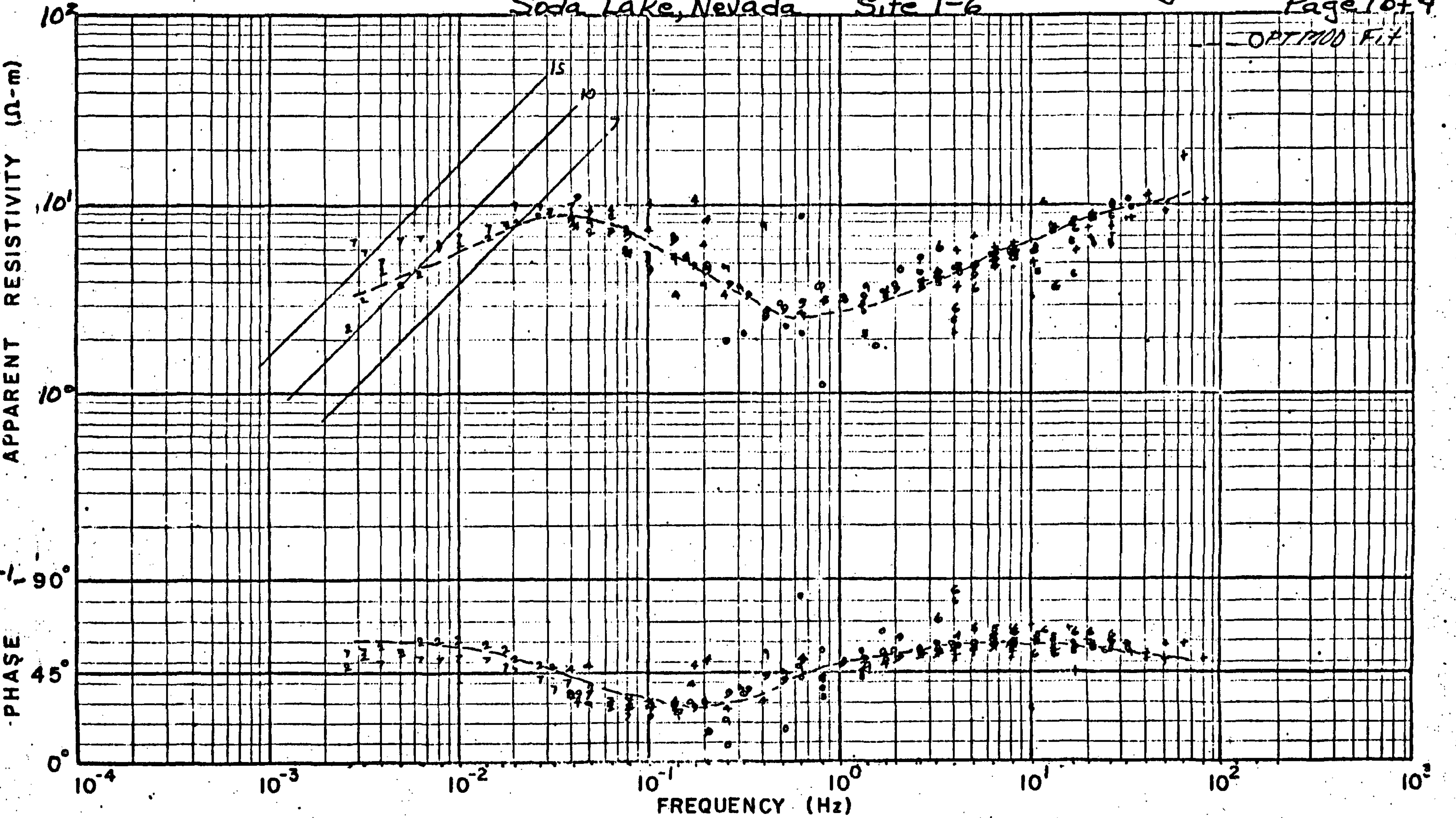
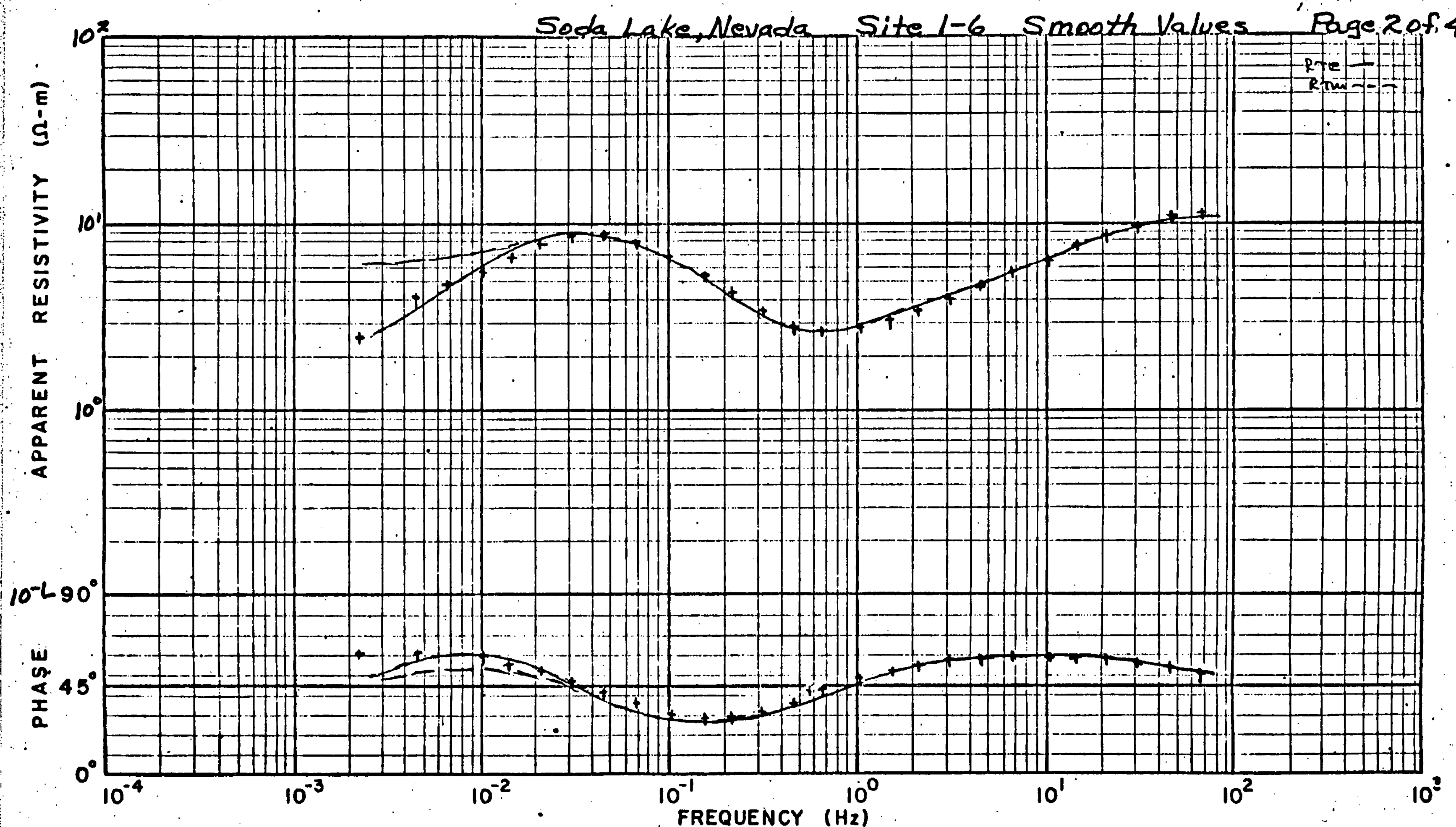


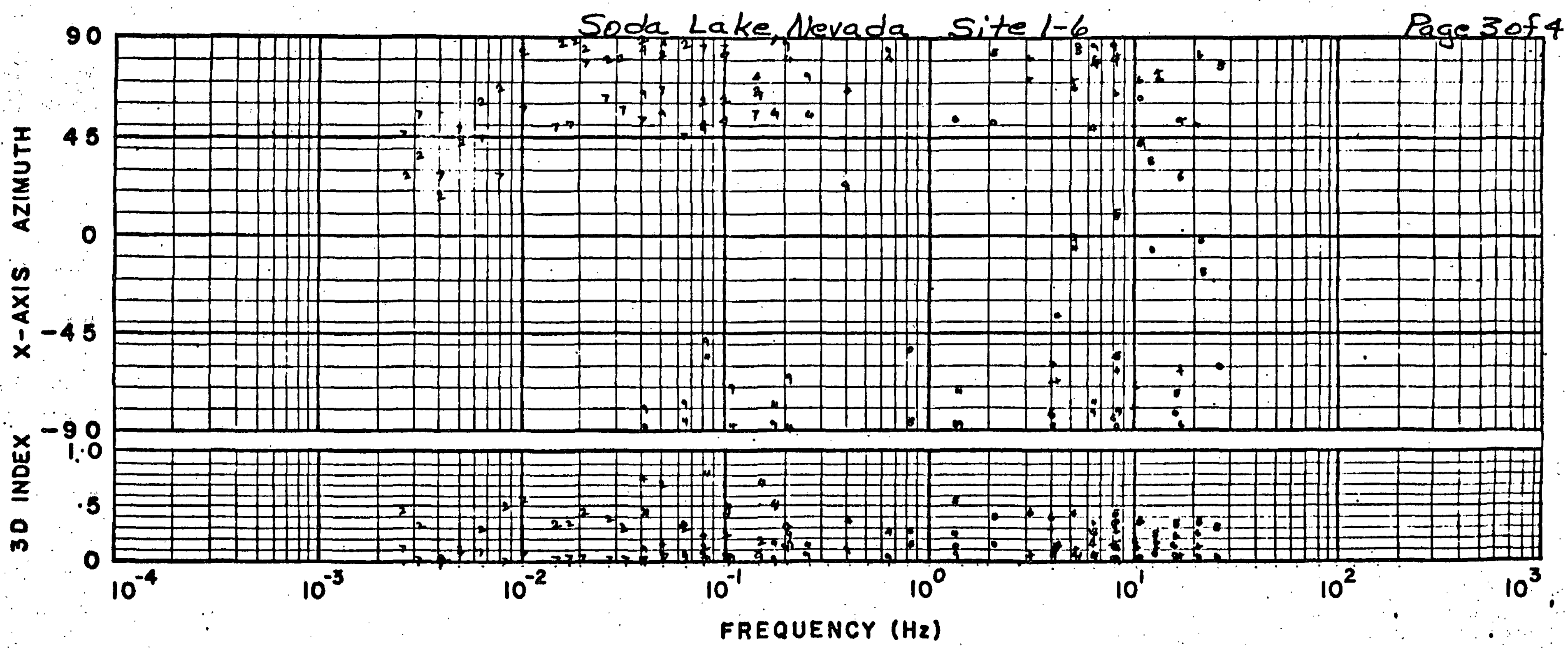
Figure II-6

Page 1 of 4

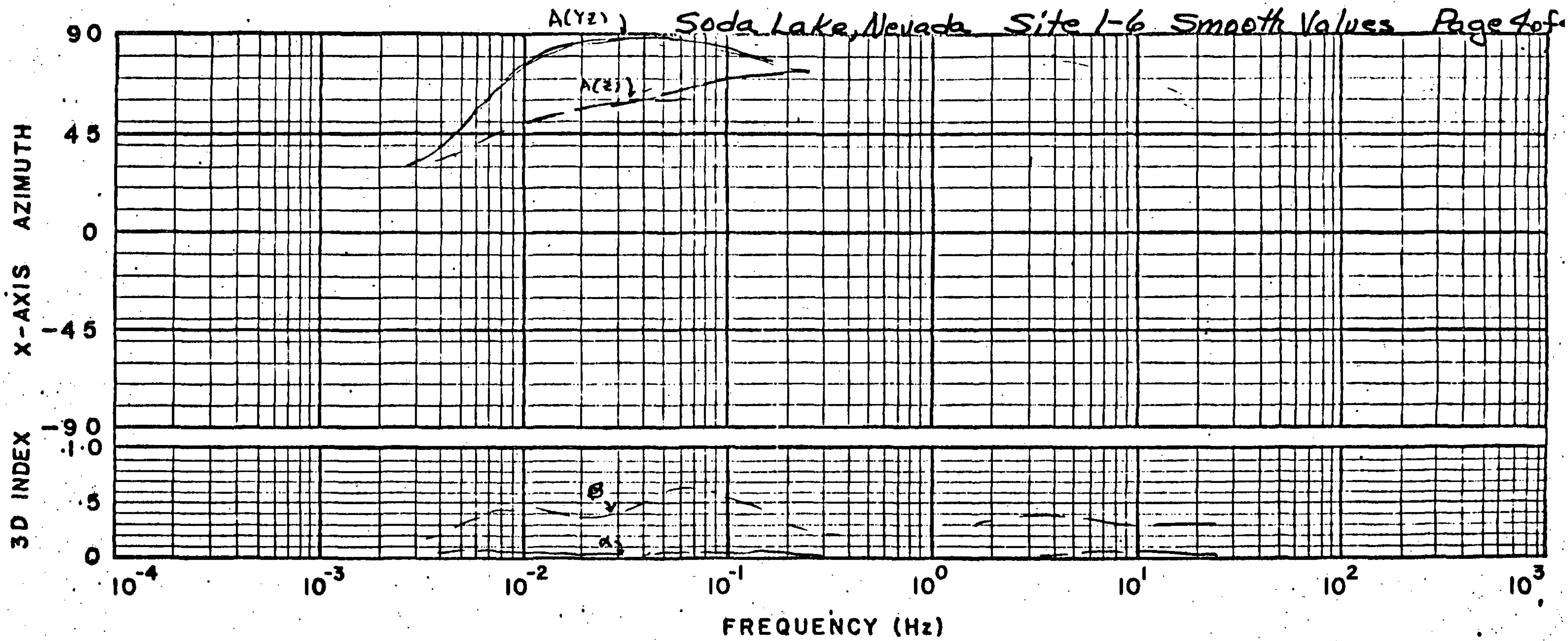




Soda Lake, Nevada Site 1-6 Smooth Values Page 2 of 4
ρTE —
ρTM - - -
APPARENT RESISTIVITY (Ω-m)
PHASE
10²
10¹
10⁰
10⁻¹ 90°
45°
0°
10⁻⁴
10⁻³
10⁻²
10⁻¹
10⁰
10¹
10²
10³
FREQUENCY (Hz)

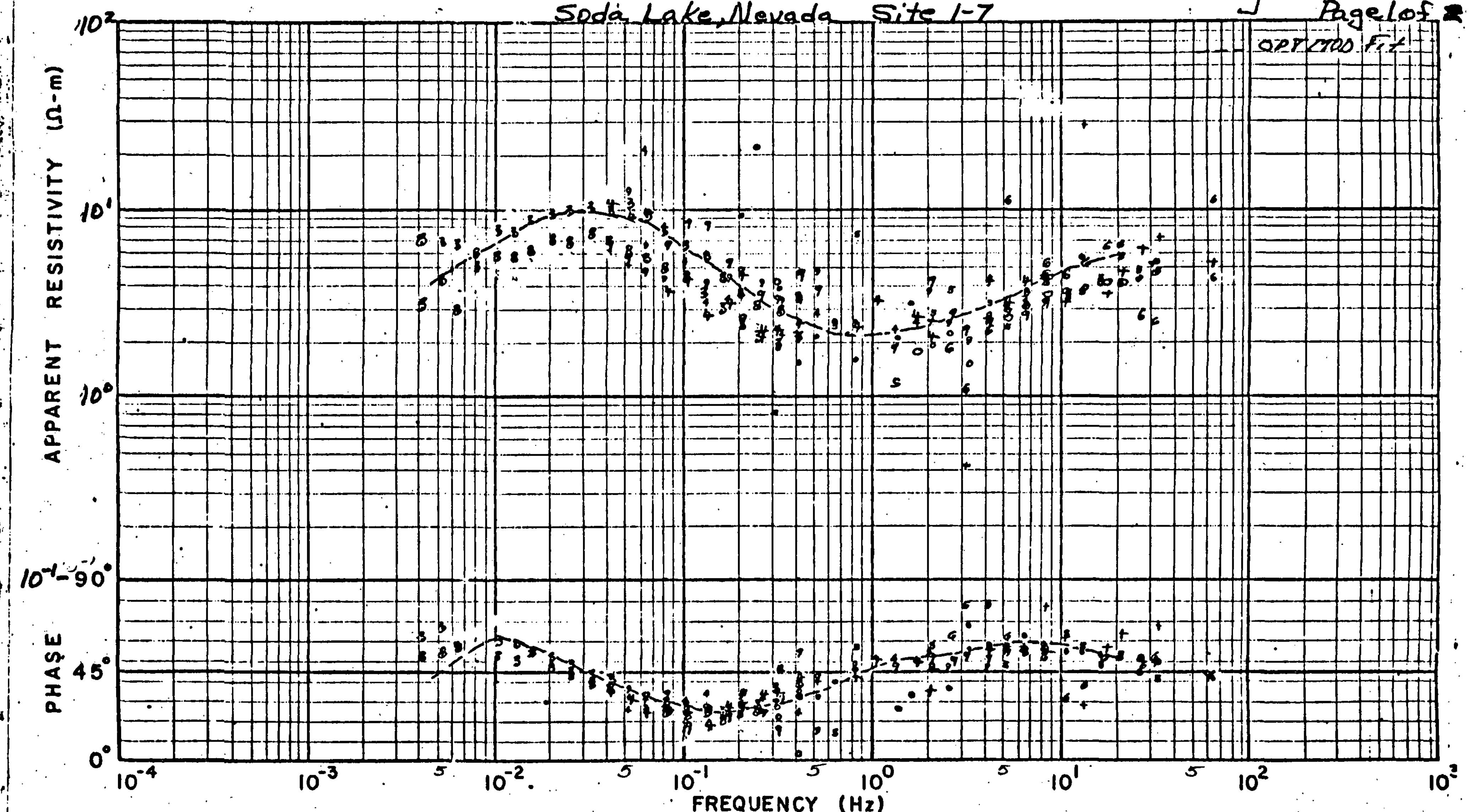


Soda Lake, Nevada Site 1-6
Page 3 of 4
X-AXIS AZIMUTH
90
45
0
-45
-90
3D INDEX
1.0
.5
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)

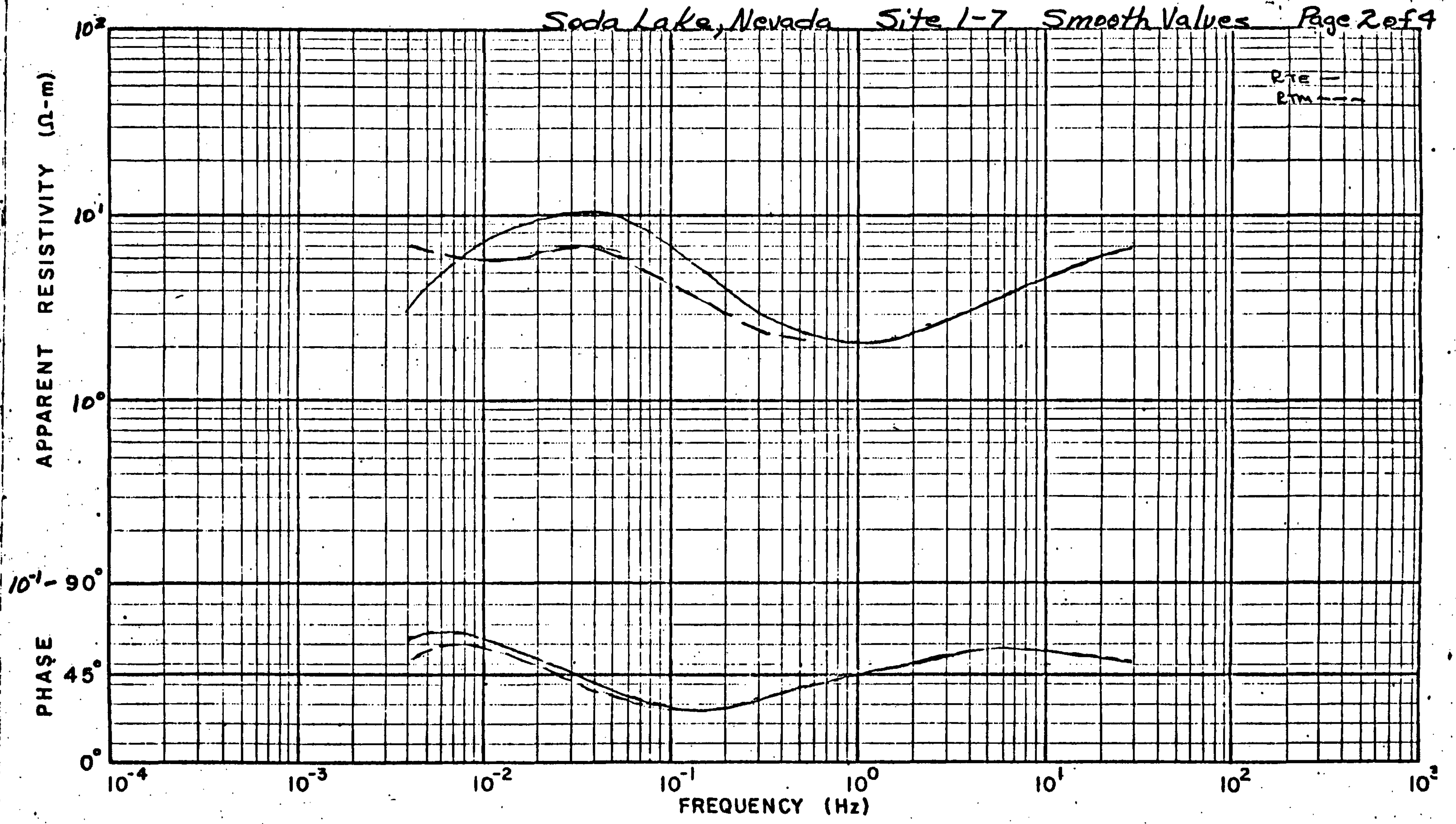


Soda Lake, Nevada Site 1-6 Smooth Values Page 4 of
A(YZ)
A(Z)
90
45
0
-45
-90
X-AXIS AZIMUTH
1.0
.5
0
3D INDEX
β y
α
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)

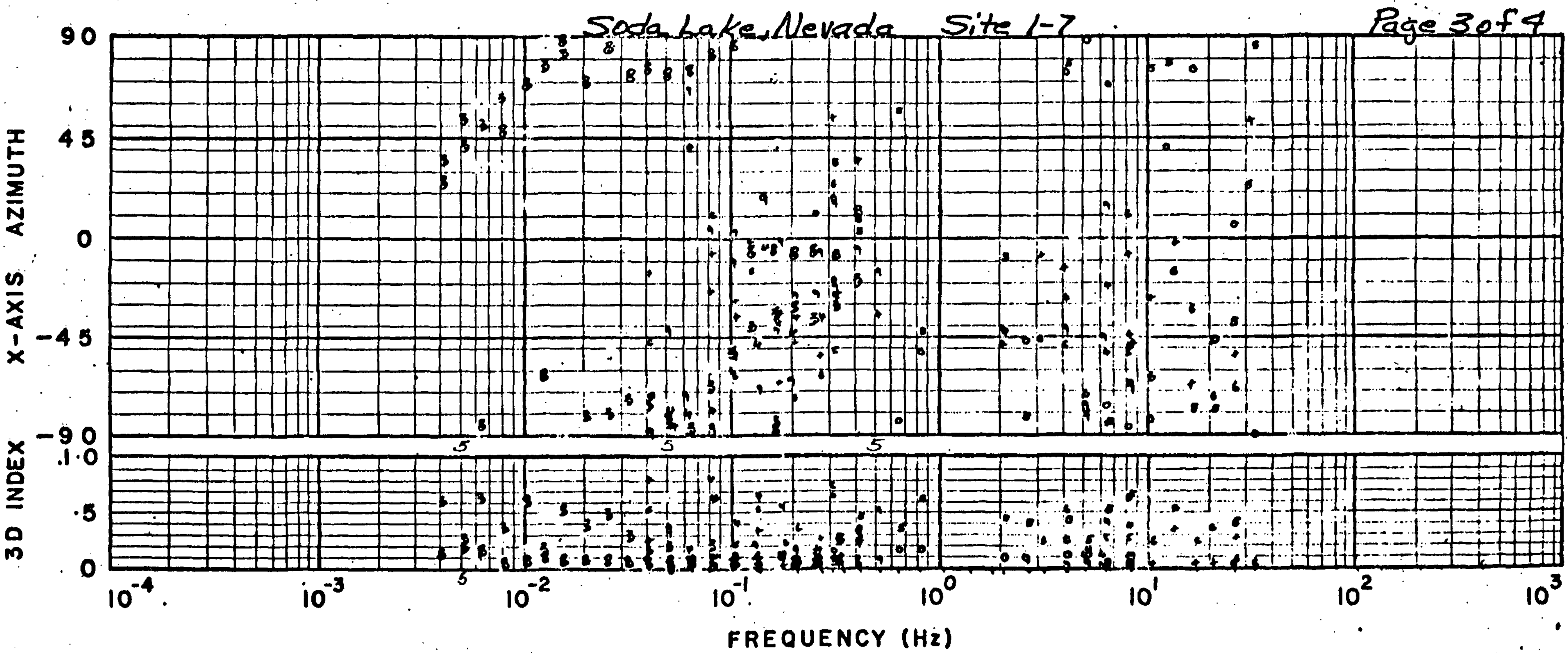
Figure II-7

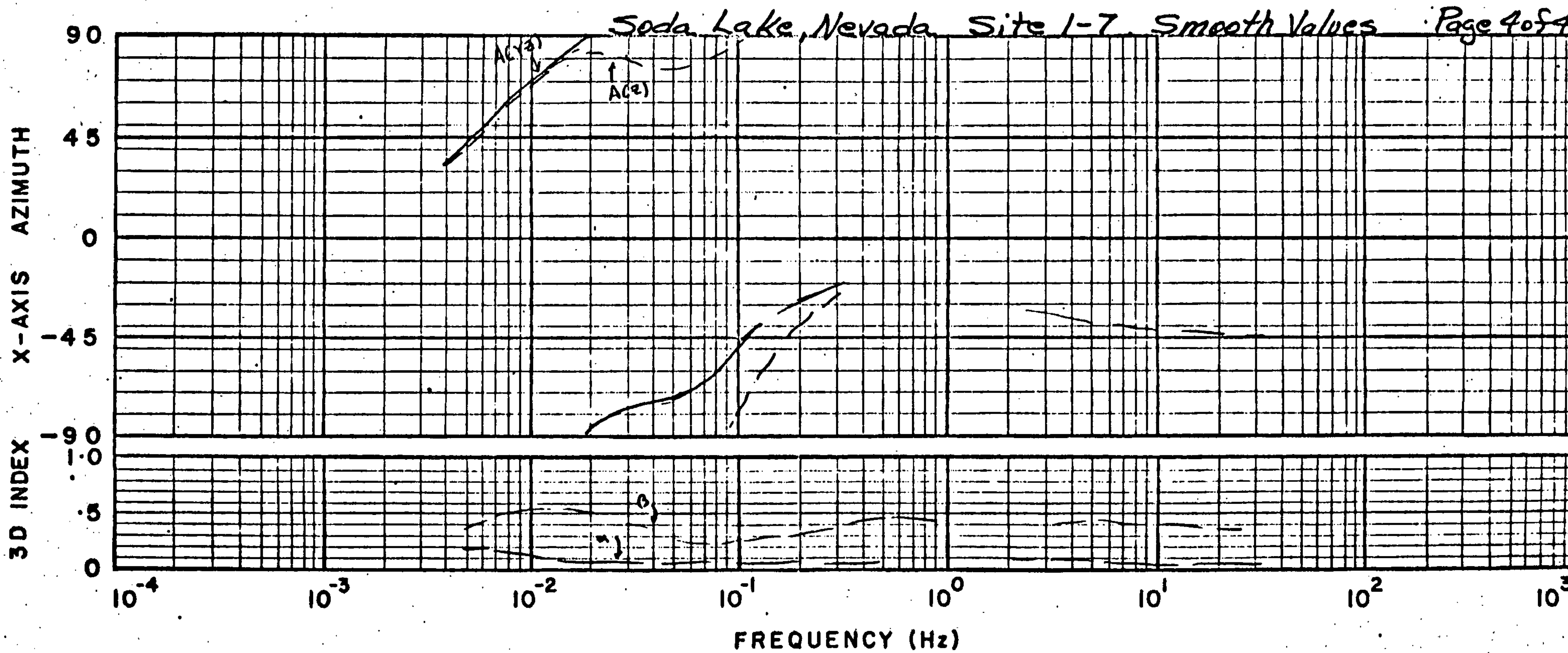


Soda Lake, Nevada Site 1-7
Page 1 of 2
OPTIMOD Fit
APPARENT RESISTIVITY (Ω-m)
PHASE
FREQUENCY (Hz)



Soda Lake, Nevada Site 1-7 Smooth Values Page 2 of 4
APPARENT RESISTIVITY (Ω-m)
PHASE
FREQUENCY (Hz)


Soda Lake, Nevada Site 1-7
X-AXIS AZIMUTH
90
45
0
-45
-90
3D INDEX
1.0
.5
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)

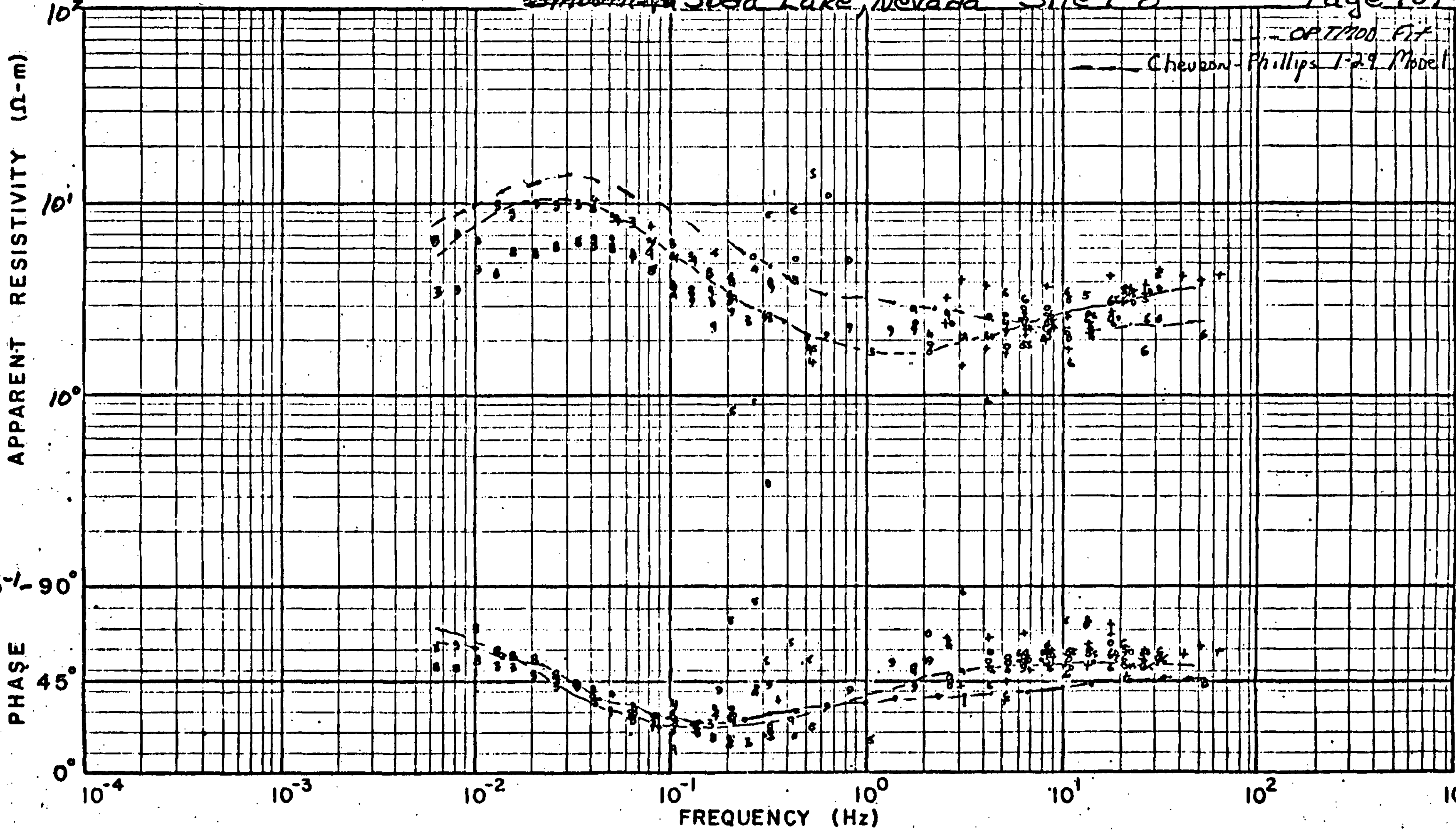


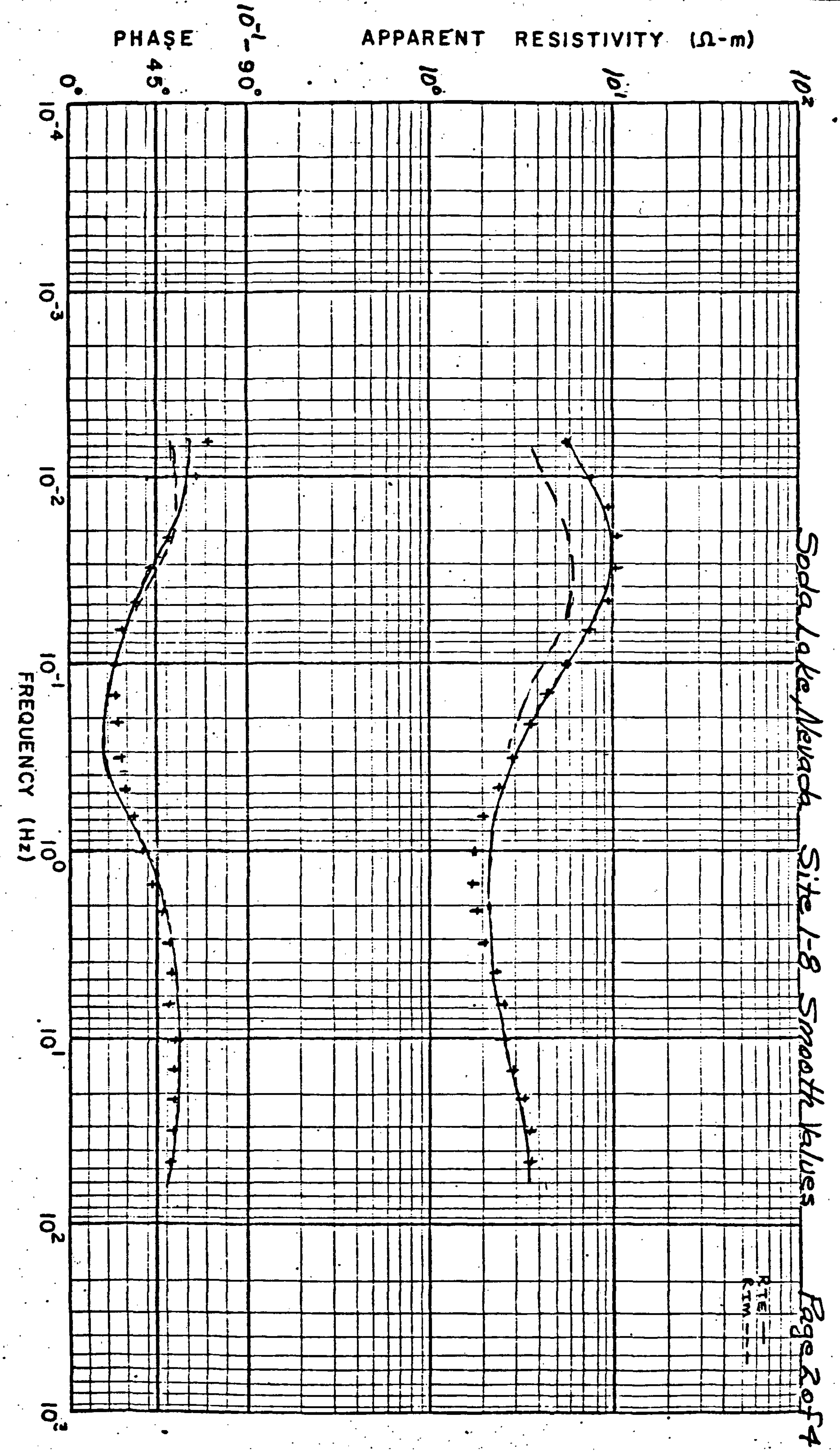
Soda Lake, Nevada Site 1-7 Smooth Values Page 4 of 4
X-AXIS AZIMUTH
90
45
0
-45
-90
3D INDEX
1.0
.5
0
A(Y3)
A(2)
FREQUENCY (Hz)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}

Figure II-8

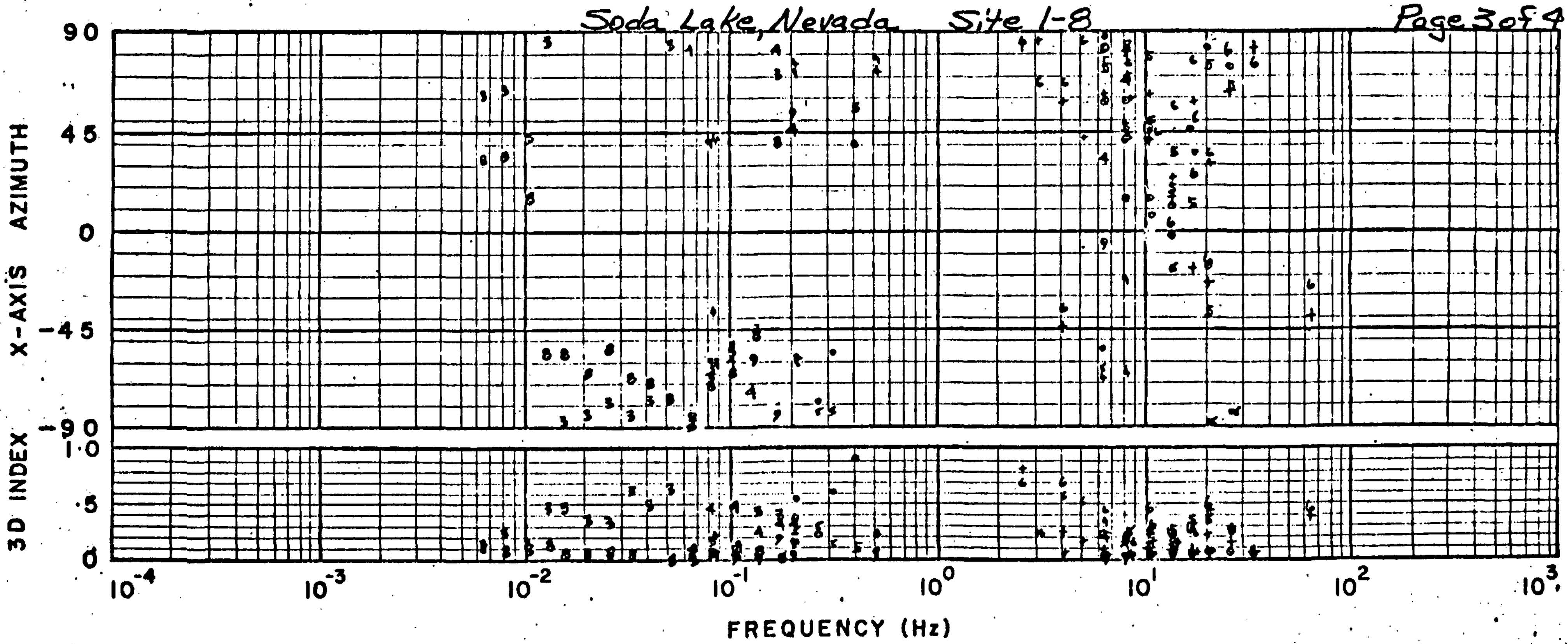
Soda Lake, Nevada Site 1-8

Page 1 of 4





PHASE
APPARENT RESISTIVITY (Ω-m)
0°
45°
90°
10^{-1}
10^{0}
10^{1}
10^{2}
FREQUENCY (Hz)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Soda Lake Nevada Site 1-8 Smooth Values
RTE —
RTM - - -
Page 2 of 4



Soda Lake, Nevada Site 1-8
Page 3 of 4
X-AXIS AZIMUTH
3D INDEX
90
45
0
-45
-90
1.0
.5
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)

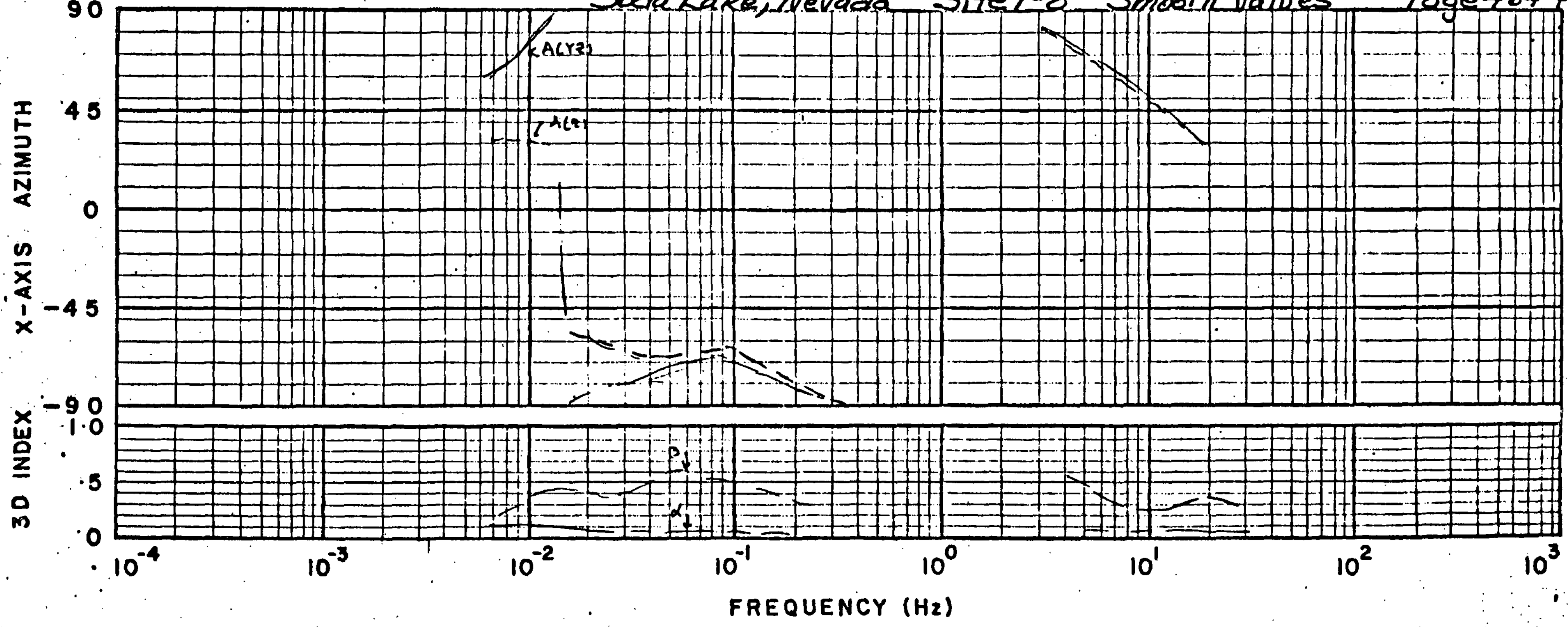
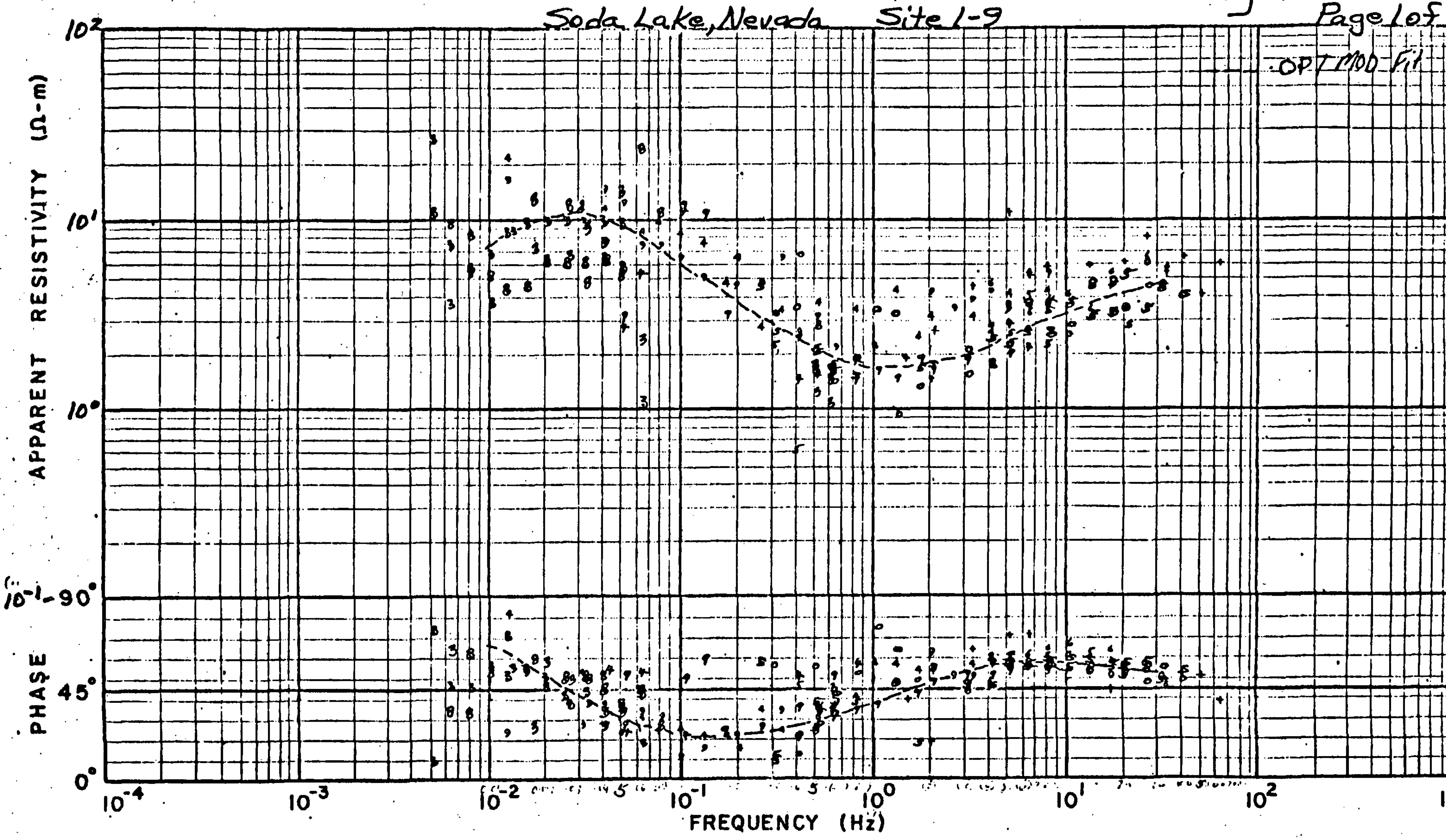
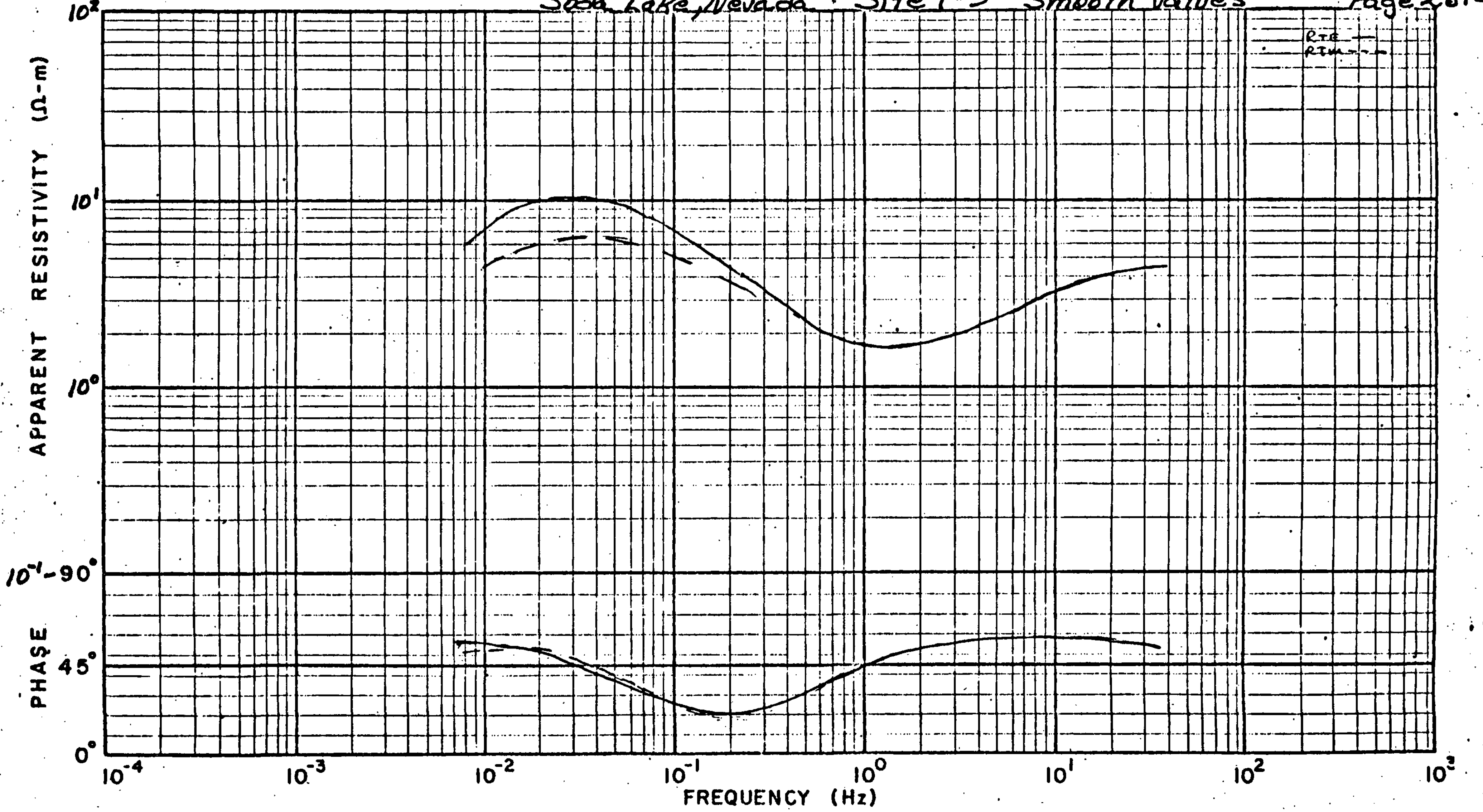
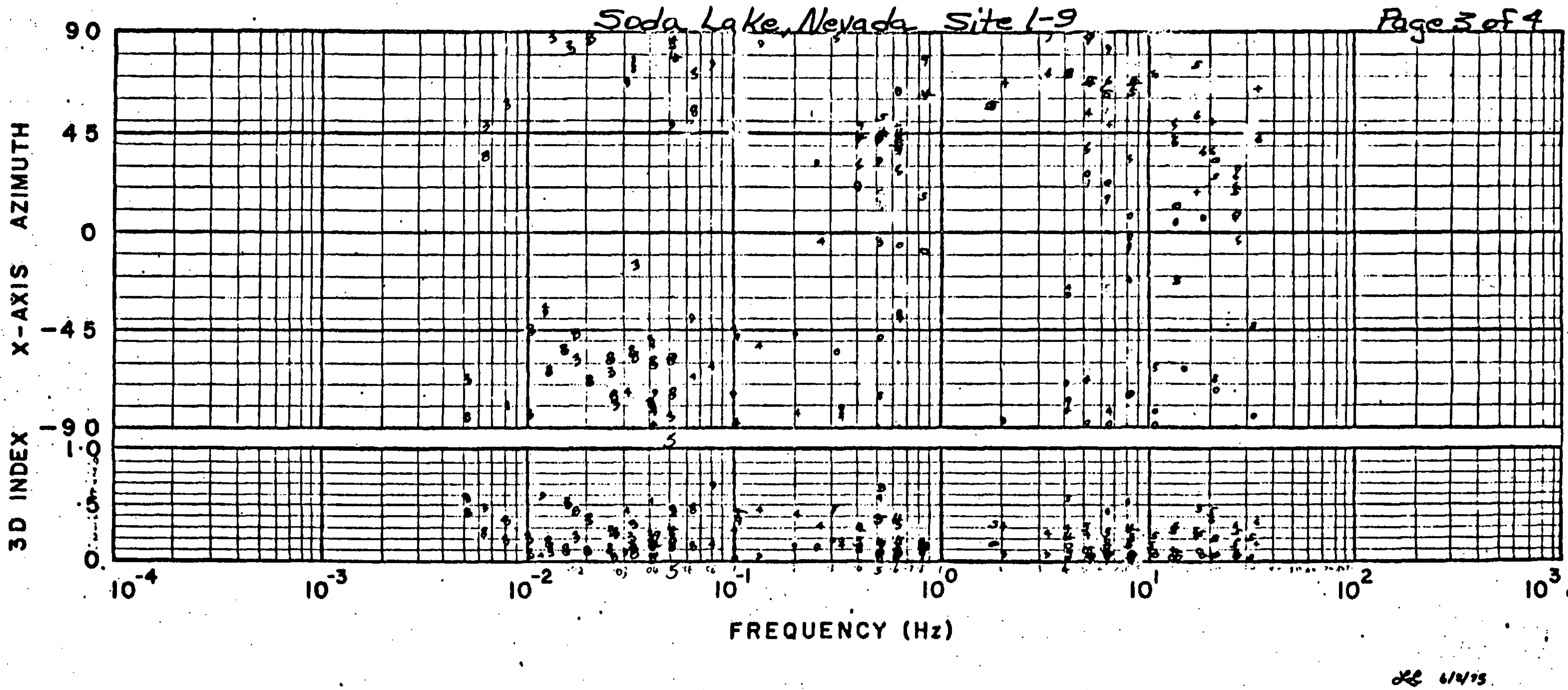

90
45
0
-45
-90
1.0
.5
0
X-AXIS AZIMUTH
3D INDEX
A(Y3)
A(X)
P
α
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)

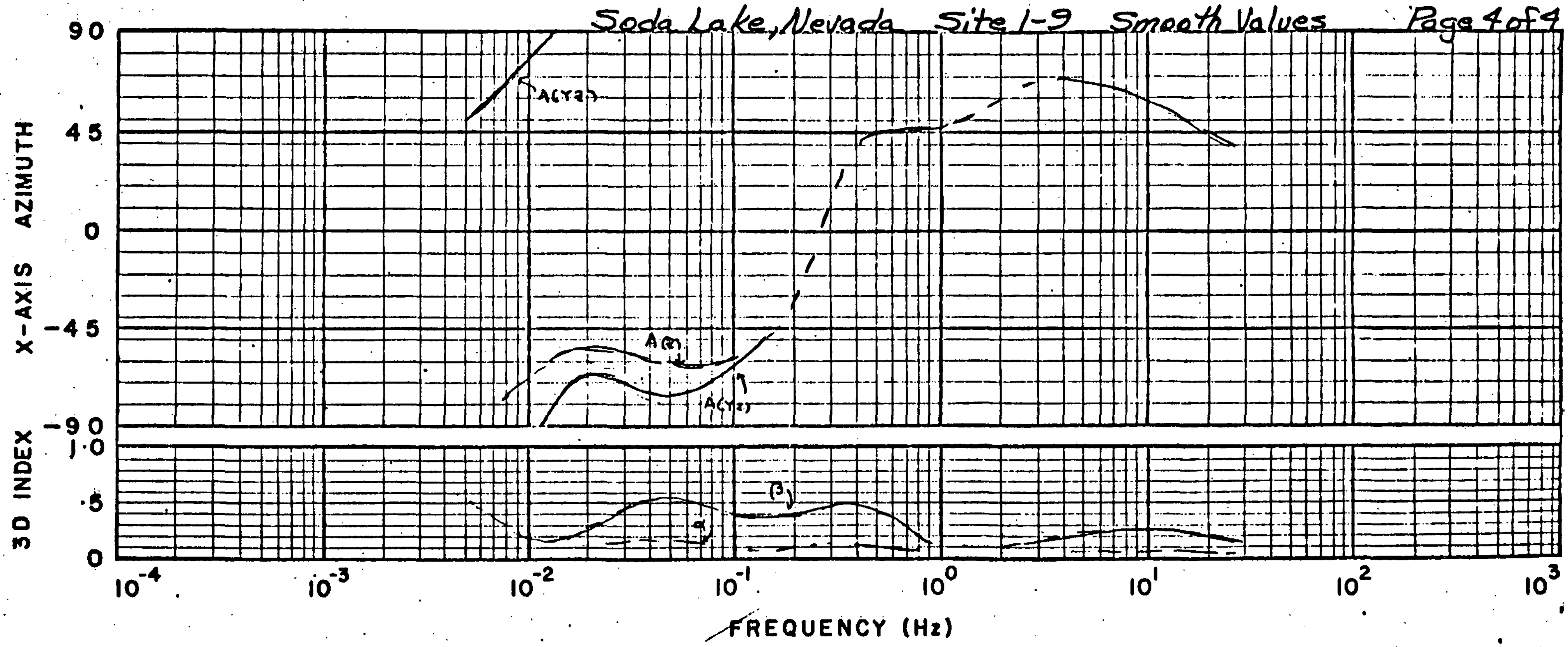
FIGURE II-9
Page 1 of 4



Soda Lake, Nevada Site 1-9 Smooth Values Page 2 of 4

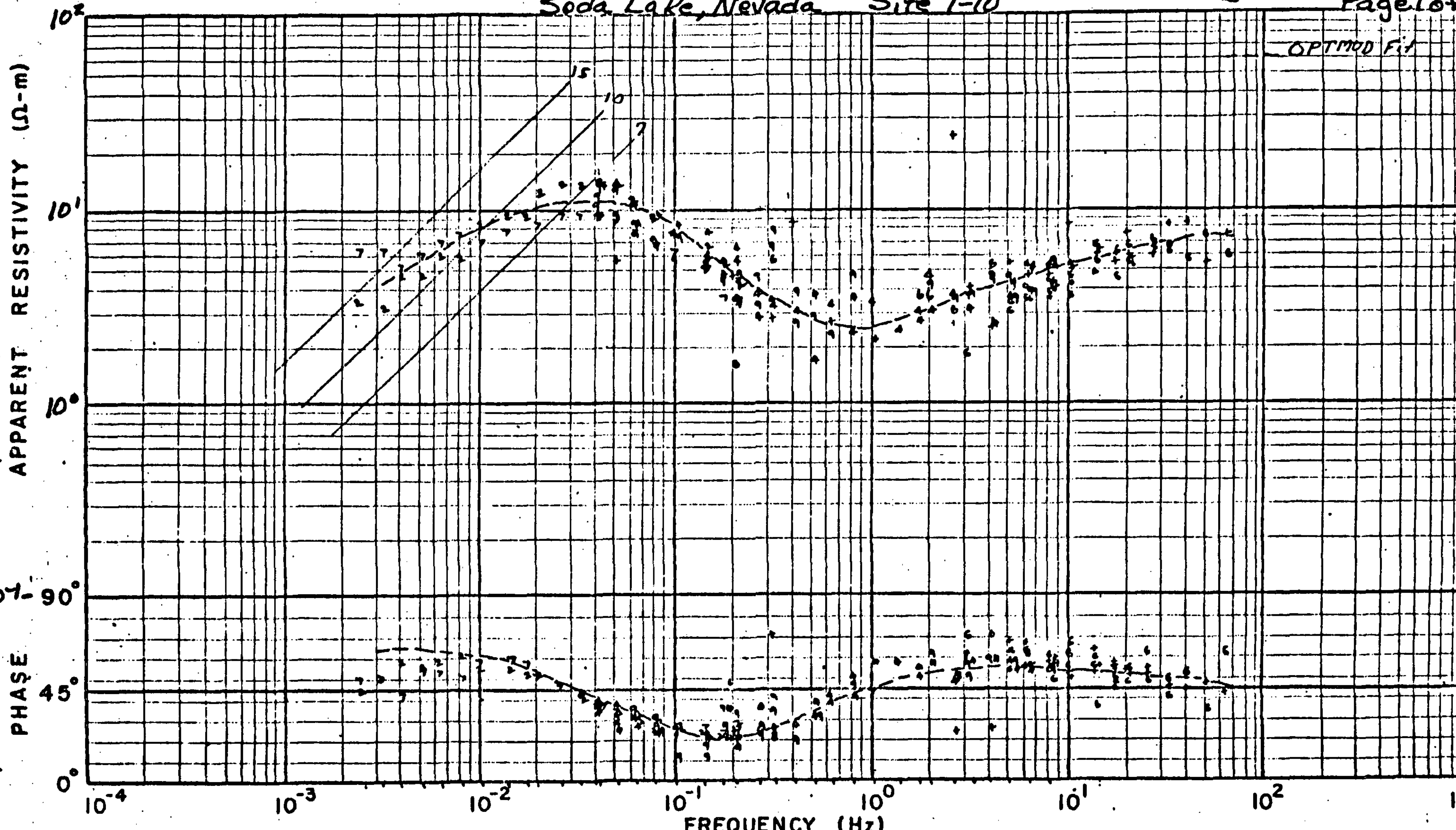


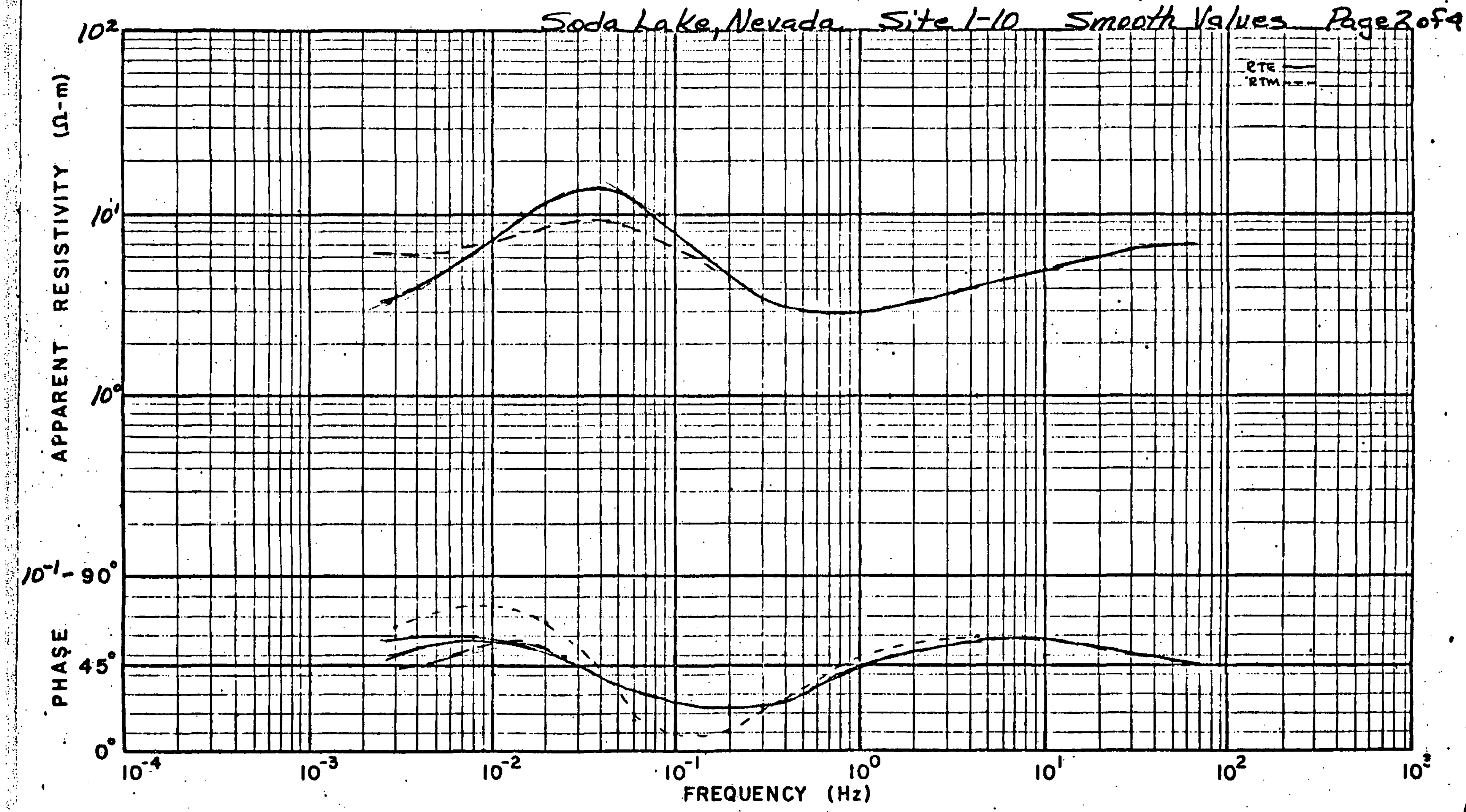

Soda Lake, Nevada Site 1-9
Page 3 of 4
X-AXIS AZIMUTH
90
45
0
-45
-90
3D INDEX
1.0
.5
0.
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)
6/4/75

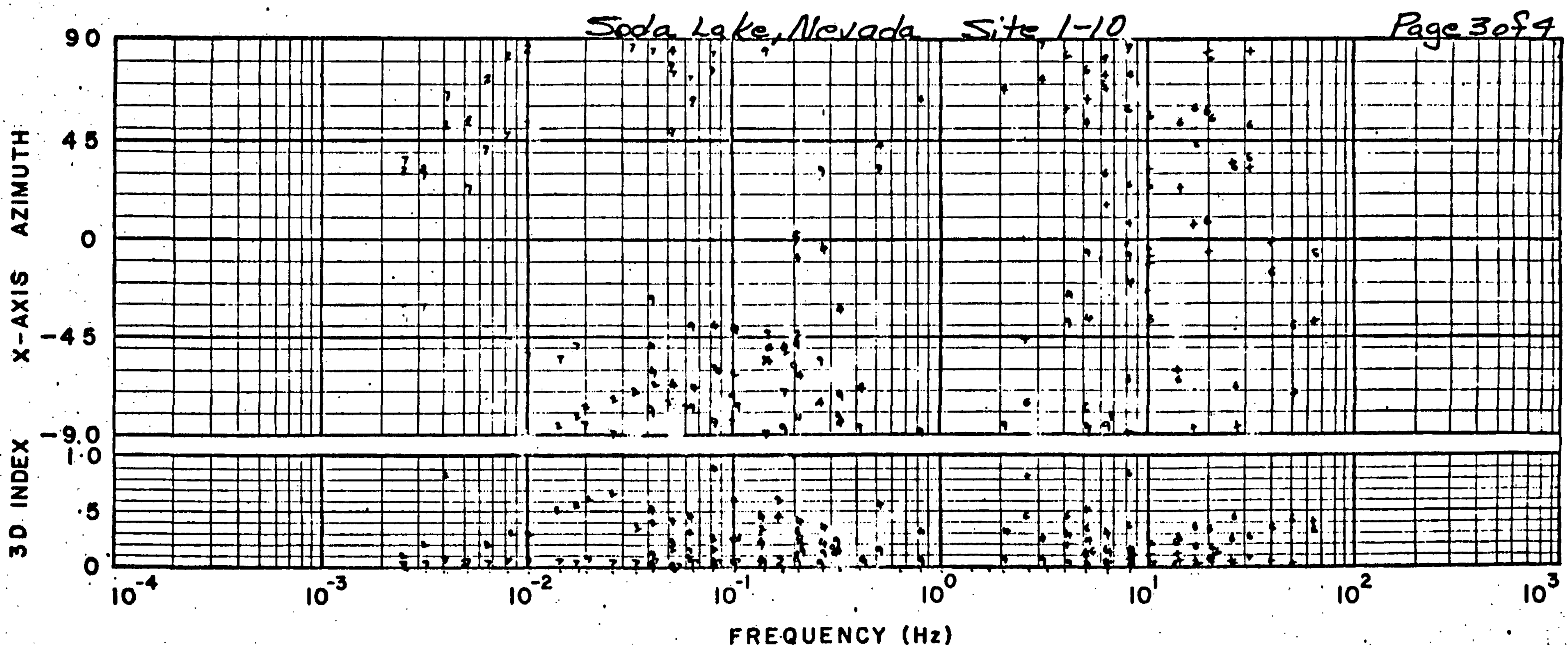


Soda Lake, Nevada Site 1-9 Smooth Values
Page 4 of 4
X-AXIS AZIMUTH
90
45
0
-45
-90
3D INDEX
1.0
.5
0
A(YZ)
A(Z)
β
α
10^-4
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3
FREQUENCY (Hz)

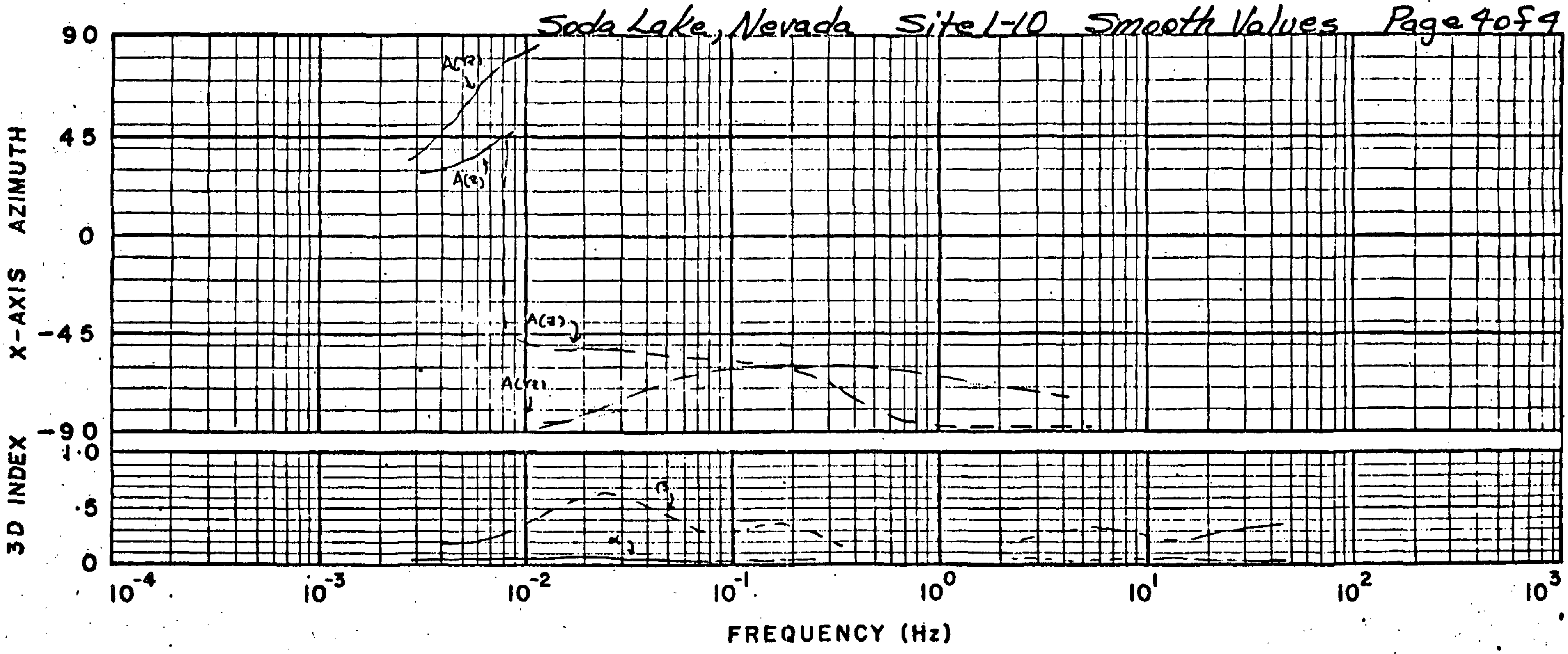
Figure - II - 10
Page 1 of 4




Soda Lake, Nevada Site 1-10 Smooth Values Page 2 of 4
ρTE
ρTM
APPARENT RESISTIVITY (Ω-m)
PHASE
10²
10¹
10⁰
10⁻¹ - 90°
45°
0°
10⁻⁴
10⁻³
10⁻²
10⁻¹
10⁰
10¹
10²
10³
FREQUENCY (Hz)



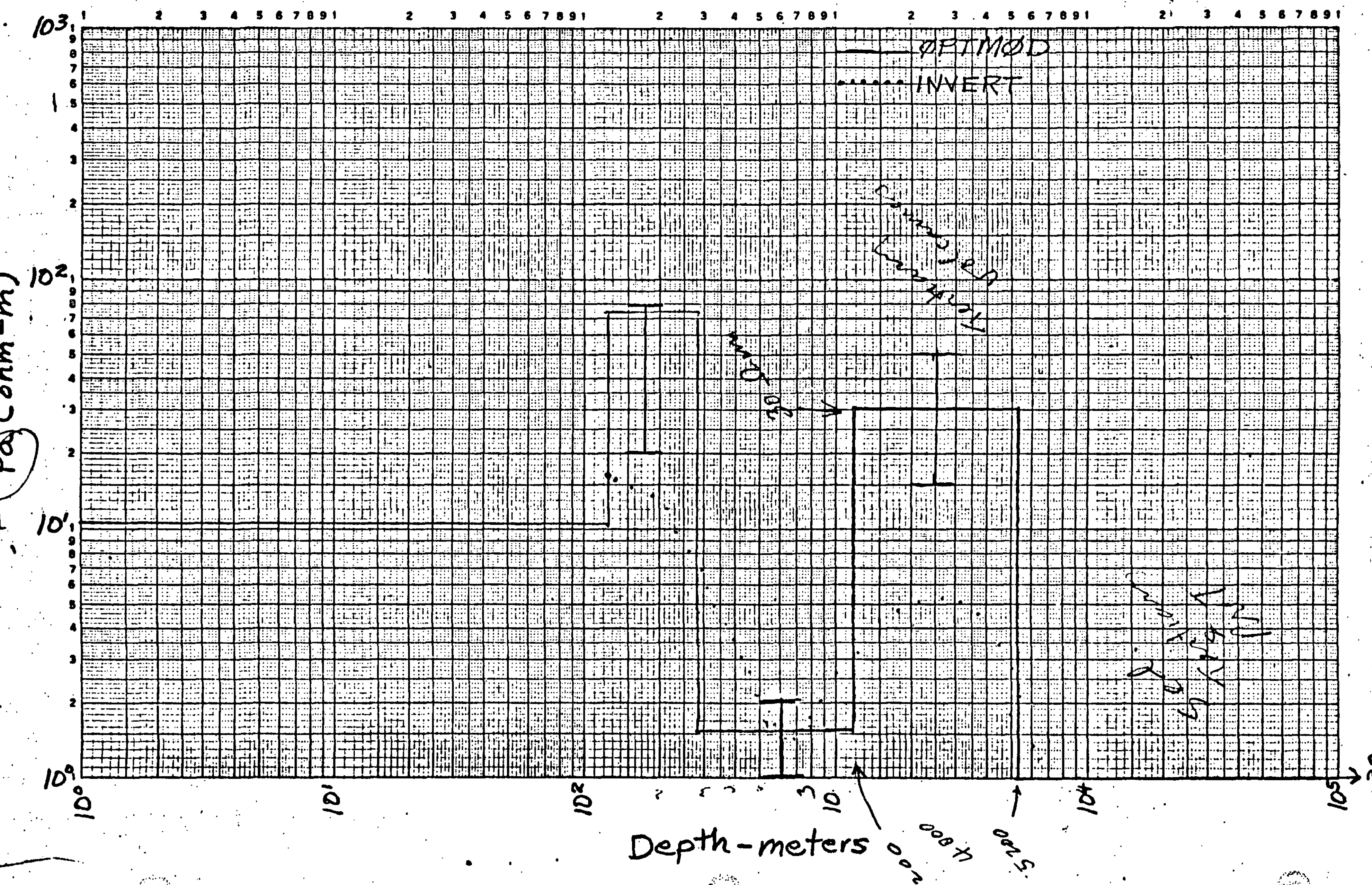
Soda Lake, Nevada Site 1-10
Page 3 of 4
X-AXIS AZIMUTH
90
45
0
-45
-90
3D INDEX
1.0
.5
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)



Soda Lake, Nevada Site L-10 Smooth Values Page 4 of 4
X-AXIS AZIMUTH
90
45
0
-45
-90
3D INDEX
1.0
.5
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
FREQUENCY (Hz)

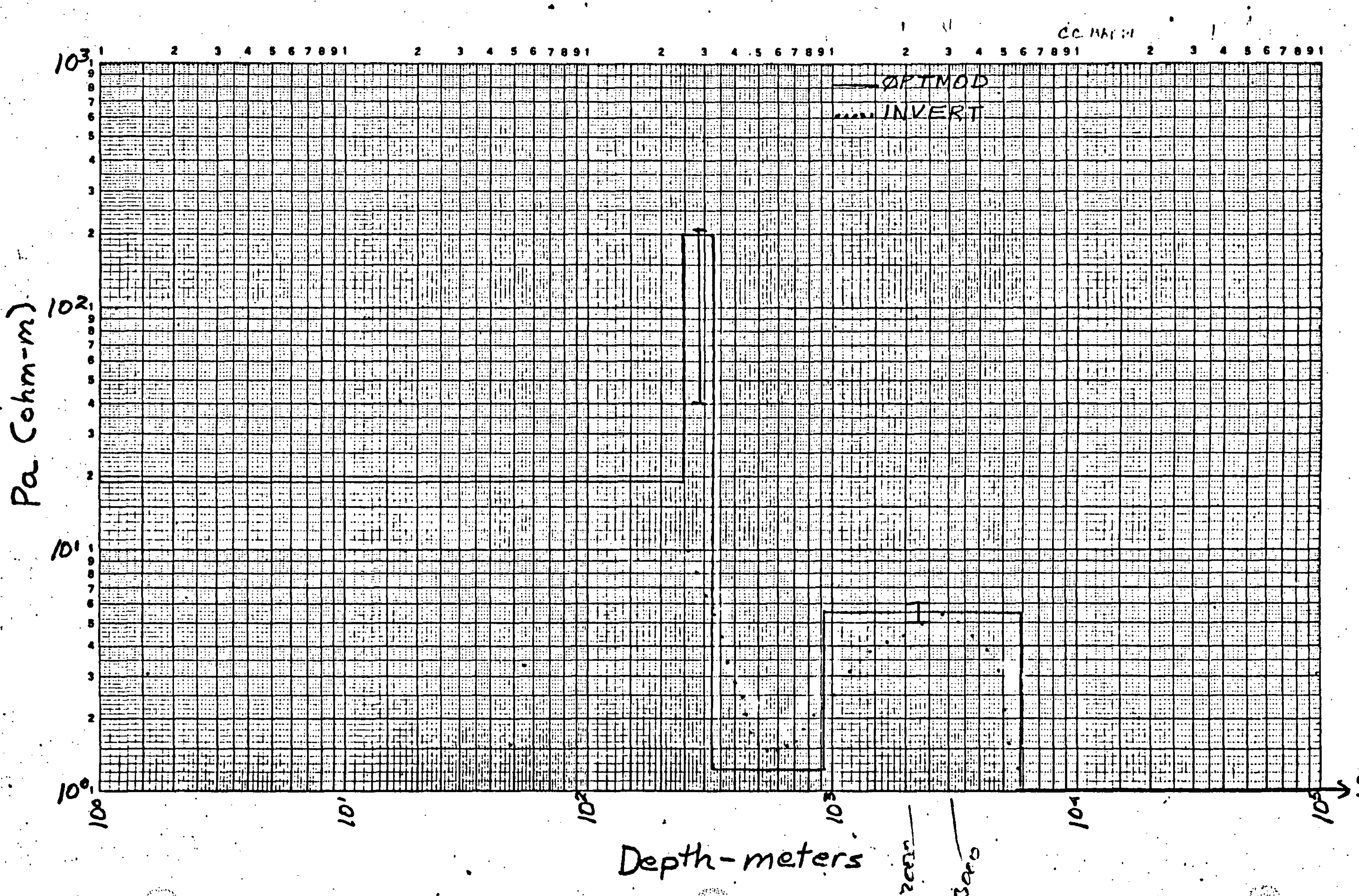
K+E LOGARITHMIC 3 X 5 CYCLES 46 7522 MADE IN U.S.A.
KEUFFEL & ESSER CO.

Figure II-11. Soda Lake, Nevada Area [redacted]
SITE 1-1



K+E LOGARITHMIC 3 X 5 CYCLES 46 7522 MADE IN U.S.A. KEUFFEL & ESSER CO.

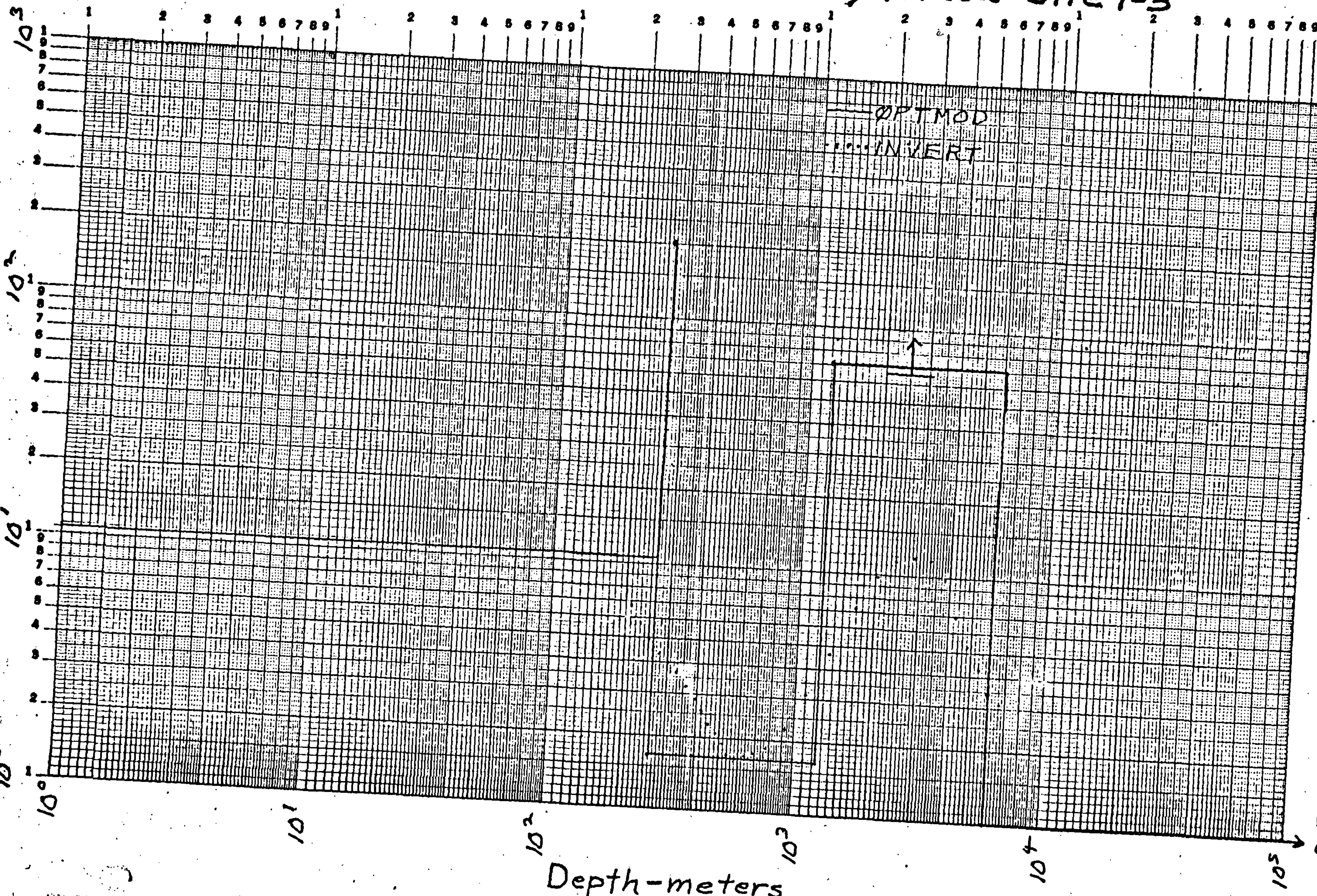
Figure II-12. Soda Lake, Nevada SITE 1-2



K·E LOGARITHMIC 3 x 5 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A.

46 7522

Figure II-13. Soda Lake, Nevada Site 1-3



K&E LOGARITHMIC 3 X 5 CYCLES 46 7522 MADE IN U.S.A. KEUFFEL & ESSER CO.

Figure II-14 Soda Lake, Nevada SITE 1-4

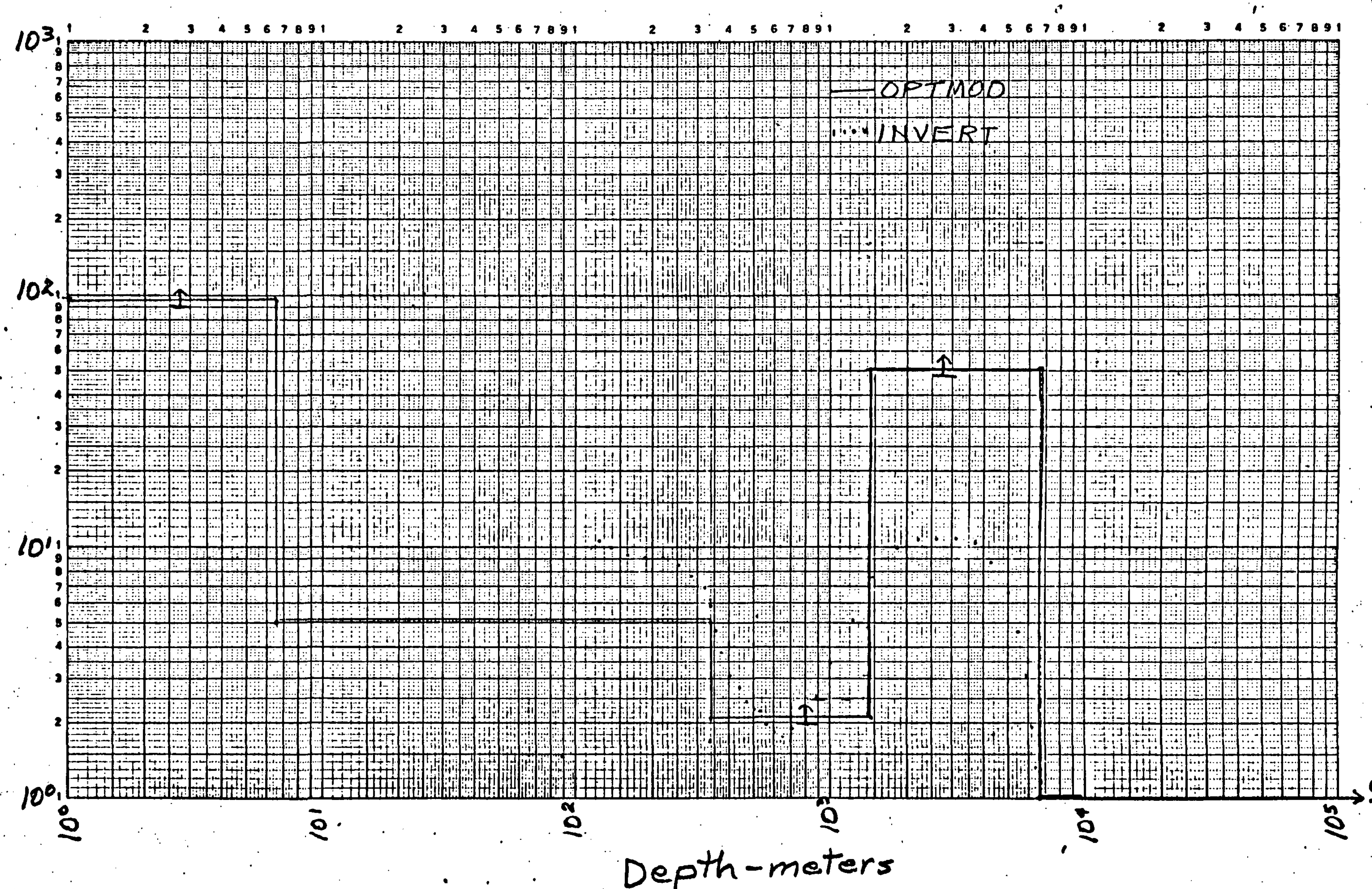
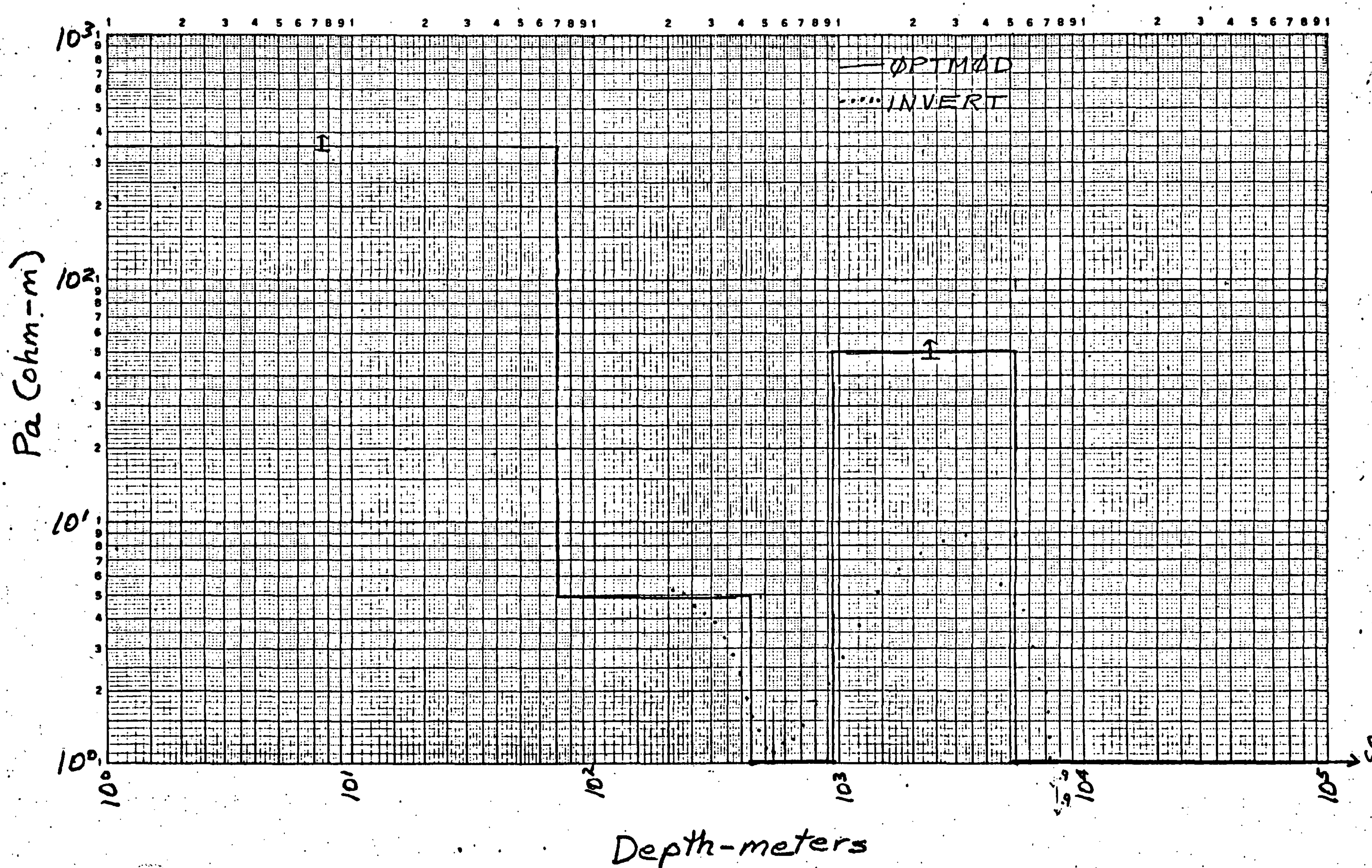
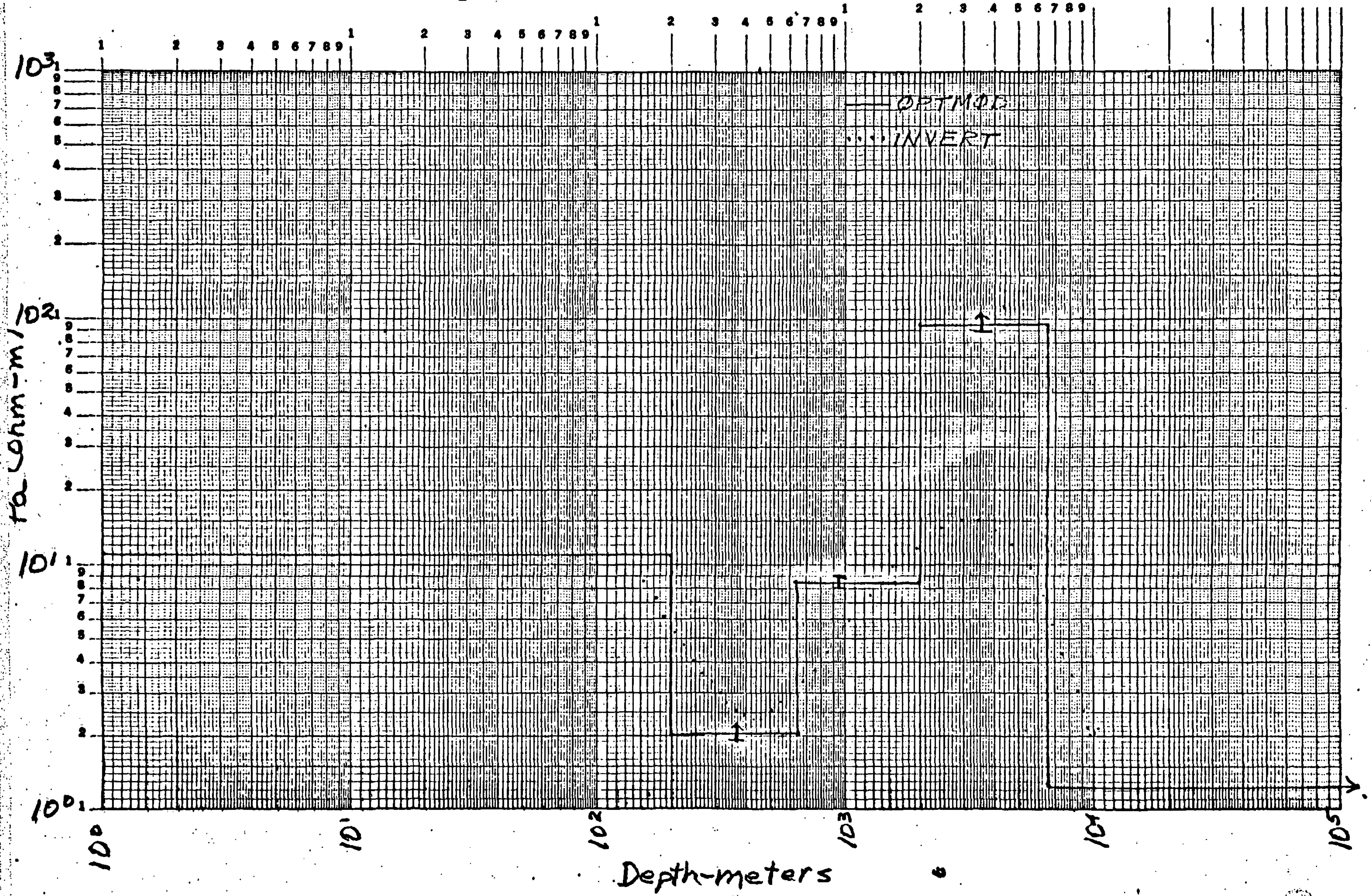


Figure II-15. Soda Lake, Nevada SITE 1-#5



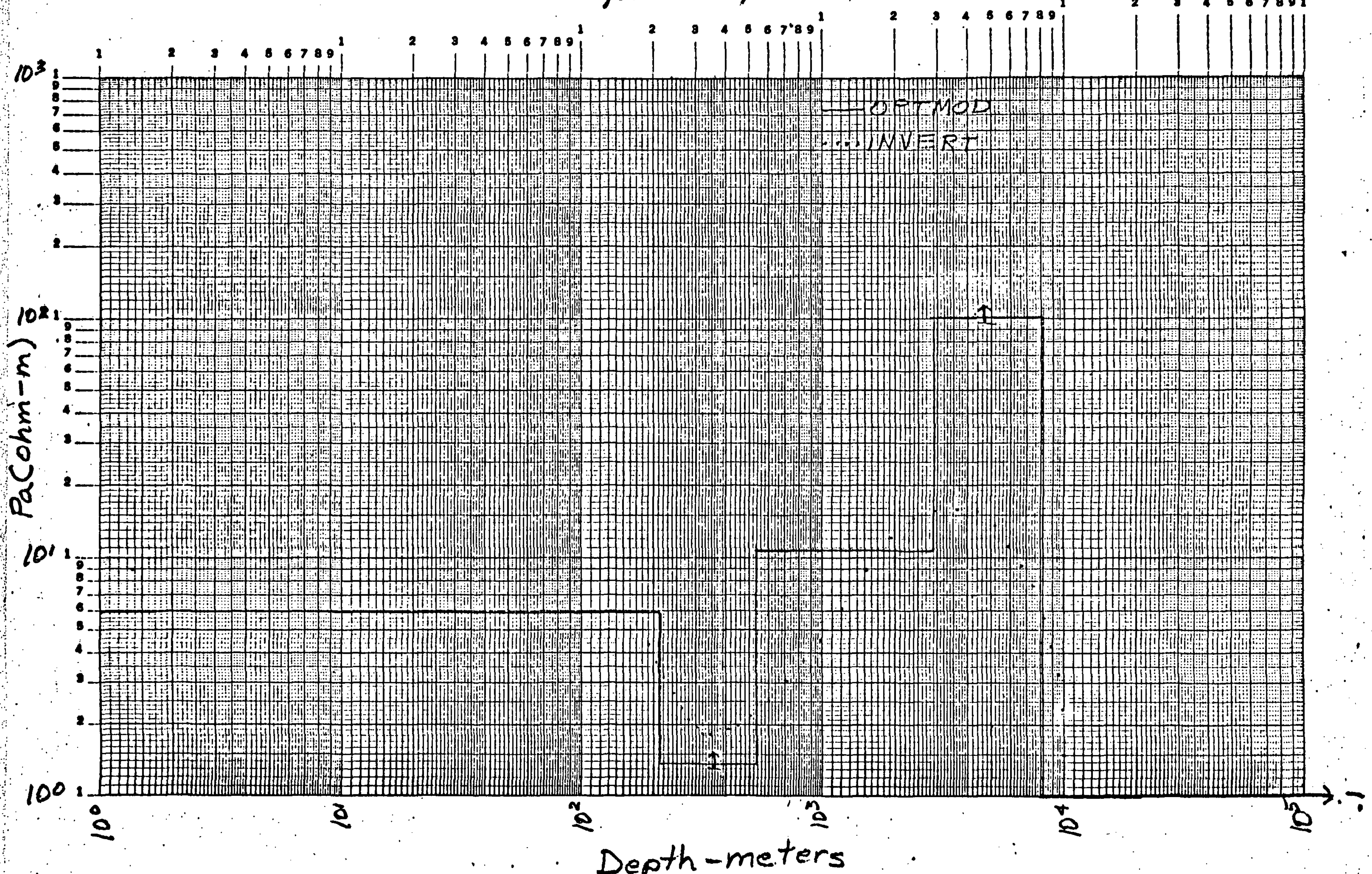
K&E LOGARITHMIC 3 x 5 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 7522

Figure II-16 Soda Lake, Nevada SITE 1-6



K·E LOGARITHMIC 3 x 5 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 7522

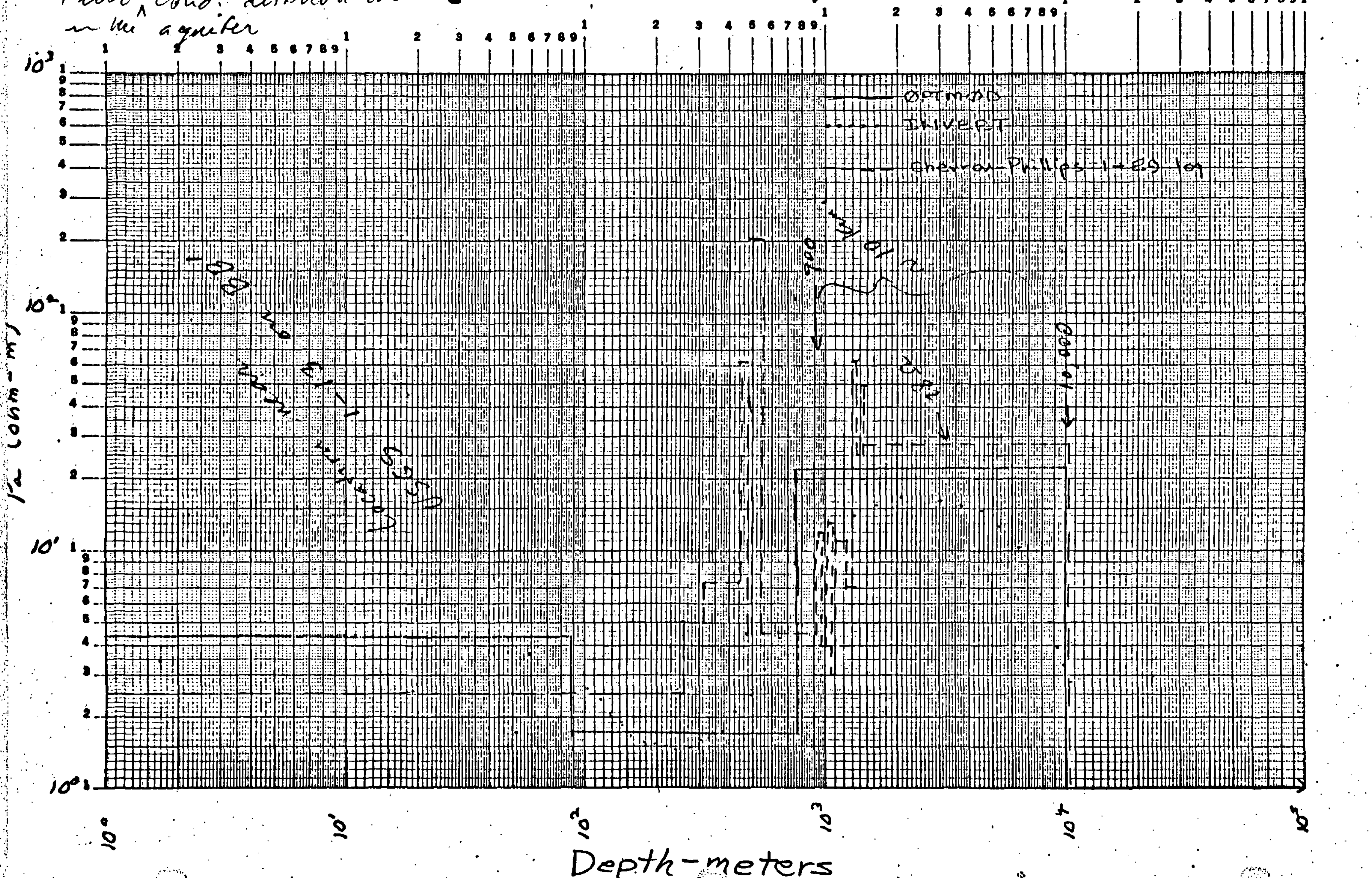
FIGURE II-17
Soda Lake, Nevada, SITE 1-7



K+E LOGARITHMIC 3 x 5 CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 7522

800'
aquifer 400'
Find lateral cond. distribution in the aquifer

Figure II-18. Soda Lake, Nevada SITE 1-8



K&E LOGARITHMIC 3 x 5 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 7522

Figure. II-19 Soda Lake, Nevada SITE 1-9

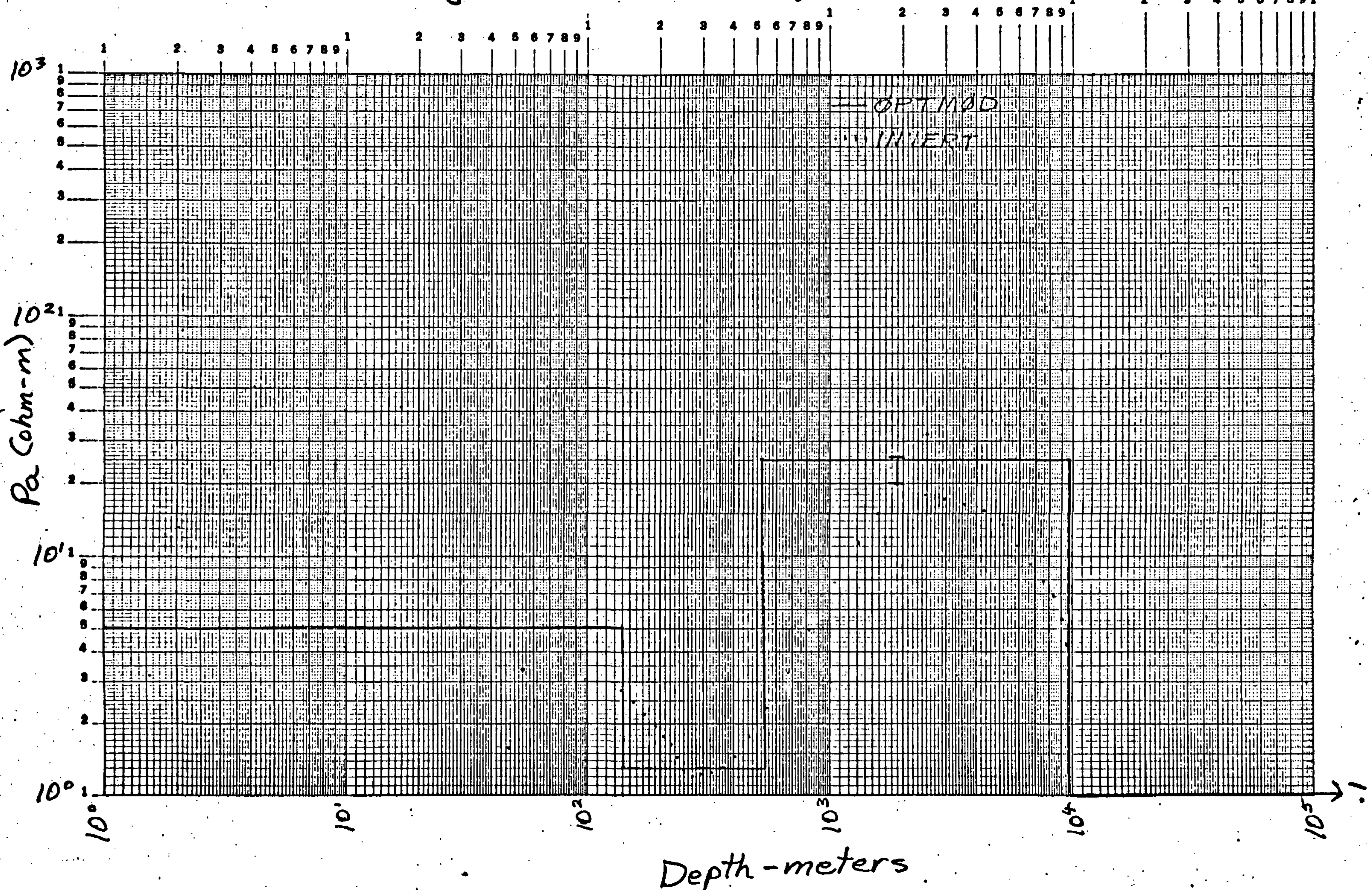


Figure II-20 Soda Lake, Nevada SITE 1-10

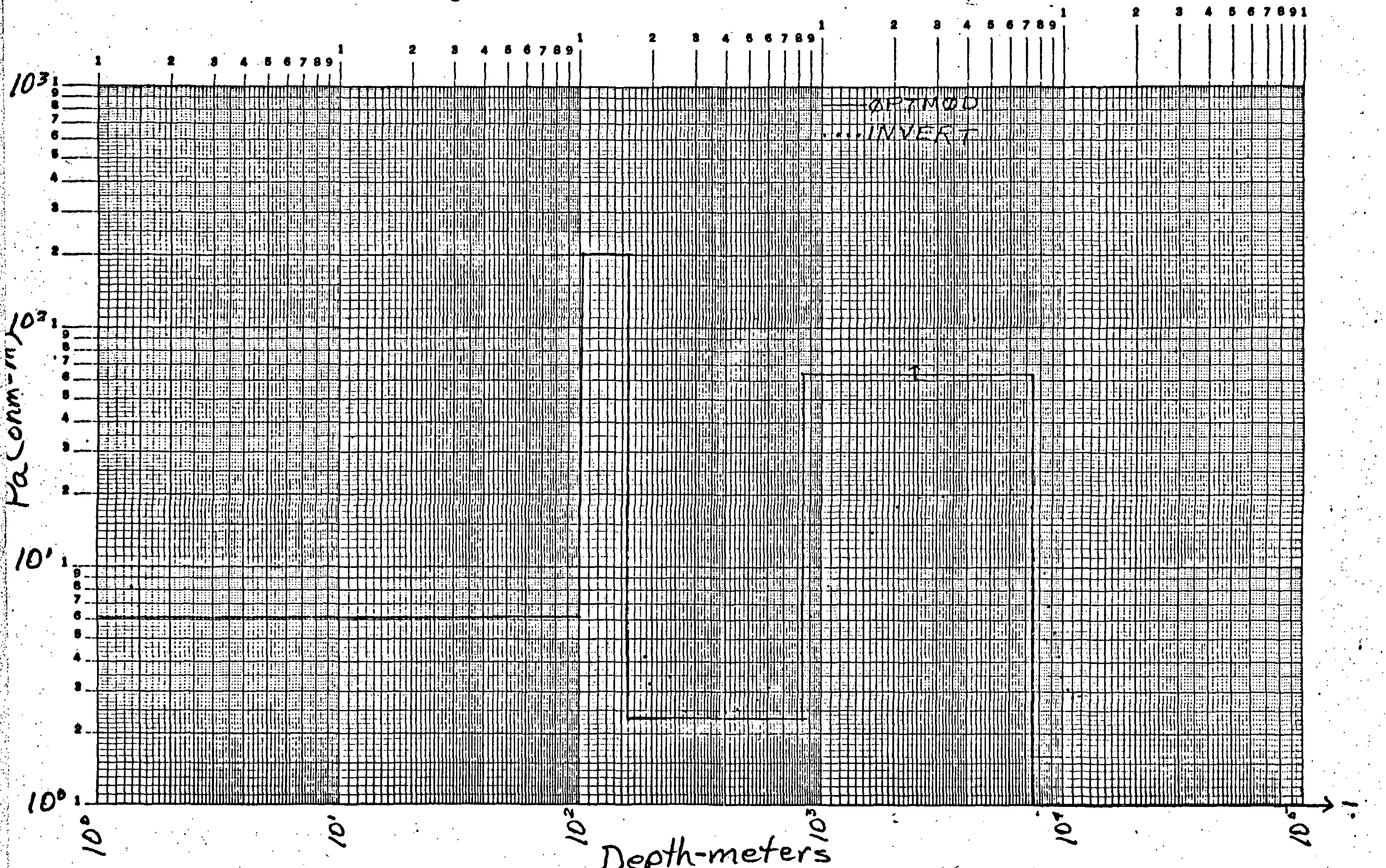


FIGURE III-1

COMPOSIT RESISTIVITY CROSS SECTION

PLOTTED FROM THE RESULTS OF THE

MAGNETO TELLURIC SURVEY

OF THE

SODA LAKE NEVADA AREA

BY

GEOTRONICS CORPORATION

FOR

SOCAL MINERALS

MAY, 1975

LEGEND

APPARENT RESISTIVITIES IN OHM-METERS

CONTOUR INTERVALS: 1,1.5,2,5,7.5,10 Ω-m

HORIZONTAL SCALE: 1" = 2000'

HORIZONTAL/VERTICAL RATIO: 0.61

PROGRAM: INVERT INVERSION USING AMPLITUDE AND PHASE

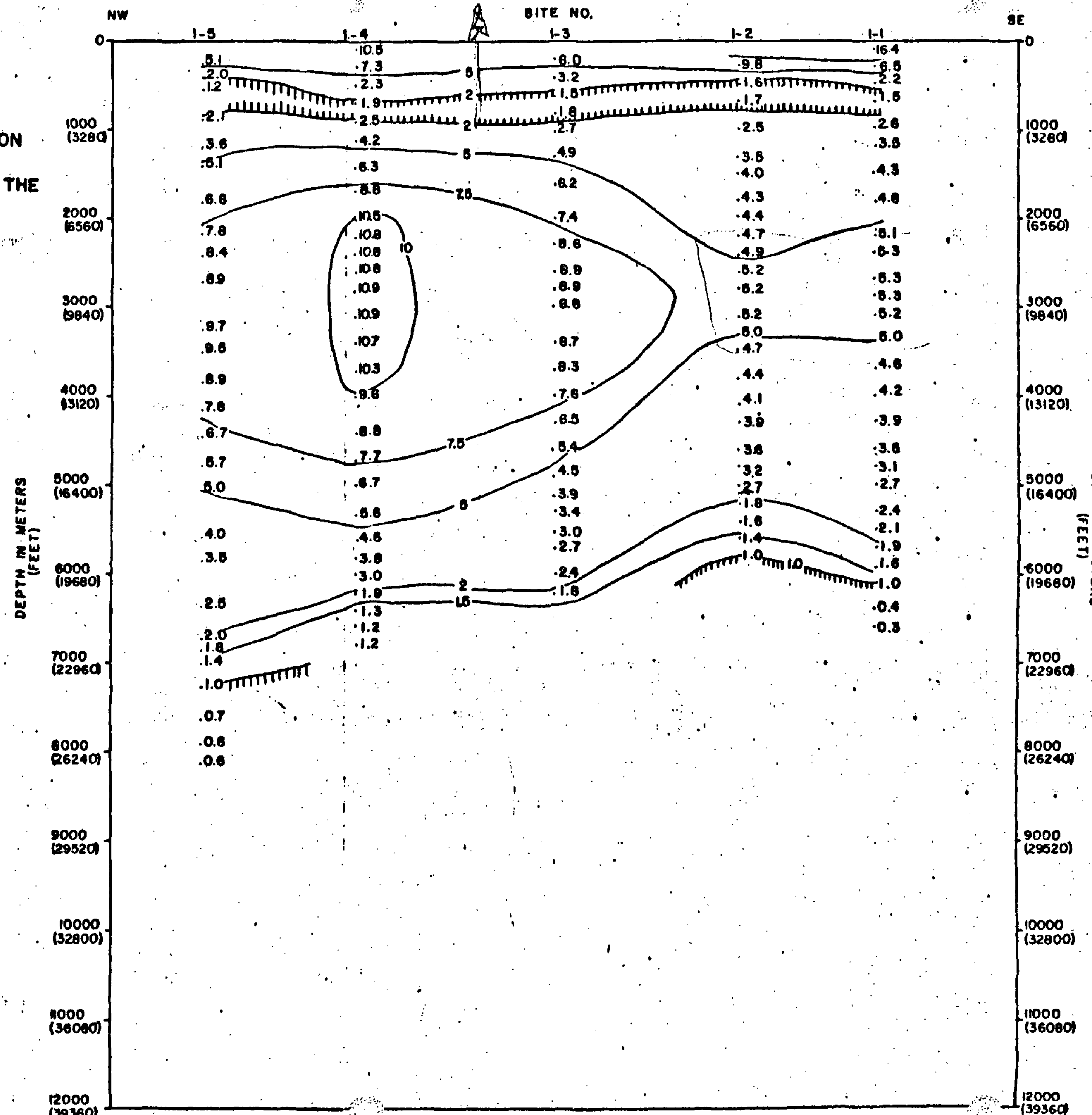


FIGURE III-2

COMPOSIT RESISTIVITY CROSS SECTION

PLOTTED FROM THE RESULTS OF THE

MAGNETO TELLURIC SURVEY

OF THE

SODA LAKE NEVADA AREA

BY

GEOTRONICS CORPORATION

FOR

SOCAL MINERALS

MAY, 1975

LEGEND

APPARENT RESISTIVITIES IN OHM-METERS

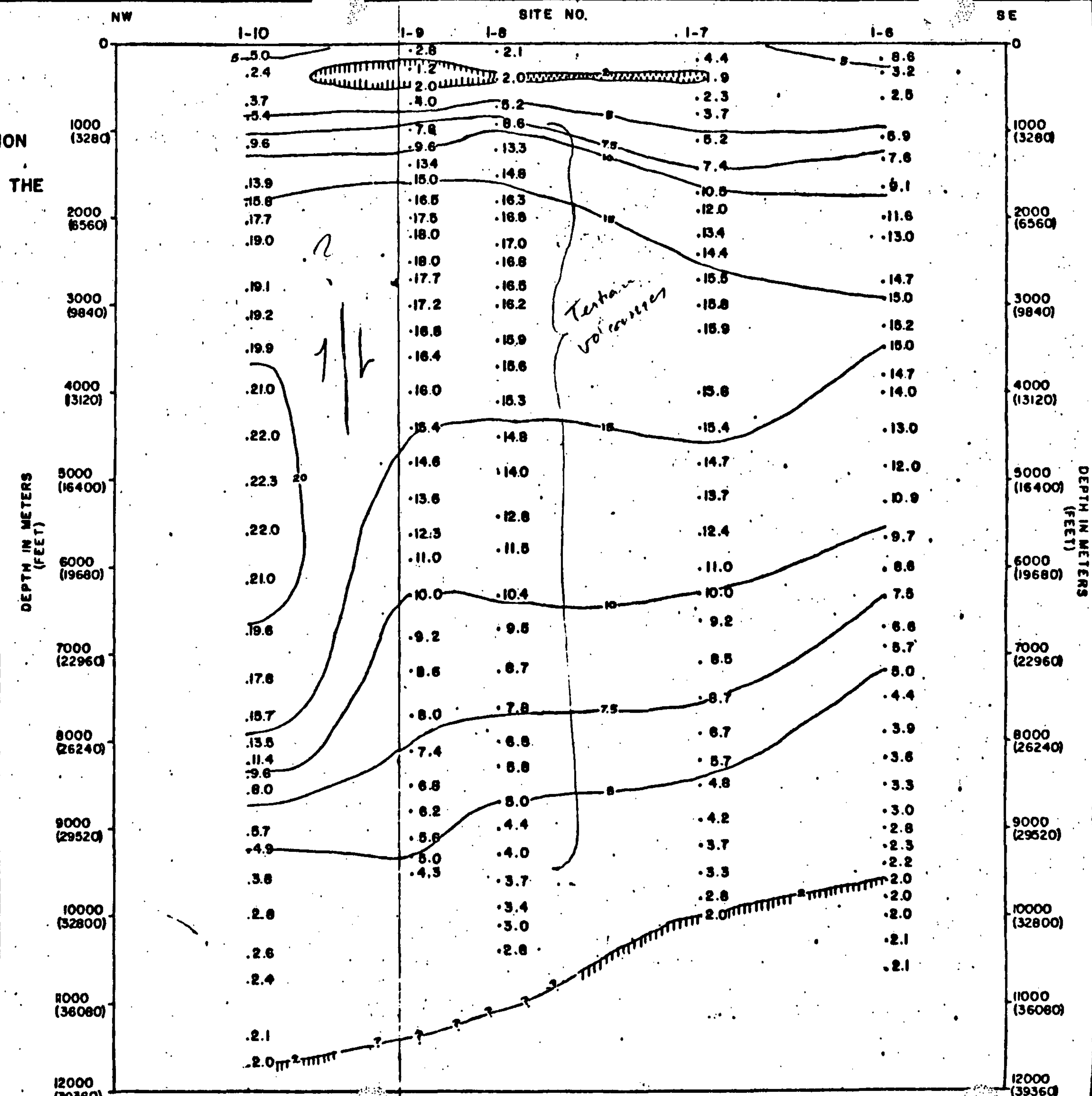
CONTOUR INTERVALS: 1,1.5,2,5,7.5,10 Ω-m

HORIZONTAL SCALE: 1"=2000'

HORIZONTAL/VERTICAL RATIO: 0.61

PROGRAM: INVERT INVERSION USING AMPLITUDE AND PHASE

0 1000 2000 3000



Correlation of the 1-D discrete-layer model

FIGURE III-3A

COMPOSIT RESISTIVITY CROSS SECTION

PLOTTED FROM THE RESULTS OF THE

MAGNETO TELLURIC SURVEY

OF THE

SODA LAKE NEVADA AREA

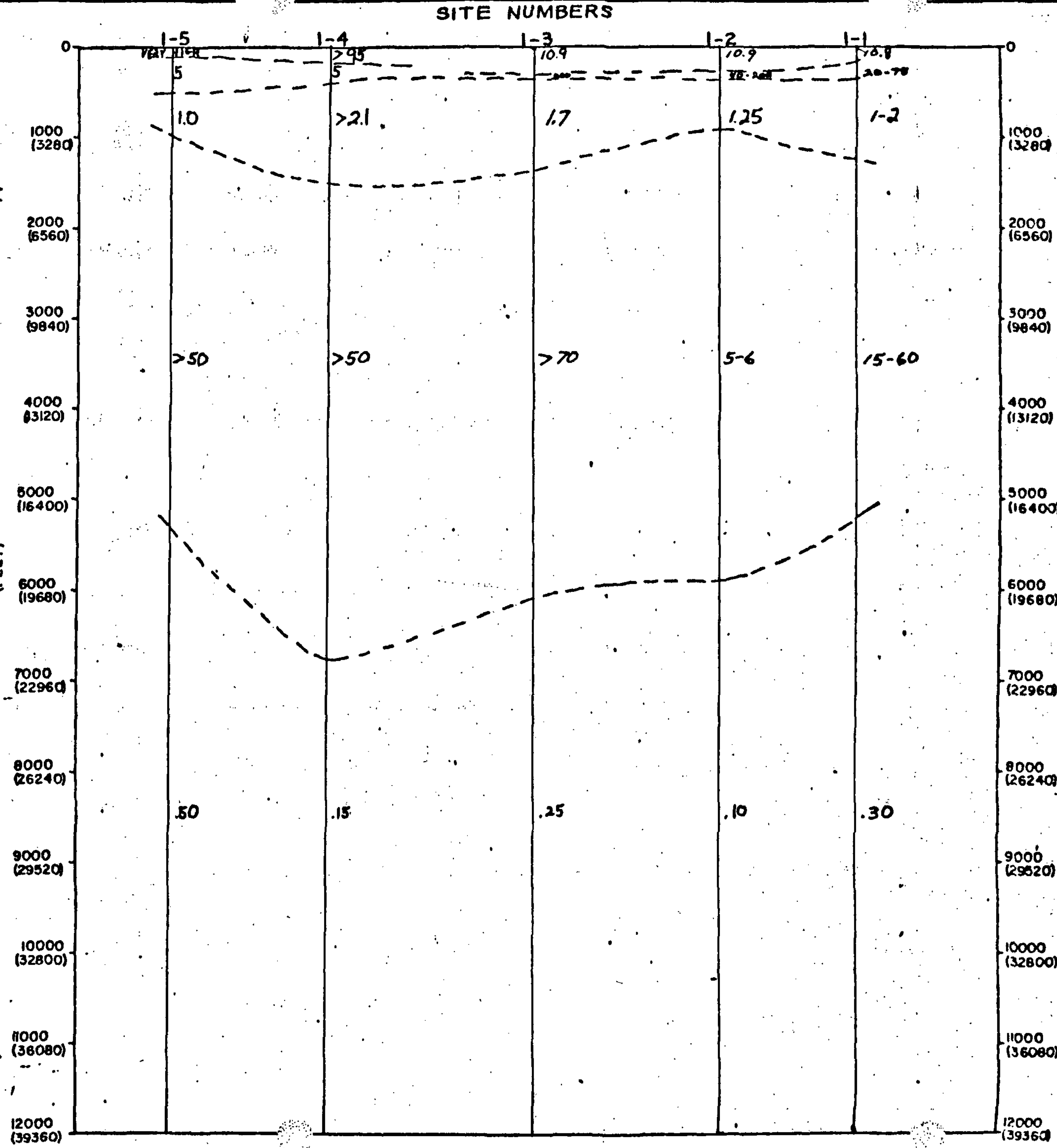
BY

GEOTRONICS CORPORATION

FOR

SOCAL MINERALS

APRIL, 1975



LEGEND

APPARENT RESISTIVITIES IN OHM-METERS

CONTOUR INTERVALS:

HORIZONTAL SCALE: 1" = 2000'

HORIZONTAL/VERTICAL RATIO: 0.61

FIGURE III-3B

COMPOSIT RESISTIVITY CROSS SECTION

PLOTTED FROM THE RESULTS OF THE

MAGNETO TELLURIC SURVEY

OF THE

SODA LAKE NEVADA AREA

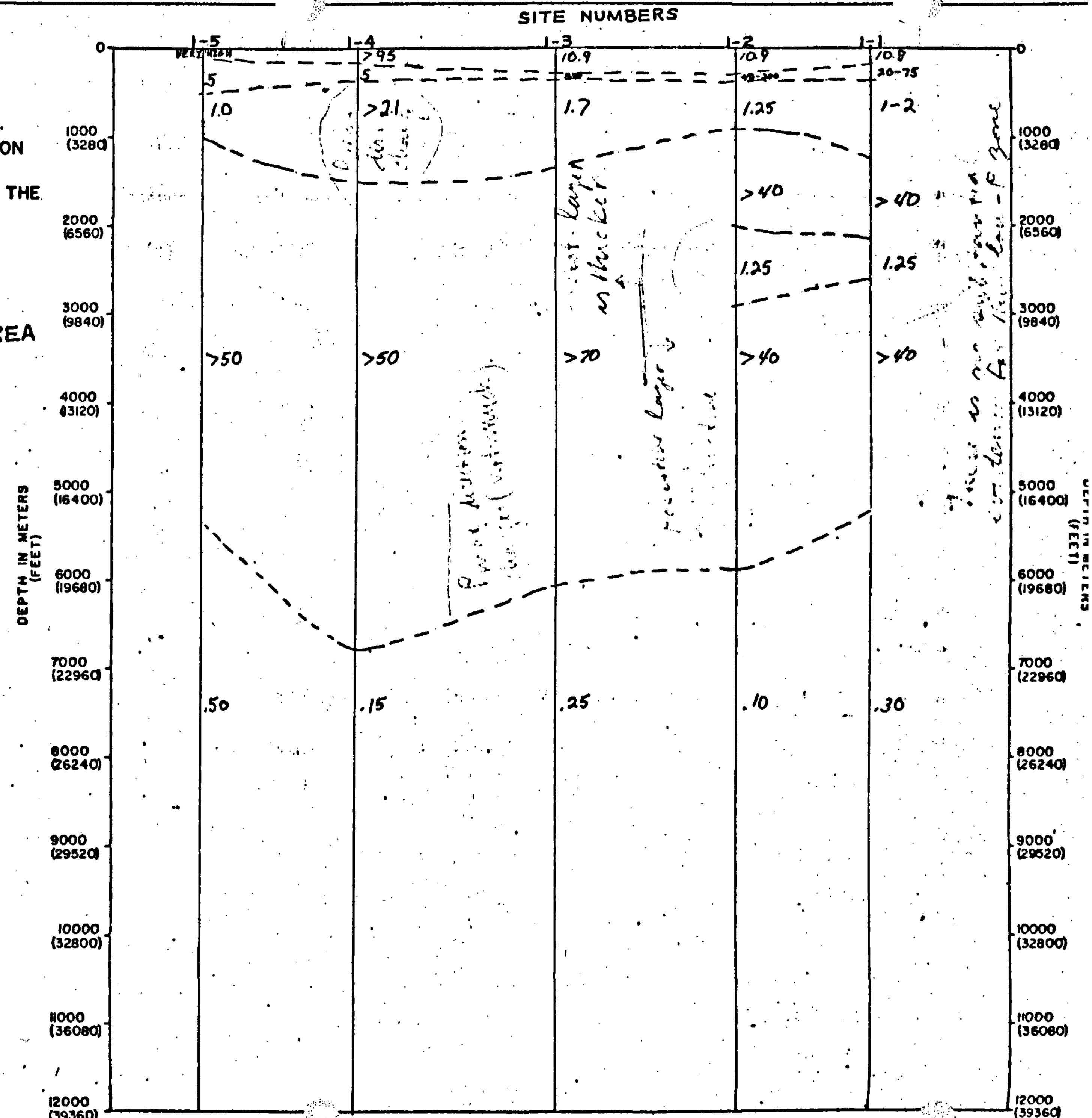
BY

GEOTRONICS CORPORATION

FOR

SOCAL MINERALS

APRIL, 1975



LEGEND

APPARENT RESISTIVITIES IN OHM-METERS

CONTOUR INTERVALS:

HORIZONTAL SCALE: 1" = 2000'

HORIZONTAL/VERTICAL RATIO: 0.61

FIGURE III-4

COMPOSIT RESISTIVITY CROSS SECTION

PLOTTED FROM THE RESULTS OF THE

MAGNETO TELLURIC SURVEY

OF THE

SODA LAKE NEVADA AREA

BY

GEOTRONICS CORPORATION

FOR

SOCAL MINERALS

APRIL, 1975

LEGEND

APPARENT RESISTIVITIES IN OHM-METERS
CONTOUR INTERVALS:
HORIZONTAL SCALE: 1" = 2000'
HORIZONTAL/VERTICAL RATIO: 0.61

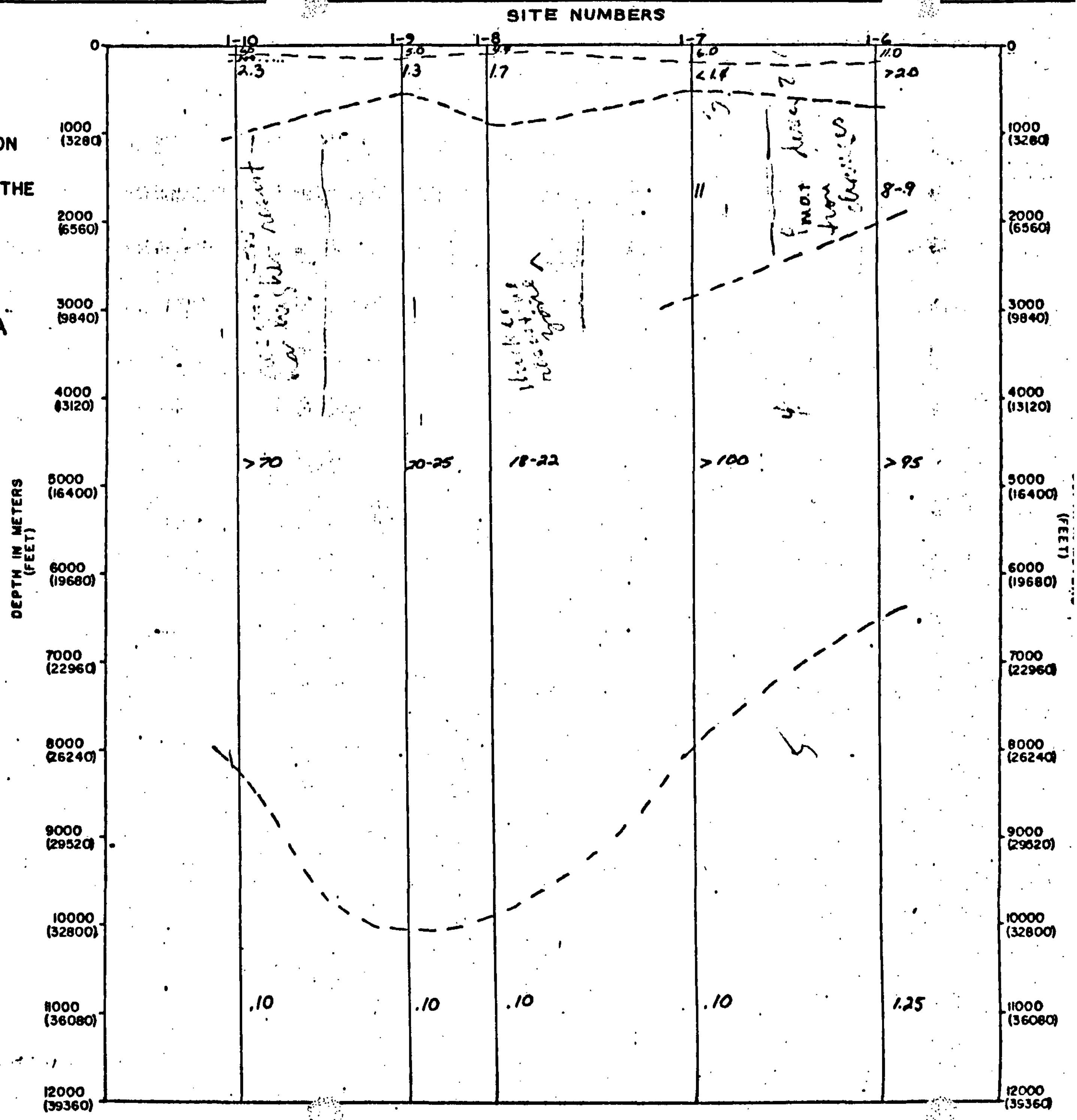


Figure III-5 OPTMOD Depth to Top Surface of Deep Conductor (Tert. & pre-Tert. sediments) (in meters) AND Maximum Impedance Direction at that Depth

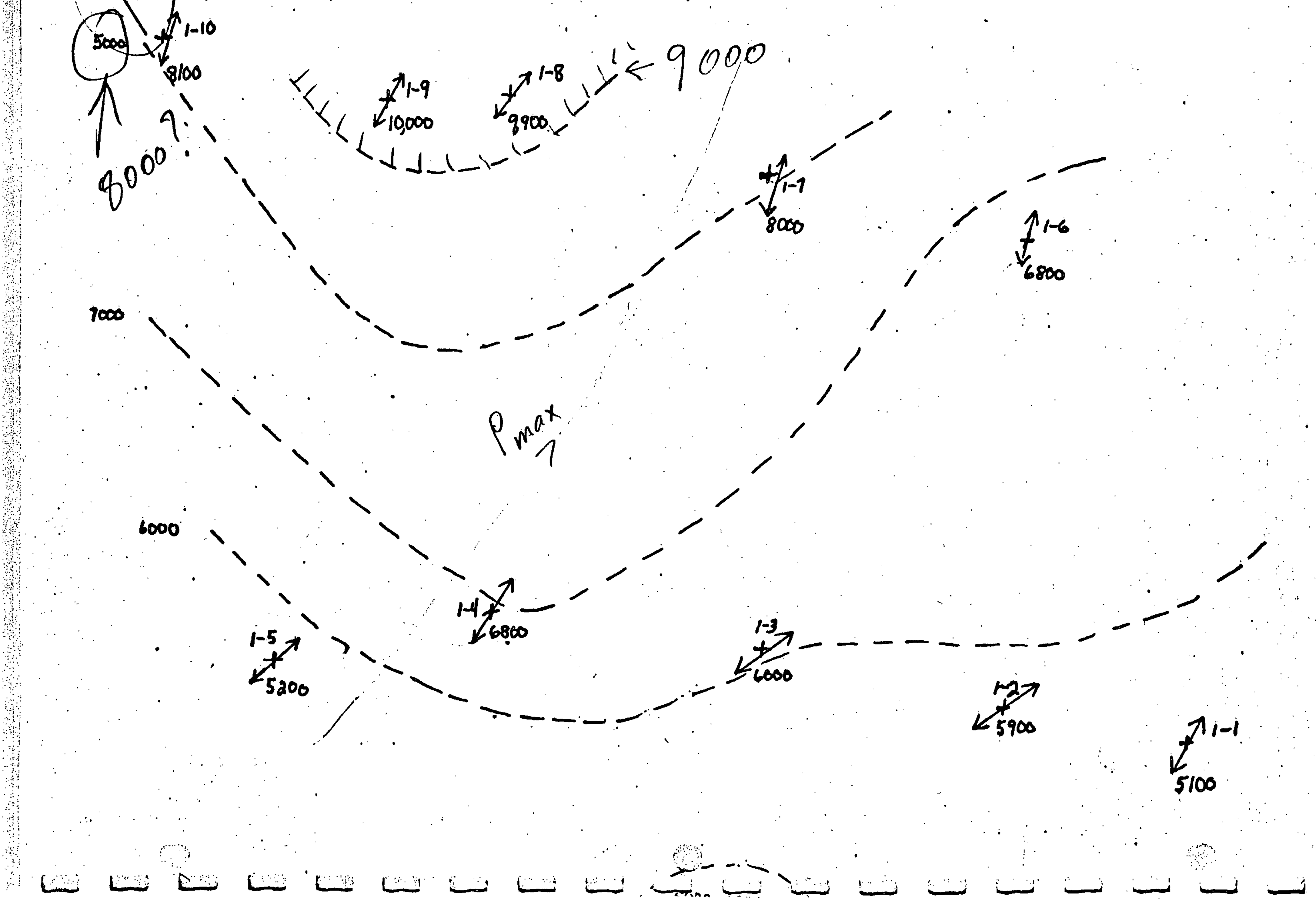


Figure III-6 OPTMOD Depth to Resistive "Basemen (ie, base of aquifer w/ hot water) (in meters) AND Maximum Impedance Direction At 3 Kilometers.

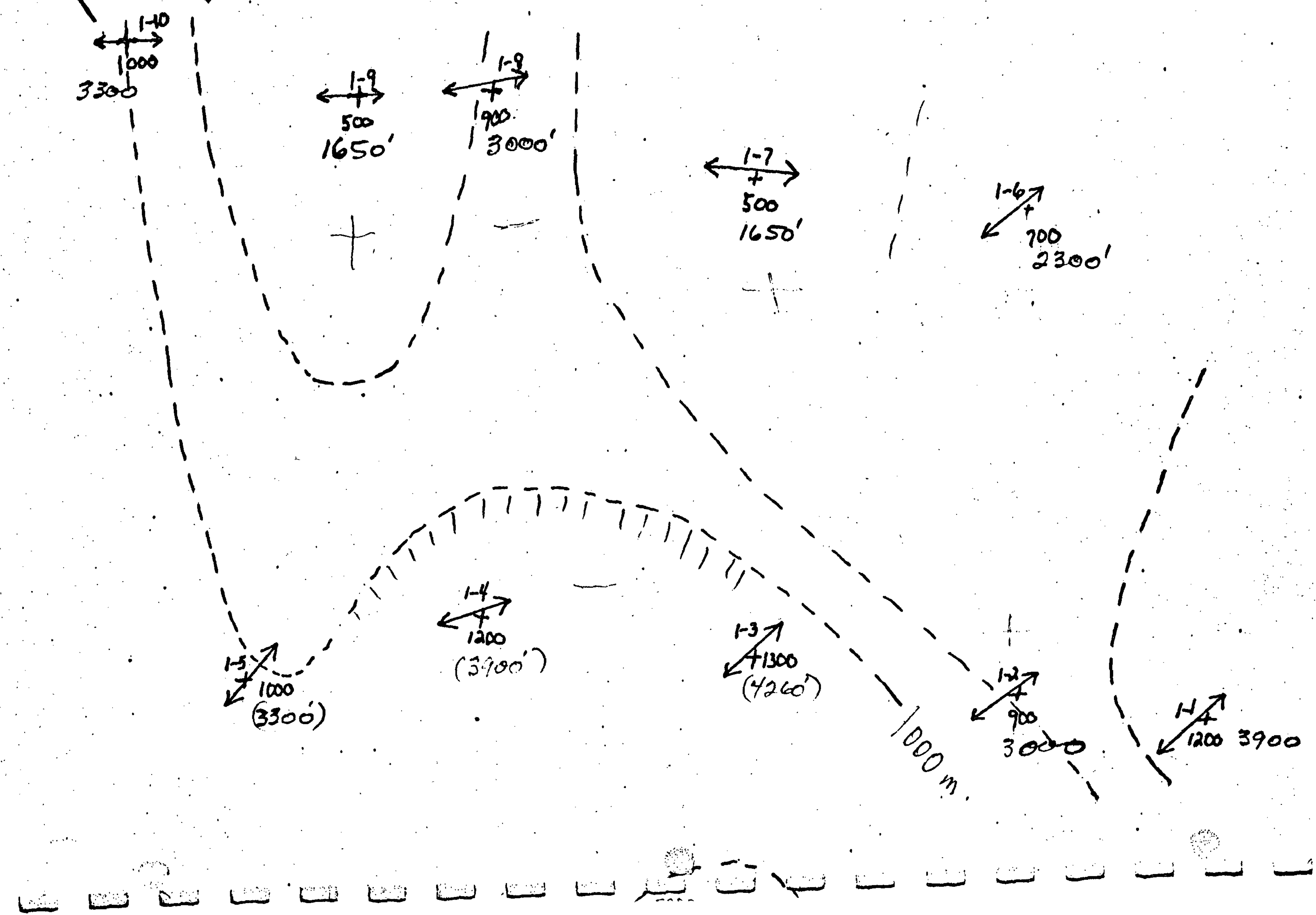
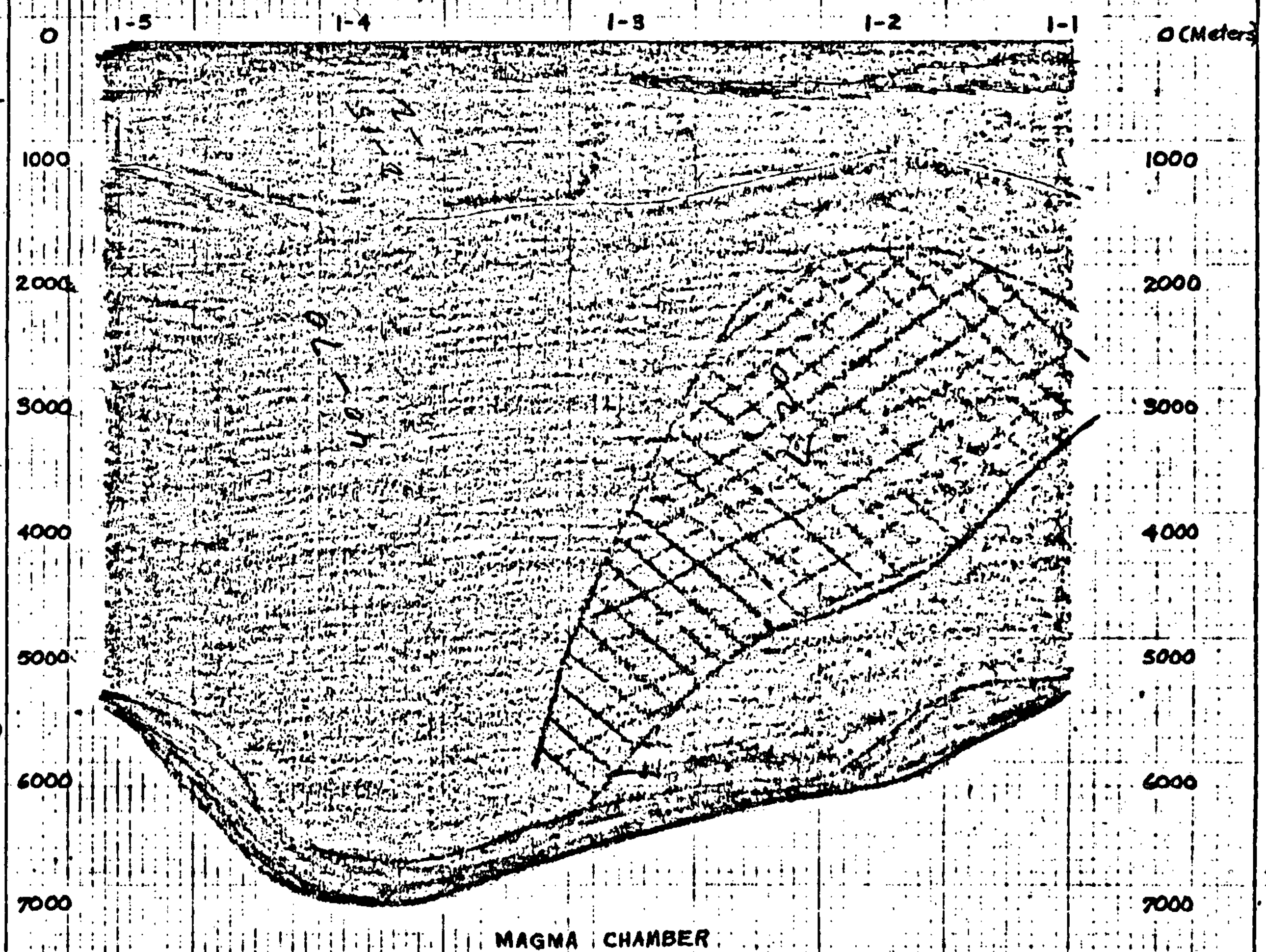


FIGURE IV-1A - LINE A-ALTERATION MODEL

PROPOSED LITHOLOGIC UNIT	PROBABLE RESISTIVITY RANGE-OHM-METERS
Upper Lahontan Valley Group (Sehoo?)	5-15
Lower Lahontan Valley Group (Wyemaha?)	2-15 (Unsaturated) 1-2 (Saturated)
Volcanics (Age Unspecified)	70+ -(Probably Quite Variable)
Truckee Formation?	1-2 (Saturated)
Tertiary (Rhyolites And Volcanics) A B C	A) 40-70+ (Unaltered) B) 20-25 (Moderate Alteration) C) <20 (Intense Alteration)
Magma Chamber	<1 (Probable)



Horizontal Scale: 1" = 2000'
Horizontal/Vertical Ratio: 0.61

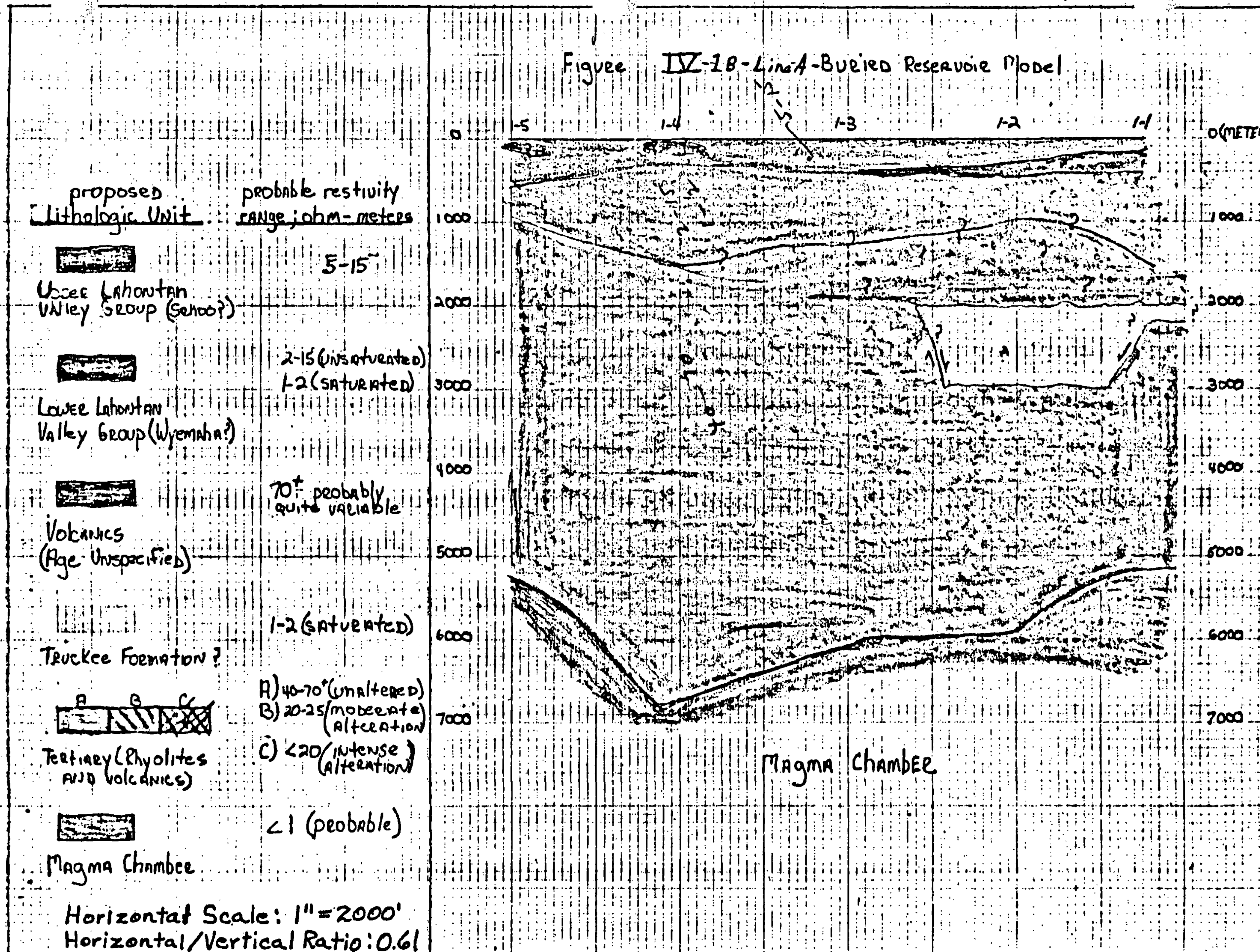
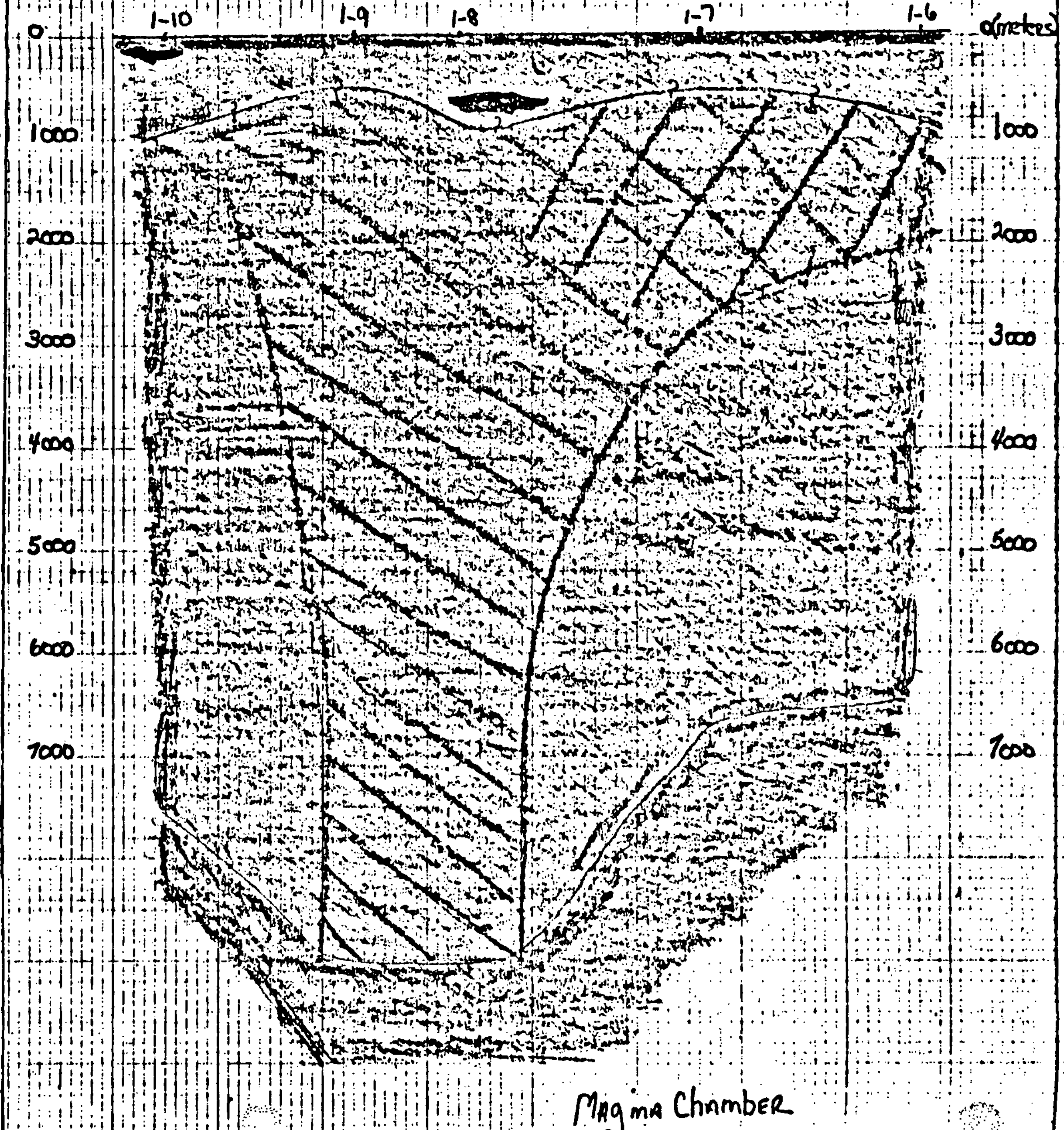


Figure IV-1B-Line A-Buried Reservoir Model
-5
1-4
1-3
1-2
1-1
0 (METERS)
1000
2000
3000
4000
5000
6000
7000
Magma Chamber
proposed Lithologic Unit
probable resistivity range; ohm-meters
Upper Lahontan Valley Group (Sehoo?)
5-15
Lower Lahontan Valley Group (Wyemaha?)
2-15 (Unsaturated)
1-2 (Saturated)
Volcanics (Age Unspecified)
70± probably quite variable
Truckee Formation ?
1-2 (Saturated)
A B C
Tertiary (Rhyolites and volcanics)
A) 40-70+ (unaltered)
B) 20-25 (moderate alteration)
C) <20 (intense alteration)
Magma Chamber
<1 (probable)
Horizontal Scale: 1" = 2000'
Horizontal/Vertical Ratio: 0.61

Figure IV-2 - Line B



Proposed Lithologic Unit	probable restivity range, ohm-meters
Upper Lahontan Valley-Group, (Sehoo ?)	5-15
Lower Lahontan Valley-Group (Wyemaha?)	2-15 (unsaturated) 1-2 (saturated)
Volcanics (Age unspecified)	70+, probably quite variable
Truckee formation ?	1-2 (saturated)
A B C Tertiary (Rhyolites and volcanics)	A) 40-70+ (unaltered) B) 20-25 (moderate alteration) C) <20 (intense alteration)
Magma Chamber	<1 (probable)

Horizontal Scale: 1" = 2000'
H-izontal/Vertical Ratio: 0.61