GL02300

DOE/ET/28392-35
78/1701.b.1.2.4
ESL-25

INTERPRETATION OF ELECTRICAL RESISTIVITY AND SHALLOW SEISMIC REFLECTION PROFILES, WHIRLWIND VALLEY AND HORSE HEAVEN AREAS, BEOWAWE KGRA, NEVADA

Christian Smith

December, 1979

EARTH SCIENCE LABORATORY
UNIVERSITY OF UTAH RESEARCH INSTITUTE
420 Chipeta Way, Suite 120
Salt Lake City, UT 84108

Prepared for the
DEPARTMENT OF ENERGY
DIVISION OF GEOTHERMAL ENERGY
UNDER CONTRACT NO. AC07-78ET-28392

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ABSTRACT

Numerical modeling and analysis of surface electrical and seismic data from the Beowawe KGRA, north-central Nevada, permit extrapolation of mapped geologic units and structures to approximately a mile (1.6 km) depth from which inferences about the geothermal system can be made. Detailed numerical modeling was completed for 78 line-mi. (125 km) of dipole-dipole resistivity data and includes compensation for topographic effects caused by the Malpais Rim scarp. The interpreted sections have as many as five distinct electrical units, one of which occurs only within the area of hydrothermal alteration along the fault set at the base of the Malpais Rim. The weight-drop seismic reflection data show numerous normal faults sub-parallel to the Malpais Rim within Whirlwind Valley west and southwest of The Geysers.

A 1,500 ft (450 m) thick zone of low resistivity at the surface northeast of The Geysers deepens to 2,000 ft (600 m) below the surface at the two Chevron Resource Co. exploration wells southwest of The Geysers. This suggests that the post-Miocene east-northeast fault set at the base of the Malpais Rim is not a conduit for hot water at shallow depths to the southwest of The Geysers. The north-northwest-striking Miocene Dunphy Pass fault zone, immediately east of The Geysers, does display low resistivities at depths greater than 2,000 ft (600 m) and may provide a deep-seated path for upwelling geothermal water to the Malpais Rim fault set.

A widespread conductive anomaly in Horse Heaven appears to be distinct from the anomaly at The Geysers. The resistivity interpretation cannot determine whether this three- by two-mile area (5 x 3 km) represents a thick

sequence of rock saturated with hot water, or carbonaceous or altered units within the Ordovician Valmy Formation. Any vast, deep geothermal reservoir lies below the depth of resolution of these surveys.

INTRODUCTION

The Beowawe geothermal system in the Whirlwind Valley, Eureka and Lander Counties, Nevada, is six miles (10 km) southwest of the town of Beowawe (Figure 1) and lies within The Battle Mountain heat flow high of north-central Nevada. The Geysers have been the subject of curiosity for years (Rinehart, 1968) and the geothermal system the subject of intermittent exploration activity since 1959. Initial exploration focused on the area within and immediately adjacent to The Geysers area (Figure 2). Drilling has encountered a reservoir of 200°C fluid at depths less than 1,000 ft (300 m) (Oesterling, 1962).

The surface expression of the Beowawe geothermal system is a 0.75 sq mi (2 sq km) sinter terrace with two clusters of hot springs, fumaroles, and weakly active geysers. Present natural geyser activity is weak due to the recent uncapping of wells on the terrace which eject water and steam to heights of 30 ft (10 m). Several hot springs boil at 95°C (Rinehart, 1968) and various chemical geothermometers indicate reservoir temperatures ranging from 200°C to 250°C (Muffler, 1978).

Garside and Schilling (1979) review the setting and hydrogeology of the Beowawe geothermal system. Zoback (1979) presents a generalized geologic map and an account of the geologic history of the region, and discusses qualitatively the results of gravity, magnetic, passive seismic, self-potential, and bipole-dipole resistivity data. Swift (1979) gives a brief, semi-quantitative assessment of the geophysical surveys conducted for Chevron Resources Co. in the Beowawe area. Struhsacker (in preparation) presents a detailed geologic map and discusses the structural patterns in the KGRA.

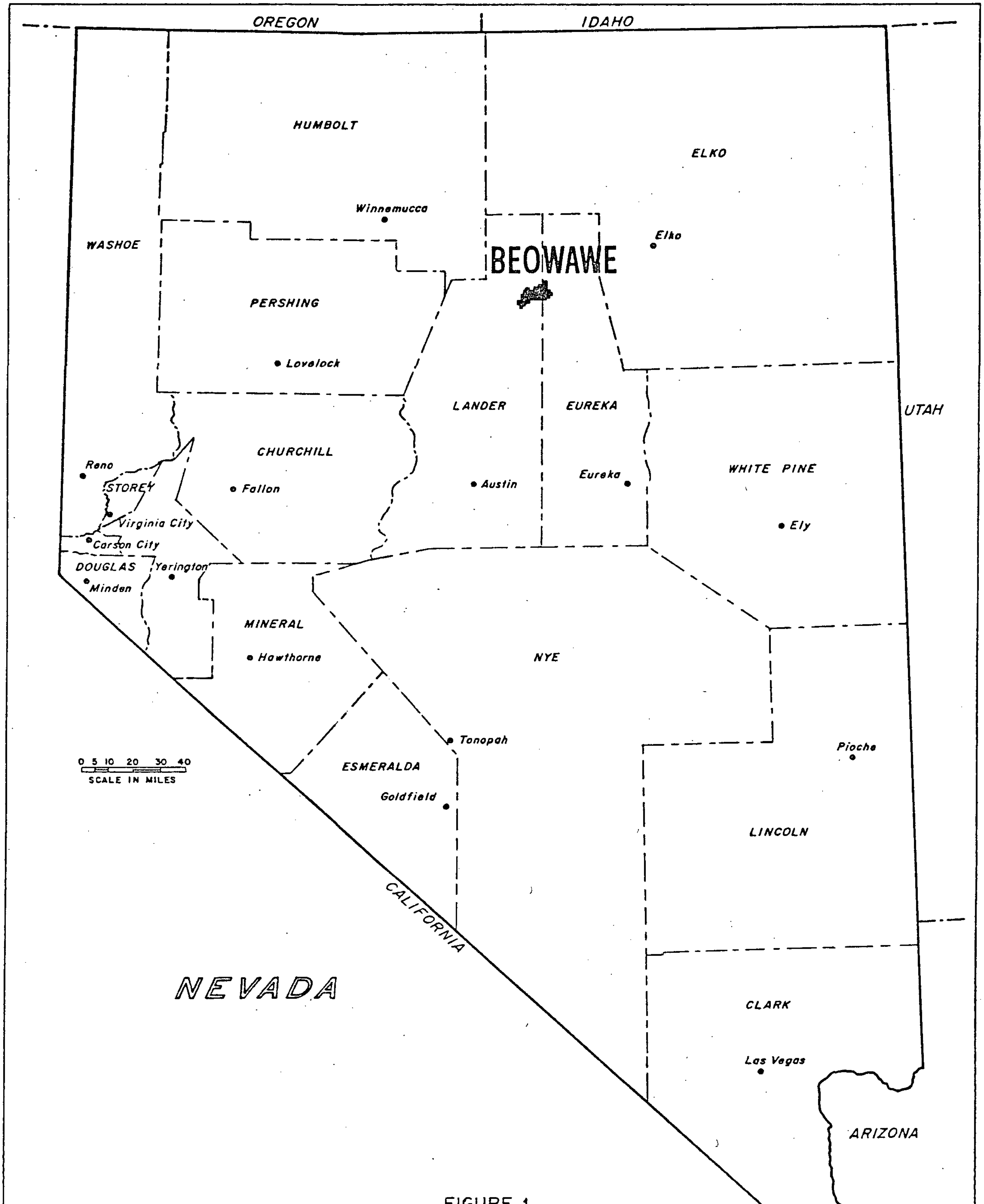

FIGURE 1
LOCATION MAP
BEOWAWE KGRA

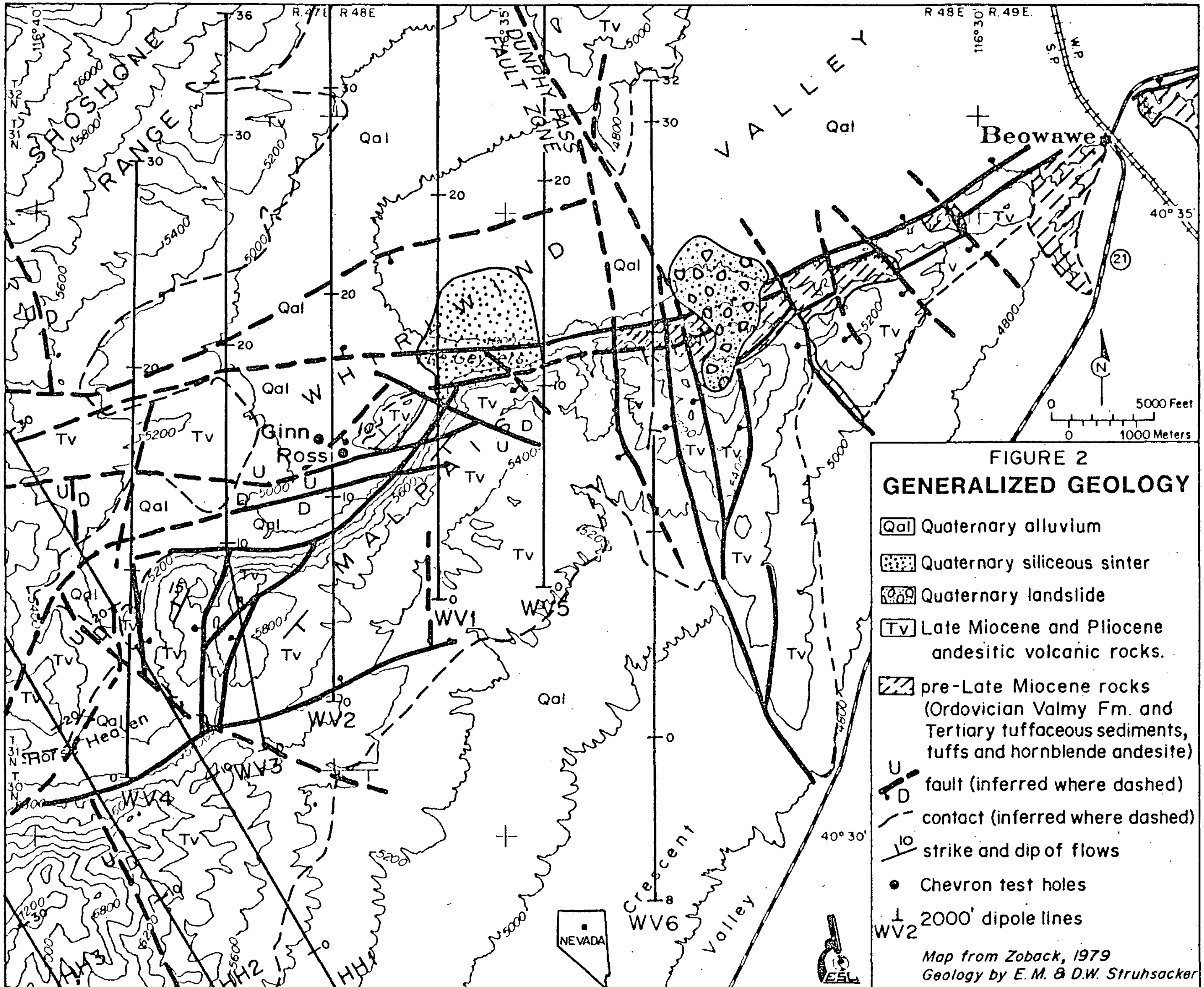

FIGURE 2
GENERALIZED GEOLOGY

Chevron Resources Co. has drilled two deep wells 1.0 mi (1.6 km) southwest of The Geysers, expanding the area of exploration interest. The dipole-dipole resistivity and weight-drop seismic data analyzed here were collected for Chevron Resources Co., and are now in the public domain as part of the Department of Energy/Division of Geothermal Energy's Industry Coupled Case Studies Program. The modeling and interpretation were funded by contract AC07-78ET-28392 as was the detailed geologic mapping of Struhsacker (in preparation). Smith et al. (1979) present an overview of the similarities between the lithologic and structural patterns as inferred from outcrop and geophysical evidence. These papers and this topical report will contribute to a comprehensive case study of the Beowawe KGRA area by the Earth Science Laboratory (ESL).

GEOLOGIC SETTING

During the late-Paleozoic Antler Orogeny, the Roberts Mountain Thrust placed at least 5,000 ft (1.4 km) of eugeosynclinal sediments, the Valmy Formation, over autochthonous miogeosynclinal carbonates. The cherts, sandstones, shales, and quartzites of the Valmy Formation are riddled with highly magnetic diabase dikes. The dikes are likely to be genetically associated with the 4,000+ ft (1.2 km) of Tertiary andesite flows that are widely exposed in the KGRA. The andesite rocks filled a north-northwest-striking mid-Miocene rift or trough (Stewart et al., 1975) that is bounded on the northeast by the north-northwest-trending Dunphy Pass fault zone (Struhsacker, in preparation), (Figure 2). A drastically thinned 200 to 500 ft (60 to 150 m) section of volcanic rock extends east of the boundary fault zone. The flows gradually taper in thickness from The Geysers toward the southwest end of Horse Heaven.

The Malpais Rim fault zone developed after the eruption of the volcanic pile and is one of several east-northeast-striking fault zones in north-central Nevada. A complex set of steeply inclined normal faults vary in strike from east-northeast to north-south, creating the Malpais Rim scarp slope and causing the subsidence of Whirlwind Valley and Horse Heaven. The general inclination of the Malpais Rim dip slope is about 5° to 10° southeast. The orientations of these faults accommodate two cusps in the overall east-northeast trend of the Malpais Rim. The Geysers occur at one of these cusps in an area where several fault patterns intersect. A set of steeply dipping east-northeast-trending faults controlling the Malpais Rim scarp slope apparently carry hot fluid to the surface. A similar fault may control hot springs at the foot of the terrace. Northwest and west-northwest-trending vertical faults may limit the northeastern and southwestern extent of present thermal activity at the surface. At the southwest end of the terrace, the Malpais scarp curves to the south-west; however, elements of the east-northeast fault set appear to continue westward into the valley, creating a subtle horst-like structure (Smith et al., 1979).

North-south-trending faults at the east end of Horse Heaven deflect the Malpais Rim from its general northeasterly trend. The structural complexity there offers potential for upward migration of thermal fluids, but no thermal features are found on the surface.

Uplift along the Malpais scarp east of the Dunphy Pass fault zone exposes the Valmy Formation, a swarm of the chalcedony-carbonate veins, and broad areas of silicification, argillization, and brecciation. Apparently, the faults controlling the Malpais scarp also served as conduits for hydrothermal fluids earlier in the evolution of the scarp.

GEOPHYSICAL SETTING

The mid-Miocene rift is a deep-seated fracture zone that has undergone both tensional and strike-slip movement (Stewart et al., 1975). It displays a prominent aeromagnetic high that extends from south-central Eureka County, Nevada, through the northern Shoshone Range five miles (8 km) west of The Geysers to near the Nevada-Oregon border. The highly magnetic diabase dikes that cut the Paleozoic section and fed the andesitic flows are presumably the source of the aeromagnetic anomaly (Stewart et al., 1975). Magnetotelluric tensor resistivities show a pronounced electrical anisotropy at low frequencies, with an electrical strike north-northwest, parallel to the trend of the diabase dikes (Swift, 1979). The Dunphy Pass fault zone is associated with a prominent seismic groundnoise anomaly (Earth Science Laboratory, 1979) and a low-resistivity zone (this report) southeast of The Geysers. Thus it appears that several geophysical techniques respond to the regional north-northwest structural grain. Others respond to the nearly perpendicular fault zone at the base of the Malpais Pass. Swift (1979) reports that an SP survey yielded a 500 mv (peak to peak) asymmetric dipolar anomaly over the area of The Geysers and best delineates the local convection system. These and other data will be addressed in an ESL case study and are beyond the scope of this report.

Two of the three resistivity surveys interpreted in this report were conducted and qualitatively interpreted by McPhar Geophysics, Inc., in July and November, 1974. The six dipole-dipole lines from these McPhar surveys cross the Malpais Rim and Whirlwind Valley, striking north-south, and are designated by the abbreviation WV for Whirlwind Valley. The third survey was completed by Phoenix Geophysics, Inc., in September, 1976. Four lines strike northwest across Horse Heaven and are designated by the abbreviation HH. The active seismic survey was carried out and discussed in 1975 by C. B. Reynolds, Inc.

RESISTIVITY INTERPRETATION

General

The ten dipole-dipole resistivity lines have been interpreted through an interactive, iterative computer modeling process. A two-dimensional geometry is assumed (infinite strike length perpendicular to the survey lines) and intrinsic resistivity values assigned for each body. The corresponding apparent resistivity values are computed by a finite-element program initially developed by Luiz Rijo (1977) and subsequently modified by the Earth Science Laboratory (Killpack and Hohmann, 1979). 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 compared by the interpreter with the observed data to determine the quality 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.

The finite-element model computes all the resistivity/PFE data values for a standard dipole-dipole 7 spread (i.e., for 7 transmitter electrodes). For observed profiles with larger spreads or multiple spreads it is necessary to generate several overlapping model geometries to simulate the observed data.

After several model iterations (2 to 9 in the present study), the interpreter obtains a satisfactory approximation to the observed data and through a comparison of the last several iterations develops an awareness of the sensitivity of the model to small changes attributable to probable non-two-dimensional aspects of the field data, questionable field data values, and the degree of ambiguity in the model. Some adjustment of the overlapping model geometries and electrical properties is required to complete the interpretation of the observed profiles.

The Malpais Rim has as much as 800 ft of relief and slopes as great as 30^{o}. The Horse Heaven ridge has as much as 1,600 ft of relief and slopes as great as 25^{o}. This topography has a marked effect on the observed apparent resistivities. Where slopes exceed 10^{o}, this topographic effect is matched mathematically in the interactive computer modeling process through the use of non-standard finite-element meshes and by assigning a high resistivity (10^5

ohm-m) to the "air" portion of the mesh. Figure A1 shows the calculated apparent resistivities for a 100 ohm-m homogeneous earth for the topography crossed by Line WV 2 (slope length 600 ft, slope angle 24°). The topographic effect is most extreme along the diagonals corresponding to the dipole located upon the slope. It is apparent that erroneous interpretations could easily be made if the terrain were not included in the model. For a more detailed discussion of topographic effects, see Fox et al. (1978).

The interpreted resistivity sections and the observed apparent resistivities for the lines that cross the Malpais Rim are shown on Plate 1; the lines that cross Horse Heaven on Plate 2. Plates 3-5 present the interpreted intrinsic resistivities at three key depth-elevation horizons: near-surface (0-400 ft depth), 3,000 ft elevation (2,000-3,000 ft depth), and 1,000 ft elevation (4,000-5,000 ft depth). The distribution of resistivities shown on Plate 5 is more speculative than those shown on Plates 3 and 4. This is due to the ambiguities in the observed data at N=6 and the uncertain resolution of the modeling at the depth interval 2.0 to 2.5 a.

A representative interpreted resistivity section across the Whirlwind Valley is shown in Figure 3 and summarized in Table 1. Lithologic logs from the nearby Chevron wells (Struhsacker, in preparation) provide control for the interpreted resistivity section which shows five distinct electrical units.

FIGURE 3

INTERPRETED ELECTRICAL CROSS-SECTION: LINE WV2

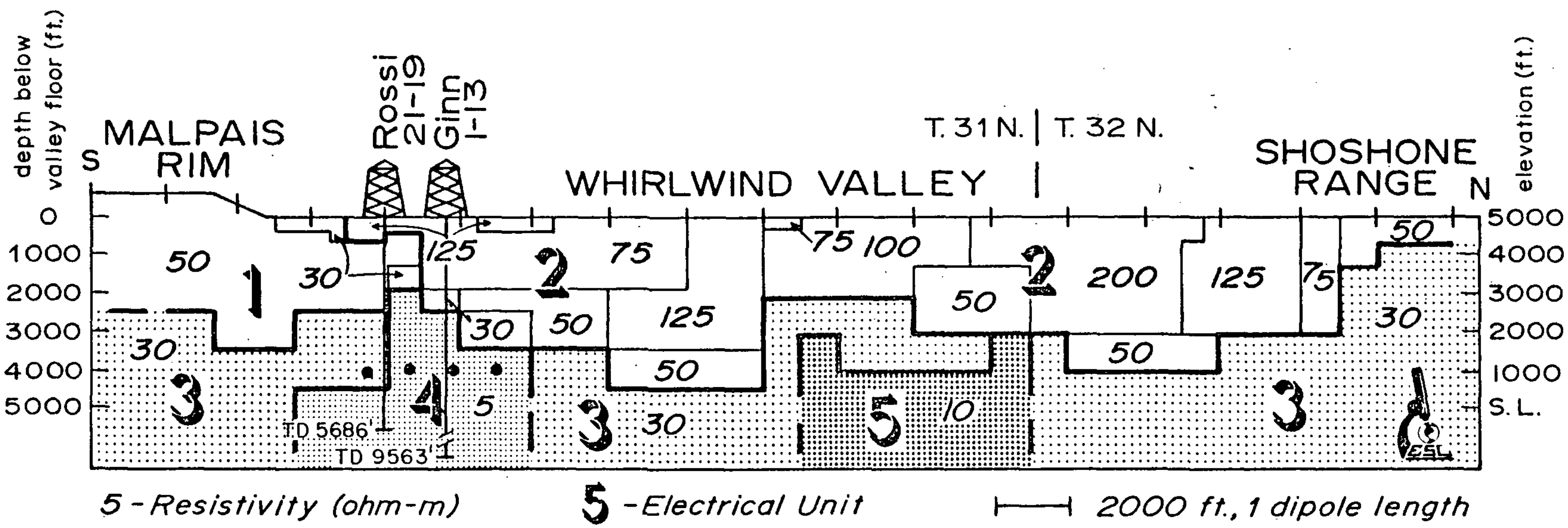

TABLE 1

ELECTRICAL UNITS AND CORRELATIVE LITHOLOGIES

Electrical Unit	Interpreted Intrinsic Resistivity (ohm-m) average	range	Correlative Lithology
1	50	35-200	Tba: Tertiary basaltic andesite.
2	100	50-250	Basalts and basaltic andesite.
3	30	20-40	Ordovician Valmy Fm. (Ov).
4	10	5-15	Hydrothermal zone, altered Tba and Ov.
5	10	5-15	Possible hydrothermal zone.

Electrical Units 1 and 2

The first two electrical units represent the resistive Miocene andesitic flow rocks. Two electrical units are needed to distinguish a subtle, and perhaps significant, variation in the resistivity of these rocks: the volcanic rocks of the Malpais Rim, electrical unit 1, consistently have a lower resistivity than do those within the Whirlwind Valley (Plate 1) and Horse Heaven (Plate 2), electrical unit 2. The only exception to this general rule occurs at The Geysers and down the hydraulic gradient from The Geysers (Lines WV 1 and WV 5, Plates 1 and 3). The shallow low resistivities reveal that the first few hundred feet of sinter and volcanic rock are saturated with the water that erupts at The Geysers. The shallow zone of hot water does not appear to affect the resistivity data further to the east, along Line WV 6 (Plates 1 and 3).

Electrical unit 1 is identified only on the lines that cross the Malpais Rim. This unit may indicate the limits of diffusion of hot water within the Rim. Permeable zones within the volcanic sequence -- breccia, rubble or fractured flows -- may allow the hot water to flow down-dip to the south or southeast, toward the Crescent Valley. Alternately, they may form channels for upwelling thermal fluids. Regardless of the direction of water flow, the series of faults within the Dunphy Pass fault zone and the numerous cross-faults south of The Geysers (Figure 2) appear to enhance the permeability and reduce the resistivity of the basaltic andesite of the Malpais Rim.

The highest interpreted resistivities that can be traced across the Beowawe area (50-250 ohm-m) belong to the andesitic rocks within the Whirlwind Valley, electrical unit 2. This unit reaches a maximum inferred thickness of more than 4,000 ft (1.2 km) in an east-west-trending graben less than 1.0 mi (1.6 km) north of the two Chevron wells (Plates 1, 4, and 5). The wells penetrated slightly more than 4,000 ft (1.2 km) of andesitic rocks of which the lower 2,000 ft (0.6 km) are hydrothermally altered (Struhsacker, in preparation). The alteration may explain why the interpreted section for WV 2 (Figure 3 and Plate 1) does not show a full 4,000 ft (1.2 km) of high resistivity (electrical unit 2) directly below the extrapolated position of the wells. Electrical unit 4, altered volcanic and sedimentary rocks, appears at approximately the same depth as the alteration.

Electrical unit 2 can be identified along all lines except the easternmost, Line WV 6 (Plate 1). Line WV 6 crosses the Dunphy Pass fault zone where the volcanic rocks thin so abruptly that they cannot be resolved with 2,000 ft dipoles. A more gradual thinning of the basaltic andesite to the southwest and west occurs within the Whirlwind Valley and Horse Heaven. Electrical unit 2 is rarely more than 1,000 ft (0.3 km) thick along Lines HH 2-4 (Plates 2-4). The westward thinning of the basaltic andesite has been noted by Zoback (1979) and Struhsacker (in preparation).

Electrical Unit 3

The third electrical unit shown in Figure 3 underlies electrical units 1 and 2 and appears in every interpreted section (Plates 1 and 2). This unit corresponds to the Ordovician Valmy Formation, a eugeosynclinal sequence that is significantly more conductive than the overlying basaltic andesite. The low resistivity suggests that the more carbonaceous members of the formation dominate its electrical response. The contacts between the resistive and conductive horizons shown in Figure 3 and Plates 1 and 2 should not be construed to illustrate precisely the Ordovician-Tertiary unconformity. Figure 3 contains several transitional 50 ohm-m bodies between the high resistivities of the volcanic rocks and the low resistivities of the meta-sedimentary rock. The transitional resistivity values may correspond to layers of quartzite or chert at the top of the Ordovician section, or to tuffaceous sediments at the base of the Tertiary section, or to ambiguities of the numerical modeling. The depth extent of the transitional resistivity values indicates the range in uncertainty of the depth of the unconformity.

The depth to electrical unit 3 increases from north to south, reflecting the known regional southeasterly dip (Smith et al., 1979). The offset along the fault set at the base of the Malpais Rim is reflected in several of the interpreted sections on Plate 1. Other abrupt offsets in the depth to electrical unit 3 (e.g., Line WV 4, Plate 2) are also thought to represent deep faulting. These offsets have been used to extrapolate mapped faults within the Whirlwind Valley and Horse Heaven (Smith et al., 1979). The geologic map, Figure 2, indicates the location of the extrapolated faults inferred from the geophysical modeling with a dashed pattern. The faults appear to have a normal sense and few are thought to flatten out at depths less than 3,000 ft (1.0 km).

Electrical Unit 4

The east-northeast fault at the base of the Malpais Rim has been thought to control the occurrence of The Geysers by all previous workers in the area (Nolan and Anderson, 1934; Oesterling, 1962; Zoback, 1979). The anomalously low resistivities of electrical unit 4 occur only in The Geysers area (Plate 1) and may therefore indicate the depths at which this fault set is permeable or has undergone intense hydrothermal alteration. Along Line WV 6 (Plates 1 and 5), a 5 ohm-m body that can only tentatively be assigned to electrical unit 4 appears at depths greater than 3,000 ft (1.0 km). It underlies a 300 ohm-m body that coincides with an outcrop of brecciated, highly silicified Valmy siltstone and quartzite, Figure 2, and may reflect alteration or primary lithology in the Valmy Formation not associated with hydrothermal activity (Swift, 1979). On the other hand, the hydrothermal silicification of the Valmy Formation may effectively seal the Dunphy Pass and Malpais Rim fault zones; the low resistivity at depth (electrical unit 4) may reveal an area where hot water is flowing beneath an impermeable fault junction. Electrical unit 4 disappears altogether west of The Geysers along Line WV 3 (Plate 1).

The limited areal extent and deepening of electrical unit 4 suggest that the east-northeast-trending, post-Miocene fault set at the base of the Malpais scarp is a conduit for upwelling geothermal water only in the area immediately adjacent to The Geysers. Near the Chevron wells, electrical unit 4 may indicate an area dominated by hydrothermal alteration rather than hydrothermal circulation. It is not possible to discriminate between the two with the resistivity data. The self-potential data discussed by Swift (1979) may make this discrimination by detecting voltages caused by the streaming potential of upwelling fluids. The SP anomaly is restricted to the area of The Geysers (Swift, 1979).

Electrical Unit 5

The fifth electrical unit shown in Figure 3 is conductive and appears to lie entirely within the Valmy Formation. Its location three miles (5.0 km) north of the Malpais Rim places it north of the northern-most inferred fault (Figure 2). The proximity of the east-northeast-trending fault set within the Whirlwind Valley to electrical unit 5 tempts the interpretation that this conductive anomaly represents a fault-controlled hydrothermal resource within the Valmy Formation. However, electrical unit 5 may merely indicate an area of carbonaceous or altered Ordovician strata.

A similar ambiguity troubles the interpretation of the large low-resistivity areas in Horse Heaven (Plate 2). The areal extent and continuity of low resistivity bodies in the Horse Heaven area far exceed those along the base of the Malpais scarp. The Horse Heaven area may contain a large, as yet untapped, geothermal resource fed by numerous cross-faults (Struhsacker, in preparation), (Figure 2). However, anomalously conductive eugeosynclinal material may be near the surface in Horse Heaven. Thermal gradient holes and self-potential surveys might resolve this ambiguity.

SEISMIC REFLECTION ANALYSIS

A weight-drop seismic reflection survey delineates several faults in a nine square mile area southwest of The Geysers (Plate 6). The practical depth of energy penetration along most lines is about 1,200 ft (0.4 km). This technique has met with critical disdain because the weight-drop source and the data recording procedures are much less sophisticated than the techniques used in oil exploration. Much of the energy produced by the weight-drop source propagates along the surface; only a small component travels vertically. The data are plagued with noise, "ringing" that can swamp valid reflections. In this survey reflections along Lines 4-7 cannot be satisfactorily picked due to noise. Two of these lines (4 and 7) cross an outcrop of basalt (Figure 2); the source of the noise on the other two partially uninterpretable lines is unknown. Where the noise is not extreme, the weight-drop technique produces data that can be used successfully to delineate shallow faults.

The trend of shallow faults inferred from seismic data in the Whirlwind Valley is predominately east-northeast (Plate 6). Near the southwest end of the valley, several of the faults merge with faults in the Shoshone Range mapped by Gilluly and Gates (1965), (Figure 2). Directly west of a low hill in the valley below the Malpais Rim and north of the Chevron wells is an area 1/2 x 1 1/2 mi (1 x 3 km) where the seismic data detect no faults. This area is an east-west horst-like structure relative to the Whirlwind Valley to the north and the base of the Malpais scarp to the south.

The dashed pattern of the faults in Plate 6 shows areas where the seismic data are sufficiently internally consistent to allow extrapolation between lines. The dotted pattern extends these inferred faults to the west where geologic control is available (Plate 6). The sense and location of these faults agree with inferences from the resistivity data. The good correlation between the faults inferred from the weight-drop seismic data and those mapped on the surface argues that this technique can produce valid geophysical interpretations in areas where reflections can be traced for several thousands of feet (1 km).

CONCLUSIONS

The electrical units inferred from the resistivity data correspond in area and thickness to lithologies mapped on the surface and encountered in the deep test wells. A shallow conductive zone has been modeled at The Geysers and shown to be distinct from the large zone of low resistivity in Horse Heaven. The two conductive zones may merge at depths greater than 4,000 ft (1.2 km). The seismic data suggest that east-west-trending faults extend west of The Geysers and form a subtle horst-like structure in the Whirlwind Valley, and that some continue into the Shoshone Range. The modeled resistivity sections imply that the north-northwest-trending Dunphy Pass fault zone may be hydraulically connected with the fault set at the base of the Malpais Scarp. Both the Horse Heaven and the Dunphy Pass fault zones may be potential geothermal exploration targets.

ACKNOWLEDGEMENTS

Much of the interpretation in this paper is based on geologic mapping by E. M. Struhsacker whose report is in preparation. Thanks are due to Connie Pixton who drafted all the illustrations and Lucy Stout who typed the manuscript.

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APPENDIX A
NUMERICAL MODEL OUTPUT

Page 25 shows the calculated apparent resistivities for a 100 ohm-m homogeneous earth for the topography crossed by Line WV 2 and documents the distortion caused by topographic effects. This location typifies the terrain of the Malpais Rim scarp; its slope length is 600 ft and its slope angle 24^{o}. For detailed documentation of topographic effects, see Fox et al. (1978).

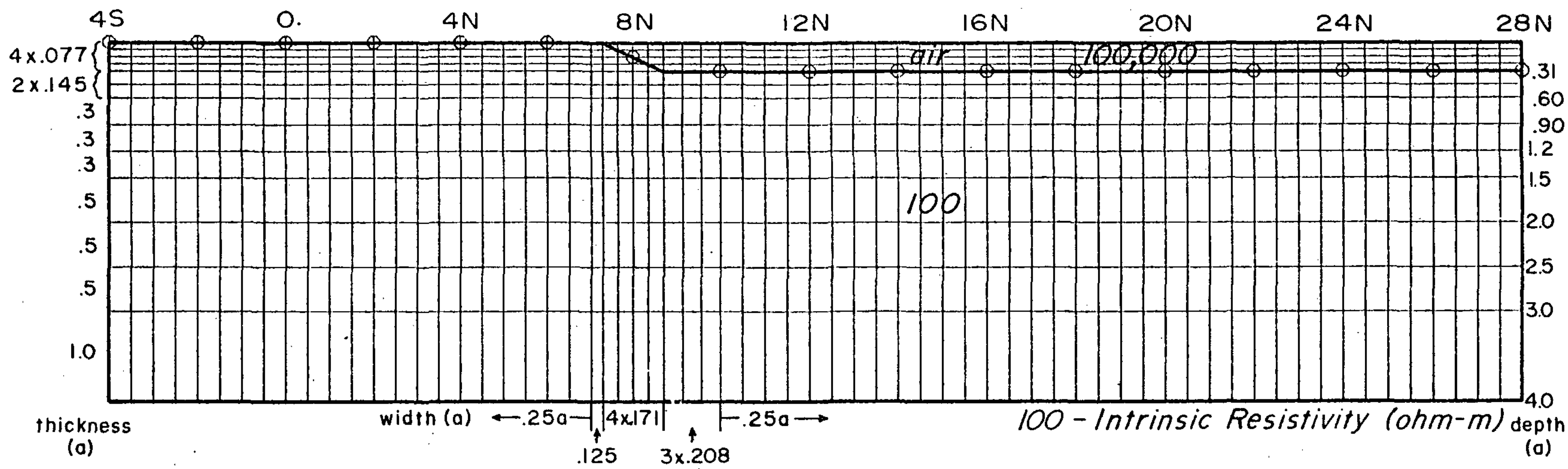
Pages 26-43 document all final models. The computed resistivity values are contoured in the same manner as the observed data (Plates 1 and 2) to facilitate comparison. The resistivities and node thickness used in the numerical models are indicated for each model. Unless otherwise indicated, all node widths are 0.25 dipole lengths.

TABLE 2

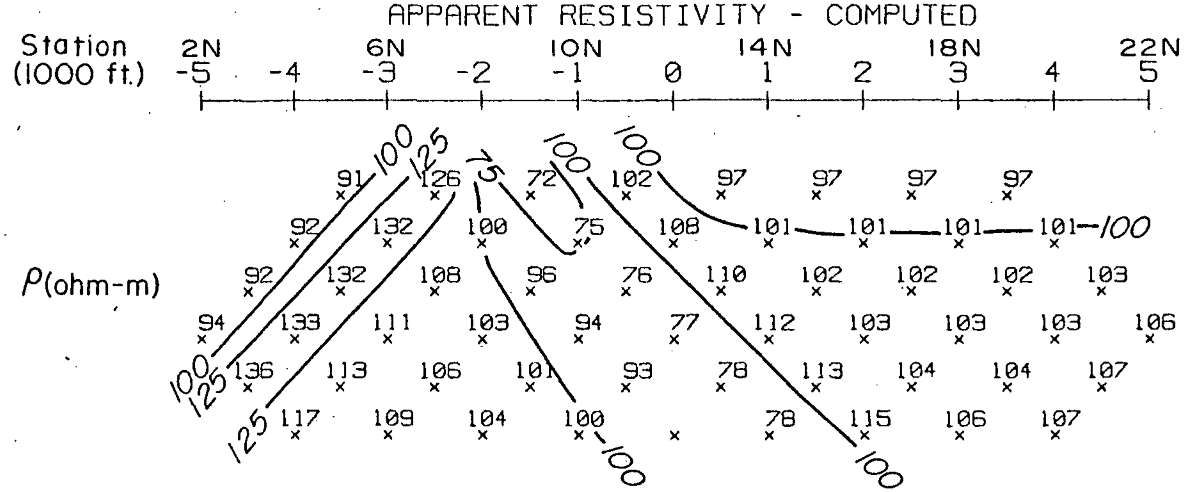
RESISTIVITY DATA SUMMARY
FINAL NUMERICAL MODELS

Line	Length (feet)	Models	Iterations	Appendix Pages
		Whirlwind Valley Area - Plate 1		
WV 1	40,000	Scarp, North	7,3	26, 27
WV 2	42,000	Scarp, North	9, 4	28, 29
WV 3	36,000	Scarp, North	4, 4	30, 31
WV 5	36,000	Scarp	6	32
WV 6	38,000	South, Scarp	2, 5	33, 34
		Horse Heaven Area - Plate 2		
WV 4	30,000	Center	5	35
HH 1	50,000	SE, NW	7, 3	36, 37
HH 2	44,000	SE, NW	4, 9	38, 39
HH 3	46,000	SE, NW	3, 5	40, 41
HH 4	42,000	SE, NW	3, 3	42, 43

WHIRLWIND VALLEY
Line WV2 Scarp
Topographic effect/Homogeneous earth
a=2000 ft.

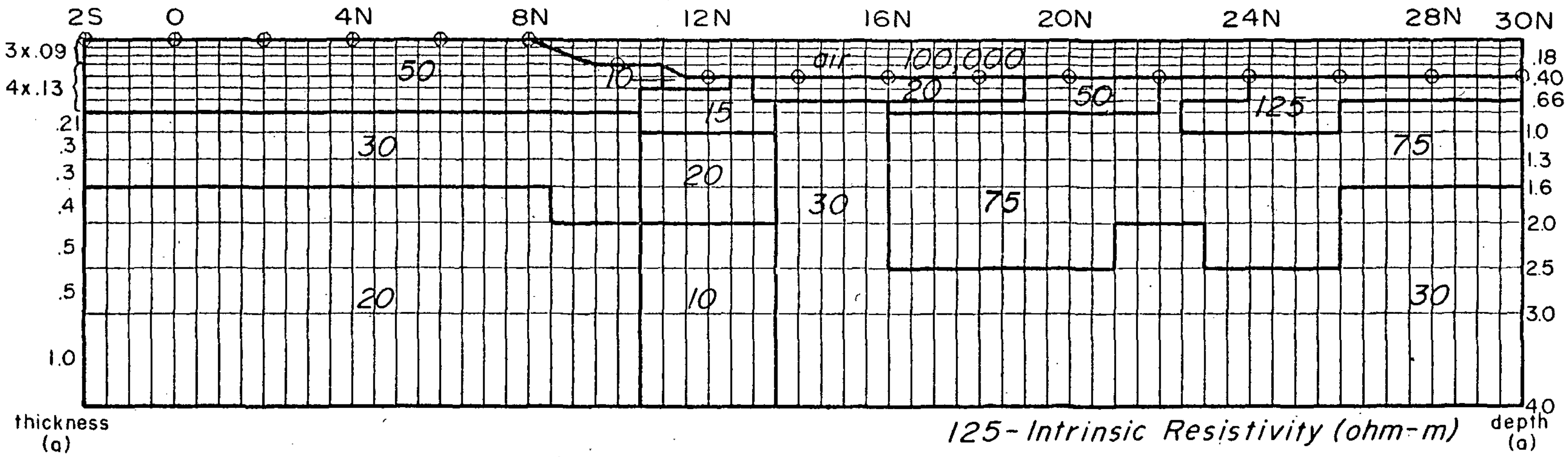


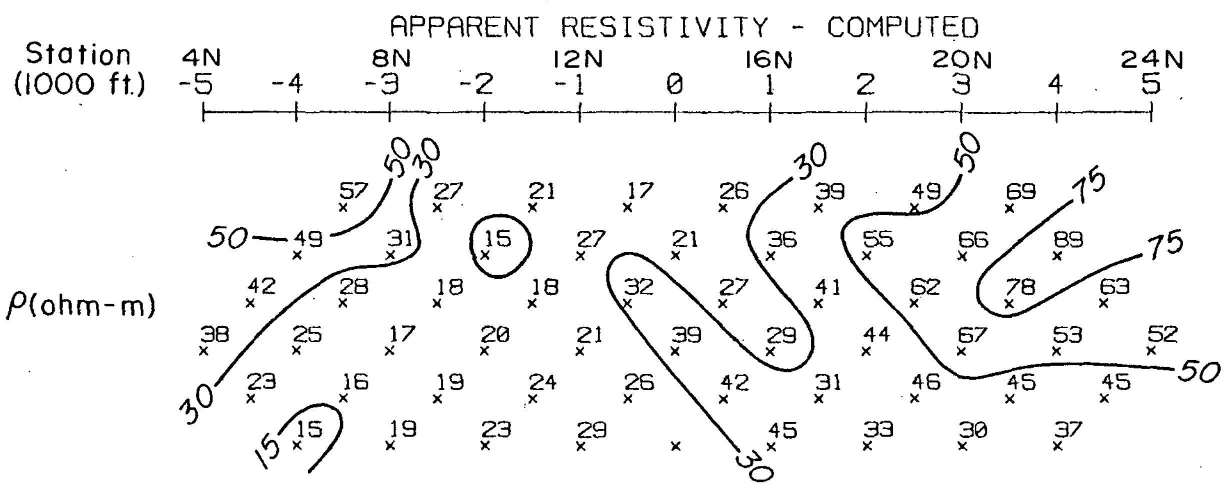
APPARENT RESISTIVITY - COMPUTED



WHIRLWIND VALLEY
Line WV1 Scarp

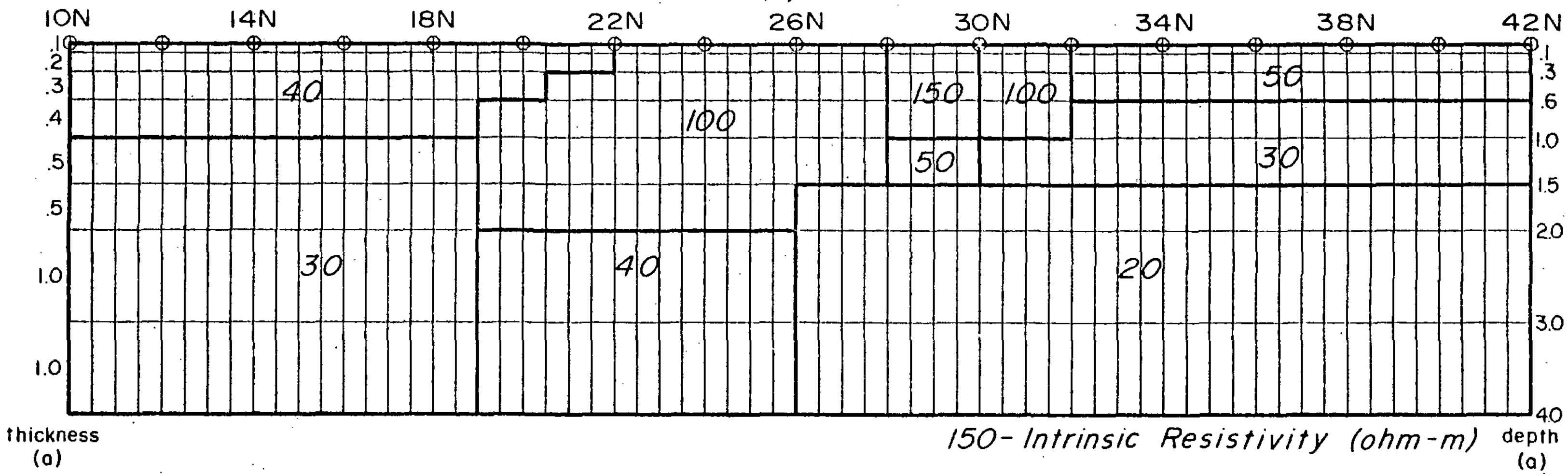
Iteration 7, a=2000 ft.



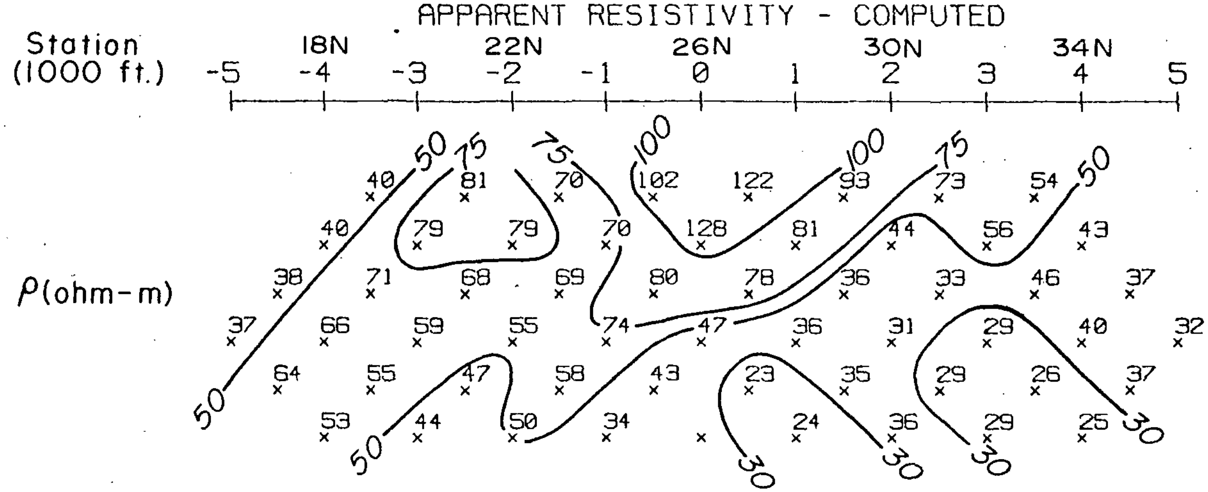


WHIRLWIND VALLEY
Line WV1 North

Iteration 3, a=2000 ft.

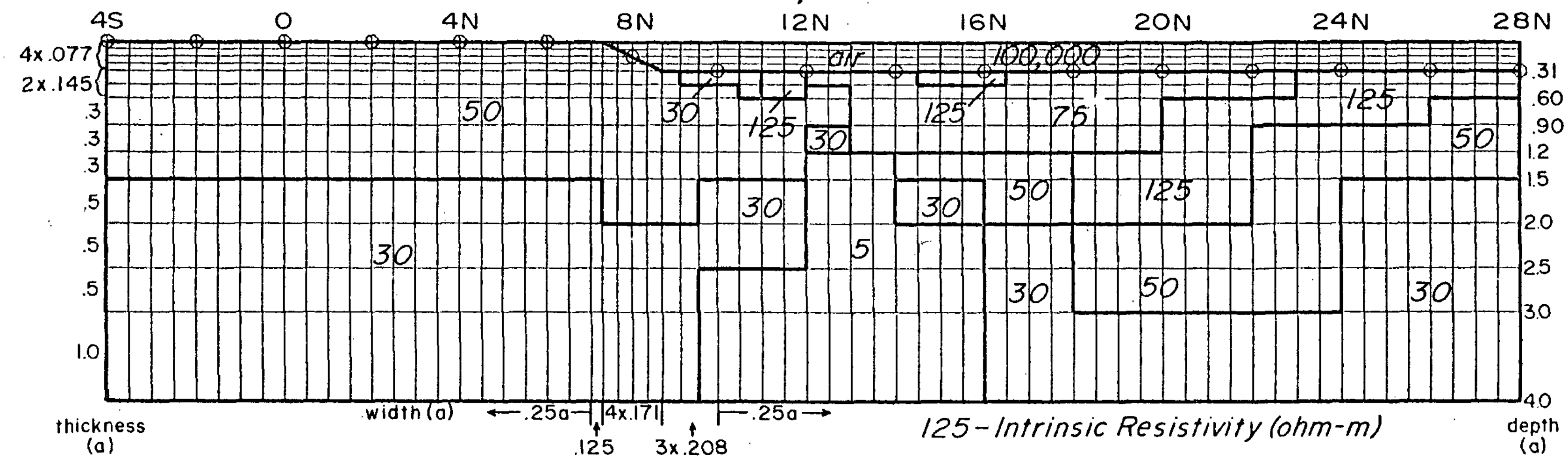


APPARENT RESISTIVITY - COMPUTED

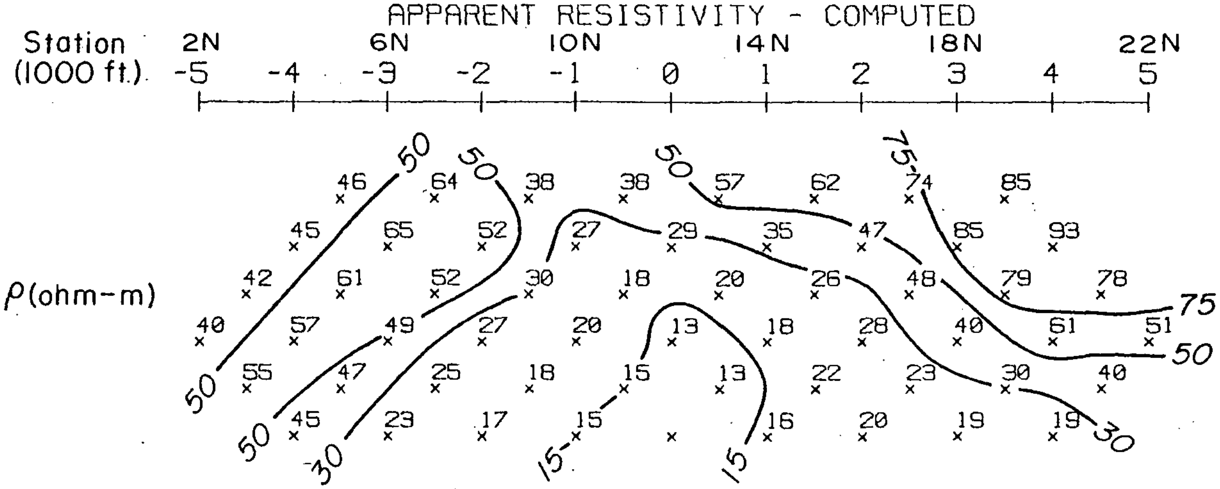


WHIRLWIND VALLEY
Line WV2 Scarp

Iteration 9, a=2000 ft.

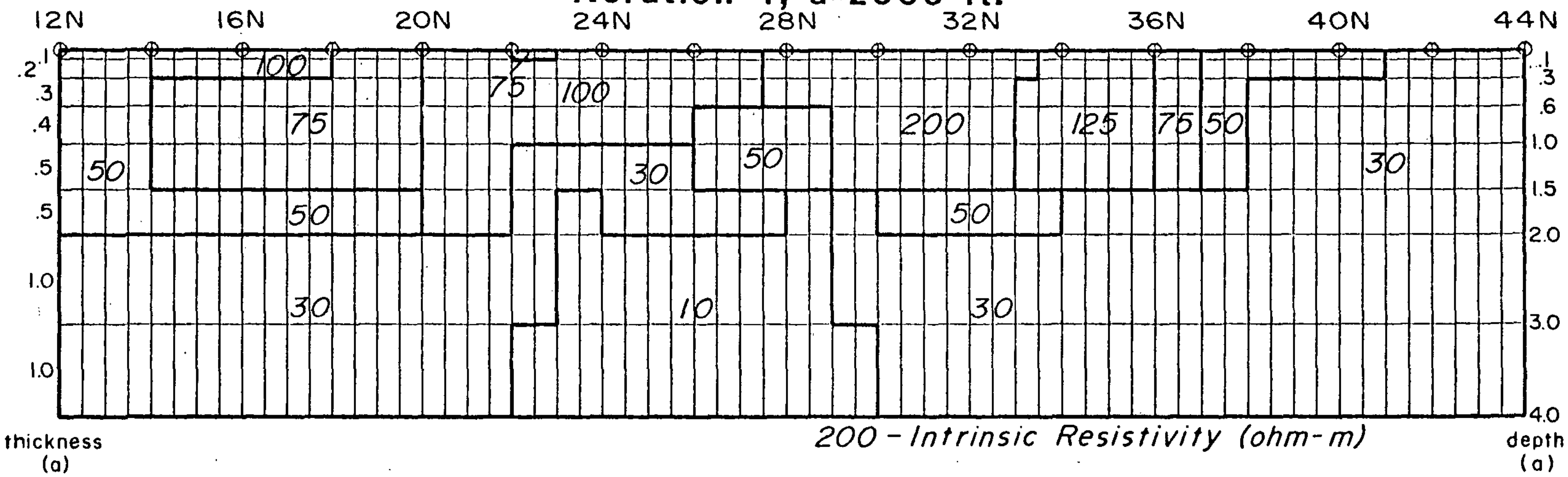


APPARENT RESISTIVITY - COMPUTED

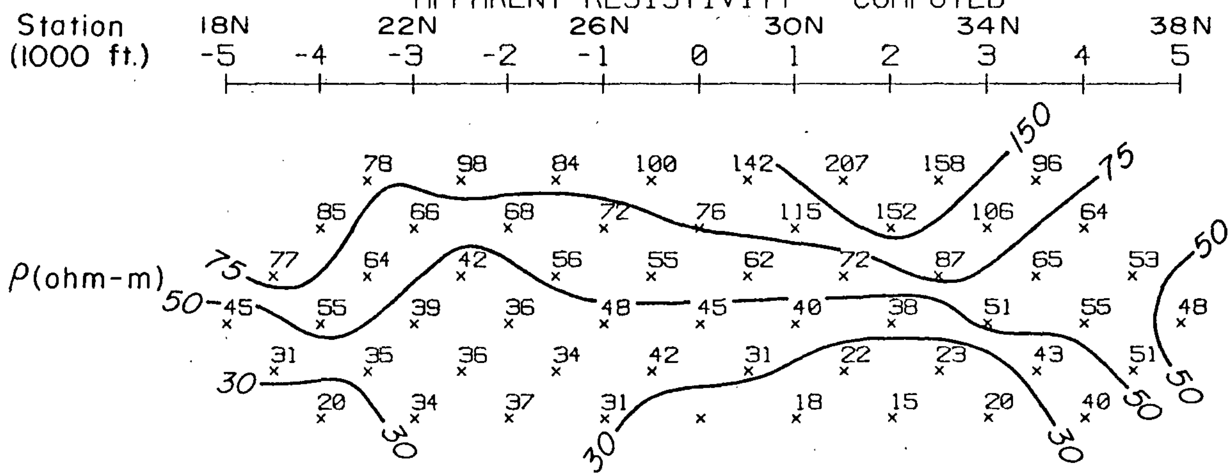


WHIRLWIND VALLEY
Line WV2 North

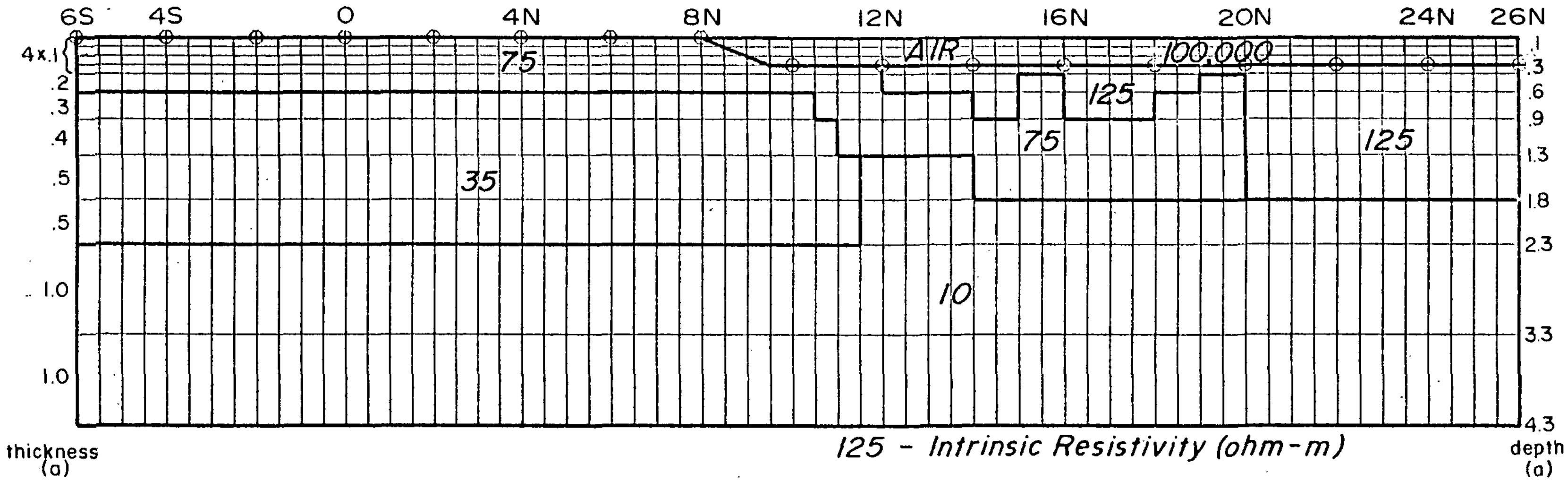
Iteration 4, a=2000 ft.

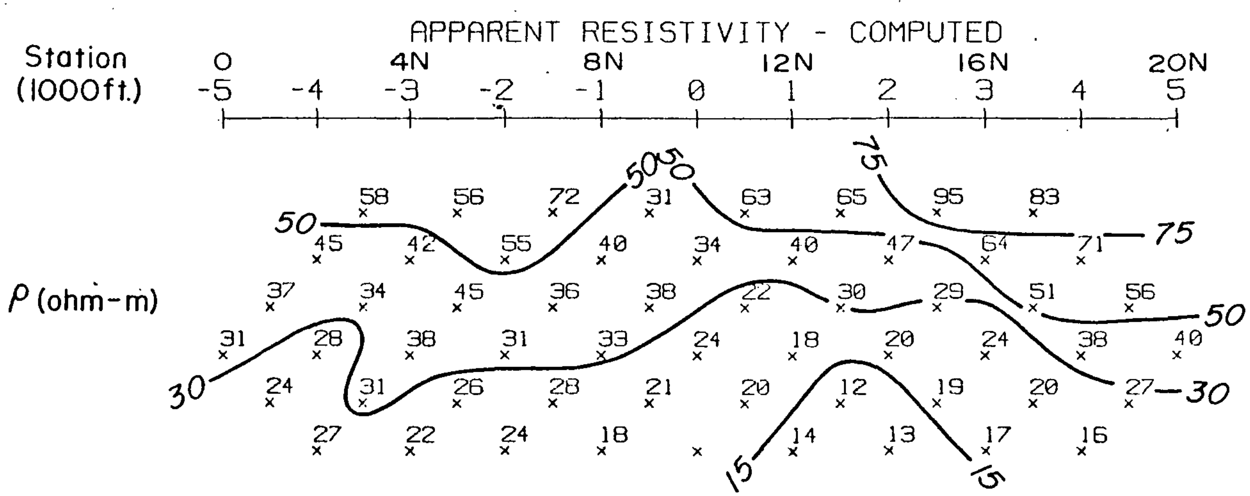


APPARENT RESISTIVITY - COMPUTED



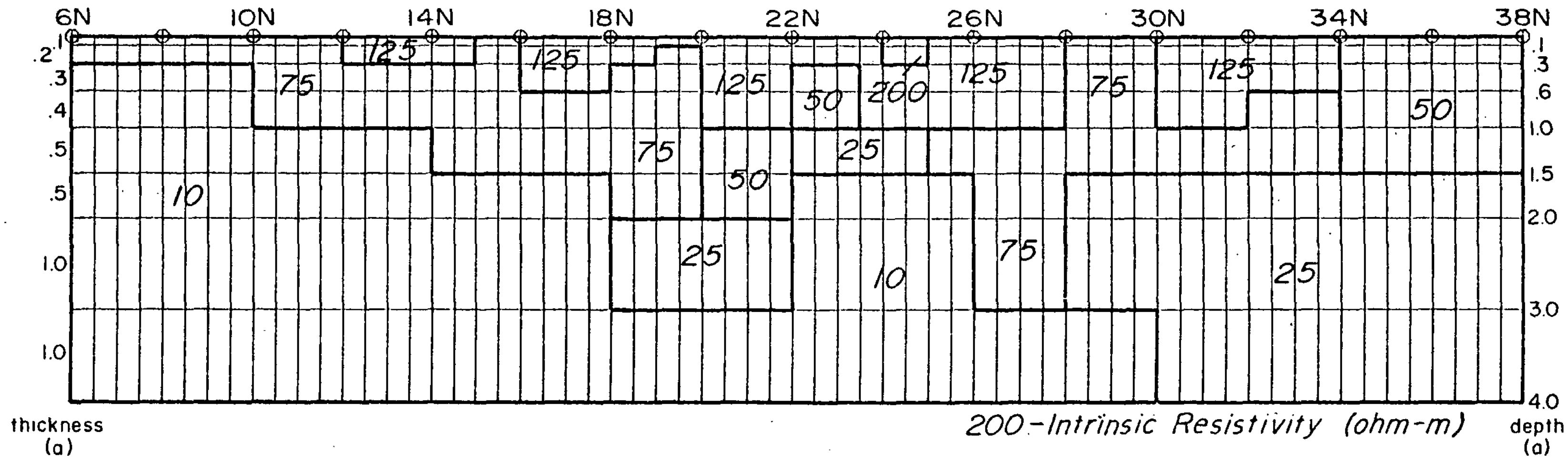
WHIRLWIND VALLEY
Line WV3 Scarp
Iteration 4, a=2000ft.

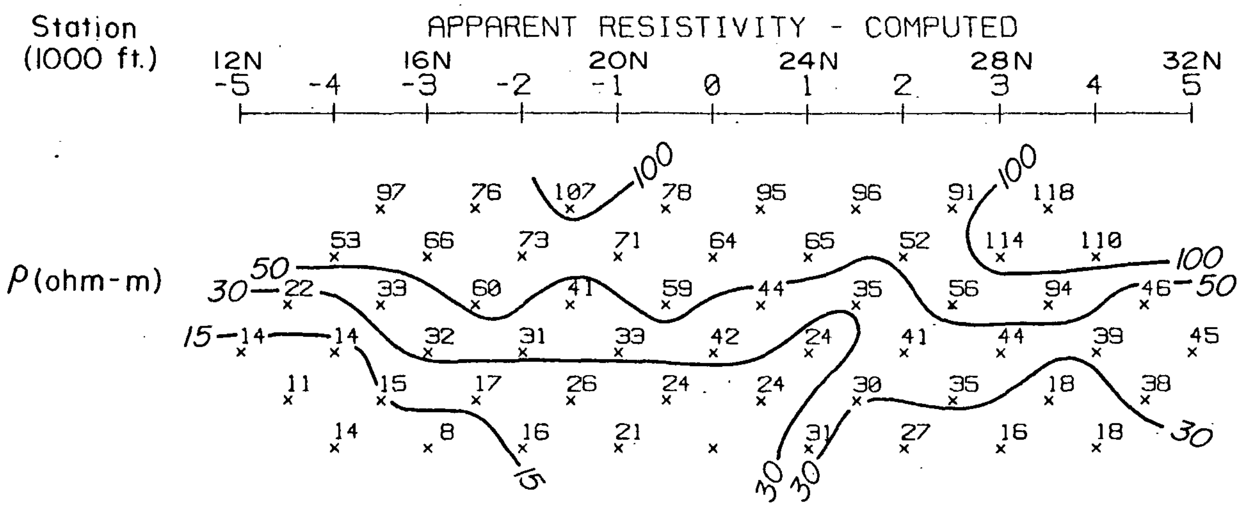




WHIRLWIND VALLEY
Line WV3 North

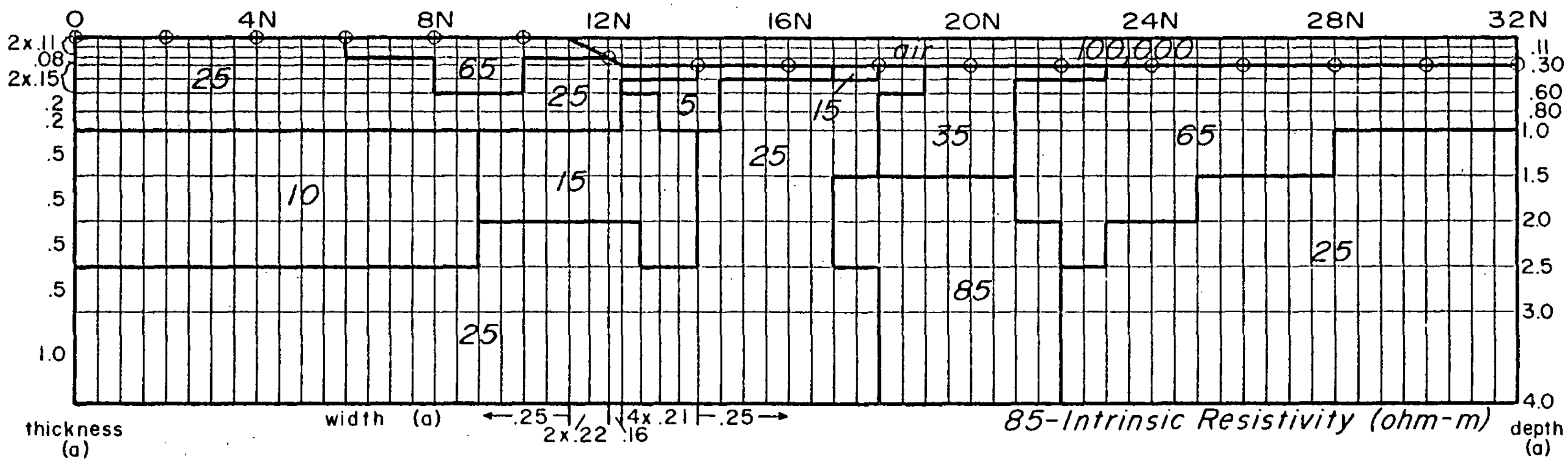
Iteration 4, a=2000 ft.

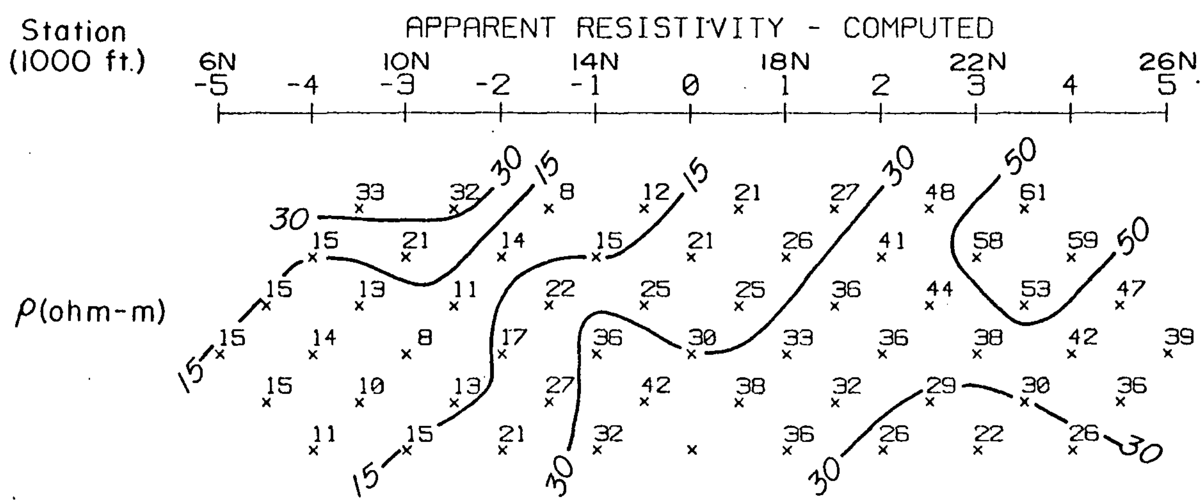




WHIRLWIND VALLEY
Line WV5 Scarp

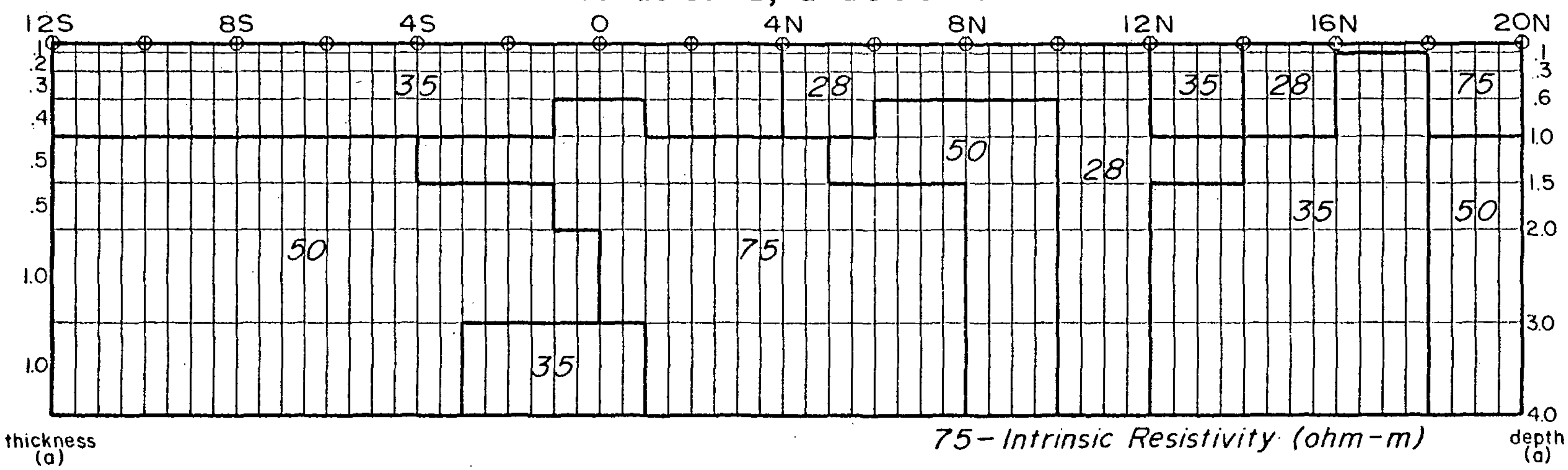
Iteration 6, a=2000 ft.

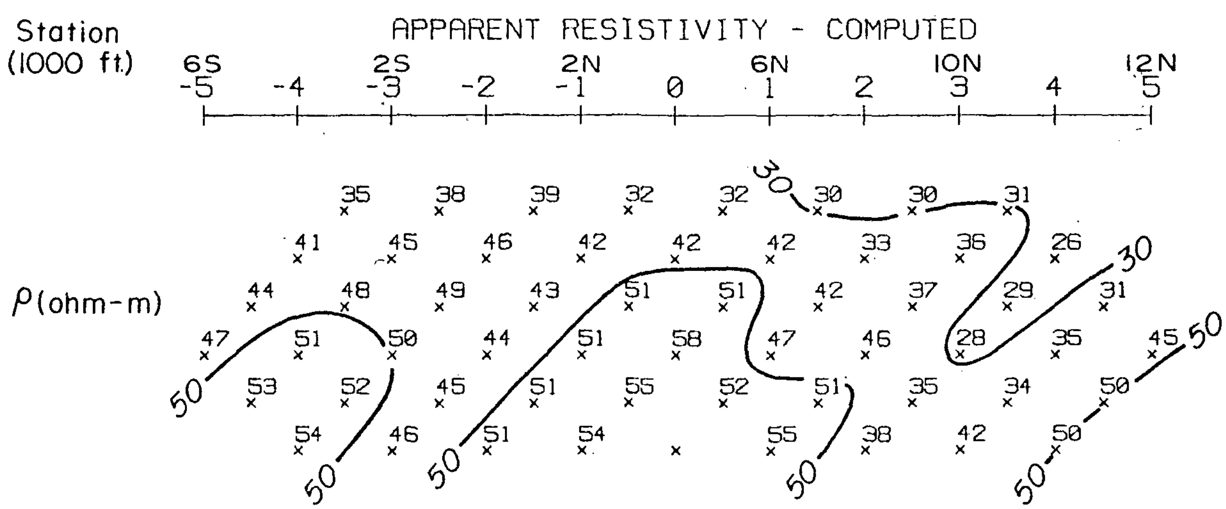




WHIRLWIND VALLEY
Line WV6 South

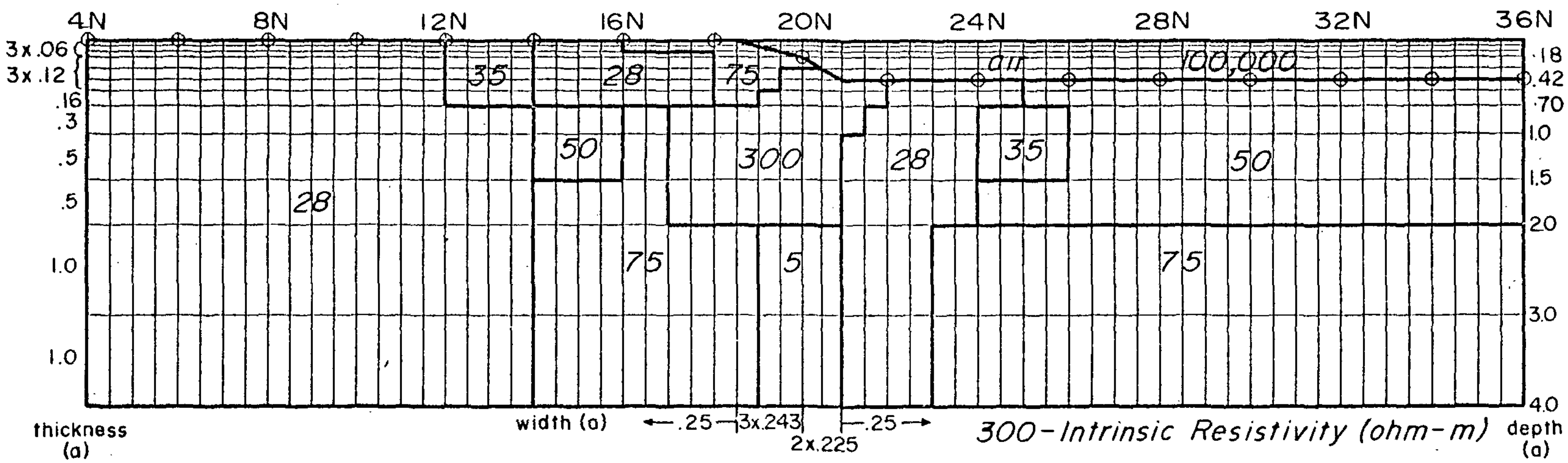
Iteration 2, a=2000 ft.

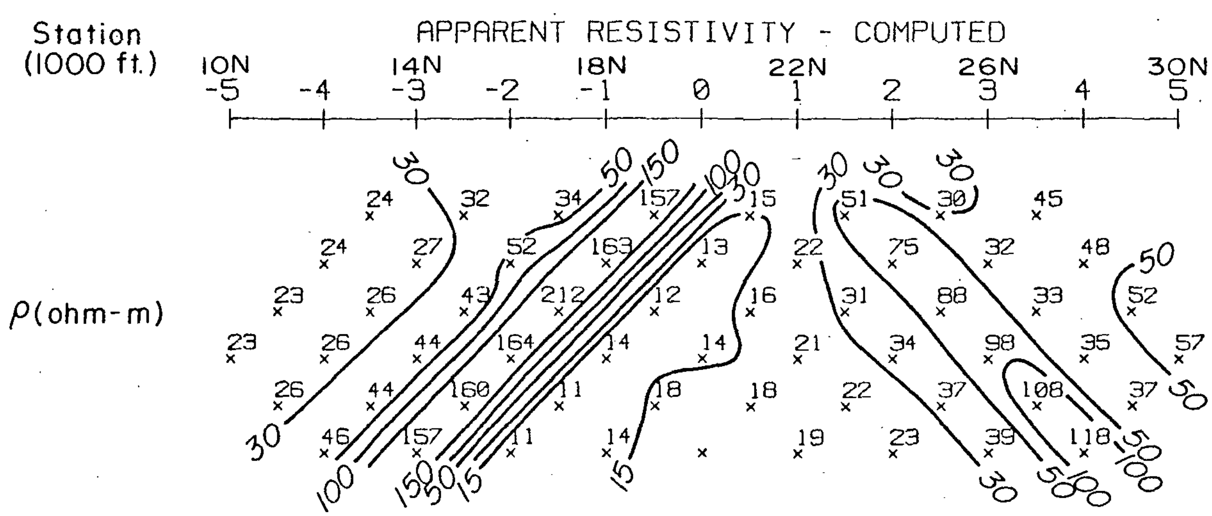




WHIRLWIND VALLEY
Line WV6 Scarp

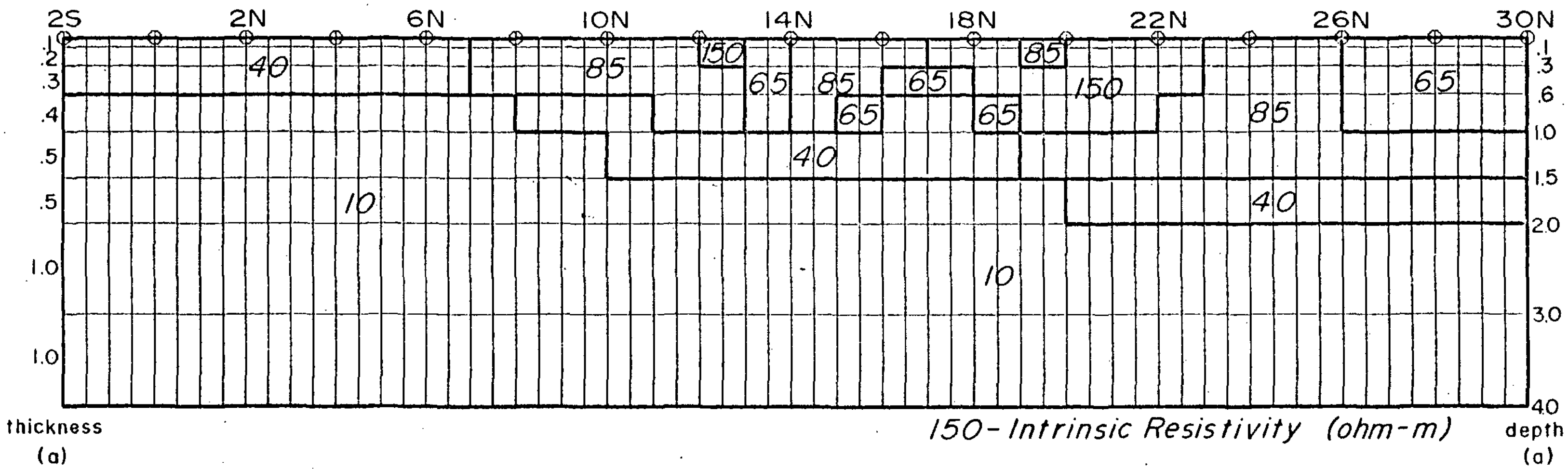
Iteration 5, a=2000 ft.

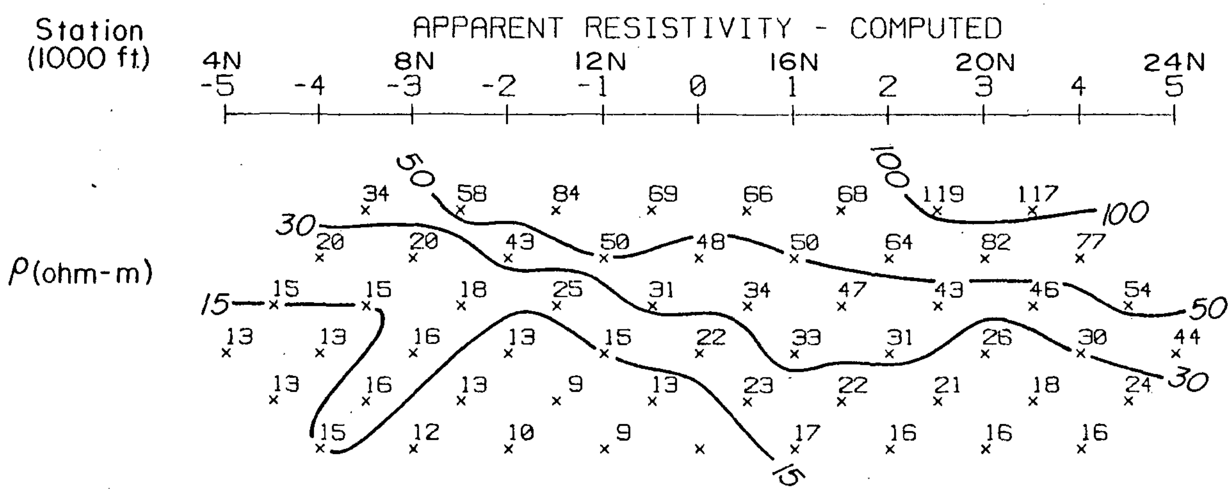




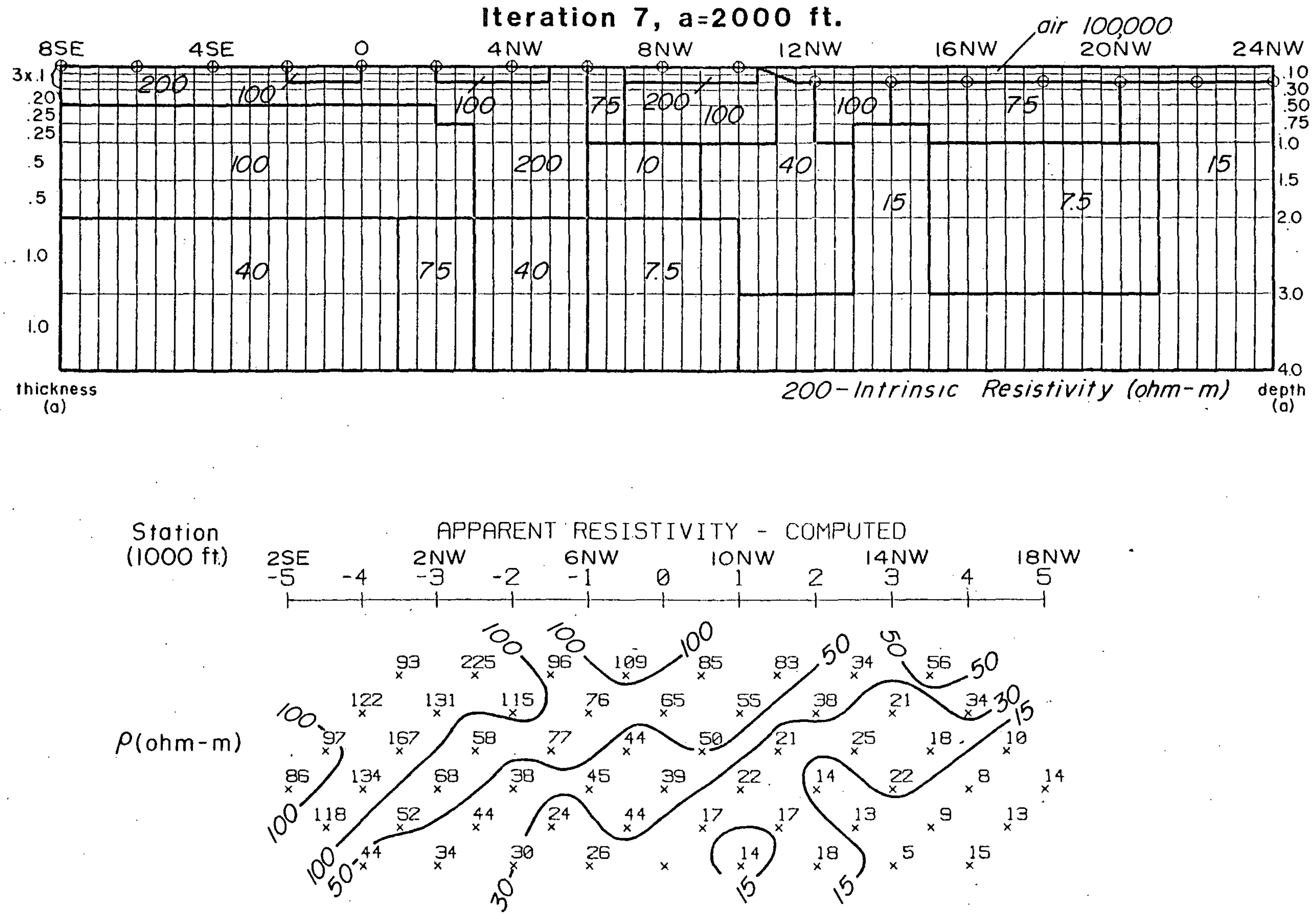
WHIRLWIND VALLEY
Line WV4 Center

Iteration 5, a=2000 ft.



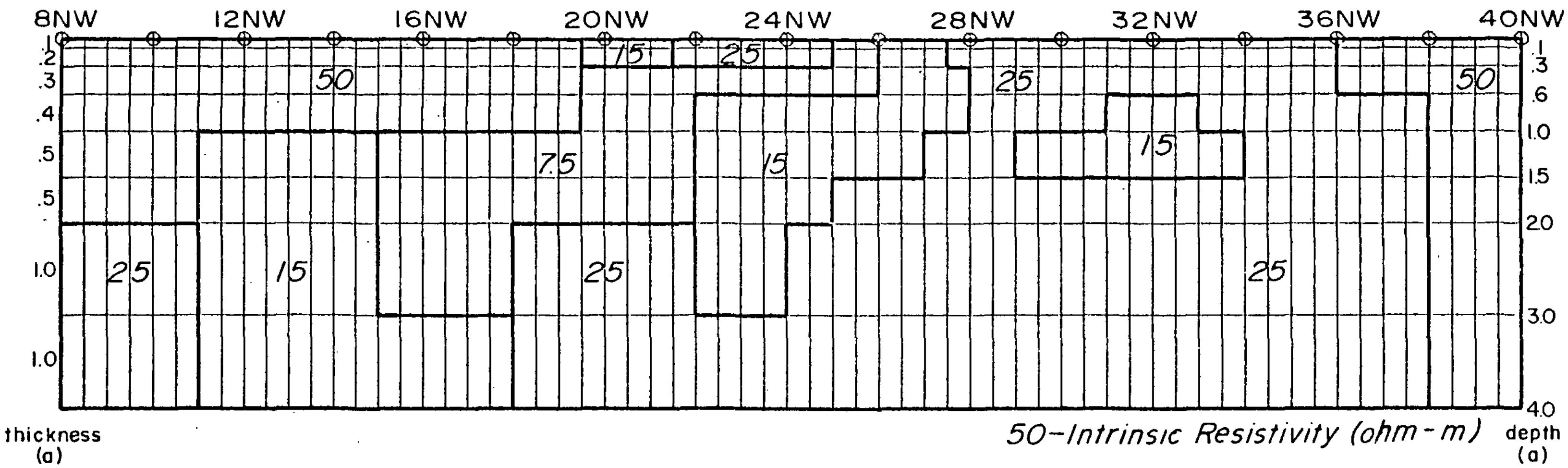


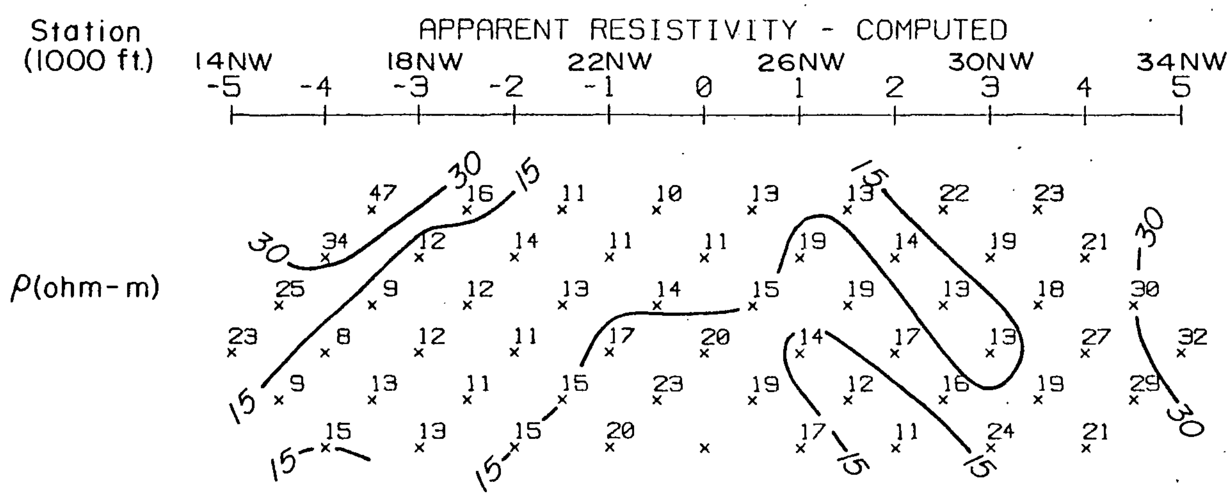
HORSE HEAVEN
Line HH1 SE



HORSE HEAVEN
Line HH1 NW

Iteration 3, a=2000 ft.





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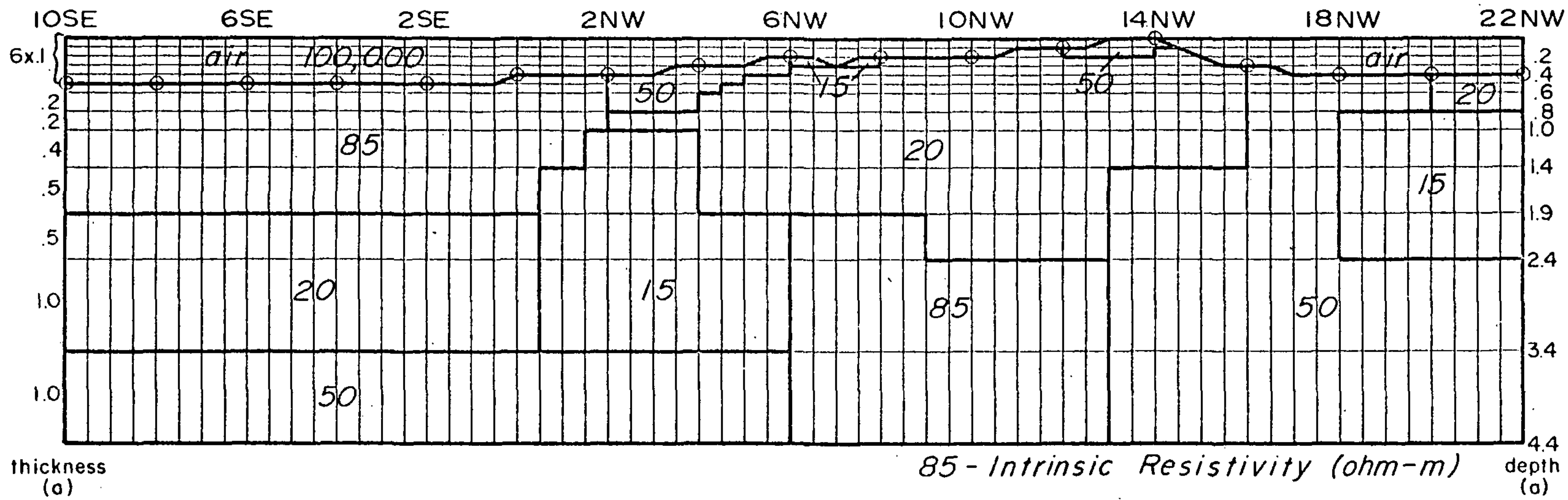
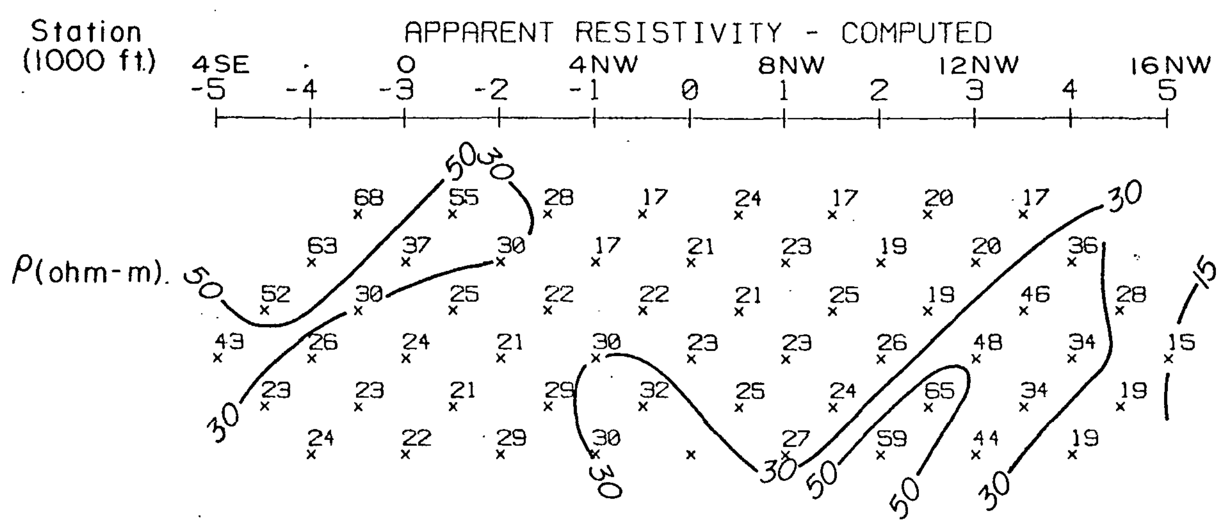
HORSE HEAVEN
Line HH2 SE

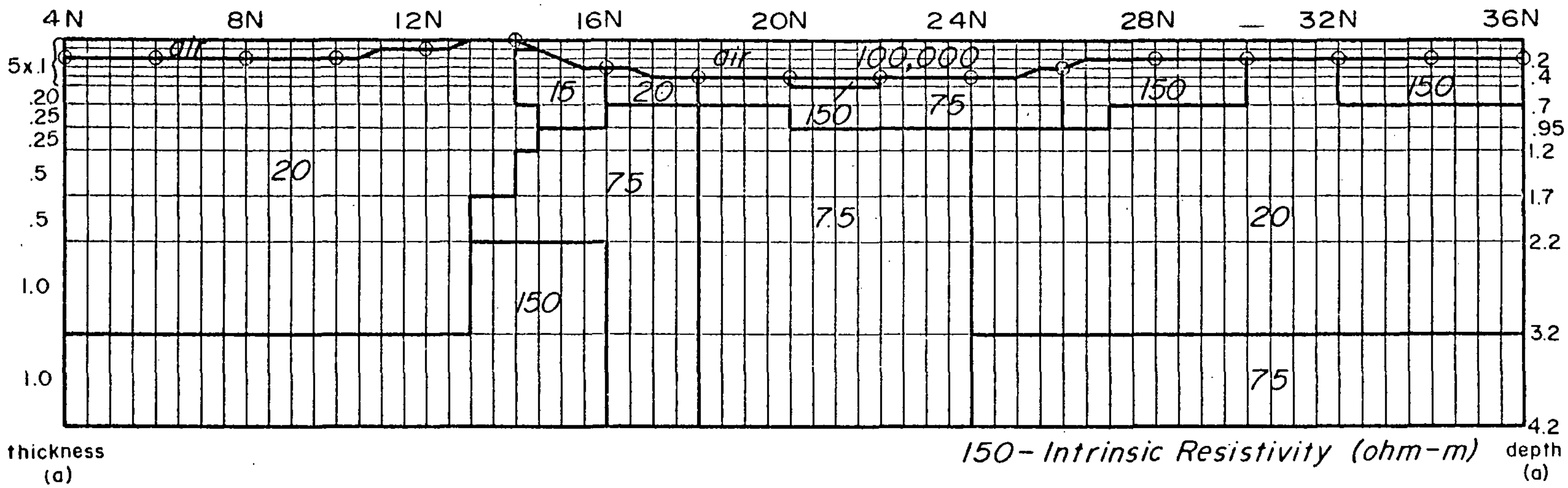
Iteration 4, a=2000ft.

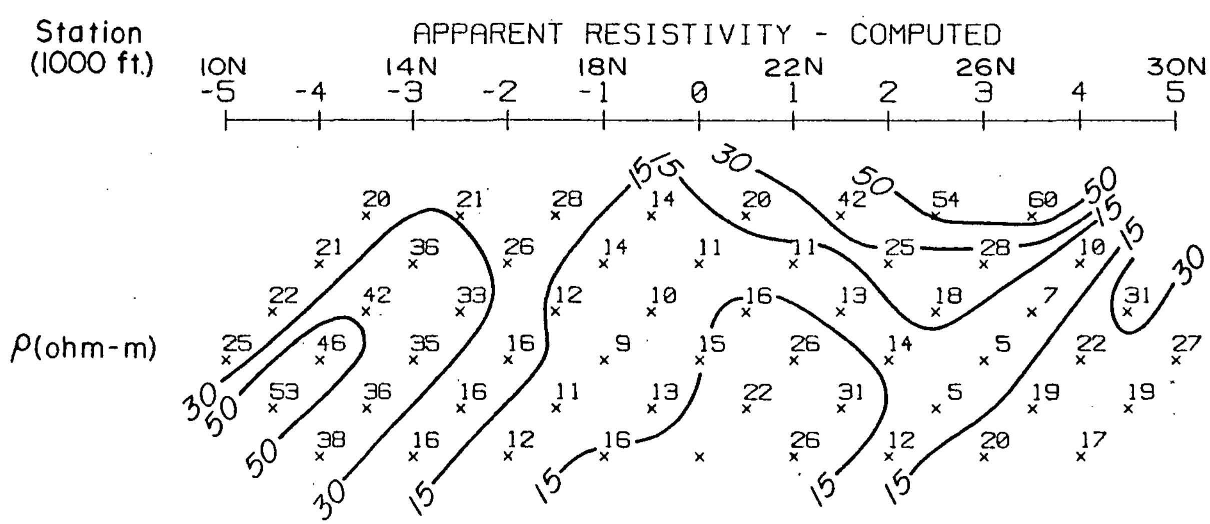




HORSE HEAVEN
Line HH2 NW

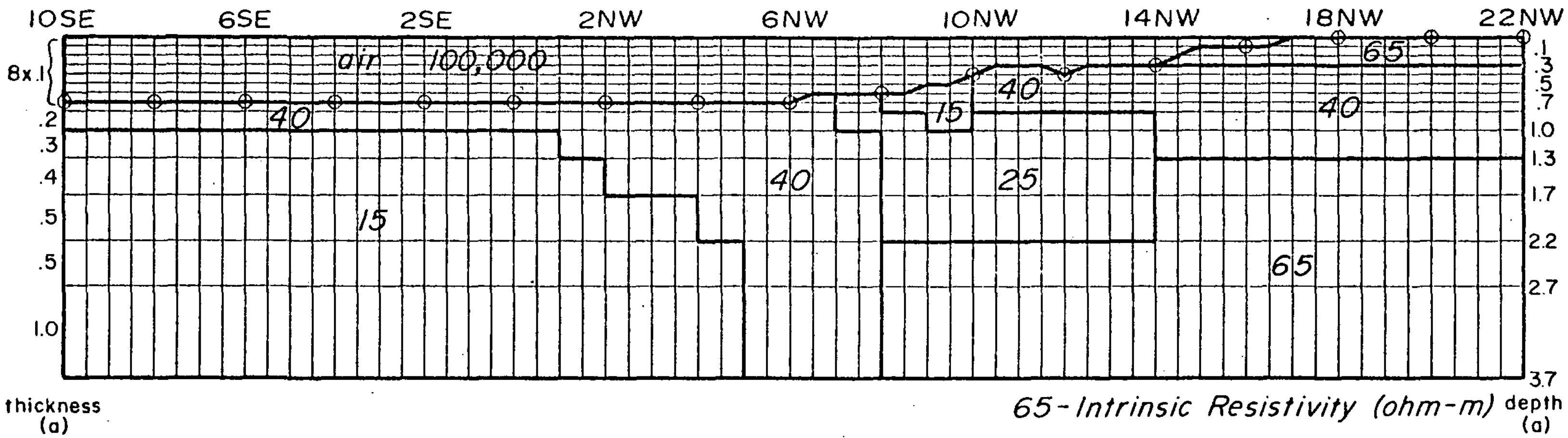
Iteration 9, a=2000 ft.

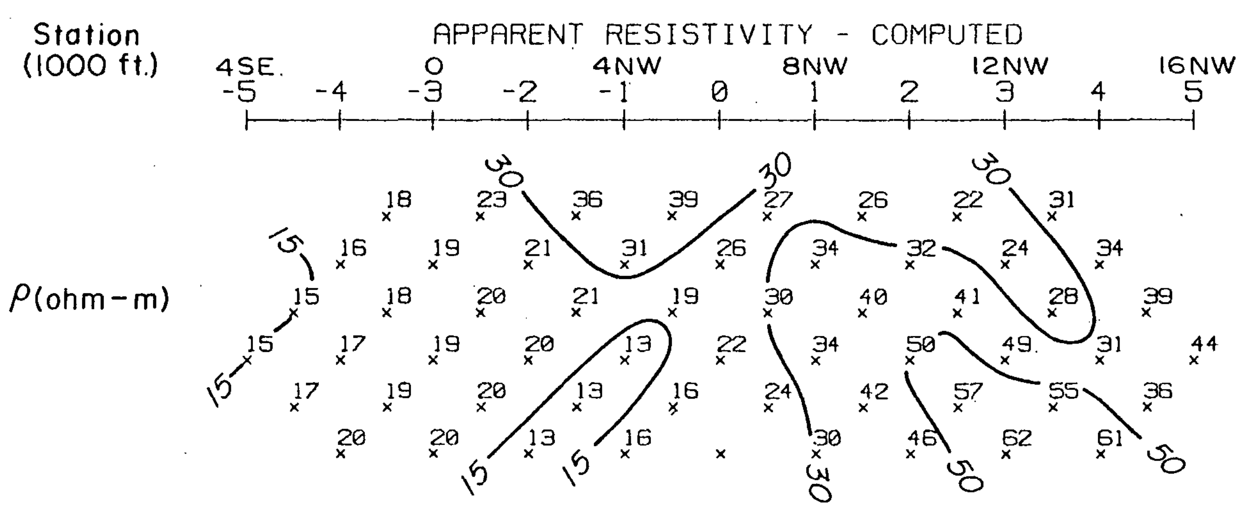




HORSE HEAVEN
Line HH3 SE

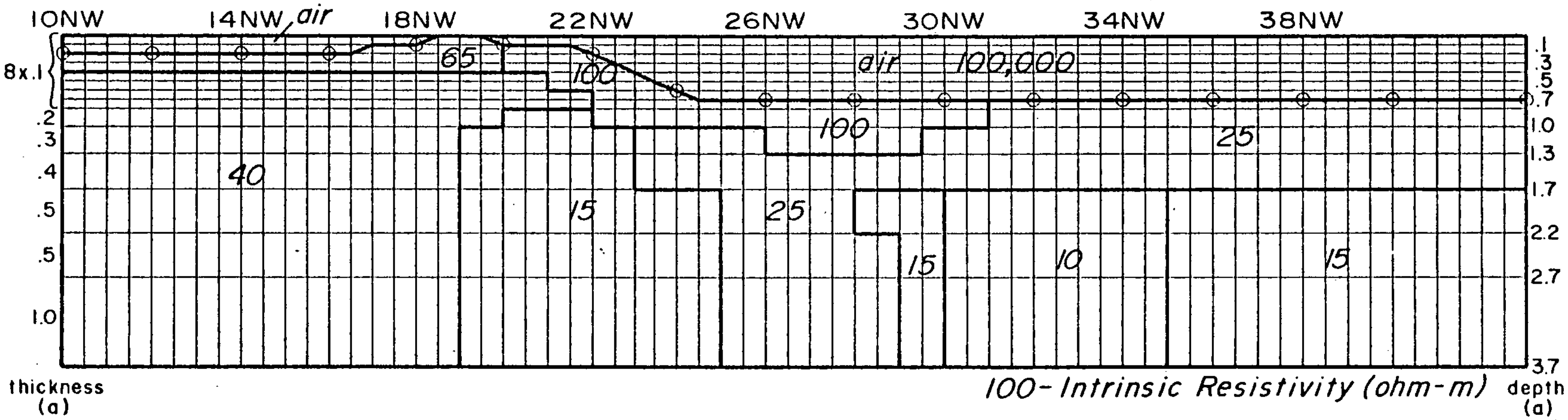
Iteration 3, a=2000 ft.

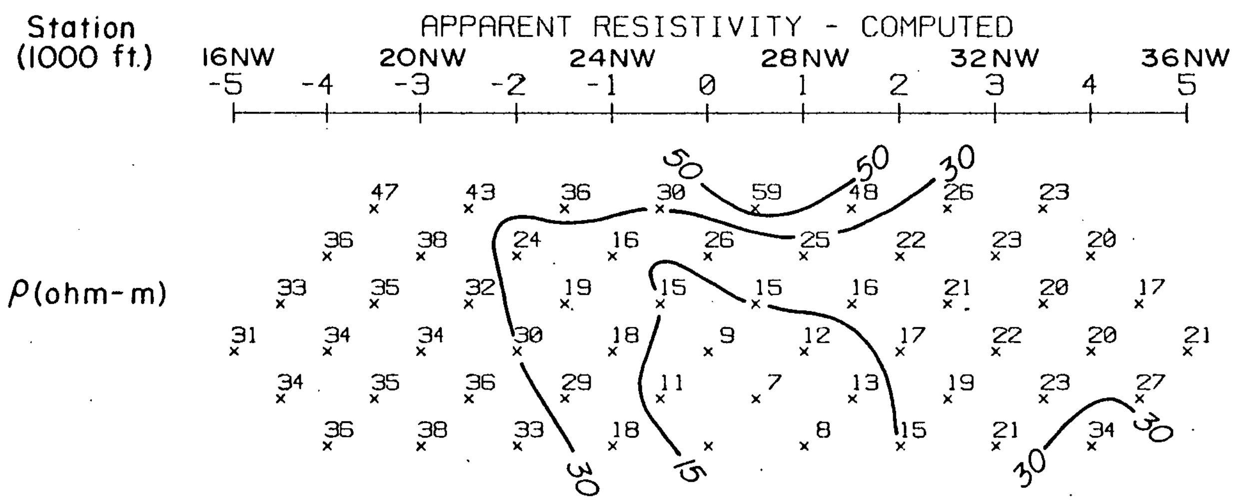




HORSE HEAVEN
Line HH3 NW

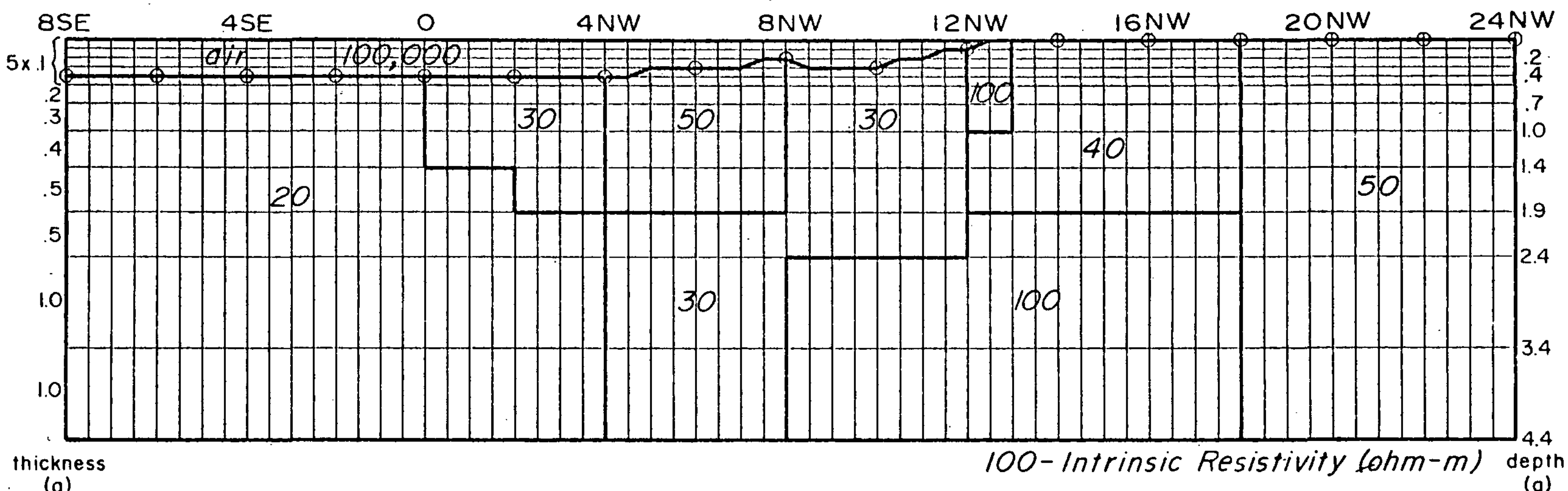
Iteration 5, a=2000 ft.

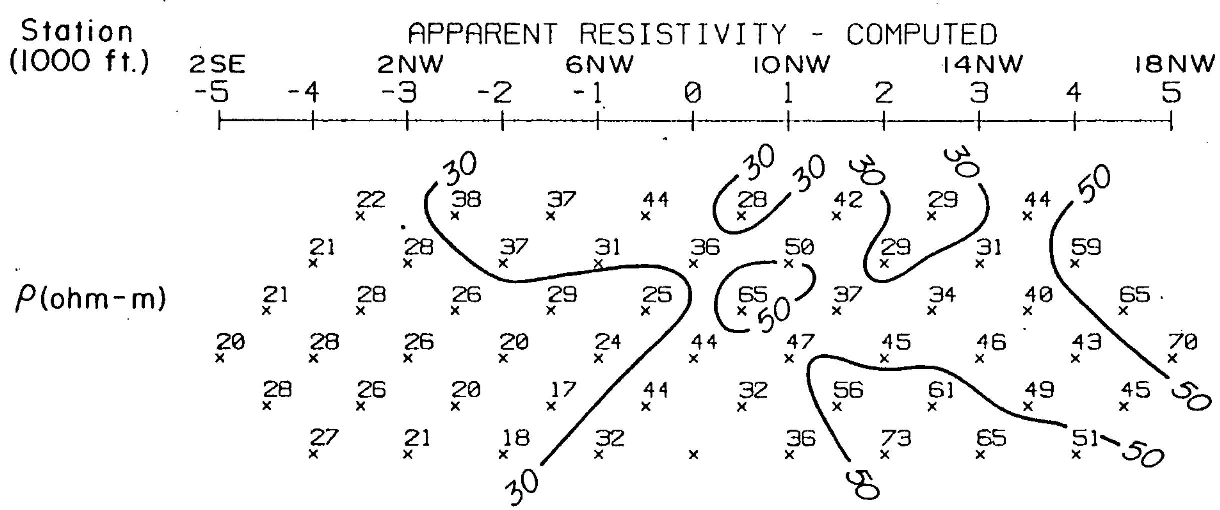




HORSE HEAVEN
Line HH4 SE

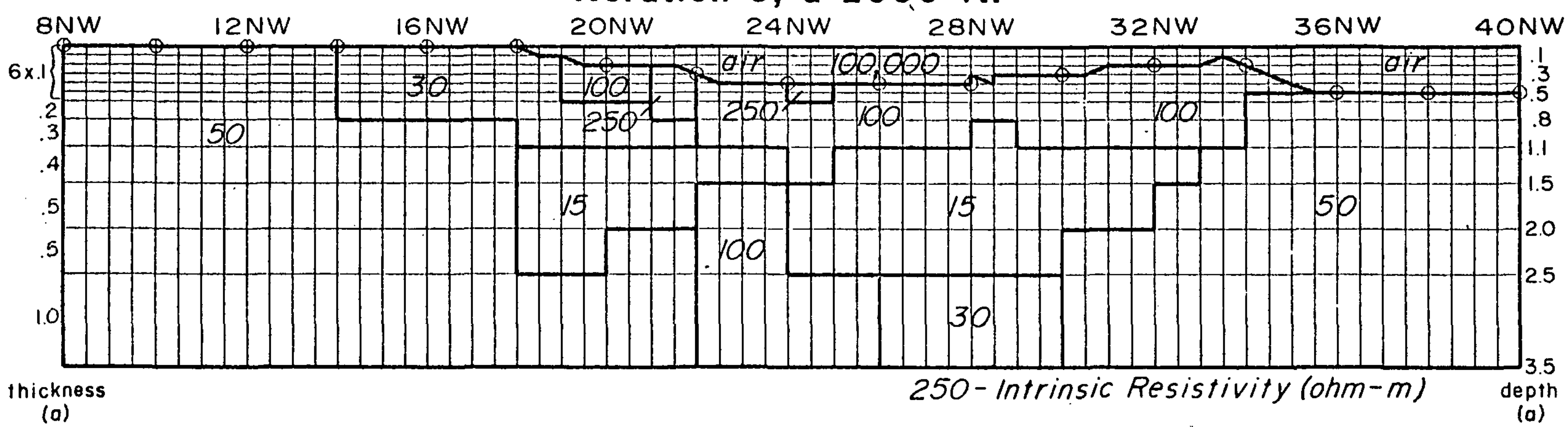
Iteration 3, a=2000 ft.

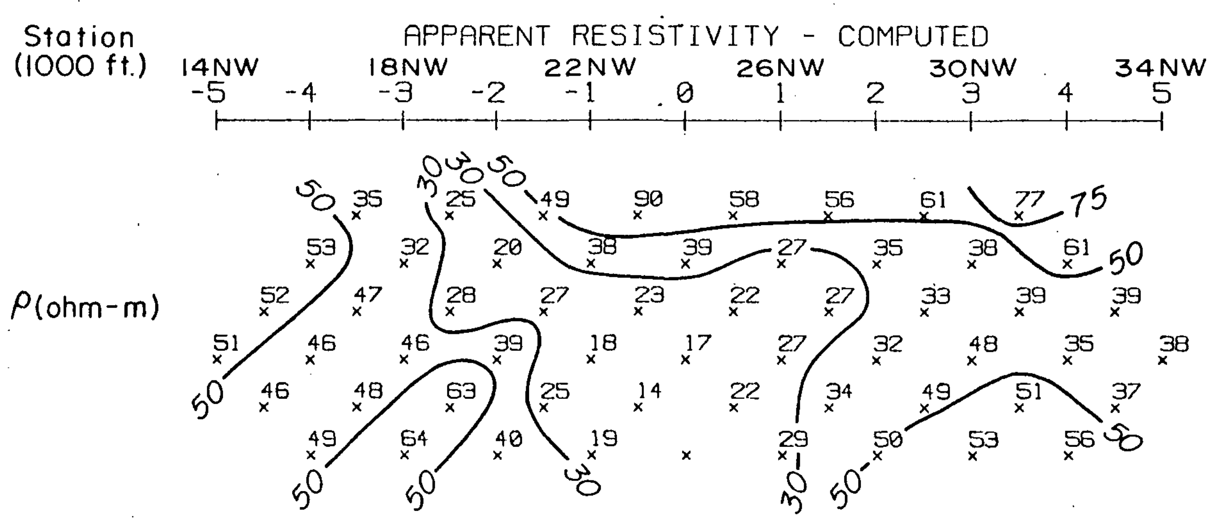


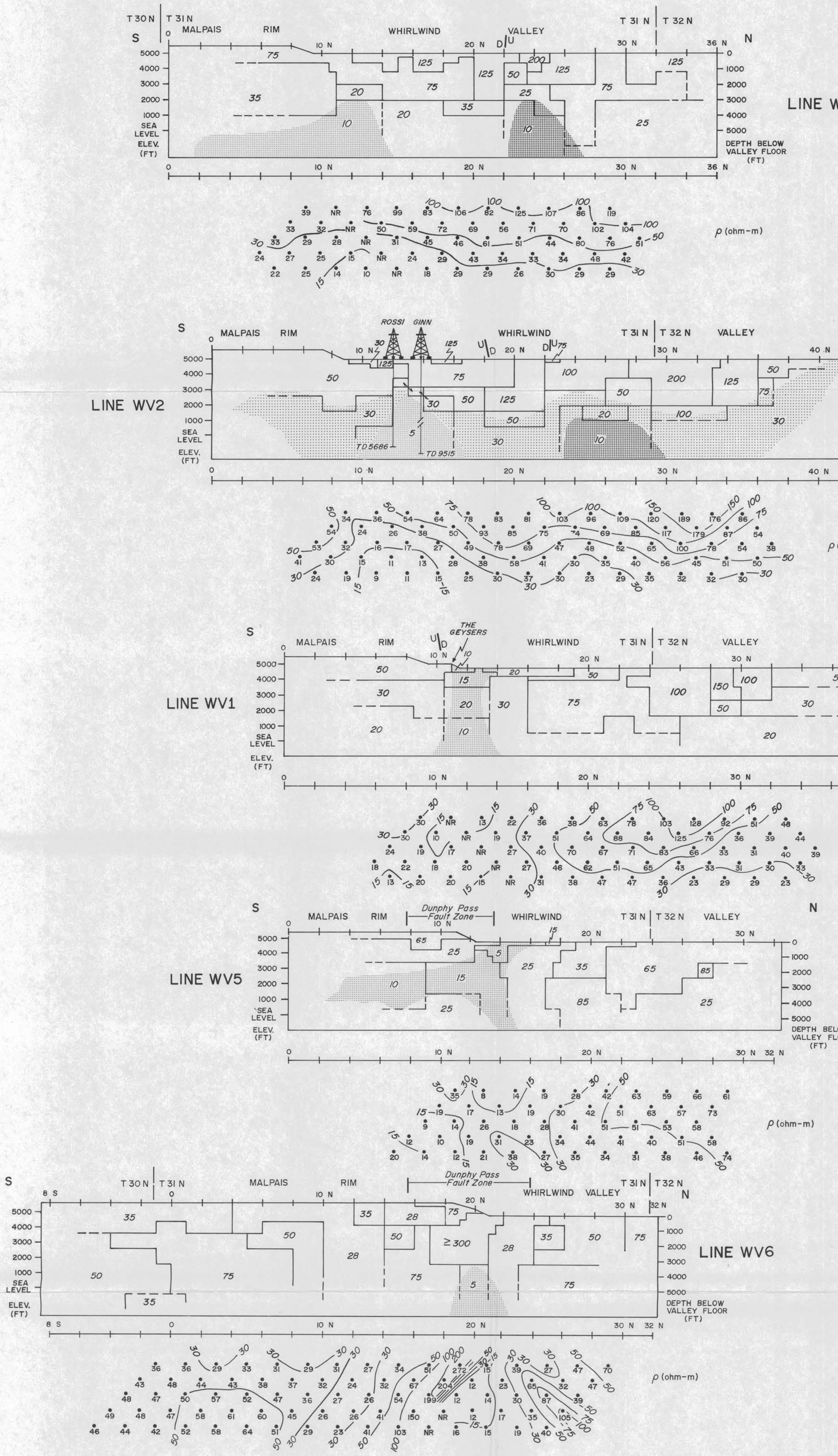


HORSE HEAVEN
Line HH4 NW

Iteration 3, a=2000 ft.







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CHRISTIAN SMITH, 1979

EXPLANATION

INTRINSIC RESISTIVITY (ohm-m) average	range	ELECTRICAL UNIT
50	35–200	1
100	50–250	2
30	20–40	3
10	5–15	4
10	5–15	5

Electrical units are contiguous areas with similar resistivities.

7.5 Intrinsic Electrical Resistivity (ohm-m)

note: Data recorded by McPhar Geophysics, July and November 1974, for Chevron Resources Co.

PLATE 1

INTERPRETED RESISTIVITY SECTION and OBSERVED APPARENT RESISTIVITY

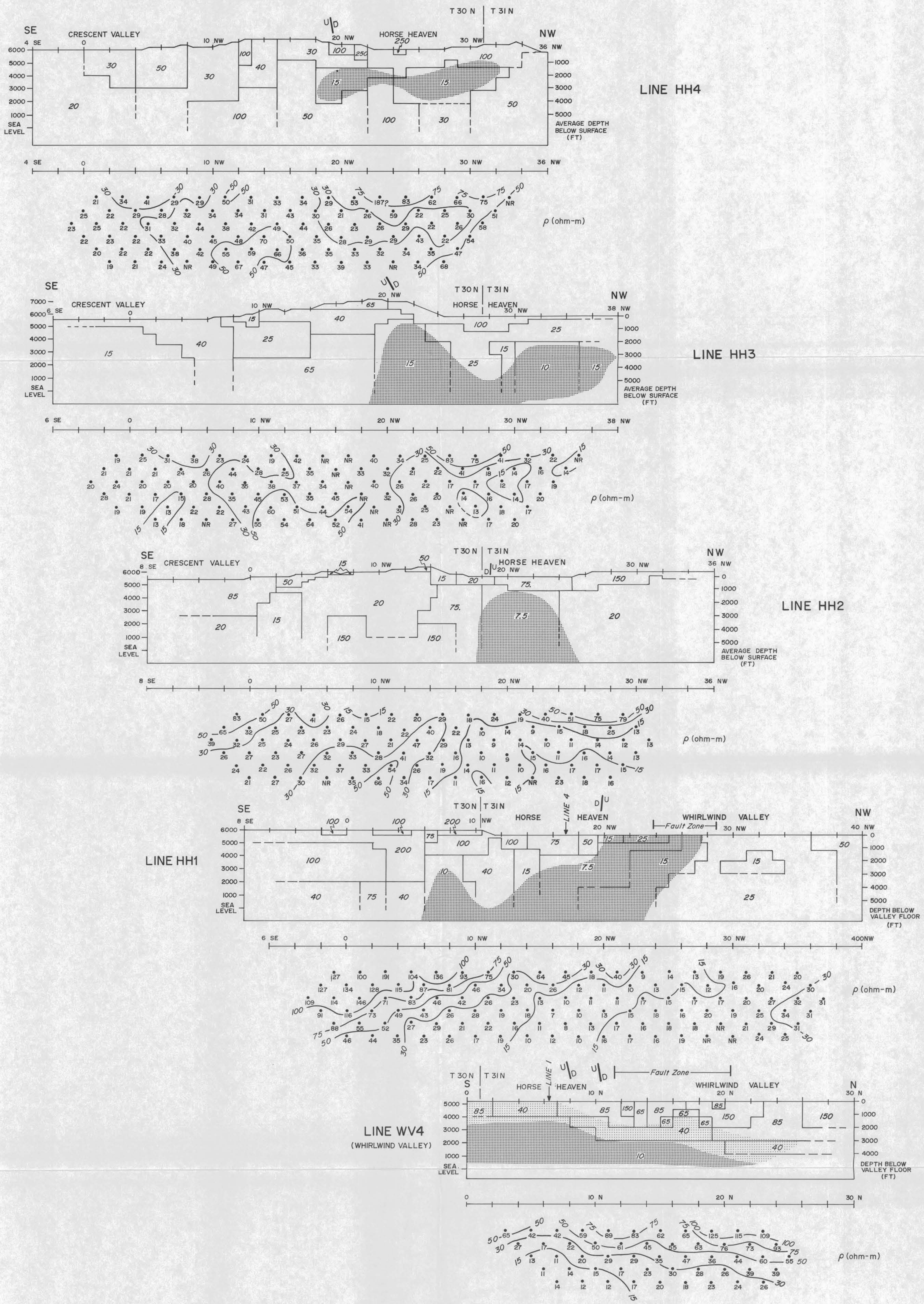
WHIRLWIND VALLEY AREA BEOWAWE KGRA

EUREKA AND LANDER COUNTIES, NEVADA

SCALE 1:48,000

2000 0 2000 4000 6000 8000 10000 12000 14000 FEET

2 1 0 2 KILOMETER



EXPLANATION

INTRINSIC RESISTIVITY (ohm-m)

average	range	ELECTRICAL UNIT
100	50-250	2
30	20-40	3
10	5-15	5

Electrical units are contiguous areas with similar resistivities.

7.5 Intrinsic Electrical Resistivity (ohm-m)

note: Data recorded by McPhar Geophysics (Line WV4), June 1974, and Phoenix Geophysics (Lines HH1-HH4), September 1976, for Chevron Resources Company.

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PLATE 2

INTERPRETED RESISTIVITY SECTION and OBSERVED APPARENT RESISTIVITY

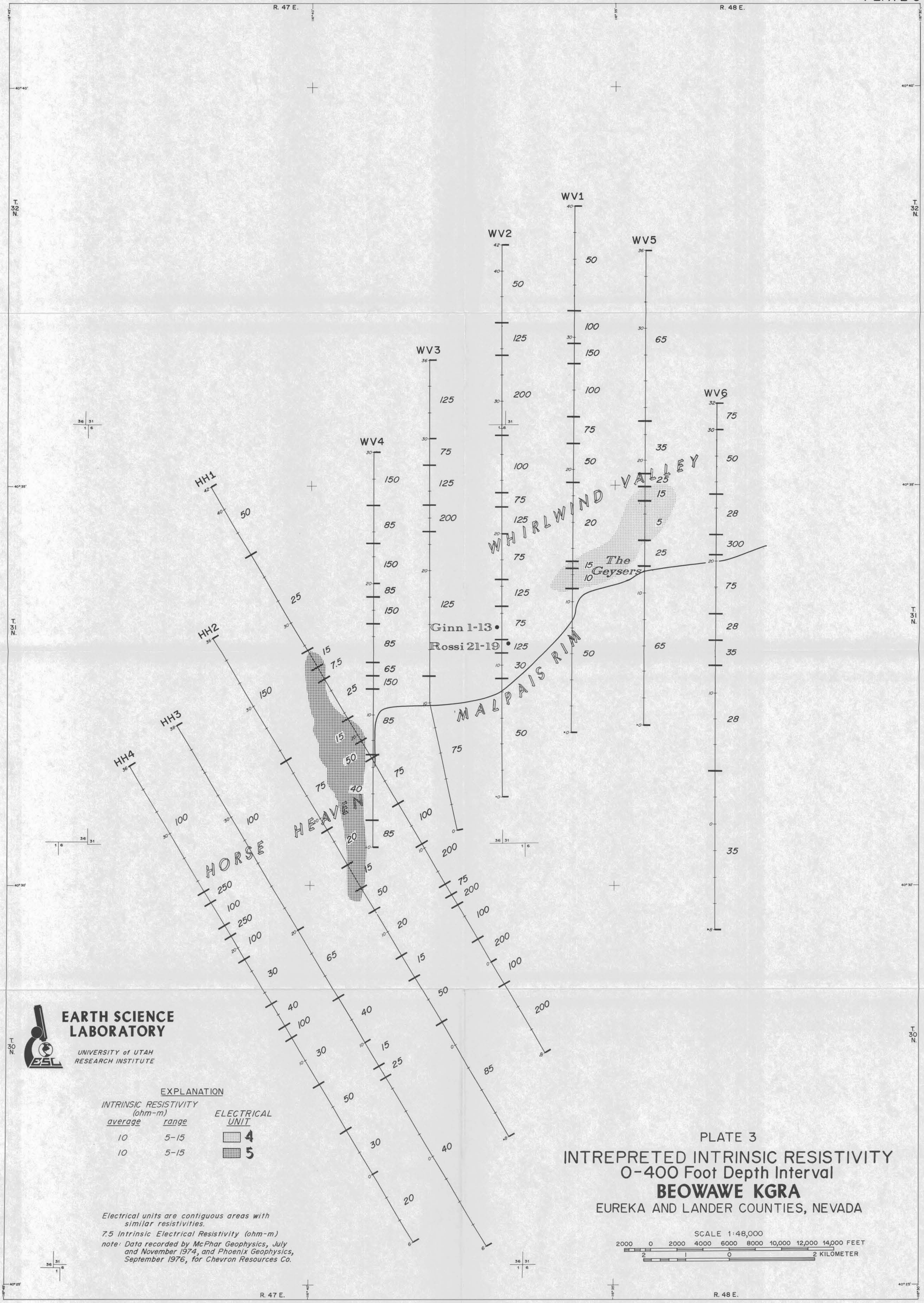
HORSE HEAVEN AREA
BEOWAWE KGRA

EUREKA AND LANDER COUNTIES, NEVADA

SCALE 1:48,000

2000 0 2000 4000 6000 8000 10000 12000 14000 FEET

2 1 0 2 KILOMETER



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EXPLANATION

INTRINSIC RESISTIVITY (ohm-m) average	range	ELECTRICAL UNIT
10	5–15	4
10	5–15	5

Electrical units are contiguous areas with similar resistivities.

7.5 Intrinsic Electrical Resistivity (ohm-m)

note: Data recorded by McPhar Geophysics, July and November 1974, and Phoenix Geophysics, September 1976, for Chevron Resources Co.

PLATE 3

INTREPRETED INTRINSIC RESISTIVITY
0-400 Foot Depth Interval
BEOWAWE KGRA
EUREKA AND LANDER COUNTIES, NEVADA

SCALE 1:48,000

2000 0 2000 4000 6000 8000 10,000 12,000 14,000 FEET

2 1 0 2 KILOMETER

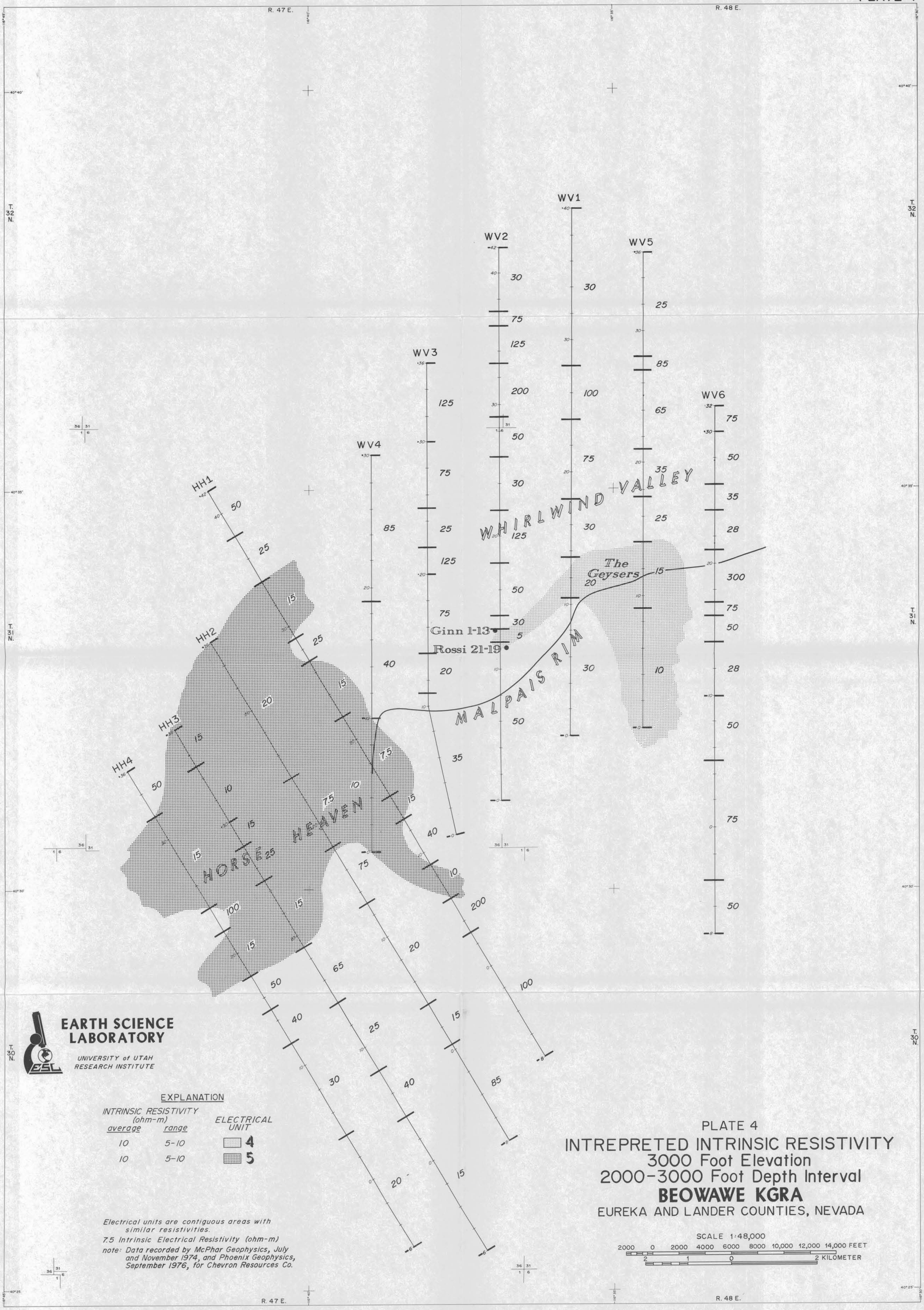
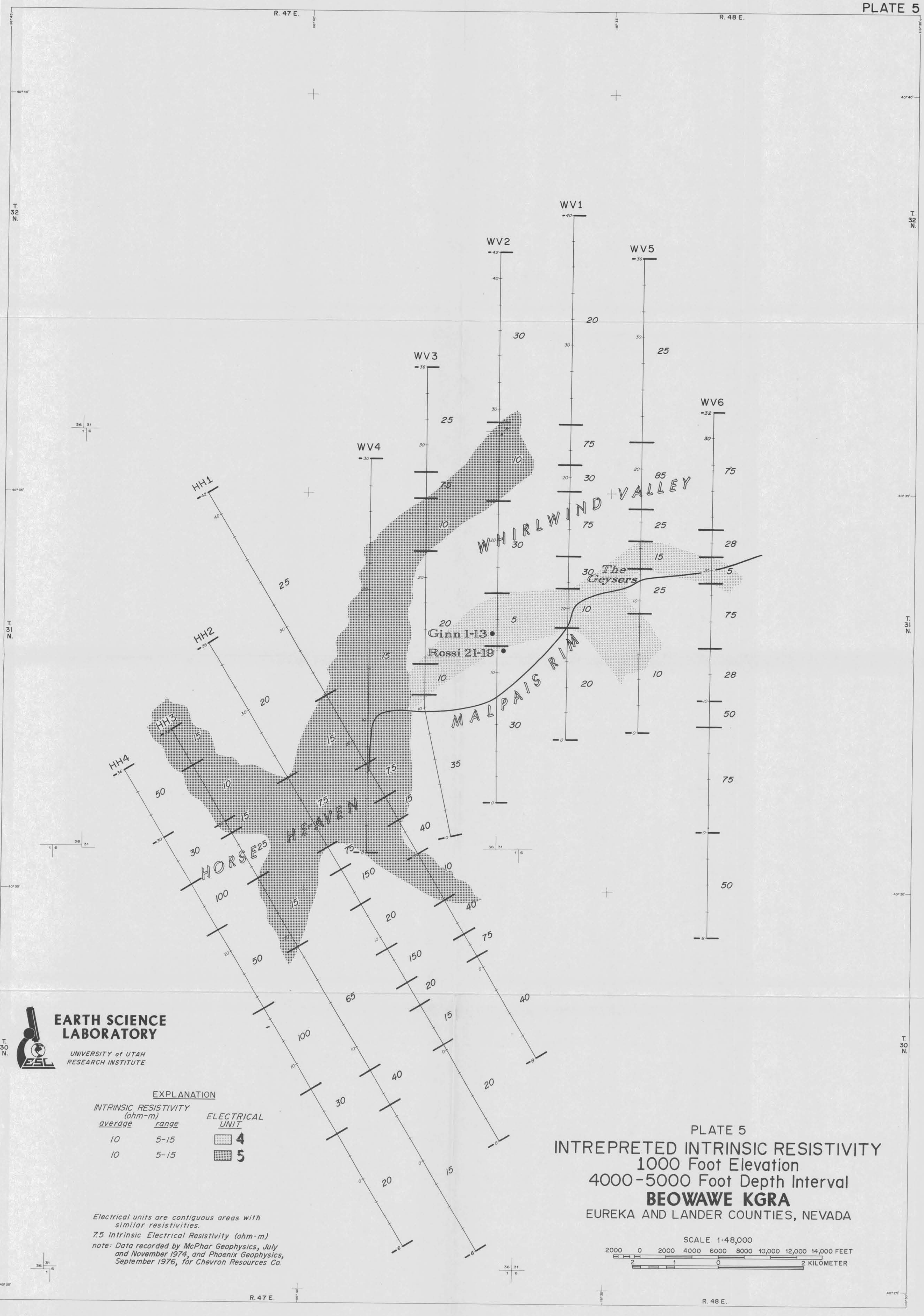


PLATE 4

INTREPRETED INTRINSIC RESISTIVITY
3000 Foot Elevation
2000–3000 Foot Depth Interval
BEOWAWE KGRA
EUREKA AND LANDER COUNTIES, NEVADA

SCALE 1:48,000
2000 0 2000 4000 6000 8000 10,000 12,000 14,000 FEET
2 1 0 2 KILOMETER



EXPLANATION

INTRINSIC RESISTIVITY (ohm-m) average	range	ELECTRICAL UNIT
10	5-15	4
10	5-15	5

Electrical units are contiguous areas with similar resistivities.

7.5 Intrinsic Electrical Resistivity (ohm-m)

note: Data recorded by McPhar Geophysics, July and November 1974, and Phoenix Geophysics, September 1976, for Chevron Resources Co.

PLATE 5

INTREPRETED INTRINSIC RESISTIVITY
1000 Foot Elevation
4000-5000 Foot Depth Interval
BEOWAWE KGRA
EUREKA AND LANDER COUNTIES, NEVADA

SCALE 1:48,000

2000 0 2000 4000 6000 8000 10,000 12,000 14,000 FEET

2 1 0 2 KILOMETER

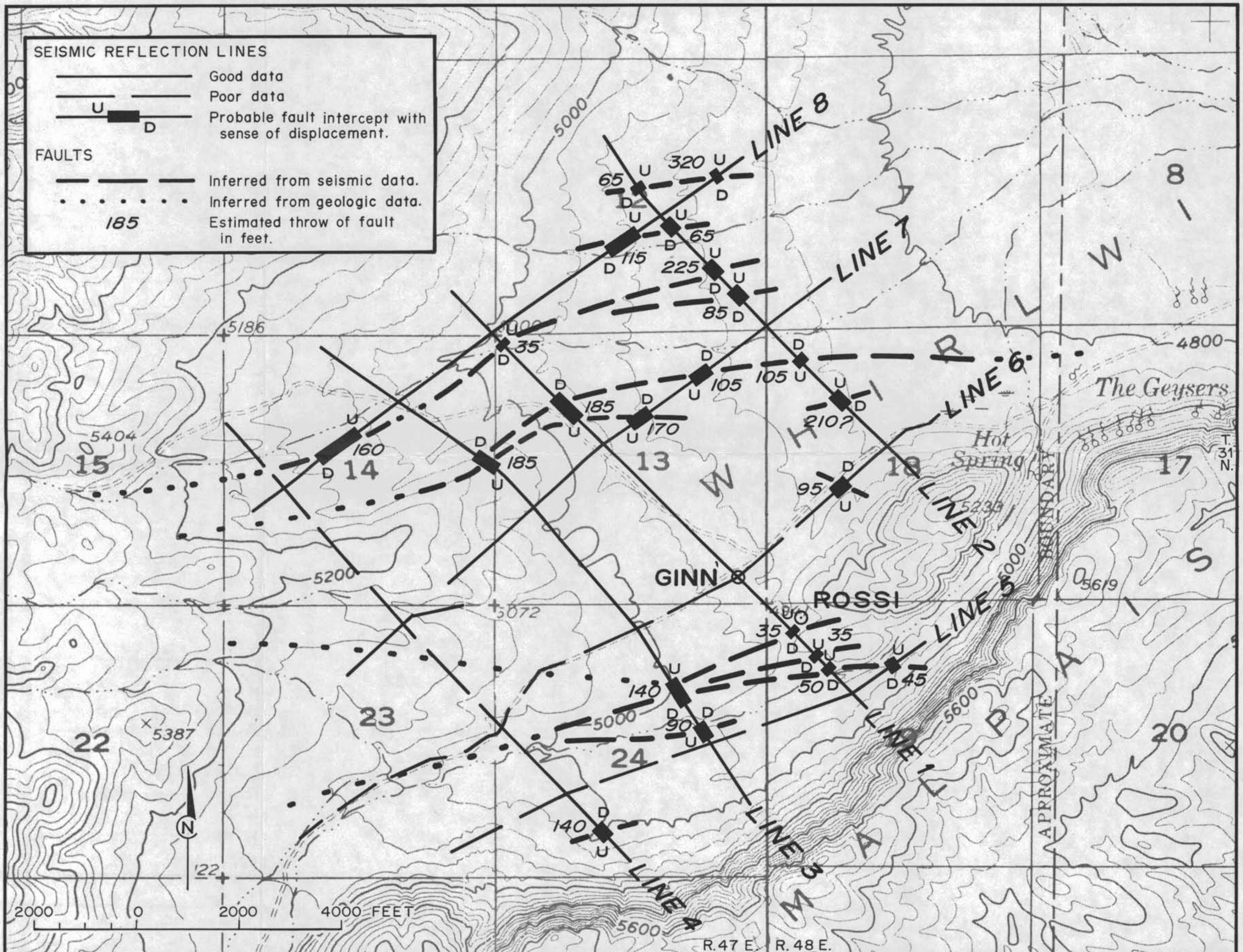


PLATE 6

SHALLOW SEISMIC REFLECTION SURVEY

Weight-Drop Method Max. Depth of Resolution ≈1200 Ft.

BEOWAWE AREA, NEVADA

CHRISTIAN SMITH, 1979