

GEOLOGIC FRAMEWORK OF EASTERN
SEQUOYAH COUNTY, OKLAHOMA

By

Jim A. Blackwood

Bachelor of Science

University of Arkansas

Fayetteville, Arkansas

1995

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1999

GEOLOGIC FRAMEWORK OF EASTERN
SEQUOYAH COUNTY, OKLAHOMA

Thesis Approved:

Gary F. Stewart

Thesis Adviser

Arthur W. Cleaves, II

Darwin L. Boardman II

Wayne B. Powell

Dean of Graduate College

ACKNOWLEDGEMENTS

The author wishes to express gratitude to Dr. Gary F. Stewart for aiding in the selection of a thesis topic, as well as providing advice, suggestions and constructive criticism. Gratitude is also expressed to the committee members, Dr. Arthur W. Cleaves II and Dr. Darwin R. Boardman for their advice and suggestions.

Appreciation is extended to Dr. Walter L. Manger, University of Arkansas, Fayetteville, Arkansas, for his suggestions, advice, and encouragement.

I would like to express thanks to Phillip R. Shelby, Consulting Geologist, Ozark, Arkansas, for his counsel regarding the geologic setting of the area.

Mr. Maurice Storm, of Barrett Resources Corporation, Tulsa, Oklahoma, provided technical support, drafting equipment and subsurface well data. He allowed me to use Barrett's resources during off hours and on weekends. I am very grateful to Mr. Storm.

Appreciation is extended to Mr. Curtis Ditzell, of Barrett Resources Corporation, for his genuine interest, and for his encouragement. Mr. Ditzell helped with structural interpretations and accompanied me on a field excursion. His advice and suggestions were very helpful.

I am very grateful to Thomas Quikla, of Hunt Oil Company, Dallas, Texas, for lending proprietary seismic data and to Larry Gerken of Masera Corporation, Tulsa, Oklahoma, who helped with the drafting of presentations.

Oxley Petroleum, Tulsa, Oklahoma, loaned copies of logs of wells drilled recently in the study area and John G. Hudson, consulting geologist, Fort Smith, Arkansas loaned copies of well logs. Jim Barber, Klabzuba Oil and Gas, Ft. Smith, Arkansas, provided

information about formation-tops in recently drilled wells. I am grateful to Oxley Petroleum, to Mr. Hudson, and to Mr. Barber.

I would like to thank my family for their endless encouragement and support throughout my academic career. I also thank my wife, Amy Lyn Blackwood. She provided support and encouragement, helped with editing and drafting, and accompanied me on many field excursions.

The scholarship provided by the Oklahoma City Geological Society helped offset some of the expenses; it was greatly appreciated.

TABLE OF CONTENTS

| Chapter | Page |
|---|------|
| I. ABSTRACT..... | 1 |
| II. INTRODUCTION..... | 2 |
| Objectives..... | 2 |
| Location of Study Area..... | 2 |
| Methods of Investigation..... | 4 |
| Geologic Setting..... | 4 |
| History of Previous Investigations..... | 8 |
| III. STRATIGRAPHY..... | 12 |
| Introduction..... | 12 |
| Upper Part, Mississippian System..... | 12 |
| Chesterian Series..... | 12 |
| Hindsville Limestone..... | 15 |
| Fayetteville Shale..... | 15 |
| Pitkin Formation..... | 16 |
| Pennsylvanian System..... | 16 |
| Morrowan Series..... | 16 |
| Hale Formation..... | 17 |
| Cane Hill Member..... | 18 |
| Prarie Grove Member..... | 18 |
| Bloyd Formation..... | 19 |
| Brentwood Member..... | 19 |
| Kessler Member..... | 20 |
| Atoka Formation..... | 20 |
| Middle Atoka..... | 22 |
| Lower Atoka..... | 23 |
| IV. STRUCURAL GEOLOGY..... | 24 |
| Regional Tectonic History..... | 24 |
| Local Structure..... | 26 |
| Methods of Investigation..... | 26 |

| | |
|--|--------|
| Faults | 32 |
| Mulberry Fault..... | 32 |
| Camp Creek Fault..... | 33 |
| Akins Fault..... | 33 |
| Greasy Creek Fault..... | 36 |
| Pine Mountain Fault..... | 36 |
| Folds and Flexures..... | 39 |
| Liberty Anticline..... | 39 |
| Little Skin Syncline..... | 39 |
| Long Anticline..... | 41 |
| Gans Anticline..... | 41 |
| Cowlington Syncline..... | 41 |
| Milton Anticline..... | 43 |
| General Conclusions..... | 43 |
| V. PETROLEUM GEOLOGY..... | 44 |
| Introduction..... | 44 |
| Trapping Mechanisms..... | 44 |
| Natural Gas Reservoirs..... | 44 |
| Cromwell Sandstone..... | 46 |
| Spiro Sandstone..... | 46 |
| Gas Fields..... | 49 |
| Redland Field..... | 49 |
| Peno Field..... | 49 |
| Greasy Creek Field..... | 52 |
| Gans Field..... | 53 |
| Sallisaw Southeast Field..... | 53 |
| Greenwood Junction Field..... | 53 |
| Roland Northwest Field..... | 54 |
| Opportunities for development of Gas Fields..... | 54 |
| VI. DISCOVERIES AND CONCLUSIONS..... | 55 |
| SELECTED REFERENCES..... | 58 |

LIST OF TABLES

| Table | Page |
|---------------------------------------|------|
| I. Fault Interpretation Criteria..... | 31 |

LIST OF FIGURES

| FIGURE | PAGE |
|---|------|
| 1. Location map of study area..... | 3 |
| 2. Geologic Provinces of Arkansas and eastern Oklahoma..... | 5 |
| 3. Regional map of Arkoma Basin, showing structural divisions..... | 7 |
| 4. Regional map of Arkoma Basin, showing main areas where gas is produced..... | 9 |
| 5. Index to surface mapping in the study area..... | 10 |
| 6. Comparative stratigraphic sequences, Ouachita, Arkoma and and Ozark provinces..... | 13 |
| 7. Type log of local stratigraphic section..... | 14 |
| 8. Informal subdivisions of Atoka Formation in Arkoma Basin, Arkansas..... | 21 |
| 9. Burrows in Atoka Formation..... | 23 |
| 10. Tectono-stratigraphic evolution of the southern edge of the North American craton..... | 25 |
| 11. Tectonic Map of Eastern Oklahoma displaying structural styles..... | 27 |
| 12. Diagrammatic cross-section showing typical growth fault..... | 28 |
| 13. Digital Elevation Model of study area..... | 30 |
| 14. Drag on Mulberry Fault..... | 34 |
| 15. Drag on Camp Creek Fault..... | 35 |
| 16. Deformed strata on Camp Creek Fault..... | 35 |

| | |
|--|----|
| 17. Dipping Strata on down-thrown block of Greasy Creek Fault..... | 39 |
| 18. Dipping Strata on upthrown block of Greasy Creek Fault..... | 38 |
| 19. Drag on Pine Mountain Fault..... | 40 |
| 20. Sandstone Dike..... | 40 |
| 21. Dipping Strata on Little Skin Syncline..... | 42 |
| 22. Sequoyah County Gas Fields..... | 45 |
| 23. Early Morrowan Paleogeography..... | 47 |
| 24. Typical Cromwell log responses..... | 48 |
| 25. Earliest Atokan Paleogeography..... | 50 |
| 26. Typical Spiro log responses..... | 51 |

LIST OF PLATES

Plate

| | |
|--|-----------|
| I. Structural Geology of the Surface..... | In Pocket |
| II. Structural Contour Map on top of Morrow..... | In Pocket |
| III. Stratigraphic Cross - Section A - A'..... | In Pocket |
| IV. Stratigraphic Cross - Section B - B'..... | In Pocket |
| V. Isolith of Cromwell Sandstone..... | In Pocket |
| VI. Base Map..... | In Pocket |

CHAPTER I

ABSTRACT

In eastern Sequoyah County, Oklahoma, natural gas is produced from structural traps developed on anticlines and fault blocks. The structural geology of the surface can be projected into the subsurface and initial estimates of the subsurface orientation of structures can be mapped. Areal surface geologic maps and subsurface structural contour maps were employed in an attempt to delineate these structures.

Gas is produced from several zones in this area. The Cromwell Sandstone (Morrowan) is the most productive reservoir. The Spiro Sandstone (basal Atokan) is also a significant reservoir in this area. Stratigraphic cross-sections, an isolith map of the Cromwell Sandstone, and analysis of typical log responses of these reservoirs were employed in an effort to better understand the facies preserved in this rock unit. Typically gas fields are developed where reservoirs are distributed on anticlines and upthrown fault blocks.

CHAPTER II

INTRODUCTION

Objectives

The primary objectives of this study were (1) to construct structural geologic maps of selected strata of the surface and of selected strata in the subsurface of the area (Plates I and II), (2) to relate the structural geology of rocks exposed at the surface to that of rocks in the subsurface, (3) to document better the thickness and extent of sedimentary rocks of the Morrowan Series and of the lower part of the Atokan Series, (4) to map the geometry and distribution of the Cromwell Sandstone (Plates III, IV and V), and (5) to provide other geologic data as well as the author's interpretations of these data relevant to the accumulation and production of natural gas.

Location of the Study Area

The area of investigation of this report is in the extreme eastern part of Oklahoma. This area is on the northern shelf of the Arkoma Basin and it includes part of the southern flanks of the Ozark Uplift. It consists primarily of the eastern half of Sequoyah County, Oklahoma (Figure 1). Included are approximately 179 square miles, in T.11N., R.25E., T.11N., R.26E., T.11N., R.27E., T.12N., R.25E., T.12N., R.26E. and T.12N., R.27E. Parts of townships adjacent to these were also studied, in order to understand better the primary area of interest.

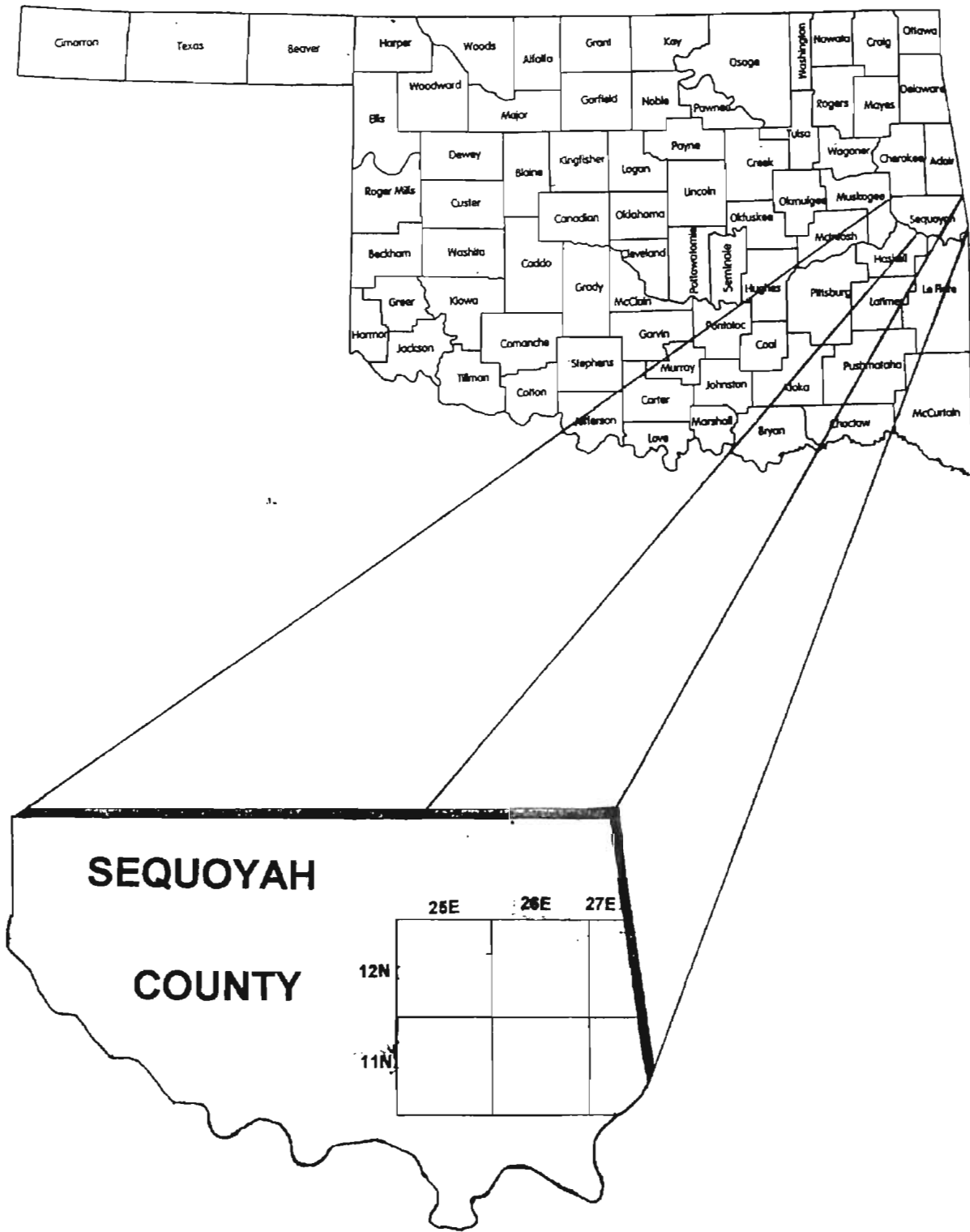


Figure 1. Location Map of Study Area

Methods of Investigation

The subsurface stratigraphy and structural geology were interpreted from maps and cross-sections. These documents were compiled from electric logs, gamma-ray logs, neutron-density logs, completion tickets, scout tickets, proprietary seismic data and areal geologic maps.

Areal structural features were interpreted with the aid of topographic maps, aerial photographs, soil surveys and existing geologic maps. Structural features mapped at the surface were projected into the subsurface.

Geologic Setting

The area of interest is on the northern margin of the Arkoma Basin (Figure 2). The Arkoma Basin is in eastern-southeastern Oklahoma and west-central Arkansas. This arcuate basin extends for approximately 250 miles in an east to west direction and ranges from approximately 20 miles wide to approximately 50 miles wide. The basin is bounded on the north by flanks of the Ozark Uplift and on the northwest it grades onto the Northeast Oklahoma Platform (Figure 2). The basin is bounded on the south by the Ouachita overthrust belt, the northern limit of which is delineated by the Choctaw Fault in Oklahoma and the Ross Creek Fault in Arkansas (Figure 2). The basin plunges beneath strata of the Cenozoic Coastal Plain in central Arkansas (Figure 2). On the southwest, the basin terminates abruptly against the Arbuckle Mountains of southern Oklahoma (Figure 2). At the present time, the Arkoma Basin is a collisional orogen that has been uplifted then complicated by local faulting and folding.

Strata of the Arkoma Basin and the Ouachita fold belt document the history of

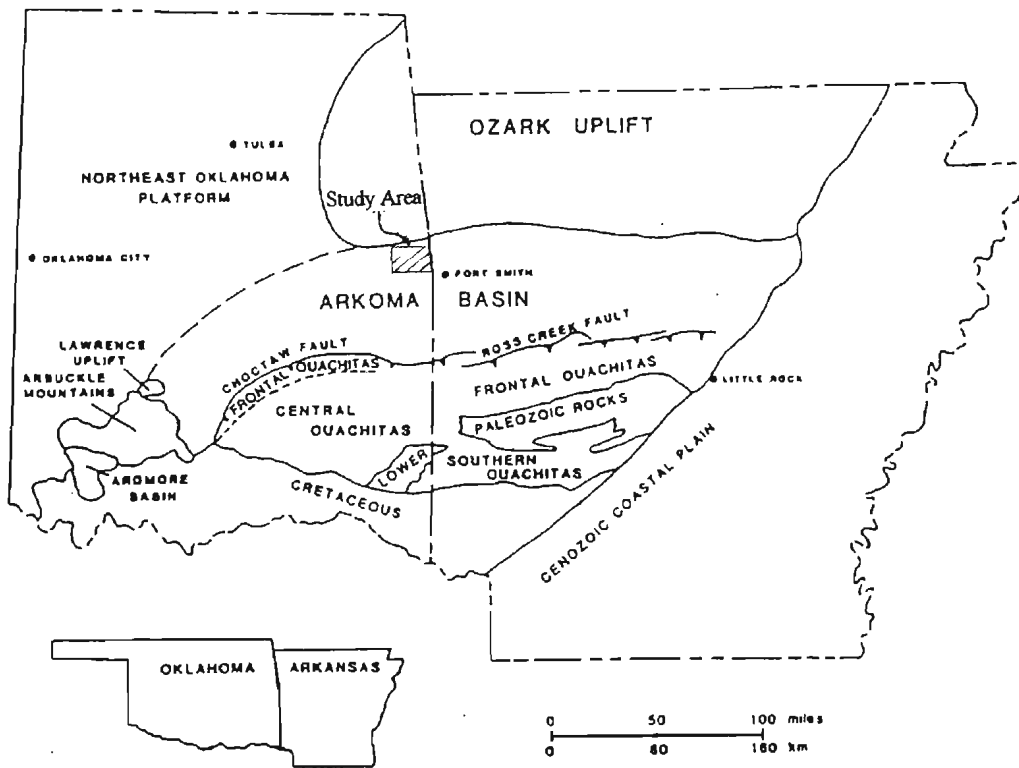


Figure 2. Geologic Provinces of Arkansas and eastern Oklahoma, and location of study area. (after Sutherland, 1988a, p. 1788)

gradual collapse and closure of the Ouachita trough and development of a foreland basin, as a result of the continental collision of the Afro-South American Plate (Gondwana) and the North American Plate (Sutherland, 1988a, p. 1787; Meckel, Smith, and Wells, 1992, p. 427). Sedimentary rocks are thinnest on the northern margin of the basin, on the ancient continental shelf. Here the sedimentary section is approximately 3000 feet thick (Branan, 1968, p. 1619). Sedimentary rocks are thickest along the southern margin of the basin, adjacent to the Ouachita overthrust belt. Here the Paleozoic sedimentary section may be thicker than 30,000 feet as a result of rapid deposition during basin subsidence, and repetition of strata by thrust faulting (Wylie, 1988, p.63).

The basin is divisible into three distinct structural units: (1) a shallow shelf where geologic structures principally are normal faults, (2) an intermediate shelf, characterized by normal faults and growth faults, and (3) a deep part of the basin characterized by growth faults and reverse faults (Haines, 1981, p. 42) (Figure 3). In each of these provinces, anticlinal and synclinal folds are associated genetically with faults.

Rocks in the Arkoma Basin primarily are of Atokan age. Most subsidence took place during the Atokan Epoch, and more than half of the sedimentary section was deposited during the Atokan (Haines, 1981, p. 47).

Sedimentary rocks of Morrowan and Atokan age, preserved within the basin, were derived primarily from the northeast and north by way of the Illinois Basin and the Ozark Dome. An additional secondary source possibly was from the Nemaha Uplift to the northwest (Sutherland, 1988a, p. 1800). The strata predominantly are shale, interbedded with sandstones and carbonates. Sedimentation was accompanied by rapid subsidence, which is manifest in a series of east trending normal (growth) faults.

Natural gas was first discovered in the basin in 1902 at Mansfield, in Sebastian County, Arkansas (Branan, 1968, p. 1619). Since that time the basin has developed into a major gas-producing province (Figure 4).. Gas has been recovered in profitable

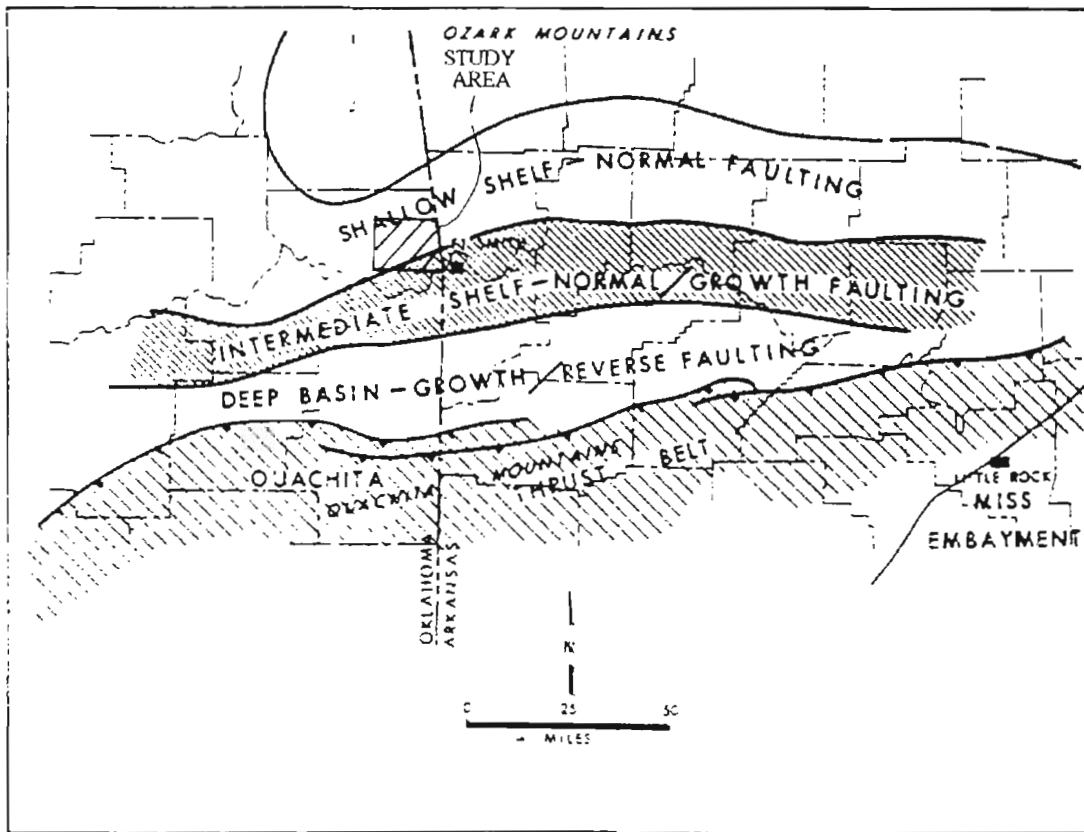


Figure 3. Regional map of Arkoma Basin showing structural divisions of the basin (modified from Haines, 1981, p. 44)

quantities from rocks ranging in age from Ordovician through Desmoinesian (Haines, 1981, p. 42). The basin primarily is a dry-gas province with no significant quantities of associated liquids. In the Morrowan and lower Atokan rocks natural-gas entrapment is primarily structurally controlled with a definite closed fold or fault block being required to trap gas. In rocks of the middle and upper Atokan Series, entrapment is stratigraphically controlled at some localities.

History of Previous Investigations

Several published reports and maps document parts of the area of interest. These and reports about adjacent areas contributed greatly to the study. Figure 5 illustrates the coverage of mapping in and around the study area.

Taff (1905, Areal Geology of the Tahlequah Quadrangle) originally mapped the area in the northern part of the present study area, in his report on geology of the Tahlequah Quadrangle. Taff documented the Salt Hollow anticline in Section 13, T.13N., R.25E., to the northeast of the present study area, but he recognized neither the existence of a fault through this anticline nor evidence of the southeastward extension of this anticline into the present area of investigation. Taff also mapped the Akins Fault in the northern part of T.12N., R.25E., (Plate I), but did not recognize the extent of this fault to the northeast. Evidence of smaller structures within the area of this report seem either to have escaped Taff's detection, or he elected to not record them.

Purdue (1907, Areal Geology of the Winslow Quadrangle) mapped the areal geology of rocks included within the northeastern part of this report -- in the northern half of T.12N., R.27E., (Plate I) -- in his report on the geology of the Winslow Quadrangle. All

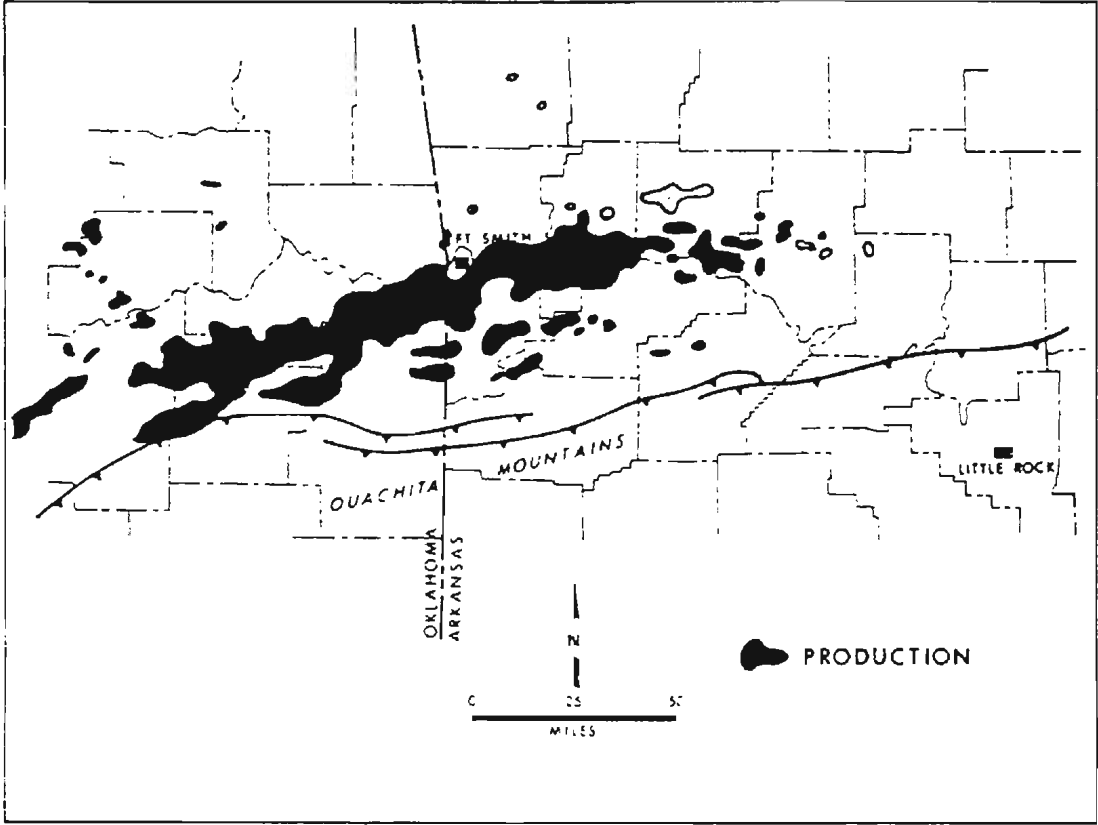


Figure 4. Regional map of Arkoma Basin showing main areas where gas is produced (after Haines, 1981, p. 44).

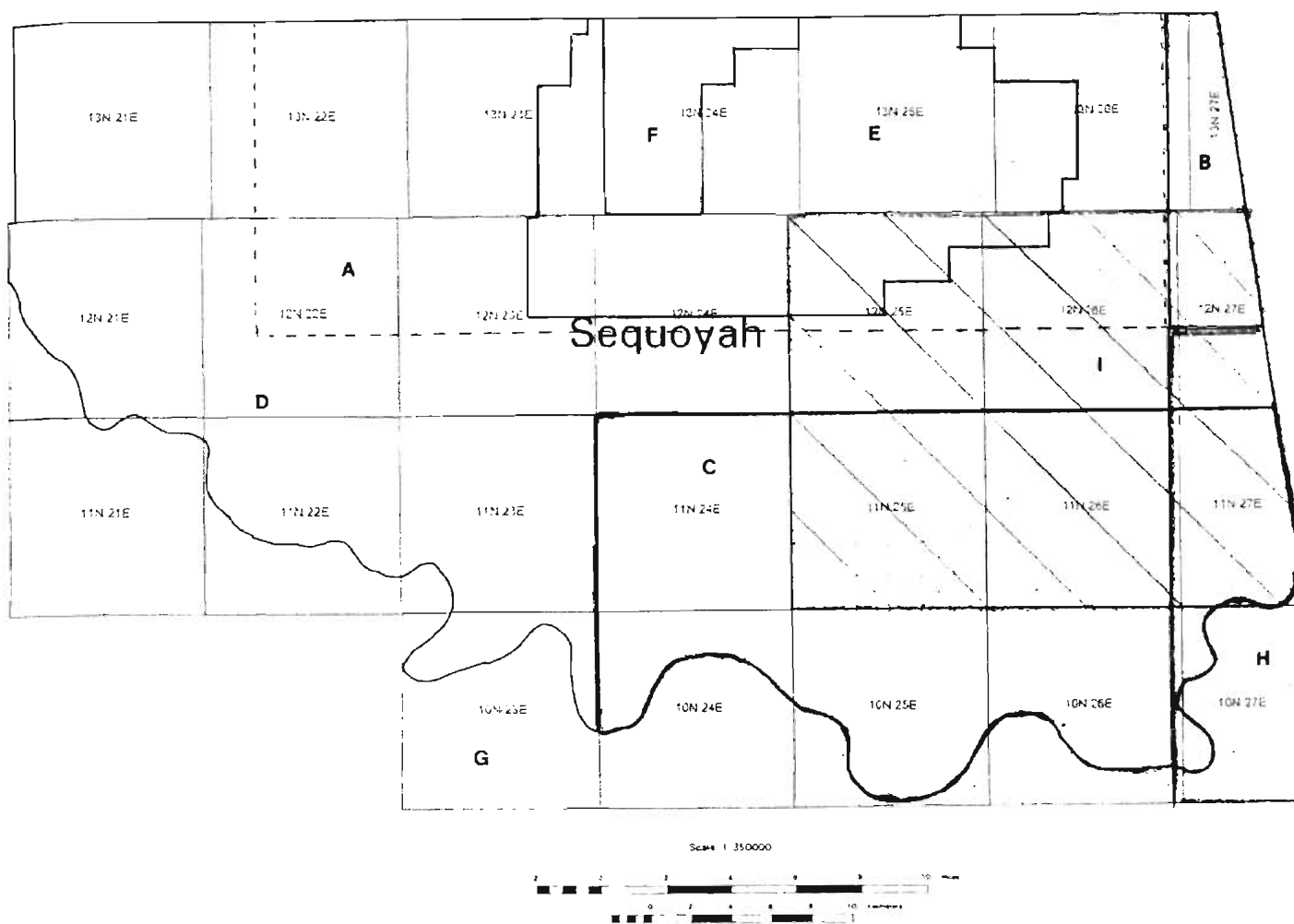


Figure 5. INDEX TO SURFACE MAPPING IN THE STUDY AREA

- A. Taff, J.A., 1905, Tahlequah Folio, Indian Territory-Arkansas: United States Geological Survey, Geologic Atlas of the United States, Folio 122. 7p. (areal geologic map, scale 1:125,000)
- B. Purdue, A.H., 1907, Winslow Folio, Arkansas-Indian Territory: United States Geological Survey, Geologic Atlas of the United States, Folio 154. 6p. (areal geologic map, scale 1:125,000)
- C. Crumpley, B.K., 1949, A field reconnaissance of the geology of southeastern Sequoyah County, Oklahoma: Unpublished Master of Science Thesis, Oklahoma University, 34p. (Plate 1, scale 1:42,240).
- D. Miser, H. D., 1954, Geologic units of Sequoyah County: Oklahoma Department of Highways (Covers entire study area)
- E. White, J.M., Jr., 1955, The Brushy Mountain structure, Sequoyah and Adair Counties, Oklahoma: Shale Shaker, v. 7. p. 5-24 (geologic map, scale 1:84,480). Also in Shale Shaker Digest. v. 2, p. 196-197, and Master of Science Thesis, Oklahoma University (1955).
- F. Huffman, G.G, and others, 1958, Geology of the flanks of the Ozark Uplift, northeastern Oklahoma: Oklahoma Geological Survey Bulletin 77, 281p. Stillwell area, Adair and Sequoyah Counties: Plate 5, scale (1:42,240).
- G. Marcher, M. V., 1969, Reconnaissance of the water resources of the Fort Smith Quadrangle, east-central Oklahoma: Oklahoma Geological Survey, Map HA-1, Fort Smith Quadrangle (Map 1, scale 1:250,000). (Covers entire study area)
- H. Haley, B. R., and Hendricks, T. A., 1971, Geology of the Van Buren and Lavaca Quadrangles, Arkansas and Oklahoma: U.S.G.S. Professional Paper 536-A, p. A1-A15 (Plate 1, scale 1:48,000)
- I. Area covered in this report.

strata was mapped as the Atoka Formation and no faults or folds were recognized.

Crumpley (1949, Areal Geologic Map of part of Sequoyah County) mapped the areal geology of the southern half of the present study area. He documented the major structures south of the Mulberry Fault. Crumpley also recognized numerous small faults and flexures north of the Mulberry Fault. These structures were too small to warrant representation on his map and were beyond the main focus of his report.

White (1955, Geologic Map of the Brushy Mountain Structure) mapped the areal geology of the northwestern part of the present study area. He recognized the extent of the Greasy Creek Fault from the northwest through the Salt Hollow Anticline, previously mapped by Taff. However, he did not find evidence to support the southeast extension of this fault into the area of this report. White extended the Akins Fault northeastward to intersect the Greasy Creek Fault (Plate I).

Huffman and others (1958) mapped the area to the north and northwest of the present study area. This report was very helpful with the understanding of stratigraphic nomenclature as well as with knowledge of the regional geologic setting of the area.

Haley (1972, Plate 1) mapped the areal geology of the southeastern part of the study area. His work included the southern half of T.12N., R.27E., and all of T.11N., R.27E.

Jefferies' (1982) thesis, "The Stratigraphy and Depositional Patterns of the Union Valley, Wapanucka and Lower Atoka Formations," provided helpful information regarding the stratigraphy of these rock-stratigraphic units.

Abolla's (1995) "Geometry and Depositional Systems of the Cromwell Sandstone..." included much of the southern portion of the study area; it was helpful in the understanding of the depositional environment of the Cromwell Sandstone.

CHAPTER III

STRATIGRAPHY

Introduction

Rocks that range in age from early Atokan through Desmoinesian are exposed in the study area. Quaternary alluvium covers a small portion of the area along the Arkansas River floodplain. Wells have penetrated rocks ranging from Desmoinesian through lower Ordovician.

In this study emphasis was placed primarily on rocks of the Morrowan Series and the lower part of the Atokan Series. However some older formations were identified and correlated in the cross-sections (Plates III and IV). Nomenclature from both Arkansas and Oklahoma is used to refer to the same rocks -- a practical matter of necessity. (See Figure 6.) An attempt was made to consistently use nomenclature that is common in description of the geology of northwestern Arkansas. This nomenclature concerns rock-stratigraphic units that are more easily correlated with outcrops in the region to the north of the study area. However, nomenclature of subsurface strata of the Arkoma Basin is used in numerous instances -- also a matter of practical necessity. (See Figure 7.)

Upper Part, Mississippian System

Chesterian Series

The Chesterian Series consists of the Hindsville Limestone, the Fayetteville Shale, and the Pitkin Limestone (Figure 7). Huffman (1951, p. 118) recognized that these strata

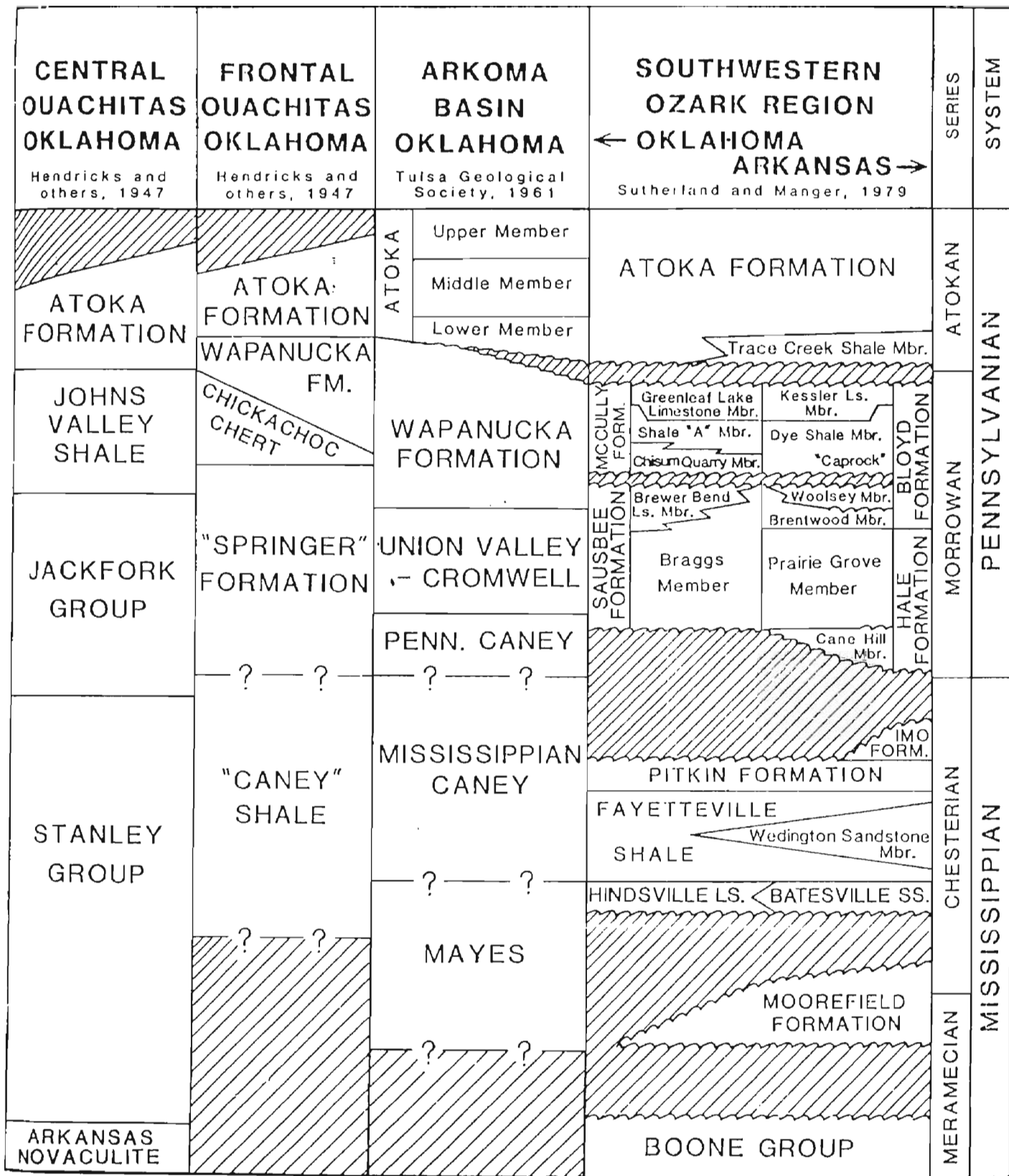


Figure 6. Comparative stratigraphic sequences, Ouachita, Arkoma and Ozark provinces. (From Sutherland, 1988a, p. 1791.)

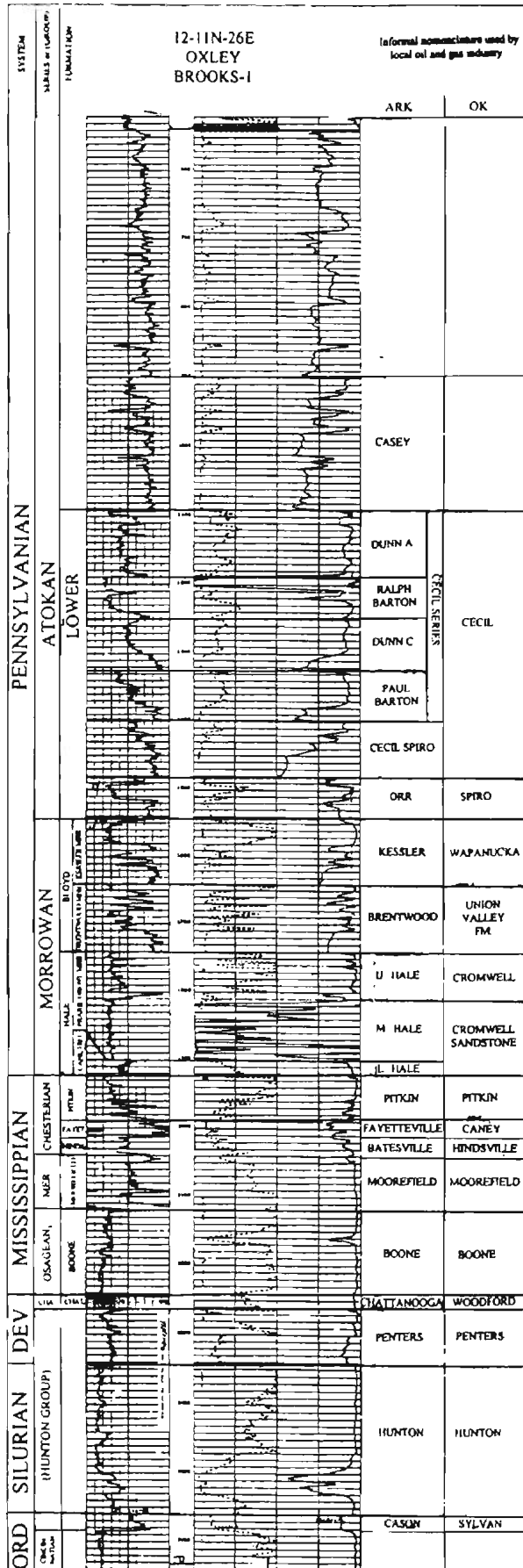


Figure 7.
Type log of local
stratigraphic section

compose a conformable sequence of beds characterized by Chesterian fauna. The Chesterian is bounded by unconformities (Figure 6).

Hindsville Limestone

The Hindsville Limestone unconformably overlies the Moorefield Formation and is overlain by the Fayetteville Shale (Figure 7). It ranges from 2 to 34 feet thick, in the study area. It is thinnest in the northeastern part of the study area. The Hindsville is dark gray crinoidal limestone (White, 1955, p. 10). It is recognizable on wireline logs by a characteristic spiky, low gamma - ray curve and as the first developed limestone below the Fayetteville Shale (Figure 7). The Hindsville was named by Purdue and Miser (1916) for exposures near the town of Hindsville, Arkansas.

In the Arkoma Basin of Oklahoma, the Hindsville Limestone and the Moorefield Formation are mapped in combination as the Mayes formation, an informal rock stratigraphic unit (Figure 6).

Fayetteville Shale

The Fayetteville Shale overlies the Hindsville Limestone and is overlain by the Pitkin Limestone (Figure 7). It ranges from 8 to 50 feet thick and is thickest in the northeastern part of the study area. The Fayetteville is dark gray to blackish gray shale. On wireline logs, it is recognized easily by a characteristic low resistivity and high gamma-ray curves; thus it is a reliable marker in the subsurface. Near the top of the Fayetteville Shale is a set of sandy strata, generally less than 10 feet thick in the study area. These beds probably could be correlated with the Wedington Sandstone Member of northern Arkansas (Figure 6). The Wedington Member commonly is shown as a "spike" on

gamma ray and resistivity logs. However, in some places it is absent. The Fayetteville Shale was named by Simonds (1891) in reference to outcrops exposed in the town of Fayetteville, Arkansas.

The Fayetteville Shale of Arkansas has been correlated with the Caney Shale of Oklahoma (Branan, 1968, p. 1625). In the Arkoma Basin of Oklahoma, it is commonly called the "Mississippian Caney" (Figure 6).

Pitkin Formation

The Pitkin Formation overlies the Fayetteville Shale and in the study area, is overlain by the Hale Formation (Figure 6). The Pitkin is separated from the overlying Pennsylvanian strata by a regional unconformity (Huffman, 1951, p. 118). The formation ranges from 40 to 130 feet thick in the study area. The rock is light to medium gray, oolitic, fossiliferous limestone. The Pitkin was originally called the "Archimedes Limestone," and was named by Ulrich (1904) after the town of Pitkin, Washington County, Arkansas. The formation crops out in the southern part of the Ozarks. Clupper (1978, p. 69) described the Pitkin as having been deposited in oolite shoals, inter-shoal areas, and anoxic reducing environments.

Pennsylvanian System

Morrowan Series

The Morrowan Series is the oldest record of the Pennsylvanian System in the study area. The Morrowan was deposited on the irregular unconformity surface that is the Mississippian - Pennsylvanian boundary in the area of this report. The lower Morrowan

represents the transgression of the Arkoma seaway, from the Ouachita trough onto the Arkoma shelf. The dominant sediment-source direction was from the northeast by way of the Illinois basin. A secondary sediment source direction was from the Nemaha Uplift to the northwest. The Morrowan Series presents a depositional pattern marked by lateral changes in facies and thickness. Much of the above information was taken from (Sutherland, 1988a, p. 1792).

In the area of this report, the Morrowan overlies the Pitkin Limestone of the Upper Mississippian Chester Series and is overlain by the Atoka Formation of the Atoka Series. It is composed of the Hale Formation and the Bloyd Formation (Figure 7).

In the study area, the Morrow thickens southward, basinward, reflecting a greater degree of subsidence in that area; it ranges from 270 feet thick in the northwest to 430 feet thick in the southeast.

Hale Formation

The Hale Formation overlies the Pitkin Limestone unconformably and is overlain by the Bloyd Formation (Figures 6 and 7). The Hale is divided into the Cane Hill Shale Member and Prairie Grove Sandstone Member. In the study area, the Hale ranges from 96 to 200 feet thick; it is mostly shale and calcareous sandstone. The Hale was named by Adams and Ulrich (1905) from outcrops on Hale Mountain, near the town of Morrow, Arkansas. Henbest (1953, pp. 1938-1942) divided the Hale Formation into the Cane Hill Shale Member and the Prairie Grove Sandstone Member.

White (1955, Geologic Map of the Brushy Mountain Structure) mapped outcrops of Morrowan rocks just to the northwest of the study area, but did not divide the Morrow into the Hale and Bloyd. Huffman and others (1958, Geologic Map of the Stilwell Area) mapped outcrops of the Hale Formation approximately ten miles to the north and

northwest of the study area.

In the Arkoma Basin of Oklahoma the Hale Formation is regarded as being equivalent to the informal "Union Valley Cromwell" (Figure 6). Often, workers of subsurface geology in Oklahoma informally divide the Cromwell into upper, middle, and lower parts. Likewise, workers in Arkansas informally divide the Hale into upper, middle and lower parts.

Cane Hill Member-

The Cane Hill Shale Member of northwestern Arkansas overlies the Pitkin Limestone unconformably and is overlain by the Prairie Grove Sandstone Member (Figure 6). The Cane Hill Member consists of shale and silty shale. A set of shaly strata between the Pitkin and the Prairie Grove Sandstone Member -- which is recorded on wireline logs in some wells in the area of this report -- could be equivalent to the Cane Hill of northwest Arkansas. It is as thick as 30 feet at some localities. In many wells it is absent or very thin. The Cane Hill Shale Member laps out at approximately the state line between Arkansas and Oklahoma.

Prairie Grove Member-

The Prairie Grove Sandstone Member overlies the Cane Hill Shale Member. It is overlain by the Bloyd Formation (Figures 6 and 7). The Prairie Grove consists primarily of shale and calcareous sandstone. Typically it grades vertically into sandy limestone. In the area of this report the Prairie Grove Member ranges from 85 to 187 feet thick.

In the subsurface of Arkansas, the Prairie Grove Member is called the "upper and middle Hale." As described above, in the subsurface of the Arkoma Basin in Oklahoma,

the Hale is mapped as the equivalent of the "Union Valley-Cromwell," which can be divided into "Cromwell" and "Cromwell Sandstone" respectively (Figure 7). The entire interval is referred to as the Cromwell, whereas the lower part, is called the Cromwell Sandstone. Therefore, in the area of this report the Prairie Grove Sandstone Member would be called the "Cromwell." The lower sandstone unit of this interval would be called the "Cromwell Sandstone." In Arkansas these strata would be called the "middle Hale."

In the area of this report, the Cromwell Sandstone has a characteristic box-shaped log signature where the rock is well developed and thickness of the Cromwell Sandstone ranges from 15 to 105 feet. This zone is a prolific source of natural gas in the Arkoma Basin.

Bloyd Formation

The Bloyd Formation overlies the Prairie Grove Sandstone Member of the Hale Formation and is overlain by the Atoka Formation of the Atoka Series (Figure 6). In the study area the Bloyd consists of the Brentwood Limestone Member below and the Kessler Limestone Member above (Figure 6). The interval primarily is shale and limestone; it is 160 to 220 feet thick in the study area. The Bloyd was named by Purdue (1907) from exposures in the vicinity of Bloyd Mountain, Washington County, Arkansas.

Brentwood Member-

The Brentwood Limestone Member overlies the Prairie Grove Sandstone Member of the Hale Formation and is overlain by the Kessler Limestone Member of the Bloyd Formation (Figure 6). The Brentwood Limestone Member ranges from 70 to 140 feet

thick in the area of this report. The Brentwood consists of shale overlain by arenaceous limestone. The Brentwood crops out near the town of Brentwood in Washington County, in northwestern Arkansas.

In the subsurface of the Arkoma Basin in Oklahoma, the Brentwood can probably be correlated with the upper part of the Union Valley Formation.

Kessler Member-

The Kessler Limestone Member of the Bloyd Formation overlies the Brentwood Member and is overlain unconformably by the Atoka Formation of the Atoka Series (Figure 6). It ranges from 63 to 134 feet thick in the study area. The Kessler is composed of shale overlain by limestone. The member thickens basinward. The upper limestone unit extends throughout much of the Arkoma Basin, where it forms a distinctive stratigraphic marker (Figure 7) that is correlative with the Wapanucka Formation.

Atoka Formation

In the area of this report, the Atoka Formation of the Atokan Series (Zachry, 1984) unconformably overlies the Kessler Limestone Member of the Bloyd Formation, of the Morrowan Series. It is unconformably overlain by the Desmoinesian Hartshorne Formation (Figure 8). In this area, the Atoka Formation is composed primarily of sandstone and shale.

The Atoka was named by Taff and Adams (1900) for exposures near the town of Atoka, Oklahoma. No type section was designated. Purdue (1907) mapped the Winslow Formation (Atokan) in the Winslow Quadrangle, which is directly northeast

| System | Series | Formation | Sandstone Unit | |
|---------------|--------------|------------|--|---|
| PENNSYLVANIAN | DESMOINESIAN | HARTSHORNE | | |
| | | ATOKAN | ATOKA | UPPER |
| | MIDDLE | | | MORRIS (SELF-TACKETT) ARECI (MOYER) BYNUM (HOOD) FREIBURG (HENSON-PEARSON) CASEY (VERNON-HUDSON NO. 1) |
| | LOWER | | | SELLS (DUNN "A"-MCGUIRE) JENKINS (RALPH BARTON-UPPER ALLEN) DUNN "B" DUNN "C" (DAWSON A-LOWER ALLEN) PAUL BARTON (BAWSON B-RUSSELL) CECIL SPIRO (HAMM) PATTERSON SPIRO (ORR-KELLY) |
| | MORROWAN | BLOYD | KESSLER LS. (WAPANUCKA) BRENTWOOD LS. | |
| | | HALE | UPPER HALE MIDDLE HALE LOWER HALE | |

Figure 8. Stratigraphic succession of informally named subdivisions of the Atoka Formation, Arkoma Basin, Arkansas. (From Zachry, 1983, p. 40)

of the study area described herein. Croneis (1930) suggested that the Winslow Formation of northern Arkansas is continuous with the earlier-named Atoka Formation of south-central Oklahoma, and proposed that the name Atoka be applied to the succession in Arkansas (Zachry, 1984, p. 10).

The Atoka has not been subdivided into formal members. An informal nomenclature has been adopted that divides the Atoka into several parts, and upper, middle and lower intervals. This system is based on key correlation markers and has no paleontological basis (Figure 8).

The Atoka Formation ranges from 300 feet thick along the northern margin of the Arkoma Basin to more than 15,000 feet along the southern margin of the basin (Zachry, 1984, p. 9). In the area described by the present report, the Atoka Formation is approximately 5000 feet thick on the downthrown side of the Mulberry Fault (Plate II) and approximately 1500 feet thick on the upthrown side of the Mulberry Fault. The entire interval can be seen on well logs in the region south of the Mulberry Fault, where the Atoka is overlain unconformably by the Hartshorne Formation of the Desmoinesian Series (Haley and Hendricks, 1972, Plate 6).

Middle Atoka-

In the study area, rocks from the middle Atoka crop out north of the Mulberry Fault. These rocks primarily are shales, sandstones, and intervals of interbedded sandstone and shale. Several distinct lithologies (for example, see Figure 9) were observed in the field but separation or definitive mapping of single beds was not feasible and was not attempted. Correlation of outcropping rocks with strata in the subsurface can be made, but that degree of mapping detail was beyond the scope of this study.

Lower Atoka-

In the area of this report, shales of the lower Atoka include the informal rock-stratigraphic units, "Spiro Sandstone" and "Cecil Series." Lower Atokan rocks are overlain by the "Casey zone" of the middle Atoka (Figure 7). The Spiro ranges from 10 to 90 feet thick in the study area. The sandstone is a prolific reservoir of natural gas in many parts of the Arkoma Basin. The Cecil Series is above the Spiro and below the "Casey zone." In the study area, it consists of five informally designated units of sandstone: Cecil Spiro, Paul Barton, Dunn C, Ralph Barton and Dunn A (Figure 7). All of the sands of the Cecil zone are productive at localities in the Arkoma Basin. In the area of this report the Ralph Barton sand is the most productive.



Figure 9. Burrows (?) in middle Atoka sandstone (NW $\frac{1}{4}$, Section 18, T.12N., R.27E.)

CHAPTER IV

STRUCTURAL GEOLOGY

Regional Tectonic History

Evolution of the Arkoma Basin and Ouachita orogenic belt reflects the opening and closing of a Paleozoic ocean basin (Houseknecht, 1983, p. 3). The series of tectonic events that deformed the basin into its present configuration are summarized below. This information was extracted from Houseknecht (1983, pp. 16-33).

During the Late Cambrian, a major episode of rifting resulted in the opening of a proto-Atlantic ocean basin. From the late Cambrian into the Devonian the southern margin of North America evolved into a passive, Atlantic-type margin that persisted throughout the early and middle Paleozoic. During the Devonian or Mississippian Period, the ocean basin began to close, accommodated by southward subduction of oceanic lithosphere beneath Llanoria (South American plate). Through Morrowan time, the Ouachita remnant ocean basin remained the major sediment trough for the region. By early Atokan time the Ouachita remnant basin had been consumed by subduction and the northward-advancing subduction complex was being pushed upon the rifted continental margin of North America. As a result of subduction and because of vertical loading, the southern margin of the North American continental crust was subjected to flexural bending, this flexure induced normal faults. By late Atokan time, the subduction complex had collided with the North American continent and the most severe structural deformation had ceased. Minor compressional deformation continued into the Permian.

The tectonic history of the Arkoma basin was controlled primarily by the Ouachita orogeny and accompanying rise of the Ozark uplift. As mentioned by (Branan, 1968,

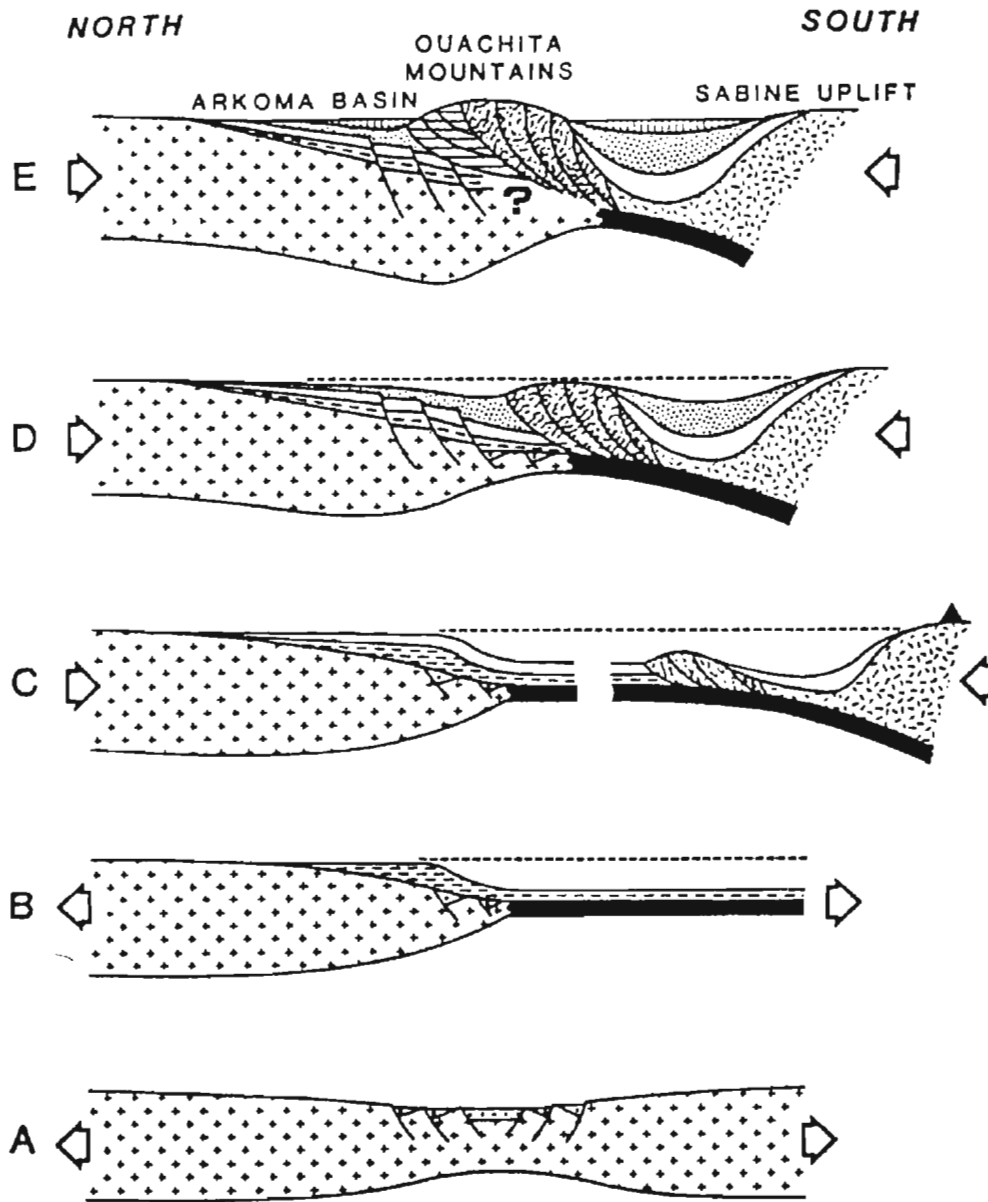


Figure 10. Hypothetical cross sections depicting tectonic evolution of southern margin of North America during (A) late Precambrian-earliest Cambrian, (B) Late Cambrian-earliest Mississippian, (C) Early Mississippian-earliest Atokan, (D) early-middle Atokan, (E) late Atokan-Desmoinesian (modified from Housenicht, 1987, p. 51).

orogeny and accompanying rise of the Ozark Uplift. As mentioned by (Branan, 1968, p. 1623), the basin is dominated by two basic structural patterns: (1) block faults generated with subsidence, while the Ozark Dome remained positive, and (2) folds and northward-overthrust belts generated by the Ouachita orogenic complex on the south (Figure 11).

Local Structural Geology

The area of this report is located on the southern flank of the Ozark Uplift and the northern shelf of the Arkoma Basin.

The area north of the Mulberry Fault (Plate I), is complicated by numerous anticlinal and synclinal flexures and normal faults. Most of the folds and faults trend northeastward.

The area south of the Mulberry Fault is within the Arkansas Valley Province. The structure within this area is composed of anticlinal and synclinal flexures as well as by normal faults and growth faults (Figure 11). Most of these structures trend in a northeasterly to easterly direction.

Deformation within the study area is thought to be a result of tensional forces generated during the deposition of the middle Atoka sediments and slight compressional forces generated during the Ouachita Orogeny.

Methods of Investigation

To describe the structural geology of the study area, a structural geologic map of the surface (Plate I) as well as a structural contour map of the subsurface (Plate II) were constructed.

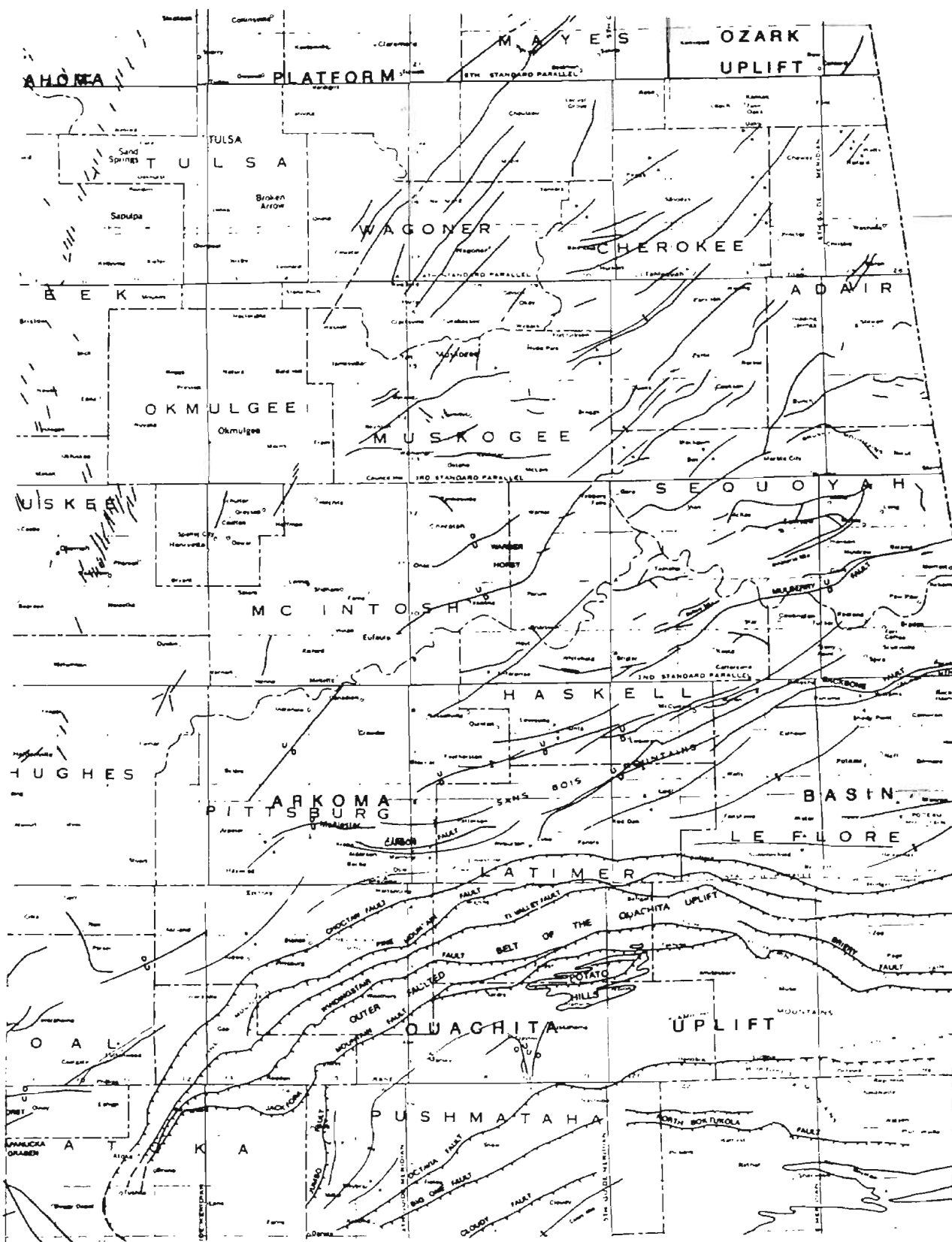


Figure 11. Principal structural features of eastern Oklahoma (from Chenowith, 1983).

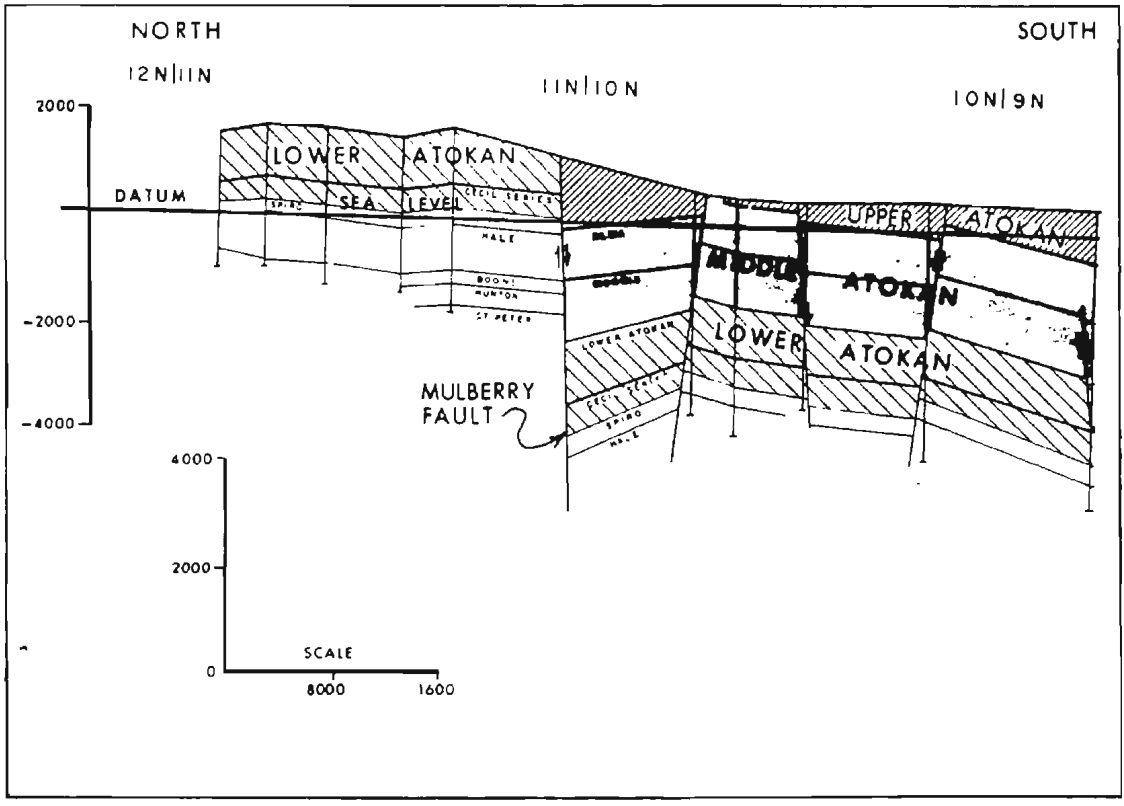


Figure 12. Diagrammatic cross-section showing typical faults in the region of the study area (from Haines, 1981, p. 45).

Topographic maps, a digital elevation model (Figure 13), aerial photographs, soil surveys, seismic data, and existing geologic maps were analyzed in order to compile the structural geologic map of the surface. Geomorphic features were used to aid in the delineation of possible faults. Suspected faults were field-checked to verify their existence.

Initial interpretations were compiled from geomorphic evidence. Analysis of the terrain suggested that drainage patterns were directly related to faulting and folding. Rectangular-dendritic drainage was observed, with many tributaries intersecting main streams at "right" angles. In some synclinal folds, streams flow near the axes (for example, Little Skin Syncline, Plate I, Section 7, T.11N., R.26E.). In some anticlinal folds, streams flow away from the axial area (for example, Liberty Anticline, Plate I, Section 26, T.12N., R.26E.). Initially all suspected faults and folds were mapped by geomorphic evidence, then additional work was done to verify or disprove interpretations. After initial interpretations were mapped, soil surveys and aerial photographs were analyzed to aid in determining the probability of these interpretations. Next, proprietary seismic data, on loan, was analyzed to aid in the determination of the probability of these interpretations. Finally, field work was conducted, in an attempt to positively verify mapped interpretations.

In the numerous areas where field work was undertaken, rocks of the middle Atoka crop out. Lithologies are very similar and at many places, beds are not laterally continuous, thus making identification of faults difficult. Also, exposures are limited and most strata are covered. Evidence of drag and of dip reversal were the primary evidence available to verify the existence of faults interpreted from geomorphic evidence. Slickensides, vein-cements, and uncommonly abundant joints and fractures aided in verification of faults. A system that ranks interpreted faults, in accordance with the degree of supporting evidence that was observed, was implemented. Faults were ranked

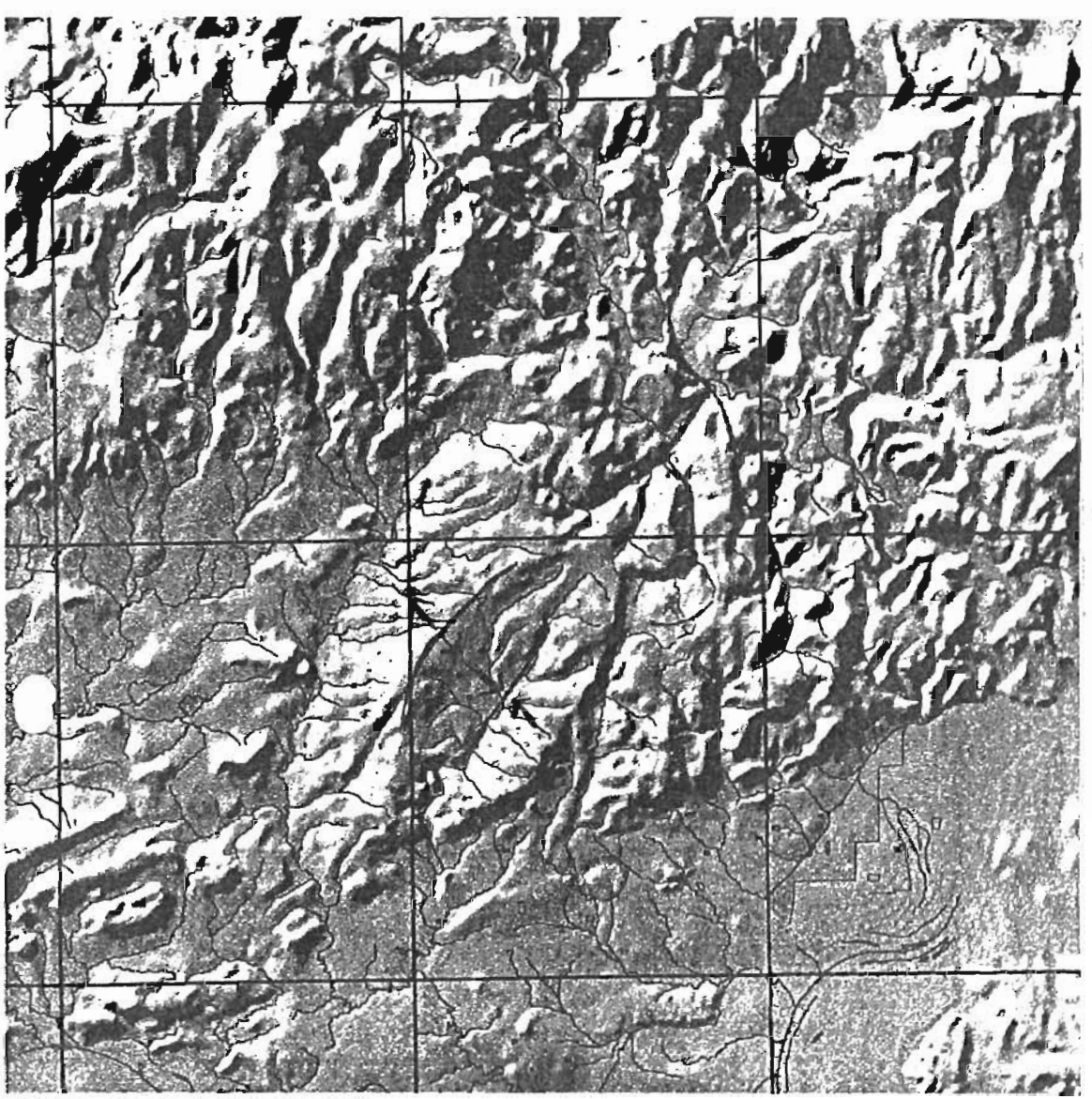
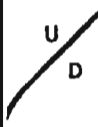
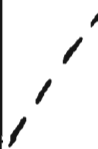
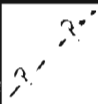


Figure 13. Digital elevation model of study area (modified from Rea and Becker, 1997)

as "identifiable," as "probable," and as "questionable" (Table 1).

Table 1. Fault-Interpretation Criteria

| Fault Classification | Geomorphic Evidence | Geological Evidence | Subsurface Geological Evidence | Symbol |
|----------------------|---|---|---|---|
| Identifiable | drainage patterns differential weathering soil types shapes of landforms | displacement of strata drag along fault dip reversal jointing slickensides increased cementation | offset of strata in wellbores unbalanced contours |  |
| Probable | drainage patterns differential weathering soil types shapes of landforms | drag along fault dip reversal jointing slickensides increased cementation | offset of reflectors on seismic cross-sections unbalanced contours decrease in porosity near faults |  |
| Questionable | drainage patterns shape of landforms | dip reversal fracturing | unbalanced contours |  |

In the area where field investigations were conducted the terrain is rugged and the area is densely vegetated. A global positioning system was employed to aid in the verification of locations of outcrops.

A structural contour map (Plate II) was constructed of the top of the Kessler Limestone (Wapanucka). Uncommonly close spacing of contour lines as well as the absence of reliable marker-beds on certain wireline logs were used to map possible faults. These data were compared with information mapped at the surface. Where possible and relevant, folds and faults observed in rocks at the surface were projected into the subsurface.

Analysis of the two maps (Plates I and II) suggests that block faulting was the major

process of deformation. The region has been dissected into horst-and-graben features, typically associated with extensional tectonics. Grabens form synclinal flexures due to downwarping by drag against associated faults. Limbs of such synclines typically form ridges (for example, see the Cowlington Syncline, Plates I and II). Horst blocks are associated with anticlinal flexures. Anticlinal flexures tend to be associated with the upthrown boundaries of tilted fault blocks (for example, see Plate I, Section 15, T.11N., R.26E.).

Faults

The Mulberry, Akins, Greasy Creek, and Pine Mountain faults are the major faults in the area (Plate I). Numerous smaller faults and fractures were interpreted and mapped on the structural maps. Many of these faults lack definitive evidence, but display geomorphic recognizable evidence; the faults are ranked accordingly.

Mulberry Fault

The Mulberry Fault is the largest structural feature in the study area. Middle Atokan rocks are against the rocks of the Savanna Formation of the Desmoinesian Series along the trace of the fault (Plate I). The Mulberry Fault coincides with the approximate hinge line of the Arkoma Basin (Woncik, 1968, p.1641) and the area just to the north of the fault is considered to be the northern margin of the basin. The Mulberry Fault separates the Arkansas River Valley Province from the flanks of the Ozark Uplift.

The Mulberry Fault is a normal fault, downthrown to the south (Plate I). It crosses through the study area from Section 9, T.11N., R. 27E., in a southwesterly direction. The fault turns abruptly southward in Section 34, T.11N., R.25E., and continues in this

general direction beyond the bounds of this report. In the eastern part of the study area, throw is estimated to exceed 5500 feet (Plate II). In the western part of the report, near the Gans anticline, throw diminishes to approximately 3500 feet (Plate II).

Several drag folds formed against the fault on the upthrown side. In Section 15, T. 11N., R. 26E., one of these structures is mapped (Plate I).

Along the trace of the fault, significant drag folding can be seen at some localities (Figure 14). Strata on the downthrown side of the fault dip as much as 30 degrees. Strata on the upthrown side, adjoining the main fault trace, show a wide range of dips, most of which are less than 12 degrees.

Camp Creek Fault

A small fault was mapped in the valley of Camp Creek (Plate I, Section 16, T.11N., R.26E.). In the southeast quarter of Section 17, T.11N., R.26E., where this fault intersects the Mulberry Fault, drag folding and dip reversal were observed (Figure 15). These beds are significantly deformed (Figure 16). This fault can be projected northward to the Muldrow Lake Dam, in Section 9, T.11N., R.26E; on the evidence of reversal of regional dip, most probably attributable to drag folding on the downthrown limb. North of the lake exposures are covered and the fault is not traceable.

Akins Fault

The Akins Fault extends through the study area from Section 18, T.12N., R.25E., on the west to Section 1, T.12N., R.25E., on the east. It forms the southern boundary of the so-called Brushy Mountain Structure. It is a normal fault, downthrown to the south. According to White (1955, p. 20), on the northern block south dip is increased by drag

near the fault; at these places dips are as high as 38 degrees. In the subsurface, data were not sufficient for determination of throw.



Figure 14. Drag folding in strata near the trace of the Mulberry Fault (NW/4, Section 18, T.11N., R.26E.).

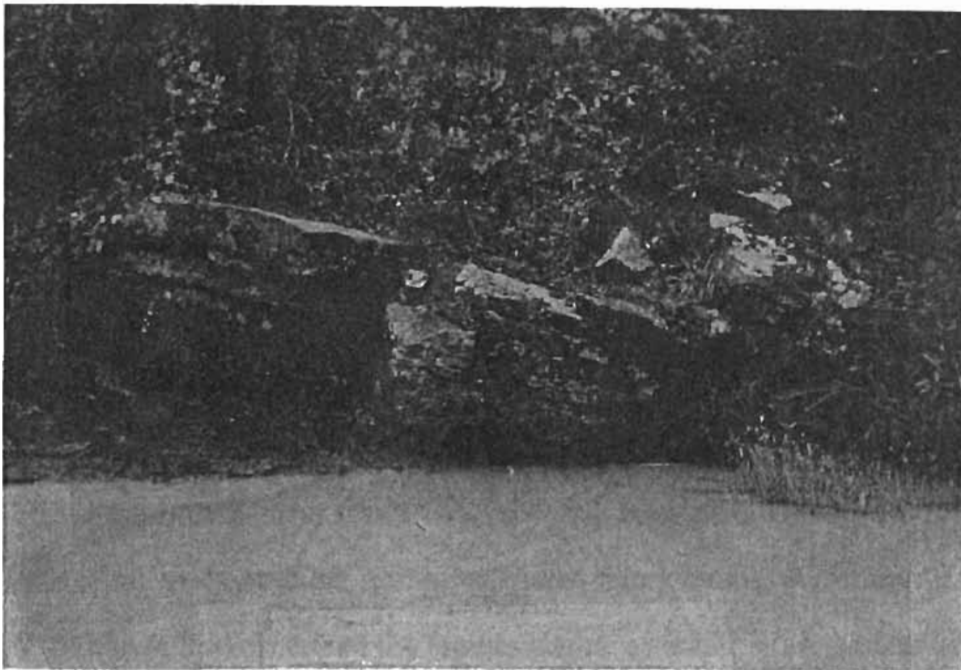


Figure 15. Drag folding in strata near the trace of the Camp Creek Fault (Section 17, T. 11N., R. 26E.).



Figure 16. Deformed strata near Camp Creek Fault (Section 17, T. 11N., R.26E.).

Greasy Creek Fault

The Greasy Creek Fault extends southward through the study area from Section 3, T. 12N., R.26E., to Section 21, T.11N., R.27E and beyond. It is the most prominent structural feature in the northeastern part of the study area. The Greasy Creek Fault was mapped by Branson (1954). White (1955) also mapped the fault in his report on the Brushy Mountain Structure (1955). However, neither author found significant evidence to support the eastward extension of the fault into the area of this report. White (1955, p.20) stated that neither the Greasy Creek Fault nor drag associated with it were found east of the area of intersection of the Akins and Greasy Creek Faults, in Section 19, T. 13N., R.26E. White (1955) described the fault as having a surface expression of a fault line scarp passing into folding.

The Greasy Creek Fault is a normal fault downthrown to the north. In the area of this report the fault is manifest by local anticlinal flexures along the fault trace (Plate I). Dip reversal was the primary form of evidence used in the identification of this fault. In Strata on the downthrown side of the fault dip locally as much as 21 degrees (Figure 17). In strata on the upthrown side of the fault, dip is highly varied, but most beds dip less than 12 degrees (Figure 18). Data were not sufficient for determination of throw. However, from subsurface mapping and balancing of contours, displacement along the fault is estimated to be less than 200 feet. Throw probably diminishes in a short distance eastward.

Pine Mountain Fault

A normal fault, downthrown to the east, was mapped from Section 2, T.12N., R.26E., to the NW ¼ of Section 30, T.12N., R.26E. (Plate I). This fault is interpreted as

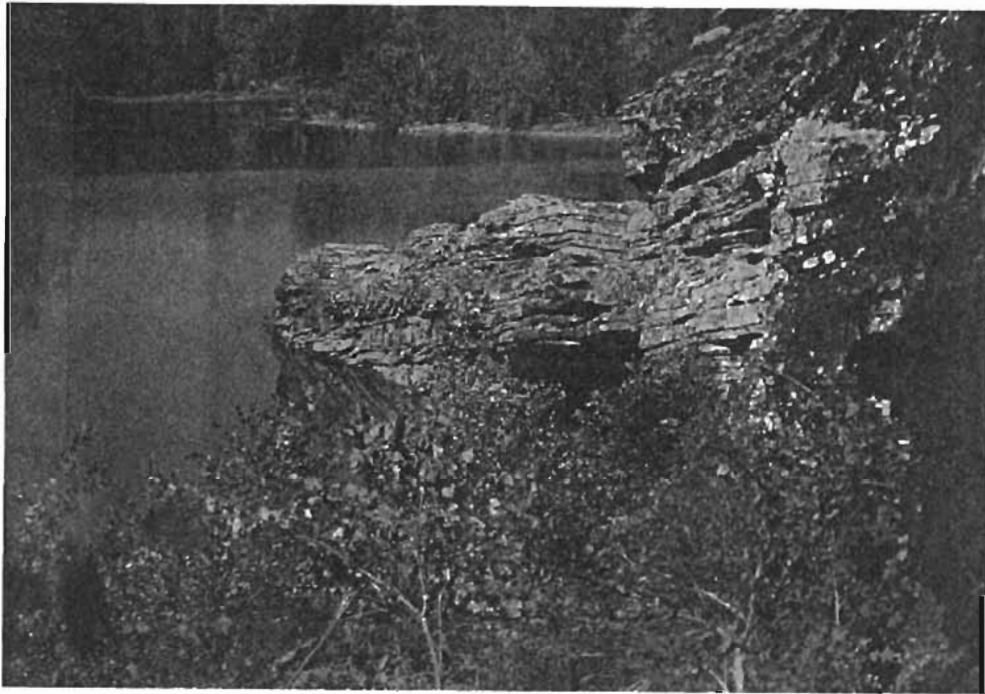


Figure 17. Northeast-dipping strata on downthrown block of Greasy Creek Fault (Plate I, NE $\frac{1}{4}$, Section 18, T.12N., R.27E.).

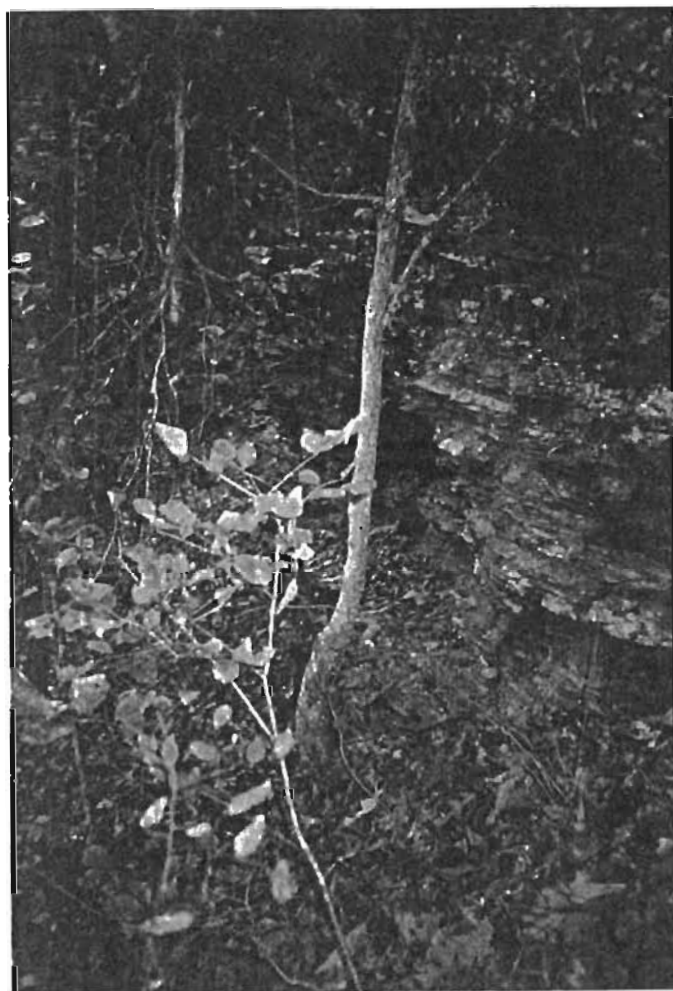


Figure 18. Southwest dipping strata along upthrown block of Greasy Creek Fault (Plate I, SE $\frac{1}{4}$, Section 12, T.12N., R.26E.).

intersecting the Greasy Creek Fault in Section 2, T.12N., R.26E. (Plate I). Along the trace of the fault, drag folds can be seen in outcrops. Drag folding on the downthrown side of the fault is shown by dips as much as 15 degrees (Figure 19). Exposures are only several, and it is difficult to determine whether rocks are in place. Locally, strata on the upthrown side of the fault dip from 5 to 12 degrees to the southwest.

Folds and Flexures

Liberty Anticline

A small anticlinal flexure that extends from Section 27, T.12N., R.26E., through Section 25, T.12N., R.26E., can be mapped on aerial photographs and topographic maps. The anticline trends northeastward, but it appears to be tilted to the northwest. In the field, most strata are covered; this fold is difficult to map. Interpretations are based largely on geomorphic evidence.

In the subsurface, a normal fault with approximately 150 feet of throw is discernible in wireline logs of the Quapaw Oil and Gas Inc., O'neal No. 1, in Section 26, T.12N., R.26E. The wellbore cut the fault at 1180 feet measured depth. When projected to the surface at a 45 degree angle, the fault approximately coincides with the axis of the anticline, as mapped at the surface.

Little Skin Syncline

Two small synclinal flexures were mapped along Little Skin Bayou in Sections 28 and 29, T.12N., R.26E., and in Section 12, T.11N., R.25E., through Sections 7 and 6, T.11N., R.26E. (Plate I). Dips as great as 12 degrees were recorded on the eastern side of

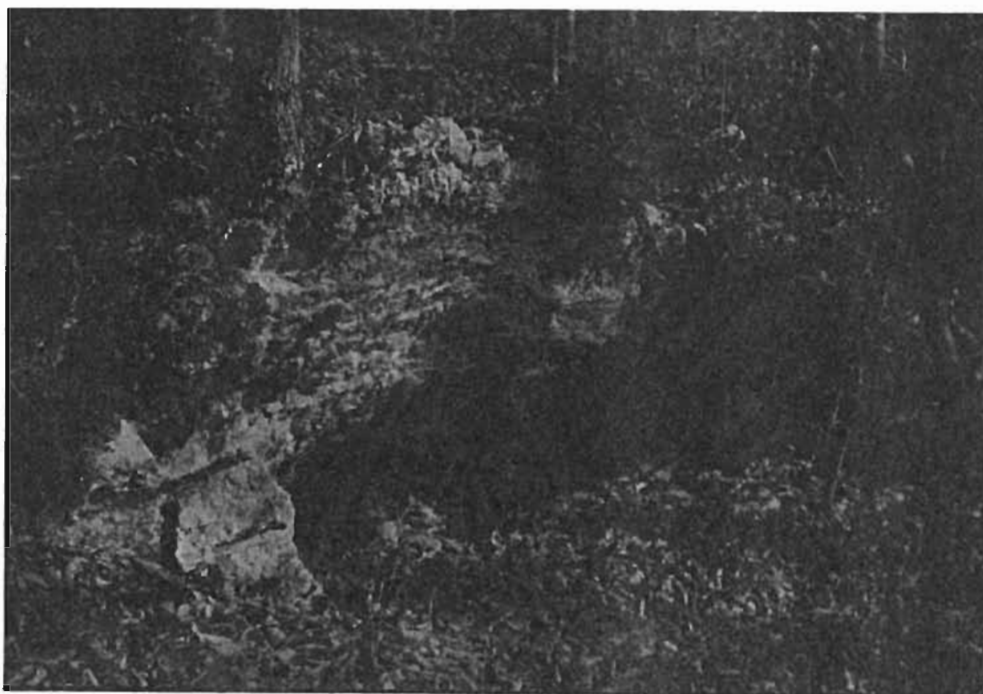


Figure 19. Drag folds in sandstone near trace of the Pine Mountain Fault
(Plate I, Section 18, T.12N., R.26E.)

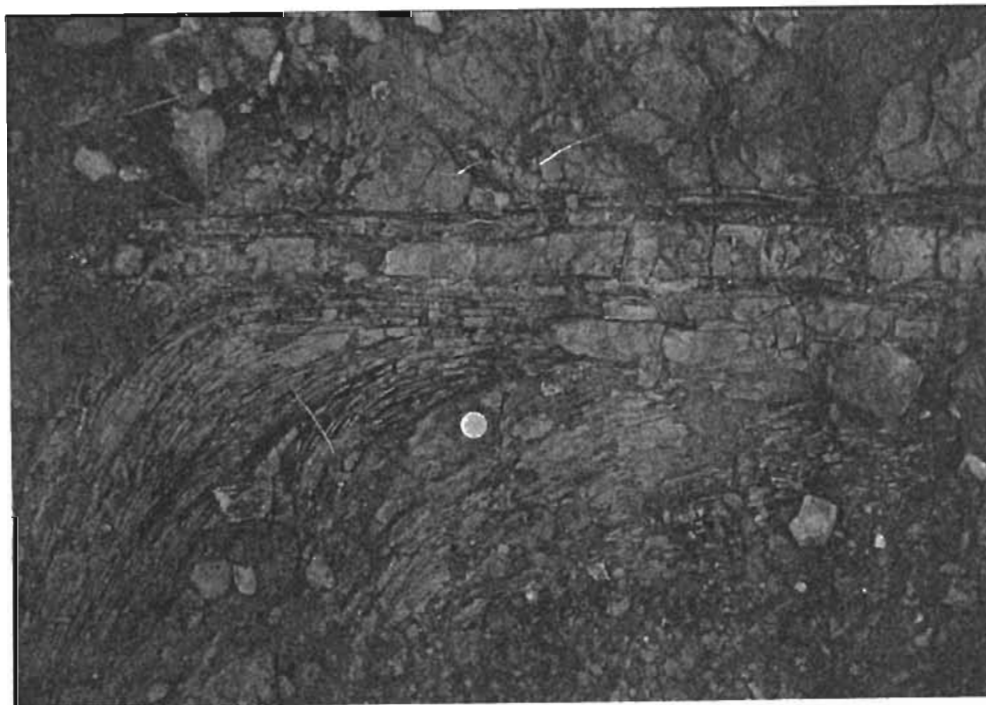


Figure 20. Sandstone dike (?) in deformed shale (NE, NE, SE, Section, 29
T.12 N., R.26E.)

the structure (Figure 21). On the western limb, dip toward the axis does not exceed 4 degrees. These flexures probably are a result of minor deformation along small northeast-trending normal faults with small vertical displacement.

Long Anticline

A small anticlinal flexure was mapped from Section 29, T.12N., R.26E., to Section 21, T.12N., R.26E. (Plate I). This flexure coincides with the approximate traces of small displacement-normal faults mapped northeastward from Section 15, T.11N., R.25E., to Section 36, T.11N., R.26E., on the south, and from Section 2, T.12N., R.26E., to Section 15, T.12N., R.26E., on the north (Plate I). The Long Anticline may have formed in response to movement on a system of deep-seated faults that extend northeastward

Gans Anticline

The northeastern nose of the is just west of the community of Gans, in Section 32, T.11N., R.25E. It extends northeastward to Section 26, T.11N., R.25E. (Plate I). Strata dip northwestward and southeastward from the axis of this flexure.

Cowlington Syncline

The Cowlington Syncline trends from Section 35, T.11N., R.25E., northeastward across the area of investigation (Plate II). The syncline is bounded by the Mulberry Fault on the north and an unnamed normal fault on the south (Plate II). The Cowlington Syncline plunges beneath Quaternary alluvium of the Arkansas River floodplain in Section 17, T.11N., R.27E. (Plate I).

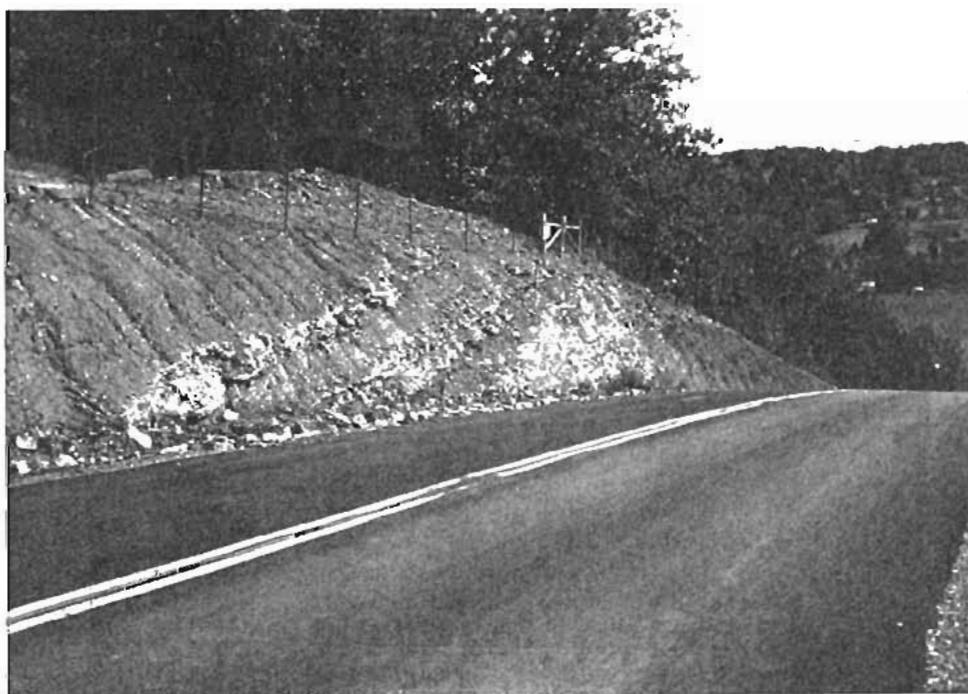
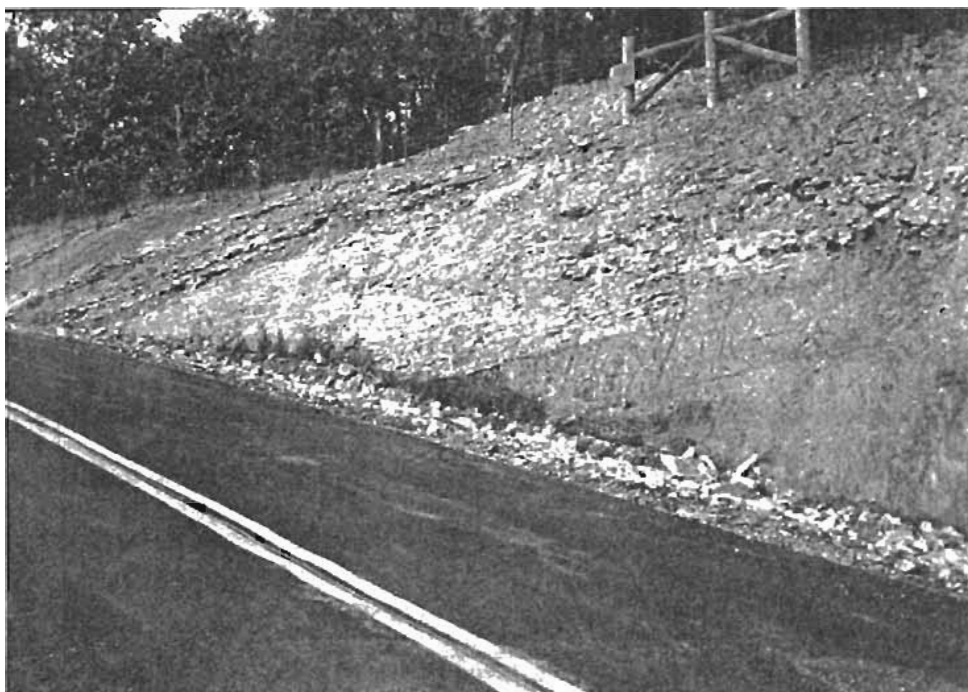


Figure 21. Dipping strata on eastern limb of Little Skin Syncline. In upper photograph, view is north-northwest; in lower photograph strata dip northwestward (Plate I, E. $\frac{1}{2}$, Section 28, T. 12 N., R. 26 E.)

Milton Anticline

The Milton Anticline is associated with a large upthrown fault block complicated by localized faulting (Plate II). The axis of the Milton Anticline extends northeastward from Section 31, T.11N., R.26E., across the southern part of the report to Section 34, T. 11N., R.27E., where it extends beyond the bounds of the study area into Arkansas (Plate II). This broad asymmetrical fold is bounded by normal faults on the north and south. On the north it abuts the Cowlington Syncline.

General Conclusions

Faults and folds in the study are results of several kinds of events. Extensional forces generated during the opening and filling of the Arkoma Basin developed an overall horst-and-graben pattern. Compressional forces that accompanied the Ouachita orogeny and subsequent closing of the Arkoma Basin complicated these features.

CHAPTER V

PETROLEUM GEOLOGY

Introduction

All commercial gas fields are in the eastern and southeastern parts of Sequoyah County (Figure 22). To date, approximately 147 Bcf of natural gas has been recovered. Several formations and groups produce: Arbuckle, Simpson, Hunton, Penters Chert, Boone, Cromwell, Brentwood, Spiro, Cecil Series, Alma, and the Brent. Production primarily is dry methane gas, but condensate is produced from some zones. Also, oil has been produced from the Brent.

The Cromwell Sandstone is the most productive formation in the study area. The Spiro Sandstone and the Hunton are also significant producers.

Trapping Mechanisms

Each gas field studied is structurally controlled; definite closed structure seems to be required for the entrapment of gas. Areal distribution of reservoir rocks is important but secondary.

Natural Gas Reservoirs

Gas has been recovered in profitable quantities from rocks of Ordovician through Atokan age in the area of this report. Most gas has been obtained from sandstone reservoirs of Morrowan age. However, rocks of the Hunton and Atokan (Figure 7) also

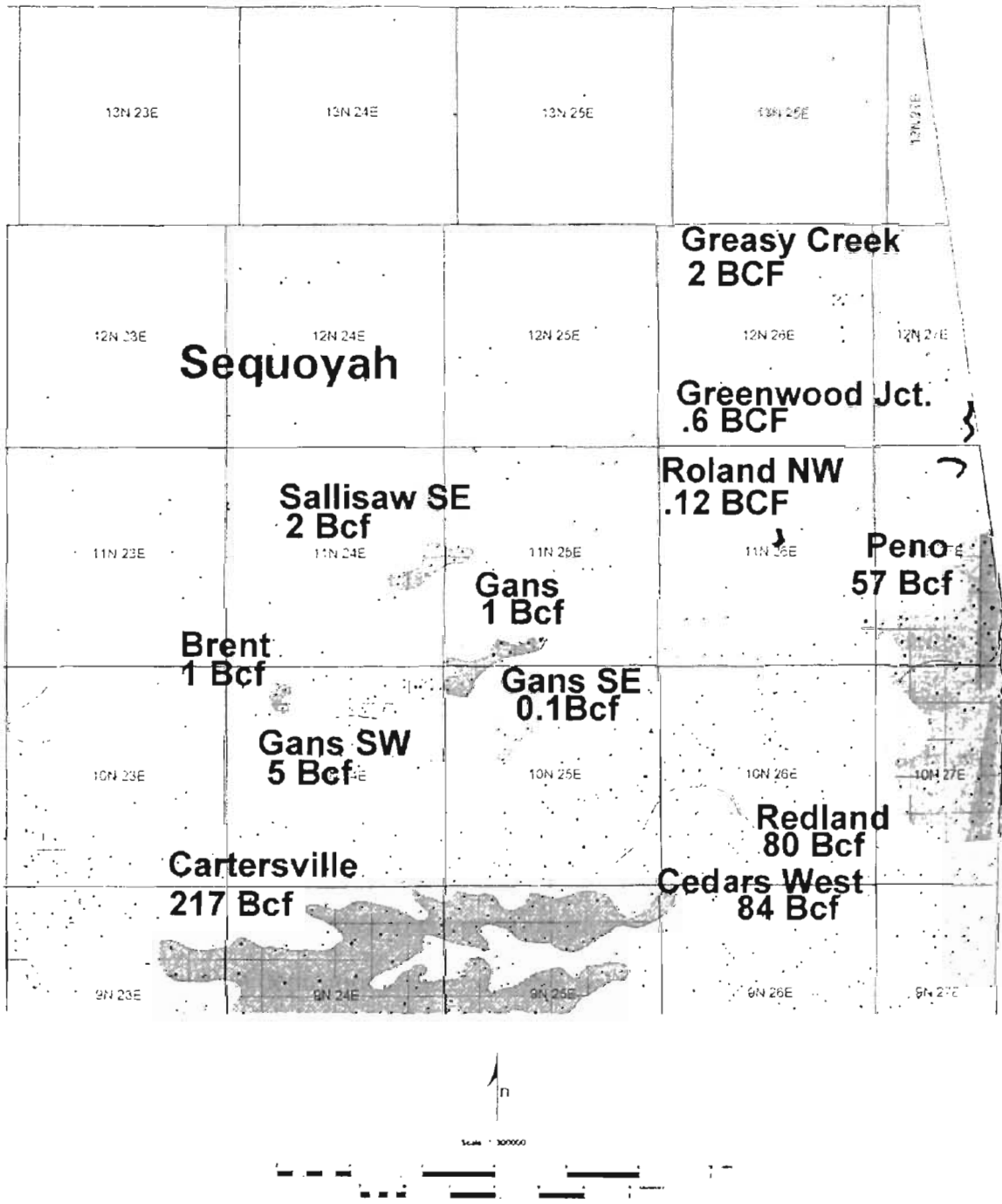


Figure 22. Sequoyah County gas fields and cumulative production.

have produced in commercial quantities. The Cromwell Sandstone and Spiro Sandstone (Figure 7) were briefly studied in an effort to understand the stratigraphy of these reservoirs.

Cromwell Sandstone

The Cromwell Sandstone is the most prolific reservoir on the northern shelf of the Arkoma Basin and in the area of this report. The Cromwell was deposited within a transgressive systems tract (Manger and Zachry, 1998, p. 6). Figure 23 illustrates the paleogeography of the area during the early Morrowan. In the study area the Cromwell Sandstone is light gray, fine grained, calcareous sandstone.

An isolith map (Plate V) as well as Stratigraphic Cross Sections (Plates III and IV) were constructed in order to illustrate the geometry and extent of the Cromwell. In this report, the Cromwell is interpreted as having been deposited in a high destructive, tide dominated-deltaic setting. The cross-sections (Plates III and IV) and the isolith map, (Plate V) provide evidence of thick channel-fill deposits as well as tidal-flat deposits. Figure 24 illustrates typical well log responses associated with the Cromwell Sandstone in this area. The characteristic box-shaped log signature is suggestive of a channel-fill facies whereas the serrated, low gamma ray and low spontaneous potential curves are suggestive of a delta plain or other low-energy environment.

An in-depth study of depositional environments was not performed. Previous investigations (Abollo, 1995; Jefferies, 1982) covered this subject..

Spiro Sandstone

The Spiro Sandstone is very productive of natural gas in the Arkoma Basin. It is

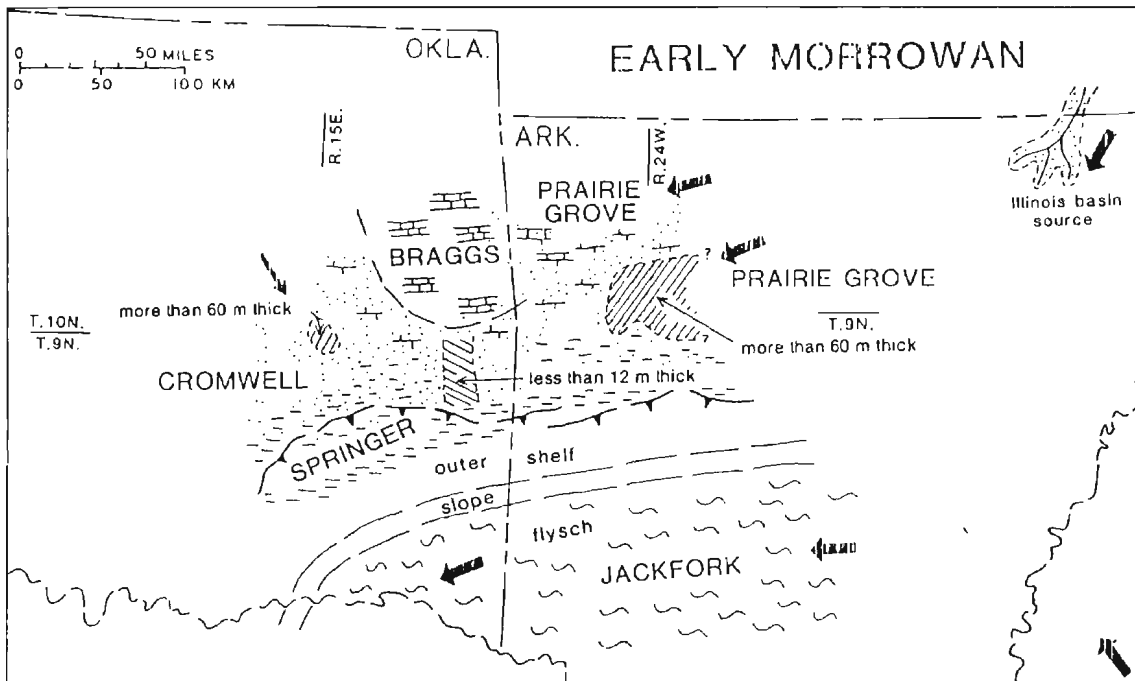


Figure 23. Early Morrowan paleogeography (from Sutherland, 1988a, p. 1793).

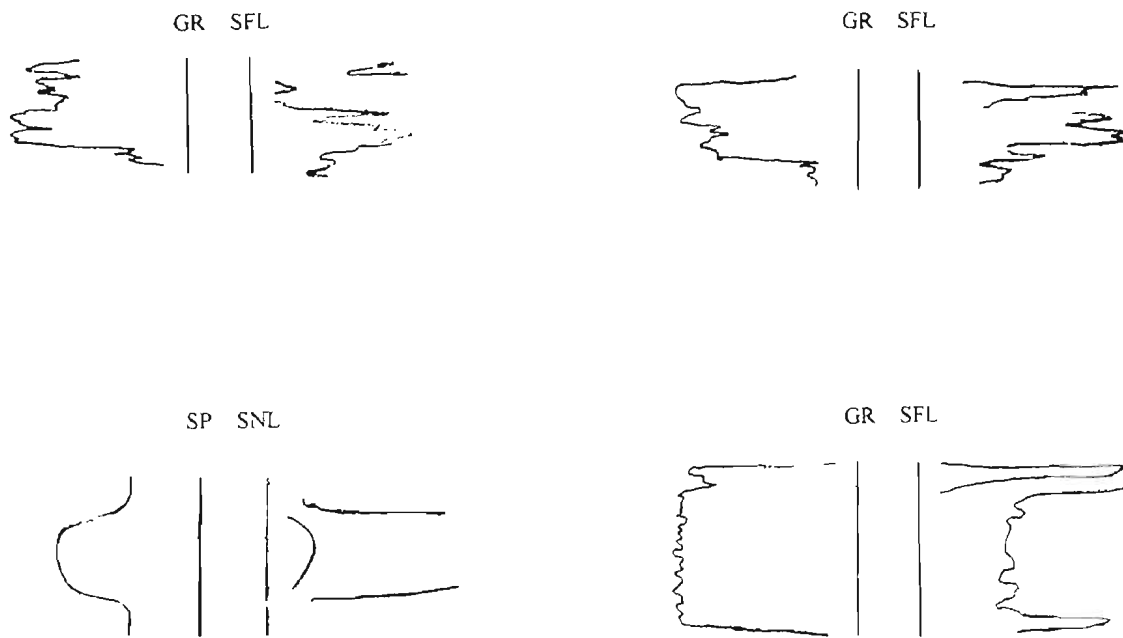


Figure 24. Cromwell Sandstone log responses judged to be typical within the study area.

better developed to the south of this study area.

The basal Atoka Spiro Sandstone was deposited on the erosional surface of the post-Morrowan unconformity. These sands were deposited in pre-transgressive channel systems (Foster Channel sands) and in widespread coastal sand complexes (Zachry, 1984, p. 16). As Atokan seas transgressed onto the Arkoma shelf sedimentation was dominated by wave-dominated prograding delta complexes. Paleogeography of the early Atokan is illustrated in Figure 25.

Two distinctive facies were recognized within the Spiro interval (Figure 26). A fining upward sequence of the Spiro is recognizable in logs of several wells. These sequences were interpreted as being a Foster-channel type facies. Coarsening-upward sequences, were interpreted as having been deposited in a prograding delta setting.

Gas Fields

Redland Field

The Redland Field (Figure 22) has produced 80 BCF of natural gas; it is the largest field in the county. Its northern extent is in the southern part of T.11N., R.26E. The field was developed on the Milton Anticline and most of the production is from the Cromwell Sandstone and the Spiro Sandstone (Figure 7).

Peno Field

The Peno Field (Paw-Paw) (Figure 22) has produced 57 BCF of natural gas; it is the second-largest field in the county. It is on the northern end of the Milton Anticline in T. 11N., R.27E. Primary production is from the Cromwell Sandstone. The Hunton, Cecil

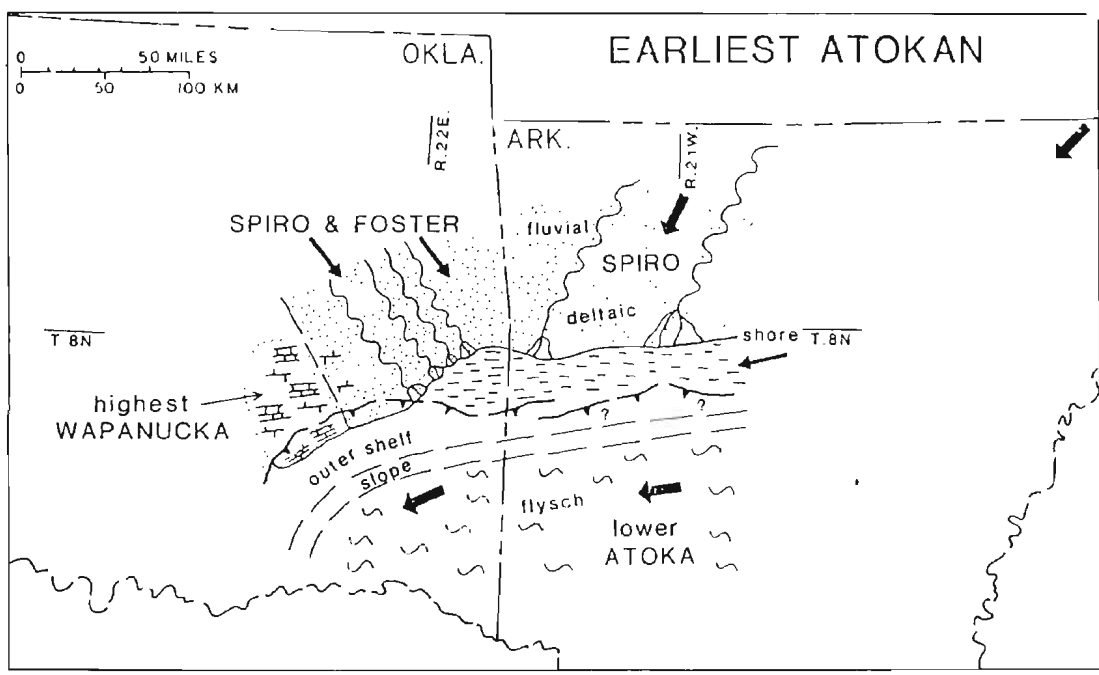


Figure 25. Early Atokan paleogeography (From Sutherland, 1988a, p. 1795).

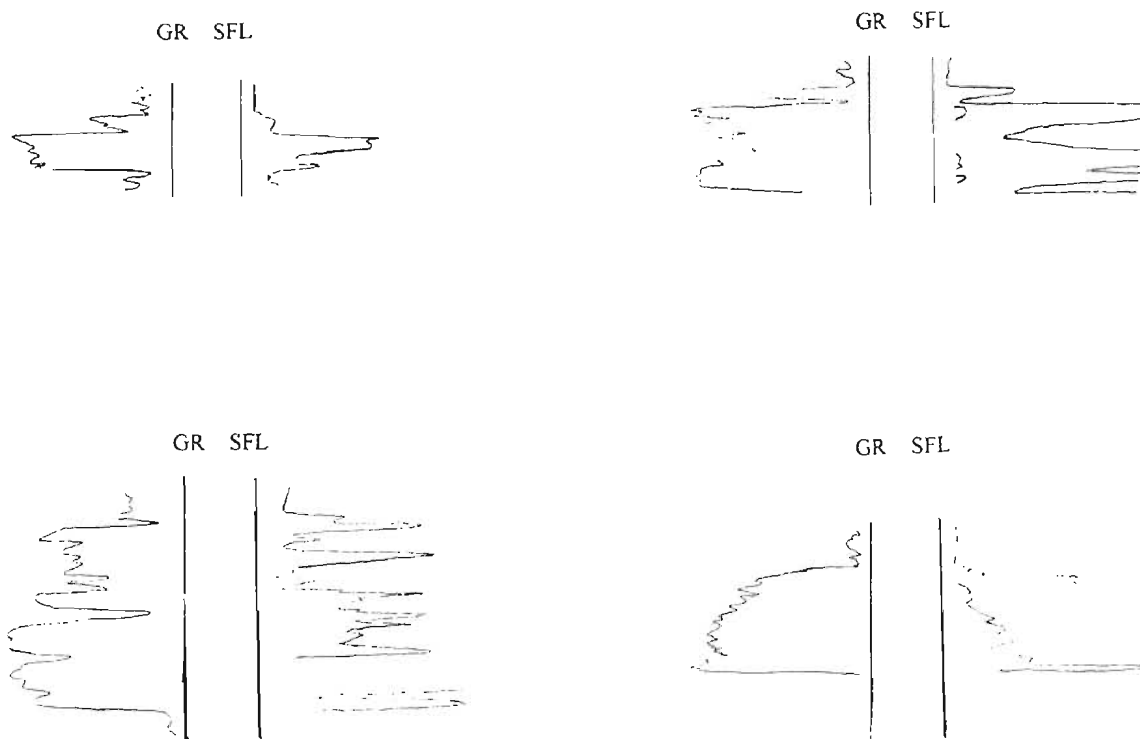


Figure 26. Spiro Sandstone log responses judged to be typical within the study. The upper set illustrate a coarsening-upward sequence; the lower set illustrates a fining upward sequence.

Series (Figure 7) and the Alma produce in the field.

The discovery well of the field was the Mobil Oil No.1 Miriam Rogers, drilled in February, 1968. It is located in SE SW NE of Section 32, T.11N, R.27 E. The well was completed in the Cromwell from perforations at 5234-5306 feet and in the Hunton from perforations at 5761-5789 feet and 5835-5844 feet. Initial production was gauged at 2157 Mcfgd on a 14/64 choke. Flowing tubing pressure was gauged at 788 psi. As of April, 1998, the well had produced 6.55 BCF and was still producing 484 Mcfgd.

Greasy Creek Field

The Greasy Creek Field (Figure 22) is in the northeastern part of T.12N., R.26E., and in the central part of T.12N., R.27E. The discovery well of the field was the Hoover & Wilson No. 1 Pine Mountain, completed in January, 1996.

The Pine Mountain No. 1 is in the SE SE SE of Section 11, T.12N, R.26E. The well encountered overpressured Cromwell Sandstone at 1800 feet and caught on fire; the drilling rig was destroyed. When the well was completed, from perforations at 1822-1852 feet, in the Cromwell, initial production was gauged at 6600 Mcfgpd on a 48/64 inch choke. Flowing tubing pressure was gauged at 440 psi. As of April 1998, the well had produced 111 MMcfg and was producing 595 Mcfgd.

The Greasy Creek Field is defined by the intersection of the Pine Mountain Fault and the intersection of the Liberty "Anticline fault" with the Greasy Creek Fault (Plate I). Closure against faults is formed at these intersections, creating two small gas fields (Plate II).

Primary production is from the Cromwell Sandstone; other zones include the Boone, and the Cecil Series (Figure 7).

At the time of the compilation of this report, the Greasy Creek field had produced

approximately 2 BCF. Ultimate recovery from the field is estimated to be greater than 5 BCF.

Gans Field

Gas was discovered on the flanks of the Gans Anticline in 1924. The field is in Sections 32 and 33, T.11N., R.25E., and Section 6, T.10N., R.25E. (Figure 22). Production is primarily from Atokan Sandstones. The field has produced approximately 1 BCF of natural gas.

Sallisaw SE

The Sallisaw Southeast field is on the Hickorynut Ridge Anticline in Sections 18 and 19, T.11N., R.25E., and Sections 13, 24 and 25, T.11N., R.24E. (Figure 22). Production is from middle Atokan sandstones, from the Spiro and the Hunton.

Greenwood Junction Field

Gas was discovered in the Greenwood Junction Field (Figure 22) by the Citizens Gas Company in 1928. The field is located in Sections 4 and 5, T.11N., R.27E. and Sections 28 and 33, T.12N., R.27E. Accurate data concerning daily or monthly production are not available; only information about cumulative production was obtained. Correlation of lithologic descriptions, from completion reports, compared to typical wireline logs; revealed that production probably was from the Ralph Barton zone of the Cecil Series in the lower Atoka (Figure 7).

An accurate interpretation of the factors responsible for entrapment of gas in this field

was difficult to obtain. The field seems to be either an anticlinal fold formed in response to the Mulberry Fault or an upthrown block formed by intersection of the Greasy Creek Fault and the Mulberry Fault. Yale Oil recently made a discovery in this field, but production information has not yet been released.

Roland Northwest Field

The Roland Northwest Field was discovered by Citizens Gas Company in 1926. The field is located in Section 15, T.11N., R.26E. Only data about cumulative production was available. The field produces from an anticlinal trap on the upthrown side of the Mulberry Fault.

Opportunities for Development of Gas Fields

Most future opportunity exists in the exploitation of deeper reservoirs within established fields. Detailed subsurface mapping as well as the acquisition of modern seismic data may aid in the mapping of anticlinal closure in these reservoirs. Also, infill drilling in these fields may bring about the maximal recovery of reserves in established reservoirs. Other opportunities exist in the testing of smaller anticlines and fault blocks expressed at the surface. Proper imaging of these structures may require the acquisition of modern seismic data. Opportunity also exists in the development of small reservoirs in Sandstones of the Atoka, some traps in which seem to be stratigraphically controlled. Most of these reservoirs are noncommercial, but increase in natural-gas prices, coupled with more economical drilling procedures, may warrant their development.

CHAPTER VI

DISCOVERIES AND CONCLUSIONS

Discoveries

Faults

Several faults not mentioned in previous publications were mapped. Greasy Creek Fault was interpreted to extend southeastward from Section 19, T.13N., R.26E., (White, 1955, Geologic Map) into the study area in Section 3, T.12N., 26E., through Section 21, T.12N., R.27E., and beyond. A fault was interpreted along Camp Creek. This fault was mapped from Section 20, T.11N., R.26E., northeastward to Section 9, T.11N., R.26E. A fault was interpreted along Wilson Branch. This fault was mapped from Section 15, T.11N., R.25E., northeastward to Section 36, T.12N., R.25E. A small fault was interpreted and mapped from Section 11, T.11N., R.25E., northeastward to Section 31, T.11N., R.25E. A small fault was interpreted along Briar Creek and mapped from Section 15, T.12N., R.26E., northeastward to Section 2, T.12N., R.26E.

Flexures

Several small folds not mentioned in previous publications were mapped. Liberty Anticline was interpreted and mapped from Section 27, T.12N., R.26E through Section 25, T.12N., R.26E. A syncline was interpreted and mapped along the approximate drainage of Little Skin Bayou from Section 12, T.11N., R.25E., northeastward to Section 6, T.11N., R.26E., and Section 29, T.12N., R.26E., northeastward to Section 28, T.12N.,

R.26E. Long Anticline was interpreted and mapped from Section 29, T.12N., R.26E., northeastward to Section 21, T.12N., R.26E.

Conclusions

1. Some folds and faults expressed at the surface can be projected into the subsurface and mapped effectively. In this study, only prominent features were mapped; more detailed surface mapping would provide a better understanding of the structural geology.
2. Most outcrops are covered, and data obtained from them is often uncertain. It is difficult to determine whether strata are in place. At most localities dips are less than five degrees; comparatively few exceed ten degrees. Strata of the middle Atoka, which is exposed in most of the study area, are very similar in lithology throughout the interval; thus differentiation among units is difficult. Dip reversal is the most definitive criterion for mapping faults at the surface. Steepened dip generally is on the downthrown blocks of faults, probably as a result of drag.
3. Several potential reservoirs are distributed within this area. The Cromwell Sandstone and the Spiro Sandstone are the most significant, although deeper reservoirs exist. The Cromwell Sandstone is unevenly distributed in the study area. Evidence suggests that at many places the Cromwell is a channel-fill facies. Two distinct facies were recognized within the Spiro interval. The upper zone is well distributed and forms a "blanket sand" throughout the study area. The lower zone (Foster Channel Sands) are sparsely distributed in the study area. This interval consists of a fining upward sequence; the rocks are interpreted as having been deposited in a fluvial deltaic setting.
4. Production of natural gas primarily is from traps developed on anticlinal flexures and



upthrown fault blocks.

SELECTED REFERENCES

- Abolo, M.G.C., 1995, Geometry and depositional systems of the Cromwell Sandstone in parts of Haskell, Latimer, LeFlore, Muskogee and Sequoyah Counties, Oklahoma: Unpublished Master of Science Thesis, Oklahoma State University, 94 p.
- Adams, G. I., and Ulrich, E. O., 1905, Fayetteville Folio: United States Geological Survey, Geologic Atlas of the United States, No. 119.
- Blythe, J. G., 1959, Atoka Formation on the north side of the McAlester Basin, Oklahoma: Oklahoma Geological Survey Circular 47, 67 p.
- Branan, C.B., 1968, Natural gas in Arkoma Basin of Oklahoma and Arkansas *in* Bebee, B.W., ed., Natural gas of North America: American Association of Petroleum Geologists, Memoir 9, v. 2, p. 1616-1635.
- Branson, C.C., 1954, Scenery and Geology of the Sallisaw Area, The Hopper, v. 14, no. 10, Oklahoma Geological Survey, pp. 154-158.
- Chenoweth, P.A., 1983, Principal structural features of Oklahoma: Pennwell Maps.
- Clupper, D.R., 1978, The lithostratigraphy and depositional environments of the Pitkin (Mississippian) in Adair County, northeastern Oklahoma (abs.): Oklahoma Geology Notes, v. 38, no. 2, p. 69.
- Croneis, C. G., 1930, Geology of the Arkansas Paleozoic area with special reference to oil and gas possibilities: Arkansas Geological Survey Bulletin 3, 457 p.
- Crumpley, B.K., 1949, A field reconnaissance of the geology of southeastern Sequoyah County, Oklahoma: Unpublished Master of Science Thesis, University of Oklahoma, 34 p.
- Fields, P.M., 1987, Subsurface geology of the Morrowan Lower Dornick Hills (Cromwell Sandstone) and the Desmoinesian Krebs (Hartshorne and Lower

- Booch Sandstones) in northern Pittsburg County, Oklahoma: Unpublished Master of Science Thesis, Oklahoma State University, 151p.
- Ferguson, C.A., 1988, Wapanucka Formation: A Morrowan-Atokan shallow-water limestone and sandstone *in*, Shelf-to-basin geology and resources of Pennsylvanian strata in the Arkoma Basin and Frontal Ouachita Mountains of Oklahoma: Oklahoma Geological Survey Guidebook 25, p. 97-100.
- Haines, R. A., 1981, Middle Atokan delta systems in the Arkoma Basin of Arkansas: *in*: Technical Proceedings of the 1981 American Association of Petroleum Geologists Mid-Continent Regional Meeting, p. 42-45.
- Haley, B. R., and Hendricks, T.A., 1972, Geology of the Van Buren and Lavaca Quadrangles Arkansas - Oklahoma: Arkansas Geological Commission Information Circular No. 20E - 20I, p. A1-A32.
- Henbest, L. G., 1953, Morrow Group and lower Atoka Formation of Arkansas: American Association of Petroleum Geologists Bulletin, v. 37, p. 1935-1953.
- Hendricks, T. A. and Parks, Bryan, 1950, Geology of the Fort Smith District, Arkansas: United States Geological Survey Prof. Paper 221-E, p. 67-94.
- Hendricks, T.A., and Parks, Bryan, 1937, Geology and mineral resources of the western part of the Arkansas coal field: United States Geological Survey Bulletin 847-E, p. 188-224.
- Houseknecht, D. W., 1987, The Atoka Formation of the Arkoma Basin: Tectonics, Sedimentology, Thermal Maturity, Sandstone Petrology, Tulsa Geological Society, Short Course Notes, April, 1987, 72 p.
- Houseknecht, D. W., 1983, Tectonic-sedimentary evolution of the Arkoma Basin and guidebook to deltaic facies, Hartshorne sandstone: Society of Economic Paleontologists and Mineralogists, Midcontinent Section, v. 1, 119 p.
- Huffman, G.G., 1958, Geology of the flanks of Ozark Uplift: Oklahoma

Geological Survey Bulletin 77, 115p.

Huffman, G.G., 1951, Geology of the Ozark Uplift, Northeastern Oklahoma: Shale Shaker, v. 2, no. 3, p. 36-42.

Huffman, G. G., 1951, Recent Investigations of pre Atoka rocks in Northeastern Oklahoma, Tulsa Geological Society Digest, v. XIX.

Jefferies, B.K., 1982, Stratigraphy and depositional patterns of the Union Valley, Wapanucka and Lower Atoka formations: Unpublished Master of Science Thesis, University of Arkansas, 55 p.

Johnson, K.S., 1988, General geologic framework of the field-trip area *in*, Shelf-to-basin geology and resources of Pennsylvanian strata in the Arkoma Basin and Frontal Ouachita Mountains of Oklahoma: Oklahoma Geological Survey Guidebook 25, p. 1-5.

Laudon, R. B., 1958, Chesterian and Morrowan Rocks in the McAlester Basin of Oklahoma: Oklahoma Geological Survey Circular 46, 29 p.

Manger, W. L., and Zachry, D. L., 1998, Morrowan (Lower Pennsylvanian) reservoir stratigraphy, southern Ozark region, northern Arkansas: Fort Smith Geological Society Field Trip Guidebook, November 12-13, 1998, 17p.

Marcher, M.V., 1969, Reconnaissance of the water resources of the Fort Smith Quadrangle, east-central Oklahoma: Oklahoma Geological Survey Map HA-1, Fort Smith Quadrangle (scale 1: 250000).

Meckel, L. D. Jr., Smith, D. G., and Wells, L. A., 1992, Ouachita foredeep basins: Regional paleogeography and habitat of hydrocarbons: American Association of Petroleum Geologists, Memoir 55, Foreland basins and fold belts, pp. 427-444

Miser, H.D. and others, 1954, Geologic map of Oklahoma: United States Geological Survey, scale 1: 500,000.

Miser, H. D., 1954, Geologic Units of Sequoyah County, Oklahoma: Oklahoma

McCaleb, J.A., 1961, The late Morrowan-Atokan stratigraphy and paleontology of Crawford County, Arkansas, Unpublished Masters Thesis, University of Arkansas 115 p.

Purdue, A. H., and Miser, H. D., 1916, Eureka Springs and Harrison Folio, United States Geological Survey Survey, Geologic Atlas of the United States, No. 202

Purdue, A. H., 1907, Winslow Folio, Arkansas-Indian Territory areal geology: United States Geological Survey, Geologic Atlas of the United States, No. 154.

Quinn, J. H., 1959, Buried Structures of the Boston Mountains, Field Guide, Fort Smith Geological Society, April 30 - May 2, 1959, p. 29-78

Raible, C.J., 1959, Geology of the Liberty Hill area, Crawford County, Arkansas: Unpublished Master Of Science Thesis, University of Arkansas, 52 p.

Rea, A., and Becker, C. J., 1997, Digital Atlas of Oklahoma, United States Geological Survey, Open File Report 97-23

Roberts, J. F., 1981, Index to surface mapping in Oklahoma (through 1976). Oklahoma Geological Survey Map GM-21 (scale 1:750,000).

Schramm , M.W., Jr., and Caplan, W.M., 1971, Southeast Oklahoma and northern Arkansas, *in* Cram. I.H., ed., Future petroleum provinces of the Mid-Continent: their geology and potential: American Association of Petroleum Geologists, Memoir 15, v. 2, p. 1636-1643.

Shelby, P.R., 1997, Consulting geologist, Personal Communication.

Simonds, F. W., 1891, The Geology of Washington County, Ark. Geol. Survey, Annual Report for 1888

Stout, R.D., 1991, Subsurface geology of the Morrowan Lower Dornick Hills (Cromwell Sandstone) in southern Hughes County, Oklahoma: Unpublished Master of Science Thesis, Oklahoma State University, 171 p.

Sutherland, P.K., 1988a, Late Mississippian and Pennsylvanian depositional history in

the Arkoma Basin area, Oklahoma and Arkansas: Geol. Society of America Bulletin, v. 100, no. 11, p. 1787-1802.

Sutherland, P.K., 1988b, Arkoma Basin *in* Sloss, L.L., ed., Sedimentary cover of North American craton, U.S., the geology of North America: Geological Society of America v. D-2, p. 331-340.

Sutherland, P.K. and Manger, W.L., 1977, Upper Chesterian-Morrowan stratigraphy and the Mississippian-Pennsylvanian boundary in northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey Guidebook 18, 185 p.

Sutherland, P.K. and Manger, W.L., 1984, The Atokan Series (Pennsylvanian) and its boundaries--a symposium: Oklahoma Geological Survey, Bulletin 136, 198 p.

Taff, J. A., 1905, Tahlequah Folio, Indian Territory-Arkansas: United States Geological Survey, Geologic Atlas of the United States, No. 122, 7p.

Tidwell, E.M., 1976, Bibliography of North American oil and gas fields from American Association of Petroleum Geologists Publications, *in* North American oil and gas Fields: American Association of Petroleum Geologists, Memoir 24, p. 300-346.

White, J.M., Jr., 1955, The Brushy Mountain structure, Sequoyah and Adair Counties, Oklahoma: Unpublished Master of Science Thesis, University of Oklahoma, 37 p.

Wylie, D.W., 1988, Arkoma Basin overview *in*, Shelf-to-basin geology and resources of Pennsylvanian strata in the Arkoma Basin and Frontal Ouachita Mountains of Oklahoma: Oklahoma Geological Survey Guidebook 25, p. 63-65.

Woncik, J., 1968, Kinta gas field, Haskell County, Oklahoma, *in* Bebee, B.W., and Curtis, B.F., eds., Natural gas of North America: American Association of Petroleum Geologists, Memoir 9, v. 2, p. 1636-1643.

Zachry, D. L., 1984, Stratigraphy and depositional framework of the Atoka Formation

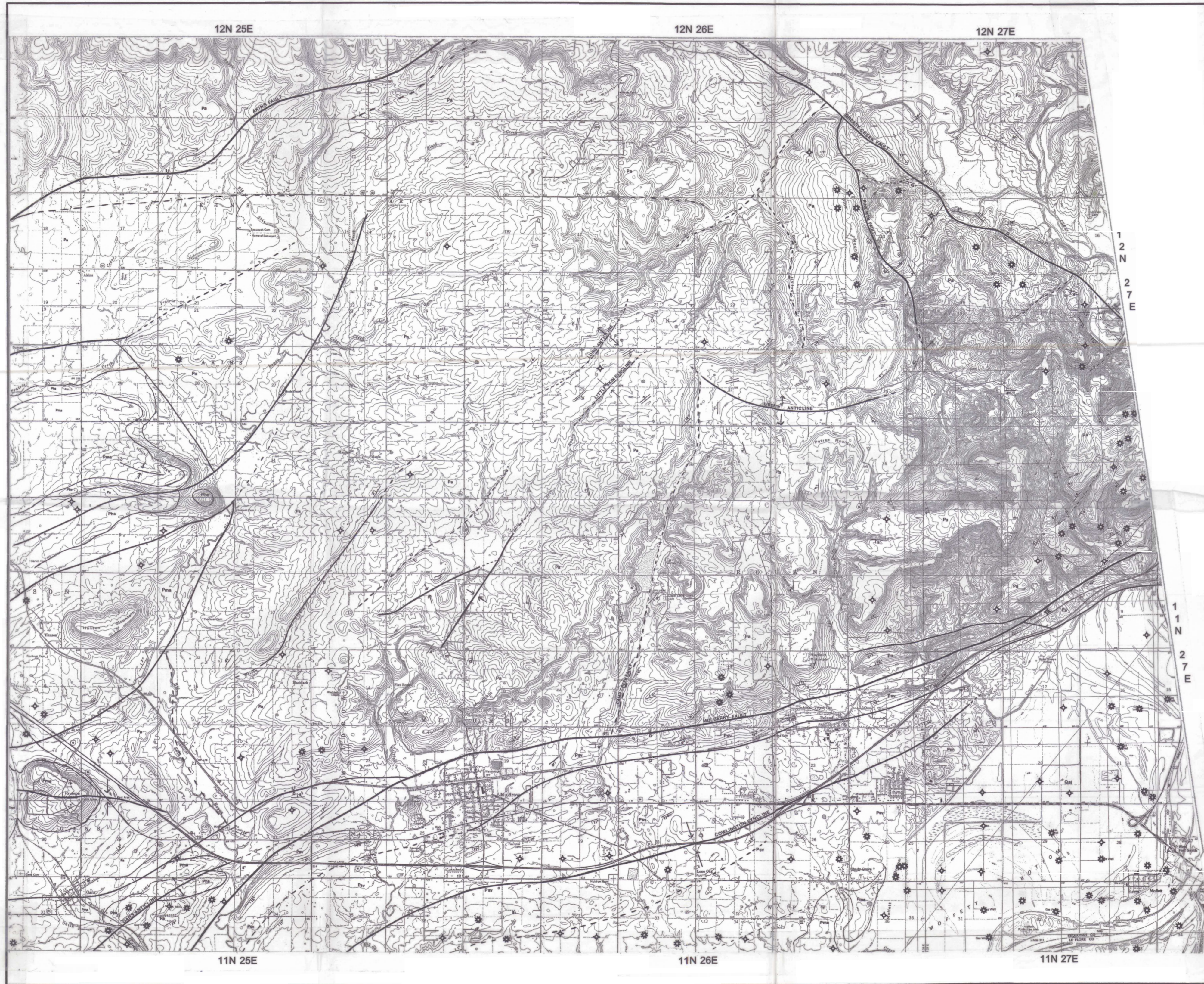
(Pennsylvanian) Arkoma Basin of Arkansas and Oklahoma, *in* Oklahoma Geological Survey, Bulletin 136, p. 9-17

Zachry, D.L., 1984, Stratigraphy and depositional framework of the Atoka Formation (Pennsylvanian) Arkoma Basin of Arkansas and Oklahoma: Oklahoma Geological Survey Bulletin 136, p. 9-17.

Zachry, D. L., 1983, Sedimentologic framework of the Atoka Formation, Arkoma Basin, Arkansas *in* Tectonic-sedimentary evolution of the Arkoma Basin and guidebook to deltaic facies, Hartshorne sandstone: Society of Economic Paleontologists and Mineralogists, Midcontinent Section, v. 1, pp. 34-52.

PLATES

1, 2, 3, 4, 5, and
6



EXPLANATION

Geologic Symbols

- Bedding appears to be horizontal
- Dip and Strike of beds
- Dip and Strike based on geomorphic evidence
- Orientation of fractures or joints
- Normal Fault
- Probable Fault
- Questionable Fault
- Anticline, arrow denotes plunge, dashed where indefinite, questioned where inferred
- Syncline, arrow denotes plunge, dashed where indefinite, questioned where inferred

Stratigraphic Section

- Quat. Alluvium
- Savanna Formation
- McAlester Formation
- Hartshorne Formation
- Atoka Formation

Well Symbols

- DRY HOLE ✕
- GAS WELL *
- INCOMPLETE ○

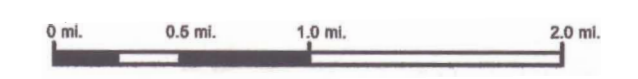
STRUCTURAL GEOLOGY OF SURFACE

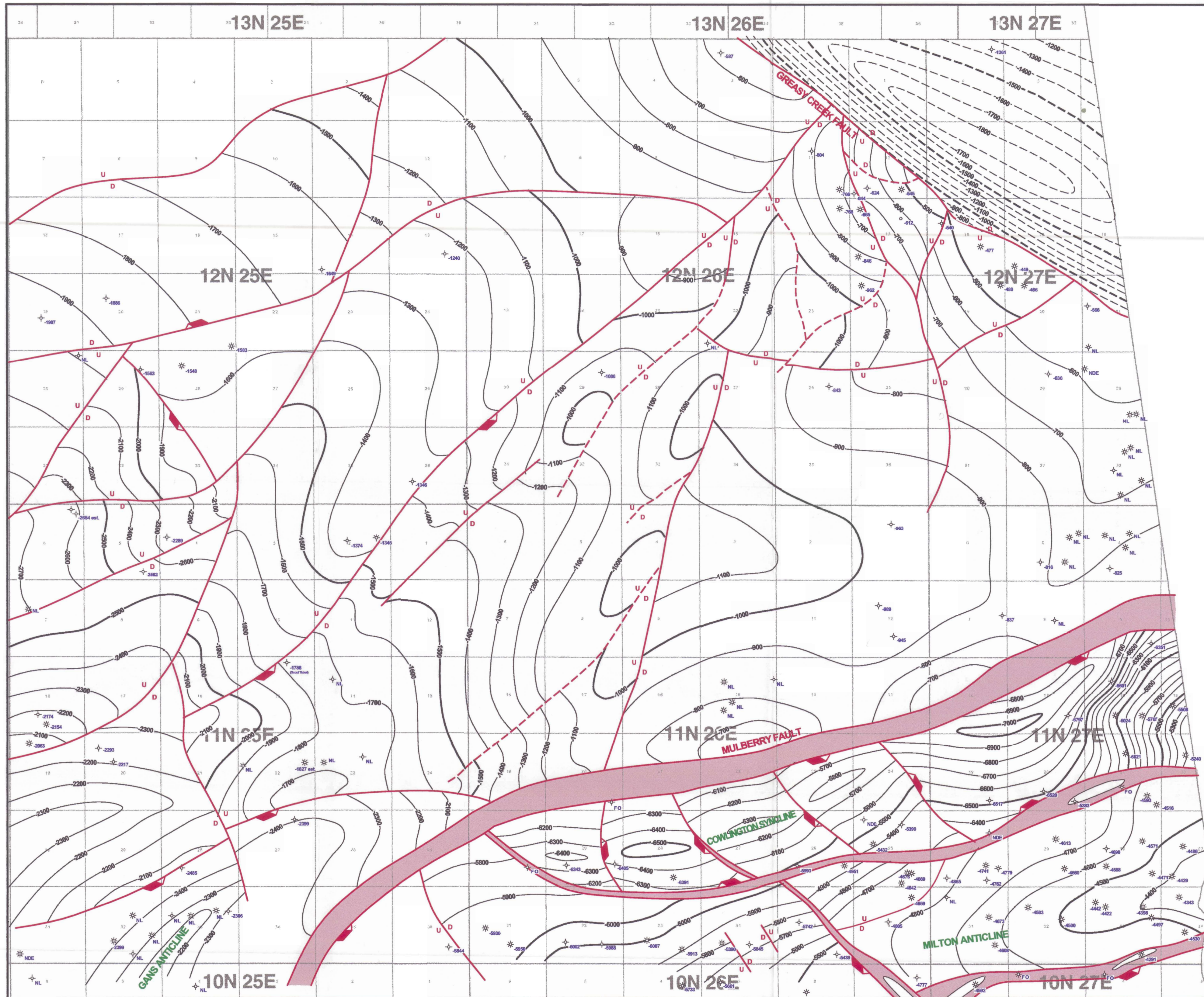
mapped on U.S.G.S. Topographic Base

December 1998

1:48,000

Plate I
Jim Blackwood





LEGEND

| | |
|---|--|
| <p>DRY HOLE ✦</p> <p>GAS WELL ✧</p> <p>INCOMPLETE ○</p> <p> NORMAL FAULT</p> <p> PROBABLE FAULT</p> <p> HEAVE</p> <p> CONTOUR LINES IN AREA OF QUESTIONABLE STRUCTURE</p> | <p>NDE = Not deep enough</p> <p>NL = No log</p> <p>est. = Estimated</p> <p>FO = Faulted out</p> <p>2500 = Structural top</p> |
|---|--|

STRUCTURAL CONTOUR MAP Top of Morrow (Wapanucka)

C. I. = 100 ft.
December 1998
1:48,000
Plate II
Jim Blackwood

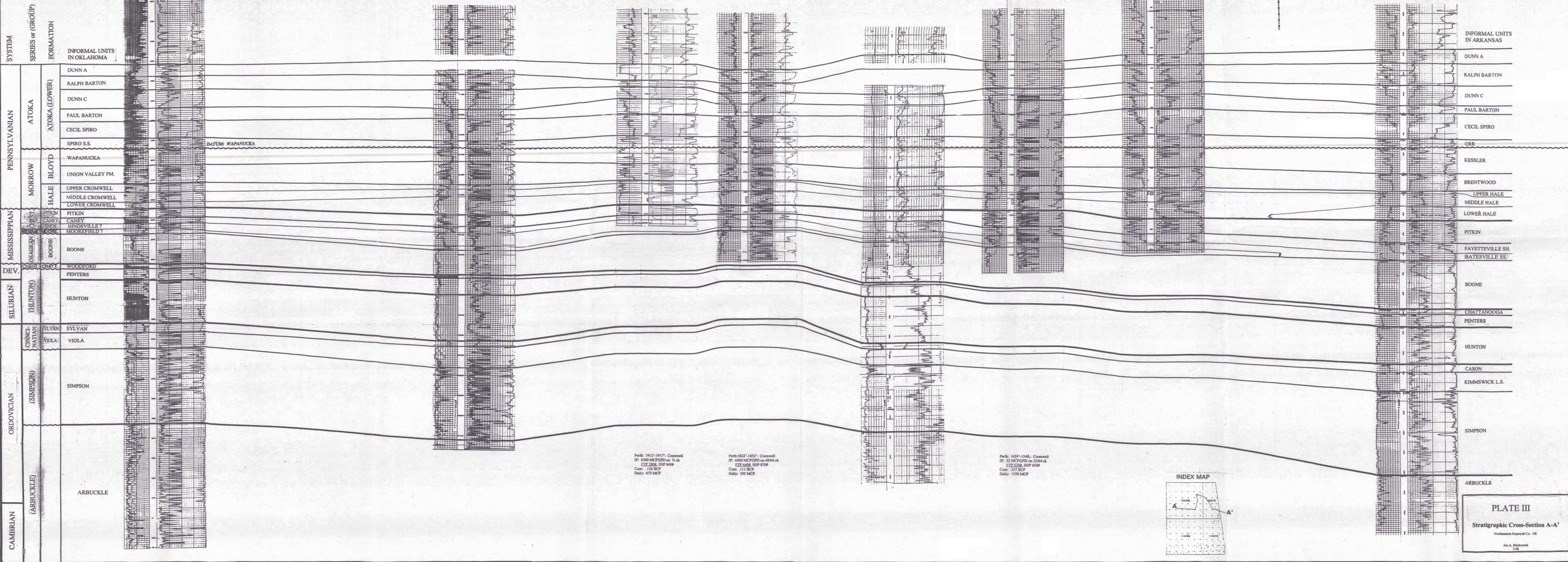
A

A'

WEST

EAST

OK ARK



8-04-83
 STEPHENS PRODUCTION
 AUSTIN O'NEAL # 1-29
 29-12N-26E
 KB: 846'
 TD: 3946'

6-07-88
 QUAPAW OIL & GAS
 O'NEAL #1
 26-12N-26E
 DF: 827'
 TD: 3144'

8-02-96
 HOOVER/WILSON
 BELL #2
 13-12N-26E
 KB: 822'
 DF: 519'
 TD: 2020'

8-23-95
 HOOVER/WILSON
 PINE MOUNTAIN #1
 11-12N-26E
 KB: 812'
 TD: 2112'

2-15-65
 MCBRIDE
 OPIE CATES #1
 18-12N-27E
 DF: 519'
 TD: 2738'

7-29-96
 HOOVER/WILSON
 WARNER #1
 19-12N-27E
 KB: 684'
 TD: 1738'

5-13-97
 HOOVER/WILSON
 BELAND HEIRS
 29-12N-27E
 KB: 860'
 TD: 2340'

4-21-74
 DIAMOND SHAMROCK
 NANCY ORR #1
 8-0N-32W
 KB: 520'
 TD: 3100'

Perfs: 1913'-1917'; Cromwell
 IP: 4300 MCFGPD on 1/4 ck
 ETP: 2800, ISIP 8400
 Cum: 134 BCF
 Daily: 675 MCF

Perfs: 1822'-1852'; Cromwell
 IP: 6400 MCFGPD on 49/64 ck
 ETP: 4600, ISIP 8700
 Cum: 111 BCF
 Daily: 595 MCF

Perfs: 1424'-1548'; Cromwell
 IP: 32 MCFGPD on 32/64 ck
 ETP: 5300, ISIP 6500
 Cum: 237 BCF
 Daily: 1550 MCF

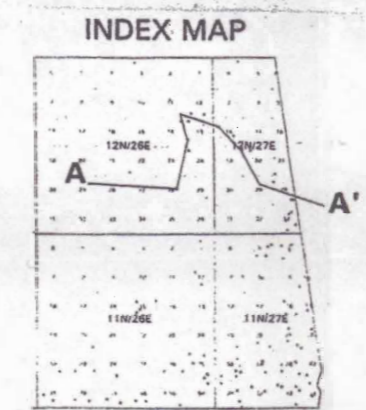


PLATE III
 Stratigraphic Cross-Section A-A'
 Northeastern Sequoyia Co. OK
 Geo. A. Blackwood
 3-58

B
WEST

B'
EAST

8-29-78
STEPHENS PRODUCTION
CLUCK NO. 1
31-11N-26E
KB 500*
TD 7116

4-28-78
STEPHENS PRODUCTION
E.C. ROWLAND NO. 2
32-11N-26E
KB 486*
TD 7260

7-8-87
STEPHENS PRODUCTION
ROWLAND NO. 4
33-11N-26E
KB 436
TD 6825

1-10-88
LYSANDER RESOURCES
OWENS NO. 1-34
34-11N-26E
KB 455
TD 6700

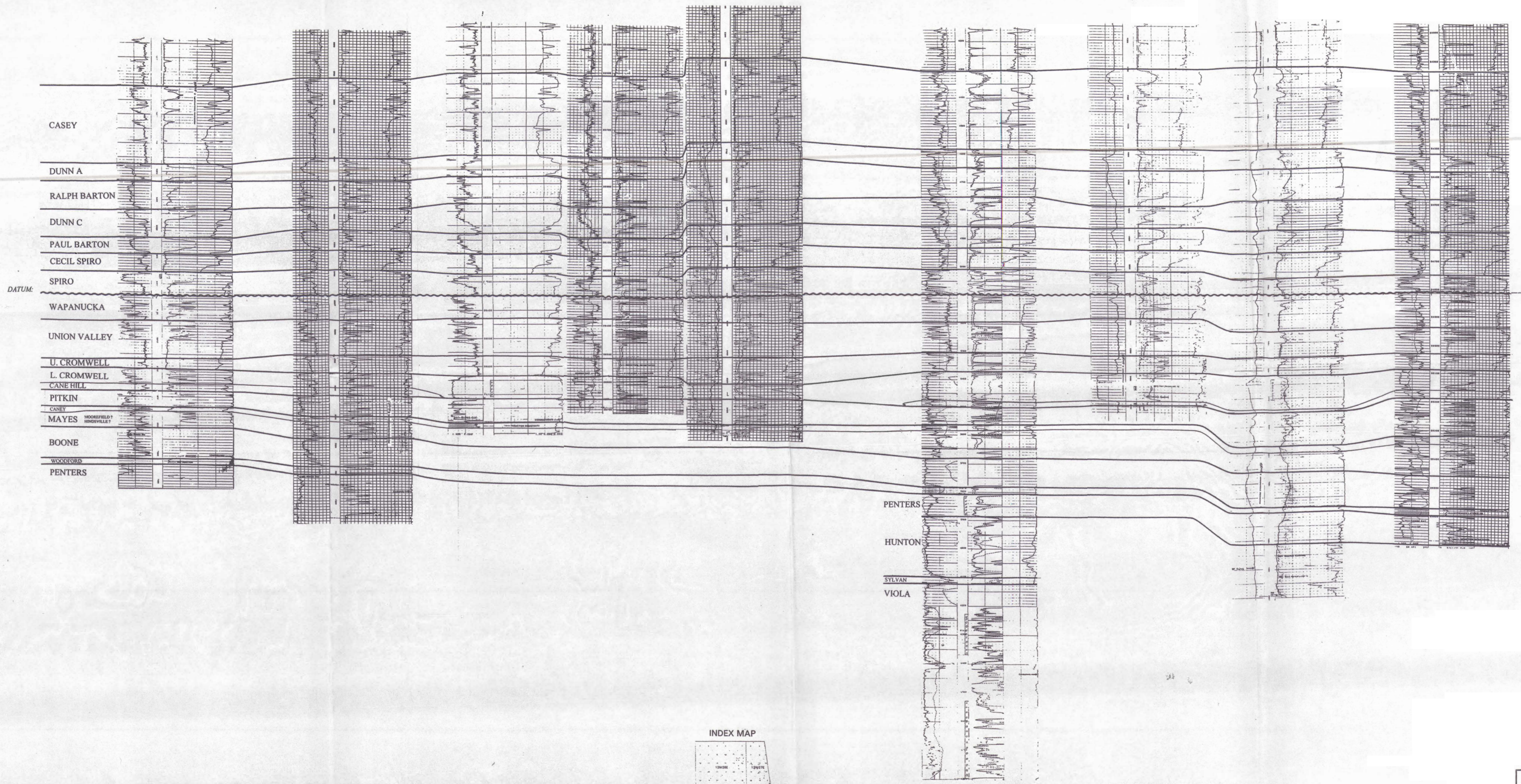
12-11-79
STEPHENS PRODUCTION
WARD #1
35-11N-26E
KB 458
TD 6728

10-22-88
OXLEY PETROLEUM
PATES FARM # 1-25
25-11N-26E
KB 428
TD 6812

3-28-74
J. LEE YOUNGBLOOD
WYLY NO. 1
31-11N-27E
KB 428
TD 5505

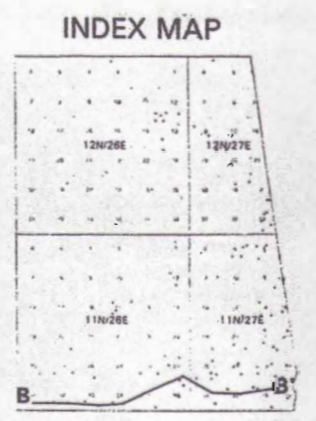
2-6-68
MOBIL OIL CORPORATION
MIRIAM ROGERS #1
32-11N-27E
KB 430
TD 6000

5-22-97
TXO PRODUCTION CORP.
OPIE CATES NO. 1
33-11N-27E
KB 414
TD 5670



Perfs. 6369'-6377': Spiro
IP: 3350 MCF/GD on 1/4 TC
Cum: 573 BCF-Cmgld. (Spiro/Crom.)
Daily: 101 MCF

Perfs. 6650'-6710': Cromwell
IP: 9338 MCF/GD on 40/64 ck
TP 854 #, STP 1736 #
Cum: 2.56 BCF
Daily: 167 MCF



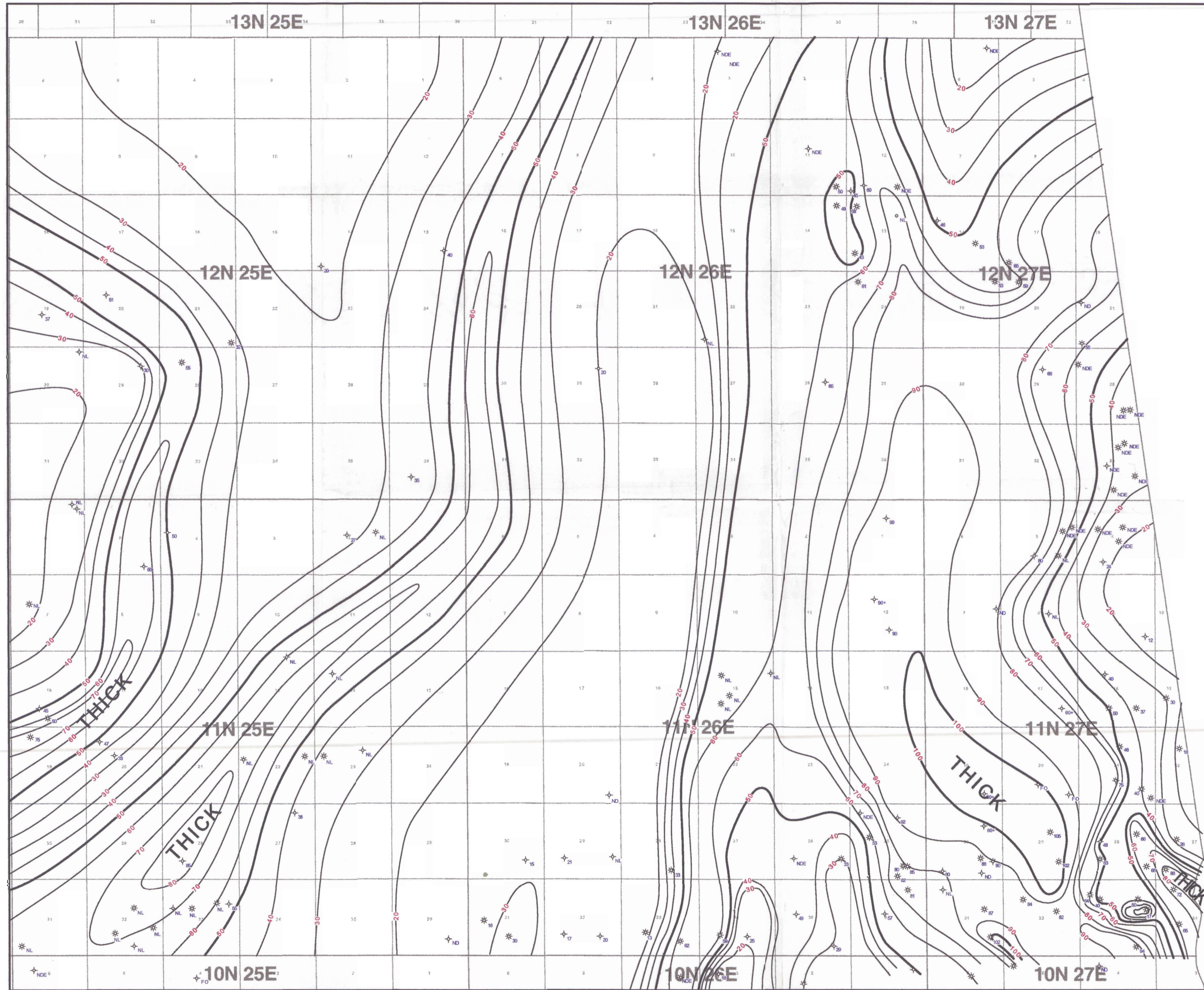
Perfs. 586'-5883': Hunton,
IP: 6450 MCF/GD on 48/64 ck
6228'-6368': Simpson
IP: 765 MCF/GD on 24/64 ck
6528'-6812': Arbuckle
IP: 1300 MCF/GD on 48/64
Cum: (cmgld): 5.16 BCF
Daily: 1NA

Perfs. 5430'-5440': Cromwell
IP: 3927 MCF/GD, FTF: 940 #
Cum: 3.25 BCF
Daily: 331 MCF

Perfs. 5234'-5306': Cromwell
IP: 5761-5789': Hunton
5835-5844': Hunton
IP: 2157 MCF/GD on 14/64 ck
FTP: 788 #
Cum: 6.55 BCF
Daily: 484 MCF

Perfs. 5624'-5636': Hunton
IP: 3650 MCF/GD on 24/64 ck
STP: 2200 #
Cum: 1.67 BCF
Daily: 76 MCF

PLATE IV
Stratigraphic Cross-Section B-B'
Eastern Sequoyah Co.
Jim A. Blackwood
4/88



LEGEND

| | |
|---|---|
| <p>DRY HOLE ✦</p> <p>GAS WELL *</p> <p>INCOMPLETE ○</p> | <p>NDE = Not deep enough</p> <p>NL = No log</p> <p>est. = Estimated</p> <p>FO = Faulted out</p> <p>-2500 = Structural top</p> |
|---|---|

CROMWELL SANDSTONE ISOLITH MAP

C. I. = 10 ft.
December 1998

Plate V
Jim Blackwood

1:48,000

0 mi. 0.5 mi. 1.0 mi. 2.0 mi.

VITA ²

Jim A. Blackwood

Candidate for the Degree of
Master of Science

Thesis: GEOLOGIC FRAMEWORK OF EASTERN SEQUOYAH COUNTY,
OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Ft. Smith, Arkansas, On January 24, 1970, the son of John E. Blackwood, Jr. (deceased) and Audrey K. Barthel.

Education: Graduated from Roland High School, Roland, Oklahoma in May 1988; received Bachelor of Science degree in Geology from the University of Arkansas, Fayetteville, Arkansas in December 1995. Completed the Requirements for the Master of Science degree with a major in Geology at Oklahoma State University in May, 1999.

Experience: Employed by University of Arkansas, Department of Geology as an undergraduate. Employed by Oklahoma State University as a graduate research assistant and as a graduate teaching assistant. Employed by Marathon Oil Company as an Intern Geologist. Employed by Barrett Resources Corporation as an Associate Geologist. Employed by Stephens Production Company as a Geologist.

Professional Memberships: American Association of Petroleum Geologists, Tulsa Geological Society, Ft. Smith Geological Society