A SUBSURFACE STUDY OF THE VIOLA SPRINGS FORMATION, NORTH-CENTRAL JEFFERSON COUNTY, OKLAHOMA

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CHAPTER I

INTRODUCTION

PURPOSE OF THE INVESTIGATION

The purpose of this investigation was to (1) analyze and interpret the geology of the Viola Springs Formation in the study area (Figures 1, 2), (2) study the source-rock potential of the Viola Springs Formation, (3) examine the Viola Springs production trend in this area, and (4) describe the petrophysical attributes that define the Viola Springs.

Location of the Study Area and Geologic Setting

The study area is located in Township 4 South, Range 5 West and Township 4 South, Range 6 West, in north-central Jefferson County, Oklahoma (Figure 1). This area is in the northwest portion of the Marietta Basin. This basin is a relatively narrow, southeastward-plunging syncline bounded on the northeast by the Wichita-Criner Trend and on the southwest by the Muenster-Waurika Arch (Figure 3).

Methods of Investigation

A structural contour map, an apparent vertical thick-

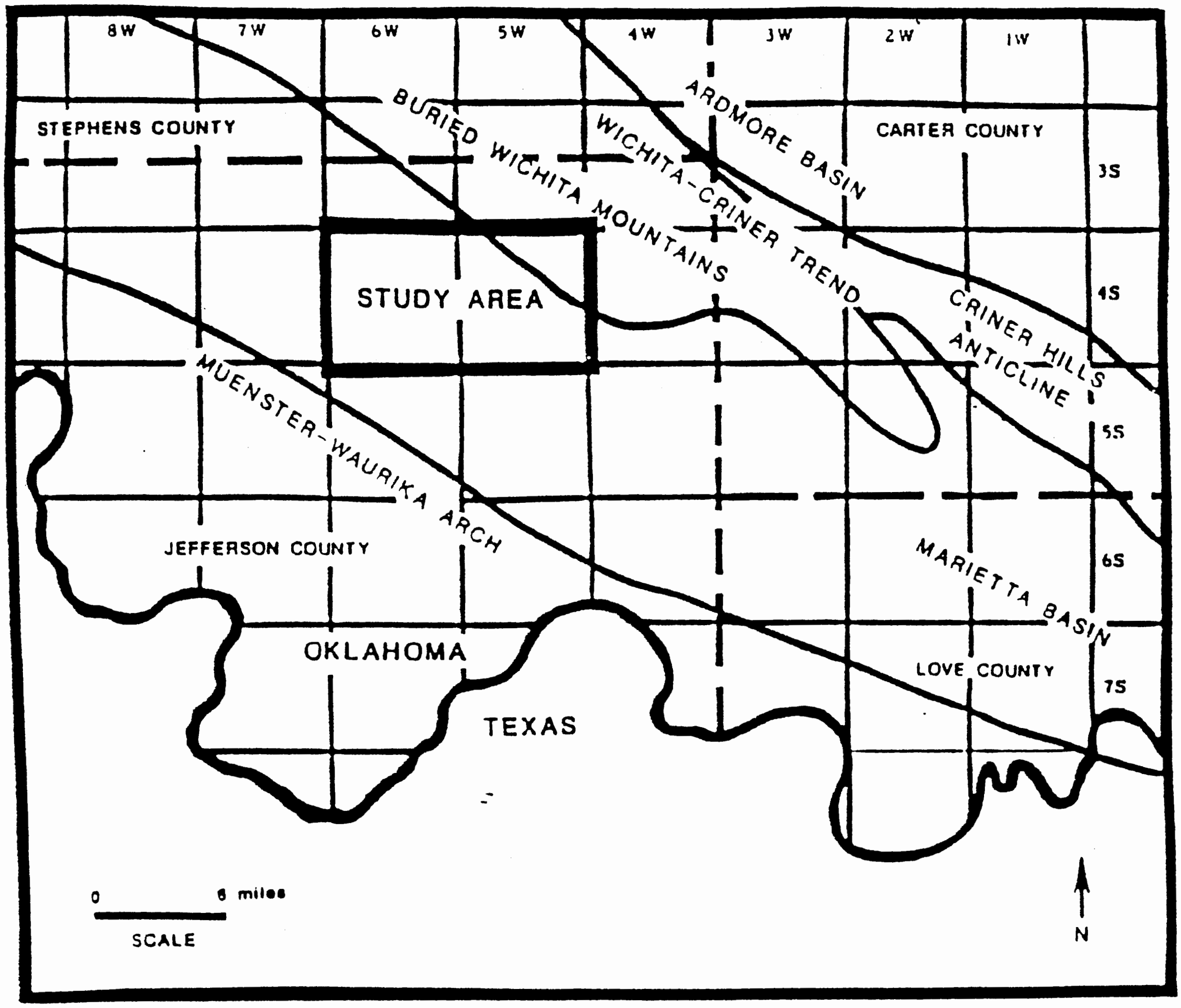

Figure 1. Location of the study area and geologic setting. Modified after Hicks (1971).

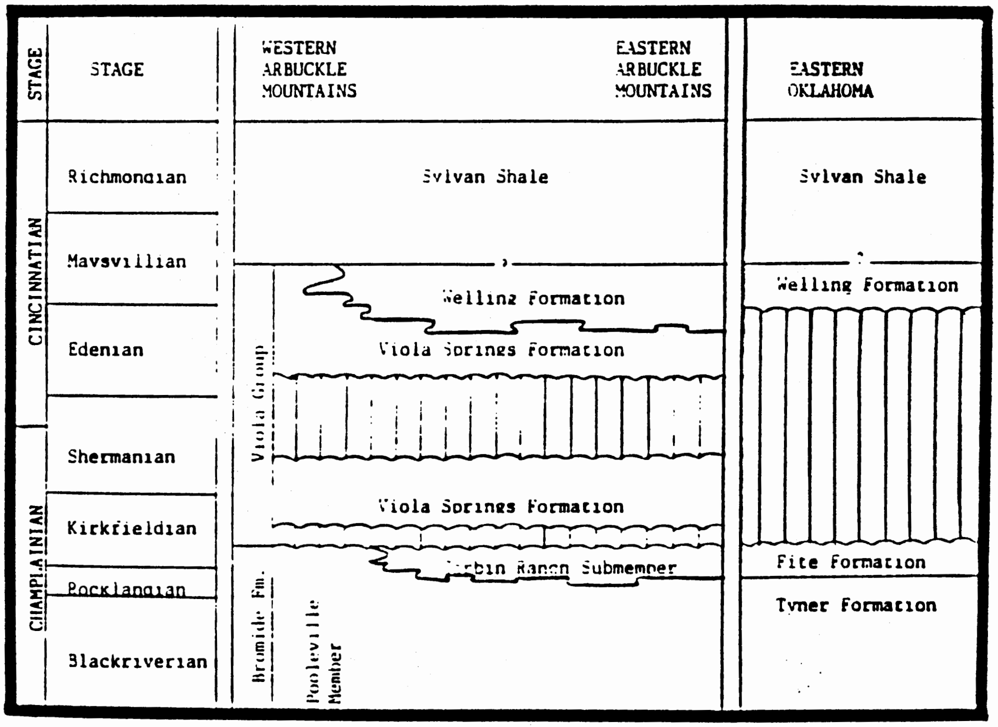

Figure 2. Stratigraphic classification of the Viola Group according to Amsden and Sweet (1983). Modified after Amsden and Sweet (1983). Strata below the Viola Springs Formation are part of the Simpson Group.

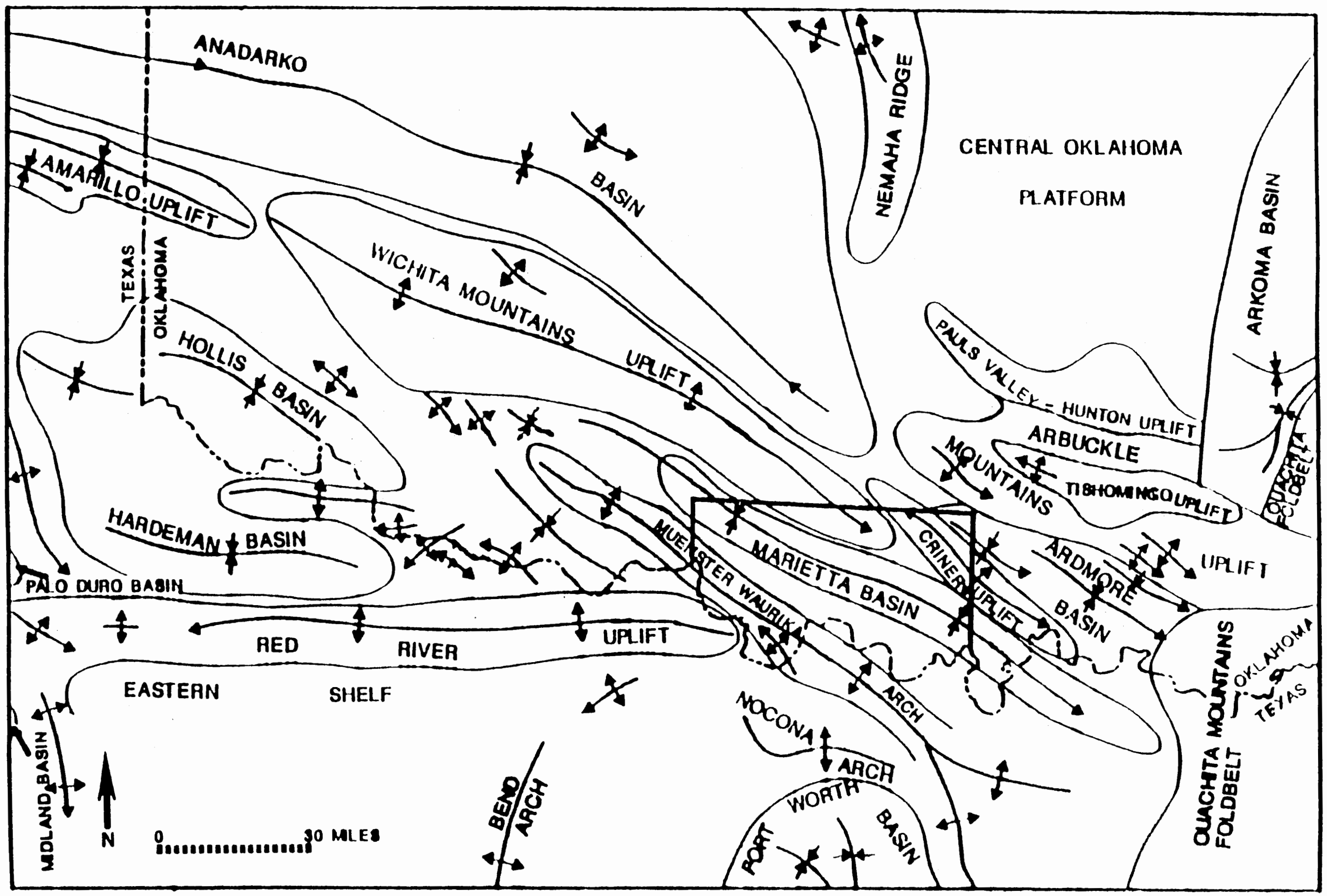

Figure 3. Geologic features of southern Oklahoma and northern Texas. Outlined area is shown in Figure 1. After Al Shaieb et al. (1981).

ness map, and three cross sections were constructed from well-log and seismic information for study of the structural geology and areal distribution of the formation. The source-rock potential of the Viola Springs was examined by analyzing results of total-organic-carbon tests, Rock-Eval Pyrolysis data, and by assessments of kerogen determined by optical techniques. The production trend was studied by examining well-production information and by attempting to define the controls responsible for this trend. Evaluation of well logs and examination of the only available core provided data from which to describe the petrophysical characteristics of the formation.

Previous Investigations

Previous investigations that have been published and that are relevant to this study are of two categories -- subsurface geology of the area and petroleum geology of the Viola Group.

Subsurface Geology

Druitt (1957) studied the general subsurface geology of Jefferson County. The stratigraphy and general geologic history of the northwest Marietta Basin were reviewed by Reeves and Mount (1961). Investigations of nearby oil fields were conducted by Hellman (1962) (Joiner City Field, Southwestern Carter County), Latham (1970) (Healdton Field, western Carter County and northeastern Jefferson County), and Giarratana (1984) (Southeast Joiner City Field, southwestern Carter and northwestern Love Counties).

Petroleum Geology of the Viola Group

Wengerd (1948) studied the Viola Group in the vicinity of the Arbuckle uplift of south-central Oklahoma. He recognized that the reservoir potential of the Viola Group is maximized by intense fracturing of strata, that porosity related to weathering may exist beneath unconformities, and that no primary porosity of economic potential exists in this group, owing to early diagenetic sealing. Evans (1981) and Waugh and Crompton (1981) published abstracts that discussed potential of the Viola Group as an oil reservoir. A general study and review of the petroleum potential of the Viola Group in the Marietta Basin was conducted by Allen (1983).

CHAPTER II

DESCRIPTIVE SUMMARY OF THE VIOLA GROUP

The Viola Group is a set of carbonate rocks that were deposited over a vast area of the present Midcontinent during the Middle and Late Ordovician (Ireland, 1966). This group is thickest in the area of the former Southern Oklahoma Aulacogen (Galvin, 1982; Smith, 1982; Grammer, 1983). In most areas of southern Oklahoma the Viola Group is overlain by the Upper Ordovician Sylvan Shale and is underlain by the Middle Ordovician Simpson Group (Figure 2) (Ireland, 1966). In the study area the Viola Group was partly truncated by pre-Desmoinesian erosion; it is overlain unconformably by the Desmoinesian Deese Group (Druitt, 1957; Tomlinson and McBee, 1959; Reed, 1959).

Stratigraphic Classification

The present time-sequence classification of the Viola Group was proposed by Amsden and Sweet (1983), who designated two formations in this group--the lower Viola Springs Formation, formerly known as the Viola Limestone, and the upper Welling Formation, formerly known as the Fernvale Limestone (Figure 2). As described above, the Viola Springs Formation is present in the study area.

The Viola Group of southern Oklahoma was described by Glaser (1965), who divided it into three units (Figure 4). By using a shelf-to-basin depositional model he recognized facies changes and subdivided the units. Briefly described, he classified the Viola Group into Units 1L, 1C, 2, and 3. Unit 1L (basin laminites) is composed of siliceous laminated mudstones that grade shelfward into Unit 1C (calcarenites). Unit 2 (calcarenitic mudstones and wackestones), does not change significantly in composition throughout the region, but it is approximately three times thicker in the basinal area than on the northeastern shelf (Figure 4). Unit 3 CM (calcarenitic mudstones and coarse-grained skeletal calcarenites), is the upper unit in the basinal areas; it grades shelfward into Unit 3C (coarse-grained skeletal calcarenites). Units 1 and 2 are equivalent to Amsden's and Sweet's (1983) Viola Springs Formation and Unit 3 corresponds to the Welling Formation.

Depositional Environment

The Viola Group of southern Oklahoma was deposited in a carbonate-ramp environment that shoaled progressively upward (Galvin, 1982; Smith, 1982; Grammer, 1983; Gentile, 1984). Deposition in the deep- and mid-ramp environments was below wave base, where currents were relatively weak and conditions were anaerobic to dysaerobic. Shallow-ramp environments were dominated by higher wave energy and oxygenated waters, but sediments were deposited below wave base.

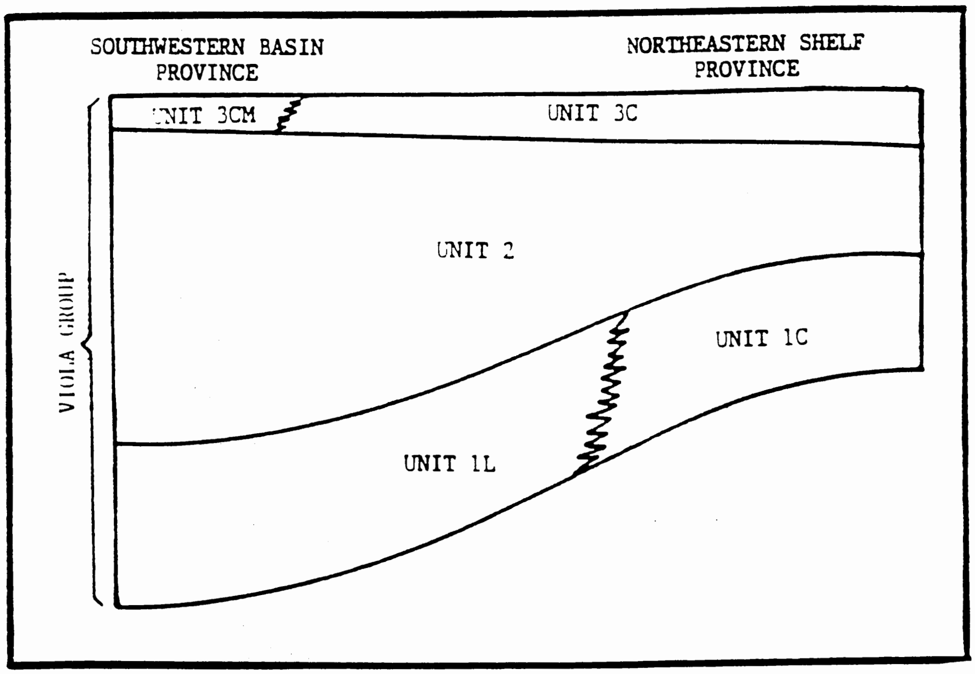

Figure 4. Classification of the Viola Group according to Glaser (1965). Modified after Gentile (1984).

Diagenesis

Throughout the region the Viola Group has been subjected to thorough diagenesis, which has virtually occluded primary porosity and destroyed any effective permeability (Wengerd, 1948; Allen, 1983; Grammer, 1983, 1985). Cementation, pressure solution, and silicification were the principle diagenetic effects (see Appendix A). Most diagenetic features are believed to have occurred relatively early in the geologic history of the Viola (Wengerd, 1948; Grammer, 1983, 1985; Gentile, 1984).

CHAPTER III

GEOLOGY OF THE STUDY AREA

General Geologic History of Southern Oklahoma

Southern Oklahoma is characterized by a consistent geologic style of paired uplifts and basins that trend generally northwestward (Figure 3). This configuration is the result of Pennsylvanian structural deformation of an extensive Cambrian-Mississippian depositional basin known as the Southern Oklahoma Aulacogen (Wickham, 1978; Garner and Turcotte, 1984). A general stratigraphic chart of southern Oklahoma is shown as Figure 5.

The aulacogenic phase was initiated during Late Precambrian to Middle Cambrian time by thermal rifting of the earth's crust, which produced a triple junction (Wickham, 1978). Two arms of this triple junction completely rifted and formed the Ouachita geosyncline. The third (failed) arm protruded into the continental interior and formed the Southern Oklahoman Aulacogen. Rifting in the aulacogen was accompanied by thinning of continental crust and injection of igneous material, mafic and acidic, intrusive and extrusive. The regime dominantly was extensional. Owing to cooling of the injected igneous

SYSTEM	SERIES	GROUP	FORMATION
CRETACEOUS	COMANCHEAN	TRINITY	
PERMIAN	WOLFCAMPIAN	PONTOTOC	
PENNSYLVANIAN	VIRGILIAN	CISCO	
	MISSOURIAN	HOXBAR	
	DESMOINESIAN	DEESE	
	ATOKAN	DORNICK HILLS	
	MORROWAN		
MISSISSIPPIAN	SPRINGERAN		
	CHESTERIAN		
	MERAMECIAN		CANEY SHALE
	OSAGEAN		SYCAMORE LIMESTONE
	KINDERHOOKIAN		WOODFORD SHALE
DEVONIAN	HELDERBERGIAN	HUNTON	BOIS D'ARC
			HARAGAN
SILURIAN	NIAGARAN		HENRYHOUSE
	ALEXANDRIAN		CHIMNEYHILL
ORDOVICIAN	CINCINATIAN		SYLVAN SHALE
		VIOLA	WELLING
	CHAMPLANIAN		VIOLA SPRINGS
		SIMPSON	BROMIDE
			MCLISH
			OIL CREEK
			JOINS
	CANADIAN	ARBUCKLE	WEST SPRING CREEK
			KINDBLADE
			COOL CREEK
			MCKENZIE HILL
			BUTTERLY-ROYER DOLOMITE
CAMBRIAN	TREMPEALEAUAN		FORT SILL LIMESTONE
	FRANCONIAN	TIMBERED HILLS	HONEY CREEK REAGAN SANDSTONE

Figure 5. General stratigraphic chart of southern Oklahoma. After Druitt (1957), Westheimer (1965), Ham (1969), Adler (1971), and Amsden and Sweet (1983).

material, normal faulting and formation of grabens initiated subsidence of the area between the bounding, more stable elements of the continental crust. The period of rifting also established the dominant structural grain of southern Oklahoma, which influenced sedimentation and tectonism (Wickham, 1978).

The subsident phase lasted from Late Cambrian to Late Mississippian. It is recorded by a section of strata that is very thick relative to that on the more stable cratonic elements (Ham, 1969). This episode of subsidence is divisible into two sub-episodes: a time of accelerated subsidence and sedimentation from Late Cambrian to Late Ordovician, and and an interval of discontinuous subsidence and more varied sedimentation during Silurian to Late Mississippian (Wickham, 1978; Garner and Turcotte, 1984).

During the earlier episode, sinking and sedimentation in the basin were more rapid than on the flanking areas (Ham, 1969). Thick sections of carbonate sediment, sand and mud accumulated as sedimentation kept pace with subsidence. Initially the basin floor was covered by the transgressive Upper Cambrian Timbered Hills Group. These strata were overlain by the predominantly peritidal Cambrian-Ordovician Arbuckle Group. During Middle Ordovician time the Simpson Group was deposited as carbonate sediment, sands, and muds. The basin subsided more rapidly; sediments that composed the Viola Group were deposited in water that probably was the deepest in the aulacogen (Grammer,1983;

Galvin, 1983).

In the latter part of the generally subsident stage, the rate of subsidence declined. Gentle regional upwarping may have occurred with shifting of depositional axes northward (Amsden, 1975; Webster, 1980). Such events could have developed in response to convergence of continents and the Acadian Orogeny (Amsden, 1975). The dominantly carbonate Hunton Group was deposited during the Silurian and Devonian. Numerous intraformational unconformities and stratigraphic variations within the group suggest that sedimentation was interrupted more often than in the early Paleozoic (Maxwell, 1959; Amsden, 1975). After deposition of the Hunton Group an extensive unconformity was developed (Maxwell, 1959). The Upper Devonian-Lower Mississippian Woodford Shale was deposited on this unconformity, throughout the region. The Woodford was overlain by the Osagean to Chesterian carbonate rocks and black shales. Rocks of the Woodford and younger Mississippian strata are of character different than the older strata; probably they represent a transition into into the deformational phase of the aulacogen (Garner and and Turcotte, 1984). Deformation was incipient near the end of Mississippian time, with gentle upwarping of the Wichita-Criner trend and of areas to its south and southwest, and with deposition of the Springer Group in subsident areas to its north and northeast (Tomlinson and McBee, 1959; Westheimer, 1965; Beckman and Sloss, 1966; Garner and Turcotte, 1984). These latter areas were to be transformed into the Anadarko and Ardmore Basins (Figure 3).

Convergence and collision of the Ouachita plate and attendant deformation with the North American plate (Kluth and Coney, 1981) operated throughout most of Pennsylvanian time. This episode activated structural deformation in southern Oklahoma along lines of weakness that had been established during the phase of rifting. Significant folding, "vertical" faulting, and wrench faulting took place (Kluth and Coney, 1981).

The earliest orogenic event was the Wichita Orogeny (Tomlinson and McBee, 1959); it is recorded by dominantly clastic rocks, deposited partly as late as Permian. The principal deformation during this orogeny started during Morrowan time and was active through Atokan time (Webster, 1980). This was followed by the deposition of Desmoinesian and Missourian strata and by intermittent tectonic activity that culminated in Late Pennsylvanian time as the Arbuckle Orogeny (Tomlinson and McBee, 1959; Ham, 1969) and by deposition of Virgilian clastic rocks. The Permian was a period of relative quiescence during which some areas continued to subside and were filled with conglomerates, red beds, and evaporites (Garner and Turcotte, 1984). Non-deposition and erosion ensued until Early Cretaceous time, when parts of southern Oklahoma were covered by shallow seas in which were deposited sandstones and shales (Lang, 1957; Westheimer, 1965). Regression of the Cretaceous seas began a period of positive relief that has persisted to the present (Lang, 1957; Westheimer, 1965).

Development of the Marietta Basin

The Marietta Basin was formed as a result of deformation during the Wichita Orogeny, which divided the former aulacogen into a series of greatly faulted and folded uplifts and basins (Wickham, 1978). The Anadarko and Ardmore Basins subsided and filled with thick accumulations of sediments during Springeran and Morrowan time. Although faulted and formed as a synclinal feature during this time, the Marietta Basin was a relatively positive feature perched between the uplifted Wichita-Criner Trend and the Muenster-Waurika Arch (Figure 4) (Reed, 1959; Tomlinson and McBee, 1959; Westheimer, 1965). Most of the basin remained above sea level and great thicknesses of pre-Pennsylvanian strata were eroded. In late Atokan time its southeastern portion was transgressed (McBee and Vaughn, 1956; Reed, 1959; Tomlinson and McBee, 1959). During Desmoinesian time, the positive areas began to subside at about the same rate as the already submerged areas, as recorded by the Deese Group (Reed, 1959; Tomlinson and McBee, 1959). The area continued to subside during Missourian time, with deposition of the Hoxbar Group (Tomlinson and McBee, 1959). Tectonic pulsations that began during Desmoinesian time culminated at the end of Missourian time with the Arbuckle Orogeny (Reed, 1959; Tomlinson and McBee, 1959). Although this orogeny greatly compressed the Ardmore Basin and formed the Arbuckle Uplift, strata in the Marietta Basin were folded gently (Reed, 1959; Tomlinson and McBee, 1959). This was followed by deposition of Virgilian sediments and of the Pontotoc Group (Ham, 1969). The basin probably was covered during Early Cretaceous (Westheimer, 1965). These sedimentary rocks were eroded from the study area, but are present to the southeast in Love County (Figure 1) (Westheimer, 1965).

Structure and Distribution of the Viola Springs Formation

A structural contour map, an apparent-vertical-thickness map, and three cross sections were constructed as a basis for interpretation of the structure and distribution of the Viola Springs Formation in the subsurface of the study area. Data sources for this study were well logs and interpreted seismic information. Depths tabulated from seismic data are approximations based on time analysis and therefore they include some degree of error. However, these errors should be within a range narrow enough to preserve validity of the interpretations. Locations of seismic lines and the interpreted results are not shown for proprietary reasons. A stratigraphic column of the study area is shown in Figure 6.

Plate I shows configuration of the Viola Springs Formation in the study area. The contact of the Viola Springs and the underlying Simpson Group was used as the reference datum, because the top of the Viola Springs is an erosional

SYSTEM	SERIES	GROUP	FORMATION
PERMIAN	WOLFCAMPIAN	PONTOTOC	
PENNSYLVANIAN	VIRGILIAN	CISCO	
	MISSOURIAN	HOXBAR	
	DESMOINESIAN	DEESE	
ORDOVICIAN	CINCINATIAN	VIOLA	VIOLA SPRINGS
	CHAMPLAINIAN	SIMPSON	BROMIDE
			TULIP CREEK
			MCLISH
			OIL CREEK
			JOINS
	CANADIAN	ARBUCKLE	WEST SPRING CREEK
			KINDBLADE
			COOL CREEK
			MCKENZIE HILL
CAMBRIAN	TREMPEALEAUAN		BUTTERLY-ROYER DOLOMITE
	FRANCONIAN		FORT SILL LIMESTONE
		TIMBERED HILLS	HONEY CREEK
			REAGAN SANDSTONE

Figure 6. General stratigraphic chart of the study area. After Druitt (1957), Westheimer (1965), Ham (1969), Adler (1971), and Amsden and Sweet (1983).

surface and probably would not represent the true structure.

The apparent-vertical-thickness map (Plate II) shows variations in thickness of the formation, primarily due to pre-Desmoinesian erosion. The map suggests that structural position dictated the differential erosion of the area; whereby structurally low areas were eroded less than structurally high areas, as deduced from the thicker stratigraphic sequences in synclinal postions.

Three true-scale cross sections (Plates III, IV, V) demonstrate relationships of principal structures in this area and effects of pre-Desmoinesian erosion. Two of the cross sections (A-A', Plate III; B-B', Plate IV) were drawn approximately perpendicular to strike; the third cross section (C-C', Plate V) was drawn appoximately parallel to strike.

The subsurface structure and distribution of the stratigraphic units principally are results of processes associated with destruction of the aulacogen. Structural configurations of the Arbuckle-Simpson-Viola Springs strata and the Deese-Hoxbar-Cisco beds are significantly different (Plates III, IV, V). The Wichita Orogeny produced the more more profound effects. The chief evidence is manifest by faulting and extensive folding in strata that are older than the Deese Group (Figure 6). Attendant to this deformation were exposure of the area and erosion (Druitt, 1957; Reed, 1959; Tomlinson and McBee, 1959). Effects of the Arbuckle Orogeny were more subtle and resulted in only minor folding

(Reed, 1959; Tomlinson and McBee, 1959), which is evident in in the Deese and younger rock-stratigraphic units (Plates III, IV, V).

Except for a small area in sections 22, 23, and 24 of Township 4 South, Range 5 West, the subsurface distribution of the Viola Springs Formation is limited to an elongate, northwest-southeast trending, down-dropped fault block (Plates I, II). This block is bounded by two sub-parallel high-angle reverse faults; locally it defines the axis of the Marietta Basin (Druitt, 1957; Allen, 1983). Structural configuration of the Viola Springs in this down-faulted central block is that of two synclines, which border the major bounding faults; the synclines are separated by an anticline. These three features, which are cut by several cross-faults, were deeply truncated by pre-Desmoinesian erosion.

The character and distribution of structures in this area correspond to the general northwest-southeast trend of most major structural features of southern Oklahoma (Figure 4) (Walper, 1970). The folds and faults resemble those associated with left-lateral wrench faulting (Figure 7), a mechanism believed to have been the underlying cause of many structures in southern Oklahoma (Tanner, 1967; Walper 1970, 1977; Carter, 1979; Booth, 1981; Haas, 1981). Compressional and extensional geometric components of wrench faulting can be recognized (Figure 7). The principle compressional component appears to have been aligned in a

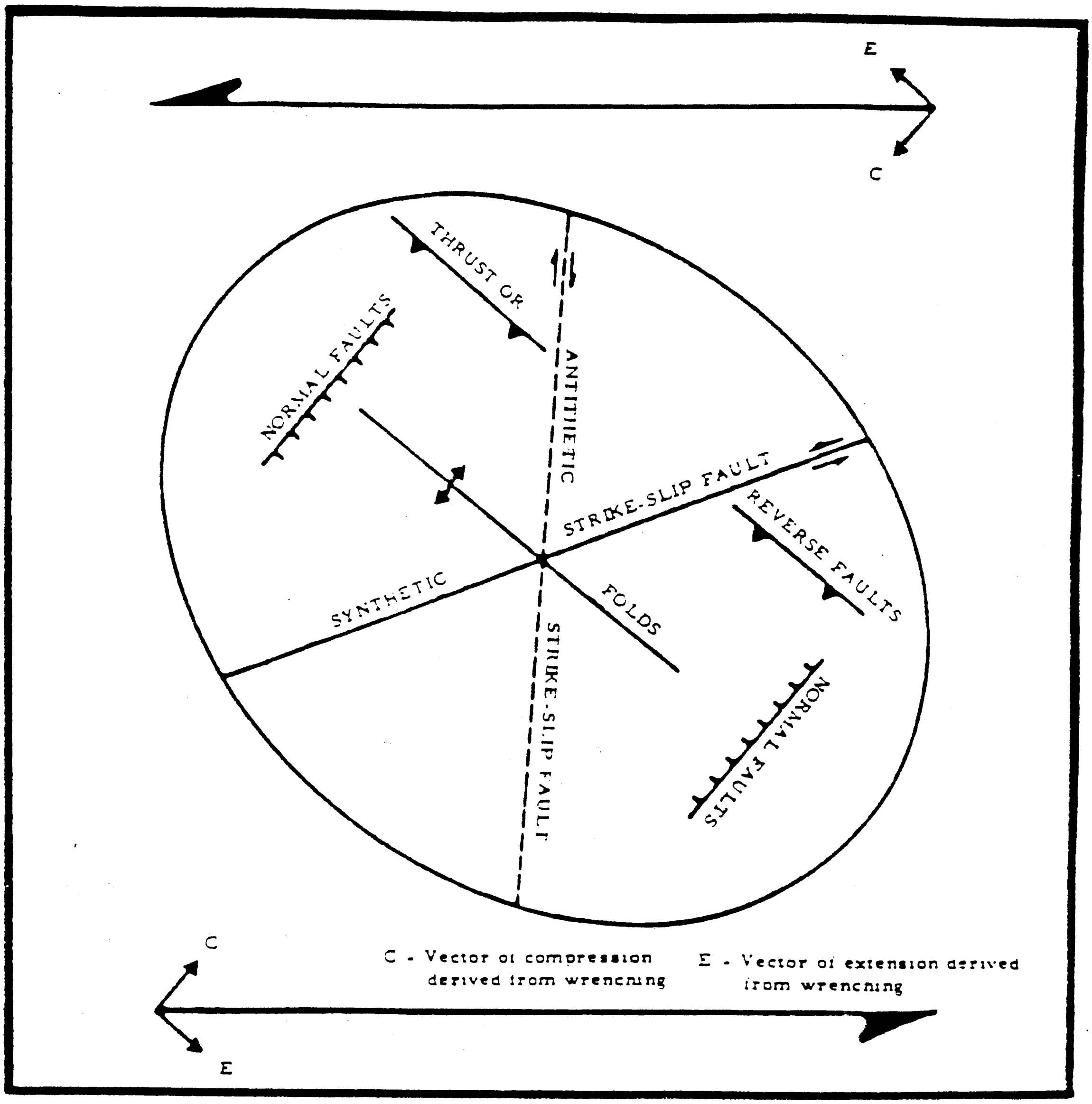

Figure 7. Strain ellipse and associated structures of left-lateral wrenching deformation. The structures in the subsurface of the study area show normal faults, reverse faults, and folds (Plate I), that geometrically are similar to those that may have been generated in a left-lateral wrench system, a mechanism believed to be responsible for development of many structures in southern Oklahoma. After Harding (1974).

southwest-northeast direction, as made evident by the northwest-southeast trends of folds and reverse faults. Two high-angle normal faults are shown that indicate extension nearly perpendicular to the presumed compressive direction (Plate I). However, insufficiency of subsurface data in this area did not allow for the detection of four other parameters important for the recognition of wrench faulting (Harding, 1974): lateral offset of folds and faults on either side of the major bounding faults, zones of antithetic faults, zones of synthetic faults, and the presence of subsurface markers to indicate the vertical and/or horizontal offset of faults. Therefore, whether the structures in this area are products of a wrench-fault regime is open to debate and can be determined from further study on a regional and local scale.

Folding of strata older than the Deese Group was initiated during the early stages of the Wichita Orogeny (Tomlinson and McBee, 1959; Reed, 1959). Continued compression tightened the folds and gave rise to major bounding faults. Crowding in the down-dropped area as the deformation proceeded was resolved by development of additional but smaller faults.

Crowding in the central block is most evident in the southeastern one-quarter of the study area (Plate I). Here the nose of an anticline is cut by a high-angle reverse fault that branches from a throughgoing, nearly vertical fault that parallels the southerly major bounding fault.

Also present are two faults that converge along the limb of the anticline with the northern syncline creating an upthrown wedge (see section 1, Township 4 South, Range 5 West and nearby areas, Plate I).

In the north-central portion of Plate I two high-angle normal faults are shown that indicate extension nearly perpendicular to the compressive direction in this area. Extension also is indicated by flattening of the folds.

A fault in the northwestern part of the map (Plate I) branches from the nearly vertical fault that parallels the southerly bounding fault (section 27, Township 4 South, Range 6 West). This branching fault probably is a releasing bend of the throughgoing fault and is coincident with the opening of the folds as the basin widened to the area northwest of the study area (Tarr et al., 1965; Hicks, 1971).

The presence or absence of the Viola Springs Formation in the subsurface of the study area was dictated by its structural position at the time of the pre-Desmoinesian erosion (Plate II). The Viola Springs ranges from zero to more than 800 feet thick. In structurally low areas thick sections of the Viola Springs were preserved (compare Plates I and II). The formation was eroded completely on structural highs, as shown by absence of the Viola Springs from the crest of the anticline and from the uplifted sides of the bounding faults (Plate I).

CHAPTER IV

SOURCE-ROCK POTENTIAL OF THE VIOLA SPRINGS FORMATION

Introduction

According to generally accepted theories, most hydrocarbons are generated from rocks that contain a critical amount of organic matter and that have undergone thermal alteration sufficient for cracking the complex chemical bonds between organic material and hydrocarbons capable of being released (Durand, 1980). These processes are dependent on preservation of organic matter, burial of sediments, and sufficient time and temperature.

Upon burial, preserved organic matter undergoes three phases of organic metamorphism (Durand, 1980; Huc, 1980). Early diagenesis occurs at low temperatures and pressures; organic matter is subjected to bacterial decay, oxidation, dehydration, and decarboxylation. Water, carbon dioxide, and biogenic methane may evolve during this phase. The result is kerogen, an amorphous material that generally consists of carbon, hydrogen, and other elements (e.g., sulfur, oxygen, nitrogen). As temperature increases during the later catagenic stage, kerogen begins to break down and produce oil and gas, through a series of disproportionation reactions. Finally, during the metagenic stage, at temperatures greater than 250 degrees C, kerogen is spent and consists of little more than carbon.

Barker (1979) suggested that four fundamental questions must be answered in order to identify potential source rocks: How much organic matter is present? What type of organic matter is present? In what stage of maturity is the organic matter? Has migration of generated petroleum occurred? Generally, these questions are answered by results of diagnostic geochemical techniques.

General Statement

In order to evaluate the source-rock potential of the Viola Springs, samples from the Kaiser-Francis No. 8-20 Dillard well (NW, NE section 20, Township 4 South, Range 5 West) were sent to GeoChem Laboratories, Inc. for the following analyses: total organic carbon (TOC), Rock-Eval pyrolysis, and visual kerogen assessment. Values of total organic carbon were determined for sixteen samples, but because of financial limitations only seven tests of Rock-Eval pyrolysis and two tests of visual kerogen assessment were done. Samples for the latter two kinds of tests were selected for their larger contents of total organic carbon.

Methods of Analysis

Total Organic Carbon

Samples were dissolved in dilute hydrochloric acid to remove the inorganic-carbon fraction of the carbonate rock. The organic carbon was burned to carbon dioxide; the amount of carbon dioxide evolved was measured by a thermal conductivity device (Tissot and Welte, 1978). Results were reported in weight-percent. This procedure determines only the amount of organic carbon present, not the total organic matter (Tissot and Welte, 1978).

The minimal amount of organic carbon that must be present in carbonate rocks to produce petroleum is generally accepted to be 0.3% (Gehman, 1962). Total-organic-carbon contents of the samples are shown in Table I.

Rock-Eval Pyrolysis

Essentially, this technique involves progressive heating of a sample in a pyrolysis device within an inert atmosphere, in order to effect the artificial maturation of organic matter (Tissot and Welte, 1978). This method determines four important parameters, which are used in the evaluation of a rock's source potential.

When a sample is heated at a steadily increasing rate the first event is volatization of free and adsorbed hydrocarbons that had been generated in the sub-surface. These show peak generation (S1) at approximately 130 degrees C (Barker, 1974). With increasing temperature, kerogen breaks down and produces a second group of volatile hydrocarbons (S2), which generally show a peak at some temperature greater than 400 C (Barker, 1974). Results (S1

TABLE I

TOTAL ORGANIC CARBON
VIOLA SPRINGS FORMATION
KAISER-FRANCIS NO. 8-20 DILLARD
SEC. 20, T. 4 S., R. 5 W.

Sample No.	Core Depth	TOC (wt. %)
KF- 1*	-5627	1.17
KF-11*	-5633	0.93
KF-12*	-5658	0.42
KF-13*	-5668	0.44
KF-14*	-5679	0.48
KF-15	-5901	1.28
KF-16	-5908	1.45
KF- 2	-5912	0.32
KF- 3	-5928	3.25
KF- 4	-5932	0.39
KF- 5	-5937	2.53
KF- 6	-5952	1.49
KF- 7	-5955	0.48
KF- 8	-5958	1.27
KF- 9	-5960	3.77
KF-10	-5963	2.76

* Denotes Unit 2, others from Unit 1L

and S2) are measured by a flame-ionization detector. Evolved carbon dioxide (S3) is measured by a thermal conductivity device (Tissot and Welte, 1978). S1, S2, and S3 are reported in milligrams per gram of rock. The fourth parameter recorded is the temperature (Tmax) at which the maximal amount of hydrocarbons was generated during pyrolysis of kerogen (S2) (Barker, 1974). Results for S1, S2, S3, and Tmax are in Table II.

The hydrogen index (S2/TOC), oxygen index (S3/TOC), genetic potential (S1 + S2, expressed in kilograms per metric ton of rock), quality index ((S1 + S2)/TOC), and transformation ratio (S1/(S1 + S2)) were determined from the data about pyrolysis. Results for the hydrogen index and oxygen index are reported in Table II; results for the others are shown in Table III, Table IV, and Table V respectfully.

Visual Kerogen Assessment

Optical techniques were used to determine the type and maturity of the kerogen. The results are reported in Table VI.

Discussion of Results

General Statement

As mentioned in the introduction to this chapter, four basic conditions must be identified and assessed in order

TABLE II

RESULTS OF ROCK-EVAL PYROLYSIS

VIOLA SPRINGS FORMATION

KAISER-FRANCIS DILLARD NO. 8-20
SEC. 20, T. 4 S., R. 5 W.

Sample Number	Tmax (C)	S1	S2	S3	Hydrogen Index	Oxygen Index
KF-1	437	0.06	5.08	0.70	434	59
KF-3	437	0.14	15.81	0.80	486	24
KF-5	437	0.10	13.27	0.48	524	18
KF-6	440	0.07	7.05	0.43	473	28
KF-8	438	0.11	6.67	0.31	525	24
KF-9	438	0.25	23.58	0.84	625	22
KF-10	438	0.20	14.53	0.65	526	23

TABLE III

GENETIC POTENTIAL

Sample No.	Kg/ton
KF- 1	5.14
KF- 3	15.95
KF- 5	13.37
KF- 6	7.12
KF- 8	6.78
KF- 9	23.83
KF-10	14.53

TABLE IV

QUALITY INDEX

Sample No.	mg/g
KF- 1	439
KF- 3	491
KF- 5	528
KF- 6	478
KF- 8	534
KF- 9	632
KF-10	534

TABLE V

TRANSFORMATION RATIO

Sample No.	Ratio
KF- 1	0.01
KF- 3	0.01
KF- 5	0.01
KF- 6	0.01
KF- 8	0.02
KF- 9	0.01
KF-10	0.01

TABLE VI

RESULTS OF VISUAL KEROGEN ASSESSMENT

		Type of Organic Matter		
		Amorphous-sapropelic		
Approximate Temperature °F(°C)	Maturation Index	Kerogen Color	Maturity Level	Assessment of samples from this study
86° (30°)	1 Unaltered	Light yellow	Immature	
122° (50°)	1+ Slightly altered	Yellow		KF-3, KF-9
	2-			KF-3, KF-9
212° (100°)	2 Moderately altered	Orange	Mature	
	2+			
	3-			
301° (150°)	3 Strongly altered	Brown		
	3+			
	4-			
347° (175°)	4 Severely altered	Brownish black		
>392° (>200°)	5 Metamorphosed	Black	Metamorphosed	

Reference scale modified after Staplin (1969).

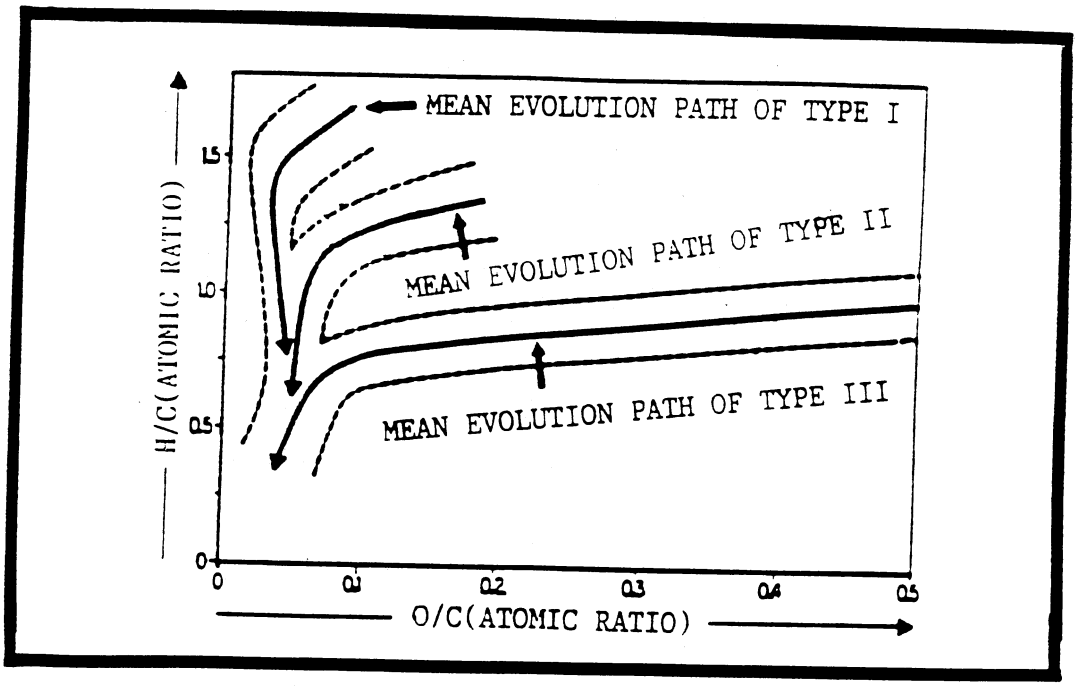

Figure 8. The van Krevelen diagram. This diagram was used by Tissot et al. (1974) to classify the type of organic matter and maturity. By studying the elemental compositions of different kerogens, they located fields for identifying the three types (shown by dashed lines). They also determined the mean evolution paths of the three types during maturation (shown by solid dark lines). Both the H/C atomic ratio and O/C atomic ratio decrease as maturation proceeds, causing the curves to move to the lower left corner. After Durand and Monin (1980).

to evaluate the petroleum-generating potential of rock: amount of organic matter present, type of organic matter, degree of maturation, and evidence of migration. The following discussions relate these parameters to source-rock potential of the Viola Springs Formation.

Amount of Organic Matter

The amount of organic matter is an important parameter in the evaluation of a rock's source potential. According to Barker (1979), organic matter must be present in sufficient quantity in order to generate hydrocarbons. Studies within regions have shown good correlation between source rocks with above-average organic-matter contents and the occurrence of petoleum in reservoirs (Barker, 1979). Total-organic-carbon contents and genetic potential were used in this study to estimate the existent organic matter in the Viola Springs Formation.

Total Organic Carbon. Data in Table I show that total-organic-carbon content ranges from 0.32% to 3.77%, with an average of 1.40%. All these values are more than the 0.3% suggested by Gehman (1962) as the minimum necessary for generation of petroleum in carbonate rocks. Overall, lithostratigraphic Unit 1L evidently contains more organic carbon than Unit 2.

Genetic Potential. Tissot and Welte (1978) proposed that semiquantitative assessment of the genetic potential of source rock can be made by addition of S1 (free and adsorbed hydrocarbons) and S2 (residual hydrocarbon potential) and by expression of the result in kilograms per metric ton (Kg/ton). This number is made meaningful by the following scale: less than 2 Kg/ton -- not an oil source rock but some gas potential; 2 to 6 Kg/ton -- moderate source rock; greater than 6 Kg/ton -- good source rock.

As reported in Table III, all samples are within the "good source rock" category except sample KF-1, which is regarded as having been taken from moderate source rock.

Type of Organic Matter

Classification of the type of organic matter is important because certain types are more likely to give up fluid petroleum than others. Results of Rock-Eval pyrolysis and of visual kerogen assessment were used to determine the type of organic matter in the Viola Springs Formation of the study area.

Modified van Krevelen Diagram. Tissot et al. (1974) classified organic matter as Types I, II, and III, depending upon the elemental chemical composition of kerogen and its position on the evolution path of a van Krevelen diagram,in which the atomic hydrogen-to-carbon ratio (H/C) is plotted against the atomic oxygen-to-carbon ratio (O/C) (Figure 8). This method was modified by Espitalie et al. (1977) by substituting the hydrogen index (HI) and the oxygen index (OI) from pyrolytic data for the H/C and O/C, respectively (Figure 9). They showed that values of these two indices are strongly related to chemical makeup of kerogen, and in particular that good correlation exists between HI and H/C and OI and O/C. The results are interpreted in the same way as the normal van Krevelen diagram (compare Figures 8 and 9). The modified van Krevelen diagram is used in this paper.

Type I kerogens show a large hydrogen index (H/C) and small oxygen index (O/C), whereas Type III kerogens have small hydrogen indices and a wider range of oxygen indices compared to Types I and II. Intermediate are the Type II kerogens. The three types have some basic chemical differences (Tissot and Welte, 1978). Type I mostly is normal and branched paraffins with some naphthenes and aromatic hydrocarbons, and is oil-prone. Type II predominantly is naphthenes and aromatic hydrocarbons; sulfur commonly is associated. Type II kerogen is capable of yielding oil and gas. Type III is gas-prone and generally contains a large percentage of polycyclic aromatic hydrocarbons and oxygenated functional groups, plus some waxes. Tissot et al. (1974) also suggested that the types are related genetically. Type I kerogen is believed to have originated from algae or the remains of disseminated organic matter extensively reworked by organisms; Type II is believed to have been derived from autochthonous organic matter, which originated from indigenous phytoplankta and zooplankta in the

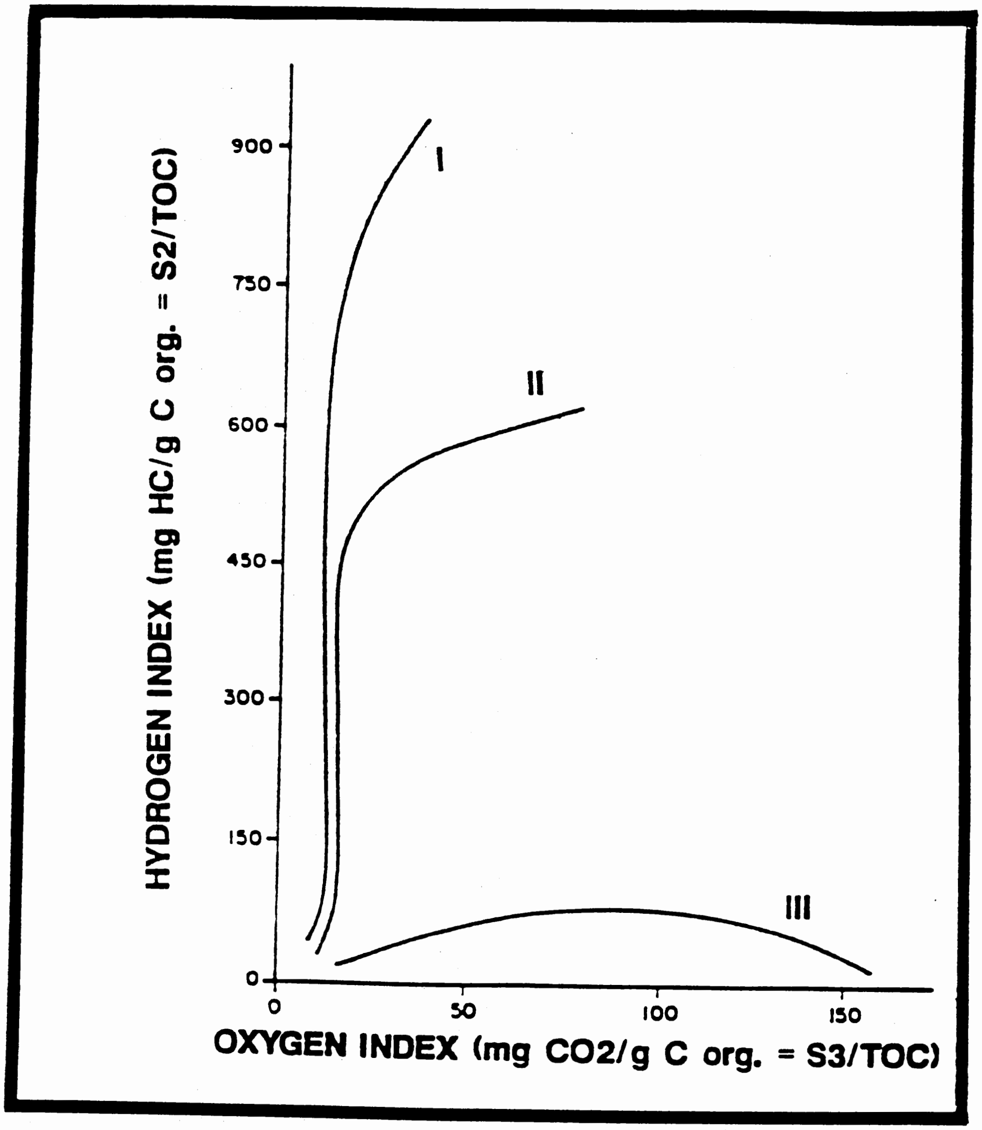

Figure 9. The modified van Krevelen diagram. This was used by Espitalie et al. (1977) to plot the hydrogen index and oxygen index from pyrolytic data, in order to determine the type of organic matter and the maturity. As in the van Krevelen diagram (Figure 8) the type is determined by a sample's position relative to the type curve, and maturity is determined by its location along the evolution path. After Tissot and Welte (1978).

water column, microorganisms in sediment, and degraded algal remains; Type III is believed to be composed of remains of terrestrial plants.

Organic matter evaluated in this study appears to consist of Type I and Type II kerogen (Figure 10); it has a relatively large hydrogen index and a small oxygen index (Figure 10 and Table II). These attributes suggest that the organic matter is related genetically to algae, phytoplankta, and zooplankta. Therefore, the type classification suggests that the Viola Springs has fairly high generative potential and is oil-prone.

Quality Index. The quality of organic matter in rock is important in determining its generative potential. Organic matter is more prone to generate hydrocarbons efficiently if it is enriched in hydrogen relative to carbon (Barker, 1979). Powell (1978) suggested that hydrocarbon content measured by pyrolysis (S1 + S2) is indicative of a sample's hydrogen content. The quotient of hydrocarbon content (in mg) and organic carbon content (TOC), expressed in milligrams of hydrocarbon (S1 + S2) per gram of organic carbon ((mg HC)/(g C org.)), is an index for measurement of source-rock potential with respect to type of organic matter. Powell (1978) considered that hydrocarbon yields greater than 80 mg/g C org. indicate excellent source-rock potential, yields of 50 to 80 mg/g C org. imply good source potential, yields of 30 to 50 mg/g C org. suggest marginal

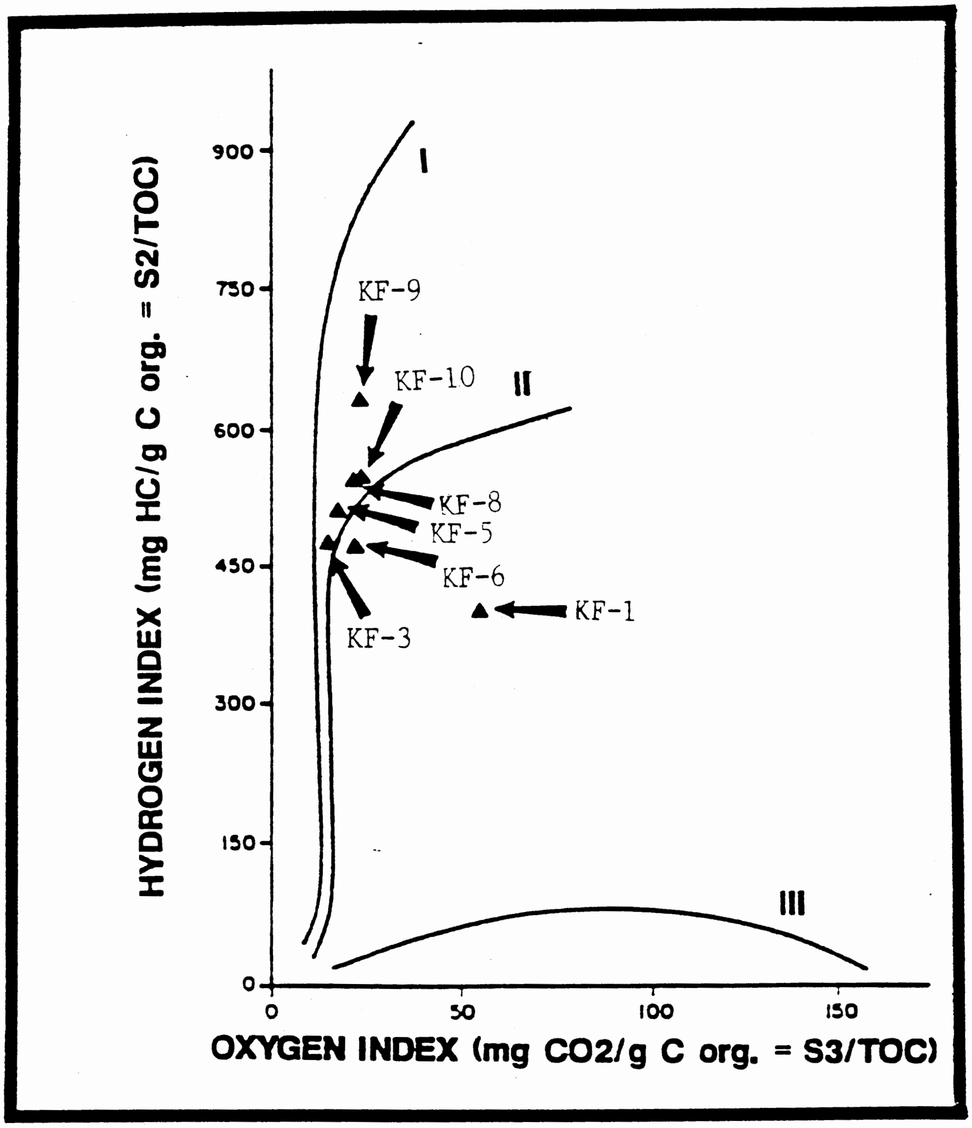

Figure 10. Results from the samples used in this study plotted on the modified van Krevelen diagram. See text for interpretations. After Tissot and Welte (1978).

source potential, and yields of less than 30 mg/g C org. indicate no potential.

On this basis, the Viola Springs shows hydrocarbon yields much in excess of the minimum required for classification as excellent source rock (Table IV).

Visual Kerogen Assessment. Kerogen in the two samples submitted for evaluation is classified as principally amorphous-sapropelic (Table VI). The organic matter basically is finely divided sapropelic matter that could have been derived from remains of algae, phytoplankta, zooplankta, spores, and pollen (Tissot and Welte, 1978). This type of kerogen is similar to Types I and II of Tissot et al. (1974). The assessment indicates that kerogen of the Viola Springs is of a type that is prone to generation of oil.

Degree of Maturation

According to Tissot and Welte (1978), the three types of kerogen mature and generate hydrocarbons as temperature increases. Thermally induced maturation is controlled by depth of burial, geothermal gradient, and time spent in a particular temperature-environment. As maturation proceeds chemical bonds among complex organic materials are cracked by a series of disproportionation-reactions that transfer hydrogen from one molecule to another. This results in production of free hydrocarbons and a kerogenous residue that is carbon-rich and hydrogen-depleted. The type of hydrocarbons produced at a particular instant depends on the degree of maturity of the kerogen during generation and the original type of organic matter. Generally, oil generation commences at about 50 degrees C, reaches the optimum at about 120 degrees C, and thereafter declines to be replaced by gas generation (Tissot and Welte, 1978). Oil generation dies out at about 150 degrees C and gas generation at about 250 degrees C (Tissot and Welte, 1978).

Information from pyrolysis and the visual kerogen assessment were used to evaluate the degree of maturity of the Viola Springs. The transformation ratio, modified van Krevelen diagram, and temperature recorded (Tmax) during the maximal generation of residual hydrocarbons (S2) were determined from results of pyrolysis. The maturation index and color of the organic matter were evaluated from the visual kerogen assessment.

Transformation Ratio. Tissot and Welte (1978) suggested that the transformation ratio serves as an index of source-rock maturity. Defined as S1/(S1 + S2), this ratio gives the amount of hydrocarbons already generated relative to the total genetic potential (see Table V) and is related to the depth of burial. A large positive increase of the transformation ratio with progressive increase of depth indicates the presence of strata where hydrocarbons have been or are being produced. Note that this measurement is not based on any reference standard but is a relative measurement among similar horizons at different depths and temperatures, and therefore at varying levels of maturity. Transformation ratios of the Viola Springs (Table V) show that very little of the potential hydrocarbons have been produced. This may be attributed to a lack of thermal maturity, but because no data are available from more deeply buried rocks, this suggestion is only an unqualified assumption.

Modified van Krevelen Diagram. In addition to being used to distinguish the types of organic matter, the modified van Krevelen diagram is also used to determine the degree of maturation (Tissot and Welte, 1978). The level of maturity is indicated by how far along the evolution path the sample is located (Figures 8 and 9). As maturation proceeds, the oxygen index drops during early stages of catagenesis, followed by a drop in the hydrogen index during the principal period of petroleum formation. This causes the type curves to move toward convergence in the lower left corner of the diagrams (Figures 8 and 9). In the state of metagenesis, when most of the soluble fraction has been eliminated, classification of kerogen is difficult. This is because the various forms of kerogen are approaching similar form of carbon residue.

Figure 10 shows results from samples of the Viola Springs. Positions of samples on the diagram indicate that organic matter in the study area is immature to slightly mature.

Maximal Temperature (Tmax). Temperature recorded during maximal generation of residual hydrocarbons (S2) during pyrolysis is referred to as Tmax (Barker, 1974). It is regarded as an indicator of maturity of organic matter, because with increasing maturation the value of Tmax rises. This is because progressively higher temperatures are required to break the chemical bonds and release the remaining hydrocarbon fraction. The reasoning for using Tmax as a gauge of maturity is based upon the assumption that the artificial maturation obtained in the laboratory under high temperature during a short time is functionally similar to natural maturation in the subsurface during vastly greater time but with less temperature.

Tmax measurements cannot be used as absolute indicators of maturity, because an exact reference standard is difficult to obtain. Claypool and Baysinger (1978) found that generally, Tmax values of immature samples peak below 470 degrees C, the exact value being dependent on the type of organic matter and lithology. Therefore, Tmax probably is used best as a relative indicator, where reference temperatures have been obtained for a particular lithology from an area of known petroleum generation.

Tmax results obtained in this study (Table II) show a very narrow range, varying only by 3 degrees C from the smallest value to the largest value. This indicates that the samples are at approximately the same level of maturity. No measurements of samples are available from strata of the Viola Springs that are buried deeper. Therefore, to characterize the organic matter as immature or mature is not possible. However, if the value determined by Claypool and Baysinger (1978) is used as a relative indicator, the samples can be classified as immature, but approaching maturity.

Visual Kerogen Assessment. Ceratin physical and chemical changes of kerogen that take place during the maturation process are diagnostic in determining the level of maturity (Robert, 1980). As maturity proceeds, kerogen becomes more carbonaceous, darker, and less transparent, with color changing from greenish light yellow through yellow and shades of brown to black. It also becomes worn and amorphous. Color and amount of alteration are used to evaluate the degree of maturity by comparing the kerogen with established reference standards. This technique was was developed by Staplin (1969).

Results from visual assessment of the Viola Springs samples are shown with references in Table VI. The samples are shown to be slightly altered to moderately altered and their colors are yellow to yellow-orange. This indicates that kerogen in the area of the Kaiser-Francis No. 8-20 Dillard is on the threshold of maturity.

Evidence of Migration

"Has migration of hydrocarbons occurred?" is the most difficult question to answer, because once oil has migrate-ed, it is difficult to tell whether it has ever been present. Although this formation seems to possess tremendous generative potential (assuming that the Kaiser-Francis No. 8-20 Dillard is representative of the entire Viola Springs), the average transformation ratio (0.01) indicates that only a minor fraction of the hydrocarbons has been released. Based on evidence from the source-rock potential study and petrographic examination, the oil generated seems to have migrated only locally within the formation because of fracturing, and much of the oil seems to be in micropores in the rock matrix (see Appendix A). This suggestion must be considered as hypothetical, because no study has been conducted to correlate the oil produced from this formation with its its source; therefore, migration of oil from other sources into the Viola Springs cannot be excluded.

Summary

Evidence drawn from available data indicates that the Viola Springs Formation in the study area may be a source rock that is at or near the threshold of petroleum generation. The formation contains amounts and kinds of organic matter that are favorable for the formation of oil, but organic material is and has been mature enough only to release the most unstable fraction of hydrocarbons. Hypothetically, accumulations of oil in the study area are dependent on this early-generated petroleum and its migration to reservoirs.

These findings imply that the study area is an area of transition. Depth of burial decreases in the northwestern part of the study area (see Chapter III) and therefore should lessen the generative potential of the formation, whereas the burial depth to the east and southeast increases, and thereby should enhance its generative potential. Such a circumstance would account for the lack of production in the northwest, the strongly varied nature of reservoirs in the study area, and the more consistent distribution of production to the east and southeast.

CHAPTER V

RESERVOIR CHARACTERISTICS

In the study area, the Viola Springs Formation ordinarily has very low to nonexistent effective porosities and permeabilities, but in numerous horizons oil is in micropores isolated in the rock matrix. These "matrix hydrocarbons" may have been generated from the ambient organic matter in the formation. The organic material forms an anastomosing meshwork that extends vertically and laterally in the rock matrix and horizontally along laminae, and that is isolated fibrous strands (Appendix A, Figures 20, 21, and 22). It is also concentrated along stylolites, which are numerous throughout the formation (Appendix A, Figure 25).

The reservoir geometry of this formation is quite complicated and a certain set of favorable circumstances must converge in order for the rock to produce large quantities of oil. Three important controls are judged by this study to be conducive to accumulation of significant oil deposits: (1) depth of burial, (2) development of an extensive fracture system, and (3) effects of pre-Desmoinesian erosion on the distribution and thickness of the formation probably on its diagenetic history.

Depth of Burial

Burial History

Burial history of the study area indicates that depths of the Viola Springs Formation have not varied greatly since latest Pennsylvanian time or Permian time (Druitt, 1957; Tomlinson and McBee, 1959; Reed, 1959; Westheimer, 1965). Feinstein (1981) demonstrated that the maximal depth of burial of the Viola Group in southern Oklahoma during pre-Pennsylvanian time was only about 3,000 feet and that conditions were not sufficient for it to have generated oil during that time. During Pennsylvanian time, the Viola Group in this area was at or near the surface until the the Desmoinesian, when the area began to subside; this process continued into the Permian (Tomlinson and McBee, 1959; Reed, 1959; Westheimer, 1965). Nondeposition and erosion ensued until Early Cretaceous, when this area was covered by shallow seas (Lang, 1957; Westheimer, 1965). After regression of the Cretaceous seas, the area was exposed, a condition that has persisted to the present (Lang, 1957; Westheimer, 1965).

Present Subsurface Temperatures

The present geothermal gradient of the area, as deter-ined from local well-log data, is about 1 degree F per 100 feet (0.8 degree C per 100 feet). Well-log and seismic study show burial depths in the study area to range from about 4,500 feet to about 7,000 feet. Therefore, subsurface temperatures range from about 110 degrees F (45 degrees C) to about 140 degrees F (59 degrees C). These temperatures are only in the vicinity of the 122 degrees F (50 degrees C) necessary to initiate the early stages of oil generation (Tissot and Welte, 1978). Present subsurface temperatures may be similar to ancient ones, but probably they have not deviated so much from past temperatures as to destroy the logical arguments made here.

Discussion

As mentioned previously (Chapter IV), significant amounts of organic matter are distributed throughout the formation and are of a type that is capable of generating oil, given the optimal thermal maturity. Study of the source-rock potential shows conditions to be only at or near the threshold of generation. As pointed out above, the present burial depth is at or near the deepest it has been and, if one accepts the hypothetical argument that the Viola Springs is its own source rock, the only oil that has evolved is that produced from the hydrocarbon fraction of kerogen that was unstable under the subsurface conditions present since latest Pennsylvanian time or Permian time. In the northwestern part of the study area, where two wells encountered dry reservoirs, the shallow depths of burial may explain the absence of oil. This may also account for the more consistent production to the east and the southeast where the formation is more deeply buried.

Fracturing

The development of an extensive fracture system appears to be foremost in the migration and accumulation of oil in the Viola Springs Formation (Wengerd, 1948; Allen, 1983). Fractures in the Viola Springs serve as permeability paths that channel the indigenous hydrocarbons into more porous zones and also contribute to the storage volume of the reservoir (Appendix A, Figures 23 and 24). Fracture intensity in the formation is controlled by both lithology and structure.

The Viola Springs is a very competent formation and throughout southern Oklahoma fracturing is commonplace (Wengerd, 1948; Glaser, 1965; Waugh and Crompton; 1981; Evans, 1981; Allen, 1983), although fractures are most numerous in the highly siliceous lower part of the formation. Allen (1983) showed that most fractures were related to lithology and structural position. He reported that the lower, highly siliceous unit had a fracture density (measured as the number of discrete fractures that intersect the outcrop surface per 10 square feet) two to four times greater than the upper more calcareous units. Also, Allen (1983) reported that the lower unit is thinly bedded and therefore more susceptible to fracturing (Stearns and Friedman, 1972). Fracturing in the Viola Springs is more abundant in the vicinities of faults and axes of folds (Allen, 1983).

According to Allen (1983), the fractures most conducive to formation of Viola Springs reservoirs are associated with extensional zones near axes of folds, where rates of change of dip are greatest. Such fractures were created by dilational effects associated with the bending of the strata. This dilation would have been accompanied by a low-pressure area where moveable fluids could have gathered (Stearns and Friedman, 1972). This mechanism helps to explain the synclinal accumulation of oil in the area of study.

Pre-Desmoinesian Erosion

Pre-Demoinesian erosion in this area greatly affected the distribution and thickness of the Viola Springs (Plate II). In addition, exposed strata probably were affected to some degree by geological processes operating at or near the surface, which may have enhanced or destroyed its reservoir qualities. Direct evidence of this was not observed in the course of this study, but according to Allen (1983) wells in the Viola Group in areas of partially truncated Viola Springs were less productive and less consistent than those in areas where complete sections of the formation are present. To the east of the study area in Township 4 South, Range 4 West, the Viola Group is preserved under the cover of younger pre-Pennsylvanian strata (Bramlett, 1985).

CHAPTER VI

PRODUCTION CHARACTERISTICS

Local Production Trend

The Viola Group has produced for several years in these nearby fields: Joiner City (Hellman, 1962; Allen, 1983), Southeast Joiner City (Waugh and Crompton, 1981; Allen, 1983; Giarratana, 1984), Orr (Allen, 1983), Cornish (Bramlett, 1985), and West Ringling (Bramlett, 1985) (Figure 11). These fields are on anticlines that rim the Marietta Basin and that are highly faulted and folded. This trend was eventually extended westward to the study area where production has proven to be erratic and poorly predictable.

Production Trend of the Study Area

Cumulative production for the first six months and calculated average daily production of 18 wells used in this study are shown in Figure 12. Locations of these wells are shown on Plate I by a well index number. The well index number is keyed to the well name and is shown in Appendix B.

Production in the study area is sporadic and is concentrated in the northerly syncline (Plate I and Figure 13).

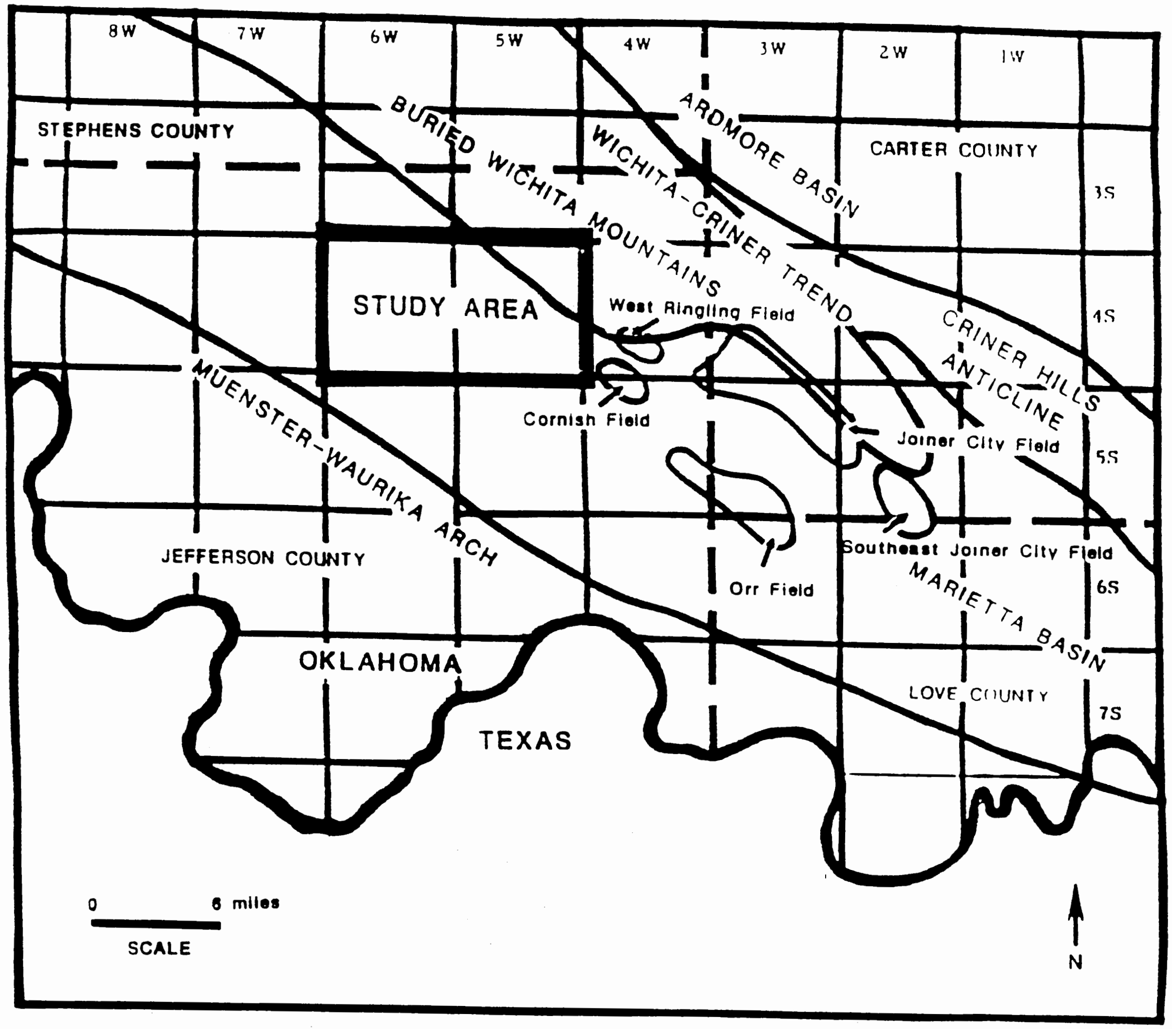

Figure 11. Locations of fields with significant production from the Viola Group. After Hicks (1971) and Allen (1983).

Well Index No.	Well Name	Cumulative Production after Six Months (in barrels)	Average Daily Production (in barrels)
1	1-18 Bennett	3,060	17
2	2-18 Bennett	1,764	10
3	1-18 Blackburn	6,770	38
4	1-18 Howard	15,460	85
5	1-18 HBH Cattle Co.	15,806	88
6	1-18 Brooks	31,288	174
7	1-19 Dennis	7,558	42
8	4-20 Worley	*	*
9	1-17 Worley	18,388	102
10	1-17 David	14,188	79
11	6-20 Dillard	*	*
12	8-20 Dillard	30,694	172
13	1-17 Bachoffer	15,725	87
14	1-21 London	382	2
15	1-16 Wilton	14,744	82
16	1-22 Donald	4,510	25
17	1-13 La Fountain	*	*
18	1-10 Jackson	*	*

* Dry and abandoned

Figure 12. Cumulative six-months production and the average daily production of the wells used in this study.

The best production appears to be concentrated on either side of the splayed normal fault in the west-central part of Township 4 South, Range 5 West (sections 17, 18, 19, and 20). Fracturing associated with development of these faults most probably was responsible for enhancing porosity and permeability of the formation. These fractures would have been an addition to any dilational fractures created by the bending of the strata during folding.

The Kaiser-Francis No. 4-20 Worley (well index no. 8) and the Kaiser-Francis No. 6-20 Dillard (well index no. 11) are located on the upthrown wedge of the splayed fault; they were dry and abandoned. This wedge was subjected to more severe erosion during pre-Desmoinesian time than were the surrounding structurally low areas, and the Viola Springs was truncated to between 200 to 300 feet in thickness. Erosion and weathering during this time may have affected the reservoir quality and source potential of the formation in and near these two wells.

Farther to the northwest, the Kaiser-Francis No. 1-13 La Fountain (well index no. 17) and the Kaiser-Francis No. 1-10 Jackson (well index no. 18) were also dry and abandoned. At these places, depth of burial to the top of the formation is only about 4,000 feet; therefore, if one accepts the hypothetical suggestion that the Viola Springs is its own source, the likelihood that the formation would generate oil is decreased. Also, fracturing may not be as well developed here as in the area to the southeast, in the

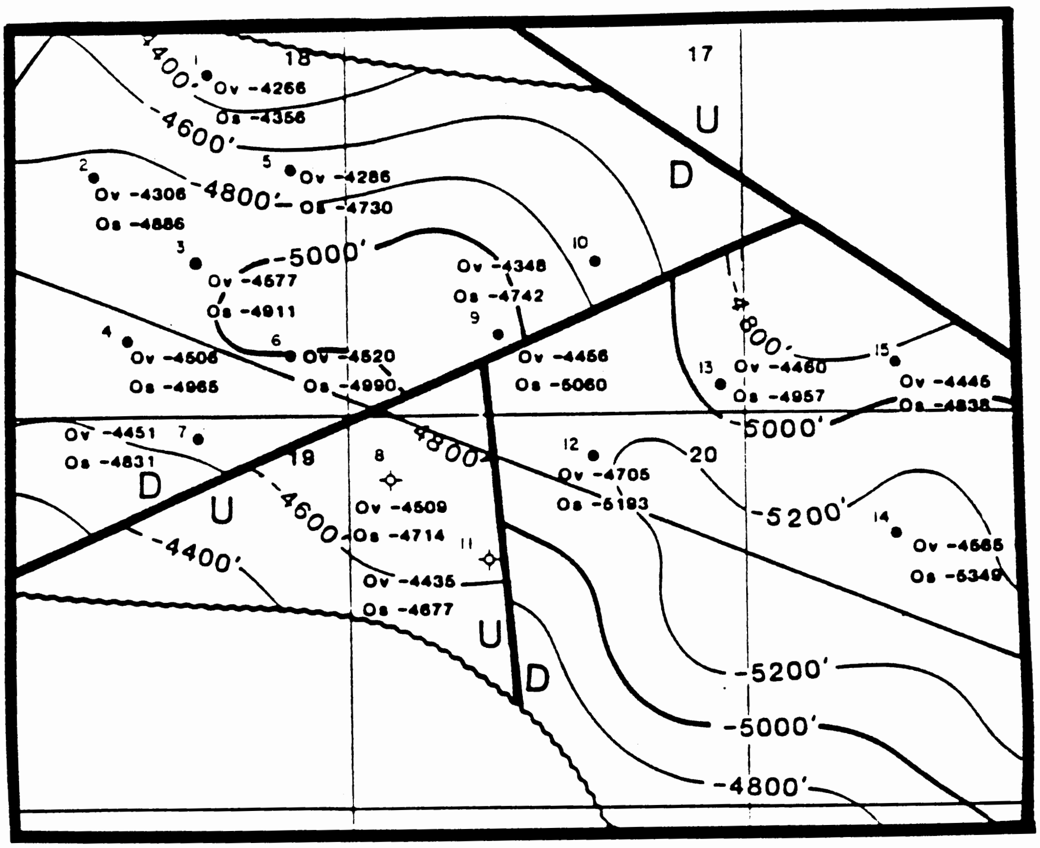

Figure 13. Map showing that production of oil is confined principally to northerly syncline (see Plate I).

locality of the splayed fault.

Well-completion Methods

Wells in the study area are completed by open-hole method, whereby casing is set at the top of the formation and the Viola is perforated at intervals where "high-porosity" peaks are shown on the porosity logs (Bramlett, 1985). As this formation seems not to have natural fluid drive, it must be stimulated extensively by acidizing, sand-fracturing, and pumping. Generally, oil production comes on line only after much of the load water used in stimulation has been pumped out of the formation. Some of the wells necessarily were restimulated shortly after initial production. Completions essentially are free of formation water, which suggests that the only moveable fluids are hydrocarbons.

CHAPTER VII

PETROPHYSICAL PARAMETERS

The Viola Group is a distinctive rock-stratigraphic unit in southern Oklahoma. It has a characteristic log signature that is recognizable throughout the area, varying only in relative thicknesses of individual subunits. Because a causal relationship exists between the chemical and physical properties of rock and the rock's log signature, to summarize the petrophysical parameters that define this formation is important. Such a discussion also is helpful in explaining the difficulty of using logs to evaluate the hydrocarbon potential of the Viola Group.

A core of the Kaiser-Francis No. 8-20 Dillard, resistivity logs, porosity logs, gamma-ray curves, spontaneous-potential curves, and data about porosity and permeability from Core Laboratories, Inc. were used in this study. Only Units 1L and 2 (Glaser, 1965) of the Viola Springs Formation (Figure 4) are considered here, because the upper part of the Viola Group is absent from the study area owing to pre-Demoinesian erosion.

Petrology

Study of the core (see Appendix A) for lithic description) from the Kaiser-Francis 8-20 Dillard well showed that in the subsurface of the study area, the Viola Springs consists of two lithotypes.

The lower unit corresponds to Glaser's (1965) Unit 1L (Figure 4). As observed in the core, it is gray to dark brown, laminated, petroliferous, highly siliceous limestone. The matrix is micritic and contains silica that in some places has completely replaced micrite. Unit 1L also contains graptolites, siliceous sponge spicules, and amorphous organic matter. Trilobites, ostracods, and brachiopods are rare. Sutured-seam stylolites (Wanless, 1979) are relatively abundant. Fractures are common; most are vertical and they appear to be more numerous in the more siliceous beds. Oil is in fractures and in micropores in the matrix (Appendix A, Figures 22, 23, and 24), where it may have been derived from the ambient organic matter.

Strata above 1L are correlative to Glaser's (1965) Unit 2 (Figure 4). The rock from the core is gray, irregularly bedded, nodular, bioturbated limestone. The matrix primarily is micrite that contains an abundant shelly fauna of trilobites, brachiopods, pelmatozoa, bryozoa, gastropods, and ostracods, with fewer graptolites and sponge spicules. Organic matter and matrix hydrocarbons also are present. Unit 2 is less siliceous than Unit 1L. The irregular beds and nodules are separated by dark seams that are non-sutured-seam stylolites (Wanless, 1979) (Appendix A, Figure 26). Calcite, silica, clay, rhombic dolomite, and organic matter are concentrated within these seams.

Porosity and Permeability

One hundred twenty-two samples from the Kaiser-Francis No. 8-20 Dillard well were analyzed for porosities and permeabilities by Core Labs, Inc. Results are presented in Appendix A.

Results of tests show that porosity and permeability of the formation are very low (Figures 29 and 30). Average porosity is 2 percent and average permeability is 0.2 millidarcy. However, averages and numbers presented on the core log may be suspect, due to horizontal cracks on a large number of samples. These cracks probably developed during the coring and handling procedures. Stratigraphic positions of cracks were compared to results of analyses. Generally, samples from places where the core is cracked tend to show larger amounts of porosity and permeability. This may account for the larger numbers obtained in Unit 2 (Figure 30, depths 5617-5684 feet), which has a tendency to crack horizontally along stylolites during handling. With this consideration in mind, actual porosities and permeabilities probably are lower than those reported.

Pore spaces observed in thin section and during examination of the core appear to be isolated micropores, filled with matrix hydrocarbons judged to have been generated from ambient organic matter (Appendix A, Figure 22). Effective permeability seems to have been induced by fracturing (Appendix A, Figures 23 and 24). Although other types of porosity and permeability were not observed, analyses conducted during this research do not preclude their existence.

Log Characteristics

Resisitivity Log

The Viola Springs generally is highly resistive. Unit 1L commonly is recorded as more than 50 ohm-meters, but Unit 2 most often shows less than 50 ohm-meters (Figure 14). In some places excursions greater than 50 ohm-meters are recorded in Unit 2. The generally large resistivity can be attributed to very low porosity and permeability, to matrix hydrocarbons, and to the general absence of conductive formation waters.

At some places a quasi-annulus effect is recorded, whereby the medium-resistivity curve shows measurements greater than that of the shallow-resistivity curve (Figure 15). This could be attributable to contamination of the formation with drilling fluids near the borehole. Mud filtrate could lower resistivity of the invaded rock to amounts less than those of the uncontaminated rock farther from the borehole, which should have only small amounts of porosity and very little conductive fluid.

Gamma-Ray Log

Units 1L and 2 show evidence of slightly different

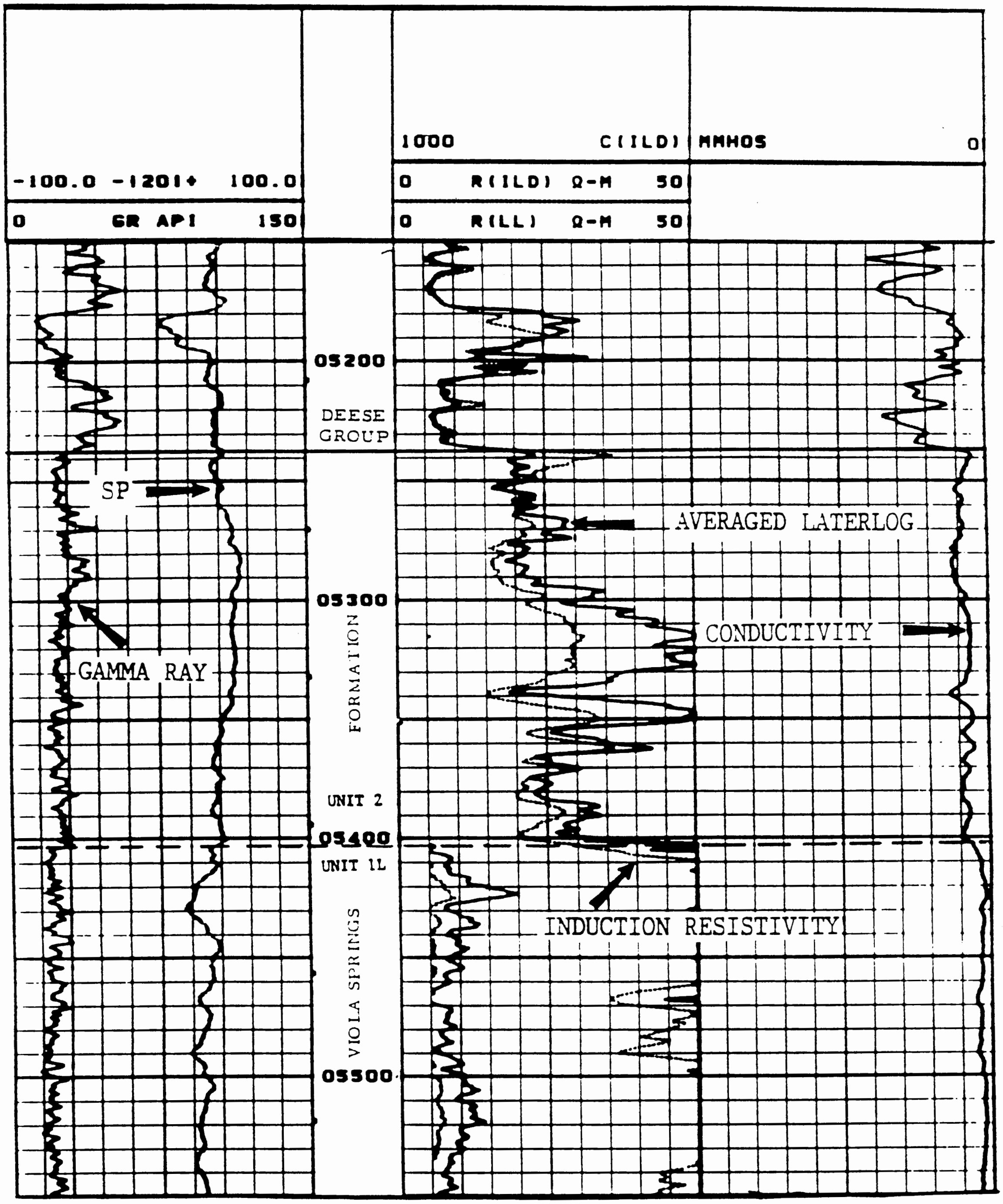

Figure 14. Log of the Viola Springs Formation, Kaiser-Francis No. 2-18 Bennett, showing the induction resistivity, averaged laterolog, conductivity, gamma-ray, and spontaneous potential curves.

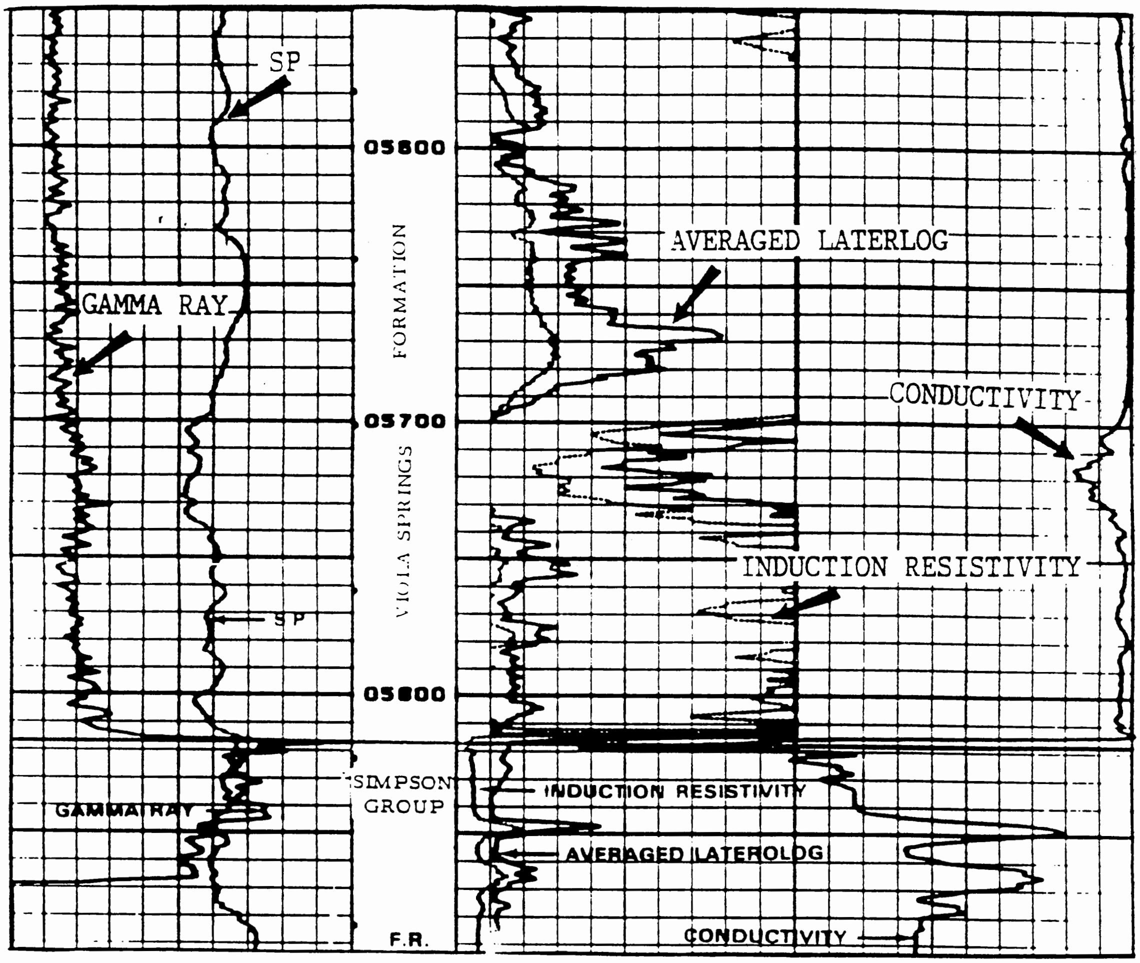

Figure 14. Continued

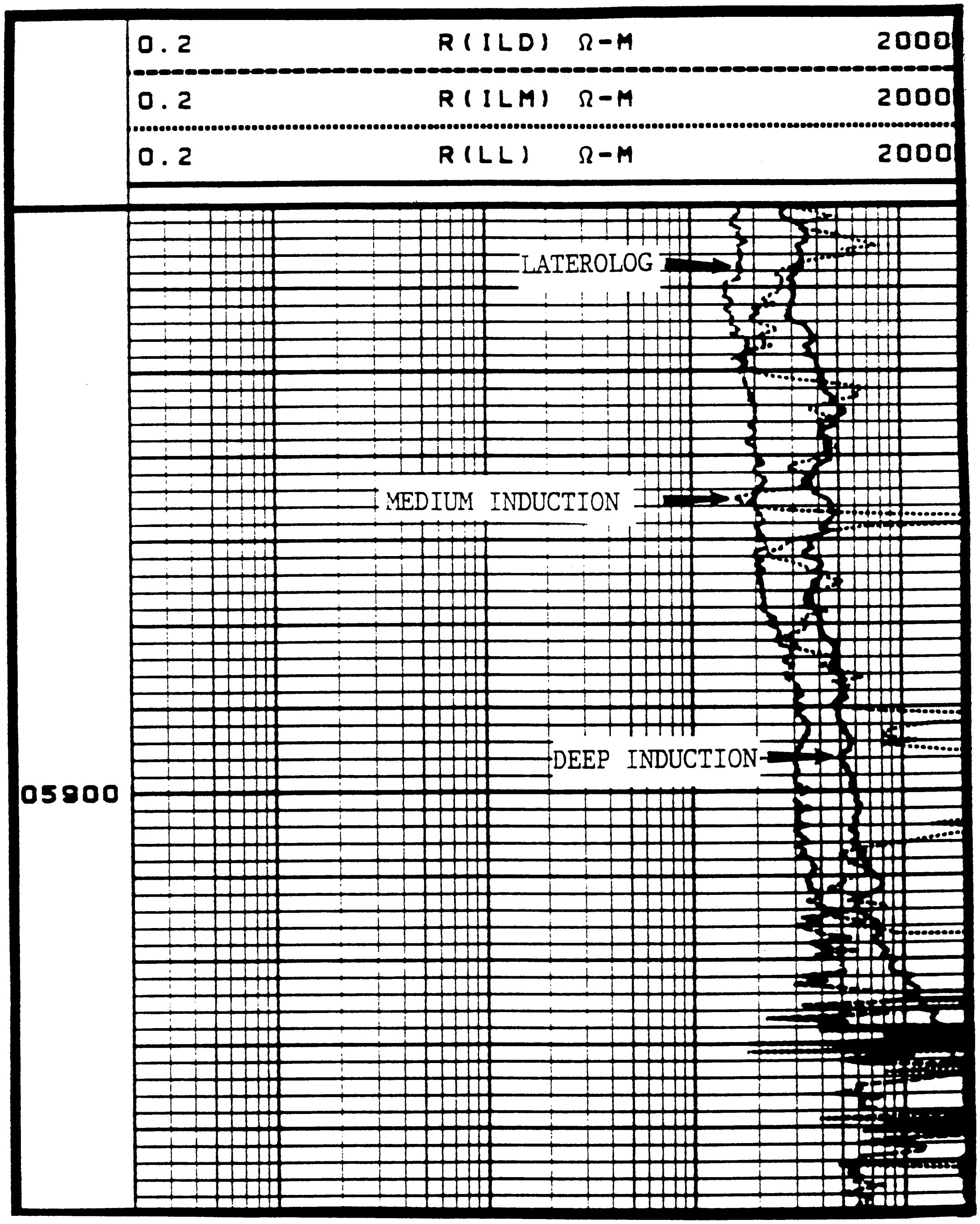

Figure 15. Dual induction laterolog of the Kaiser-Francis No.8-20 Dillard, illustrating the quasi-annulus effect, whereby the medium induction curve reads larger than the shallow investigating laterolog.

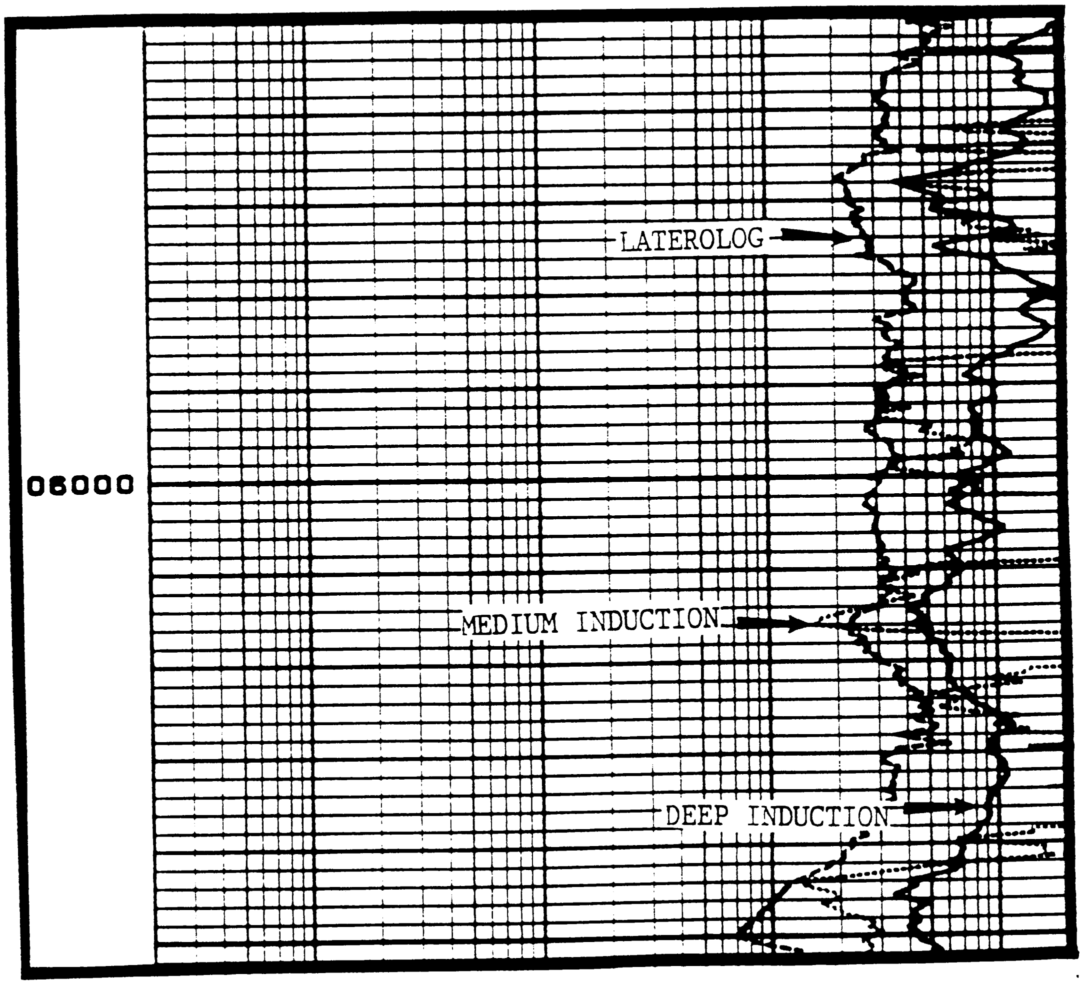

Figure 15. Continued

gamma-ray properties (Figure 14). Gamma-ray intensity of Unit 1L is about 30 API units in the lower part, decreasing upward to approximately 15 API units. Unit 2 generally is recorded as about 30 API units, which indicates that Unit 2 contains slightly more clay than most of Unit 1L.

Spontaneous-potential Log

The Viola Springs is recorded as a poorly developed spontaneous potential curve (Figure 14) because of the general lack of permeability and of free formation water.

Porosity Logs

Density, neutron, and sonic logs of wells used in this study were available (Figures 16 and 17). All three types of logs indicate that within a given well, the formation is porous throughout; generally the logs show approximately the same porosity. However, inspection of the rock and analysis of thin section shows that such porosities tend to be overestimated. Discrepancies arise because the rock matrix contains a significant fraction of silica, clay, organic matter, and matrix hydrocarbons, in addition to calcite. However, calcite generally is assumed to compose almost all of the rock, and logs are calibrated accordingly. The net effect of this compositional variation lowers matrix density, increases hydrogen content gauged by the neutron tool, and increases the interval transit time read by the sonic tool, all of which lead to erroneously calculated

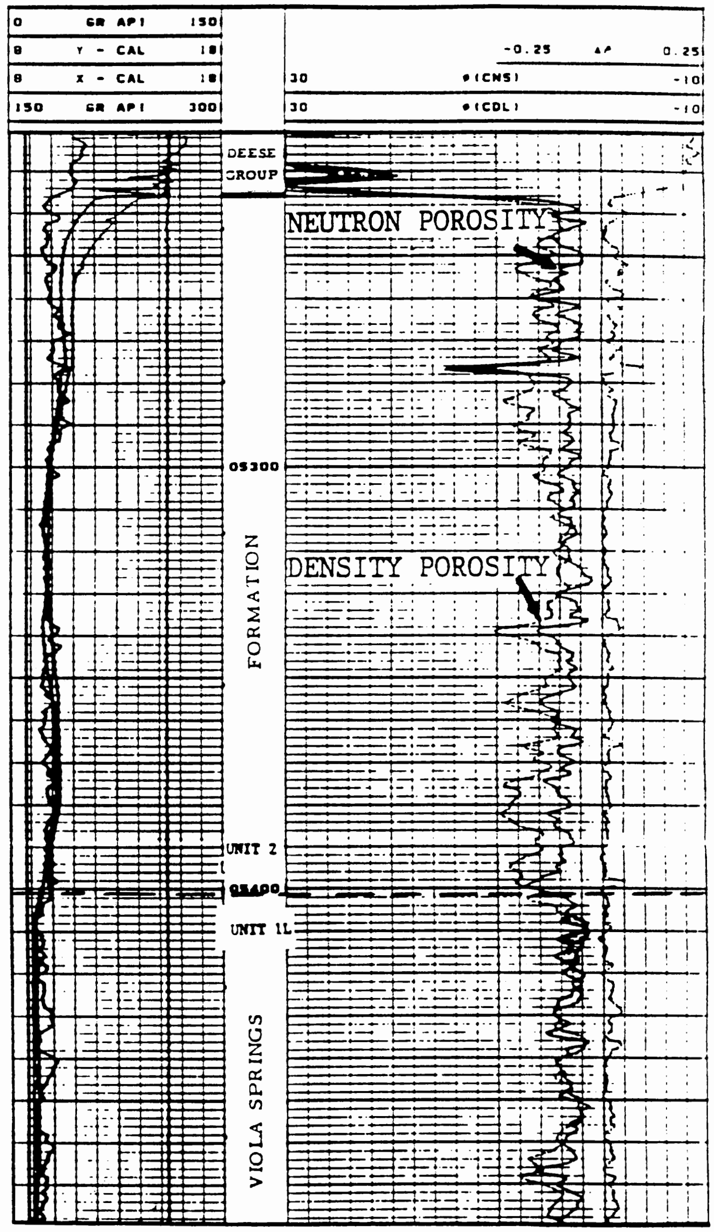

Figure 16. Density-neutron log of the Kaiser-Francis No. 2-18 Bennett. Notice that the density and neutron curves indicate porosity throughout the Viola Springs. This general pattern was observed in all porosity logs inspected from the study area.

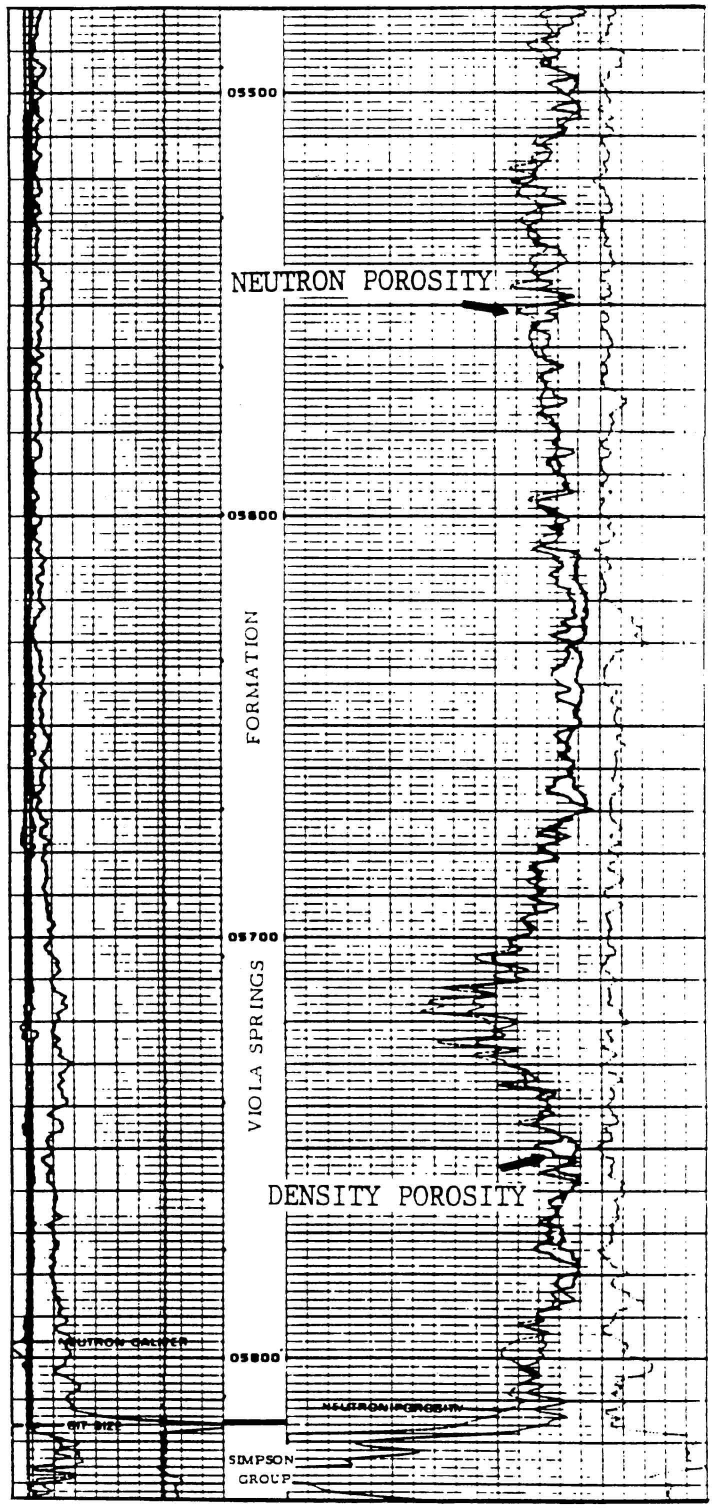

Figure 16. Continued

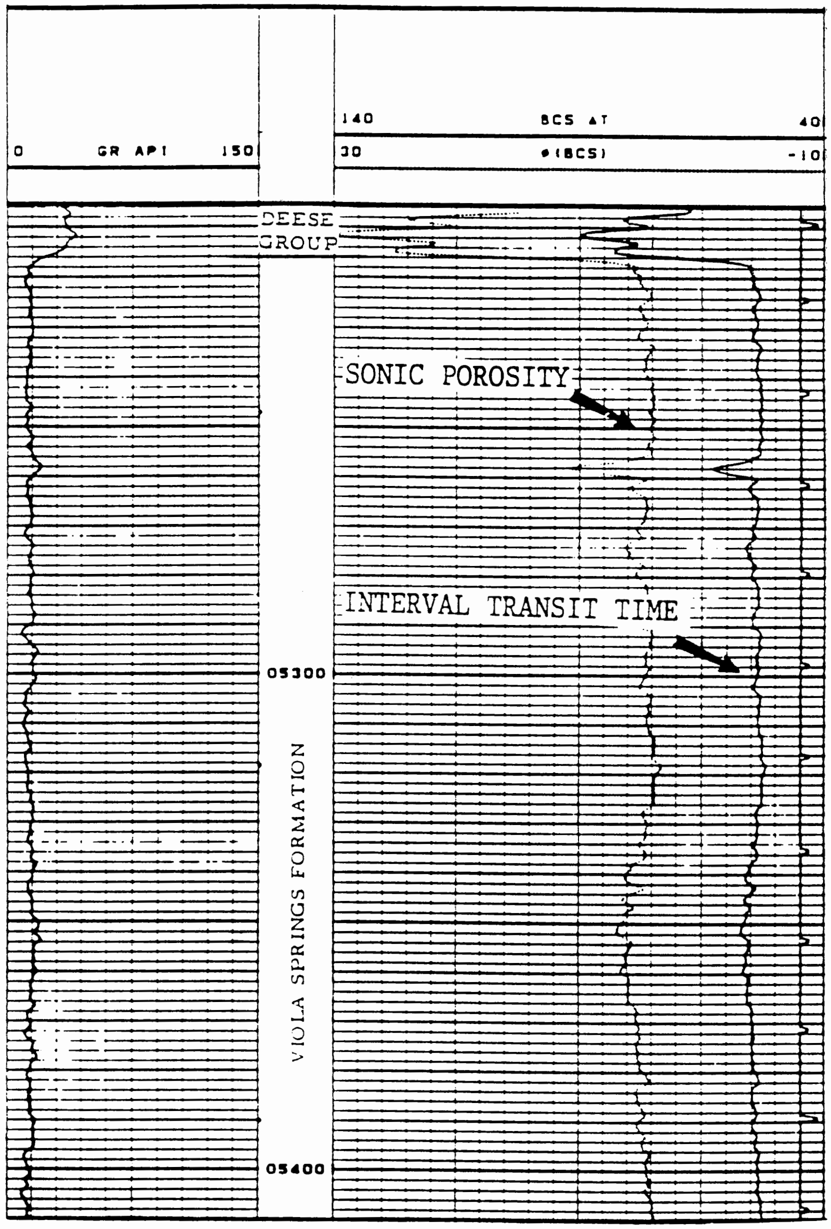

Figure 17. Sonic log of the Kaiser-Francis No. 1-17 David. The curve indicates porosity throughout the Viola Springs Formation.

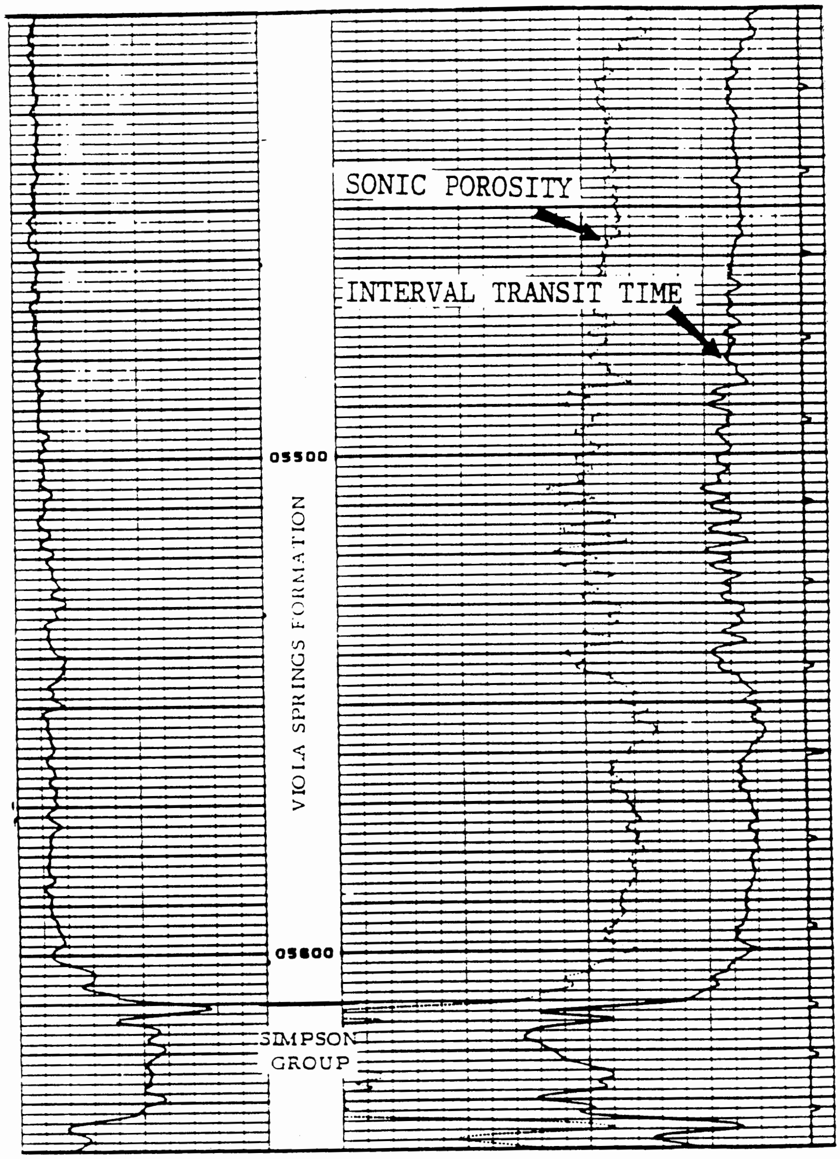

Figure 17. Continued

porosities.

In some strata, porosity curves show significant excursions to the left, indicating highly porous zones (Figure 18). This implies that other types of porosity other than those described above may be present in the formation. However, because examination of such zones was not possible with the available information, they are not readily explainable.

Implications for Log Evaluation

The accurate interpretation of any formation for its hydrocarbon potential is dependent on reliability of the log-derived data. Definition of valid log parameters for such interpretations of the Viola Springs Formation is difficult, because most log-derived values used in conventional interpretation are dependent on relatively uncomplicated reservoir geometry, discrete lithologies, and presence of conductive formation fluids, none of which appears to be the general case in this formation.

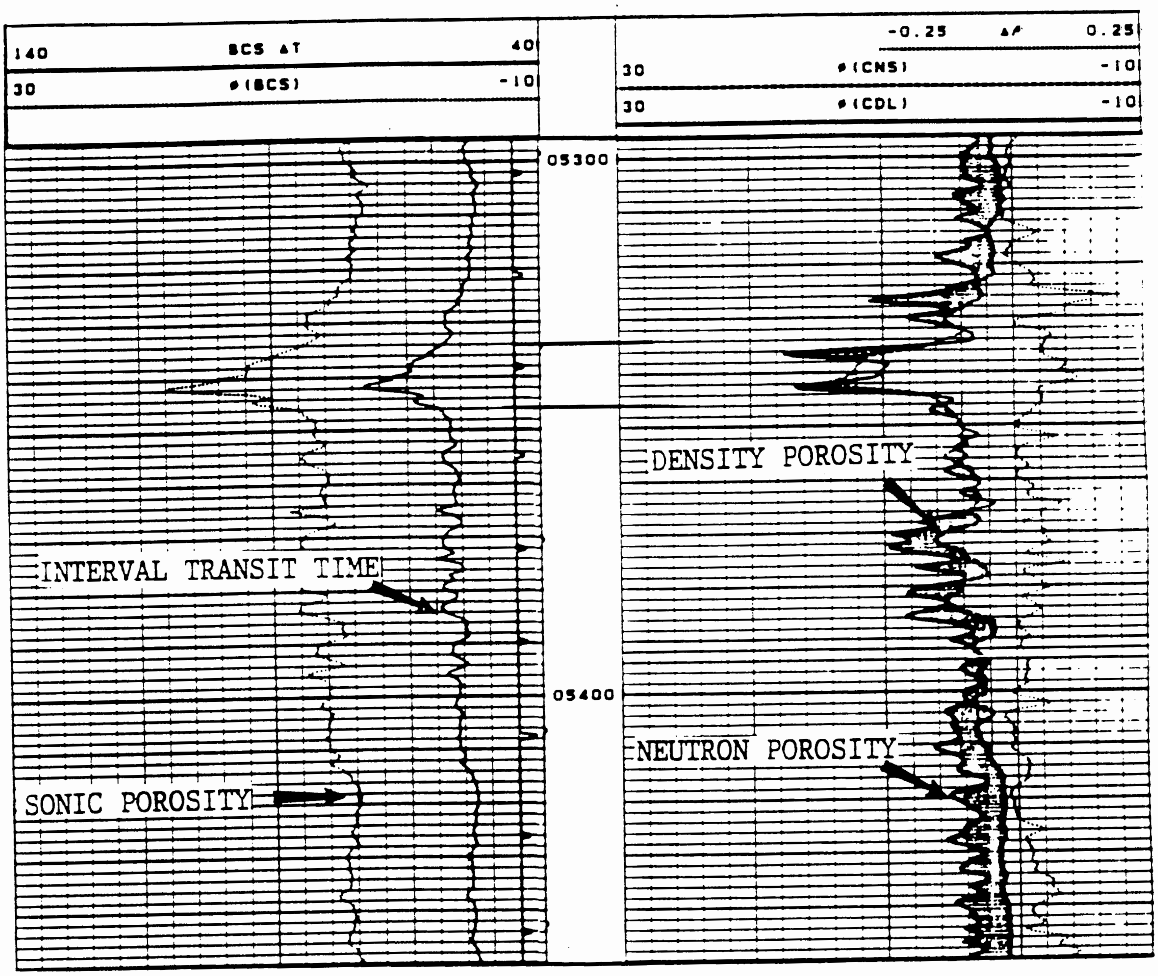

Figure 18. Sonic (left) and density-neutron (right) logs from the Kaiser-Francis No. 1-18 HBH Cattle Co. Note the indicated porous zones from 5334-5346 feet and 5478-5596 feet.

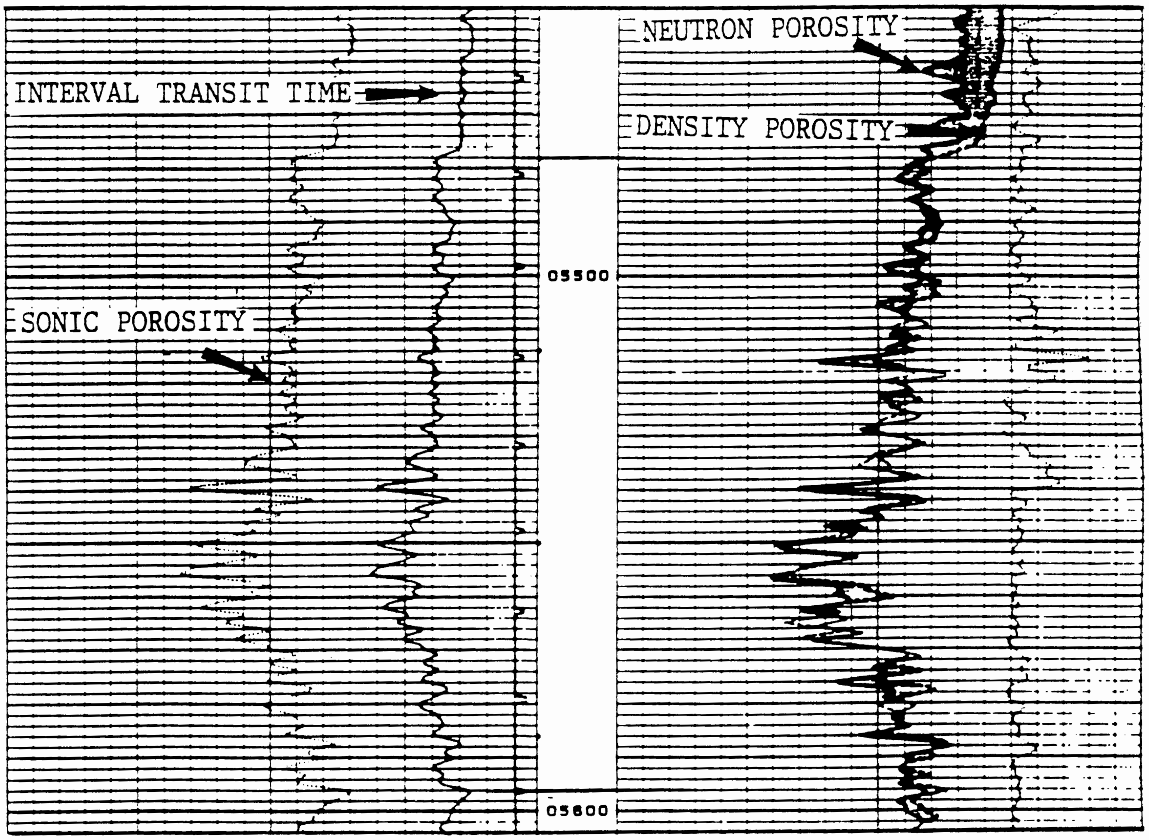

Figure 18. Continued

CHAPTER VIII

SUGGESTIONS FOR FUTURE STUDY

Oil to Source-rock Correlation

Results of study of the source-rock potential of the Viola Springs suggest that at least locally, the organic matter present is of type and quantity to generate hydrocarbons, given sufficient thermal maturity. However, in this study no attempt was made to demonstrate unequivocally that oil in the Viola Springs is primarily indigenous; thereby no attempt was made to exclude other possible sources. In recent years several techniques have been developed and several studies have been conducted to correlate sources (see Tissot (1984) for references). Therefore, an investigation to determine whether this formation is its own source would be worthwhile, and would contribute to understanding of the factors that are integral in develpment of production trends.

Future Production Potential

The best production potential for the Viola Springs may may be to the southeast of the study area, near the axis of the Marietta Basin (Figure 19). Here, depths of the formation range to 14,000 feet (Reed, 1959; Westheimer, 1965).

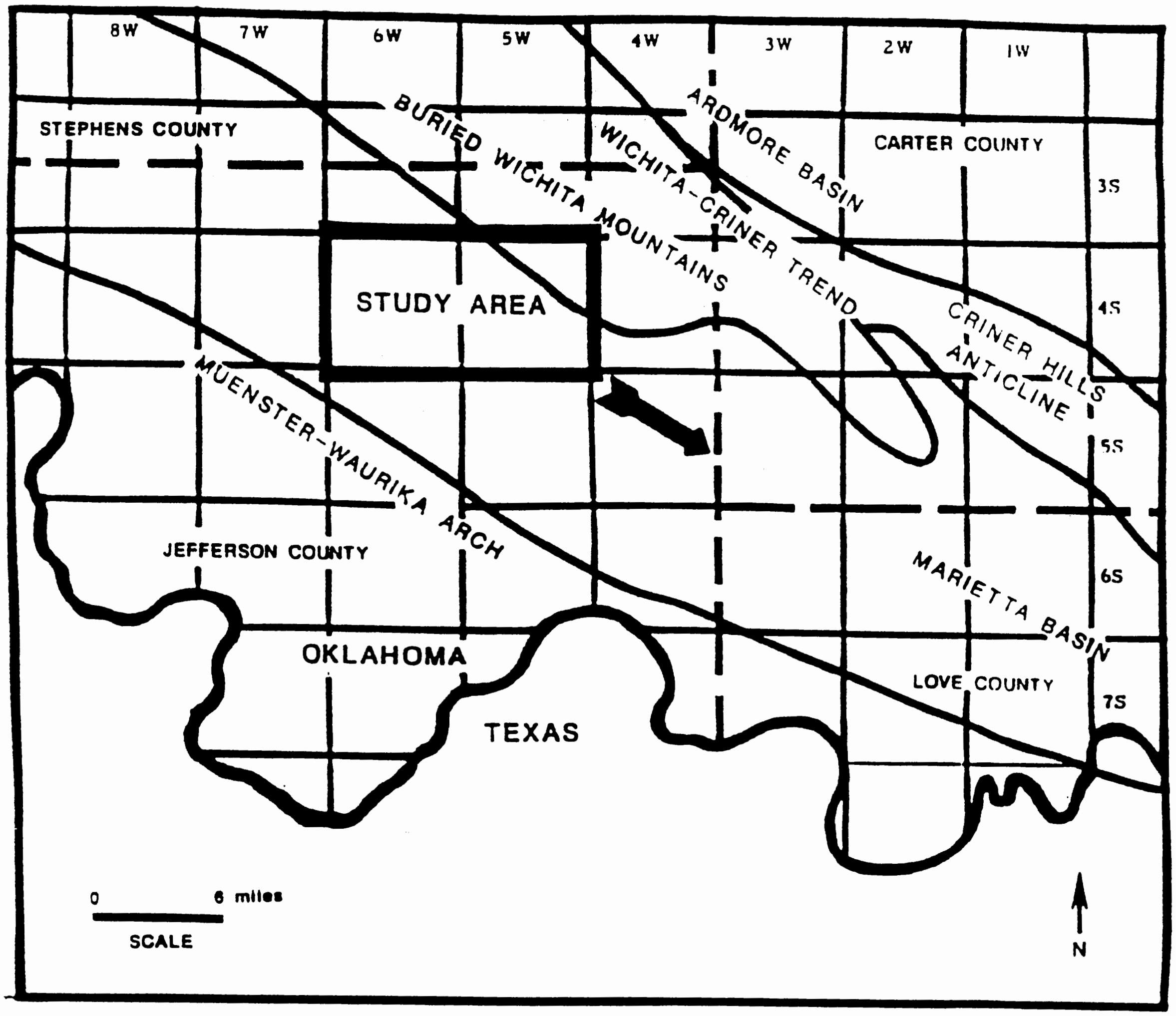

Figure 19. Map indicating that potential production trends may be to the southeast of the study area in the central Marietta Basin. After Hicks (1971).

Assuming a geothermal gradient consistent with that in the study area, these depths should be more than sufficient for generation of hydrocarbons. This suggestion is based on three critical assumptions: (1) the amount of organic matter is not substantially less than that found in the study area; (2) the type of organic matter is essentially the same as that found in the study area; and (3) the existence of favorable reservoirs. This is a relatively untested area, because most exploration of the basin has been confined to structures on its flanks (Waugh and Crompton, 1981; Allen, 1983).

CHAPTER IX

CONCLUSIONS

The following conclusions have been made from this study:

1. Assuming that the Kaiser-Francis No. 8-20 Dillard is representative of the Viola Springs in the study area, the formation contains organic matter that is of type and quantity to qualify as an excellent source-rock for generation of hydrocarbons. However, the organic matter is mature enough only to be at the threshold of generation; therefore, only a small fraction of the hydrocarbons have been generated.

2. Hypothetically, the oil produced from this formation may have been generated and may have migrated locally within the formation to form indigenous oil reservoirs where conditions were favorable for localizing oil accumulations. However, this must be considered an unqualified assumption. Further study is needed to determine an oil-to-source correlation, for possible exclusion of other sources.

3. Burial history of this area indicates that depths required for kerogen in the Viola Springs to have reached the state of thermal maturity determined in this study were

most probably attained since latest Pennsylvanian or Permian.

4. Structure of the Viola Springs in the area of study was formed by tectonic processes associated with destruction of the aulacogen. Areal distribution of the formation in the subsurface was determined by structural position and erosion before deposition of the Desmoinesian Deese Group.

5. Oil production from this reservoir is erratic and poorly predictable, due to large internal variation of porosity and permeability within the Viola Springs.

6. The uncommon petrophysical characteristics of this formation make it difficult to predict and analyze reservoir trends using traditional subsurface methods. Physical and chemical variations within the formation do not conform to the general lithologic and reservoir homogeneity that are assumed in analyses based on conventional interpretive techniques.

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APPENDIXES

APPENDIX A

CORE ANALYSIS

CORE ANALYSIS

The core from the Kaiser-Francis 8-20 Dillard well (NW 1/4, NE 1/4, section 20, Township 4 South, Range 5 West, Jefferson Co.) was the only one from the study area available for inspection. Location of the well is shown in Plate I and Figure 13. Of a total thickness of 548 feet of the Viola Springs Formation only two intervals composing 133 feet were cored. Unfortunately, this lack of direct information from cores necessarily limits any definitive interpretation of the formation, but certain features are present by which one may draw reasonable inferences and correlate to lithologies described by previous investigators.

The two cored intervals represent two different lithotypes and correspond to Glaser's (1965) lithostratigraphic Units 1L and 2 (Figure 4). Therefore, the units are considered separately in the following summary descriptions. The log of the core is shown in Figure 28.

Core Description - Unit 1L

The core of unit 1L (Figure 20) is from 5,899 to 5,965 feet below the surface. The sections from 5,940 to 5,951 feet and from 5,903 to 5,904 feet were lost during coring. This unit mostly is finely laminated limestone and chert

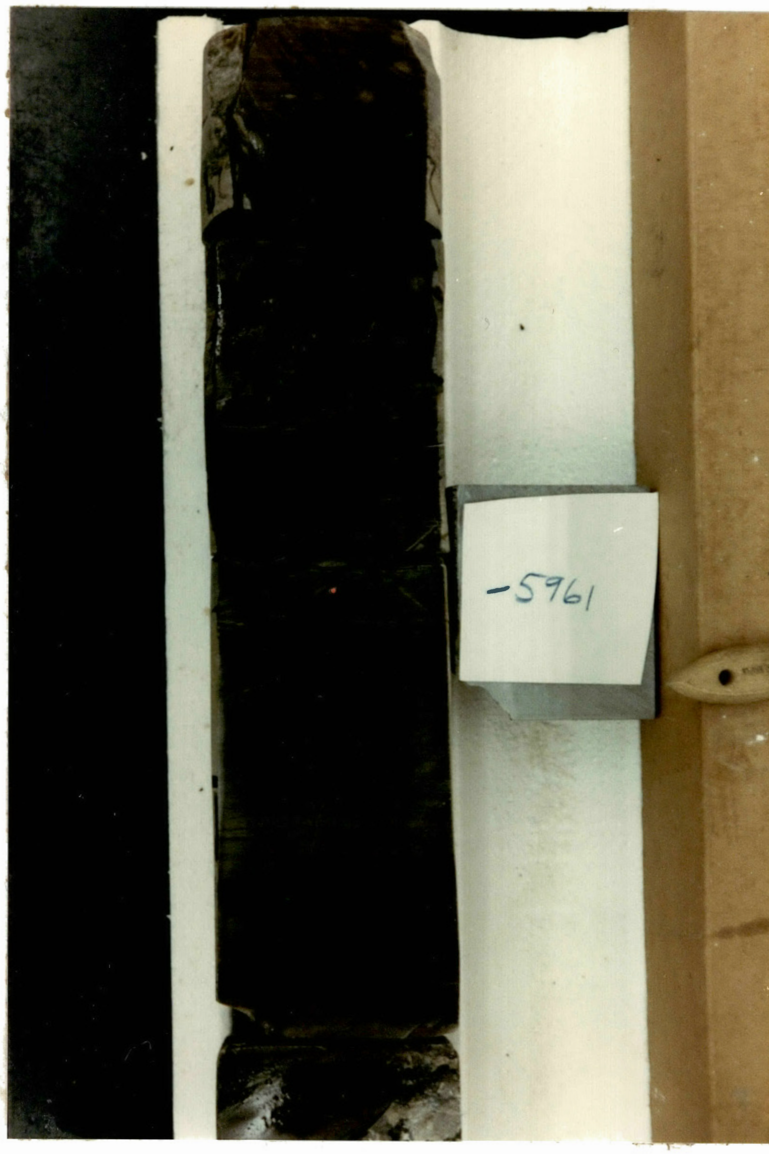

Figure 20. Photograph of Unit 1L. This unit mostly is finely laminated limestone and chert with sparse partings of shale. Light and dark color variation is due to increased amounts of organic matter in the darker horizons. Depth shown is below the surface. Scale of photograph: 1 inch equals approximately 6 inches.

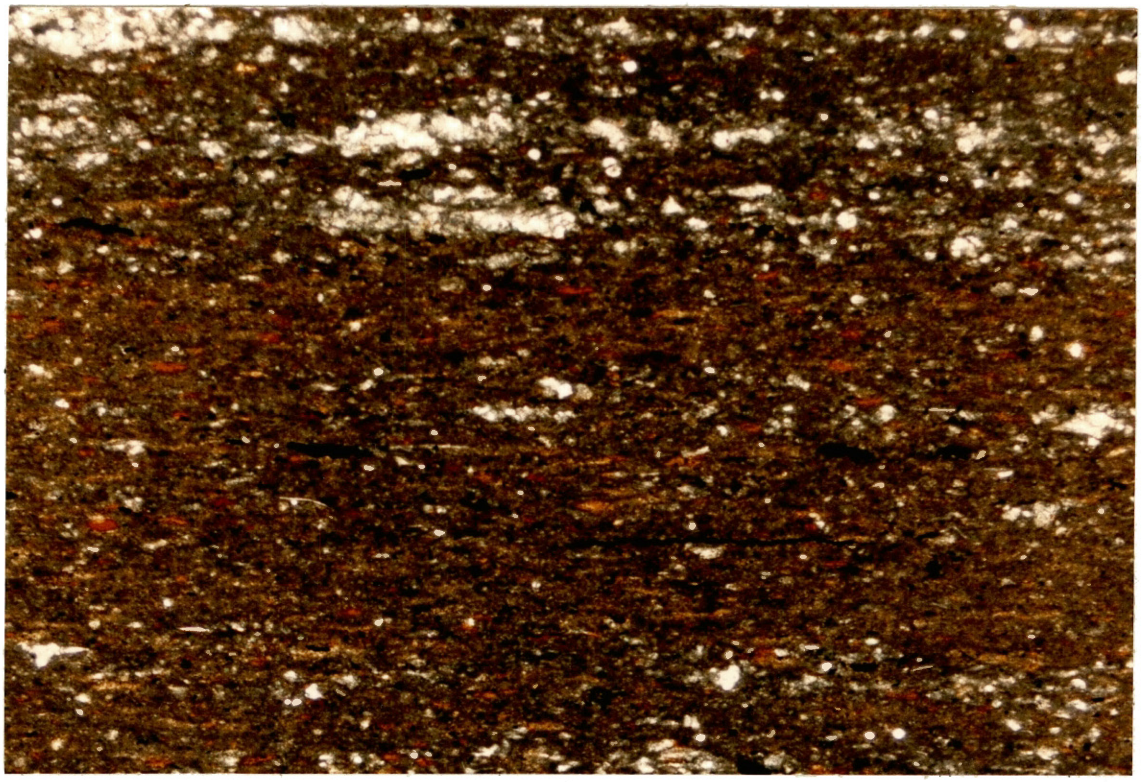

Figure 21. Thin-section photomicrograph of lithology typical of Unit 1L, which is finely laminated, micritic, and cherty. X-ray diffraction data showed this sample to contain calcite and silica. Dark coloration is from organic matter. Note the absence of shelly fossils. Porosity and permeability are generally absent. From Kaiser-Francis No.8-20 Dillard, core depth 5,962 feet. Magnification 40x. Plane-polarized light.

with sparse partings of shale (Figure 21). The rock is mudstone. Micrite and chert are principal components of the matrix. Chert, which probably is of diagenetic origin (Glaser, 1965; Galvin, 1982; Smith, 1982; Grammer, 1983; Gentile, 1984), has completely replaced micrite in some places. Minor constituents are pyrite, amorphous organic matter, phosphate, and clays. Graptolites and siliceous sponge spicules are common; trilobites, ostracods, and brachiopods are rare. Organic matter is along laminae, forms a three-dimensional network, and is distributed randomly throughout the matrix as fibrous strands (Figure 22). The rock ranges from gray to dark brown, giving the core a banded appearance. The brown and dark brown colors are indicative of increased amounts of organic matter. Fractures are common in this unit (Figures 23 and 24) and most are nearly vertical. They are filled with calcite, quartz, and "dead oil". Cherty strata appear to be the more broken. Differentiating between whether the open fractures of the broken core were primary or were induced during the coring coring procedure was not possible. This core was not oriented, so to determine the fracture directions was impossible. Sutured-seam stylolites (Wanless, 1979) are common (Figure 25) and cementation of the rock appears to be complete (Figure 21).

Lithic features of the rock indicate a subtidal, anaerobic environment. Supporting evidence includes laminated structures, small variation in kinds of fauna, and

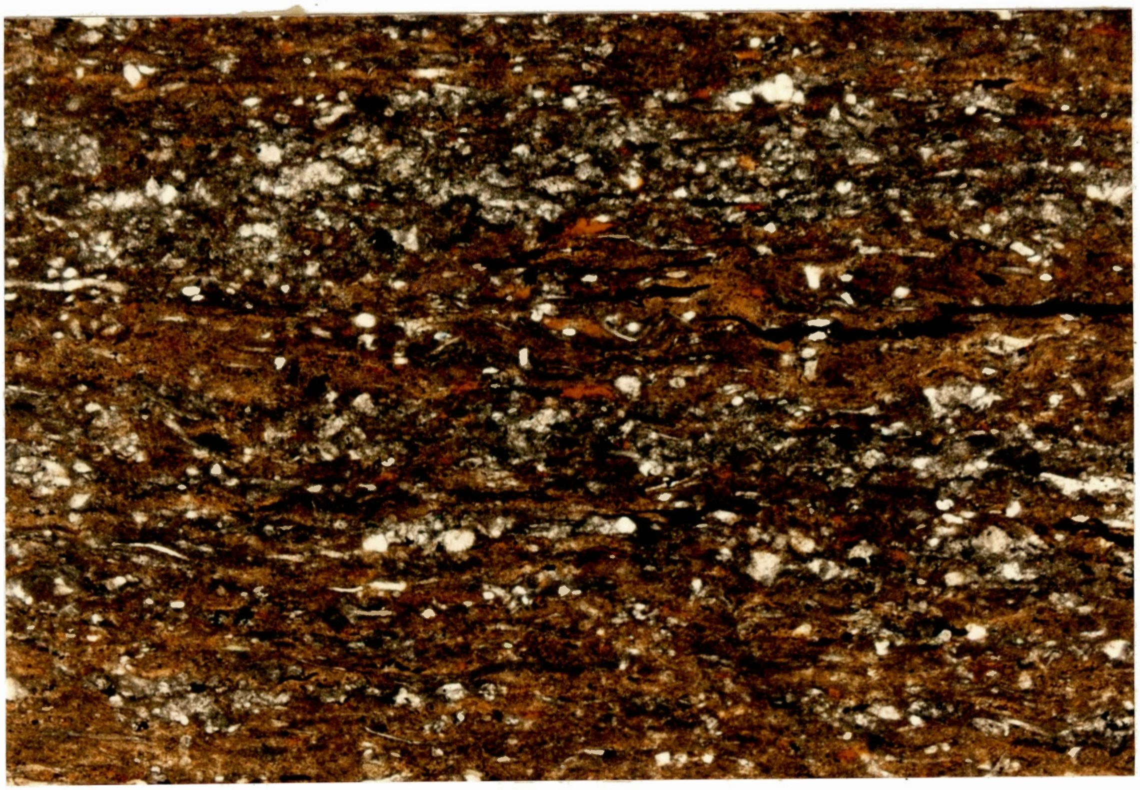

Figure 22. Thin-section photomicrograph showing horizontal orientation of organic matter. Where viewed in three dimensions, the organic matter may extend laterally and vertically, being concentrated along laminae and as isolated fibrous strands. "Dead oil" accompanies the organic matter in micropores. From the Kaiser-Francis No. 8-20 Dillard, core depth 5,955 (Unit 1L).Magnification 40x. Plane-polarized light.

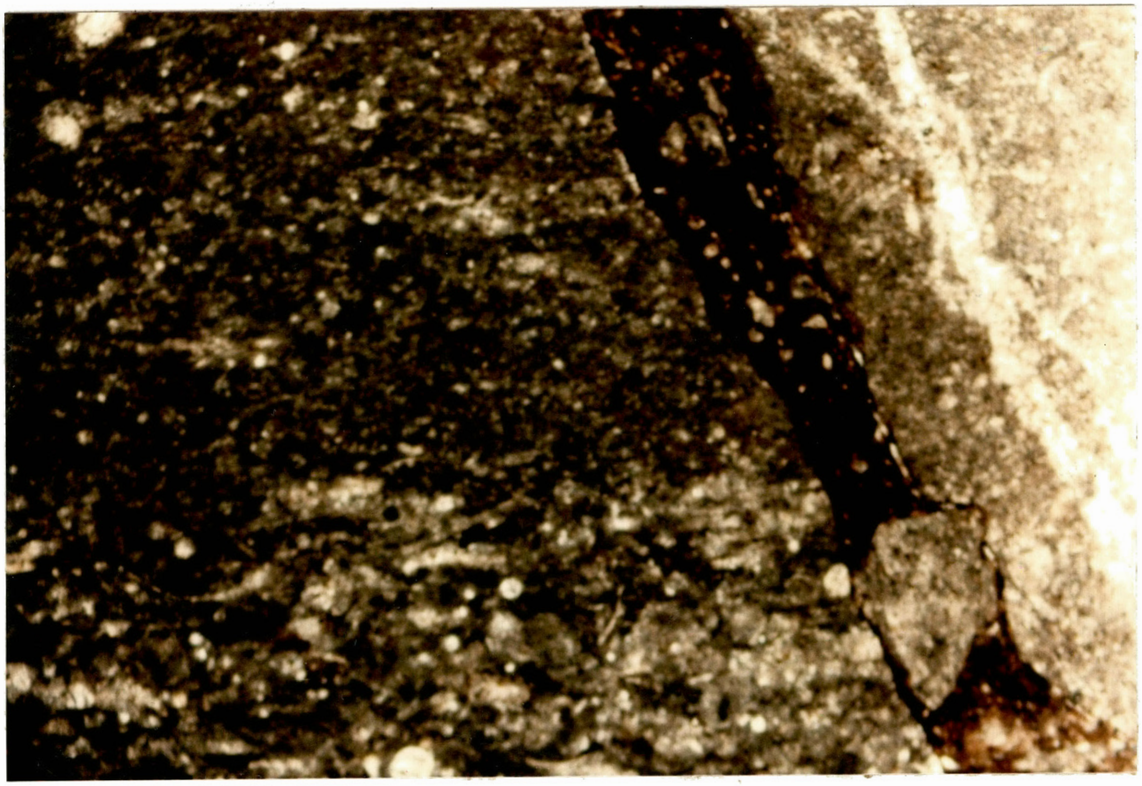

Figure 23. Thin-section photomicrograph of a fracture filled with "dead oil". Note breccia in the fracture. From the Kaiser-Francis No. 8-20 Dillard, core depth 5,963 feet (Unit 1L). Magnification 40x. Plane-polarized light.

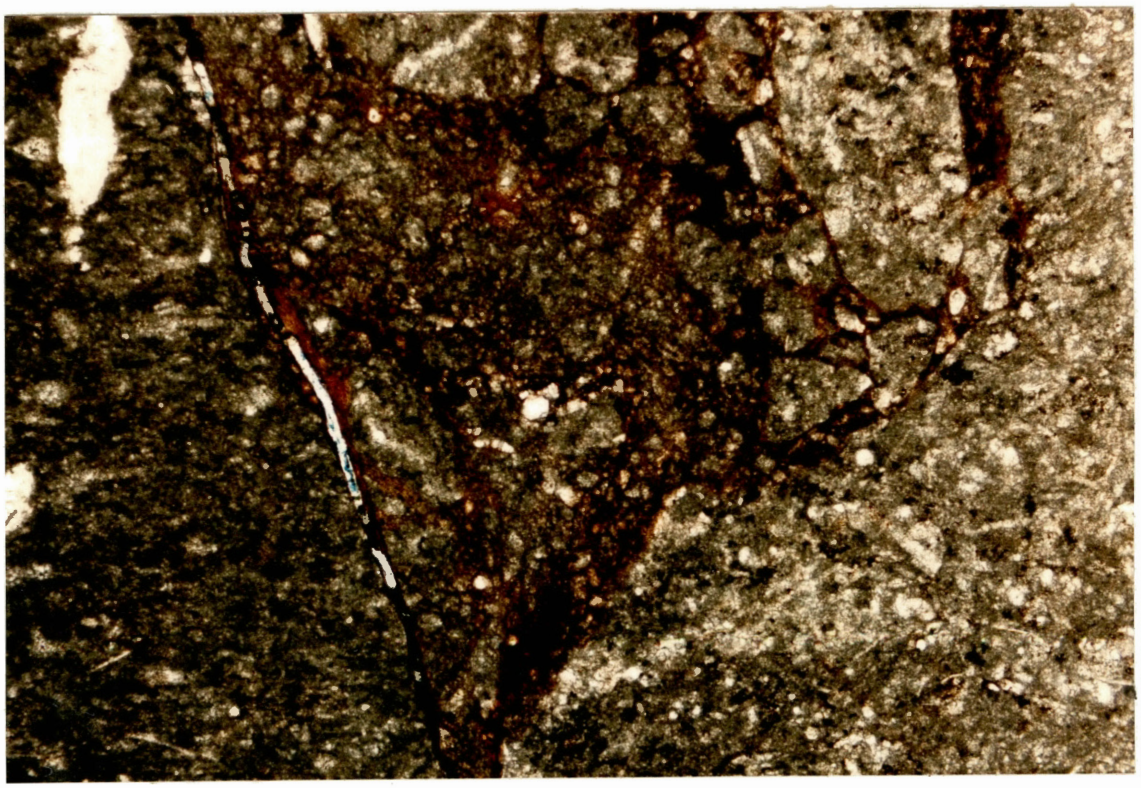

Figure 24. Thin-section photomicrograph of fractures filled with "dead oil". Note brecciated nature of fractures. From the Kaiser-Francis No. 8-20 Dillard, core depth 5,938 feet (Unit 1L). Magnification 40x. Plane-polarized light.

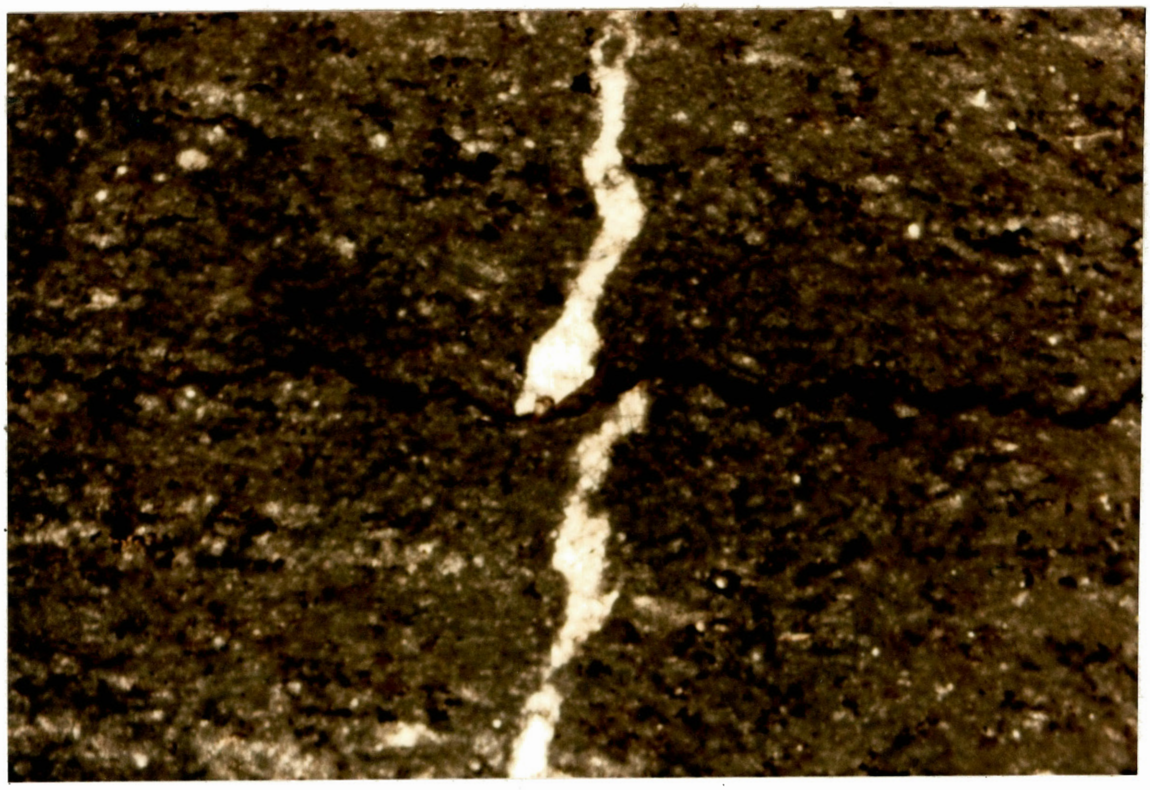

Figure 25. Thin-section photomicrograph of a stylolite, showing offset of a silica-filled vein. Dark material concentrated along the stylolite is organic matter. From the Kaiser-Francis No. 8-20 Dillard, core depth 5,964 feet (Unit 1L). Magnification 40x. Plane-polarized light.

significant amounts of preserved organic matter, which suggest reducing conditions. Such an interpretation is consistent with that of several previous investigators (Galvin, 1982; Smith, 1982; Grammer, 1983; Gentile, 1984).

Core Description - Unit 2

The core of this unit (Figure 26) is from 5,617 to 5,684 feet below the surface. Sections from 5,652 to 5,653 feet and 5,638 to 5,639 feet were lost during coring.

This unit is nodular, irregularly bedded limestone, intensely bioturbated. Nodules and bedding are separated by non-sutured-seam stylolites (Figure 26) (Wanless, 1979). This unit ranges from packstone to wackestone. The matrix is primarily micrite and it contains an abundant shelly fauna (Figures 27 and 28). The rock is less siliceous than Unit 1L. The principle biota are trilobites, brachiopods, pelmatozoa, and ostracods, with smaller amounts of graptolites, sponge spicules, bryozoans, gastropods, and disseminated amorphous organic matter. The non-sutured-seam stylolites contain calcite, silica, clay minerals, rhombic dolomite, and organic matter.

The rock matrix is gray and the non-sutured-seam stylolites range from dark brown to black. Fractures are common, but not as abundant as in Unit 1L. Most fractures appear to be filled with calcite. Cementation appears to be complete (Figures 27 and 28).

Unit 2 seems to have been deposited in an aerobic en-

Figure 26. Photograph of a section of Unit 2. This unit is nodular, irregularly bedded limestone. The dark horizontal bands are non-sutured-seam stylolites separating nodules and bedding. Depth shown is below the surface. Scale of photograph: 1 inch equals approximately 6 inches.

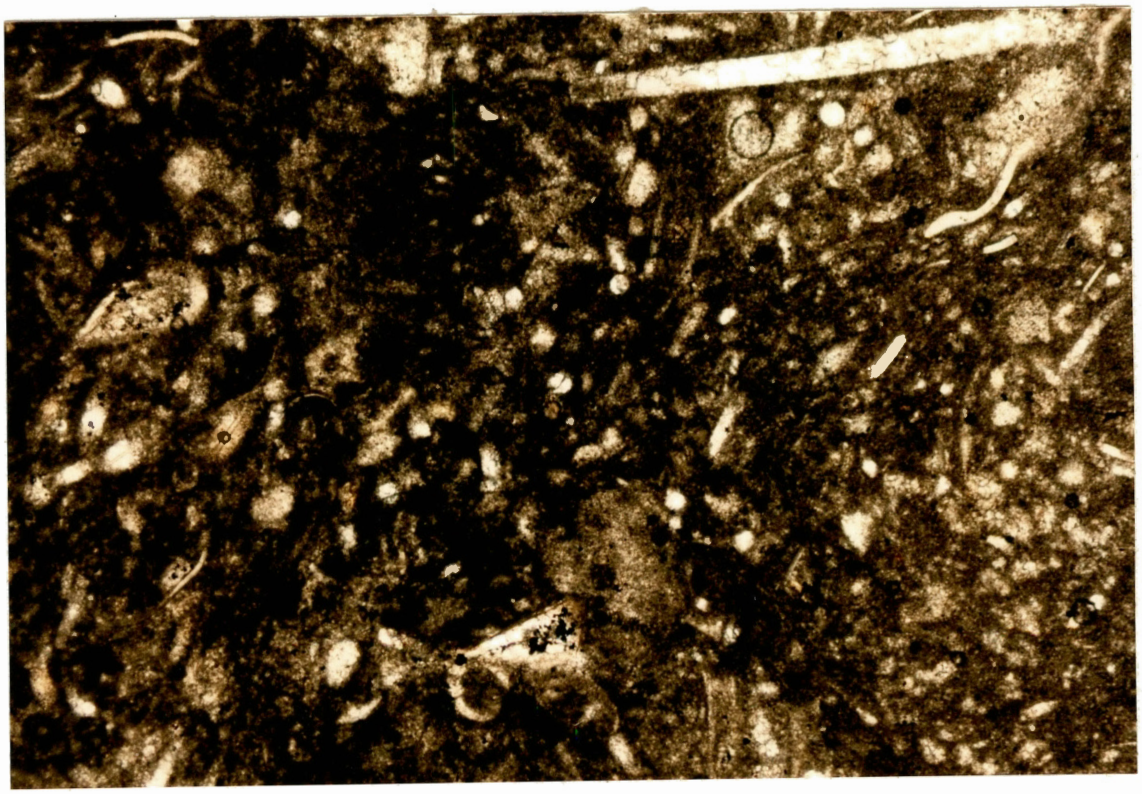

Figure 27. Thin-section photomicrograph from the Kaiser Francis No. 8-20 Dillard. Core depth 5,652 feet. Matrix is micritic. This example is from Unit 2. Note increased shelly-fossil content compared to Unit 1L (Figure 21). Also note the absence of porosity and of evidence of permeability, a general characteristic of this formation. Magnification 40x. Plane-polarized light.

Figure 28. Thin-section photomicrograph showing bedding disturbed by bioturbation, a feature commonly observed throughout Unit 2. From the Kaiser-Francis No. 8-20 Dillard, core depth 5,660 feet. Magnification 40x. Plane-polarized light.

vironment. The primary evidence is increased diversity of fauna and bioturbation. This indicates a shoaling upward of the depositional environment, although the sea floor floor probably was below wave base. This interpretation is consistent with that of several previous investigators (Galvin, 1982; Smith, 1982; Grammer, 1983; Gentile, 1984).

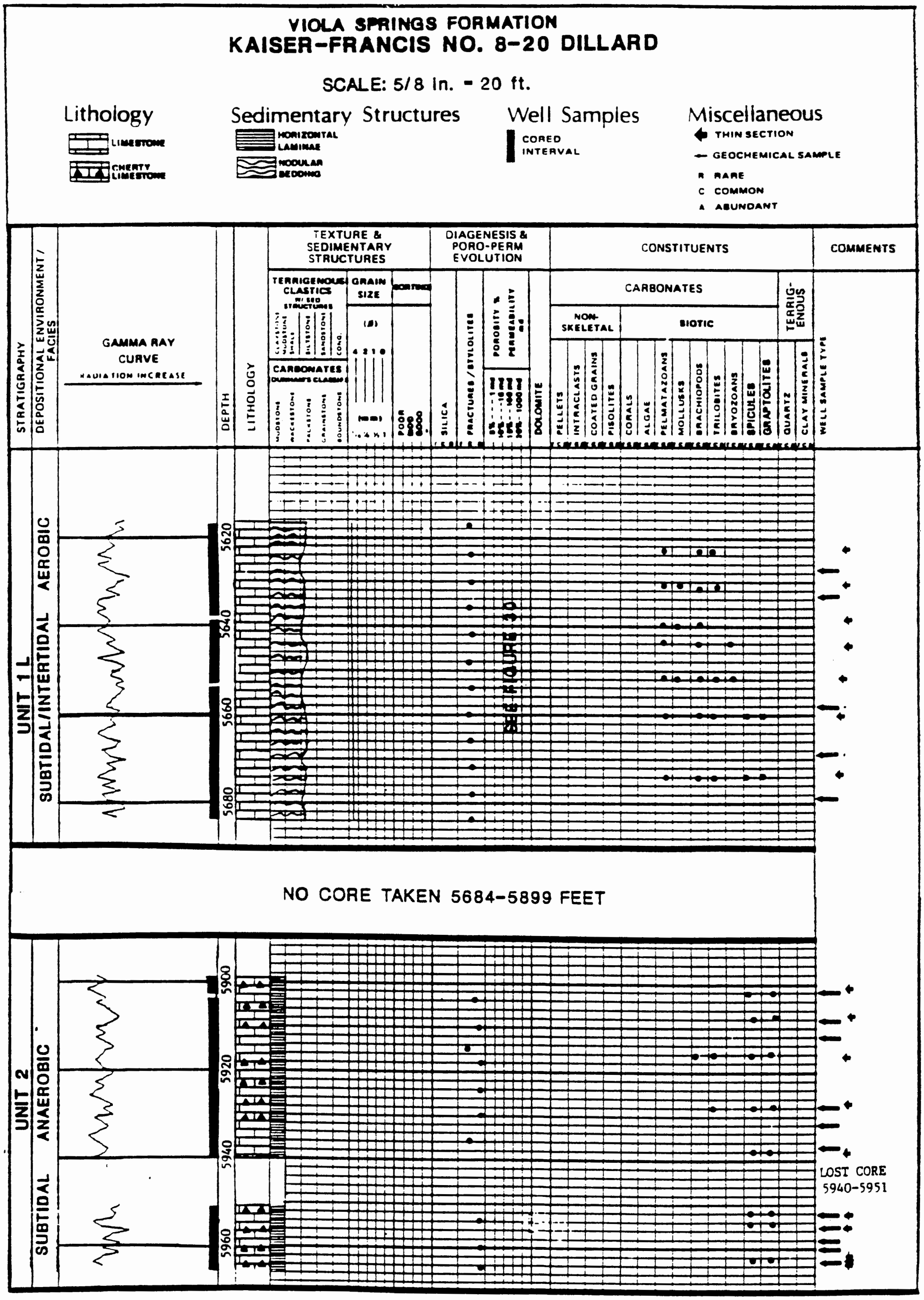

Figure 29. Core log of the No. 8-20 Dillard.

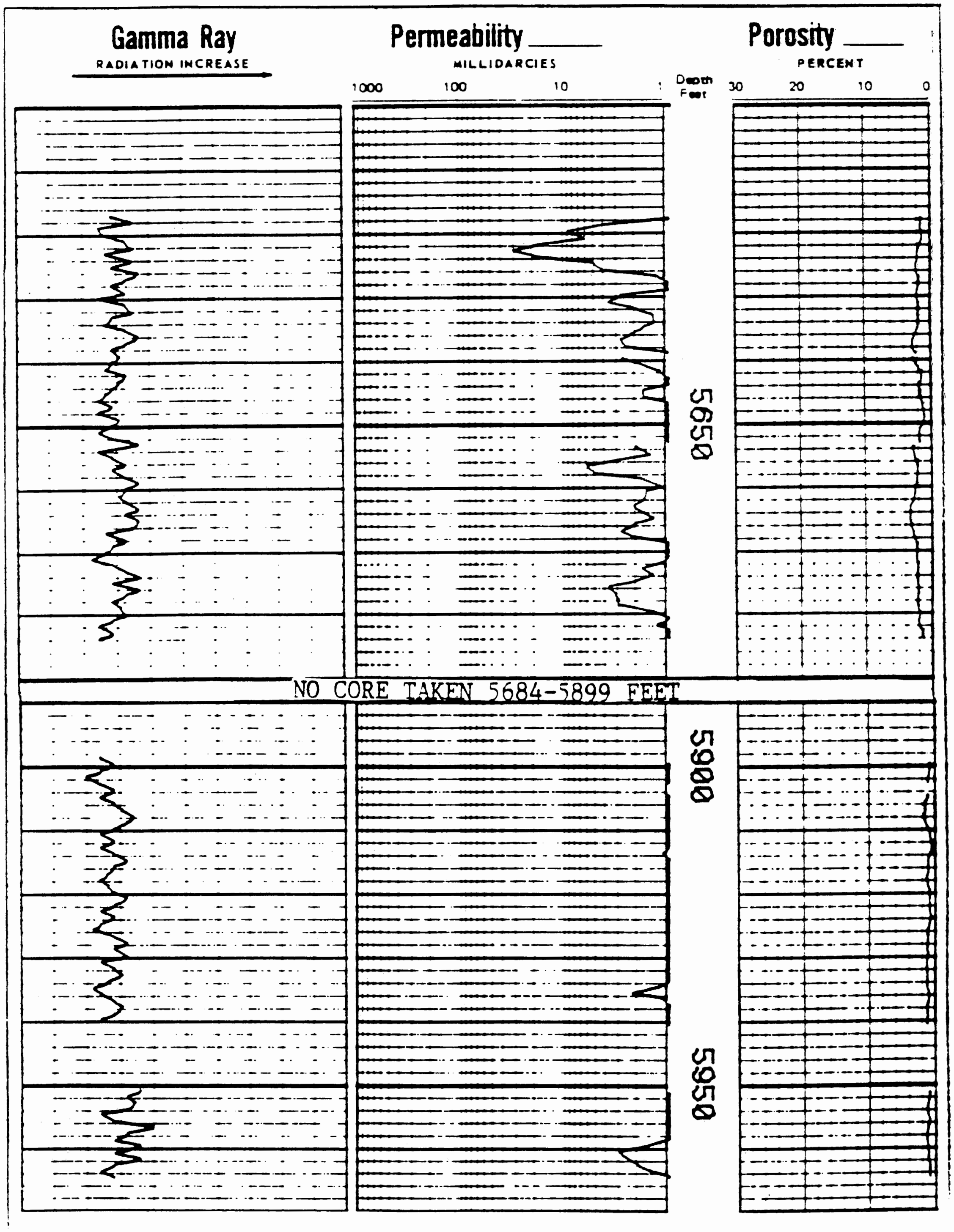

Figure 30. Plots of gamma-ray, permeability, and porosity, Kaiser-Francis 8-20 Dillard.

APPENDIX B

LOCATIONS, NAMES, AND INDEX NUMBERS OF WELLS USED IN THIS STUDY

LOCATIONS, NAMES, AND INDEX NUMBERS

OF WELLS USED IN THIS STUDY

Well Index No.	Well Name	Location
1	1-18 Bennett	NW 1/4 NE 1/4, SEC. 18, T4S R5W
2	2-18 Bennett	SE 1/4 NW 1/4, SEC. 18, T4S R5W
3	1-18 Blackburn	NE 1/4 SE 1/4, SEC. 18, T4S R5W
4	1-18 Howard	NW 1/4 SE 1/4, SEC. 18, T4S R5W
5	1-18 HBH Cattle Co.	SE 1/4 NE 1/4, SEC. 18, T4S R5W
6	1-18 Brooks	SE 1/4 SE 1/4, SEC. 18, T4S R5W
7	1-19 Dennis	N 1/2 NW 1/4 NE 1/4, SEC. 19, T4S R5W
8	4-20 Worley	NW 1/4 NW 1/4 NW 1/4, SEC. 20, T4S R5
9	1-17 Worley	N 1/2 SE 1/4 SW 1/4, Sec. 17, T4S R5W
10	1-17 David	NW 1/4 SE 1/4 Sec. 17, T4S R5W
11	6-20 Dillard	SE 1/4 NW 1/4 Sec. 20, T4S R5W
12	8-20 Dillard	NW 1/4 NE 1/4 Sec. 20, T4S R5W
13	1-17 Bachoffer	SE 1/4 SE 1/4 SE 1/4, Sec. 17, T4S R5
14	1-21 London	N 1/2 SE 1/4 NW 1/4, Sec. 21, T4S R5W
15	1-16 Wilton	SE 1/4 SW 1/4, Sec. 16, T4S R5W
16	1-22 Donald	NW 1/4 SW 1/4, Sec. 22, T4S R5W
17	1-13 La Fountain	NE 1/4 NE 1/4, Sec. 13, T4S R6W
18	1-10 Jackson	NW 1/4 SE 1/4, Sec. 10, T4S R6W

VITA

Gary Dale Beach

Candidate for the Degree of

Master of Science

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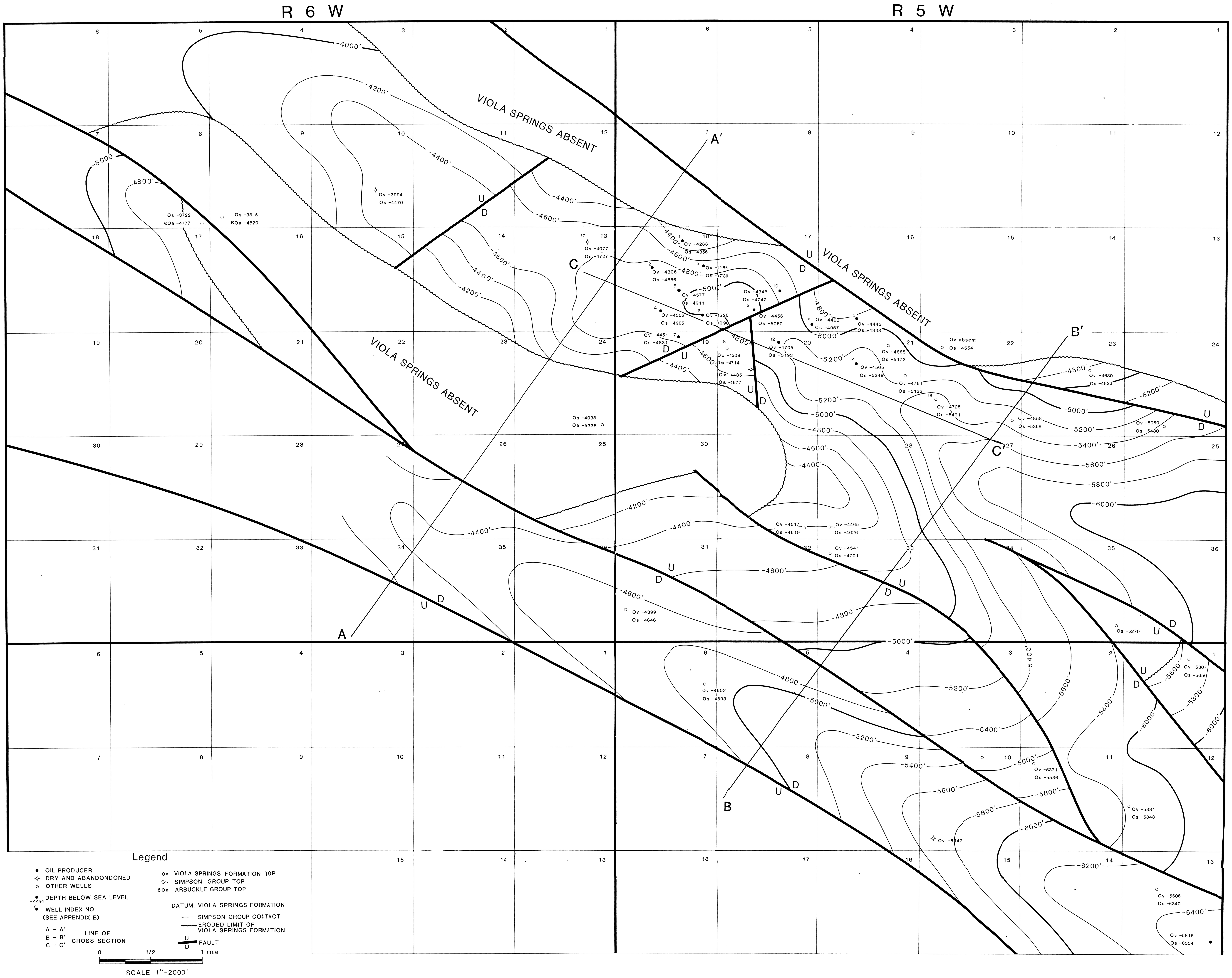
Education: Graduated from Claremore High School, Claremore, Oklahoma, May, 1971; received Bachelor of Arts degree with a major in history from the University of Oklahoma in May, 1975; received a Bachelor of Science degree with a major in geology from Oklahoma State University in Decemcember, 1983; completed requirements for the Master of Science degree at Oklahoma State University in July, 1989.

Professional Experience: Exploration Technologist, Amoco Production Company, Tulsa, Oklahoma, February, 1976, to January, 1982; Geological Assistant, Kaiser-Francis Oil Company, Ardmore, Oklahoma, May, 1984, to May, 1985; Geologist, Exploration Systems Group, Amoco Production Company, Houston, Texas, August 1985 to present.

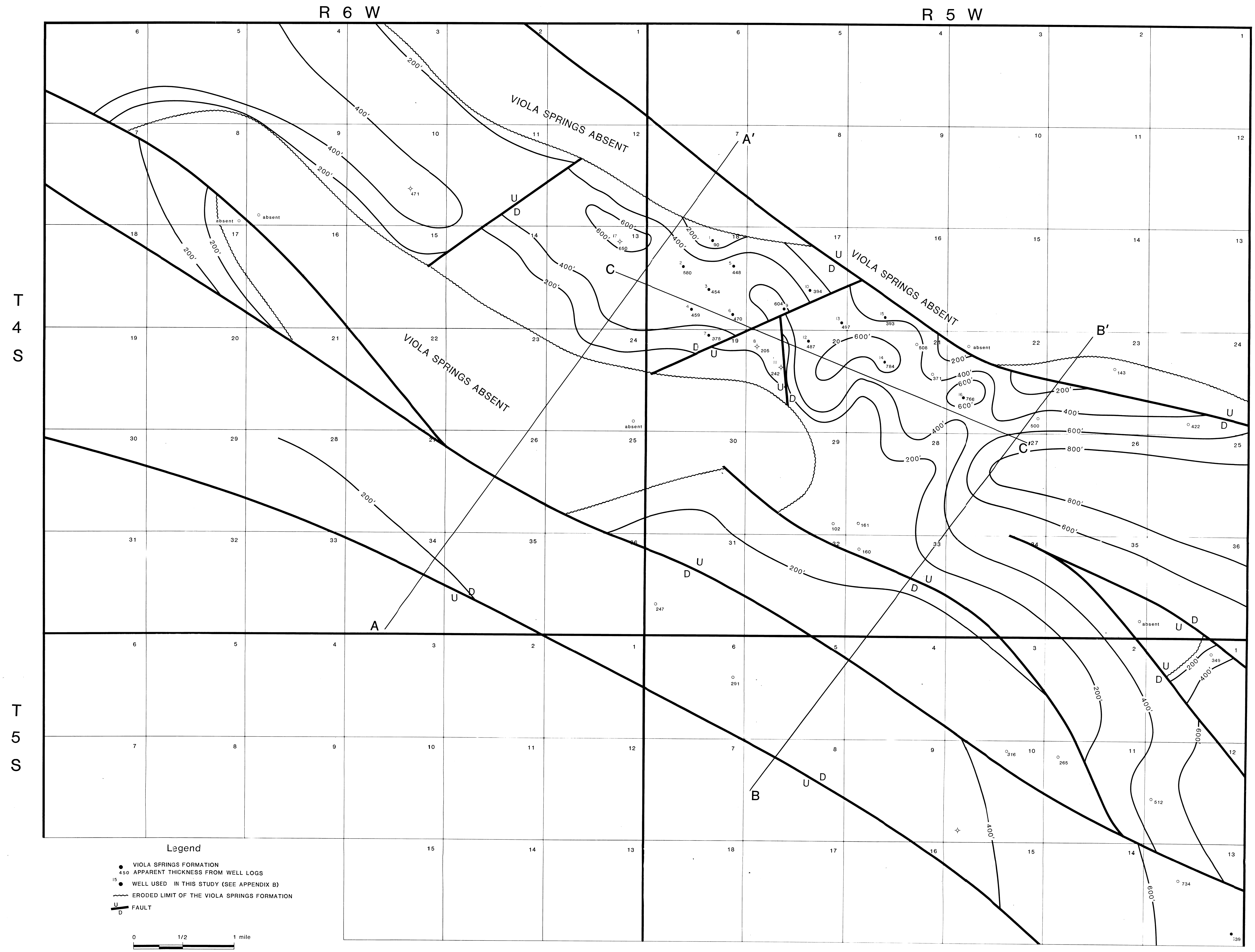


CONTOUR INTERVAL : 200'

THE VIOLA SPRINGS FORMATION
STRUCTURAL CONTOUR MAP OF
NORTH CENTRAL
JEFFERSON COUNTY, OKLAHOMA

GARY D. BEACH
M.S. THESIS
OKLAHOMA STATE UNIVERSITY

PLATE I
STRUCTURE MAP



Legend

- 450 VIOLA SPRINGS FORMATION APPARENT THICKNESS FROM WELL LOGS
- 15 WELL USED IN THIS STUDY (SEE APPENDIX B)
- ERODED LIMIT OF THE VIOLA SPRINGS FORMATION
- U/D FAULT

0 1/2 1 mile

SCALE 1''–2000'

CONTOUR INTERVAL : 200'

APPARENT VERTICAL THICKNESS MAP OF THE VIOLA SPRINGS FORMATION

NORTH CENTRAL
JEFFERSON COUNTY, OKLAHOMA

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OKLAHOMA STATE UNIVERSITY

PLATE II

APPARENT VERTICAL THICKNESS MAP

SCALE: 1" = 400'
NO VERTICAL EXAGGERATION

CROSS SECTION A-A′
NORTH CENTRAL
JEFFERSON COUNTY, OKLAHOMA

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M.S. THESIS
OKLAHOMA STATE UNIVERSITY

PLATE III
CROSS SECTION A-A′

CROSS SECTION B-B'

NORTH CENTRAL
JEFFERSON COUNTY, OKLAHOMA

GARY D. BEACH

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OKLAHOMA STATE UNIVERSITY

PLATE IV

CROSS SECTION B-B'

SCALE: 1″ - 400′

NO VERTICAL EXAGGERATION

CROSS SECTION C′-C′

NORTH CENTRAL
JEFFERSON COUNTY, OKLAHOMA

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PLATE V

CROSS SECTION C-C′