PART THREE

CASE HISTORIES

Chapter 3
Ryckman Creek and Whitney Canyon Fields Uinta County, Wyoming

3.1 INTRODUCTION

The Ryckman Creek and Whitney Canyon fields are located in the Western Wyoming Overthrust Belt, some ten miles (6 km) north of Evanston, Wyoming (Figure 3.1). Both fields occupy a prominent position in the hydrocarbon production of the Rocky Mountain states. Ryckman Creek, a prolific oil producer which has reserves of over 50 MMB of oil and over 150 BCF of gas, was the first substantial discovery in the Overthrust area. Whitney Canyon's estimated reserves of 3.1 TCF of gas place it firmly in the category of gas giant. These statistics, plus the extremely complex geology of the area, make the two fields an interesting target for electrical exploration.

Production at both Ryckman Creek and Whitney Canyon fields is from anticlinal traps on the hanging wall of the Absaroka Thrust Fault. As shown in Figure 3.2, the fields lie at the northern end of a roughly north-south trending line of oil and gas fields. This trend is directly controlled by the thrust faulting in the area.

A single line of resistivity/phase data was obtained over Ryckman Creek and Whitney Canyon, using a dipole spacing of 1,700 feet (520 m). The data were obtained on two separate occasions, during October, 1979, and August, 1980.

3.2 GEOLOGIC BACKGROUND

Exploration History of the Overthrust Belt

While oil springs in the Overthrust Belt were probably known by native Americans and trappers for some time, the first published account of the occurrence of oil is by Clayton (1848), who described the 1847 passage of the Mormons through Wyoming in their journey to Salt Lake City. Clayton noted the Hilliard oil spring in southern Uinta County, and commented:

> "When the oil can be obtained free from sand, it is useful to oil wagons. It gives a nice polish to gunstocks and has been proved to be highly beneficial when applied to sores on horses, cattle, etc."

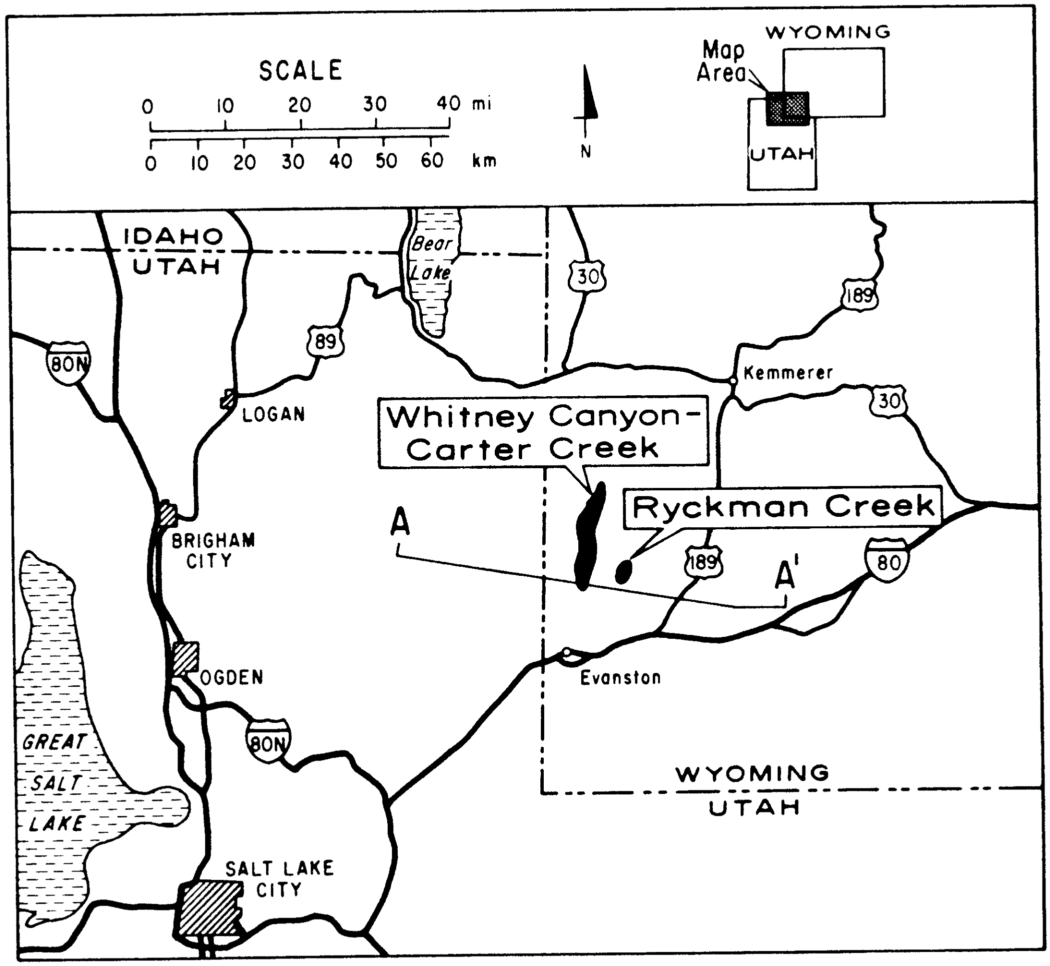


Figure 3.1. Location map of Ryckman Creek and Whitney Canyon-Carter Creek Fields.

A shallow well was drilled on the spring and the oil was sold locally to pioneers and settlers.

Oil springs like the one at Hilliard spurred a fair amount of interest in the area by small oil companies and individuals. The first significant drilling activity occurred in 1867 at the present-day Stove Creek Field and in 1868 at the nearby Carter Spring Field, both of which produced less than 20 barrels per day. Similar production was encountered at Twin Creek and Spring Valley in 1885, and at Fossil in 1902.

The discovery of the Labarge oil seep in 1907 generated a good deal of excitement in the area, but the first significant oil production in the Overthrust did not occur until 1924, when the Texas Production Company discovered Labarge Field. The discovery well was completed in Paleocene sands at 568 feet (173 m), and while the production rate of ten barrels per day was not very exciting by today's standards, the well nonetheless set off an oil boom in the general area. By 1928, some 85 new wells had been completed.

At the end of World War II, only Labarge and North Labarge Fields were producing, and for many years the combination of regionally low production, complex geology, high drilling costs, and lack of transportation outlets discouraged the major oil companies from entering the area. A turnaround in this situation began in

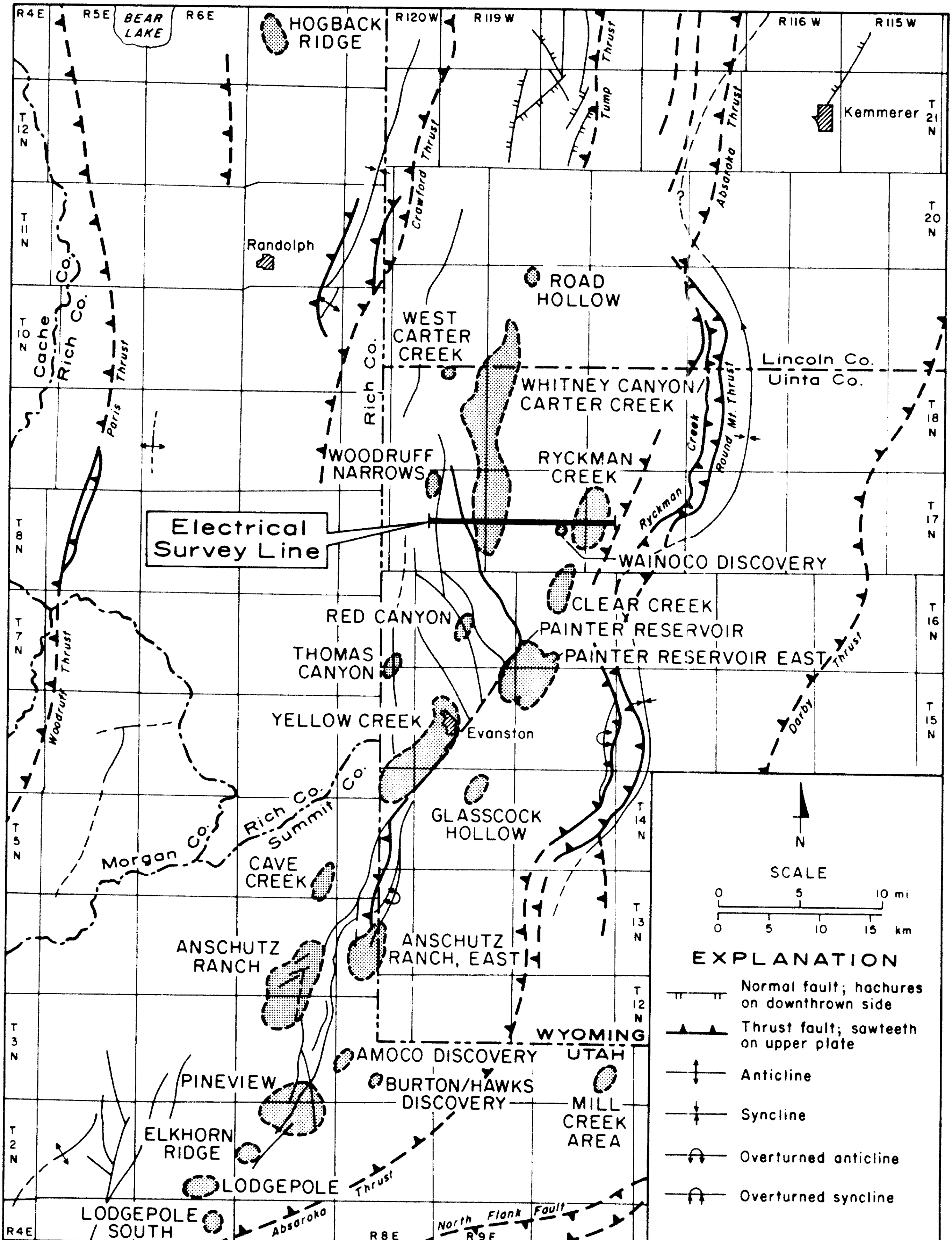


Figure 3.2. Utah-Wyoming Overthrust Belt fields and discoveries. Some information on these fields is provided in Table 3.1. Geology from Blackstone and VerPloeg (1981).

1949 with the entry of the first major into the area (Shell Oil Company), and with General Petroleum Corporation's discovery of oil at Tip Top in the North Labarge area in 1951. A number of exploration wells were drilled in the Overthrust during the next 25 years. Almost all of these were dry, but they served to help define the subsurface structure and to delineate potential reservoirs. A few were moderately successful: Willow Creek was discovered in 1957 and extended in 1974, and Mickelson Creek was discovered in 1960.

In 1975, the lackluster performance of Overthrust production came to a spectacular end with the American Quasar discovery at Pineview in Summit County, Utah. The discovery well, #1 Newton Sheep Co., established the first Overthrust production from the important Nugget Sandstone reservoir, flowing 550 BOPD and 270 MCFGPD between 9,928 and 9,936 feet (3,026 and 3,028 m). Later drilling established production in the Twin Creek, Stump, and Frontier formations as well.

It was at this time that congressional legislation passed over a century earlier came into play. In 1862 and 1864, Congress had granted the mineral rights to an extensive swath of land to the Union Pacific Railroad as an incentive to complete the western leg of the nation's first transcontinental railroad. As a result of this legislation, Union Pacific controlled every other square mile for 20 miles on each side of its track, with the federal government retaining the rights to the remaining sections. In 1969, prior to any significant Overthrust discoveries, Union Pacific granted exclusive exploration rights to Amoco Production Company for approximately 7.4 million gross acres (30,000 sq km), extending from northeastern Colorado to northeastern Utah and including much of the now productive Wyoming-Utah Overthrust area. Amoco was given access to odd-numbered sections, and Champlin Petroleum Company, a company Union Pacific had acquired in 1970, had access to the even-numbered sections. As a result of these events, Amoco and Champlin have played a dominant role in exploration and production in the Overthrust; Amoco alone owns an interest in 24 of the 26 producing fields in the Overthrust Belt. Farmouts and lease acquisitions account for the numerous secondary participants in the area.

In 1976, Amoco made a major discovery at Ryckman Creek on acreage obtained from Union Pacific. The discovery propelled the Overthrust region to the forefront of petroleum exploration in the United States. The discovery well, #1 Champlin-224-Amoco A, was drilled on a seismically-defined anticline by Amoco, Chevron, and Champlin Petroleum. After extensive testing for potential reservoirs, the well was completed in the Nugget sandstone, flowing an initial 288 BOPD from a 200-foot (60 m) oil column and 310 MCFGPD from a 300-foot (90 m) gas-condensate column. A second Nugget well was completed in March 1977, confirming the discovery, and production was extended to the Thaynes in December 1979 with the completion of a third well, 23 Ryckman Creek. Gas was noted in two zones of the Thaynes at 23 Ryckman Creek, and the well was dually completed in the Nugget and Thaynes. Subsequent development of Ryckman Creek has firmly established it as a major oil producer and as a respectable gas producer. Total reserves are estimated to be 150 billion cubic feet of gas and 50 million barrels of oil and condensate.

Since the Pineview and Ryckman Creek discoveries, development of Overthrust production has continued unabated. In March 1977, the discovery well was completed in the Twin Creek at Lodgepole Field, just eight miles southwest of Pineview. Production is currently from the Twin Creek and the Nugget.

Whitney Canyon was the next discovery. Several shallow dry holes had been drilled in the area in 1903 and 1945, but it was not until October 1976 that the area was committed to a deep test. The discovery well, #1 Amoco-Chevron-Gulf WI Unit, was originally projected to the Phosphoria at 13,400 feet (4,080 m) as a test of a subsurface seismic structure. However, a jammed core barrel and a break in the drill pipe due to high hydrogen sulfide gases prevented completion in the Phosphoria, and the hole was sealed off above that formation. The hole was then completed in the Thaynes in August 1977. Perforated between 9,178 and 9,266 feet (2,792-2,824 m), the well flowed gas at the rate of 4.7 MMCFGPD along with 196 bbls of condensate and 9 bbls of water. A second Whitney Canyon well, #2 Amoco-Chevron-Gulf WI Unit, was drilled in May 1977 some 1,900 feet (580 m) northeast of the discovery well. Initial production was from the Thaynes. An extensive testing program for other promising formations established production in the Bighorn, which had not yet been productive in the Overthrust. The Madison and Weber also proved to be good reservoirs in these tests. A third well, #1 Champlin-457 Amoco-A, was spudded in October 1977. It had shows or production in the Phosphoria, Weber, Thaynes, Frontier, Bighorn, Darby, and Mission Canyon.

In February 1978, Chevron spudded its #1-32 Chevron Federal well north of Whitney Canyon in Lincoln County. Gas was produced in the Madison and Weber, opening up Carter Creek Field. Amoco then redrilled #1 Kewanee-Federal, which had been abandoned by Chevron at 8,550 feet (2,606 m) in 1976, and found production in the Bighorn. Located between Whitney Canyon and Carter Creek, this well unitized the two fields to a single, north-south oriented gas field.

Table 3.1 lists the major Overthrust discoveries of the past seven years. Many of these fields have enormous potential reserves, and the prospect for future discoveries is quite bright.

TABLE 3.1: OIL AND GAS FIELDS OF THE OVERTHRUST BELT[1]

Field	Location	Operator	Discovery Well Completion Date	Production[2]	Producing Formations
Pineview	Summit Co., Ut.	American Quasar	1/75	O,G	Frontier Stump Twin Creek Nugget
Ryckman Creek	**Uinta Co., Wyo.**	**Amoco Prod.**	**9/76**	**O,G**	**Nugget** **Thaynes**
Yellow Creek	Uinta Co., Wyo.	Amoco Prod.	7/76	G,C	Twin Creek Phosphoria
Lodgepole	Summit Co., Ut.	American Quasar	3/77	O,G	Twin Creek
Whitney Canyon	**Uinta Co., Wyo.**	**Amoco Prod.**	**8/77**	**G,C**	**Thaynes** **Phosphoria** **Weber** **Mission Canyon** **Lodgepole** **Darby** **Bighorn**
Elkhorn Ridge	Summit Co., Ut.	American Quasar	9/77	O,G	Twin Creek
Painter Reservoir	Uinta Co., Wyo.	Chevron USA	10/77	O,G	Nugget
Hogback Ridge	Rich Co., Ut.	American Quasar	10/77	G	Dinwoody Phosphoria
Anschutz Ranch	Summit Co., Ut.	Anschutz Corp.	10/78	G,C	Twin Creek Nugget
Clear Creek	Uinta Co., Wyo.	Chevron USA	6/78	O,G	Nugget
Lodgepole South	Summit Co., Ut.	Colorado Energetics	9/78	G	Kelvin
Carter Creek	Uinta Co., Wyo.	Chevron USA	7/79	G,C	Weber Madison
East Painter Reservoir	Uinta Co., Wyo.	Chevron USA	8/79	G,C	Nugget

TABLE 3.1 Continued

Field	Location	Operator	Discovery Well Completion Date	Production[2]	Producing Formations
Cave Creek	Uinta Co., Wyo.	Amoco Prod.	10/79	G,C	Weber Madison Phosphoria
Red Canyon	Uinta Co., Wyo.	Amoco Prod.	12/79	G,C	Weber
Anschutz Ranch East	Summit Co., Ut.	Amoco Prod.	12/79	O,G	Nugget
Two Medicine Creek	Glacier Co., Mont.	Rainbow Resources	1/80	O	Sun River
Mill Creek	Summit Co., Ut.	Exxon	7/80	O	Three Forks Darby
Glasscock Hollow	Uinta Co., Wyo.	Amoco Prod.	9/80	G,C	Nugget
[SE-SW-8-T29N-R114W]	Sublette Co., Wyo.	American Quasar	10/80	G	"Mississippian" Bighorn
Blackleaf Canyon	Teton Co., Mont.	Rainbow Resources	12/80	G	Sun River
Woodruff Narrows	**Uinta Co., Wyo.**	**Chevron USA**	**4/81**	**G,C**	**Bighorn**
Thomas Canyon[3]	Uinta Co., Wyo.	Chevron USA	7/81	G	Madison
[NW-NW-28-T3N-R8E]	Summit Co., Ut.	Burton/Hawks	mid '81	O	Kelvin Stump
[NW-SE-19-T3N-R8E][4]	Summit Co., Ut.	Amoco Prod.	mid '81	G	Preuss
Road Hollow	Lincoln Co., Wyo.	Exxon	10/81	G	Bighorn
[NW-SE-23-T17N-R119W]	**Uinta Co., Wyo.**	**Wainoco**	**early '82**	**O,G**	**Ankareh**
West Carter Creek[5]	Uinta Co., Wyo.	Amoco Prod.	11/82	G,C	Bighorn Madison

[1]Updated to 12/31/82; includes significant discoveries
[2]O=oil, G=gas, C=condensate
[3]Abandoned due to high hydrogen sulfide content
[4]Temporarily abandoned due to high water production
[5]Preliminary designation

Particularly germane to the discussion of the Ryckman Creek/Whitney Canyon electrical data are the recent discoveries at Woodruff Narrows (also called Woodruff Mountain Field) and the unnamed discovery by Wainoco at NW-SE-23-T17N-R119W. The Woodruff Narrows discovery well, #1-4H Amoco-Federal, was completed in the spring of 1981 as the deepest producer in the Overthrust Belt. The well flowed 2.8 MMCFGPD and 15 BPD of condensate from the Bighorn at 16,736-16,780 feet (5,101-5,115 m). Note that this well is 2.4 miles (3.9 km) north of the western end of the electrical survey line. The data there show a very strong anomaly, as will be discussed later. To date no deep wells have yet been drilled south of Woodruff Narrows; Chevron spudded its #1-16H Chevron-State well, SE-SW-16-T17N-R120W, on April 24, 1982, but the well was abandoned after reaching a total depth of only 3,215 feet (980 m). Amoco is currently drilling its #1 Champlin-804 Amoco-C in SE-NW-9-T17N-R120W, but this site is still two miles (3 km) north of the survey line.

The Wainoco discovery is located just west of Ryckman Creek, approximately half a mile (1 km) south of station 10 on the electrical survey line. The discovery well, B-1 Amoco-Champlin 370, flowed 230 BOPD and 840 MCFGPD from the Triassic Ankareh Formation between 12,418 and 12,602 feet (3,785-3,841 m). Production is from a structural unit separate from that of the Ryckman Creek Field. A second well, Chevron #1-14E, was drilled and abandoned one mile (1.6 km) north of the Wainoco discovery well, or 2,000 feet (610 m) north of the survey line. Total depth was 12,800 feet (3,900 m) in the Ankareh.

Geologic History of the Wyoming Overthrust Belt

Although a complete description of Overthrust geologic history cannot be reasonably presented here, a brief outline is offered for purposes of general understanding. A number of interesting papers on this subject are published or referenced in the 1977 Wyoming Geologic Association's Guidebook.

As described by Peterson (1977), Blackstone (1977), Rose (1977), and others, western Wyoming was the location of the western margin of the North American craton during Precambrian time. West of the craton there existed a miogeosynclinal depositional shelf, in which several depositional troughs were located (Figure 3.3). These troughs were formed as a result of rifting some 850 million years ago, and they show a remarkable similarity in shape to the modern-day Thrust Belt of the western United States.

During Precambrian time, western Wyoming received clastic deposition from erosion of the craton to the east. Erosion came to an end during the early Cambrian, when a prolonged era of subsidence brought a sequence of marine and littoral rocks. Deposition continued throughout the Paleozoic except for an erosional episode during the Silurian. Devonian and Mississippian sedimentation involved mostly deep marine carbonates, changing to shallower environments during the Pennsylvanian and the Permian. Post-Devonian deposition was significantly affected by the Antler Orogeny to the west. By the end of the Paleozoic, some 35,000 feet (10,670 m) of sediments had been deposited in the area.

Early Triassic sedimentation consisted primarily of clastics. Deposition was minimal during the middle Triassic. The Sevier Orogeny in northeastern Nevada and northwest Utah elevated most of present-day Idaho during Jurassic time, disrupting the sedimentation pattern established in the Cambrian. The western Overthrust area received no Jurassic sediments, and coarse clastics were deposited toward the east.

The major thrust faulting of western Wyoming began in early Cretaceous time. The mechanism for this activity is not fully understood. Two hypotheses exist, one that the upper plate was shoved over the lower one, and the other that the lower plate slid underneath the upper one due to gravitational forces. Rubey and Hubert (1959) suggested that abnormal fluid pressures may have had a major contribution to the overthrusting activity. Tectonic activity continues today, as judged by seismicity in the area.

Current Geology

Table 3.2 summarizes the stratigraphy of the Ryckman Creek/Whitney Canyon area. Several thousand feet of Tertiary sediments overlie the overthrust strata, as shown in the generalized cross-section A-A' of Figure 3.4. Detailed cross-sections of Ryckman Creek and Whitney Canyon are shown in Figures 3.5 and 3.6, respectively. The electrical line location with respect to these fields is shown in Figure 3.7. Figure 3.8 is a structure map of Ryckman Creek, contoured on the top of the Nugget Sandstone; Figure 3.9 is a structure map of Whitney Canyon, contoured on top of the Mission Canyon Formation.

Reservoir Geology

Reservoir data on Ryckman Creek and Whitney Canyon fields are presented in Tables 3.3 and 3.4, respectively.

The structure at Ryckman Creek is an asymmetric, overturned, north-south trending anticline on the hanging wall of the Absaroka Thrust Plate (Figure 3.4). The structure has some 1,500 feet (460 m) of closure. A total hydrocarbon column of 515 feet (157 m) is found in the prolific Nugget Sandstone, including a 215 foot (66 m) column of oil and a 300 foot (90 m) gas cap. The Nugget is some 800 feet (240 m) thick at Ryckman Creek. It consists of a massive, cross-bedded, cross-laminated, white to red-brown, porous, quartzose sandstone with well rounded, well

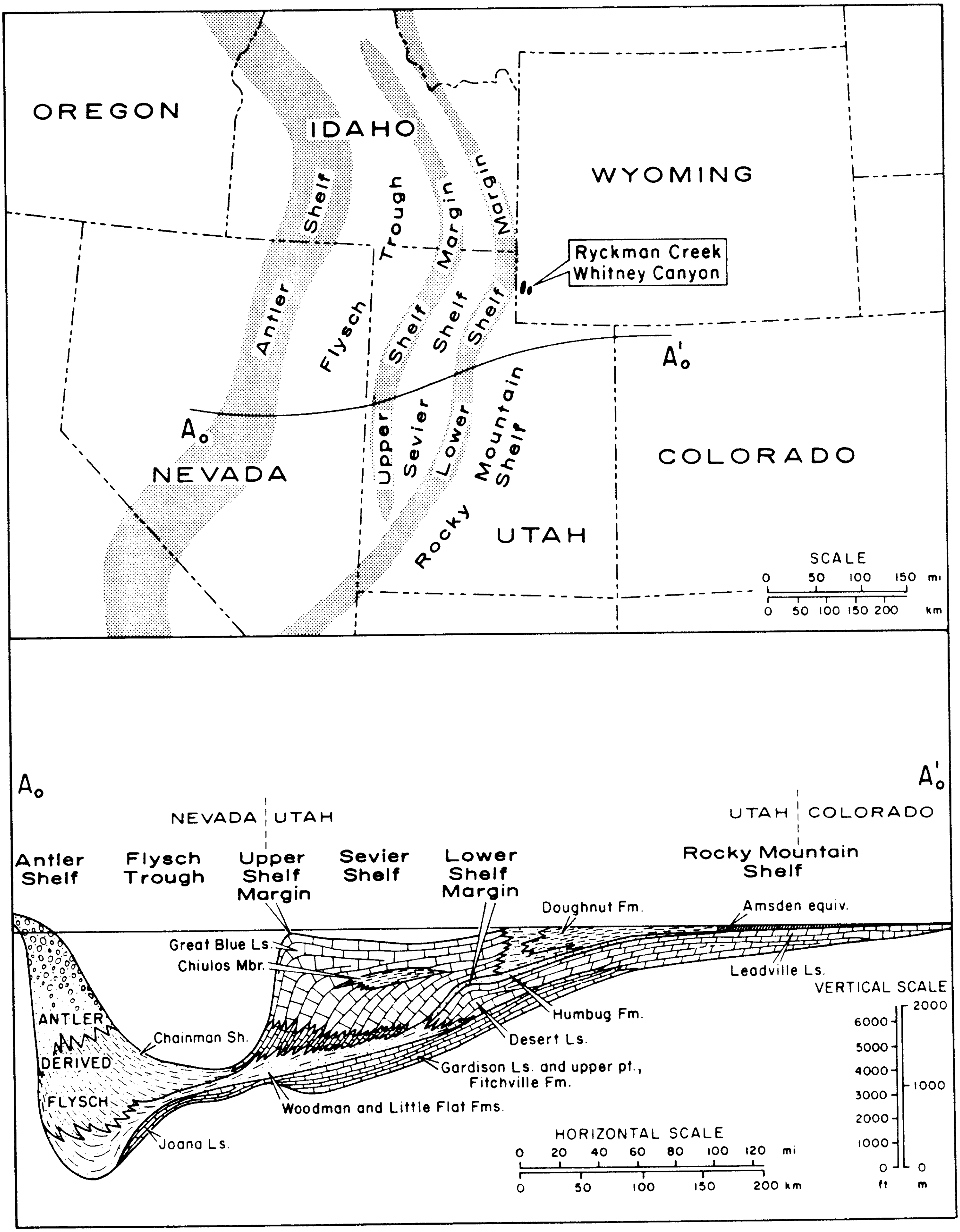


Figure 3.3. Paleozoic depositional environment in the west-central United States. From Rose (1977).

TABLE 3.2: STRATIGRAPHIC DESCRIPTION OF RYCKMAN CREEK AND WHITNEY CANYON FIELDS

System	Symbol	Formation	Lithologic Description
CENOZOIC ROCKS			
Tertiary			
Eocene	–	Wasatch-Green River Fms. (undifferentiated)	Shales and sandy shales with a basal conglomerate
		(unconformity) ----------	
Paleocene	Te	Evanston Fm.	
		upper part	Shale
MESOZOIC ROCKS			
Cretaceous		conglomerate	Conglomerate
		lower part	Silty shale
	Ka	Aspen Sh.	Sandy shale
	Kbr	Bear River Fm.	Shales with a basal sandstone
		(unconformity) ----------	
	KJg	Gannett Group	Interbedded shales and sandy shales with a basal unit of fossils and conglomerates
		(unconformity) ----------	
Jurassic	Jst	Stump Ss.	Calcareous sandstones, shales, and sandy limestones
	Jp	Preuss Ss.	Shale
	Jtc	Twin Creek Fm.	Interbedded limestones, conglomeratic limestones, and shales
		(unconformity) ----------	
Triassic	TRn	Nugget Ss.	Fine to medium grained, well rounded, well sorted, quartzose sandstone with 5-10% feldspar; *hosts oil and gas at Ryckman Creek*
	TRa	Ankareh Sh.	Sandy shale with middle conglomeratic unit; *hosts oil at the Wainoco discovery well, NW-SE-23-T17N-R119W*
	TRt	Thaynes Ls.	Limestone with dolomitic and shale sections; *hosts gas at Ryckman Creek and at the fractured southern portion of Whitney Canyon*
	TRws	Woodside Sh.	Sandy shale
	TRd	Dinwoody Fm.	Sandy shale; *hosts non-commercial gas at Whitney Canyon*
PALEOZOIC ROCKS			
Permian	Pp	Phosphoria Fm.	Interbedded shales and fossiliferous limestones; *hosts sour gas at Whitney Canyon*
Pennsylvanian	IPw	Weber Ss.	Sandstone with minor siltstone, shale, and carbonate beds; *hosts gas at Whitney Canyon*
	IPm	Morgan Fm. (Amsden Fm.)	Interbedded sandstones, shales, and dolomites
Mississippian	Mmc	Mission Canyon Fm. (Madison Ls.)	
		Upper unit	Limy dolomites and dolomites with nodular anhydrite
		Middle unit	Limy dolomite, bioclastic; *hosts extensive gas at Whitney Canyon*
		Lower unit	Shaly micritic limestones and dolomite limestones
	Ml	Lodgepole	Dolomitic limestones and limy dolomites; *hosts gas at Whitney Canyon*

TABLE 3.2 Continued

System	Symbol	Formation	Lithologic Description
		(unconformity)	
Devonian	Dd	Darby Fm.	Carbonates, anhydrites, siltstones, and shales; *hosts gas in the highest portion of the Whitney Canyon structure*
		(unconformity)	
Ordovician	Obh	Bighorn Dol.	Limy dolomite with minor shale beds; *hosts gas at Whitney Canyon and Woodruff Narrows*
Cambrian	€g	Gallatin Ls.	Limestone

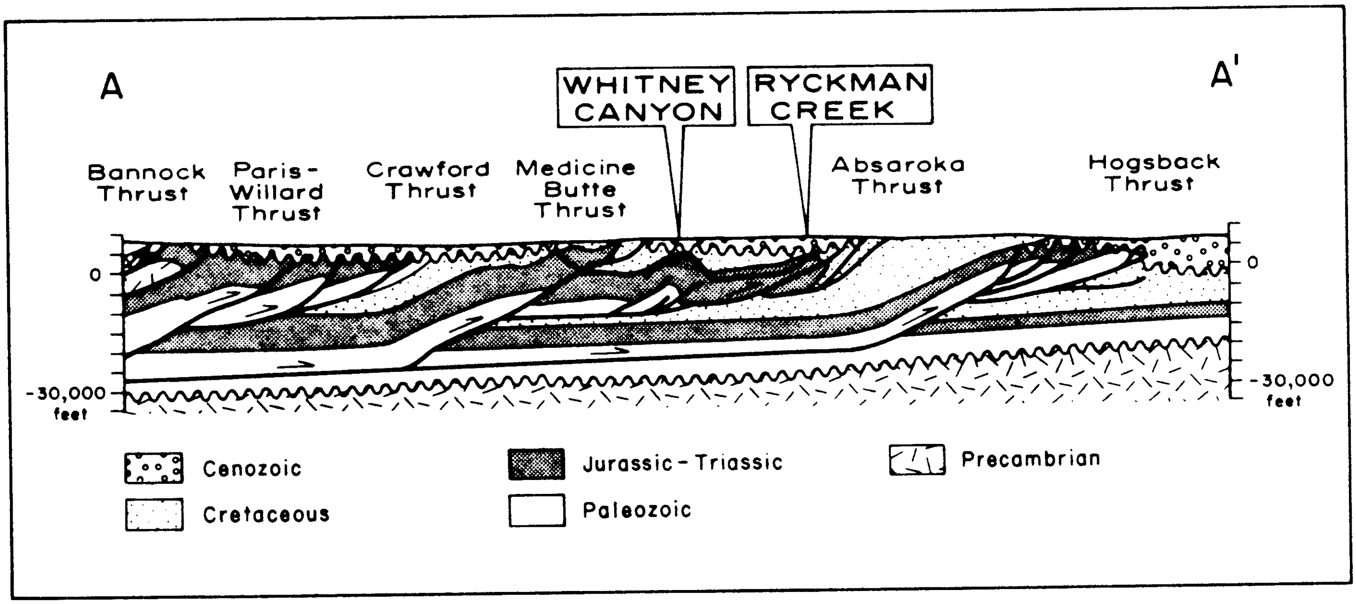


Figure 3.4. Generalized geologic cross-section A-A' across the Utah-Wyoming Overthrust Belt, with no vertical scale exaggeration. Figure 3.1 shows the map location. After Dixon (1982).

sorted, fine grains. Porosity is quite high throughout the unit at the discovery well; permeability is anisotropic, being highest in a vertical direction. Oils are paraffinic, high in gravity, and low in sulfur; gas is similarly low in sulfur.

Ryckman Creek has an active water drive. At present, only oil is produced. Stripped natural gas has been re-injected back into the gas cap since 1977 in order to maintain reservoir pressure, supplemented by nitrogen injection beginning in 1981. Total oil production varies from 100 to 1,200 BOPD per well. Low-sulfur gas and condensate are also obtained from the Thaynes, which has primarily fracture porosity.

The Whitney Canyon-Carter Creek complex, now considered a gas giant, produces gas and condensate from eight pay zones in a large, north-south trending anticline on the hanging wall of the Absaroka Thrust Plate. The Whitney Canyon-Carter Creek structure is about 4x15 miles (6x24 km) in size and has some 4,500 feet (1,400 m) of closure.

Some 70 to 80 percent of the field's reserves are found in the Mission Canyon Formation, a regressive carbonate and evaporite sequence. As indicated in

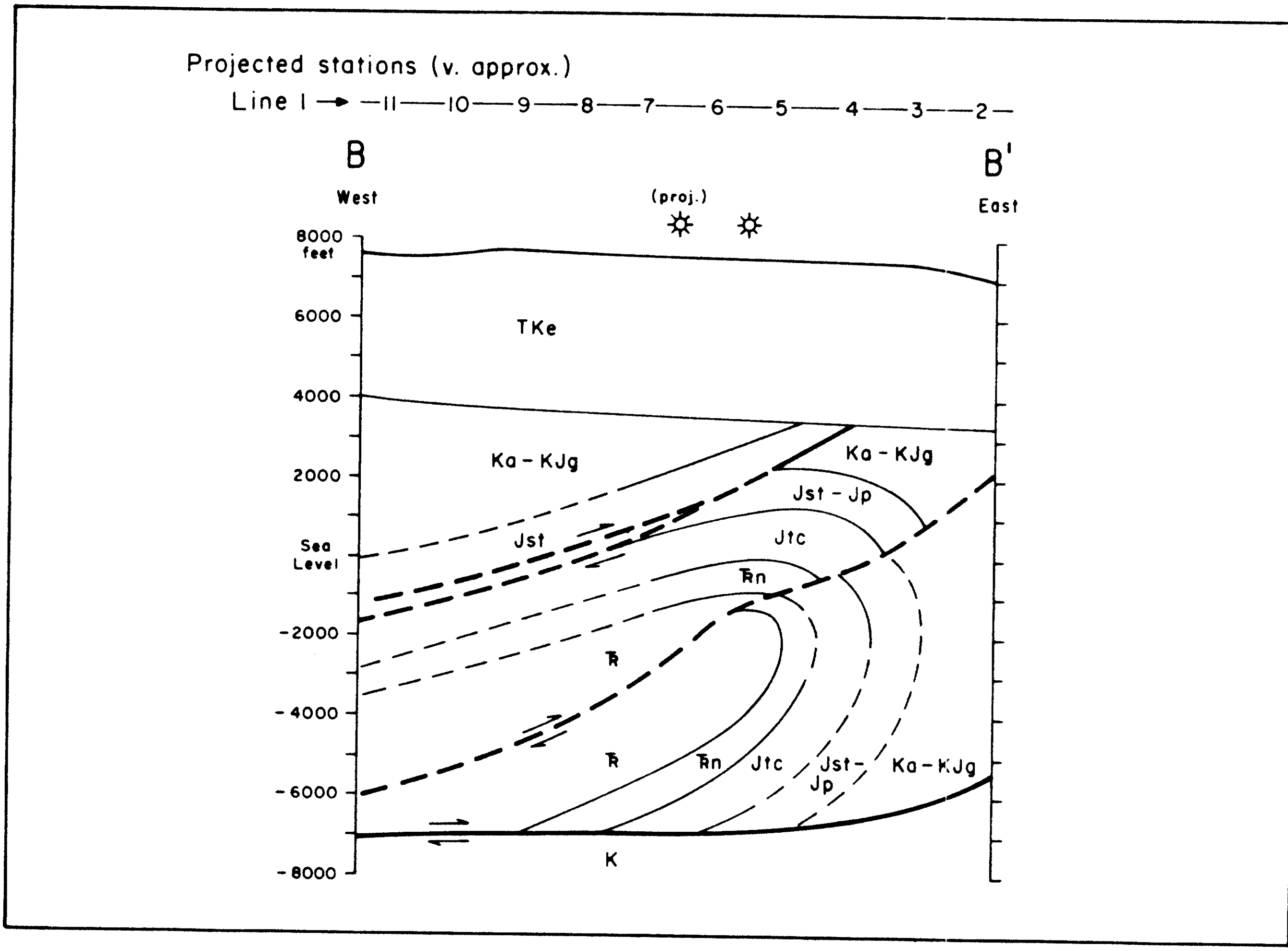


Figure 3.5. Geologic cross-section B-B' across Ryckman Creek Field, with no vertical scale exaggeration. Refer to Figure 3.7 for map location. Geology from Kelly and Hine (1977).

the stratigraphic description of Table 3.2, the producing zone is a bioclastic limy dolomite which was deposited in a high-energy shoreline environment. Porosity is primarily matrix type, with some fracturing enhancement. Gas is high in sulfur.

Other commercial producing formations at Whitney Canyon are the Thaynes, Phosphoria, Weber, Lodgepole, Darby, and the Bighorn. The carbonates and shales of the Thaynes have both matrix and porosity permeability. Production is from interbedded dolomites; as of 1981, production had only been established in the more fractured southern flank of the Whitney Canyon anticline. The Thaynes hosts the only sulfur-free gas in the field. The Phosphoria shales and limestones host an undetermined amount of sour gas, which Hoffman and Kelly (1981) call non-commercial. The Weber shows matrix and fracture porosity, and the gas has a very high hydrogen sulfide content. The Lodgepole Formation, a transgressive sequence of limy dolomites and dolomitic limestones, has primarily matrix porosity with some fracture porosity evident. Production may prove to be favorable across the full area of the field. Gas is high in hydrogen sulfide. The Darby production is from a limy dolomite zone near the top of the formation. Since the top of the Darby is substantially eroded toward the north end of Whitney Canyon, production is limited

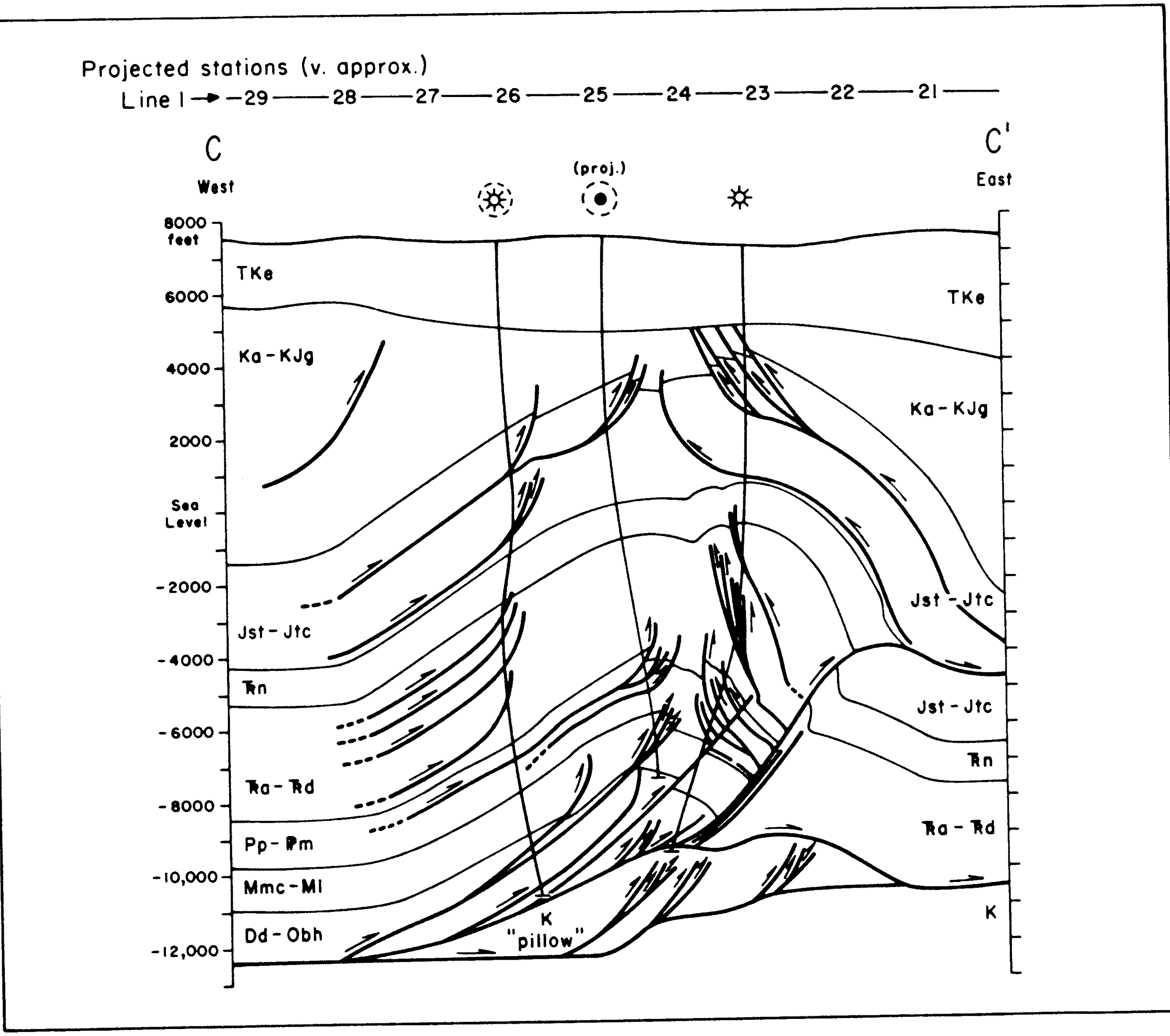


Figure 3.6. Geologic cross-section C-C' across Whitney Canyon Field, with no vertical scale exaggeration. Refer to Figure 3.7 for map location. Geology from Hoffman and Kelly (1981).

to the highest portion of the Whitney Canyon structure, and the Darby is therefore not expected to be a major reservoir. Porosity in the Darby is due to fracturing, and gas is fairly low in hydrogen sulfide (1.0%). The Bighorn Dolomite produces gas from two zones of fracture type porosity, located at the top of the formation. Gas is relatively low in hydrogen sulfide (0.63%).

The source of the hydrocarbons at Whitney Canyon has been determined by chromatography to be the subthrust Cretaceous strata. Hence, primary migration can be dated as post-Cretaceous.

Due to the high hydrogen sulfide content of the gas, most of the wells which had been drilled at the time of the electrical survey had been shut in pending completion of a gas-sweetening plant, which was begun in 1980 and came on line in October 1982. The $340 million plant has now reached its total capacity of 12,600 barrels per day of natural gas liquids and 6,000 barrels per day of condensate. The

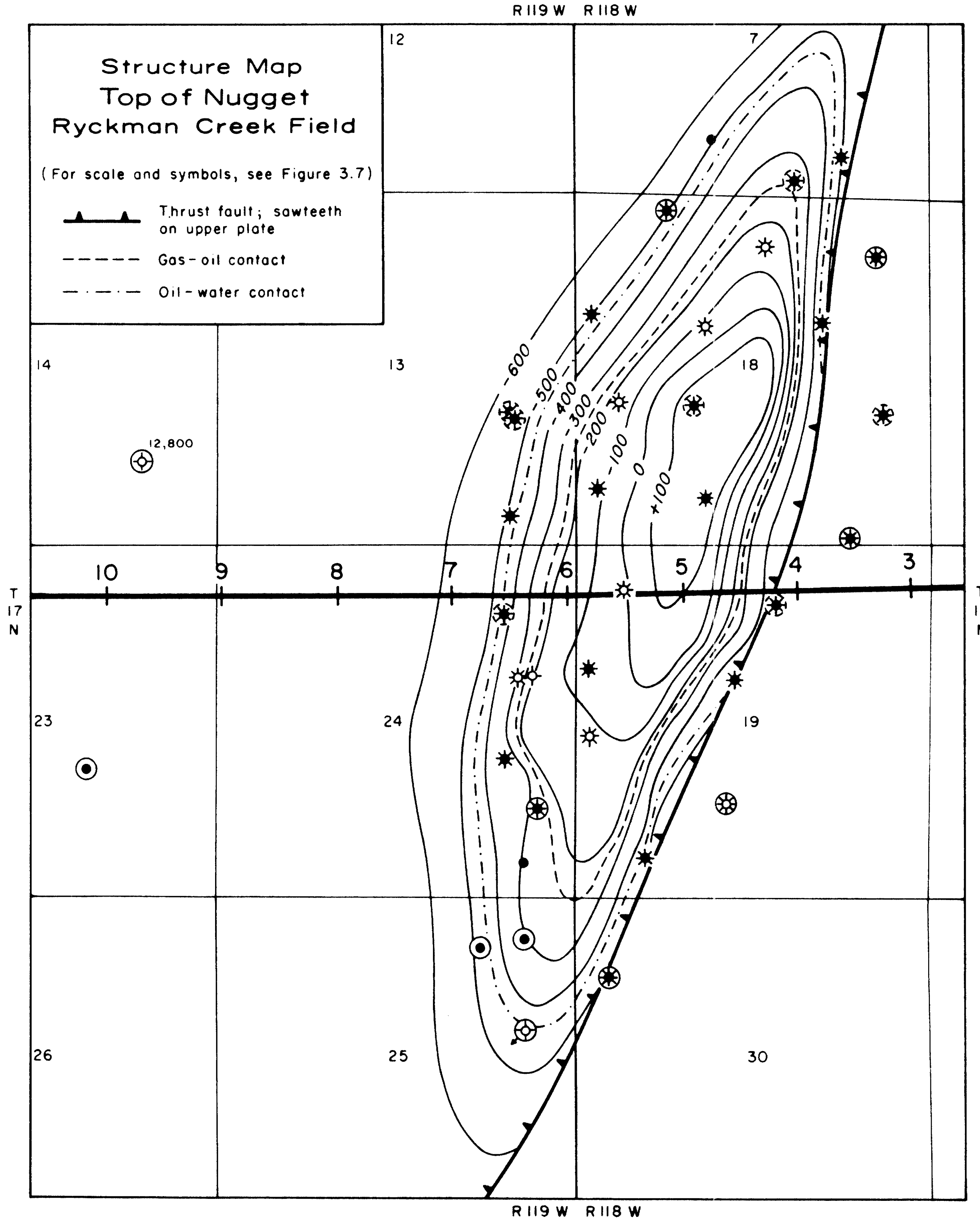


Figure 3.8. Structural map of Ryckman Creek Field, contoured on top of the Nugget Sandstone. Contour interval: 100 feet (30 m). Geology from *The Overthrust Belt, 1981 (Petroleum Information).*

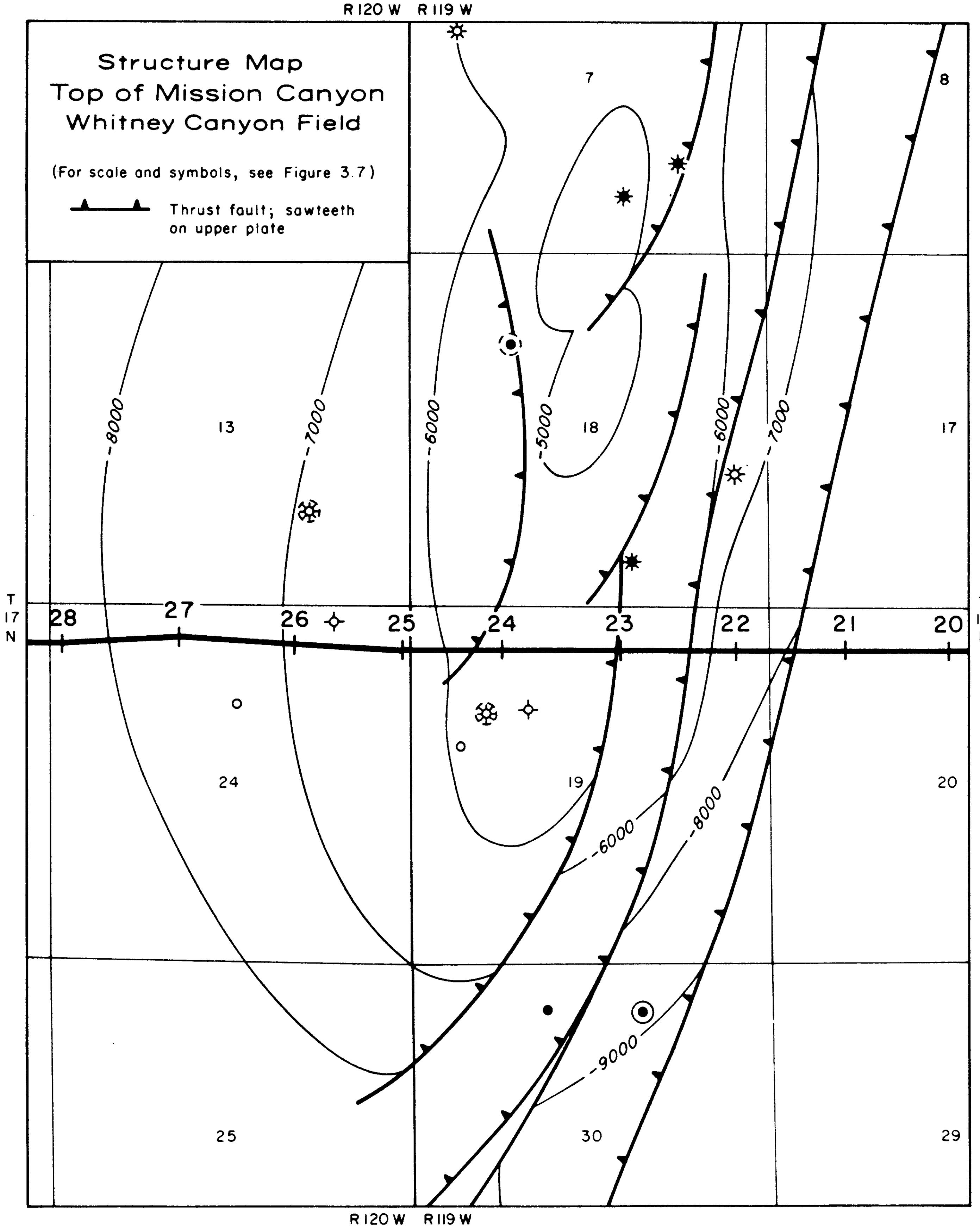


Figure 3.9. Structural map of Whitney Canyon Field, contoured on top of the Mission Canyon Formation. Contour interval: 1,000 feet (305 m). Geology from Hoffman and Kelly (1981).

Figure 3.7
LINE LOCATION MAP
Ryckman Creek and Whitney Canyon Fields
Uinta Co., Wyoming

SCALE 1:24000

Sources
Base: U.S.G.S. 7.5' Quad (Little Dee Creek, Wyo., 1965, photorevised 1978; Three Forks, Wyo., 1965, photorevised 1978)
Well Data: Petroleum Information Lease-Ownership (W-189, W-190; record take-offs 9-11/82)

Explanation of Symbols

Standard Well Symbols

- Drillhole for which information is unobtainable
- Drilling in progress at time of map preparation
- Shut in
- Abandoned
- Dry hole with total depth indicated
- Oil well
- Gas well
- Oil and gas well
- Gas injection well
- Water injection well
- Water well

Culture Symbols

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

Special Well Symbols

- 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
- 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: 100 feet

Zonge Engineering & Research Organization, Inc.

TABLE 3.3: RESERVOIR CHARACTERISTICS OF RYCKMAN CREEK FIELD

General Field Data

Region: Western Wyoming Overthrust Belt
Production: Oil, gas
Type of Trap: Structural; thrust-faulted anticline
Producing Formations and Depths: Nugget Ss., 7,800 ft
Thaynes Ls., 9,800 ft
Other Significant Shows: None
Total Reserves: 150 BCFG, 50 MMBO
Productive Area: 1,000 acres
Field Operator: Amoco
Number of Producing Wells (10/79): 18
Number of Shut-in Wells (10/79): 0
Number of Dry or Abandoned Wells (10/79): 1
Well Casing Data: 13-3/8 inch at 1,962 ft, 9-5/8 inch at 8,422 ft (discovery well)

Discovery Well

Name: 1 Ryckman Creek WI Unit
Location: NW-NW-19-T17N-R118W
Completion Date: 9/22/76
Total Depth: 14,795 ft
Perforations: 7,804-7,808 ft, 7,860-7880 ft (Nugget)
Initial Potential: 310 MCFGPD, 288 BOPD
Treatment: Breakdown perforations with KCl water; acidize with 500 gals of 15% HCl

Reservoir Data: Nugget Sandstone

Discovery: 9/22/76, 1 Ryckman Creek WI Unit, NW-NW-19-T17N-R118W
Lithology: Quartzose sandstone
Age: Triassic/Jurassic
Type of Trap: Structural; thrust-faulted anticline
Drive Mechanism: Active water drive
Initial Pressure: BHP 2,900 psi at gas/oil contact in discovery well
Recent Pressure (12/78): BHP, 2,881 psi at gas/oil contact in discovery well
Reservoir Temperature: 140°F at gas/oil contact in discovery well
Gross Thickness of Reservoir Rock: 815 ft
Porosity: 15% average
Permeability: Average 76 millidarcies, range 1.5-945 millidarcies. Primarily matrix porosity and permeability, relatively constant across the field, minor fracture porosity.
Oil/Gas Column: Maximum of 515 ft: 215 ft oil column, 300 ft gas cap
Gas/Oil Ratio: 1,108:1 on the discovery IP
Original Gas/Oil Contact: −235 ft true vertical depth
Original Oil/Water Contact: −450 ft true vertical depth
Gas Character: 1,239 BTU/cu ft

Gas Analysis:	Methane	77.86%
	Ethane	11.27
	Propane	5.25
	Iso-Butane	1.11
	n-Butane	0.33
	iso-Pentane	0.25
	Hexanes	0.19
	Heptanes +	0.21
	Nitrogen	2.31
	Carbon dioxide	0.05
	Hydrogen sulfide	nil

Oil Character: Low sulfur, paraffin base crude; gravity 47.4°API; pour point 30°F

Oil Analysis:	Sulfur (wt %)	0.026%
	Hydrogen sulfide	nil

TABLE 3.3 Continued

Water Saturation: 21%
Water Salinity: 12,800 ppm NaCl
Cumulative Production (9/76-12/78): 1,558,669 BO; 2,338 BCFG
Estimated Primary Recovery: Not reported
Type of Secondary Recovery: Not reported
Estimated Ultimate Recovery: 40-50 MMBO; 100-150 BCFG

Reservoir Data: Thaynes Limestone

Discovery: 12/79, 23 Ryckman Creek, NE-NE-24-T17N-R119W
Lithology: Carbonates and shales
Age: Triassic
Type of Trap: Structural; thrust-faulted anticline
Reservoir Temperature: 155°F (est.)
Gross Thickness of Reservoir Rock: 1,100 ft
Porosity: Not reported
Permeability: Natural fractures
Oil/Gas Column: Not reported
Gas/Oil Ratio: 26,000:1
Gas Character: 1,239 BTU/cu ft

Gas Analysis:	Methane	78.80%
	Ethane	10.20
	Propane	5.20
	iso-Butane	1.10
	n-Butane	0.30
	iso-Pentane	0.20
	Hexanes	0.20
	Heptanes +	0.20
	Nitrogen	2.30
	Carbon dioxide	0.05
	Hydrogen sulfide	nil

Condensate Character: Low sulfur; gravity 47.4°API; pour point 30°F

Condensate Analysis:	Sulfur	0.026%
	Hydrogen sulfide	nil

Estimated Primary Recovery: Not reported
Type of Secondary Recovery: Not reported
Estimated Ultimate Recovery: Not reported

TABLE 3.4: RESERVOIR CHARACTERISTICS OF WHITNEY CANYON FIELD

General Field Data

Region: Western Wyoming Overthrust Belt
Production: Gas, oil
Type of Trap: Structural; thrust-faulted anticline

Producing Formations and Depths:	Thaynes Ls., 9,200 ft
	Phosphoria Fm., 11,800 ft
	Weber Ss., 11,200 ft
	Mission Canyon Fm., 12,600 ft
	Lodgepole Ls., 13,000 ft
	Darby Fm., 13,500 ft
	Bighorn Dol., 14,200 ft

Other Significant Shows: Dinwoody Fm., 11,200 ft
Total Reserves: 3.1 TCFG, 66 MMBO
Productive Area: 38,000 acres

TABLE 3.4 Continued

Field Operator: Amoco
Number of Producing Wells (8/80): 0 (shut in awaiting completion of gas-sweetening plant)
Number of Shut-in Wells (8/80): 7
Number of Dry or Abandoned Wells (8/80): 0
Well Casing Data: 20 inch at 80 ft, 13-3/8 inch at 2,500 ft, 9-5/8 inch at 12,500 ft, 7 inch at 16,500 ft (typical Chevron wells)

Discovery Well

Name: 1 Amoco-Chevron-Gulf WI Unit
Location: SW-SE-18-T17N-R119W
Completion Date: 8/18/77
Total Depth: 10,691 ft, plugged back to 9,503 ft
Perforations: 9,178-9,182 ft, 9,183-9,221 ft, 9,221-9,266 ft (Thaynes Ls.)
Initial Potential: 4,713 MCFGPD, 196 BCPD, 9 BWPD
Treatment: Acidized with 2,000 gals of 15% HCl

Reservoir Data: Thaynes Limestone

Discovery: 8/18/77, 1 Amoco-Chevron-Gulf WI Unit, SW-SE-18-T17N-R119W
Lithology: Carbonates and shales
Age: Triassic
Type of Trap: Structural; thrust-faulted anticline
Drive Mechanism: Gas expansion
Initial Pressure: BHP 3,685 psi (DST) with 5/8 ck
Recent Pressure (4/79): BHP 3,713 psi (DST)
Reservoir Temperature: 195°F
Gross Thickness of Reservoir Rock: 1,100 ft
Porosity: 3.7% average, range 0-8%; fracture porosity dominates matrix porosity
Permeability: Unknown
Oil/Gas Column: 75 ft gas
Gas/Oil Ratio: 48,000:1
Original Gas/Water Contact: Undetermined
Gas Character: Low sulfur gas; 1,210 BTU/cu ft; gravity 0.76° API

Gas Analysis:	Methane	79.50
	Ethane	6.68
	Propane	2.62
	iso-Butane	1.06
	n-Butane	0.64
	iso-Pentane	0.44
	n-Pentane	0.32
	Hexanes	0.33
	Heptanes +	1.80
	Nitrogen	6.51
	Carbon dioxide	0.10
	Hydrogen sulfide	nil (150 ppm)

Water Salinity: 2,000 ppm NaCl (DST SW-SE-7-T17N-R119W)
Water Resistivity: 1.05 ohm-meters at 195°F
Estimated Primary Recovery: Not determined
Type of Secondary Recovery: Not determined
Estimated Ultimate Recovery: Not determined

Reservoir Data: Phosphoria Formation

Discovery: 1977, 1 Amoco-Chevron-Gulf WI Unit, SW-SE-18-T17N-R119W
Lithology: Shales, limestones
Age: Permian
Type of Trap: Structural; thrust-faulted anticline
Reservoir Temperature: 200°F
Gross Thickness of Reservoir Rock: 600 ft

TABLE 3.4 Continued

Porosity: Not reported
Permeability: Fairly tight
Oil/Gas Column: Not reported
Gas/Oil Ratio: 57,000:1
Gas Character: Sour gas; 1,125 BTU/cu ft

Gas Analysis:	Methane	73.52%
	Ethane	8.11
	Propane	2.00
	iso-Butane	0.80
	n-Butane	0.80
	iso-Pentane	0.18
	n-Pentane	0.19
	Hexanes	0.15
	Heptanes +	0.15
	Nitrogen	2.60
	Carbon dioxide	4.80
	Hydrogen sulfide	6.70

Estimated Primary Recovery: Not reported
Type of Secondary Recovery: Not reported
Estimated Ultimate Recovery: Believed to be substantial, but undetermined as of 1981

Reservoir Data: Weber Sandstone

Discovery: 1978, 2 Amoco-Chevron-Gulf, NE-NE-SE-18-T17N-R119W
Lithology: Sandstone
Age: Pennsylvanian
Type of Trap: Structural; thrust-faulted anticline
Reservoir Temperature: 205°F
Gross Thickness of Reservoir Rock: 750 ft
Porosity: 4.6% average, range 2-12%; fracture porosity dominates matrix porosity
Permeability: 0.02 to 150 millidarcies
Oil/Gas Column: 180 ft gas
Gas/Oil Ratio: 48,000:1
Gas Character: Sour gas; 1,100 BTU/cu ft; gravity 1.09° API

Gas Analysis:	Methane	57.00
	Ethane	5.82
	Propane	2.02
	iso-Butane	0.49
	n-Butane	0.57
	iso-Pentane	0.27
	n-Pentane	0.20
	Hexanes	0.22
	Heptanes +	5.95
	Nitrogen	1.01
	Carbon dioxide	5.11
	Hydrogen sulfide	21.34

Estimated Primary Recovery: Not reported
Type of Secondary Recovery: Not reported
Estimated Ultimate Recovery: Not reported

Reservoir Data: Mission Canyon Formation

Discovery: 1978, 2 Amoco-Chevron-Gulf, NE-NE-SE-18-T17N-R119W
Lithology: Limy dolomites and limestones
Age: Mississippian
Type of Trap: Structural; thrust-faulted anticline
Reservoir Temperature: 210°F
Gross Thickness of Reservoir Rock: 1,500 ft

TABLE 3.4 Continued

Porosity: 6.6% average; range 2-20%; both matrix and fracture porosity
Permeability: 0.01-300 millidarcies; both matrix and fracture permeability
Oil/Gas Column: 335 ft
Gas/Oil Ratio: 51,000:1
Gas Character: Sour gas; 1,150 BTU/cu ft; gravity 0.85° API

Gas Analysis:		
	Methane	67.16%
	Ethane	6.30
	Propane	1.87
	iso-Butane	0.47
	n-Butane	0.46
	iso-Pentane	0.22
	n-Pentane	0.17
	Hexanes	0.25
	Heptanes +	1.51
	Nitrogen	0.60
	Carbon dioxide	5.75
	Hydrogen sulfide	15.24

Estimated Primary Recovery: Not reported
Type of Secondary Recovery: Not reported
Estimated Ultimate Recovery: Not reported

Reservoir Data: Lodgepole Limestone

Discovery: 5/5/81, 1-6F Chevron-Federal, SW-SW-6-T18N-R119W
Lithology: Dolomitic limestone, limy dolomite
Age: Mississippian
Type of Trap: Structural; thrust-faulted anticline
Reservoir Temperature: 215°F (est.)
Gross Thickness of Reservoir Rock: 500-750 ft
Porosity: 5.3% average; range 2-12%
Permeability: Not reported
Oil/Gas Column: 113 ft
Gas/Oil Ratio: Not reported
Gas Character: Sour gas; gravity 0.85° API
Gas Analysis: Hydrogen sulfide 15.5%
Estimated Primary Recovery: Not reported
Type of Secondary Recovery: Not reported
Estimated Ultimate Recovery: Not reported

Reservoir Data: Darby Formation

Discovery: 1979, 1 Champlin-457 Amoco-A, SW-SE-17-T17N-R119W
Lithology: Carbonates, anhydrite, siltstone, shale; production from limy dolomite
Age: Devonian
Type of Trap: Structural; thrust-faulted anticline
Reservoir Temperature: 215°F (est.)
Gross Thickness of Reservoir Rock: 700-800 ft
Porosity: 4.5% average; range 2-10%
Permeability: 0.01-80 millidarcies; fracture permeability
Oil/Gas Column: 21 ft
Gas/Oil Ratio: Not reported
Gas Character: Gravity 0.70° API
Gas Analysis: Hydrogen sulfide 1.0%
(other figures, see data on Bighorn Dolomite)
Estimated Primary Recovery: Not reported
Type of Secondary Recovery: Not reported
Estimated Ultimate Recovery: Not reported

TABLE 3.4 Continued

Reservoir Data: Bighorn Dolomite

Discovery: 12/29/78, 2 Amoco-Chevron-Gulf, NE-NE-SE-18-T17N-R119W
Lithology: Limy dolomite
Age: Ordovician
Type of Trap: Structural; thrust-faulted anticline
Drive Mechanism: Gas expansion
Initial Pressure: BHP 6,300 psi (DST)
Recent Pressure (4/79): BHP 6,300 psi (DST)
Reservoir Temperature: 220°F
Gross Thickness of Reservoir Rock: 600 ft
Porosity: 0-7%, primarily fracture porosity, with some matrix porosity
Permeability: None; fracture permeability
Oil/Gas Column: 40 ft
Gas/Oil Ratio: 55,000:1
Original Gas/Water Contact: Variable
Gas Character[1]: Low sulfur gas, 1,135 BTU/cu ft

Gas Analysis[1]:	Methane	84.86%
	Ethane	6.75
	Propane	2.02
	iso-Butane	0.48
	n-Butane	0.44
	iso-Pentane	0.27
	n-Pentane	0.23
	Hexanes	0.45
	Heptanes +	1.22
	Nitrogen	0.71
	Carbon dioxide	1.95
	Hydrogen sulfide	0.63

Water Salinity: 35,000 ppm NaCl (SW-SE-18-T17N-R119W)
Water Resistivity: 0.12 ohm-meters at 220°F (SW-SE-18-T17N-R119W)
Estimated Primary Recovery: Not determined
Type of Secondary Recovery: Not determined
Estimated Ultimate Recovery: Not determined

[1] Includes Darby production

daily production of some 1,200 long tons (1,220 metric tons) of sulfur makes the plant the second largest sulfur producer in the United States.

The Wainoco discovery well west of Ryckman Creek, which was spudded after completion of the electrical survey, produces from the Ankareh Formation. Few details are available on this new, unnamed field. Woodruff Narrows, located north of the western end of the electrical survey line, produces gas from the Bighorn.

Well-Casing Information

The discovery well at Ryckman Creek is set with 13-3/8-inch (34.0 cm) casing at 1,962 feet (598 m) with 250 sacks of cement. Production casing of 9-5/8-inch (24.5 cm) diameter is set at 8,422 feet (2,567 m) with 700 sacks of cement. It is assumed that most subsequent wells are cased in a similar way. The greater production depths at Whitney Canyon require a more complex arrangement. In typical Chevron wells, 20-inch (50.8 cm) surface casing is set at 80 feet (24 m). Production casing begins with 13-3/8-inch (34.0 cm) at 2,500 feet (760 m), then telescopes to 9-5/8-inch (24.5 cm) at 12,500 feet (3,800 m) and 7-inch (17.8 cm) at 16,500 feet (5,030 m).

The well-casing modeling for this chapter uses a casing diameter of 13-3/8 inches (34.0 cm) for both Ryckman Creek and Whitney Canyon.

3.3 DISCUSSION OF THE DATA

Introduction

A resistivity/phase crew of eight persons, headed by Zonge Engineering geophysicist Norman R. Carlson, was mobilized to the Ryckman Creek area October 27, 1979. Work progressed on schedule despite early snows, and data collection took only three days. Data were obtained on this phase of the survey for transmitter stations 0,1 to 8,9 (see Plate 3.1).

On July 30, 1980, data collection was resumed by extending the Ryckman Creek line across the Whitney Canyon gas field. Stations on the Ryckman Creek line were reoccupied, and the last transmitting dipole (8,9) was re-read in order to insure continuity in data collection. Data repeated well and the line was extended to transmitting dipole 29,30, just past the western edge of Whitney Canyon.

Data collection during this phase of the survey was significantly slower than during the Ryckman Creek phase due to frequent thunderstorm activity. Extremely long averages were necessary in order to assure research-quality data. In addition, strong cultural noise was present in the area due to the development of the Whitney Canyon gas processing plant and the area's pipelines and powerlines. These problems contributed to making the Whitney Canyon data four times as expensive per line mile as the Ryckman Creek data. The crew completed the survey August 24, 1980.

Topography on the survey was only moderate, and surface culture was fairly light. Numerous cased wells were in place at Ryckman Creek at the time of the survey, but Whitney Canyon was fairly undeveloped.

Data were obtained at the standard roll-along resistivity/phase frequencies: 0.125, 0.25, 0.5, and 1.0 Hz. The dipole spacing for these data was a=1,700 feet (518 m). Total surface coverage for the project is 11.9 line-miles (19.2 line-km); total subsurface coverage is 9.3 line-miles (15.0 line-km).

The apparent resistivity, apparent polarization, and REM data are presented in Plate 3.1 at the back of this Chapter. It may be unfolded for reference while reading the text.

Line Interpretation

A single east-west line traversed the Ryckman Creek and Whitney Canyon fields and a considerable amount of background. The field data are presented in Plate 3.1. The repeat diagonal (left-plunging 8,9 diagonal) shows data from the two field sessions; numbers on top are from the Ryckman Creek survey in 1979, and numbers on the bottom are from the Whitney Canyon survey in 1980. The "stretching out" of the data in the center part of Whitney Canyon is the result of a logistical move designed to avoid culture problems. A pipeline lies at station 23.0; in order to avoid placing an electrode near it, the crew chief elected to advance the electrodes one-half station such that transmitting dipole 22.5,23.5 was used instead of 22,23 and 23,24.

APPARENT RESISTIVITY DATA

The general trends in the apparent resistivity data correlate well with geologic trends in the Ryckman Creek/Whitney Canyon area, which are illustrated in the cross-sections of Figures 3.4, 3.5, and 3.6. Resistivity layering is high-over-low, with high resistivities correlating quite well with upper Tertiary sediments of the Wasatch and Green River formations, and low resistivities correlating with lower Tertiary and upper Cretaceous sediments of the Evanston, Aspen, and Bear River formations. The very near surface layer is quite high in resistivity, possibly indicating lower water saturation in the surface sediments.

Superimposed upon the layering effects are three anomalously low resistivity areas. The eastern anomaly, centered on station 5.5, correlates with the Ryckman Creek production, although the anomaly extends both east and west well past the limits of the field. The second anomaly, centered between stations 23 and 27, correlates very well with the Whitney Canyon production. The third anomaly, the strongest of the three, lies on the extreme western end of the line. No hydrocarbon production has yet been established in that area.

In order to determine the cause of these anomalies, five possible sources are examined: well casings, surface culture, topography, subsurface structure, and electrochemical alteration due to the presence of hydrocarbons at depth.

Well-Casing Effects

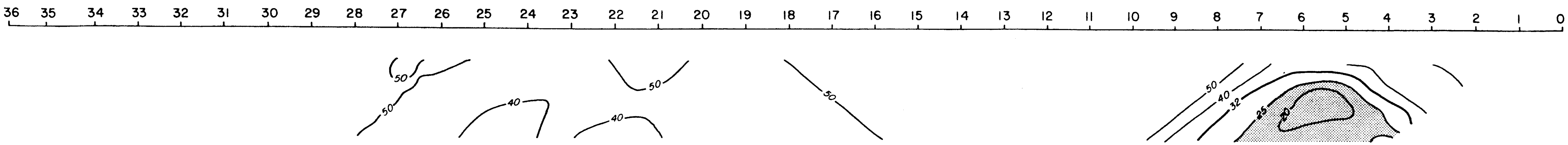
The effects of well casing on electrical survey data are extremely difficult to assess. The "PIPE" model of Holladay and West (1982) was developed to estimate the effects of well casings on IP data. Unfortunately, there are serious problems which limit the application of the model to field situations. These problems are discussed in some detail in Chapter 2 and in many of the case histories presented in this study, but briefly they involve ambiguities regarding assignment of surface impedances to the casings, the variability of casing responses, inability to specify multiple diameters for the casings, and an inability to take into account possible casing interconnection by collection pipeline networks. "Overmodeling" effects resulting from assumptions dictated by program limitations are presented in this and subsequent chapters.

Despite these difficulties, the "PIPE" model represents the first serious effort to deal with the effects of well casings, and it is useful as a starting point for discussing these effects in the Ryckman Creek/Whitney Canyon data. The map of Figure 3.7 shows wells in production, being drilled, and undrilled at the time of the electrical survey. At Ryckman Creek, seven producing wells fell within one a-spacing of the line, and two were being drilled. For the purposes of the model, all of these wells were treated identically, assuming that drill stem produces effects which are identical to those of production casing. At Whitney Canyon, only one cased well fell within one a-spacing of the line at the time of the survey. The deep hole at SE-NE-20-T17N-R119W was being drilled during the survey; mechanical problems forced its abandonment during completion of the west end of the line and the rig was moved 20 feet (6 m) or so, where it was drilled as a dry hole to a total depth of 16,434 feet (5,009 m). This well and the one at SW-NW-19-T17N-R119W were included in the model.

The well-casing model results for apparent resistivities are shown in Figure 3.10. A very strong effect has been calculated at Ryckman Creek; peak anomaly values reach two-thirds the background resistivity. The calculated residual (field data minus well-casing effects) shows no correlation with the field, but only a low resistivity, westward-dipping layer at depth. Evidence from other fields suggests that "PIPE" tends to "overmodel" field data, and there is some subtle evidence of overmodeling at Ryckman Creek. Note, for example, the depression of the 32 ohm-meter contour over the field, and the associated high resistivity, left-plunging 3,4 and right-plunging 7,8 diagonals. Unless one believes that anomalously *high* resistivities are actually present over the field at moderate depths, this is evidence of over-

Figure 3.10. Well-casing model of apparent resistivity data for the Ryckman Creek/Whitney Canyon line. Model includes 22 wells at Ryckman Creek and 9 wells at Whitney Canyon. Model parameters: casing diameter = 13-3/8 inches (34.0 cm), casing resistivity = 2.0 x 10^{-7} ohm-meters, surface impedance = 0.5 + 0.5 i, background resistivity = 50 ohm-meters. Figure 3.7 shows well locations.

a. Well-Casing Model



b. Well-Casing Residual

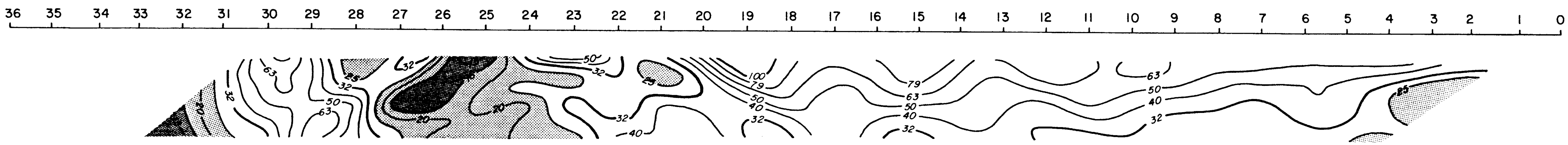


Figure 3.11. Topographic model of apparent resistivity data for the Ryckman Creek/Whitney Canyon line. Background resistivity = 50 ohm-meters. Plate 3.1 shows topography.

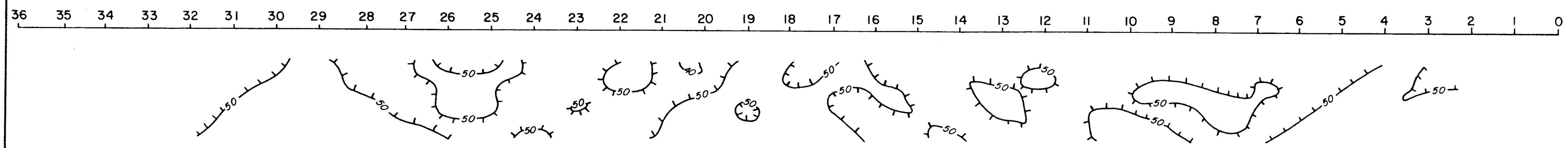
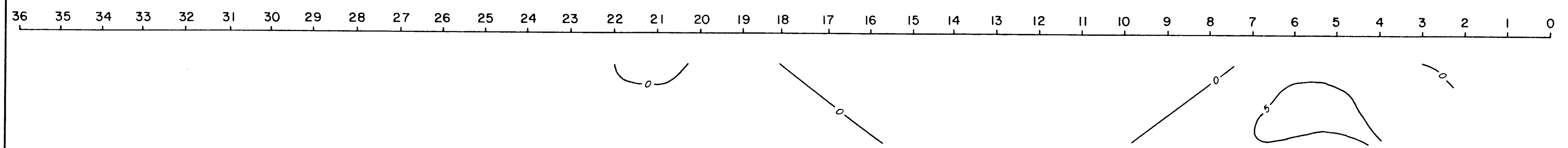


Figure 3.12. Well-casing model of apparent polarization data for the Ryckman Creek/Whitney Canyon line. Model parameters: same as in Figure 3.10. Figure 3.7 shows well locations.



modeling by "PIPE." Therefore, it is difficult to draw any quantitative conclusions regarding the effects of well casings at Ryckman Creek based on the results of this modeling.

The situation over Whitney Canyon is different, if only because the field had not yet been fully developed when these data were collected. The calculated well-casing effect is broad and fairly subtle, on the order of 10 to 20 percent, and the residual bears a strong resemblance to the original field data. Since the model represents a worst-case approximation, it is safe to conclude that well casings have very little to do with the anomaly measured at Whitney Canyon.

The very strong anomaly on the west end of the line is unrelated to well-casing effects, since no producing wells were located there at the time of the survey.

Surface Culture Effects

Considering now the problem of surface culture, pipelines cross the line at stations 5.3, 6.2, 6.8, 17.8, and 23.0. These pipelines might be expected to behave similarly to those modeled in section 2.6. The pipeline at station 17.8 is connected to a pipeline which runs parallel to the survey line 0.5 a-spacing to the north. However, the data show no obvious effects from this feature. There are also no near-surface effects resulting from three pipelines which cross the line at Ryckman Creek. The data in the vicinity of the pipeline at station 23 are actually resistive—exactly opposite the sign which would be expected—so it is doubtful that it exerts any influence of a conductive nature upon the data. The only other surface culture on the line consists of two fences east of Ryckman Creek; these appear to have little or no influence on the data. Hence, we can conclude that surface culture probably does not cause any recognizable electrical effects on the line.

Topographic Effects

Topography on the Ryckman Creek/Whitney Canyon line is appreciable, as shown in Plate 3.1. In order to obtain an estimate of topographic changes on the apparent resistivity data, the topography was gridded with a very fine mesh and was modeled with the two-dimensional program "2DIP." The results are shown in Figure 3.11. As can be seen, topography can be expected to produce values of apparent resistivity which are slightly too high or low in isolated portions of the line. The changes are generally less than about 20 percent, however, and other effects in the data dominate topographic effects. Hence, the interpretation is not affected to any significant degree by topographic effects.

Subsurface Structure Effects

Subsurface structure appears to have a substantial influence on the data in portions of the pseudosection. As can be seen in the geologic cross-sections, a relatively undisturbed section of 2,000 to 4,000 feet (600-1,200 m) of Tertiary and upper Cretaceous sediments overlies some 10,000 to 15,000 feet (3,000-4,500 m) of overthrusted Mesozoic and Paleozoic strata. Most of the features in the apparent resistivity pseudosection result from changes within the overburden. As noted earlier, these sediments contribute to high-over-low resistivity layering, with Tertiary units showing high resistivities and lower Tertiary to Cretaceous units showing low resistivities.

On the extreme east and west ends of the line, the Tertiary/Cretaceous overburden thins or disappears entirely due to thrust faulting. The thinning east of Ryckman Creek brings the low-resistivity Cretaceous sediments closer to the surface in that direction, resulting in a zone of low resistivities which extends eastward. This in no way explains the existence of the lateral, deep, conductive anomaly which correlates with the lateral extent of the hydrocarbons, but it may help explain why the anomaly spreads out so far horizontally.

The influence of overthrust units underlying the Tertiary/Cretaceous overburden is minimal across most of the line (except, as noted, at the western and eastern ends of the line). This is because the zone of influence of apparent resistivity is about two a-spacings, or roughly 3,500 feet (1,100 m)—shallower than the top of the overthrust strata. An exception occurs near the Whitney Canyon Anticline (Figure 3.6), where the overthrust strata lie within 2,500 feet (750 m) of the surface. Here, there is a possibility that the data from the deeper n-spacings are partly influenced by overthrust structure. However, there is no likelihood that a significant portion of the broad conductive anomaly at Whitney Canyon is merely a structural effect.

Towards the far west end of the line, Cretaceous, Triassic, and Jurassic sediments are thrust all the way to the surface along the Medicine Butte Thrust Fault. The behavior of the apparent resistivities in this area strongly suggests that the shape and strength of the anomaly is at least partly due to the outcropping of these overthrust strata.

Alteration Effects

Having failed to explain away the Whitney Canyon and Ryckman Creek apparent resistivity anomalies as the result of well casings, surface culture, topography, and subsurface structure, we are left with the very likely possibility that these anomalies, which are so well correlated with the lateral extent of the hydrocarbons, are due to alteration effects in the sediments directly overlying the hydrocarbons. This conclusion is very uncertain for Ryckman Creek due to problems with the well-casing model, but is quite firm for Whitney Canyon, where only a few wells were cased at the time of the survey. A more detailed discussion of the alteration theory is given in the conclusions of this chapter.

APPARENT POLARIZATION (DECOUPLED PHASE ANGLE) DATA

When these data were originally obtained, a three-point quadratic extrapolation was applied to the raw phase data to separate polarization from electromagnetic coupling. The results showed a low-over-high polarization section due to undercorrection at depth, as described in section 1.8; this led to an appearance that anomalies extended to and became more pronounced at depth. The present set of data, which has been decoupled using proprietary techniques described in section 1.8, shows no pervasive, deep effects. Instead, isolated zones of moderate polarization are noted, the most interesting of which are due to features which are fairly shallow. This demonstrates the acute need for proper processing of this type of data.

The decoupled phase data of Plate 3.1 show two shallow zones of potential interest. At Ryckman Creek, a small bank of phase values which are twice the background value correlates well with the lateral extent of the hydrocarbons. The anomaly appears to be a near surface feature. A similar, but weaker anomaly is found at Whitney Canyon.

Well-Casing Effects

In order to gain some qualitative insight into the effects of well casings, a "PIPE" model was run, using a complex surface impedance which provided the best fit to the phase data, and including the effects calculated for both well casings and drill stem in wells being drilled at the time of the survey. The results of this model are shown in Figure 3.12. Note that the maximum anomaly at Ryckman Creek occurs at the n=3 plot point beneath station 5.5, and that the anomaly has a rounded, chevron-shaped appearance, with effects extending diagonally to depth. In contrast, the field data show a maximum effect at n=2, and the shape of the field anomaly is more tabular and horizontal in appearance. A second model, including only casings in producing wells (i.e., including no drill stem) showed only a slightly better match with the data. A third model, including only drill stem effects (i.e., including no producing wells), showed a slightly poorer match to the data than the model of Figure 3.12. All three of these models suggest that well-casing effects, if they exist at all, tend to make the anomaly in the field data appear to be deeper than it really is. The conclusion, therefore, is that well casings do not cause the majority of the polarization at Ryckman Creek, although they may contribute to its overall strength at deeper n-spacings.

The second shallow polarization anomaly seen on the line is found over Whitney Canyon. It lies at about the same depth in the pseudosection as the anomaly at Ryckman Creek, but it has a more discontinuous shape due to the combination of thunderstorm-related noise and what may be localized changes in polarizability of the Tertiary and Cretaceous sediments. The well-casing model of Figure 3.12 shows a weak effect calculated for the drill stem in the hole being drilled south of station 19.2; note that the strength of the model anomaly and the trends (e.g., a left-plunging 18,19 diagonal) indicate that the drill stem probably does not cause much of a polarization anomaly, although a slight effect may be evident in the field data. A second model, calculated for well casings only (no drill stem), shows a barely detectable deep anomaly at the center of the producing field, while the field data show a contorted responsive zone near the surface (ignoring the n=6 data point beneath station 24, which appears to be noisy). Therefore, while well-casing effects may account for some of the isolated, deeper responses and for a portion of the shallower response beneath station 19, they do not account for the very shallow anomaly at Whitney Canyon. In fact, well-casing effects may explain why the anomaly is only moderately correlated with the lateral extent of the hydrocarbons. By subtracting calculated well-casing effects from the field data, one can see that the resulting high polarization areas would correlate even better with the hydrocarbons than do the anomalies in the field data.

Surface Culture Effects

Three pipelines cross the line over Ryckman Creek. Modeling suggests that the response of a pipeline would be strongest at n=1, expanding to depth in a very sharply-defined, chevron-shaped anomaly (see section 2.6). The anomalies would be predictably asymmetric, depending upon the position of the pipeline with respect to the electrode positions. The superposed effect would be strongest at the surface, but would show deeper, high-low, geometric diagonal effects. None of this character is evident in the data. Instead, the measured anomaly is strongest at n=2, not n=1, and it has a very horizontal, vertically-limited extent which is not indicative of geometric effects from surface features.

The pipeline which crosses the line at station 17.8 does not appear to produce an anomalous effect of any significant degree. Again, the strongest effect would be at the n=1 stations, where no recognizable effect is seen. The pipeline at station 23.0 may contribute somewhat to the diagonal effects which appear to emanate from that area, but the character of the data indicates that the pipeline's influence is of secondary importance.

The two fences east of Ryckman Creek do not appear to influence the field data at all.

Subsurface Structure Effects

The anomalies measured over Ryckman Creek and Whitney Canyon fields cannot be attributed to subsurface structure, since most structure lies well below the effective penetration of the apparent polarization data.

Alteration Effects

The fact that the shallow anomalies correspond in plan view to the lateral extent of the hydrocarbons implies, in the absence of other explanations, that there is alteration of some sort in the near-surface sediments, and that the alteration is causally linked to the presence of the hydrocarbons at depth. The polarization anomalies may be due to low-grade sulfide mineralization, changes in clay characteristics, or some unknown alteration effect due to vertical migration of hydrocarbons and/or waters from depth. More will be said of this in the conclusions of this chapter.

Other Polarizable Features

The zone of high polarization, found near the surface between stations 29 and 30, is very isolated and is therefore of little interest. It occurs near the surface expression of the Medicine Butte Thrust Fault; perhaps the overthrust sediments are slightly mineralized or altered at the surface. A second zone of high polarization is found at depth between stations 15 and 18. This feature is exceedingly difficult to explain by any theory other than that involving a localized facies change. It is believed that culture and structure have little to do with this feature.

One of the most interesting aspects of these data is the absence of high polarization in the conductive zone on the far west end of the line. If Ryckman Creek and Whitney Canyon can be used as examples of what a hydrocarbon anomaly should look like in this area, it is questionable that the conductive zone is due to hydrocarbons, since it lacks a polarization response. However, insufficient data have been obtained in this area to make such a judgement.

RESIDUAL ELECTROMAGNETIC (REM) DATA

The REM data show high-over-low resistivity layering, as do the apparent resistivity data. The somewhat contorted appearance of the high resistivity region (positive REM numbers) is primarily the result of the fact that numbers are quite small, and hence reflect minor subsurface and cultural effects. Superimposed on these effects are four anomalous areas: Ryckman Creek, west of Ryckman Creek, Whitney Canyon, and the west end of the line.

Ryckman Creek and Whitney Canyon Fields

The Ryckman Creek anomaly is highly conductive and appears to extend to considerable depth, much as observed in the apparent resistivity data. However, note that the REM anomaly is better bounded with respect to the location of the hydrocarbons. This is probably because REM quadrature data are less sensitive to resistivity layering, and the conductive Cretaceous sediments which broaden the resistivity anomaly are not being picked up as well by REM. This is a distinct advantage of REM quadrature data: they are more sensitive to lateral resistivity changes than they are to layering changes. We would still like to see a better cut-off at the edges of the anomaly, but at least the highest portion of the strongest portion of the anomaly corresponds to the producing field.

The Whitney Canyon REM anomaly is narrower than the resistivity anomaly, possibly because the REM data are affected by the lateral high resistivity change at the surface between stations 22 and 24. This tends to limit the eastern extension of the anomaly and to produce high resistivity diagonals (left-plunging 22,23, and right-plunging 23,24). It is interesting to note that the REM anomaly becomes significantly stronger at depth, and has a more consistent shape than the apparent resistivity anomaly.

Other Anomalous Features

The deep anomaly west of Ryckman Creek is unique to the REM data set. Hints of this feature are seen in the apparent resistivity and apparent polarization data, but only in the REM data is a definable anomaly seen. The reason for this is probably that REM data are penetrating below the zone of influence of the galvanic data, and hence are picking up a response from conductive material at depth. The anomaly appears to have two zones of maximum strength, beneath station 12 and beneath station 15. The zone beneath station 15 may be largely due to a localized high resistivity unit near the surface. An example of this is found in the discussion of section 2.8. The anomalous zone beneath station 12 may be similarly affected, but to a lesser degree. However, the region between stations 12 and 14 appears to be generally anomalous overall, and could possibly be associated with hydrocarbons.

The conductive anomaly on the far west end of the line is strongly correlated with the conductive anomaly found in the apparent resistivity data. The REM values are much more negative (conductive) than those observed anywhere else on the line. The most likely explanation for this feature involves the presence of highly conductive sediments which have been brought to the surface by thrusting along the Medicine Butte Thrust Fault. An alternative possibility is that the anomaly is connected with alteration due to hydrocarbons, but not enough data were gathered to comment further upon this possibility.

3.4 CONCLUSIONS

Ryckman Creek and Whitney Canyon

REVIEW OF THE DATA

The Ryckman Creek Field shows a strong conductive anomaly in the apparent resistivity and REM quadrature data. The anomaly extends from intermediate depths to below the pseudosection grid. Well-casing modeling was performed on the Ryckman Creek data, resulting in a residual, resistive anomaly which is interpreted as an "overmodeling" effect. This result, coupled with the inherent difficulties in applying the well-casing model, makes it impossible to determine quantitatively the extent of well-casing effects upon the data. However, the fact that well-casing effects calculated at Whitney Canyon do not even *qualitatively* model the anomaly measured there (i.e., the trends in the data and the trends in the modeled data are completely different), suggests by example that well casings may not play a major role in the anomaly at Ryckman Creek. Hence, there is a strong possibility that a conductive anomaly exists in the Ryckman Creek data which is independent of well-casing effects. This anomaly does not appear to be influenced significantly by surface culture or topography; subsurface structure tends to spread the anomaly out but cannot explain the lateral changes. Thus, there seems to be a columnar alteration zone which is relatively more conductive than the surrounding rocks. The REM data suggest that it extends to considerable depth.

The apparent polarization data at Ryckman Creek show a thin, flat-lying, polarizable zone lying less than 1,000 feet (300 m) deep. This anomaly cannot be reasonably explained by effects due to well-casings, surface culture, or subsurface structure. Instead, it appears to be due to alteration of near-surface sediments directly over the much deeper hydrocarbon trap.

The Whitney Canyon Field also shows strong apparent resistivity and REM anomalies which extend from very close to the surface to considerable depths. The apparent resistivity anomaly cannot be approximated either qualitatively (shape, character, and location) or quantitatively (strength) by even a worst-case well-casing model. In fact, the data very strongly indicate that well casings, surface culture, topography, and subsurface structure have very little to do with the existence or shape of the conductive anomaly. Hence, it is difficult to avoid the conclusion that the anomaly is due to conductive alteration of the strata overlying the reservoir. The very good correlation of the anomaly with the lateral extent of the hydrocarbons suggests that the alteration is causally linked to the presence of the hydrocarbons at depth.

The apparent polarization anomaly at Whitney Canyon shows a very complex pattern, possibly due to a fair amount of thunderstorm-related noise. There is a slight suggestion of polarization responses over the field. These seem to be very near-surface features. Well-casing models suggest that effects due to well casings have little to do with the Whitney Canyon polarization anomaly, and in fact, the model data and the field data are quite different in general character. It is also extremely unlikely that the anomaly is influenced significantly by surface culture. Again, the conclusion is that the areas of higher polarization are due to alteration of near-surface sediments, although the overall effect is much less than that observed at Ryckman Creek.

POSSIBLE SOURCES OF THE ANOMALIES

Two distinctive effects are evident in the Ryckman Creek and Whitney Canyon data: a deep, conductive, relatively non-polarizable zone (the so-called "deep anomaly") lying just above the hydrocarbons, and a shallow, relatively non-conductive, polarizable zone (the "shallow anomaly") lying far above the hydrocarbons. Both are believed to be related to upward migration of material from the traps themselves, as described in section 2.4.

The deep conductive anomalies may be due to the upward leakage of saline water from the reservoirs, whose connate water resistivities are typically less than 1 ohm-meter. The active water drive at Ryckman Creek is an ideal candidate to transport the saline waters vertically out of the trap, as suggested by Roberts (1980), and the Whitney Canyon drive might be expected to behave in a similar manner. Energized by a strong hydraulic gradient due to the geometry of the traps and decreased hydrostatic pressures in the overlying sediments, the brine waters from the traps would rise vertically, making the overlying zones appear to be relatively conductive to an electrical survey. Eventually the decreased temperature and pressure would decrease the solubility of salts sufficiently that they would precipitate. This would determine the top of the conductive anomaly.

The conductive anomalies measured over the two fields are similar in magnitude, despite the enormous differences between them in terms of trap size and total reserves. Perhaps both anticlines are equally effective at expelling saline waters from the reservoirs. If the dissolved salt content of the reservoir waters of the two fields were roughly equal, and if the rate of expulsion were roughly equal, one might expect the two anomalies to be similar in magnitude, keeping in mind the difference in field size. The slightly stronger Ryckman Creek anomaly may reflect the fact that Nugget reservoir waters are apparently lower in total dissolved solids than the Whitney Canyon reservoir waters; alternatively, it may also reflect enhancement by well-casing and surface culture effects.

The fact that the Whitney Canyon anomaly extends all the way to the surface, and the Ryckman Creek anomaly does not, may be related to solubility considerations. Waters rising from traps at Whitney Canyon are hotter, in that they originate from greater depths. These higher temperature waters might be expected to retain dissolved salts farther up the column of ascent than would cooler waters rising from Ryckman Creek. Other considerations may enter into this as well, and may even dominate the proposed temperature effect. A great deal of experimental work remains to be done regarding this subject.

The polarizable anomalies may be due to alteration of the near-surface sediments by vertically-migrating hydrocarbons of low molecular weight. The two most likely sources of alteration are pyrite precipitation and changes of the ion exchange characteristics of clays. Pyrite would be formed by the combination of free iron and hydrogen sulfide. Iron can usually be found to some degree in meteoric waters or in the matrix structure of sedimentary rocks, especially sandstones. Hydrogen sulfide can originate in the trap as a dissolved gas or it can be manufactured by reduction of hydrocarbons by anaerobic bacteria. The hydrogen sulfide content of the Nugget and Thaynes reservoirs at Ryckman Creek is extremely low; hence bacterial action is the more likely source of sulfur there. On the other hand, Whitney Canyon reservoirs are typically quite high in hydrogen sulfide, so either source is possible there. The Ryckman Creek polarization anomaly is significantly stronger than the Whitney Canyon anomaly, but it is difficult to understand why. Perhaps the shallower reservoirs at Ryckman Creek in some way contribute a greater supply of hydrocarbons available for reduction in the subsurface than do the deeper traps at Whitney Canyon. Also, the diffusion by horizontally flowing aquifer waters might tend to dissipate a tall column of ascending hydrocarbons more than a short column. The role of clays in this dynamic situation is not completely understood, but changes in cation-exchange capacity, absorption by clays of rising gases, etc., are subjects for future investigation.

A final note may be of interest here. There has been some discussion in the petroleum industry that hydrocarbons migration may be heavily influenced in its direction of motion by faults, and that electrical anomalies might therefore be displaced laterally from the location of the hydrocarbons. With its intermediate-angle thrust faulting, Ryckman Creek and Whitney Canyon provide a good test of this hypothesis. If any offset to the anomalies were to be observed, we would expect it to be towards the east of the hydrocarbons. Such an effect is not dominant in these data, suggesting that, in this case, upward migration of either light hydrocarbons or waters is not heavily influenced by the considerable thrust faulting present across the line.

Other Anomalies Observed on the Line

Two anomalies over non-producing areas are found on this line of data: one on the center of the line at depth, the one on the far west end of the line. Both are of possible interest in regard to hydrocarbons.

The anomaly towards the center of the line is best defined in the REM data as a conductive zone at great depth, although hints of it are seen in the apparent resistivity and apparent polarization data. Some high resistivity surface material probably tends to enhance the overall magnitude of this anomaly, especially towards the west. The electrical interpretation places the most inherently responsive zone between stations 11 and 15. Although no near-surface polarization anomaly occurs in conjunction with this feature, the variation between the polarization anomalies at Ryckman Creek and Whitney Canyon suggests that this may not be a critical consideration in terms of a hydrocarbon indicator. The anomaly is considered to be fairly well-defined overall.

Subsequent to completion of this survey line, Wainoco spudded in a discovery well some 2,500 feet (760 m) south of station 10.2. This well produces oil and gas from the Ankareh Formation at a depth of 12,418 to 12,602 feet (3,785 to

3,841 m). The well is too far away from the electrical line (1.5 a-spacings) to relate to the data. A second well was drilled by Chevron north of the survey line, but it was dry, with no shows; total depth was in the Ankareh at 12,800 feet (3,901 m). Since the line drawn between the two wells crosses a narrow resistive zone between the Ryckman Creek anomaly, and the deep, weaker anomaly west of Ryckman Creek, and since the second well is more than one a-spacing from the line, no conclusions can be drawn at this time regarding extension of the Wainoco production. However, the data suggest that drilling directly on the line would best be done in one of two spots: 1) on the deep anomaly between stations 11 and 15, ideally on station 13, and 2) on the western edge of the Ryckman Creek anomaly, which may be extended westward due to alteration from a second reservoir at depth. The second possibility is the less preferred of the two. The Ankareh production in the Wainoco well could be related to either possibility. Again, subsurface geology and seismic data should be used in conjunction with these electrical data to formulate the best exploration strategy. Several additional lines of data should ideally be obtained in order to define the planar extent of the anomaly.

A second area of interest lies on the extreme west end of the line. The extremely low resistivities (much lower than those observed over the two known fields), and the coincidence of this feature with the upthrown Mesozoic strata along the Medicine Butte Thrust do not tend to strongly favor it as a hydrocarbon target. However, the character of the anomaly cannot be ascertained since it lies on the extreme end of the line. The line would have to be extended about three miles (5 km) in order to evaluate this feature.

Some incentive for additional work in this area may be found in the 1981 discovery at Woodruff Narrows, 2.4 miles (3.0 km) north of the anomaly. This well flowed an initial 2.8 MMCFGPD from a Bighorn reservoir at 16,736 to 16,780 feet (5,101 to 5,115 m). Looking at the situation rather optimistically, a southward extension of Woodruff Narrows along the trend of overthrust fields would bring it across the west end of the survey line. The proper placement of several more electrical lines in the vicinity, and a combined interpretation of electrical, seismic, and subsurface geologic information should prove to be an optimum exploration strategy. Seismic and geologic data would establish the structural context for future drilling, and electrical data would establish the likelihood of hydrocarbons through the existence of overlying alteration patterns.

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Plate 3.1
RESISTIVITY/PHASE PSEUDOSECTION DATA
Ryckman Creek and Whitney Canyon Fields
Uinta Co., Wyoming

Line 1
a = 1,700 feet

Explanation of Symbols

Standard Well Symbols

- Drillhole for which information is unobtainable
- Drilling in progress at time of map preparation
- Shut in
- Abandoned
- 10,420 Dry hole with total depth indicated
- Oil well
- Gas well
- Oil and gas well
- Gas injection well
- Water injection well
- Water well

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)

Culture Symbols

- Metal pipeline, presumed grounded
- US Ungrounded pipeline: non-metal or suspended
- Metal fence
- Electric fence
- Buried telephone or power cable
- Telephone line or standard voltage power line
- Major high voltage power line
- Radio, microwave, or other communications station or tower
- DC pump

Other Symbols

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

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