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INTERPRETATION OF THE DIPOLE-DIPOLE ELECTRICAL RESISTIVITY SURVEY, TUSCARORA GEOTHERMAL AREA, ELKO COUNTY, NEVADA

Claron E. Mackelprang

February 1982

Work performed under contract number DE-AC07-80ID12079

EARTH SCIENCE LABORATORY
University of Utah Research Institute
Salt Lake City, Utah

Prepared for
U.S. Department of Energy
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NOTICE

NOTICE

TABLE OF CONTENTS

ILLUSTRATIONS

ABSTRACT

Interpretation of Tuscarora geothermal area model results has suggested that low resistivity zones on two dipole-dipole lines (9 and 16) and possibly on a third (line 5) are related to thermal fluids. These two-dimensional models have delineated what appear to be aquifers within the valley sediments and the Tertiary volcanics. Structural breaks noted at the surface by geologic mapping are also evident in the interpretive models.

The area southeast of the hot springs in Hot Creek is poorly delineated by the current dipole-dipole coverage, yet this appears to be the most promising prospect area based upon the available data coverage. Exploratory drilling is currently moving in this direction. Perhaps additional dipole-dipole lines could aid in the selection of future drill sites.

INTRODUCTION

The Tuscarora geothermal area is located at the northern end of Independence Valley approximately 47 miles north-northwest of Elko, Nevada (Figure 1). This prospect was discovered by AMAX Exploration, Inc., Geothermal Branch, in 1977. Hydrogeochemical analyses have indicated a reservoir temperature of 216°C (Pilkington et al., 1980). AMAX's exploration program has included drilling of 38 shallow thermal gradient holes, one deep (1658 m) exploration hole, gravity and aeromagnetic surveys and electrical surveys consisting of SP, dipole-dipole and MT data.

This report presents an interpretation of the dipole-dipole resistivity data which have been modeled using a 2-D finite element computer algorithm developed at the Earth Science Laboratory (Killpack and Hohmann, 1979). This interpretation and modeling was completed in support of AMAX's exploration program as a participant in the Department of Energy's Industry-Coupled Geothermal Program.

GENERAL GEOLOGY

Independence Valley is a north-south-trending graben in the Basin and Range Province. It is bordered on the east by the Independence Range and on the west and northwest by the Tuscarora and Bull Run Mountains, respectively (Figure 1). The northern Independence Mountains consist of Ordovician quartzites, shales, cherts and volcanic rocks (Plate I) thrust over lower Paleozoic carbonate rocks (Churkin and Kay, 1967). These rocks were subsequently eroded and overlain by Mississippian to Permian shale, chert and quartzite tentatively correlated with the overlap assemblage by Miller et al. (1981).

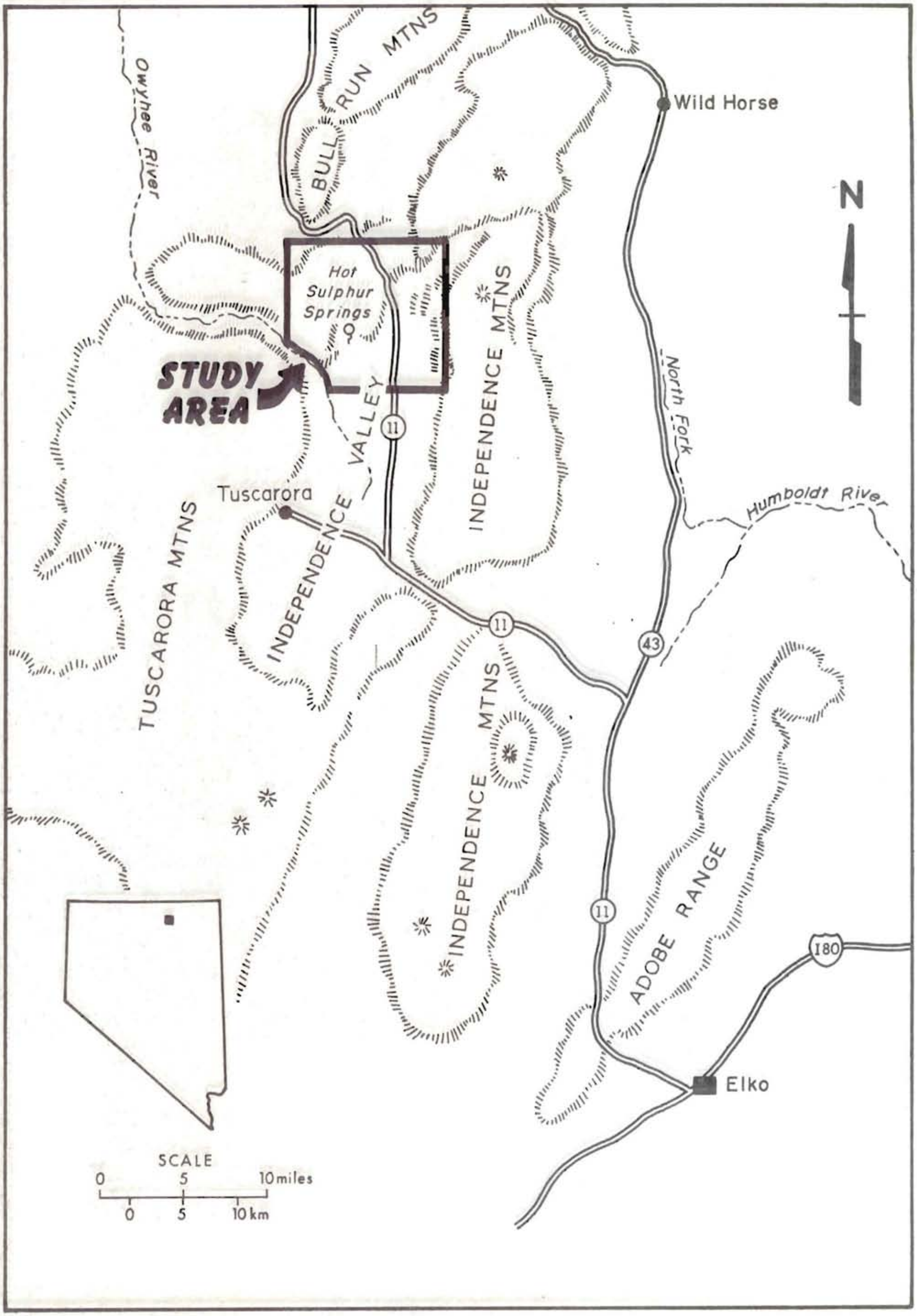

FIGURE 1. LOCATION MAP AND PHYSIOGRAPHIC SETTING OF THE TUSCARORA AREA, ELKO COUNTY, NEVADA

The Tuscarora Mountains consist of Tertiary volcanic and sedimentary rocks overlying Ordovician rocks (Hope and Coats, 1976). In the Bull Run Mountains, lower Paleozoic limestone and quartzite and a Tertiary porphyritic andesite intrusive are exposed (Decker, 1962). Mesozoic rocks are lacking in the area except for Cretaceous intrusive rocks in the Bull Run Mountains.

The area is structurally complex. Thrust faults and associated folds developed during the Late Devonian Antler Orogeny (Roberts et al., 1958) and were reactivated again during the Permian-Triassic Sonoma Orogeny (Silberling, 1975). During Tertiary time east-west tensional forces produced north-south-trending horst and grabens by normal faulting. The north-south faults are the dominant Tertiary structures in the Tuscarora geothermal area with perhaps the most significant of the faults being the range boundary fault on the west side of the Independence Mountains (Sibbett, 1981).

Faults trending N10°E and N40°W on the western side of the study area bound a horst which exposes a source vent for tuff-breccia. The vent area is uplifted relative to the rest of the horst with the bounding faults being convex upward where well exposed. This evidence, along with massive quartz veins within the vent and along some of the bounding structures, suggests an intrusion at depth (Sibbett, 1981).

Another major structure, trending north to N20°E, occurs along Hot Creek. This structure, though poorly exposed, has controlled emplacement of several basaltic-andesite plugs trending N10°W and the surface expression of the geothermal system (Sibbett, 1981).

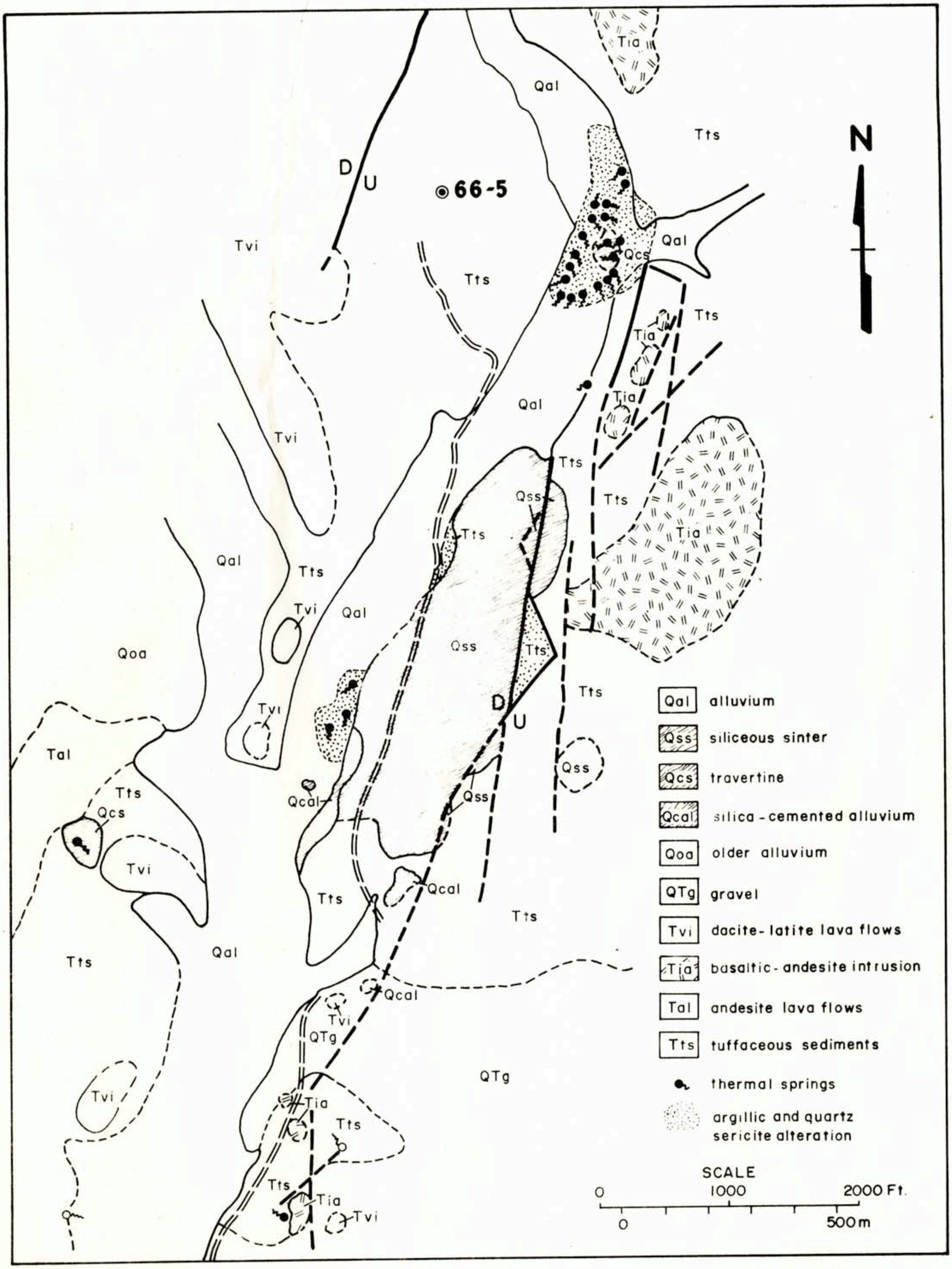

FIGURE 2. DETAILED GEOLOGY OF THE HOT SPRINGS AREA, TUSCARORA AREA, NEVADA (AFTER SIBBETT, 1981)

GEOTHERMAL SETTING

Sibbett (1981) describes the numerous hot springs and extensive sinter deposits that occur at Hot Sulphur Springs (Figure 2). The main sinter mound is 1000 m by 330 m and 35 m high but does not have currently active springs on it. Three springs in the alluvium at the western foot of the mound are depositing silica. Most of the spring activity occurs in a small area 400 meters upstream from the large sinter mound. The springs form a roughly triangular pattern and have temperatures of 55-95°C. The hotter springs are depositing both siliceous and calcareous sinter, sulfur and sublimates. A few of the springs are boiling at the surface and there is one small steam vent. The Na/K/Ca geothermometer indicates a reservoir temperature of 181° to 228°C (Pilkington et al., 1980).

A few small thermal springs occur south and southwest of the main thermal area. A thermal spring on the west side of Hot Creek issues from the top of a low calcite and sediment mound. An intermittently flowing thermal spring occurs 900 meters south of the main sinter mound. Yet another spring with a flow of 75-100 liters/minute is located 3 km south-southwest of the main sinter mound. The only other thermal spring reported in the valley (Garside and Schilling, 1979) is Petaini Springs located 11 km southeast of Hot Sulphur Springs near the mouth of Jerritt Canyon.

ELECTRICAL RESISTIVITY SURVEY

The dipole-dipole survey was conducted during the interval July 3 through August 6, 1979 by Mining Geophysical Surveys, Inc. Three resisitivity lines totaling 33 line-miles and labeled 5, 9, and 16 were surveyed using conventional 7-spread electrode configurations and dipole spacings of 610 meters (2000 feet). Data were collected at "n" - spacings of $1/2$, and 1 to 5.

Survey Procedure

The resistivity measurements were made in the Time-Domain mode using an EGC model R20A receiver capable of reading the primary voltage from 150 microvolts to 100 volts full scale. The power supply and a Geotronics model FT-20 transmitter were capable of 20 amps current output. A timing cycle of 2.0 seconds "on" and 2.0 seconds "off" repeated with polarity reversed was employed. Data measurements were taken during the "on" portion of the cycle. Current in amperes and primary voltage in millivolts were observed for a minimum of two full cycles, and more where low signal and high telluric "noise" were encountered. Repeat stations show reciprocity and indicate good data quality.

Lines 5 and 9 are east-west-trending lines each comprised of three 7-spreads. Line 16 is a diagonal line trending roughly northwest-southeast and consisting of two 7-spreads. Lines 9 and 16 cross one another in close proximity to Hot Sulphur Springs. Line 5 is located approximately 2 miles north of the hot spring area. Plate I also shows the location of these lines.

Model Results

The field data were modeled using a 2-D finite element computer program developed at the University of Utah Research Institute/Earth Science Laboratory Division (Killpack and Hohmann, 1979).

Resistivity models determined to be "best fits" to the observed data have been constructed through an iterative process for each of the resistivity lines. Plate II shows the calculated models with the observed resistivity values. Plate III shows the calculated models and the calculated resistivity derived from them. The "goodness of fit" may be evaluated by comparing the data values on these plates. These models are non-unique but appear to give good agreement to mapped geology. Lines 5 and 9 have sufficient topographic variation to warrant the use of a model incorporating effects due to topography as well as resistivity inhomogeneities. The models for the three lines are discussed individually below.

Interpretation

Line 5 The computed model for this line shows two areas of anomalously low (4 Ω-m) resistivities. The first extends from the surface at Jack Creek to a depth of about 1,300 feet where it projects westward several thousand feet into Tertiary tuffaceous sediments. Jack Creek apparently follows a zone of structural weakness; at least two north-south-trending faults are mapped between stations C3 and C4 of spread 3 (see Plate I). This faulting has juxtaposed Paleozoic sediments against Tertiary volcanics and sediments. The computed resistivities at this transition change from about 10 ohm-meters on the west to 500 ohm-meters over the Paleozoics. The 4 ohm-meter zone rising to the surface at Jack Creek corresponds to this fractured zone with some contribution likely from the saturated Quaternary alluvium associated with the stream.

The 4 ohm-meter zone occurring within the Tertiary sediments to the west of Jack Creek is not easily explained. No surface manifestations of thermal waters such as hot springs, sinter deposits or alteration exist nearby. Thermal gradient holes located along Jack Creek disclosed slightly anomalous temperatures (~24°C) at a depth of 100 meters. Because of the cooling effect from the large volume of surface waters, these weakly anomalous temperatures may be significant. The low (4 Ω-m) resistivity zone at depth west of Jack

Creek may be the result of thermal fluids (?) issuing along the major structures in the drainage which then flow westward into permeable zones (aquifers) within the Tertiary tuffaceous sediments. Numerous faults trend north through the mountain range. One of these occurs near station C7 on spread 2 and may account for the apparent rise towards the surface of the 4 ohm-meter zone by allowing thermal fluids to percolate upwards within the fault zone. It is interesting that the station interval C6 to C7 on spread 2 lies approximately two miles due north of the Hot Sulphur Springs.

The second area displaying anomalously low resistivities occurs on the western end of spread 1 at depths of 1500 to 2000 feet. This area lies well outside the area covered by the detailed geologic mapping. Hence, little can be said regarding this unexplained anomaly other than the U.S. Geological Survey's Geologic Map of Nevada shows the surface rocks to be volcanic in composition with ages of roughly 17-43 million years.

Another significant feature along line 5 appears to be the northern end of the volcanic vent. This area lies between stations C6, spread 1 and station C1, spread 2 and appears to have moderate resistivities of 50-60 ohm-meters.

Line 9 This line crosses through the hot spring area and is generally normal to geologic and structural contacts. The resistivity distribution is much more complex on this line than on line 5. The recent alluvium and the Tertiary tuffaceous sediments at the surface on the west end of the line exhibit resistivities of 10 to 20 ohm-meters. Another large zone of low (5 Ω-m) resistivity occurs at a depth of about 2000 feet beneath these rocks. This low-resistivity zone is very likely similar in composition to that observed at depth on the western end of line 5. The geologic explanation for this conductive zone remains a mystery the zone when combined with that on the west end of line 5 appears to have a substantial areal extent.

The 300 ohm-meter material adjacent to the conductive zone is interpreted to be Paleozoic rocks. The 50 and 70 ohm-meter material at the surface, extending east from station C4 on spread 3 for approximately 8,000 feet, coincides with the mapped volcanic vent. Sibbett (1981) postulates an intrusive body at depth beneath the vent area as shown on Figure 3 (taken from his report). His evidence for this intrusion is that the vent area is uplifted relative to the horst upon which it sits and the bounding faults, where well exposed, are convex upward. Massive quartz veins within the vent and along some of the bounding faults are given as further evidence.

The 70-90 ohm-meter material at depth beneath the volcanic vent area (spread 3) is interpreted to be the intrusive body. Numerous faults cut the vent area at the surface. These fractures likely extend to depth and may merge with fracture zones in the intrusion. These may give rise to the 20 ohm-meter body required in the model at depth beneath station C5.

Spread 2 is centered over the hot spring area. Plate II shows the observed apparent resistivities to be fairly low (<10 Ω-m) over the central portion of this spread. These data have been matched reasonably well (Plate III) with the computed model having a thick, conductive (2 Ω-m) layer or zone that approaches the surface beneath Hot Creek (stations C2-C3). These low resistivities are believed to be caused by thermal fluids and associated alteration minerals formed as the fluids move through the sediments prior to their release as hot springs along Hot Creek. The sinter deposit adjacent to station C3 is evident on the computed model as a thin, 35 ohm-meter body at the surface.

The Tertiary basaltic-andesite intrusion outcropping near station C4 appears on the model as a shallow, 35 ohm-meter body. The deeper 35-75 ohm-meter bodies may indicate a continuation of this intrusive at depth or perhaps the Paleozoic quartzites. The 150 ohm-meter material at depth beneath station C1, spread 2, is most likely to be Paleozoic carbonates.

Finally, the eastern end of line 9 (spread 1) crosses the alluvial fill at the northern end of Independence Valley and terminates on the Paleozoic rocks comprising the Independence Mountains. High apparent resistivities in excess of 150 ohm-meters are observed over these rocks.

Line 16 The significant resistivity feature along this line is the conductive zone extending southeast from Hot Creek (Plate II). This zone has been modeled with 2 ohm-meter material that plunges to depths of about 4,000 feet in sections 15 and 16, T41N, R52E (Plate I). Quaternary alluvium, the predominant material at the surface along this line, corresponds to 35-50 ohm-meter resistivities. Tertiary tuffaceous sediments and the large sinter deposit are exposed to the northwest. The 2 ohm-meter zone is thought to indicate thermal fluids issuing from great depths which fill aquifers within the alluvium and sediments. The fluids rise to the surface via fracture zones to the Hot Creek area where they exit as hot springs. The moderate resistivities (35-50 Ω-m) occurring at the surface along the south half of the line are probably best explained by partially saturated alluvium. The 10 ohm-meter layer beneath this horizon may indicate older ground water that has had time to become slightly more saline. The southernmost end of the line approaches the Paleozic sediments and a resultant increase in resistivity is recorded.

The northern end of the line shows a very low resistivity in the surface

GEOLOGIC SECTIONS OF THE TUSCARORA GEOTHERMAL AREA
(After Sibbet)

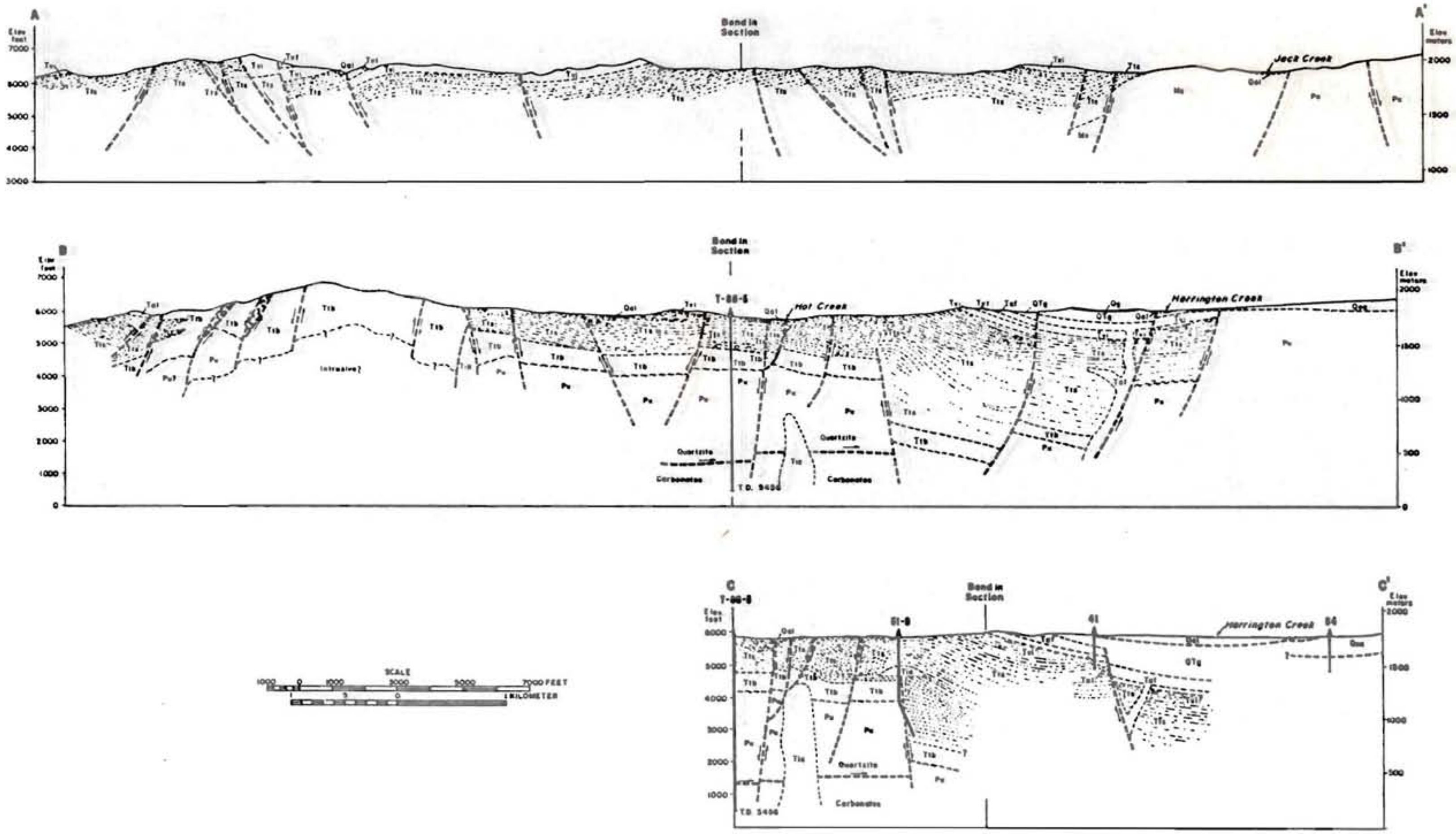

FIGURE 3

alluvium. A more moderate resisitivity occurs in the underlying Tertiary tuffaceous sediments. More resistive material is evident at depth which probably indicates the Paleozoic sediments.

DISCUSSION

The high-temperature geothermal reservoir at Tuscarora has proven to be a very elusive drill target. Geologic mapping has shown the area to be structurally complex. The geothermal model hypothesized by Sibbett (1981) has meteoric waters circulating down along the major range front fault systems where they are heated at great depths. These thermal fluids then rise along major fractures and perhaps into gravel aquifers at the base of or within the tuffaceous sediments and ultimately reach the surface as hot springs along Hot Creek. The main application for the dipole-dipole resistivity survey has been the delineation of structural features and conductive zones that may be indicative of thermal fluids or their channel ways.

The anomalous zone noted by the resistivity data on line 5 near Jack Creek is not readily explained. Thermal fluids rising along mapped faults and into aquifers within the tertiary tuffaceous sediments might be an explanation, although this hypothesis is untested. Line 9 infers, however, a strongly fractured zone beneath spread 2 in the center of the line. This zone and the accompanying low resistivities are probably related to the geothermal system. It is not necessary, however, for all fractures or anomalous resistivities to be directly associated with thermal fluids. Drill holes 51-9 and 66-5 both encountered fractures but only 66-5 contained thermal fluids at a shallow depth. Hole 51-9 was essentially a dry hole with lost circulation occurring at the bottom of the hole (Sibbett, personal comm.).

Line 16 has also indicated what appears to be an aquifer or conduit for these thermal fluids rising from depth within the valley sediments and into the fracture zone at Hot Creek. No drill test has been completed to date on this anomaly in the valley. Should thermal fluids be found there, then the geothermal reservoir may be located southeast of Hot Creek as hypothesized by Sibbett.

Exploratory drilling is currently underway at Tuscarora. The siting of future drill tests could be aided by additional dipole-dipole resistivity lines placed south of line 9.

ACKNOWLEDGEMENTS

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REFERENCES

Churkin, M. Jr., and Kay, M., 1967, Graptolite-bearing Ordovician siliceous and volcanic rocks, northern Independence Range, Nevada: Geological Society of America Bull., v. 78, p. 651-668.

Decker, R. W., 1962, Geology of the Bull Run Quadrangle Elko County, Nevada: Nevada Bureau of Mines and Geology, Bull. 60, 65 p.

Garside, L. J., and Schilling, J. H., 1979, Thermal waters of Nevada: Nevada Bureau of Mines and Geology, Bull. 91, 160 p.

Hope, R. A., and Coats, R. R., 1976, Preliminary geologic map of Elko County, Nevada: U. S. Geological Survey Open-File Report 76-779, scale 1:100,000.

Killpack, T. J., and Hohmann, G. W., 1979, Interactive dipole-dipole resistivity and IP modeling of arbitrary two-dimensional structures: Univ. of Utah Res. Inst., Earth Science Laboratory report 15, 120 p.

Miller, E., Bateson, J., Dinter, D., Dyer, R., Harbarbaugh, D., and Jones, D. L., 1981, Thrust emplacement of Schoonover Sequence, Northern Independence Mountains, Nevada: Geological Society of America Bull. (in press).

Pilkington, H. D., Lange, A. L., and Berkman, F. E., 1980, Geothermal exploration at the Tuscarora Prospect in Elko County, Nevada: Geothermal Resources council, Transactions v. 4, p. 233-236.

Roberts, R. J., Hotz, R. E., Gilluly, J., and Ferguson, H. G., 1958, Paleozoic rocks of North-Central Nevada: American Association of Petroleum Geologists Bull., v. 42, p. 2813-2857.

Sibbett, B. S., (1981), Geology of the Tuscarora Geothermal Prospect, Elko County Nevada: Geological Society of America Bulletin.

Silberling, N. J., 1975, Age relationships of the Golconda Thrust fault, Sonoma Range, north-central Nevada: Geol. Soc. Amer., Special Paper 163, 28 p.

Wieduwilt, W. G., 1979, Resistivity Survey Tuscarora Project Elko County, Nevada for AMAX Exploration, Inc.: Mining Geophysical Surveys, Inc. project report, 8 p.

PLATE I

EXPLANATION

QUARTERNARY

- Qss — Siliceous sinter.
- Qal — Alluvium and talus, recent deposits.
- Qls — Landslides
- Qoa — Older Alluvium, currently being eroded but conformable with present geomorphic surface.
- Qg — Gravel, quartzite boulders, glacial outwash, not graded to present drainage, deformed.
- Qt — Glacial till deposits.
- QTg — Gravel, quartzite pebbles to boulders.

TERTIARY

MIOCENE

- Taf — Porphyritic andesite lava flows with 5-10%, 2-5mm phenocrysts of andesine and augite in a vitric matrix. Overlies Tvt and Tvi.
- Tvt — Weakly welded ash-flow tuff, 7% 1-3mm sanadine crystals in black vitric matrix.
- Tvi — Porphyritic quartz latite and dacite lava flows, 20% 2-6mm phenocrysts of K feldspar, andesine, quartz and augite in a red to black felsitic matrix.
- Tia — Porphyritic basaltic-andesite intrusions, 15-25%, 3mm phenocrysts of plagioclase, augite and biotite in a felsitic matrix.

OLIGOCENE

- Tal — Porphyritic andesite and basaltic-andesite lava flows, 10-30%, 2-4mm phenocrysts in an olive-gray to black matrix.
- Tts — Tuffaceous sediments, non-resistant waterlaid tuffs, tuffaceous sands, volcaniclastic conglomerate lenses and interbedded 3 to 6m thick, non-welded tuffs.
- Ttb — Tuff breccia, heterogeneous vent facies deposit of pyroclastic breccia, lapillistone and ash-flow tuffs. Contains pebble to block-size xenoliths of Paleozoic rocks.

MISSISSIPPIAN TO PERMIAN

- Ms — Schoonover Formation (Fagan, 1962).

PALEOZOIC UNDIFFERENTIATED

- Pu — Argillite, quartzite, chert and greenstone.

- Contact, dashed where inferred or approximate.
- Fault, dashed where inferred, dotted where covered.
- Thrust fault, dashed where inferred.
- Slump block of rock which has moved as a unit.
- Collapse and shear breccia.
- Strike and dip of bedding or contact, single bar indicates dip measured in outcrop, double bar indicates dip calculated from outcrop pattern or estimated from aerial photographs. (45, 10)
- Plunging syncline.
- Plunging anticline.
- Geothermal exploration hole.
- 43 Location and number of K-Ar samples.

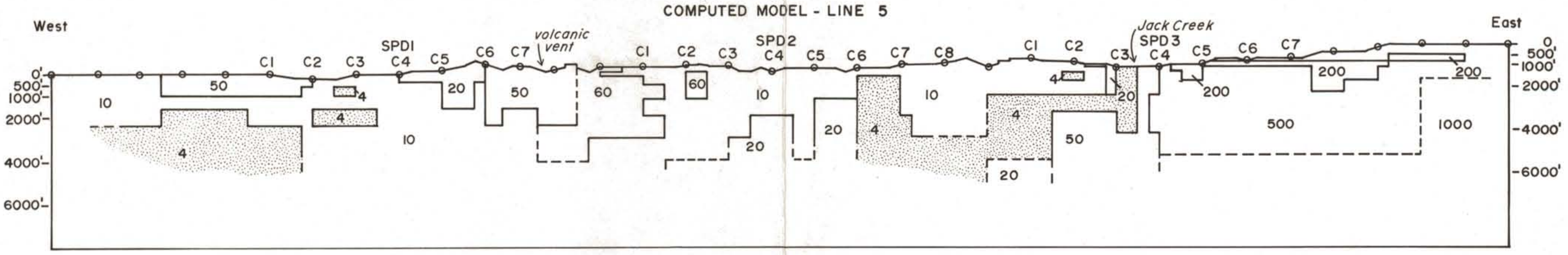
Contour interval 40 feet.

- Resistivity lines

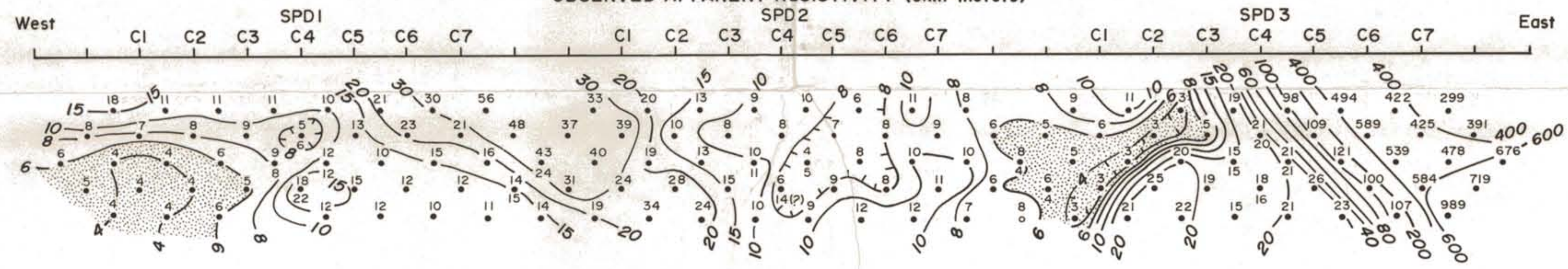
PLATE II

TUSCARORA PROJECT - ELKO COUNTY, NEVADA

COMPUTED MODEL - LINE 5

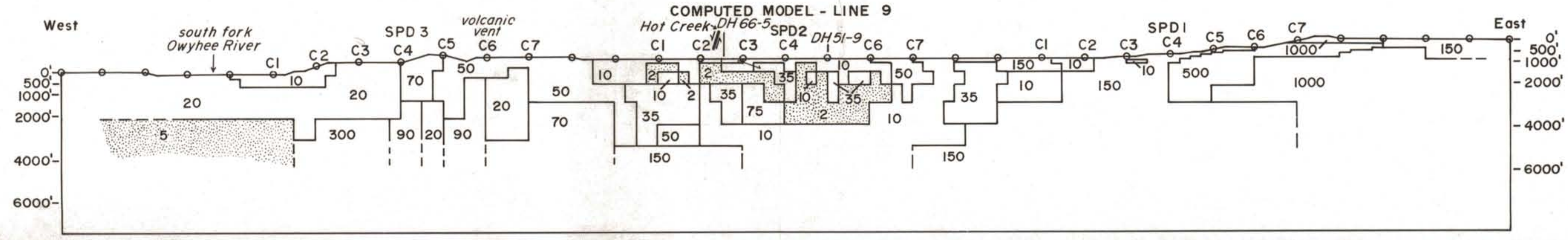


OBSERVED APPARENT RESISTIVITY (ohm-meters)



TUSCARORA PROJECT - ELKO COUNTY, NEVADA

COMPUTED MODEL - LINE 9



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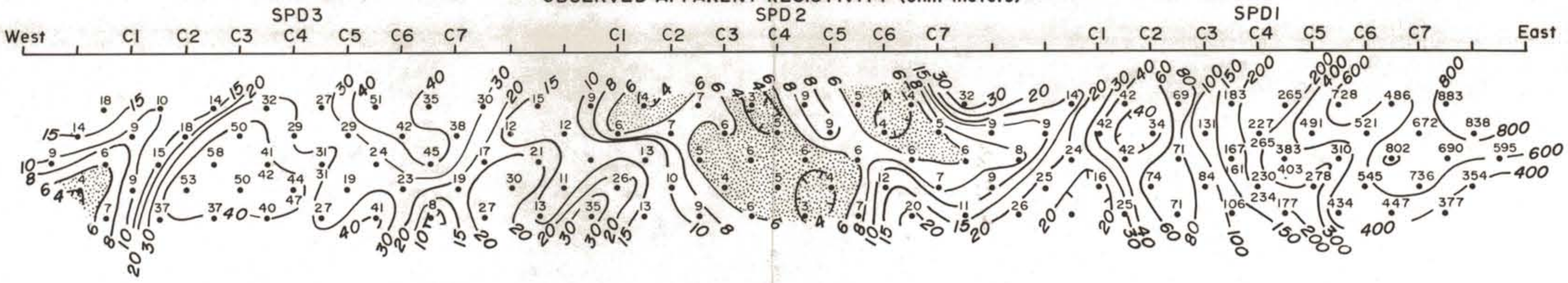
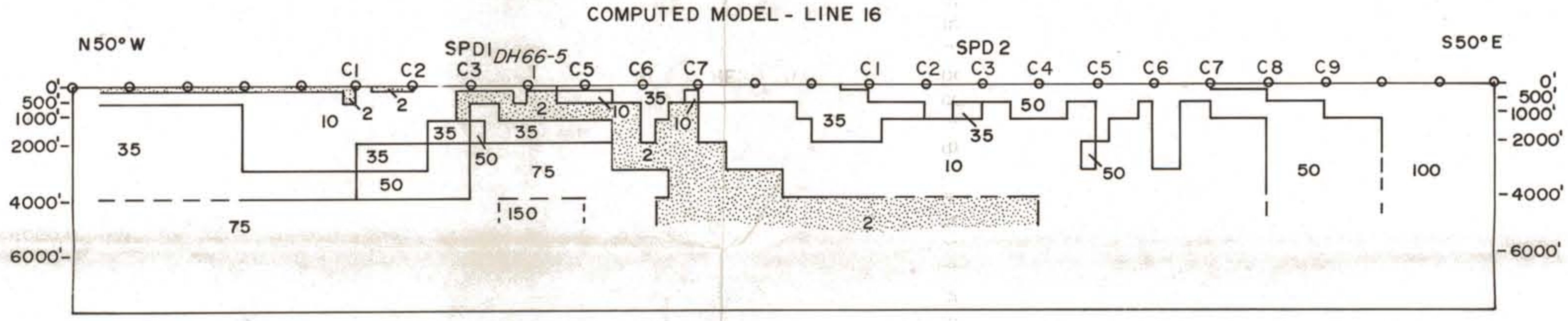
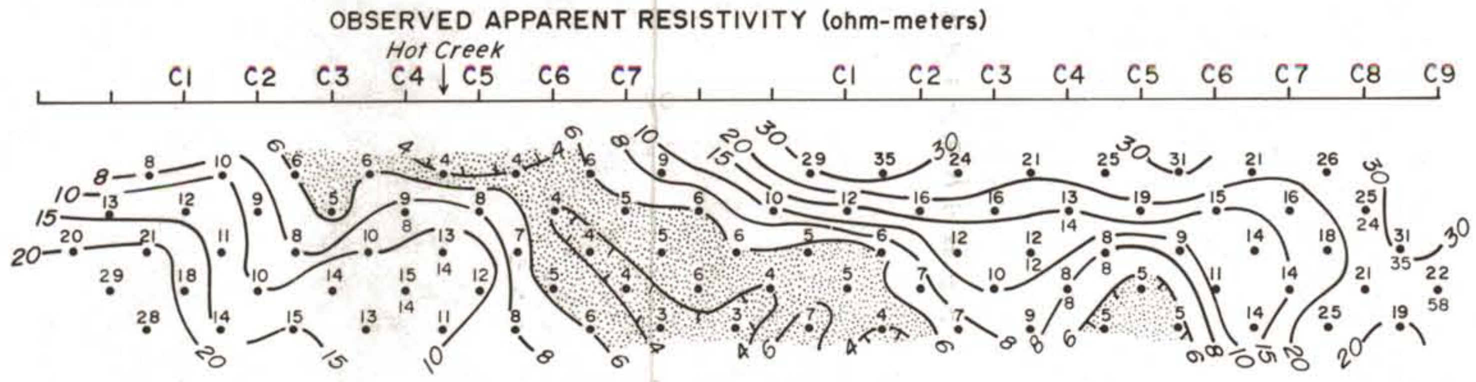


TUSCARORA PROJECT - ELKO COUNTY, NEVADA

COMPUTED MODEL - LINE 16



OBSERVED APPARENT RESISTIVITY (ohm-meters)



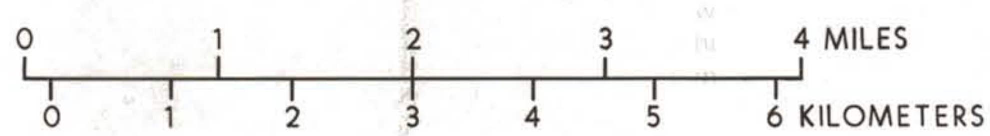
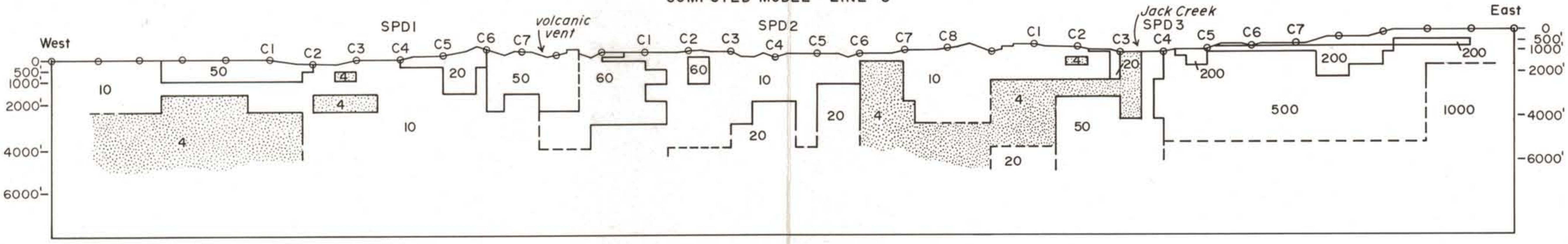


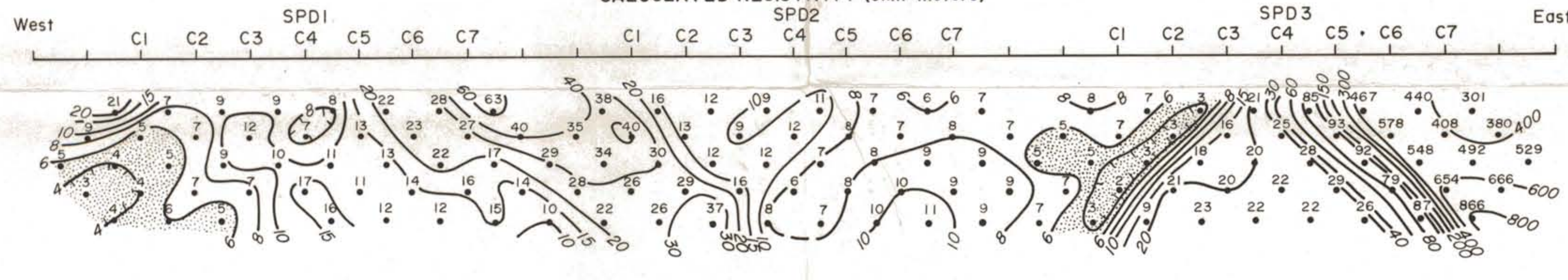
PLATE III

TUSCARORA PROJECT-ELKO COUNTY, NEVADA

COMPUTED MODEL - LINE 5

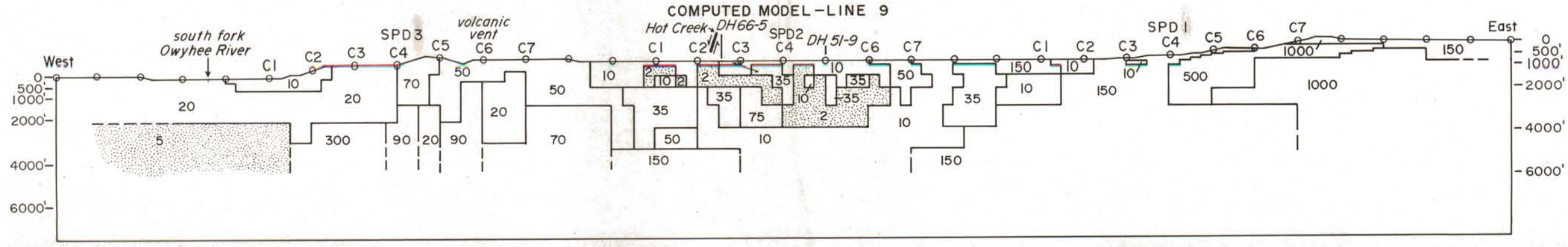


CALCULATED RESISTIVITY (ohm-meters)

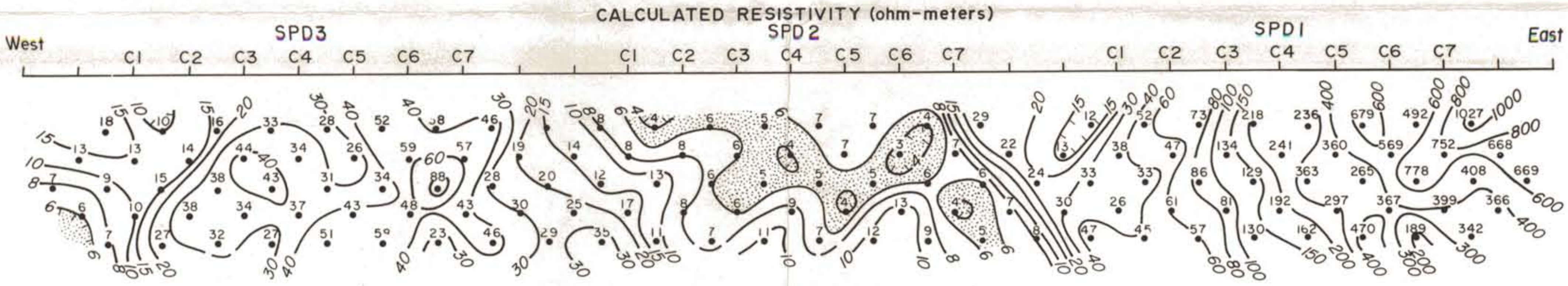


TUSCARORA PROJECT-ELKO COUNTY, NEVADA

COMPUTED MODEL - LINE 9

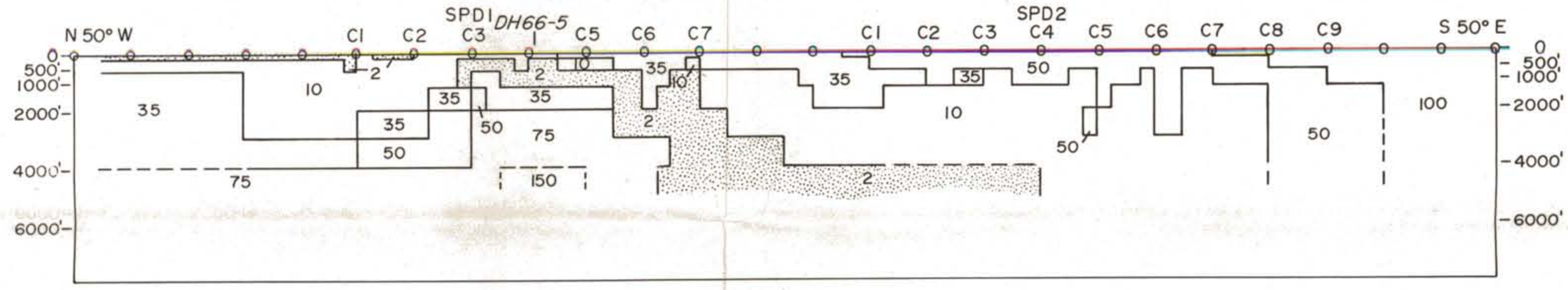


CALCULATED RESISTIVITY (ohm-meters)



TUSCARORA PROJECT-ELKO COUNTY, NEVADA

COMPUTED MODEL LINE 16



CALCULATED RESISTIVITY (ohm-meters)