Chapter 7
Trap Spring Field
Nye County, Nevada

7.1
INTRODUCTION

Trap Spring Field is located in the north-south trending Railroad Valley, which lies between the Grant Range and the Pancake Range in east-central Nevada (Figure 7.1). The field is approximately 65 miles (105 km) southwest of Ely, Nevada. Trap Spring is only the second economic oilfield in the state, and is one of only six known fields in the entire Basin and Range Province of the western United States. Production is from Oligocene volcanics between 3,200 and 4,950 feet (975-1,510 m).

Three lines of resistivity/phase data were run across Trap Spring Field, using a dipole spacing of 1,250 feet (381 m).

7.2
GEOLOGIC BACKGROUND

Exploration History of Trap Spring Field

The Basin and Range area has been of interest to exploration geologists since the late 19th century, when the first claims were filed for oil-shale lands near Elko, Nevada. These lands were shown to be uneconomic when they were developed between 1916 and 1920, although interest persisted in them for some years afterwards.

Oil was first discovered in the Basin and Range area in 1904, at Rozel Point, near Salt Lake. The well was relatively uneconomic, and the exploration outlook for the area was dim until Shell Oil Company discovered the Eagle Springs Field in 1954. This discovery spurred a flurry of activity, resulting in the drilling of some 200 dry holes over the next two decades, partly on the basis of erroneous conceptions of Basin and Range geology (Foster, 1979).

In 1973, geologists from Filon Exploration Company undertook an investigation of promising new wildcat targets across the United States, based upon the concept of using existing productive fields with well-defined structures as models for exploration in the adjacent areas (Dolly, 1979; Foster, 1979). The area of the

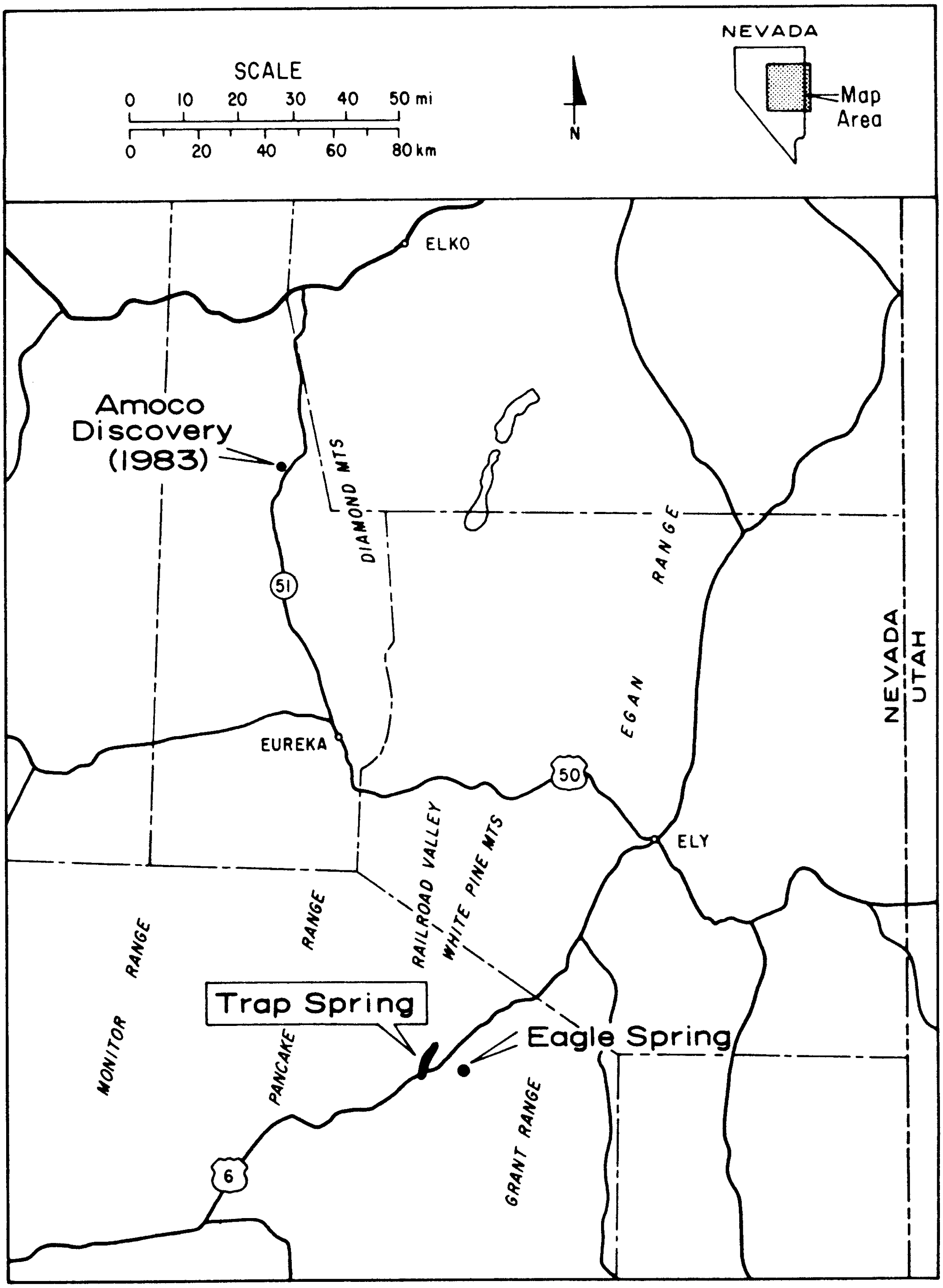


Figure 7.1. Location map of Trap Spring Field.

Railroad Valley was targeted in this program, using Eagle Springs as an exploration model. The Eagle Springs production is from the Garrett Ranch Group volcanics, and the trap is controlled by basin faulting, stratigraphic thinning, and folding of the reservoir rocks. Filon used these geological parameters in a program of photographic geomorphic mapping, which succeeded in identifying a number of favorable targets.

This was followed by the shooting of several seismic lines, one of which crossed the Railroad Valley westward to the Trap Spring area. Encouraged by the geomorphic/seismic data and by oil shows in Shell Oil Company's No. 1 Lockes Well, Filon and a number of other investors spudded Northwest Exploration Trap Spring No. 1, which was completed successfully in late 1976. The discovery well pumped 1,200 BOPD with open hole completion, producing from a pay zone some 800 feet (250 m) thick in the Garrett Ranch Group. More than two dozen wells have been drilled in subsequent years, half of which are currently producing. Production from Trap Spring varies considerably, but the average was about 3,000 BOPD in 1978.

The economics of oil production at Trap Spring are not entirely favorable. Completed wells typically cost around $500,000 and transportation costs are considerable for this remote field. As a result, it is often cheaper to transport oil from neighboring states than it is to produce Trap Spring oil for the limited market in Nevada.

Recent drilling has been undertaken in Railroad Valley by several parties. In 1978, a well near Currant produced oil but it is believed to be non-economic. Northwest Exploration has continued its work in the area. Wexpro Company and Supron Energy have also been active of late (McCaslin, 1980, 1981b). A recent discovery by Amoco in Pine Valley (Oil & Gas Journal, 1983; McCaslin, 1983) marks the third commercial field in Nevada. Initial production was 346 barrels of 27° API gravity, low pour point oil and 767 barrels of water per day. Amoco announced that two zones are productive, but did not elaborate on which ones they are.

Geologic History of the Trap Spring Area

Since few wells have penetrated pre-Cretaceous sediments at Trap Spring, little is known about Paleozoic and pre-Paleozoic geology. The known geologic history of the Railroad Valley area begins with the Cretaceous, when Paleozoic limestones and shales were subjected to downwarping and erosion, followed by episodes of lacustrine deposition. The first Basin and Range faulting in the early Oligocene (36 million years ago) resulted in further downwarping of the sediments, followed by successive erosion/deposition cycles. Downwarped areas were filled in with the fluvial and lacustrine sediments of the Sheep Pass and Newark Canyon formations. These lacustrine sediments are present at Eagle Springs, but are absent in the Trap Spring area, either because they were never deposited on the upwarped topography there, or because they were eroded away during the periodic episodes of uplift which interrupted their deposition.

The first volcanics appeared with the ash flows of the Stone Cabin Formation 34 million years ago. These deposits were the result of the extensive volcanism which characterized the Tertiary period in western North America. Most of the volcanics in the Railroad Valley area were ejected explosively from nearby vents and were deposited as density flows of superheated pyroclasts and gases (French and Freeman, 1979). Settling, cooling, and compaction led to a zonation of welding density, while weathering and degassing processes altered the feldspars to clays in certain zones of the ash flows. Episodes of eruption, deposition into low-lying areas, erosion, and Basin and Range uplift built up a sequence of rhyolites, dacites, quartz latites, and rhyodacites which constitute the Pritchards Station Formation (the producing horizon at Trap Spring) and the Windous Butte Formation. These two volcanic formations are part of the Garrett Ranch Group.

The cessation of volcanism was followed by an erosional episode, resulting in the so-called "Unconformity A," which separates the Oligocene volcanics from an overburden of Tertiary-Quaternary valley fill. These recent sediments comprise the

Horse Camp Formation, a sequence of clay-filled, carbonate-cemented sandstones, siltstones, marlstones, and Pliocene playa-lake deposits.

Current Geology

A simplified geologic cross-section along an east-west traverse across east-central Nevada is presented in Figure 7.2. This illustrates the general character of the horst-and-graben faulting of the Basin and Range area.

Figure 7.3 shows the electrical line locations at Trap Spring. Figure 7.4 shows the depth to Unconformity "A" and the important graben faults. Note that line 2 of the electrical survey is parallel to this faulting. Figure 7.5 is an isopach map of the Oligocene Garrett Ranch Group.

The present-day stratigraphy is described in Table 7.1, and a geologic cross-section corresponding to line 3 of the survey is presented in Figure 7.6.

Reservoir Characteristics

Production at Trap Spring is entirely from the Pritchards Station Formation of the Garrett Ranch Group. This tuff has considerable vertical variation in the degree of welding. Depending upon welding, pore-filling mineralization, and compaction due to degassing, the rock matrix porosity varies from 1 percent to over 70 percent. However, permeability is extremely low—about 0.1 millidarcy. The reason for this is that pore spaces in these volcanics are not interconnected since they are formed by the escape of discrete gas bubbles from the rock. As a result, oil is not found in the pore spaces. Instead, it is found in the numerous cooling joints and fractures which characterize volcanics of this type. There is evidence (Dolly, 1979) that the more densely welded sections are more intensely fractured, making them more likely to host oil. The trap is confined at the top by a heavily weathered zone, in which clay alteration has created an impermeable layer by filling the available joints and fractures.

The source of the oils at Trap Spring and Eagle Springs is believed to be the Sheep Pass Formation (Upper Cretaceous through Eocene lacustrine deposits), which is not present at Trap Spring, or the Chainman Formation (Mississippian shales), an immature source rock in the Trap Spring area. Migration is believed to have occurred during Miocene to Pliocene time.

Table 7.2 presents pertinent data on the reservoir characteristics of Trap Spring. Several items are of interest here. First, note that no gas is dissolved in the

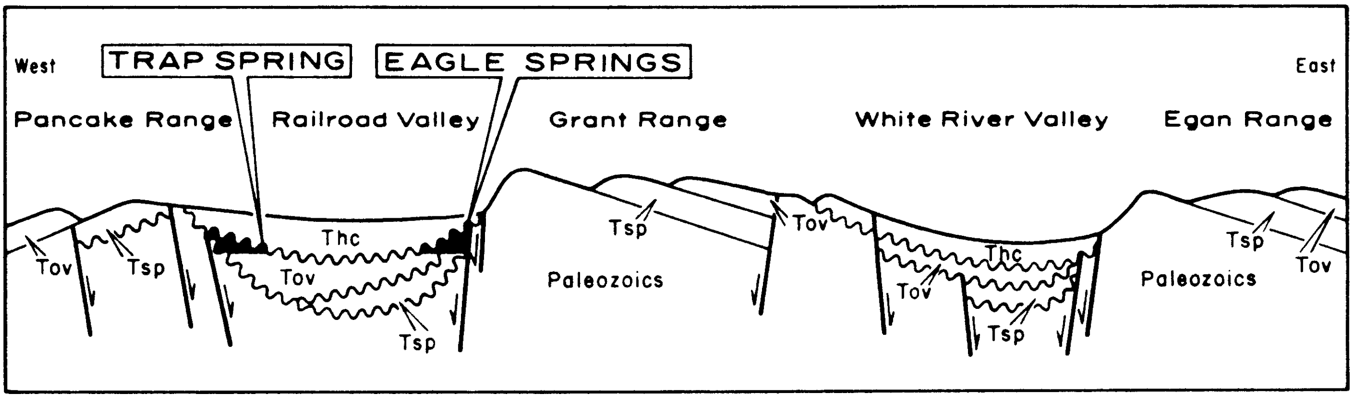


Figure 7.2. Schematic depiction of the Basin and Range geology of eastern Nevada along an east-west traverse. Note: Tsp = Sheep Pass Formation. Production in the Railroad Valley is from Oligocene volcanics. No hydrocarbons have yet been found in Oligocene sediments in the White River Valley, which is located east of the Railroad Valley.

TABLE 7.1: STRATIGRAPHIC DESCRIPTION OF TRAP SPRING FIELD

System	Symbol	Formation	Lithologic Description
CENOZOIC ROCKS			
Quaternary	Qal	Playa lake deposits	Interbedded claystone and conglomerate
Tertiary			
Miocene/Pliocene	Thc	Horse Camp Fm.	Unconsolidated valley fill: sands, gravels, conglomerates
		(Unconformity "A")	
Oligocene	Tov	Garrett Ranch Group	
		(ash zone)	Weathered ash and clay; forms an impermeable cap over volcanics
		Windous Butte Fm.	Ash flow tuff, mostly absent in the immediate Trap Spring area
		Upper unit	Partly to densely welded tuff
		Lower unit	Densely welded tuff with a vitreous basal section
		Pritchards Station Fm.	Ash flow tuff with large numbers of plagioclase and large biotite phenocrysts, high in mafic content; *hosts all of the oil at Trap Spring*
		(weathered zone)	Bentonitic sandstone
		Stone Cabin Fm.	Ash flow tuff with abundant phenocrysts, low in mafic content
		Upper unit	Slightly to densely welded tuffs with abundant quartz and feldspars and some biotite
		Middle unit	Partly welded at the top, densely welded at the bottom
		Lower unit ("Calloway Well Fm.")	Non-welded to welded tuffs with some pumice fragments
		(unconformity)	
PALEOZOIC ROCKS			
Mississippian	Mch	Chainman Fm.	Shales; not present in some Trap Spring holes
Devonian	Dg	Guilmette Fm.	Fractured dolomite with conodonts; deepest unit penetrated at Trap Spring

oils—a very unusual situation. This raises the interesting possibility that the trap is imperfectly sealed to lighter hydrocarbons, or, alternatively, that the gases dissipated during migration. Duey (1979) notes that the missing low-carbon molecules may imply partial bacterial alteration; he also notes that the lower-gravity oils toward the south may indicate increased bacterial action in that direction. It is also interesting to note that the reservoir waters have a fairly high resistivity of about 1 ohm-meter.

Approximately 2.5 MMBO had been recovered from Trap Spring at the time of the electrical survey. Production is now in decline, but the oil reserves are by no means depleted (Duey, 1983).

Groundwater Characteristics

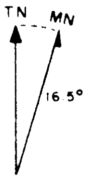
The Trap Spring area water table lies at or near the surface of the ground, accounting for the numerous springs and ponds found there. The water is quite saline.

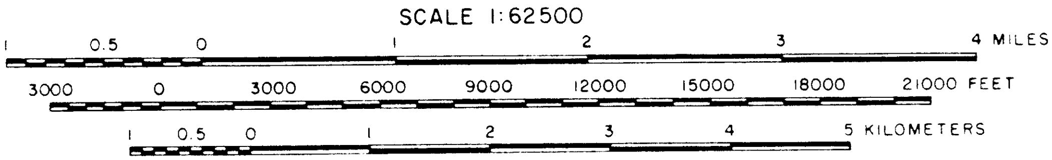
Figure 7.3

LINE LOCATION MAP

Trap Spring Field

Nye Co., Nevada





Sources
Base: U.S.G.S. 15' Quad (Blue Eagle Springs, Nev., 1964)
Well Data: Duey (1979)

Explanation of Symbols

Standard Well Symbols

⊙	Drillhole for which information is unobtainable
○	Drilling in progress at time of map preparation
ϕ	Shut in
∅	Abandoned
-ϕ- 10,420	Dry hole with total depth indicated
●	Oil well
☼	Gas well
✸	Oil and gas well
☼	Gas injection well
↗ρ w	Water injection well
∘	Water well

Culture Symbols

ϕ	Metal pipeline, presumed grounded
ϕ G	Ungrounded pipeline: non-metal or suspended
ǂ	Metal fence
ǂ	Electric fence
≷	Buried telephone or power cable
T	Telephone line or standard voltage power line
⊼	Major high voltage power line
ϙ	Radio, microwave, or other communications station or tower
⌐	DC pump

Special Well Symbols

(●) DS 2000	Drilling in progress at the time of the electrical survey; number indicates the amount of drill stem in the hole at the time of data collection
⊙	Well spudded in after completion of the electrical survey
● 0.7	Number indicates distance of well from the line in terms of a-spacings; all wells within 1.0 a-spacings indicated (pseudosections only)

Other Symbols

U.S.G.S. standard symbols or as labeled

Map-Specific Symbols

Topographic contour interval: 200 feet

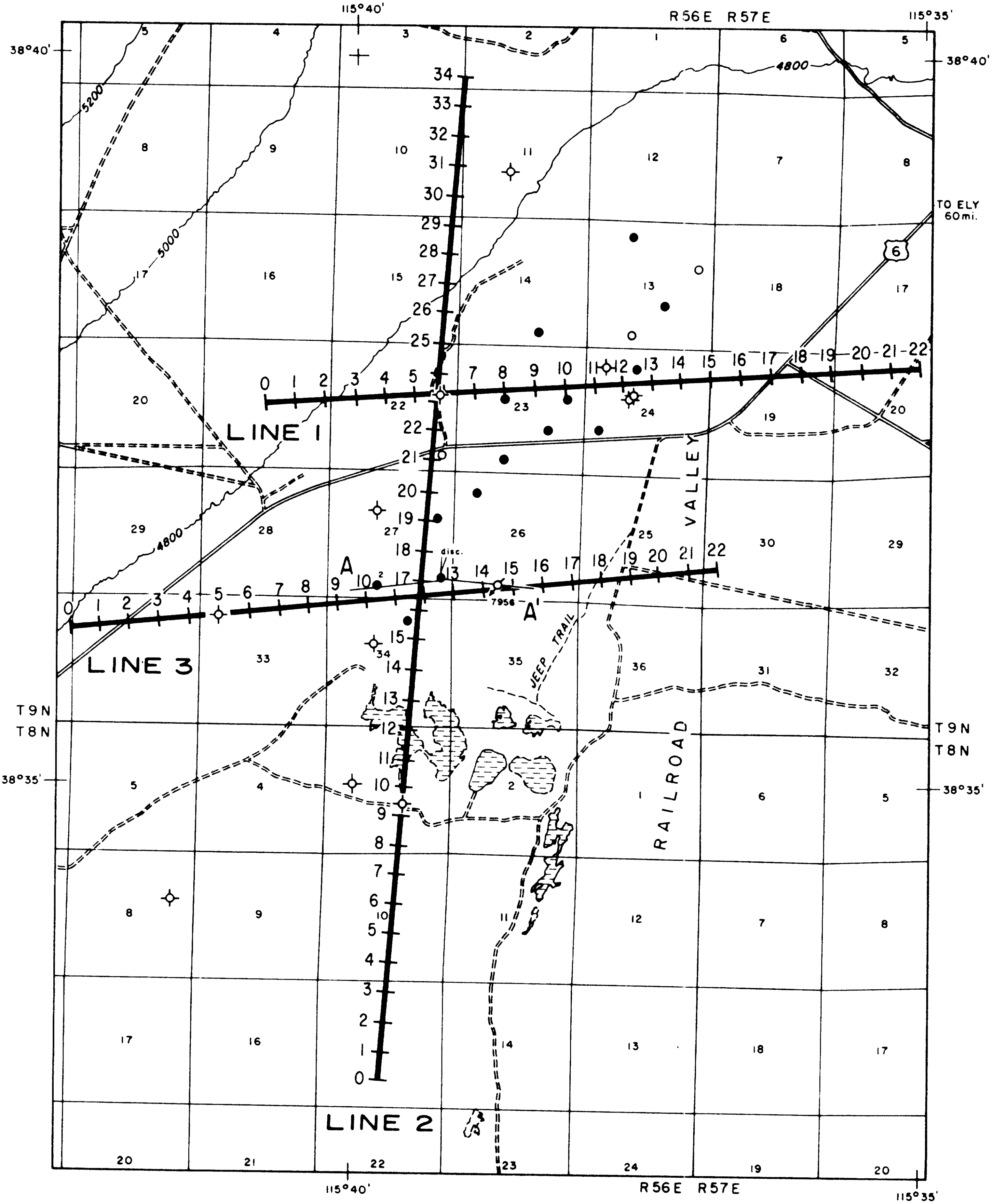
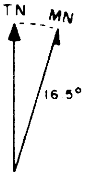

115°40'
R56E R57E
115°35'
38°40'
4800
5200
5000
TO ELY 60mi.
6
LINE 1
LINE 2
LINE 3
VALLEY
RAILROAD
JEEP TRAIL
A
A'
disc.
7956
T9N
T8N
38°35'
115°40'
R56E R57E
115°35'

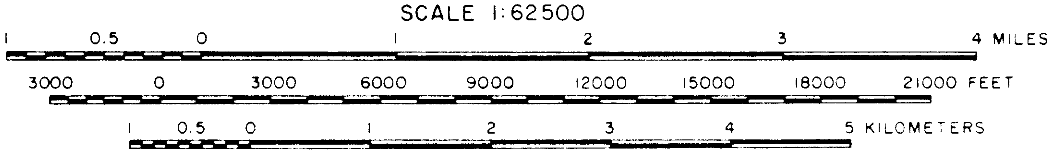
Figure 7.4

STRUCTURE MAP–TOP OF UNCONFORMITY "A"

Trap Spring Field

Nye Co., Nevada





Sources
Base: U.S.G.S. 15′ Quad (Blue Eagle Springs, Nev., 1964)
Well Data: Duey (1979)
Geology: Duey (1979)

Explanation of Symbols

Standard Well Symbols

⊙	Drillhole for which information is unobtainable
○	Drilling in progress at time of map preparation
ϕ	Shut in
⌀	Abandoned
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☼	Gas well
✹	Oil and gas well
☼	Gas injection well
ρ W	Water injection well
∘	Water well

Culture Symbols

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⩚	Major high voltage power line
Ÿ	Radio, microwave, or other communications station or tower
⌂	DC pump

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⦿	Well spudded in after completion of the electrical survey
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Other Symbols

U.S.G.S. standard symbols or as labeled

Map-Specific Symbols

Structure contour interval: 500 feet
Datum: Mean sea level

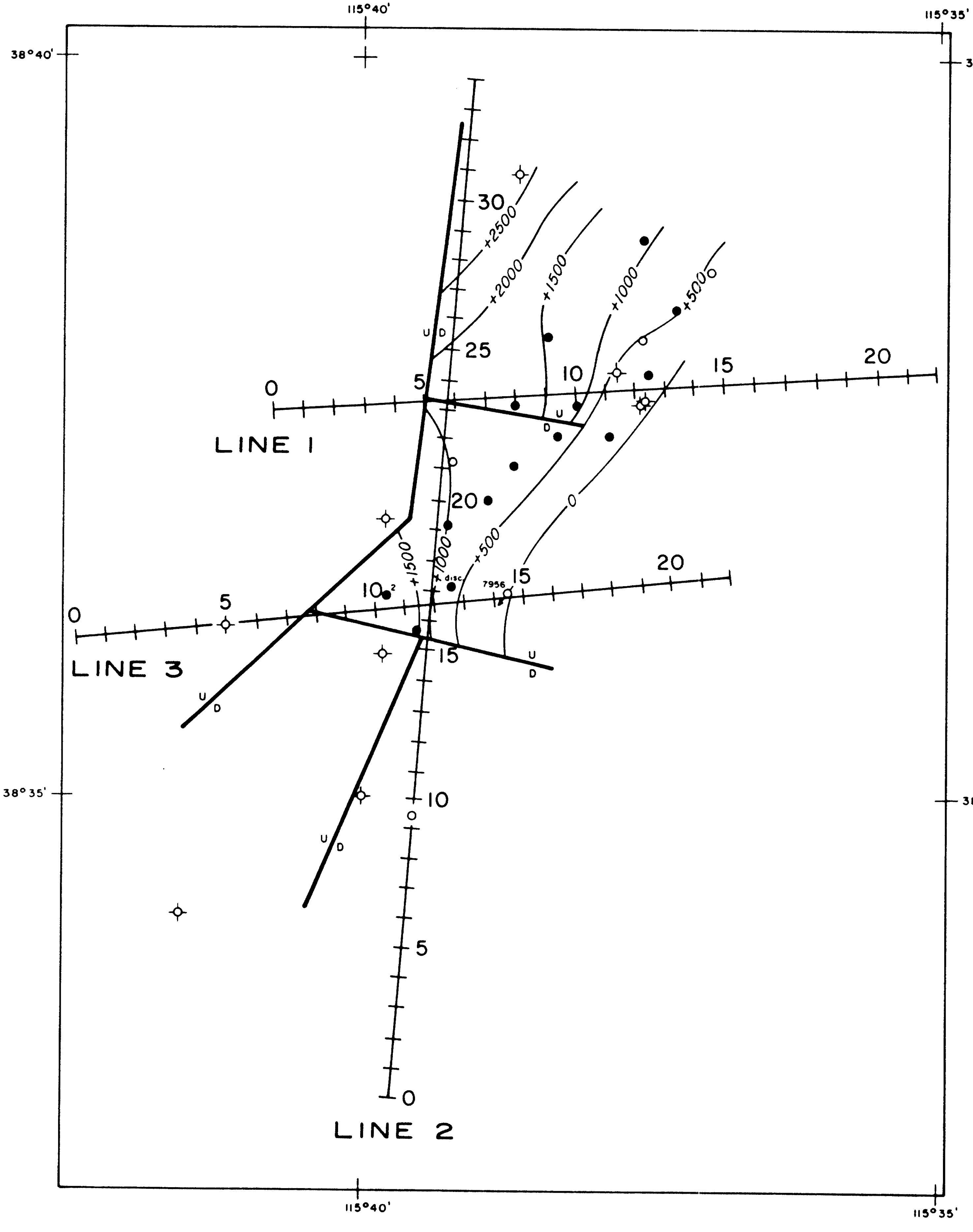
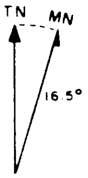
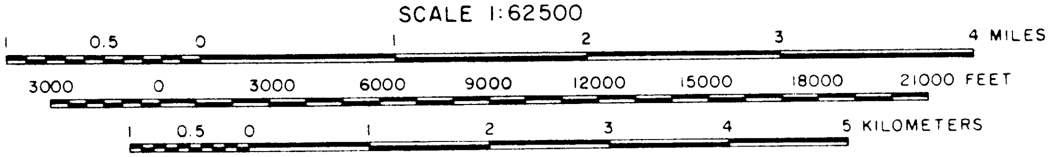

115°40'
115°35'
38°40'
38°40'
LINE 1
0
5
10
15
20
LINE 2
0
5
10
15
20
25
30
LINE 3
0
5
10
15
20
+2500
+2000
+1500
+1000
+500
+1500
+1000
+500
0
disc
7956
U
D
38°35'
38°35'
115°40'
115°35'

Figure 7.5
ISOPACH MAP—GARRETT RANCH GROUP
Trap Spring Field
Nye Co., Nevada





Sources
Base: U.S.G.S. 15' Quad (Blue Eagle Springs, Nev., 1964)
Well Data: Duey (1979)
Geology: Duey (1979)

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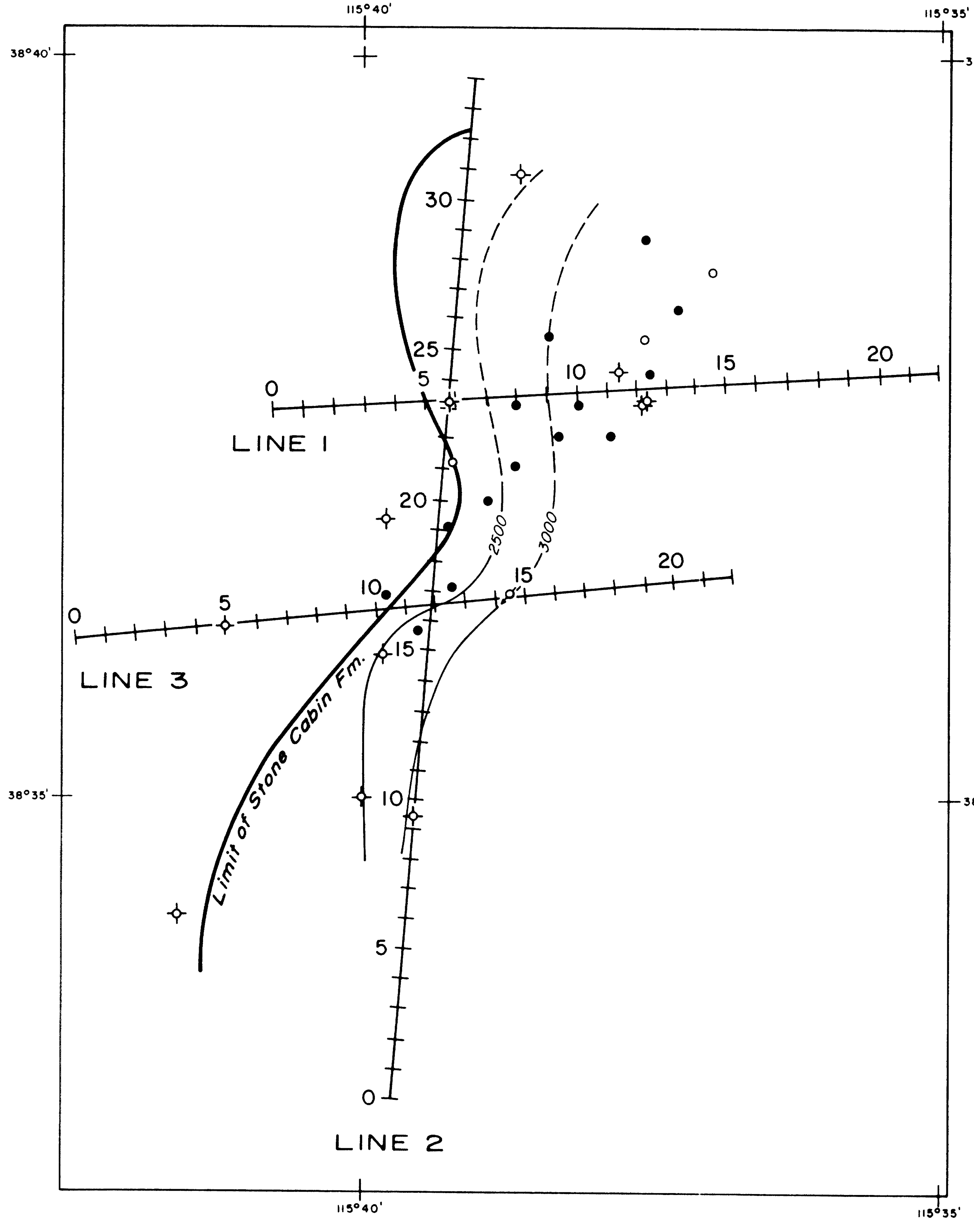
Other Symbols

U.S.G.S. standard symbols or as labeled

Map-Specific Symbols
Isopach contour interval: 500 feet



115°40'
115°35'
38°40'
38°35'
LINE 1
LINE 2
LINE 3
Limit of Stone Cabin Fm.
2500
3000
0
5
10
15
20
25
30

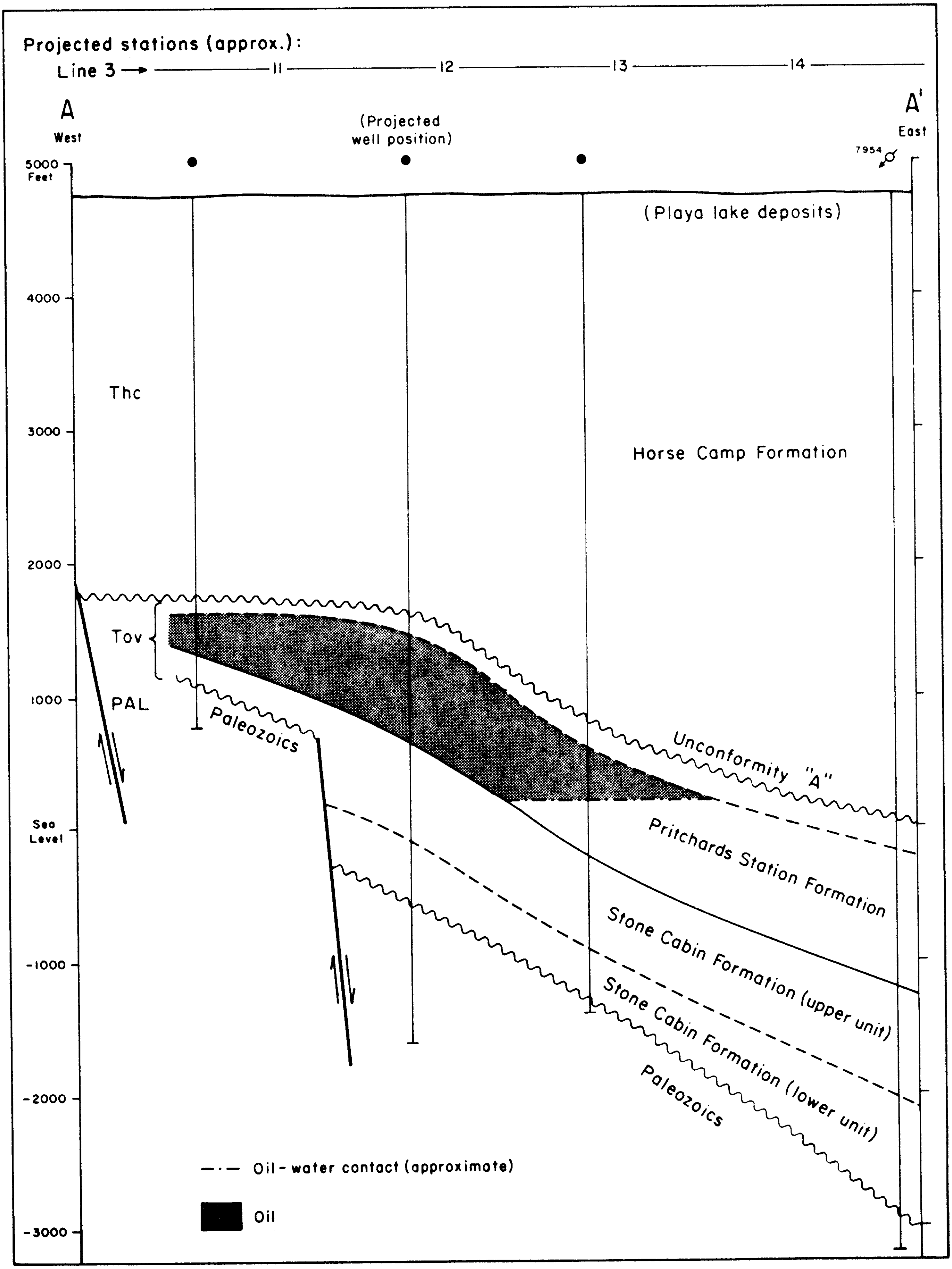


Figure 7.6. Geologic cross-section A-A', with no vertical scale exaggeration; this may be compared with the data from line 3 of the electrical survey. Refer to Figure 7.3 for map location. After Duey (1978).

TABLE 7.2: RESERVOIR CHARACTERISTICS OF TRAP SPRING FIELD

General Field Data

Region: Basin and Range Province
Production: Oil
Type of Trap: Stratigraphic and structural
Producing Formations and Depths: Pritchards Station Fm., 3,200 to 4,950 ft
Other Significant Shows: None
Total Reserves: Not reported
Productive Area: Proved 1,280 acres, unproved 960 acres
Field Operator: Northwest Exploration, Texaco
Number of Producing Wells (1979): 14
Well Casing Data: Surface casing 9-5/8 inch to 150-450 ft, production casing 7 inch to volcanics (typical Northwest Exploration wells). Production casing 7 or 9-5/8 inch, some with 6 inch liner, and some open hole completed in the Garrett Ranch (typical Texaco wells).

Discovery Well

Name: Northwest Exploration No. 1 Trap Spring
Location: SE-SE-27-T9N-R56E
Completion Date: 11/30/76
Total Depth: 6,137 ft (Pritchards Station)
Perforations: None, open hole completion
Initial Potential: Pumping 417 BOPD
Treatment: None

Reservoir Data: Pritchards Station Formation

Discovery: 11/30/76; Northwest Exploration No. 1 Trap Spring, SE-SE-27-T9N-R56E
Lithology: Ash flow tuff
Age: Oligocene
Type of Trap: Stratigraphic and structural
Drive Mechanism: Water
Gross Thickness of Reservoir Rock: 800 ft
Porosity: Fracture (cooling joints and fractures in volcanics)
Permeability: Unknown, usually large within the trap; less than 0.1 millidarcy outside the fracture zones
Oil Column: 1,700 ft
Gas/Oil Ratio: No gas
Original Oil/Water Contact: Approx −200 ft
Oil Character: Black; gravity 21.5°API (varies from 21°API in the south to 28°API in the north); pour point 0 to 5°F (increases to 40°F toward the north)

Oil Analysis:		
	Pristane/phytane ratio	1.24
	Sulfur	0.8%
	Methane	none

Water Saturation: Unknown
Water Salinity: Low, 5,400 ppm TDS
Water Resistivity: 1.10 ohm-meters at 68°F
Daily Average Production (12/78): 3,450 BOPD
Estimated Primary Recovery: Unknown
Type of Secondary Recovery: None
Estimated Ultimate Recovery: Unknown

Well-Casing Information

Well-casing diameters and well completion practices vary somewhat at Trap Spring Field. Surface casing is typically 9-5/8 inches (24.5 cm) in diameter and is set as deep as 450 feet (140 m). Production casing for Northwest Exploration wells is almost universally 7 inches (17.8 cm) in diameter, but a few Texaco wells have production casings as large as 9-5/8 inches (24.5 cm). Although a 7-inch diameter is probably a typical figure, a worst-case 9-5/8-inch diameter was assumed for the computer models.

7.3 DISCUSSION OF THE DATA

Introduction

Directed by Zonge Engineering geophysicist Norman R. Carlson, a resistivity/phase crew of eight persons was mobilized to the Trap Spring area on November 1, 1979. Two parallel lines and a single cross-line were run with a dipole spacing of 1,250 feet (381 m). Data were obtained at 0.125, 0.25, 0.5, and 1.0 Hz. Work was completed on November 17. A total of 18.7 surface line-miles (30.1 line-km) and 12.8 subsurface line-miles (20.6 line-km) of coverage were obtained on this project.

Data collection went very smoothly at Trap Spring. Contact resistance of the ground was very low, permitting full utilization of the maximum transmitter output current of 18 amperes. Electrical noise was minimal, topography was flat, and surface culture was virtually nonexistent. All pipelines in the area were suspended in the air in order to prevent corrosion from the alkaline surface deposits. Hence, the pipelines can be considered to be ungrounded for purposes of their effect on the electrical data, except to the degree that they are electrically continuous with cased production wells.

Topographic effects at Trap Spring are virtually nonexistent, since less than 100 feet (30 m) of elevation change occurs across all three of the lines. The lines on this survey were set up without prior knowledge of subsurface geology. Unfortunately, all three lines were run near sub-parallel subsurface faulting. This has made the data more difficult to interpret than usual.

The data for lines 1, 2, and 3 are presented in Plates 7.1, 7.2, and 7.3, respectively. These are found at the end of this section and can be unfolded for reference while reading the text.

Line 1 Interpretation

As shown in the line location map of Figure 7.3, line 1 was run at a N 86° E orientation across the northeast-trending axis of the oil field. The field data are presented in Plate 7.1.

APPARENT RESISTIVITY DATA

A very distinctive pattern of high/low/high resistivity layering is evident in the data. The surface high resistivity unit probably corresponds to the recent playa-lake deposits at the top of the sedimentary section. The underlying low resistivity unit is probably related to water-saturated, unconsolidated sediments of the Horse Camp Formation. The apparent resistivities observed on the pseudosection are quite typical of valley fill in central Nevada, as judged by numerous surveys conducted in that area for mining and petroleum companies. The high resistivity unit at depth correlates with the Oligocene volcanics, which are generally impermeable, and with the Paleozoic dolomites which lie beneath them.

A major lateral change near station 7 is seen in the pseudosection data: low resistivity materials west of station 7 are shallower, while those toward the east are considerably deeper. The lowest resistivities occur where a sub-parallel graben fault lies directly beneath the line (Figure 7.4), but the fault terminates at station 5, where a north-south fault with the west side thrown up crosses the line. The depth to the low resistivity layer is clearly less west of station 5 than east of station 7, indicating a significant amount of lateral displacement. The data also show a shallow but distinctive eastern dip to the sediments, an observation which is corroborated by the local geology.

Superimposed on these layering effects is a very subtle, discontinuous, low resistivity zone which may correlate in a general way to the projected lateral extent of the hydrocarbons. In the statistical classification of section 2.2, this anomaly would be classified as "poor."

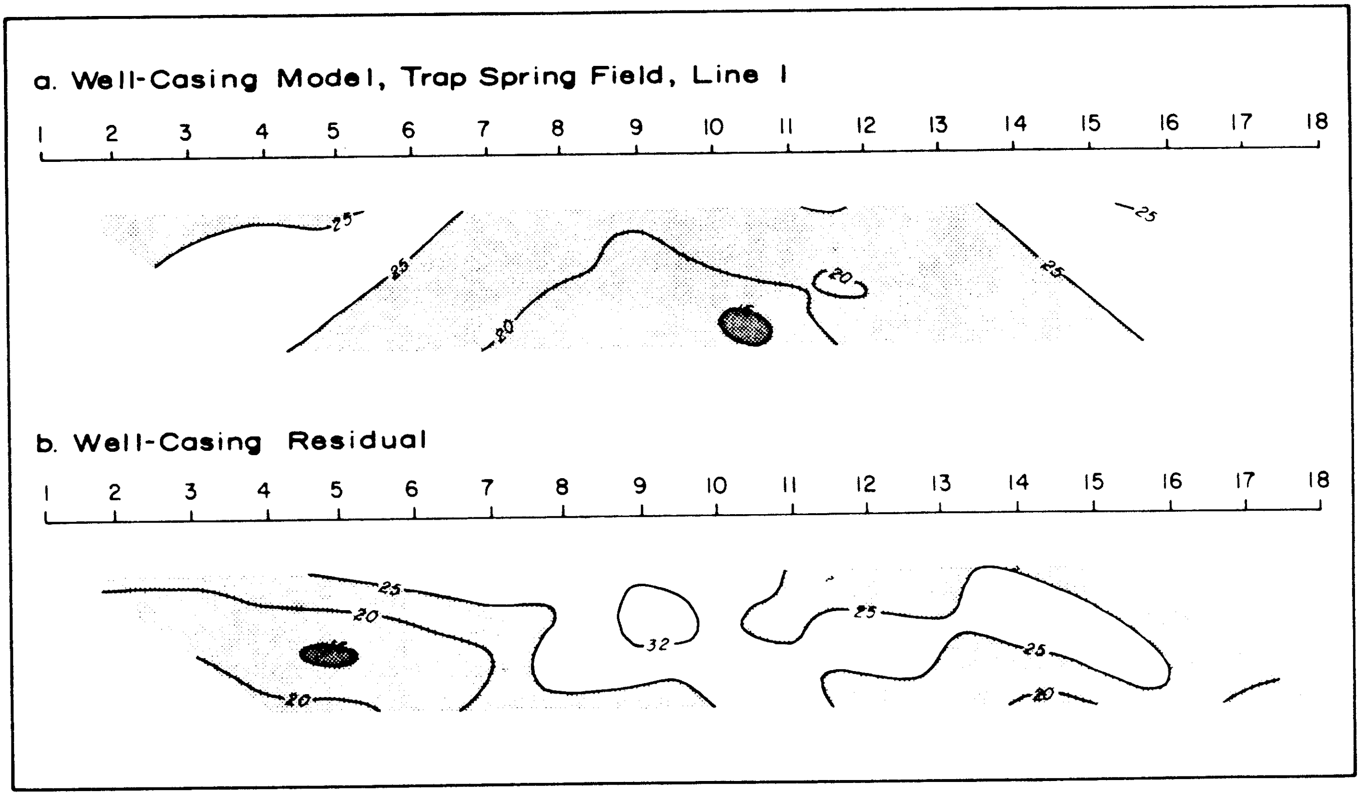
In an effort to determine the origin of this very small perturbation in the data, the "PIPE" model of Holladay and West (1982) was used to simulate a *worst-case* effect due to current channeling by well-casings, despite substantial questions raised earlier (section 2.5) to the applicability of this algorithm to field data. A well-casing diameter of 9-5/8 inches (24.5 cm) was used for the modeling. The modeling results, shown in Figure 7.7, show a broad, conductive anomaly which has many of the features seen in the field data. Using the superposition method described in section 2.5, the well-casing model data were removed from the field data to obtain the well-casing residual data of Figure 7.7b. These residual data show no trace of a low resistivity anomaly. Hence, if the model correctly represents well-casing effects, it can be argued that no anomaly related to the hydrocarbons is seen in the line 1 data.

The problem encountered in attempting to reach such a conclusion is that the residual data show a relatively strong high resistivity zone in the areas where the well-casing model showed the strongest effect. This may be due to overcorrecting by the "PIPE" model—that is, the model is calculating a much stronger effect due to casings than actually occurs in the ground. Since the casings south of stations 8 and 10 are connected electrically by a pipeline, it might be expected that the calculated well-casing effect would be even stronger if the model could accommodate such a pipe, in which case the residual would be even more anomalously resistive. Therefore, it is strongly suspected that the "PIPE" model is overmodeling the data in this particular case.

It is instructive to examine the opposite extreme of a worst-case well-casing model, i.e., what interpretation results from the assumption that *no* well casing effects are present on line 1? In this case, a rather tentative argument can be made for the existence of a conductive zone at depth between stations 9 and 11. However, this could hardly be called a "classic" anomaly. It is very subtle and would not represent a very good drilling target if found over a prospect. There are two possible explanations for this: 1) little or no electrochemical alteration exists over the line, or 2) the effects of the parallel graben fault underlying the survey line have reduced or eliminated the conductive anomaly.

APPARENT POLARIZATION (DECOUPLED PHASE ANGLE) DATA

Polarization layering west of the graben fault near station 5 is high-over-low, while the layering to the far east side of the line is low-over-high. The valley-fill sediments of the playa-lake deposits and the upper Horse Camp Formation appear to have a low polarizability, which is consistent with findings on other projects in Nevada. Middle portions of the Horse Camp Formation appear to have higher polar-



a. Well-Casing Model, Trap Spring Field, Line 1

b. Well-Casing Residual

Figure 7.7. Well-casing model of apparent resistivity data for line 1, Trap Spring Field. Model parameters: 7 cased wells, casing diameter = 9-5/8 inches (24.5 cm), casing resistivity = 2.0 x 10^{-7} ohm-meters, surface impedance = $0 + 1.30i$, background resistivity = 25 ohm-meters. Figure 7.3 shows well locations.

izability, suggesting the possible activation of clays in those sediments. The materials above the volcanics and the Paleozoic sediments also appear to be weakly polarizable, probably because of a weathered clay layer at the base of the Horse Camp (Duey, 1978).

Superimposed on the above effects is a strong polarization anomaly which appears in the form of an inverted chevron bounded by the right-plunging 11,12 and the left-plunging 13,14 diagonals. The anomaly is distorted by high diagonals (left-plunging 12,13; right-plunging 7,8) and by a low diagonal (right-plunging 5,6). Many of these features have a suspicious appearance similar to that of cultural contamination, and the cased wells near stations 8, 10, and 12.5 are immediately suspect. However, the well near station 12.5, which is farthest from the line, appears to have the strongest effect by far. This suggests two possibilities: 1) the surface impedances of wells at Trap Spring vary considerably, making the fixed-impedance well-casing modeling of limited use, or 2) much of the response observed on line 1 is not due to well-casing effects, but instead is caused by some lateral polarization change in the subsurface, a change which is shifted to the eastern edge of the field. Based on examination of the data from lines 2 and 3, the first possibility is slightly more likely.

A well-casing model was run in an attempt to match the polarization data. Unfortunately, the "PIPE" algorithm requires a single surface impedance value for *all* well-casings. The model data, shown in Figure 7.8, have some similarity to the field data; the major response, however, is shifted towards the west, as would be expected if there were major differences in well-casing impedances among the wells.

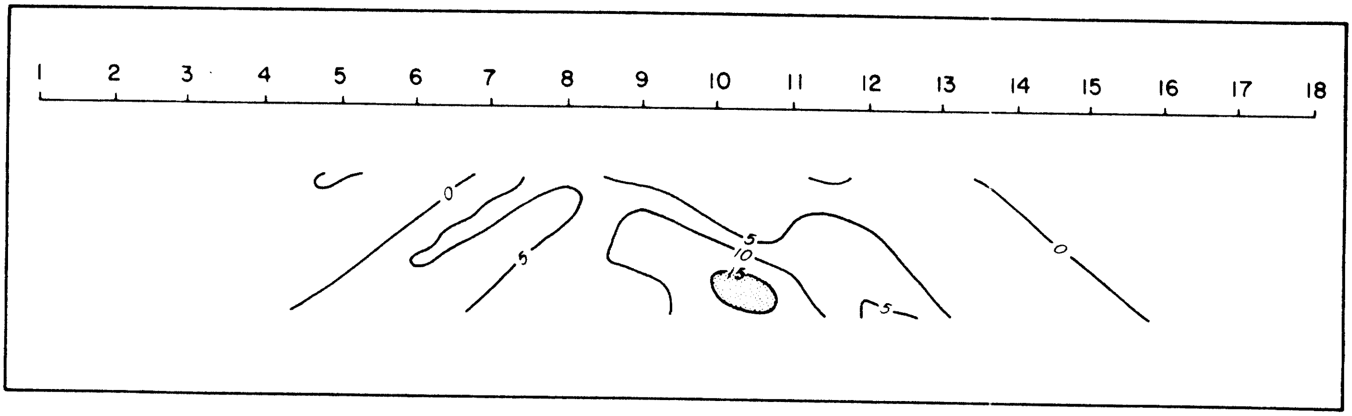


Figure 7.8. Well-casing model of apparent polarization data for line 1, Trap Spring Field. Model parameters: same as in Figure 7.7. Figure 7.3 shows well locations.

RESIDUAL ELECTROMAGNETIC (REM) DATA

There is a strong REM anomaly at depth on line 1, centered on the eastern edge of the field. The anomaly shows strong similarities to the apparent resistivity and apparent polarization anomalies. The response appears to have two primary causes: 1) geologic layering effects, which appear to be unusually strong for REM data, and 2) an effect from the cased well north of station 12.5. There is also a fair possibility that there is a residual response which is related to alteration above the producing field.

Line 2 Interpretation

Line 2 was run up the long axis of Trap Spring Field, in a N 3° E orientation. The data are presented in Plate 7.2.

APPARENT RESISTIVITY DATA

The apparent resistivity layering on line 2 is high-over-low. As found earlier, the resistive surface unit corresponds to playa-lake and upper Horse Camp sediments, and the deeper, more conductive unit can be attributed to lower Horse Camp sediments. In this context, all of the gross resistivity changes observed on line 2 make sense. Faults occur in the subsurface beneath stations 15 and 23 (see Figure 7.4), resulting in a greater depth to Unconformity "A" on the southern portion of the line. The data show this rather well: the bottom low resistivity layer appears to become deeper toward the south. An especially abrupt change of depths at the fault near station 15 is indicated by the data. A sharply uplifted block around station 3 is also indicated, but no geologic information is available for this area. It is of interest to note that low resistivities at depth are generally found north of station 19, where a north-south fault lies within one a-spacing of the line to as far north as station 32 (Figure 7.4). This correlation may indicate that the data are heavily influenced by this fault.

The resistivity of the surface layer varies rather dramatically. The shallow saline pond lying between stations 11 and 13 appears to cause the low resistivity, right-plunging 12,13 and left-plunging 11,12 diagonals. Some very strong polarization and REM responses are also attributed to the pond. The fact that all three data sets are affected in this way probably indicates the presence of polarizable clays in the pond or strong geometric effects from the large resistivity contrasts associated with this body of saline water.

The data show very little evidence of a low resistivity zone which is uniquely correlated with the producing field. This immediately suggests that well casings have a minimal effect on the data. Hence, it appears that the well-casing model of Figure 7.9 is strongly overmodeling the data. Perhaps strong corrosion on the casings has raised their surface impedances to a very high value, diminishing their impact on the data. Extremely high impedance values are required in modeling in order to force a match with the data, and these values are of questionable validity.

The lack of a well-defined resistivity anomaly on line 2 may be related to the fact that the line was run sub-parallel to major graben faulting. It is not unusual for such faulting to contaminate field data and render uninterpretable an otherwise well-defined anomaly. However, many of the bizarre effects normally seen when paralleling a fault are not seen on line 2, so this explanation is not entirely satisfactory. An alternative possibility is that the orientation of the line with respect to the long axis of the field may heavily bias the data with off-line effects.

APPARENT POLARIZATION (DECOUPLED PHASE ANGLE) DATA

Apparent polarization layering on line 2 is low-high-low. Playa-lake and upper Horse Camp deposits are associated with low polarization values, and middle Horse Camp sediments are moderately polarizable. The strongly polarized left-plunging 11,12 diagonal is probably related either to water-saturated clays or to geometric effects arising from the pond between stations 11 and 13.

A fairly well-defined zone of high polarization values has a good correlation to the lateral extent of the hydrocarbons. A worst-case well-casing model was run, adjusting the complex surface impedance of the casings in order to obtain a best fit to the data. The results, shown in Figure 7.10, show a very good correspondence to the pattern of the observed polarization anomaly. While there are problems in applying this modeling routine (see the discussion of line 1), the model results do raise doubts as to whether or not any inherent polarizable response is directly associated with the ground.

RESIDUAL ELECTROMAGNETIC (REM) DATA

The trends in the REM data generally follow those in the apparent resistivity data. The REM data show a strongly layered appearance on the north end of the line, indicating a high/low/high layering. Note that only the first two layers are seen in the apparent resistivity data; REM may be penetrating somewhat deeper, detailing the third, high resistivity layer at depth. Part of this effect, however, may be related to the contaminating effects of the sub-parallel graben fault on the north half of the line, or to off-line effects from the producing field. In addition to this effect, there appears to be a modest response over the field where the line crosses it. This response does not show increasing conductivity at depth, nor does it have a broad, well-defined shape typical of alteration due to hydrocarbons. Therefore, the anomaly is considered to be very weak.

Line 3 Interpretation

Line 3 parallels line 1, running in the same N 86° E direction. The data are presented in Plate 7.3.

APPARENT RESISTIVITY DATA

A high-over-low resistivity layering situation prevails across the entire line. As observed on the previous two lines, high resistivities are linked to playa-lake and upper Horse Camp sediments, and low resistivities are linked to the bulk of the Horse Camp at depth. Toward the far west end of the line, the upward-faulted volcanics and Paleozoic sediments are indicated by high resistivities.

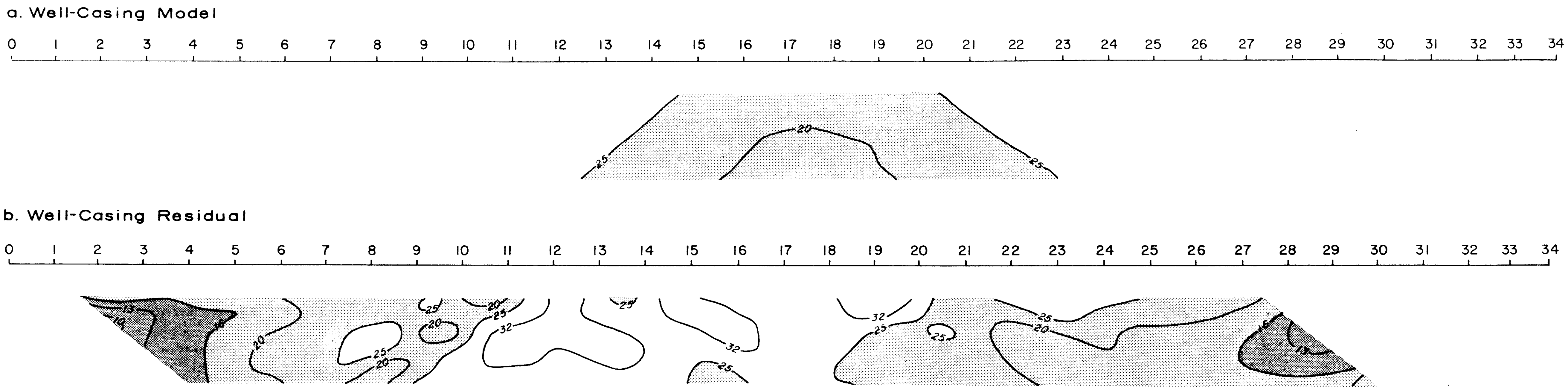


Figure 7.9. Well-casing model of apparent resistivity data for line 2, Trap Spring Field. Model parameters: 8 cased wells, casing diameter = 9-5/8 inches (24.5 cm), casing resistivity = 2.0 x 10^{-7} ohm-meters, surface impedance = 0 + 1.30i, background resistivity = 25 ohm-meters. Figure 7.3 shows well locations.

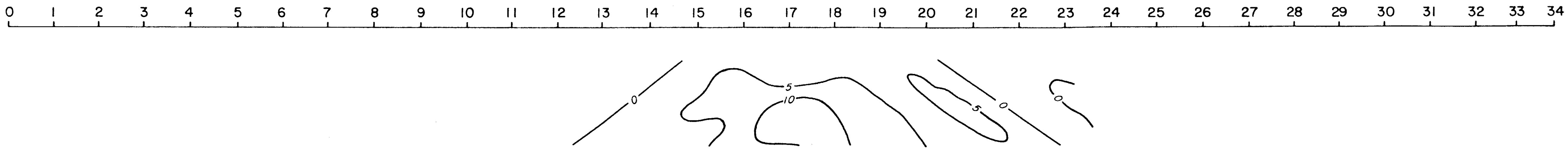


Figure 7.10. Well-casing model of apparent polarization data for line 2, Trap Spring Field. Model parameters: same as in Figure 7.9. Figure 7.3 shows well locations.

Superimposed on these effects is a fairly well-defined, low resistivity anomaly which correlates rather well with the lateral extent of the hydrocarbons. This is clearly the best anomaly on any of the three lines at Trap Spring. The anomaly appears to be fairly deep and does not seem to extend to the surface. It appears to be limited on its western edge by the high resistivity, right-plunging 4,5 and 5,6 diagonals, which result from a block of resistive material at the surface. The anomaly may actually extend a bit east and west of the actual limits of the field itself.

In an effort to determine the character of well-casing effects upon the data, a "PIPE" model was run. The results are presented in Figure 7.11. The greatest effect calculated by "PIPE" lies at depth between stations 11 and 14. While some of the trends in the modeled data resemble trends in the field data, the residual pseudosection clearly indicates that the data are being overmodeled.

A brief review of the results from lines 1 and 2 is very helpful here. Neither of these lines showed a definable apparent resistivity anomaly, indicating that well-casing effects on apparent resistivities are minimal, despite the fact that both lines have three cased wells within 0.3 to 0.7 a-spacings of the line. If all six of those wells failed to show a significant response, a similar result should be expected from the three wells near line 3, which lie at equivalent distances (0.5 to 0.8 a-spacings), and are expected to be the same size, depth, and age. More importantly, note that two of the wells on line 3 (near stations 11.2 and 12.6) are the same wells encountered on line 2. If these wells do not respond on line 2, it is highly improbable that they *do* respond on line 3! Hence, in order for the line 3 anomaly to be due primarily to well casings, it would have to be due only to the effects of the cased well near station

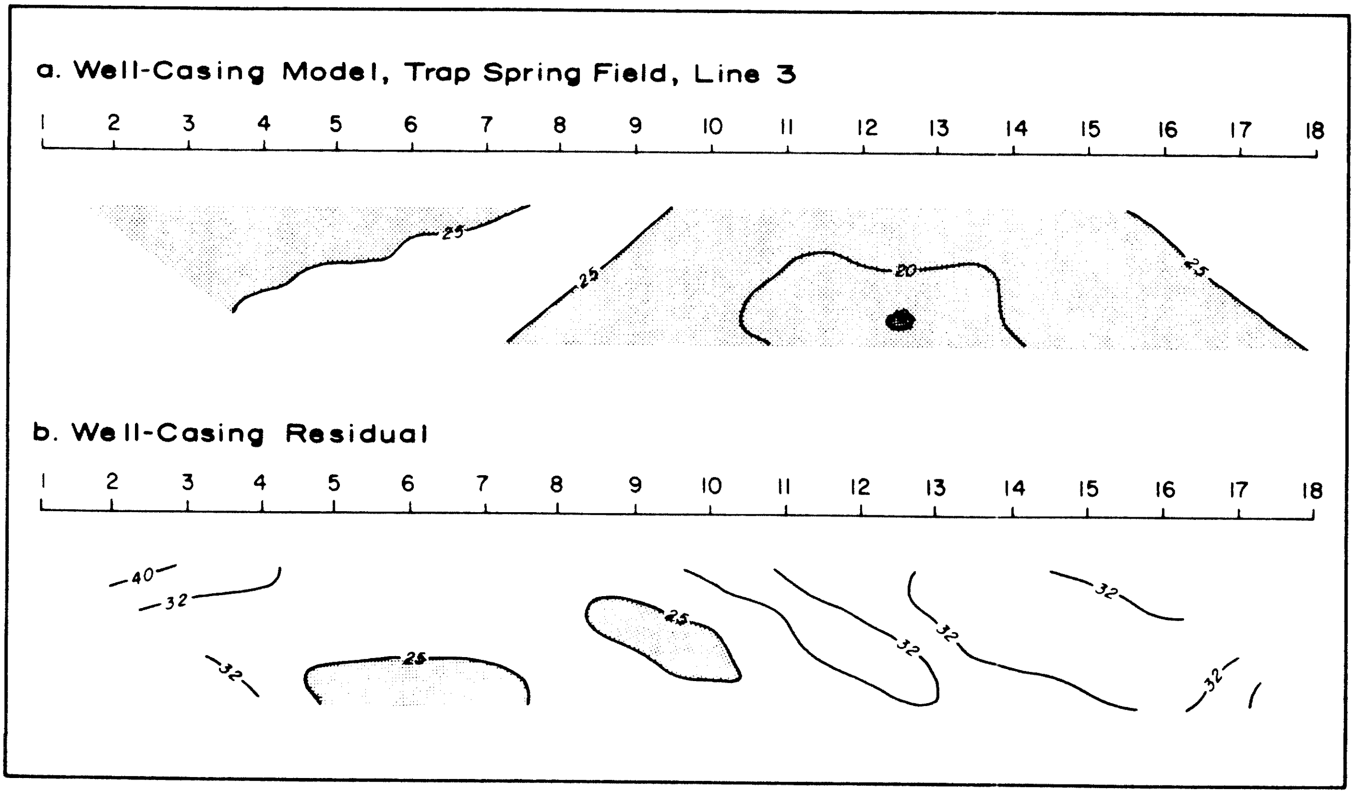


Figure 7.11. Well-casing model of apparent resistivity data for line 3, Trap Spring Field. Model parameters: 5 cased wells, casing diameter = 9-5/8 inches (24.5 cm), casing resistivity = 2.0 x 10^{-7} ohm-meters, surface impedance = 0 + 1.30i, background resistivity = 25 ohm-meters. Figure 7.3 shows well locations.

10.3. This is not only unlikely from a statistical point of view, but it also would fail to represent the data adequately, as shown by computer modeling. Hence, it is possible but highly unlikely that the observed anomaly on line 3 is influenced significantly by well casings.

No surface culture is found on line 3, and topography is virtually nonexistent, so these do not affect the interpretation. Subsurface geology might be suspected as a possible explanation for the anomaly, since the trends in the data are similar to the trends observed in the geologic cross-section (Figure 7.6) and on the structure map (Figure 7.5). A reasonable case for geologic influence on the data can be made in this instance, assuming that the Horse Camp Formation has strong electrical zoning which follows the structural trends of the volcanics. However, if this were the case, a considerable broadening of the conductive feature toward the west would be expected, as would strong conductive diagonal effects from the region in which the conductive layer meets the main graben fault near station 7. Since neither of these occur, it appears that there is a deep conductive zone directly above the producing field, possibly due to brine water discharge from the trap.

APPARENT POLARIZATION (DECOUPLED PHASE ANGLE) DATA

The polarization layering is the same as that observed on lines 1 and 2: playa-lake deposits have low polarization values associated with them, middle Horse Camp units have higher polarization values, and deeper units are again low in polarization. The phase angle pseudosection matches the known geology extremely well.

A very substantial zone of high polarization correlates very well with the lateral extent of the hydrocarbons. In an effort to determine the source of the anomaly, a worst-case well-casing model was run, changing the complex surface impedance value of the wells to obtain a best fit to the field data (Figure 7.12). Keeping in mind the restrictions of the model, it can be seen that there is some similarity between the model data and the field data, although the maximum anomaly calculated by the model is shifted with respect to the field data. However, considering the consistency of matches between field phase data and model data on all three lines, it is likely that most of the response observed on line 3 can be attributed to the combination of geologic layering and well-casing effects. This does not, however, rule out the possibility of a hydrocarbon-related polarization response on the line.

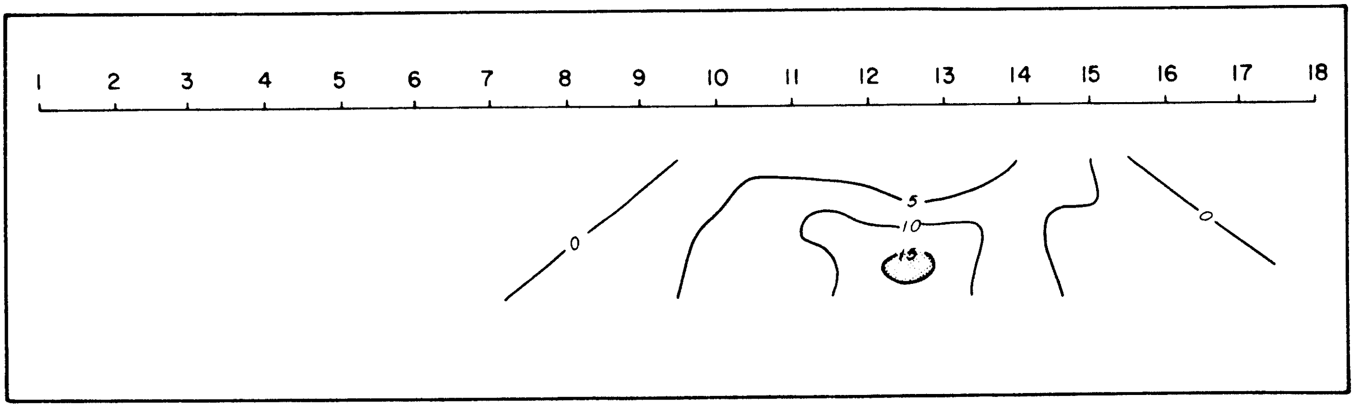


Figure 7.12. Well-casing model of apparent polarization data for line 3, Trap Spring Field. Model parameters: same as in Figure 7.11. Figure 7.3 shows well locations.

RESIDUAL ELECTROMAGNETIC (REM) DATA

As observed on the other two lines, REM partly reflects the high-over-low resistivity layering of the geology. Note, for example, the close correspondence of the REM data to the apparent resistivity data, with the exception that, once again, REM appears to be penetrating more deeply than resistivity.

The data show a very strong conductive anomaly which correlates quite well with the limits of oil production. Some of the overall effects at depth probably reflect some influence from the conductive layer there, but the sharply defined, vertical anomaly in the middle parts of the pseudosection cannot be readily explained by lithologic and structural features in the subsurface. If geology were the sole cause of the anomaly, a considerable broadening and "spilling over" of that feature might be expected toward the west. Since such an effect is not seen, the REM data indicate the existence of a conductive zone which lies above the hydrocarbon trap at depth. The strong correlation of the anomaly with the lateral extent of the hydrocarbons suggests that the two may be linked causally.

7.4
CONCLUSIONS

Review of the Data

The data from Trap Spring Field show rather variable results. Very weak to nonexistent conductive anomalies are correlated with the lateral extent of the hydrocarbons on lines 1 and 2, while a strong anomaly is observed on line 3, especially in the REM data. The inconsistency of the anomalies may be related to the fact that all three lines, to one degree or another, were run directly over and sub-parallel to significant subsurface faulting. This unfortunate situation occurred due to the lack of geologic information at the time the survey was designed. A look at the faulting pattern as it is currently known would suggest that the data from line 2 would be the worst affected, and that data from line 3 would be the least affected. Interestingly enough, line 2 shows the poorest correlation of anomalies with hydrocarbons while line 3 shows the best correlation. Hence, there is reason to believe that subsurface structure has contaminated the data to some degree on lines 1 and 2.

Well casings appear to have little or no influence on the apparent resistivity data at Trap Spring. Each line lies within the zone of influence of at least three cased oil wells, all of which are probably similar in terms of size, depth, and age. Further, two of the three wells near line 3 are the same ones near line 2. The fact that only line 3 shows an anomaly, while the other two lines do not, suggests that well casings do not cause the line 3 anomaly. In order to argue that well casings produce the anomaly, one would have to believe that only a single well—the one which is unique to line 3—has any effect upon any of the data. Since even worst-case computer modeling shows that the effects from this single well would not explain the anomaly, this is not considered a valid explanation.

The effects of subsurface structure are quite obvious in the data, and the apparent resistivity anomaly on line 3 is probably influenced to some degree by these effects. However, structural features cannot explain the presence of the well-bounded, lateral anomaly, nor its correlation with the lateral extent of the hydrocarbons. Instead, it is believed that the anomaly on line 3 represents a "deep anomaly" which is causally linked to the presence of hydrocarbons at depth.

All three lines show well-defined polarization anomalies which are strongest over the production zone. Well-casing models successfully reproduced the major trends in the field data, although not always in exactly the same portion of the pseudosection. In contrast to the resistivity/REM responses, it is possible that the combination of responses from polarizable layers and well casings account for much of the anomalous behavior observed in the apparent polarization data. Hence, any "shallow" polarizable anomalies which exist in the sediments above Trap Spring Field may be quite subtle, if they exist at all.

Some Speculations

The presence of a "deep anomaly" on line 3 and the apparent weakness or absence of a "shallow anomaly" on all three lines may provide some valuable evidence about the anomaly mechanism at Trap Spring. The "deep anomaly" is normally attributed to brine discharge from hydrocarbon traps. In this case, the low permeability of the weathered ash seal over the Oligocene volcanics, and indeed the highly impermeable nature of the welding in the volcanics themselves, seems to present an objection to this explanation. However, the high-angle graben faulting shown in Figure 7.6 may contribute the needed degree of permeability to leak reservoir waters into the overlying Horse Camp Formation. The strength of the anomaly on line 3 and the apparent absence of anomalies in the fault-complicated data from lines 1 and 2, may reflect the relatively high connate water resistivities in the trap; alternatively, it may indicate that the brine discharge occurs at a rather slow rate. A closely related explanation for the anomaly is that these waters influence the surface conduction and cation-exchange capacities of clays in the lower Horse Camp Formation.

In evaluating the apparent lack of a clear "shallow anomaly," it should be noted that Trap Spring is something of a geologic anomaly, in that no methane is dissolved in the oils (a situation which is repeated at Eagle Springs Field on the east side of the Railroad Valley). Whether the methane has already leaked out of the trap, was lost during primary migration, or has been degraded by bacterial action in the trap is not known, but the current lack of any dissolved gases may have a profound impact on both the character of associated electrical anomalies and on our understanding of electrochemical anomaly mechanisms. The absence of methane suggests that the "shallow anomaly" mechanism over the field would be effectively neutralized. With no methane present in the sediments, no hydrocarbon-clay interactions would be expected. Neither would the precipitation of pyrite be expected, since there are no methane molecules available to be reduced to hydrogen sulfide.

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