

DEPOSITIONAL ENVIRONMENTS, RESERVOIR TRENDS,
AND DIAGENESIS OF RED FORK SANDSTONES
IN PORTIONS OF BLAINE, CADDO, AND
CUSTER COUNTIES, OKLAHOMA

By

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TABLE OF CONTENTS

Chapter	Page
I. ABSTRACT	1
II. INTRODUCTION	3
Objectives and Methods	3
Previous Investigations	6
III. STRUCTURAL FRAMEWORK	9
Regional Setting	9
Local Structural Geology	10
IV. STRATIGRAPHIC FRAMEWORK	12
Correlations	15
V. GEOMETRY OF THE RED FORK SANDSTONES	16
Lower Red Fork	17
Trends and Widths	17
Boundaries	17
Thickness	17
Upper Red Fork	18
Trends and Widths	18
Boundaries	18
Thickness	18
VI. INTERNAL FEATURES	19
Sedimentary Structures	19
Interstratification	24
Horizontal Laminations	24
"Massive" Bedding	24
Medium- and Small-Scale Cross-Bedding	24
Convolute Bedding and Slump Structures	28
Bioturbation	28
Rootlets and Nodules	28
Texture	34
Fossils	34
Coal and Organic Shale	34

Chapter	Page
VII. DEPOSITIONAL ENVIRONMENT.	40
Introduction	40
Lower Red Fork	42
Upper Red Fork	53
VIII. PETROLOGY AND DIAGENESIS.	62
Purpose and Methods.	62
Lower Red Fork	62
Composition and Classification.	62
Diagenetic Constituents.	63
Porosity.	67
Paragenesis	72
Upper Red Fork	72
Composition and Classification.	72
Diagenetic Constituents.	77
Porosity.	88
Paragenesis	93
IX. PETROLEUM GEOLOGY	95
X. CONCLUSIONS	99
BIBLIOGRAPHY	101
APPENDIX -- CORE DESCRIPTIONS	109

TABLE

Table	Page
I. Oil and Gas Production From Red Fork Sandstones.	95

LIST OF FIGURES

Figure	Page
1. Map Showing Location of the Study Area.	4
2. Type Log Showing Markers and Principal Subdivisions of the Interval Studied.	5
3. Relationship Between the Lowermost Red Fork Marker and the Inola Limestone Development	14
4. Photograph of the Southport No. 2 Switzer, Lower Red Fork . . .	20
5. Photograph of the Davis No. 1 Herring, Lower Red Fork	21
6. Photograph of the Conoco No. 1-14 Meachum, Upper Red Fork . . .	22
7. Photograph of the Conoco No. 1-A Snider, Upper Red Fork . . .	23
8. Sharp Contact Within the Southport No. 2 Switzer, Depth 10,407.3 Feet, Lower Red Fork.. . . .	25
9. Gradational Contact Within the Davis No. 1 Herring, Depth 10,881 Feet, Lower Red Fork	26
10. Horizontal Laminations Within the Conoco No. 1-A Snider, Depth 12,290 Feet, Upper Red Fork	27
11. Small Scale Cross-bedding Within the Conoco No. 1-14 Meachum, Depth 12,337.8 Feet, Upper Red Fork	29
12. Slump Structures Within the Conoco No. 1-A Snider, Depth 12,373.0 Feet, Upper Red Fork	30
13. Homogenized Zone Within the Southport No. 2 Switzer, Depth 10,400 Feet, Lower Red Fork	31
14. Burrowing, Conoco No. 1-A Snider, Depth 12,402 Feet, Upper Red Fork.	32
15. Rootlet, Conoco No. 1 Hoffman, Depth 12,407.8 Feet, Upper Red Fork.	33
16. Calcrete Developed in a Subareal Exposure, Possible Levee, Conoco No. 1 Hoffman, Upper Red Fork.	35

Figure	Page
17. Discrete Fossil Bed, Southport No. 2 Switzer, Depth 10,398 Feet, Lower Red Fork.	36
18. Productid Brachipod From the Conoco No. 1 Hoffman, Depth 12,419.8 Feet, Upper Red Fork	37
19. Thin Coal Beds From the Conoco No. 1 Hoffman, Depth 12,420 Feet, Upper Red Fork.	39
20. Schematic Dip Cross-section Through the Study Area.	43
21. Coarsening Upward Sequence Within the Southport No. 2 Switzer, Depth 10,431 Feet, Lower Red Fork.	45
22. Cross-section, D-D', Through the South Thomas Field, T.14N., R.13-14W. Lower Red Fork.	46
23. Isopach Map of the Lower Red Fork, T.14N., R.13-14W. South Thomas Field.	48
24. Cross-section E-E', T.13N., R.14-15W. Lower Red Fork, Submarine-Canyon Channel.	50
25. Cross-section F-F', T.12N., R.11-12W., Lower Red Fork, Submarine Channel	51
26. Cross-section G-G', T.12-13N., R.16W., Lower Red Fork, Submarine Fan	52
27. Conceptual Model for Deposition of the Lower Red Fork Sands, Sediments From the Shelf Area to the North and East Were Transported Down Slope to the Basin Area. . .	54
28. Calcareous Nodule (Calcrete) From the Conoco No. 1 Hoffman, Depth 12,408.8 Feet, Upper Red Fork	55
29. Cross-section, H-H', T.12N., R.15-16W., Dip Section Across Upper Red Fork East Clinton Field	57
30. Cross-section, I-I', T.12N., R.15-16W., Strike Section Across Upper Red Fork East Clinton Field	58
31. Isopach Map of the Upper Red Fork, T.12N., R.15-16W., East Clinton Field.	59
32. Conceptual Model for Deposition of the Upper Red Fork Sandstones--Deltaic Conditions Prevailed.	61
33. Ternary Diagram (QRF) Depicting the Minerologic Composition of the Davis No. 1 Herring and the Southport No. 2 Switzer, Lower Red Fork.	64

Figure	Page
34. Photo-micrograph Showing General Characteristics of the Lower Red Fork Sandstone (Top, Plane Polarized Light - Bottom, Crossed Nichols).	65
35. Photo-micrograph of Compaction Features; Broken Mica Grain and Squeezing of Detrital Mud Fragments, Lower Red Fork (Crossed Nichols)	66
36. Photo-micrograph of Syntaxial Quartz Overgrowths in the Lower Red Fork (Plane Polarized Light).	68
37. Photo-micrograph of Chlorite, Lower Red Fork (Plane Polarized Light).	69
38. SEM Photo-micrograph of Authogenic Chlorite, Lower Red Fork .	70
39. SEM Photo-micrograph of Chlorite and Illite, Lower Red Fork .	70
40. Photo-micrograph of Feldspar Overgrowths, Lower Red Fork (Crossed Nichols)	71
41. Photo-micrograph of Dissolution of Detrital Mud Fragments Producing Secondary Porosity (Plane Polarized Light). . . .	73
42. SEM Photo-micrograph of Secondary Porosity in the Lower Red Fork.	74
43. Paragenetic Sequence of the Lower Red Fork in the South Thomas Field (Solid Lines Indicate the Process Was Continuous Without Interruption; Dashed Lines Indicate Sporadic Activity).	75
44. Ternary Diagram (QRF) Depicting the Minerologic Composition of the Conoco No. 1 Meachum and the Conoco No. 1-A Snider, Upper Red Fork.	76
45. Photo-micrograph Showing General Characteristics of the Upper Red Fork Sandstone (Top, Plane Polarized Light; Bottom, Crossed Nichols).	78
46. SEM Photo-micrograph of Deformed Mica Fragment, Upper Red Fork.	79
47. SEM Photo-micrograph of a Fractured Quartz Grain, Upper Red Fork.	79
48. Photo-micrograph of Syntaxial Quartz Overgrowths, Upper Red Fork (Plane Polarized Light).	80
49. Photo-micrograph of Kaolinite, Upper Red Fork (Crossed Nichols).	81

Figure	Page
50. SEM Photo-micrograph of Kaolinite, Upper Red Fork	82
51. SEM Photo-micrograph of Syntaxial Quartz Overgrowths, Upper Red Fork.	83
52. Photo-micrograph of Calcite, Upper Red Fork (Crossed Nichols).	84
53. SEM Photo-micrograph of Dolomite, Upper Red Fork.	85
54. Photo-micrograph of Feldspar Overgrowth (Crossed Nichols) . .	86
55. Photo-micrograph of Calcareous Nodules, Conoco No. 1 Hoffman, Depth 12,502 feet, Upper Red Fork.	88
56. Photo-micrographs of "Clean" Non-porous, Upper Red Fork (Top, Plane Polarized; Bottom, Crossed Nichols)	89
57. Photo-micrograph of "Dirty" Porous, Upper Red Fork (Top, Plane Polarized; Bottom, Crossed Nichols)	90
58. SEM Photo-micrograph of Porosity in the Upper Red Fork. . . .	91
59. Paragenetic Sequence of the Upper Red Fork in the East Clinton Field (Solid Lines Indicate the Process Was Countinuous Without Interruptions; Dashed Lines Indicate Sporadic Activity).	93
60. Map Showing Location of Fields Numbered 1-12 in Table I	96
61. Core Description, Southport No. 2 Switzer	112
62. Core Description, Davis No. 1 Herring	114
63. Core Description, Conoco No. 1 Hoffman	116
64. Core Description, Conoco No. 1 Meachum	118
65. Core Description, Conoco No. 1 Fransen	120
66. Core Description, Conoco No. 1-A Snider	122

LIST OF PLATES

Plate	In Pocket
1. Structural Contour Map of the Top of the Pink Limestone .	"
2. Structural Contour Map of the Lowermost Red Fork Marker Bed	"
3. Dip Oriented Stratigraphic Cross Section A-A'	"
4. Dip Oriented Stratigraphic Cross Section B-B'	"
5. Strike Oriented Stratigraphic Cross Section C-C'	"
6. Net-Sandstone Isopach Map of the Lower Red Fork	"
7. Net-Sandstone Isopach Map of the Upper Red Fork	"
8. Isopach Map of the Entire Red Fork Format	"

CHAPTER I

ABSTRACT

The Red Fork sandstone was divided into the Upper and Lower Red Forks which are separated by a consistent marker bed. The Red Fork interval thickens markedly across the study area from 250 feet in the northeast to over 1300 feet in the southwest. Most of the thickening is within the Lower Red Fork. A structural contour map of the lowermost Red Fork marker bed shows distinct steepening of dip in a southeast-trend. The Lower Red Fork format thickens abruptly southwestward along this trend. These data are the basis for interpretation of a hinge line during deposition of the Lower Red Fork.

The Lower Red Fork is believed to have been deposited in shelf-to-basin transitional terrain. Sands were located in delta-front, submarine-channel fill and possibly submarine-fan terrain. The lack of marked thickening of the Upper Red Fork indicates an absence of a hinge line. Main gas producing sands are located in the East Clinton Field which is believed to be the site of the maximal progradation of a deltaic complex. Evidence for these interpretations was obtained from cores, basic geometric relationships of stratigraphy, and from the general geologic setting.

Sandstones of the Lower Red Fork are sublithic to lithic arenites; the Upper Red Fork is sublithic arenite. The dominant lithic fraction is detrital mud fragments. The main diagenetic alterations of both the

Upper and Lower Red Fork sandstones were destruction of primary porosity by compaction and cementation. Dissolution chiefly of mud fragments has produced well-developed secondary porosity. Clays of the Lower Red Fork mainly are secondary chlorite; clays of the Upper Red Fork mostly are secondary kaolinite.

Present oil and gas production from Red Fork sandstones is most abundant from localities on the paleoshelf.

CHAPTER II

INTRODUCTION

(The area of investigation consists of 18 townships, T. 12 N. through 14 N., and R. 11 through 16 W.; it includes parts of Blaine, Caddo, and Custer Counties, Oklahoma (Figure 1). The interval of interest, the Red Fork sandstone, is defined as the shale and sand zone between the Pink limestone and a basal marker of the zone, shown in Figure 2.) The Inola limestone is absent or unidentifiable from the log characteristics across the western portion and parts of the eastern portion of the study area.

Objectives and Methods

(The objectives of this study are: (1) to infer reliably the depositional environments of the Red Fork sandstones, (2) to determine oil and gas reservoir trends within the study area, and (3) to define the nature and sequence of diagenetic changes that have affected the Red Fork sandstones.)

Trends, geometry, and boundaries of the Upper and Lower Red Fork sandstones were determined through examination of gamma-ray, induction, and compensated density neutron logs of more than 500 wells. These data were used in preparation of two stratigraphic cross sections, net-sand isopach maps of both Upper and Lower Red Fork sandstone trends, and an isopach of the entire Red Fork interval.

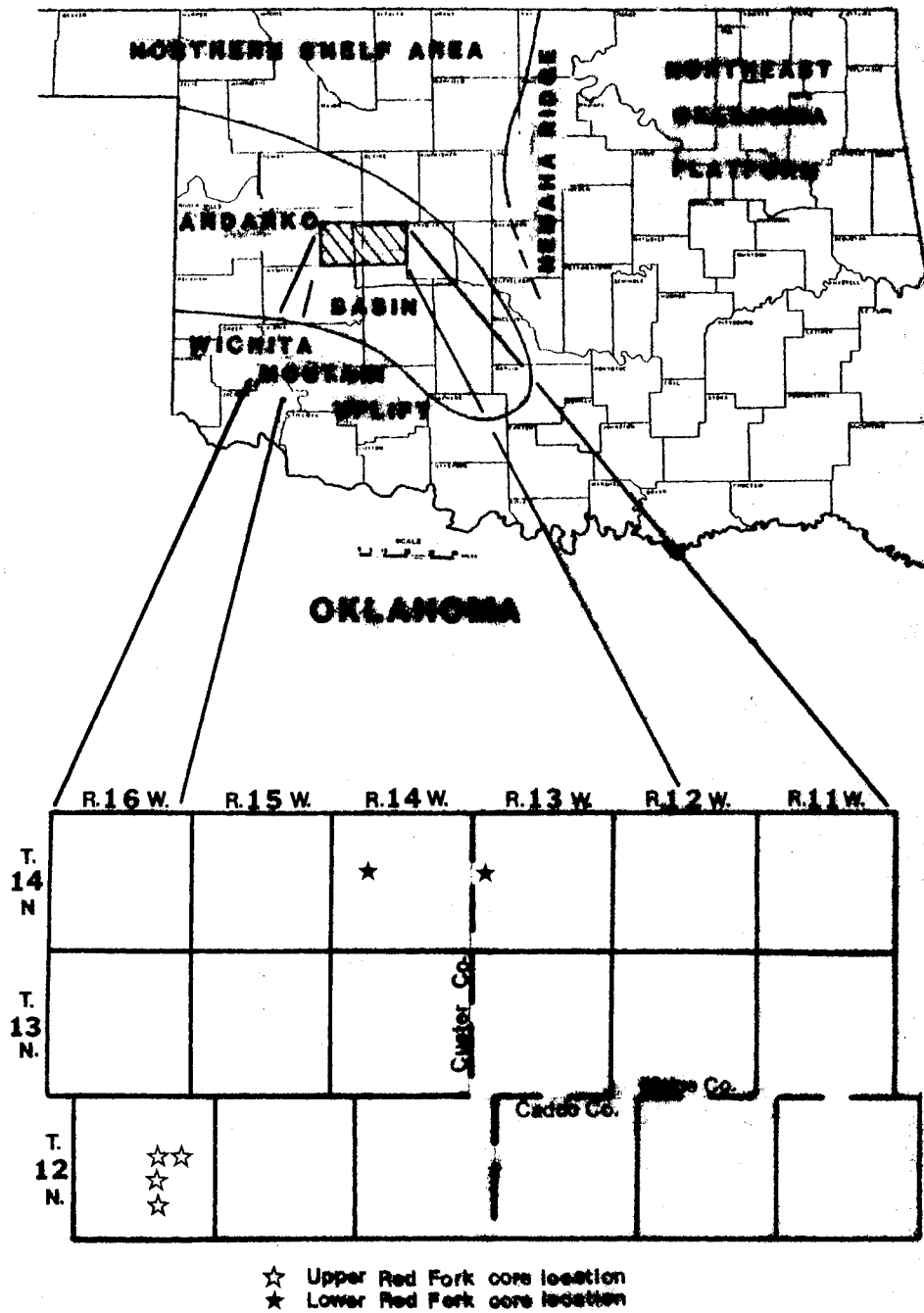
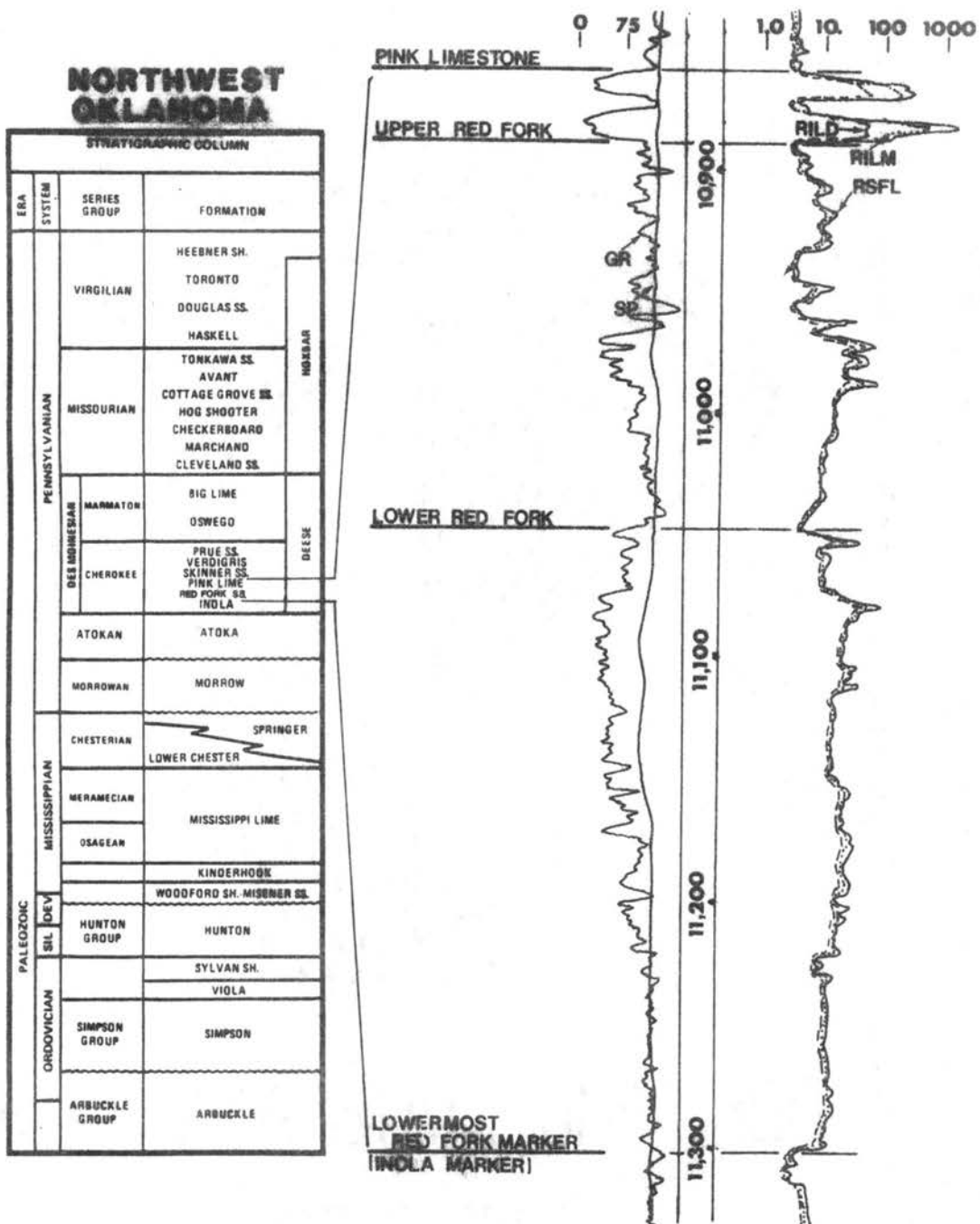


Figure 1. Map Showing Location of the Study Area

★



TYPE LOG
SEC. 14, T.13N., R.13W.
BLAINE OK.

Figure 2. Type Log Showing Markers and Principal Subdivisions of the Interval Studied

Two cores from the Lower Red Fork and four from the Upper Red Fork were analyzed. Described were vertical sequences, sedimentary structures, textures, and mineralogical constituents (Appendix). Interpretation of this data was essential in forming hypotheses concerning the depositional environments. Petrographic compositions and diagenetic alterations were analyzed by petrographic examination of 51 thin sections, by scanning electron microscopy and energy dispersive x-ray analyzer, and by x-ray diffraction analysis of samples.

Two structural contour maps were prepared, one of the top of the Pink Limestone and the other of the lowermost Red Fork marker.

Previous Investigations

The Red Fork is within the Cherokee "Group." Haworth and Kirk (1894) first used the name "Cherokee" for the sequence of black shale below the Pennsylvanian "Oswego" (Fort Scott) Limestone and above Mississippian in Cherokee County, Kansas (Withrow, 1968). The term was applied to the same stratigraphic interval in Oklahoma. Basic stratigraphic nomenclature was refined by the Oklahoma Geological Survey (Branson, 1954), with division of the Cherokee Group into the Krebs and Cabaniss" Groups (Withrow, 1968). In 1956, the term "Cherokee" was readopted for Kansas and Missouri with Krebs and Cabaniss being reduced to the rank of subgroups (Howe, 1956).

The Red Fork sandstone is the subsurface stratigraphic equivalent of the Taft Sandstone Member, upper Boggy Formation. The subsurface equivalents include the Chicken Farm sandstone (also called the Chicken Ranch sand) of Oklahoma County and the Earlsboro sand of Pottawatomie County (Jordan, 1957). The Burbank sandstone of Osage County originally

was thought to be equivalent to the Red Fork; however, regional correlations suggest that it could be equivalent to the "lower part of the Boggy Formation or to both the Red Fork and Bartlesville" (Jordan, 1957, p. 6). The Red Fork sandstone was first named by L. L. Hutchison in 1911 for a shallow oil-producing sandstone near the town of Red Fork, Oklahoma, southwest of Tulsa.

Extensive investigations have contributed to a generally sound knowledge of the depositional environment of the Red Fork on the Northern Shelf area and on the Northeastern Oklahoma Platform (Figure 1).

McElroy (1961) made a regional study of the Red Fork in north-central Oklahoma, across the Nemaha Ridge. He determined that fluvial deposition of the Red Fork was affected by the Nemaha Ridge. Thalman (1967) studied the productive Oakdale field in Woods and Major Counties, Oklahoma and determined that two genetic units of channel-fill sandstone deposition, Upper and Lower Red Fork, overlie each other. His interpretation, was that a "river-bar" or a "bar-finger" environment with a fluvial "river-bar" believed to be most likely in light of more recent work. Withrow (1969) studied the Wakita Trend (Alfalfa and Grant Counties, Oklahoma) and Oakdale Fields (Woods County, Oklahoma) and proposed off-shore or barrier-bar depositional environments. Berg (1968) agreed with Withrow's interpretation. Glass (1981) studied the same area and showed that a more probable interpretation is that of a dominately fluvial system.

The Red Fork of Alfalfa, Major, and Woods Counties, Oklahoma, was described as fluvial (Lyon, 1971), and in Kingfisher County, Oklahoma, well-defined fluvial systems were shown (Zeliff, 1976). All of these authors described very fine-grained to fine-grained sandstone with

medium-to coarse-grained sand only as "channel-lag" above erosional surfaces. Quartz is the dominant mineral with overall composition varying between sub-lithic sandstone and sub-arkose.

Whiting's (1982) study included most of the Anadarko Basin. He described the entire Red Fork as having been deposited in deep marine water. This interpretation was based on study of six cores. One of Whiting's cores was from the South Thomas Field and was located between two cores from the South Thomas Field used in this study.

CHAPTER III

STRUCTURAL FRAMEWORK

Regional Setting

(The study area is located within the Anadarko Basin (Figure 1). The asymmetric Anadarko Basin is bounded on the south by the Amarillo-Wichita Uplift, on the east by the Nemaha Ridge, and on the north by the Northern Oklahoma Platform (Figure 1). Dip on the Northern Platform increases gently southward toward the steep and highly faulted northern margin of the Amarillo-Wichita uplift (Figure 1).

The Anadarko Basin is one element in a series of north-northwesterly trending basins and uplifts from the Ouachita fold belt of southeastern Oklahoma and northeastern Texas to the Texas Panhandle. The Anadarko Basin was described by Schatski (1946) as an example of the aulacogen, a long trough or furrow of anomalously thick sediments extending into the craton at a high angle to a major fold belt (the Ouachita System).

Using the concepts explained by Burke and Dewey (1973) and Hoffman, Dewey, and Burke (1974), an aulacogen can be divided into three stages: a rifting stage, a subsiding stage, and a deformation stage. This interpretation fits the Anadarko Basin well. The rifting stage was dominated by intrusive and extrusive rocks of Middle Cambrian age. The subsiding stage is reflected in Late Cambrian through Devonian sedimentation. These rocks are predominantly carbonate and clean, well-sorted

quartz sands. The deformation stage is represented by siliceous clastic rocks of Carboniferous Age. Basins and uplifts within the aulacogen are probably Pennsylvanian features produced during the deformation stage (Hoffman et al., 1974). However, the Wichita-Criner and Arbuckle Uplifts are apparently due in large measure to left lateral strike-slip faulting associated with the Ouachita thrust (Shelton, Al-Shaieb et al., 1977).

The Nemaha Ridge [or Nemaha Range (Davis, 1983)] (Figure 1) is mainly a post-Mississippian, pre-Middle Pennsylvanian structural feature that extends from southeastern Nebraska to south-central Oklahoma. By Desmoinesian time, the Nemaha Ridge was mostly covered and was not a major source of detrital sediments (Cole, 1969; Moore, 1979). A major unconformity separates eroded and tilted Mississippian and pre-Mississippian rocks from Desmoinesian Cherokee strata (Huffman, 1959).

The Amarillo-Wichita uplift became active during late-Morrowan time; however, it was not until Atokan time that the extreme thickness of the Granite Wash shed from this uplift accumulated (Moore, 1979). The influence of the Granite Wash did not directly affect the deposition of the Red Fork sandstone within the study area.

A more detailed structural and historical study which is well documented in literature is beyond the scope of this study.

Local Structural Geology

Structural geologic maps prepared for this study were constructed using as mapping datum, the top of the Pink Limestone (Plate I), and the lowermost Red Fork marker bed (Plate II).

Both structural contour maps show homoclinal S. 20° W. The dip is

nearly uniform at about 1° (Plate 1). The lowermost Red Fork marker bed structure map, however, shows variation in dip from about 1° (100 feet per mile) in the northeast to slightly more than 3° (300 feet per mile) in the southwest.

Anticlinal noses and synclines are abundant. In T. 14 N., R. 15 W., variation in the normal dip could be evidence of faulting (Plate I). However, because no seismic data were available for testing this hypothesis, and because no wells seem to have cut faults, no faults were shown on structural contour maps.

CHAPTER IV

STRATIGRAPHIC FRAMEWORK

(The Red Fork Sandstone is part of the Cherokee Group¹, Desmoinesian Series, Pennsylvanian System. The Cherokee Group is composed of interbedded sand and shale "packages" that are separated by limestone marker beds (Jordan, 1957).)

The type log and stratigraphic column (Figure 2) shows units that are above and below the Red Fork sandstone within the study area. Northeast of the study area, the Bartlesville sandstone format is recognized as the lowermost part of the Cherokee Group (Ahmeduddin, 1968; Zelif, 1976). However, within the study area, the Bartlesville is absent or is undefined.

The Cherokee-Atoka boundary is below the basal marker used in this study. Determination of the specific stratigraphic position and log characteristics of the Cherokee-Atoka boundary was not included in the definition of the problem considered herein. The Inola Limestone is present only locally; in these places, it defines the base of the Red Fork format. In areas west of the study area, the Novi Limestone commonly is used to define the top of the Atokan Series. However, this

¹The Cherokee Group has been reduced to informal status or at least superseded in some subfields of applied geology, especially where areal geologic mapping is concerned (Oakes, 1953). The formal names of Krebs Group and Cabaniss Group commonly are not applied in correlation and mapping of rocks in the subsurface of Northern Oklahoma. Therefore, the traditional term "Cherokee Group" is used here to include all strata bounded above by the Marmaton Group and below by the Atokan Series.

marker also is absent within the study area (Neil, 1982). Because of the difficulty in correlating basal marker beds in the study area, a method of solution was based on the work of Busch (1971). The Red Fork interval was considered to be a genetic increment of strata, defined at the top by a time-lithologic marker (the Pink Limestone) and at the base by the top of the Inola "marker." The Inola "marker" is illustrated in Figure 3. This log signature was correlatable throughout the study area. Where the Inola Limestone was developed, it was found consistently 5 to 10 feet lower than the proposed marker bed. This marker has been interpreted as an unconformity (Glass, 1981; Withrow, 1968).

The boundary between the Upper and Lower Red Fork was correlated and mapped after examination of many logs within the study area. The log signature is consistent except in the extreme southeastern part of the study area. Some of the boundaries used in this portion of the study area were based on estimated thicknesses of units rather than actual bed-to-bed correlations. Less than 10 logs were processed in this manner.

The boundary between the Upper and Lower Red Fork sand zone is believed to be disconformable; it is used as a time-lithologic feature, as suggested by Busch (1971) (see also Glass, 1981, and Withrow, 1968).

The boundary of the Upper Red Fork genetic increment of strata was the top of the Pink Limestone, which is overlain by the Skinner genetic increment within the study area. The Pink limestone is quite consistent throughout much of the area. However, in the southwestern part, the Pink limestone is absent, but the shale in the stratigraphic position of the Pink is correlatable (Plates III, IV and V).

LOWERMOST RED FORK MARKER BED

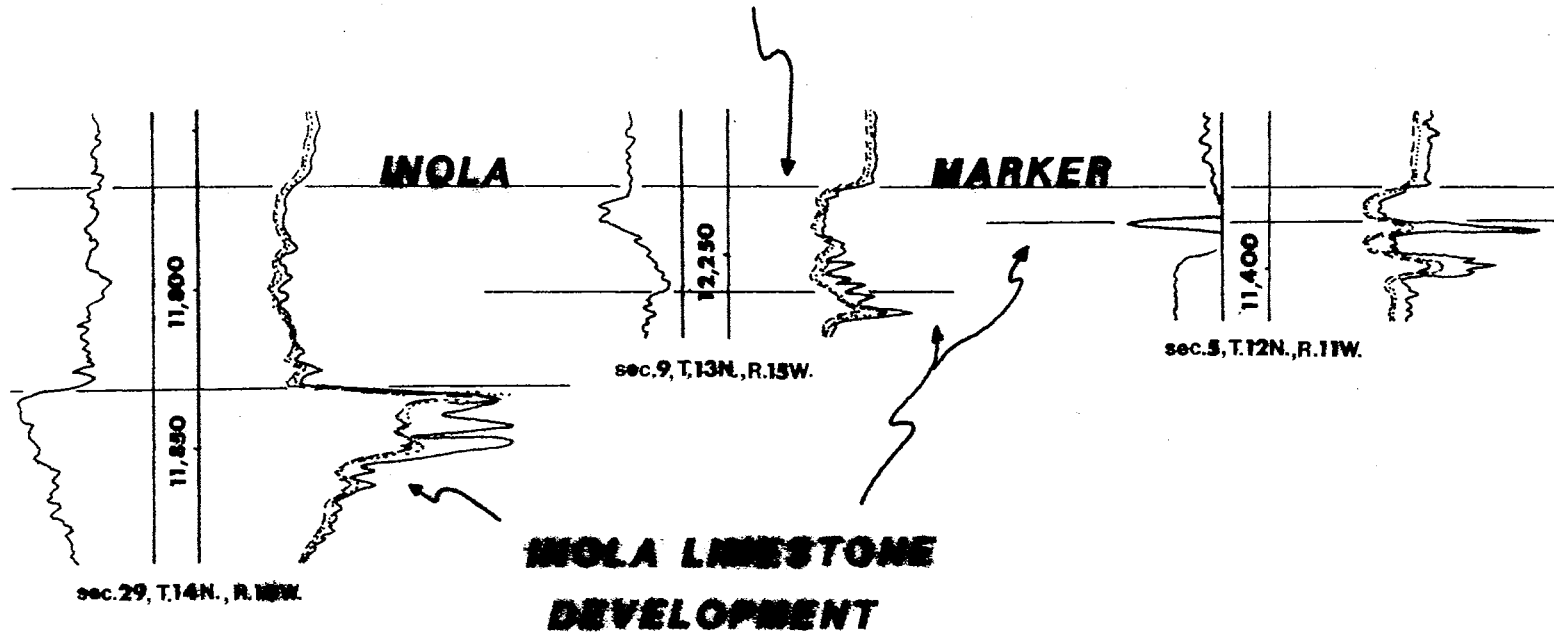


Figure 3. Relationship Between the Lowermost Red Fork Marker and the Inola Limestone Development

Correlations

The Red Fork interval thickens markedly across the study area (Plates III, IV and V). Primarily owing to this thickening, a standard preliminary correlation network was found not to be exceptionally useful in this study. Instead, the electric logs from T. 14 N., R. 14 W., in the South Thomas Field, were correlated carefully. To this nucleus of correlated logs, additional logs were correlated and thus a network of correlated logs was assembled.

All electric logs that were released by companies and available as of June, 1983, were used in this study; this group included approximately 500 logs. Generally, dual induction and neutron-density logs were necessary to make reliable correlations.

CHAPTER V

GEOMETRY OF THE RED FORK SANDSTONES

Isopach maps of the Lower and Upper Red Fork were used to delineate and predict trends and distribution of the sandstones (Plates VI and VII). Because the spontaneous potential curve in the study area showed little or no response (Figure 2), criteria for recognition of sandstone were based on the gamma ray curve. Deflections of less than 75 A.P.I. units were considered to show sandstone. This measurement was determined from core-to-log comparisons and from comparison of logs to completion and production records.

Within the study area, the Red Fork sandstone can be divided into two distinct units (Figure 2).

Clearly the sandstones are multistoried. As many as 25 depositional units¹ may be stacked which accounts for the great thicknesses of sandstone (more than 400 feet) at some localities in the study area. This is different from the general circumstances in the northern shelf area, where two or three sand bodies are commonly the maximal number present and 100 feet is usually the thickest net sand (Glass, 1981; Robertson, 1983; Withrow, 1969).

¹A "depositional unit" is roughly equivalent to a stratum, a unit of few to several feet in thickness, deposited in one basic episode. These units may be bounded below by shale, or by sandstone. In the latter instance, evidence of episodic deposition is judged to exist, although it may not be clearly discernible.

Lower Red Fork

Trends and Widths

The Lower Red Fork Sandstone is a complex system made up of many sand bodies. Three distinct northeast-southwest trends are mappable (Plate VI). One trend extends from the northeastern part of T. 14 N., R. 13 W. to the southeastern part of T. 13 N., R. 15 W.; a second trend can be traced from the northern half of T. 14 N., R. 12 W. to the southwestern part of T. 13 N., R. 14 W.; a third trend extends from the northeastern part of T. 13 N., R. 11 W. to the southwestern part of T. 12 N., R. 13 W. Each trend ranges from one mile to several miles in width. The greatest expanse of Lower Red Fork sandstone is in the southwestern portion of the study area (T. 12 N., R. 16 W.) at which locality the two trends described first apparently merge. The belt of sandstone at this locality is wider than 15 miles (Plate VI).

Boundaries

Individual sandstone bodies show gradational lateral and basal contacts in the northeastern half of the study area. In the southwestern half, abrupt erosional basal contacts and abrupt lateral contacts are common. Variation in thickness, structural dip, and sparse well control make exact correlations of individual sandstone units difficult.

Thickness

Thickness of individual sandstone units in the Lower Red Fork is as much as 50 feet in some instances. Net-sand thickness exceeds 400 feet in the south half T. 13 N., R. 16 W.

Upper Red Fork

Trends and Widths

The Upper Red Fork sandstone system is less complex than the Lower Red Fork. A single trend, approximately 2 to 3 miles wide, extends along the southern margin of the study area (Plate VII). Width of this trend increases from 2 to 12 miles (Plate VII) in T. 12 N., R 15, and 16 W. Isolated bodies of sandstone thicker than 25 feet are mapped but correlation among them is uncertain (Plate VII).

Boundaries

An easily correlated, 5- to 10-foot thick sandstone immediately below the Pink limestone is present in the northern two-thirds of the study area (Plate VI). Other sandstone bodies in the northern two-thirds of the area apparently are laterally and vertically inconsistent in position. This inconsistency may be only apparent, a result of poor well control. In the southern portion of the study area, sandstones show sharp basal contacts. Sandstones show abrupt lateral contacts in an elongate trend into T. 12 N., R. 15 and 16 W., where lateral inter-fingering of sandstone is common (Plate VII).

Thickness

Thickness of sandstone in the Upper Red Fork interval ranges from 0 to 145 feet. Because no single sandstone unit is thicker than about 10 to 25 feet, total thickness of sandstone in the Upper Red Fork interval is almost directly proportional to the number of depositional units. These units are as numerous as 15 in T. 12 N., R. 16 W.

CHAPTER VI

INTERNAL FEATURES

Six cores were examined in order to determine the character of internal features of the Red Fork sandstone within the study area. Two cores are from the South Thomas Field in T. 14 N., R. 13 and 14 W. (Figures 4, 5). These cores are from the Lower Red Fork. The other four cores were from areas in or near the East Clinton Field, in T. 12 N., R. 16 W. (Figures 6, 7). These cores are from the Upper Red Fork.

—Sedimentary Structures

(In approximate order of overall abundance, common sedimentary structures are interstratified sandstone and shale, horizontal laminae, "massive" bedding, medium- and small-scale crossbeds, convolute beds, slump structures, bioturbated beds, single burrows, a single possible rootlet, and calcareous nodules.) Although a detailed and consistent vertical sequence of sedimentary structures is not evident in the Red Fork cores, an overall general vertical sequence is as follows: (1) dark gray shale in lowermost position, overlain abruptly by, (2) massive cross-bedded sandstone, and (3) interstratified sandstone and shale that show evidence of burrows, flowage, slump structures, and horizontal laminae.

The Conoco No. 1 Hoffman (Sec. 15, T. 12 N., R. 16 W.) is different from the other cores examined. Several features found in this core are



Figure 4. Photograph of the Southport
No. 2 Switzer, Lower
Red Fork

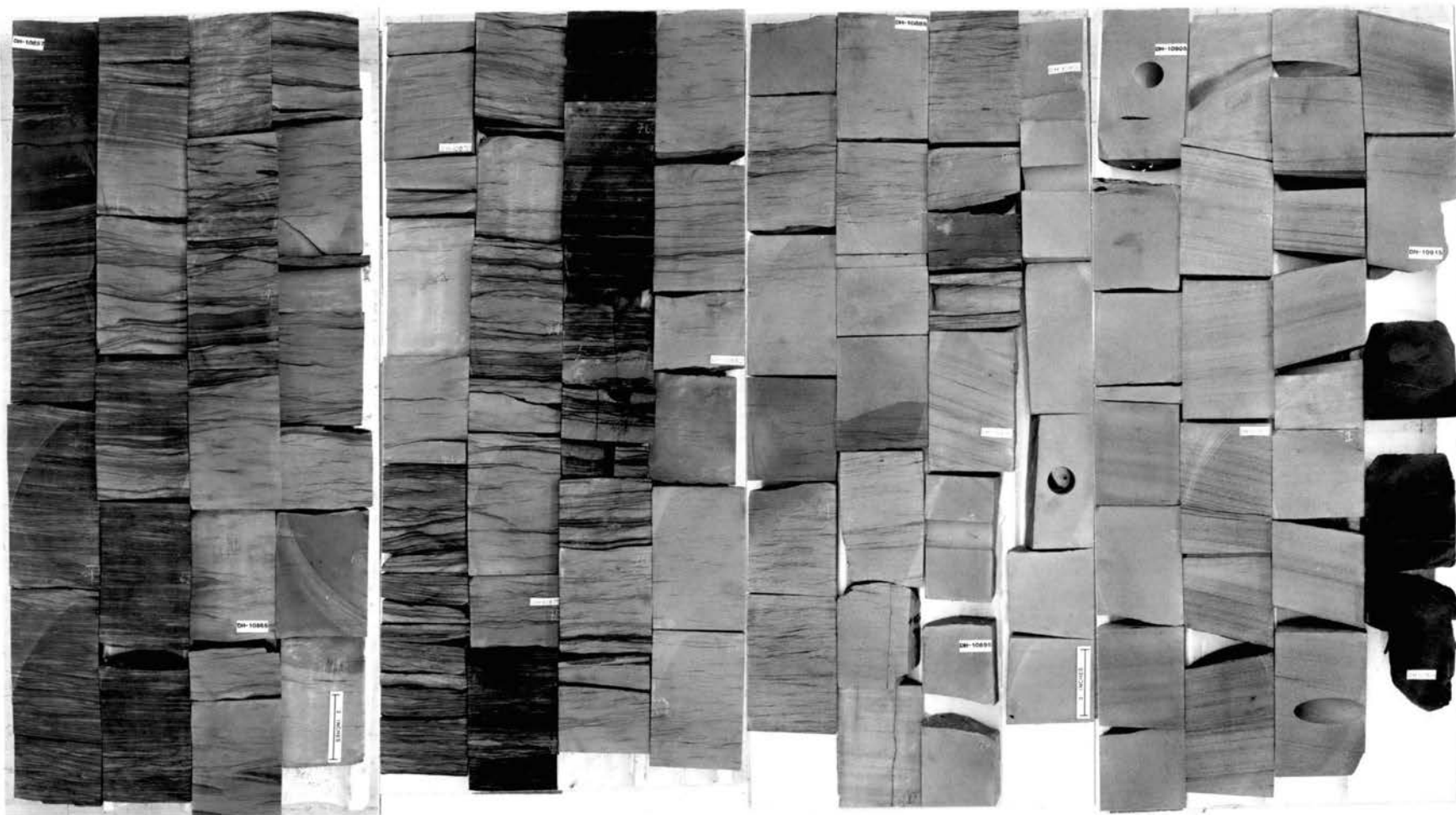


Figure 5. Photograph of the Davis No. 1
Herring, Lower Red Fork



Figure 6. Photograph of the Conoco No. 1-14
Meachum, Upper Red Fork

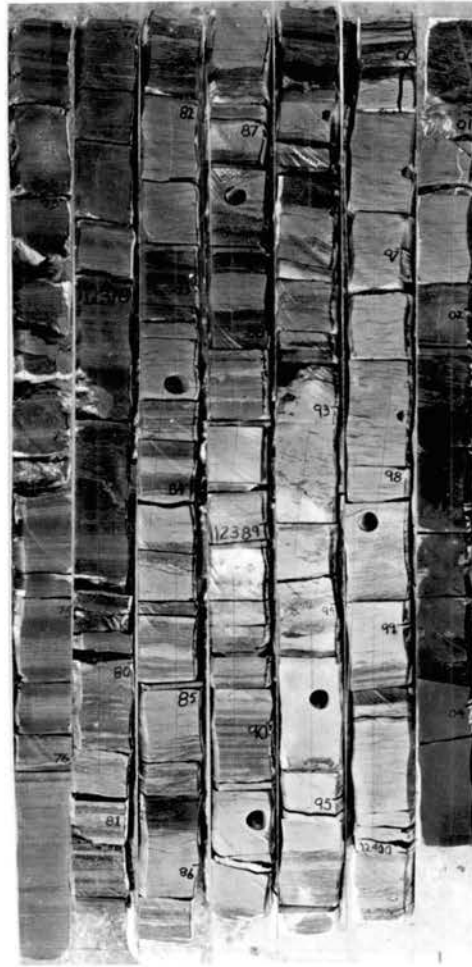


Figure 7. Photograph of the Conoco No. 1-A
Snider, Upper Red Fork

rare or absent in the other cores. These features include a coal bed, richly organic shale, a rootlet, a burrowed zone, and calcareous nodules.

Interstratification

Interstratification of sandstone and shale is common to all six cores. (Interstratification is more abundant in predominantly shaly intervals. Most interstratified beds effectively are "horizontal," but in some instances low-angle initial dip is detectable.)

(Contacts between zones of interstratified sandstone and shale and massive sandstone or shale is both sharp (Figure 8) and gradational (Figure 9); sharp contacts are the more common.)

Horizontal Laminations

Horizontal laminae were recorded in all cores examined, generally within interstratified zones of beds thicker than laminae. This feature is developed best and is most common in the Conoco No. 1-A Snider (Figure 10).

"Massive" Bedding

"Massive" sandstone also was recorded in all cores examined. It is most common in the Conoco No. 1 Meachum and the Southport No. 2 Switzer and is least common in the Conoco No. 1 Hoffman. Contacts of units of "massive" sandstone above units with other sedimentary structures tend to be sharp and erosional.

Medium- and Small-Scale Cross-Bedding

Medium- and small-scale cross-bedding are present in four of the



Figure 8. Sharp Contact Within the
Southport No. 2 Switzer,
Depth 10,407.3 Feet,
Lower Red Fork



Figure 9. Gradational Contact Within the Davis
No. 1 Herring, Depth 10,881 Feet,
Lower Red Fork



Figure 10. Horizontal Laminations Within the Conoco No. 1-A Snider, Depth 12,290 Feet, Upper Red Fork

cores examined, being absent in the Conoco No. 1 Hoffman and the Conoco No. 1 Franzen. Small-scale cross-bedding is the more abundant. It is associated with clayey beds. Medium-scale cross-bedding was observed within zones of sandstone (for example, in the Conoco No. 1 Meachum (Figure 11)).

Convolute Bedding and Slump Structures

Although not a dominant feature of the Red Fork sandstones, convolute beds are rather common. These features are developed best in the Conoco No. 1-A Snider (Figure 7) and the Conoco No. 1 Meachum (Figure 6). Convolute beds are associated with interstratified zones in which shale is the major rock type. Slump structures in the Conoco No. 1-A Snider are preserved best in sections of shale (Figure 7, 12).

Bioturbation

Bioturbated beds are present but not common in the Conoco No. 1-A Snider, the Southport No. 2 Switzer, and the Conoco No. 1 Hoffman. In all three cores, bioturbation is detectable within zones of interstratified sandstone and shale. Commonly "homogenized" rock is seen with single burrows not distinctly evident (Figure 13). However, several horizontally oriented burrows are preserved within the Conoco No. 1-A Snider (Figure 14). None of the burrowing was related to a specific trace fossil.

Rootlets and Nodules

Markings that appear to be several small coalified roots are within the core from the Conoco No. 1 Hoffman (Figure 15). Also within this sequence is a section approximately 10 feet thick, within which

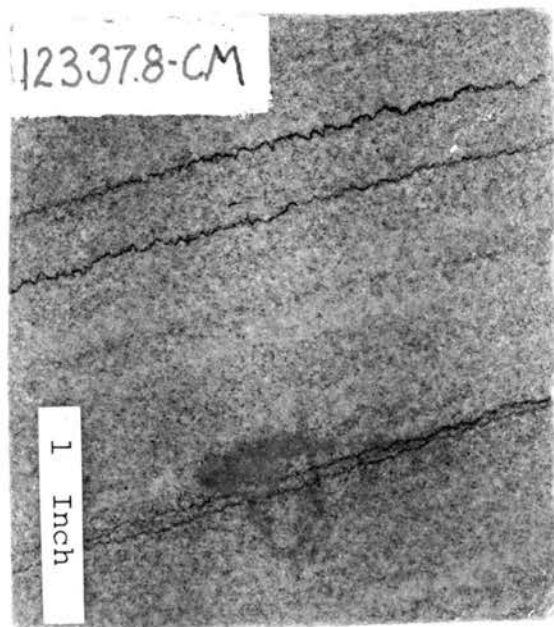


Figure 11. Small Scale Cross-bedding Within
the Conoco No. 1-14 Meachum,
Depth 12,337.8 Feet, Upper Red
Fork



Figure 12. Slump Structures Within the Conoco No. 1-A
Snider, Depth 12,373.0 Feet, Upper Red
Fork

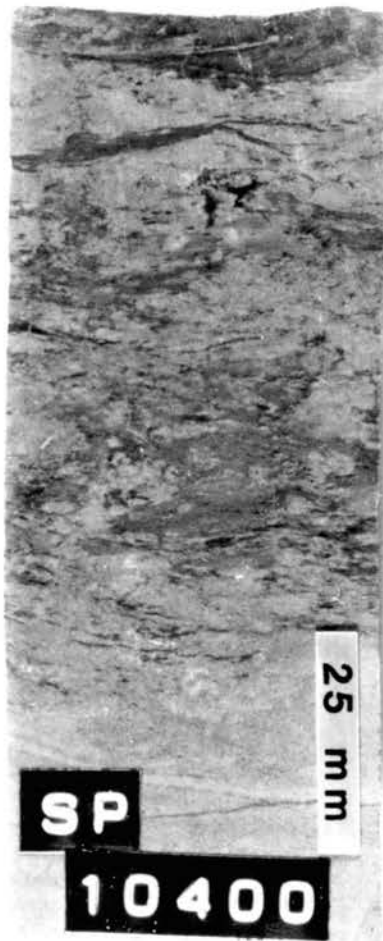


Figure 13. Homogenized Zone Within
the Southport No. 2
Switzer, Depth 10,400
Feet, Lower Red Fork



Figure 14. Burrowing, Conoco No. 1-A Snider,
Depth 12,402 Feet, Upper Red Fork

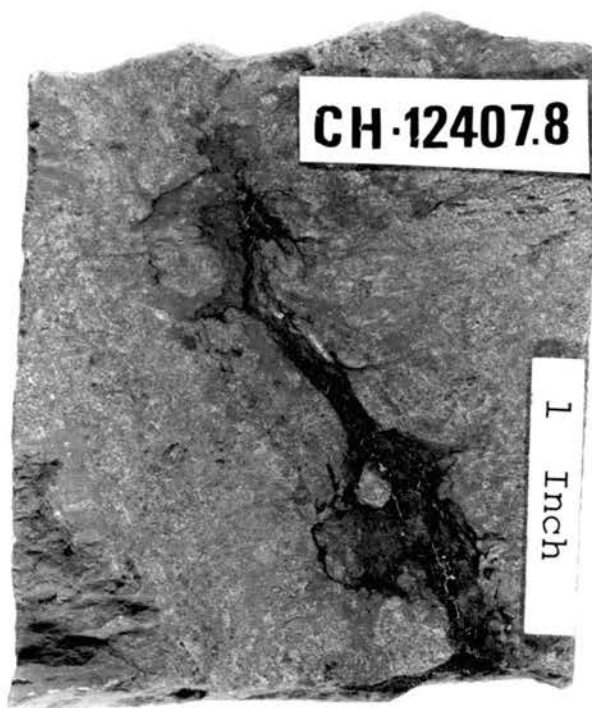


Figure 15. Rootlet, Conoco No. 1
Hoffman, Depth 12,407.8
Feet, Upper Red Fork

calcareous nodules are abundant (Figure 16). These nodules appear to have formed in place.

Texture

The Red Fork sandstone bodies show slight vertical change in grain size. Excluding clay-sized fractions, the range in grain size is from silt to medium-grained sand. The dominant size is very fine-grained sand. Whiting (1982) reported a consistent upward vertical decrease in grain size within the cores he observed. Both coarsening upward and fining upward sequences were detected in this study. These are very subtle and are quite variable within a specific core. (Most of the Red Fork Sandstone is moderately sorted to well sorted, with subrounded to subangular grains.)

Fossils

Fossils identified tentatively as productid and liquilid brachiopods were contained in cores from the Southport No. 2 Switzer (Lower Red Fork) (Figure 17) and the Conoco No. 1 Hoffman (Upper Red Fork) (Figure 18). The two groups of fossils were similar in appearance and composition. Because of poor preservation and diagenetic alteration, accurate naming of the fossils was not possible (Finney, 1983).

Coal and Organic Shale

As mentioned above, the Conoco No. 1 Hoffman core includes features that were not present in the other cores. Among these features is abundant organic matter. The uppermost 17 feet of the core includes dark, extremely fissile organic shale with pyritized fossils, possibly

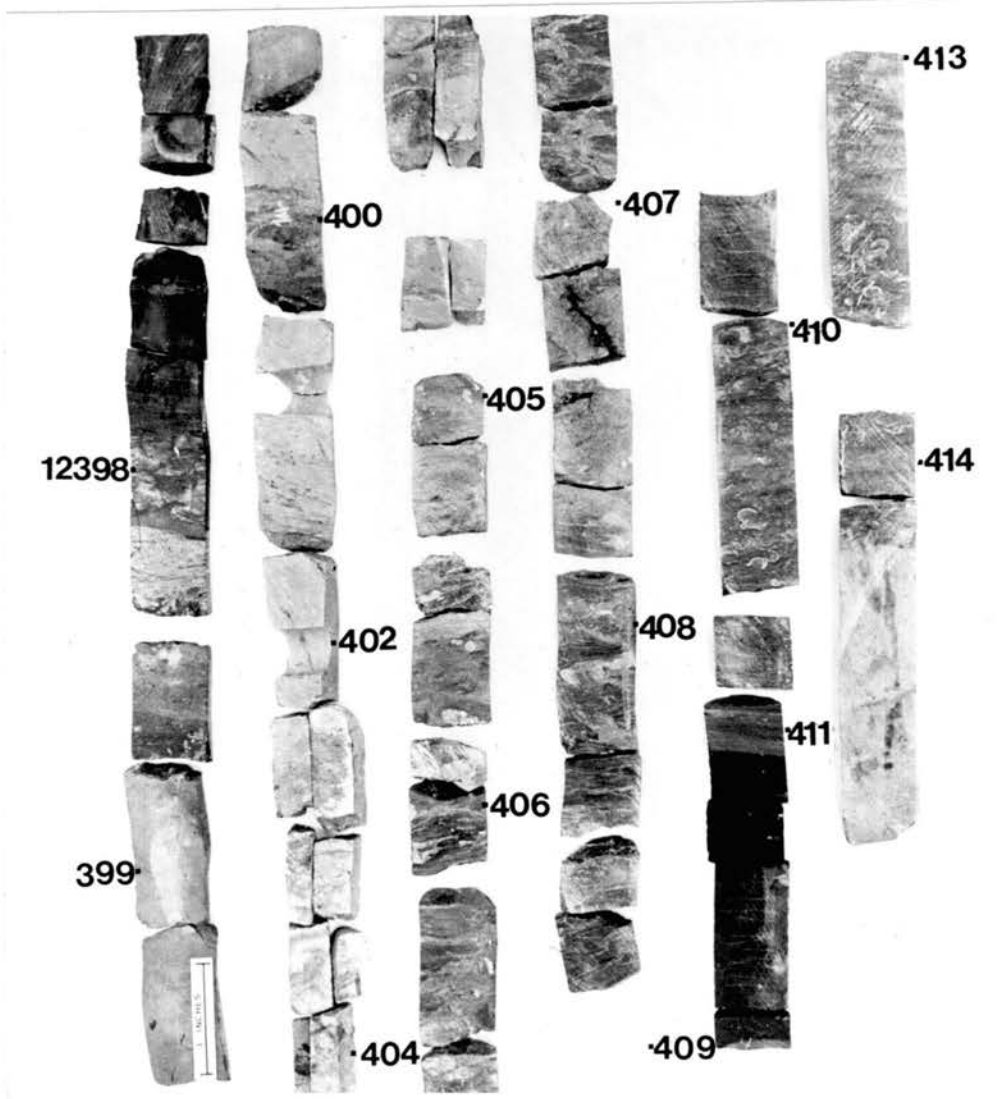


Figure 16. Calcrete Developed in a Subareal Exposure, Possible Levee, Conoco No. 1 Hoffman, Upper Red Fork



Figure 17. Discrete Fossil Bed,
Southport No. 2
Switzer, Depth
10,398 Feet, Lower
Red Fork

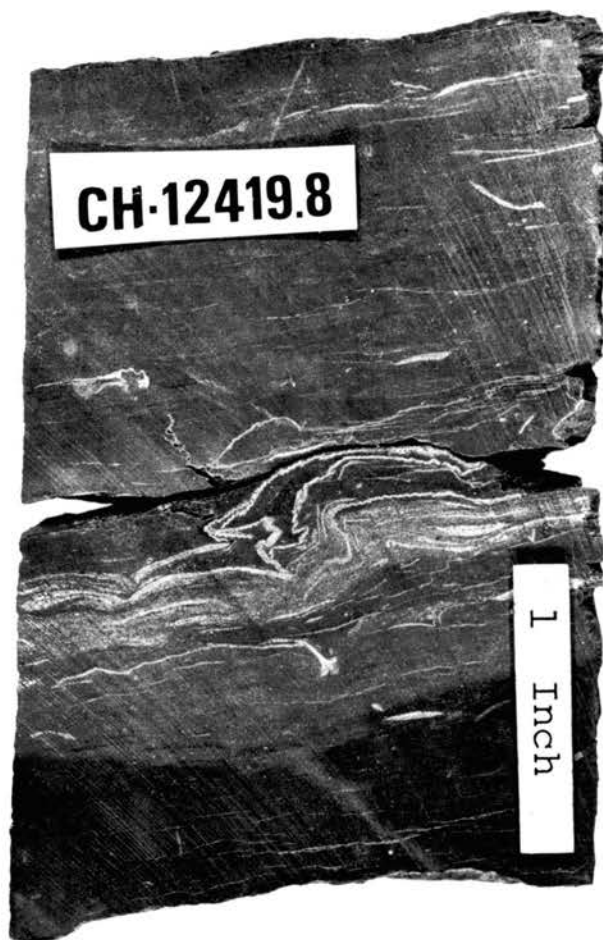


Figure 18. Productid Brachiopod from the Conoco
No. 1 Hoffman, Depth 12,419.8 Feet,
Upper Red Fork

lingulid brachiopods. At depth 12,420 (Figure 19) are three beds of coal. Although each bed is only about 1/4 inch thick, the coaly material shows no direct evidence of transportation, but neither is underclay detectable. Apparently these beds are present in nearby wells within the East Clinton Field. The seeming lateral conformity of these beds suggests that they may have formed in place.

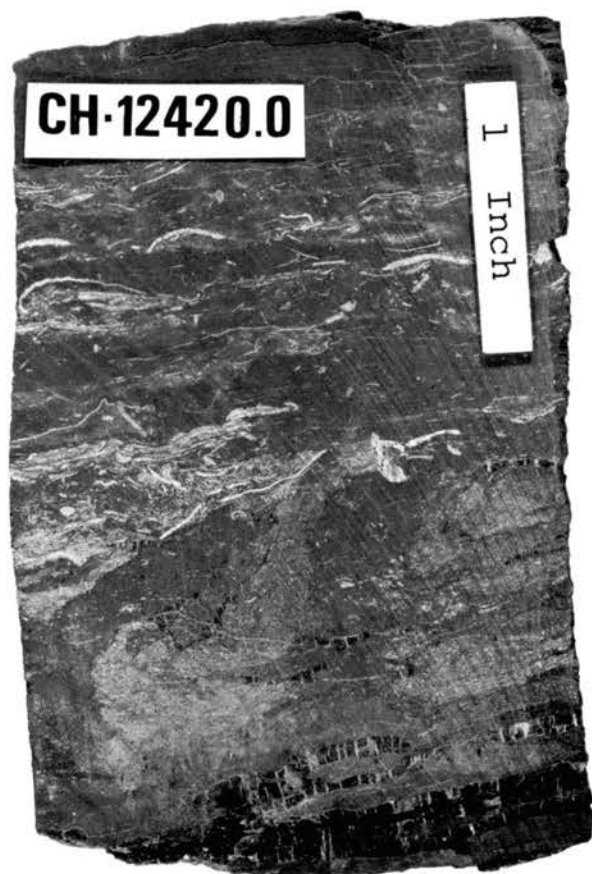


Figure 19. Thin Coal Beds From the Conoco No. 1 Hoffman,
Depth 12,420 Feet, Upper Red Fork

CHAPTER VII

DEPOSITIONAL ENVIRONMENT

Introduction

(Fluvial or shallow marine depositional environments have been proposed as the depositional setting of the Red Fork sandstones in the Northern Shelf area (Berg, 1968; Glass, 1981; Withrow, 1969). The regional depositional setting proposed by Whiting (1982) was deep marine including submarine fans and turbidites.)

Three hypotheses were proposed for the depositional environments of the Upper and Lower Red Fork. These were: (1) a deltaic-fluvial setting, (2) a deep-marine setting, and (3) a slope setting.

A vast amount of published work outlines the properties of deltaic environments. The most frequently cited publications relevant to this study are Allen (1965), Brown (1969, 1979), Elliot (1974, 1978), Fisher et al. (1970), Fisher (1969), Fisher and McGowen (1969), Sutton (1975), and Visher et al. (1971). The most helpful work was by Coleman and Prior (1982).

Many studies of deep-marine sandstones (turbidites) have dealt with rocks exposed in Europe; several are clearly applicable to subsurface work. These papers are Bouma (1972), Ghibaudo (1981), Hiscott (1981), Hiscott and Middleton (1981), Howell and Normark (1982), Kumar (1982), Rupke (1978), and Shelton (1967).

The most applicable articles were those which applied to a

(transition zone, such as shelf-slope-basin.) Such papers as by Asquith (1970), Bloomer (1971), Garcia (1981), Walker (1978), and the classic work by Rich (1951) and Van Siclen (1958).

In the present work, division of the Red Fork into upper and lower zones is consistent with work by other geologists (Berg, 1968; Glass, 1981; Withrow, 1969). As mentioned previously, division of the Red Fork into two genetic units (as described by Busch, 1971) is believed to be critical for reliable interpretation of depositional setting. Whiting (1982) did not make such a division which may account for the difference between his interpretation and that which follows. (However, stratigraphy of the Lower Red Fork in the study area fits to some degree with Whiting's interpretation.)

The marker distinguishing the Upper and Lower Red Fork is generally at the top of a persistent sandstone which may be isolated from sandstones below. Above the marker is a consistent coarsening upward sequence, as interpreted from the gamma ray electric log pattern (for example, see Plates III, IV, and V). Interpretation of the marker is that it represents either a disconformity or a transgressive-regressive episode.

Inconsistent variation in grain size was observed within the cores studied. Dominantly the sandstone is very fine-grained to fine-grained sand. Coarsening- or fining-upward sequences interpreted from logs were not of the classic case, i.e., persistent fine to coarse or coarse to fine gradation. What was interpreted as fining or coarsening upward was an increase or decrease in the clay size. The very fine- to fine-grained nature of Red Fork sandstone has been reported by numerous workers from work on the Northern Shelf (Berg, 1969; Glass, 1981; Withrow, 1968). Therefore, observance of very fine- to fine-grained

sand size within the Anadarko Basin is quite consistent with evidence drawn from nearby areas that were closer to the source.

Lower Red Fork

Examination of the gross isopach map (Plate VIII) in comparison with the cross-sections (Plates III, IV) (Figure 20) shows that thickening of the Red Fork zone format occurred chiefly within the Lower Red Fork interval. The Upper Red Fork is relatively consistent in thickness throughout the study area (Figure 20). A change in dip is observed on the lowermost Red Fork marker bed structure map within the southwestern half (Plate II). This anomaly observable on the isopach map of the entire Red Fork interval (Plate VIII), the structural contour map (Plate II), and cross-sections (Plate III, IV) is interpreted as a hinge line that trends from T. 12 N., R. 13 W. to T. 13 N., R. 16 W. (For analogs, see Asquith, 1970, and Bloomer, 1971.) It is believed to have existed during deposition of the Lower Red Fork interval. Berg (1969) observed a similar feature to the east, in T. 11 and 12 N., R. 9 and 10 W., which can be extended into the present study.

Two interpretations based on the lowermost Red Fork marker bed structural contour map (Plate II), and the isopach map of the entire Red Fork interval (Plate VIII) which supports this interpretation of a shelf-slope hinge line are: (1) the "shelf" area in the northeast part of the study area shows dip of approximately 1° and (2) the "slope" area shows dip of approximately 3° . As discussed above, the transition from one general rate of dip to the other occurs within a narrow, linear trend. This evidence combines into an interpretation of shelf-slope setting during deposition of the Lower Red Fork, with the marginal part of

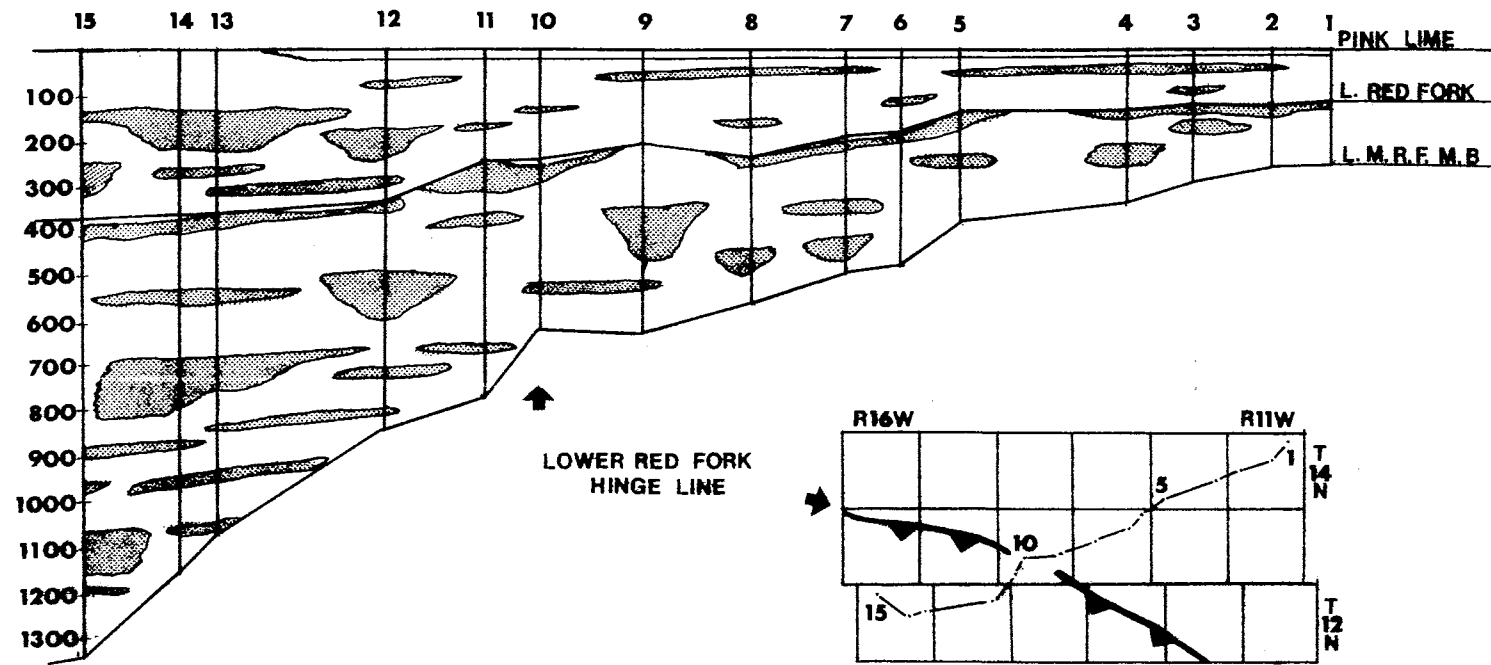


Figure 20. Schematic Dip Cross-section Through the Study Area

the deep Anadarko Basin having been southwest of the proposed hinge line (Figure 23). (See analogous circumstances in Asquith, 1970; Bloomer, 1971; Chevron, 1983).

Two cores described in Chapter VI and the Appendix, the Davis No. 1 Herring and the Southport No. 2, are from the Lower Red Fork. Both wells are in the South Thomas Field, which is highly productive of oil and gas (Chapter VIII). As mentioned previously, several hypotheses were proposed as to the interpretation of the observed features. Because some sedimentary structures can develop in more than one depositional environment (for example, cross-bedding or horizontal laminations), examples were proposed that would include most or all of the features described.

In the Herring and Switzer cores, features that were judged to be unlikely to have developed under conditions described in a deep-water turbidite model (Bouma, 1962; Walker, 1978; Whiting, 1982) were as follows: (1) possible shallow-water liquid brachiopod fossils from the Southport No. 2 Switzer (Figure 4), (2) lenticular bedding characteristics of ripples (Figure 3), (3) richly organic shale from the Southport No. 2 Switzer (Figure 3), and (4) a coarsening-upward sequence in the Southport No. 2 Switzer (Figure 21). The gamma ray-electric log responses, compared to cores, show interstratified shale sequences which increase in number upward and give the aspect of a fining-upward sequence. In cross-section (Figure 22), the apparent coarsening-upward sequences are also believed to be the result of a decrease in the number of interstratified shale sequences. In the Davis No. 1 Herring, a shale is lowermost; it is believed to have been deposited in a pro-delta setting.

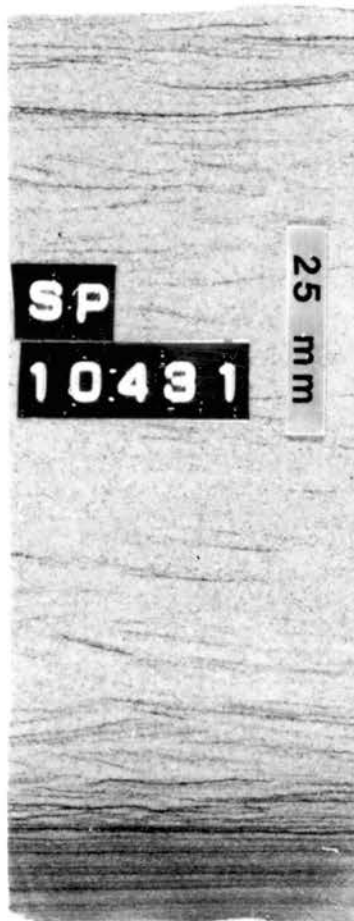
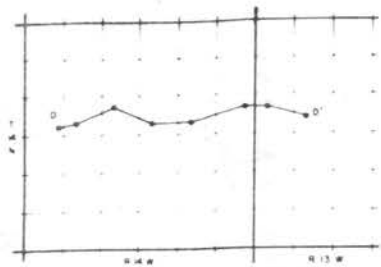
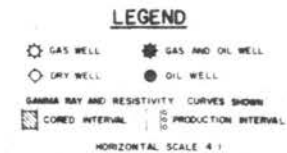


Figure 21. Coarsening Upward Sequence
Within the Southport No. 2
Switzer, Depth 10,431 Feet,
Lower Red Fork



D—D'
STRIKE SECTION
SOUTH THOMAS FIELD
LOWER RED FORK SANDSTONE



D

D'

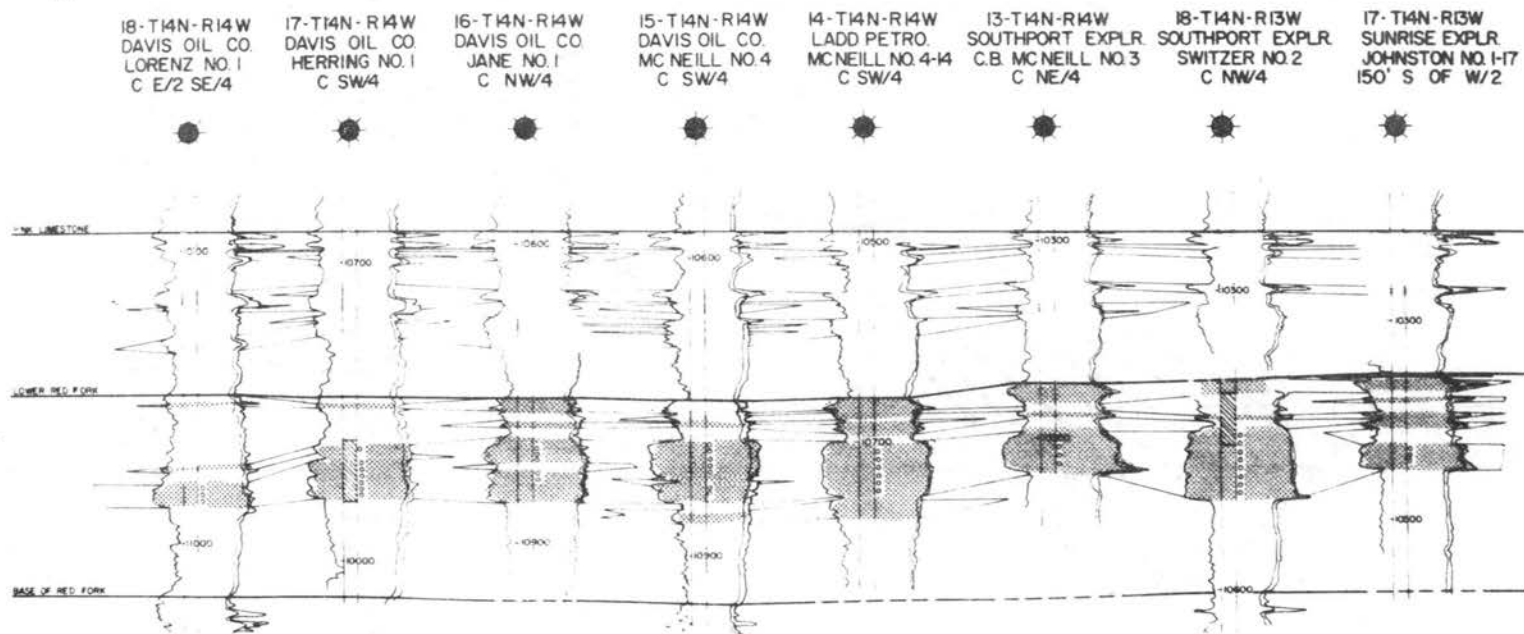


Figure 22. Cross-section D-D', Through the South Thomas Field, T.14N., R.13-14W.,
Lower Red Fork

A multistoried complex of lenticular and channel sands can be inferred from the cross-section across the South Thomas Field (Figure 22). The gamma ray and density-neutron log responses¹ of the Sunrise Exploration No. 1-17 Johnston, Section 17, T. 14 N., R. 13 W. (Figure 22), indicates a possible coal bed at the top of the Lower Red Fork. The multistoried sandstone and coal bed are believed to have been deposited near the outer limits of a deltaic complex (Coleman, 1981) above the shelf-slope hinge line.

A detailed isopach map of the Lower Red Fork shows the location of the two cores and distribution of sandstone within the South Thomas Field (Figure 23). Figure 23 is believed to indicate that the source area of sandstone for the South Thomas Field was located to the northeast out of the study area. The proposed environmental interpretation of Red Fork sandstone in the South Thomas Field, based on convergent evidence from maps, cross-sections, and cores, is that of a subaqueous deltaic complex. (For analog, see Coleman and Prior, 1982.) The site of deposition of sand composing the reservoir in the South Thomas Field is believed to have been the maximum extent of deltaic progradation within the Lower Red Fork.

Plate VI indicates an elongate sand body trending southwestward through the northeastern part of T. 13 N., R. 14 W. This sand body is interpreted as having been deposited on a shelf-to-basin slope. As mentioned above, the most probable interpretation for this trend is believed to have been a submarine-canyon channel fill that extended into the "basin" from the South Thomas delta complex. A cross-section through this sand body suggests channel-like morphology. (For similar evidence, see Shelton, 1977.) Little or no sand seems to have been

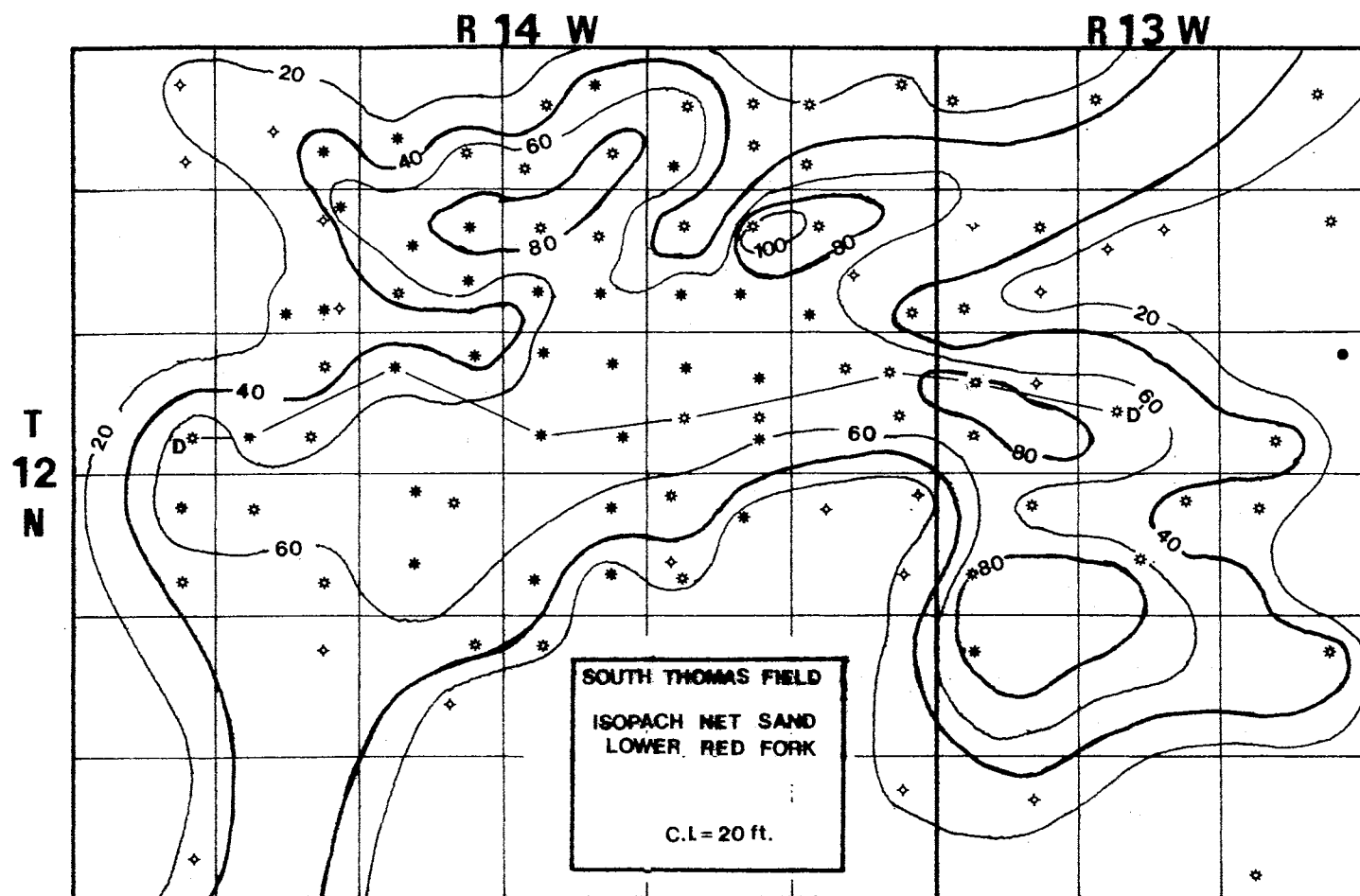


Figure 23. Isopach Map of the Lower Red Fork, T.14N., R.13-14W. South Thomas Field

deposited on either side of a narrow, thick sand section (Figure 24). This thick sandstone body shows evidence of basal erosion; its position within a shale section also tends to support the interpretation of a submarine channel (Bloomer, 1977).

The sandstone development within the southeastern portion of the study area (Plate VI, T. 13 N., R. 11 W. to T. 12 N., R. 12 W.) may be a slope channel. Evidence supporting this interpretation is based on the Lower Red Fork net-sand isopach map, which indicates an elongate trend (described above). A cross section through a portion of this trend reveals basal erosion within a shale section indicating a channel (Figure 25). As compared to the South Thomas Field, the lower stratigraphic position of the trend tends to support the hypothesis that deposition within the trend was earlier than the South Thomas Field sand. This sandstone development will be referred to as the Bridgeport development in further discussion, because of the Red Fork production from Bridgeport Field.

In the area of T.12 and 13 N., R. 15 and 16 W., sands are thicker at some places (Plate III). Morphologies of sand bodies, their apparent transport from the South Thomas and Squaw Creek area, their log characteristics (Figure 26), and their location down-dip from the postulated slope zone are believed to be evidence that justifies the interpretation of a submarine fan. No cores are available to test the hypothesis of a turbidite sequence; however, Figure 26 shows thick multistoried sand bodies and abrupt lateral discontinuities that are characteristic of proximal turbidite fans (Bouma, 1972; Howell and Normark, 1982; Shelton, 1967).

As mentioned in the discussion of the South Thomas delta complex,

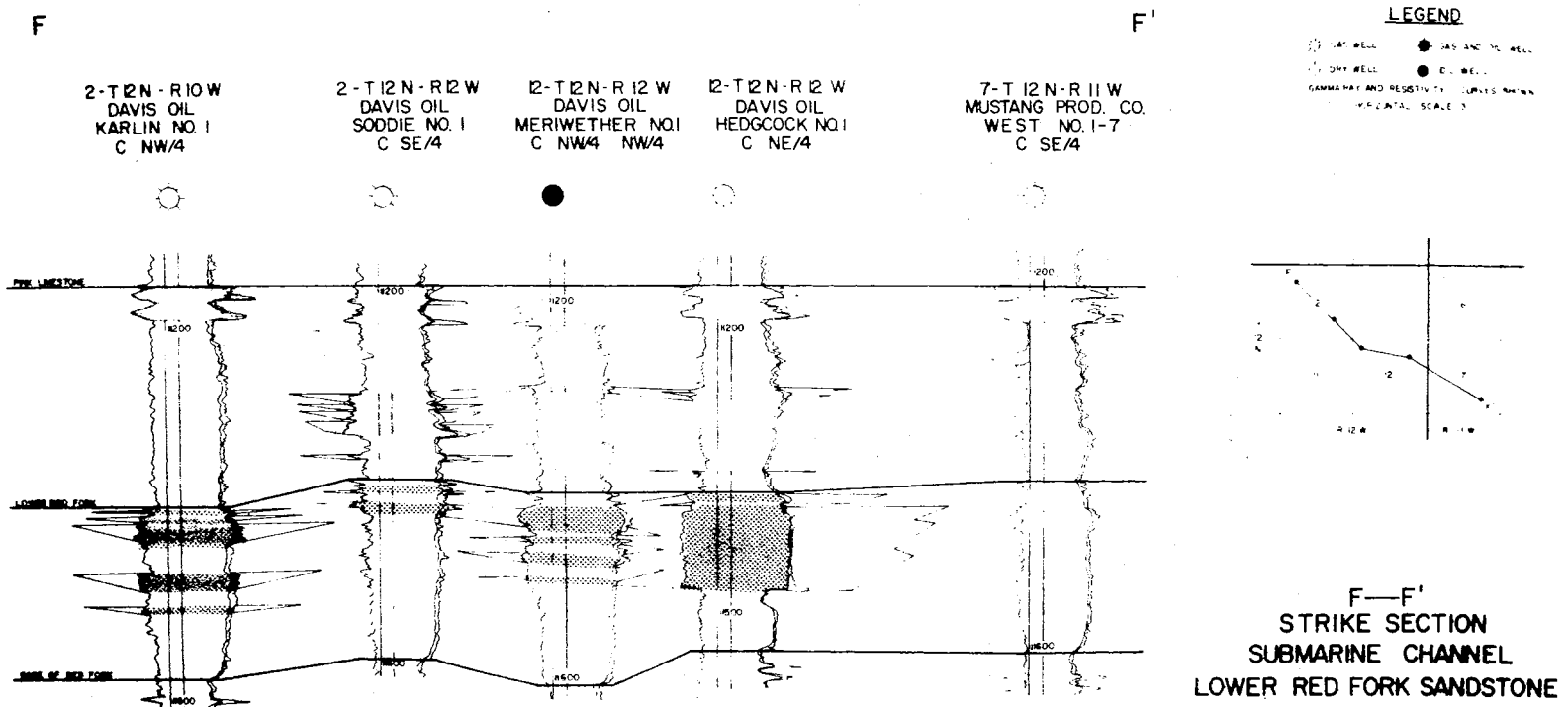


Figure 25. Cross-section F-F', T.12N., R.11-12W., Lower Red Fork, Submarine Channel

delta complex, the most likely immediate source area was fluvial complexes to the north and northeast (Berg, 1969; Glass 1981; Thalman, 1967; Zeff, 1976). Sandstone in the Bridgeport area was also fed from the northeast (Berg, 1969). A block diagram (Figure 27) shows the proposed interpretations.

Upper Red Fork

Unlike the Lower Red Fork, the Upper Red Fork zone shows no marked increase in thickness, a property judged to indicate absence of a slope zone or a hinge line (Figure 23). Also, the Upper Red Fork generally includes much less sandstone. The only identifiable trend, T. 12 N., R. 11 and 15 W. (Plate IV), is interpreted as a channel that originated to the east. This elongate sand body broadens into a thick lenticular unit in the eastern half of T. 12 N., R. 15 W., the site of the Weatherford Field. The thickest portion extends into the East Clinton Field of T. 12 N., R. 16 W. This seems probably to have been the maximal progradation of a deltaic lobe.

As mentioned previously, the Conoco No. 1 Hoffman has petrographic features that are different from those in other cores. These features are difficult to explain as having originated in a deep water setting: (1) a coal bed (Figure 22); (2) abundant shallow water productid and inquilid brachiopods (Figure 21); (3) shale rich in organic matter having pyritized fossils; (4) a burrowed zone (Figures 16, 18); and (5) calcrete nodules believed to have formed in place (Figures 16, 28). All these features can be explained as having been deposited within deltaic environments or associated shallow-marine environments (Brown, 1979; Coleman, 1981).

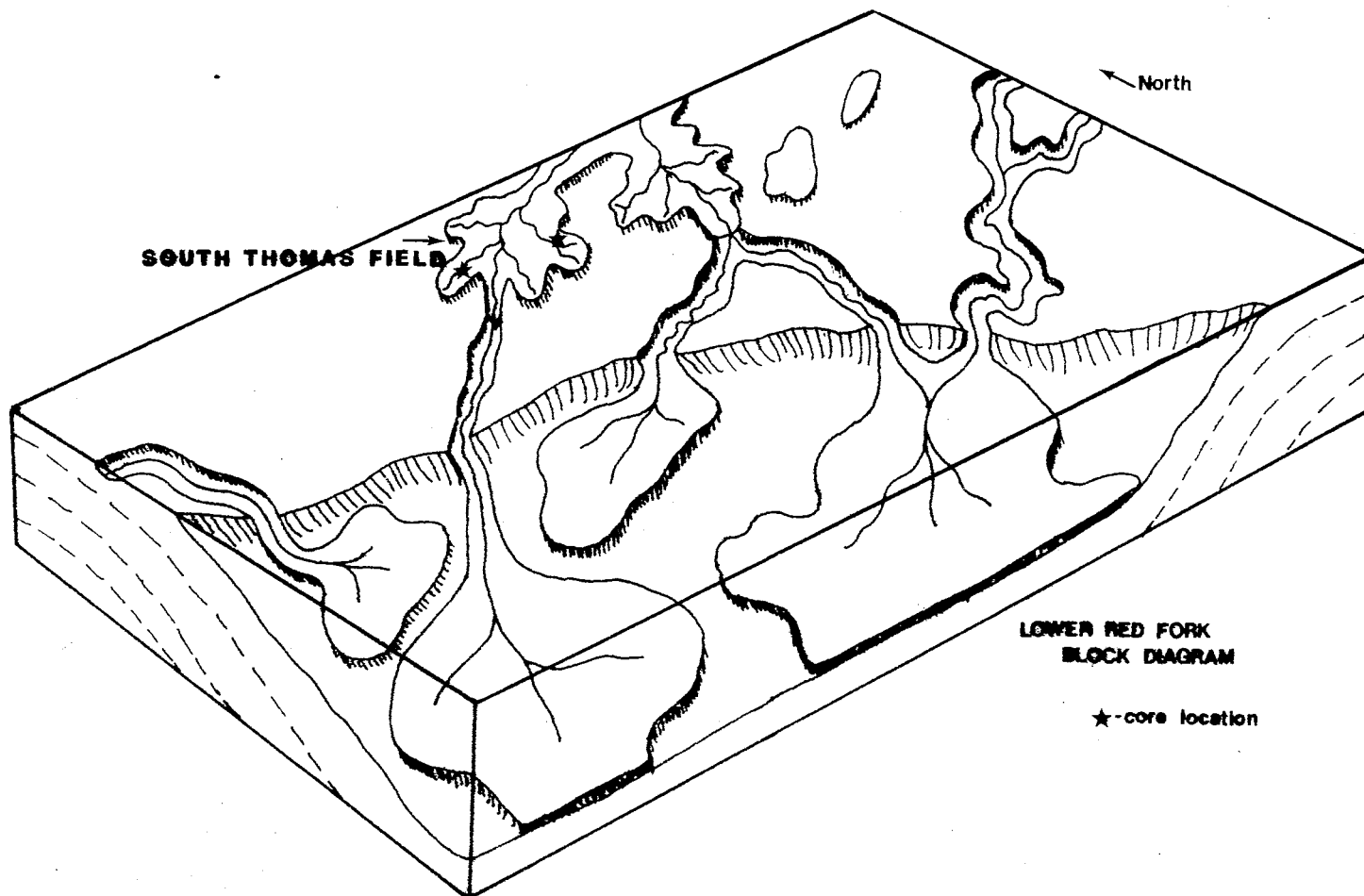


Figure 27. Conceptual Model for Deposition of the Lower Red Fork Sands, Sediments From the Shelf Area to the North and East Were Transported Down Slope to the Basin Area.



Figure 28. Calcareous Nodule (Calcrete)
from the Conoco No. 1
Hoffman, Depth 12,408.8
Feet, Upper Red Fork

The coal and organic rich shale are interpreted as being from an interdistributary bay, perhaps like the bays on the seaward side of the Mississippi delta (Coleman and Prior, 1982; Coleman and Gagliano, 1965; Elliot, 1974). The presumed shallow-water fossils (Muir-Wood, 1960; Moore, Laliker, and Fisher, 1952), are pyritized, characteristic of deposition in an interdistributary bay (Coleman and Prior, 1982). Rootlet marks, burrows, and calcrete nodules which are within one zone (Figure 15), are interpreted as subareal levee having been deposited under subareal conditions (Coleman, 1981). The Hoffman core shows no evidence of mass slumping or other disruption of beds that would indicate transportation from shallow to a deeper water.

The Conoco No. 1-14 Meachum core (Figure 6) is interpreted as part of a distributary mouth-bar sequence. The shale at the base is interpreted as a prodelta shale. Most of the core is sandstone (Figure 6). The log (Figure 29) indicates that the base is erosional, which is indicative of a channel-like setting (Bloomer, 1977; Coleman, 1982). The cross-section also reveals that the Conoco No. 1-A Snider core is higher stratigraphically than the Meachum core (Figures 29, 30). Because of interstratified sandstone and shale, this core is interpreted as a crevasse-splay deposit (Coleman, 1981; Coleman and Prior, 1982; Elliot, 1974). Evidence of slumping near the top of the Conoco No. 1-A Snider core may have originated from mud diapirism (Coleman and Gagliano, 1965; Elliot, 1974).

A detailed net-sand isopach map of the Upper Red Fork East Clinton Field, showing locations of the four cores (Figure 31), indicates bifurcated channels and increase in sandstone to the southeast of T. 12 N., R. 16 W. This is believed to have been an extension of the same complex

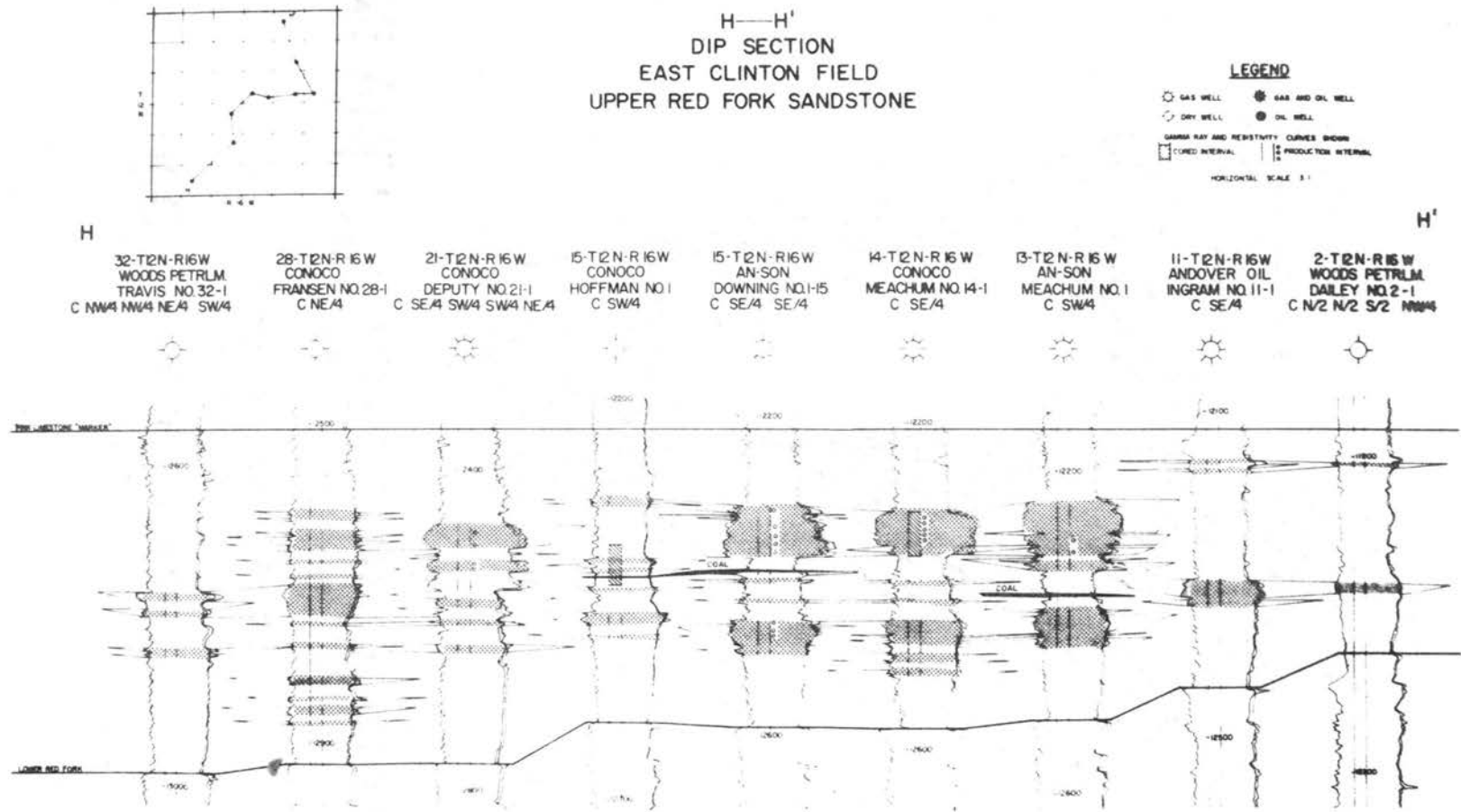
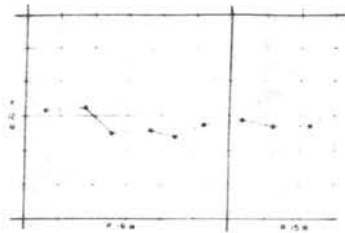


Figure 29. Cross-section H-H', T.12N., R.15-16W., Dip Section Across Upper Red Fork, East Clinton Field



|-----|
STRIKE SECTION
EAST CLINTON FIELD
UPPER RED FORK SANDSTONE

LEGEND

- GAS WELL
- GAS AND OIL WELL
- DRY WELL
- OIL WELL
- LAMINA RAY AND RESISTIVITY CURVES SHOWN
- ▨ CORE INTERNAL
- ▩ PRODUCTION INTERVAL
- HORIZONTAL SCALE 1"

18-T12N-R16W AN-SON SOAR NO 1 C SW/4 SE/4	17-T12N-R16W AN-SON GHOLSTON NO.1 C SE/4	21-T12N-R16W CONOCO DEPUTY NO 21-1 C W/2 NE/4	22-T12N-R16W CONOCO SNIDER NO. 1-A S/2 S/2 NE/4	23-T12N-R16W CONOCO M.L. AGAN NO 1 SE/4 NW/4 SW/4	24-T12N-R16W C.I.G. EXPLR MEACHUM NO. 1-21 C NW/4	19-T12N-R15W AN-SON GOLDIE NO. 1-19 NW/4 SW/4 NE/4 NW/4	20-T12N-R15W AN-SON STIDHAM NO. 1-20 E/2 E/2 W/2 NW/4	21-T12N-R15W AMOCO TILLIE NO. 1 C NW/4
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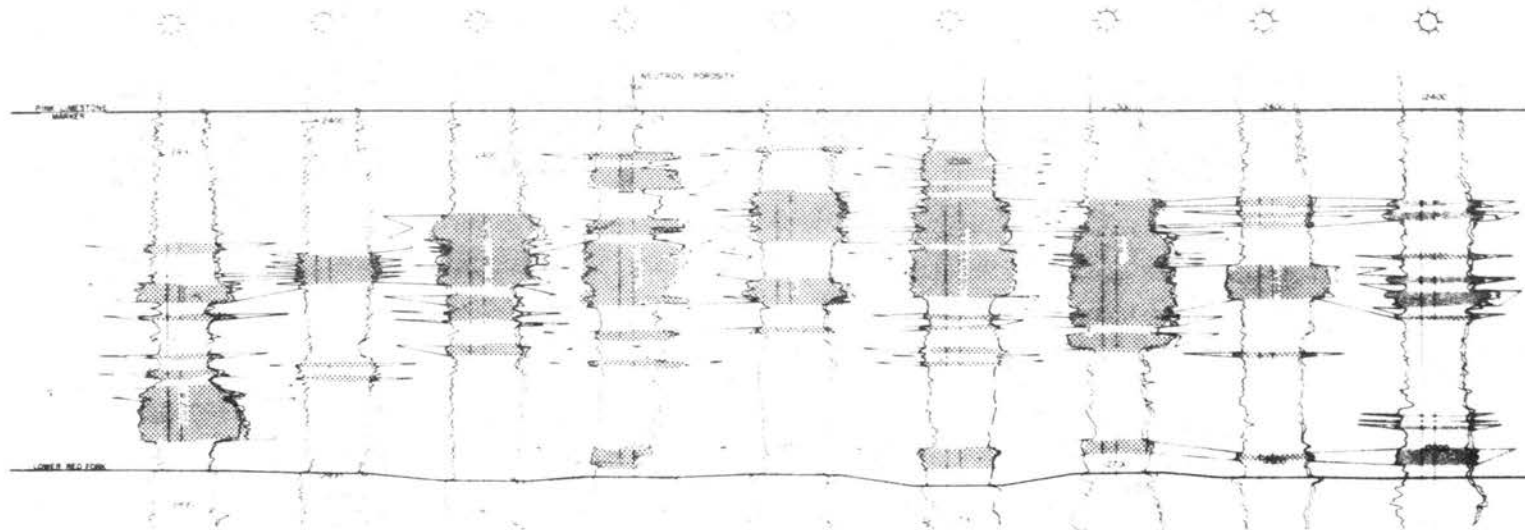


Figure 30. Cross-section I-I', T.12N., R.15-16W., Strike Section Across Upper Red Fork, East Clinton Field

that occurs in the East Clinton Field.

The combination of cross-sections (Figures 29, 30) and an isopach map (Figure 31) with locations of cores shown is indicative of a deltaic complex. Position Conoco No. 1-14 Meachum core corresponds with a thick channel area interpreted from the isopach map (Figure 31) and the cross section (Figure 29). Interpretation of the Conoco No. 1 Hoffman core as having been deposited in an interdistributary bay is consistent with evidence on the isopach map (Figure 31) and cross section (Figure 29). The Conoco No. 1-A Snider core is believed to have been a nonchannel deposit, but Figures 30 and 31 show evidence of a channel in the sequence below the core. The Conoco No. 1 Franzen core is shale and no environmental interpretation was made, but a thick channel area is interpreted from the isopach map (Figure 31).

Source of sand in the Upper Red Fork probably was from the east. A block diagram based on the proposed interpretation is shown in Figure 32.

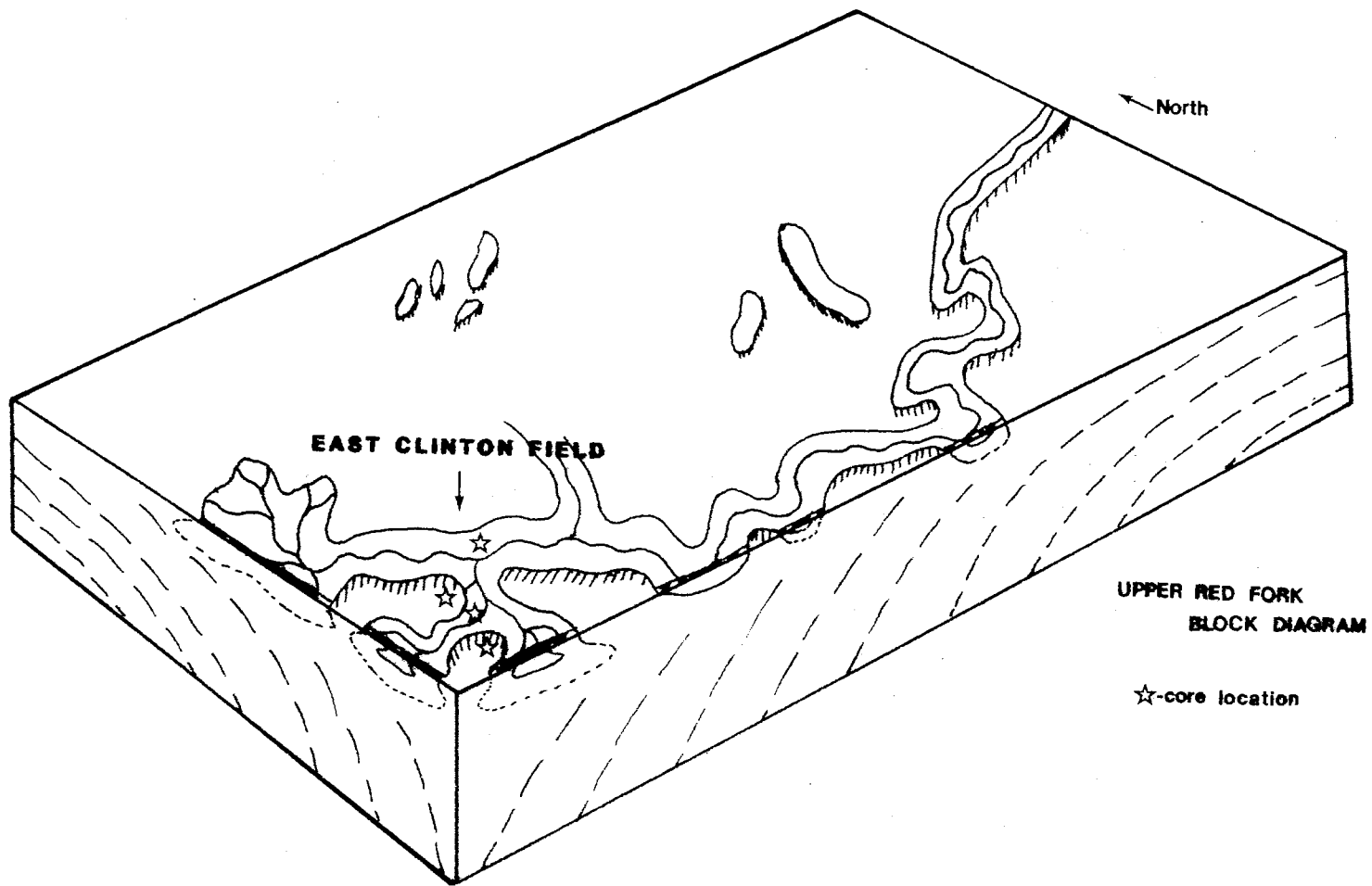


Figure 32. Conceptual Model for Deposition of the Upper Red Fork Sandstones--Deltaic Conditions Prevailed.

CHAPTER VIII

PETROLOGY AND DIAGENESIS

Purpose and Methods

(Purpose of petrographic analysis of the Red Fork was two-fold: (1) to determine textural and mineralogical compositions and (2) to document diagenetic changes) with emphasis on the types of secondary porosity.

Methods used for determination of qualitative and quantitative compositions were routine thin section analysis, x-ray diffraction of powdered and "clay-extracted" (Kiltrick, Patrick, and Hope, 1963) samples, and scanning electron microscopy coupled with an energy dispersive x-ray analyser.

The present reservoir quality of both the Upper and Lower Red Fork sandstone has been influenced strongly by diagenetic alterations, precipitates, secondary minerals, and dissolution features.

Dissolution features are the most significant, because they control the amount of secondary porosity. The Red Fork reservoirs examined are mesogenetic (Schmidt and McDonald, 1979), with no observable primary porosity.

Lower Red Fork

— Composition and Classification

Twenty-three thin sections from the two Lower Red Fork Cores

(Appendix) were examined to determine detrital components and classification. The observed data were plotted on a QRF diagram (Folk, 1968). The Davis No. 1 Herring plotted as a sublithic arenite (Figure 33) and the Southport No. 2 Switzer plotted as a lithic to sublithic arenite (Figure 33). (The rock is mostly very fine grained.)

(The primary end member is quartz, ranging from 28% to 63%. ~~Vol-~~canic and metamorphic rock fragments are present, but the dominant rock fragments are mud fragments. These account for 4% to 40% of the total grains. Feldspar is least abundant, composing only a trace to 5%.) Sodic and potassic feldspars were observed. The general character of the Lower Red Fork is shown in Figure 34.)

Diagenetic Constituents

(The Lower Red Fork has undergone extensive diagenesis. As mentioned above, precipitates, secondary minerals, and dissolution features are evident.) (Complete reduction of primary porosity was accomplished by: (1) compaction (the reservoir is 10,300 feet or more deep), (2) precipitation of cements, dominated by syntaxial quartz overgrowths; and (3) precipitation of authogenic minerals.)

(Compaction of the reservoir can be deduced readily by observation of broken mica flakes and clastic deformation of mud fragments squeezed between grains and forming a pseudo-matrix (Figure 35).) (Grain-to-grain contacts of quartz were due to secondary quartz overgrowth and not compaction.) (Compaction and deformation of the mud fragments probably were the processes most destructive to the primary porosity (Figure 35).)

(Quartz is the dominant cement with a much smaller percentage of

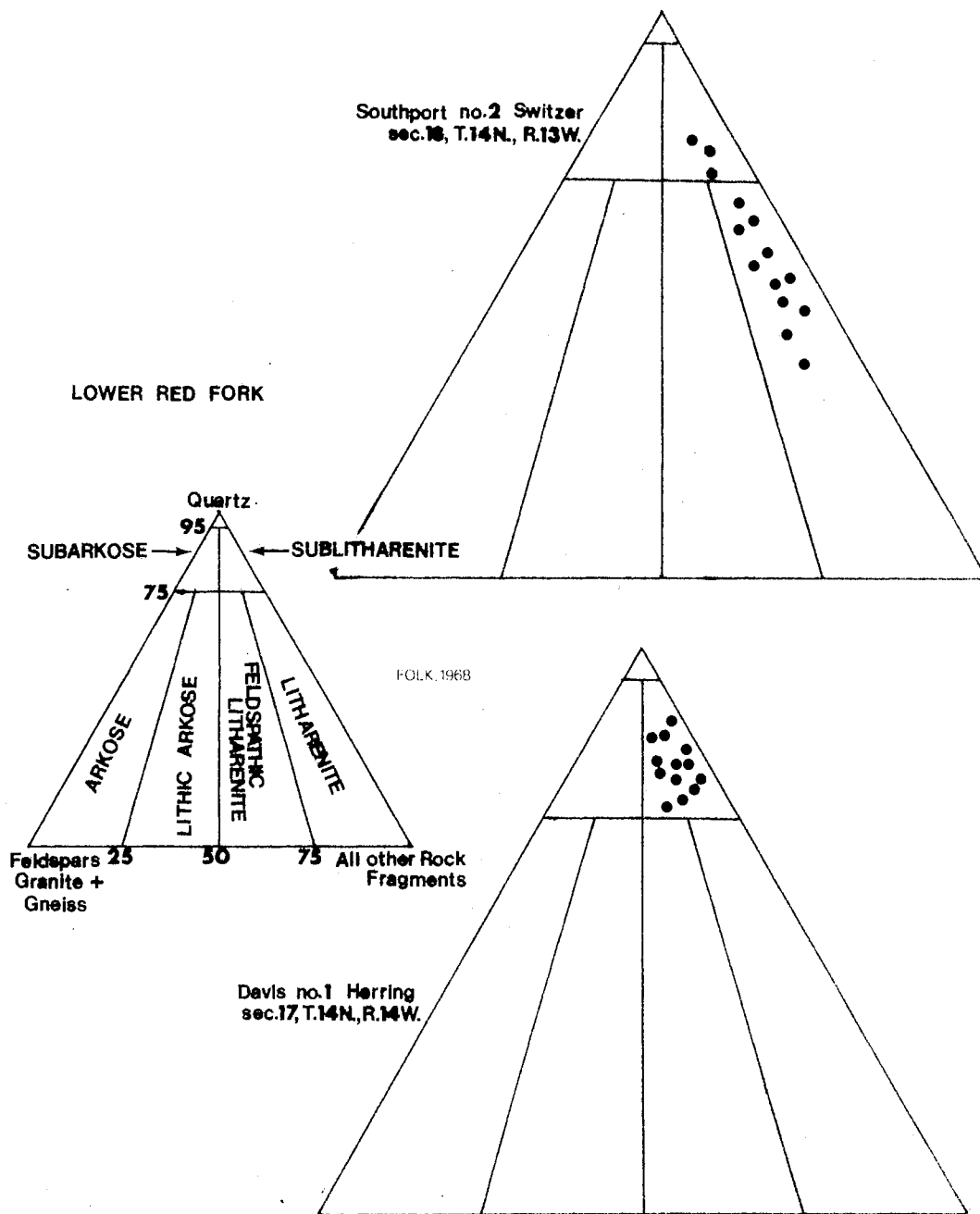


Figure 33. Ternary Diagram (QRF) Depicting the Mineralogic Composition of the Davis No. 1 Herring and the Southport No. 2 Switzer, Lower Red Fork

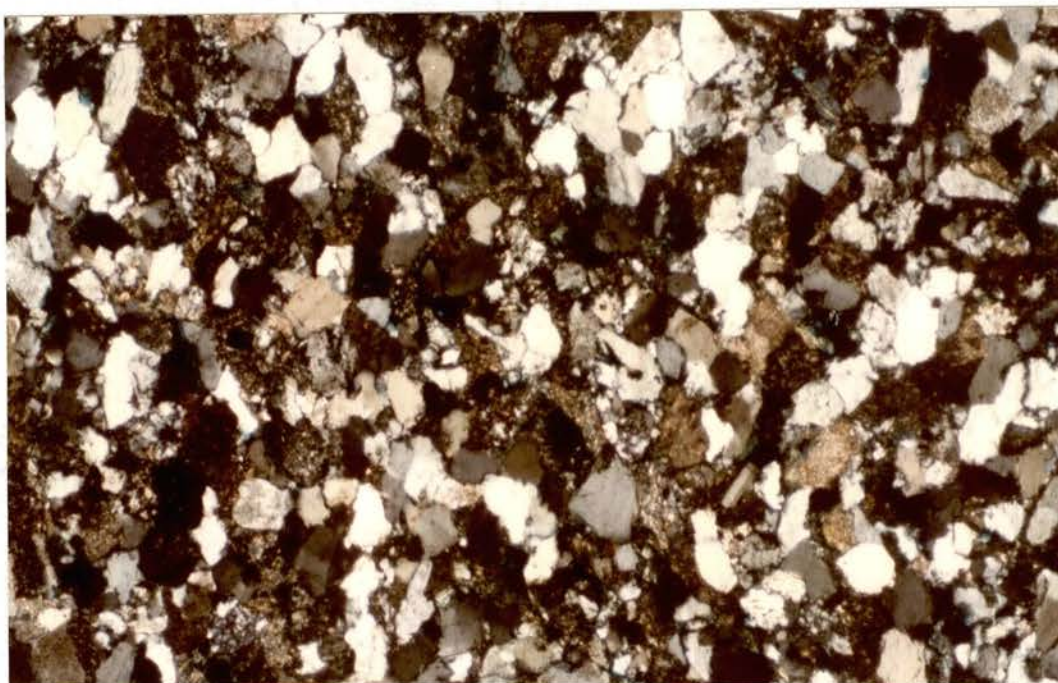
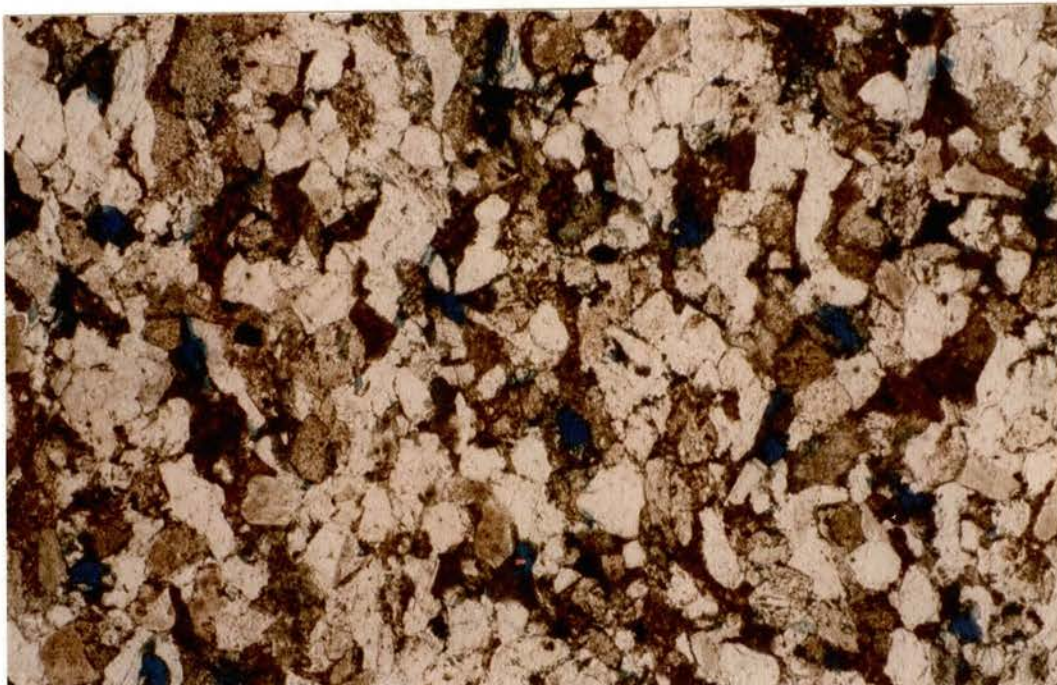


Figure 34. Photo-micrograph showing General Characteristics of the Lower Red Fork Sandstone (Top, Plane Polarized Light - Bottom, Crossed Nichols)



Figure 35. Photo-micrograph of Compaction Features; Broken Mica Grain and Squeezing of Detrital Mud Fragments, Lower Red Fork (Crossed Nichols)

calcite cement having been observed) Syntaxial quartz cement is subtle but apparent in plane polarized light (Figure 36). (Quartz cement accounts for an estimated 5% to 8% of the total quartz present.) (Calcite cement was observed locally where detrital clay was reduced. The average was less than 5% of all thin sections examined. However, in some instances, calcite cement is as much as 17% of the rock.)

(The main alteration products within the Lower Red Fork formation are clays. In order of abundance, authigenic clays formed were chlorite, illite, and kaolinite (Figure 37)) (Chlorite and illite occur together (Figures 38, 39), and kaolinite is sparse.) Abundance of chlorite is attributable to chloritization of detrital mud fragments. Illite developed within some mud fragments. When clays formed in pores, secondary porosity was reduced, but during ensuing episodes of fluid migration, clays tended to retard precipitation of other minerals. Thus, clays are contributory to preservation of porosity, in some respects. The unfavorable aspect of authigenic clays is that permeability is reduced, reported to be as low as 0.1 md (Whiting and Levine, 1983) as a result of clay platelets that clog the pore throats (Figures 38, 39).

Feldspar overgrowth can be observed in Figure 40. In some instances, the detrital inner portion of the feldspar was observed to have undergone dissolution with replacement by calcite and kaolinite.

Porosity

Porosity within the South Thomas Field is classified as mesogenetic in nature (Schmidt and McDonald, 1979), a diagenetic classification indicating that no primary porosity is preserved. This classification was determined from inspection of thin sections and SEM analysis. The

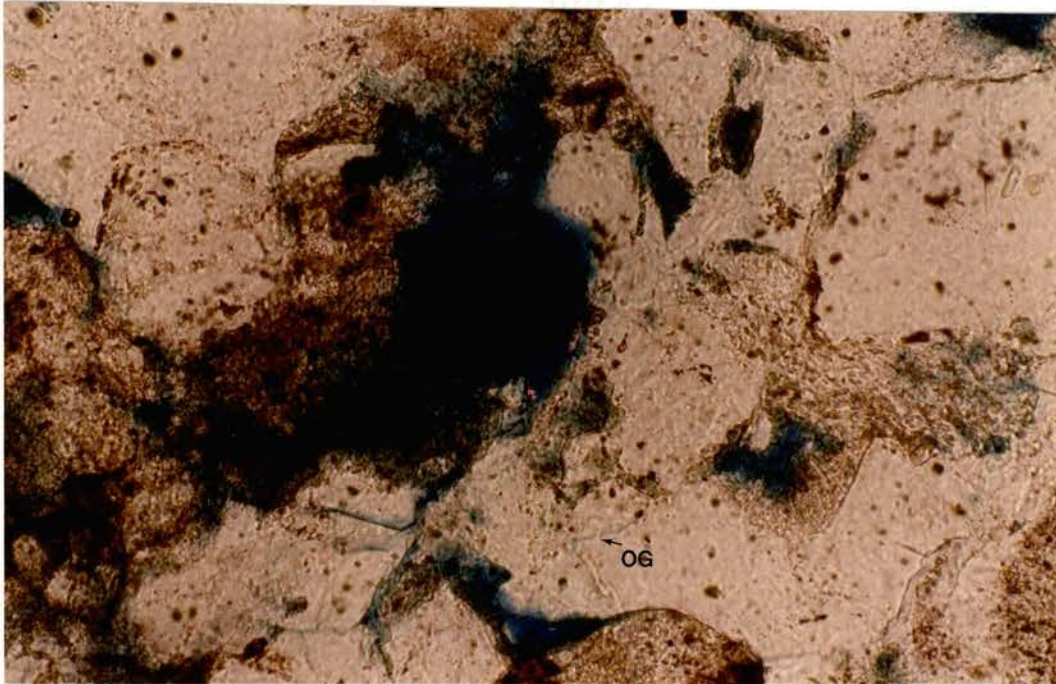


Figure 36. Photo-micrograph of Secondary Quartz-overgrowths in the Lower Red Fork (Plane Polarized Light).

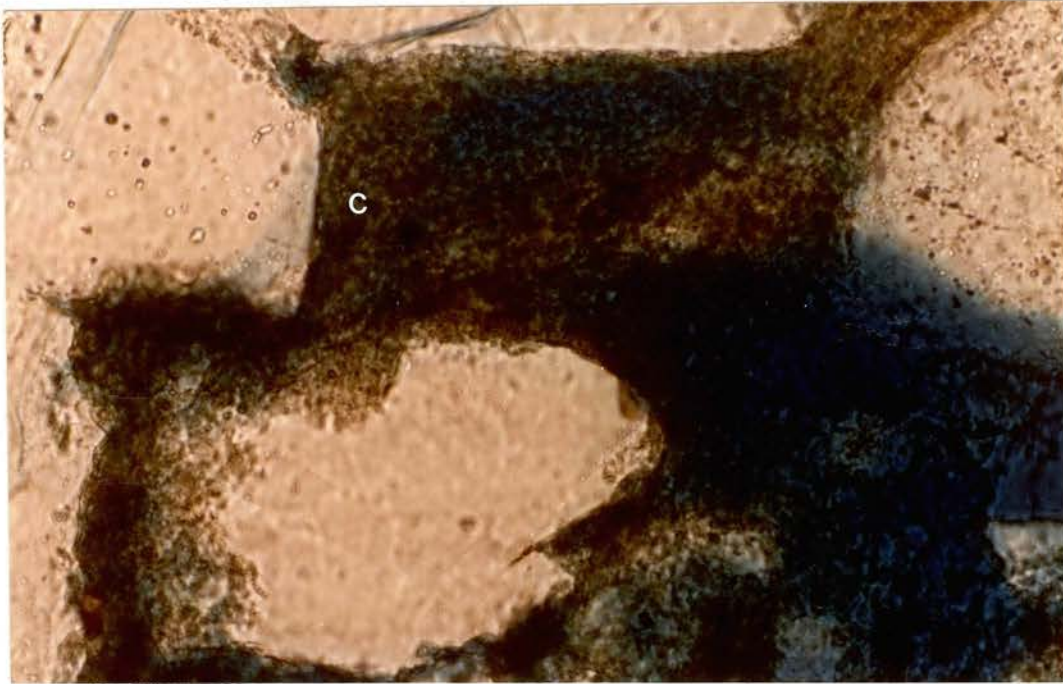


Figure 37. Photo-micrograph of Chlorite, Lower Red Fork
(Plane Polarized Light)

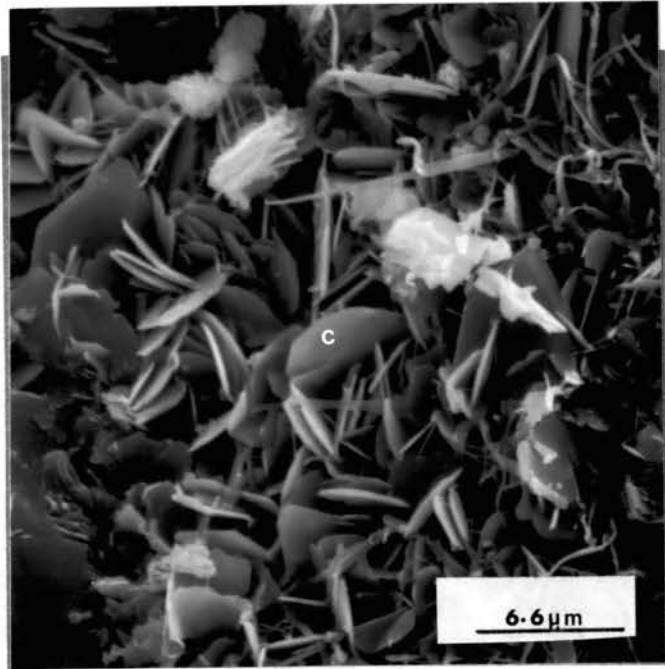


Figure 38. SEM Photo-micrograph of Authogenic Chlorite, Lower Red Fork

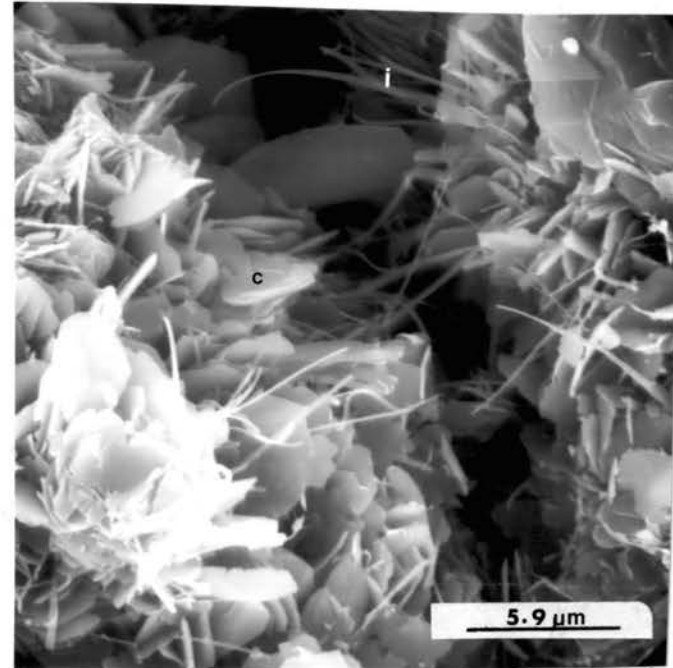


Figure 39. SEM Micrograph of Chlorite and Illite, Lower Red Fork



Figure 40. Photo-micrograph of Feldspar Overgrowths,
Lower Red Fork (Crossed Nichols)

fact of no significant primary porosity is attributable due to the depth and diagenetic alterations described above. The porosity originated dominantly by dissolution of siliceous mud fragments (Figure 41) and possibly calcite cement. Porosity averages 5% to 8% within thin sections examined although log porosity is higher due to microscopic porosity generated within the clay platelets (Figure 42).

Paragenesis

Overlapping of events is characteristic of sandstone reservoirs where dynamic pore water systems can cause changes in pH, Eh, dissolved solubles, etc., through geologic time and space. Several stages of precipitation and dissolution of events was observed in the Lower Red Fork. Chlorite can be observed early as rims around Quartz grains inhibiting overgrowths and late as pore filling precipitation. A paragenetic sequence diagram depicting this and the timing of other events is shown in Figure 43.

Upper Red Fork

Composition and Classification

Twenty-eight thin sections from Upper Red Fork cores were examined to determine detrital components and classification. The observed data was plotted on a ORF diagram. Sandstones of the Upper Red Fork generally are cleaner than those of the Lower Red Fork, plotting within the sublithic arenite field (Folk, 1968) (Figure 44). The rock dominantly is very fine grained.

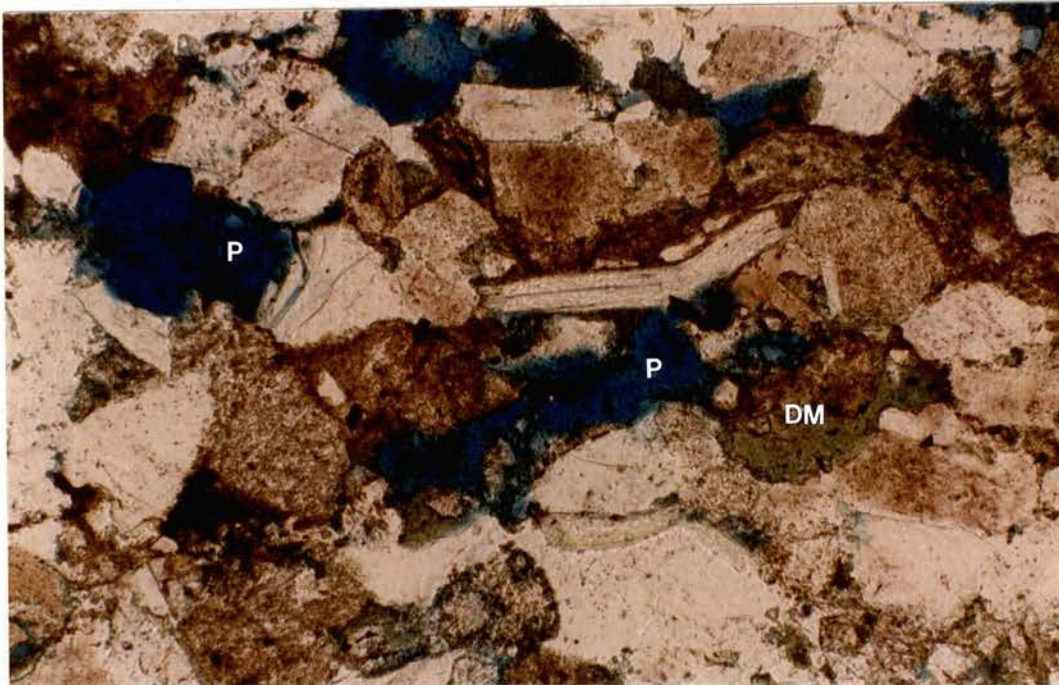


Figure 41. Photo-micrograph of Dissolution of Detrital Mud Fragments Producing Secondary Porosity (Plane Polarized Light)

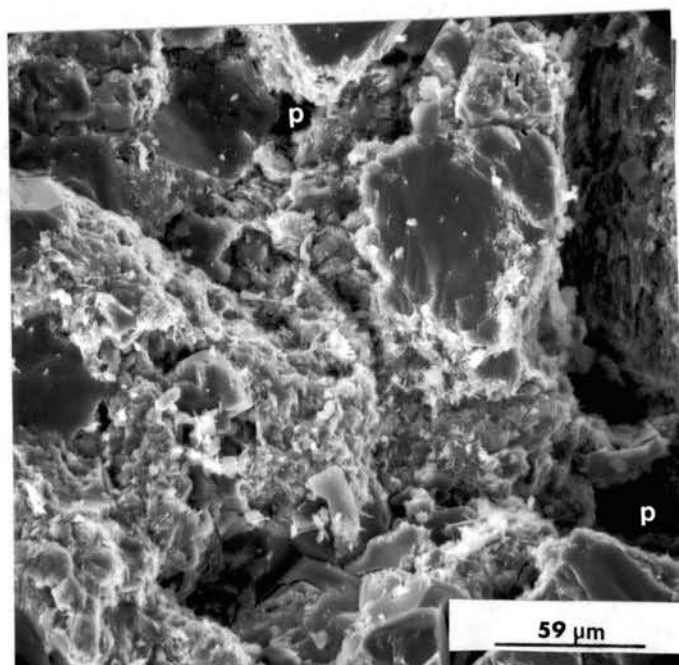


Figure 42. SEM Photo-micrograph of Secondary Porosity in in the Lower Red Fork

LOWER RED FORK

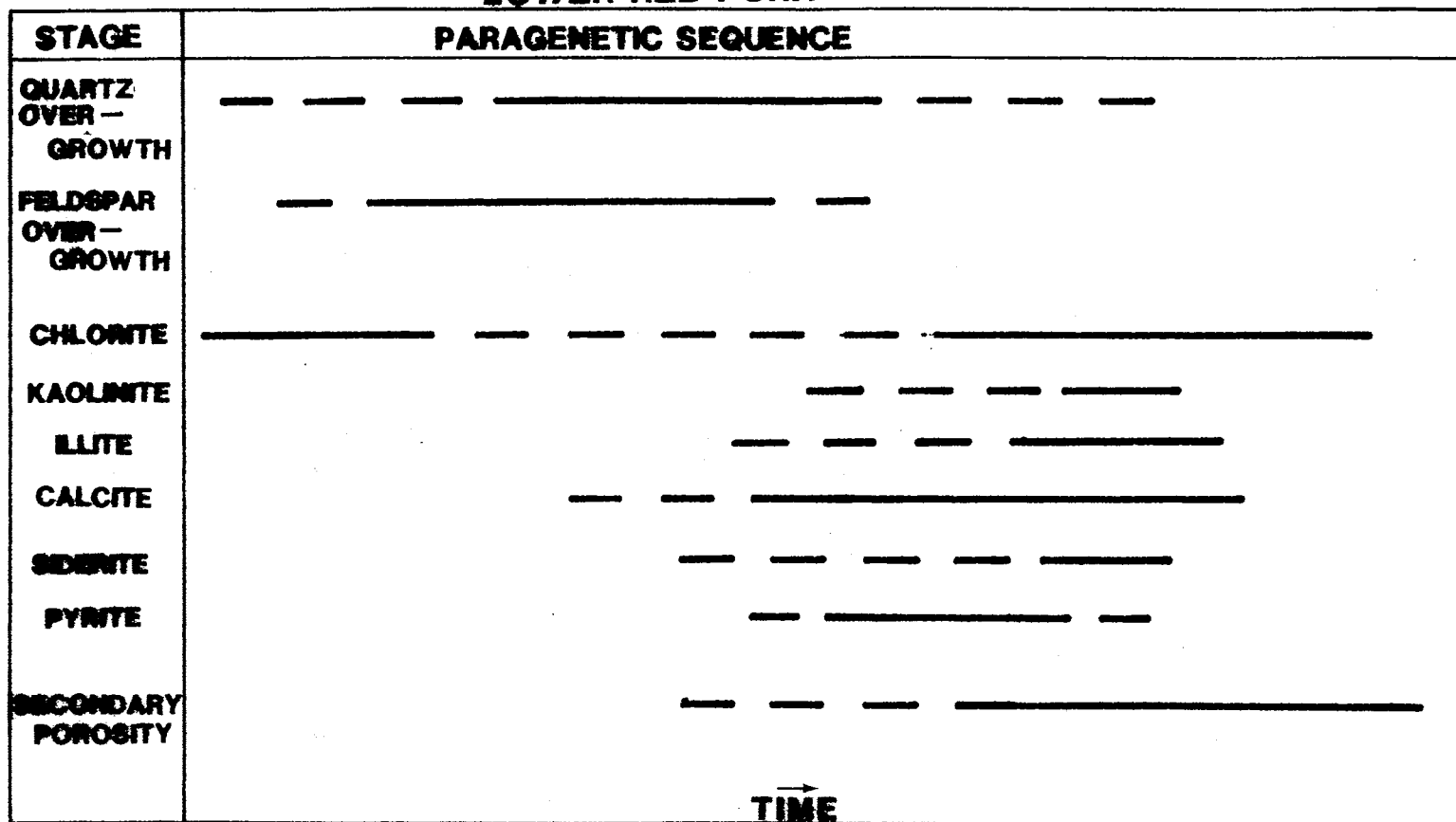


Figure 43. Paragenetic Sequence of the Lower Red Fork in the South Thomas Field
 (Solid Lines Indicate the Process Was Continuous Without Interruption;
 Dashed Lines Indicate Sporadic Activity.)

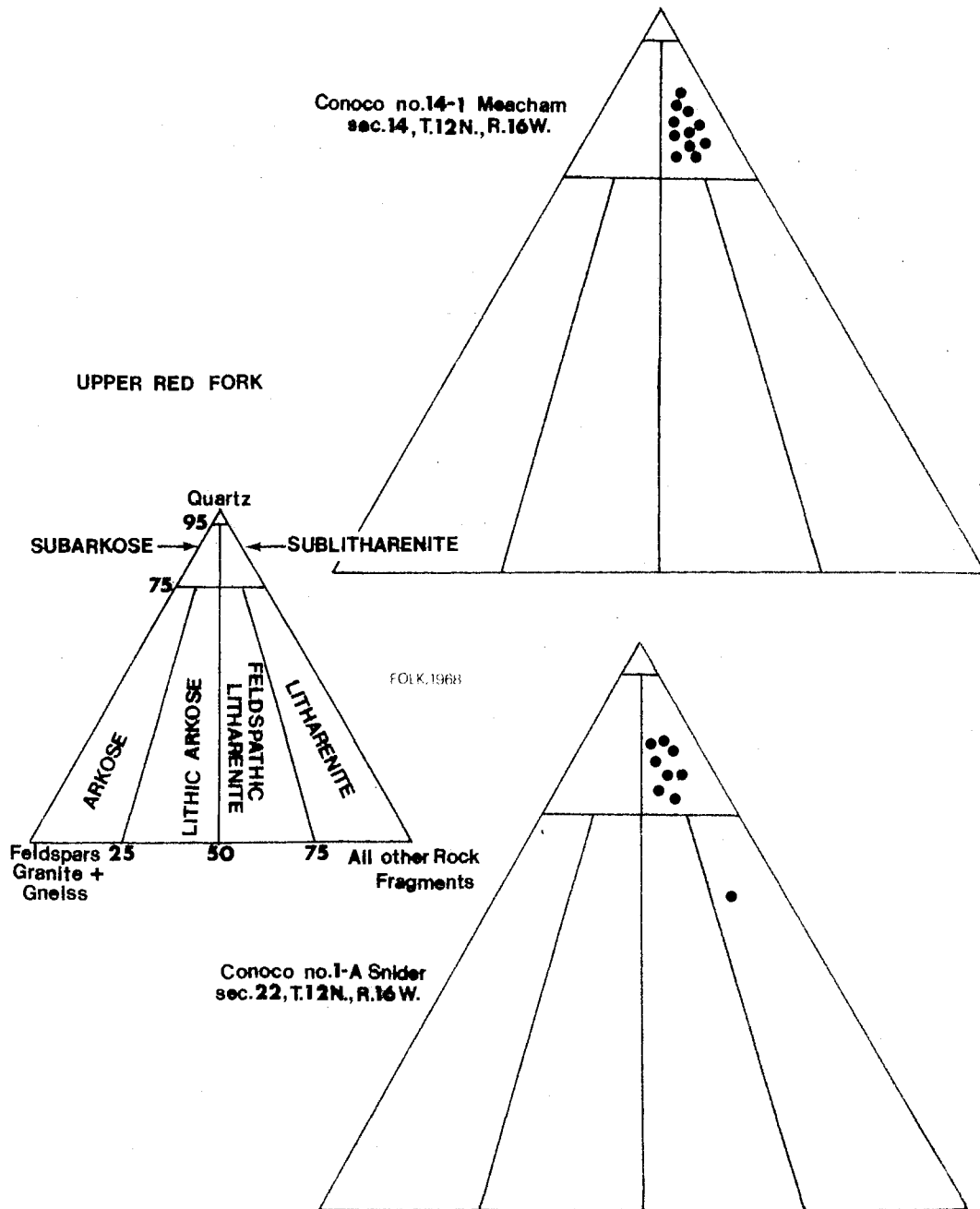


Figure 44. Ternary Diagram (QRF) Depicting the Mineralogical Composition of the Conoco No. 1 Meachum and the Conoco No. 1-A Snider, Upper Red Fork

The primary mineral is quartz, which composes 40% to 75% of the total volume. Rock fragments are less abundant, ranging from a trace to 27%. Feldspar is least abundant, from a trace to 5%. Sodic and potassic feldspar were observed, with overgrowths being sodic in composition. The general compositional and textural character of the Upper Red Fork is shown in Figure 45.

Diagenetic Constituents

As in the Lower Red Fork, sandstones of the Upper Red Fork were strongly affected by diagenetic changes. The major feature affecting the Upper Red Fork was the reduction of primary porosity. The Upper Red Fork is believed to have been affected by compaction (the reservoir is at depths of 12,300 feet or more) and cementation by syntaxial quartz overgrowths.

Compaction of the Upper Red Fork reservoir is indicated in Figure 46, where a deformed mica fragment can be observed. In Figure 48, a quartz fragment shows a fracture that may have been caused by compaction.

Syntaxial quartz cement is abundant as can be seen in Figure 49. SEM also document the overgrowths (Figure 48).

Diagenetic products within the Upper Red Fork are clay minerals, calcite, and dolomite. Kaolinite is the most abundant clay (Figures 50, 51). Chlorite is not as common or well developed as in the Lower Red Fork (Figure 52). Calcite was observed but not as a primary cement. Evhedral dolomite was documented in SEM (Figure 53) but was not observed in thin sections.

Feldspar overgrowths (Figure 54) are sodic whereas the grains

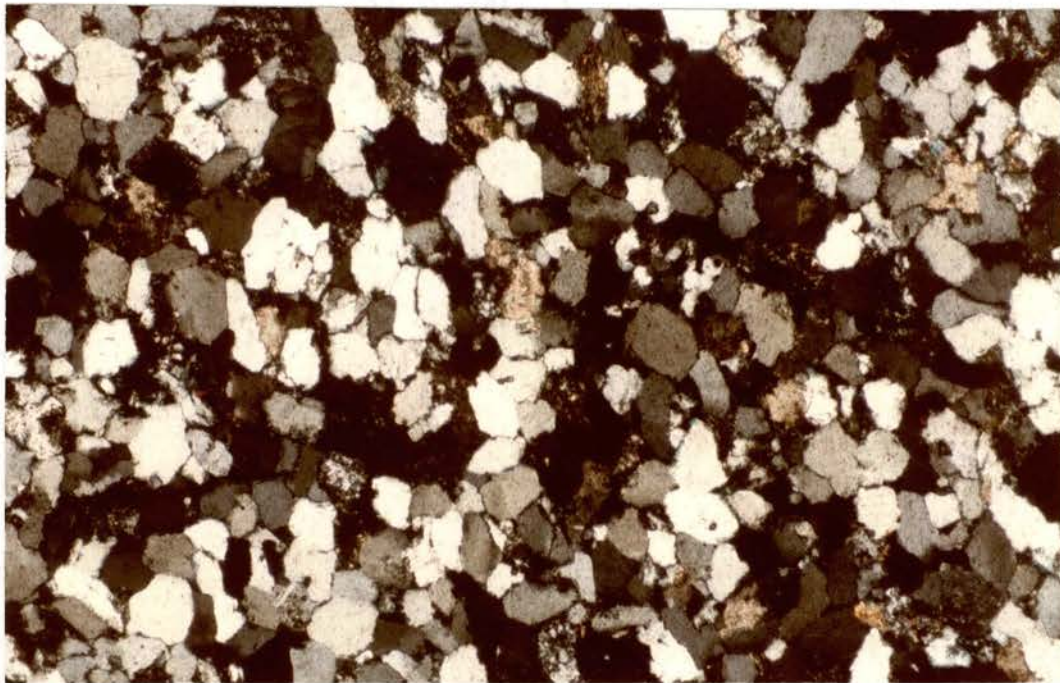
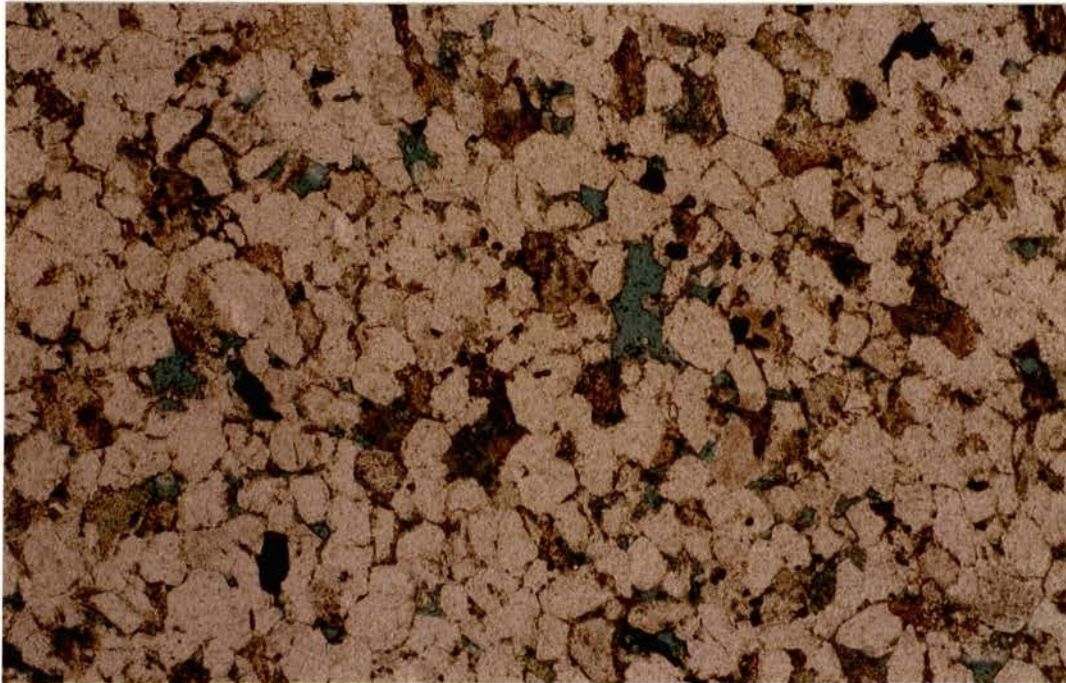


Figure 45. Photo-micrograph showing General Characteristics of the Upper Red Fork Sandstone (Top, Plane Polarized Light - Bottom, Crossed Nichols)

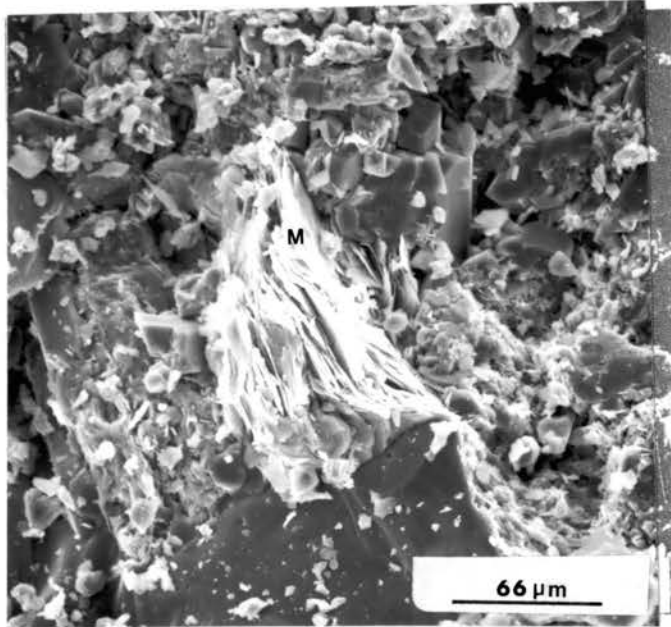


Figure 46. SEM Photo-micrograph of Deformed Mica Fragment, Upper Red Fork

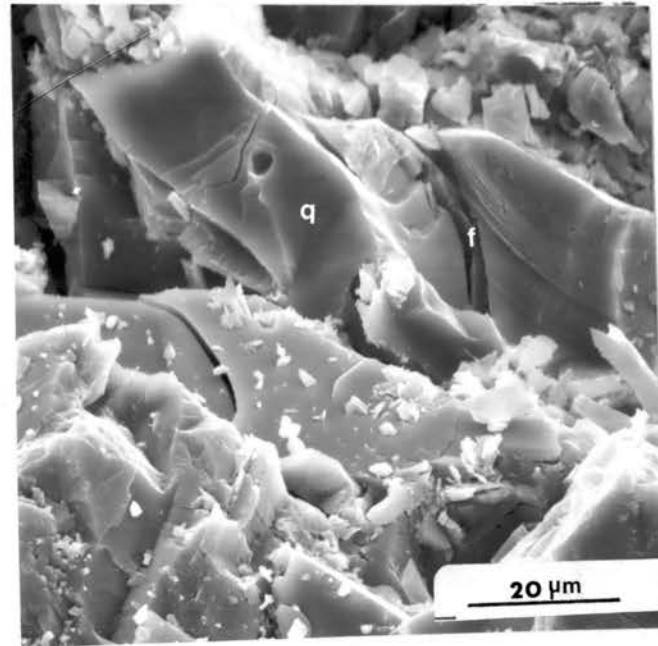


Figure 47. SEM Photo-micrograph of a Fractured Quartz Grain, Upper Red Fork

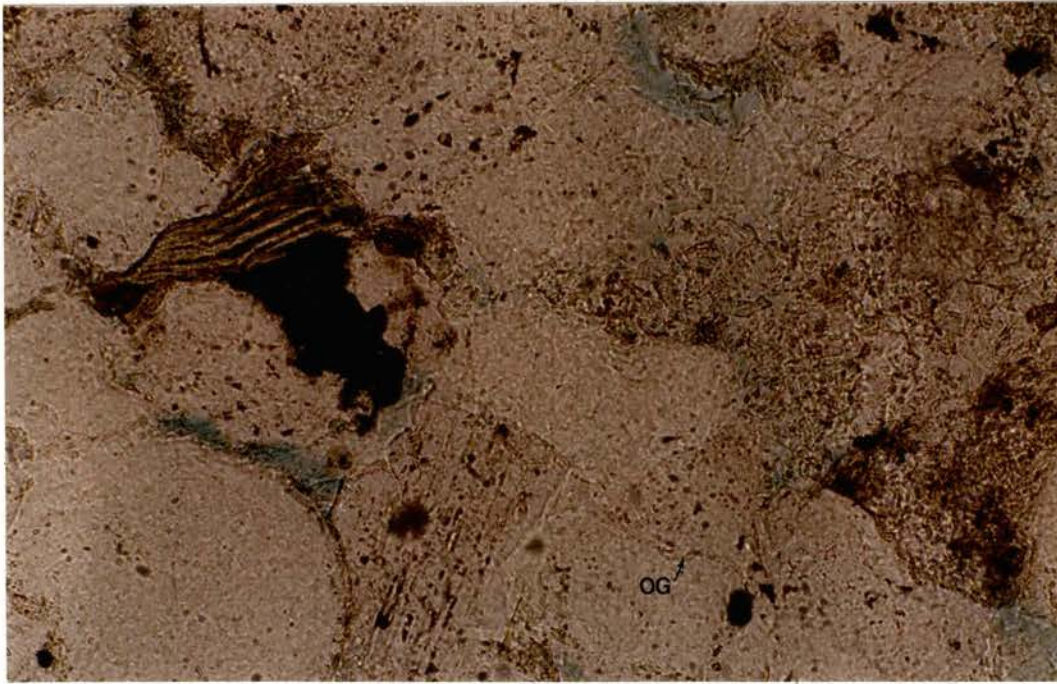


Figure 48. Photo-micrograph of Syntaxial Quartz Overgrowths, Upper Red Fork (Plane Polarized Light)

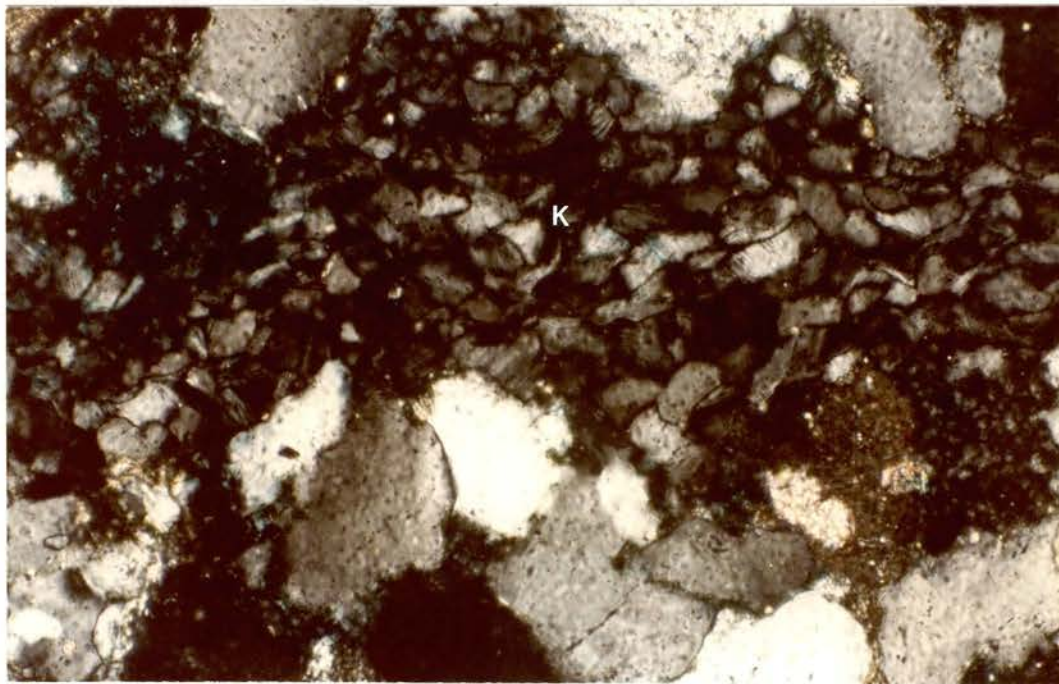


Figure 49. Photo-micrograph of Kaolinite, Upper Red Fork
(Crossed Nichols)

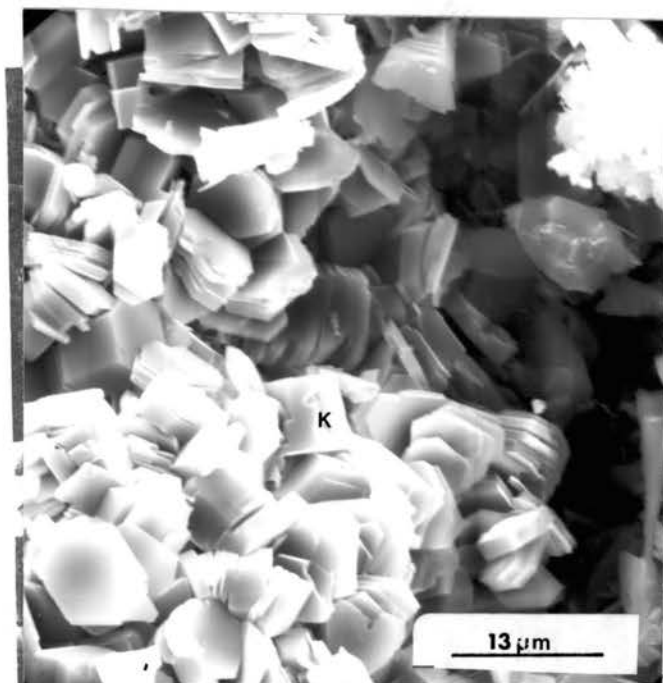


Figure 50. SEM Photo-micrograph of
Kaolinite, Upper
Red Fork

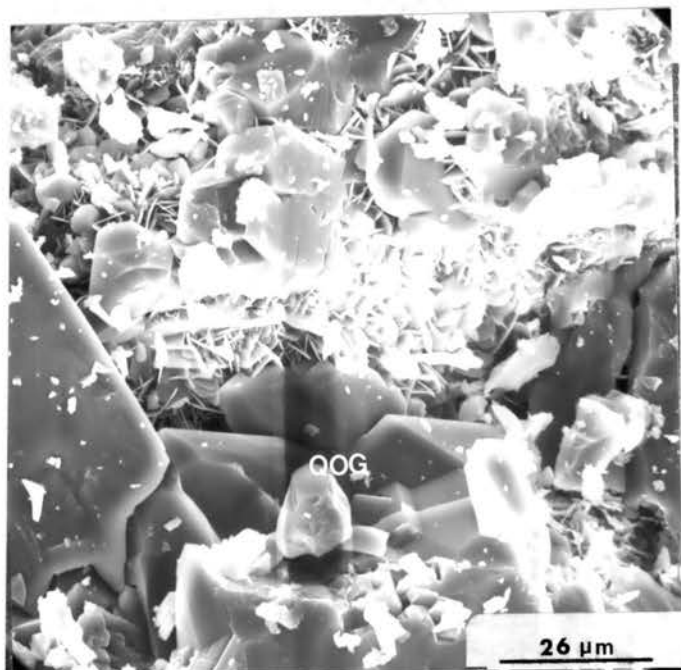


Figure 51. SEM Photo-micrograph of Syntaxial Quartz Overgrowths, Upper Red Fork

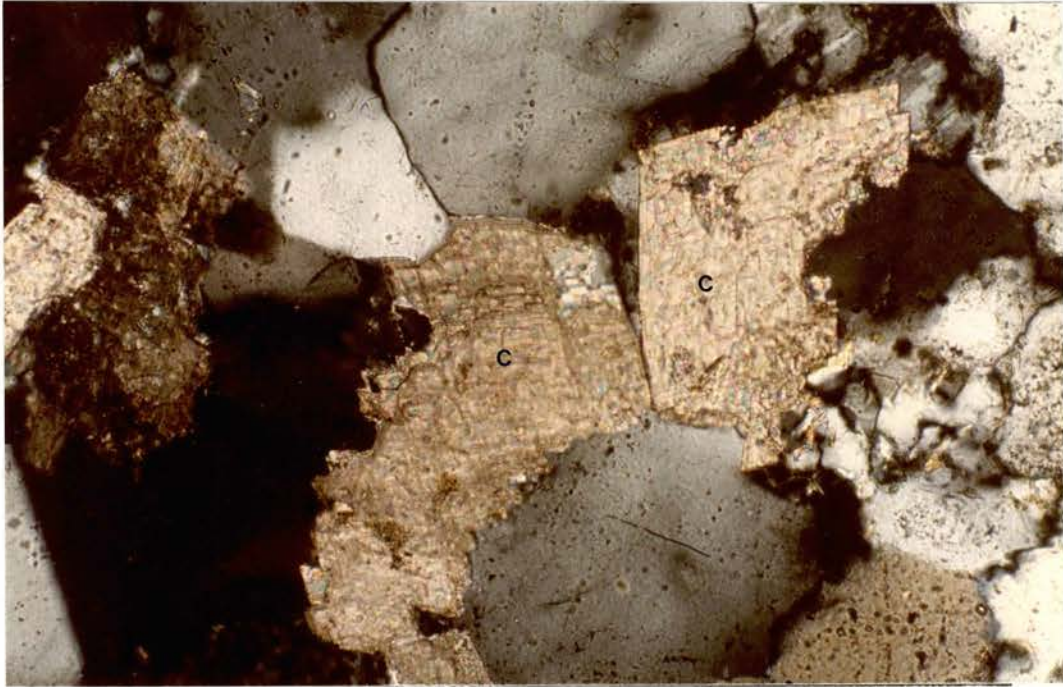


Figure 52. Photo-micrograph of Calcite, Upper Red Fork (Crossed Nichols)

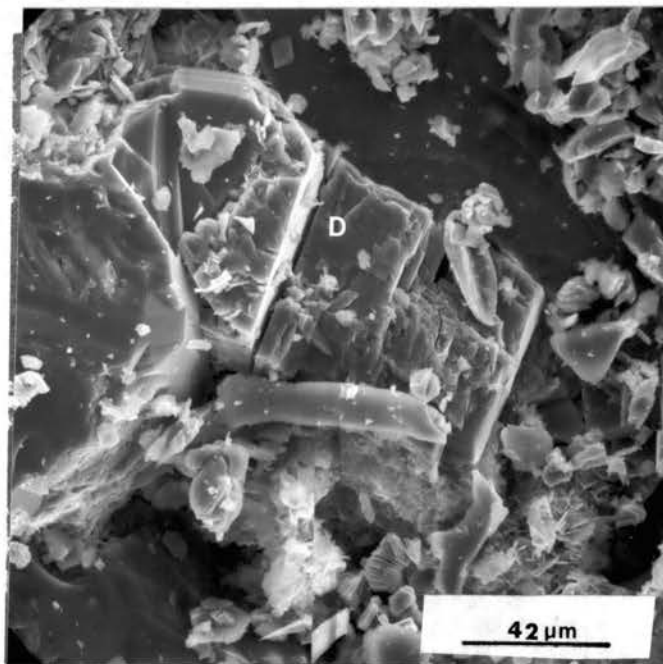


Figure 53. SEM Photo-micrograph of Dolomite, Upper Red Fork

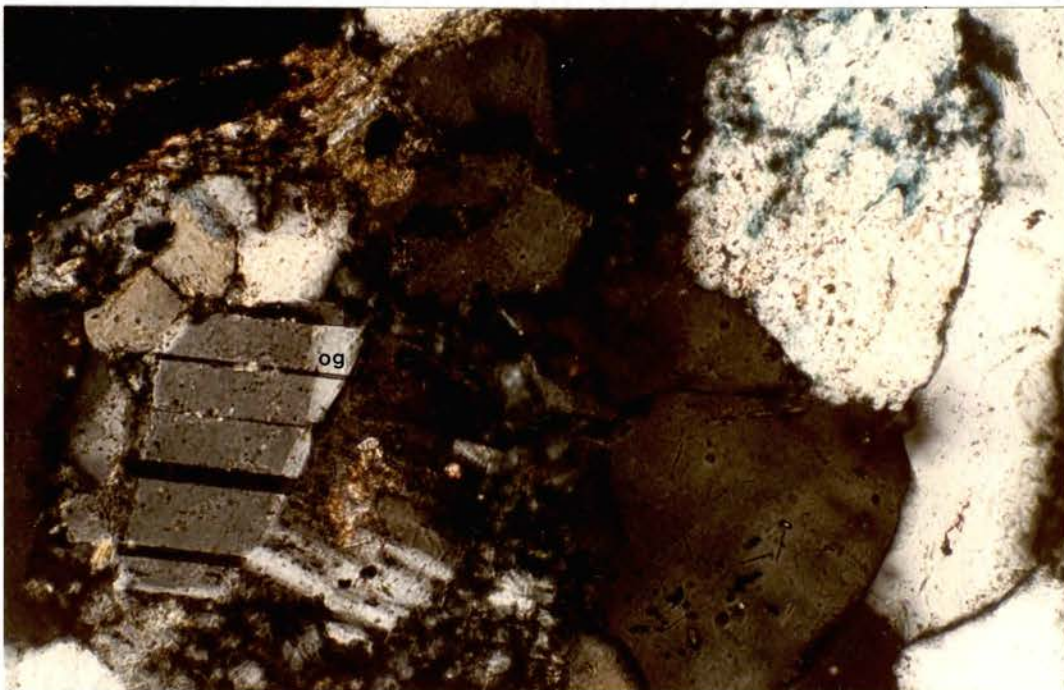


Figure 54. Photo-micrograph of Feldspar Overgrowth
(Crossed Nichols)

commonly are potassic. This may account for resistance of the overgrowth to dissolution in cases where the detrital grains have been dissolved. Alteration of potassic feldspar is believed to have contributed to formation of kaolinite. As mentioned in Chapters VI and VII, the Conoco No. 1 Hoffman can include what appear to be calcrete nodules. In thin section, this material appears to have formed in-place, evidence that supports the interpretation of calcrete nodules (Figure 55).

Porosity

Secondary porosity within the Upper Red Fork is documented well by observable evidence of dissolution of detrital chloritized pseudomatrix or sedimentary chloritized mud fragments. Association of porosity and mud fragments is recorded in a series of thin section-photographs. In Figure 56, a "clean" tight sandstone from a depth of 12,320 feet in the Conoco No. 1 Meachum is shown. Figure 57 shows a "dirty" sandstone from a portion of the same thin section. These photographs indicate that when little or no detrital matrix or mud fragments are present no porosity is present, either secondary or primary (Figure 56). Where mud fragments were present, they were dissolved, producing secondary porosity (Figure 57). This section of the core shows 10% to 12% porosity on the compensated density-neutron log.

Pore filling authigenic kaolinite is the major process in reducing secondary porosity. Authigenic kaolinite was formed by alteration of mud fragments and feldspars (Figure 51). Abundant microporosity is observed under analysis SEM, whereas thin sections reveal large pores but suggest little permeability (Figure 58) (Whiting and Levine, 1983).

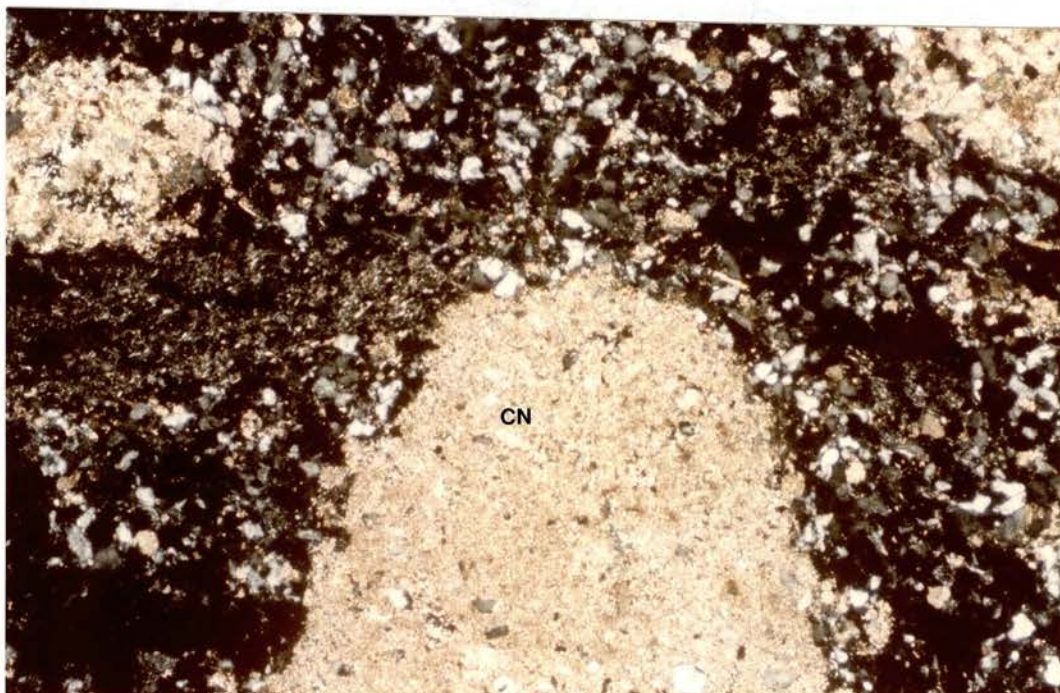


Figure 55. Photo-micrograph of Calcareous Nodules,
Conoco No. 1 Hoffman, Depth 12,502
Feet, Upper Red Fork

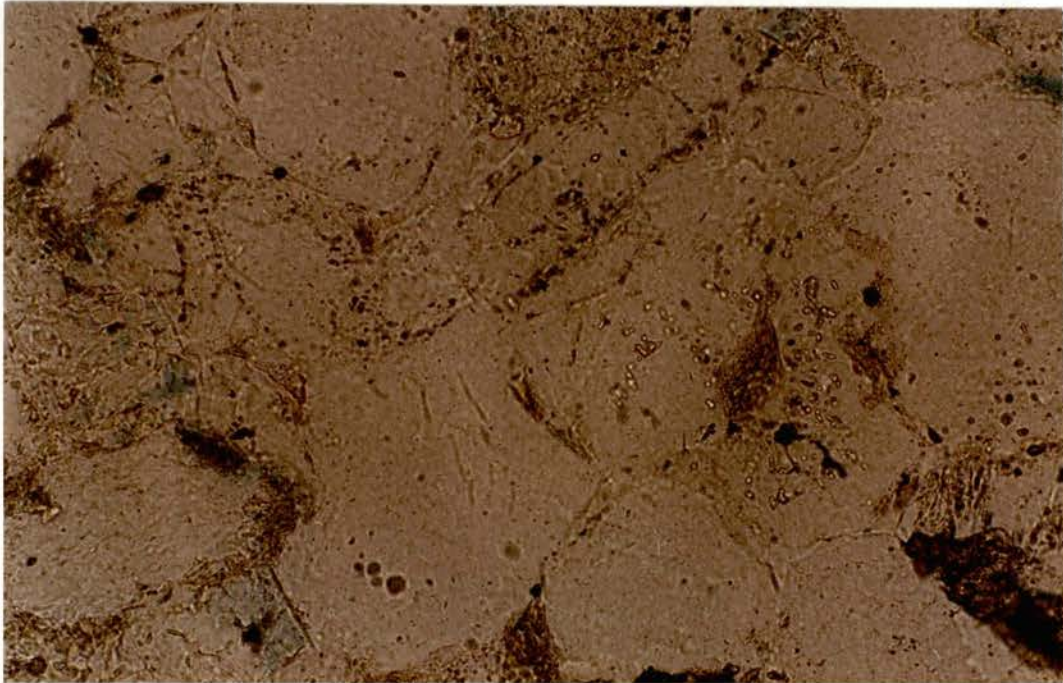


Figure 56. Photo-micrographs of "Clean" Non-porous,
Upper Red Fork (Top, Plane Polarized;
Bottom, Crossed Nichols)

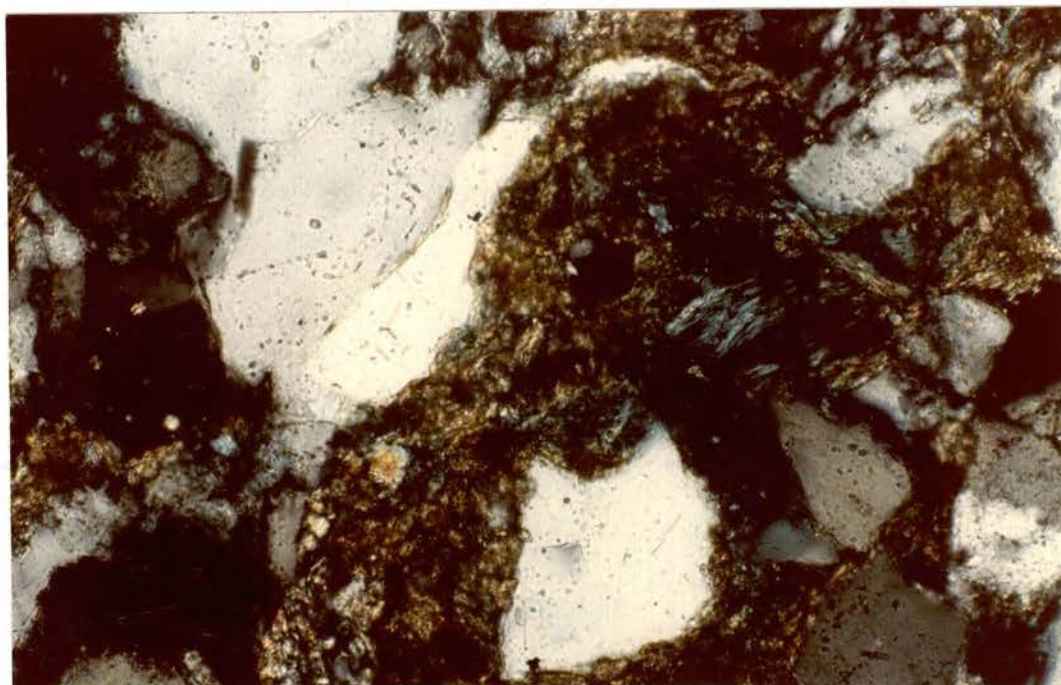
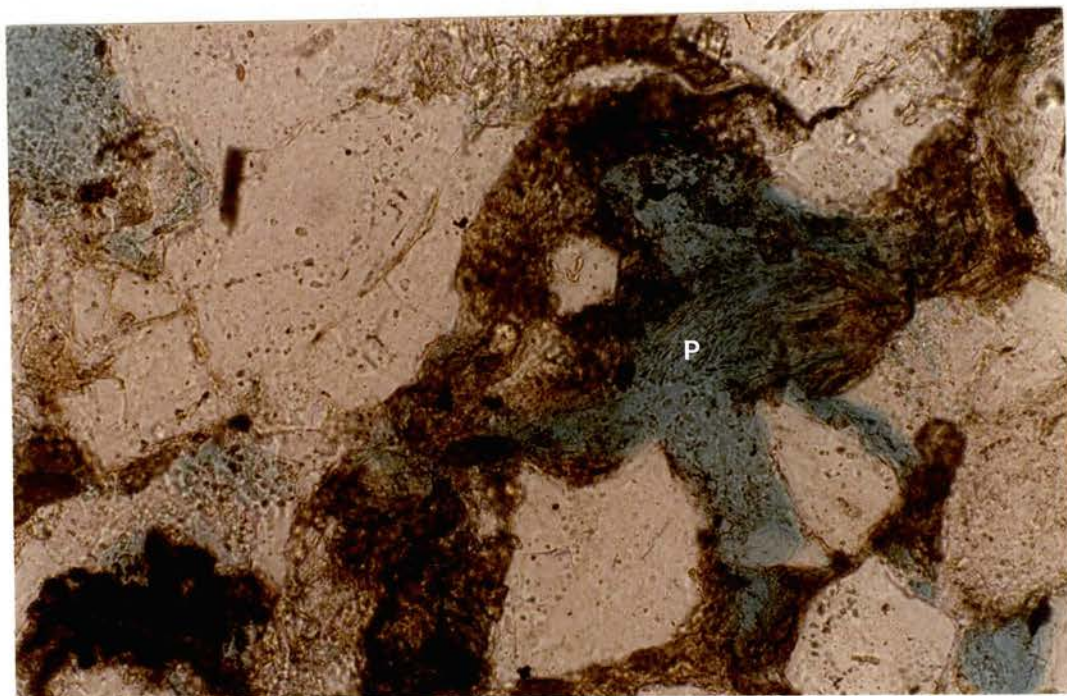


Figure 57. Photo-micrograph of "Dirty" Porous,
Upper Red Fork (Top, Plane Polarized;
Bottom, Crossed Nichols)

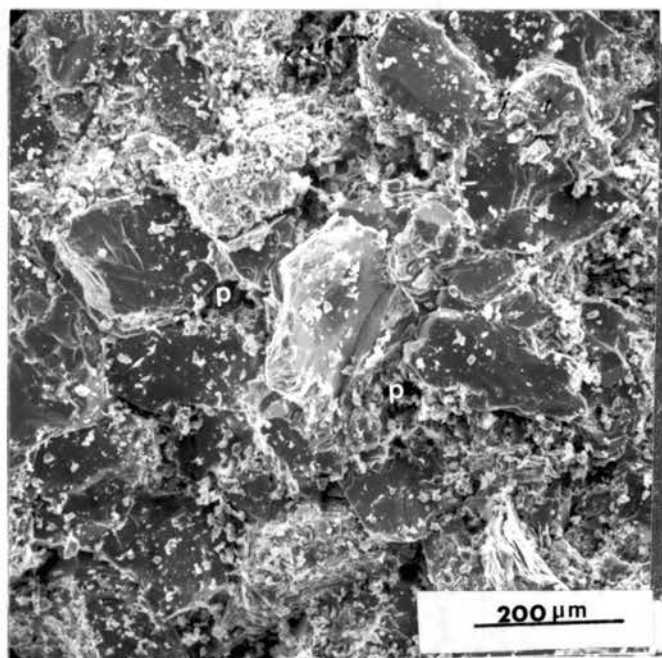


Figure 58. SEM Photo-micrograph of Porosity in the Upper Red Fork

Paragenesis

Chlorite occurred early as a grain coating which inhibited quartz overgrowths. Feldspar overgrowths occurred before or during precipitation of calcite cement. Kaolinite occurred late, filling fractures and pores. Secondary porosity began after quartz and feldspar overgrowths ended. A paragenetic sequence diagram shows timing of these events and others is shown in Figure 59.

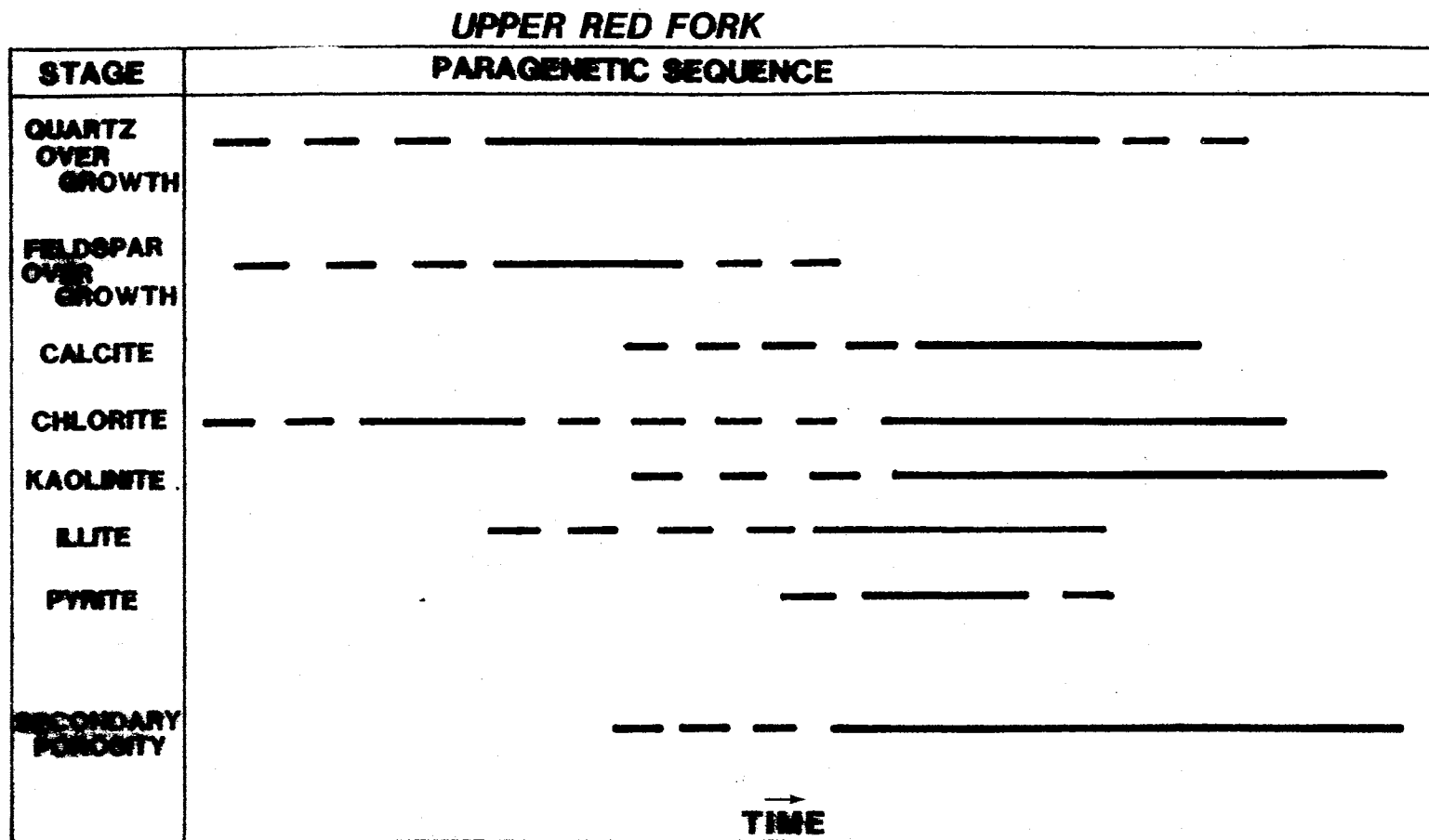


Figure 59. Paragenetic Sequence of the Upper Red Fork in the East Clinton Field
 (Solid Lines Indicate the Process Was Continuous Without Interruptions; Dashed Lines Indicate Sporadic Activity)

CHAPTER IX

PETROLEUM GEOLOGY

Within the study area, the Red Fork Sandstone was produced first in October, 1964 from the Sun Oil Company Burns lease, SE SW Section 25, T. 14 N., R. 13 W., producing at a depth of 10,616 feet. This well and a second well, within the same section, had produced 185,442 B0 and 443 MMCFG of natural gas as of December 31, 1982.

Total production from the Red Fork wells per field within the area is shown in Table I (location of fields shown in Figure 60). Most of the production has been since discovery of the South Thomas Field in April, 1976.

The South Thomas Field has produced abundant oil and gas from the Lower Red Fork sands over the relatively short period of 5 years. The Squaw Creek and the Geary Fields (Table 1 and Figure 60) also have produced large quantities of oil and gas over a period of more than 10 years. Most of the Upper Red Fork production in the study area is less than 4 years old, and recent discoveries have been toward the deeper part of the basin. The East Clinton Field has excellent gas production; of note is the Conoco No. 1 Meachum. The cored interval discussed previously has produced more than 6.7 BCF in approximately 3.5 years.

Traps in Red Fork reservoirs are stratigraphic. With the reservoir sands encased in impermeable shale, the lenticular and gradational lateral boundaries of the sand, in conjunction with post-depositional dip,

TABLE I
OIL AND GAS PRODUCTION FROM RED FORK SANDSTONES*

Discovery Date	Field Name	Number of Wells	Total Oil Production, Barrels 12/82	Average Oil Production Per Well, Barrels	Total Gas Production, 12/82, MCF	Average Gas Production Per Well, MCF	
1	10/64	Squaw Creek - LRF	7	204,671	29,239	792,693	113,242
2	9/69	Bridgeport - South and West - LRF	12	47,024	3,918	6,089,241	468,403
3	9/71	Indianapolis - LRF	1	22,984	22,984	528,797	528,797
4	10/72	Geary - LRF	15	793,523	52,901	29,663,152	1,977,543
5	11/72	Northwest Weatherford - LRF	1	997	997	40,666	40,666
6	1/75	Watonga - Chickasha Trend - LRF	2	28,565	1,428	1,959,795	979,897
7	4/76	South Thomas - LRF	71	2,983,624	42,022	81,871,309	1,153,117
8	1/79	Elm Grove - LRF	6	1,507	281	780,757	130,126
9	5/80	South Weatherford - URF	2	4,277	2,138	332,721	166,360
10	6/80	East Clinton - URF	16	477,818	29,864	42,582,124	2,661,383
11	12/81	Libbie - URF	2	3,734	1,867	-	-
12	1/82	Carpenter - URF	1	10,100	10,100	459,066	459,066
		136	4,578,824	33,804	165,100,321	1,213,973	

*For locations of fields, see Figure 60.

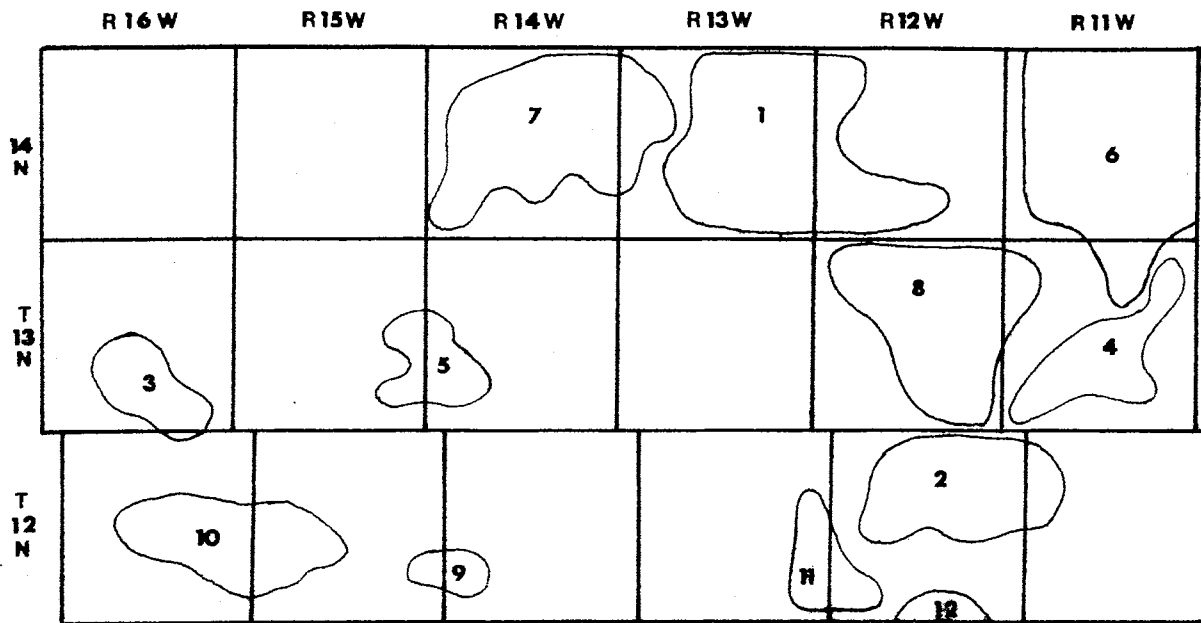


Figure 60. Map Showing Location of Fields Numbered 1-12 in Table I

has created traps with monoclinal and homoclinal structure. Source of oil for the Pennsylvanian sands on the Northern Shelf has been suggested to be the immediately enclosing shales (Hatch and Leventhall, 1982; Robertson, 1983; Mason, 1982). In light of the abundant organic matter observable in cores, enclosing shales seem to be the most likely sources of Red Fork production in the study area. Some of the best Red Fork production has been from the East Clinton and the South Thomas Fields (Table I), which, interpreted as deltaic sequences, would be expected to have derived oil from the enclosing organic shales (Waples, 1981).

A critical consideration in future exploration would be to define Upper and Lower Red Fork genetic units more precisely. This criterion would be based on the definition of depositional environments and prediction of trends. Because the better production comes from deltaic reservoirs, it seems important to concentrate exploration on the shelf area, and to seek the thick deltaic deposits that almost certainly form other traps in this part of the study area.

CHAPTER X

CONCLUSIONS

The principal conclusions of this investigation are:

1. The Red Fork interval within the study area generally is thicker than on the Northern Shelf of the Anadarko Basin. In the study area, the entire Red Fork interval is thicker than 250 feet, whereas on the Northern Shelf, the interval is about 100 feet thick, on the average.

2. Structural contour maps show homoclinal dip at about S. 20° W. The dip is nearly uniform at about 1° on the structural contour map of the Pink limestone. Dip ranges from about 1° in the northeast to more than 3° in the southwest on the structural contour map of the lowermost Red Fork marker bed.

3. Based on an isopach map of the entire Red Fork interval and associated cross sections, a shelf-slope hinge line was interpreted to trend north-northwesterly through the study area.

4. The marker bed used to separate the Upper and Lower Red Fork formats is consistently mappable; it may record a disconformity.

5. Variation in thickness geometry, and trends of the Lower Red Fork is more complex than in the Upper Red Fork.

6. Lithologic information from cores shows an overall general, ascending vertical sequence as follows: (1) dark gray shale overlain abruptly by (2) massive or cross-bedded sandstone, and (3) interstratified sandstone and shale that show evidence of burrows, flowage, slump

structures and horizontal laminae.

7. Deposition of sandstone in the Lower Red Fork seems to have been influenced strongly by a shelf-slope hinge line.

8. Cores from the South Thomas Field show evidence indicating that sands were deposited in a deltaic complex. The complex is believed to have been at maximal basinward extent during deposition of the Lower Red Fork.

9. From log characteristics and net-sand isopach maps, associated major depositional environments proposed as having existed during deposition of the Lower Red Fork are submarine canyons and submarine fans.

10. The fact of no marked thickening of the Upper Red Fork was judged to indicate absence of an accentuated slope zone or hinge line.

11. The main complex of producing sandstones of the Upper Red Fork is within the East Clinton Field of T. 12 N., R. 16 W., which probably records the maximal progradation of deltaic complex.

12. The Lower Red Fork is lithic to sublithic arenite, fine-grained to very fine-grained.

13. The Upper Red Fork is sublithic arenite, very fine grained and is noticeably cleaner than the Lower Red Fork.

14. No primary porosity was observed within thin sections of sandstones from the Upper or Lower Red Fork. Most of the porosity is secondary, from dissolution of mud fragments.

15. The dominant clay in Lower Red Fork sandstones is chlorite.

16. The dominant clay in Upper Red Fork sandstones is kaolinite.

17. Oil and gas traps in the Red Fork are stratigraphic.

18. Most of the oil and gas production has been from sandstones

deposited in or associated with deltaic environments; this is an especially strong relationship in the Lower Red Fork of the South Thomas Field and the Upper Red Fork of the East Clinton Field.

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APPENDIX

CORE DESCRIPTIONS

WELL: Southport No. 2 Switzer (Figure 61)
 LOCATION: C-NW Sec. 18, T.14N., R.13W.
 CORED DEPTH: 10,395 to 10,440 feet
 STRATIGRAPHIC LOCATION: Lower Red Fork
 WELL STATUS: Gas, 6/78 production intervals 10,445-453;
 10,449-488; 10,491-410.

The core is sublithic arenite sandstone and dark gray to black shale. The stratigraphic position of the core is within the Lower Red Fork with the lower 15 feet of the core in what is believed to be a deltaic distributary channel. The interbedded shale and sandstone is believed to be inter-deltaic in origin.

The basal unit, from 10,422 to 10,443 feet, is composed of sandstone which is compositionally sublitharenite. The sandstone is "massive" with some small-scale crossbedding present. A slump feature is present at the top of the core at 10,423 feet. This basal unit, from comparison of the gamma-ray dual induction logs is believed to be the uppermost zone of a distributary mouth bar channel sequence.

The interval from 10,417 to 10,421 feet, is dominated by shale with interbedded sandstone. The interbedded sequences have lenticular wavy bedding, erosional surfaces, soft sediment deformation and where the sand is thick enough, small-scale crossbedding. The lower contact of this unit is erosional, the upper contact is gradational.

The next unit, from 10,408.5 to 10,417 feet is composed of dark black organic shale. Some thin silty lenses occur within the upper portion of this unit which is interpreted as an interdistributary bay sequence.

A massive sandstone unit is present from 10,408.5 to 10,411.5. This sandstone is sublithic to lithic arenite in composition. Sharp erosional contacts are present below and above. This unit is believed to be a minor deltaic distributary channel.

A zone from 10,405 to 10,408.5 feet has some silty layers dominated by shale. The shale is massive and dark gray. A gradational contact is present with the interbedded unit described below. Interdistributary bay is believed to be the origin.

The zone from 10,398 to 10,405 is lithic arenite sandstone. The lower two feet of this zone is interbedded sand and shale with what is believed to be an erosional contact with the upper section of this zone. The sandstone has cross-bedding as the dominant sedimentary feature. Mottling is present within this zone from a undetermined cause.

The uppermost zone from 10,398 to 10,395 is black to dark gray massive shale. Several discrete layers of lingulid and productid

brachiopods are present. The uppermost 6 inches has disturbed bedding of an undetermined origin. Interdistributary bay is believed to be the origin with storms possibly causing the deposition of the shallow marine fossils.

WELL: Davis N. 1 Herring (Figure 62)
LOCATION: C-SW Sec. 17, T.14N., R.14W.
CORED DEPTH: 10,858 - 10,918 feet
STRATIGRAPHIC POSITION: Lower Red Fork
WELL STATUS: Oil, Lower Red Fork, 3/80, production
interval 10,885-90; 10,899-937.

The core is lithic to sublithic sand and shale. The stratigraphic position of the core within the Lower Red Fork is high. A dark shale is overlain by massive sandstone and above this by an interbedded sandstone. The producing zone is the same interval as the core.

The lowermost zone, from 10,918 to 10,915, consists of gray to black shale which is interpreted as a distal delta-unit. The contact between the sand above and this zone is missing from the core but is believed to be erosional because of the lithologic contrast.

The next unit, from 10,878 to 10,915, feet is composed of lithic to sublithic sandstone which is interpreted as being deposited in a distributary mouth bar within a delta complex. Features of this unit are medium-scale crossbedding at the bottom overlain by a massive sandstone. A small shale break of 3 inches is present at 10,888 feet with erosional surfaces above and below. Above this is 10 feet of rippled and small-scale cross bedding. This unit is the producing zone.

The next unit, from 10,857 to 10,878, is composed of interbedded sand and shale with a 5 foot section of sandstone from 10,866 to 10,871. The interbedded unit is dominated by shale. Lenticular and wavy bedding characterizes the sand intervals. The shale is dark to light gray. The 5 foot section of sandstone is dominated by ripples and small-scale crossbedding. The lower contact of this sand section is erosional while the upper contact is gradational.

WELL: Conoco No. 1 Hoffman (Figure 63)
LOCATION: C-SW Sec. 15, T.12N., R.16W.
CORED DEPTH: 12,380 - 12,429 feet
STRATIGRAPHIC POSITION: Upper Red Fork
WELL STATUS: Dry and abandoned, 5/80.

The core is separated into three distinct units. A light gray shale is overlain by a slightly calcareous litharenite sandstone followed by a dark black organic shale. Both pyritized and calcareous fossils, calcareous nodules, and a coal seam are present.

The lower unit is composed of light gray massive shale with several fossil zones. The fossils are dominantly of one type, tentatively identified as productid brachiopods. As this type of brachiopod occurs in a range of shallow marine environments, it does not serve as an environmentally diagnostic fossil. Also within this zone is a coal bed composed of three layers, all approximately 1/4" thick. Slight traces of root remains are present in the coal bed and the coal bed shows no direct evidence of transportation. These features seem to indicate a lagoonal or swamp environment which was occasionally inundated by sea water.

The intermediate zone from 12,397-12,415 is composed of litharenite sandstone which has abundant calcite nodules. The basal contact of this unit is sharp with a very fine grained sandstone overlying the previous unit. From 12,413 to 12,414 feet, a zone of sandstone, high in matrix, with fossils, productid brachiopods, is found. A one foot section, 12,411 to 12,412 feet, of black siliceous shale has sharp contacts above and below. The interval from 12,400 to 12,411 feet has calcium carbonate nodules, burrowing, and coalified root remain called a rootlet. A massive sand from 12,398 to 12,400 is overlain by shale with a sharp contact. This unit is believed to be an indication of subaerial exposure as would be found in a levee deposit in a deltaic complex.

A gradational contact separates a black, highly organic shale from the sandstone unit. This extremely fissile shale shows no stratification except for one 2" zone of tan, extremely siliceous claystone. This interval also has a few pyritized fossils which suggest a reducing environment. This unit is interpreted as forming in a marsh or inter-distributary bay environment.

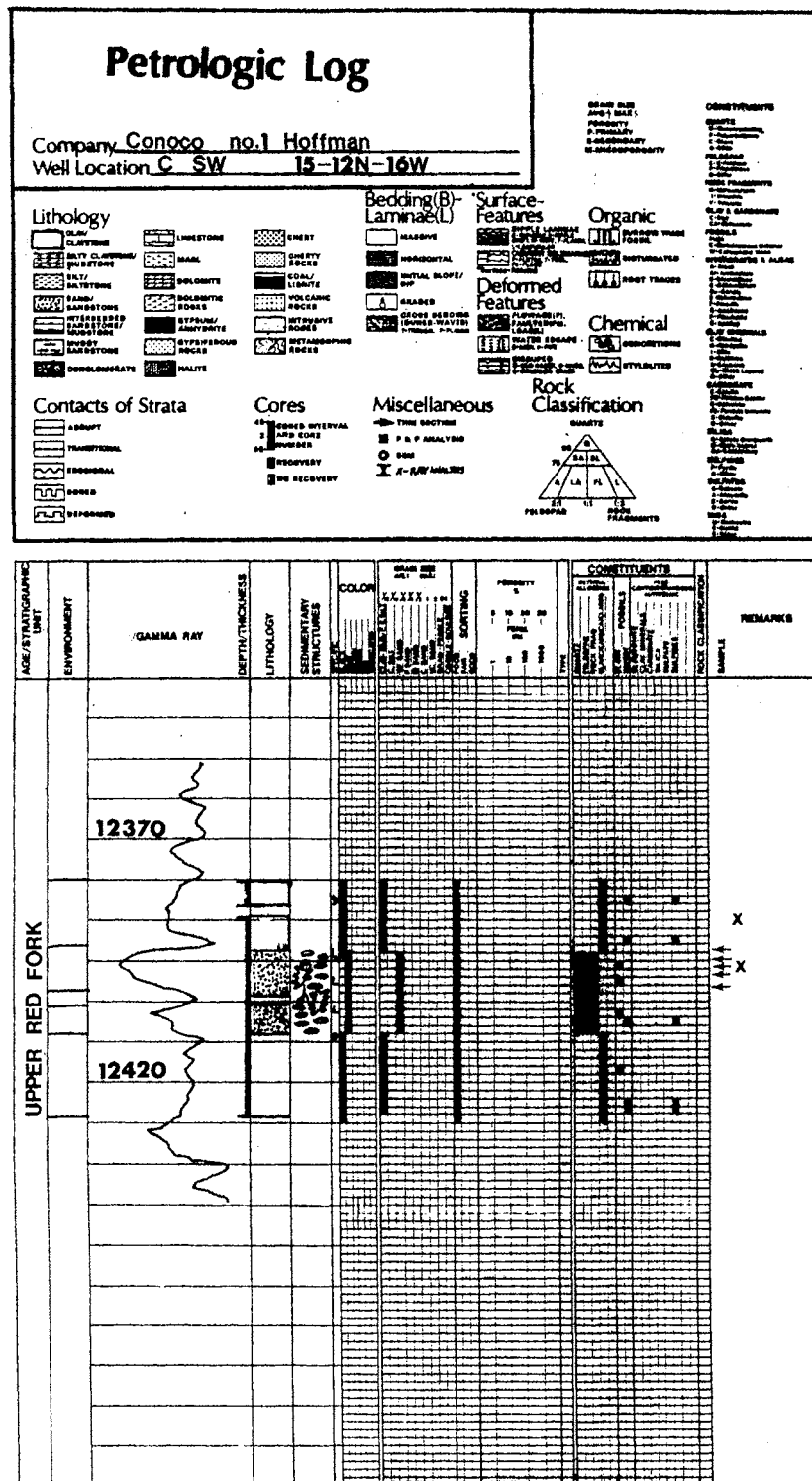


Figure 63. Core Descriptions, Conoco No. 1 Hoffman

WELL: Conoco No. 1 Meachum (Figure 64)
LOCATION: C-SE Sec. 14, T.12N., R.16W.
CORED DEPTH: 12,303 - 12,355 feet.
STRATIGRAPHIC LOCATION: Upper Red Fork
WELL STATUS: Gas, 1/81, production interval 12,310-12,346 feet. No treatment.

The core from the east Clinton Field is dominated by sublitharenite sandstone with an average porosity of 12%. The core also contains the production interval, 12,310 to 12,346 feet. The well has produced over 4.8 billion cubic feet of gas in 13 months as of 7/82 from this interval.

At the base of the core is a shale, one foot in thickness, which is interpreted as a distal-delta unit. It has within it pyrite, disturbed horizontal laminations, slumps, concretions and an erosional surface.

The next unit, from 12,343 to 12,354 feet, is a unit of interbedded shale and sandstone. The interval from 12,353 to 12,354 is a zone dominated by sand with crossbedding and wavy irregular horizontal bedding. At the base of this unit from 12,343 to 12,352 feet is a zone with more shale than sand. Features within this unit are horizontal laminations, interbedded sandstone and claystone, wavy irregular bedding, small-scale cross bedding and ripples, and convolute bedding. This zone is also interpreted as a delta-front of close proximity to a distributary-mouth bar.

From 12,303 to 12,343 is a zone of 40 feet dominated by sand which is interpreted as a distributary-mouth bar sequence. Characteristic features are small to medium scale cross-bedding, erosional contact surfaces, ripples, convolute bedding, rip-up clasts and irregular, wavy bedding. The sand, although porosity is developed, is very dense and showed a welded appearance in thin-section.

WELL: Conoco No.1 Franzen (Figure 65)
LOCATION: E/2 E/2 N/2 NE Sec. 27, T.12N., R.16W.
CORED DEPTH: 12,612 to 12,662 feet
STRATIGRAPHIC POSITION: Upper Red Fork
WELL STATUS: Dry and Abandoned, 9/81.

The core is composed of shale. One interval of interbedded silt to very fine-grained sand is recorded from 12,645 to 12,653 feet.

WELL: Conoco No. 1-A Snider (Figure 66)
LOCATION: S/2 S/2 NE Sec. 22, T.12N., R.16W.
CORED DEPTH: 12,372 to 12,419 feet
STRATIGRAPHIC POSITION: Upper Red Fork
WELL STATUS: Gas, Red Fork, 1/80, production intervals
12,474-482; 12,491-522; 12,536-541.

The core is of sublitharenite sandstone and shale. The stratigraphic position of the core within the upper Red fork sand zone is high. The deposition of this core is believed to be adjacent to a deltaic complex.

The basal unit, from 12,402 to 12,419 feet, is composed of a massive dark to light gray shale which containing sporadic burrowing and a few concretions. A change in the unit occurs from 12,407 to 12,409 feet when the shale is interbedded with sandstone lenses. This interbedded interval contains burrowing and lenticular bedding. The entire basal unit probably represents distal or pro-delta deposits.

A sharp contact marks the base of a interbedded unit from 12,382 to 12,402 which is composed of very fine grained litharenite sandstone. Crossbedding within the sand is common toward the bottom. Ripples dominate the upper sand bodies. Burrowing is characteristic throughout the unit. Rip-up clast are present from 12,393 to 12,394 feet. This unit is believed to be a distributary-mouth bar upon which floods or high flow advanced over.

The uppermost top unit, from 12,372 to 12,382 feet is composed of horizontally bedded shales. It is interpreted as distal-delta. The shale contains intermixed very fine grain sand grains, interpreted as being caused by burrowing. Slumps are found at 12,373, 12,378 and 12,379 feet. These slumps are most likely associated with subsidence of a delta.

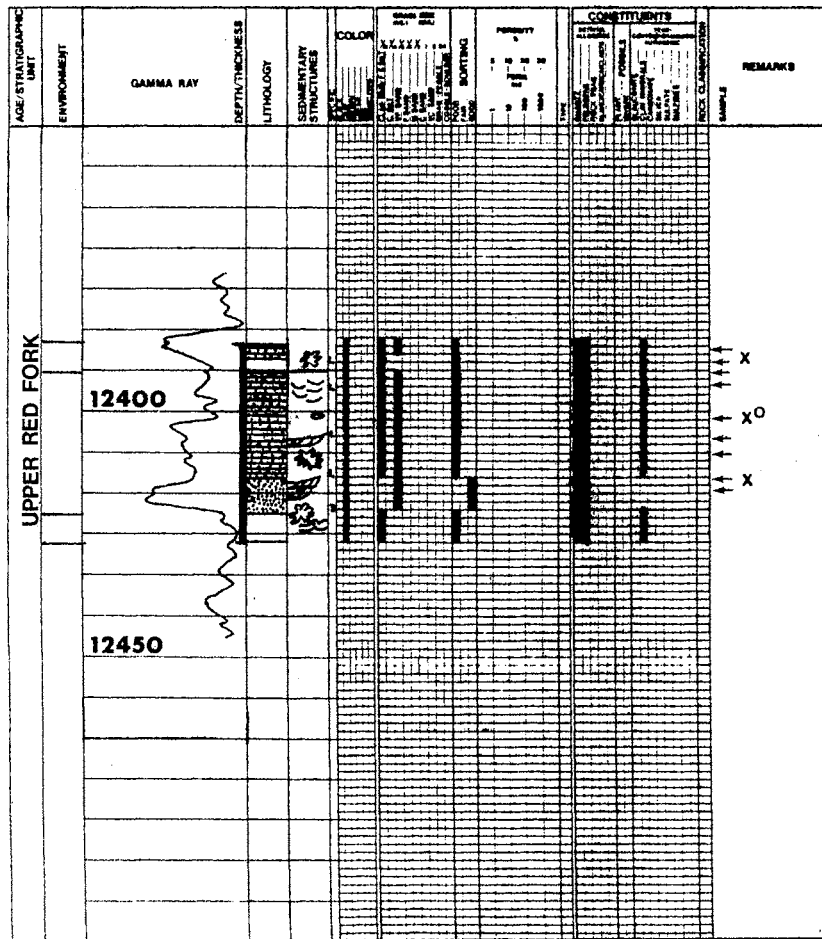
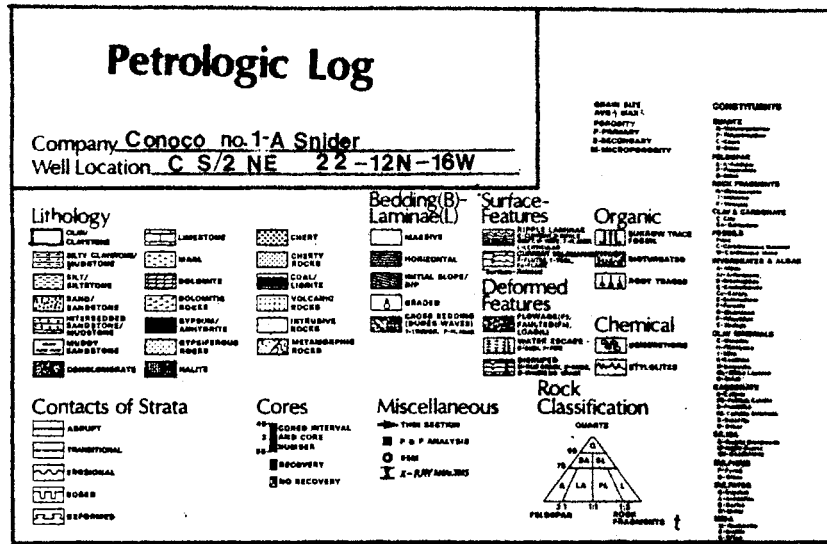


Figure 66. Core Description, Conoco No. 1-A Snider

VITA ²

Christopher Lee Johnson
Candidate for the Degree of
Master of Science

Thesis: DEPOSITIONAL ENVIRONMENTS, RESERVOIR TRENDS, AND DIAGENESIS
OF RED FORK SANDSTONES IN PORTIONS OF BLAINE, CADDO, AND
CUSTER COUNTIES, OKLAHOMA

Major Field: Geology

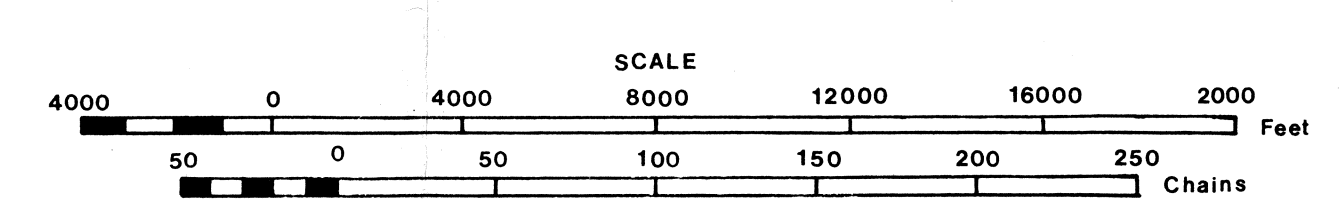
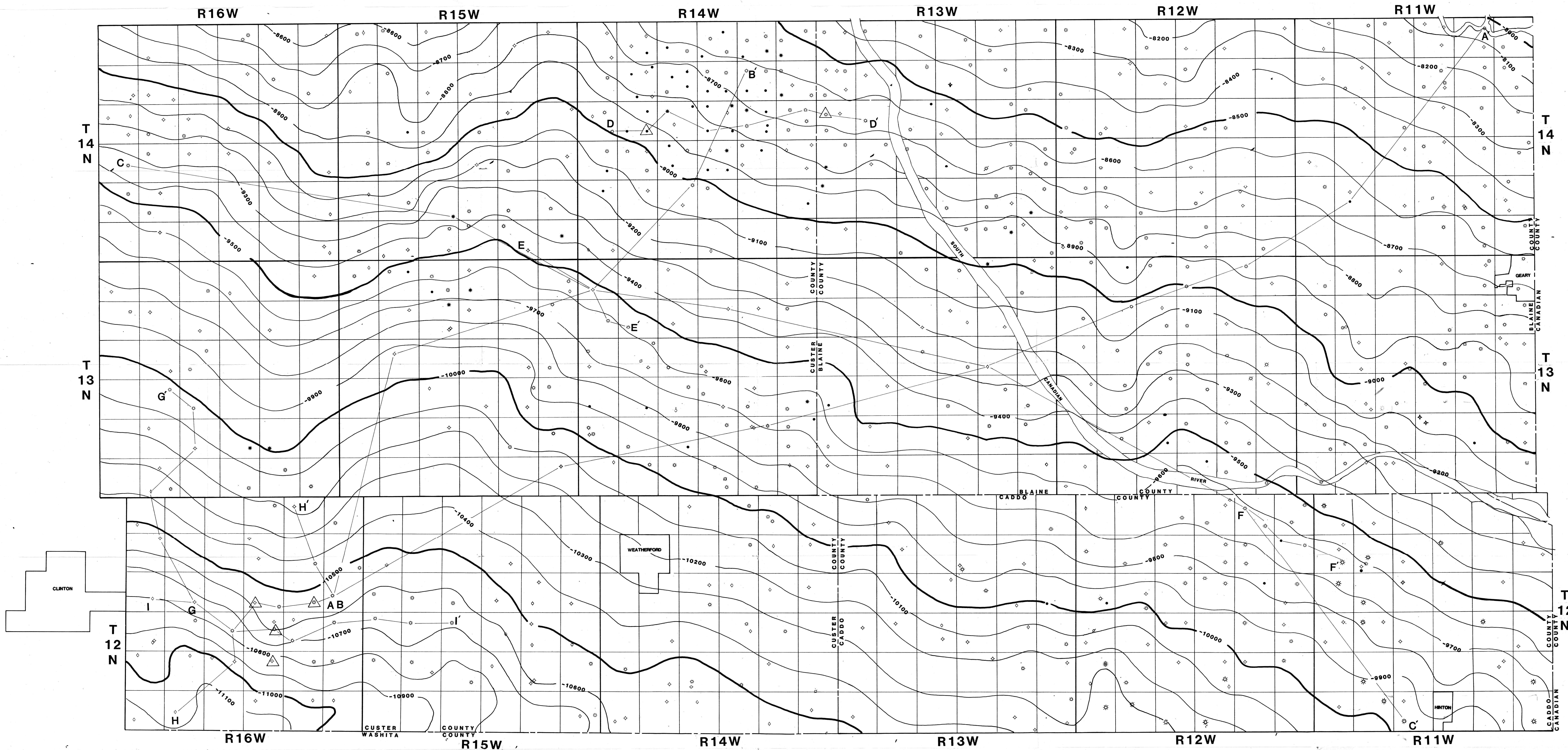
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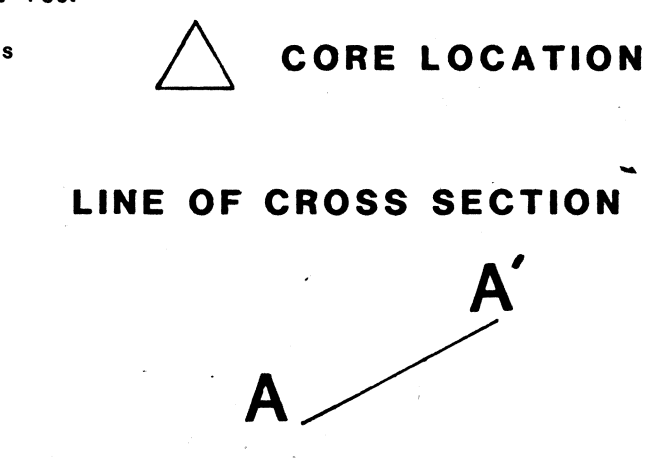
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- LEGEND
- Location
 - Dry Hole
 - Oil Well
 - ★ Abandoned Oil Well
 - ★ Gas Well
 - ★ Abandoned Gas Well



STRUCTURAL CONTOUR MAP OF THE PINK LIMESTONE

CONTOUR INTERVAL=100 FEET

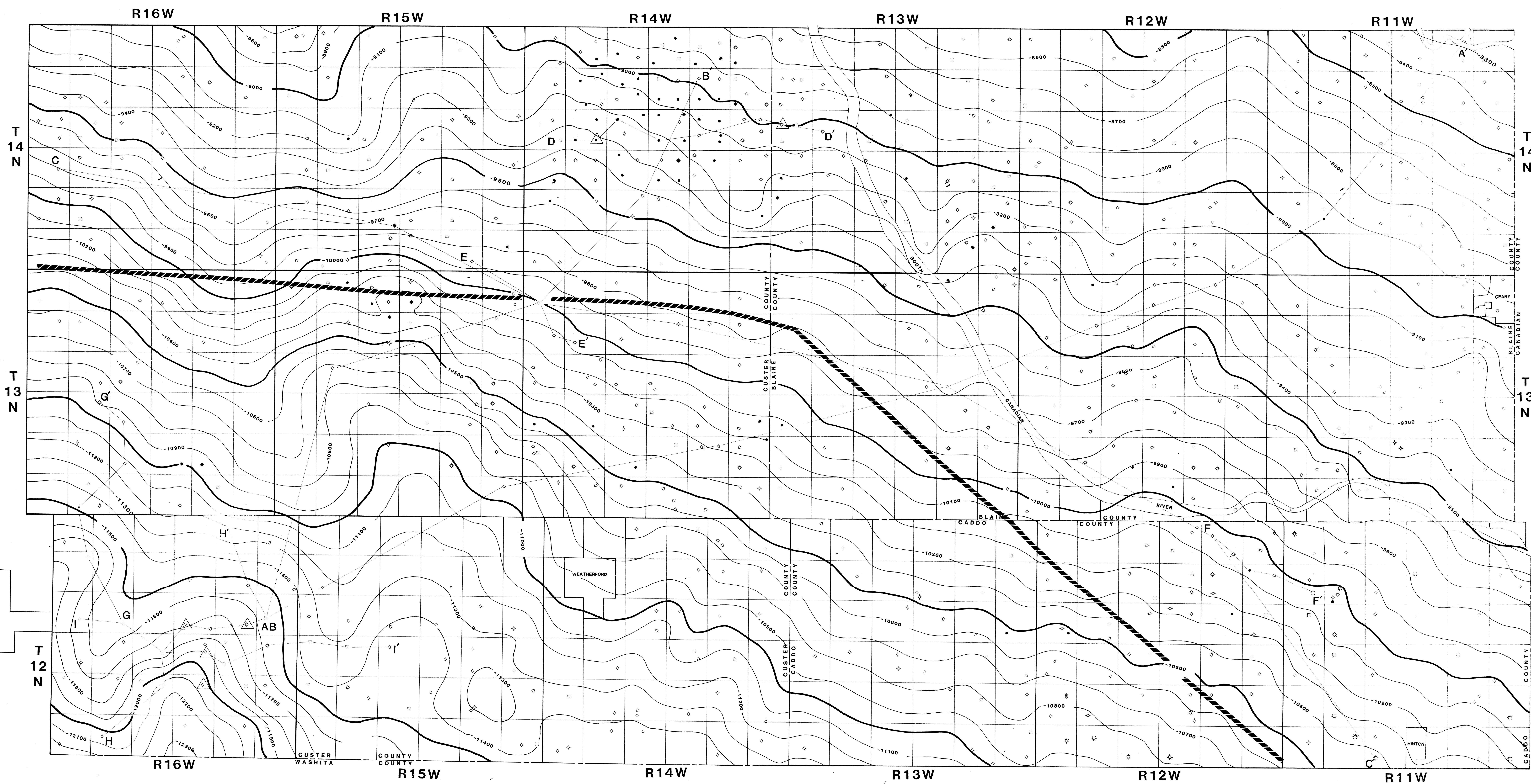
Christopher Lee Johnson

M.S. THESIS OKLAHOMA STATE UNIVERSITY
MAY 1984



PLATE I
STRUCTURAL MAP - PINK LIMESTONE

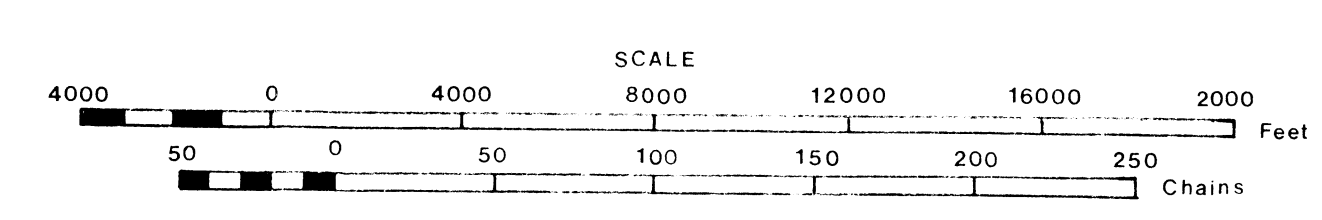
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**STRUCTURAL CONTOUR MAP
OF THE LOWERMOST
RED FORK MARKER BED
(INOLA MARKER)**

CONTOUR INTERVAL=100 FEET.

Christopher Lee Johnson
M.S. THESIS OKLAHOMA STATE UNIVERSITY
MAY 1984



- LEGEND**
- Location
 - ◇ Dry Hole
 - Oil Well
 - Abandoned Oil Well
 - ◇ Gas Well
 - Abandoned Gas Well
 - △ CORE LOCATION
 - ▬ LOWER RED FORK HINGE LINE
 - ▬ LINE OF CROSS SECTION



PLATE II
STRUCTURAL MAP-LOWERMOST RED FORK BED

A

A'

1

13-T12N-R16W
NW/4 SW/4
AN-SON CORP.
NO. 1-13 MEACHUM

2

36-T13N-R15W
E/2 NW/4
ARKLA EXPL.
NO.1-36 HAMBURGER

3

26-T13N-R14W
NE/4
AMOCO PRODUCTION CO.
NO.1 MARIAN STUTZMAN

4

14-T13N-R13W
SW/4
AN-SON CORP.
NO.1-14 BIXLER

5

8-T13N-R12W
E/2 NE/4
SANGUINE INC.
NO. 1 HALL

6

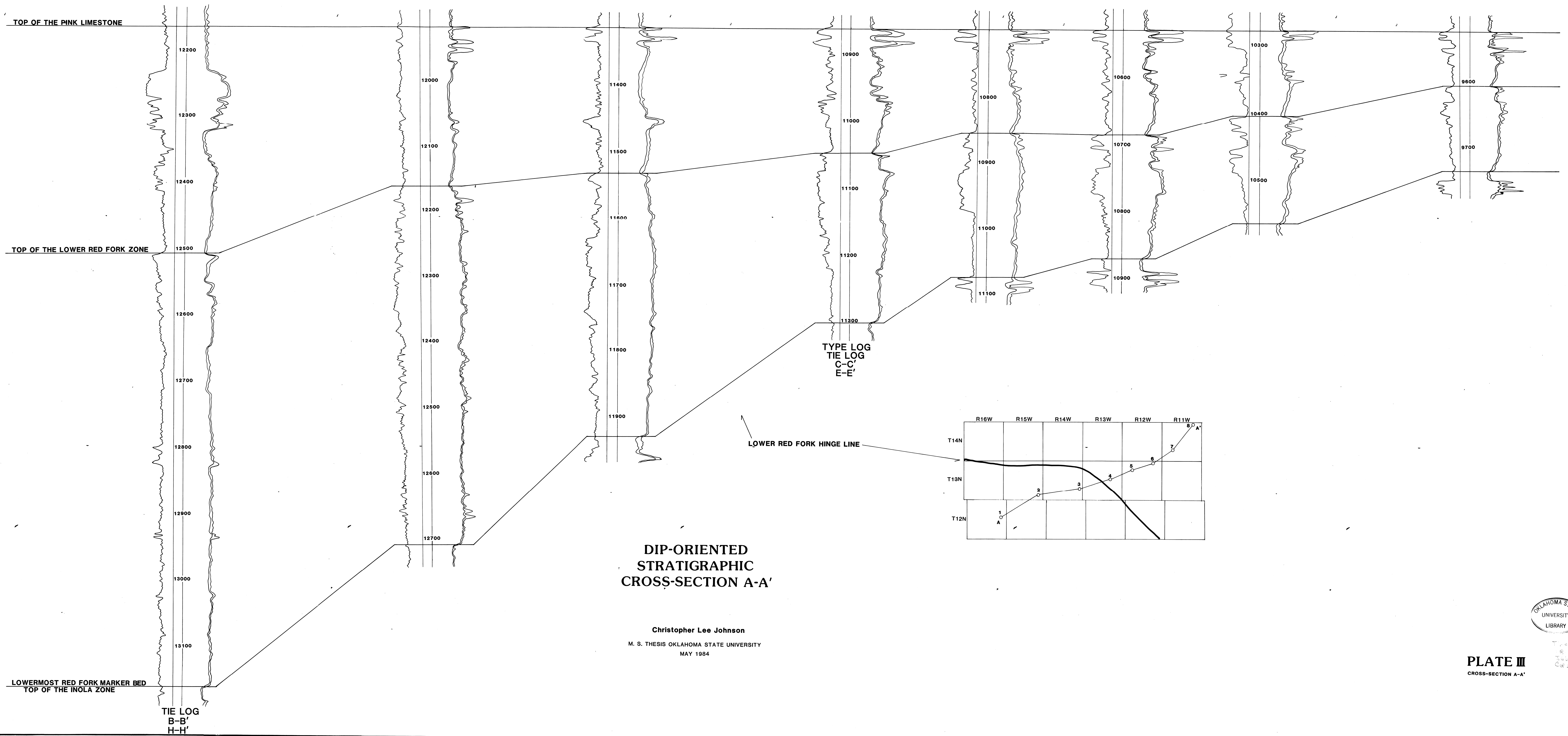
2-T13N-R12W
NE/4
COTTON PETROLEUM CORP.
NO. 1 BERG 'A'

7

29-T14N-R11W
NE/4
DAVIS OIL CO.
NO. 1 BEEN UNIT

8

2-T14N-R11W
NE/4
WESSLY EXPL. INC.
NO. 1 WHITE BREAST



DIP-ORIENTED STRATIGRAPHIC CROSS-SECTION A-A'

Christopher Lee Johnson

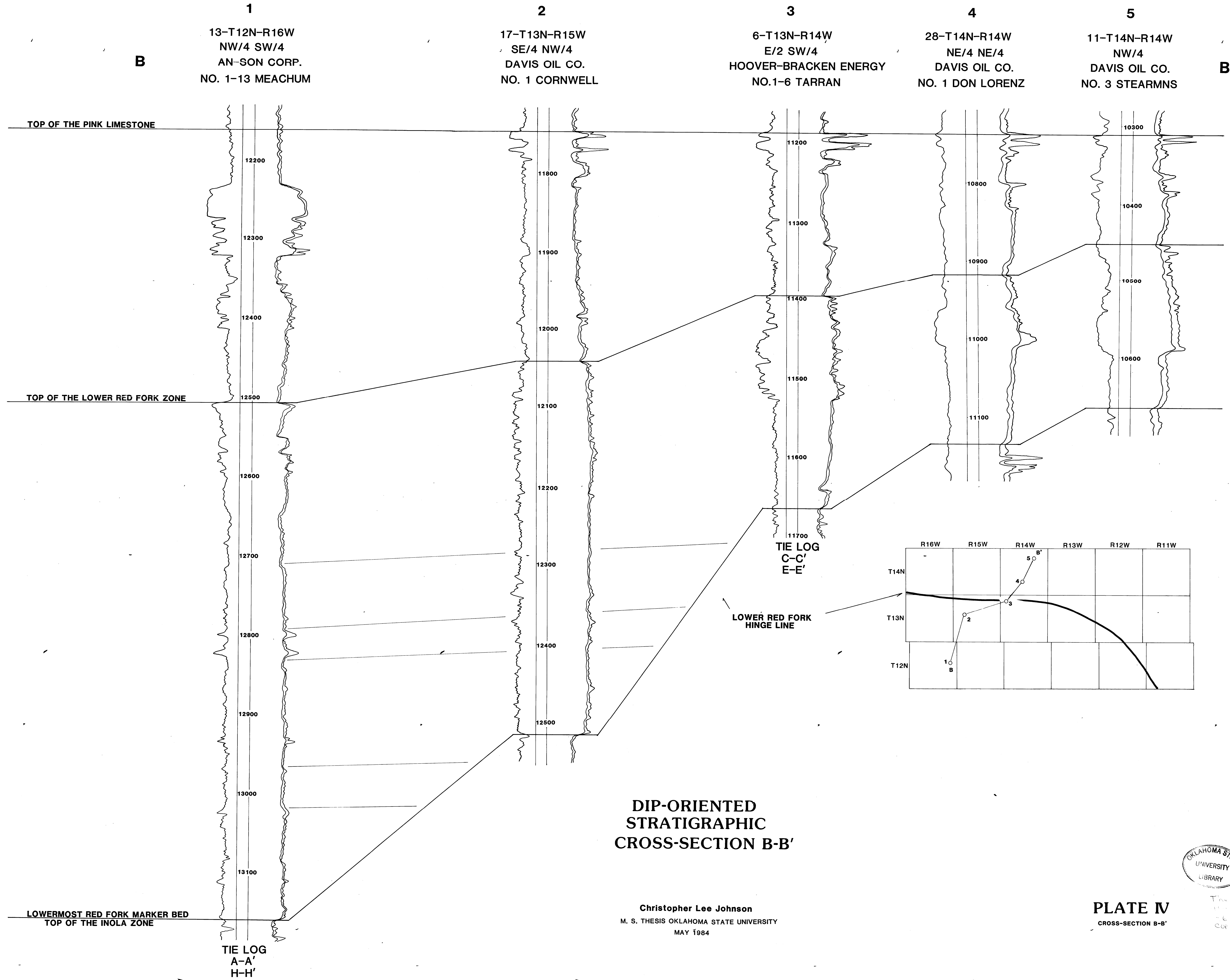
M. S. THESIS OKLAHOMA STATE UNIVERSITY
MAY 1984



PLATE III
CROSS-SECTION A-A'

B

B'



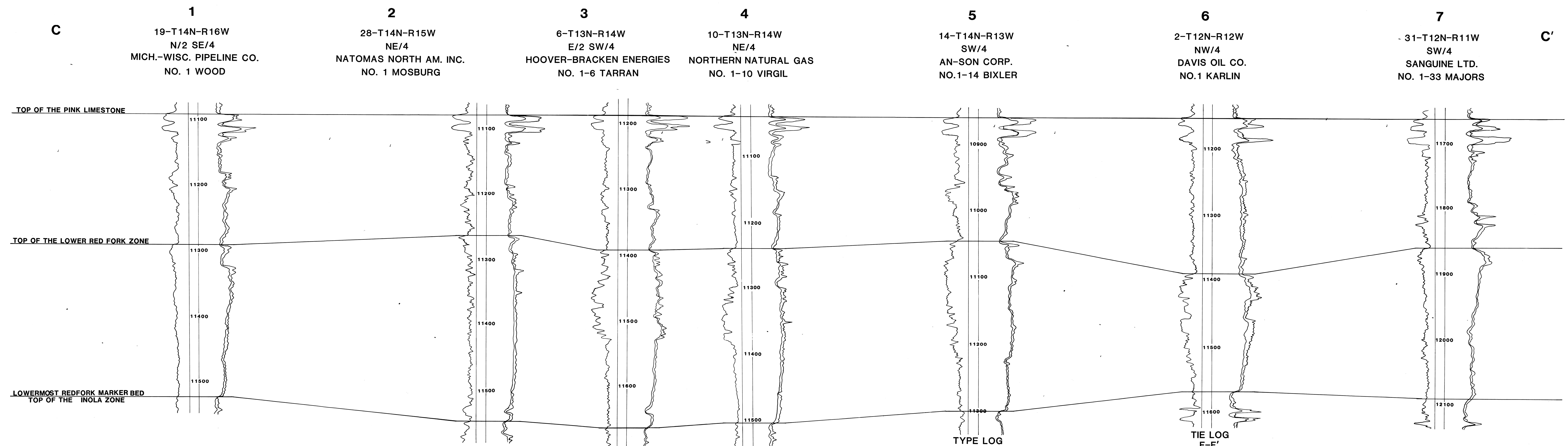
**DIP-ORIENTED
STRATIGRAPHIC
CROSS-SECTION B-B'**

Christopher Lee Johnson
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MAY 1984

PLATE IV
CROSS-SECTION B-B'

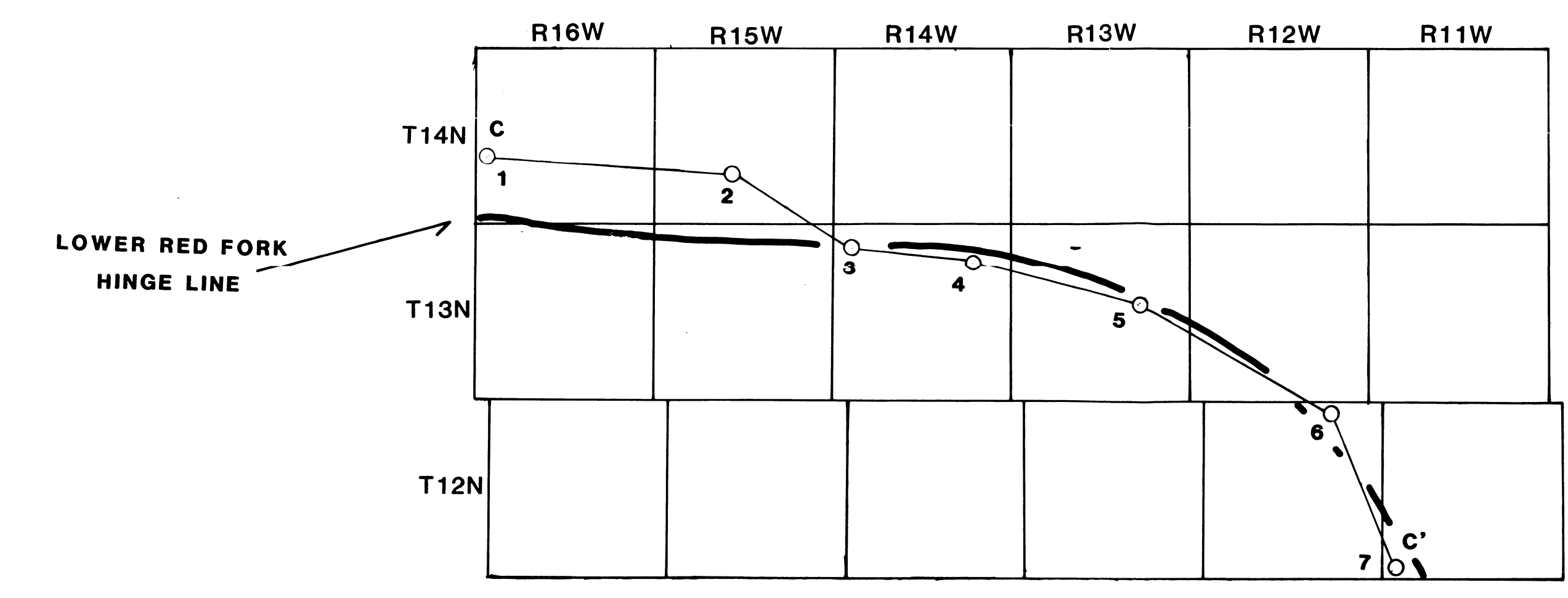


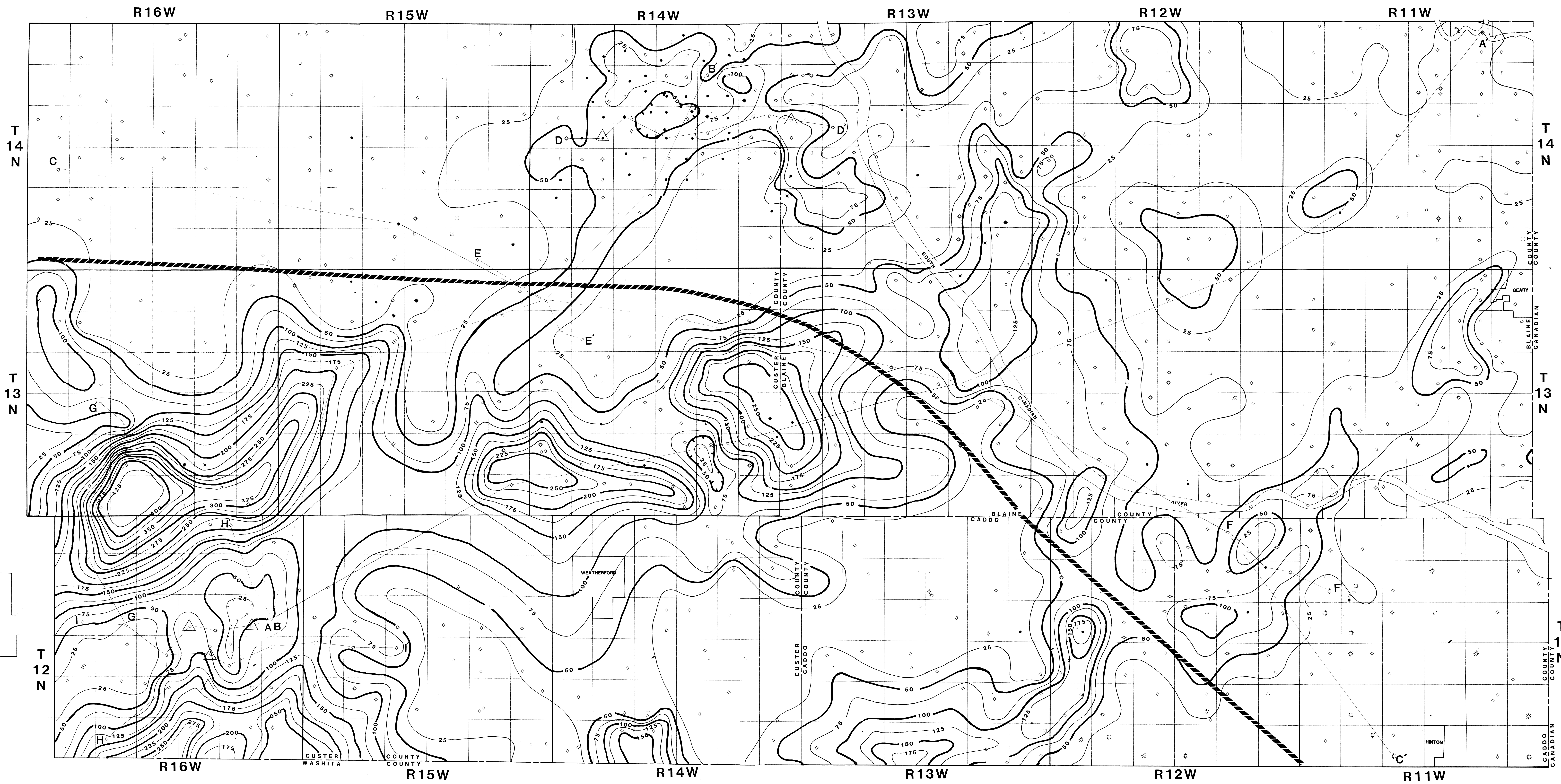
The
file
is
in
copy



**STRIKE-ORIENTED
STRATIGRAPHIC
CROSS-SECTION C-C'**

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**NET-SANDSTONE
ISOPACH MAP OF
THE LOWER RED FORK
CONTOUR INTERVAL-25 FEET
BASED ON ≥ 75 A.P.I. GAMMA RAY UNITS**

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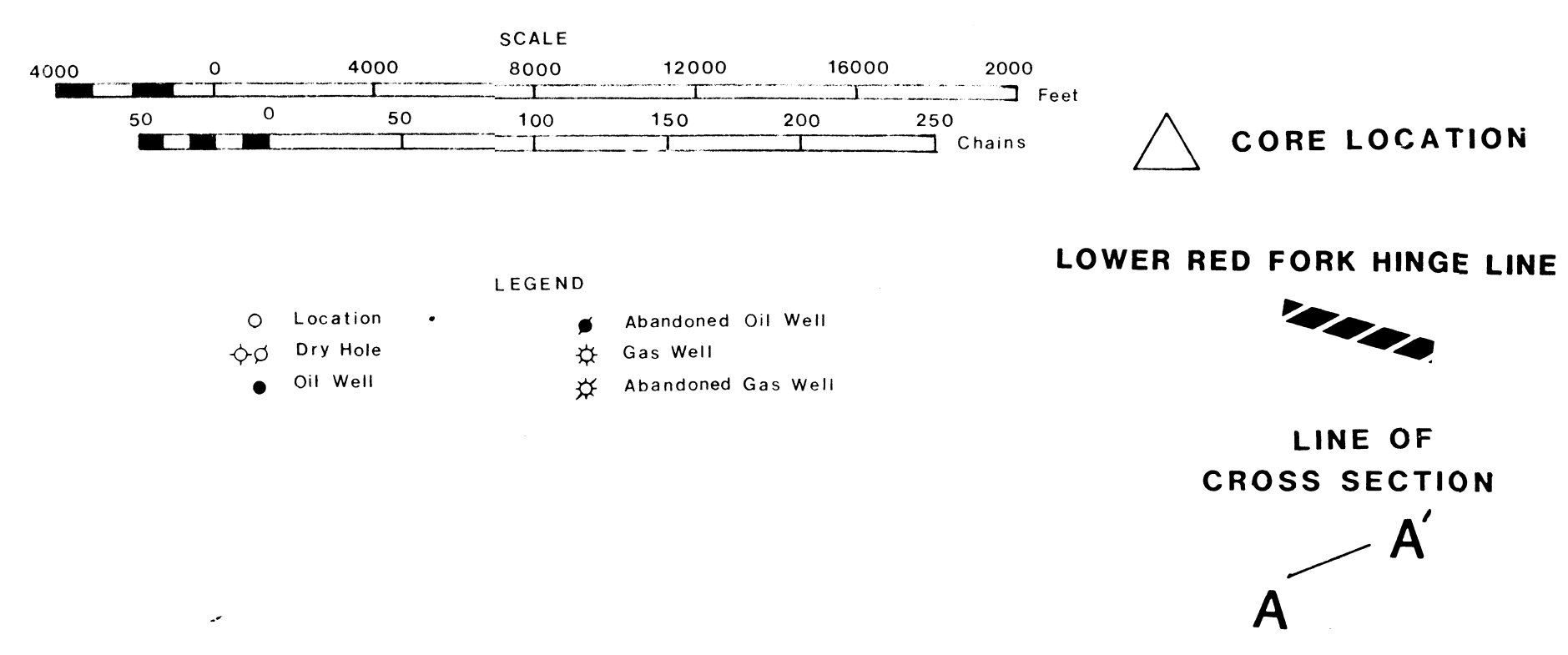
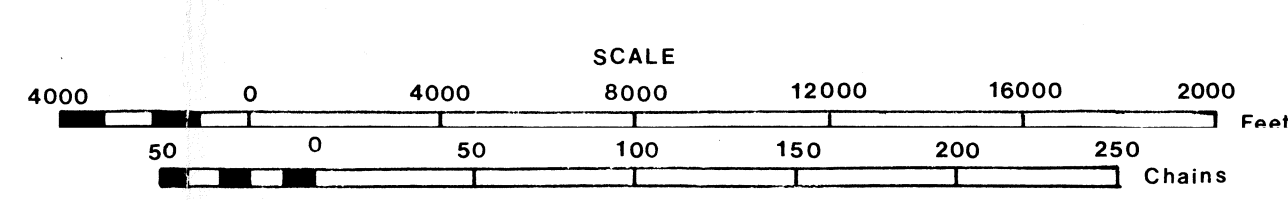
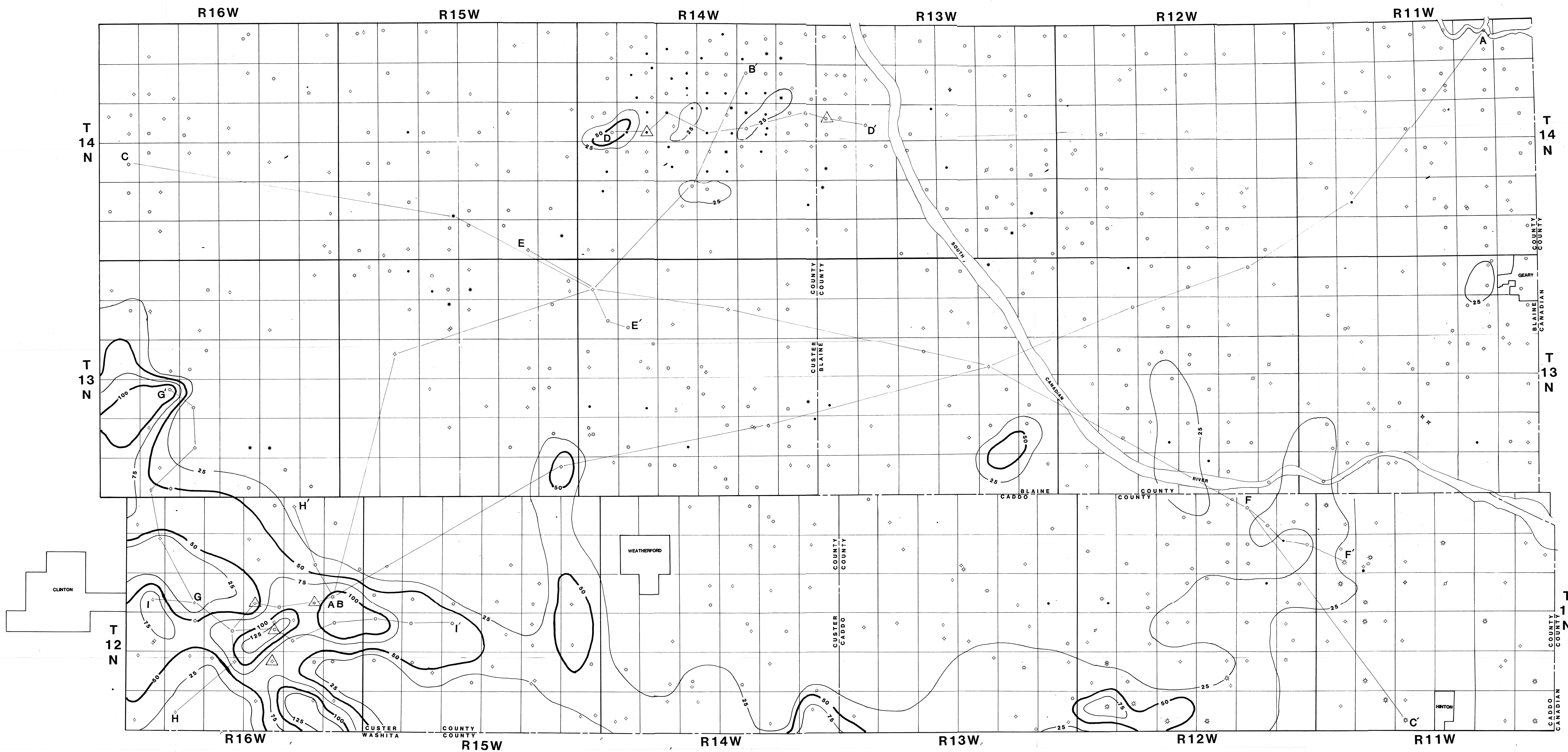


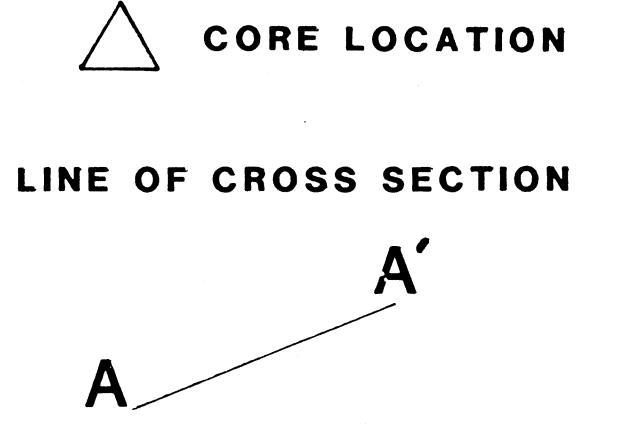
PLATE VI
 ISOPACH MAP-LOWER RED FORK



T 105
 104
 216
 Q62 2



- LEGEND**
- Location
 - ◇ Dry Hole
 - Oil Well
 - ▲ Abandoned Oil Well
 - Gas Well
 - ⊠ Abandoned Gas Well



**NET-SANDSTONE
ISOPACH MAP OF
THE UPPER RED FORK
CONTOUR INTERVAL=25 FEET**

BASED ON ≥75 A.P.I. GAMMA RAY UNITS

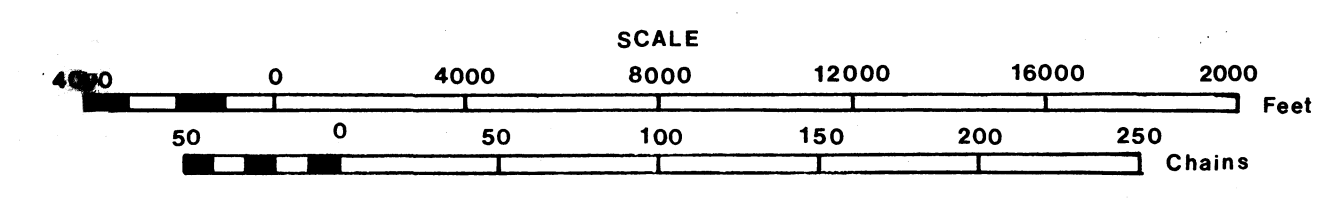
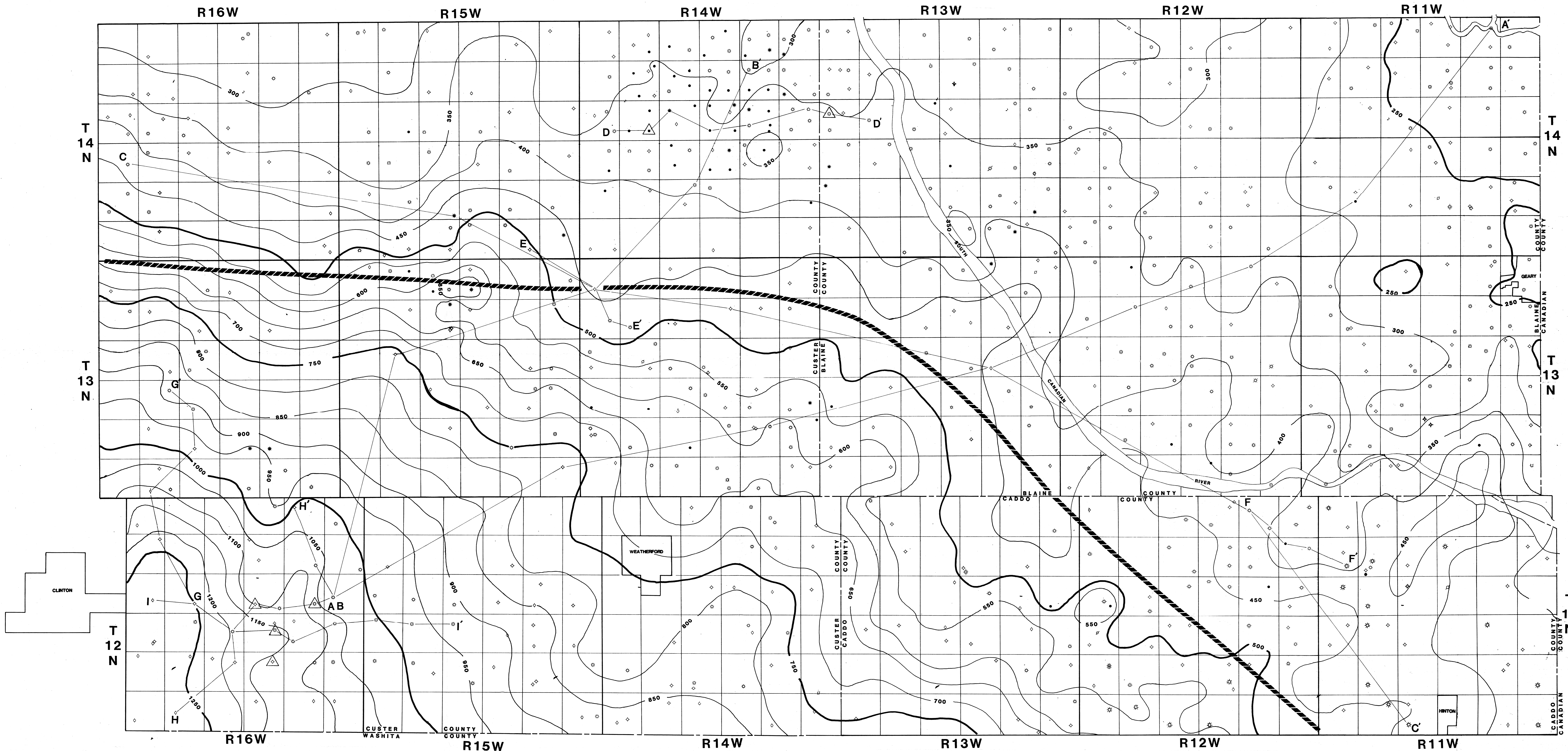
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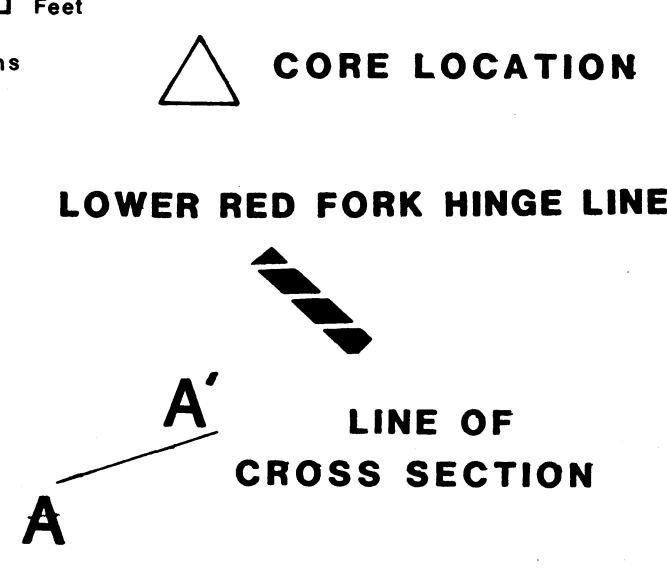


PLATE VI
ISOPACH MAP-UPPER RED FORK

Thesis
1984
366 d
COP 2



- LEGEND**
- Location
 - ◇ Dry Hole
 - Oil Well
 - ◻ Abandoned Oil Well
 - ⊙ Gas Well
 - ⊗ Abandoned Gas Well



**ISOPACH MAP
OF THE ENTIRE
RED FORK FORMAT**

TOP OF THE PINK LIMESTONE TO
THE LOWERMOST RED FORK MARKER BED

CONTOUR INTERVAL=50 FEET

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PLATE VIII
RED FORK INTERVAL ISOPACH

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