DOE/ET/28392-37
78-1701.b.1.1.8
ESL-26

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NUMERICAL MODELING AND INTERPRETATION OF DIPOLE-DIPOLE RESISTIVITY AND IP PROFILES COVE FORT-SULPHURDALE KGRA, UTAH

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December, 1979

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Prepared for the
DEPARTMENT OF ENERGY
DIVISION OF GEOTHERMAL ENERGY
Under Contract EG-78-C-07-1701

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ABSTRACT

The Cove Fort-Sulphurdale Known Geothermal Resource Area (KGRA) is located near the junction of the Pavant Range and the Tushar Mountains in south-central Utah. The area has been the site of an intensive geothermal exploration effort by Union Oil Company since 1975. This report presents the electrical resistivity data obtained by Union Oil Company and a subsequent survey conducted for the Earth Science Laboratory, and a detailed numerical interpretation of both data sets.

The detailed modeling permits a characterization of the intrinsic electrical resistivity to depths exceeding 2,000 feet. An area of over two square miles with bulk in-situ resistivities of four-to-five ohm-m is delineated at Sulphurdale near the Union Oil Co. well CFSU #42-7. The low-resistivity rocks define the area of extensive hydrothermal alteration in response to the presence of clay minerals and conductive thermal fluids. In contrast the area north and east of Cove Fort is typified by high (100-300 ohm-m) resistivities to depths exceeding 2,000 feet. This is an area of Cretaceous and Paleozoic sedimentary rocks where two attempts to drill to reservoir depth failed because of extreme drilling problems. The high resistivities are not considered encouraging for the presence of a deeper reservoir. The electrical resistivity interpretation has defined several areas of probable upward migration of thermal fluids along north-trending normal faults. Some of these areas may have potential for direct heat geothermal utilization.

Two lines of induced polarization data indicate large volumes of

Cretaceous and Paleozoic sedimentary rocks may be mineralized with one- to two-weight percent sulfides. Geologic studies indicate much of this mineralization predates the present geothermal system.

INTRODUCTION

The Cove Fort-Sulphurdale Known Geothermal Resource Area (KGRA) is located near the junction of the Pavant Range and the Tushar Mountains in south-central Utah (Figure 1). The area is central to several geothermal areas including the Monroe-Joseph KGRA to the east and Roosevelt Hot Springs and Thermo KGRAs to the west and south.

The Cove Fort-Sulphurdale area has been the site of an intensive geothermal exploration effort by Union Oil Company since 1975. In 1977 Union Oil Company entered into a cost-sharing exploration and development program with the Department of Energy (then the Energy Research and Development Administration), Division of Geothermal Energy. This contract, one part of the Industry Coupled Program, Case Studies Utah, provided for the drilling of three deep exploration wells and the release to the public of the resulting technical data and certain pre-existing surface and subsurface data (Union Oil Co., 1978a).

In 1978 the Earth Science Laboratory, University of Utah Research Institute (ESL/UURI) began geological, geophysical and geochemical studies of the Cove Fort-Sulphurdale area to develop a better understanding of the geologic factors controlling the geothermal system. This report is a result of one phase of these studies. An integrated case study unifying the geological, geophysical, and geochemical information is in progress and will be reported later. This work was funded by the Department of Energy, Division of Geothermal Energy.

GEOLOGY

The Cove Fort-Sulphurdale geothermal area is located in the transition zone between the Colorado Plateau on the east and the Basin and Range Province on the west (Figure 1). It lies along the northwestern margin of the Marysvale volcanic field. Paleozoic and Mesozoic sedimentary rocks are exposed to the north and Tertiary volcanics to the east and the south. The Quarternary Cove Fort basalt field and alluvium border the area on the west.

The Marysvale volcanic field lies near the eastern edge of the Pioche-Beaver-Tushar mineral belt which is the locus of numerous Tertiary intrusions and related mineral deposits (Rowley and others, 1968; Callaghan, 1973). The geology of the region has been studied by many workers. Recent detailed geologic mapping of the Cove Fort-Sulphurdale KGRA was reported by Moore and Samberg (1979), who reviewed the earlier studies and include an annotated bibliography of 57 references by B. Sibbett. This review will not be duplicated here.

The geology of the KGRA is dominated by lava flows and ash-flow tuffs of late Oligocene to mid-Miocene age that were deposited on faulted sedimentary rocks of Paleozoic to Mesozoic age (Moore and Samberg, 1979). These rocks were locally metamorphosed and mineralized by Tertiary intrusives. Drilling by Union Oil Co. penetrated the Tertiary volcanic rocks at depths ranging from 500 feet in the north (Forminco #1) to 2,000 feet at CFSU #42-7 near

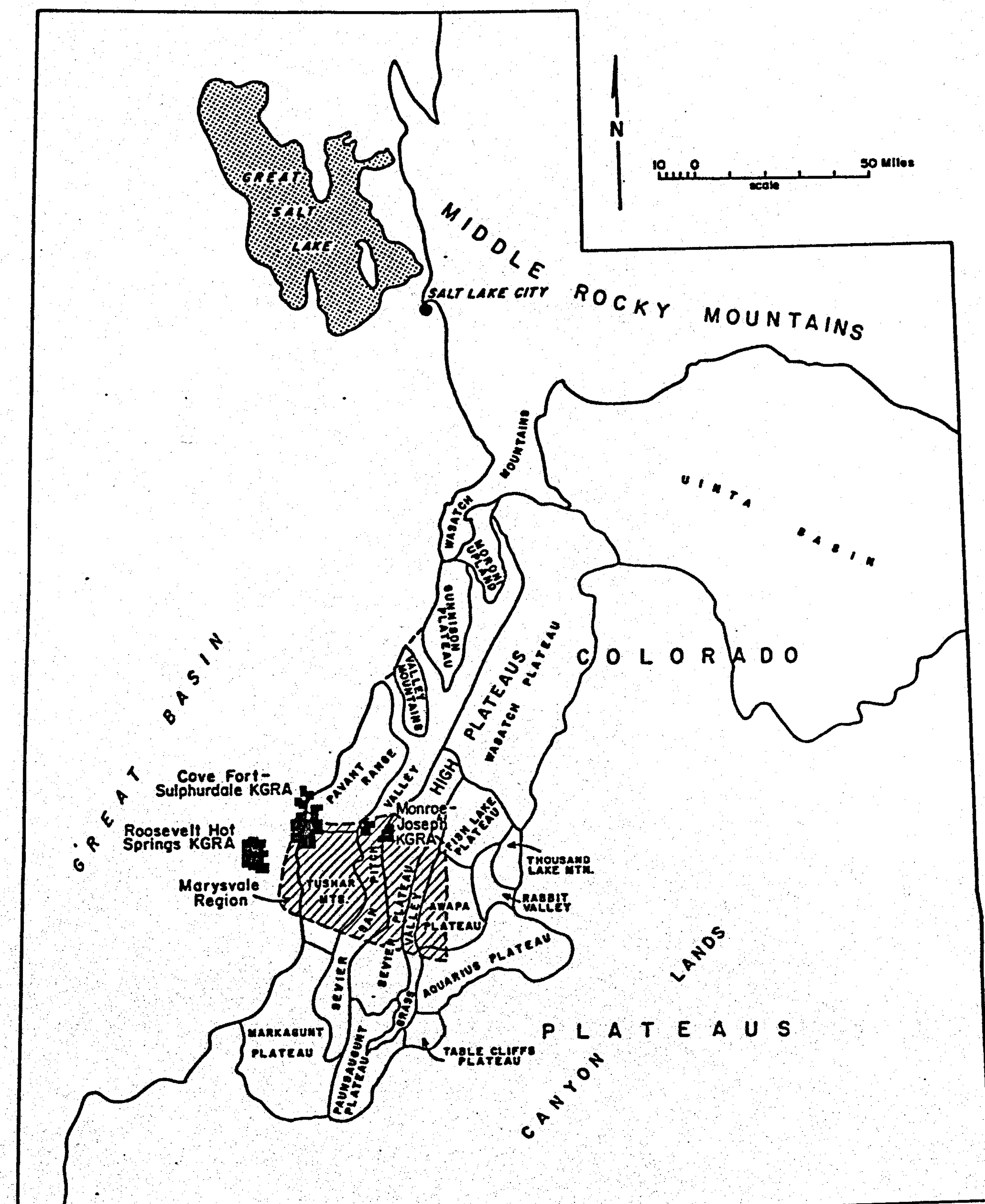

Figure 1. Map of Utah illustrating the location of the Cove Fort-Sulphurdale KGRA, the adjacent geothermal resource areas, and the divisions of the High Plateaus. The approximate outline of the Marysvale region is shown by the ruled pattern (modified from Callaghan, 1973).

Sulphurdale (Moore and Samberg, 1979). The volcanic and sedimentary rocks were subject over wide areas to hydrothermal alteration and locally to the introduction of pyrite. The oldest alteration and mineralization is related to the mid-Tertiary intrusives and the most recent alteration can be related to the still active hydrothermal system (Moore and Samberg, 1979).

Moore and Samberg (1979) show that the geothermal system is structurally controlled by normal faults. North-northwest and north-east-trending steeply dipping faults probably control fluid flow within the geothermal reservoir, while low-angle gravitational glide blocks provide an impermeable cap for the geothermal system in the central part of the area.

Volcanic stratigraphy, hydrothermal alteration, and the structural setting of the KGRA are discussed in detail by Moore and Samberg (1979). The interpretation of electrical resistivity data reported here is developed as a complimentary study which uses their 1:24,000 geologic map as a base.

GEOPHYSICS

A considerable amount of geophysical work has been completed in the Cove Fort-Sulphurdale area. Data from several surveys conducted by Union Oil Co. were made available to ESL/UURI and released to the public domain through the Industry Coupled Program. This work includes a shallow temperature gradient survey of 25 holes, a gravity survey, a near-surface reflection seismic survey (Union Oil Co., 1978a), and a dipole-dipole electrical resistivity survey (Phoenix Geophysics, Inc., 1976).

More recent work completed by the Earth Science Laboratory includes a resistivity survey (Mining Geophysical Surveys, Inc., 1978) and a low-level aeromagnetic survey. A detailed gravity survey was completed by the Department of Geology and Geophysics, University of Utah. All of this work was funded by contracts with the DOE/DGE. An integrated case study which addresses all the geoscience data to date is in preparation.

Electrical Resistivity Surveys

Phoenix Geophysics Incorporated completed a reconnaissance geophysical survey in the Cove Fort area for Union Oil Company in November 1976. The survey consisted of three widely spaced dipole-dipole lines with an electrode length (a) of 1,000 feet and readings of electrode separations N=1 to N=6. The 19.5 line miles of dipole data were supplemented by ten Schlumberger depth soundings.

The Earth Science Laboratory contracted Mining Geophysical Surveys to complete six additional lines totalling 19.5 line miles of dipole-dipole data in September 1978. A dipole length of 1,000 feet was also used for these profiles and the apparent resistivity values were determined for N=1 to N=6, and N=7. Induced polarization data were recorded for most of two lines until low signals and relatively high noise levels made further IP recording too slow and costly. Table 1 summarizes the resistivity data considered in this study.

The locations of all lines are indicated on Plates I and II. The observed data are presented in standard pseudosection format on Plates III and IV, together with the interpreted resistivity distributions in section form.

TABLE 1

COVE FORT-SULPHURDALE - RESISTIVITY DATA SUMMARY

Plate	Data Set	Line	Direction	Length (1000 feet)	Models	Appendix Pages
III	PG for UOC-1976	AA'	N50°W	24	W/2,E/2	1,2
III	PG for UOC-1976	BB'	N30°E	34	S/3,CTR,N/3	3,4,5,
III	PG for UOC-1976	LL'	~East	45	W/5,CW/5,CTR,CE/5,E/5	6,7,8,9,10
IV	MGS for ESL-1978	1*	East	16	CTR	11
IV	MGS for ESL-1978	2	~East	16	CTR	12
IV	MGS for ESL-1978	3*	N15°E	15	CTR	13
IV	MGS for ESL-1978	4	S60°E	15	CTR	14
IV	MGS for ESL-1978	5	S75°E	25	W/2,E/2	15,16
IV	MGS for ESL-1978	6	East	16	CTR	17

CONTRACTORS

PG-Phoenix Geophysics, Inc.
MGS-Mining Geophysical Surveys, Inc

CLIENT

UOC-Union Oil Company
ESL-Earth Science Laboratory

*Induced Polarization data also obtained.

INTERPRETATION

The dipole-dipole resistivity data have been interpreted through an interactive computer modeling process. A two-dimensional geometry is assumed (infinite strike length perpendicular to the survey line) and intrinsic resistivity values are assigned for each body. The corresponding apparent resistivity values are computed by a finite-element program initially developed by Rijo (1977) and subsequently modified by Killpack and Hohmann (1979) at the Earth Science Laboratory. The program uses a fine mesh near the electrodes (i.e., near the surface) where the current density is large and potentials are rapidly changing. The mesh gradually becomes coarser with increased distance from the electrode positions (at depth). The dimensions of the mesh are scaled in units of 'a', the fundamental dipole length, and are indicated in the program output.

The apparent resistivity values are computed for dipole separations N=1-6 and then manually compared with the observed data by the interpreter to determine the goodness of fit and the model changes needed to achieve a better fit. The interpretation rarely proceeds to a perfect match of observed and model data because of the time involved, the three-dimensional aspects of the field resistivity distributions, and the ambiguities of position, intrinsic resistivity, and size of body that cannot be resolved (i.e., are not unique). A satisfactory fit is obtained when a majority of the pseudosection data values are within 10% of the observed resistivity values and when the directions of the observed resistivity changes have been matched. In the presence of large resistivity contrasts and complex three-dimensional resistivity distributions, one must accept a less satisfactory agreement between computed and observed data values.

The ESL finite-element program (Killpack and Hohmann, 1979) computes all the resistivity data values for a standard dipole-dipole 7 spread (7 transmitter electrodes). For observed profiles with larger spreads or multiple spreads, it is necessary to generate several overlapping models to simulate the observed data. In the present study, Lines AA', BB', LL', and 5 were simulated by two to four overlapping models.

After several model iterations (6 to 9 in the present study), the interpreter obtains a satisfactory approximation to the observed data. The sensitivity of the model to small changes, probable non-two-dimensional aspects of the field data, questionable field data values, and the degree of ambiguity in the model is determined through a comparison of the last several iterations. Some adjustment of the overlapping model geometries and electrical properties may be required to complete the interpretation for long profiles.

The amount of data (39 line-mi) and the scale of the interpretive sections (1:24,000) present a problem in data presentation. All numerical model output has been annotated and relegated to Appendix A to facilitate comparison with the observed data. This comparison is strongly encouraged for all areas of serious interest.

Plates I and II show the location of all lines and present a summary of the intrinsic resistivity distribution at depth intervals of 0-300 feet

(0-0.3a) and 1500-2000 feet (1.5-2.0a) respectively. The interpreted resistivity sections are presented in Plates III and IV. Plates I thru IV are more easily comprehended when colored to enhance the appearance of resistivity contrasts and to indicate trends or continuity. Reproduction costs are prohibitive for including colored plates in this report. A resistivity grouping is suggested for coloring in the explanation of Plates III and IV.

The reader is again reminded of the non-uniqueness of the interpreted resistivity distribution for a given profile of observed data. The interpretations presented in Plates III and IV are limited by the grid size which becomes coarser with depth, the validity of the two-dimensional model, the goodness of fit of computed to observed data values, and the choice of body size, position and resistivity. The interpretative model for the induced polarization data is very dependent upon a good approximation to the true resistivity distribution. It is the philosophy of this interpreter to try to fit the observed data using a minimum number of different resistivity values. This tends to reduce the number of small gradational resistivity changes which may actually be present but enhances the representation of abrupt resistivity changes as might be expected from structural features and major lithologic changes.

The non-unique aspect of modeling observed resistivity data is not satisfying. Nonetheless, careful modeling of dipole-dipole resistivity data offers a more accurate representation of earth resistivity distribution than any other electrical method. The non-uniqueness is further reduced by utilizing a network of profiles, several of which intersect. The integration of geologic data, such as the 1:24,000 map of Moore and Samberg (1979) can further reduce interpretational ambiguities. Plates I and II illustrate the integration of multiple profiles with the geologic data.

Table I summarizes the presentation of interpreted sections (accompanied by plots of the observed data) and the model results. A detailed written description of the interpreted resistivity structure for each line would be awkward and lengthy; the interpreted sections best explain the resistivity structure in detail. The following text describes briefly each area in terms of the key features or general nature of each line.

Union Oil Company Reconnaissance Lines, 1976. (Plate III)

Line AA'

Line AA' trends approximately N50°W approximately 2,000 feet north of Sulphurdale and is the southernmost survey line. Two overlapping models were used to simulate the observed apparent resistivity data for this line. The final model iterations provide a good fit to the observed data--generally within ±10% for resistivity values above 15 ohm-m and within ±2 ohm-m for lower resistivity values.

The modeled resistivity distribution indicates a background level of 20 ohm-m resistivity extending to depth which can be associated with the overall section of Tertiary volcanics (see geologic section AA' of Moore and Samberg, 1979). Superposed on this are areas of 100 ohm-m along the eastern end of the line which are probably due to the densely welded Three Creeks Tuff (unaltered) and possibly to latite porphyry stocks which extend to depth. A thin resistive zone (100 ohm-m) northwest of Sulphurdale is attributed to the Cove Fort basalt flows under a thin layer of alluvium. A well-defined area of 4 ohm-m which occurs immediately north of Sulphurdale is approximately 4,000 feet across and extends from the surface to great depth (greater than 2,500 feet). These low resistivities are attributed to extensive clay alteration of volcanic rocks and to saline, high temperature fluids which rise to the surface.

Line BB'

This line trends approximately N30°E subparallel to the general alluvium-volcanic interface and to several normal faults. In view of this the two-dimensionality assumed in numerical modeling is clearly violated--severely in some places, minimally in others. The modeling was undertaken with an awareness of this limitation in order to help develop the mapped resistivity distribution of Plates I and II. The observed data were matched more closely than justified by the geometric assumptions. The low-resistivity zone associated with hydrothermal alteration at Sulphurdale is modeled as a 5 ohm-m body, a minor difference with the 4 ohm-m model of Line AA'. The model from station 0 to station 120N is strongly influenced by non-two-dimensionality. Much higher intrinsic resistivities, 50 to 300 ohm-m, are noted north of this station as a major east-west structure is crossed which brings Mesozoic and Paleozoic sediments to the surface. A near-surface layer of 25 ohm-m corresponds to alluvium and Tertiary volcanics above the water table which is greater than 1051 feet deep in Formineo #1.

Line LL'

Line LL' follows a major east-west structural feature which cuts across the Tushar Mountains and continues west through Cove Fort. The two-dimensional modeling assumption is again violated in places. Moderate to low resistivities (40 to 10 ohm-m) east of station 20W which extend to considerable depth are associated with various Tertiary tuffs and flows on the west flank of the Tushar Mountains. The more complex region of higher (30-100 ohm-m) resistivity bodies with vertical sides reflects the presence of Paleozoic rocks beneath and north of the profile. West of station 150W (near Cove Fort) north trending structures dominate the geology and resistivity distributions and the interpretational model is valid. A major Basin and Range fault with displacement exceeding 2,000 feet is suggested by the resistivity model. An upper layer of 20 to 30 ohm-m corresponds to unsaturated alluvium which varies from 600 to 1,000 feet in thickness. This is in agreement with unpublished information on water-table depths in the area. Intrinsic resistivities below the water table drop to a rather uniform 10-15 ohm-m. A narrow zone of 5 ohm-m resistivity near station 180W which is on strike with a northeast-trending fault mapped by Moore and Samberg (1979) suggests the upward migration of thermal waters, and perhaps alteration, along a buried north-trending structure.

Earth Science Laboratory Lines, 1978 (Plate IV)

Lines 1, 2 and 6

Lines 1, 2 and 6 trend east-west in the northern portion of the KGRA, north of Union Oil Co. Line LL'. All lines used a 1,000 foot electrode separation. Lines 1 and 2 are typified by moderate (20 to 50 ohm-m) resistivities from the surface to depths of 300 to 2,000 feet. The corresponding geologic units are alluvium, Tertiary volcanics, and the Cretaceous Price River Conglomerate (see geologic cross section BB' of Moore and Samberg, 1979). The underlying Mesozoic and Paleozoic sedimentary rocks have been modeled with resistivities of 100-300 ohm-m.

Line 6 crosses a series of high-angle normal faults near station 0, bringing resistive Cretaceous and Paleozoic sedimentary rocks to the surface. A 2,000 foot wide zone of 5 ohm-m resistivity extends to depth immediately west of the fault trace projected by Moore and Samberg (1979). The low resistivities are attributed to conductive thermal waters rising along the fault zone. The resistivity model for the western half of Line 6 suggests the westward migration of these fluids at depths of 600 feet or greater within the alluvium. Satisfactory agreement was achieved between the computed resistivity values and the corresponding observed data for Lines 1, 2 and 6.

Line 3

Line 3 trends N20°E across the inferred east-west structure close to Union Oil Company's drill hole Forminco # 1. Moderate near-surface resistivities (10-30 ohm-m) increase to 200 ohm-m at depth along the northern half of the line. South of station 3S 10 to 20 ohm-m resistivities correspond to alluvium and volcanic rocks.

Lines 4 and 5

These resistivity profiles cross alluvium and volcanic rocks between Sulphurdale and Cove Fort and run roughly perpendicular to north-trending

Basin and Range faulting. Pronounced vertical resistivity discontinuities suggest faulting near station 0 on each line. Intrinsic resistivities are generally low, 5 to 30 ohm-m, for most of these lines. Resistive-over-conductive layering in alluvium and volcanic rocks is indicated along the west half of Line 5.

Induced Polarization Data (Plate IV)

Lines 1 and 3

Initial plans for the resistivity survey included induced polarization measurements for several lines with the aim of documenting sulfide and/or alteration product responses from the geothermal system. When traversing lower resistivity units on the south end of Line 3 the potential differences between receiving electrodes decreased rapidly with increasing transmitter-receiver separation. The resulting low signal strengths and high noise levels resulted in very long reading times and forced a cutoff of the IP measurements.

Mining Geophysical Surveys, Inc. conducted the resistivity/induced polarization survey in the time-domain mode of operation using an EGC model R20A receiver and Geotronics FT-20 (20 amp) transmitter. The apparent polarization response was recorded in units of millivolt-seconds-per volt, or milliseconds. The induced polarization data taken for Lines 1 and 3 are shown on Plate IV. The induced polarization data were modeled simultaneously with the later iterations of the resistivity model. In the interests of limiting the total number of bodies for a model, and of economy, the observed induced polarization data were not matched as closely as the resistivity values.

The observed apparent polarization values on Lines 1 and 3 range from 3 to 16 milliseconds (ms). Polarization values of 3-6 ms can be considered a normal background level for most unmineralized sediments and rock units. Modeling of these data indicates background level polarizations for alluvium and near-surface volcanic rocks on the south end of Line 3 and parts of Line 1 (Plate IV). Larger values of 10 to 16 ms were observed on N=1-6 separations throughout Line 1 and for the northern portion of Line 3. The intrinsic polarizations modeled to match these observed values are 15 to 30 ms, the higher polarizations occurring at depths generally greater than 600 feet along Line 1.

Several empirical relationships have been developed by the mining industry (personal communication, G. D. Van Voorhis; Pelton et al., 1976; Katsube, et al., 1976) which relate the electrical resistivity and polarization to the sulfide content of the rocks measured. If the modeled resistivities and polarizations represent the in situ rock properties, then we can infer the following sulfide content for units traversed by Lines 1 and 3:

Resistivity (ohm-m)	Polarization (ms)	Estimated Sulfide Content (wt.%)
30	10	1.8
50	15	1.7
200	15	0.8
50	30	>2
100	30	1.7
300	30	1

In reality clay minerals, zeolites, and other minerals also give rise to polarization effects. Moore and Samberg (1979) report the occurrence of pyrite in acid-altered rocks and as quartz-pyrite veins in Forminco #1. They also note local concentrations of pyrite, galena, sphalerite, chalcopyrite, and pyrrhotite in CFSU #31-33 and CFSU #42-7. The major mineralizing event appears to be mid-Tertiary in age and the present polarization data is too limited to speculate on the net polarization characteristics due to pyrite, clay, and zeolite formation resulting from the present geothermal system.

DISCUSSION

A comparison of the resistivity distribution with geologic data was undertaken by superimposing transparent maps of intrinsic resistivity for a series of depth intervals over the geologic base map of the same scale. Plate I shows the modeled resistivity for the depth interval 0-300 feet. Lateral effects due to non-two-dimensional geometries are the least and resolution the greatest for this depth interval. This map is most useful for comparing with and extending the mapped geology and associating resistivities with a given geologic unit. Table II presents a summary of resistivity properties determined in large part from Plate I.

Inspection of Plate I shows that many resistivity changes are closely associated with mapped lithologic changes in areas of outcrop. In areas of alluvial cover the projections of several faults are noted as pronounced resistivity changes on Lines 6, 2, AA', and 4. It is surprising that resistivities for most of the surveyed area are below 50 ohm-m when the continuous water table is 300 to over 1000 feet deep. Substantial moisture

TABLE II

INTERPRETED ELECTRICAL RESISTIVITIES

GEOLOGICAL UNITS AT COVE FORT-SULPHURDALE

Geologic Unit	Electrical Resistivity (ohm-m)	Polarization (ms)	Line Coverage
Qal-alluvium			
near-surface, above water table	20-50	-	W/2 6, LL', 5, AA'
below water table	10-20	-	W/2 6, LL', 5, AA'
Tertiary Volcanics			
Tj, To, Tbc - ash flow tuffs poorly welded, probably altered	5-10	-	S/2 3; E/3 5, 4
Tb, lava flows	20-100	6-10	1, 2, 3, 6, AA'
Tbt - densely welded tuff	100	-	E end AA'
Cretaceous Sediments			
Kp - Price River Conglomerate	30-50	6-15	W/2 1, N/2 3
Mesozoic and Paleozoic Sediments			
ŦRu, Pc, ₽o, Pk - siltstones, sandstones, limestones, and shales	100-300	15-30	1, 6
Hydrothermal Alteration Areas			
Tbt, Tb, Tn;	4-5	-	AA', BB', 4
Qal	5		4, 6

must be present as vadose water or local perched aquifers. The low-resistivity zone associated with the known geothermal system at Sulphurdale covers more than four square miles.

Plate II shows the modeled resistivity distribution for the depth interval 1500-2000 feet. This is the deepest depth interval which can be modeled with reasonable confidence (being 1.5-2 a) and corresponds to depths below the water table.

Dominantly high (50-300 ohm-m) resistivities are mapped north and east of Cove Fort on Lines 1, 2, 3, 6, BB', and LL'. The geothermal system, if present, is poorly expressed in these electrical data. Resistivites of 100-300 ohm-m seem incompatible with high rock porosity filled with conductive thermal waters. Drill holes Forminco # 1 and CFSU #14-29 were terminated by drilling problems prior to evaluating the deep reservoir potential in this area (Union Oil Company, 1978b; 1979). In contrast a coherent two-square-mile area of 4-to-5 ohm-m resistivities around Sulphurdale is bordered by 20-30 ohm-m resistivities. The low resistivities arise from the clay alteration of the volcanic rocks and the conductive geothermal fluids.

Five ohm-m resistivities on the western portions of Line 6 and of AA' define a zone of conductive thermal waters rising along a covered Basin and Range fault.

Inspection of mapped resistivity distributions for the interval 2000-3000 feet (not included in this report) indicates a reduction in the extent of low-resistivity zones on Lines 6, 5, 4, and BB'. The interpretation becomes speculative at these depths but a resistive bottom is indicated for several of the low-resistivity zones which occur at depths of 1500 to 2000 feet.

CONCLUSION

Detailed numerical modeling of a substantial resistivity data base has permitted a detailed characterization of the electrical resistivity to depths exceeding 2000 feet. A low (4-5 ohm-m) resistivity area of more than two square miles is associated with the Sulphurdale area. Union Oil Company well CFSU-#42-7 encountered saline fluids at temperatures of 344°F in this area (Union Oil Co., 1978c). Paleozoic rocks north and east of Cove Fort exhibit high resistivities (100-300 ohm-m) to depths exceeding 2000 feet and are not encouraging for the presence of a shallow high temperature geothermal reservoir.

The resistivity method when interpreted quantitatively is very sensitive to lithologic changes and is useful for the extension of surface mapping into areas of alluvial cover. Hydrothermal fluids rising along steeply dipping faults have been delineated in the present study.

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____, 1979, Cove Fort-Sulphurdale Unit Well #14-29, Technical Report.

APPENDIX A

COVE FORT-SULPHURDALE - RESISTIVITY DATA SUMMARY

Plate	Data Set	Line	Direction	Length (1000 feet)	Models	Appendix Pages
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IV	MGS for ESL-1978	2	~East	16	CTR	12
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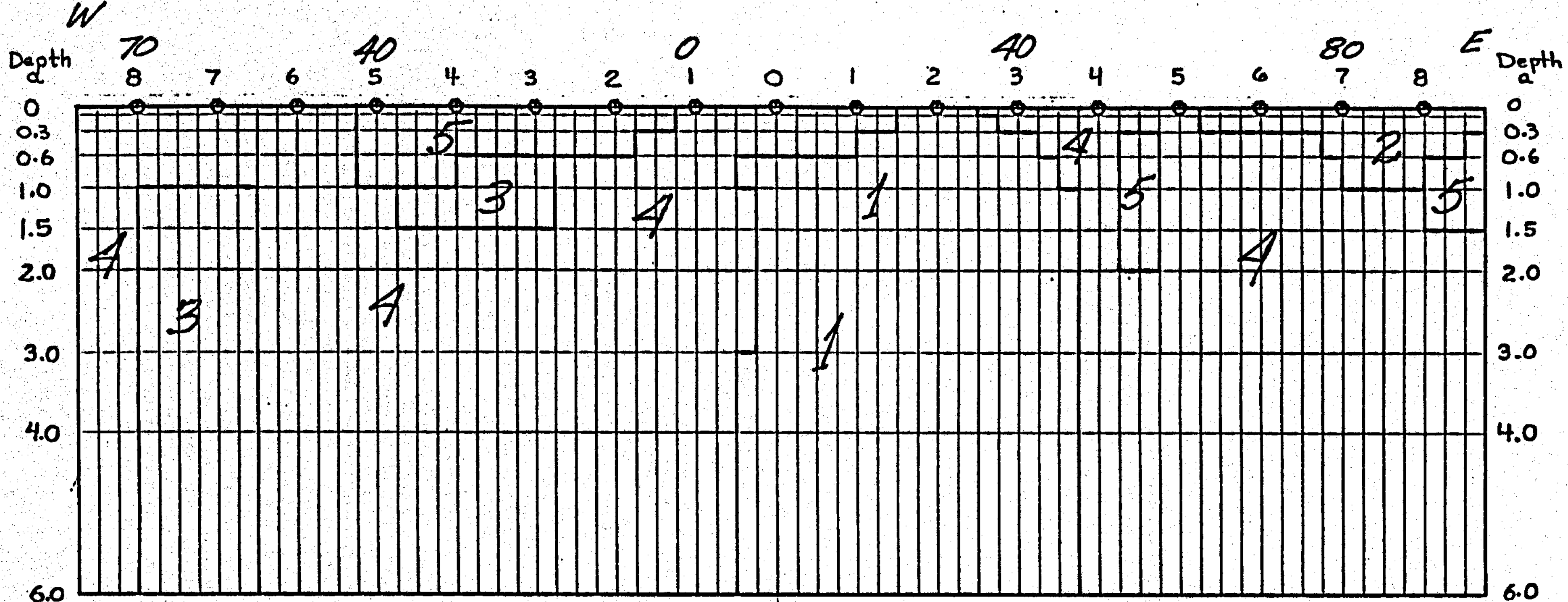
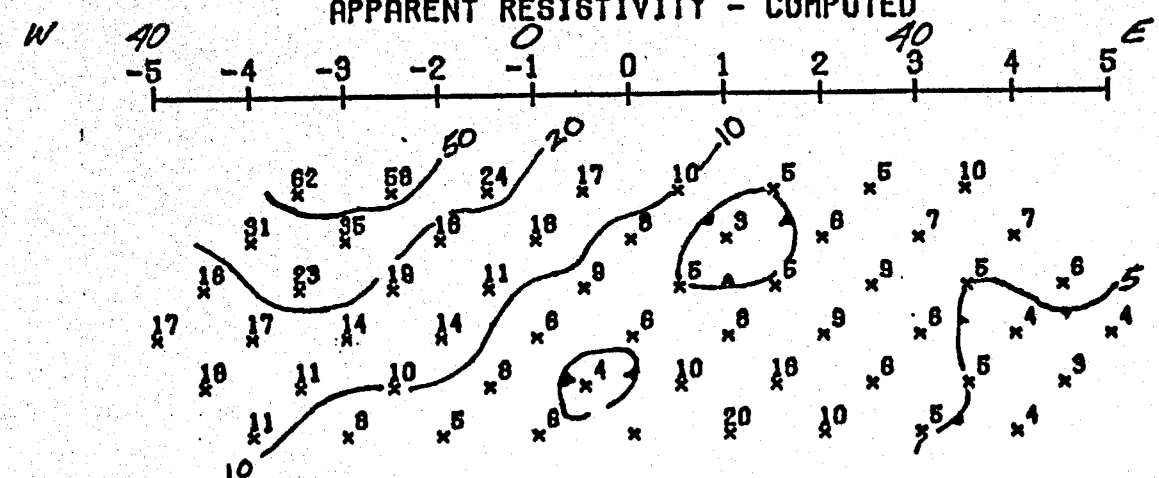
IV	MGS for ESL-1978	4	S60°E	15	CTR	14
IV	MGS for ESL-1978	5	S75°E	25	W/2,E/2	15,16
IV	MGS for ESL-1978	6	East	16	CTR	17

Pages A1 through A17 document all final models. The computed intrinsic resistivity values are contoured in the same manner as the observed data (Plates III and IV) to facilitate comparison. The body numbers and resistivities used in the computational models are indicated for each model. The body numbers correspond to those on the interpretational sections except in areas of overlapping geometries where some adjustments have been made. Table 1 is repeated above to serve as an index to this Appendix.

NUMERICAL MODEL

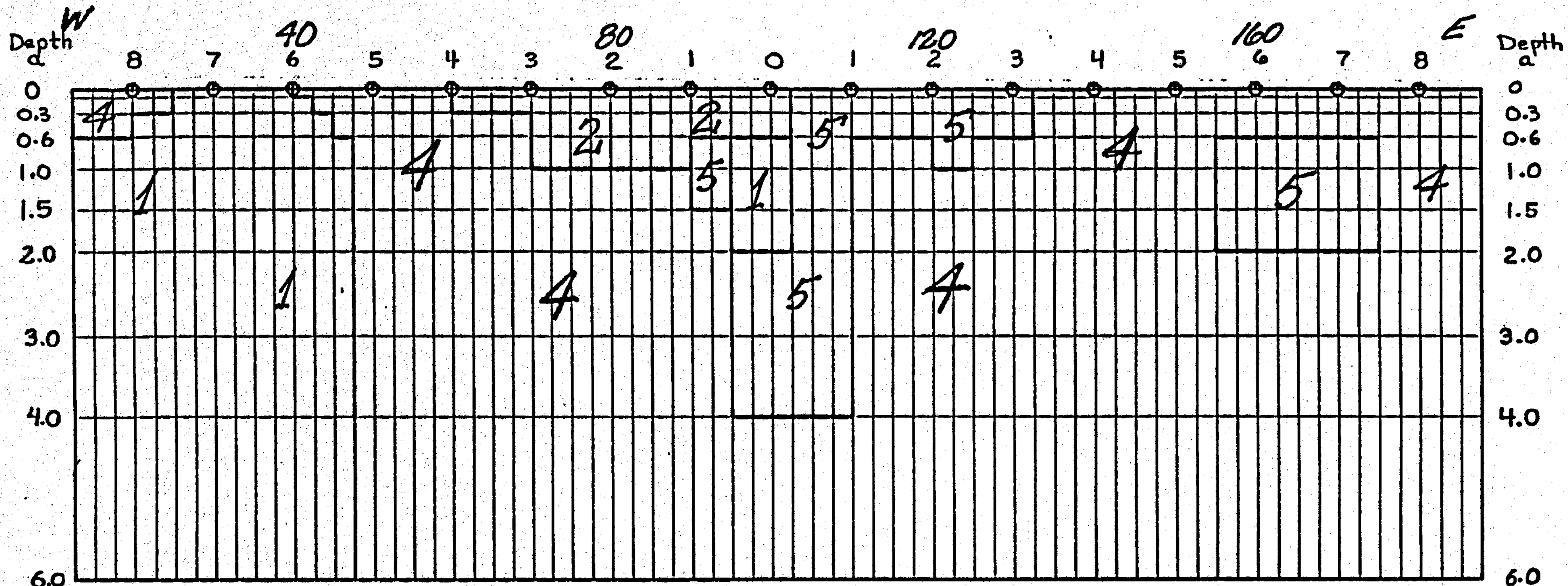


APPARENT RESISTIVITY - COMPUTED

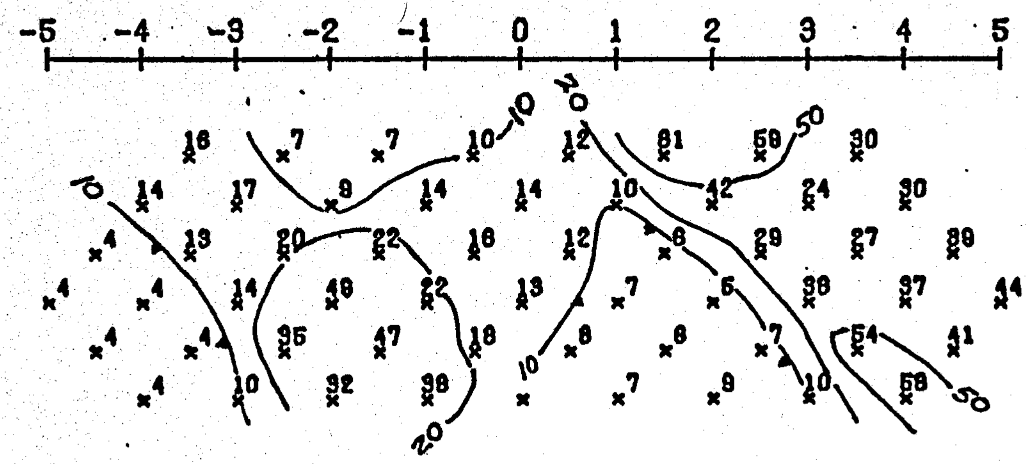


BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	4	
2	7	
3	10	
4	20	
5	100	

NUMERICAL MODEL



APPARENT RESISTIVITY - COMPUTED

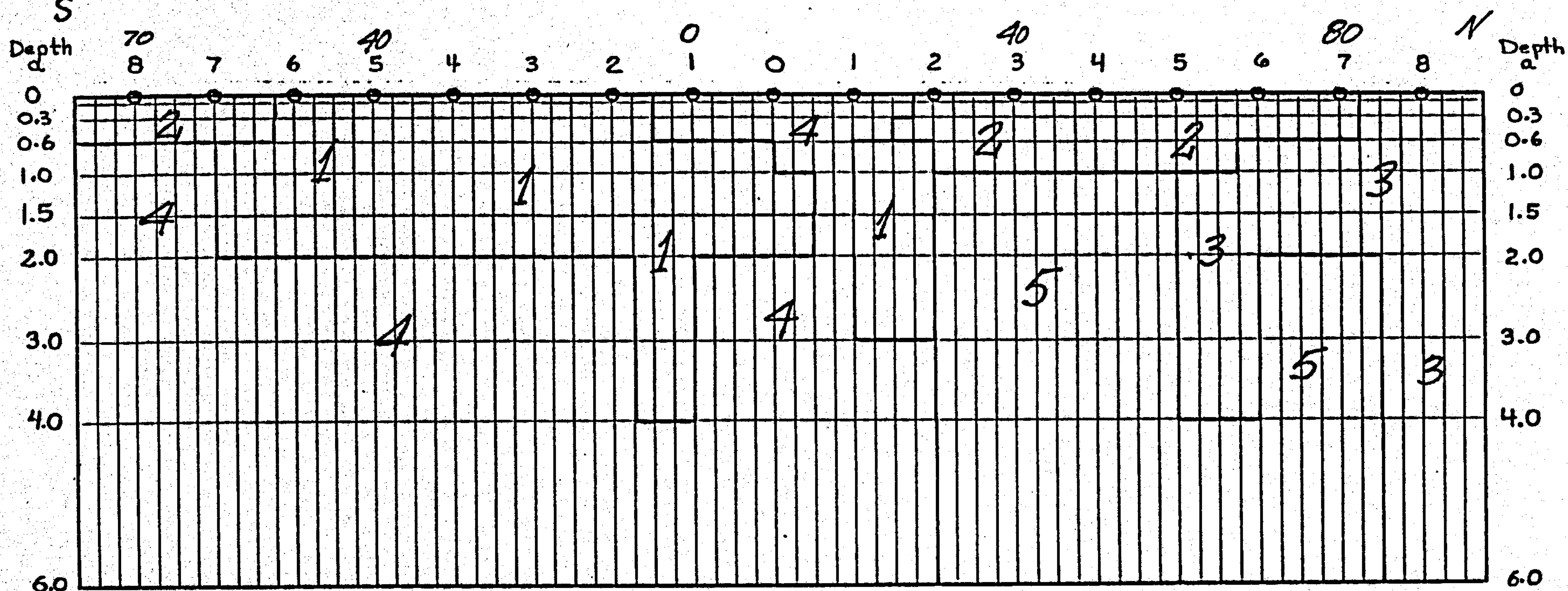


BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	4	
2	7	
3	10	
4	20	
5	100	

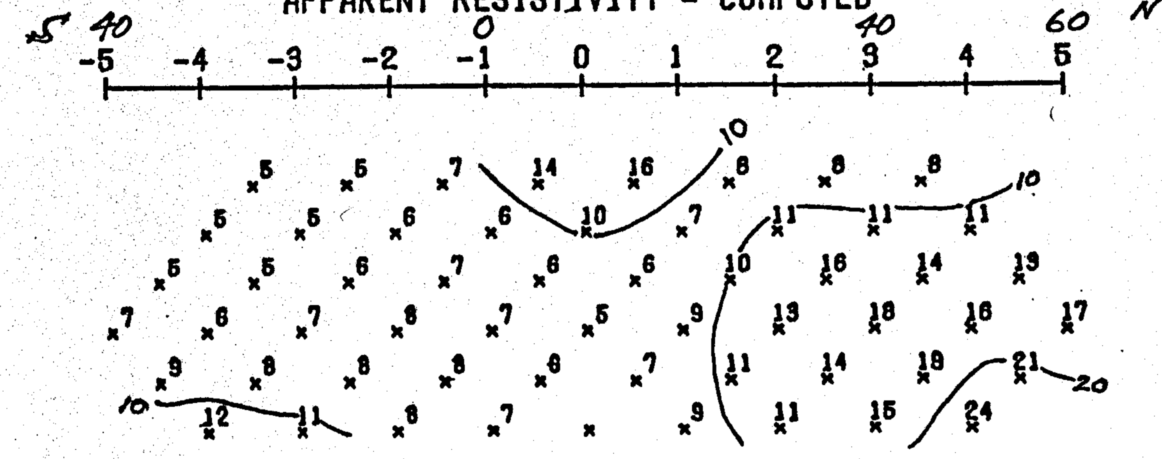
A 2

LINE AA E/2 I-9

NUMERICAL MODEL



APPARENT RESISTIVITY - COMPUTED

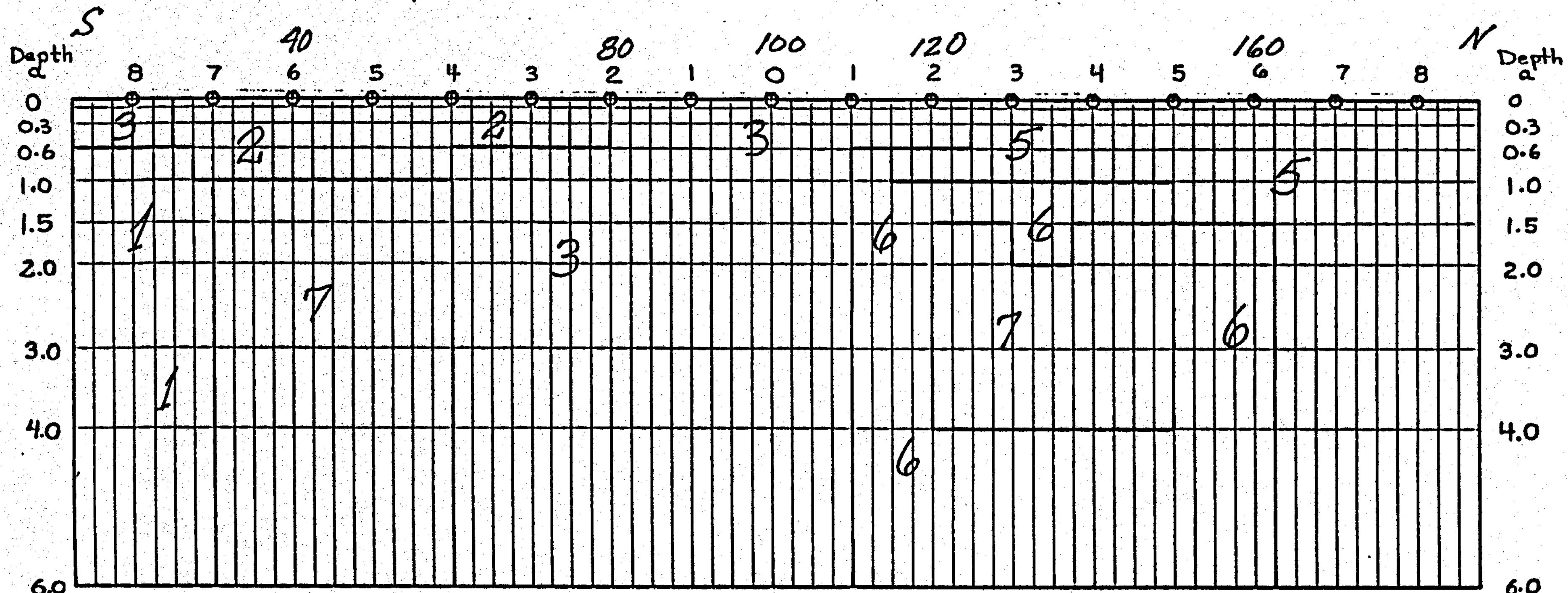


BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	5	
2	.7	
3	11	
4	20	
5	100	

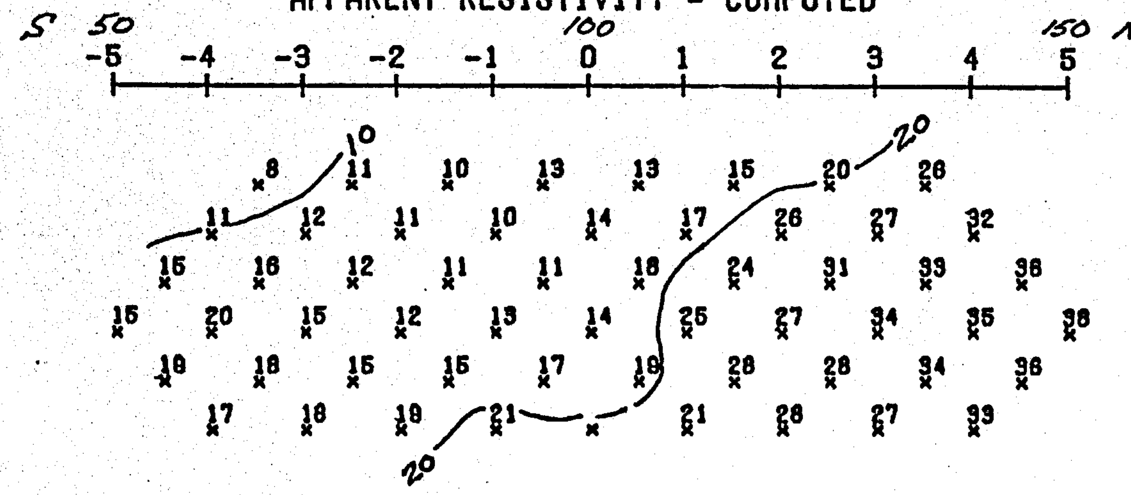
A 3

LINE BB S/3 I-3

NUMERICAL MODEL



APPARENT RESISTIVITY - COMPUTED

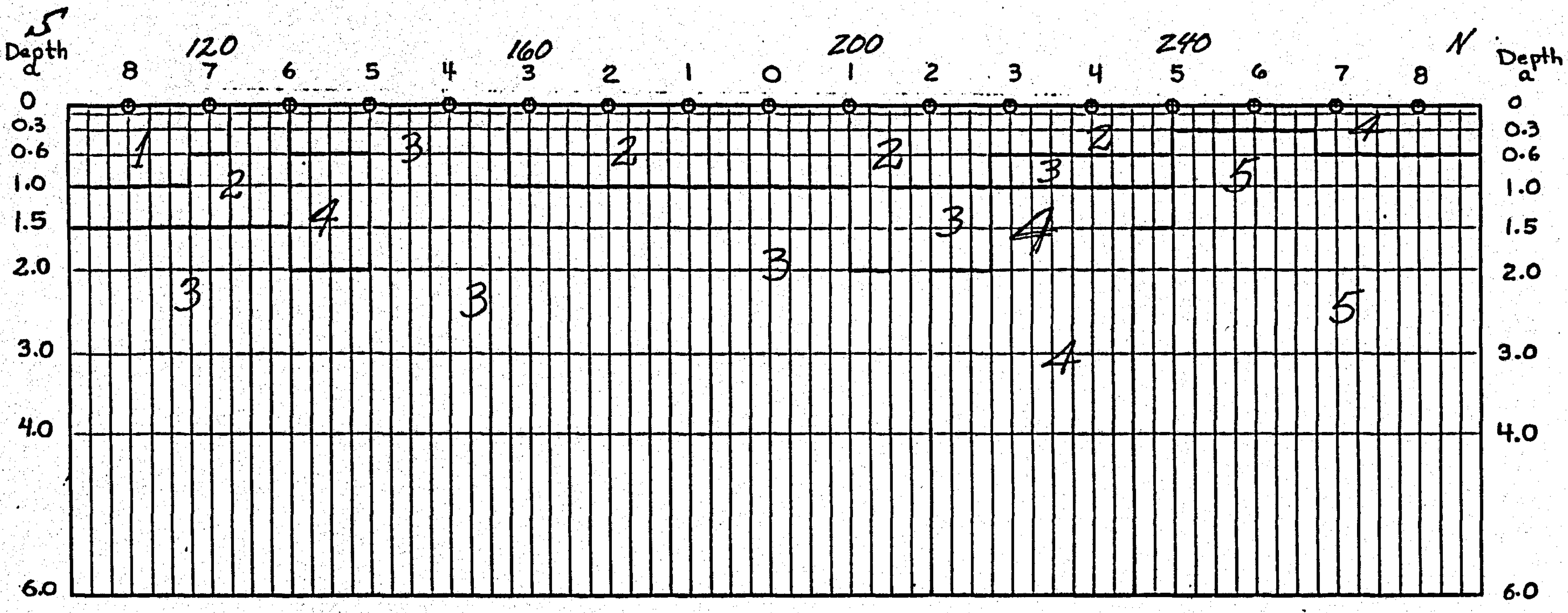


BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	5	
2	8	
3	13	
4	20	
5	25	
6	50	
7	100	

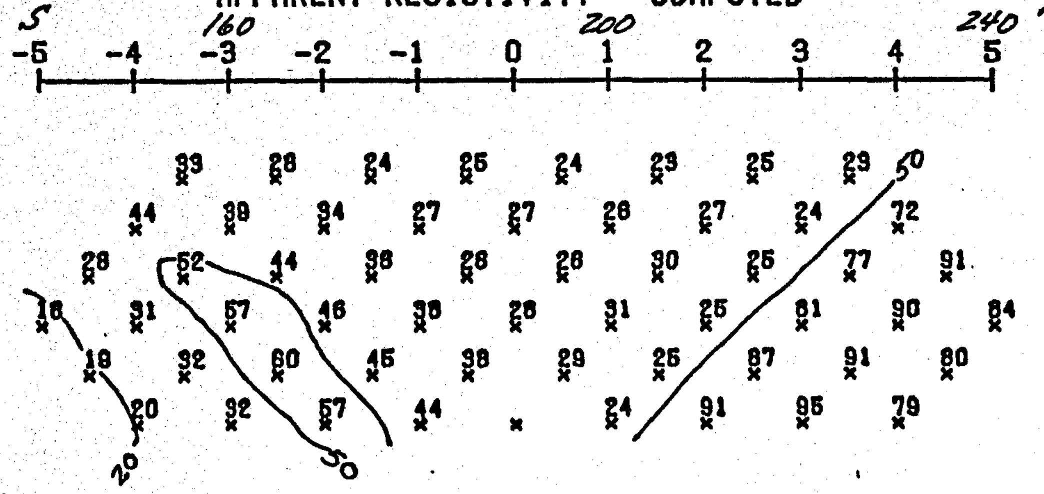
A 4

LINE BB, CTR, I-4

NUMERICAL MODEL



APPARENT RESISTIVITY - COMPUTED

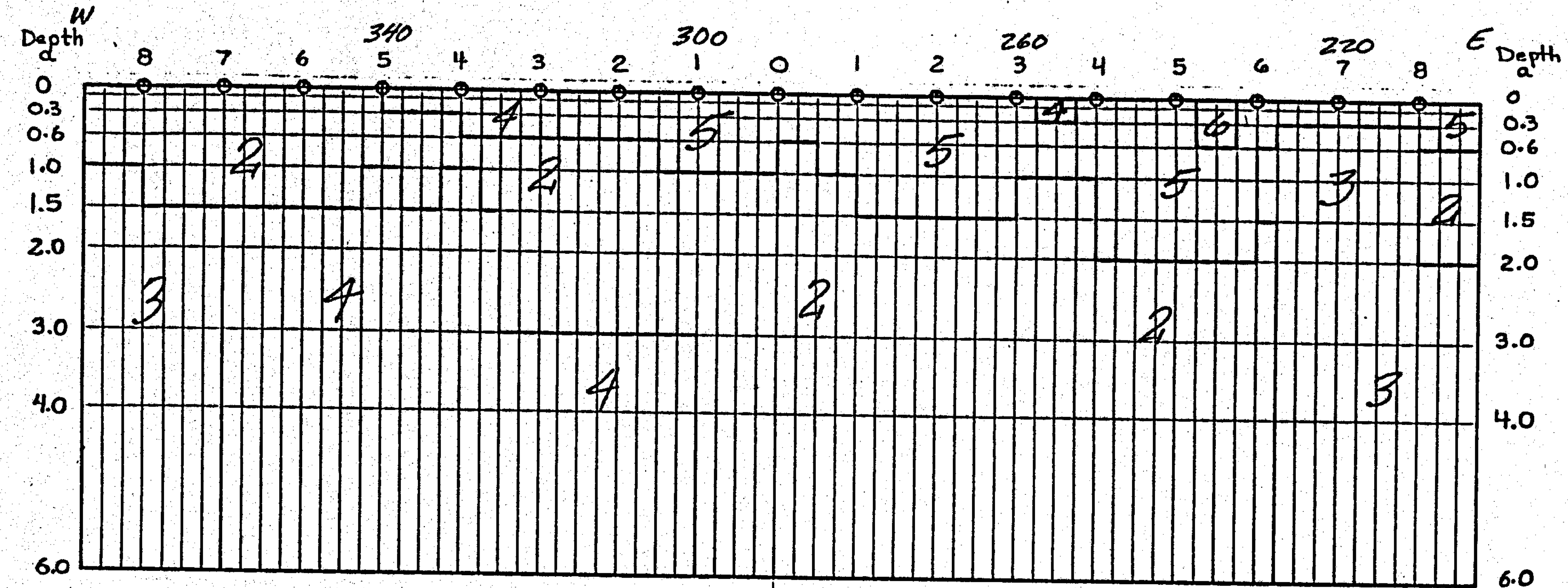


BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	11	
2	25	
3	50	
4	100	
5	300	

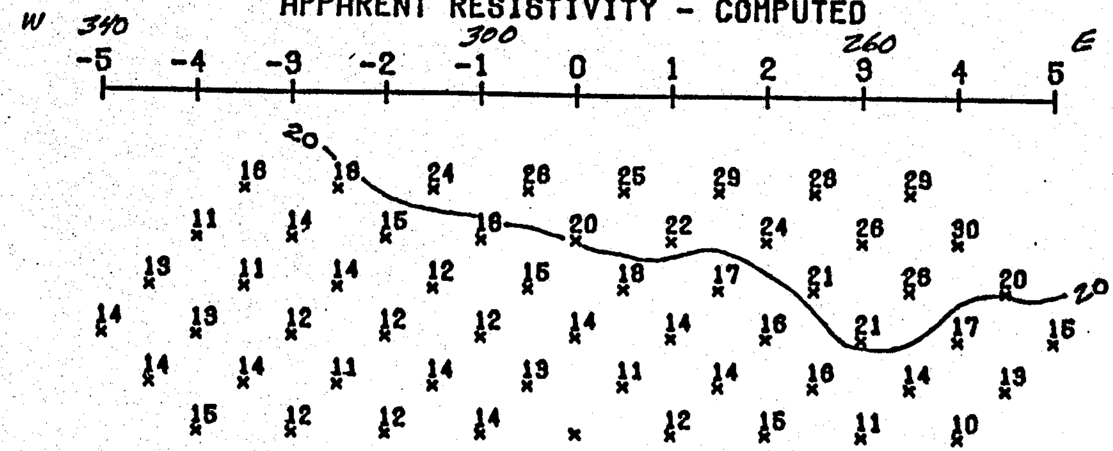
A 5

LINE BB, N13, I-5

NUMERICAL MODEL



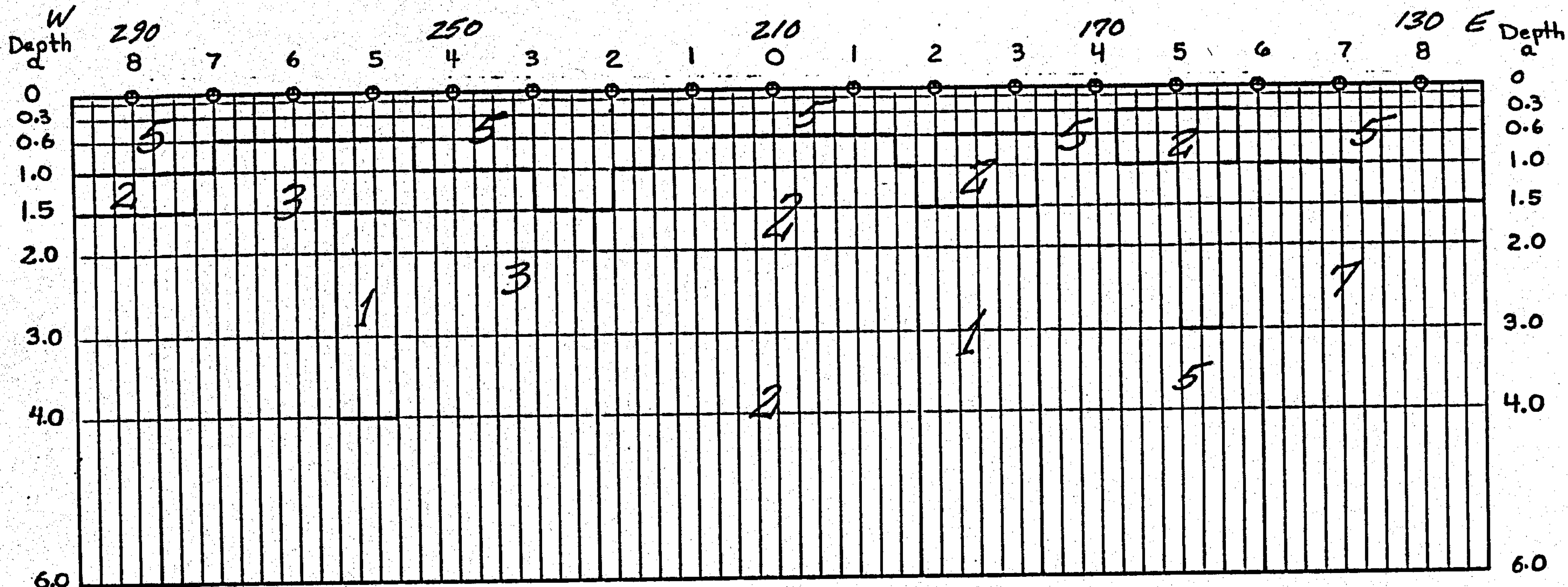
APPARENT RESISTIVITY - COMPUTED



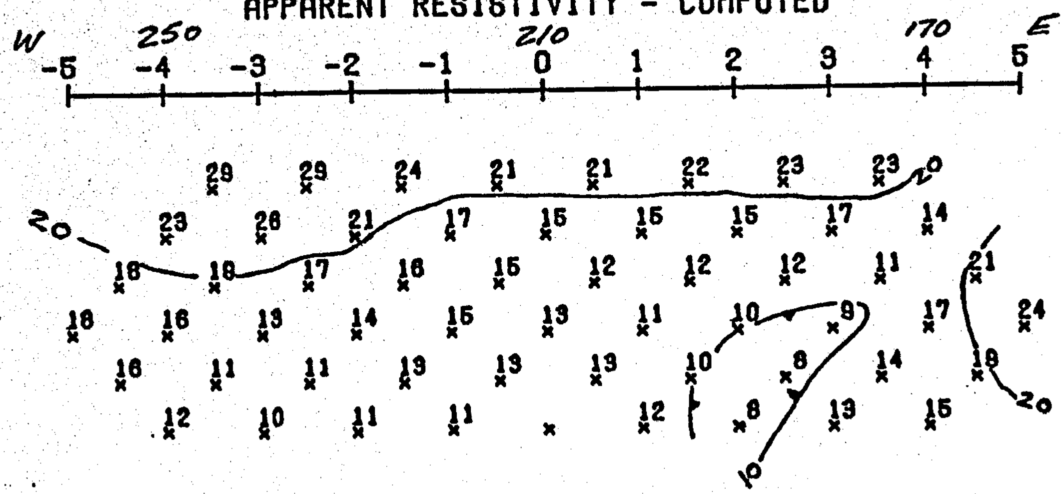
BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	5	
2	10	
3	15	
4	20	
5	30	
6	40	

CF LL CW/5 I-6 2.0

NUMERICAL MODEL



APPARENT RESISTIVITY - COMPUTED



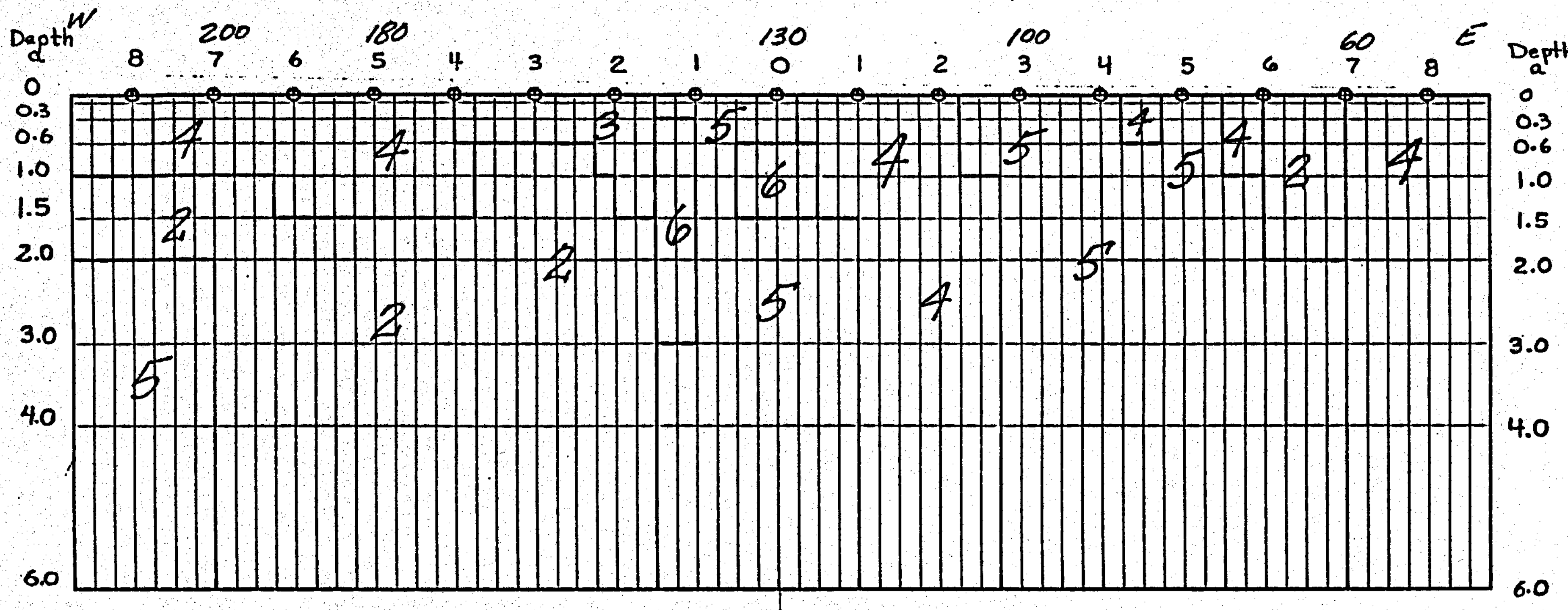
BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	5	
2	10	
3	15	
4	20	
5	30	
6	40	
7	50	

A7

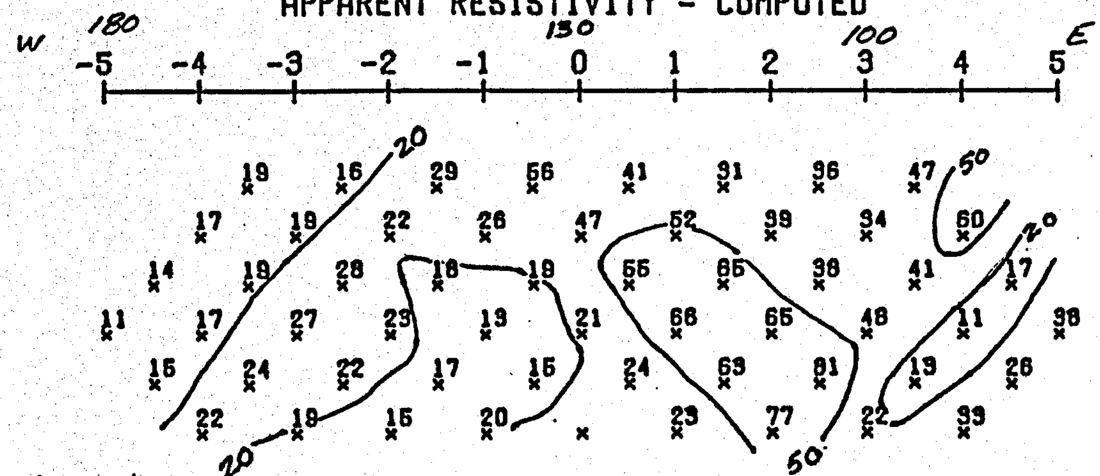
LINE LL, CW/5, I-6

CF LL CTR I-5 2.0

NUMERICAL MODEL



APPARENT RESISTIVITY - COMPUTED

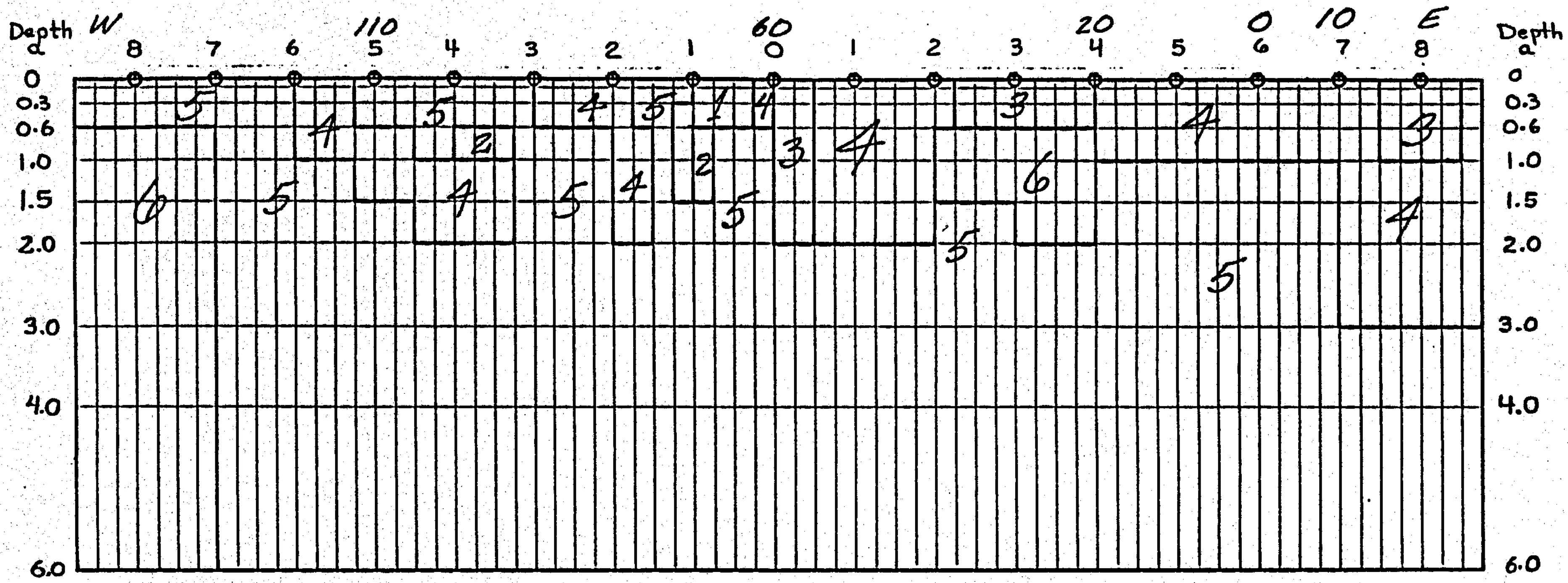


BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	.5	
2	10	
3	20	
4	30	
5	50	
6	100	

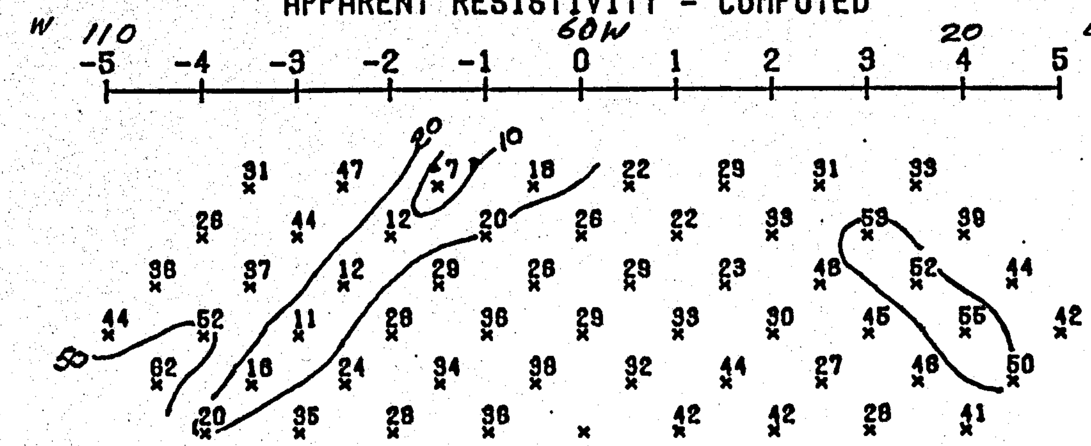
A 8

LINE LL, CTR, I-5

NUMERICAL MODEL



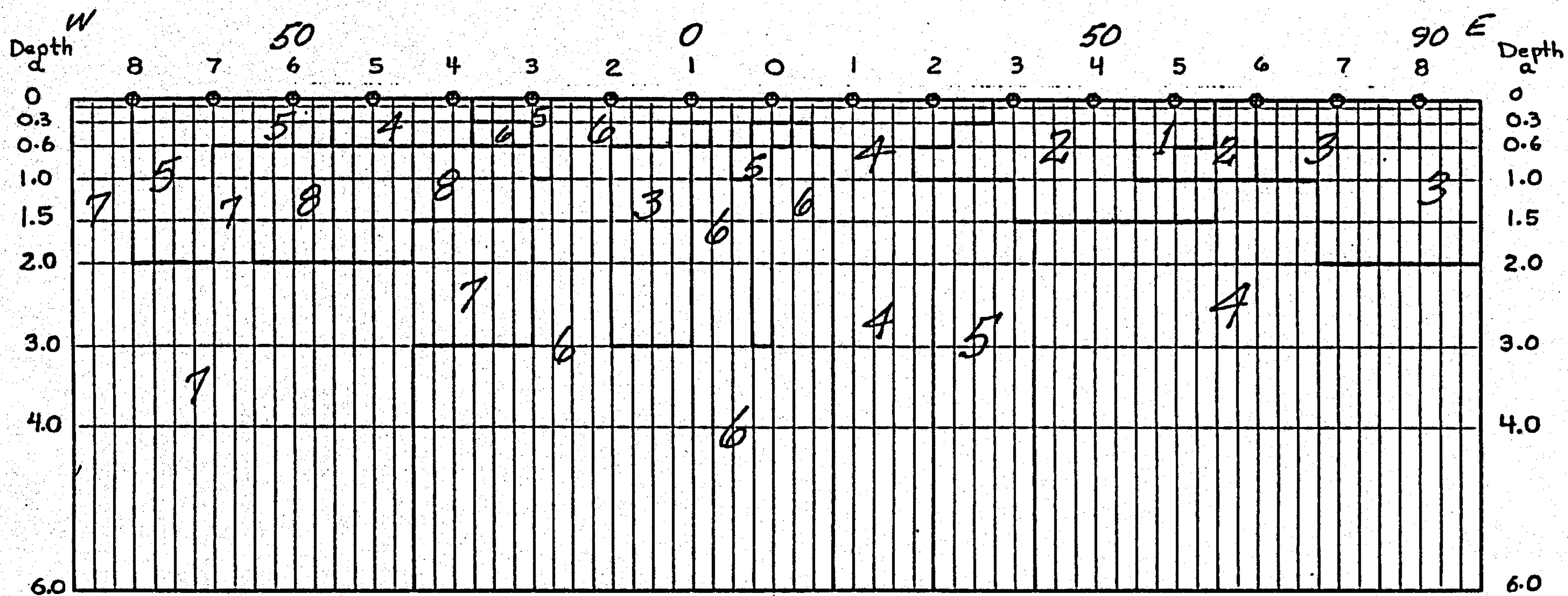
APPARENT RESISTIVITY - COMPUTED



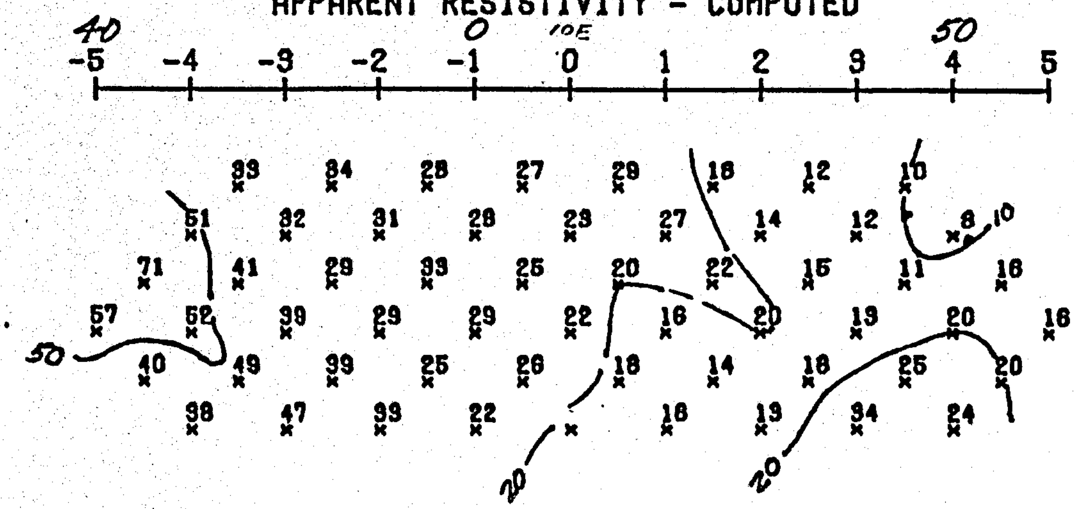
BODY No.	RESISTIVITY (ohm-m)	IP (ms)
1	5	
2	10	
3	20	
4	30	
5	50	
6	100	

CF LL E/5 I-6 2.00

NUMERICAL MODEL



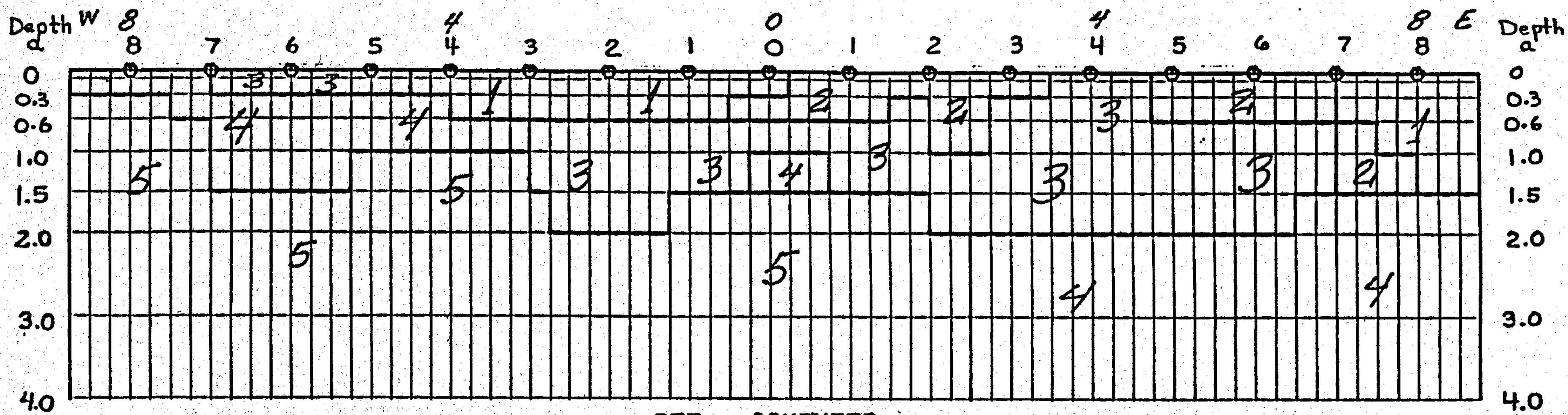
APPARENT RESISTIVITY - COMPUTED

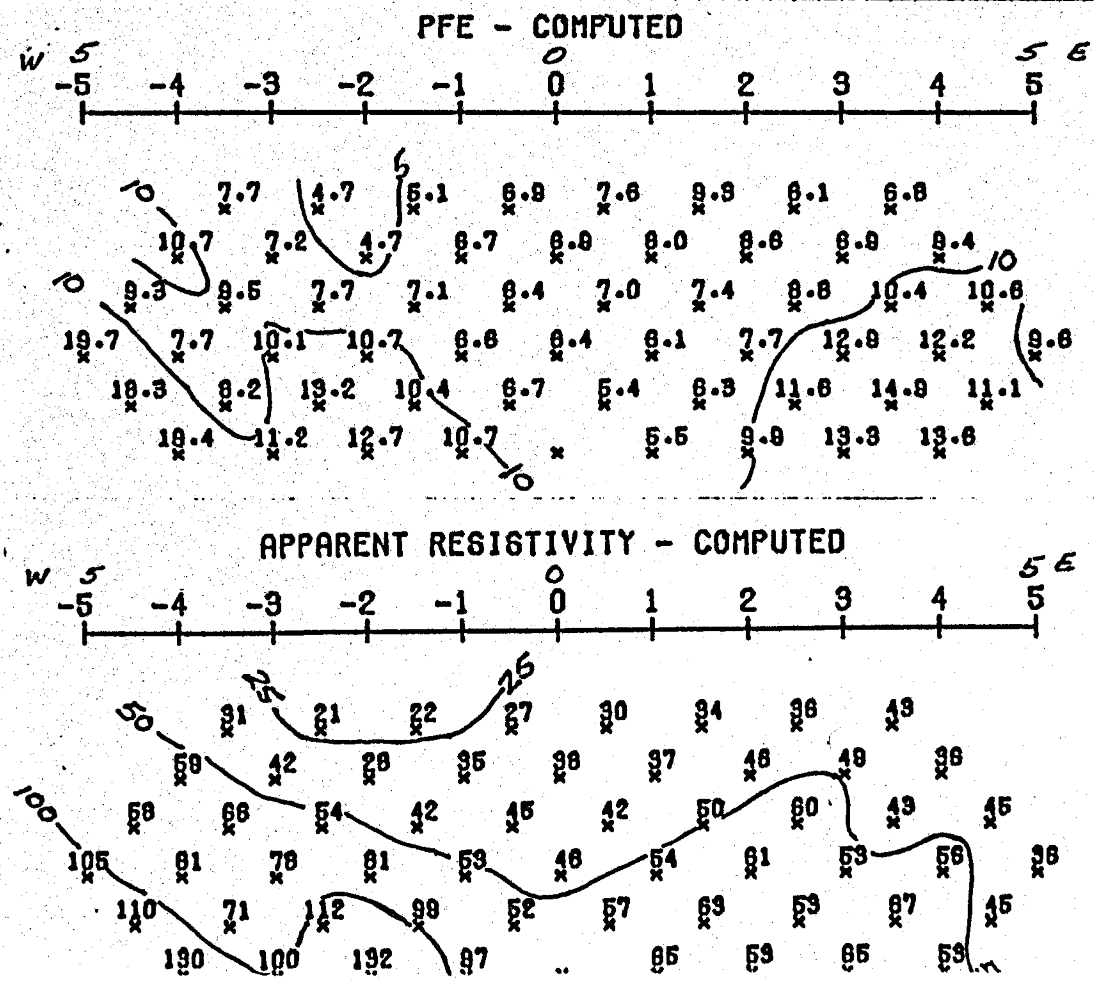


BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	5	
2	10	
3	15	
4	20	
5	30	
6	40	
7	50	
8	100	

CF 1 I-5 2.00

NUMERICAL MODEL





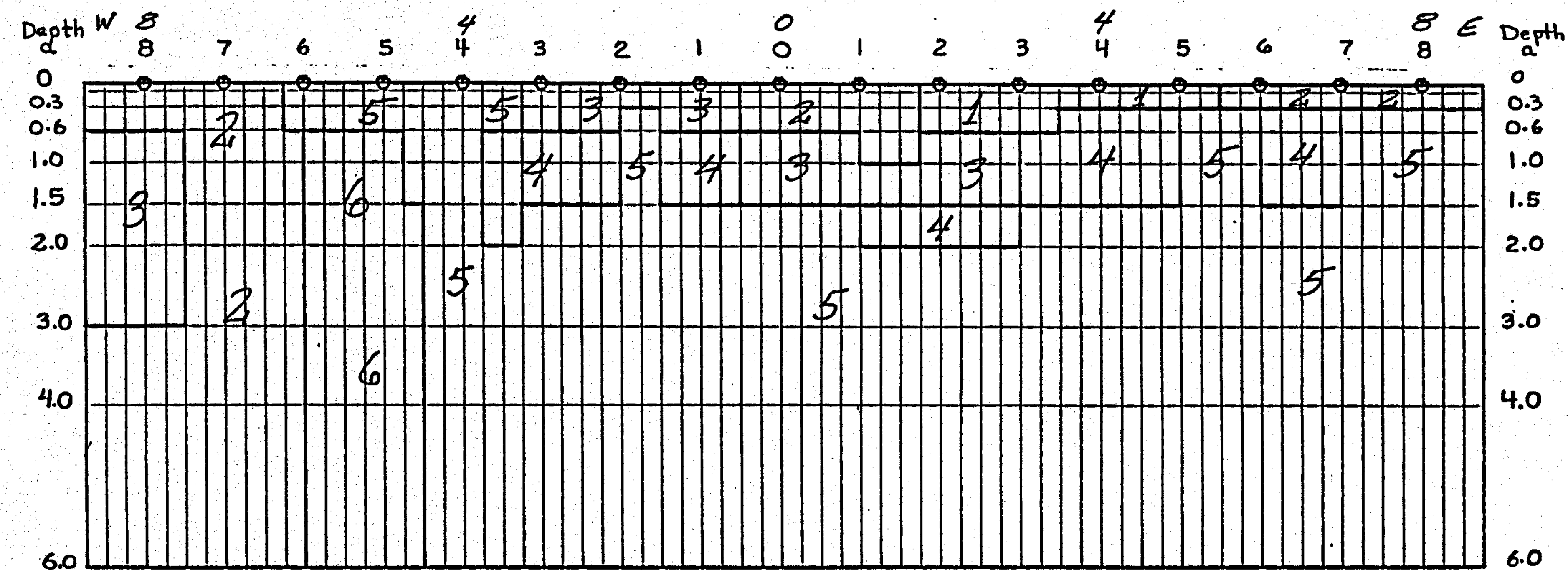
BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	20	6
2	30	10
3	50	6
4	100	30
5	300	30

A 11

LINE 1, CTR, I-5

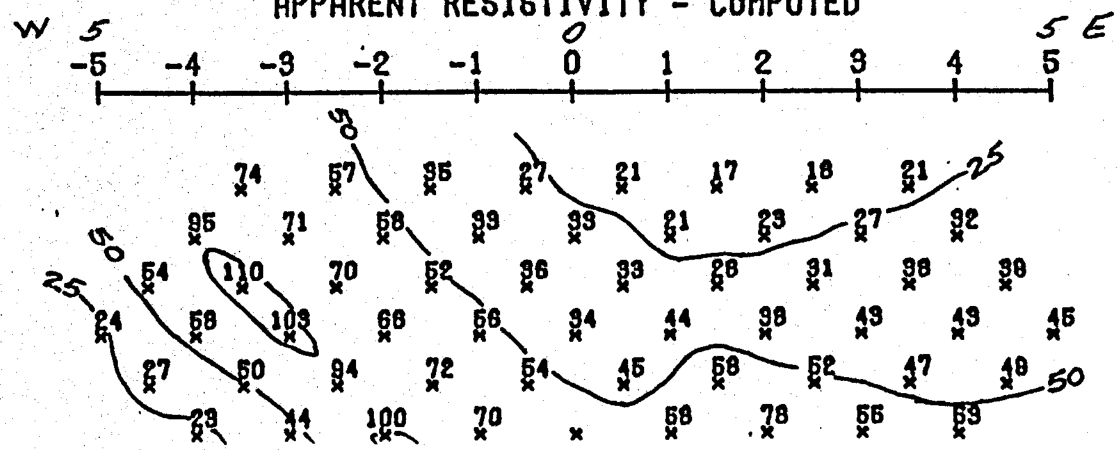
CF I-5 2.00

NUMERICAL MODEL



BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	15	
2	20	
3	30	
4	50	
5	100	
6	200	

APPARENT RESISTIVITY - COMPUTED

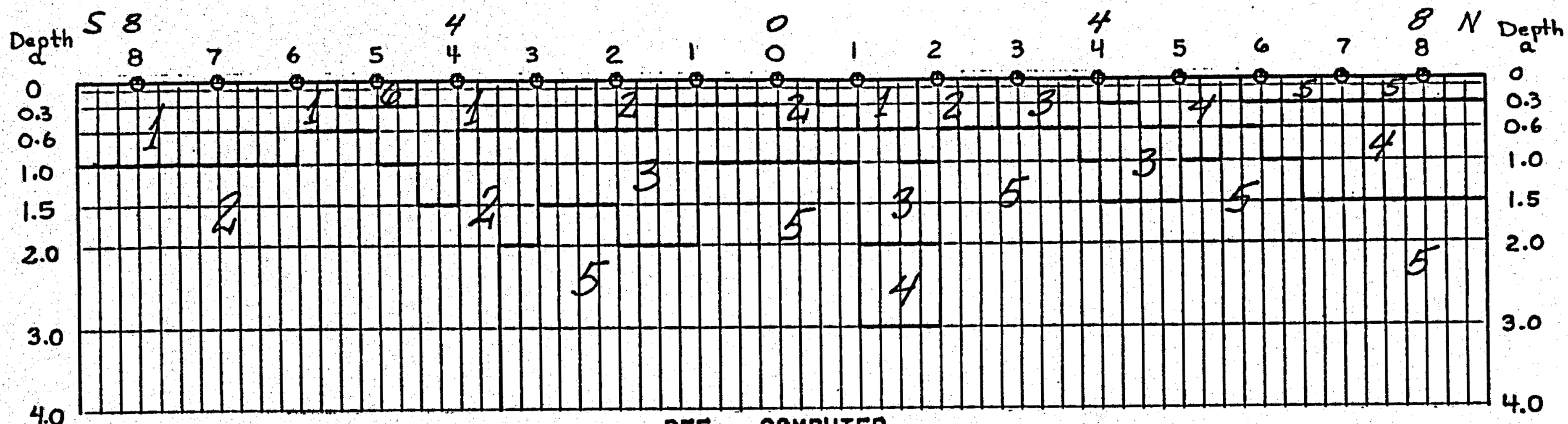


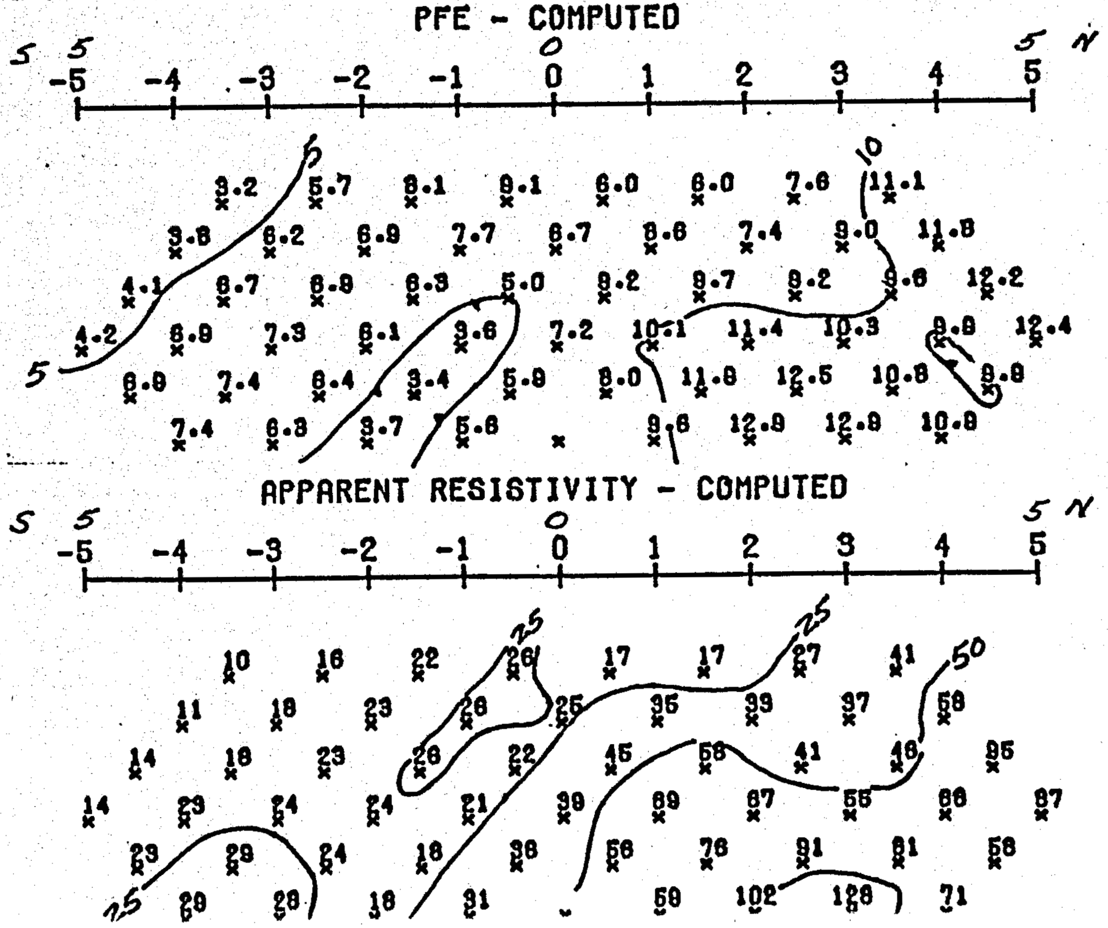
A 12

LINE 2, CTR, I-5

CF 3 I-6 2.00

NUMERICAL MODEL





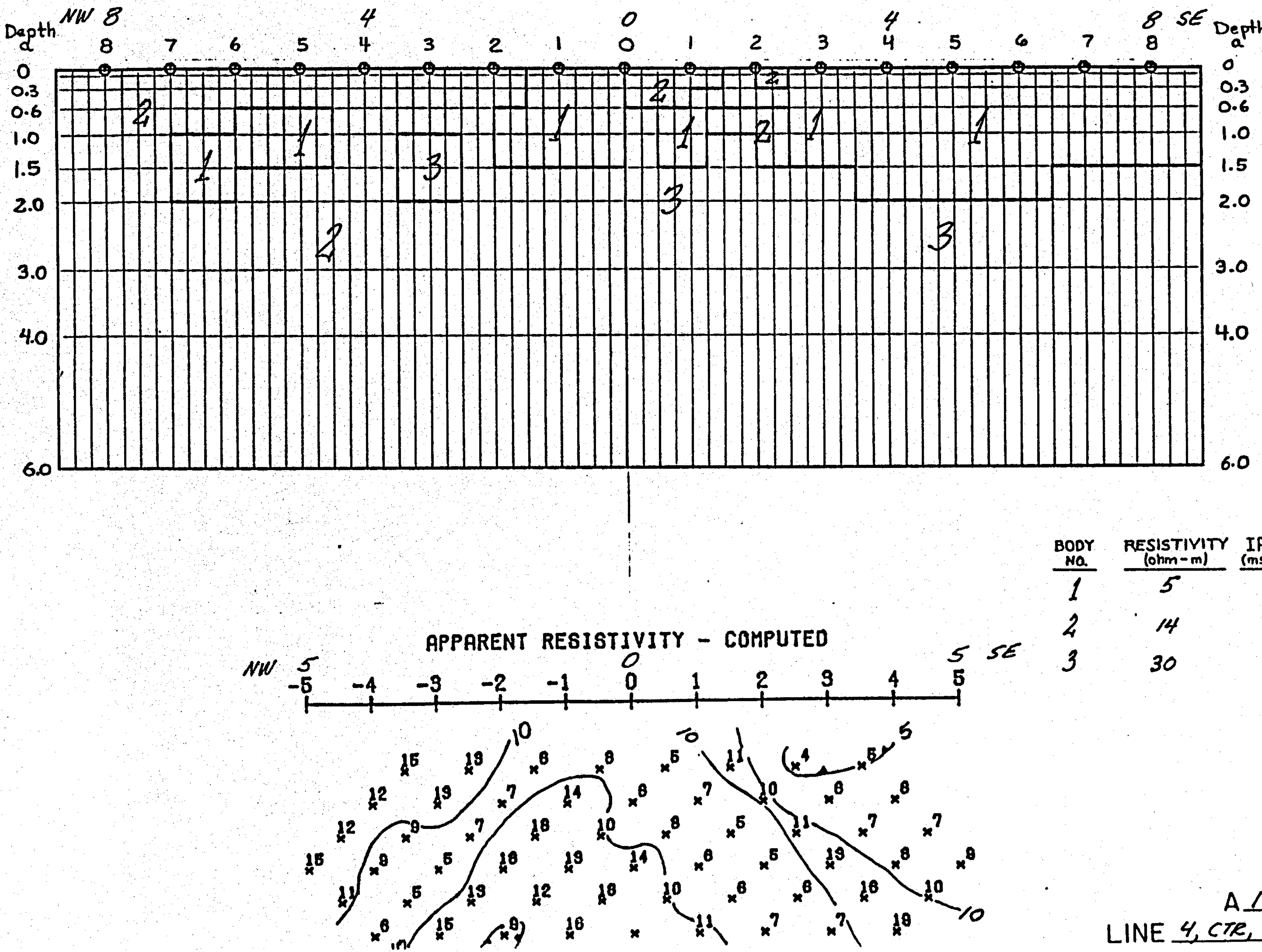
BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	10	3
2	20	8
3	30	10
4	50	15
5	200	15
6	5	3

A 13

LINE 3, CTR, I-6

CF 4 I-6 2.00

NUMERICAL MODEL



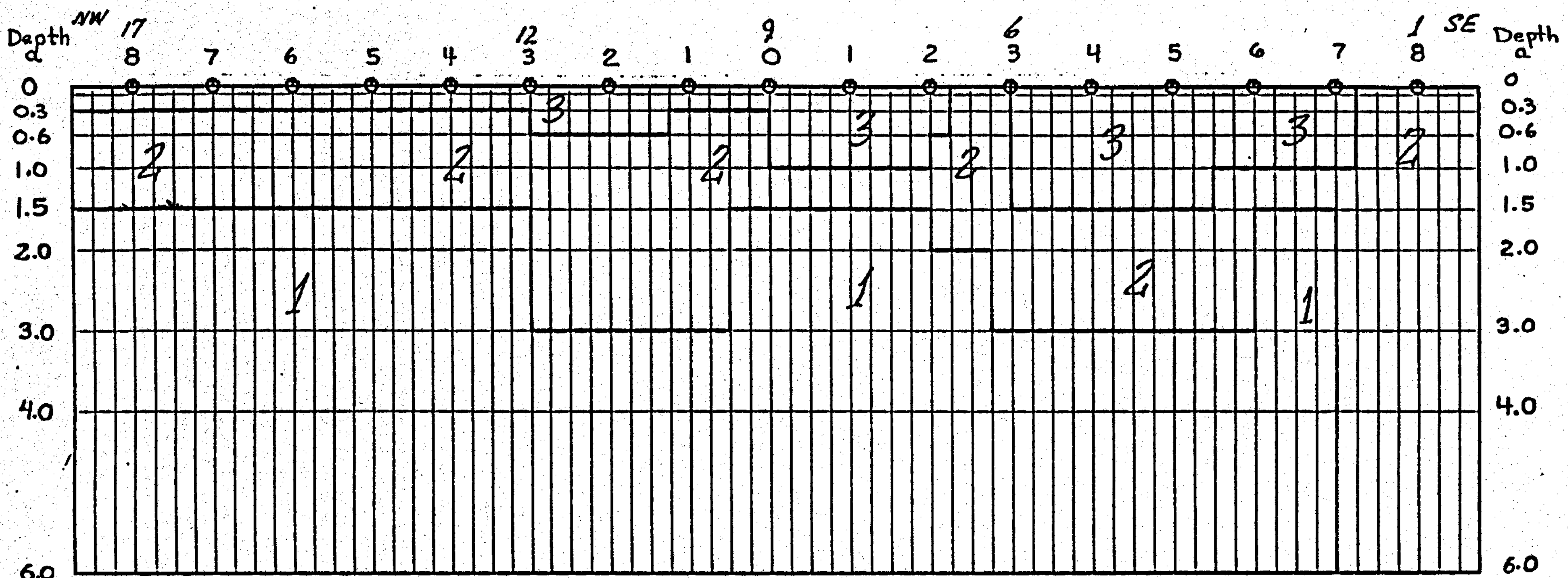
BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	5	
2	14	
3	30	

A 14

LINE 4, CTR, I-6

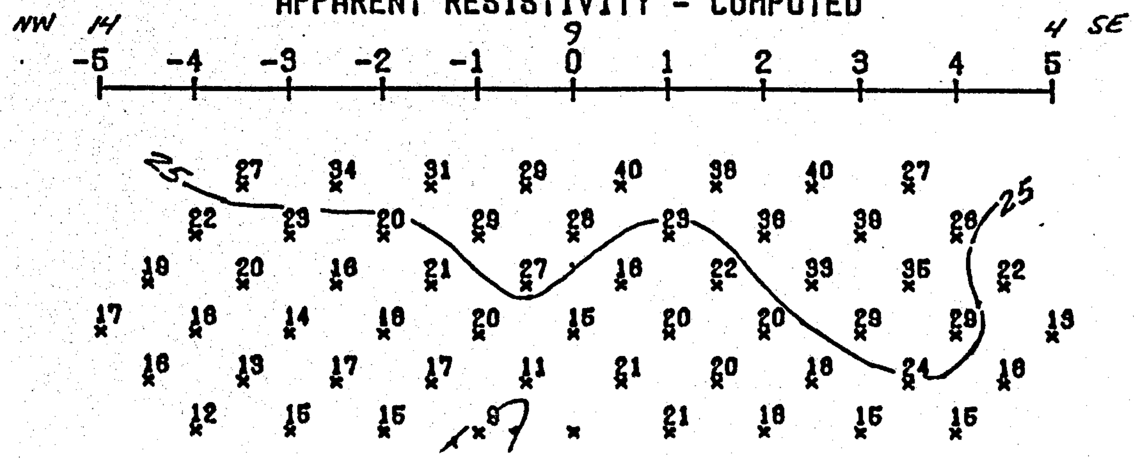
CF 5 W/2 I-5 2.00

NUMERICAL MODEL



BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	10	
2	20	
3	50	

APPARENT RESISTIVITY - COMPUTED

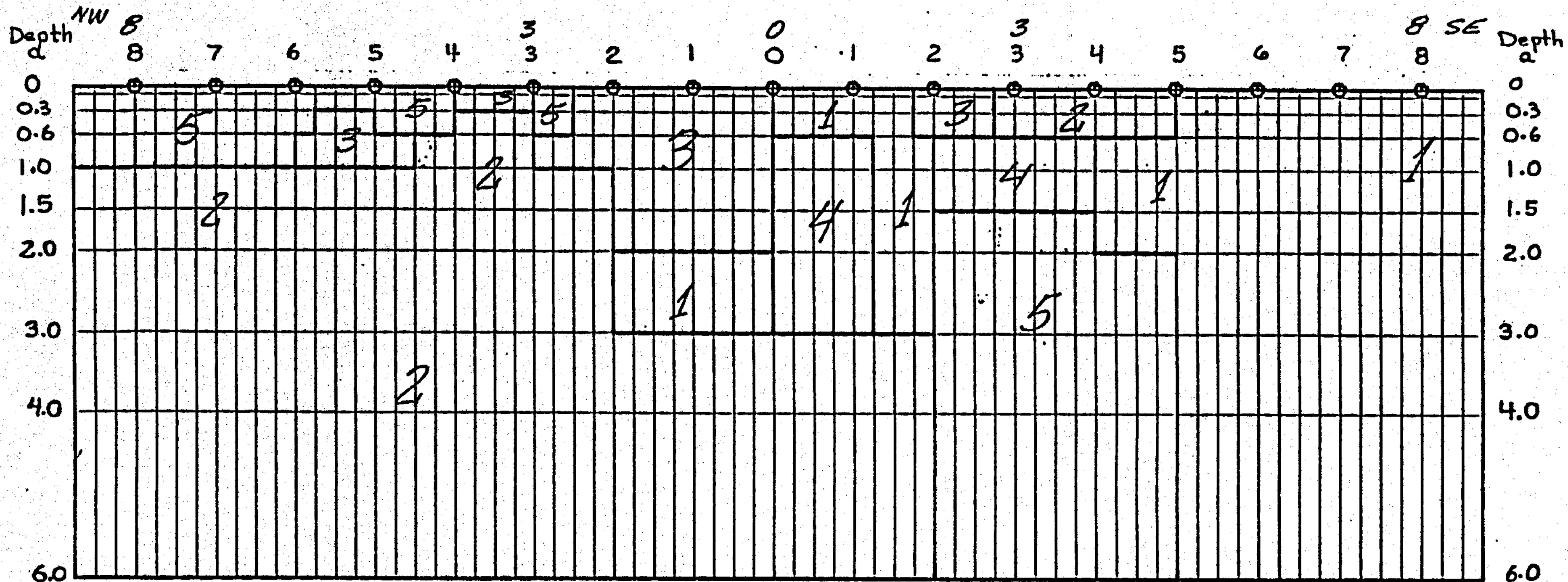


A 15

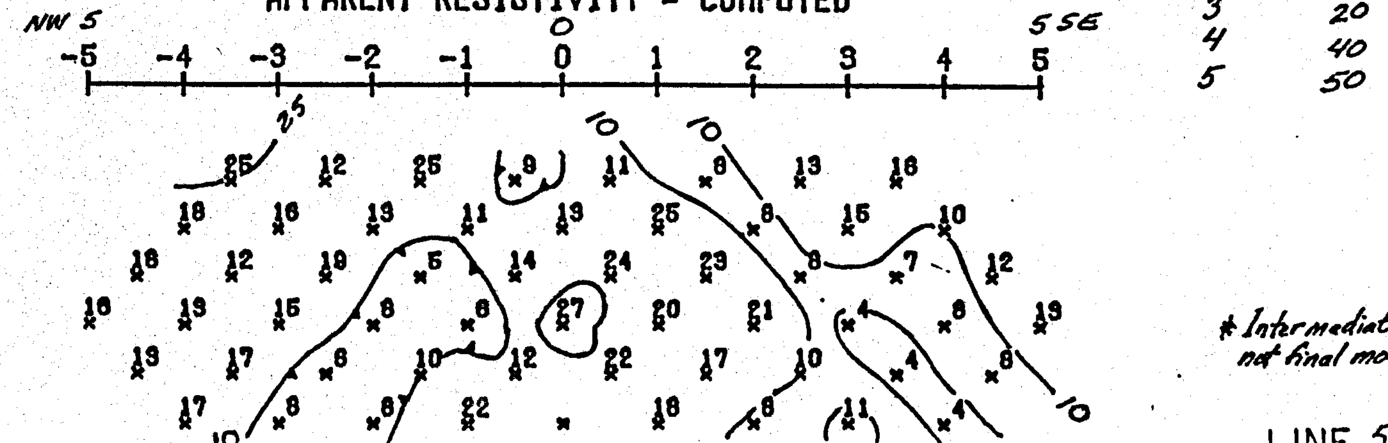
LINE 5, W/2, I-5

CF 5 E/2 I-5 2.00

NUMERICAL MODEL



APPARENT RESISTIVITY - COMPUTED



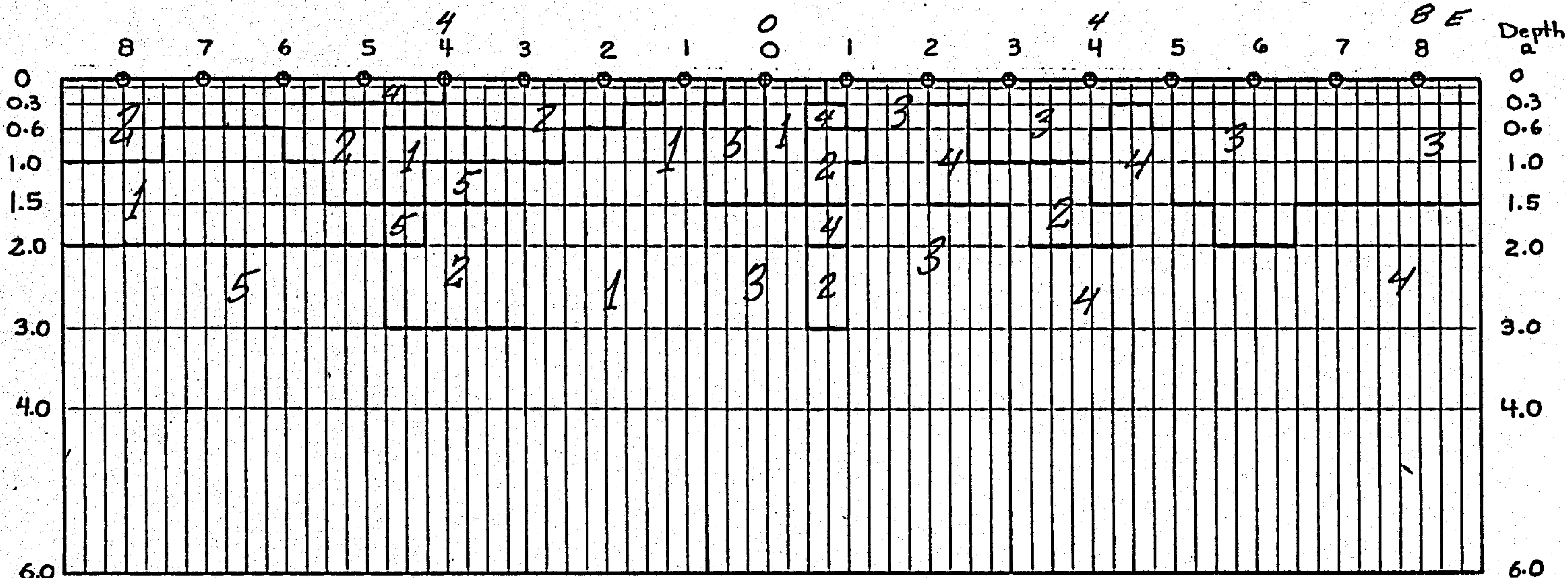
BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	5	
2	10	
3	20	
4	40	
5	50	

* Intermediate result not final model

A 16

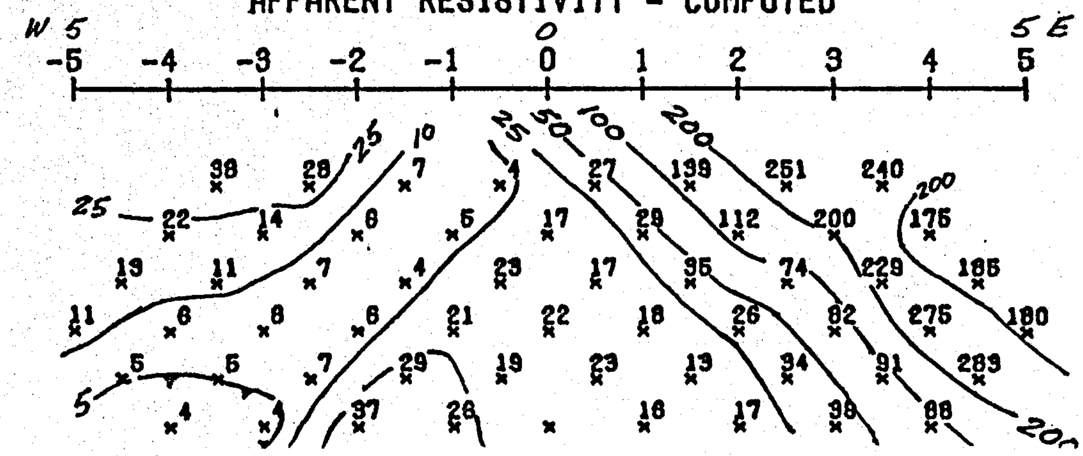
LINE 5 E/2 I-5*

NUMERICAL MODEL



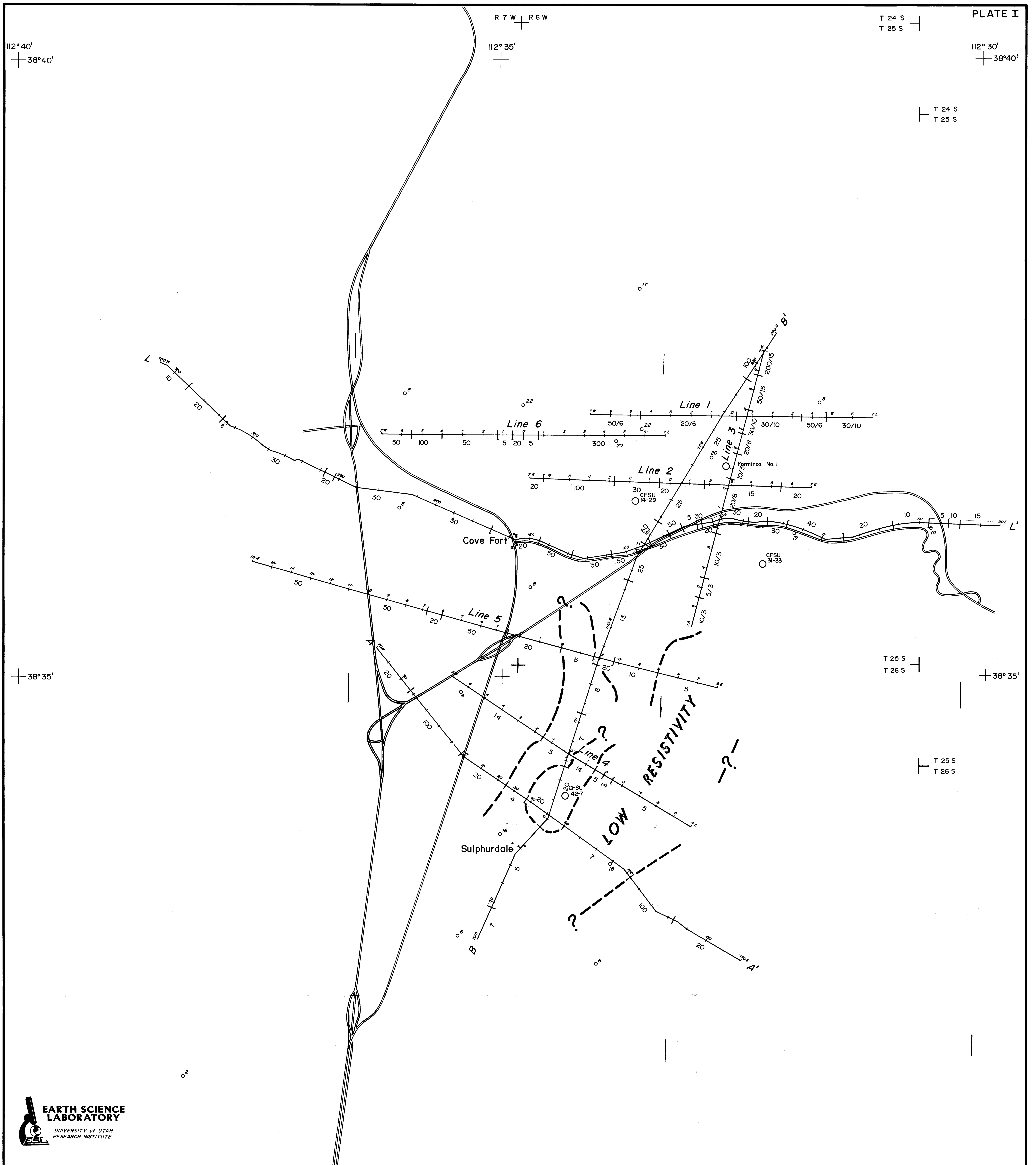
BODY NO.	RESISTIVITY (ohm-m)	IP (ms)
1	5	
2	50	
3	300	
4	100	
5	20	

APPARENT RESISTIVITY - COMPUTED



A 17

PLATE I



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EXPLANATION

INTRINSIC RESISTIVITY (ohm-m)

- $100 \le \rho$
- $45 < \rho < 100$
- $25 < \rho \le 45$
- $15 < \rho \le 25$
- $8 < \rho \le 15$
- $5 < \rho \le 8$
- $\rho \le 5$

20 ← Intrinsic Electrical Resistivity (ohm-m)
50/30 ← Chargeability (IP effect-ms) Lines 1 and 3 only

note: This map overlays the Geologic Map of the Cove Fort-Sulphurdale KGRA by Moore and Samberg, 1979

Interpretation by H. P. Ross

N

PLATE I

INTERPRETED ELECTRICAL RESISTIVITY
DEPTH INTERVAL 0-300 FEET

COVE FORT-SULPHURDALE KGRA

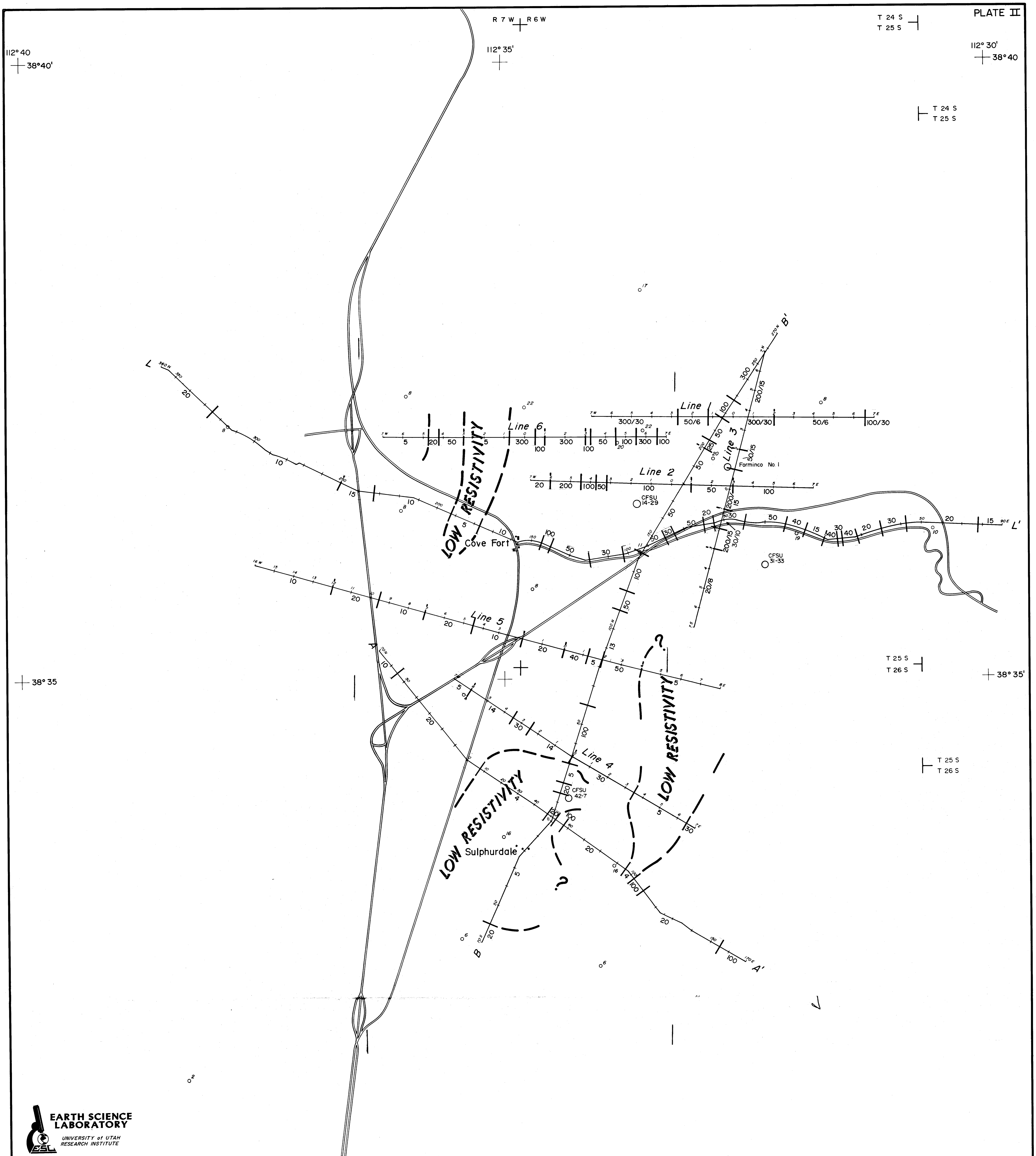
BEAVER AND MILLARD COUNTIES, UTAH

SCALE 1:24,000

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

38°30' 112°40' 112°35' 38°30' 112°30'



EXPLANATION

INTRINSIC RESISTIVITY (ohm-m)

- 100≤ρ
- 45≤ρ<100
- 25<ρ≤45
- 15<ρ≤25
- 8<ρ≤15
- 5<ρ≤8
- ρ≤5

20← Intrinsic Electrical Resistivity (ohm-m)
50/30← Chargeability (IP effect-ms)
Lines 1 and 3 only

note: This map overlays the Geologic Map of the Cove Fort-Sulphurdale KGRA by Moore and Samberg, 1979

Interpretation by H. P. Ross

PLATE II

INTERPRETED ELECTRICAL RESISTIVITY
DEPTH INTERVAL 1500-2000 FEET

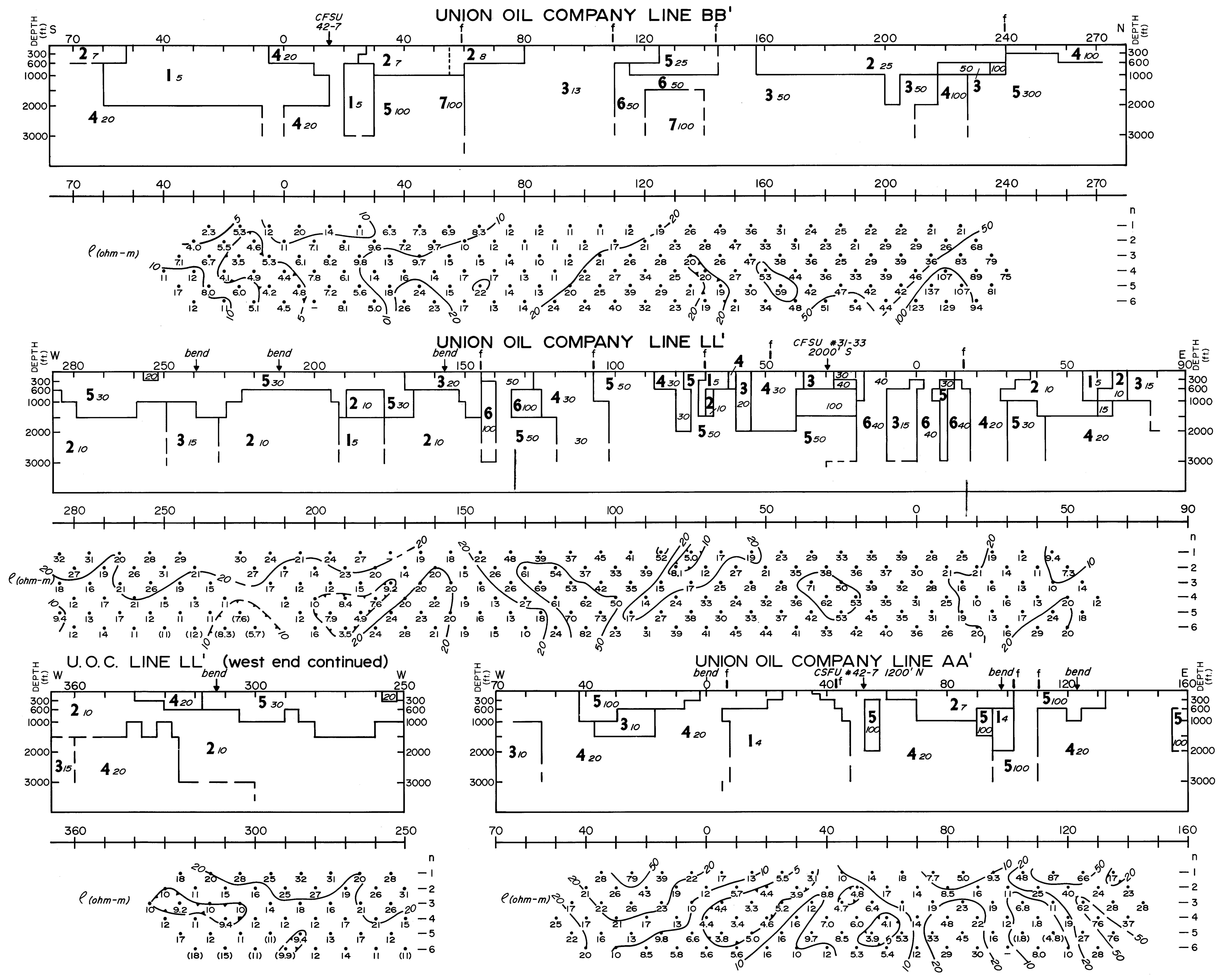
COVE FORT-SULPHURDALE KGRA

BEAVER AND MILLARD COUNTIES, UTAH

SCALE 1:24,000

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER



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EXPLANATION

f — faulting suggested by resistivity model and geology

3 — body number from numerical model

50 — intrinsic electrical resistivity (ohm-m)

note: Data recorded by Phoenix Geophysics Inc., November 1976.

Interpretation by H. P. Ross

INTRINSIC RESISTIVITY (ohm-m)

- $100 \leq \rho$
- $45 < \rho < 100$
- $25 < \rho \leq 45$
- $15 < \rho \leq 25$
- $8 < \rho \leq 15$
- $5 < \rho \leq 8$
- $\rho \leq 5$

PLATE III

INTERPRETED RESISTIVITY SECTION and OBSERVED APPARENT RESISTIVITY

COVE FORT - SULPHURDALE KGRA

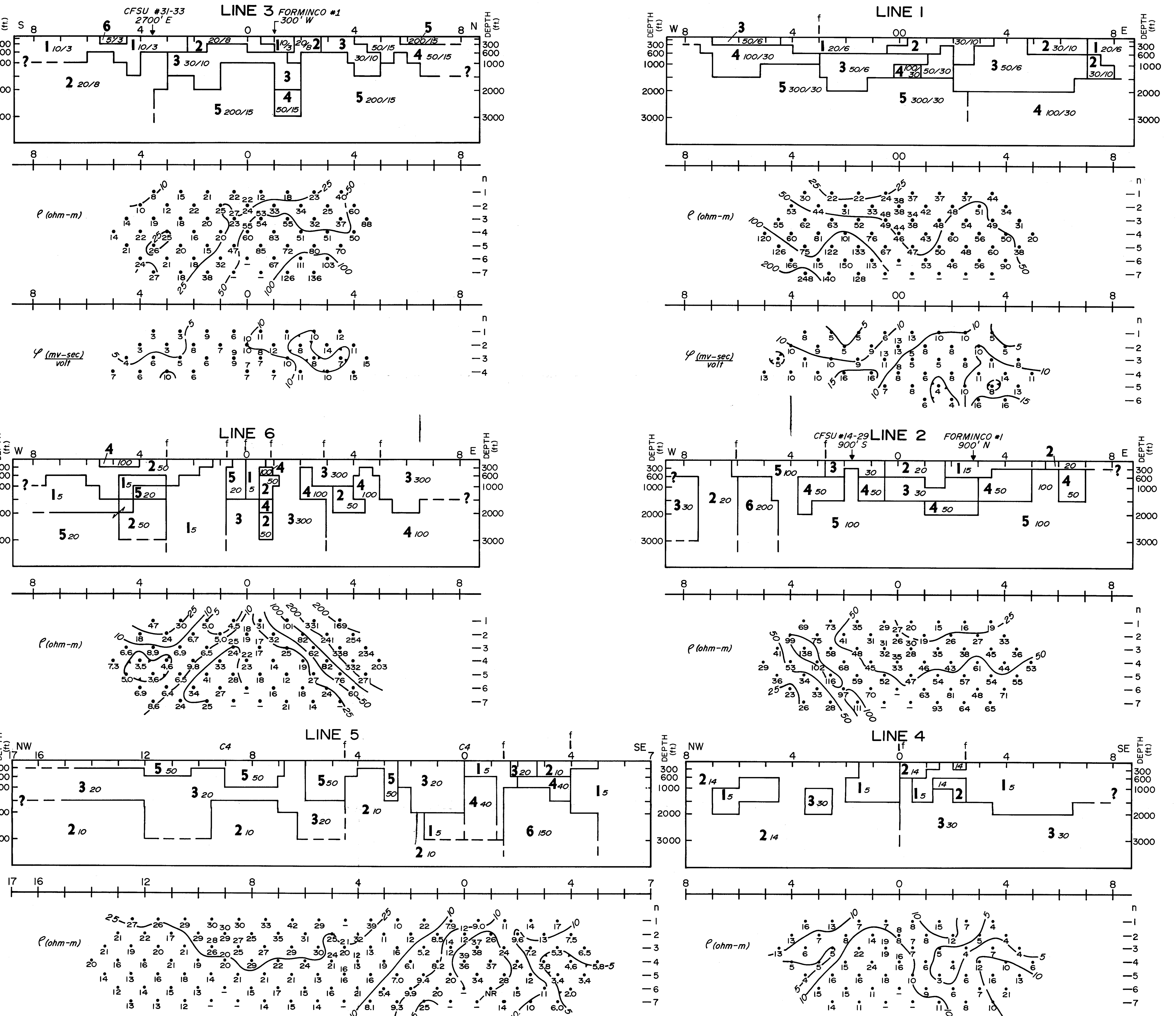
BEAVER AND MILLARD COUNTIES, UTAH

SCALE 1:24,000

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

PLATE IV



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EXPLANATION

f — faulting suggested by resistivity model and geology

3 — body number from numerical model

50/6 — intrinsic electrical resistivity (ohm-m) / polarizability (millivolt seconds/volt)

note: Data recorded by Mining Geophysical Surveys, September 1978. Apparent Polarization was recorded only for Lines 1 and 3.

Interpretation by H. P. Ross

INTRINSIC RESISTIVITY (ohm-m)

- $100 \le \rho$
- $45 < \rho < 100$
- $25 < \rho \le 45$
- $15 < \rho \le 25$
- $8 < \rho \le 15$
- $5 < \rho \le 8$
- $\rho \le 5$

PLATE IV

INTERPRETED RESISTIVITY SECTION and OBSERVED APPARENT RESISTIVITY

COVE FORT-SULPHURDALE KGRA

BEAVER AND MILLARD COUNTIES, UTAH

SCALE 1:24,000
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER