ELECTRICAL RESISTIVITY SURVEY AT
BIEBER PROSPECT
MODOC COUNTY, CALIFORNIA

Prepared for

AMAX EXPLORATION, INC.

Geothermal Group

December, 1975

by

Aldo Mazzella

TERRAPHYSICS
815 SOUTH TENTH STREET
RICHMOND, CALIFORNIA 94804
(415) 234-8961

Abstract

A reconnaissance electrical resistivity survey was conducted by Terraphysics in the Bieber area, Modoc County, California.

A combination of telluric and magnetotelluric methods was used. Some shallow d.c. resistivity measurements were obtained in the vicinity of Bassett and Kellog Hot Springs.

The results indicate that a shallow low resistivity zone ($<$10 ohm meters) encompasses both the Kellog and Bassett Hot Springs areas. Narrow zones of about 4 ohm meters are observed over the hot springs areas.

A deep-seated source for the hot springs was not clearly evident. A 16 ohm meter apparent resistivity low was observed in the Bassett Hot Springs area on the 0.05 Hz data.

The data indicate that a number of faults may run through the area. Two features appear to intersect south of the Bassett Hot Springs area, suggesting that the thermal waters may be moving along fault conduits.

Additional electrical survey work is recommended in the region.

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Introduction

Terraphysics conducted electrical surveys in the vicinity of Bieber, in Lassen and Modoc counties, California, on behalf of the Geothermal Group of Amax Exploration, Inc. The work was performed during the intervals 6 August - 16 September, 15-17 November and 14 December 1975. Telluric, magnetotelluric (MT) and d.c. resistivity measurements were made.

Survey Objective

The objective of the survey was to aid in the evaluation of the geothermal energy potential in the area. Various hot springs exist in the region.

Many geophysical techniques are used to evaluate a geothermal area. Since a decrease in resistivity usually occurs where the temperature of the earth increases, an electrical resistivity survey can be a useful diagnostic technique. The resistivity change with temperature can be on the order of 2.5%/C^{o} (Keller and Frischnecht, 1970). Consequently, resistivity decreases on the order of a factor of five (5) or more may be associated with geothermal brines (Keller, 1970). Intrinsic resistivities of less than 10 ohm meters may be expected.

If a geothermal area is at a sufficiently high temperature that a vapor phase is present, higher electrical resistivities are likely. Zohdy, et. al. (1973) report intrinsic resistivities of about 75-130 ohm meters for a vapor-dominated layer in Yellowstone National Park.

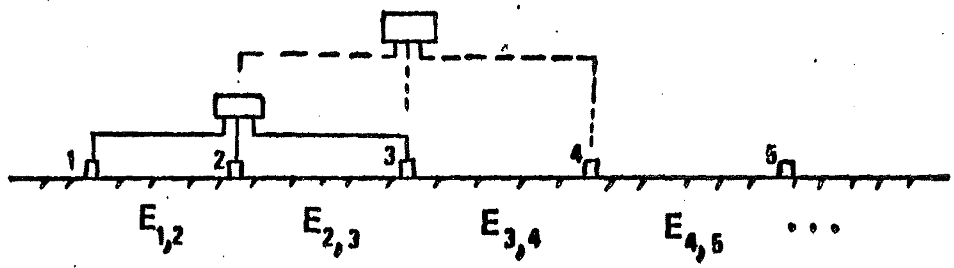
Procedure and Instrumentation

A combination of telluric and magnetotelluric methods was used as a reconnaissance technique. The collinear telluric method, illustrated in Figure 1, has been described by Dahlberg (1945), and Boissonnas and Leonardon (1948). The technique involves measuring the ratio of the electric fields (E) between two adjacent collinear dipoles. After the readings are completed at one station, the instruments are moved to the next site and the next dipole ratio is measured.

The electric field ratio is proportional to the square root of the apparent resistivity ratio beneath the particular dipoles, see Figure 1, (Slankis and Becker, 1969; Slankis, Telford and Becker, 1972). Successive ratios are referenced back to an initial dipole to obtain a relative resistivity profile across the region.

The equipment is itemized in Table 1 and illustrated in the schematic of Figure 1. Porous pots are used as electrodes for the telluric dipoles. Each electrode consists of a porous ceramic cup and a copper rod in a saturated copper sulphate solution. Voltages from two adjacent telluric dipoles are narrow-band filtered, amplified (2 Itaco filters) and displayed on an X-Y chart recorder (Simpson). The voltage ratio is easily measured as the slope of the resulting X-Y plot. An example of such data is shown in Figure 2. Measurements are usually made at 0.05 Hz and may be supplemented by data at other frequencies, such as 8 Hz, to provide additional depth information. A theoretical example is described in Appendix A.

Magnetotelluric measurements are made at intervals along the telluric lines to provide control points for calibrating the relative telluric profiles. Continuous profiles of apparent resistivity values across the area are obtained.



ELECTRIC FIELD RATIO

$$\frac{E_{i,j}}{E_{1,2}} = \frac{E_{2,3}}{E_{1,2}}\,\frac{E_{3,4}}{E_{2,3}}\cdots\frac{E_{i,j}}{E_{i-1,j-1}} = \left(\frac{\rho_{a\,i,j}}{\rho_{a\,1,2}}\right)^{\frac{1}{2}}$$

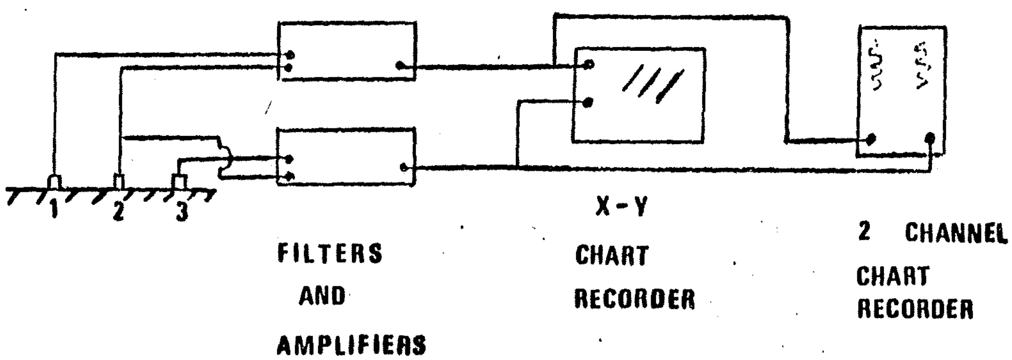
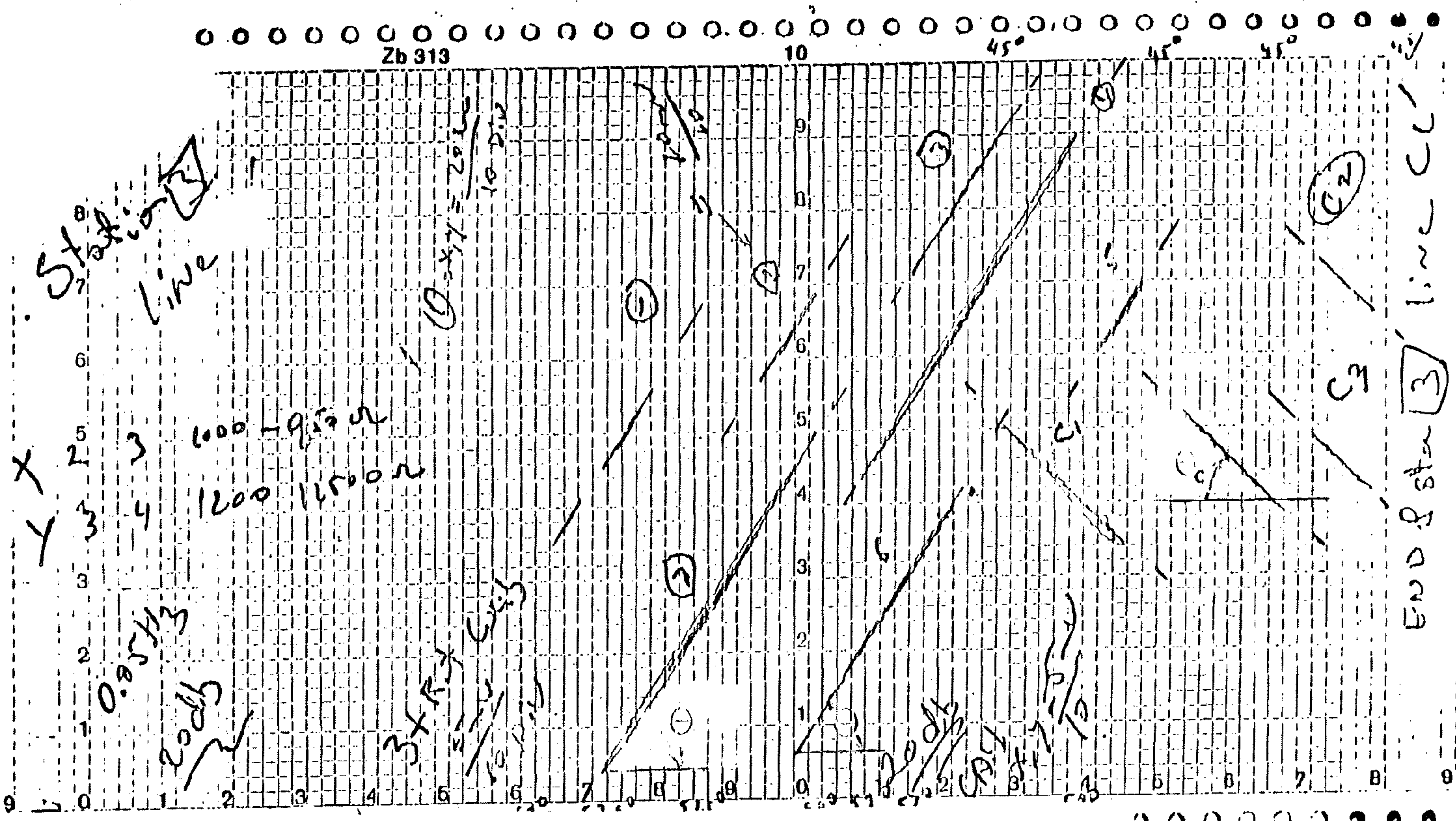


Figure 1. Collinear telluric method and instrumentation

Table 1

Equipment Used on the Bieber, California Survey

4	Ithaco model 4211 filters with amplifier options
2	Simpson X-Y model 2745 chart recorders
1	2 channel Brush 222 chart recorder
1	2 channel Gulton model TR 722J chart recorder
1	Develco 3 component superconducting Josephson Junction magnetometer
1	Tektronix 2 channel oscilloscope
2	2 channel amplifiers
1	2 channel 60 Hertz notch filter
1	500 watt shallow d.c. resistivity transmitter
5	Reels wire (30,000 feet)
1	Toyota Landcruiser, 4 wheel drive
1	Ford 3/4 ton, 4 wheel drive pickup
1	Chevrolet 1/2 ton pickup with instrument camper shell
1	Vacuum pump (for pumping vacuum on cryogenic devices)
1	Liquid He Transfer line
1	Liquid He Level indicator
1	60 liter Liquid He dewar (Amax)
3	100 liter Liquid He dewars (Rentals)
1	Simpson digital voltmeter



Telluric data, 0.05 Hz

Figure 2. The X axis represents the voltage monitored from dipole 2-3 and the Y axis represents dipole 3-4. The ratio of the voltages of these adjacent dipoles is determined from the tangent of the angle Θ from the expression

$$\frac{V_{3,4}}{V_{2,3}} = \frac{\tan \Theta}{\tan \Theta_c}$$

Calibration of the instruments is taken into consideration by the measurement of the angle Θ_c

The electric field ratio is obtained from the expression

$$\frac{E_{3,4}}{E_{2,3}} = \frac{V_{3,4}}{L_{3,4}} \cdot \frac{L_{2,3}}{V_{2,3}} = \frac{L_{2,3}}{L_{3,4}} \frac{\tan \Theta}{\tan \Theta_c}$$

Where $L_{2,3}$ and $L_{3,4}$ are the lengths of the dipoles 2-3 and 3-4 respectively.

The electric field (E_x) is measured at the same stations used for the collinear telluric data. The orthogonal magnetic field component H_y is measured with a Josephson Junction ("J.J.") magnetometer. Scalar apparent resistivities ρ_{a_x} are calculated from the expression

$$\rho_{a_x} = \frac{.2}{f} \left(\frac{E_x}{H_y} \right)^2$$

where E_x is in millivolts/km, H_y is in gammas and f is the frequency in Hertz (Hz).

Measurements are made at a narrow-band frequency of 0.05 Hz, although additional measurements at other frequencies such as .1, .8 and 8 Hz are sometimes obtained.

The orthogonal pair of field components E_y and H_x are measured at some stations, with the resulting determination of apparent resistivity ρ_{a_y} giving an indication of the anisotropic nature of the earth.

D.C. resistivity measurements were taken in some areas, using Wenner arrays with "a" spacings up to 400 meters. These provide near-surface resistivity information.

Where warranted, dipole-dipole arrays are used to obtain deeper resistivity properties. Measurements are obtained with 300 to 600 meter dipoles having separations up to 6 km. These techniques provide a check on the 8 Hz telluric and MT data.

In summary, the field procedure is as follows:

1) Telluric lines are run in a direction normal to geologic strike where feasible.
2) MT measurements are made at appropriate sites to calibrate the telluric lines.

3) D.C. resistivity measurements are taken to determine shallow resistivity properties.
4) Results of the above may warrant supplementary deeper resistivity soundings and/or electromagnetic (EM) measurements over possible geothermal target zones.

Field Operation at Bieber

In the Bieber survey, telluric dipoles ranging from 0.4 to 1.5 km in length were employed, depending on topographic conditions. Telluric measurements were made at 8 and 0.05 Hz.

Geologic strike in the area runs between north and northwest. Telluric lines were run east-west and northeast-southwest as determined by roads and access, and as specified by the client. One hundred thirty (130) telluric stations were measured. A total of thirty-six (36) MT stations were occupied at strategic locations on the telluric lines. In addition, twenty-five (25) d.c. resistivity measurements were made.

Composition of Crew

A detailed summary of the work and personnel is documented in Appendix B. The personnel involved on the project are listed below.

Phase I : 6 August - 16 September 1975

A. Pessah	Party Chief	Instrumentation, survey and data analysis
L. Donahue	Field Engineer	Survey, wire crew, vehicle maintenance
W. Harvey	Field Technician	Instrumentation, equipment maintenance, wire crew
P. Guzman	Field Hand	Wire crew, equipment maintenance

Phase II : 15-17 November 1975

A. Pessah	Party Chief	Instrumentation, survey and data analysis
P. Guzman	Field Hand	Wire crew, equipment maintenance

In addition, A. Mazzella spent eight (8) days with the crew in the field.

A total of eighty-seven (87) field man days were worked in the Bieber, California area over a period of thrity-nine (39) days.

Operating Conditions

During Phase I, weather was generally favorable and work proceeded smoothly except during ten (10) days when lightning, rain, and wind hindered the work. In Phase II, rain impaired travel during one (1) day.

The personnel stayed at the Juniper Tree Motel in Adin, California during both phases of the work. Maximum commuting time to the farthest station was about 35 minutes.

Specific vehicles used in the project were a Toyota Landcruiser (4 wheel drive), a Ford 3/4 ton pickup (4 wheel drive) and a Chevrolet 1/2 ton pickup with a camper shell (Table 1).

DATA

The location of the telluric lines and stations are shown in Plate 1. (The Figures and Plates for the data are in the second binder).

The telluric profiles are plotted in Figures 3 through 9. The relative electric field strength is plotted on the left side ordinate. The station locations are projected on the abscissa at the top of the plot, with the E-field ratio plotted midway between the electrode stations.

Each station represents an average of 5 to 10 measurements. Standard deviations were calculated and shown as error bars. In some cases, in particular when the ground becomes anisotropic, a wide variation in ratios was observed. The various values are plotted.

MT readings are shown in the rectangles at their corresponding locations. The average resistivity and standard deviation are indicated. Telluric values between MT readings on a given profile were adjusted linearly to correspond to the MT readings. An apparent resistivity scale in ohm meters is shown on the right side ordinate. A summary of all the magnetotelluric data is presented in Table 2.

Contour maps of apparent resistivities for the 0.05 and 8 Hz frequencies are depicted in Plates 2 and 3 as described from the profile data. Lines were calibrated by the MT readings. The apparent resistivities are plotted in logarithmic contour intervals.

Orthogonal telluric measurements were obtained at five sites. At some sites, wide variations in both the phase and amplitude ratio were observed over a period of time. These data were averaged over a number of cycles. The ratio of the components and the approximate direction of the main axis of the telluric ellipses are summarized in Table 3.

The results of d.c. resistivity measurements are summarized in Table 4. Wenner data on line AA', stations 25-28 in the area of Kellog Hot Springs, are plotted in Figure 10. A Wenner sounding on line CC', stations 10-13 over Bassett Hot Springs is plotted in Figure 11. A Wenner resistivity sounding on line AA', stations 18 to 19, 1.6 kilometers south of Bassett Hot Springs, is plotted in Figure 12.

PLACE Bieber, California

TABLE 2 MAGNETOTELLURIC DATA

Apparent Resistivity Ohm Meters ∓ Standard Deviation (Number of Samples)

LINE & STATION	LENGTH IN FEET	DATE	0.05 H_Z	8.0 Hz			COMMENTS
AA' 0-1	3150	8/29	149 ± 50 (20)	138 ± 61 (21)			
3-4	3150	8/29	55 ± 20 (17)	63 ± 25 (17)			
9-10	2250	8/26	72 ± 38 (14)	8.3 ± 2.6 (16)			
15B-16	1910	8/25	13 ± 7 (13)	28 ± 9/ (2) 5 ± 3/ (6) 11 ± 11/ (8) all			
16-17	1734	8/25	18 ± 6 (18)	Noisy signal			
24A-25A	2660	8/25	18 ± 3/ (8) 7 ± 3/ (13) 11 ± 6/ (21) all	16 ± 4/ (5) 3.9 ± 1.5/ (9) 6 ± 6 (14) all			Windy two distinct groups .05 & 8 Hz.
27-28	2530	8/25	121 ± 43 (9)	8 ± 3 (16)			
32-33	2375	8/26	52 ± 26 (19)	4.6 ± 2.7 (21)			

PLACE BIEBER, CALIFORNIA

TABLE 2 MAGNETOTELLURIC DATA

APPARENT RESISTIVITY OHM METERS ∓ STANDARD DEVIATION
(NUMBER OF SAMPLES)

LINE & STATION	LENGTH IN FEET	DATE	0.05 Hz	8.0 Hz			COMMENTS
BB' 24-25	3030	8/27	84 ± 43 (25)	40 ± 32 (12)			Windy 8Hz noisy
30-31	1420	8/27	56 ± 14/(23) 140 ± 33/(9) 80 ± 44/ (31)all	54 ± 31 (19)			Two groups 0.05 Hz
CC' 6-7	3350	9/3	45 ± 20 (19)	14 ± 5 (20)			
9-10	1775	9/3	49 ± 20/(16) 17 ± 5/ (8)	32 ± 10/ (8) 16 ± 8/ (20)			two groups on 0.05 & 8Hz
12-13	3330	8/26	18 ± 5 (21)	4.7 ± 3.8 (18)			
17-18	2640	8/28	24 ± 8 (23)	24 ± 15 (23)			
DD' 4-5	3190	9/14	15 ± 7 (20)	31 ± 11 (23)			
12-13	2730	9/14	35 ± 26 (20)	6.6 ± 3.4 (23)			

PLACE Bieber, California

TABLE 2 MAGNETOTELLURIC DATA

Apparent Resistivity Ohm Meters ∓ Standard Deviation
(Number of Samples)

LINE & STATION	LENGTH IN FEET	DATE	0.05 Hz	8.0 Hz			COMMENTS
DD' 33-34	2300	8/28	16.9 ± 7.5 (22)	8.9 ± 6.8 (19)			
38-39	2315	11/7	81 ± 59 (36)	5.2 ± 1.3 (20)			
EE' 2A-2B	1350	9/15	137 ± 85 (20)	14 ± 5/ (15) 58 ± 7/ (5) 25 ± 20/(20)all			two groups 8 Hz
1-2A	2600	9/10	203 ± 94 (19)	14 ± 10 (19)			
FF' 54-55A	2025	9/14	124 ± 67 (17)	162 ± 34 (23)			
F'F" 0-1	3800	9/8	189 ± 87 (21)	40 ± 29 (18)			
4A-5	2955	9/5	50 ± 27 (11)	16 ± 11 (16)			
10-11	2880	9/6	120 ± 32 (15)	24 ± 18 (20)			

PLACE Bieber, California

TABLE 2 MAGNETOTELLURIC DATA

Apparent Resistivity Ohm Meters ∓ Standard Deviation
(Number of Samples)

LINE & STATION	LENGTH IN FEET	DATE	0.05 Hz	8.0 Hz	0.1 Hz	0.8 Hz	COMMENTS
FF" 17-18	2025	9/6	10.7 ± 4.3 (19)	2.6 ± 1.8 (20)			
XX' 2-3	2640	11/15	33 ± 15 (22)	12.6 ± 8.2 (15)	16 ∓ 12 (7)	—	windy, cold poor signal level, correlation 0.1 0.8 Hz
7-8	1850	11/16	112 ± 22 (21)	24 ± 14 (12)	69 ∓ 29 (14)	38 ∓ 17 / (13) 258 ∓100 / (8)-?	2 groups 0.8 Hz, very windy
BB' 30B-West	400	8/27	47 ∓ 17 (8)	86 ∓ 64 (10) (noisy)			East-West Telluric Direction windy, 8 Hz noisy

Table 3

Orthogonal Telluric Measurements
0.05 Hz

Location Line	Location Station	Telluric Ratio NS/EW	Approximate Direction Telluric Field	Comments
AA'	5	1.2 ∓ .2	S 41° E	2 groups appear dominant
		1.8 ∓ .5	N 61° E	
AA'	25	2.6 ∓ .4	S 70° E	
DD'	39	.33 ∓ .05	S 72° E	2 groups
		1.44 ∓ .68	S 35° E	
DD'	2	.90 to .29	S 48° E 90° phase between 2 components	Wide variation in both phase and amplitude
FF"	(0-1)	.82 ∓ .43	S 24° E	2 groups
	(0-A)	1.5 ∓ .11	N 74° E	

Table 4

D.C. Resistivity, Bieber Area, Wenner Array

Location	a Spacing meters	Apparent Resistivity, ρ_a ohm meters
Line AA'		
Station 15-16	152	14.5
Station 18-19	3	28.8
(sounding)	15	7.6
	61	10.7
	152	7.1
	305	7.1
Line AA'		
Station 26	15	13.7
26-27	287	4.3
27	15	7.2
27-28	250	7.8
28	15	19.1
28-29	291	6.8
29	15	24.4
Line CC'		
Station 10 to 13	3	24.9
(sounding)	15	15.0
	30	10.1
	76	3.4
	183	3.8
	340	4.3
	732	7.6
	1016	10.0
Line CC'		
Station 17-18	268	13.9
Line DD		
Station 39	15	23.5
Station 38-39	235	6.2
Pumpkin Center	15	13.3

Sources of Error

The principal sources of error in the telluric-magnetotelluric methods are:

1) Station locations and dipole lengths are determined from topographical maps, bench marks, and actual field measurements. In general, dipole lengths are determined to within 5%. The possibility of the accumulation of small errors yielding a large uncertainty after a number of stations, was reduced by taking magnetotelluric measurements at intervals along the telluric profiles. Telluric values between MT readings were adjusted linearly to correspond to the MT values.

2) Errors due to instrumentation are kept to a minimum by calibrating the instruments at each station. In some cases, calibrations were taken both before and after each frequency reading.

3) When the earth becomes highly anisotropic, a phase shift can occur between measurements of adjacent telluric dipoles. In this case, the E-field ratio depends upon the polarization of the incident field, and in general wide variations in both amplitude and phase are observed. Attempts are then made to obtain information over as much of the area as possible with MT readings and d.c. resistivity measurements.

4) In some areas, considerable noise is observed on the higher frequency data, 8 Hz; probably caused by local industrial electrical activity. Attempts are made to minimize any error from these near-field sources by careful inspection of each cycle of data on high speed oscillographic records. However, considerable scatter in the data usually results.

Discussion of Data

Geological Province

The Bieber area lies in the Modoc Plateau province in northeastern California. This is a broad volcanic highland built up of irregular masses of a wide variety of volcanic materials, but predominantly basalt. "Numerous cones and shield volcanos scattered over the plateau and extensive block fault systems with largely vertical movements are responsible for a surface with considerable relief." (Oakeshott, 1971).

The Cascade Range, a high chain of volcanic peaks, lies to the west of Bieber. There is little difference in ages of volcanism or rock types between the Cascade Range and Modoc Plateau. (Oakeshott, 1971).

Very recent volcanism has occurred in the Cascade Range. Mount Lassen,about 72 kilometers southwest of Bieber, last errupted in 1914 to 1917; and there is indirect evidence that Mount Shasta, about 96 kilometers to the northwest of Bieber, may have errupted in the eighteenth century (Oakeshott, 1971).

Bieber Area

The topography of the Bieber area consists of mountains and a wide valley at an elevation of about 1200 meters. In general, high apparent resistivity values are observed near the mountainous areas, reflecting volcanic rocks, while low resistivity values are observed in the valleys, reflecting lake bed deposits (Jenkins, 1943).

The resistivity data depicted in Plates 2 and 3 indicate a complicated resistivity pattern between the town of Nubieber and Adin, California, an area encompassing both Bassett Hot Springs and Kellog Hot Springs.

(a) 8 Hz Data

The 8 Hz data shown on Plate 2 delinate a number of low apparent resistivity values. These could be associated with hot geothermal brines, highly conductive saturated lake bed deposits (swamps) or a combination of the two. Resistivity lows (<5 ohm meters) are observed in both the Bassett Hot Springs and Kellog Hot Springs areas.

The 8 Hz data indicate a low resistivity zone (<10 ohm meters) encompassing both the Kellog and Bassett Hot Springs areas. Narrow zones of about 4 ohm meters are observed directly over the hot springs.

The resistivity low extending to the northeast of Bassett Hot Springs probably reflects the saturated lake bed deposits in the Big Swamp area.

(b) D.C. Resistivity Measurements

D.C. resistivity measurements were taken in various areas to check the 8 Hz data and to give some additional interpretation insight.

The results of a Wenner sounding with spacing up to a = 1000 meters over Bassett Hot Springs (line CC', stations 10-13) are shown in Figure 11. The apparent resistivity value at 340 meters (4.3 ohm meters) corresponds very well with the 8 Hz data (4.3 ohm meters). A 3-layer interpretation of the sounding is shown. A very conductive region, 3.1 ohm meters is indicated, starting at a depth of 15 meters and extending to a depth of 250 meters.

Resistivity data obtained at the largest separations are probably influenced by lateral resistivity variations. An increase in near-surface resistivity on both sides of Bassett Hot Springs is indicated from the 8 Hz telluric data of Figure 5. This could cause the thickness of the second layer in the above interpretation to appear shallower than it really is. Two-dimensional modelling would be required to evaluate the contribution of these lateral resistivity variations.

The resistivity sounding shown in Figure 12 was obtained one kilometer directly south of the Bassett Hot Springs on line AA', stations 18 to 19. The thick low resistivity layer (<3 ohm meters) observed to the north is now absent, although the apparent resitivities are still on the order of 7 to 8 ohm meters.

Resistivity data taken in the Kellog Hot Springs area, shown in Figure 10, indicate fairly large lateral near-surface resistivity variations. The resistivity low (4.3 ohm meters) between stations 26 to 27, taken at an "a" spacing of 287 meters, agrees very well with the 8 Hz data there (3.7 ohm meters, skin depth 342 meters).

These d.c. resistivity results are in agreement with the 8 Hz resistivity pattern indicated in Plate 2.

<u>(c) 0.05 Hz Data</u>

The 0.05 Hz data reflect deeper resistivity properties of the area. The data, however, still are affected by near-surface resistivity properties. The large resistivity low (< 20 ohm meters), shown in Plate 3 in the Big Swamp area, still may be reflecting saturated lake bed deposits.

The 0.05 Hz data to the south of Bassett Hot Springs and southwest of Kellog Hot Springs show a fairly complicated structural pattern. Jenkins, 1943, indicates a contact between the lake bed deposits and Pliocene basalt in this area. The apparent resistivity high peak (30 ohm meters) on line AA', station 18-19 (Figure 3) may be associated with an intrusion or uplifted ridge of this basalt, possibly due to faulting. This fault or contact may extend to the northwest to line CC', station 11-12 and possibly to line DD', station 5-6.

An apparent resistivity high peak of 120 ohm meters also occurs in the Kellog Hot Springs area, line AA', station 27-28. These resistivity highs may be associated with areas where the pore spaces in the rocks have been filled by silica deposited from the geothermal brines. Again this mechanism may be fault controlled.

The data indicate that another fault may run southwest to northeast just south of Bassett Hot Springs near the town of Bieber. The fault is seen in both the 8 and 0.05 Hz data of Plates 2 and 3, and appears to intersect the northwest trending feature just south of Bassett Hot Springs.

An apparent resistivity low ($<$ 16 ohm meters) occurs on line AA', stations 14B to 16 and 20 to 25A. The 8 Hz data in this area are less than 10 ohm meters. While the 0.05 Hz data may still be reflecting a thick layer of lake bed deposits, this area warrants further study for its geothermal potential.

The apparent skin depth at 0.05 Hz for a resistivity of 16 ohm meters is about nine kilometers. The actual sensing depth, however, is usually much less, depending upon the intrinsic resistivities of various formations occurring in the area. Multifrequency MT data with a complete model solution would be required to determine the actual properties and depths.

Summary and Recommendations

The present resistivity survey indicates that a shallow low resistivity zone (< 10 ohm meters) encompasses both the Kellog and Bassett Hot Springs areas.

A deep-seated source for the hot waters was not clearly evident. The 0.05 Hz data indicate an apparent resistivity low of about 16 ohm meters occurs in the Bassett Hot Springs area.

A number of faults are indicated in the area. This suggests that the hot springs may be fed by fault conduits and the source could lie outside the surveyed area.

Additional survey work is recommended in the area just south of Kellog Hot Springs. In view of accessibility and the rough terrain, selected sites for MT readings may prove sufficient. Additional readings near Pumpkin Center, four kilometers south of Bassett Hot Springs, would help define the resistivity pattern and the possible fault.

Low frequency MT soundings at selected sites, such as line AA', stations 22-23, may help to locate the source of the hot waters. In view of the three-dimensional nature of the area, solutions for impedance tensors (Grillot, 1975) and at least two-dimensional modelling probably would be required to unfold its deep intrinsic properties.

Aldo Mazzella
Registered Geophysicist
State of California GP 842

APPENDIX A

Theoretical telluric results over hypothetical models are shown in Figures A1 and A2. The difference between the two models is the inclusion of a 1 ohm meter body in Figure A2. This could be representative of a geothermal target.

Two points are of particular note.

(1) The telluric response is characteristically dominated by resistivity variations occurring beneath the measuring stations. This is seen in both the figures.

(2) The use of multifrequencies provides some initial determination of depth information. For example, a significant difference is observed between the 0.03 Hz telluric response over the two models; the 8 Hz response is not affected. Th 8 Hz E.M. wave in this case does not significantly penetrate to the depth of the 1 ohm meter body. (The skin depth of an 8 Hz E.M. wave is 562 meters in a 10 ohm meter material. The top of the 1 ohm meter body is 500 meters deep). These results place a bound on the depth of the anomoly observed on the 0.03 Hz data. It must be deeper than a few hundred meters and less than a few thousand meters. A more precise depth could, of course, be determined with intermediate frequency data.

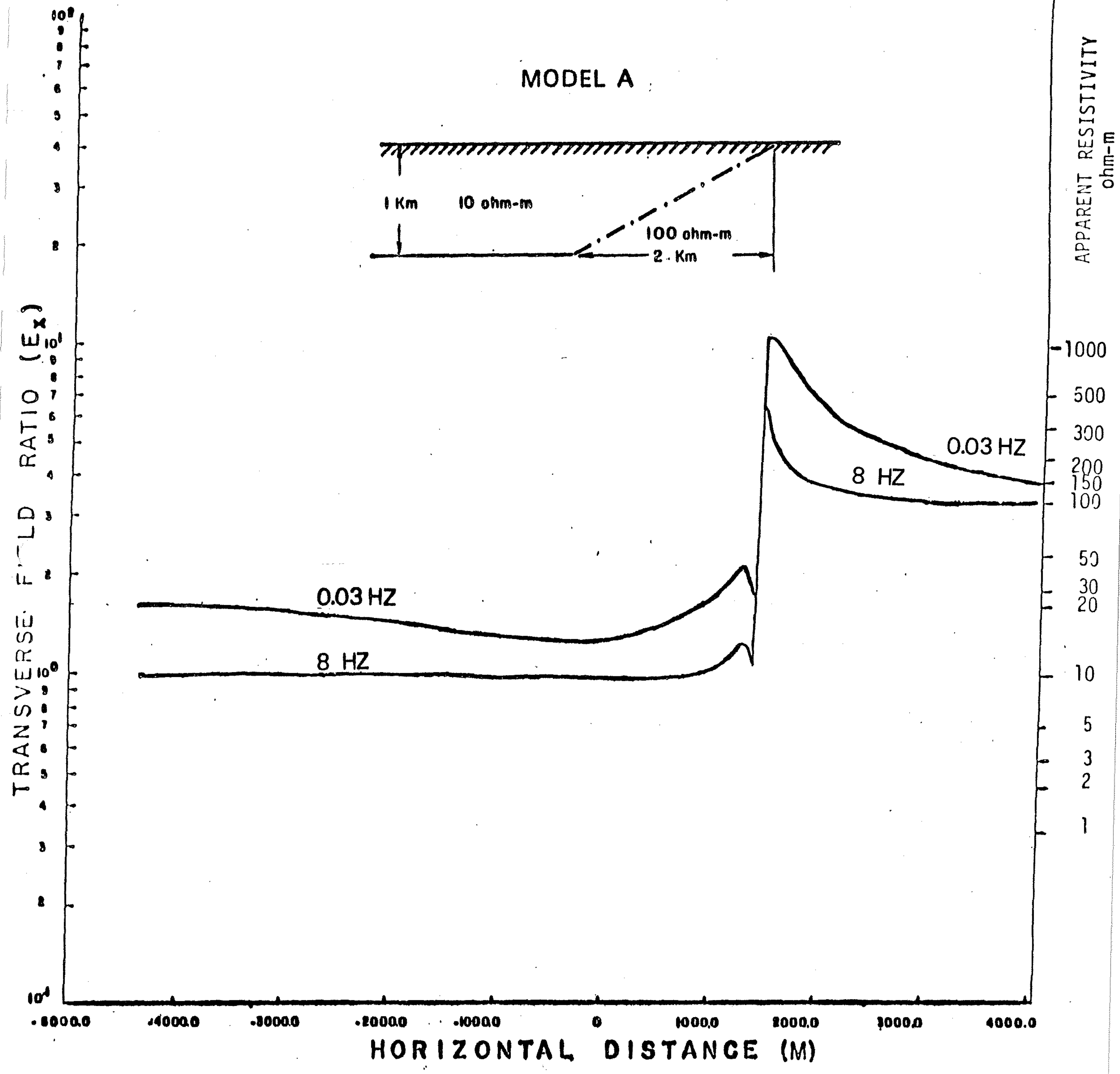


Figure A1. Telluric response at 8 Hz and at 0.03 Hz over Model A.

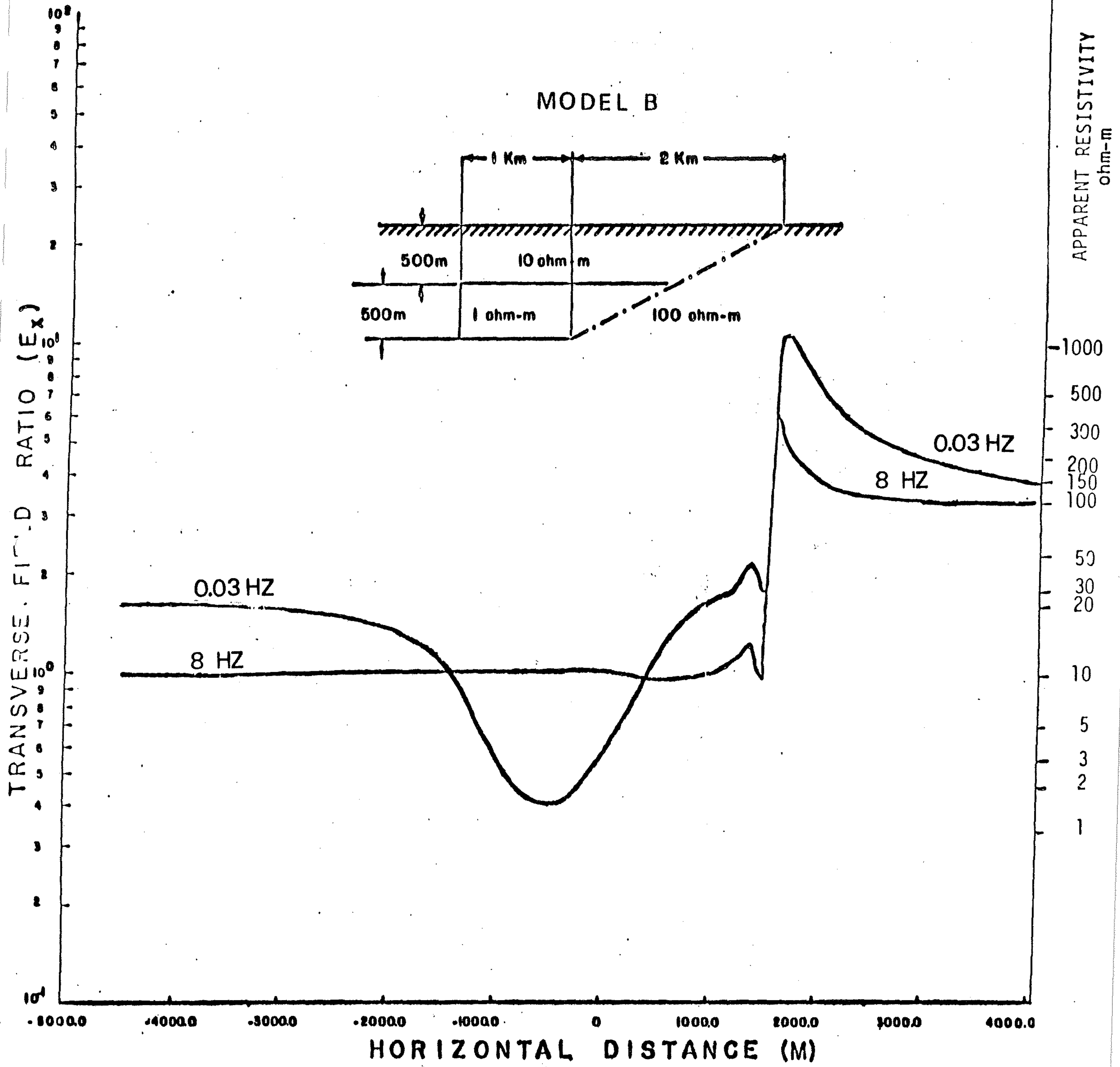


Figure A2. Telluric response at 8 Hz and at 0.03 Hz over Model B, inclusion of a one ohm meter body at 500 meters depth.

Appendix B

Personnel and Operations Summary

MONTH

August

TERRAPHYSICS

PROJECT Bieber, California

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S Hz 05	01	08	8		PERSONNEL MAZZELLA	PESSAH	GUZMAN	HARVEY	DONAHUE
Wed.	6th			Mobilization from Richmond, CA to Bieber, CA							X	X		
Thu.	7th			Equipment maintenance and survey area							X	X		
Fri.	8th	T	4	Line AA' Stations (ST) 8, 9, 10, 11	X			X			X	X		
		OT	--	Line AA' (Low signal level, poor data ST 5 and 2 orthogonals)	X						X	X		
Sat.	9th	T	3	Line AA' ST 12, 13, 14A (Low signal level, poor data ST 15)	X			X			X	X		
		OT	1	Line AA' (Low signal level ST 19A)	X						X	X		
Sun.	10th			Day off										
Mon.	11th	T	1	Line AA' (Low signal level, poor data ST 16, 17)	X			X			X	X		
		OT	1	Line AA' (Low signal level, poor data ST 25B) ST 19A	X						X	X		

TECHNIQUE CODES T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS

R - D.C. RESISTIVITY EM - ELECTROMAGNETIC (ACTIVE)

MONTH

August

TERRAPHYSICS

PROJECT Bieber, California

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S Hz .05	.01	.08	8		MAZZELLA	PESSAH	GUZMAN	HARVEY	DONAHUE
Tue.	12th	T	--	Line AA' (Low signal level, poor data ST 16, 17, 18, 19A)							X	X		
Wed.	13th	T	6	Line AA' ST 25, 27, 28, 29, 30, 31	X			X			X	X		
		OT	1	Line AA' ST 25B	X			X			X	X		
Thu.	14th	T	12	Line AA' ST 32, 25B, 16, 17, 18, 19A, 20, 21, 22, 23, 24, 25	X			X			X	X		
Fri.	15th	T	10	Line BB' ST 21, 22, 23, 24, 25, 26, 27, 28, 29, 30	X			X			X	X		
Sat.	16th	T	3	Line BB' ST 31, 32, 33 lightning storm in the afternoon	X			X			X	X		
Sun.	17th			Day off										

TECHNIQUE CODES T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS

R - D.C. RESISTIVITY EM - ELECTROMAGNETIC (ACTIVE)

MONTH

August

TERRAPHYSICS

PROJECT Bieber, California

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S Hz 05	01	08	8		MAZZELLA	PESSAH	GUZMAN	HARVEY	DONAHUE
Mon.	18th	T	--	Line CC' (Poor data because of the rain and lightning ST 11, 12) Data analysis and vehicle maintenance							X	X		
Tue.	19th	T	9	Line CC' ST 11, 12, 13, 14, 15, 16, 17, 18, 19	X			X			X	X		
Wed.	20th	T	2	Line DD' (Low signal levels, lightning activity ST 31, 32) Line DD' Survey stations and data analysis	X			X			X	X		
Thu.	21st	T	3	Line DD' (Rain and lightning ST 33, 34, 35) Data analysis	X			X			X	X		
Fri.	22nd	T	6	Line DD' ST 36, 37, 38, 39, 40, 41 2 stations were backpacked	X			X			X	X		
Sat.	23rd	T	3	Line DD' ST 42, 43, 44 Backpacked all 3 stations	X			X			X	X		

TECHNIQUE CODES T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS
R - D.C. RESISTIVITY EM - ELECTROMAGNETIC (ACTIVE)

MONTH

August

TERRAPHYSICS

PROJECT Bieber, California

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S Hz 05	01	08	8		MAZZELLA	PESSAH	GUZMAN	HARVEY	DONAHUE
Sun.	24th			Day off										
Mon.	25th	T	2	Line DD' ST 45, 46	X			X			X			X
		MT	4	Line AA' (15-16), (16-17), (24-25), (27-28) (Poor signals and correlation (15-16), (16-17), (24,25), local industrial noise)	X			X		X		X		
Tue.	26th	T	4	Line AA' ST 33, 34, 35, 36	X			X			X			X
		MT	5	Line AA' ST (9-10), (33-32); Line BB' ST (30-31) Low signals; Line CC' ST (12A-13), (Poor correlation (12A-12B)	X			X		X		X		
Wed.	27th	T	3	Line AA' ST 37, 38, 39	X			X			X			X
		MT	4	Line BB' ST (24-25), (30-31), (30B-30C) (East-West) Line CC' ST (17A-18) (Very windy, poor data)	X			X		X		X		
Thu.	28th	MT	2	Line CC' ST (17-18)	X			X			X	X		
				Line DD' ST (33-34) Survey west part of Lines AA' & CC'	X			X						X
Fri.	29th	T	7	Line AA' ST 1, 2, 3, 4, 5, 6, 7	X			X			X	X		X
		MT	2	Line AA' ST (0-1), (3-4)	X			X			X	X		X

TECHNIQUE CODES T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS

R - D.C. RESISTIVITY EM - ELECTROMAGNETIC (ACTIVE)

MONTH

August/Sept.

TERRAPHYSICS

PROJECT Bieber, California

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S Hz 05	0.1	0.8	8		PERSONNEL MAZZELLA	PESSAH	GUZMAN	HARVEY	DONAHUE
AUGUST Sat.	30th	T	3	Line AA' ST 16, 17	X			X			X	X		X
				Line CC' ST 10	X			X			X	X		X
		MT	1	Line AA' ST (16-17)	X			X			X	X		X
Sun.	31st			Day off										
SEPTEMBER Mon.	1st			Labor Day Holiday										
Tue.	2nd	T	--	Line CC' (Low signal level, poor data ST 9)							X	X		X
		MT	--	Line CC' ST (9-10)							X	X		X
Wed.	3rd	T	3	Line CC' ST 9, 8, 7	X			X			X	X		X
		MT	2	Line CC' ST (9-10), (6-7)	X			X			X	X		X
Thu.	4th	T	2	Line CC' ST 6, 5	X			X			X	X		X
				Line FF" (Poor signal level ST 5)	X			X			X	X		X

TECHNIQUE CODES T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS R - D.C. RESISTIVITY EM - ELECTROMAGNETIC (ACTIVE)

MONTH

September

TERRAPHYSICS

PROJECT Bieber, California

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S Hz 05	01	08	8		PERSONNEL MAZZELLA	PESSAH	GUZMAN	HARVEY	DONAHUE
Fri.	5th	T	6	Line FF" ST 5, 6, 7, 8, 9, 10 (To be repeated ST 11)	X			X			X	X		
		MT	1	Line FF" ST (4A-5)	X			X			X	X		
Sat.	6th	T	7	Line FF" ST 11, 12, 15, 16, 17 (8 hz is bad on ST 13, 14)	X			X			X	X		
		MT	2	Line FF" ST (10-11),[(8 hz is bad/windy ST (18-17)]	X			X			X	X		
Sun.	7th	T	2	Line FF" ST 13, 14	X			X			X	X		
		MT	1	Line FF" ST (17-18) (1/2 day field, 1/2 data and adm. work)	X			X			X	X		
Mon.	8th	T	5	Line FF" ST 1, 2, 3, 4B, 5	X			X			X	X		
		OT	1	Line FF" ST (0-1)	X						X	X		
		MT	2	Line FF" ST (0-A), (0-1)	X			X			X	X		
Tue.	9th	T	--	Line FF' (Rain, lightning, no data ST 50-51)							X	X		
		MT	--	Line FF' (Rain, lightning, no data ST 51)							X	X		
Wed.	10th	R	6	Line CC' ST 12 50' Wenner (W) & 1111' Line AA' ST 26-27, 940'W; 27-28, 820' W; 28-29, 955' W; 27, 50' W (Tried MT, lightning storm activity)							X	X		

TECHNIQUE CODES T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS

R - D.C. RESISTIVITY EM - ELECTROMAGNETIC (ACTIVE)

MONTH

September

TERRAPHYSICS

PROJECT Bieber, California

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S Hz .05	.01	.08	8		MAZZELLA	PESSAH	GUZMAN	HARVEY	DONAHUE
Thu.	11th	R	4	Line CC' ST 10 to 13 3333' W, 250' W & 100 W							X	X		
				Line CC' ST 17-18 880' W							X	X		
				(Lightning activity)										
Fri.	12th	T	3	Line FF' ST 51, 52, 53	X			X			X	X		
				(Lightning started at 12:30 P.M.)										
		R	1	Line CC' ST 12-13 600' W	X			X			X	X		
Sat.	13th	T	2	Line FF' ST 54, 55A (No good, ST 56)	X			X			X	X		
			1	Line FF' ST 55A	X			X			X	X		
		R	3	Line CC' ST 10-13 2400' W & 10' W 50' W at pumpkin center						X	X	X	X	
Sun.	14th	T	9	Line FF' ST 56, 57, 58	X			X			X	X		
				Line DD' ST 7, 8, 9, 10, 11, 12	X			X			X	X		
		MT	2	Line DD' ST (4-5), (12-13)	X			X		X			X	
Mon.	15th	MT	2	Line EE' ST (1-2A), (2A-2B)	X			X		X			X	
				(Heavy rain in the afternoon)										
				Line AA' ST 26, 28, 29 50' W										
		Mobilization		Pack equipment, mobilization to next job							X	X		
Tue.	16th	T	6	Line DD' ST 1, 2, 3, 4, 5, 6	X			X		X			X	
		OT	4	Line DD' ST 2, 39	X			X		X			X	
				Line AA' ST 5B, 25B	X			X		X			X	

TECHNIQUE CODES T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS

R - D.C. RESISTIVITY EM - ELECTROMAGNETIC (ACTIVE)

MONTH

September

TERRAPHYSICS

PROJECT Bieber, California

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S Hz 05	0.1	0.8	8		PERSONNEL MAZZELLA	PESSAH	GUZMAN	HARVEY	DONAHUE
Wed.	17th			Mobilization, return to office, Richmond, CA						X			X	

TECHNIQUE CODES T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS

R - D.C. RESISTIVITY EM - ELECTROMAGNETIC (ACTIVE)

MONTH

November/December

TERRAPHYSICS

PROJECT Bieber, California (Phase II)

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S Hz 05	0.1	0.8	8		PERSONNEL MAZZELLA	PESSAH	GUZMAN	HARVEY	DONAHUE
Fri.	14th			Mobilization to Bieber, CA							X	X		
Sat.	15th	T	4	Line XX' ST 2, 3, 4, 5	X			X			X	X		
		MT	1	Line XX' ST (2-3)	X	X	X	X			X	X		
Sun.	16th	T	2	Line XX' ST 6, 7 (Backpacked)	X			X			X	X		
		MT	1	Line XX' ST (7-8)	X	X	X	X			X	X		
Mon.	17th	MT	2	Line DD' ST (38-39) [(Industrial noise, poor data ST (9-10)]	X	X	X	X			X	X		
		R	2	Line DD' ST 39 50' W, 38-39 772' W							X	X		
Tue.	18th			Mobilization, left Bieber, CA							X	X		
DECEMBER														
Sun.	14th	R	6	Line AA' ST (18-19) 10', 50', 200', 500', 1000' Wenner						X				
				Line AA' ST (15-16) 500' W						X				

TECHNIQUE CODES T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS R - D.C. RESISTIVITY EM - ELECTROMAGNETIC (ACTIVE)

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WENNER ARRAY

BIEBER, CA

LINE CC

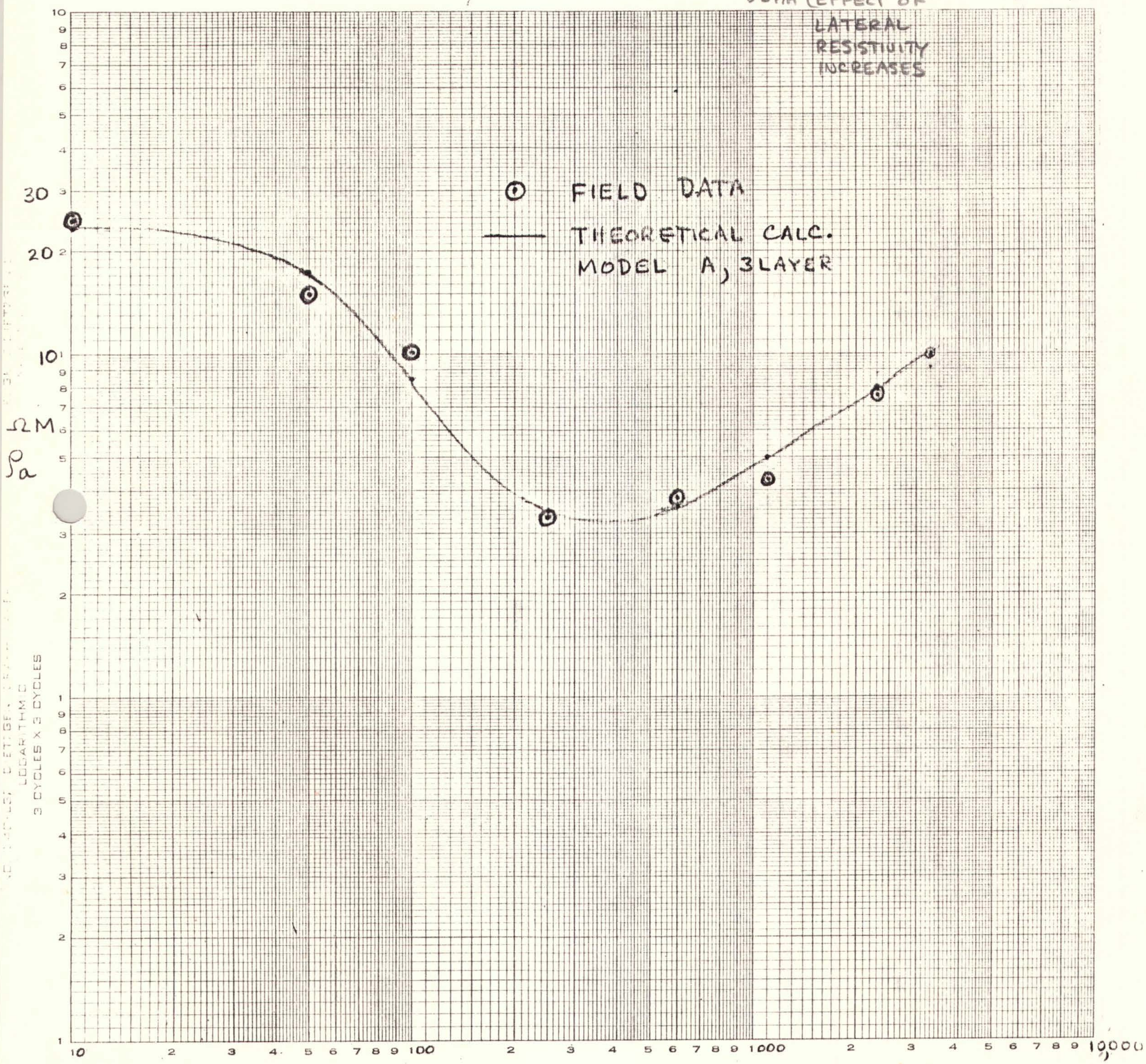
STATIONS 10 TO 13

MODEL A

h_1 = ~~48.9 ft~~ 14.9 m ρ_1 = 23.2 ΩM

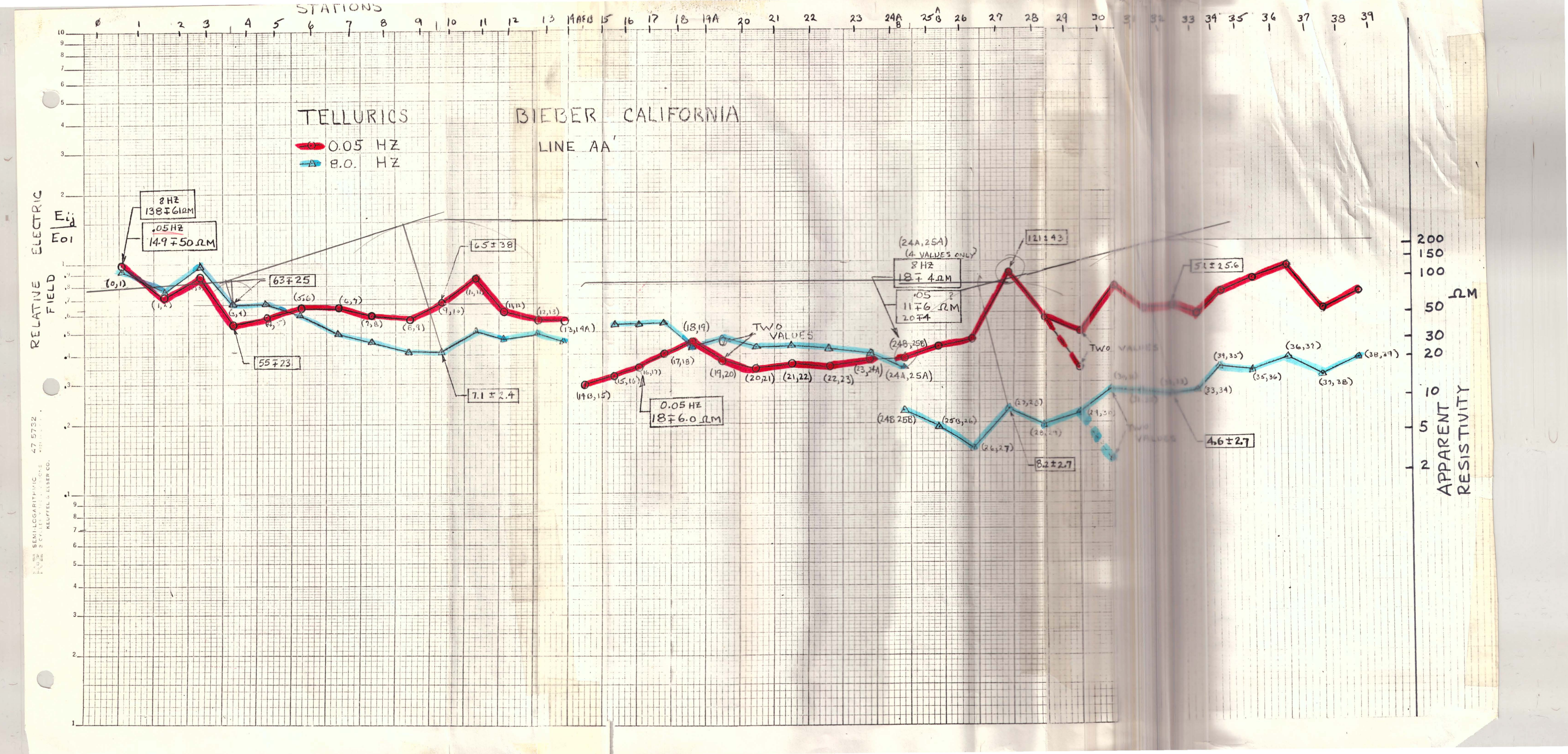
MAY BE GREATER DEPTH (EFFECT OF LATERAL RESISTIVITY INCREASES ← h_2 = 780 ft 238 m ρ_2 = 3.1 ΩM

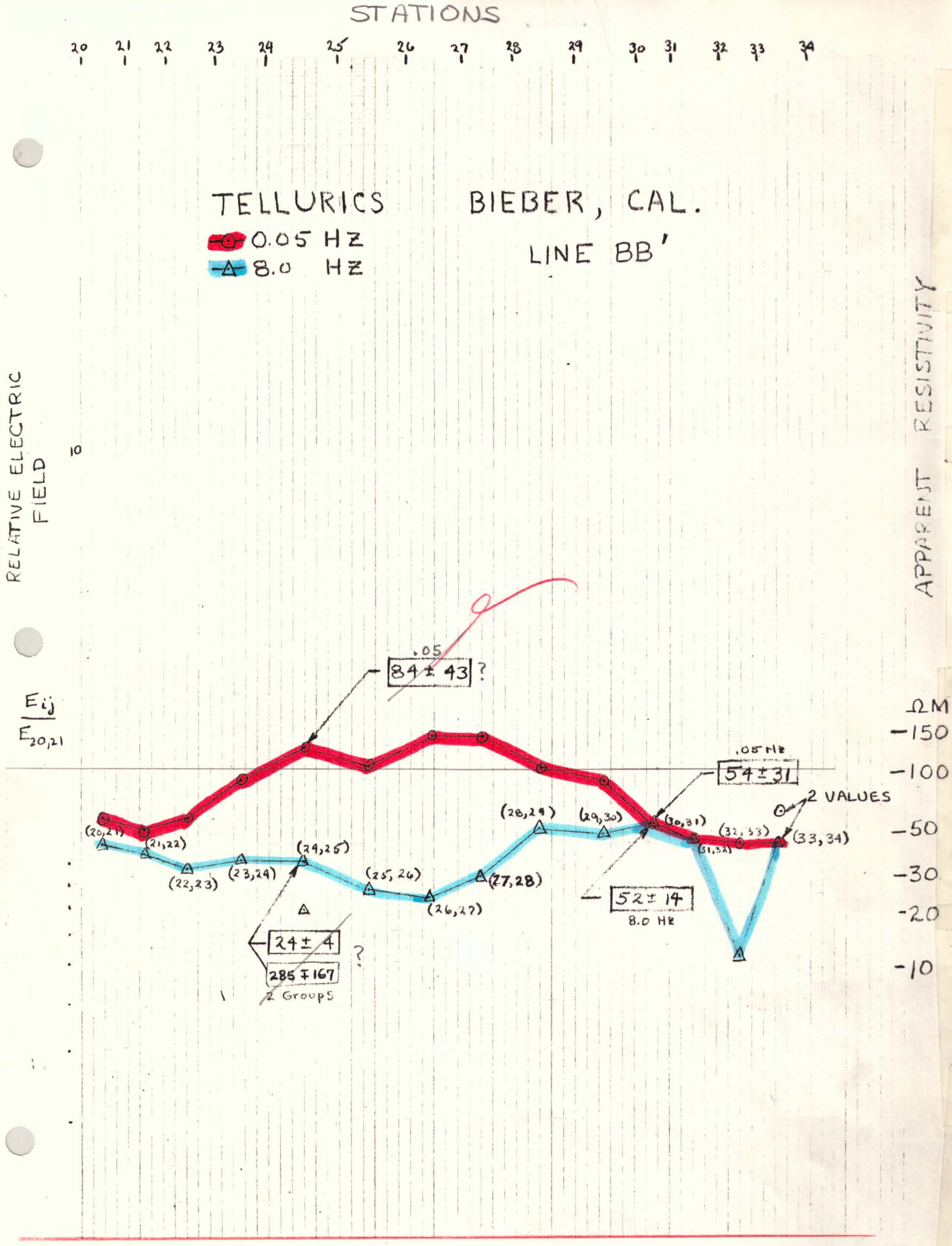
ρ_3 = 18.2 ΩM

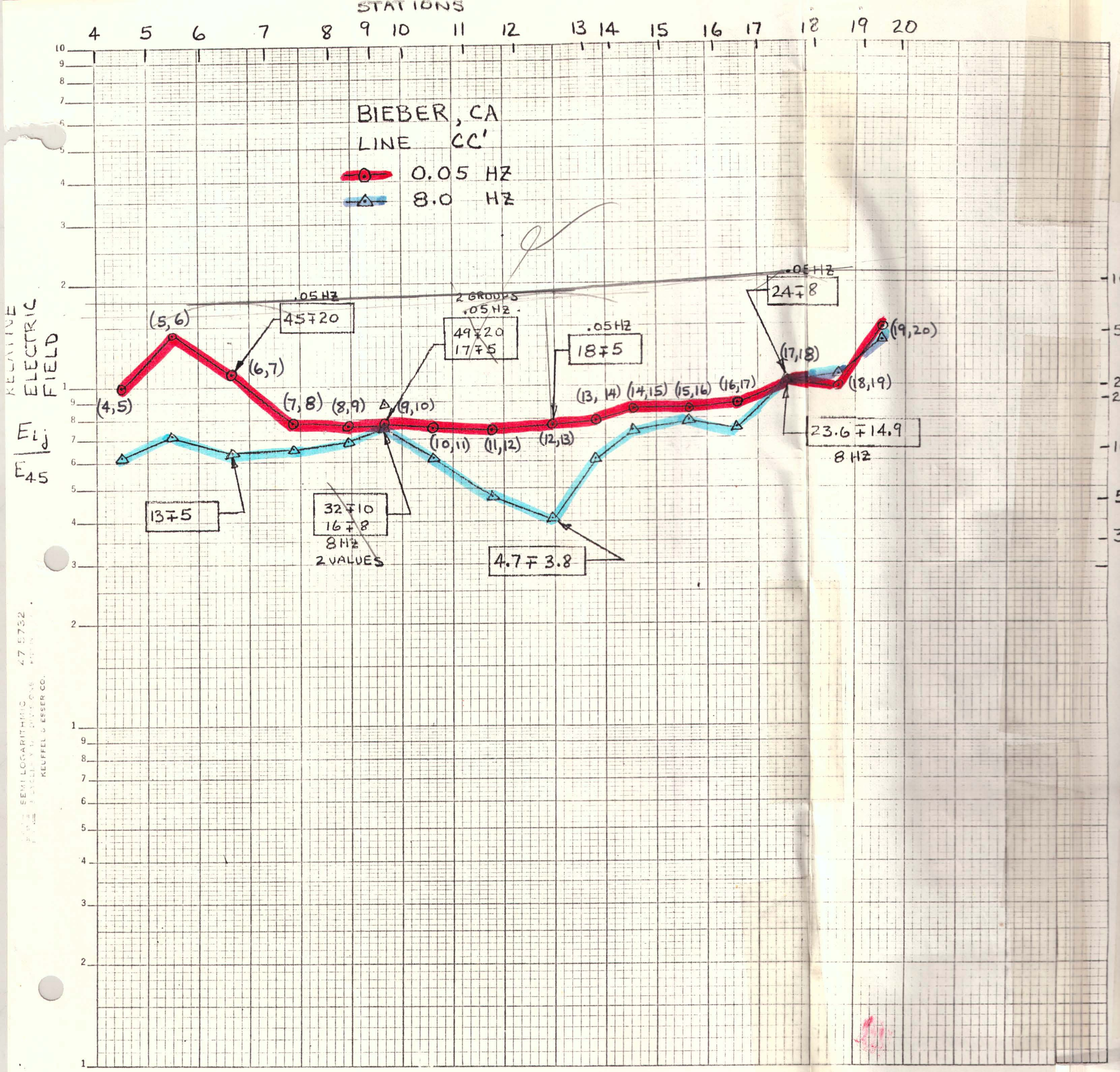


a FEET

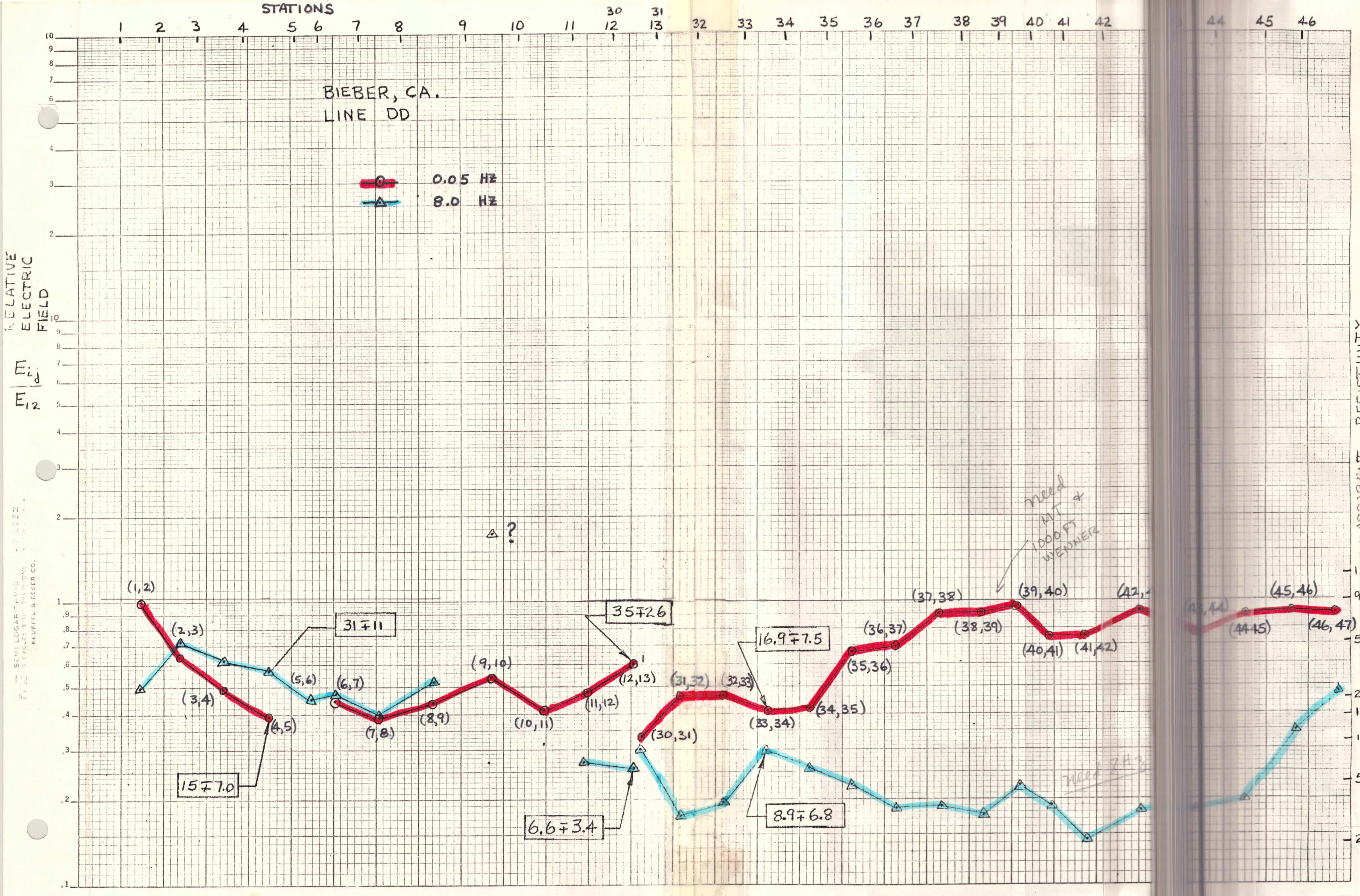
WENNER SPACING

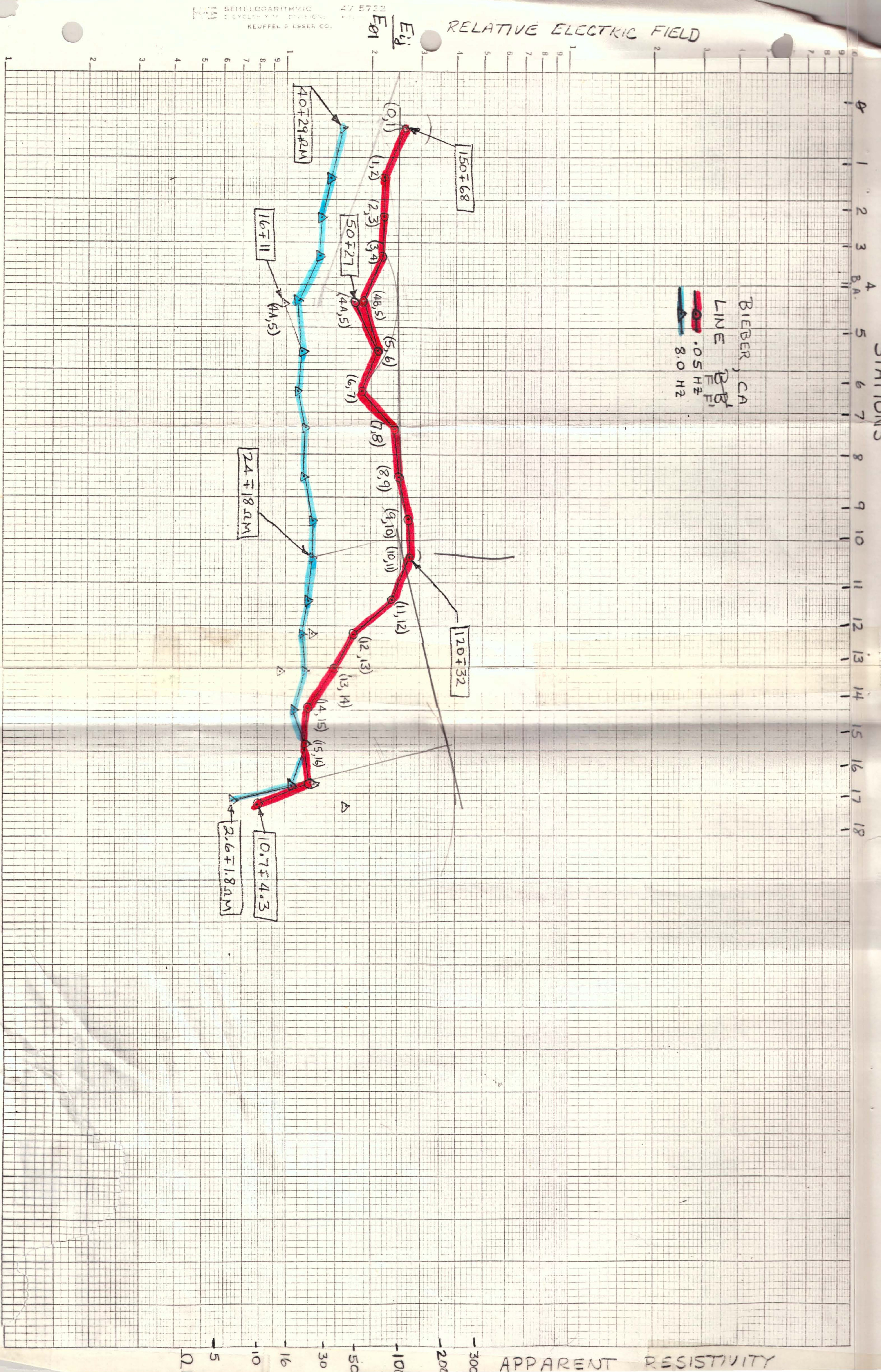

STATIONS
TELLURICS
BIEBER CALIFORNIA
LINE AA'
0.05 HZ
8.0. HZ
RELATIVE ELECTRIC FIELD
Eij / E01
8 HZ 138 ∓ 61 ΩM
.05 HZ 14.9 ∓ 50 ΩM
63 ∓ 25
55 ∓ 23
65 ∓ 38
7.1 ± 2.4
0.05 HZ 18 ∓ 6.0 ΩM
TWO VALUES
(24A, 25A) (4 VALUES ONLY)
8 HZ 18 ∓ 4 ΩM
.05 11 ∓ 6 ΩM 20 ∓ 4
121 ± 43
51 ± 25.6
TWO VALUES
8.2 ± 2.7
4.6 ± 2.7
ΩM
APPARENT RESISTIVITY


STATIONS
20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
TELLURICS BIEBER, CAL.
0.05 HZ
8.0 HZ
LINE BB'
RELATIVE ELECTRIC FIELD
10
APPARENT RESISTIVITY
Eij / E20,21
ΩM
150
100
50
30
20
10
.05
84 ± 43 ?
.05 Hz
54 ± 31
2 VALUES
(20,21)
(21,22)
(22,23)
(23,24)
(24,25)
(25,26)
(26,27)
(27,28)
(28,29)
(29,30)
(30,31)
(31,32)
(32,33)
(33,34)
52 ± 14
8.0 Hz
24 ± 4
285 ∓ 167
2 Groups
?

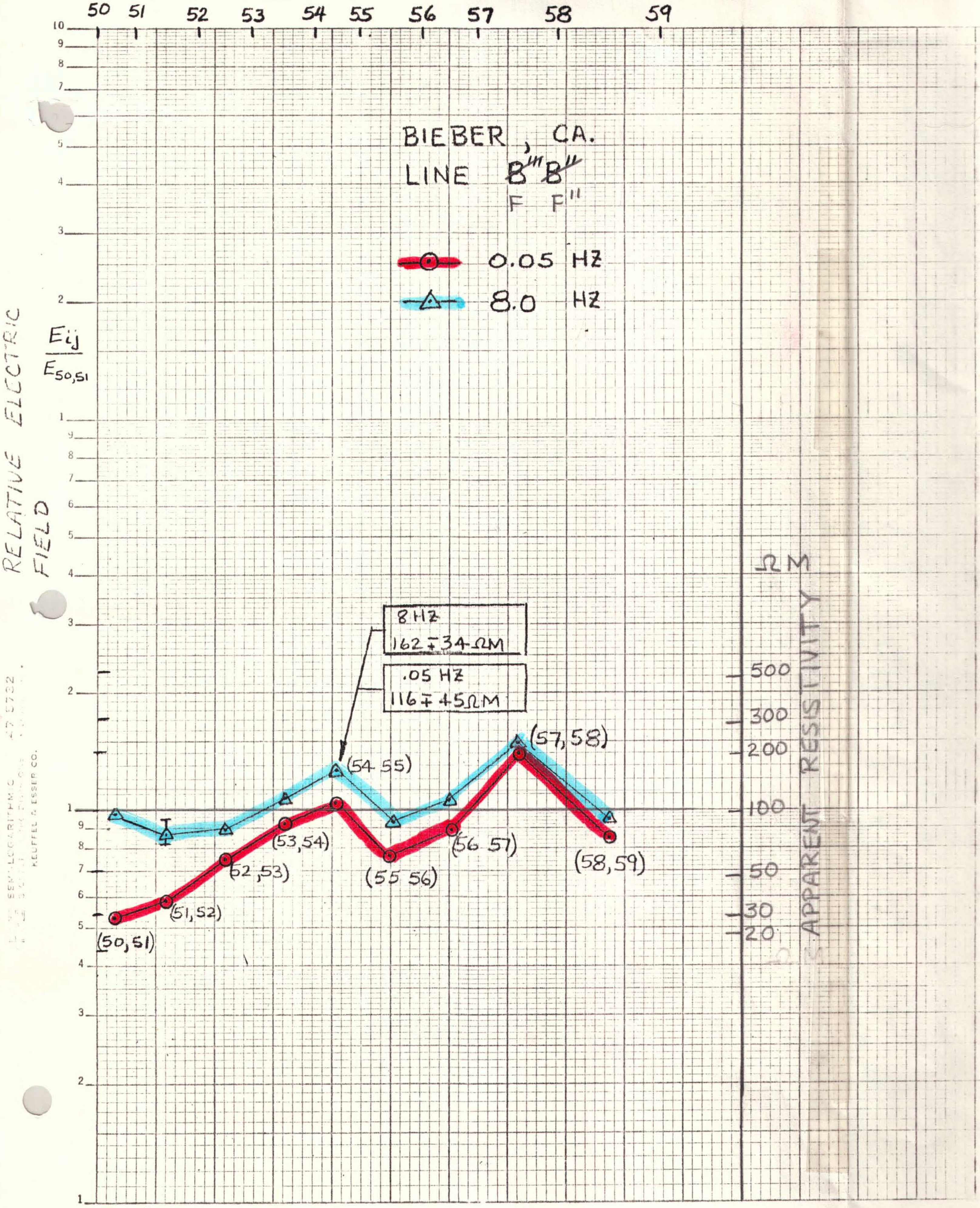


STATIONS
BIEBER, CA
LINE CC'
0.05 HZ
8.0 HZ
RELATIVE ELECTRIC FIELD
E_{ij}/E_{45}
(4,5)
(5,6)
(6,7)
(7,8)
(8,9)
(9,10)
(10,11)
(11,12)
(12,13)
(13,14)
(14,15)
(15,16)
(16,17)
(17,18)
(18,19)
(19,20)
.05 HZ
45∓20
2 GROUPS
.05 HZ
49∓20
17∓5
.05 HZ
18∓5
.05 HZ
24∓8
23.6∓14.9
8 HZ
13∓5
32∓10
16∓8
8 HZ
2 VALUES
4.7∓3.8
KEUFFEL & ESSER CO.


STATIONS
BIEBER, CA.
LINE DD
0.05 HZ
8.0 HZ
RELATIVE ELECTRIC FIELD
$\frac{E_{ij}}{E_{12}}$
APPARENT RESISTIVITY Ω M
31 ∓ 11
35 ∓ 26
16.9 ∓ 7.5
15 ∓ 7.0
6.6 ∓ 3.4
8.9 ∓ 6.8
need MT & 1000 FT WENNER
SEMI-LOGARITHMIC
KEUFFEL & ESSER CO.



RELATIVE ELECTRIC FIELD
$\frac{E_{ij}}{E_{01}}$
STATIONS
BIEBER, CA
LINE
.05 Hz
8.0 Hz
150∓68
40∓29 ΩM
50∓27
16∓11
24∓18 ΩM
120∓32
10.7∓4.3
2.6∓1.8 ΩM
APPARENT RESISTIVITY
Ω



50 51 52 53 54 55 56 57 58 59
BIEBER, CA.
LINE B'''B'' F F''
0.05 HZ
8.0 HZ
RELATIVE ELECTRIC FIELD
Eij / E50,51
8 HZ
162 ∓ 34 ΩM
.05 HZ
116 ∓ 45 ΩM
(50,51)
(51,52)
(52,53)
(53,54)
(54 55)
(55 56)
(56 57)
(57,58)
(58,59)
ΩM
APPARENT RESISTIVITY
500
300
200
100
50
30
20
KEUFFEL & ESSER CO.