Chapter 6
Lisbon Field
San Juan County, Utah

6.1 INTRODUCTION

Lisbon Field is located in the Paradox Basin, some 32 miles (51 km) south of Moab, Utah (Figure 6.1). The field lies on the western flank of the northwest-trending Lisbon Valley-Dolores Anticline, one of the five major salt folds in the basin. Oil and gas are produced from the Mississippian Leadville Formation, with some of the wells acting as gas injection wells as a part of a pressure-maintenance program. Hydrocarbon accumulation is controlled by a faulted anticline in the Paleozoic rocks, a structure which is not directly related to the structure in the overlying salt.

Lisbon Field is a major producer for the area and was an important discovery by Pure Oil Company in 1960 not only because of its size, but also because it proved the reservoir potential of Mississippian and Devonian rocks in the Paradox Basin. Ultimate production is expected to be about 42 million barrels of oil and 250 billion cubic feet of gas, of which most of the oil and a small fraction of the gas have now been recovered.

Three lines of resistivity/phase data were run across Lisbon Field using a dipole spacing of 2,000 feet (610 m).

6.2 GEOLOGIC BACKGROUND

Exploration History of Lisbon Field

The Paradox Basin has had an erratic and not always successful exploration history. The first indication of hydrocarbons dates back to 1879, when E.L. Goodridge noted an oil seep near Mexican Hat, Utah. This was not developed commercially until a well was completed in the Rico Formation in 1908. After an initial surge of development, the Mexican Hat field was eventually abandoned, and subsequent activity in the Paradox Basin was sparse despite discoveries in adjoining provinces. Southeast Utah did not see another producer until the discovery of Crescent Junction Field in 1946.

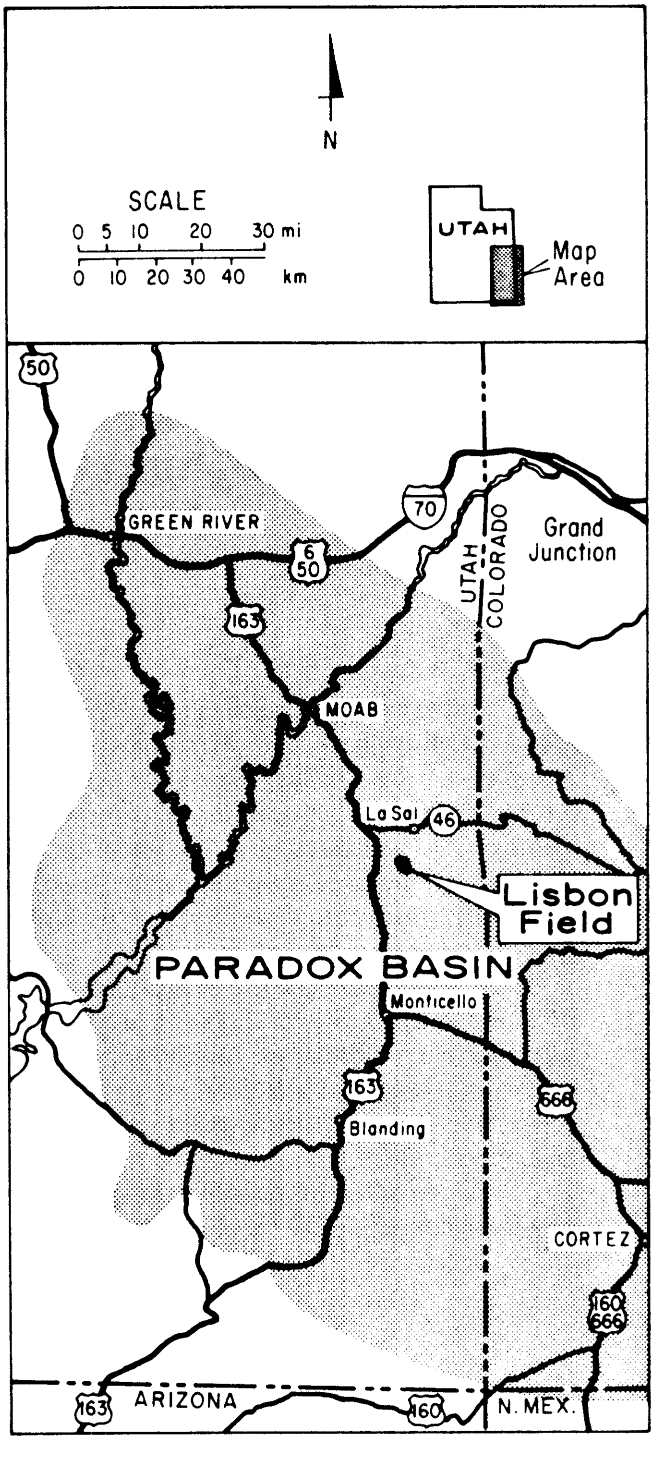

Figure 6.1. Location map of Lisbon Field.

Exploration activity did not really pick up until it was realized that Pennsylvanian rocks constituted potentially attractive petroleum targets. The first significant Pennsylvanian production in Utah was recorded at Boundary Butte in 1948, followed by a Shell Oil discovery at Desert Creek six years later. A third, very significant discovery by Texaco in 1956 at Aneth Field finally erased the Paradox Basin's stigma of being a poor producing province.

While most of the industry focused attention on Pennsylvanian targets, the Pure Oil Company (now merged with Union Oil Company of California) began to explore for traps of Mississippian age. Pure's Big Flat discovery in 1957, which followed a program of geologic and seismic studies, was the first Mississippian discovery in the Paradox Basin. Although it proved to be a mediocre producer, the Big Flat find sparked a flurry of Mississippian tests during the next several years, none of which were successful.

Pure Oil was not deterred, and an ambitious program of geologic structure and seismic mapping was undertaken with the intent of finding promising anticlinal structures in Mississippian strata. This program identified two good targets southwest of the Lisbon Valley-Dolores salt anticline. The anticline had been mapped as early as the 1900s, and it was first drilled in 1927, but exploration for Paleozoic targets had been made difficult by the effects of the overlying Paradox Salt. Gravity methods were ineffective in the area, and seismic interpretation in the 1950s could not always distinguish reflections from the various lithologic units; indeed, the fault which bounds Lisbon Field to the northeast could not be distinguished on the basis of seismic data, but was inferred by correlation. In any case, Pure persevered and spudded wells on both of its targets in 1959. The discovery well at Lisbon was completed January 4, 1960, flowing 587 BOPD from the McCracken Sandstone of Devonian age. Declining production led to its recompletion in the Leadville Formation, a Mississippian unit, and the well was later reconverted to a McCracken oil producer and a Leadville gas injection well.

The discovery at Lisbon was marked as one of the most significant of 1960 in the United States. It proved the potential of Mississippian and Devonian strata in the Paradox Basin, although the promise of these strata has never been completely fulfilled. In addition to Lisbon Field, current Leadville producers in San Juan County include Big Indian (1961), Little Valley (1961), Cleft (1962), and Hook and Ladder (1977). None of these has been as successful as Lisbon, which continues to be a major producer in the area.

Recent exploration in the Paradox Basin has focused attention primarily on Pennsylvanian strata, especially the Ismay and Desert Creek zones of the Paradox Formation, which are easily the most productive in the area. The traps in these strata are both structural and stratigraphic in nature.

Geologic History of the Paradox Basin

The stratigraphic sequence at Lisbon Field is listed in Table 6.1. Most of the sediments were deposited in shallow water environments during episodes of tectonic subsidence. Local sedimentation patterns were heavily dependent on Precambrian, continental-scale rift development, and on the formation and flowage of Pennsylvanian salts.

About 1.5 billion years ago, a series of major rift systems developed in the western United States as a result of crustal compression from the north. As shown in Figures 6.2 and 6.3, two of these lineaments intersected one another on the northeastern boundary of the present-day Paradox Basin. The northeast trend, known as the Colorado Lineament, extended from the Grand Canyon area to Minnesota and was characterized by left-lateral normal faults. Its conjugate trend, the Olympic-Wichita Lineament, extended from Washington to southern Oklahoma, running northwest to southeast with right-lateral strike-slip displacement. Together these two trends produced Precambrian faults running northwest-southeast and folds running northeast-southwest. The faulting which developed during this time heavily influenced the later geologic history of the Paradox Basin.

TABLE 6.1: STRATIGRAPHIC DESCRIPTION OF LISBON FIELD

System	Symbol	Formation	Lithologic Description
MESOZOIC ROCKS			
Cretaceous	Kmc	Mancos Sh.	Shales, mudstones, and siltstones
	Kd	Dakota Ss.	Sandstones, conglomerates, shales, mudstones, and coal beds
		(unconformity)	
	Kbc	Burro Canyon Fm.	Sandstones, conglomerates, and mudstones
Jurassic	Jm	Morrison Fm.	
	Jmb	Brushy Basin mbr.	Mudstones; minor limestones and shales
	Jms	Salt Wash mbr.	Sandstones and mudstones
		San Rafael Group	
	Js	Summerville Fm.	Sandy mudstones, shales, and fine-grained sandstones
	Je	Entrada Ss.	
		Moab mbr.	Fine-grained eolian sandstone
		Slick Rock mbr.	Fine-grained eolian and shallow marine sandstone with occasional coarse grains
	Jca	Carmel Fm. (Dewey Bridge mbr. of Entrada Ss.)	Siltstones, silty shales, gypsum, and thin beds of fossiliferous limestone
		(unconformity)	
Jurassic/Triassic		Glen Canyon Group	
	JTRna	Navajo Ss.	Cross-bedded eolian sandstone with a few cherty limestone beds
	JTRka	Kayenta Fm.	Fine-grained sandstones, mudstones, and lacustrine limestones
	JTRw	Wingate Ss.	Massive, cliff-forming, cross-bedded eolian sandstone
		(unconformity)	
Triassic	TRc	Chinle Fm.	
	TRcc	Church Rock mbr.	Siltstones and fine-grained sandstones with no bentonite
	TRco	Owl Rock mbr.	Mudstones and thin lacustrine limestones with no bentonite
		Petrified Forest mbr.	Claystones, mudstones, siltstones, and some sandstones; bentonitic
	TRcm	Moss Back mbr.	Cross-bedded sandstone with conglomeratic limestone-chert-quartzite lenses, silicified wood, and bentonite; hosts uranium in Lisbon Field area
	TRcb	Monitor Butte mbr.	Claystones and clayey-micaceous sandstones; bentonitic
	TRcs	Shinarump mbr.	Conglomeratic basal sandstone with bentonite; hosts uranium in Monument Uplift area
		(unconformity)	
	TRm	Moenkopi Fm.	Fine-grained, cross-bedded sandstones, siltstones, and mudstones
PALEOZOIC ROCKS			
		(unconformity)	
Permian	Pc	Cutler Fm.	
		Upper unit	Conglomerates, siltstones, mudstones, and arkosic sandstones; local cherts and limestones
		(unconformity)	
		Lower unit	Mudstones and sandstones
		(unconformity)	

TABLE 6.1 Continued

System	Symbol	Formulation	Lithologic Description
Pennsylvanian		Hermosa Group	
	₱hu	Honaker Trail Fm. (Upper Hermosa)	Fossiliferous limestone with sandstones, siltstones, mudstones, and shales; hosts minor amounts of hydrocarbons in the Paradox Basin
		Paradox Fm.	
	₱hi	Ismay zone	Dolomites, siltstones, shales, and anhydrites; hosts major amounts of hydrocarbons in the southern Paradox Basin
	₱hd	Desert Creek zone	Hosts major amount of hydrocarbons in the southern Paradox Basin
	₱hp	Paradox Salt (Akah and Barker Creek zones)	Salt with thin beds of shale, anhydrite, siltstone, and dolomite; fractured; *non-commercial oil in a 15-foot bed at Lisbon Field*
		Pinkerton Trail Fm. (Lower Hermosa)	Dolomites and limestones with some dolomitic siltstones, shales, and anhydrites
	₱m	Molas Fm.	Silty and sandy shales
		(unconformity) ———	———
Mississippian	Ml	Leadville Fm. (Redwall Ls.)	Dolomitic and fossiliferous limestone with a weathered karst-type upper boundary; *dolomites host most of the hydrocarbons at Lisbon Field* and at a few other Paradox Basin fields
		(unconformity) ———	———
Devonian	Do	Ouray Ls.	Limestone with poor porosity; *hosts non-commercial gas and condensate in more porous zones at Lisbon Field*
		Upper unit	Dense lithographic limestone
		Lower unit	Medium crystalline limestone with thin beds of dolomite
	De	Elbert Fm.	
		Upper mbr.	Arenaceous limestone with thin beds of shale
		McCracken Ss. mbr.	Dolomitic sandstones, sandy dolomites, and dolomitic shales with erratic porosity and permeability; *hosts minor amount of oil at Lisbon Field*
	Da	Aneth Fm.	Glauconitic dolomite with siltstone partings; hosts oil primarily at Aneth Field
		(unconformity) ———	———
Cambrian	€l	Lynch Dol.	Argillaceous dolomite with thin shale beds
	€m	Maxfield Ls. (Muav Ls.)	
	€o	Ophir Sh. (Bright Angel Sh.)	Shale and siltstone
	€t	Tintic Qtzite. (Tapeats Ss.)	Shale and siltstone at top grades downward to coarse-grained sandstone
PRECAMBRIAN ROCKS			
		(unconformity) ———	———
Precambrian	p€	— —	Granitic and metamorphic rocks

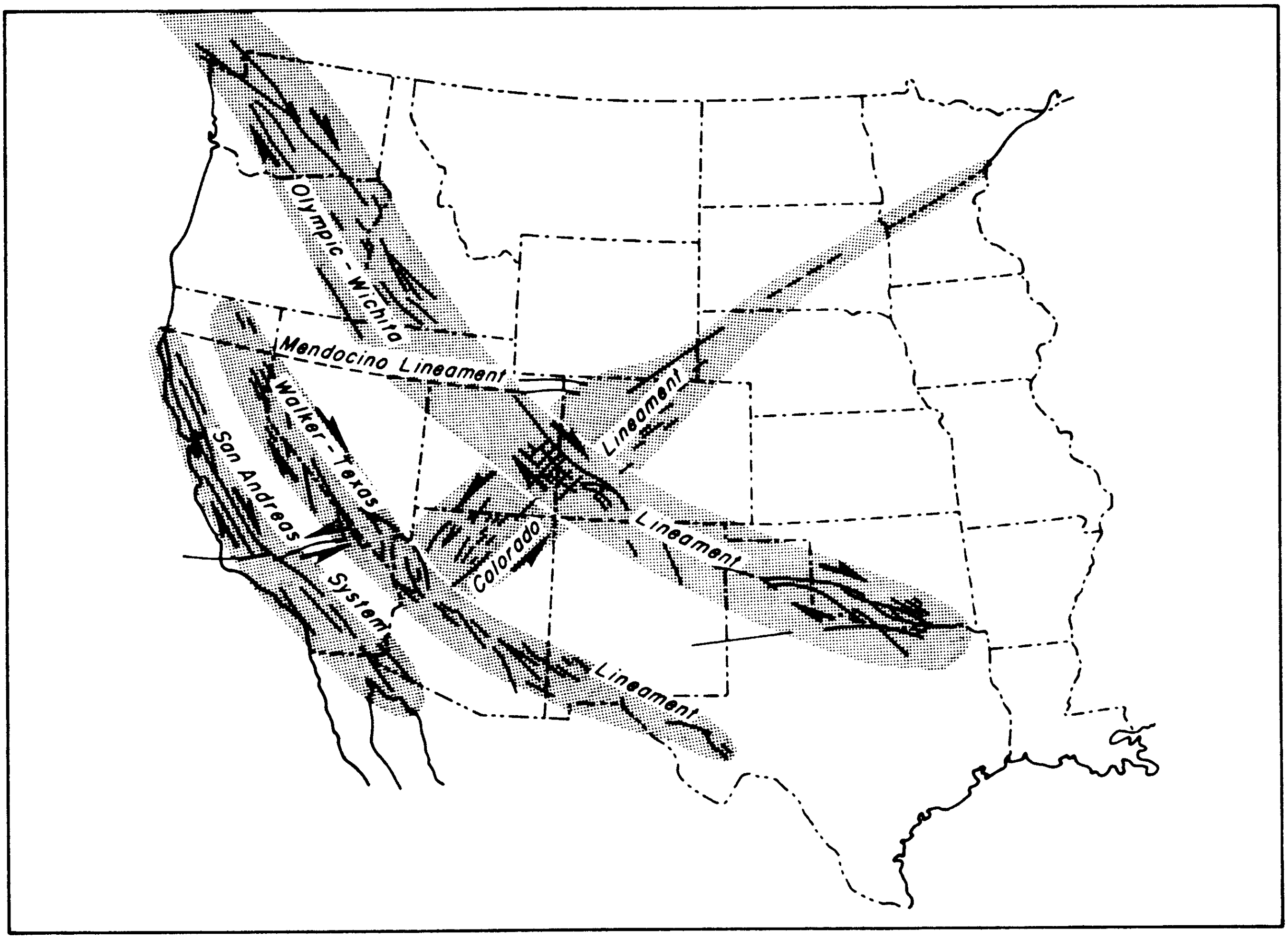

Figure 6.2. Major Precambrian lineaments. Arrows show the sense of strike-slip offset. After Baars and Stevenson (1981).

The early Paleozoic period in the Paradox Basin area was relatively quiescent tectonically, although minor fault movement, subsidence, and uplift contributed to local changes in depositional patterns. The first Paleozoic sediments were laid down in the middle-to-late Cambrian as a transgressive marine and littoral sequence advancing from the west. Uplift during the early Ordovician resulted in non-deposition or complete erosion of sediments from Ordovician to mid-Devonian in age. The only exception appears to be the Aneth Formation, a thin lens of siltstones and dolomites of mid-Devonian age which extends over the south-central portion of the Paradox Basin. The Aneth is a producing zone at Aneth Field but is not present at Lisbon Field.

Subsidence during the late Devonian and early to middle Mississippian permitted the transgression of waters from the west and the south, resulting in deposition of the reservoir rocks at Lisbon Field. Devonian sediments in the area involve three units. The McCracken Sandstone, which is the basal unit of the Elbert Formation, consists of sandstones, dolomites, and shales. The Upper Elbert consists of limestones, shales, and dolomites. The Ouray Limestone is made of relatively dense limestones. Shows of gas have been found in all three units, but only the McCracken

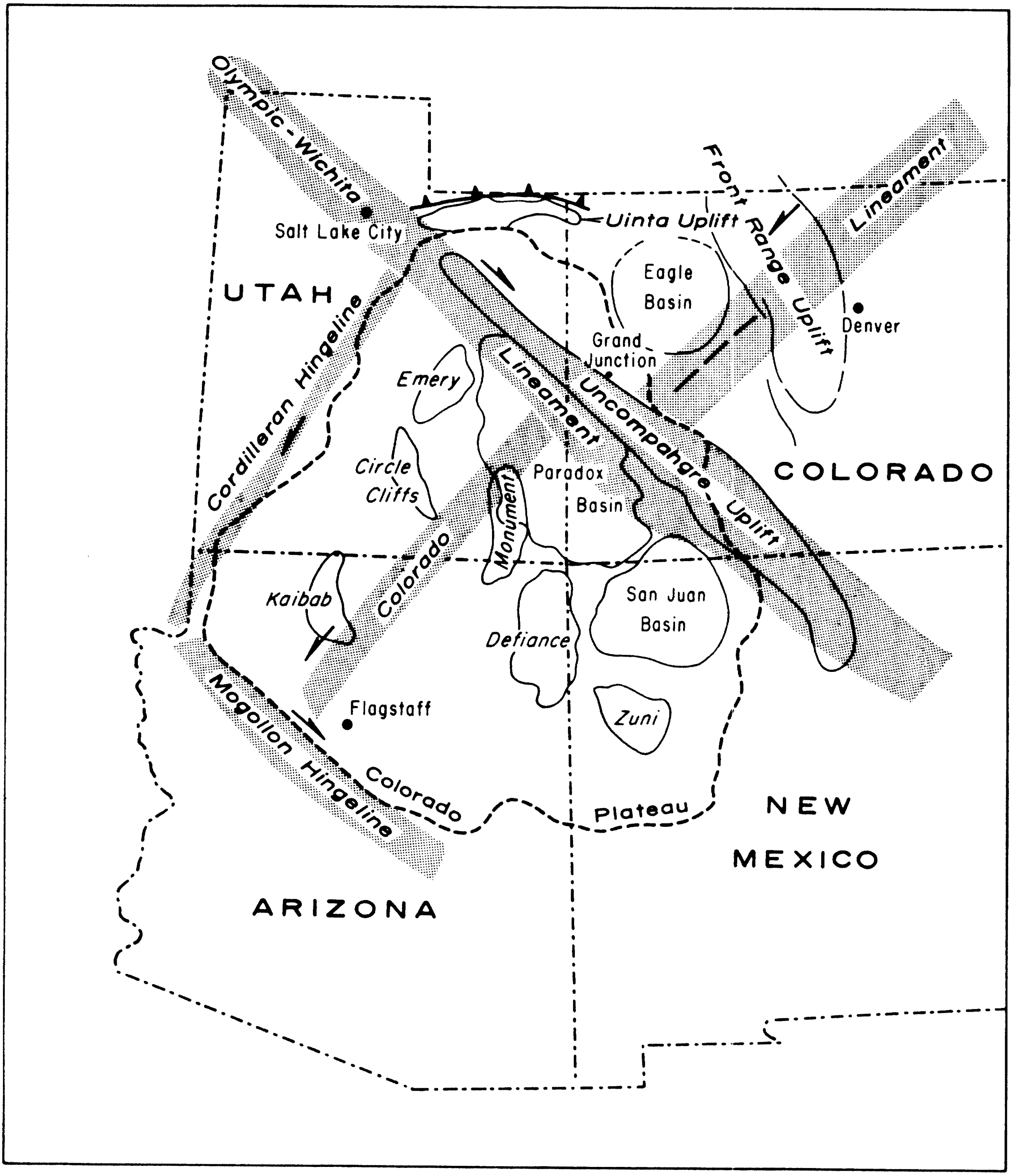

Figure 6.3. Map of the major structural features affecting Paleozoic sedimentation in the west-central United States. Compare this with Figure 6.2. After Baars and Stevenson (1981).

has proved productive (and only marginally, at that). Mississippian sediments were deposited on a broad, shallow marine shelf which dipped gently to the northwest. The single Mississippian unit in the Paradox Basin is the Leadville Formation (known elsewhere as the Redwall Limestone) which constitutes the chief economic reservoir at Lisbon Field.

Tectonic activity slowly increased in late Mississippian time, accelerating in the Pennsylvanian to form the basis of the Rocky Mountain uplift. In the Paradox Basin, the most important features of this event were the Uncompahgre Uplift to the northeast and the Defiance Uplift to the south (Figure 6.3). These features, plus concurrent right-lateral offset along the Olympic-Wichita Lineament, contributed to the formation of the first major topographic expression of the Paradox Basin. Mississippian rocks, which formed the tops of the uplifted areas, were severely eroded, and clastic debris up to 20,000 feet (6,000 m) in thickness was deposited in the low-lying areas from source materials in the Uncompahgre Uplift. The eroded surface of the Mississippian rocks developed a karst topography which is preserved at depth today, and which is also found in much of the central United States.

During the middle Pennsylvanian, the area underwent a period of subsidence due to continued fault movement and clastic deposition, allowing great thicknesses of evaporites to be accumulated. This material is known as the Paradox Salt, and its importance to the local geology is chiefly due to its flow characteristics. It is believed that lateral salt flow was initiated during deposition by the continued loading of arkoses and clastics from the northeast. The salt appears to have flowed laterally to the southwest at first, but this motion was inhibited by the succession of northwest-trending basement faults of the Precambrian Olympic-Wichita Lineament. The salt was then directed upward toward the surface along the fault faces, forming salt diapirs. Areas from which the salt had flowed became depressed and continued to be filled with erosional debris, maintaining the flow mechanism through Permian time.

Permian sediments consist of the Cutler Formation, derived at first from erosion of local hills and ridges, which were generally of low relief, and later from more distant sources. Tectonic activity ceased during Permian time, and the area remained relatively quiescent during the deposition and erosion cycles of the Mesozoic. Salt flow also slowed considerably at this time, although secondary flow from diapirs produced salt "pillows" in the basin.

A minor marine transgression occurred over the Colorado Plateau at the beginning of the Triassic. Waters were shallow and of low energy, producing the siltstones, fine-grained sandstones, ripple marks, and dessication features of the Moenkopi Formation. A change to primarily fluvial and lacustrine environments led to the deposition of Chinle sediments, beginning with bentonitic claystones, mudstones, siltstones, and sandstones, and ending with non-bentonitic units of otherwise similar lithology. The uranium deposits found at Lisbon Field are found in one of the bentonitic units of the Chinle, the Moss Back Member.

The Jurassic-Triassic Glen Canyon Group, consisting of the Wingate, Kayenta, and Navajo formations, probably represents a change to eolian and fluvial environments. The massive, cliff-forming, fine-grained Wingate Sandstone appears to be wholly eolian. The subsequent Kayenta Formation derives its sediments of sandstones, mudstones, and limestones from shallow lacustrine and fluvial sources. The spectacularly cross-bedded Navajo Sandstone is probably mainly eolian, but it also includes some playa-lake beds of cherty limestone.

A second transgression of Mesozoic seas during Jurassic time deposited the silty shales and silty sandstones of the San Rafael Group. Again, depositional environments were of low energy, involving shallow sea-floor sedimentation. Some units appear to be eolian; particularly noteworthy among these is the Slick Rock Member of the Entrada Sandstone, which forms the beautiful and intricate arches and bridges at Arches National Park. Late Jurassic time brought the cross-bedded eolian sandstones, fluvial mudstones, and lacustrine limestones and shales of the Morrison Formation. Similar rocks were laid down to form the Burro Canyon Formation.

Transgression of the Jurassic-Cretaceous seas across the interior of the United States produced the mudstones, shales, and siltstones which characterize the Dakota Sandstone and the Mancos Shale of the Paradox Basin. Marine deposition was concurrent with the onset of the Laramide Orogeny. In most areas of the western United States, the Laramide was an extremely important event which shaped many of the geologic patterns we see today. It was also important in the Paradox Basin area, producing normal faulting with reverse drag on reactivated Precambrian fault patterns. Most of these faults were also overturned to the east, and the uplift of the Colorado Plateau caused streams to flow toward the southwest, cross-cutting the salt anticlines (hence the name "Paradox Basin"). Baars and Stevenson (1981) suggest that the elastic Paradox Salt was crucial in the area's resistance to the severe overthrusting and folding which characterizes the Cordilleran-Mogollon hingelines of Arizona and central Utah.

Salt flow in the Paradox Basin has continued unabated to this date, although not at the original rate established in Pennsylvanian time. It is important to note that the effects of salt flow have caused a wide difference in Paleozoic and post-Paleozoic structure. This fact has made successful seismic interpretation for anticlinal Paleozoic traps a challenging enterprise in the Paradox Basin.

Current Geology

The line location map, topography map, and geologic maps for the Lisbon Field project are presented in Figures 6.4 to 6.8. These maps may be compared to the cross-sections of Figures 6.9 and 6.10.

It is clear from the preceding discussion that the structure of the Paradox Salt is a dominant pattern in Paradox Basin geology. Figure 6.6 is a structural contour map of the top of the Paradox. The prominent northwest-southeast basement fault is flanked to the southwest by the Lisbon Valley-Dolores Anticline. Figure 6.7 shows that the anticline is due primarily to a thickening of the Paradox Salt unit, which is the result of Pennsylvanian and post-Pennsylvanian flowage.

The Paleozoic structure does not correspond directly to the Pennsylvanian structure, which is illustrated by the Mississippian structure map of Figure 6.8. Note the block faulting which is controlled by two high angle, northwest-southeast trending normal faults. The upthrown block on the southwest flank of the southwest fault forms several anticlinal closures which host hydrocarbons at the Lisbon, Hook and Ladder, and Little Valley fields. Big Indian and Wilson Canyon are found on the upthrown block of the northeast fault. It is worthwhile to note that there are alternative views of the secondary fault patterns depicted here (Smith and Prather, 1981).

The cross-sections A-A′ of Figure 6.9 and B-B′ of Figure 6.10 show the Lisbon Field structure from south to north and from southwest to northeast. The cross-section A-A′ corresponds to the data of electrical line 1. The cross-section B-B′, which can be compared to the data of electrical lines 2 and 3, clearly shows the thickening of the Paradox Formation northeast of the Mississippian anticline.

Plate 5.2
RESISTIVITY/PHASE PSEUDOSECTION DATA
Little Buck Creek Field
Niobrara Co., Wyoming

Line 2
a = 1,000 feet

Explanation of Symbols

Standard Well Symbols

⊙	Drillhole for which information is unobtainable
○	Drilling in progress at time of map preparation
ϕ	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

Culture Symbols

ϕ	Metal pipeline, presumed grounded
ϕ UG	Ungrounded pipeline: non-metal or suspended
⟊	Metal fence
⟊	Electric fence
≀	Buried telephone or power cable
T	Telephone line or standard voltage power line
⩚	Major high voltage power line
Y	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

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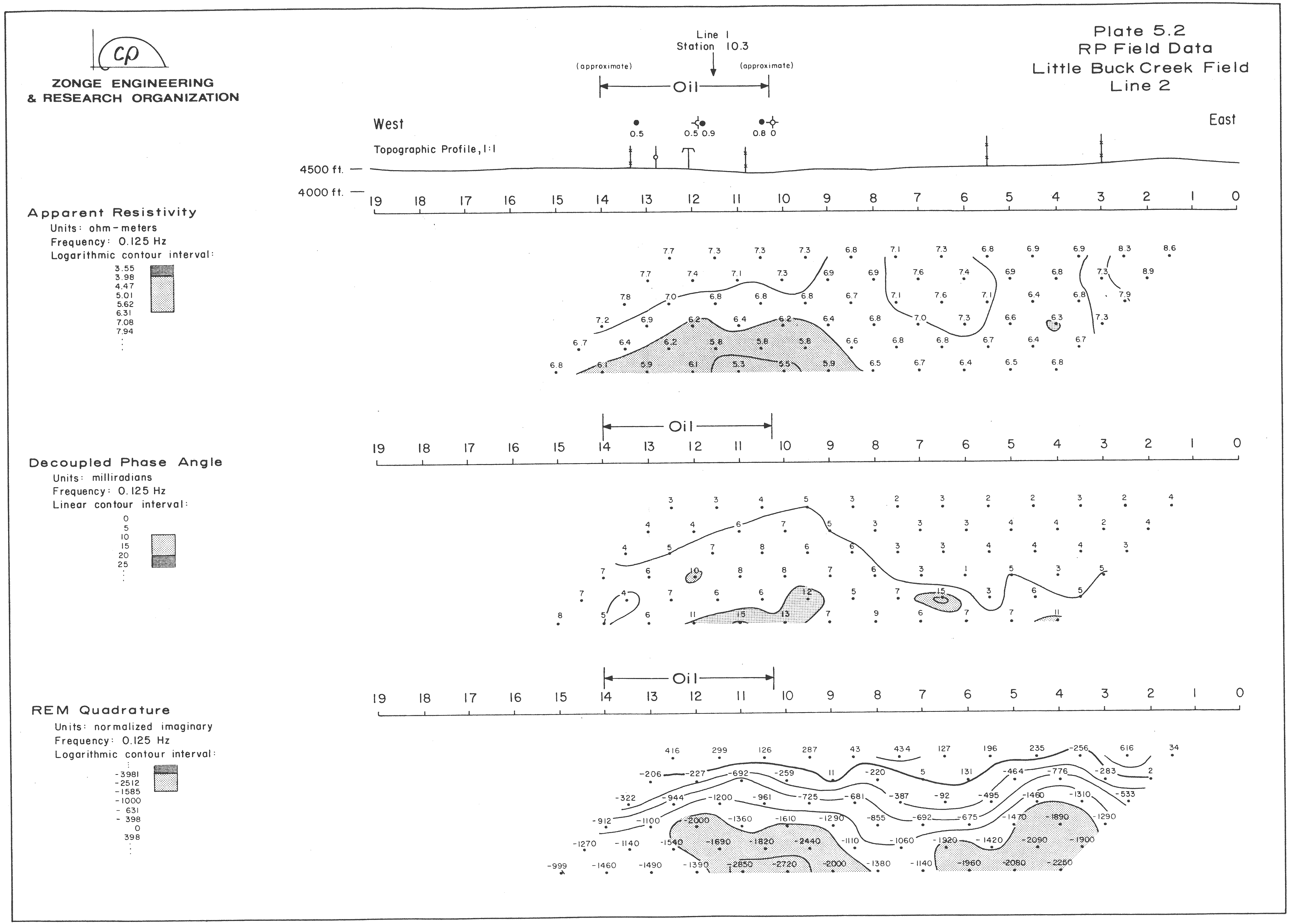
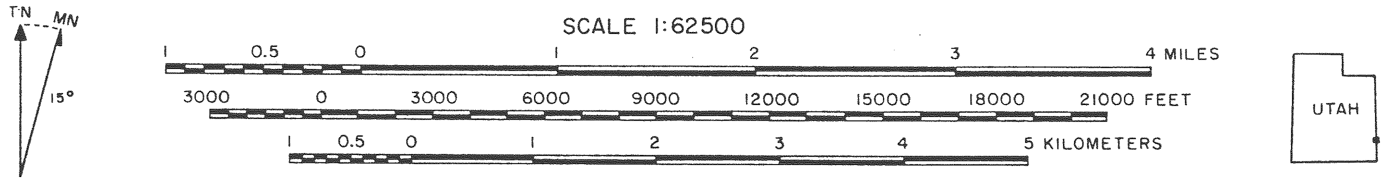


Figure 6.4
LINE LOCATION MAP
Lisbon Field
San Juan Co., Utah



Sources
Base: U.S.G.S. 15' Quad (Lisbon Valley, Ut., 1954; Hatch Rock, Ut., 1954)
Well Data: Petroleum Information Lease-Ownership (U-67, U-68; record take-offs 8-12/82); Bradley (1975); Budd (1960); Clark (1978); Latch (1978 a,b,c); Mitchell (1961); Parker (1961, 1968); Smith (1978)

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
- w Water injection well
- ○ Water well

Culture Symbols

- Metal pipeline, presumed grounded
- UG Ungrounded pipeline: non-metal or suspended
- Metal fence
- Electric fence
- Buried telephone or power cable
- T 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

- 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

- —·— oil-water contact
- — — gas-oil contact
- ▨ oil or gas production

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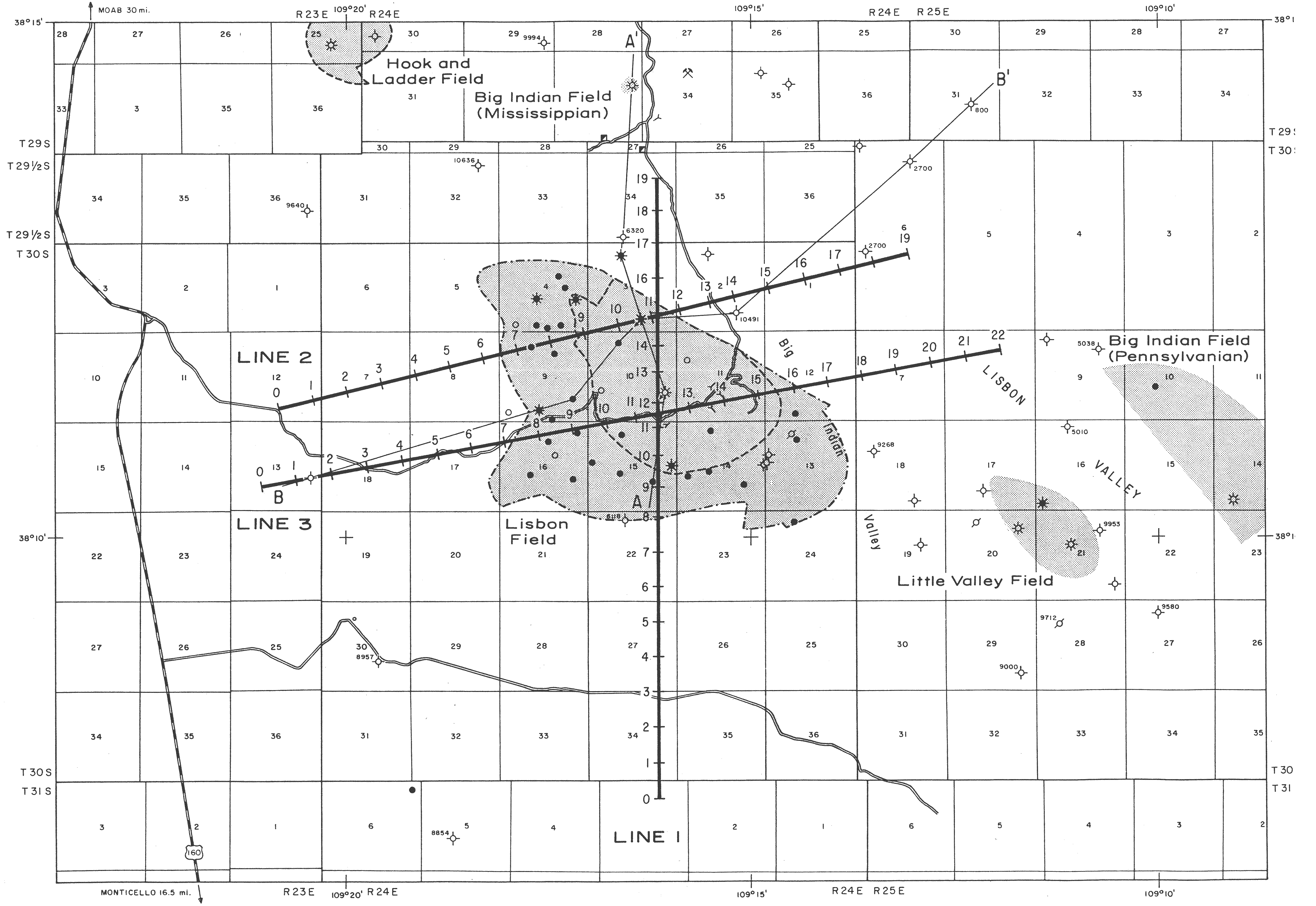
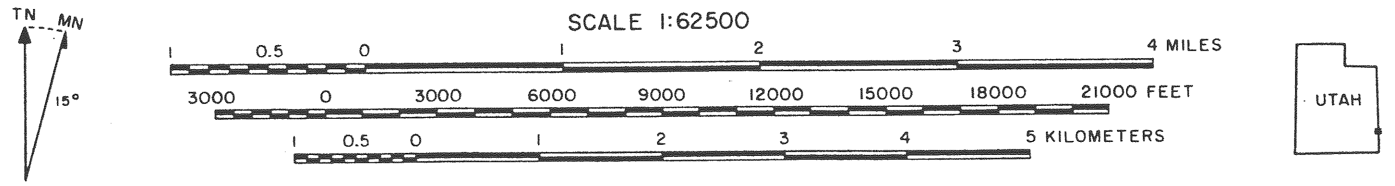


Figure 6.5
SURFACE TOPOGRAPHY MAP
Lisbon Field
San Juan Co., Utah



Sources
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Culture Symbols

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- UG Ungrounded pipeline: non-metal or suspended
- Metal fence
- Electric fence
- Buried telephone or power cable
- T 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

Map-Specific Symbols

Topographic contour interval: 200 feet

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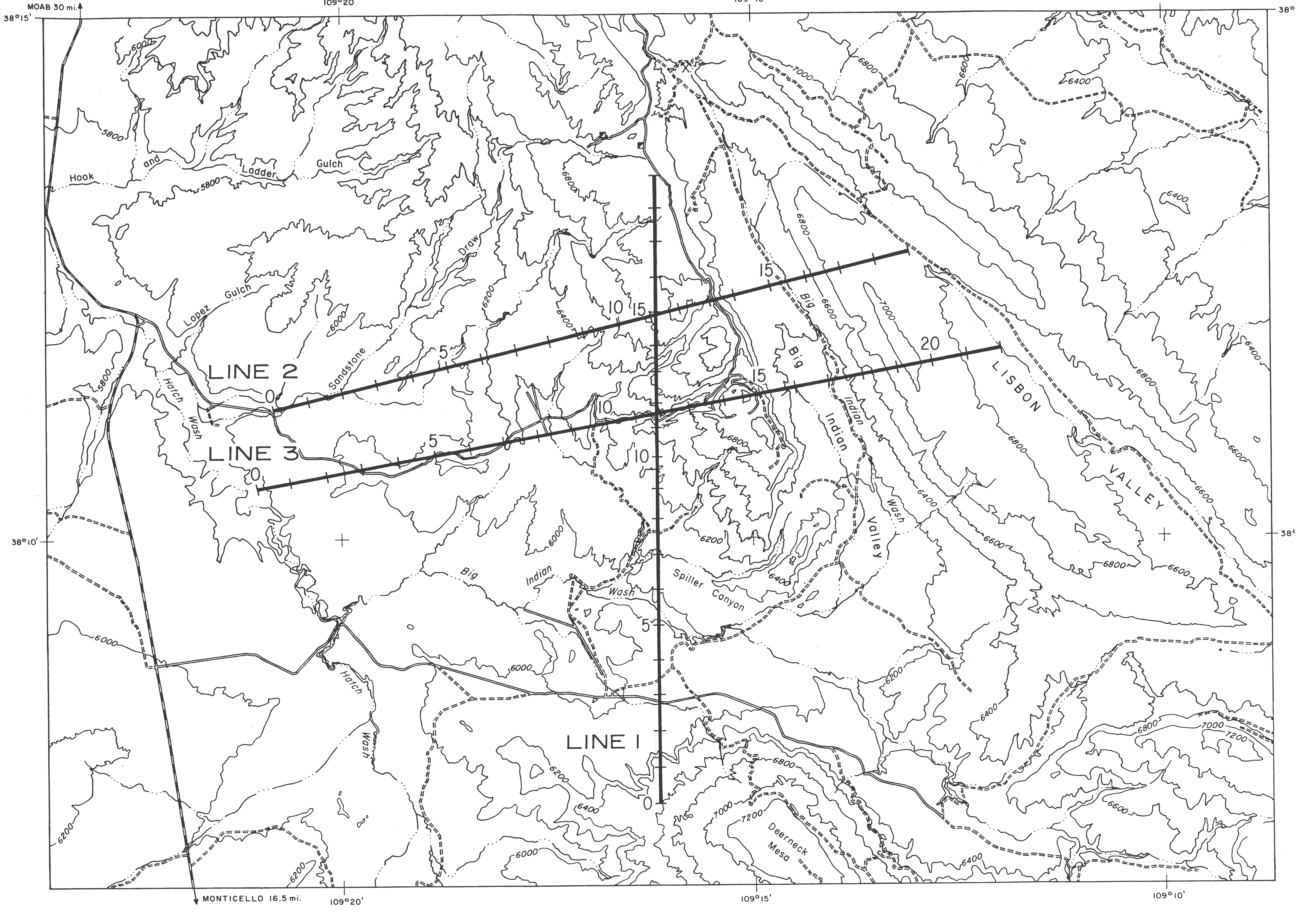
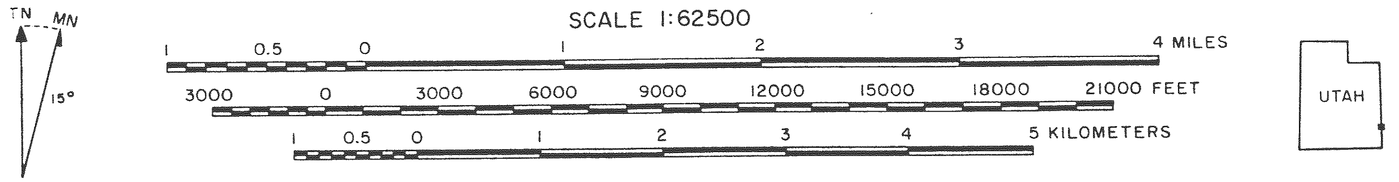


Figure 6.6
STRUCTURE MAP—TOP OF UPPER PARADOX
Lisbon Field

San Juan Co., Utah



Sources
Base: U.S.G.S. 15' Quad (Lisbon Valley, Ut., 1954; Hatch Rock, Ut., 1954)
Well Data: Petroleum Information Lease-Ownership (U-67, U-68; record take-offs 8-12/82); Bradley (1975); Budd (1960); Clark (1978); Latch (1978 a,b,c); Mitchell (1961); Parker (1961, 1968); Smith (1978)
Geology: Parker (1961, 1968); Clark (1978); Latch (1978 a,b,c); Smith (1978)

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- 0.5 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

Structure contour interval: 500 feet

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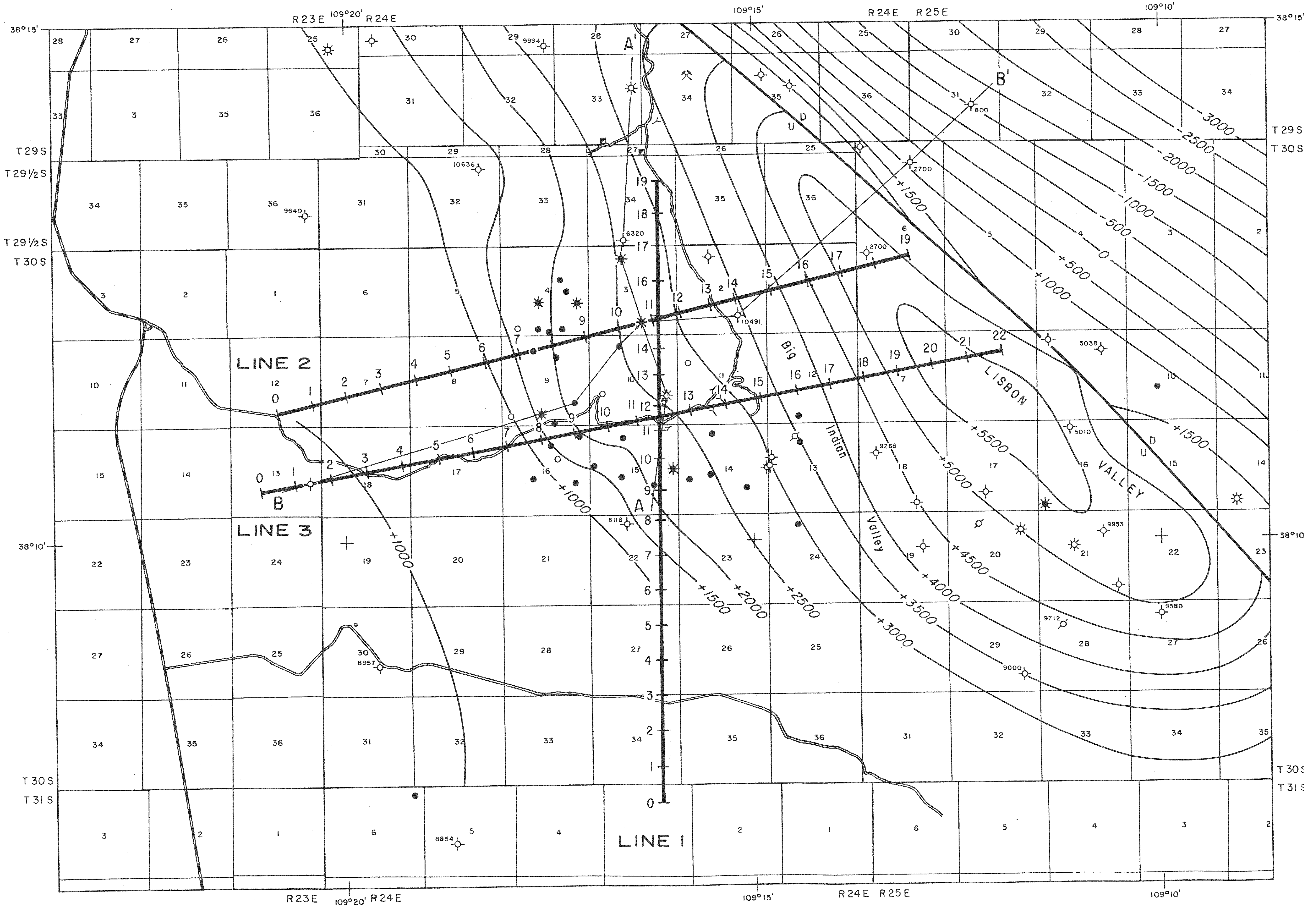

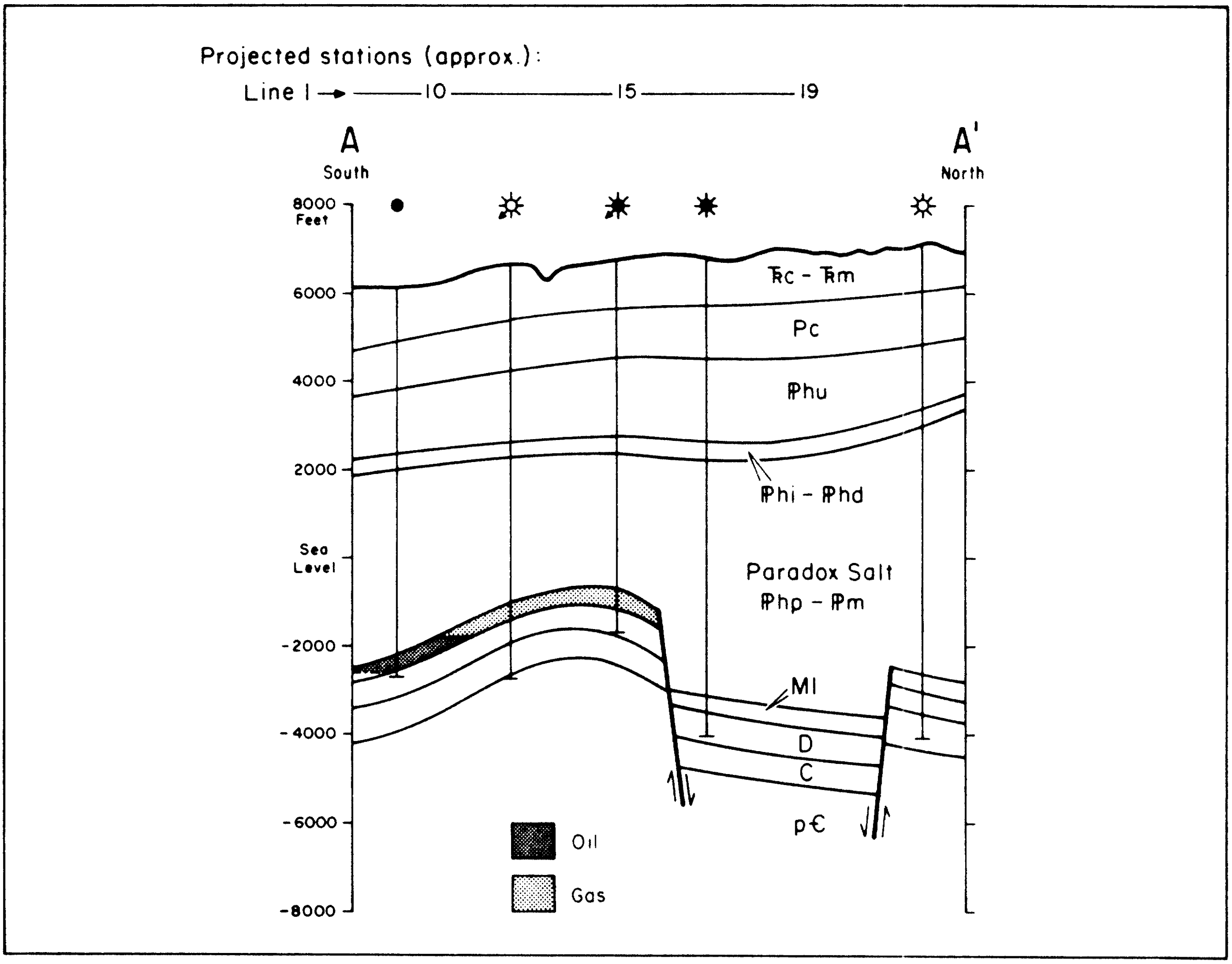

Figure 6.9. Geologic cross-section A-A', with no vertical scale exaggeration; this may be compared with the data from line 1 of the electrical survey. Refer to Figure 6.4 for map location. Geology from Parker (1961).

Reservoir Geology

Although some shows have been observed in the Paradox Salt at Lisbon Field, the only economic production has come from Devonian and Mississippian rocks. The Devonian reservoir is the McCracken Sandstone Member of the Elbert Formation. McCracken porosity and permeability vary erratically, and the unit is only a secondary oil producer. Some production has also come from the Upper Devonian Ouray Limestone. The Mississippian reservoir is the Leadville Formation, the stratigraphic equivalent of the Redwall Limestone, which outcrops prominently in the Grand Canyon of Arizona. Leadville production accounts for most of the production at Lisbon. Both oil and gas are found in the more porous zones of dolomite beds. The trap is formed by a faulted anticline; oil is found in a ring-shaped feature due to the high relief of the enclosing structure, and gas is found in the
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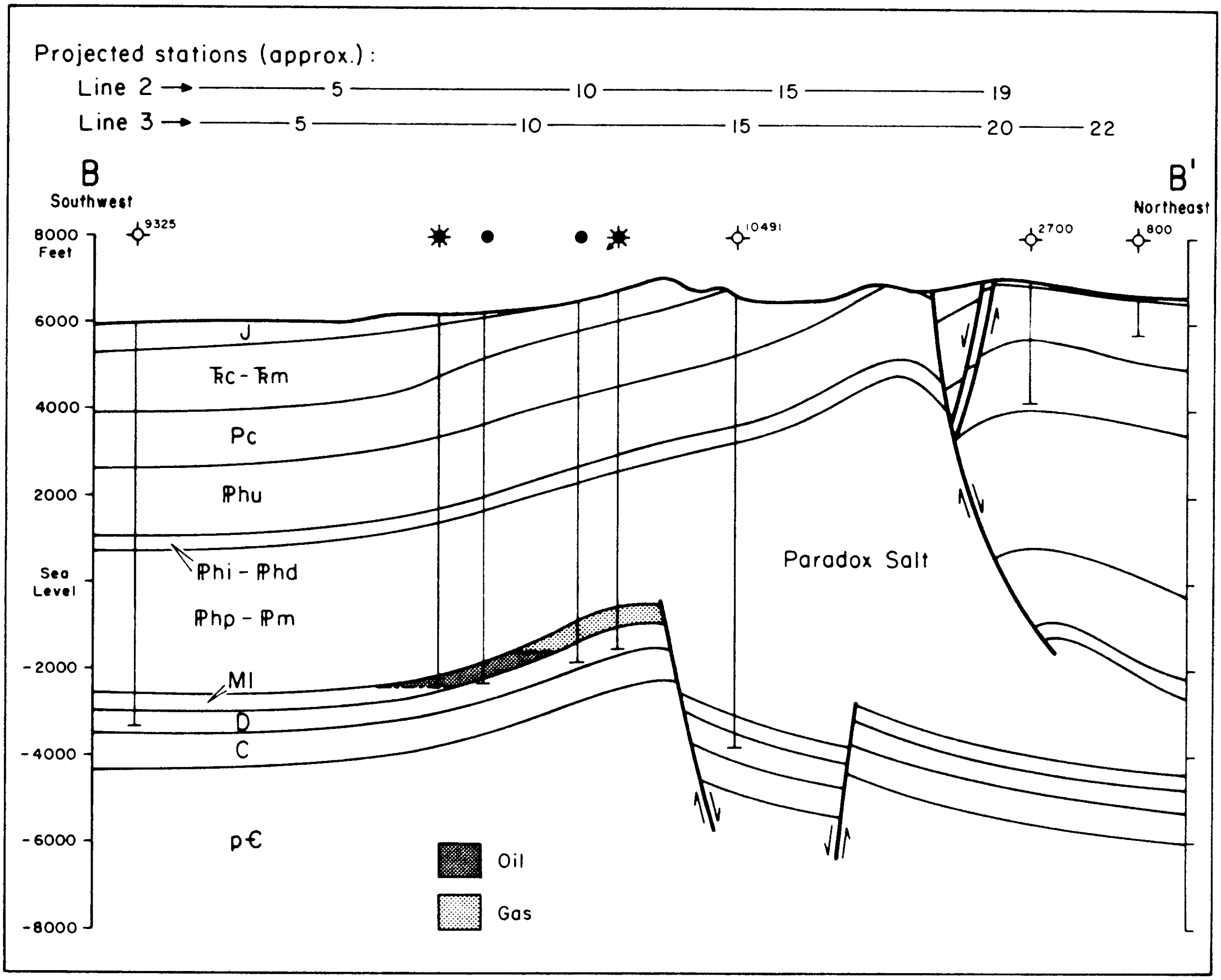

Figure 6.10. Geologic cross-section B-B′, with no vertical scale exaggeration; this may be compared with the data from lines 2 and 3 of the electrical survey. Refer to Figure 6.4 for map location. Geology from Parker (1961).

structural cap (see Figures 6.9 and 6.10). The trap has a closure about equal to the total hydrocarbon-condensate column; hence, it is filled nearly to the spill point. The recovered oil, gas, and water are separated at each well, measured, and piped under pressure to a central plant. The constituents are then stage-separated. Oil is stabilized and marketed, gas is stripped, compressed, and reinjected back into the gas cap, and salt water is injected back into the Leadville through a dry well south of the field.

Table 6.2 presents statistical information on the Leadville and McCracken reservoirs. The differences in BTU and other characteristics have suggested to some that the hydrocarbons in the two reservoirs have two distinct source beds. These source beds are unknown, although the black shale section of the Paradox Forma-

TABLE 6.2: RESERVOIR CHARACTERISTICS OF LISBON FIELD

General Field Data

Region: Paradox Basin
Production: Oil, gas
Type of Trap: Structural; faulted anticline
Producing Formations and Depths: Leadville Fm., 7,500-8,500 ft
Elbert Fm., McCracken Ss. mbr., 8,300 ft
Other Significant Shows: None
Total Reserves: 250 BCFG, 44.3 MMBO
Productive Area: Proved 5,120 acres in Leadville and 1,050 acres in McCracken
Field Operator: Union Oil
Number of Producing Wells (12/80): 12 (plus 3 injection wells)
Number of Shut-in Wells (12/80): 12
Well Casing Data: Surface casing 13-3/8 inch to about 73 ft; 9-5/8 to 10¾ inch casing to between 700 and 1,200 ft; production casing 5½ or 7 inch to total depth (typical well). Paradox section is cemented.

Discovery Well

Name: Pure Oil No. 1 SW Lisbon USA
Location: NE-NW-10-T30S-R24E
Completion Date: 1/5/60
Total Depth: 8,440 ft
Perforations: 7,567-7,970 ft (Leadville); 8,261-8,293 ft, 8,310-8,348 ft (McCracken)
Initial Potential: Flow 179 BOPD, 4,376 MCFGPD (Leadville); 586 BOPD (McCracken)
Treatment: HyFlo, acid, sand-oil fracture

Reservoir Data: Leadville Formation

Discovery: 1/5/60, Pure Oil No. 1 SW Lisbon USA, NE-NW-10-T30S-R24E
Lithology: Dolomite and limestone
Age: Mississippian
Type of Trap: Structural; faulted anticline
Drive Mechanism: Expanding gas cap and gravity drainage
Initial Pressure: 2,982 psi at −2,400 ft
Reservoir Temperature: 127°F (est.)
Gross Thickness of Reservoir Rock: 225 ft
Porosity: 5.5% average; highly variable, 1 to 21%; mainly fracture porosity
Permeability: 22 millidarcies average; highly variable, 0.01-1,100 millidarcies
Oil/Gas Column: 1,870 ft
Gas/Oil Ratio: 1:1,200 at base of oil ring, 37,500:1 at top of gas cap
Original Gas/Oil Contact: −1,800 ft
Original Oil/Water Contact: −2,570 ft
Gas Character: Sour; 740 BTU (1,207 BTU in oil ring); specific gravity 0.97
Gas Analysis:

	Lisbon No. 1 USA C-4-T30S-R24E −2,200 ft	Lisbon No. 2 -21-F 21-T30S-R25E −2,450 ft
Methane	40.1%	61.03%
Ethane	8.5	5.19
Propane	5.2	1.38
Nitrogen	15.5	13.03
Oxygen	trace	not analyzed
Argon	0.1	not analyzed
Helium	1.0	not analyzed
Hydrogen	0.1	not analyzed
Carbon dioxide	26.7	15.42
Hydrogen sulfide	0.0	2.17

TABLE 6.2 Continued

Oil Character: Sour, yellow to red; gravity 54°API (71°API in gas cap)
Oil Analysis: Carbon dioxide 20%
Water Saturation: 39%
Water Salinity: High, 70,000 to 100,000 ppm TDS
Water Resistivity: 0.045 to 0.06 ohm-meters at 127°F
Daily Average Production (12/80): 53,230 MCFGPD, 1,894 BOPD, 3,729 BWPD
Cumulative Production (1/60-12/80): 363 BCFG, 42.7 MMBO, 11.4 MMB liquids
Estimated Primary Recovery[1]: 250 BCFG (70%), 25.7 MMBO (30%)
Type of Secondary Recovery: Controlled pressure decline by crestal gas injection
Estimated Ultimate Recovery[1]: 250 BCFG (70%), 42.9 MMBO (47%)

Reservoir Data: Elbert Formation, McCracken Sandstone member

Discovery: 1/5/60, Pure Oil No. 1 SW Lisbon USA, NE-NW-10-T30S-R24E
Lithology: Dolomitic sandstones and shales, sandy dolomites
Age: Devonian
Type of Trap: Structural; faulted anticline
Drive Mechanism: Solution gas
Initial Pressure: 2,713 psi at 8,271 ft
Reservoir Temperature: 131°F
Porosity: 8%
Permeability: 2.6 millidarcies
Original Oil/Water Contact: −2,300 ft
Gas Character: Sweet; 1,300 BTU
Oil Character: Red, waxy; gravity 43° to 50°API
Water Saturation: 43%
Water Salinity: High, 70,000 to 100,000 ppm TDS
Water Resistivity: 0.043 to 0.058 ohm-meters at 131°F
Daily Average Production (1981): 26 BOPD
Cumulative Production (1962-9/65): 202,838 MCFG, 110,805 BO, 4,552 BW
Estimated Primary Recovery: 1,375,800 BO (20%)
Type of Secondary Recovery: None
Estimated Ultimate Recovery: 1,375,800 BO (20%)

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[1] Initial estimates for oil, which are apparently much too low.

tion, where stains are found today, has been suggested as a likely candidate. Accumulation in the present-day traps may have occurred in the late Mississippian or Pennsylvanian times, according to Parker (1968).

Groundwater Characteristics

The groundwater regimes of the Paradox Basin can be divided into three distinct hydrostratigraphic units (Thackston, McCulley, and Preslo, 1981). The upper unit, which lies above the Paradox Formation, is high in calcium, magnesium, and bicarbonates. It also contains a variable level of sodium chloride, much of which appears to originate in the upper Pennsylvanian Honaker Trail Formation. No sodium-rich evaporites have been reported in the Paradox Basin, and Thackston, McCulley, and Preslo (1981), speculate that most of the sodium is supplied by "ion exchange in clay-rich strata and alteration of plagioclase." The flow characteristics of the upper unit are controlled primarily by gravity. At Lisbon, this would mean that flow would be into Hatch Wash, immediately south and west of the producing field.

The middle flow regime is in the Paradox Formation. The high evaporite content in the Paradox causes it to behave as an acquitard. Permeability is usually very limited, and although some shows of brine water and hydrocarbons have been observed in the Paradox, these pockets are quite isolated. It is not surprising, therefore, that water composition in the middle regime is quite variable. In general, the total count of dissolved solids is high; principal ions are sodium, chlorine, potassium, calcium, and magnesium.

The lower flow regime lies primarily in the Mississippian Leadville Formation. Flow is generally unrestricted and is very extensive due to good permeabilities. The flow direction is primarily controlled by subsurface structure, but the general regional flow in the basin is toward the southwest. The salinity of these waters is quite high, about 66,000 to 82,000 parts per million of total dissolved solids. Areas overlain by the Paradox Salt appear to be more saline than areas outside the basin which are not overlain by salts, indicating that some solution of the Paradox salts is occurring. However, it is unlikely that any significant mixing of the middle and lower hydrostratigraphic units occurs. Instead, most of the salt contribution from the Paradox probably occurs by means of mechanical solution in the vicinity of fractures and faults in the salt body.

Well-Casing Information

Normal drilling practice at Lisbon is to set a 13-3/8-inch (34.0 cm) casing from the surface to as deep as 73 feet (22 m) depending upon surface conditions. Casing of 9-5/8 to 10-3/4 inches (24.5-27.3 cm) diameter is then set to 700 to 1,200 feet (210-365 m). The well is then drilled to total depth, 5-1/2 or 7-inch (14.0 or 17.8 cm) production casing is set, and the Paradox Salt section is cemented. Well-casing models used for interpretation use a casing diameter of 10-3/4 inches.

6.3
DISCUSSION OF THE DATA

Introduction

A resistivity/phase crew of eight persons, headed by Zonge Engineering geophysicist Norman R. Carlson, was mobilized to the Lisbon Field project on April 11, 1980. Two subparallel lines and one cross-line were run using a dipole length of 2,000 feet (610 m); data were obtained at 0.125, 0.25, 0.5, and 1.0 Hz. Work continued through May 2. A total of 22.6 surface line-miles (36.3 line-km) were covered; total subsurface coverage was 13.6 line-miles (22.0 line-km).

The Lisbon project presented a number of difficulties typical of those which can confront an electrical survey of this type. Topography was significant, involving numerous mesas with steep cliffs. This slowed production at times and produced topographic effects in the data. Heavy electrical noise was encountered from electrical storms during most of the survey, and extensive stacking and averaging were required to obtain acceptable data. Production had to be terminated on several days due to danger of electrical shock from lightning. Another source of noise was the workings in the subsurface uranium mines at Lisbon. Mine machinery and railways powered by direct electrical current produced large shifts in the ground potential observed at the surface, necessitating strategic planning of data acquisition. Culture was a significant problem at Lisbon Field. Cultural features consisted of numerous cased wells, grounded surface collection pipelines, telephone lines, medium to heavy duty powerlines, and fences. Pipelines and well casings produced the majority of cultural contamination in the data, while powerlines contributed significant amounts of 60 and 180 cycle noise.

The apparent resistivity, apparent polarization, and REM data for lines 1, 2, and 3 are presented as Plates 6.1, 6.2, and 6.3 at the back of this chapter. They may be unfolded for reference while reading the text.

Line 1 Interpretation

As shown in Figure 6.4, line 1 traversed Lisbon Field from south to north. Permit restrictions prevented the acquisition of data off the northern end of the field, but a fair amount of background information was obtained to the south. The field data are presented in Plate 6.1.

APPARENT RESISTIVITY DATA

The apparent resistivity layering is high/low/high on line 1. The data show a shallow southerly dip similar to that depicted in the cross-section A-A′ (Figure 6.9). The high resistivities at the surface, which pinch out north of the middle of the line, may be correlated with lower Jurassic and upper Triassic sediments which outcrop south of the oilfield. There is probably a general trend toward high resistivities at the surface across the entire line, indicating that the surface rocks are probably dry. The middle, low resistivity layer can be correlated quite well to the lower Triassic Chinle and Moenkopi formations and the Permian Cutler Formation. As shown in Table 6.3, well logs show these units to be low in resistivity. The high resistivity layer at depth corresponds to Pennsylvanian sediments, particularly the highly resistive Paradox Salt.

TABLE 6.3: WELL LOG RESISTIVITIES[1] LISBON FIELD

	Lisbon Unit #B-616 SE-NE-NW-16-T30S-R24E		Lisbon Unit #B-99 SE-SW-9-T30S-R24E	
Formation	**Average Resistivity (ohm-meters)**	**Range in Resistivities (ohm-meters)**	**Average Resistivity (ohm-meters)**	**Range in Resistivities (ohm-meters)**
Chinle, Moenkopi (Triassic)	20	8-30	20	8-32
Upper Cutler (Permian)	35	10-250	30	10-150
Lower Cutler (Permian)	50	15-250	45	15-100
Honaker Trail (Pennsylvanian)	80	15-≫250	100	10-≫450
Upper Paradox (Pennsylvanian)	100	40-≫250	100	20-≫250
Paradox Salt (Pennsylvanian)	≫250	5-≫250	≫250	10-≫250
Leadville (Mississippian)	80	20-500(?)	60	20-1000(?)
Ouray, Elbert (Devonian)	500(?)	250-1000(?)	500(?)	250-1000(?)

[1] Schlumberger Laterolog 3

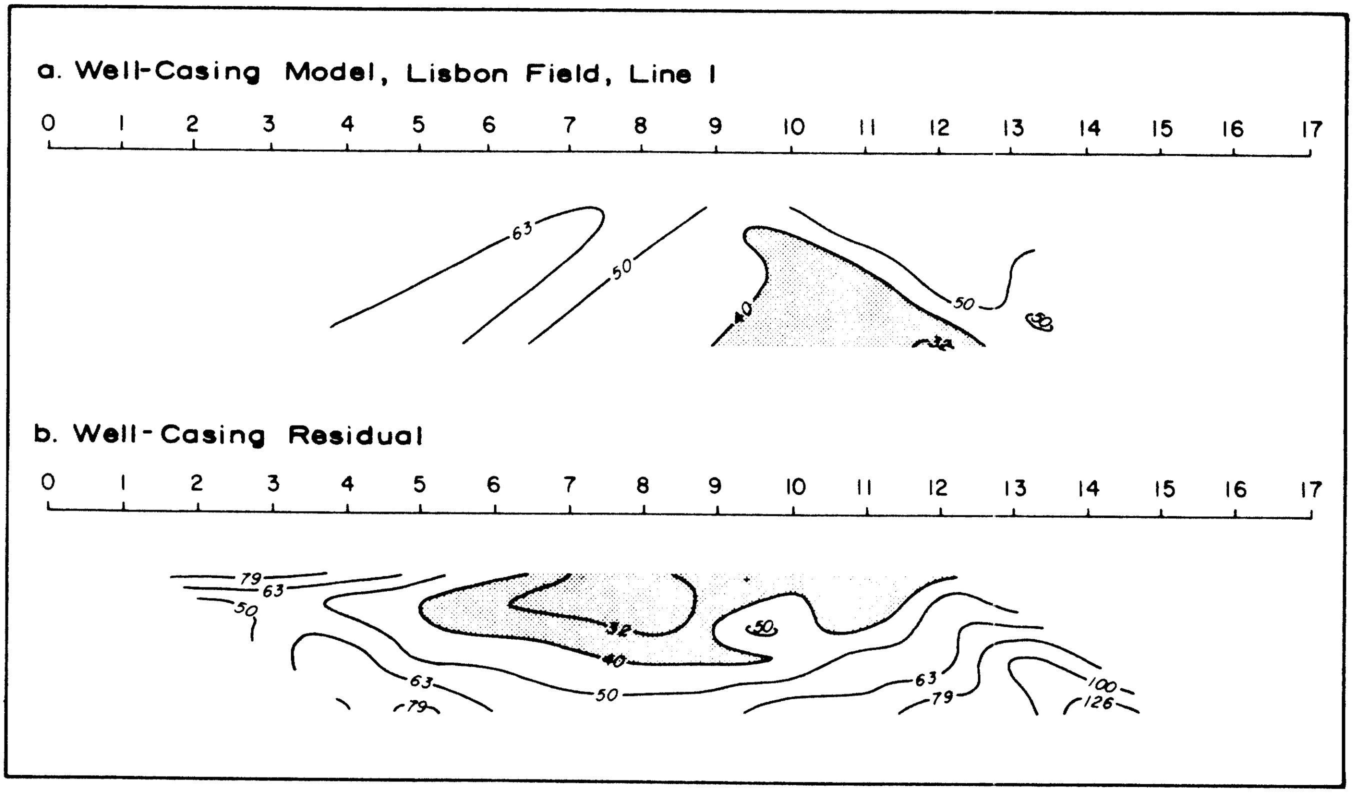
Superimposed upon the layering effects is a broad zone of low resistivities extending from the surface to moderate depths. The southern edge of the low resistivity zone corresponds roughly to the southern edge of the producing field. The right-plunging, high resistivity diagonal 10,11 and premature data cut-off towards the north prevent drawing any conclusions as to how well the data correlate with the northern edge of the producing field.

In order to determine the origin of the conductive anomaly, four possibilities will be examined: culture, surface topography, subsurface structure, and hydrocarbon-related electrochemical alteration.

There is an extensive amount of culture near line 1, including five cased wells within one dipole spacing of the line. A well-casing model was constructed to simulate the apparent resistivity data, using the "PIPE" algorithm of Holladay and West (1982). Despite serious qualifications regarding application of this model to field data (section 2.5), the algorithm is useful in presenting a *worst-case* scenario regarding well-casing effects. A well-casing diameter of 10-3/4 inches (27.3 cm) was assumed, even though many casings are only 9-5/8 inches (24.5 cm) in diameter at Lisbon, and despite the fact that all casings are only 5-1/2 to 7 inches (14.0-17.8 cm) in diameter at depths greater than about 1,000 feet (300 m).

The well-casing model data and residual data are presented in Figure 6.11. The model data show a chevron-shaped, low resistivity zone centered between stations 9 and 10; the strongest effect occurs along the 8,9 right-plunging diagonal. Note that while the field data show the low resistivity zone at intermediate to shallow depths, the well-casing model shows a significant effect at all depths. Hence, it is not surprising that the residual data, which show the residual of the field data after removal of calculated well-casing effects, show an anomaly very similar to that seen in the original field data. Therefore, one can conclude that, even in the most severe application of the "PIPE" model, well casings do not account for all the conductive anomaly observed on line 1.

The potential effects of other culture along line 1 should also be considered. There is no evidence that the fence at station 6 has any effect on the apparent resistivity data. There is also no evidence of effects from the powerlines at stations



a. Well-Casing Model, Lisbon Field, Line 1

b. Well-Casing Residual

Figure 6.11. Well-casing model of apparent resistivity data for line 1, Lisbon Field. Model parameters: 23 cased wells, casing diameter = 10-3/4 inches (24.5 cm), casing resistivity = 2.0 x 10^{-7} ohm-meters, surface impedance = 0 + 0.2*i*, background resistivity = 60 ohm-meters. Figure 6.4 shows well locations.

13.5 and 17.8, or the one parallel to line north of station 17.8, and by inference, one would not expect much of an effect from the powerline at station 8.4. On the other hand, one can see that there may be some effects due to the pipelines, especially the double pipelines at stations 7.1 and 7.8. There are, however, three objections to the assumption that pipelines are responsible for the anomaly. First, and most important, the anomaly clearly overshoots the expected zone of influence of the pipelines, since it appears to extend past the north end of the line. Second, a strong pipeline effect should present itself as a strong, chevron-shaped anomaly similar to that illustrated in section 2.6, yet no evidence of such an effect can be seen in the data. The right-plunging 8,9 and left-plunging 10,11 diagonals might be related to the pipelines but only one leg of each chevron is present. Third, several pipelines on lines 2 and 3 show no effects on the data at all, despite the fact that they are located closer to electrode stations than any of the pipelines on line 1. It can therefore be concluded that pipelines do not cause a major portion of the anomalous response on line 1, although they may contribute to it.

Since the line crossed a number of mesas and ravines, it is appropriate to consider the effects of topography. The two-dimensional model "2DIP" was used to estimate topographic effects. The model results, which are reproduced in Figure 6.12, indicate that topography does not contribute to the anomaly seen on line 1.

The possibility that subsurface lithologic structure causes or contributes significantly to the conductive anomaly is considered to be minimal. The changes which produce the anomaly are certainly located within 2,000 to 3,000 feet (600-900 m) of the surface, and one can readily see from the cross-section A-A' (Figure 6.9) that insufficient structural changes occur at these depths to explain this anomaly. One could argue that the middle, low resistivity layer, which was noted earlier, appears to outcrop in the vicinity of the anomaly. However, the anomaly is certainly due to a vertical resistivity change and cannot be attributed to a shallowly dipping, outcropping layer. Figure 6.13 shows a model analogue to support this conclusion: note that the outcropping, low resistivity layer produces only layering effects, not the sharp lateral-type effects seen in the field data.

We have seen that the resistivity anomaly observed on line 1 cannot be readily explained by the effects of culture, topography, or subsurface structure, and it is unlikely that any combination of these three effects produces the anomaly, although they probably contribute to it. Hence, we are left with the alternative that

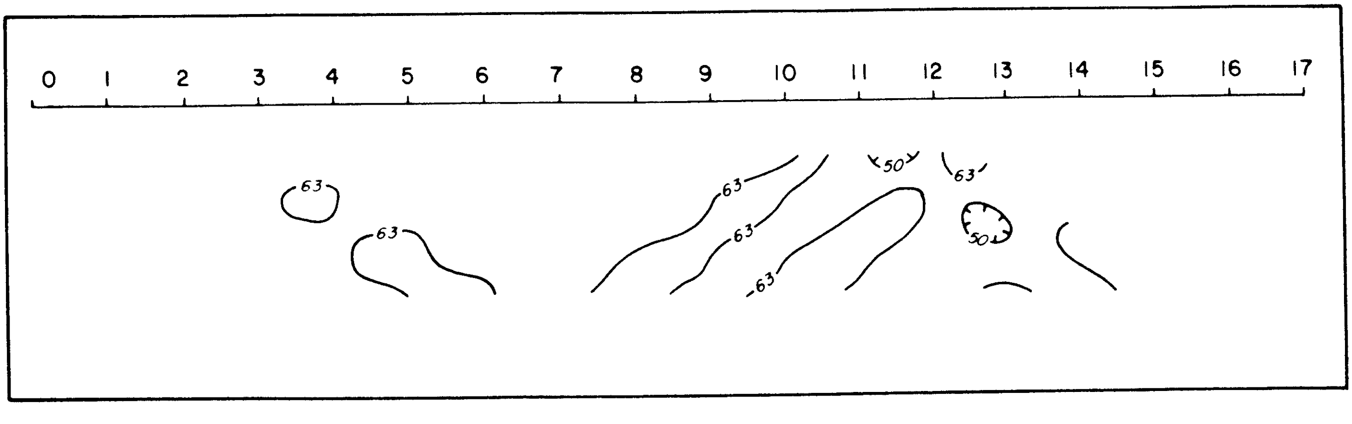


Figure 6.12. Topographic model of apparent resistivity data for line 1, Lisbon Field. Background resistivity = 60 ohm-meters. Plate 6.1 shows topography.

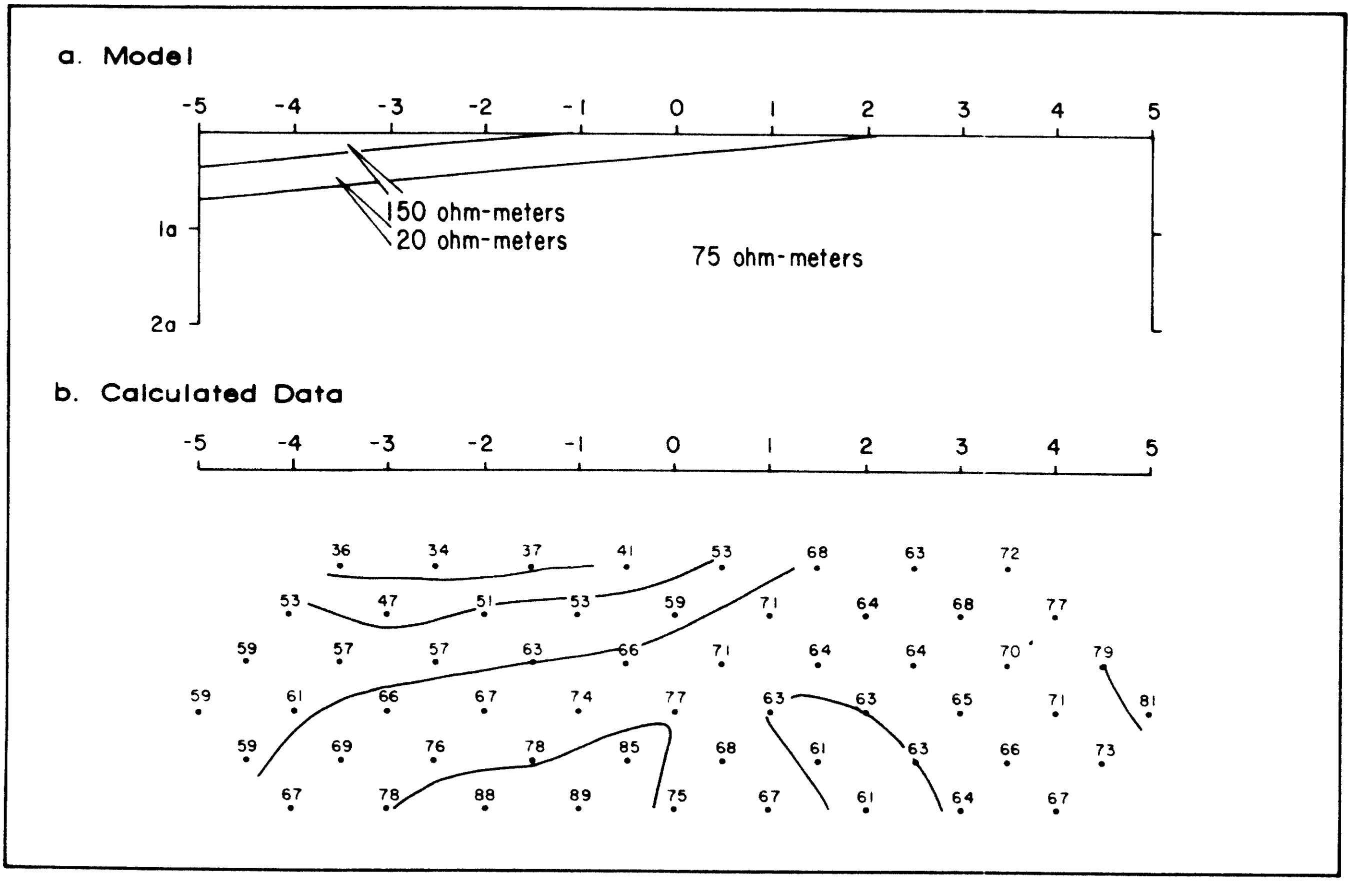


Figure 6.13. Two-dimensional resistivity model of a shallowly dipping, outcropping conductive layer.

a true low resistivity zone exists in the sediments directly overlying the hydrocarbons. Modeling indicates that the bottom of this zone may lie as deep as 3,000 feet (900 m), and it appears to extend upward to the near-surface rocks. Due to the complexity of the data, it is not possible to distinguish fine structure within this zone.

APPARENT POLARIZATION (DECOUPLED PHASE ANGLE) DATA

The polarization data show a high-over-low layering. High polarization values appear to be associated with the high resistivity Jurassic and upper Triassic sediments, and low polarization values appear to be associated with all the sediments below. The only feature of interest is a rather convoluted polarization high at depth, which consists primarily of a few anomalous values along the right-plunging diagonals 6,7 and 7,8. However, there is no indication that the higher polarization values are correlated with the lateral extent of the hydrocarbons. It is probable that the isolated highs are due to the combination of a slight amount of noise, geometric effects of outcropping of lithologic layers, and minor effects of well casings.

RESIDUAL ELECTROMAGNETIC (REM) DATA

The REM data show a broad, relatively conductive zone which correlates well with the lateral extent of the hydrocarbons. The REM data provide two advantages over the galvanic data on line 1. First, effects due to layering are de-emphasized, since the quadrature component of REM responds primarily to lateral resistivity changes and not layering. This explains the more clearly defined shape of the REM anomaly, since "smearing-out" effects of low resistivity layers are not as strong as they are with galvanic data. Second, the effective penetration of REM is often deeper than that of the galvanic data. The strongest portion of the anomaly is at n=3, which may be some 3,000 feet (900 m) deep, suggesting that conductive alteration may exist in sediments as deep as the Upper Paradox. Apparent resistivity data tend to support this conclusion.

Line 2 Interpretation

Line 2 was run in an east-northeast direction over the Lisbon Field mesa area into the Big Indian and Lisbon valleys. Sufficient coverage was obtained to provide data over both ends of the producing field. The data are shown in Plate 6.2.

APPARENT RESISTIVITY DATA

As was observed on line 1, the apparent resistivity layering is high/low/high on line 2. The cross-section B-B′ (Figure 6.10) and the well-log resistivities of Table 6.3 indicate that the surface high resistivity layer is associated with Jurassic and upper Triassic sediments; the middle, low resistivity layer is associated with lower Triassic and Permian sediments, and the high resistivity layer at depth is associated with Pennsylvanian units, in particular the highly resistive Paradox Salt.

A very strong zone of low resistivities correlates very well with the lateral extent of the producing zone on line 2. The zone appears to extend from near the surface to considerable depth. Following the procedure used in the discussion of line 1, the source of the low resistivity anomaly will be investigated by examining four possibilities: culture, surface topography, subsurface structure, and hydrocarbon-related electrochemical alteration.

Eight cased producing wells lay within one dipole spacing of line 2. In order to develop a worst-case description of well-casing effects, a "PIPE" model was run, including all cased wells within three dipole spacings of the line.

The well-casing model data and residual data are presented in Figure 6.14. The model data show a strong, low resistivity zone concentrated beneath station 9. It extends from stations 7 to 11 near the surface and fans out at depth due to geometric effects. The shape of the model anomaly at depth faintly resembles the shape of the anomaly in the field data, so it is not surprising that the residual data, which show field data minus calculated well-casing effects, have an appearance which is quite different from the original field data. This residual pseudosection (Figure 6.14b) shows a weak zone of low resistivities at intermediate depths between stations 6 and 7, and a shallower, stronger zone of low resistivities between stations 9 and 12. The two are separated by what appears to be a slightly resistive zone beneath stations 8 to 9, although it is possible that this zone is an artifact of overcorrection by the well-casing model. In any case, the data clearly show a conductive anomaly which cannot be attributed entirely to well casings. It is quite likely, based upon the discussion of Chapter 2, that well casings affect the data to a far lesser degree than shown in the worst-case modeling presented here.

Other types of culture present a potential problem on line 2. Three powerlines cross the line at station 7.2, and another crosses at station 11.4. Since the powerlines and several pipelines are clustered together, their effects cannot be easily separated. The pipeline near station 8 may contribute to the low resistivities on the left-plunging 8,9 diagonal and the right-plunging 7,8 diagonal; certainly this pipeline has a strong effect upon the phase data. However, the strongest effect should occur at n=1 and n=2, an effect which is not observed in the resistivity data. The pipelines

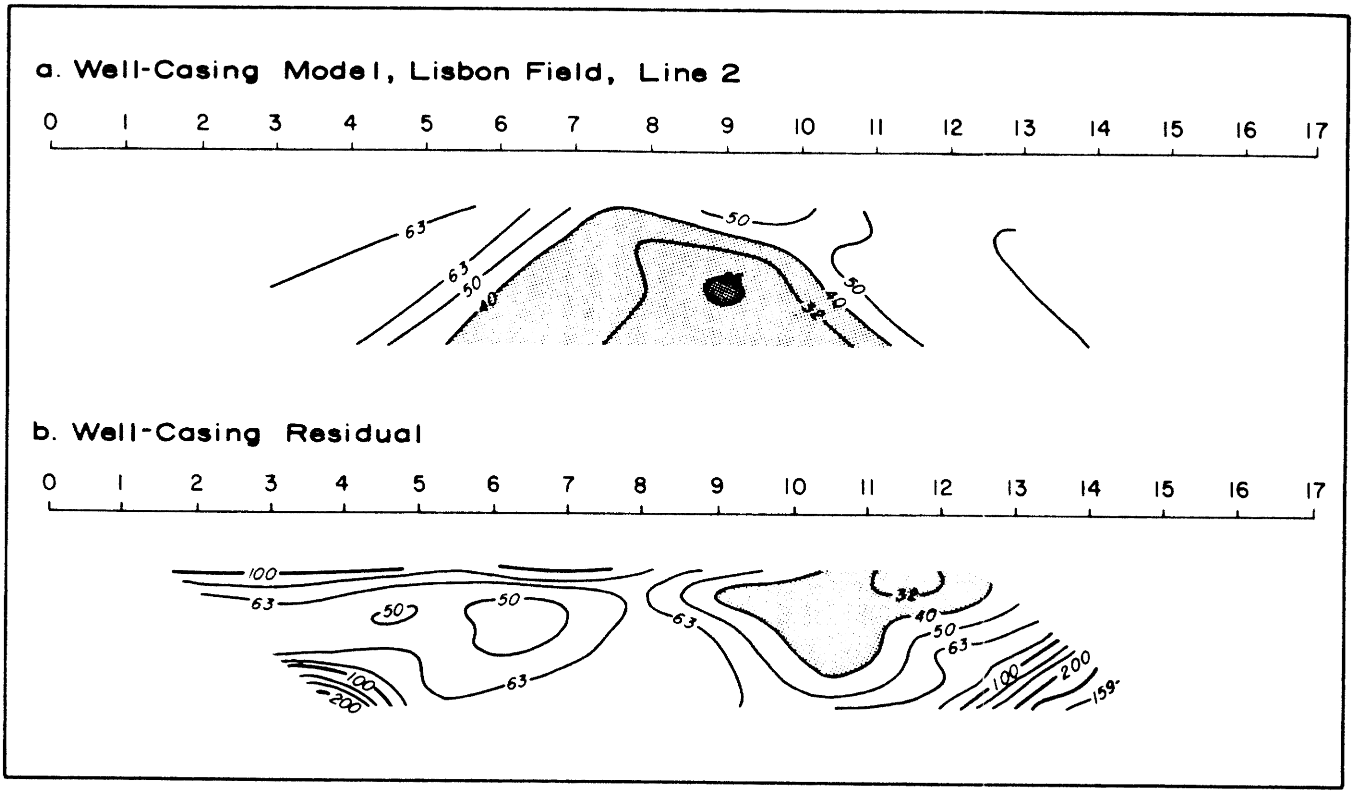


Figure 6.14. Well-casing model of apparent resistivity data for line 2, Lisbon Field. Model parameters: 19 cased wells, casing diameter = 10-3/4 inches (24.5 cm), casing resistivity = 2.0 x 10^{-7} ohm-meters, surface impedance = 0 + 0.2i, background resistivity = 60 ohm-meters. Figure 6.4 shows well locations.

between stations 11 and 12 probably have a minimal effect on the resistivity data. This conclusion is supported by the absence of strong diagonal effects from this area and by the fact that the phase data show no anomalous effects near stations 11 and 12. Thus, surface cultural effects are indeed seen in parts of the data, but these effects do not explain the presence of the lateral conductive anomaly.

Topographic effects on line 2 are relatively minor, as shown by the "2DIP" topographic model of Figure 6.15. The mesa on the east end of the field appears to make a minor contribution to the low resistivity zone of the field data, but this is obviously a secondary effect.

Subsurface structure apparently does contribute to the conductive anomaly on line 2. Low resistivity sediments of lower Triassic and Permian age outcrop between stations 10 and 15, the approximate location of the surface expression of the anomaly. The correlation is not spectacular, but a comparison of the cross-section B-B′ of Figure 6.10 and the field data from line 2 shows that some structural influences may be present in the data. However, the analog model of Figure 6.13, presented earlier, shows that an outcropping, shallowly-dipping layer cannot explain the presence of a strong, lateral resistivity change of the type seen in the data.

If the line 2 data were examined as an independent set of information, it would be possible to reach one of two very different conclusions: 1) the conductive anomaly can be explained by the combination of cultural, topographic, and structural effects, or 2) the anomaly is due to a conductive zone overlying the hydrocarbons, complicated to some degree by other effects. However, the line 2 data are

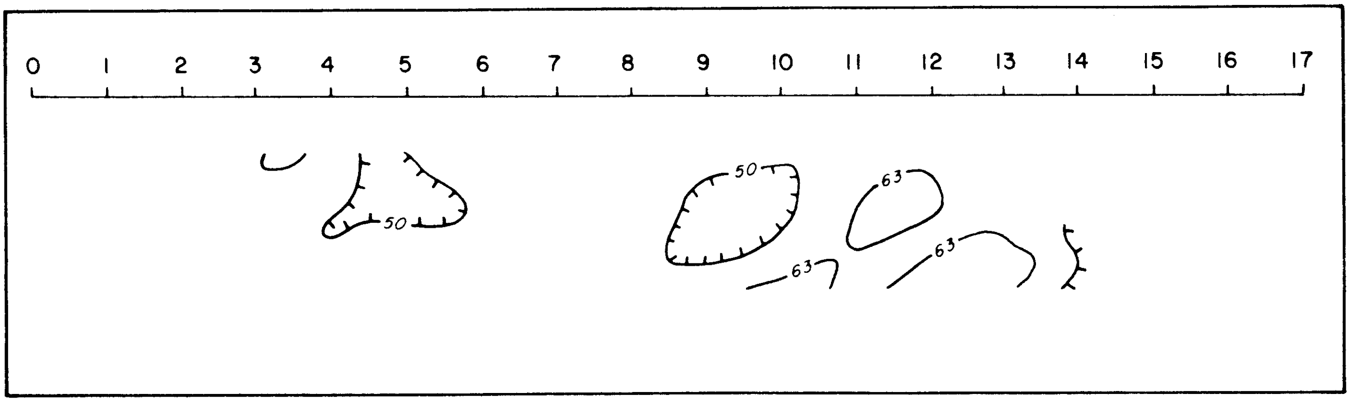


Figure 6.15. Topographic model of apparent resistivity data for line 2, Lisbon Field. Background resistivity = 60 ohm-meters. Plate 6.2 shows topography.

not an independent set of data, but are augmented by information from lines 1 and 3. The interpretation of these lines favors the existence of a conductive zone which is laterally correlated with the location of the hydrocarbons. It is more likely, then, that the anomalies on line 2 are at least partially caused by a conductive alteration zone rather than being caused entirely by cultural, topographic, and structural effects.

APPARENT POLARIZATION (DECOUPLED PHASE ANGLE) DATA

As on line 1, polarization on line 2 is high-over-low. The high phase angle values at the surface are clearly correlated with the high resistivity sediments of Jurassic and upper Triassic age, and low phase angle values are associated with older sediments. Superimposed on the high-over-low layering is a zone of high polarization centered on station 8. This zone is due to a feature at or very near the surface, and that feature is almost certainly the pipeline at station 7.9. This pipeline results in the left-plunging 8,9 diagonal and possibly contributes to the high and low polarization effects along right-plunging diagonals 6,7 and 7,8. Curiously, the pipelines between stations 11 and 12 seem to have little effect upon the data. This illustrates the unpredictability of cultural effects and argues against placing too much faith in modeling routines which attempt to simulate these features.

There is a possibility that material at depth on the eastern end of the line may be slightly polarizable. This response, if it has any true significance, is probably associated with upper Pennsylvanian sediments, which lie closer to the surface toward the east due to a thickening of the Paradox Salt in that direction.

None of the high polarization values on line 2 can be even remotely correlated to the surface projection of the lateral extent of the hydrocarbons.

RESIDUAL ELECTROMAGNETIC (REM) DATA

The REM data bear a resemblance to the apparent resistivity data, but the conductive effects appear to originate from a deeper source than suggested by the galvanic data. The anomalous zone, which is characterized by strong negative numbers, is located approximately between stations 6 and 12, correlating quite well with the lateral extent of the hydrocarbons.

Line 3 Interpretation

Line 3 was run roughly parallel to line 2. It traversed considerable topographic changes across Lisbon Field, and extended into Lisbon Valley. The data are presented in Plate 6.3. The offset diagonal on the west end of the line is a consequence of moving the transmitting dipole 1,2 to 1.5, 2.5 in order to minimize the effects of a pipeline crossing the line at station 2.

APPARENT RESISTIVITY DATA

Apparent resistivity layering is high/low/high at the west end of the line; to the east, the resistive surface layer appears to pinch out. As noted earlier, the surface high resistivities are associated with Jurassic and upper Triassic rocks. The middle, low resistivities are associated with lower Triassic and Permian sediments, and the high resistivities at depth are due to the more resistive Pennsylvanian sediments, especially the Paradox Salt.

A strong, conductive zone is superimposed on the layering effects. The conductive zone correlates relatively well with the lateral extent of the hydrocarbons and appears to extend from the surface to considerable depths. The eastern limit of the conductive zone is not well defined due to the shortness of the line in that direction and to the peculiar high resistivity effects there. These high resistivity values are probably due to the combination of topographic effects, the downfaulting of high resistivity Jurassic sediments east of station 18, and possible effects due to caves and void spaces in subsurface uranium mines.

Ten cased wells lie within one dipole spacing of the line. As a worst-case estimate of the effects of the casing, the "PIPE" model was run, including all cased wells within three dipole spacings of the line. The model data and residual data are shown in Figure 6.16. The model calculates a maximum chevron-shaped anomaly centered between stations 8 and 9. In the residual plot (field data minus calculated well-casing effects) of Figure 6.16b, a conductive zone still persists between stations 8 and 14, possibly extending to station 16. The residual anomaly is strongest near the surface but also seems to have some depth extent.

Three powerlines at station 6.8 have little if any effect upon the data, a finding which is consistent with observations of powerline effects on lines 1 and 2. The pipeline at station 2 is cathodically protected. When the crew began to acquire data from transmitting dipole 1,2, a spuriously large phase shift was observed, and the dipole was moved to 1.5, 2.5. The apparent resistivity data show little or no influence from this pipeline. The pipeline at station 9.8 also has little or no influence on the data.

In order to examine topographic effects on line 3, a "2DIP" model was run. The results are shown in Figure 6.17. While some of the diagonal features seen in the data can be explained by topography, the basic anomalous trend cannot be explained in this manner.

As noted in the discussion of lines 1 and 2, the outcropping of low resistivity Triassic sediments between stations 12 and 15 probably serves to enhance the conductive anomaly. However, it is clear from the model of Figure 6.13 that the conductive anomaly cannot be explained by outcropping effects. An examination of the cross-section of Figure 6.10 shows that subsurface structural effects probably do not influence the data to any significant degree. Therefore, one must conclude that, on line 3, a conductive zone of some vertical extent exists in the sediments overlying the hydrocarbons.

APPARENT POLARIZATION (DECOUPLED PHASE ANGLE) DATA

As observed on the other two lines at Lisbon Field, line 3 shows high-over-low polarization layering. Surface high values, which pinch out east of station 10,

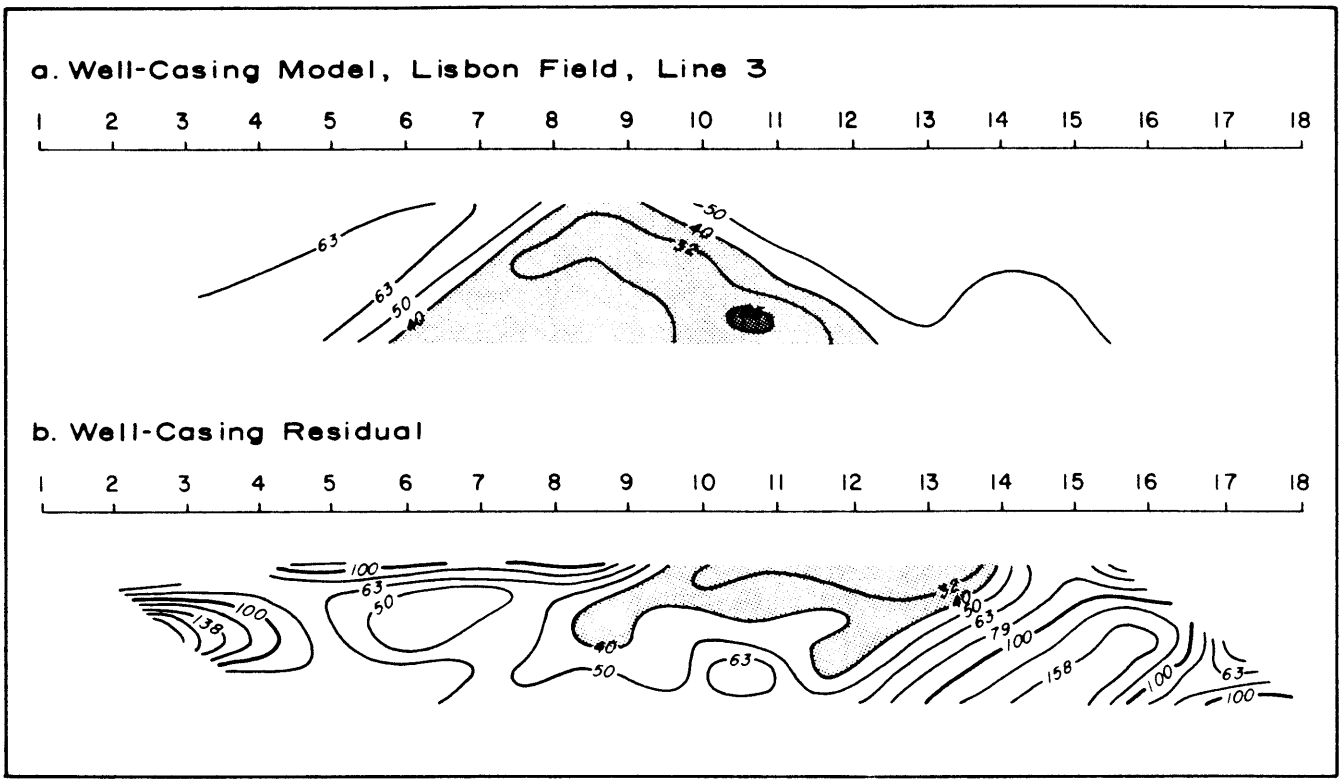


Figure 6.16. Well-casing model of apparent resistivity data for line 3, Lisbon Field. Model parameters: 24 cased wells, casing diameter = 10-3/4 inches (24.5 cm), casing resistivity = 2.0 x 10^{-7} ohm-meters, surface impedance = 0 + 0.2i, background resistivity = 60 ohm-meters. Figure 6.4 shows well locations.

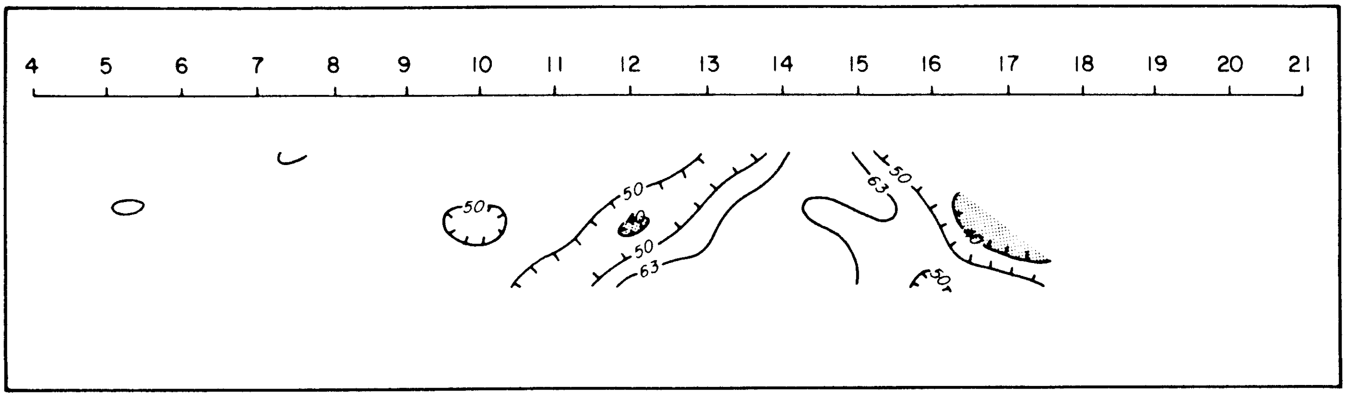


Figure 6.17. Topographic model of apparent resistivity data for line 3, Lisbon Field. Background resistivity = 60 ohm-meters. Plate 6.3 shows topography.

are associated with Jurassic and upper Triassic sediments. The very near-surface zone appears to be relatively non-polarizable. Other low polarization values on the line are associated with Triassic and older sediments. There is some evidence that slightly higher numbers at depth may be associated with Pennsylvanian rocks. The powerlines at station 6.8 appear to have caused high polarization diagonals (left-plunging 7,8, and right-plunging 6,7), although there is no evidence that resistivity information was affected.

There is a slight deepening of the five milliradian contour between stations 8 and 12, but this could easily be a subtle well-casing effect. Otherwise, there is no evidence that the sediments overlying the hydrocarbons have an anomalous polarization response.

RESIDUAL ELECTROMAGNETIC (REM) DATA

The REM data show a strong conductive zone roughly located between stations 7 and 12, although topographic and other geometric effects appear to have limited the eastern extent of the anomaly. The data also show a complex pattern which suggests considerable influence from structural, topographic, and cultural features. For example, the high positive values at the n=1 plot point beneath station 6.5 are probably due to the powerlines at station 6.8. Due to these rather substantial effects, the REM data show little additional information on line 3, but they do serve to define the lateral extent of the conductive anomaly more sharply.

6.4
CONCLUSIONS

Review of the Data

The data at Lisbon Field show a strongly conductive anomaly which correlates well with the lateral extent of the hydrocarbons. The anomaly appears to be caused by alteration effects at intermediate to shallow depths in Triassic through upper Pennsylvanian sediments. There is no trace of a polarization anomaly which correlates with the hydrocarbons.

The interpretation of the conductive anomaly at Lisbon Field is influenced by how much the data are truly affected by current channeling due to cased production wells and pipelines. If one takes the well-casing model to be strictly correct, applies *worst-case* assumptions to it, and then removes the calculated well-casing effects from the field data, a moderate, residual anomaly still remains. However, if the conclusions of section 2.5 are correct, and the model is greatly overcorrecting for well-casing effects, then the actual residual anomaly at Lisbon is very much stronger than suggested by the model results.

The important point to consider in regard to well-casing effects is that, no matter what is assumed regarding the applicability of the "PIPE" algorithm, a residual, bona fide, conductive zone almost certainly exists in the sediments overlying the Lisbon Field hydrocarbons. In other words, well casings do not cause this anomaly, they merely tend to enhance it. Arguments have been advanced in this chapter against possible explanations of the anomaly as due to surface culture, topography, or subsurface structure. Hence, it can be concluded with some certainty that the sediments above the hydrocarbons have been electrochemically altered.

Possible Sources of the Anomalies

It is proposed that an upward migration of hydrocarbons from their trap at depth has created a reducing environment over Lisbon Field, which causes or contributes to the conductive anomaly. In this proposed mechanism, light hydrocarbons migrate vertically from the trap through the overlying sediments, eventually reaching the surface. In this particular field, it is doubtful that saline waters migrate vertically from the trap in sufficient quantity to affect the electrical measurements. This is because of the extremely low permeability and great thickness of the Paradox salt, which directly overlies the trap and may act as a significant barrier to upward movement of saline waters. On the other hand, geochemical literature (Duchscherer, 1980) contains evidence that migration of light hydrocarbons is relatively unimpeded even in materials of low permeability, such as salts. Hence, the hydrocarbons might reach the upper sediments, while waters from depth may not.

Electrically responsive alteration thus appears to occur in relatively shallow sediments of Triassic, Permian, and possibly Pennsylvanian age. Since no "shallow" polarization anomaly was measured on this survey, the "pyrite mechanism," which is widely accepted by many workers, appears to have little to do with the anomaly mechanism at Lisbon Field. Instead, an increase in ion mobility and availability in sediments at medium depths appears to be of primary importance. Insufficient information exists to speculate upon the source of these ions. Future geochemical and hydrological investigations at Lisbon should focus on the influence of vertically migrating hydrocarbons upon local salinity distributions, flow patterns, and water evaporation of the type described by Nisle (1941), in the upper hydrostratigraphic regime above the Paradox Salt. Clays, which are found in Triassic sediments at Lisbon, should also be investigated regarding their role in causing the electrical anomaly.

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Plate 6.1
RESISTIVITY/PHASE PSEUDOSECTION DATA
Lisbon Field
San Juan Co., Utah

Line 1
a = 2,000 feet

Explanation of Symbols

Standard Well Symbols

- ⊙ Drillhole for which information is unobtainable
- ○ Drilling in progress at time of map preparation
- ⌽ Shut in
- ø 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

Culture Symbols

- ⌽ Metal pipeline, presumed grounded
- ● UG Ungrounded pipeline: non-metal or suspended
- ┼ Metal fence
- ╪ Electric fence
- ⌇ Buried telephone or power cable
- T 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

- ⊙ 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

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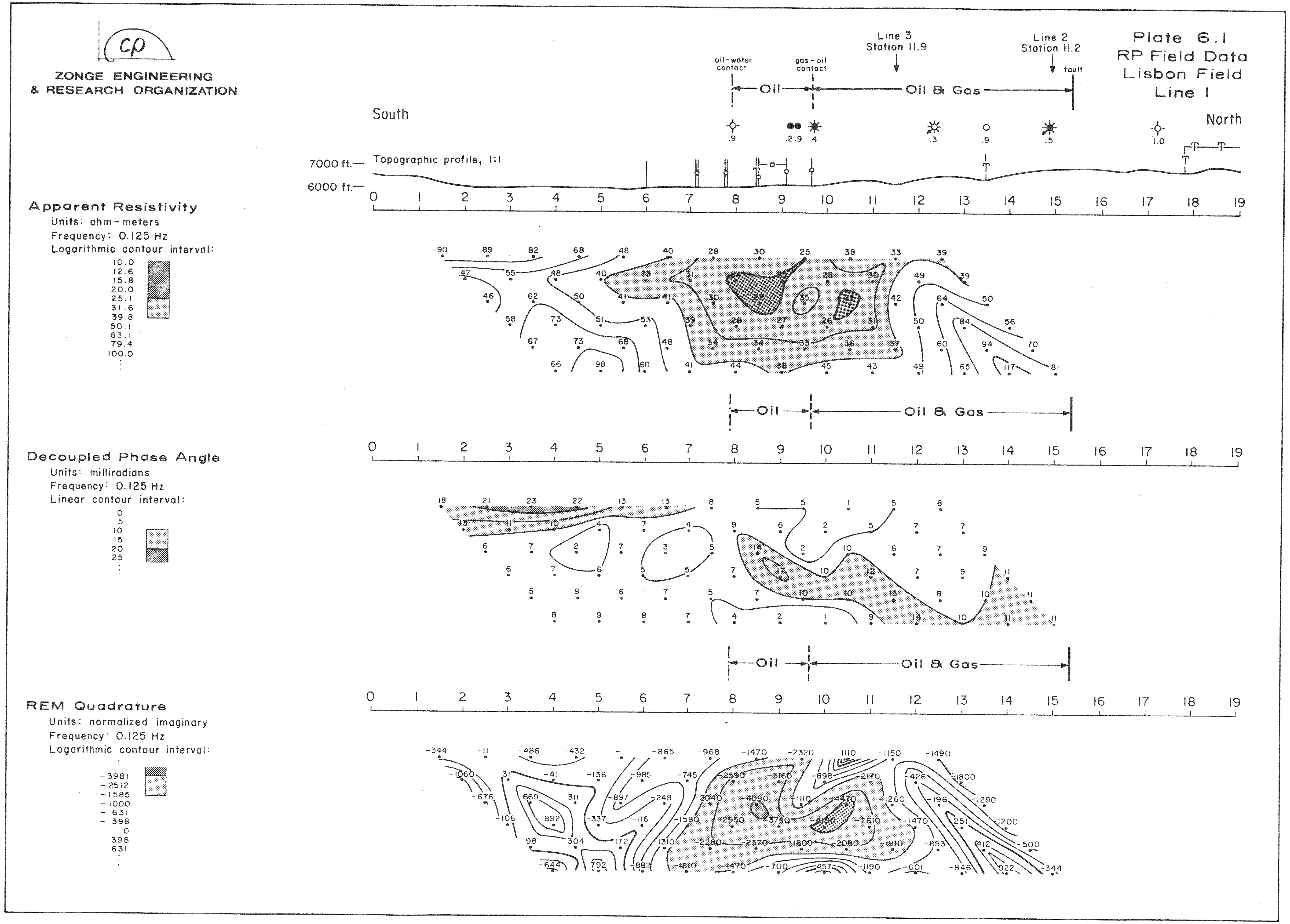

Plate 6.2
RESISTIVITY/PHASE PSEUDOSECTION DATA
Lisbon Field
San Juan Co., Utah

Line 2
a = 2,000 feet

Explanation of Symbols

Standard Well Symbols

⊙	Drillhole for which information is unobtainable
○	Drilling in progress at time of map preparation
ϕ	Shut in
ø	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

Culture Symbols

ϕ	Metal pipeline, presumed grounded
● UG	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
Y	Radio, microwave, or other communications station or tower
⌂	DC pump

Special Well Symbols

◉ 05 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

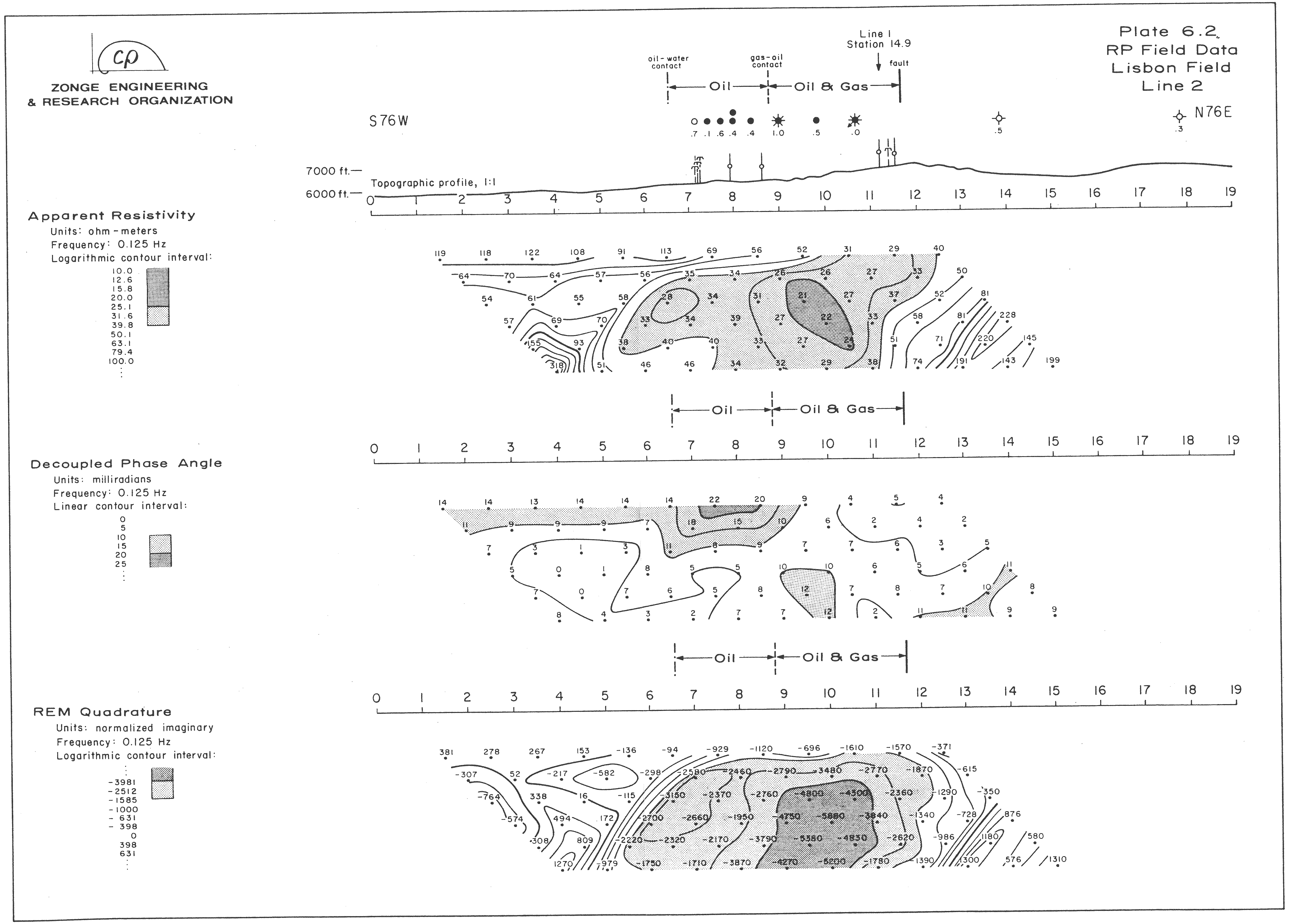

Plate 6.3
RESISTIVITY/PHASE PSEUDOSECTION DATA
Lisbon Field
San Juan Co., Utah

Line 3
a = 2,000 feet

Explanation of Symbols

Standard Well Symbols

- ⊙ Drillhole for which information is unobtainable
- ○ Drilling in progress at time of map preparation
- ⌽ Shut in
- ø 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

Culture Symbols

- Metal pipeline, presumed grounded
- UG Ungrounded pipeline: non-metal or suspended
- Metal fence
- Electric fence
- Buried telephone or power cable
- T 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

- ⊙ 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

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