DOE/ET/27011-1

# TUSCARORA AREA, NEVADA

## Geothermal Reservoir Assessment Case History

## Northern Basin and Range

FINAL REPORT

1 October 1978 - 9 September 1980

MASTER


H. D. PILKINGTON


August 1981

WORK PERFORMED UNDER CONTRACT

DE-AC08-79ET27011


AMAX Exploration, Inc.
7100 W. 44th. Avenue
Wheat Ridge, Colorado 80033

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U. S. DEPARTMENT OF ENERGY
DIVISION OF ENERGY TECHNOLOGY
Under Contract DE-AC08-79ET27011

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ABSTRACT

The Tuscarora prospect is located at the north end of Independence Valley approximately 90 km north-northwest of Elko, Nevada. The prospect was discovered in 1977 and in 1978 was made a part of the Geothermal Reservoir Assessment Case Study program of the Department of Energy under contract DE-AC08-79ET27011.

Geothermal exploration on the prospect consisted of an integrated program of geologic, hydrogeochemical and soil geochemistry studies. Geophysical exploration included heatflow studies, aeromagnetic, self-potential, gravity, dipole-dipole resistivity and magnetotelluric surveys. Exploration drilling includes thirty-two shallow thermal gradient holes, six intermediate depth temperature gradient wells and one 5454 foot test for discovery well.

Shallow low-temperature reservoirs were encountered in the Tertiary rocks and in the Paleozoic rocks immediately beneath the Tertiary. Drilling problems forced the deep well to be stopped before the high-temperature reservoir was reached.

## INTRODUCTION

The Tuscarora geothermal prospect is 90 kilometers north-northwest of Elko, Nevada (Figure 1) and can be reached by means of Nevada State Highways 225 and 226. Highway 226 traverses the east side of the prospect.

The Tuscarora prospect was discovered in the summer of 1977 during a regional geothermal reconnaissance of Nevada. The hydrogeochemical analysis of Hot Sulphur Springs indicated a possible reservoir with a minimum subsurface temperature of 216$^{o}$C based upon a mixing model.

During 1978, AMAX submitted a proposal in response to the Department of Energy (DOE) RFP No. ET-78-R-08-0003, Geothermal Reservoir Assessment Case Study and was awarded a contract providing partial funding for the exploration of the property. Detailed results of the exploration funded by the DOE has been published through the University of Utah Research Institute as a part of the DOE contract DE-AC08-79ET27011, Geothermal Reservoir Assessment Case Study, Northern Basin and Range, Tuscarora area.

## EXPLORATION HISTORY

The geothermal exploration at the Tuscarora prospect funded by DOE contract DE-AC08-79ET27011 includes geochemical and geophysical studies as well as exploration drilling done in 1977, 1978, 1979 and 1980. For this report the exploration will be summarized by exploration methods rather than chronologically to avoid repetition.

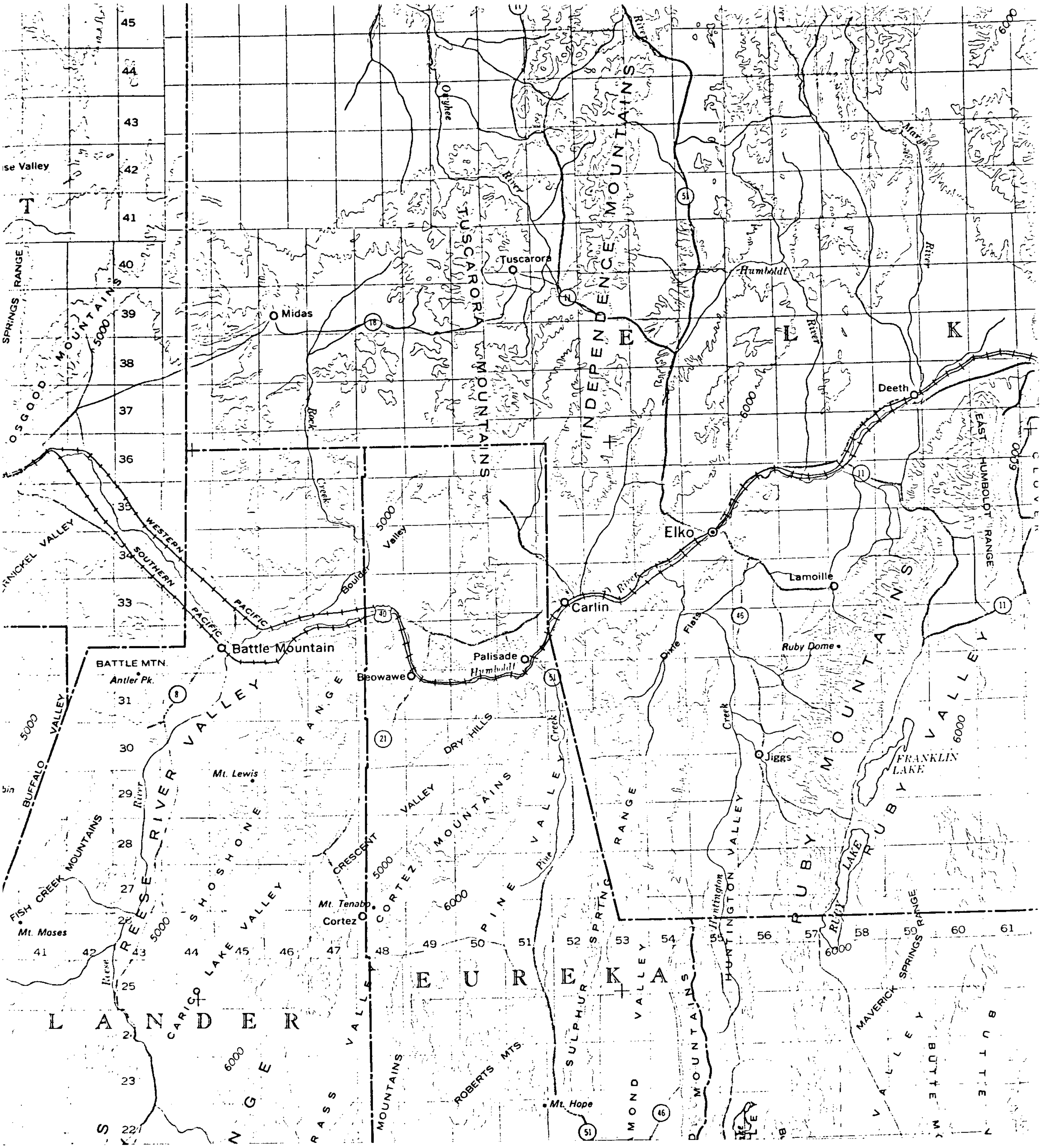



Figure 1. Location map for the Tuscarora geothermal prospect, Elko County, Nevada

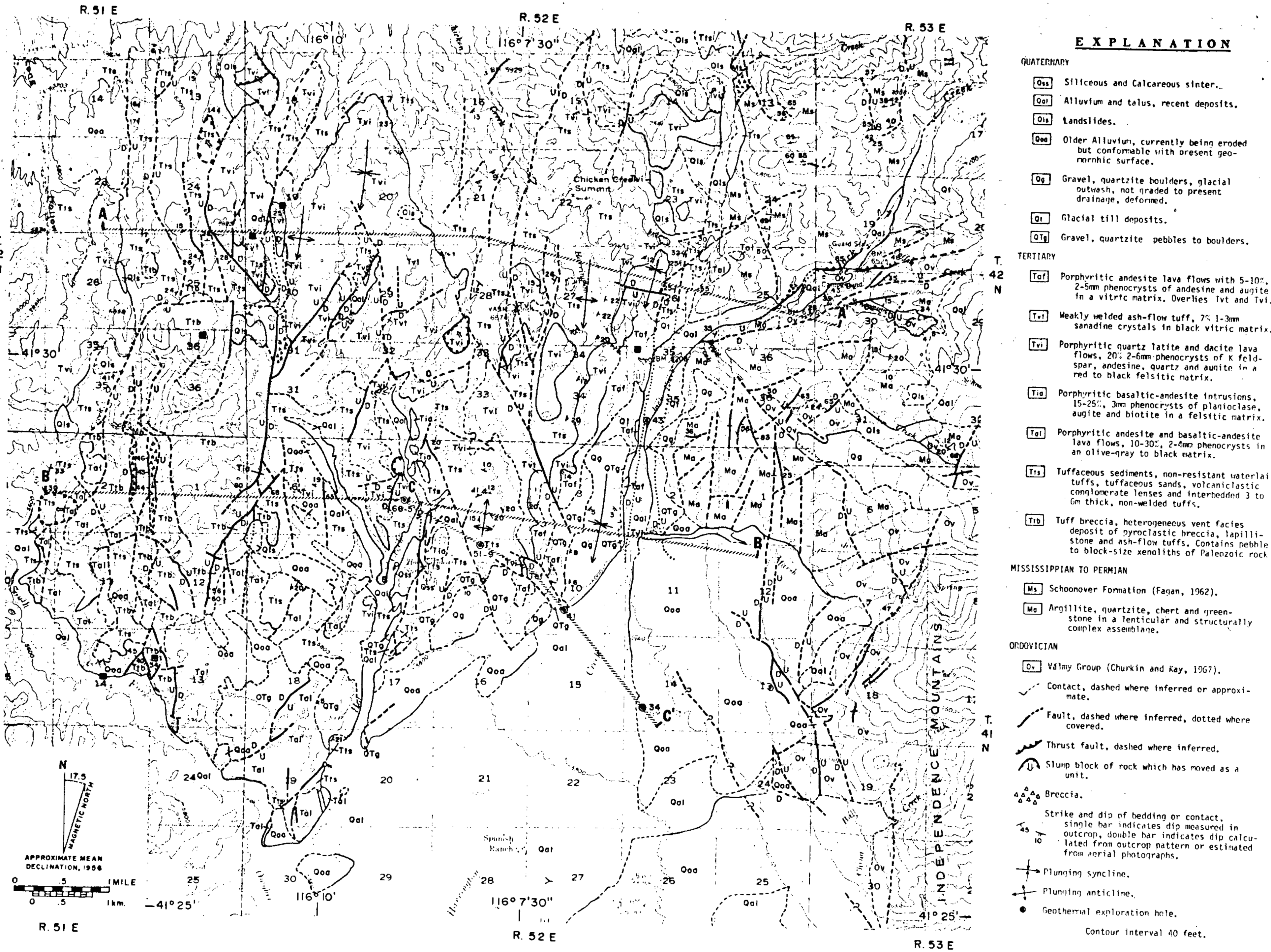



Figure 2. Geologic map of the Tuscarora area, Nevada after Sibbett (1980)
Mapping done under DOE contract DE-AC07-80ID12079

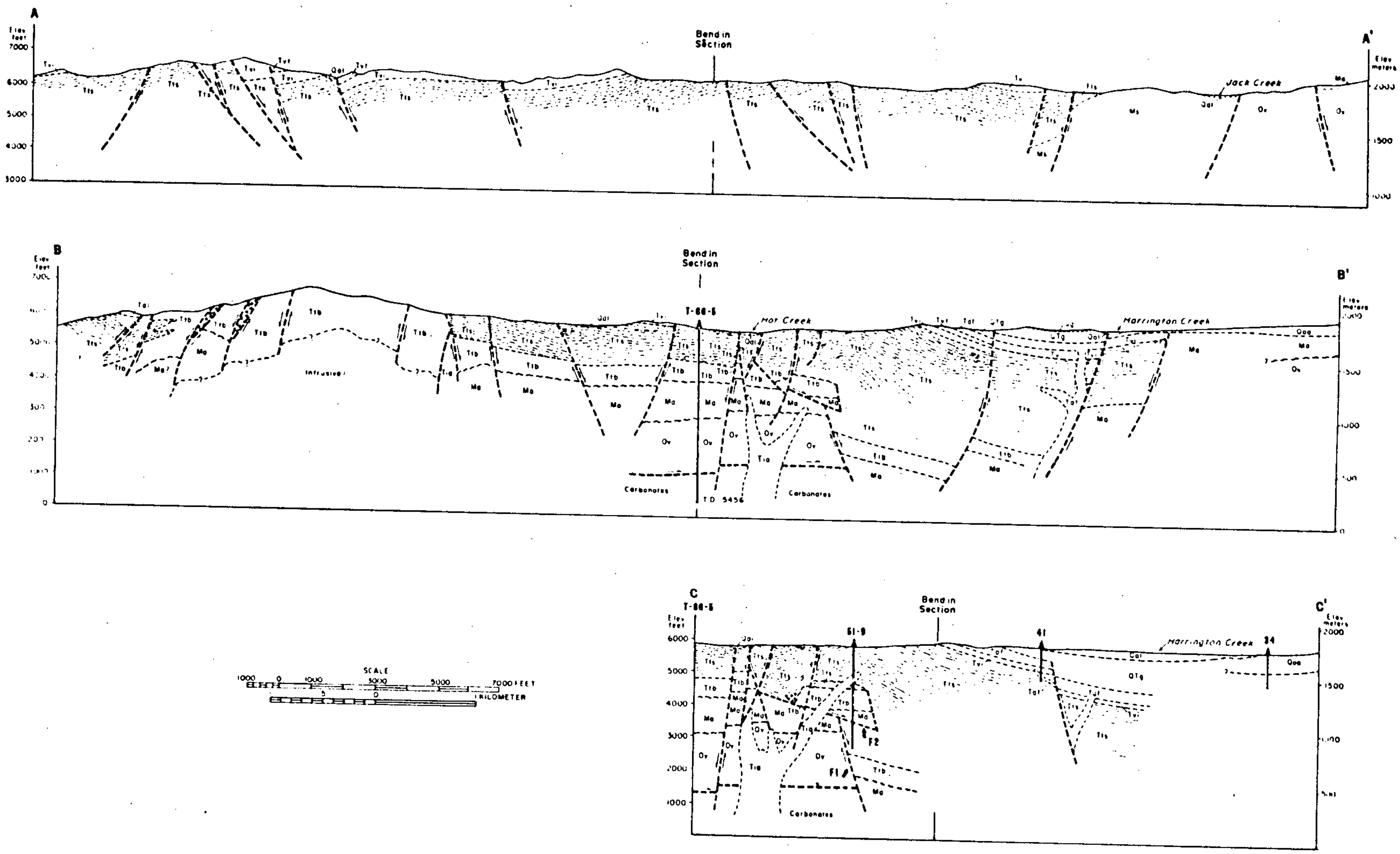



Figure 3. Geologic cross sections of the Tuscarora area after Sibbett (1980)
Work done under DOE contract DE-AC07-80ID12079

## Geological

The Independence Mountains are composed of a thick sequence of Paleozoic sedimentary rocks according to Hope and Coates (1976). The present day range was located near the tectonic boundary between the miogeosyncline to the east and the eugeosyncline to the west. Lower Cambrian eugeosynclinal sediments were thrust eastward along the Roberts Mountain thrust during the Antler orogeny. These rocks were then eroded and were unconformably overlain by Mississippian to Permian shale, chert and quartzite as mapped by Sibbett (1980) as seen on Figure 2. The Schoonover Formation (Fagan, 1962) was thrust over or faulted against these rocks (Figure 2) in the northern Independence Mountains.

The Tertiary rocks in the Tuscarora area consist of a thick sequence of intercolated sediments, tuffs, ashflow tuffs and minor flows of volcanic origin (Figure 2). These rocks range in age from Late Eocene or Early Oligocene (41-34 m.y.) to Late Miocene to Early Pliocene (17-6 m.y.). The Tertiary sequence thickens northward into Bull Run Basin where thicknesses of 2,000 to 5,000 feet are reported (Decker, 1962).

The flanks of Independence Valley contain rather extensive deposits of terrace gravels. The deposits are thin, usually 10 to 60 feet, with a coarse bouldery surface. Recent valley fill and alluvium occur along all major valleys. Siliceous sinter has been deposited by Hot Sulphur Springs for a considerable period of time.

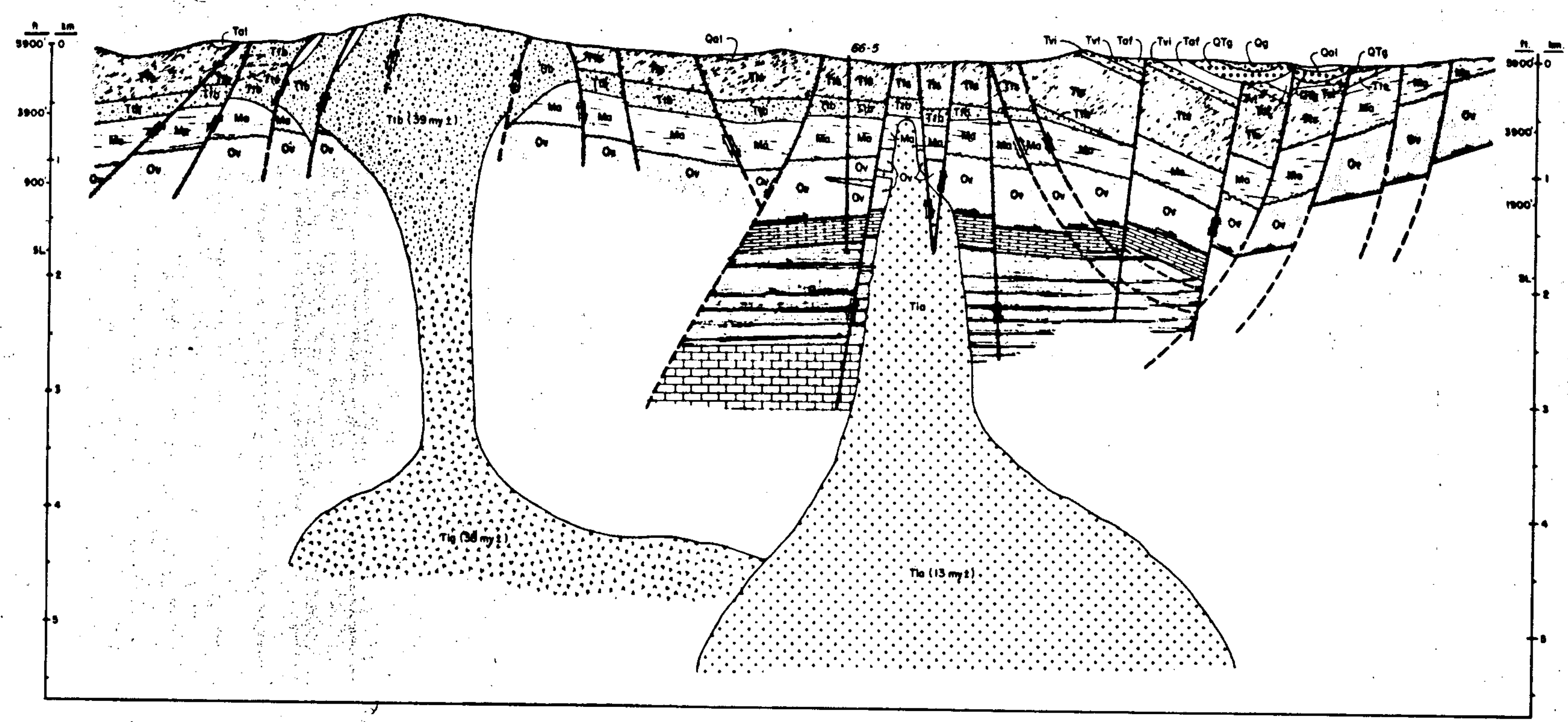



Figure 4. Geologic cross section (E-W) through well 66-5, after Pilkington (1980).

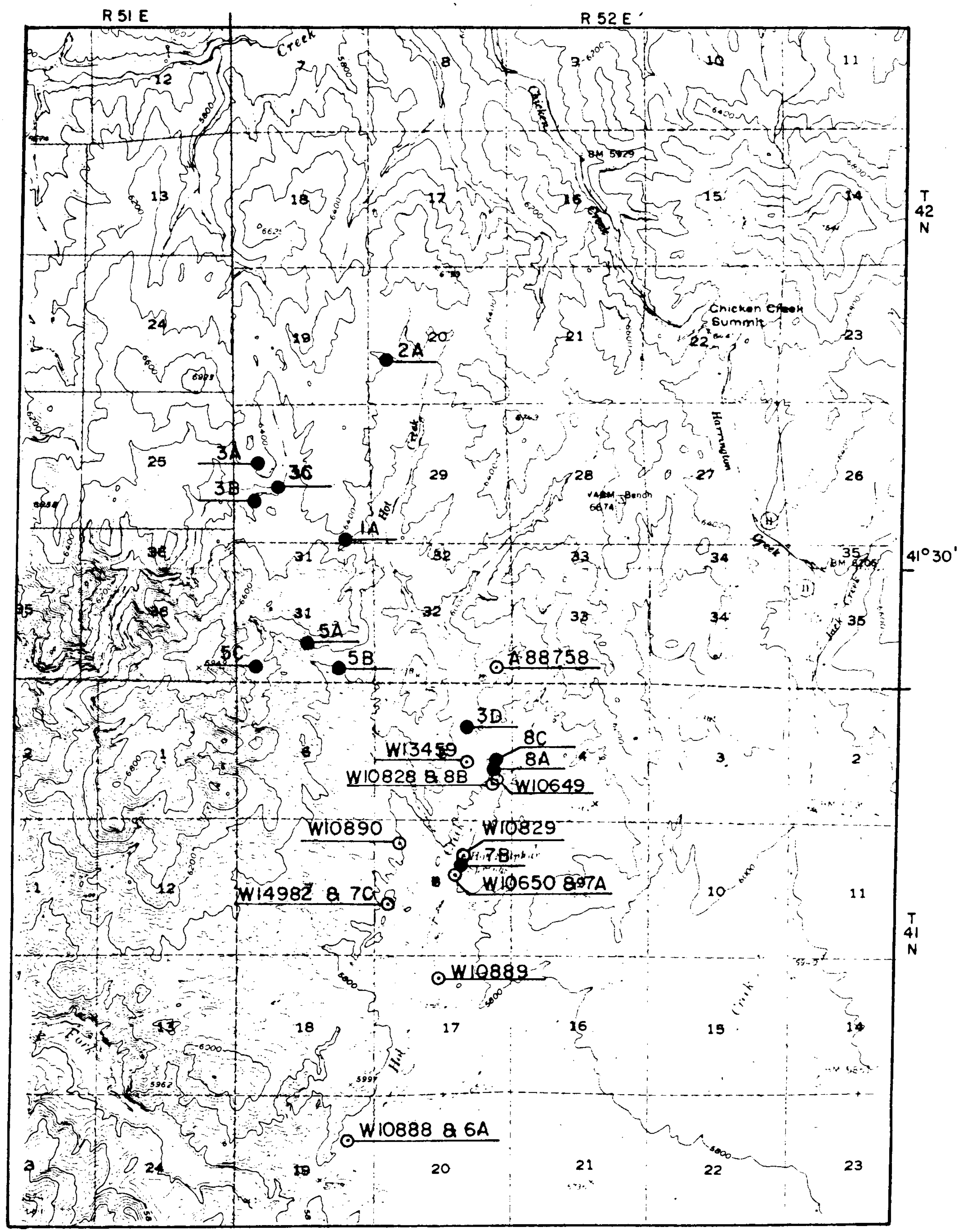
The Tuscarora area has had a long and complex structural history. The Antler Orogeny developed isoclinal folds with east-west axes. The deformation culminated in low angle thrusts which carried the western facies rocks eastward over the miogeosynclinal rocks (Figure 3).

The earliest Cenozoic structures in the area were volcano-tectonic features associated with the 34-41 m.y. crystal tuffs and tuff breccias (Figure 4). Contemporaneously the area was subjected to extensional forces resulting in Basin and Range structures. Independence Valley represents a basin formed by such extension.

The Basin and Range structures are offset by two sets of strike-slip faults (Figure 2). The northeast trending left-lateral faults are part of the Midas Trench lineament system. The conjugate right-lateral faults become the dominent set northward into the Owyhee uplift. Movement on the conjugate shears began about 15 m.y. ago and continues to the present.

## Geochemical

Geochemical exploration at the Tuscarora prospect includes both hydrogeochemical and soil geochemistry studies. A total of 27 water samples have been studied in the immediate area of the Tuscarora prospect (Figure 5). The chemical analyses of the waters are shown in Table I. Ten of the samples were collected and analysed by AMAX in 1977, 1978, 1979 and 1980. Seventeen samples were collected by David Cole of the University of Utah Research Institute in 1980 under DOE contract DE-AC07-80ID12079.




⊙ AMAX
● UURI

Figure 5. Location map for hydrogeochemical samples at the Tuscarora project.

The waters contain relatively low total dissolved solids and are characterized as sodium bicarbonate waters. The discrepencies between the silica and alkali geothermometers is thought to be related to mixing of the thermal waters with cold groundwaters. The $Cl-SiO_2$ enthalpy mixing model gives a reservoir temperature of 216$^{o}$C with a cold water fraction of 54 percent. The correlation between the mixing model temperature and the alkali geothermometer lends credibility to both calculations.

The geochemical character of the thermal waters at Tuscarora suggests the water has had some residence time in carbonate rocks. The residence time had to be long enough to establish the sodium bicarbonate signature. Such a signature could have originated in a deep reservoir in the Lower Paleozoic miogeosynclinal carbonate rocks. From a study of the hydrogeochemical data one can deduce a heat source to the south or southeast of the thermal springs.

As a part of the DOE funded exploration at Tuscarora, soil geochemistry was done along four east-west traverses. Selected samples were run for multi-element analyses to determine what, if any, elements show correlation with either geological or geophysical anomalies. The preliminary survey indicated some correlation with Hg, As, Sb, F and $NH_3$. Faults along which geothermal fluids have migrated give anomalies as shown on Figure 6.

Table I - Chemical Analyses of Hydrogeochemical Samples, Tuscarora Area, Nevada

| | W10649 NESE5T41NR52E | W10650 SWNE8T41NR52E | W10828 5T41NR52E | W10829 NWSW8T41NR52E | W10888 SW19T41NR52E |
|---|---|---|---|---|---|
| T°C | 95.0 | 89.0 | 95.0 | 20.0 | 28.0 |
| Flow (gpm) | 100.0 | 3.0 | 30.0 | 2.0 | 30.0 |
| pH | 9.23 | 7.59 | 8.85 | 9.02 | 8.15 |
| Cl | 15.0 | 15.0 | 16.0 | 10.0 | 11.0 |
| F | 7.6 | 9.8 | 7.0 | 2.3 | 1.6 |
| $SO_4$ | 60.0 | 70.0 | 48.0 | 22.0 | 17.0 |
| $HCO_3$ | 201.8 | 319.6 | 283.0 | 172.0 | 195.8 |
| $CO_3$ | 92.8 | 0.0 | 40.0 | 40.0 | 0. |
| $SiO_2$ | 170.0 | 170.0 | 140.0 | 79.0 | 62.0 |
| Na | 150.0 | 190.0 | 160.0 | 120.0 | 81.0 |
| K | 21.0 | 17.0 | 22.0 | 1.2 | 5.1 |
| Ca | 1.0 | 12.0 | 6.0 | 3.0 | 11.0 |
| Mg | 0.2 | 0.3 | 0.6 | 0.2 | 3.4 |
| Li | 0.8 | 1.0 | 0.9 | 0.1 | 0.1 |
| B | 0.9 | 0.9 | 0.7 | 0.0 | 0.0 |
| $NH_3$ | 0.9 | 1.1 | 1.0 | 0.2 | 0.3 |
| TDS | 704.1 | 806.7 | 725.2 | 452.0 | 388.3 |
| Ec(k) | 722.0 | | | | |
| $T_qSiO_2$ | 167.0 | 169.0 | 149.0 | 122.0 | 111.0 |
| $T_cSiO_2$ | 146.0 | 146.0 | 133.0 | 96.0 | 83.0 |
| TNa-K | 227.0 | 171.0 | 224.0 | 14.0 | 135.0 |
| TNa-K-Ca | 228.0 | 181.0 | 209.0 | 73.0 | 87.0 |

Table I.
Page 2
Chemical Analyses of Hydrogeochemical Samples/Tuscarora

| | W10889 | W10890 | A88758 | W14982 | W13459 |
|---|---|---|---|---|---|
| | NE18T41NR52E | NW8T41NR52E | SE32T42NR52E | NWSW8T41NR52E | NWSE5T41NR52E |
| $T^oC$ | 19.0 | 26.0 | --- | 57.0 | 107.0 |
| Flow (gpm) | 1.0 | 1.0 | 3.0 | 3.5 | 840.0 |
| pH | 9.0 | 9.41 | 8.5 | 7.2 | 9.2 |
| Cl | 9.8 | 14.0 | 7.2 | 18.0 | 30.0 |
| F | 2.3 | 0.5 | 0.2 | 1.3 | 5.5 |
| $SO_4$ | 22.0 | 36.0 | 10.0 | 33.0 | 150.0 |
| $HCO_3$ | 180.0 | 27.2 | 20.0 | --- | 264.0 |
| $CO_3$ | 36.0 | 36.0 | 12.0 | --- | 72.0 |
| $SiO_2$ | 79.0 | 46.0 | 96.0 | 170.0 | 140.0 |
| Na | 110.0 | 31.0 | 20.0 | 170.0 | 240.0 |
| K | 1.3 | 6.5 | 3.4 | 12.0 | 22.0 |
| Ca | 3.0 | 14.0 | 18.0 | 20.0 | 25.0 |
| Mg | --- | 1.9 | 3.0 | 2.8 | 2.2 |
| Li | 0.1 | 0.0 | 0.1 | 0.7 | 0.6 |
| B | 0.2 | 0.0 | 0.2 | 0.8 | 1.3 |
| $NH_3$ | 0.3 | 0.5 | --- | --- | --- |
| TDS | 444.0 | 213.6 | 179.8 | 898.6 | 986.6 |
| Ec(k) | | | 185.0 | 864.0 | |
| $T_qSiO_2$ | 122.0 | 98.0 | 131.0 | 167.0 | 149.0 |
| $T_cSiO_2$ | 96.0 | 68.0. | 108.0. | 146.0 | 133.0 |
| TNa-K | 22.0 | 290.0 | 267.0 | 189.0 | 210.0 |
| TNa-K-Ca | 74.0 | 79.0 | 172.0 | 162.0 | 136.0 |

Table I.
Page 3
Chemical Analyses of Hydrogeochemical Samples/Tuscarora

| | 1A<br>SE30T42NR52E<br>UURI | 2A<br>SW20T42NR52E<br>UURI | 3A<br>NW30T42NR52E<br>UURI | 3B<br>NWSW30T42NR52E<br>UURI | 3C<br>NESW30T42NR52E<br>UURI |
|---|---|---|---|---|---|
| $T^{o}C$ | 10.5 | 11.5 | 15.0 | 16.5 | 10.0 |
| Flow (gpm) | | | | | |
| pH | 6.1 | 6.2 | 6.35 | 6.15 | 6.45 |
| Cl | 6.0 | 4.0 | 5.0 | 4.0 | 5.0 |
| F | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 |
| $SO_4$ | 5.0 | 4.0 | 6.0 | 4.0 | 7.0 |
| $HCO_3$ | 32.8 | 47.2 | 47.0 | 54.2 | 54.0 |
| $CO_3$ | ---- | --- | --- | --- | --- |
| $SiO_2$ | 43.0 | 48.0 | 40.0 | 43.0 | 50.0 |
| Na | 7.0 | 6.0 | 10.0 | 7.0 | 10.0 |
| K | 3.0 | 4.0 | 2.5 | 4.0 | 4.0 |
| Ca | 5.0 | 4.0 | 6.0 | 4.0 | 5.0 |
| Mg | 2.0 | 1.0 | 2.0 | 2.0 | 2.0 |
| Li | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| B | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| $NH_3$ | --- | --- | --- | --- | --- |
| TDS | 72.0 | 76.0 | 88.0 | 96.0 | 124.0 |
| Ec(k) | --- | --- | --- | --- | --- |
| $T_qSiO_2$ | 95.0 | 100.0 | 92.0 | 95.0 | 102.0 |
| $T_cSiO_2$ | 64.0 | 70.0 | 61.0 | 64.0 | 72.0 |
| TNa-K | 384.0 | 460.0 | 311.0 | 432.0 | 374.0 |
| TNa-K-Ca | 61.0 | 73.0 | 56.0 | 75.0 | 74.0 |

Table I.
Page 4
Chemical Analyses of Hydrogeochemical Samples/Tuscarora

| | 3D<br>SE30T42NR52E<br>UURI | 5A<br>SW20T42NR52E<br>UURI | 5B<br>NW30T42NR52E<br>UURI | 5C<br>NWSW30T42NR52E<br>UURI | 6A=W10888<br>NESW30T42NR52E<br>UURI |
|---|---|---|---|---|---|
| $T^{o}C$ | 9.6 | 14.5 | 17.5 | 18.5 | 21.0 |
| Flow (gpm) | | | | | |
| pH | 6.7-7.35 | 7.5 | 7.15-7.20 | 7.2 | 7.5 |
| Cl | 5.0 | 7.0 | 6.0 | 9.0 | 13.0 |
| F | 0.2 | 0.2 | 0.2 | 0.2 | 1.6 |
| $SO_4$ | 5.0 | 7.0 | 17.0 | --- | 17.0 |
| $HCO_3$ | 75.0 | 65.0 | 74.0 | 77.0 | 232.0 |
| $CO_3$ | ---- | --- | --- | --- | --- |
| $SiO_2$ | 41.0 | 61.0 | 25.0 | 60.0 | 52.0 |
| Na | 12.0 | 14.0 | 11.0 | 19.0 | 80.0 |
| K | 4.0 | 6.0 | 2.50 | 7.0 | 5.0 |
| Ca | 8.0 | 6.0 | 14.0 | 11.0 | 11.0 |
| Mg | 2.0 | 2.0 | 1.0 | 2.0 | 3.0 |
| Li | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| B | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| $NH_3$ | --- | --- | --- | --- | --- |
| TDS | 96.0 | 122.0 | 116.0 | 142.0 | 292.0 |
| Ec(k) | --- | --- | --- | --- | --- |
| $T_qSiO_2$ | 93.0 | 111.0 | 72.0 | 111.0 | 104.0 |
| $T_cSiO_2$ | 62.0 | 82.0 | 40.0 | 81.0 | 74.0 |
| TNa-K | 348.0 | 384.0 | 299.0 | 299.0 | 180.0 |
| TNa-K-Ca | 66.0 | 87.0 | 41.0 | 82.0 | 87.0 |

Table I.
Page 5
Chemical Analyses of Hydrogeochemical Samples/Tuscarora

| | 7A=W10650 SWNE8T41NR52E UURI | 7B SWNE8T41NR52E UURI | 7C=W14982 NWSW8T41NR52E UURI | 8A NESE5T41NR52E UURI | 8B=W10828 NESE5T41NR52E UURI | 8C SENE5T41NR52E UURI | 8D NESE5T41NR52E UURI |
|---|---|---|---|---|---|---|---|
| $T^{o}C$ | 89.0 | 82.0 | 56.0 | 43.0 | 95.0 | 59.0 | 85.0 |
| Flow (gpm) | | | | | | | |
| pH | 6.9 | 7.2 | 6.25 | 7.62 | 7.35 | 8.0 | 7.65 |
| Cl | 18.0 | 18.0 | 19.0 | 16.0 | 6.0 | 14.0 | 7.0 |
| F | 10.8 | 11.0 | 8.6 | 8.7 | 8.2 | 9.0 | 6.9 |
| $SO_4$ | 52.0 | 65.0 | 34.0 | 50.0 | 55.0 | 45.0 | 48.0 |
| $HCO_3$ | 352.0 | 365.0 | 484.0 | 382.0 | 345.0 | 291.0 | 355.0 |
| $CO_3$ | ---- | --- | --- | --- | --- | --- | --- |
| $SiO_2$ | 129.0 | 126.0 | 122.0 | 103.0 | 104.0 | 136.0 | 99.0 |
| Na | 151.0 | 152.0 | 169.0 | 145.0 | 148.0 | 140.0 | 139.0 |
| K | 15.0 | 15.0 | 11.0 | 19.0 | 20.0 | 20.0 | 18.0 |
| Ca | 10.0 | 11.0 | 19.0 | 17.0 | 1.0 | 3.0 | 8.0 |
| Mg | 0.5 | 0.5 | 3.0 | 2.0 | 0.5 | 0.5 | 0.5 |
| Li | 0.71 | 0.77 | 0.49 | 0.64 | 0.64 | 0.56 | 0.62 |
| B | 0.13 | 0.8 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| $NH_3$ | --- | --- | --- | --- | --- | --- | --- |
| TDS | 576.0 | 602.0 | 646.0 | 536.0 | 508.0 | 500.0 | 478.0 |
| Ec(k) | --- | --- | --- | --- | --- | --- | --- |
| $T_qSiO_2$ | 152.0 | 150.0 | 149.0 | 139.0 | 139.0 | 155.0 | 137.0 |
| $T_cSiO_2$ | 127.0 | 125.0 | 123.0 | 112.0 | 113.0 | 131.0 | 11.0 |
| TNa-K | 216.0 | 216.0 | 183.0 | 241.0 | 244.0 | 250.0 | 240.0 |
| TNa-K-Ca | 184.0 | 183.0 | 159.0 | 194.0 | 225.0 | 216.0 | 200.0 |

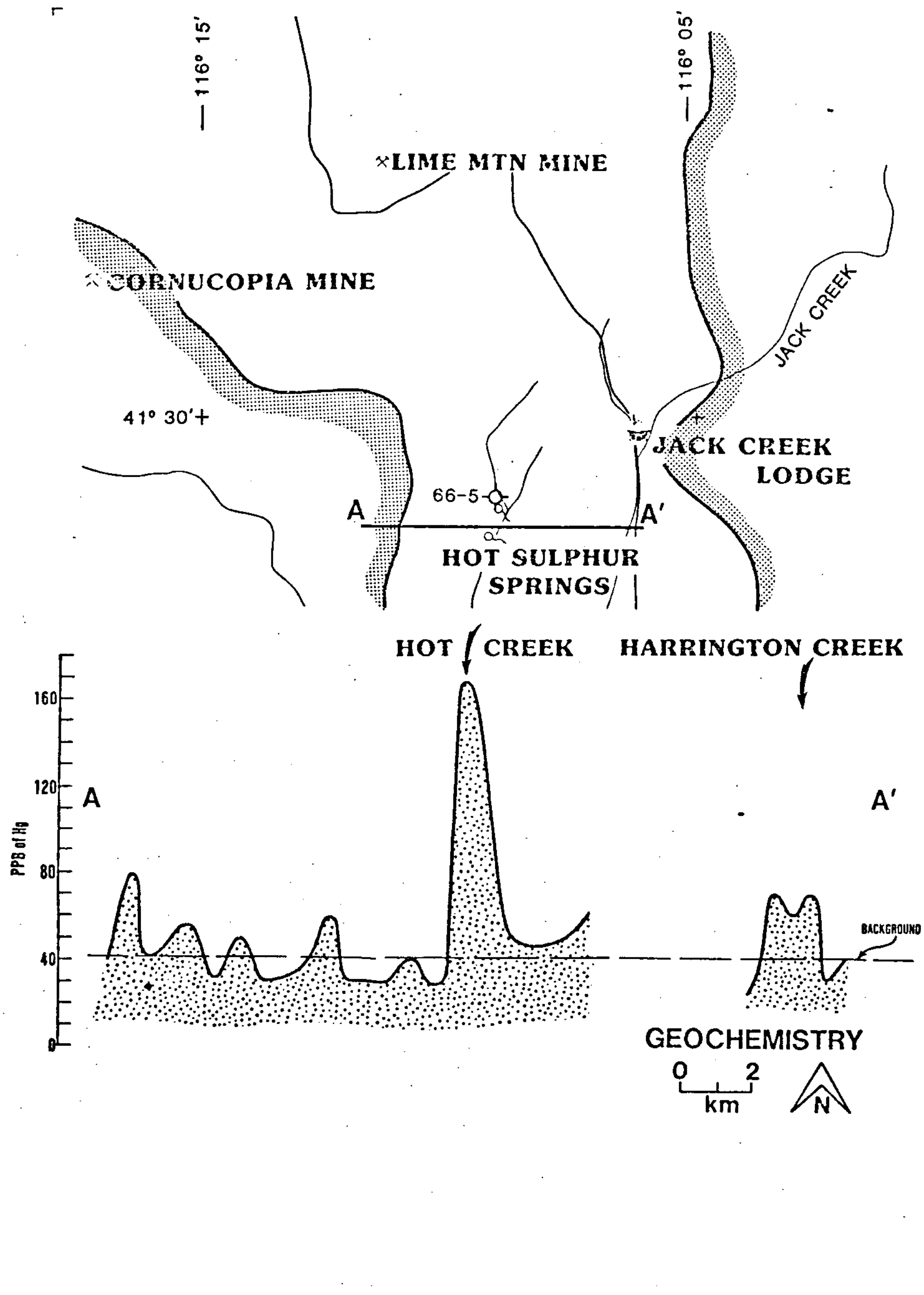



Figure 6. Soil mercury profile across the Tuscarora prospect.

## Geophysical

Geophysical exploration includes a thermal gradient program, gravity survey, aeromagnetic survey, electrical surveys and a passive seismic survey.

The thermal anomaly constitutes the most positive of the geophysical anomalies at Tuscarora. The thermal anomaly is based upon data collected from thirty-eight temperature gradient drill holes which range from 40 to 522 meters deep. The temperature gradients range from 13 to 2,558$^{o}$C/km. The heatflow (Figure 7) varies from less than 2.0 to as much as 49.1 H.F.U. with approximately 20 km$^2$ within the 10 H.F.U. contour.

The residual magnetic intensity maps (Figure 8) exhibits several significant anomalies. A major magnetic low occurs at the north end of the Independence Valley. The two magnetic highs in the northern part of the area probably represent intrusions. The linear northeasterly trends across the map are parallel to the Midas lineament.

The complete Bouguer gravity map (Figure 9) shows the northeasterly trending Midas structure cutting across the Basin and Range structure of Independence Valley. The bounding faults of the ranges appear as pronounced north-south gradients. A gravity low coincident with the magnetic low occurs at the north end of Independence Valley.

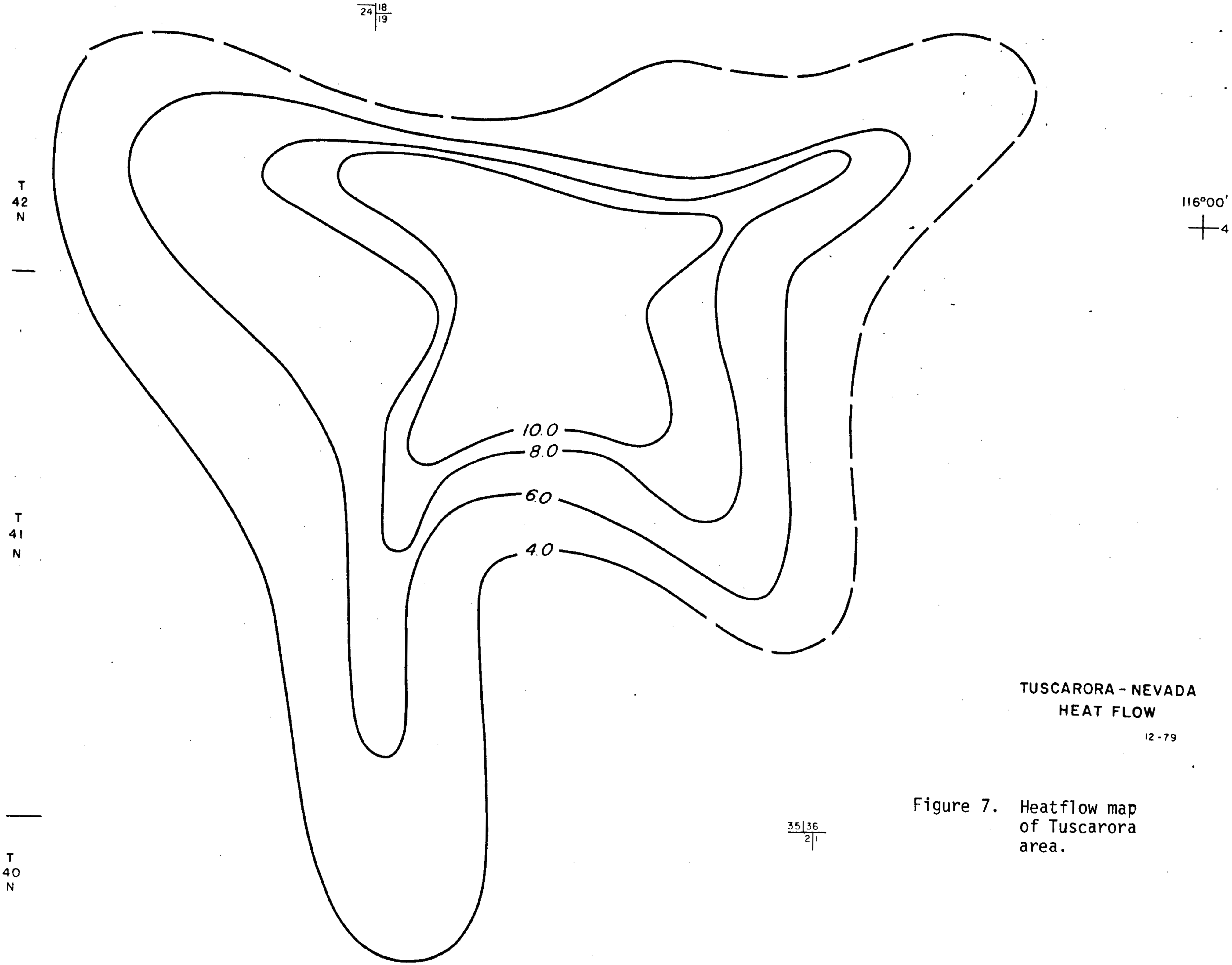



Figure 7. Heatflow map of Tuscarora area.

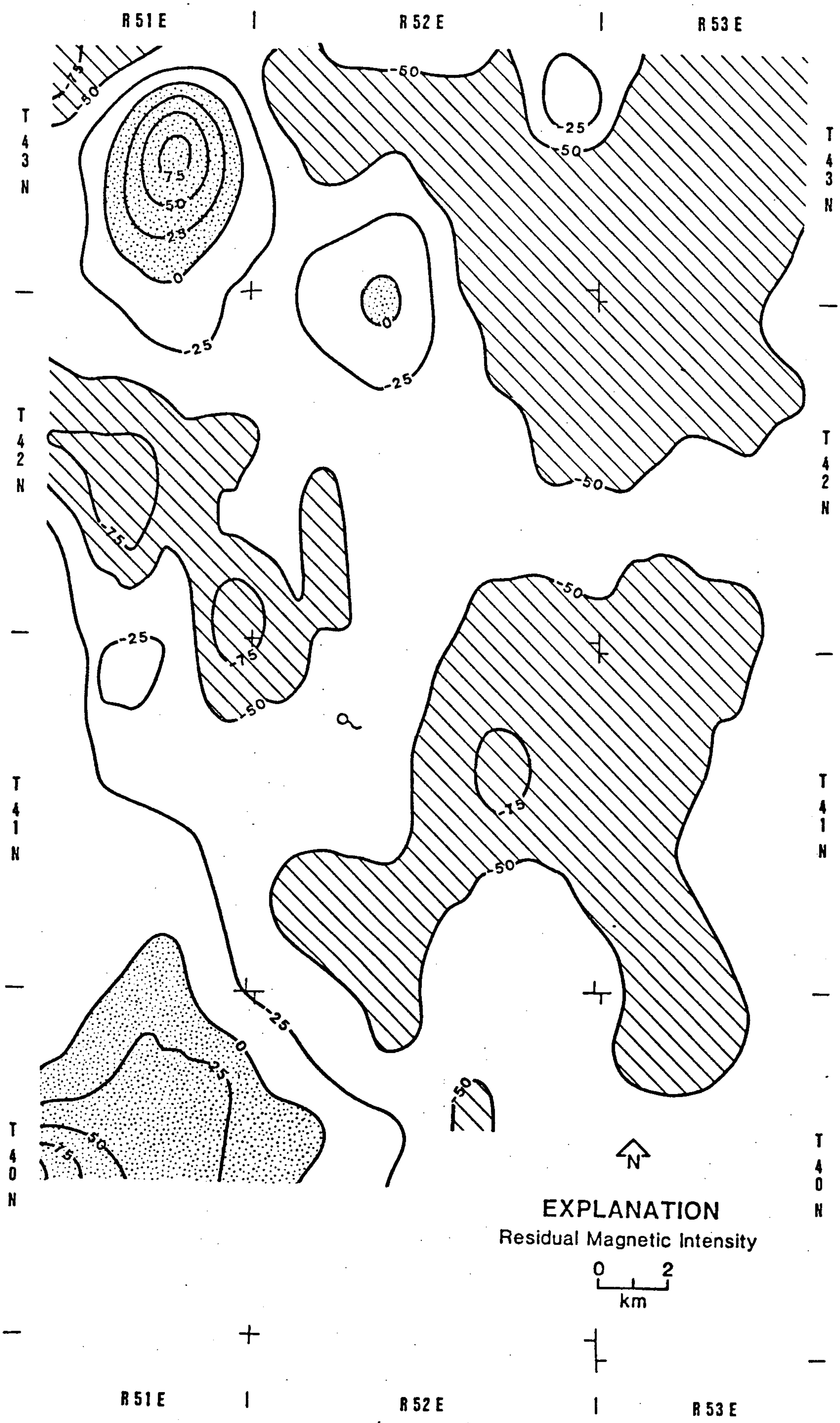



Figure 8. Residual magnetic map.

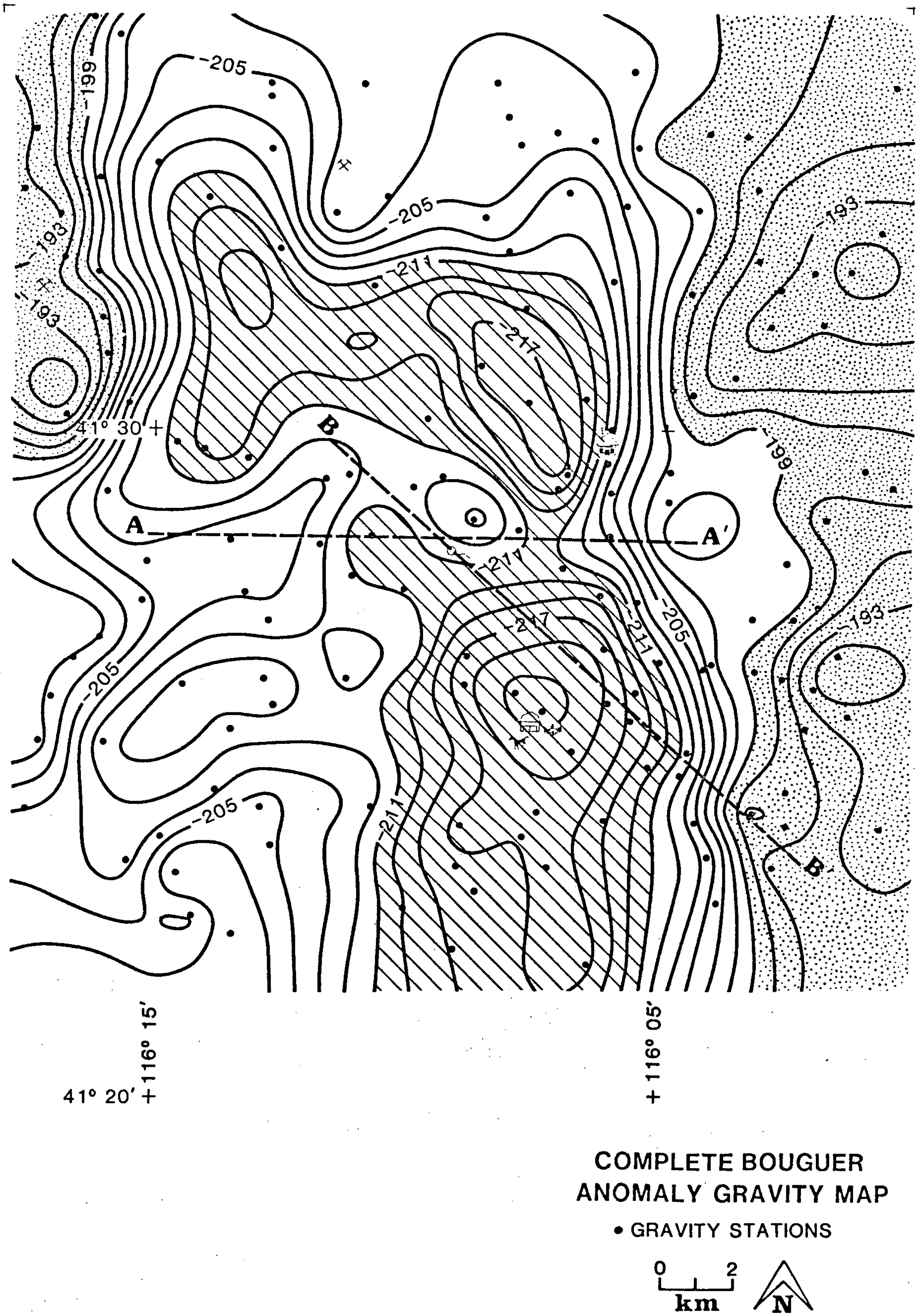



Figure 9. Complete Bouguer gravity map.

A passive seismic survey was conducted over an eleven-day period in September of 1978 using a 15 station detector array. Figure 10 shows the distribution of epicenters which ranged from 3 to 13 km deep. Most of the activity appears to be concentrated along the intersection of a northwest trending right-lateral fault, a segment of the northeast trending Midas lineament and the Independence Mountain bounding fault. Poisson's Ratio contour for depths less than 5 km shows a concentration of high values (.35) at the north end of Independence Valley.

Electrical surveys conducted at Tuscarora include a self-potential survey, a dipole-dipole resistivity survey and a magnetotelluric survey. In general, the SP survey shows the northeasterly linear Midas trend and the resistive rocks of the Independence Mountains. Dipole-dipole resistivity was done along three lines (Figure 11) across the thermal anomaly. The resistivities for N=2 spacing are shown in the plan view. Figure 12 shows the observed apparent resistivity psuedosection along the B-B' at the top and a smoothed 2-D model on the lower part. The psuedosections were modelled by Claran Mackelprang of the University of Utah Research Institute. A zone of conductive rocks, less than eight ohmmeters, thickens and deepens to the southeast. The conductive layer has been interpreted to be an alteration cap above a possible reservoir.

A tensor magnetotelluric survey was done along the same lines as the dipole-dipole survey. Psuedosections of the Tm made for line A-A' as shown in Figure 13. There is good agreement between the observed and the calculated resistivity. Howard Ross and Claran Mackelprang of the University of Utah Reserach Institute have modelled portions of the

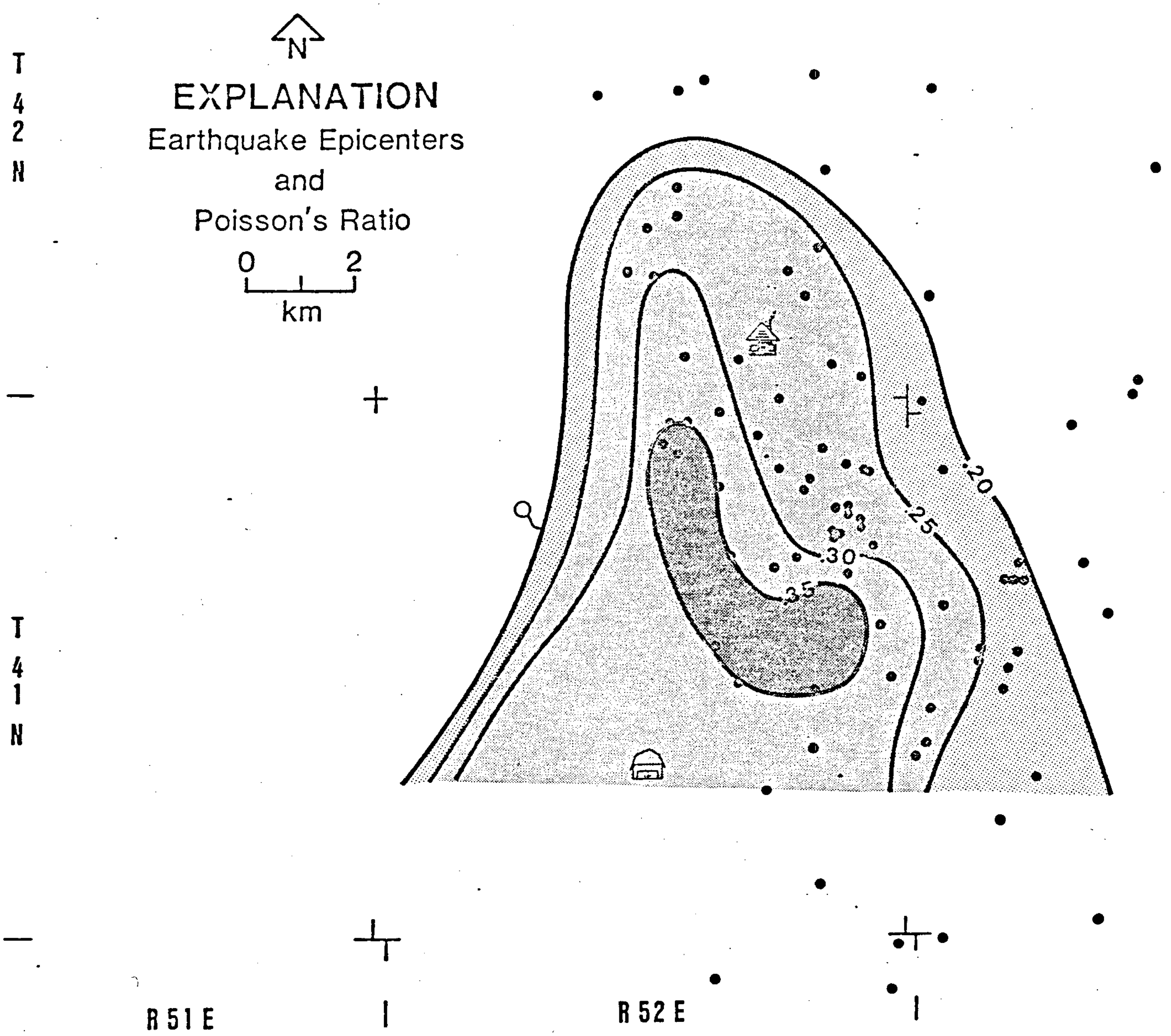
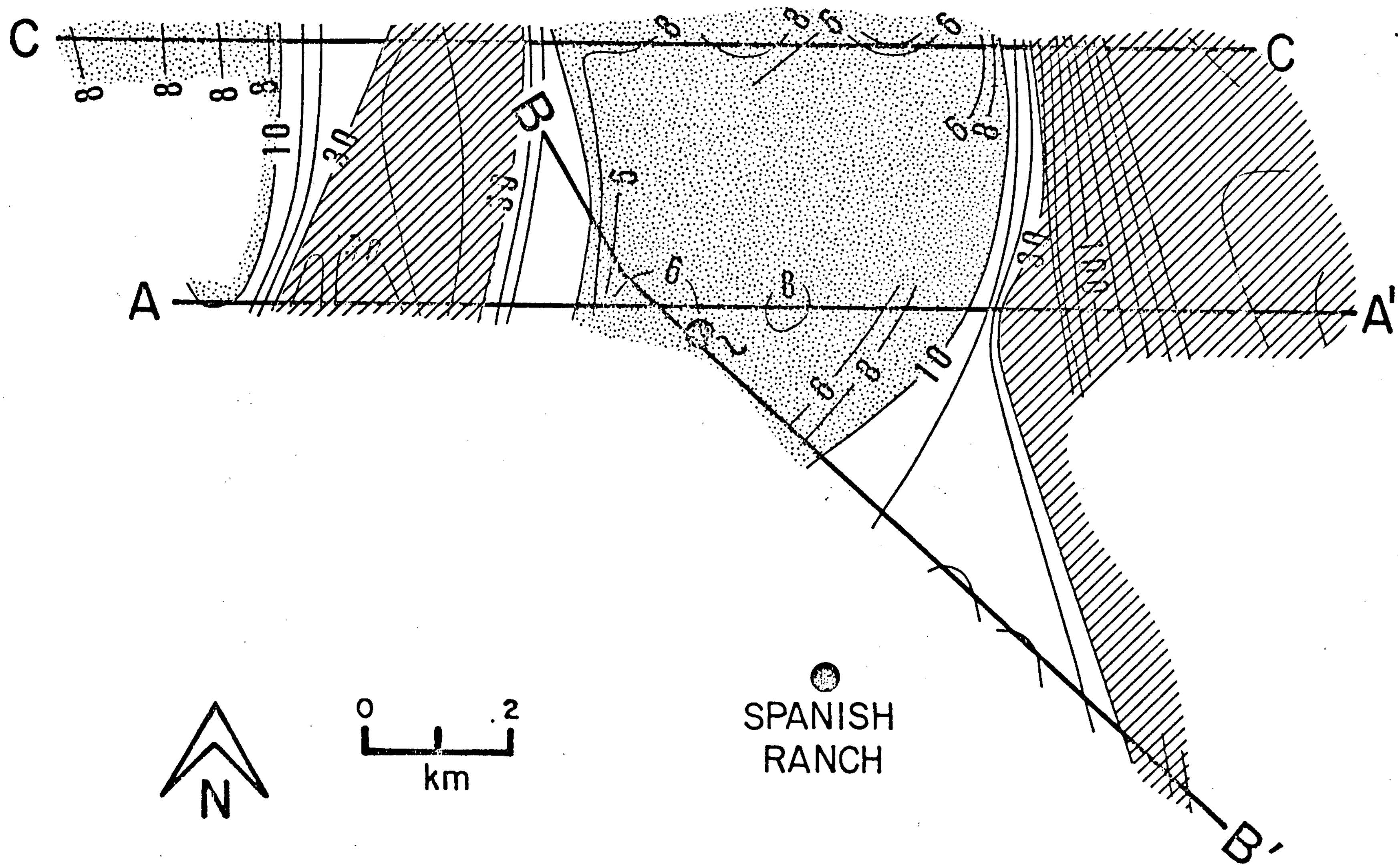



Figure 10. Map of Poisson's Ratio and epicenter locations.




# DIPOLE-DIPOLE RESISTIVITY

N=2 A=610m

Figure 11. Plan view of dipole-dipole resistivity showing location of profiles (after Berkman, 1980).

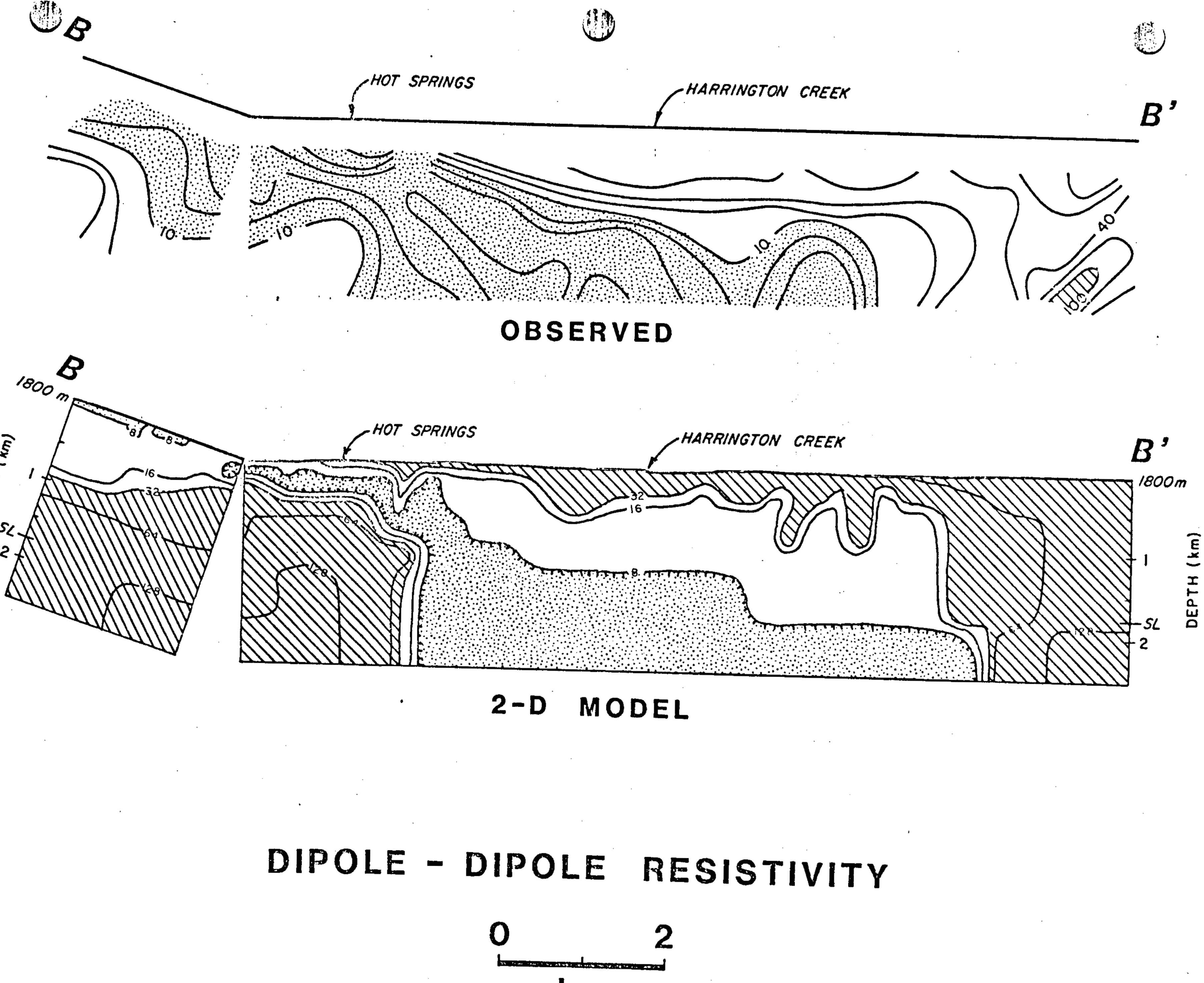
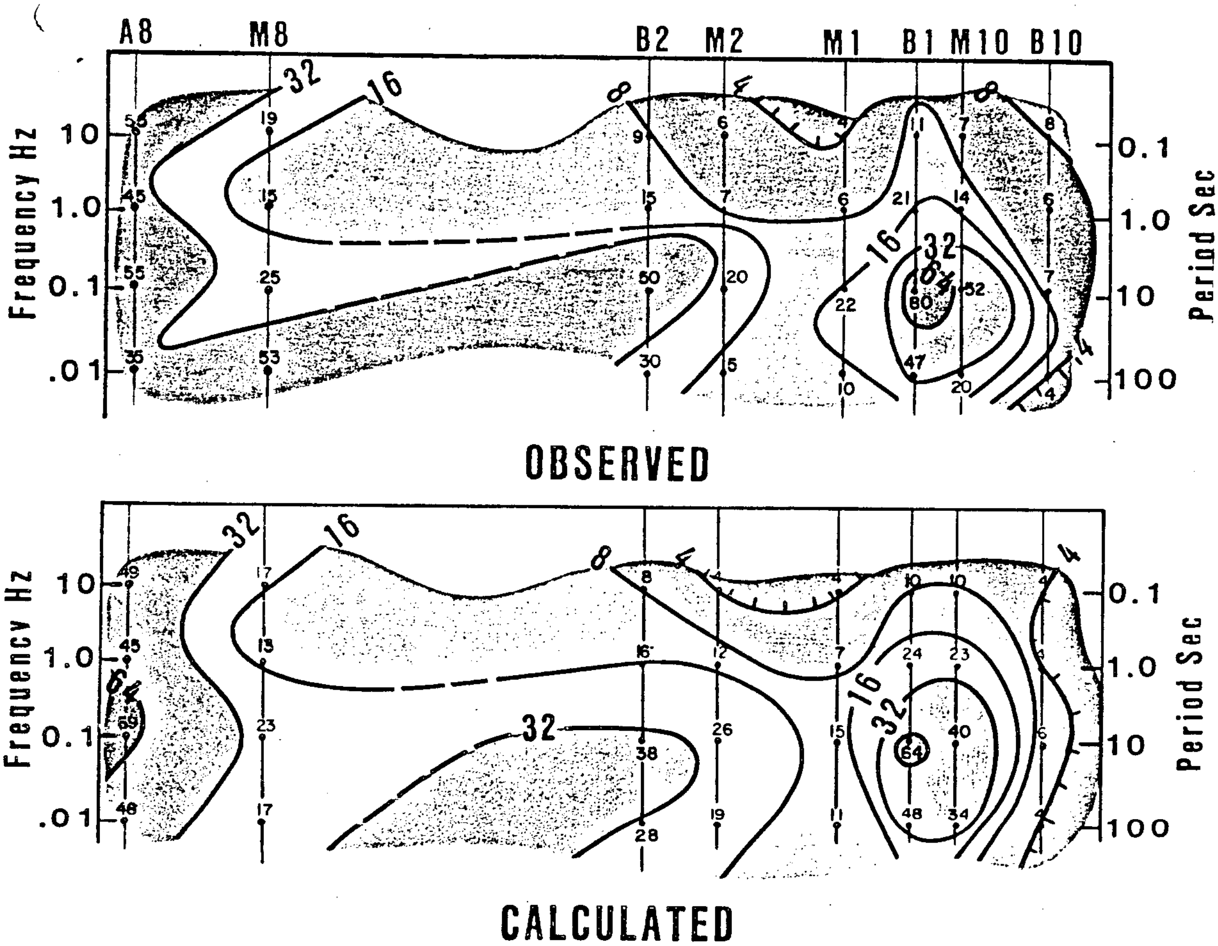



Figure 12. Resistivity sections along line B-B' showing observed and modelled resistivity.




# LINE A-A'
# MT PSEUDOSECTION
# APPARENT RESISTIVITY Tm MODE
# (OHM-METERS)

Figure 13. Observed and calculated apparent resistivity in the Tm mode along line A-A' (after Lange, 1981).

Tuscarora MT as shown at the top of Figure 14. The geologic section along line A-A' has been positioned below the model to show agreement between the model and geology. The low resistivity zone of five ohmmeters or less may represent altered rocks, a geothermal reservoir or heat source.

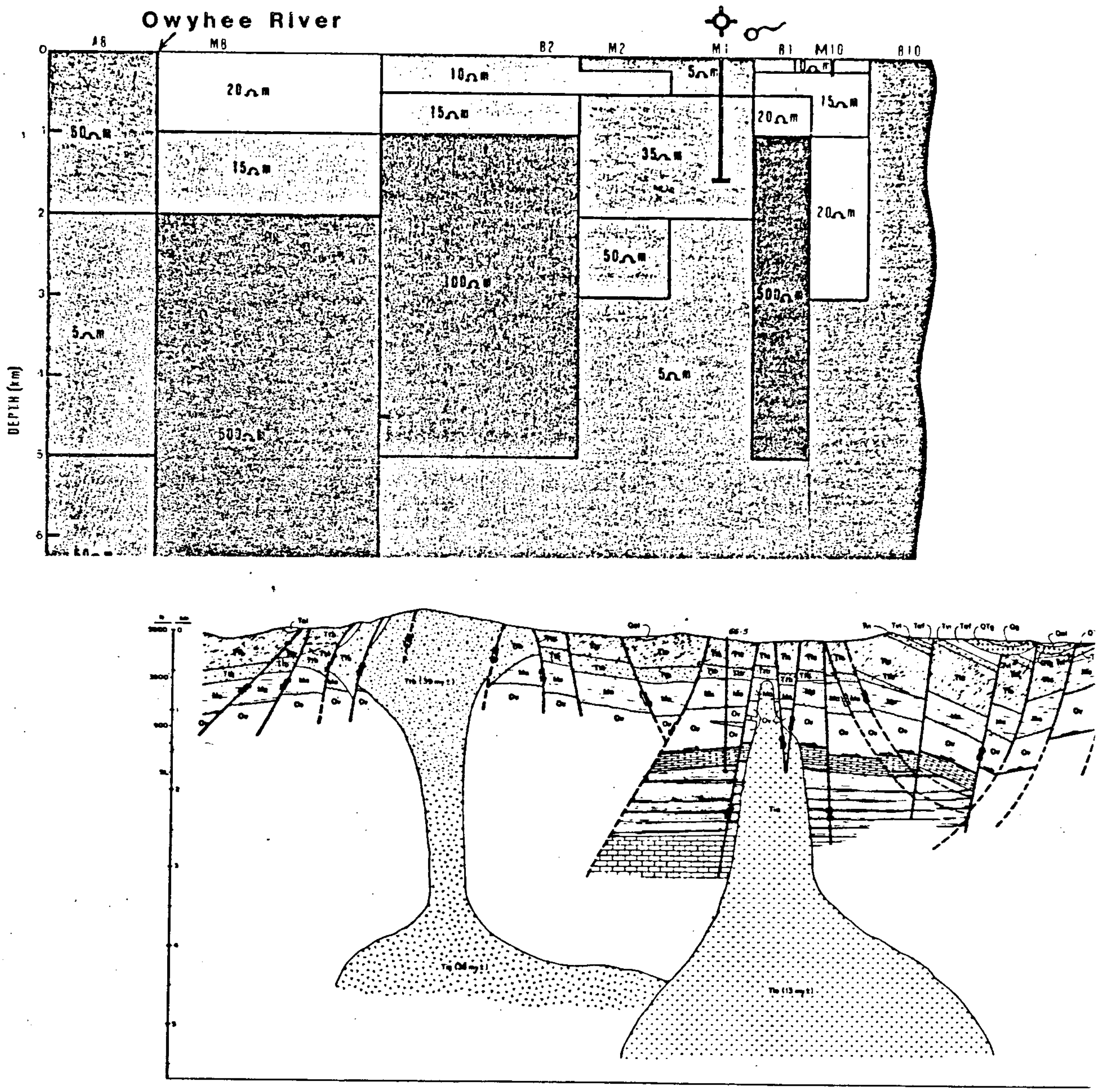
## Drilling

The exploration drilling at the Tuscarora prospect done under the DOE contract DE-AC08-79ET27011 includes thirty-two shallow thermal gradient holes, six intermediate depth thermal gradient wells and one test for discovery well.

### Shallow Thermal Gradient Holes

A total of thirty-two shallow thermal gradient holes were drilled at the Tuscarora prospect. The holes range from 40 to 100 meters deep. The holes were drilled by four different contractors in 1977, 1978 and 1979 with different types of truck mounted rotary drills. In general the shallow gradient holes were drilled with air, using either a 6 3/4" tri-cone roller bit or a 6" rotary percussion hammer to TD. The holes were completed by installing 3/4" PVC tubing, capped on the bottom, to TD, back-filling the annulus around the PVC with drill cuttings to within 10 feet of the surface and then emplacing a 10-foot cement plug in the annulus.

Three distinct drilling environments were present on the prospect, the alluvial cover in the northern end of Independence Valley, the Paleozoic




LINE A–A′

MT–2D MODEL

Tm MODE

Figure 14. MT-2D model along line A-A' compared with geologic section (after Ross, Mackelprang and Lange, 1981).

sediments on the western flank of the Independence Mountains and finally the volcanics and volcaniclastic sediments in the main part of the prospect. Two drilling problems were encountered in the shallow hole programs.

The first problem was artesian flow of water which could be encountered in all three environments. When artisian flow was encountered, drilling was switched to rotary methods with drilling mud to contain the water flow, and holes completed as described above. The second problem was related to keeping the holes open when drilling through the gravel deposits. Often times the air circulation would remove all the matrix material holding the gravel in place, and the hole would cave. Various combinations of foam, mud and casing were used on such holes. Only one hole was completely lost due to drilling problems in the overburden although in several 2-30 meters would be lost before the PVC could be installed.

## Intermediate Depth Gradent Wells

A total of six intermediate depth temperature gradient holes were drilled in 1979 to confirm the downward continuation of the thermal anomaly. Five of the holes reached depths of 1,040 feet (317 meters) and one was drilled to a depth of 530 meters (1,740 feet).

The drilling plan called for a 9 7/8" hole to 10% of TD or minimum of 60 feet into bedrock, set 7" casing, drill to TD with a 6" or 6 3/4" hole, and set a capped 1" black iron pipe to bottom and fill with water. The holes were all drilled with mud and a heavy viscous mud was left in the annulus around the 1" black pipe. A ten foot cement plug was placed in the upper 10 feet of the hole. A blow-out preventer was on site to be used if needed and mud temperatures, in and out, were monitored to determine when, or if, the BOP was needed.

Two problems were encountered while drilling the intermediate depth thermal gradient holes. Two of the holes had overburden problems. The glacial and/or terrace gravels vary from a few feet to as much as 70 feet in thickness and consist of quartzite boulders 6 to 12 inches in diameter set in a matrix of finer gravel, sand, and clay. Whenever the drilling disrupts the matrix, either by removal in the drilling fluid or by the physical disruption by shouldering the boulders aside, caving becomes a problem. The problem was overcome when the bit was followed down with casing. Once the gravels had been penetrated, then the casing was cemented into place and drilling continued.

Lost circulation was a problem in the volcanic and volcaniclastic rocks in the vicinity of the thermal springs. One or more thermal water bearing aquifers were encountered in the two holes adjacent to Hot Creek. The thermal fluids had altered the rocks so that it was possible to drill ahead by adding water whenever lost circulation zones were encountered since water and drill cuttings combined to form a drilling mud.

The intermediate depth gradient holes established the presence of a shallow low-temperature reservoir in the volcaniclastic rocks near the hot springs. The waters encountered were in the 50 to 100°C range which suggests some aquifers contained mixed thermal and meteoric waters and others may have had direct communication with the conduits feeding the hot springs.

## Test for Discovery Well

On February 6, 1980, Brinkerhoff-Signal #2 started to move on site. The weather was warm and wet and consequently the move took 11 days. The well was spudded on February 16, 1980 and completed at a TD of 5,454 feet on April 29, 1980. The drilling history of well 66-5 is given in Table II.

At a depth of 4,760 feet a major lost circulation zone was encountered requiring a cement job. At 4,970 another cement plug was required. Lost circulation was again encountered from 5,184-5,214 feet and was never controlled in spite of 5 LCM-gel pills, 3 cement plugs and one open hole squeeze job. Switched to drilling with water and advanced to 5,409 feet with problems. Using aerated water, reamed hole to 5,359 feet when well began to flow. The well was rigged up for a flow test and tested. The well bore was unloaded and produced approximately 3,000 bbls of fluid at a maximum temperature of 107$^{o}$C (225$^{o}$F) as shown in Table III.

After the flow test, the hole was continued using 8 3/4" bit to a TD of 5,454 feet. The well bridged at 2,730 feet while logs were being run, ran in hole, cleaned out bridge and tagged bottom at 5,289 feet. Ran GO DIL-GR, BHC-GR-Cal but hole bridge again at 2,790 feet and could not run temperature survey. It was decided not to try and clean hole again and rig-down started. The well was completed by installing a WKM 13 3/8" valve and the well was put in suspension (Figure 15). The logging history of well 66-5 is given in Table IV.

Table II. Drilling History Well 66-5, Tuscarora Prospect, Elko County, Nevada.

| | |
|---|---|
| 2-16-80 | Spud. Gel-water. 17-1/2 in hole |
| 2-17-80 | Drlg 844. Gel-water |
| 2-18-80 | Stuck pipe @ 970. Gel-cellex-water. Drlg. 1063 |
| 2-19-80 | Repairs. Drld to 1324 |
| 2-20-80 | Drlg. 1420. Lost 65 bbl mud. NB #2 |
| 2-21-80 | Drlg 1504 |
| 2-22-80 | Drld to 1567. Tripping for shock sub |
| 2-23-80 | Drlg 1736. Losing 2-4 bbl/hr |
| 2-24-80 | Drlg 1795. Losing 2-4 bbl/hr. Mix LCM |
| 2-25-80 | Drld to 1869. Tripping for bit |
| 2-26-80 | NB #3. Drld to 1926. Tripping for shock sub |
| 2-27-80 | Drlg 2092 |
| 2-28-80 | Drld to 2232. Formation change. Losing fluid 2-5 bbl/hr POH |
| 2-29-80 | Mixed LCM and gel pill. Spotted at 2232. Regained 100% returns Conditioning hole for logging |
| 3-1-80 | Ran Schlumberger logs. Made wiper run. Preparing to run casing |
| 3-2-80 | Ran 785 ft 13-3/8, 61.-#, K-55 Butt and 1447 ft, 13-3/8 54.5#, K-55 Butt w/guide shoe and insert float. Shoe was welded on, bottom 3 jts Bakerlok. 8 centralizers run. BJ cemented w/3295 $ft^3$ 1:1 poz + 35% silica flour + 2% gel + .4% R-5 + .25% R-11 Tailed in w/686 $ft^3$ Class G + 40% silica flour + .4% R-5 + .225% R-11. No returns to surface |
| 3-3-80 | WOC. Tried to run Schlumberger CBL-tool failed |
| 3-4-80 | Ran CBL. WOO |
| 3-5-80 | Sanded back csg. Rebuild loc |
| 3-6-80 | N.U. BOPE. Rebuild location |
| 3-7-80 | " " |
| 3-8-80 | " " |
| 3-9-80 | Tested BOPE. Drld out cmt. Lost 85 bbl 2233-2280. Drld to 2315. POH for BHA |
| 3-10-80 | Drld 12-1/4 hole to 2500. Mud: gel-cellex-water. POH for Kuster survey |
| 3-11-80 | Ran Kuster survey. Drld to 2642 |
| 3-12-80 | Tripped for bit. NB #5. Drlg 2761 |
| 3-13-80 | Drld to 2798. Backed off bit. Screwed back into bit. POH. RR #4. Drlg 2813 |
| 3-14-80 | Tripped for NB #6. Drlg 2909 |
| 3-15-80 | Drld to 2961. Twisted off. POH. RIH w/overshot; caught fish POH w/fish |
| 3-16-80 | Kuster survey. NB #7. Drlg. 2977 |
| 3-17-80 | Drld to 3068. TOH for NB #8. Drlg. 3088 |
| 3-18-80 | Formation change. Fluid loss 10-65 bbl/hr. Drlg 3241 |
| 3-19-80 | Drld to 3275. Tripped for NB #9. Tripped for wrong stabilizers |

| | |
|---|---|
| 3-20-80 | Tripped for wrong stabilizers. Drlg 3408 |
| 3-21-80 | Drilling 3555 |
| 3-22-80 | Drld to 3561. Tripped for NB #10. Drlg. 3607 |
| 3-23-80 | Drlg 3757 |
| 3-24-80 | Drld to 3802. Tripped for NB #11. Drlg. 3821 |
| 3-25-80 | Drlg 3954 |
| 3-26-80 | Drlg 4106 |
| 3-27-80 | Drld to 4118. POH. Ran GO Temp log. Ran Kuster survey NB #12. Drlg. 4141 |
| 3-28-80 | Drlg. 4350 |
| 3-29-80 | Drld to 4417. Tripped for NB #13 |
| 3-30-80 | Drlg. 4585 |
| 3-31-80 | Drld to 4768. Lost 1120 bbl. Tripping for bit |
| 4-1-80 | NB #14. Mixed LCM. Hole sloughing. POH. Build volume |
| 4-2-80 | RIH. Lost 45% returns. Ran Kuster survey. Mix LCM pill |
| 4-3-80 | Spotted LCM pill. CO hole. Still losing. Spotted 175 $ft^3$ Class G cement. RIH tagged cement |
| 4-4-80 | Cleaned out cement. Cleaned out mud pits. Mixing new mud |
| 4-5-80 | Drld to 4970. Lost circulation. Building volume |
| 4-6-80 | Build mud volume. RIH drilled out bridge @ 4820. Mix LCM. C.O. hole to 4970. Drld to 4987 w/partial returns. Pits empty. Building volume |
| 4-7-80 | Spotted gel-LCM pill. Spotted 175 $ft^3$ Class G. Cleaned out cement. Drlg. 5014 |
| 4-8-80 | Drld to 5184. Lost circulation. Spotted gel-LCM pill. Drld to 5214. POH-5 stands. Mixing gel pill |
| 4-9-80 | Spotted gel-LCM pill. Spotted 141 $ft^3$ Class G. WOC. Tried to fill hole - no returns. RIH and tagged cement. Spotted 175 $ft^3$ Class G. WOC |
| 4-10-80 | RIH. Drld firm cement. Lost circ. @ 5180. Spotted 175 $ft^3$ Class G. Mixed mud. WOC. Drld hard cement to 5184. Lost returns |
| 4-11-80 | Mixed LCM pill and spotted @ 5184 w/70% returns. Waited 2 hrs. Established 100% returns @ 5184. Drld cement to 5187. Lost returns. Drld w/10% returns to 5214 Spotted LCM pill - 10% returns |
| 4-12-80 | Spotted 440 gal sodium silicate followed by 175 $ft^3$ Class G cement. Drld cement to 5215 w/complete returns |
| 4-13-80 | Drld to 5247. Losing too much fluid. Spotted LCM pill. Ran Kuster survey |
| 4-14-80 | W.O. Loggers. Ran spinner and tracer surveys. Tool failure. W.O. tools |
| 4-15-80 | Ran temp. survey. Circ. hole. Ran tracer and spinner surveys. Tools failed |
| 4-16-80 | Ran caliper log. Experimented w/pump rates and measured fluid loss for water. Ran tracer survey. Tool failed. RIH w/Lynes packer. Set packer. Pumped cement. Squeezed at 650 psi |
| 4-17-80 | ROH w/packer. WOC. Drld cement. Drlg @ 5287 w/water |
| 4-18-80 | Drld to 5374. Hole not cleaning. Mixing gel to pill to clean hole. |
| 4-19-80- | Drld to 5409. Swept hole w/gel pill. Rigging up for air |

| | |
|---|---|
| 4-20-80 | Began using aerated water. Reamed to 5359. Well began flowing and flashing steam over shaker. Hole caving. Lost circ. Regained circ. POH. Monitor well |
| 4-21-80 | Rig up for flow test |
| 4-22-80 | Rig up for flowtest. Ran Pruett temp and press survey. RIH w/drillpipe to lift off well |
| 4-23-80 | Attempted to flow well. Ran Pruett temp and press survey. laid down 8" collars. Preparing to reduce hole |
| 4-24-80 | Cleaned out fill. Swept w/gel pill. Drld to 5454 w/aerated water. 8 3/4" hole |
| 4-25-80 | Drawworks broke. Stuck pipe. Freed pipe. Hole caving. Made short trip. Mix gel pill. 210' firm fill. Hard fill 5244-5307 Short trip - 60' fill 45 min. Waiting on loggers |
| 4-26-80 | Wait on loggers |
| 4-27-80 | Ran logs. Bridge @ 2730. RIH cleaned out bridge 2730-2909. Tagged bottom @ 5289. POH |
| 4-28-80 | Ran Sperry Sun survey. Ran GO DIL-GR, BHC-GR-Cal Temp log would not go past 2790. Rigging down |
| 4-29-80 | Rig released 0800 |

Table III. Field Notes on Flow Test of Well 66-5
Tuscarora, Nevada (Enthalpy, Inc., 1980)

| TIME | COMMENTS |
|---|---|
| 1450 | Air on @ 1500' |
| 1458 | Water returns - 156°F 75 psig |
| 1502 | Air off-no flow T.D.S. 340 ppm pH 7.8 |
| 1508 | Water returns - 159°F 10 psig |
| 1510 | 185°F 35 psig T.D.S. 320 ppm pH 8.8 |
| 1515 | Water returns |
| 1518 | 197°F 20 psig T.D.S. 500 ppm pH 8.2 |
| 1528 | 188°F 10 psig |
| 1545 | 186°F 8 psig T.D.S. 600 ppm pH 8.4 |
| 1558 | 210°F 26 psig soapy |
| 1610 | 210°F 20 psig soapy |
| 1611 | Shut-in; air off, added 10 stands of drill pipe |
| 1700 | 1st water returns 144°F |
| 1703 | 204°F 10 psig |
| 1705 | 221°F 125 psig (surge) |
| 1707 | 215°F 35 psig |
| 1710 | 198°F 5 psig soapy |
| 1716 | 217°F 50 psig soapy - air off |
| 1730 | 200°F 20 psig soapy - air on |
| 1737 | 225°F 15 psig no more soap added |
| 1743 | 207°F 25 psig |
| 1750 | 198°F 20 psig |
| 1755 | 205°F 25 psig |
| 1812 | 220°F 20 psig |
| 1820 | 220°F 20 psig |
| 1835 | 222°F 21 psig |
| 1844 | 221°F 19 psig T.D.S. 800 ppm pH 9.0 |
| 1857 | 222°F 19 psig |
| | Estimate of water flow approx. 1200 Bl/hr. |

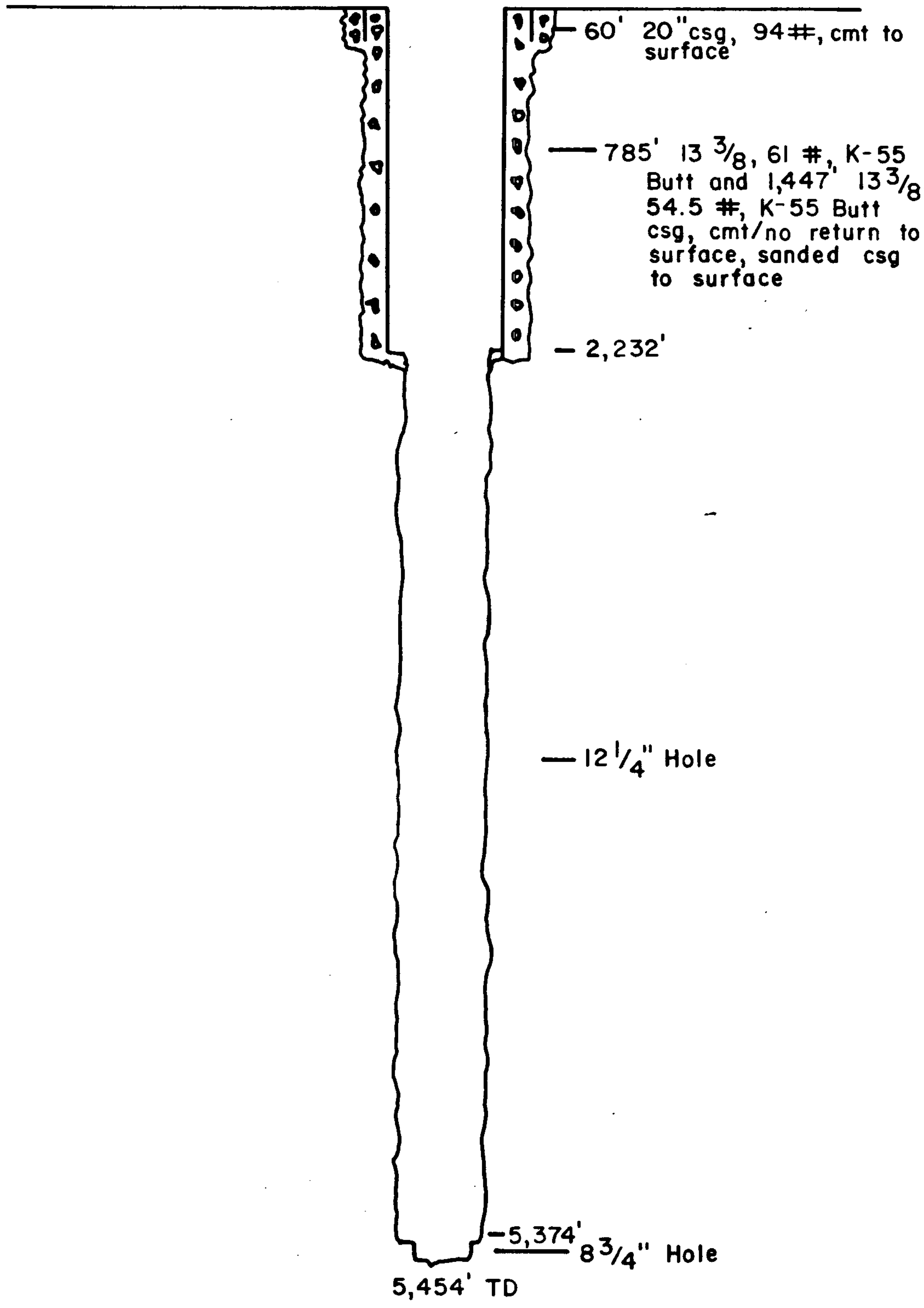



Figure 15. Well Completion Schematic Diagram for 66-5.

Table IV. Logging History for Well 66-5
Tuscarora, Nevada

| Date | Type of Log | Logged Interval | Total Depth |
|---|---|---|---|
| 1 March 80 | Temperature Schlumberger | 52-2228' | 2232' |
| 1 March 80 | Caliper-Schlumberger | 71-2226' | 2232' |
| 1 March 80 | Borehole Compensated Sonic | 61-2218' | 2232' |
| 1 March 80 | Dual Induction-SFL | 76-2232' | 2232' |
| 3 March 80 | Temperature-Schlumberger | 55-2144' | 2232' |
| 3 March 80 | Cement Bond Log | 60-2157' | 2232' |
| 27 March 80 | Differential Temp-GO | 20-4111' | 4118' |
| 15 April 80 | Temperature-GO | 3800-5237' | 5246' |
| 22 April 80 | Temperature-Pruett | 200-5250' | 5359' |
| 22 April 80 | Pressure Pruett | 150-5250' | 5359' |
| 27 April 80 | BHC Sonic Log-GO | 2227-5187' | 5454' |
| 27 April 80 | Dual Induction Laterlog-GO | 2227-5187' | 5454' |
| 28 April 80 | Temperature Log | 2227-5187' | 5454' |

The unusually warm and wet winter weather caused major problems with the access road and drill pad, greatly adding to the costs. Another problem which seems to come up on geothermal wells is that drill capacity often proves inadequate for the hole (Pfaff, 1980) both in terms of draw-works and pump capacities. Some balance must be reached which will allow enough additional capacity to handle difficult drilling conditions, lost circulation problems and sloughing ground without running the costs out of sight. Finally, a problem which comes up time after time is that logging companies arrive on a remote site with tools that do not operate properly, and do not have back up tools or components with them.

The test for discovery well located a low temperature reservoir, and it is probable that most of the fluids produced come from the zone between the casing and 3,000 feet. The geothermal fluids produced during the flow test have a chemical signature (Table 1) which indicates mixing of thermal water and groundwater in the fractured argillites of Mississippian age beneath the altered impermeable cap of Tertiary volcanic and volcani-clastic rocks (Figure 16). Considerable fluid loss occurred while drilling, especially in the lower part of the hole and it was impossible to determine an equilibrium temperature at TD.

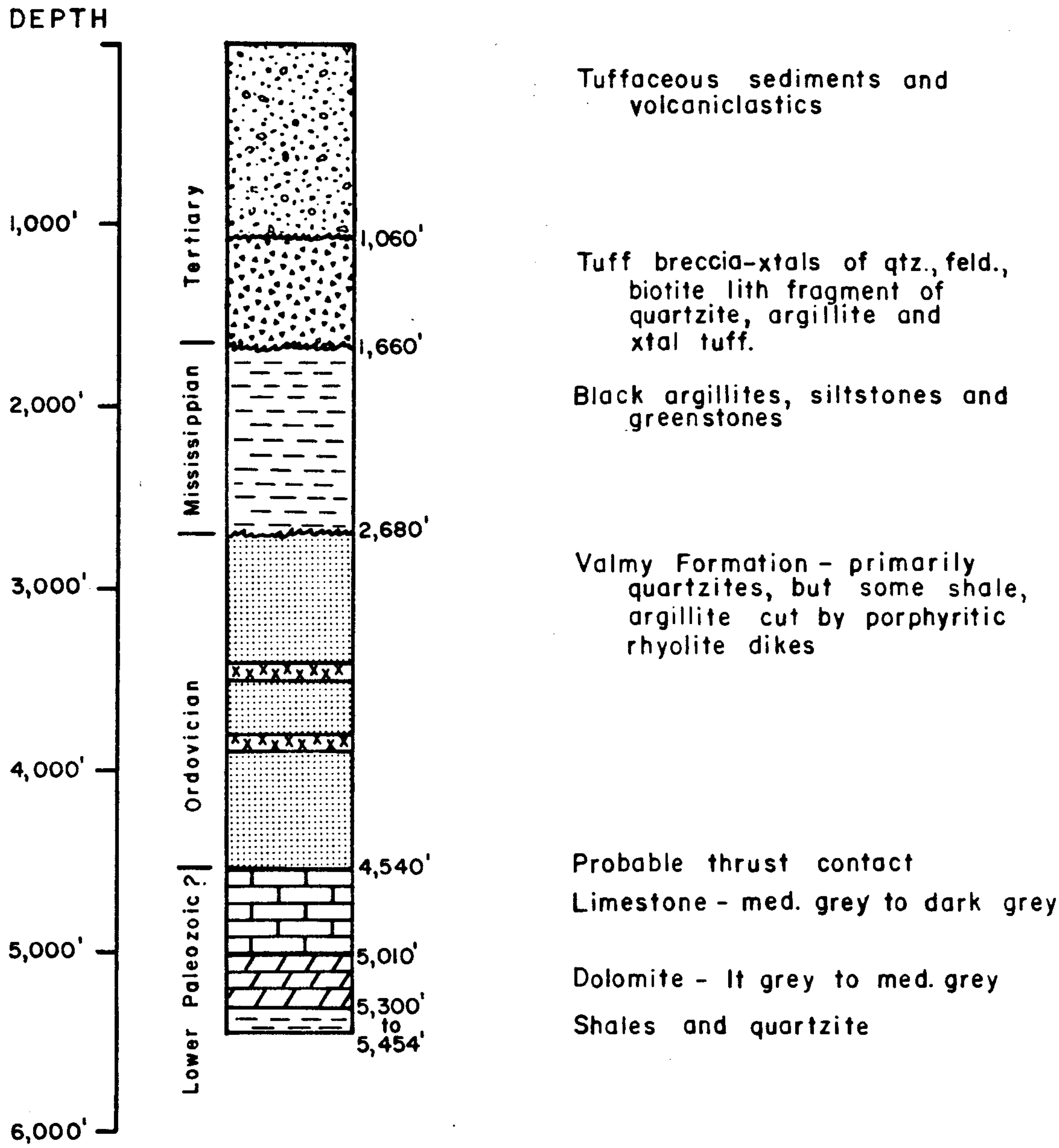



Figure 16. Generalized Stratigraphic Section for Well 66-5.

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