GEOMETRY AND DEPOSITIONAL SYSTEMS OF THE CROMWELL SANDSTONE (MORROWAN LOWER DORNICK HILLS) IN PARTS OF HASKELL, LATIMER, LE FLORE, MUSKOGEE AND SEQUOYAH COUNTIES, OKLAHOMA

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CHAPTER I

ABSTRACT

In the Arkoma Basin of northeastern Oklahoma, the Cromwell Sandstone consists of one single well-distributed member. This member lies disconformably on the underlying Pitkin Limestone (Upper Mississippian) and is bounded conformably at its top by the unnamed limestone referred to as the Union Valley Limestone. The petrography of the Cromwell, which includes calcareous sandstones with shale interbeds, is quartz-arenite to sublitharenite.

On the basis of evidence provided by subsurface mapping and cores, the Cromwell Sandstone is interpreted as having accumulated in wave-modified river-dominated deltaic systems. Three major delta lobes were identified in the study area. All of them trend from north to south and probably confirm the northerly cratonic source for the sediments. The sandstone contains distributary channel, reworked interdistributary, and delta-fringe deposits of a wave-modified river-dominated delta sequence.

CHAPTER II

INTRODUCTION

The Arkoma Basin is one of the most prolific dry gas producing provinces in North America. Most of the production comes from Atokan and, to a lesser extent Morrowan sandstone units. The first discovery well occurred in the early 1900's at Mansfield, Sebastian County, Arkansas. From that time few academic studies have been undertaken in the basin. The present work is primarly concerned with the Cromwell Sandstone, a member of the Morrowan Union Valley Formation. Based exclusively on subsurface data, the research has focused on the stratigraphy and structural geology, it attempts to provide detailed interpretation concerning the depositional systems of Cromwell Sandstone.

Location of the study area.

The zone of investigation is located on the northern shelf of Arkoma Basin, Oklahoma. It includes parts of Haskell, Latimer, Le Flore, Muskogee, and Sequoyah counties. This area of approximately 1188 miles consists of 33 townships from T. 7 N to T. 11 N and R. 21 E to R. 27 E. (Figure 1).

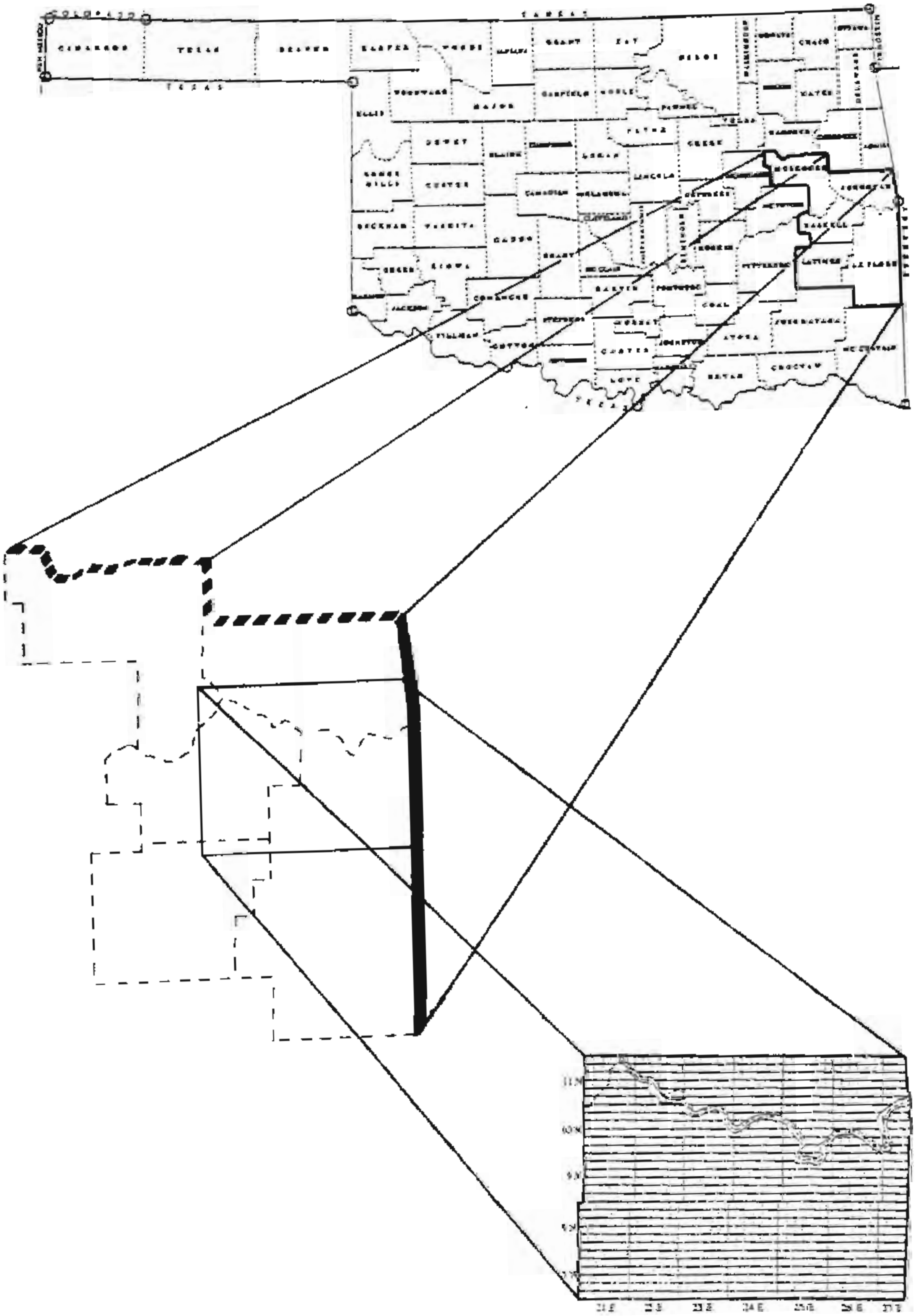

Figure 1. Location map of the study area.

Principal emphasis of the study.

The major topics covered in this thesis are:

1. The stratigraphy of the Cromwell Sandstone in relation to underlying Mississipian System and overlying Middle Pennsylvanian Series;
2. The identification and description of local and regional structural elements favorable for hydrocarbon entrapment;
3. The determination of the geometry, lateral distribution, and boundaries of the Cromwell Sandstone;
4. The identification of depositional systems within the Cromwell Sandstone.

Tools and Methods of Investigation

The completion of the present study first required the collection of subsurface data. A total of 596 well logs including electric logs, gamma ray logs, compensated neutron and formation density logs and scout tickets were obtained from Oklahoma City Log Library, and used for this study. Two cores of Cromwell Sandstone obtained from the Core and Sample Library of the Oklahoma Geological Survey were described and recorded as Petrologs. Additional information was provided by Herndon maps.

The completion of the objectives has necessitated a number of investigative techniques. A structural contour map of the top of the Wapanucka marker limestone was prepared to identify anticlinal features, faults, and overall structure. The stratigraphy, geometry, lateral distribution, and depositional systems of Cromwell Sandstone were described and interpreted by means of a net sandstone isolith map, isopach map, well log motif map, well log patterns, and six stratigraphic cross-sections that used the bottom of Wapanucka Limestone as reference datum. Besides these, an examination of the cores allowed direct determination of lithology, sedimentary structures, and fossil content within specific wells. Thin sections taken from the cores furnished information regarding Cromwell detrital and authigenic constituents. All of these were used as additional criteria for interpreting the depositional environment.

Geologic Setting

The area of interest is part of the Arkoma basin. The Arkoma Basin developed along the front of the Ouachita Mountains. The basin corresponds to an east-west trending trough that extends across part of west-central Arkansas and east-south eastern Oklahoma. Its width ranges from 20 to 50 miles. Its length is approximately 250 miles. The Arkoma basin is bounded to the south by the Choctaw Fault in Oklahoma and the Ross Creek Fault in Arkansas. The Ozark dome and the northeast Oklahoma Platform are the north and northwest boundaries (Figure 2). Recently, Valderrama and others (1994) interpreted the boundary between the frontal Ouachitas fold and thrustbelt, and the foreland Arkoma Basin as a triangle zone. These authors demonstrated that blind thrusting at deeper levels has passively uplifted the frontal Kiowa Syncline in the Arkoma Basin.

Although the Arkoma Basin is considered an Atokan-aged basin due to the great amount of sediments deposited at that time (Branan, 1968), the subsidence started in the Mississippian and occurred intermittently through Desmoinesian time (Hemish, 1994; Roberts, 1994). This is shown in Figure 3. As stated by Sutherland (1988), the

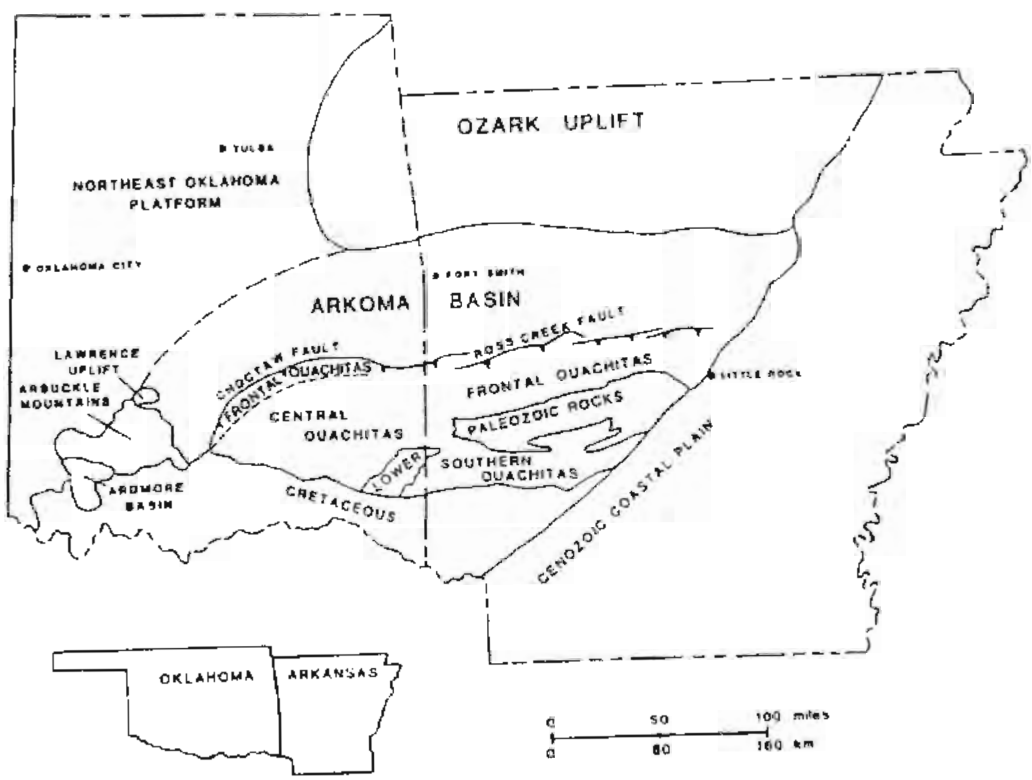

Figure 2. Arkoma Basin of Oklahoma and Arkansas, and surrounding geologic provinces (from Sutherland, 1988b, p. 332).

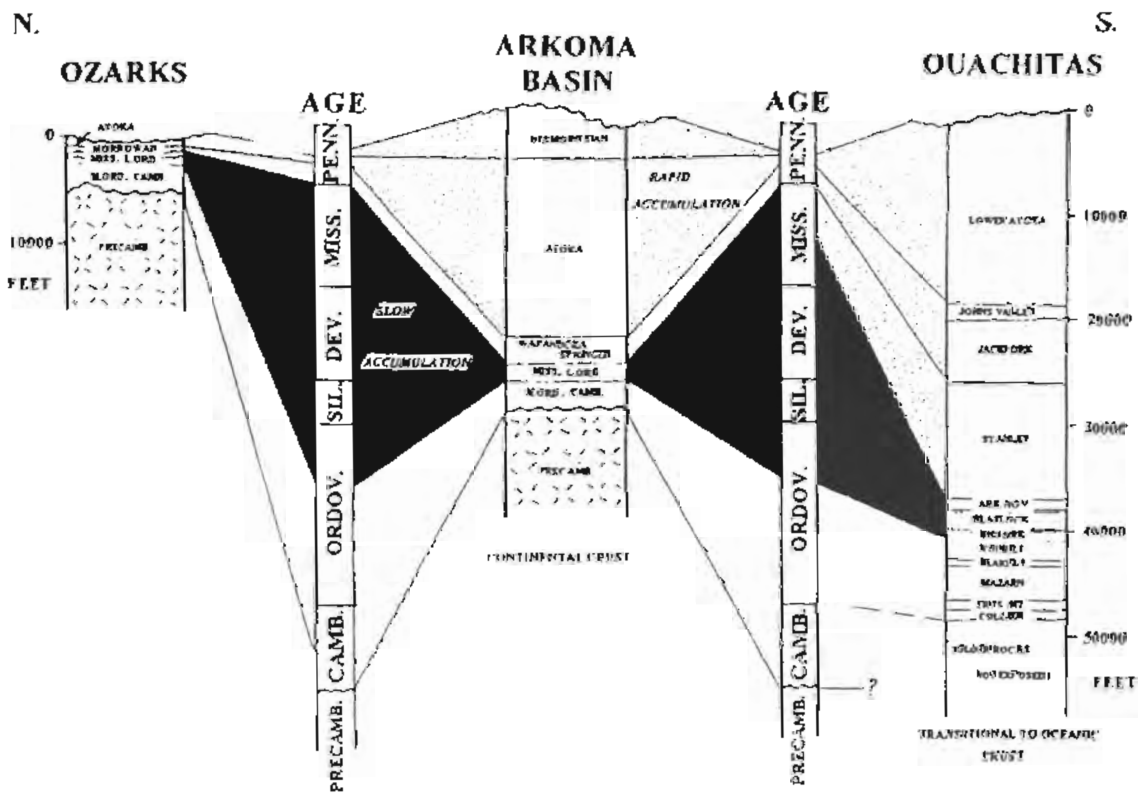

Figure 3. Time-thickness diagram, Paleozoic units of the Ozark Uplift, Arkoma Basin, and Ouachita Mountains (from Roberts, 1994, p. 140).

end of the major subsidence of the Arkoma is marked by a post-Krebs regional unconformity. The amount of sediment in the basin increased toward the south. For instance the thickness of sedimentary rocks within the areas adjacent to Ouachita Foldbelt is estimated to be 30,000 feet (Branan, 1968). According to Hemish (1994) sedimentation through Desmoinesian in the Arkoma Basin was fluvial-deltaic, and was dominated by an alternation of regressive and transgressive phases during which widespread coal swamps were developed.

The depositional history is well documented by Sutherland (1988a) who believed that most of the sediment preserved in the basin was derived from the continental interior west and north of the Ozark uplift. The strata are primarily shale with some sandstone and carbonate of Mississippian and Pennsylvanian age. The sedimentation was marked by the rapid rate of subsidence. As a consequence of this rapid subsidence, a series of east-west trending normal faults were generated in early Atokan time and continued to move through late Atokan time. The growth faults presumably developed by movement in the basement, and remained perpetuated by additional basement movement and/or sedimentary loading and slumping (McQuillan, 1978). The surface geology of the Arkoma Basin is structurally characterized by several large anticlinal valleys flanked by high surface-relief synclines (Woncik, 1968).

The first Arkoma Basin discovery well in 1902 encouraged more exploration within the basin. Today several natural gas fields exist such as Red Oak Field which is considered as the largest field in the Arkoma Basin. It has ultimate reserves of greater than 2 T C F methane (Houseknecht, 1991). Recent studies by Werner (1992) demonstrated that the thick thrusted overburden in Arkoma basin and Ouachita area resulted in hydrocarbon generation in late Atokan/Desmoinesian time and also caused the high thermal maturities of the organic material.

Natural gas entrapment is controlled by the degree of porosity and permeability of Atokan and Morrowan sands. Although Branan (1968), Schramm and Caplan (1971) suggested that stratigraphic traps played a major role in hydrocarbon entrapment within the basin, it appears clearly today that trapping mechanism within the basin is more related to structure rather than stratigraphy (Woncik, 1968; Hathon and Houseknecht, 1988; Houseknecht, 1991).

CHAPTER III

STRATIGRAPHIC FRAMEWORK

Introduction

Much has been written regarding the stratigraphy of the area. Early papers include Mather (1915), Wallis (1915), Shannon and Trout (1917), Gould (1925), Stone and Cooper (1930),Wilson (1935, 1937), Moore (1947), Oakes and Knechtel (1948), Knechtel (1949). Most recently Sutherland (1988a) discussed and correlated the regional stratigraphy of Upper Mississippian and Lower Pennsylvanian formations across the Arkoma Basin from the Ozark shelf to the Ouachita trough (Figure 4). The active period of Carboniferous deposition in shallow water facies occurred from the Chesterian through to early Atokan time in the broad Arkoma shelf.

The stratigraphy dealt with this chapter primarily discusses the Union Valley-Cromwell Formation and its relationship with underlying and overlying formations. The stratigraphic column of the study area is illustrated with a log in Figure 5. It involves the Chesterian Series, Morrowan Series, and Atokan Series. The downward extension of Mississippian Chester has not been determined, as almost all the wells failed to penetrate this series in the area. Therefore, the unique formation present corresponds to the upper part of Pitkin rocks. The Morrowan series is represented by

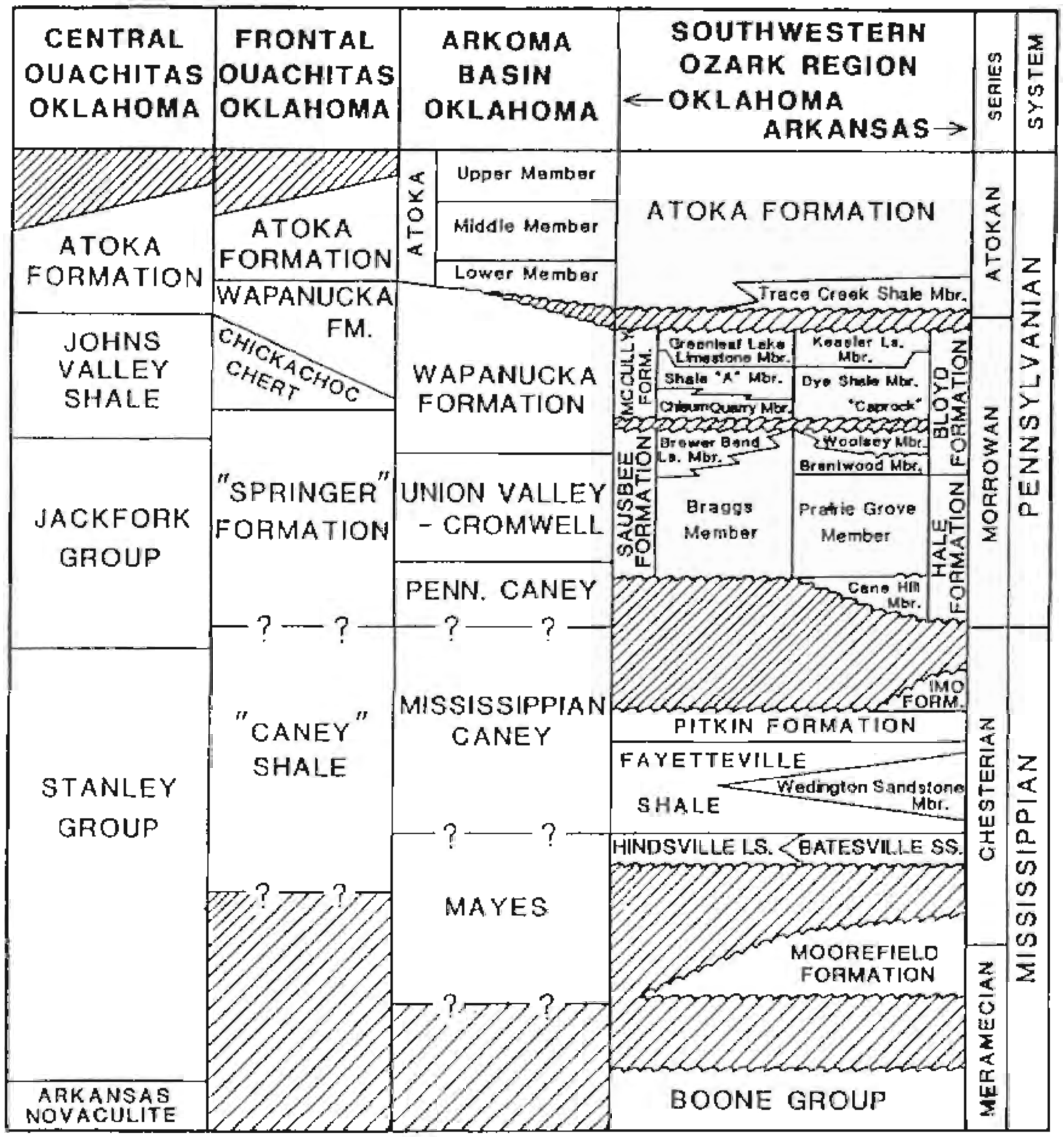

Figure 4. Regional stratigraphy of Upper Mississipian and Lower Pennsylvanian (from Sutherland, 1988b, p.333).

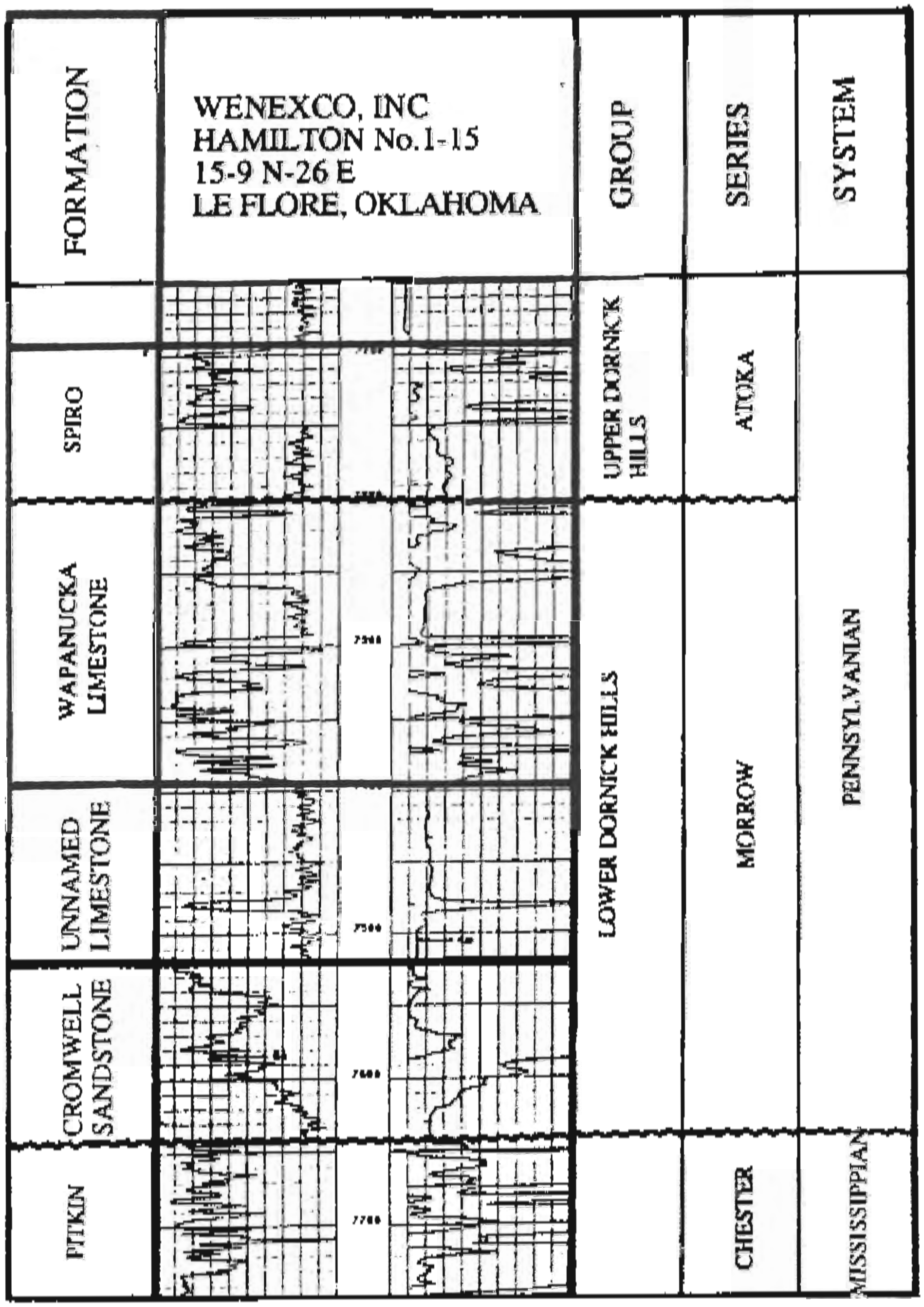

Figure 5. Type log of Upper Mississipian and Lower Pennsylvanian rocks of the investigation area.

Lower Dornick Hills Group contains Union Valley Formation at the bottom and Wapanucka Formation at the top. The Atokan Series overlies the Morrowan Series and comprises the Atoka Formation. It is advisable to note that the terms upper and lower Dornick Hills are used in subsurface geologic nomenclature. Finally the Desmoinesian Series, which includes in ascending order Krebs Group, Cabaniss Group, and Marmaton Group, overlies the Atoka. (Table 1).

Upper Mississipian Series

Chesterian Series.

The Upper Mississippian Chesterian Series is bounded below by an unconformity. It consists primarily of the Fayetteville Shale and the Pitkin Limestone in western Arkansas and eastern Oklahoma. To the southwest of the Arkoma Basin, the Pitkin is absent. It has undergone a facies change to shale and corresponds to the Mississippian Caney Shale. Therefore, the upper unit of Mississipian in this portion of the basin is the Caney Shale overlain by the Mayes Formation. However, as the Caney is partly Pennsylvanian, Whiteside (1994) on the basis of conodonts, believed that it is incorrect to use the terms Caney and "Springer" Formations respectively as equivalent to the chronostratigraphic subdivisions of Mississippian and Pennsylvanian in northwestern Ouachita Mountains. According to Mereweth and others (1963), the Fayetteville and the Pitkin Formations belong probably to the same sedimentary unit. In a note published on Wagoner, Cherokee, and Muskogee Counties, Oklahoma, Orgren (1980) explained the major transition from the deposition of the

Table 1: Upper Mississippian, Lower and Middle Pennsylvanian Stratigraphy
(modified from Sutherland, 1988b; Oakes, 1953, 1977)

Desmoinesian Series	Marmaton Group	Holdenville Shale Wewoka Formation Wetumka Shale Calvin Sandstone
	Cabaniss Group	Senora Formation Stuart Formation Thurman Sandstone
	Krebs Group	Boggy Formation Savanna Formation McAlester Formation Hartshorne Sandstone
Atokan Series	Upper Dornick Hills Group	Atoka Formation
Morrowan Series	Lower Dornick Hills Group	Wapanucka Formation Union Valley Formation
Chesterian Series		Pitkin Formation Fayetteville Shale

Fayetteville Shale to the Pitkin Limestone in two ways. First, the decreasing of the amount of incoming terrigenous materials during a still-stand allowed carbonates to develop on the accumulated terrigeneous sediments. Second, the two formations were laterally equivalent, and were eventually brought to rest on one another due to of a transgression of the seas.

The Fayetteville Shale was first named by Simonds in 1891 (Gould, 1925) in reference to the rocks exposed in Fayetteville Arkansas. This formation is conformably underlain by the Hindsville Limestone in the southwestern Ozark region. Scattered outcrops near the northwestern corner of Sequoyah County are dark bituminous shale with a few sandstone and limestone lentils (Stone and Cooper, 1930). The Fayetteville Shale in Arkansas has been correlated with the Caney Shale (Branan, 1968). The maximum thickness of about 50 m for this unit was determined by Sutherland (1981) in eastern Oklahoma.

The Pitkin Limestone lies conformably upon the Fayetteville Shale. The term Pitkin derived from the locality of Pitkin, Arkansas. It was first used by Adams and Ulrich in 1904 (Gould, 1925). The Pitkin Formation is present within the study area, but only few wells penetrate it. Be that as it may, the thickness of the unit is not more than 50 feet. The Pitkin Formation crops out in the southern part of the Ozarks, due to faulting. Depositional environments in northeastern Oklahoma, as described by Clupper (1978) were dominated by oolite shoals, inter-shoal areas, and anoxic reducing environments.

Mississippian-Pennsylvanian Boundary

The relationship between the Mississippian System and the Pennsylvanian System is not clearly explained in Arkoma Basin literature. Most of the geologists consider the bottom of the Cromwell Sandstone as the base of the Pennsylvanian, although the typical Morrowan Series begins with the Pennsylvanian Caney in the central and southern parts of the Arkoma basin (Sutherland, 1988a; 1988b). Nevertheless, the Mississippian-Pennsylvanian boundary has been recorded as being an unconformity in the southern Mid-Continent (Gould, 1935; Sutherland, 1980, 1980, 1981, 1988a, 1988b; Manger and Sutherland, 1980; Manger, 1993). This unconformity occurred across the Arkoma Basin from the Ozark shelf to the Ouachita trough and resulted from a marine withdrawal throughout the southern Mid-Continent region (Sutherland, 1980a, 1980b). Grayson (1990) used the conodont faunal assemblages to demonstrate the absence of the unconformity in southwestern part of the Arkoma Basin. For Manger and Sutherland (1980), the magnitude of the unconformity between Chesterian and Morrowan Series is variable compared to the type Namurian Series of Europe. The Mississippian-Pennsylvanian unconformity in southern Ozark uplift was recently examined by Manger (1993) who concluded that the unconformity developed as a consequence of first loading of the crust by the rising Ouachitas. In the area of investigation, Pennsylvanian strata overlie the Mississippian strata unconformably

Pennsylvanian System

Morrowan Series

The Morrowan Series, originally placed in the Mississippian by Branan (1891) is now considered to be Early Pennsylvanian in age. In reality the Morrowan was first referred to as a series by the Committee on Stratigraphy of the National Research Council (Moore and others, 1944). The Morrowan Series presents a complex depositional pattern which is characterized by both lateral facies changes and major variations in facies changes. Basically, in the Arkoma basin the formations are shales, sandstones, and limestones. According to Sutherland (1980, 1988a, 1988b) carbonate decrease in percentage southward at the expense of shales and sandstones in the Morrowan interval below the Wapanucka Limestone (Figure 6). In Oklahoma, the Morrowan strata consist mainly of two members that constitute the lower Dornick Hills Group. These members are the Union Valley Formation and Wapanucka Formation, in ascending order. The boundary between the two formations is generally conformable although local unconformities are reported within the basin (Busby, 1983, 1986). In the area of investigation the Morrowan interval is unconformable on the Pitkin Limestone. The term "Jefferson" Sandstone is currently used by subsurface geologists to indicate the sand below the Cromwell (Jordan, 1957). The Jefferson is absent throughout the study area.

The Union Valley Formation

Hollingsworth (1933) suggested the name Union Valley in reference to Union Valley schoolhouse, Pontotoc Co., Oklahoma, to designate the sandstone between

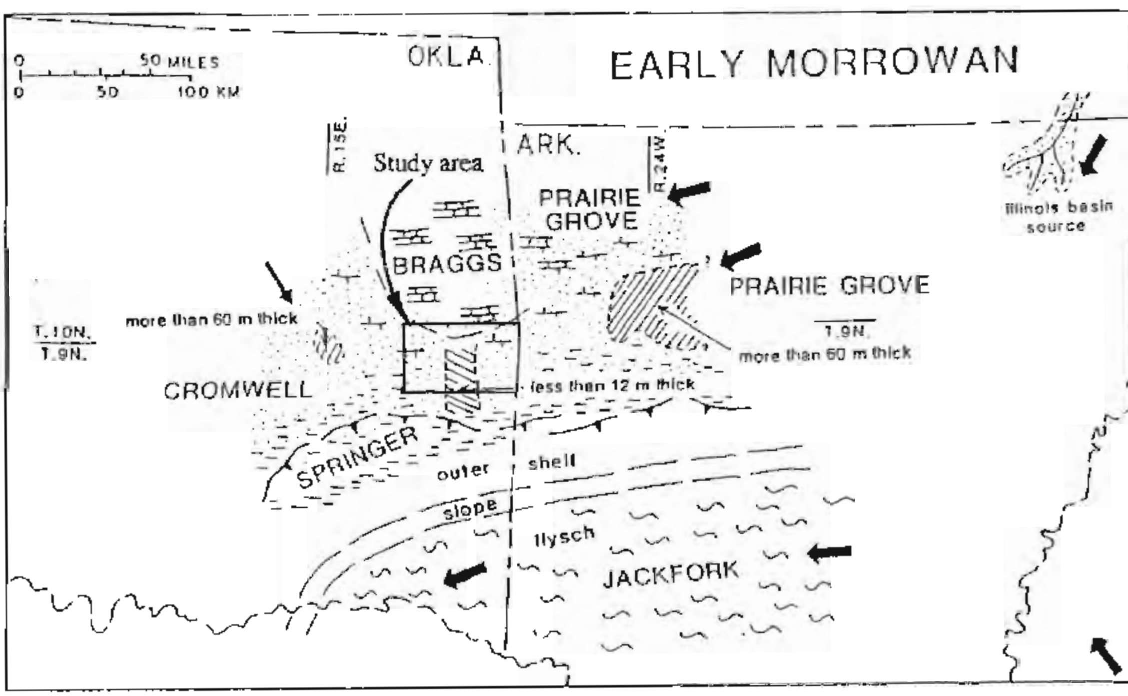

Figure 6. Early Morrowan paleogeographic map (modified from Sutherland, 1988a, p. 1793).

"Springer" shale below and the Wapanucka Formation above. The Union Valley was considered as a member of the Wapanucka Formation until 1936, when Hyatt raised it to the status of formation (Barker1951). The Union Valley Formation is composed of a lower sandstone unit, known in subsurface geology as Cromwell Sandstone, and an unnamed limestone member referred to informally as the Union Valley Limestone

The Cromwell Sandstone has been correlated to the Braggs Member of the Sausbee Formation in the southwestern Ozark, Oklahoma and in Arkansas and to the Union Valley Sandstone in Oklahoma (Sutherland, 1988a, 1988b). The term "Cromwell" sandstone was named for the Cromwell Oil and Gas Co. after the discovery of a giant oil field in Seminole County (Jordan, 1957) (Figure 1). The Cromwell Sandstone is well distributed throughout the study area, and is ranked as the second pay unit in the Kinta Gas Field. This sandstone varies from 35 feet to 290 feet thick. It is composed of multiple calcareous sandstones interbedded with thin gray to black shales. In many well logs, the percentage of shale decreases upward at the expense of sandstone and/or carbonate. In some portions of the basin, the black shale content becomes very important and the S.P curve appears almost flat on the log. The contact between the Cromwell Sandstone and the underlying the Pitkin Limestone is abrupt.

The unnamed limestone, in contrast to the Cromwell Sandstone, is present within only part of the entire study area. As many places it is thinner than to 35 feet. This member is separated conformably from the Cromwell Sandstone below and from the Wapanucka Formation above by shales. No detailed descriptions of the subsurface unnamed limestone have been published to date.

The Wapanucka Formation

The Wapanucka Formation conformably overlies the above Union Valley Formation. This formation was described initially by Taff (1901) and the type locality is near the town of Wapanucka, Johnston Co.Oklahoma (Figure 1). The Wapanucka is widespread in eastern Oklahoma. In addition it constitutes one of the best seismic-reflection markers in the Arkoma Basin and is a good horizon for subsurface mapping too. Exposures are in the frontal ridges of the Ouachita Mountains. In this area, the formation consists of interbedded spiculiferous packstones, carbonate mudstones, pelmetozoan-rich limestone, oolitic grainstone, and shale (Sutherland, 1981). Sutherland (1988) interpreted deposition of the Wapanucka as having taken place on the outer shelf. Recently, Mauldin (1992) suggested that there are potential hydrocarbon accumulations within Wapanucka facies in the frontal Ouachitas.

The Wapanucka is bounded unconformably above by the Atokan Series. Nevertheless, Grayson (1978), using the conodont evidence, demonstrated that the Wapanucka Formation contains the Morrowan-Atokan chronostratigraphic boundary. Similarly in 1984, he concluded that the uppermost Wapanucka units were deposited during Atokan time and correspond to the Spiro Sandstone in the northeastern part of the basin. Within the study area the Wapanucka Formation ranges in thickness from 27 feet in northwest to 330 feet in the southeast. Part of the Wapanucka Formation was truncated before deposition of the Atokan Series; therefore the upper boundary is unconformable (Lumsden and others, 1971).

Atokan Series

The regional unconformity that separates the Morrowan and Atokan series, is present across the entire area except along the southern margin of the Arkoma shelf and in the deep basin (Sutherland, 1988a, 1988b). This unconformity is believed to terminate along an approximate northeast-southwest strandline through southeastern Adair County (Bradley, 1977) (Figure 1).

The Atokan Series involves the Atokan Formation named for town of Atoka, Oklahoma (Taff and Adams, 1900). This unit represents the transition from sedimentation on a passive rifted margin to sedimentation in a foreland basin (Ross and Houseknecht, 1988). According to Zachry and Sutherland (1984), the Atokan Formation can be divided into informal lower, middle, and upper units. The Lower Atoka, containing the Spiro, accumulated on the stable northern shelf of a closing ocean basin and was deposited before the development of syndepositional faults. The Middle Atoka, in constrast, is mainly composed of shale with few thick sandstone members and comprises slope-system submarine fans and deep-basin turbidites formed during the development of syndepositional faults. Finally the upper Atokan strata represent a shallow-marine deltaic system, the deposition of which post-dated the syndepositional faults. The basal Atokan Spiro Sandstone constitutes one of the most important hydrocarbon-bearing units in the Arkoma Basin.

The Atokan strata generally thicken southward from the Ozark Uplift. In Haskell County, for example, exposures range from 4,000 to 7,000 feet thick (Shannon and Trout, 1917). Similarly thicknesses of more than 15,000 feet were recorded for the adjacent area to the Ouachita fold belt by Zachry (1982). Bercutt (1959) proposed that the northwestward thinning of the Atoka should be attributed to overlap rather than to intensive erosion. The Atokan Series is overlain by the Desmoinesian Series.

Desmoinesian Series

In the Arkoma Basin and adjacent areas to the northwest, the Desmoinesian Series includes in ascending order: Krebs Group, Cabaniss Group, and Marmaton Group. Only the Krebs Group is present across the Arkoma Basin. It is composed of the Hartshorne Sandstone, McAlester Shale, Savanna Sandstone, and Boggy Formation. The Hartshorne Sandstone is a major gas reservoir rock.

Conclusions

The Cromwell Sandstone is the oldest Morrowan lithostratigraphic unit present throughout the study area. It was been deposited disconformably upon the top of Chesterian Pitkin Limestone. This sandstone is bounded conformably at its top by the unnamed limestone referred to informally as the Union Valley Limestone. The Cromwell ranges from 35 to 290 feet thick and it consists of calcareous sandstones interbedded with thin gray to black shales. The proportion of shale increases toward the base of the interval.

CHAPTER IV

STRUCTURAL FEATURES

Introduction

The Arkoma Basin is known as one of the most heavily faulted gas-producing basins in the world. Its development was tectonically influenced by the Ouachita orogeny and the Ozark uplift. Consequently, folding, block faulting, and overthrusting have resulted.

Summary of Previous Investigations

Few previous works dealing with the tectonic evolution and deformation style of the area exist in literature. Houseknecht (1983) described Pennsylvanian tectonic history of the southern margin of North America as involving five steps, roughly characterized by a rifting phase followed by subsidence and deposition of typical "shelf slope-rise strata". More recently Roberts (1994) described the tectonic and stratigraphic evolution of the Ouachita region. According to Roberts evolution was very intense during the Paleozoic. Thus from Cambrian to Devonian, the southern margin was stable and dominated by moderate to slow sedimentation (Figure 7a). From Mississippian to Morrowan, due to extensional block faulting, the shelf edge shifted far to the north. Also great accumulation of thick sandstone-rich turbidite submarine fans took place

(Figure 7b). During the middle Atokan time, a thrust belt developed over the block faulting within the basin (Figure 7c). Basement duplexes affected the foredeep basin and remodified the thrust faults during Late Pennsylvanian to Early Permian. Presently the configuration of the region depends on the erosional activity and subsidence of the Gulf of Mexico (Figure 7d).

As mentioned previously, the tectonic history of the Arkoma Basin and vicinity was controlled by the Ouachita belt, which deformed all Pennsylvanian strata and uplifted the Ozark Dome. Therefore, the distribution of structural styles appears to be disproportional, as demonstrated by White (1956) (Figure 8). The outstanding structural geology of the Arkoma Basin is dominated by two basic structural patterns: (1)block faults generated with subsidence of the basin (whereas, the Ozark Uplift on the whole remained positive), and (2) folds and northward-overthrust belts generated by the Ouachita orogenic complex on the south (Branan, 1969).

Local Structural Geology

To identify and to describe the structurale of the study area, a structural contour map was constructed of the top of the Wapanucka Limestone (Plate I). Regional dip is southeastward at an average of 300 feet per mile. Structural features include several faults and folds (closures and noses), axes of which trend chiefly northeasterward.

Faults

Analysis of the structural contour map confirms the idea that major block faulting of deep beds took place in the investigation area (Branan, 1968). The faults include normal faults and rare reverse faults. They developed during the Morrowan and early

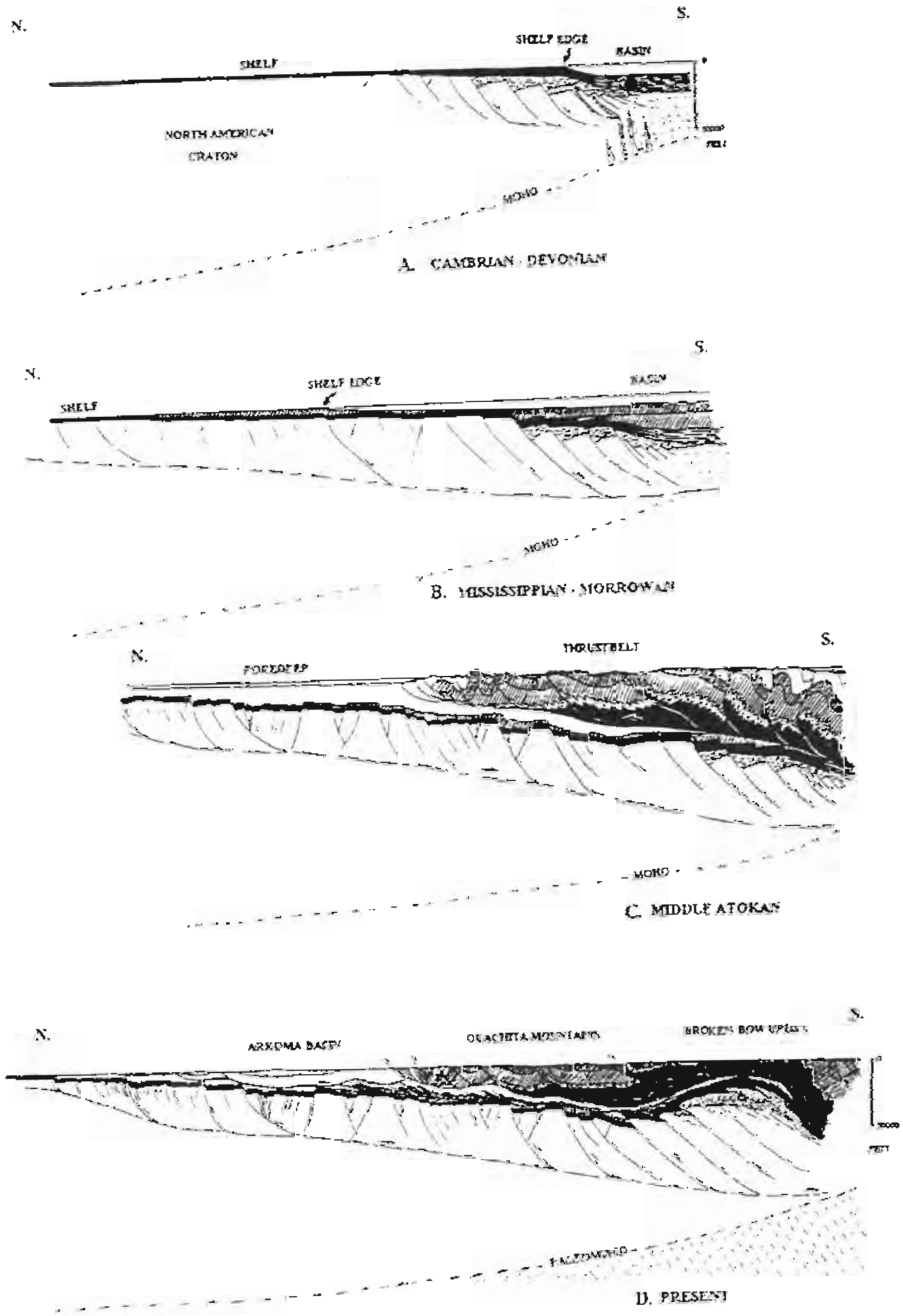

Figure 7. Tectono-stratigraphic evolution of the southern edge of the North America Craton (from Roberts, 1994, p. 154-155).

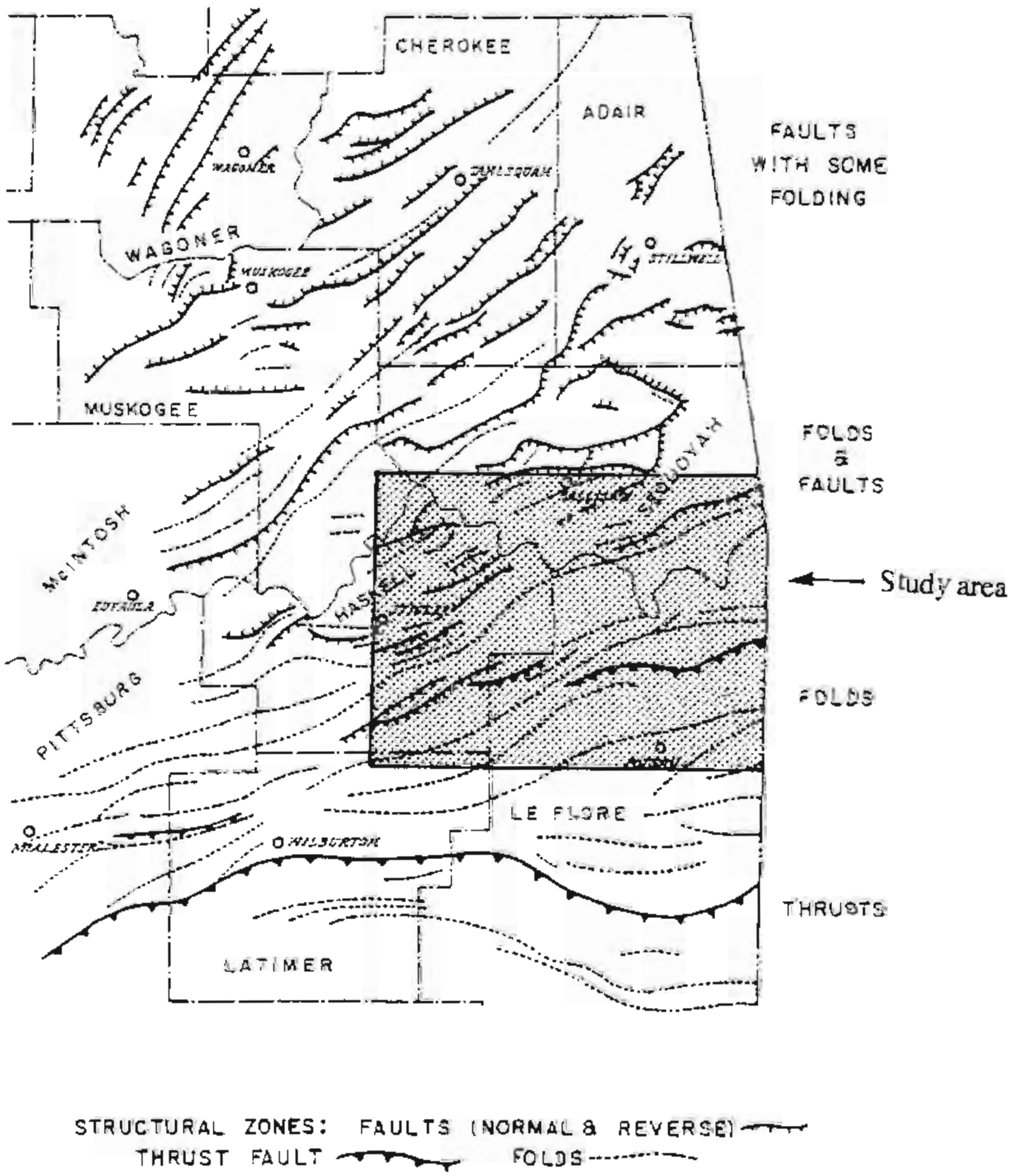

Figure 8. Occurrence of structural styles in Eastern Oklahoma (modified from White, 1956, p. 15).

Atokan as a result of great sediment loading and/or basement movement.

They can be divided into two groups based on the attitude:

The first group of faults strikes northeastward at 60 degrees on the average and dips generally to the southeast. Considered as major faults, they show the structural configuration of the area. The displacement varies considerably from place to place, and it generally increases basinward, i.e. from north to south (Figure 9). The minimum throw is less than 100 feet, whereas the maximum are more than 6000 feet. Commonly throw is down to southeast. Also some of these faults extend across a large part of the area. In this group, the most important faults are : Mulberry Fault, South Kinta Fault, South Carterville Fault, and Backbone Fault (Plate I). The Mulberry Fault cuts across the study area from northwest corner of T.8 N., R.21 E. to the northern half of T.11 N., R.27 E., more than 40 miles. This fault divides the study area into two unequal parts. According to Woncik (1968), it apparently corresponds to the approximate hinge line of the basin. The same author also argued that the fault likely represents the northern limits of gas accumulation in Haskell and Le Flore Counties. Throw of Mulberry Fault is not constant along its extension; it is ranging roughly from 6300 feet to 600 feet respectively in T.10 N., R.23 E and T.8 N., R.21 E. The South Carterville Fault is south of Mulberry Fault; and extends from T.7 N., R.21 E. to T.10 N., R.27 E. From place to place it branches into several small faults trending in the same direction. This fault has the minimal throw of about 600 feet in T.10 N., R.27 E. and the maximal throw of more than 6000 feet in T.7 N., R.22 E. and T.8 N., R.23 E. (Plate I). Similar to the Mulberry Fault, the South Carterville Fault dips to the southeast. The Backbone Fault dips southeastward and extends southwestward from T.9 N., R.27 E. to about 3 miles south of Bokoshe. Its

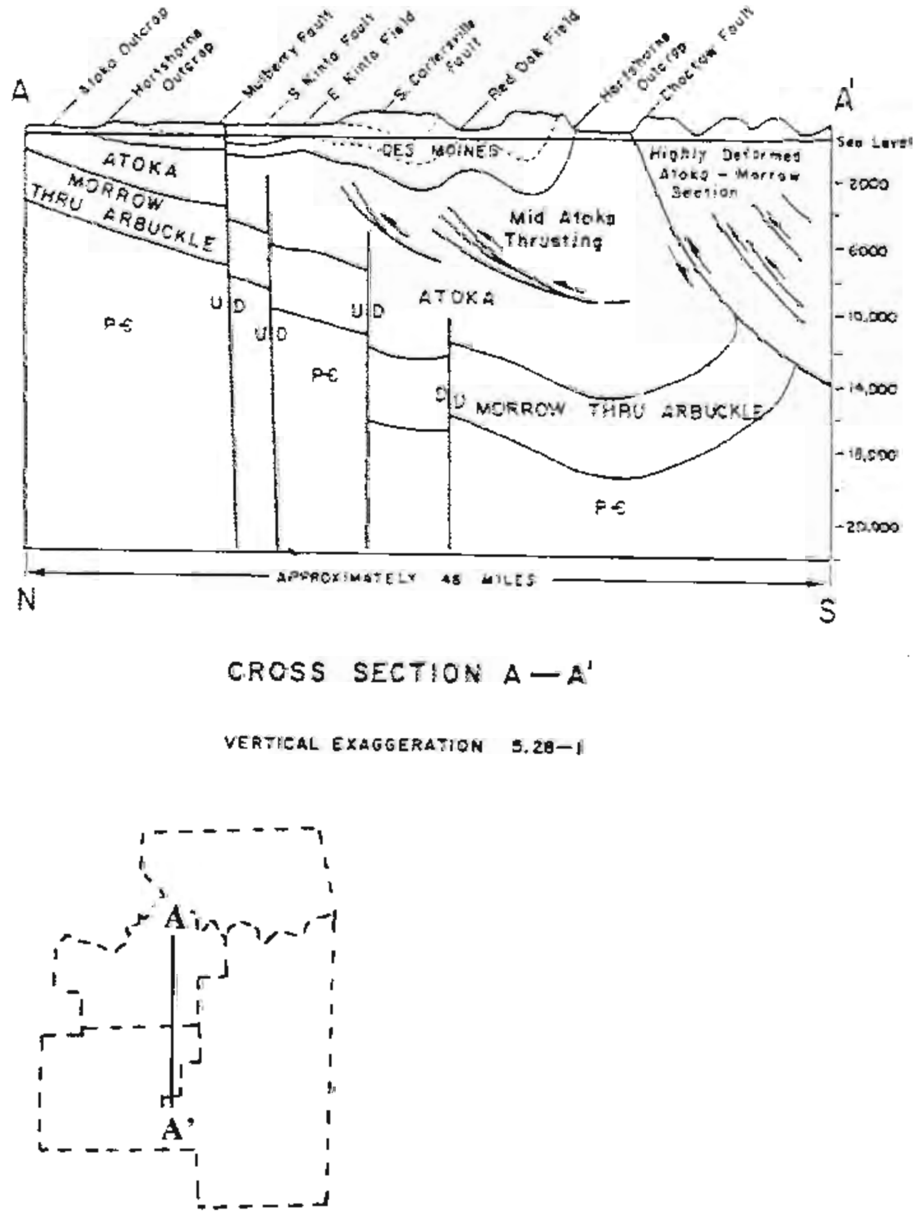

Figure 9. North-south structural cross-section across Arkoma Basin (modified from Branan, 1968, p. 1628).

throw averages of 700 feet in the area. Also considered as a major fault is the South Kinta Fault which is between the Mulberry Fault and the South Carterville Fault (Plate I). With a throw averaging 800 feet this fault is subparallel to the Mulberry Fault. Part of the fault which occurs in the northwestern corner of the area was identified and defined at the surface as the Porum Syncline by Shannon and others (1917). In reality it represents the southeastern boundary of the Whitefield uplift. This fault has a "constant" throw, approximately 2900 feet. The last fault of this group in the study area is an unamed fault that extends at 2.5 miles north of Poteau trending in southwest-northeast. Its throw ranges between 2200 feet and about 6000 feet. This fault corresponds to the Canaval Syncline on the surface.

A second group of faults strikes northward or northeastward, whereas the dip is to the southeast, northwest, east or west (Plate I). They are minor antithetic and synthetic faults. McQuillan (1978) suggested that these faults developed by the basement movement. At the stratigraphic level of the Wapanucka throws typically are less than 1500 feet.

Folds

Besides the faults, several structural closures and noses occur in the area (Plate I). They were identified at the surface as anticlines and synclines by Shannon and others (1917) and by Stone and Cooper (1930). These structural features strike northeasterly or easterly. Several are broken by block faulting. Most of the hydrocarbons discovered in this portion of the Arkoma Basin were probably trapped by these structural highs. The most significant closures identified on the structure map can be described as follows:

The Vian Anticline enters the area from the north of Tahama and plunges southwestward within the Whitefield uplift. At approximately 1 mile southeast of the Vian Anticline in T.11 N., R.22 E, R.23 E. and R.24 E was developed a broad "trough" faulted downward or both sides. This trough trends northeastward and plunges northeastward. A positive closure south of Stigler, in T.9 N., R.21 E. is an extension of the Kanima Anticline from Section 31 to Section 15. This fold locally forms as a nose.

The Cowlington Syncline, defined at the surface, corresponds to the faulted "trough" developed south of the Mulberry Fault.

The Kinta Anticline is a small fold lying south of Mulberry Fault in T.8 N., R.21 E.

The Siloam Syncline is approximately 5 miles long. The axis is oriented almost exactly north along the line that separates T.8 N., R.21 E. and T.8 N., R.22 E.

The Milton Anticline is lengthened to the south by the Lequire Anticline. Although this fold dies out at depth of some places, it extends northeast throughout the area. Some closures are seen in T.8 N.,T.9 N. of R.23 E.,T.9 N., R.24 E.,T.10 N., R.25 E., and T.11 N., R.27 E. A great number of producing wells in the Kinta Field were drilled on the Milton Fold.

The Brazil Anticline extends in a northeastwardly direction from the border of Latimer and LeFlore Counties to a point about 3 miles south of Bokoshe. With a length of 8 miles, the Brazil structure constitutes a good producing trap.

The Backbone Anticline merges with the Backbone Fault described earlier. The axis of this anticline is hard to recognize on the surface because of block faulting. Nonetheless the closure is clearly demonstrated in R.26 E., and R.27 E. of T.8 N. and it seems to end in T.8 N.,R.23 E.

The Poteau Anticline is a northward-plunging nose, which enters the area of investigation from T.7 N., R.26 E., about 4 miles east of Poteau. Almost all the production in the Poteau Field is derived from this fold.

Besides these folds, another one lengthens northeasterly across T.9 N., R.26 E. It is cut in both sides by faults.

Conclusions

Faults and folds in the study were developed under the tectonic influence of the Ouachita Mountains. Their major trend is northeastward. Several discovery wells show that the primarily trapping mechanism is related to folding rather than faulting.

CHAPTER V

DEPOSITIONAL FRAMEWORK

Introduction

A depositional environment is a geographic and/or a geomorphic area where sediments accumulate. Depositional systems are three-dimensional bodies of rock that represent a grouping of genetically related facies. Depositional systems can be described and identified on the subsurface on the basis of several criteria. Evidence commonly used is of numerous kinds. In the case of the Cromwell Sandstone subsurface mapping, well-log patterns and petrography of cores are discussed in this chapter.

Geometry and Distribution of the Union Valley Formations

Stratigraphic Cross-Sections

Cross-section A-A'

Cross-section A-A' extends from T.10 N., R.27 E. to T.11 N., R.21 E. in an east west direction (Plate II). A slight thinning of the Union Valley formations, related to a structural high, is observed in Section 2, T.10 N., R.23 E. (Well 304). From that well the Cromwell Sandstone varies in thickness from an average of 90 feet in the east to an average of 65 feet in the west. In Section 8, T.10 N., R.24 E. (Well 162) and Section 9, T.10 N., R.25 E. (Well 180c), the sandstone is massive with sharp upper and lower contacts. Elsewhere a few shale interbeds are within the unit. The unnamed limestone above the Cromwell Sandstone is locally absent along the line of section. This limestone, together with the underlying and overlying shale, thickens eastward to about 150 feet and westward to about 120 feet. The Wapanucka Formation shows great variation of thickness, ranging between 80 feet and 200 feet as a result of significant truncation at its top. In fact, the upper unit of this formation is non-existent in the western part of the area illustrated by the cross-section. The Stigler Syncline at the surface, is probably related to the intense truncation of the Wapanucka Limestone (Plate I).

Cross-Section B-B'

Cross-section B-B', an east-to-west section extends from T.8 N., R.27 E. to T.8 N., R.21 E. (Plate II). The Cromwell interval is included in an anticline in section 8, T.8 N., R.25 E. (Well 25); this anticline is bounded on both sides by faults (Plate I). The upper sandstone contact appears to be abrupt along the section, whereas the lower contact remains transitional except in Section 3, T.8 N.,R.27 E. (Well 54). The Cromwell Sandstone has a minimum thickness of 80 feet in Section 33, T.9 N., R.23 E. (Well 300). The rest of the section generally shows a "constant" thickness of approximately 100 feet. In this section the Cromwell interval is a limy sandstone with shale interbeds at the top and essentially shale at the base. However well 13 of section 17, T.8 N. R.24 E. is dominated by shale and thin limestone. The unnamed limestone, where present, is thinner than 5 feet. The whole interval, including shale, thickens eastward and thins westward. The overlying Wapanucka Formation thins in Section 8, T.8 N., R.25 E. (Well 25), Section 33, T.9 N., R.23 E. (Well 300), Section 2, T.8 N., R.22 E. (Well 325) and Section 14, T.8 N., R.21 E. (Well 501) in relation to the Atokan unconformity. The thicker rocks in Section 17, T.8 N., R.24 E. (Well 13) corresponds to a nose on Plate I. Just as the one found in Section 18, T.8 N., R.21 E., this thickened interval likely represents the Kinta Anticline (Plate I). The Wapanucka Formation locally involves upper limy sandstone separated from the lower limestone by a shale break.

Cross-Section C-C'

Cross-section C-C' is an east-to-west section that extends from T.7 N., R.26 E. to T.7 N., R.21 E. (Plate II). This cross-section is characterized by the presence of the Carnaval Syncline in Section 34, T.8 N., R.25 E. and the Lequire Anticline at the western edge. The Carnaval Syncline represents the footwall of two faults that bound its sides. The Cromwell Sandstone has a lower, gradational contact and an abrupt upper contact. The thickness of this unit varies considerably from 300 feet in Section 26, T.7 N., R.26 E. (Well 594) to 70 feet in Section 6, T.7 N., R.22 E. (Well 551). Apart from the Well 525 in Section 7, T.7 N., R.21 E., the shale content within the interval is large. Thus the Cromwell Sandstone tends to be shaly sandstone or shaly limestone. The whole interval representing the unnamed limestone and bounding shale thickens significantly at the expense of the underlying Cromwell in Section 34, T.8 N., R.25 E. (Well 41). Thickness of the Wapanucka Limestone also shows great variations. The maximum thicknesses (~320 ft.) occur at the western edge of the section. Finally, compared to areas described by other stratigraphic cross-sections the Wapanucka Limestone has a higher shale content.

Cross-Section D-D'

Cross-section D-D' is a north-to-south cross-section that extends from T.11 N., R.27 E. to T.7 N., R.26 E. (Plate III). The Cromwell lower boundary with the underlying Pitkin Limestone is abrupt at the north end of the section and becomes gradational as the section extends to the south. The upper boundary, on the other hand, remains abrupt. Despite the existence of a slight syncline in section 30, T.11 N., R.27 E. (Well 404), the Cromwell Sandstone thickens southward. For instance from an average of 100 feet in the north, the thickness increases to 280 feet in section 26, T.7 N., R.26 E. (Well 594). The Cromwell sub-shale pinches out toward the north and the clay content increases within the entire unit in the south. The unnamed limestone overlying the Cromwell Sandstone is well developed at the north end of the cross section. Its thickness averages 20 feet in Section 30, T.11 N., R.27 E. This thickness decreases progressively basinward until it reaches zero. The Wapanucka Limestone thickens slightly to the south as far as Section 3, T.8 N., R.26 E. (Well 45), where thickness increases abruptly, probably related to Backbone Fault and Anticline. The log signature of this formation, is in addition, consistent along the cross-section.

Cross-Section E-E'

Cross-section E-E' extends from T.11 N., R.24 E. to T.7 N., R.23 E. (Plate III). Although the Cromwell Sandstone is present within a structural low bounded by an adjacent structural high near the southern end of the cross-section, the unit thickens from north to south. The maximum thickness is 130 feet in Section 28, T.8 N., R.23 E. The Cromwell lower contact is abrupt in Section 12, T.11 N., R.24 E. (Well 440) .Elsewhere on the cross-section it is gradational. However, along the whole section the upper contact is commonly sharp. The stratigraphic cross-section E-E' demonstrates that Cromwell lithology varies significantly from place to place. The unit is massive at the northern end of the section but appears to be essentially a silty shale in Section 21, T.7 N., R.23 E. (Well 575). Within the other wells it is interbedded with shale or includes sandstone, limy sandstone at the top and shale at the bottom. The unnamed limestone forms a thin bed of less than 10 feet, which is, in addition, not widespread. The shale directly on top of the Cromwell Sandstone ranges in thickness between 70 feet and 180 feet. Just as with the Wapanucka Limestone, this shale thickens gradually basinward.

Cross-Section F-F'

Cross-section F-F' extends from T.11 N., R.21 E. to T.7 N., R.21 E. in a southerly direction (Plate III). Strata shown on this cross-section are cut by several faults, some of which have generated the Cromwell structural high in Section 15, T.7 N., R.21 E. (Well 535). The Cromwell lower contact remains gradational, whereas, the upper contact is abrupt in Well 368 in Section 16, T.9 N., R.22 E. and Well 545 in Section 27, T.7 N., R.21 E., and gradational northward. Thickness of the Cromwell Sandstone is almost constant averaging 100 feet with the exception of Section 16, T.9 N., R.22 E. (Well 368) and Section 15, T.7 N., R.21 E.(Well 535). In these last cases the whole interval thins. The Cromwell unit is sandstone and limy sandstone, with shale interbeds. The shale below the Wapanucka Limestone includes discontinuous thin limestone. It varies in thickness from 70 feet (Well 535) to nearly 200 feet (Well 548) in relation to the Cromwell anticlines and synclines. The base of the Wapanucka Limestone is subparallel with the underlying beds in the northern and central part of the section. However, erosion at the top of this formation abruptly reduced the thickness to 50 feet in section 7, T.7 N., R.22 E. (Well 548). The Wapanucka Limestone is thickest at the southern extremity of the section.

In summary, the stratigraphic cross-sections provided in this study indicate that the Cromwell sandstone involves one single member with expectable variation in thicknesses. The sandstone is massive within the maximum-thickness trends of the net sandstone isolith map (Plate V) and exhibits both abrupt upper and lower contacts. Elsewhere, the Cromwell contains a few shale interbeds, a sub-shale interval, or is essentially a silt-shale bed. Therefore, the upper and lower contacts appear either sharp, gradational or both. Despite the numerous faults, and structural highs and lows observed, the Cromwell Sandstone commonly thickens basinward, i.e. from north to south.

Union Valley Isopach Map

The Union Valley Isopach Map (Plate IV) was constructed to determine the geometry and lateral continuity of the interval between the bottom of the Cromwell Sandstone and the bottom of the Wapanucka Limestone, as well as to estimate the configuration of the basin before the deposition of the Union Valley rock units. The map confirms the presence of these rocks units within the entire study area. The gross-isopach contour lines tend to be oriented northwest-southeast i.e. parallel to the trend of the basin. These lines are closely spaced in T.9 N., R.23 E.; R.25 E. of T.9 N. and T.10 N., and R.26 E. of T.9 N. and T.10 N. probably due to rapid deepening. Elsewhere, they are more or less regularly spaced. Generally the Union Valley thickens southward. Thickness ranges from a minimum of 40 feet in T.11 N., R.23 E. to more than 500 feet east of Poteau (T.7 N., R.26 E.). Large changes in thickness across short distance occur along South Kinta Fault and along the southwestern and northeastern parts of Mulberry Fault, suggesting that these faults were active during deposition. The thickening trends seem to be related to Cromwell environment (channelization), to irregularities of Pitkin surface (paleovalleys), and to some extent to the transition between the ramp and the deeper basin (southern area of study). The thinning trend, however, are associated with the structural highs.

Cromwell Net Sandstone Isolith Map

This map, constructed on a contour interval of 10 feet, illustrates the variation in thickness, geometry and trends of the Cromwell interval. No evidence of sandstone pinchouts against unconformity surfaces was observed. The patterns obtained from the isolith map (Plate V) indicate that deposition of Cromwell Sandstone occurred within a deltaic framework. In fact, three north-to-south trending delta lobes are noted in the area (Figure 10). In the western part of the map, a lobe extends from north of T.11 N., R.21 E. to south of T.7 N. R.21 E., R.23 E and R.24 E. Configuration of contour lines suggests that, this delta lobe branches into two major distributary channels at about two miles northeast of McCurtain. The second delta lobe was in the area from T.11 N.,R.24 E. to T.8 N.,R.24 E. Three distributary channels developed south of the Arkansas river. These two delta lobes range in net-sandstone-isolith thickness from 10 feet to more than 60 feet. The third lobe was developed along the border of Oklahoma and Arkansas. Besides the significant downdip progradation of more than 30 miles, this delta lobe is the thickest of the three; a maximum thickness of 67 feet is recorded. This deltaic lobe includes several distributary channels. Areas between these three delta lobes probably represent the marginal delta front and farther south in the basin they correspond to the distal delta. More importantly is the north-south thickness trends which indicate a northern source of sediments deposited in these deltaic facies.

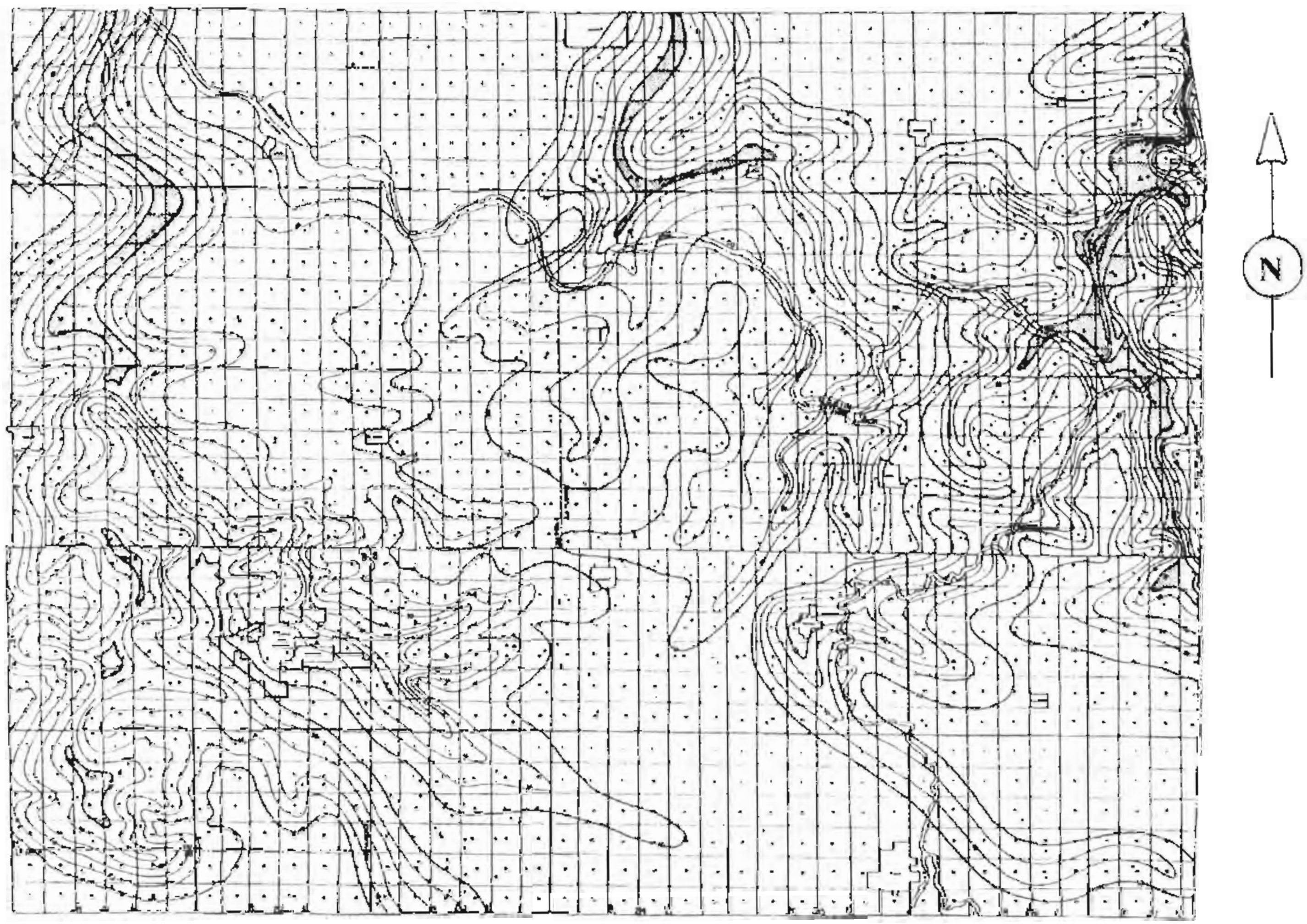

Figure 10. Cromwell Sandstone isolith map of the study area.

Legend: < 50 feet; > 50 feet

Net Carbonate Isolith Map of the Union Valley Limestone

The name Union Valley Limestone used here refers to the unnamed limestone above the the Cromwell Sandstone. The distribution of the Union Valley Limestone as inferred from the net isolith map (Plate VI), demonstrates that this limestone is not present over the entire area of investigation. The thickness varies from 0 foot to 35 feet. The area of thickest net-carbonate rock is in T.11 N., R.26 E. and R.27 E. In most cases thick zones coincide in general location with channel deposits of the Cromwell sandstone.

Well Log Patterns

The well log records graphically measured or computed physical characteristics of the rock section encountered in a well. Since the mid 1960's, when the idea of using well logs as sedimentological tools was first developed, several geologists have qualitatively used the well log profile to analyze facies and depositional environments. Resistivity and gamma-ray curves provide excellent definition of sand-shale contacts. Furthermore, these two curves when recorded with the spontaneous potential are very useful for correlations and lithologic determinations. The resistivity curves, which are heavily affected by oil and gas, are less used to interpret depositional environments.

Figure 11 classifies electrofacies according to the spontaneous-potential curve. Upper and lower contacts are either abrupt or gradational. Four main shapes, including cylinder shape, bell shape, funnel shape, and egg shape, can be either serrated or smooth. The combination of the base map and the well-log pattern for selected individual wells is the log motif map (Plate VII). The primary use of the log motif map is to show the log-shape characteristics of the interval studied over the area. According to

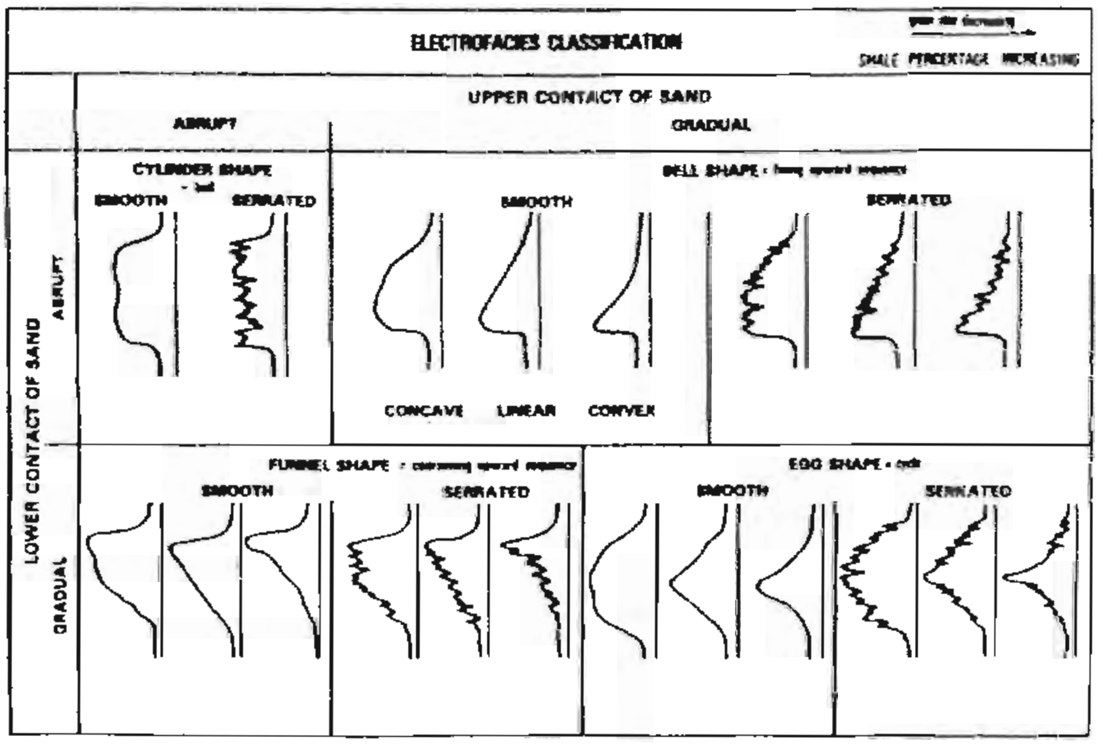

Figure 11. Classification of electrofacies by log shapes (from Schlumberger, 1989, p. 86).

Shelton (1972) this map can also be helpful in delineating trends and estimating edges of the sandstone bodies. Consequently, in addition to subsurface mapping and the description of continuous cores, the log motif map can provide an additional criterion for the interpretation of depositional systems. Thicker sandstone trends were distinguished from thin zones on the motif map by the addition of 10-feet and 60-feet contour lines derived from the net sandstone isolith (Plate V).

The Cromwell Sandstone exhibits a great variety of well log patterns. Basically four well log shapes are present (Figure 12). A geometrical configuration of the log shape defines coarsening upward sequences and fining upward sequences. Abrupt lower or upper contacts are lithologically related changes. They form in response to textural and compositional modification of the sediments and may represent unconformities or different environmental conditions. It is often noted that abrupt lower contacts occur in distributary channels, incised channel fills, or at the bases of turbidites. Transitional profiles are indicative of gradual changes in the particle size. Interbedded sands, silts and shales, which are indicated by a serrated spontaneous-potential and gamma-ray log shape, indicate interaction of different depositional conditions such as changes in water level, or sediment carrying power. However, smooth spontaneous potential and gamma ray log shapes indicate a fairly constant sediment accumulation and may reflect periods of uniform conditions.

Numerous smooth and serrated cylinder-shaped gamma ray and spontaneous p potential patterns characterize the Cromwell Sandstone that accumulated within the thickest net sandstone isolith trends. Most of these patterns show sharp lower erosional contact and sharp upper contact, suggestive of distributary channel sands

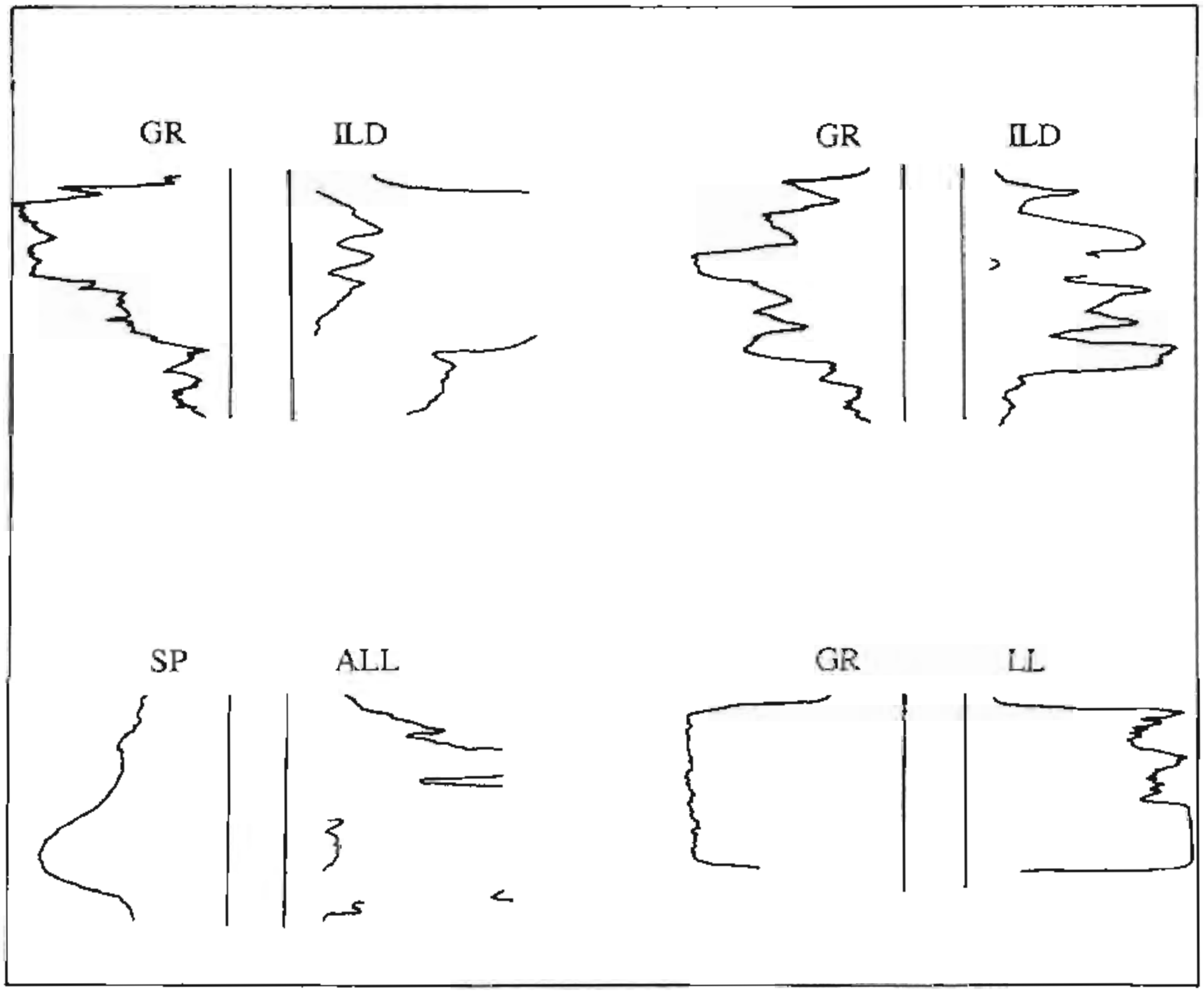

Figure 12. Typical Cromwell Sandstone electric log responses.

(Brown and others, 1973). They may also indicate graded-bed buildup by turbidity currents as suggested by many geologists. According to some geologists, distributary channels are formed from the accumulation of thick sediments at the bottom of the channel as a result of continuous compactional subsidence during deposition.

The serrated funnel-shaped well log patterns are noted between or at the edge of the maximum-thickness trends. They indicate gradational lower contacts and abrupt upper contacts. The typical coarsening upward sequences observed here were formed due to the upward increase of particle size. Such well log shapes are similar to those representing delta-marine fringe sands, barrier-bar sands or distributary-mouth bar sands. For Brown and others (1973), these shapes can be associated with distributary-mouth bar channels. The highly serrated funnel-shaped well log patterns throughout T.8 N., R.25 E. have numerous fine grained interbeds of prodelta marine clays. These patterns are typical of distal delta-front sands. In the northwestern part of the study area, the Cromwell Sandstone displays abrupt lower contacts and transitional upper contacts. The smooth or slightly serrated bell shaped patterns which have resulted are indicative of alluvial point-bar sand units, or distributary channels with abandoned channel fill. Other well log patterns in the eastern part of the study area, have composite shapes with both transitional upper and lower boundaries. The lower part corresponds to a serrated funnel, whereas, the upper part is a lightly smooth bell. These well log patterns usually characterize progradational build up of alluvial sand over delta marine fringes.

In brief, the Cromwell Sandstone in the study area consists of one member which is locally massive, but often interbedded with shales and/or silts. The entire Cromwell interval shows several well log patterns. Each of them is an indicative of a specific facies within the deltaic system.

Petrology of Cromwell Sandstone

Only two cores of the Cromwell Sandstone have been considered in this study. One of them comes from within the investigation area, another one is from outside of the area (Table II). These two cores were described in order to obtain additional information regarding the depositional environment.

Description of Cores

Midwest Oil Corporation, Gardner # 1

This well is within the of Red Oak Field, at 2052' NSL, 4060' EWL Section. 13, T.6 N., R.20 E. , Latimer County. The cored interval was 13789-13890 feet. The upper and lower contacts of Cromwell Sandstone are absent within the cored interval. The core consists primarily of gray siltstone to very fine-grained sandstone with alternating limestone and black shale. However the lowermost sand interval includes bioturbated fissile black shale with poorly preserved primary structures.

Strata between 13789 and 13805 feet are limy siltstone with very few black shale interbeds. Burrows are at the top, whereas rare laminations are at the base. This interval includes a few crinoids and rare brachiopods.

Strata from 13805 to 13829 feet include coarse carbonaceous siltstone interbedded with black shale. A 10-foot interval of silty shale at the top of these strata is dominated by low-angle cross bedding. The siltstone below is laminated and burrowed. Fossils are rare crinoids and brachiopods. Vertical fractures are numerous at the 13825 foot level

Table II: Core locations

Operator	Well	Location
Humble Oil &Refining Company	Roye Unit # 1	810' S & 300' W of C Sec. 9, T.8 N., R.21 E.
Midwest oil Company	Gardner # 1 Red Oak	2052' NSL & 4060' EWL Sec. 13, T.6 N., R.20 E

(Figure 13).

Strata between 13829 and 13886 feet include quite homogeneous very fine-grained sandstone which contains locally carbonate rock, and black shale with hematite infilling. Several sedimentary structures occur. Most of them are illustrated by widespread discontinuous laminations, cross-bedding, vertical fractures, and burrows (Figures 14 and 15). Stylolites are at the depth of 13834 feet (Figure 16), 13838 feet, and 13849 feet.

Based on sedimentary structures, composition and fossils, this core probably represents a marginal delta-front deposit that was modified by marine processes.

Humble Oil and Refining Company, Roye # 1

The Roye Unit # 1, located at 810' S. and 300' W. of C. sec. 29, T.8 N.,R.21 E., Haskell County belongs to N.E. Lequire Field. The interval cored was 6574-6623 feet The upper and lower contacts of the Cromwell Sandstone are absent. This core contains very fine to fine sandstone with local alternating limy sandstone and black shale.

Strata between 6574 and 6582 feet are gray fine sandstone, limy sandstone, and black shale interbeds. The carbonate-rock content more than elsewhere is particularly high at the bottom. Common sedimentary structures include burrows and wavy laminations (Figures 17 and 18).

Strata between 6582 and 6623 feet contain predominantly very clean gray to brown fine-grained sandstone. Sandstone from 6608 to 6615 feet and near the bottom are often very fine-grained and include thin black shale interbeds. Within this interval, convolute bedding is abundant (Figure 19). Other sedimentary structures present include parallel laminations, some burrows, and wavy bedding. Minor crinoid debris and brachiopods

(Figure 13).

Strata between 13829 and 13886 feet include quite homogeneous very fine-grained sandstone which contains locally carbonate rock, and black shale with hematite infilling. Several sedimentary structures occur. Most of them are illustrated by widespread discontinuous laminations, cross-bedding, vertical fractures, and burrows (Figures 14 and 15). Stylolites are at the depth of 13834 feet (Figure 16), 13838 feet, and 13849 feet.

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Humble Oil and Refining Company, Roye # 1

The Roye Unit # 1, located at 810' S. and 300' W. of C. sec. 29, T.8 N.,R.21 E., Haskell County belongs to N.E. Lequire Field. The interval cored was 6574-6623 feet. The upper and lower contacts of the Cromwell Sandstone are absent. This core contains very fine to fine sandstone with local alternating limy sandstone and black shale.

Strata between 6574 and 6582 feet are gray fine sandstone, limy sandstone, and black shale interbeds. The carbonate-rock content more than elsewhere is particularly high at the bottom. Common sedimentary structures include burrows and wavy laminations (Figures 17 and 18).

Strata between 6582 and 6623 feet contain predominantly very clean gray to brown fine-grained sandstone. Sandstone from 6608 to 6615 feet and near the bottom are often very fine-grained and include thin black shale interbeds. Within this interval, convolute bedding is abundant (Figure 19). Other sedimentary structures present include parallel laminations, some burrows, and wavy bedding. Minor crinoid debris and brachiopods

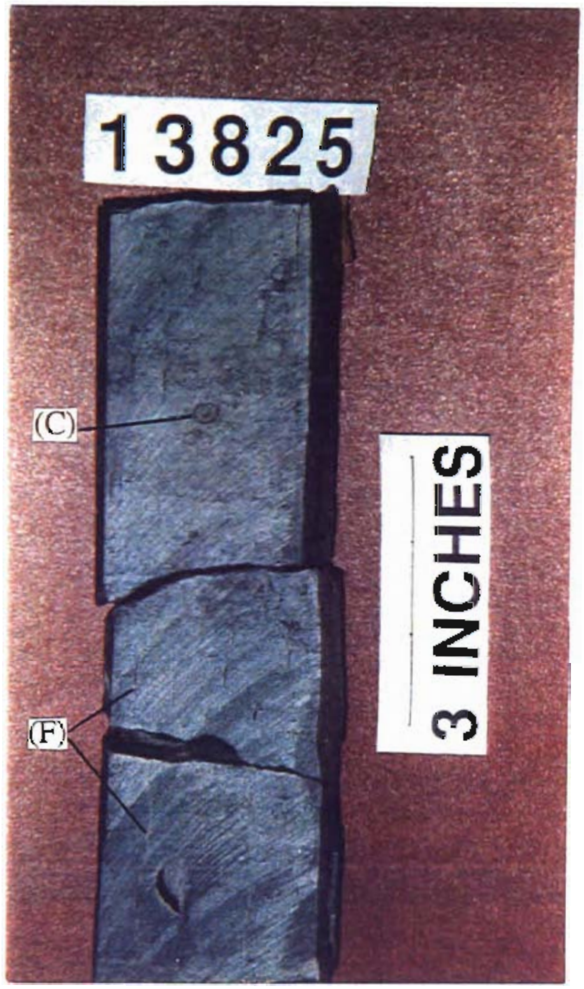

Figure 13. Vertical fracture (F) and crinoid fragment (C) in the Cromwell Sandstone of Gardner # 1, Red Oak.

Figure 14. Discontinuous laminations disturbed by burrows in the Cromwell Sandstone of Gardner # 1, Red Oak.

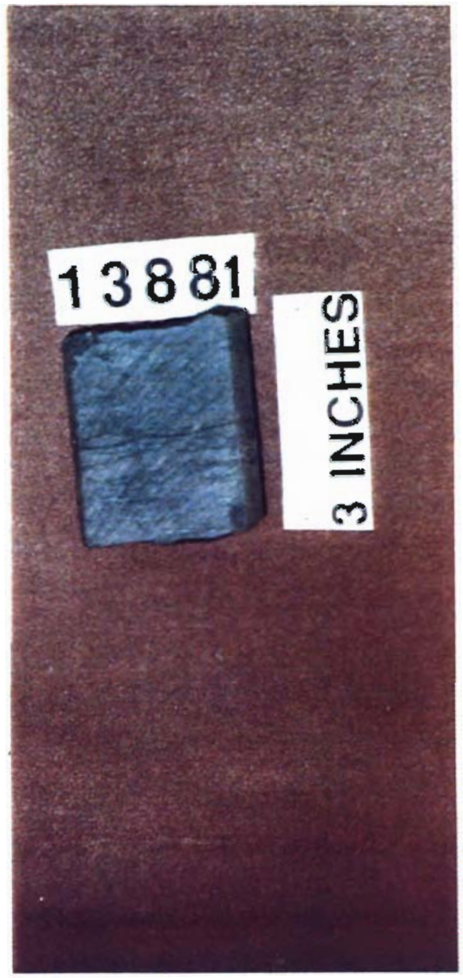

Figure 15. Cross lamination in the Cromwell Sandstone of Gardner #1, Red Oak.

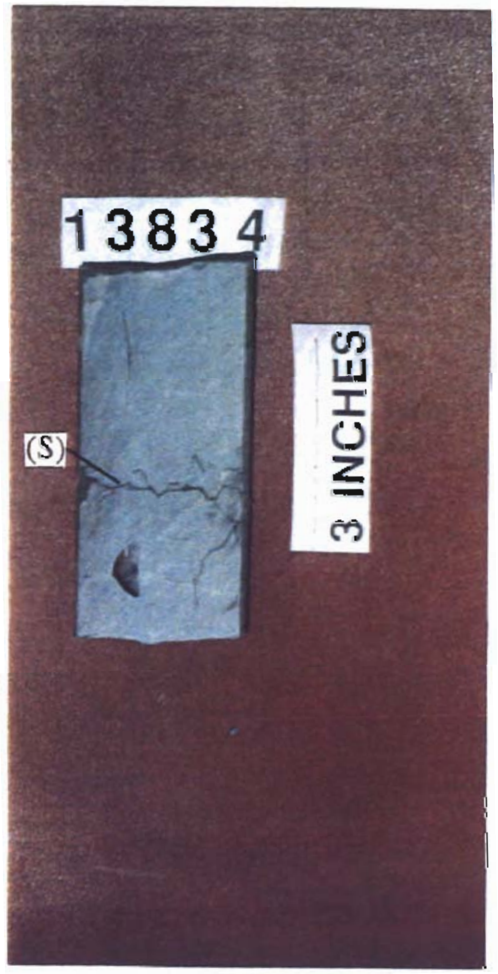

Figure 16. Stylolite (S) in the Cromwell Sandstone of Gardner # 1, Red Oak.

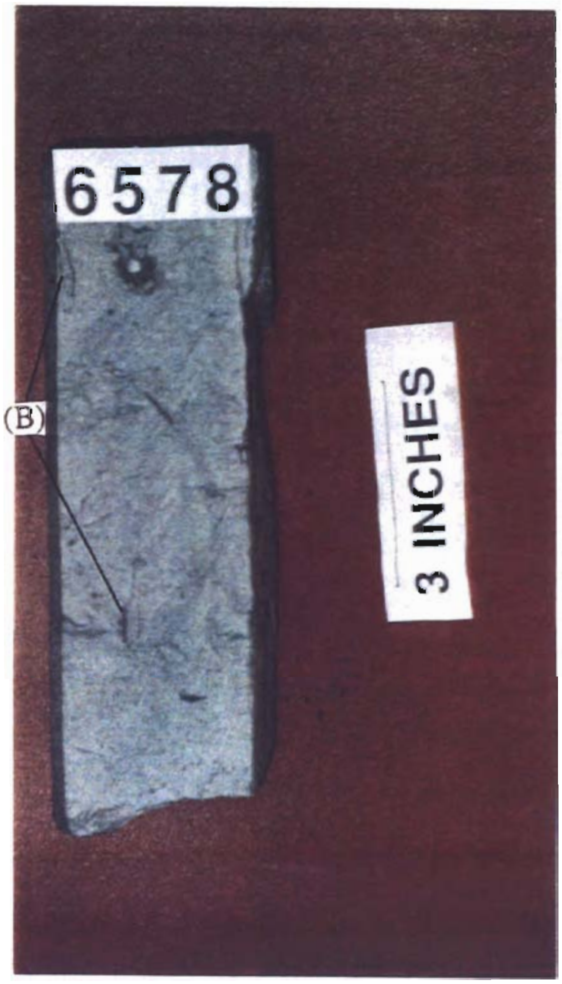

Figure 17. Vertical burrows (B) in the Cromwell Sandstone of Roye Unit # 1.

Figure 18. Possible wavy laminations in the Cromwell Sandstone of Roye Unit # 1.

are at the top of the interval too.

This core may have been deposited in a deltaic environment. Particularly it corresponds to a marginal delta front with marine reworking.

Microscopic observations

Microscopic observations of twenty three thin sections demonstrate that the Cromwell Sandstone corresponds to quartz arenite and sublitharenite (Figure 20), according to Folk's classification (1974). Despite the slight differences between the constituent percentage, the bulk composition is quite homogeneous and includes both detrital and authigenic constituents.

Detrital constituents

Detrital constituents, with an average percentage of 85 %, consist predominantly of monocrystalline quartz and polycrystalline quartz, chert fragments, shell fragments, feldspars, muscovite, biotite, and zircon.

Monocrystalline quartz is the most important detrital constituent. In general, the dimensions vary from very fine to medium sand; the shapes are either angular subangular, or subrounded. Grains are commonly imbricated, especially when the cement is lacking due to compaction (Figure 21).

Polycrystalline quartz occurs as composite grains. It represents less than 5 % of detrital grains. It is usually scattered within the detrital matrix. Polycrystalline quartz exhibits undulose extinction suggesting a metamorphic origin.

Feldspar is present as rare sodium plagioclase grains that are recognizable by their characteristic twinning.

Mica includes muscovite and biotite. Muscovite forms long needles that are

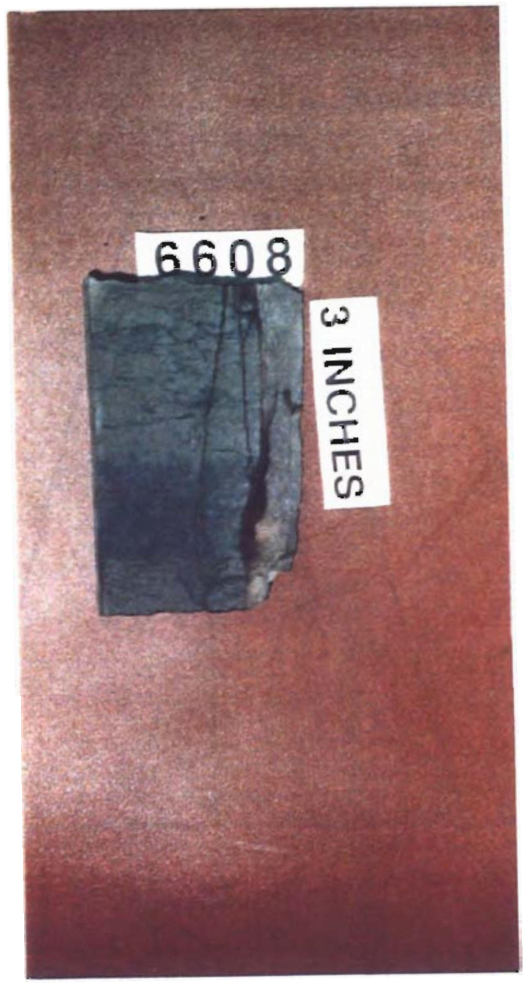

Figure 19. Disturbed bedding by burrows in the Cromwell Sandstone of Roye Unit # 1.

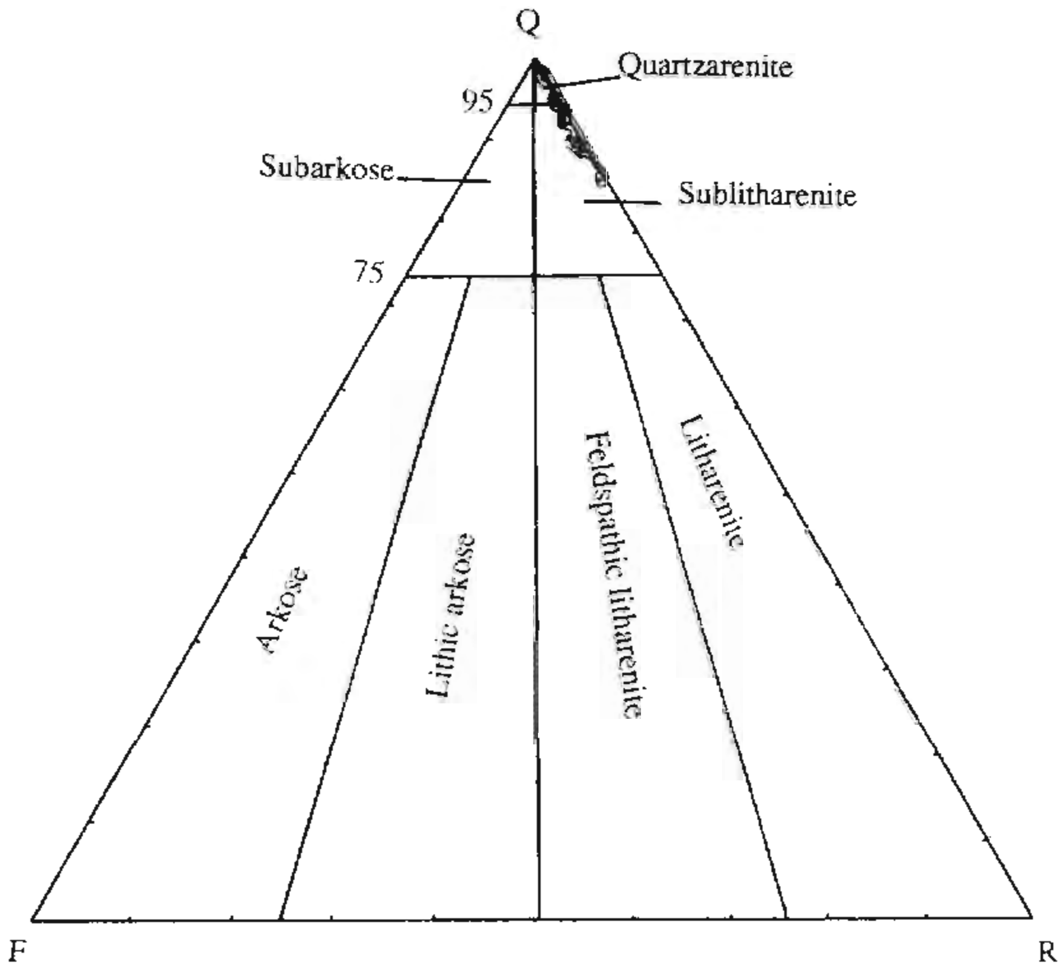

Figure 20. Detrital composition of Cromwell Sandstone in Q-F-R diagram (from Folk, 1984).

commonly deformed and/or broken, presumably because of compaction of the sediments after deposition (Figure 22). Biotite is exceedingly rare.

Scattered zircon grains are nearly constant in abundance throughout all the samples but in every sample they represent less than 1 %.

Invertebrate skeletal debris is sporadic in the rocks. Invertebrate material consists principally of broken crinoid and brachiopod fragments (Figure 23).

Besides shell fragments, some rock fragments represented by carbonate, chert, mud chips, and metamorphic rocks were noted. Metamorphic rock fragments are the most abundant of the overall rock fragments. They contain quartz and muscovite (Figure 24).

Detrital matrix is silty and clayey, and averages 8 percent.

Authigenic constituents

Authigenic constituents average less than 15 percent of the total composition. They include primarily cements and clays. The amount of cement varies according to samples. Cements involve calcite, hematite infilling, and chalcedony. Calcite cement dominates.Ordinarily, it replaced detrital constituents. Hematite is present only in some thin sections, in the form of films developed probably in relation with the deformation of the rock (Figure 25). Chalcedony forms fibrous grains associated with monocrystalline quartz. Non-detrital clay is illustrated exclusively by rare chlorite mixed with calcite.

In conclusion, additional evidence from core and thin section descriptions provided in this paragraph is useful to interpret the depositional systems of the Cromwell Sandstone. This evidence includes sedimentary structure, fauna content, texture and overall composition.

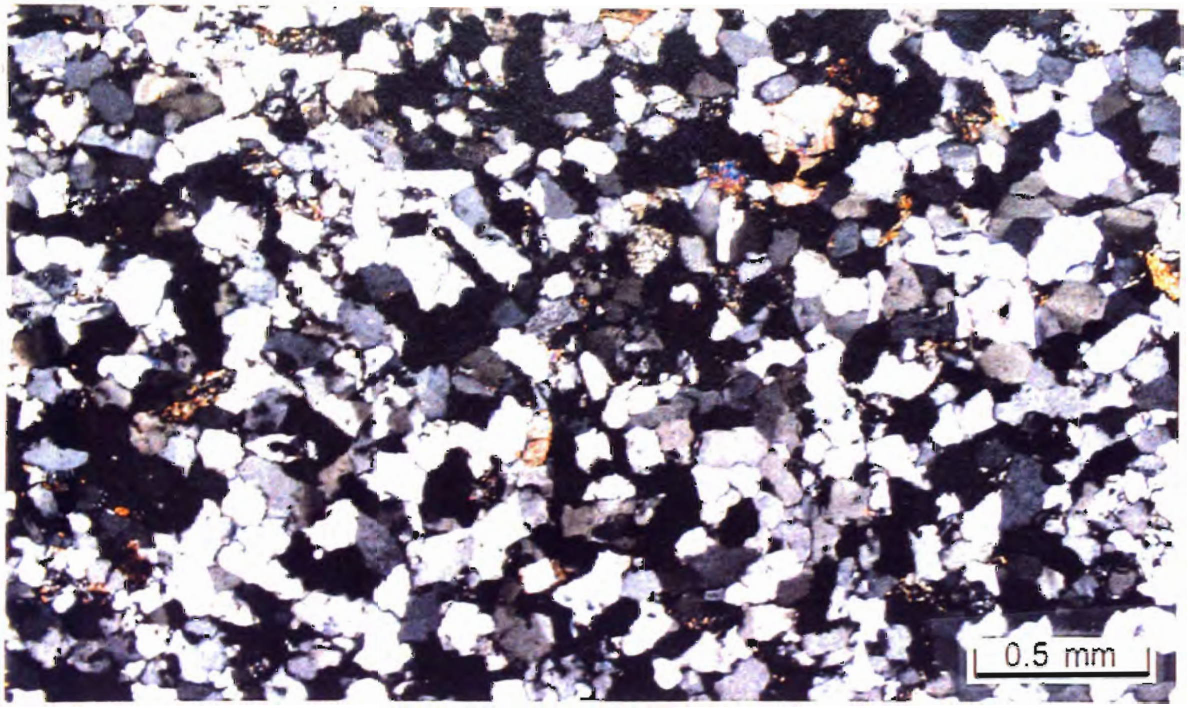

Figure 21. Imbrication of quartz grains, Gardner # 1, Red Oak, depth 13843 feet.

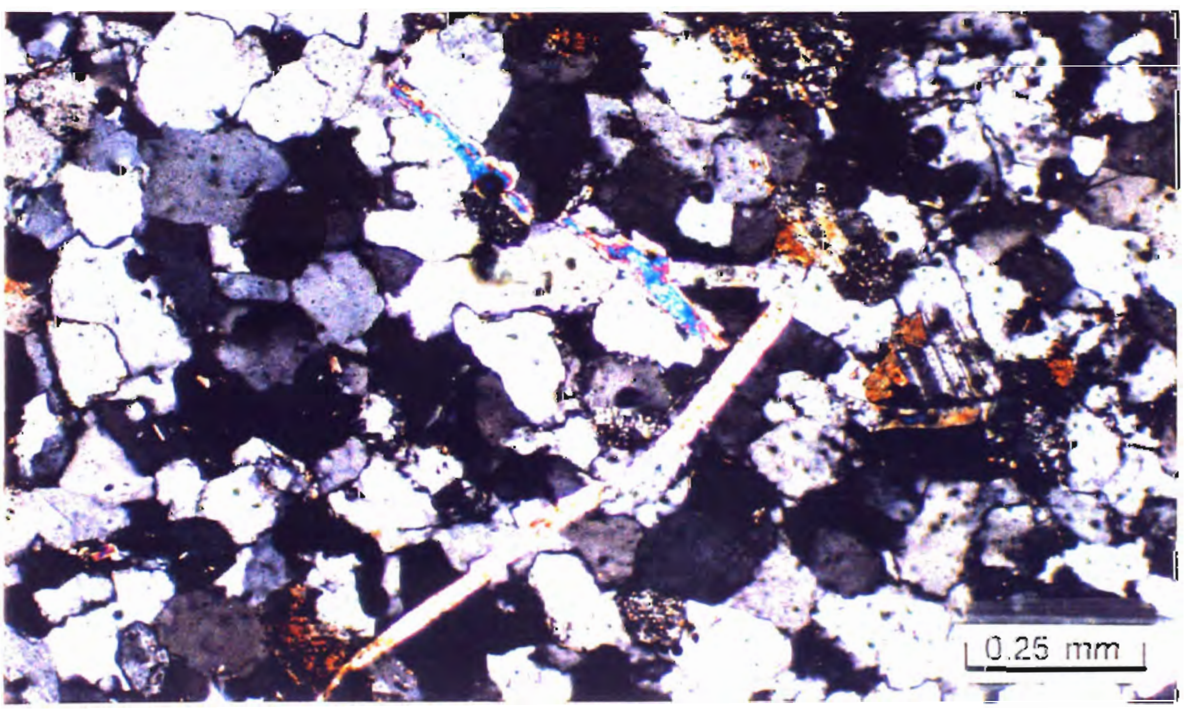

Figure 22. Long needles of muscovite deformed and/or broken probably due to compaction, Roye Unit # 1, depth 6590 feet

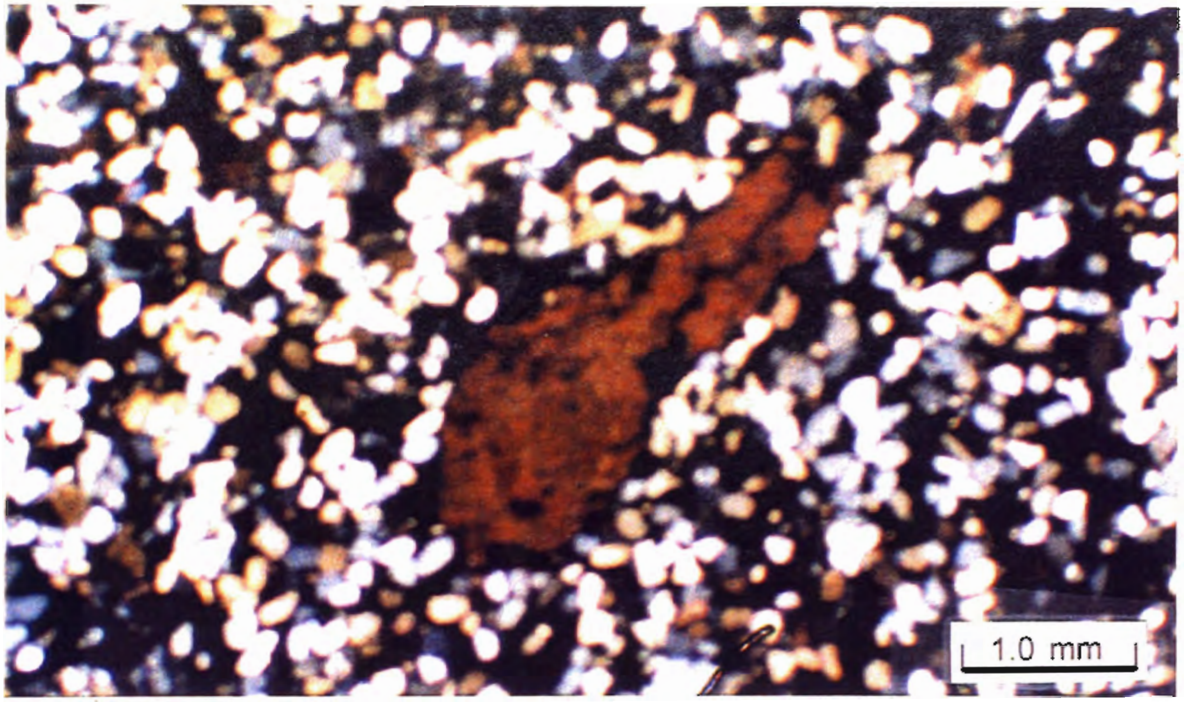

Figure 23. Skeletal debris of brachiopods, Gardner # 1, Red Oak, depth 13790 feet.

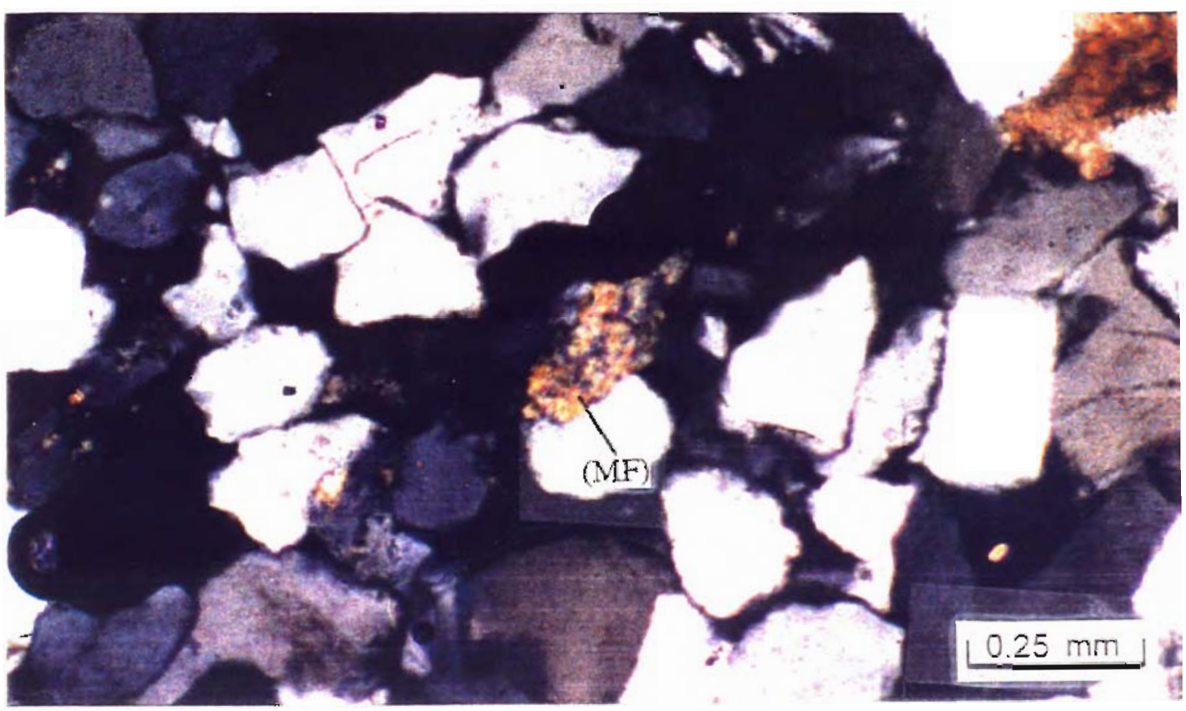

Figure 24. Metamorphic rock fragment (MF), Roye Unit # 1, depth 6603 feet.

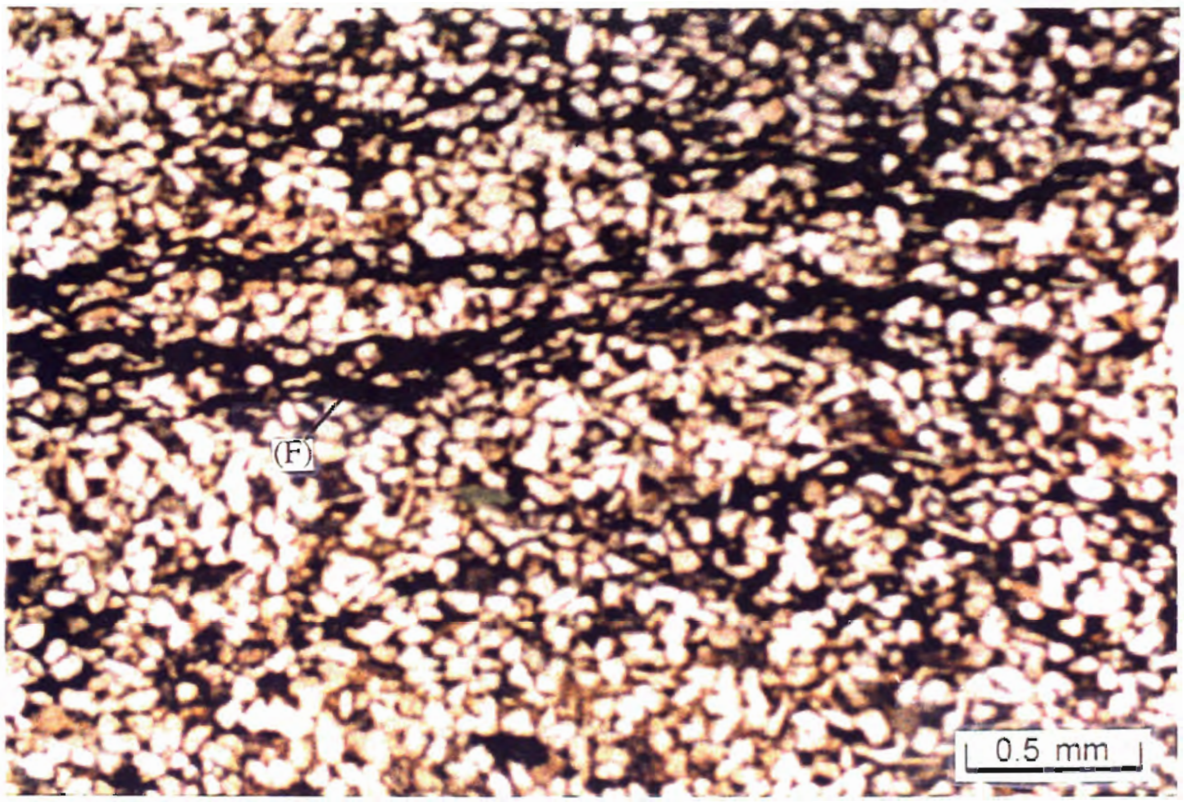

Figure 25. Film of hematite (F), Gardner #1, Red Oak, depth 13887 feet.

Delta models

The sediments that are derived directly from rivers are accumulated rapidly where these rivers enter a standing body of water such as oceans, inland seas, estuaries, lakes bays or lagoons to form deltas. Delta systems involve several distinct sub-environments influenced by the interaction of fluvial and marine processes. The recognition of delta sub-environments and the interacting physical processes is useful to reconstruct the nature of the delta.

Based primarily on the physical processes interacting within the delta, several classification schemes have resulted. Coleman and Wright (1975) defined six discrete delta models based on multivariate analysis of parameters from a wide range of modern deltas. Each model is illustrated by a sand-distribution pattern (Figure 26). Although Coleman's and Wright's scheme requires an extremely broad assemblage of data based in terms of the number of samples and the number of parameters, it appears to be weakened because idealized vertical sequences cannot summarize deltaic facies patterns, due to extreme vertical and lateral variations. Fisher and others (1969) and Galloway (1975) developed a classification applicable to both modern and ancient deltaic successions. These authors distinguished two major types of delta: high-constructive and high-destructive (Figure 27). These models shall be discussed in more detail in the ensuing discussion.

High-constructive deltas

High-constructive deltas are fluvially-dominated deltas formed by extensive basinward progradation involving low bed/suspended load ratios. These deltas show

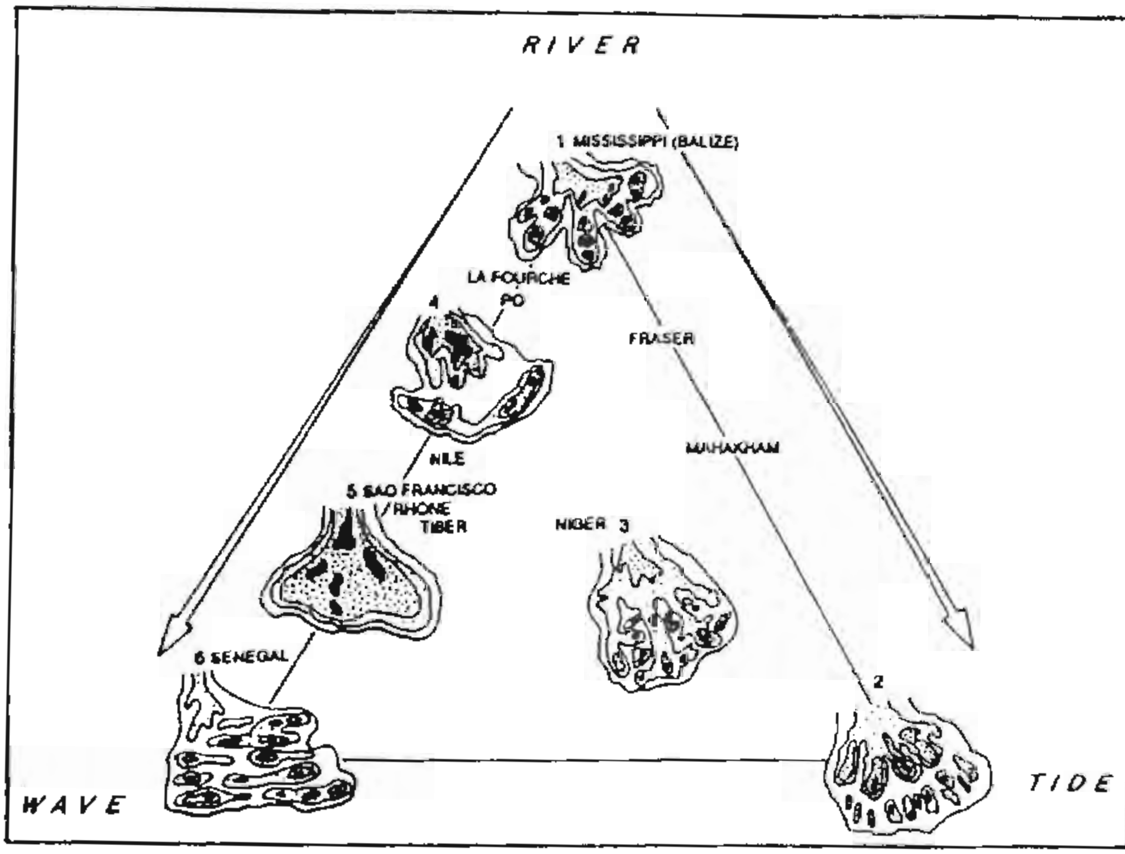

Figure 26. Sandbody geometries of the six delta types of Coleman and Wright (1975) plotted on the river-, wave- and tide-dominated tripartite classification of Galloway (1975). From Bhattacharya and Walker, 1992, p. 158.

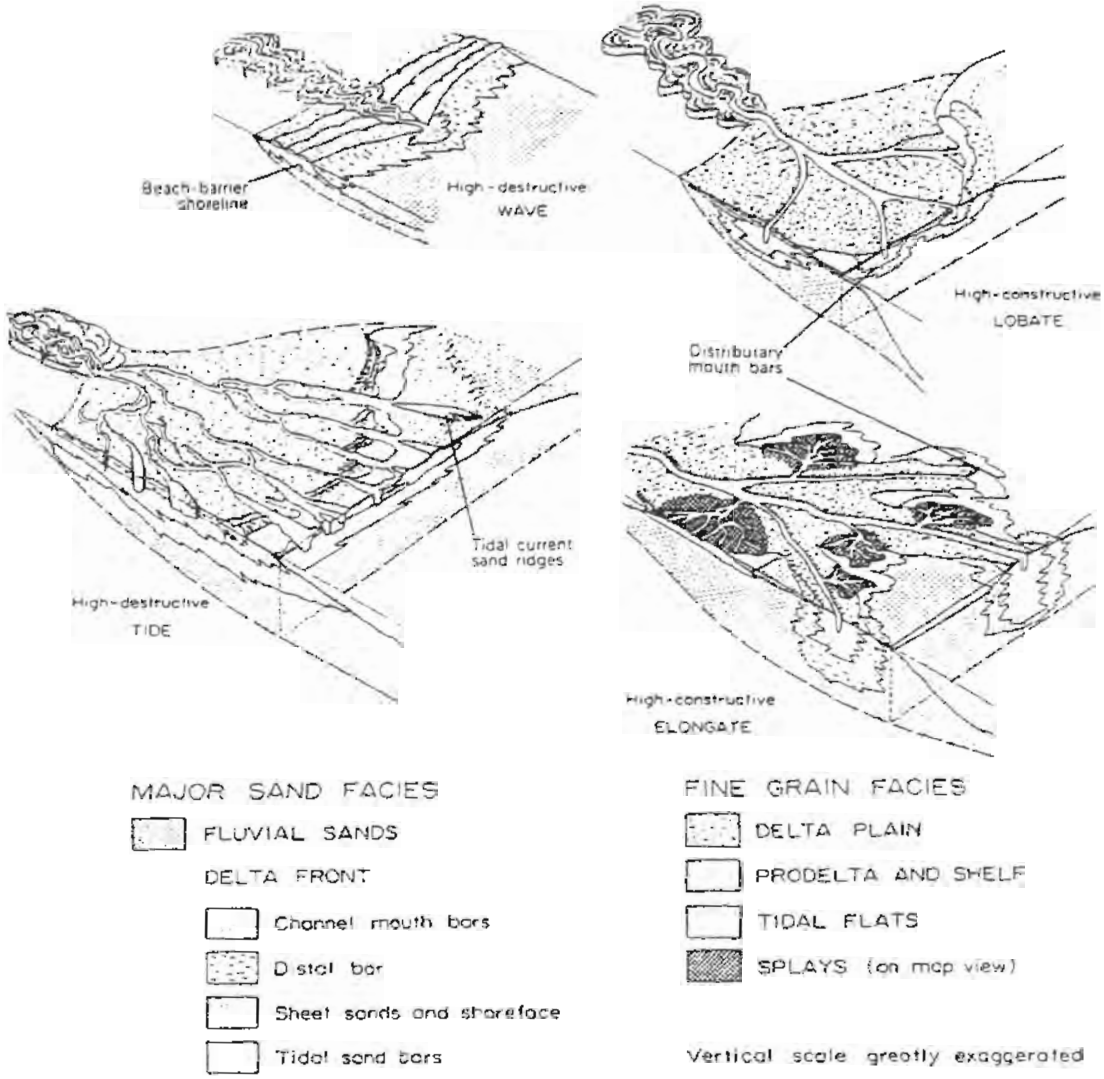

Figure 27. High-constructive and high-destructive delta types (modified from Fisher and others, 1969, fig. 19)

distinct, temporally separate constructional and destructional phases. The constructional facies, which constitute the great bulk of total sediment volume deposited, result from both aggradation and progradation. During active progradation, contemporaneous marine reworking of deltaic sand is minimal. The destructional phase takes place after the abandonment of the delta lobe. Facies developed during this phase are volumetrically insignificant. In addition, they are commonly restricted to distal parts of the delta and consist of small barrier, marsh, and reworked strand-plain sands (Brown and others, 1973). Other important features of the high-constructive deltas are the low sand/mud ratio and the good development of crevasse splays in the delta plain. On the basis of the coastline morphology of the prograded delta facies or the net sandstone isolith configuration, high-constructive deltas are subdivided into elongate and lobate types.

High-constructive elongate deltas

The idealized vertical sequence and block diagram through a high-constructive elongate delta shows that this delta is primarily characterized by a narrow, elongate delta front sand body, a very thick prodelta and dip-elongate geometry (Figure 28). The delta-front sandstone is composed of channel-mouth bar facies which subside rapidly into relatively deep water and are consequently deformed by slumps, mud diapirs and highly contorted sand bodies (Brown and others, 1973). Brown and others (1973), Cleaves (1975),and Cleaves (1987) recognized these facies as the best reservoir units. The characteristically thick prodelta is formed in response to the delta'sprogradation into deep water. Sedimentary structures associated with high-constructive elongate deltas include laminated to contorted mud and silt within the prodelta facies. The distal channel-mouth bar, as mentioned previously, is composed of highly contorted sand.

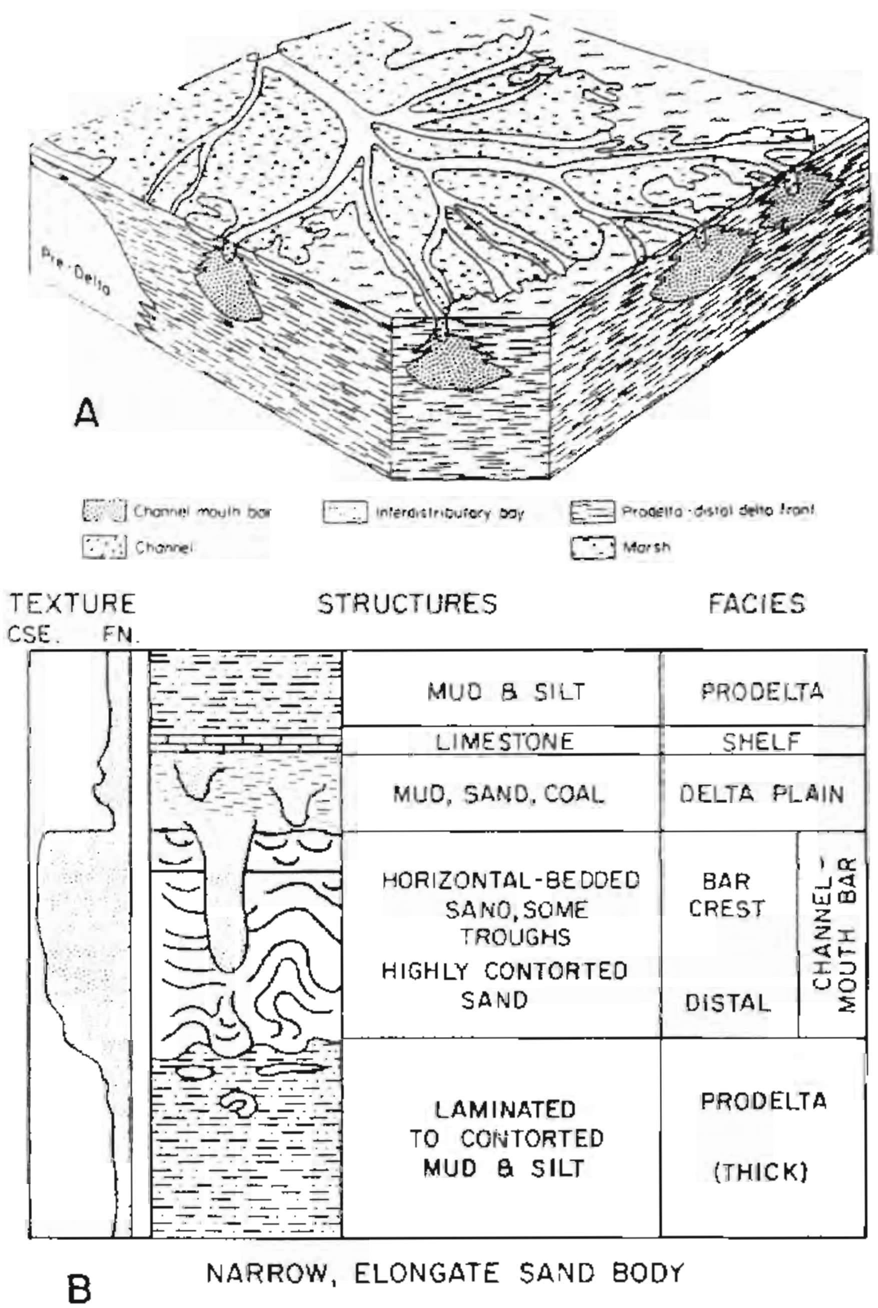

Figure 28. High-constructive elongate delta
(A): Block diagram
(B): Vertical sequence
(from Brown, 1979, p. 52).

whereas the bar-crest facies is dominated by horizontal-bedded sand and some ripples. The delta plain includes overbank mud, crevasse-splay sands and peat. In addition to these major features, the net sandstone isolith map of elongate high-constructive deltas has axes of maximum sand deposition pratically normal to basinal depositional strike (Figure 29).

High-constructive lobate deltas

The high-constructive lobate deltas are built up chiefly of the same genetic facies as the high-constructive elongate deltas, even though vertical and lateral distribution of facies differs. These deltas are characterized by delta-fringe sheet sand, lobate geometry, contemporaneous growth faults, and by the absence of well defined bar fingers (Figure 30). The prodelta is thin and exhibits laminated mud and silt. Distal facies of the delta front include interbedded rippled sand and mud whereas the proximal delta facies contain large-scale cross-bedding, horizontally bedded sands and oscillation ripples. The mud, sand and peat dominate within the delta front. In addition, the delta-front sands are reworked by marine processes to produce a sheet sand formed by the coalescence of channel-mouth bars. The coalescent sheet sand defines the broad, lobate sand isolith pattern. The pattern exhibits significant basinward progradation with the maximum sand axes perpendicular or at fairly high angles to basin depositional strike (Figure 31). The delta-fringe sheet sandstone, proximal and distal distributary channel fill, crevasse splays and marine transgressive sheet sandstones constitute the reservoir units within these types of deltas (Cleaves, 1987).Trapping mechanisms involve roll-over anticlines, updip faulting and downdip pinchout of sand bodies (Brown 1979).

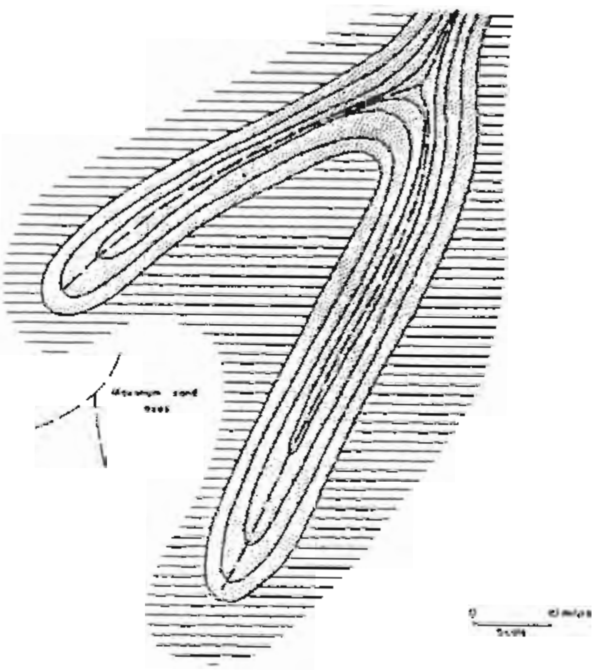

Figure 29. Net sand pattern of high-constructive elongate delta systems (from Fisher and others, 1969, fig. 61).

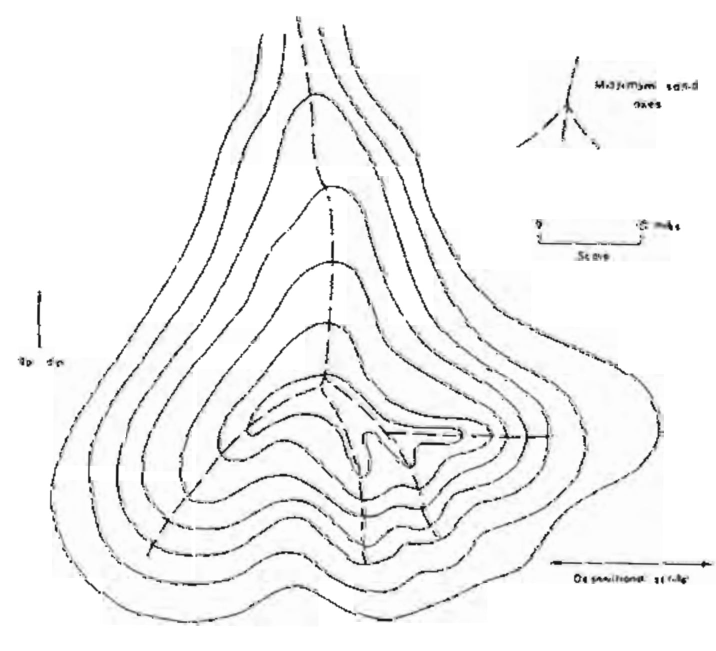

Figure 31. Net sand pattern of high-constructive lobate delta systems (from Fisher and others, 1969, fig. 59).

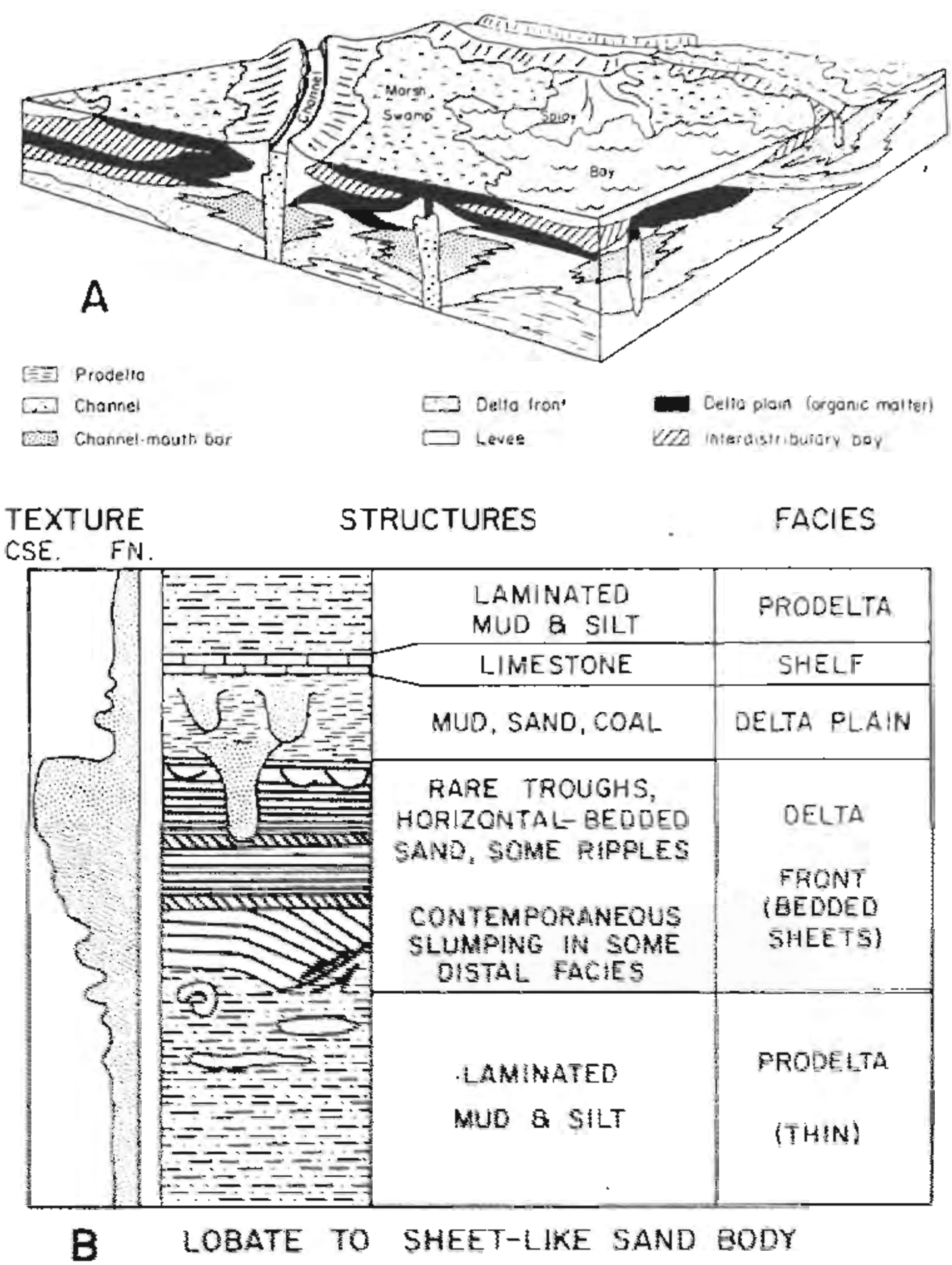

Figure 30. High-constructive lobate delta
(A): Block diagram
(B): Vertical sequence
(from Brown, 1979, p. 51).

High-destructive deltas

High-destructive deltas form in a setting in which marine processes such as waves, tides and currents predominate over fluvial processes in generating deltaic facies. The accumulation and redistribution of sediments supplied by distributary channels is controlled by the energy of the receiving basin. In these deltas, all facies exhibit only minor basinward progradation. The fluvial sediments are reworked contemporaneously with lobe progradation. Generally constructive and destructive delta phases are not vertically distinct and marine redistributed sand bodies represent the great perponderance essential of the sediment accumulated. High-destructive deltas are often fed by a high bed-load trunk stream with a small drainage basin. In addition they may involve meandering distributaries on delta plains. On the basis of identified or inferred marine processes which generate the principal sand facies of the delta, they can be subdivided into high-destructive wave-dominated deltas and high-destructive tide-dominated deltas.

High-destructive wave-dominated deltas

This type of delta contains distinctive facies formed when wave and longshore drift rework river-derived sediment parallel to strike. The resulting shape is cuspate with two-distinct maximum sand axes. The primary axis is strike-oriented and the secondary axis parallels the dip-oriented distributary and channel mouth bar facies (Figure 32). High-destructive wave-dominated delta are sand-rich and include a thin prodelta mud. In contrast to high-constructive elongate deltas, the progradation of the channel mouth bar is much less extensive here as a result of redistribution of sands by longshore drift lateral. The major eservoir facies are represented by strand-plain, channel mouth-bars and meandering distributary channels (Cleaves, 1987).

High-destructive tide-dominated deltas

High-destructive tide-dominated deltas involve tidally reworked coarse-grained sediments which are commonly dispersed from the distributary mouth bar into linear sand bodies. These sand bodies trend parallel to the tidal-current direction and perpendicular to depositional strike (Figure 33). Various facies of the tide-dominated deltas are all thin. Consequently they cannot be easily identified within the context of the overall complex.

Discussion of Depositional Systems

Depositional systems of the Union Valley Formation in Arkoma Basin have been interpreted differently by geologists. As a result of their investigations, Sutherland (1971), Jefferies (1982), Rascoe and Adler (1983), and Stout (1991) point out marine processes to have been at the origin of Union Valley deposition. Visher and others (1971), Cockrell (1985), and Fields (1987) mentioned deltaic processes. According to Withrow (1969) both river and ocean currents have influenced the deposition of Cromwell Sandstone.

In the present case, subsurface mapping of the Union Valley Formation demonstrates that Cromwell Sandstone is present over the entire study area. Increase in thickness is more than likely related to channelization, as shown by the net-sandstone isolith map (Plate V), and stratigraphic cross-sections (Plates II, III,). From the net-sandstone isolith map, three major trends of the sand are delineated. These are oriented from north to south and clearly indicate that the source of Cromwell was northward. Based on petrography this source was probably a crystalline terrain. However McQuillan (1978) assigned a northeasterly and easterly source of Cromwell, with a limited

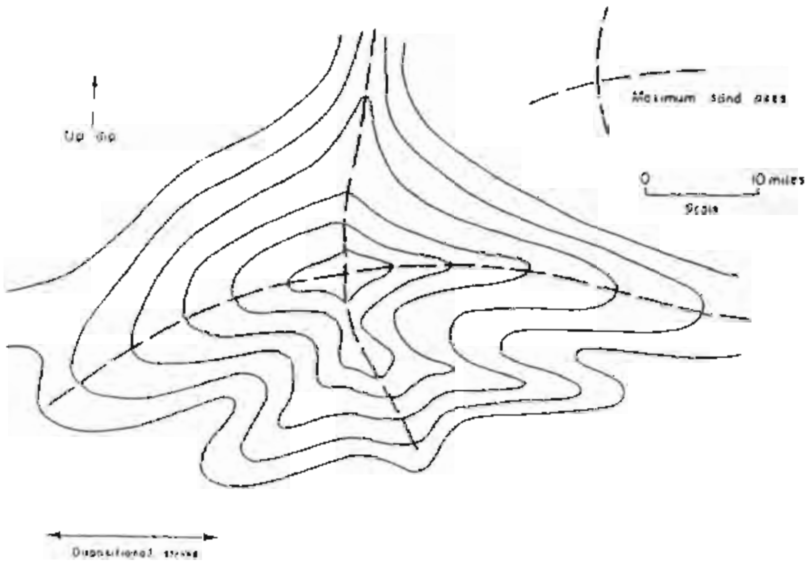

Figure 32. Net sand pattern of high-destructive wave-dominated delta systems (from Fisher and others, 1969, fig. 67).

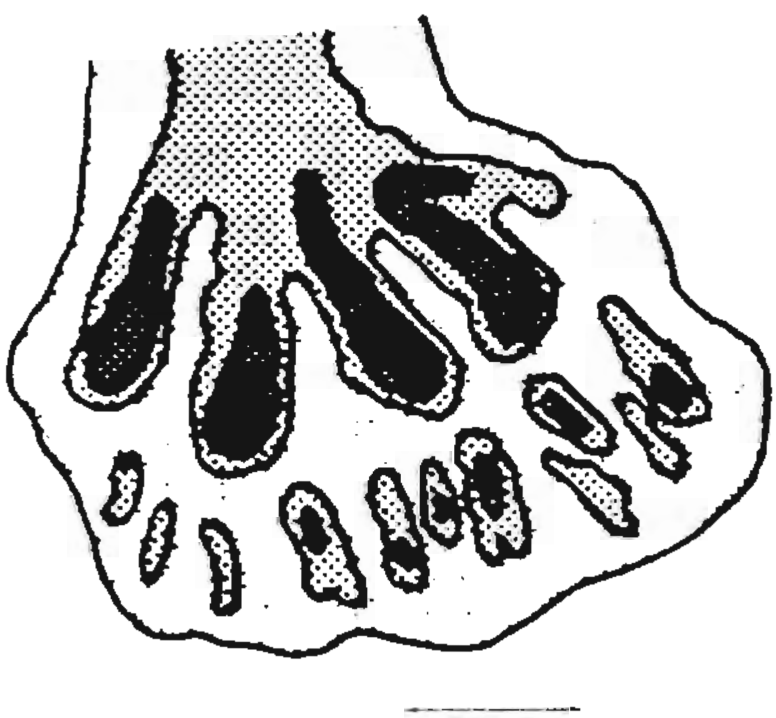

Figure 33. Theoretical net sand pattern of high-destructive tide-dominated delta (modified from Coleman, 1981, p. 110).

contribution of sediments from the north. Analysis of the spontaneous-potential and gamma-ray well log patterns produced groupings of funnel, bell, cylinder, or funnel/bell signatures. As stated previously, these patterns agree with those attributed to distributary-channel sands, reworked interdistributary sands, delta-fringe sands, barrier-bar sands, or distributary-mouth bar sands. However, the predominantly coarsening-upward sequence within the study area may be interpreted as a deltaic progradation in accordance with Galloway and Hobday (1983), and Davis (1992). Besides the geometry of the Cromwell body, characteristics such as sedimentary structures, fossils, textures, and constituents allow us to interpret the Cromwell Sandstone in the study area as a deltaic deposit the upper part of which was reworked by marine processes.

CHAPTER VI

CONCLUSIONS

The following conclusions can be drawn from the present investigation:

1. The Morrowan series includes the Union Valley Formations at the bottom and Wapanucka Limestone at the top; Morrowan rocks are present over the entire study area.
2. Lower and upper boundaries of the Morrowan series are delineated by unconformities.
3. The Cromwell Sandstone is primarily a quartz-arenite and sublitharenite and commonly thickens basinward.
4. Structural features are chiefly northeasterly trending faults and folds. Some structures were active when the Morrowan strata were deposited.
5. Evidence from subsurface maps, well log patterns, and cores suggests that the Cromwell Sandstone is composed of deltaic deposits more or less reworked by marine processes.
6. Finally, although petroleum geology has not been discussed in this study, trapping mechanisms are typically documented by structural geology rather than stratigraphy.

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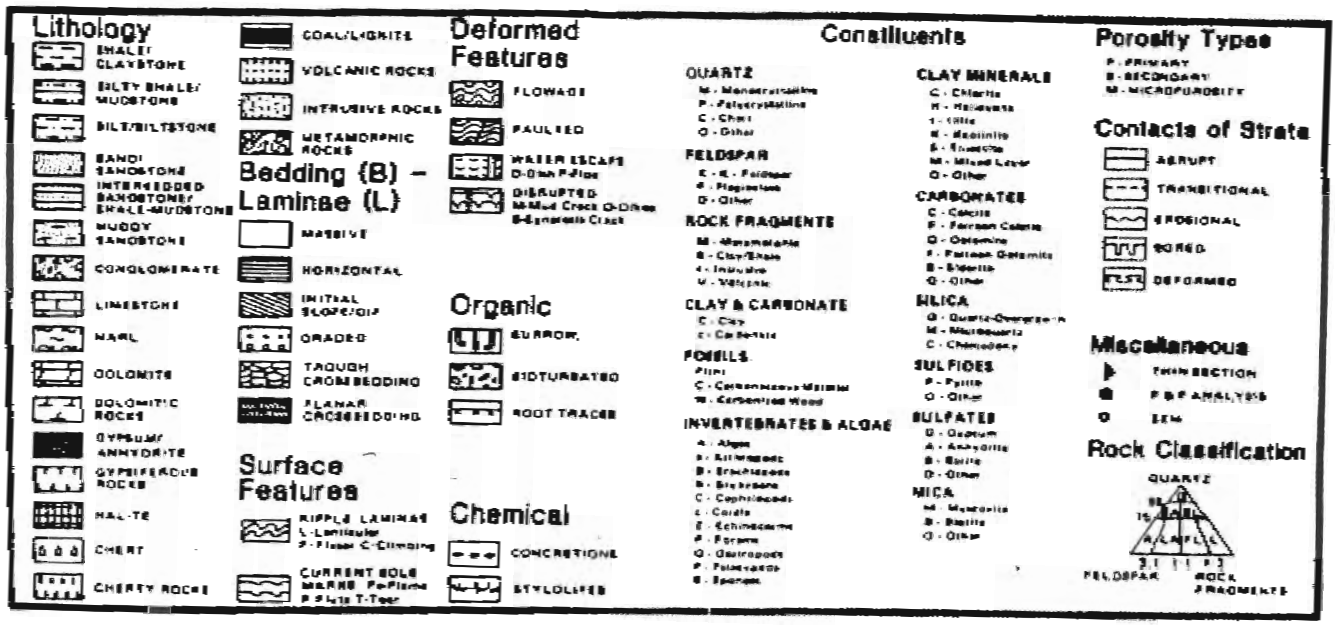
APPENDIX A

CORE DESCRIPTIONS

PETROLOGIC LOG

Well: Roye Unit # 1
Location: 810' S & 300' W of C
sec. 9, T.8 N.,R.21 E.
Haskell County, Oklahoma

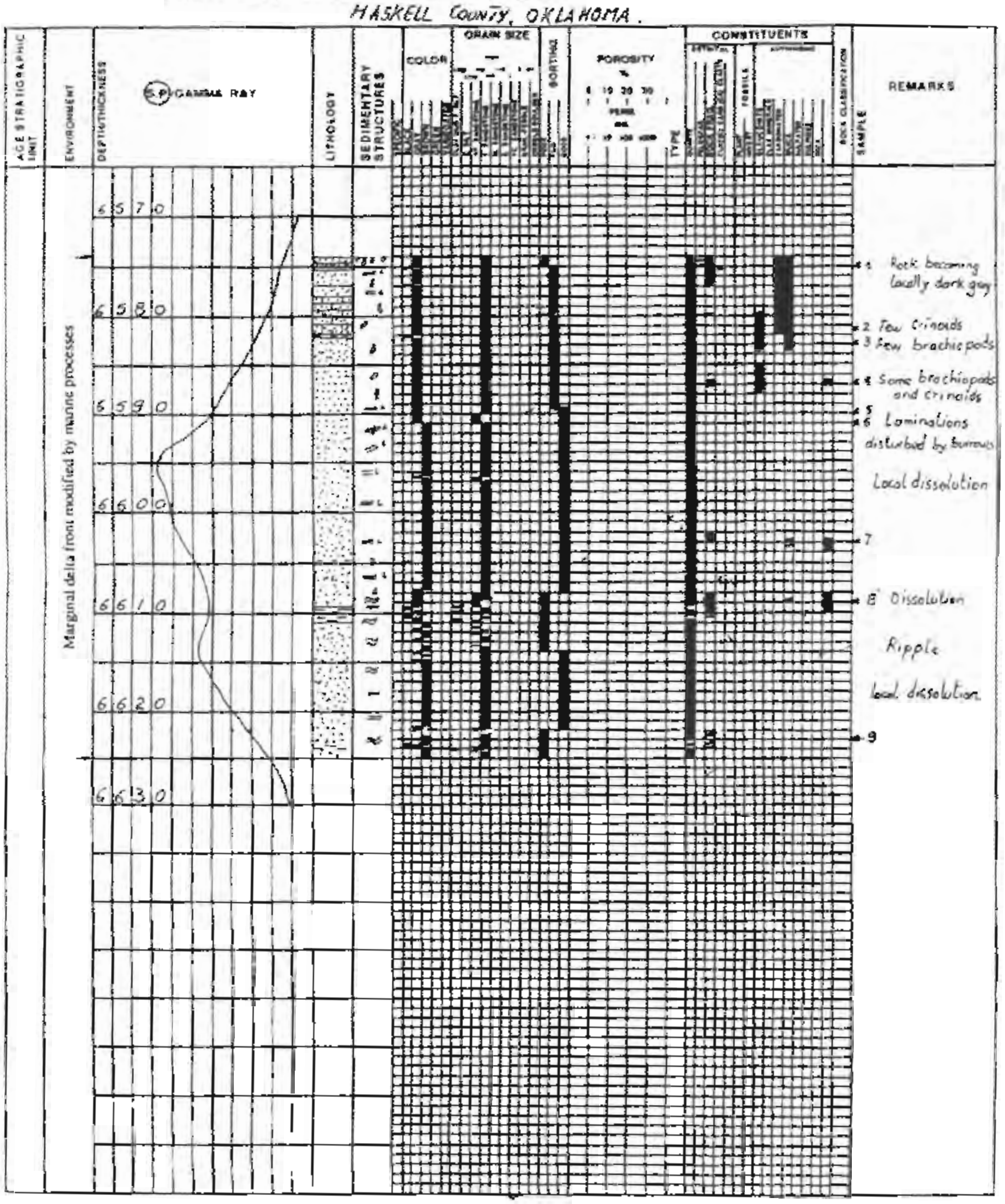


Company HUMBLE OIL & REFINING COMPANY

Well Name/Location Roye Unit #1 1810's & 300'W of C. 29-8N-21E

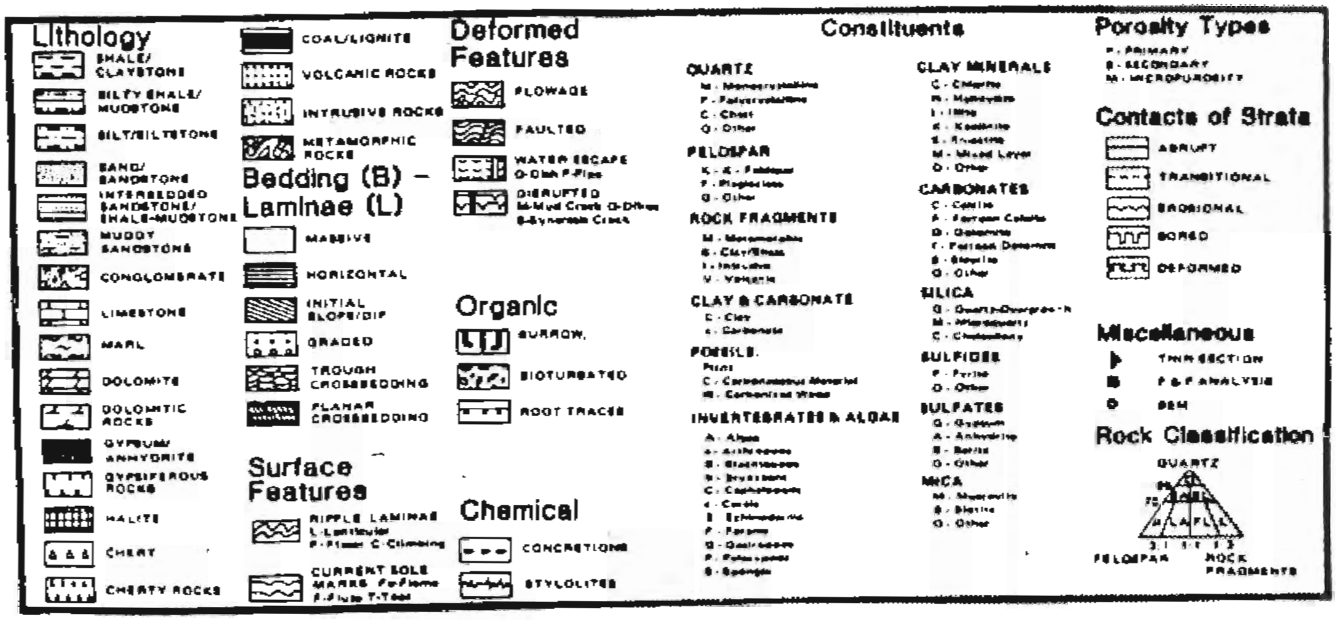
HASKELL COUNTY, OKLAHOMA.

Petrologic Log



PETROLOGIC LOG

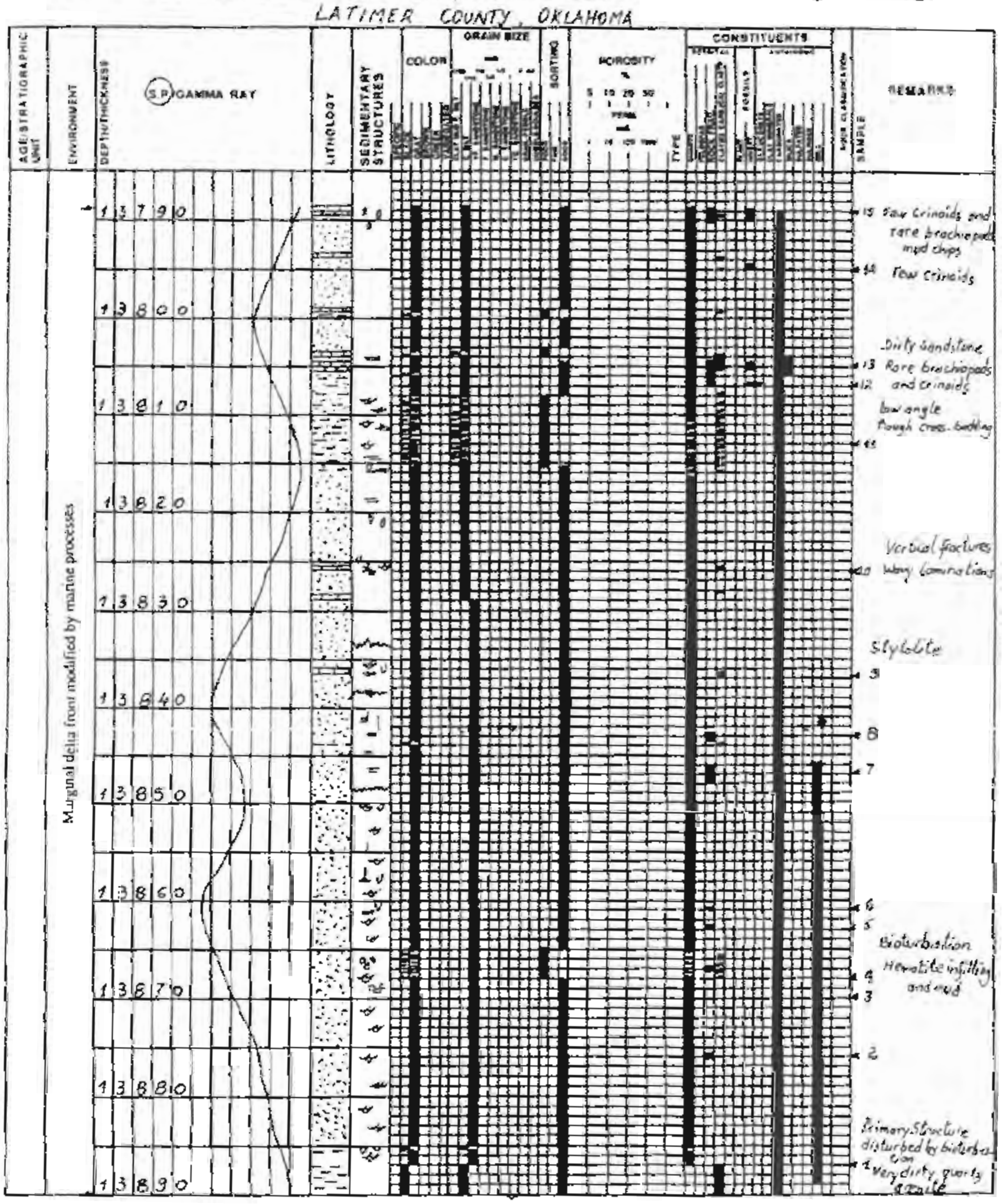
Well: Gardner # 1 Red Oak
Location: 2052' NSL & 4060' EWL
Sec. 13, T.6 N.,R.20 E.
Latimer County, Oklahoma



Company MIDWEST OIL CORPORATION

Well Name/Location Gardner #1 Red Oak /2052' NFL & 4060' FWL 12-6N-20E **Petrologic Log**

LATIMER COUNTY, OKLAHOMA



APPENDIX B

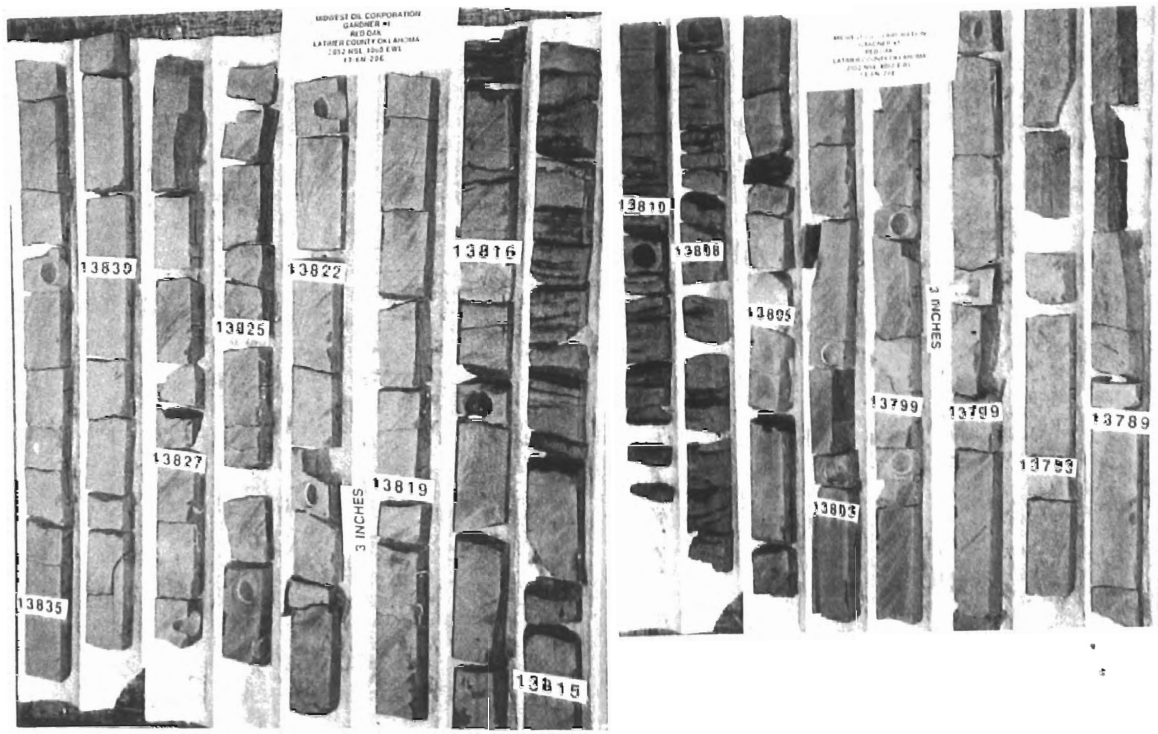
COMPOSITE CORE PHOTOGRAPHS

ROYE UNIT # 1

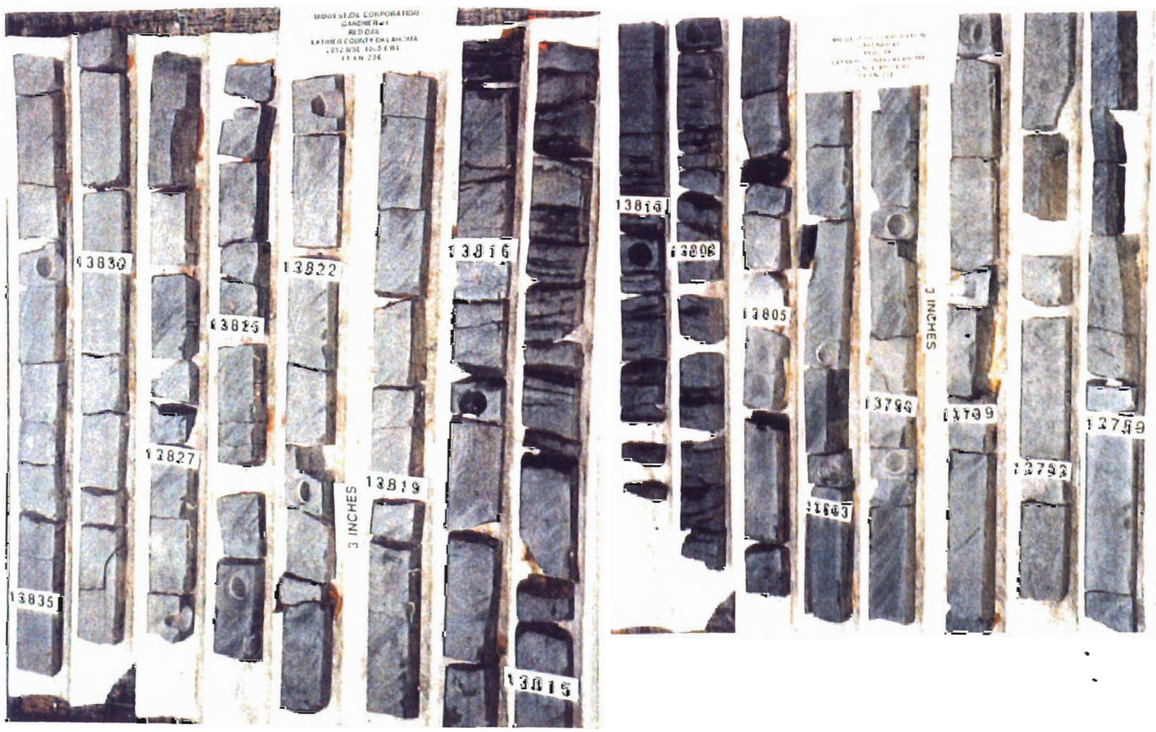
HUMBLE OIL & REFINING COMPANY
ROYE UNIT #1
N.E. LEQUIRE
ASKELL COUNTY OKLAHOMA
810' S & 300' W OF C.
29-8N-21E.

GARDNER # 1 RED OAK

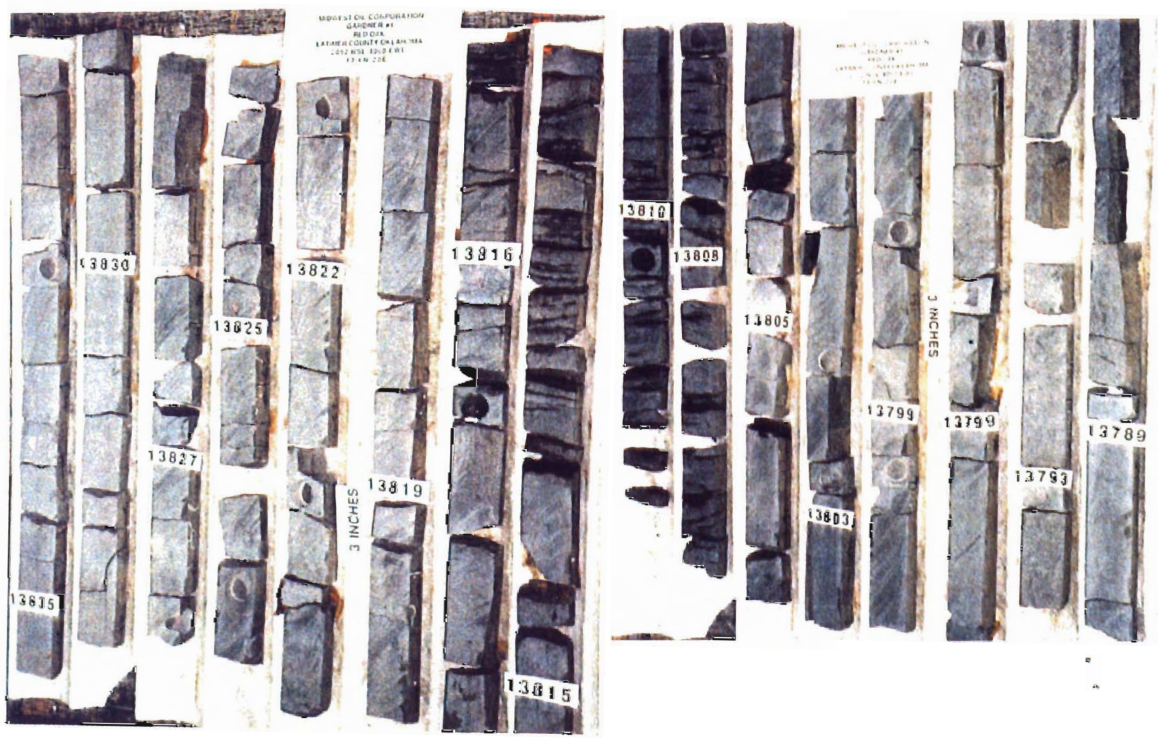
MIDWEST OIL CORPORATION
GARDNER # 1
RED OAK
LATIMER COUNTY OKLAHOMA
2052' NSL, 4060' EWL
13-6N-20E



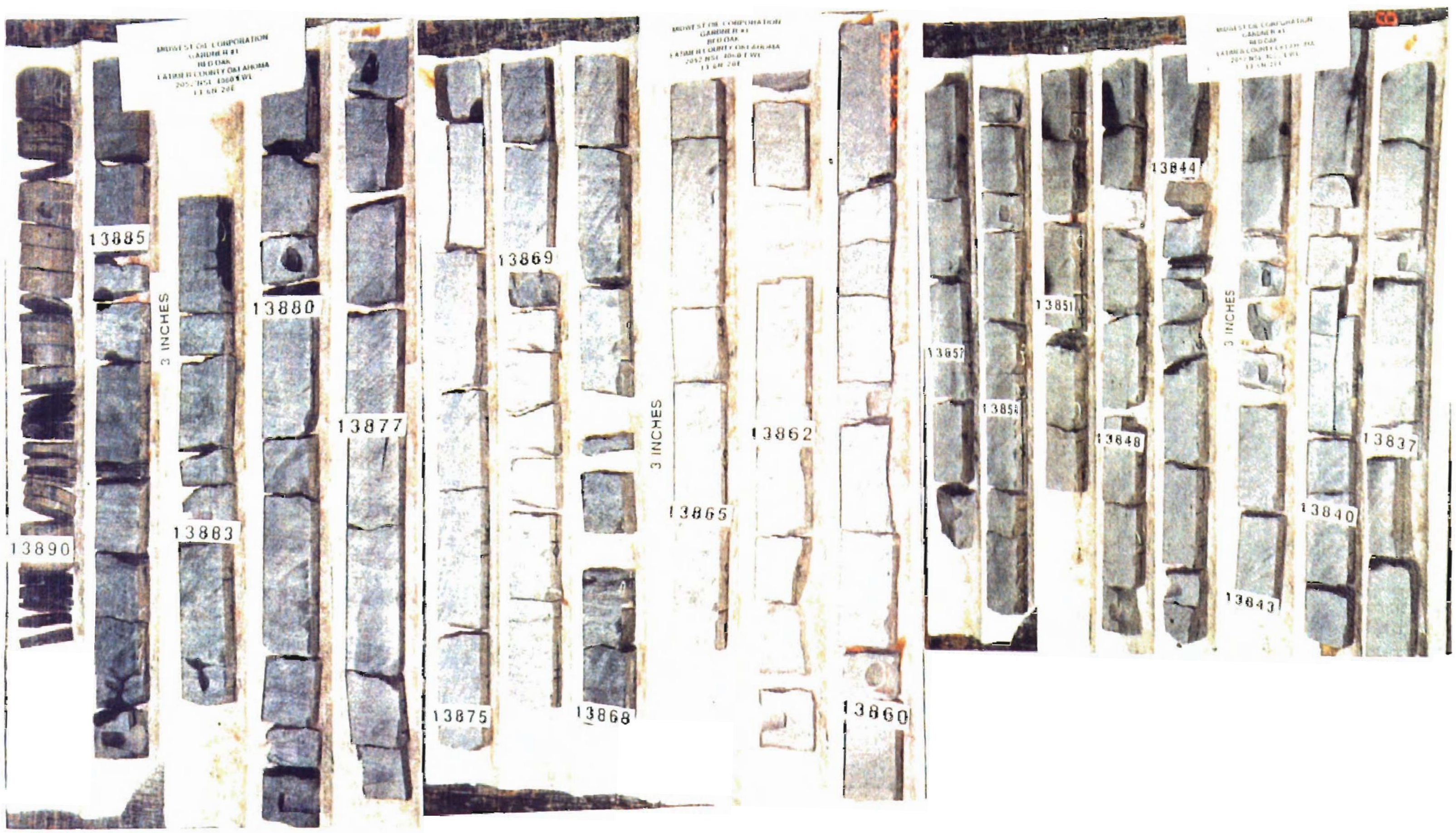
MIDWEST OIL CORPORATION
GARDNER # 1
RED OAK
LATIMER COUNTY OKLAHOMA
2052' NSL, 4060' EWL
13-6N-20E



MIDWEST OIL CORPORATION
GARDNER # 1
RED OAK
LATIMER COUNTY OKLAHOMA
2052' NSL, 4060' EWL
13-6N-20E



MIDWEST OIL CORPORATION
GARDNER # 1
RED OAK
LATIMER COUNTY OKLAHOMA
2052' NSL, 4060' EWL
13-6 N-20 E



VITA

Martin Guy Claude Abolo

Candidate for the Degree of

Master of Science

Thesis: GEOMETRY AND DEPOSITIONAL SYSTEMS OF THE CROMWELL SANDSTONE (MORROWAN LOWER DORNICK HILLS) IN PARTS OF HASKELL, LATIMER, LE FLORE, MUSKOGEE AND SEQUOYAH COUNTIES, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Nomayos, Cameroon, On March 27, 1961, the son of Jean Louis Abolo and Veronique Mani Mfegue.

Education: Graduated from Lycee de Sangmelima, Sangmelima, Cameroon in June, 1980; received Bachelor of Science degree and Master of Science degree in Geology from University of Yaounde I in June, 1984 and October, 1985,respectively. Spent six months of intense research in Bundesanstalt fur Geowissenschaften und Rohstoffe, Hannover, Germany for the completion of the Degree Of Doctor of Philosophy, February, 1992 to August, 1992. Completed the requirements for the Master of Science degree with a major in Geology at Oklahoma State University in December 1995.

Experience: Teaching Assistant, Department of Earth Sciences , University of Yaounde I, Cameroon, January 1985 to May 1990; employee as Natural Sciences Teacher, College Mongo Beti and Institut Samba, Yaounde, from September 1985 to May 1991, employed as geologist during summer 1988, National Hydrocarbon Corporation, Cameroon; pre-employed as geologist, December 1992 to May 1993, National Hydrocarbon Corporation, Cameroon

Professional Memberships: Junior Member of the American Association of

Petroleum Geologists, member of Society for Sedimentology Geology.

Plates II, III, IV, V, VI, VII, and VIII.

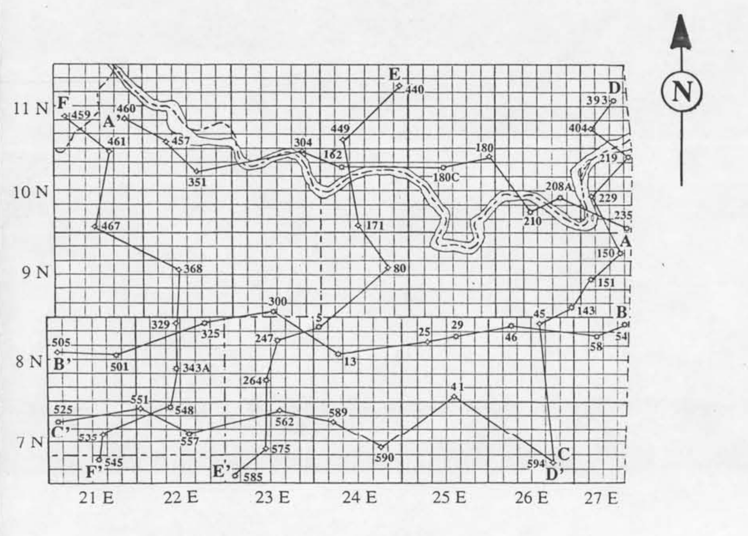


PLATE II :

E-W STRATIGRAPHIC CROSS-SECTIONS

SECTION A-A'

SECTION B-B'

SECTION C-C'

0 1 2 Miles

Martin Guy ABOLO	Oklahoma State University	M.S. 1995

PLATE III :

N-S STRATIGRAPHIC CROSS-SECTIONS

SECTION D-D'

SECTION E-E'

SECTION F-F'

Martin Guy ABOLO	Oklahoma State University	M.S. 1995

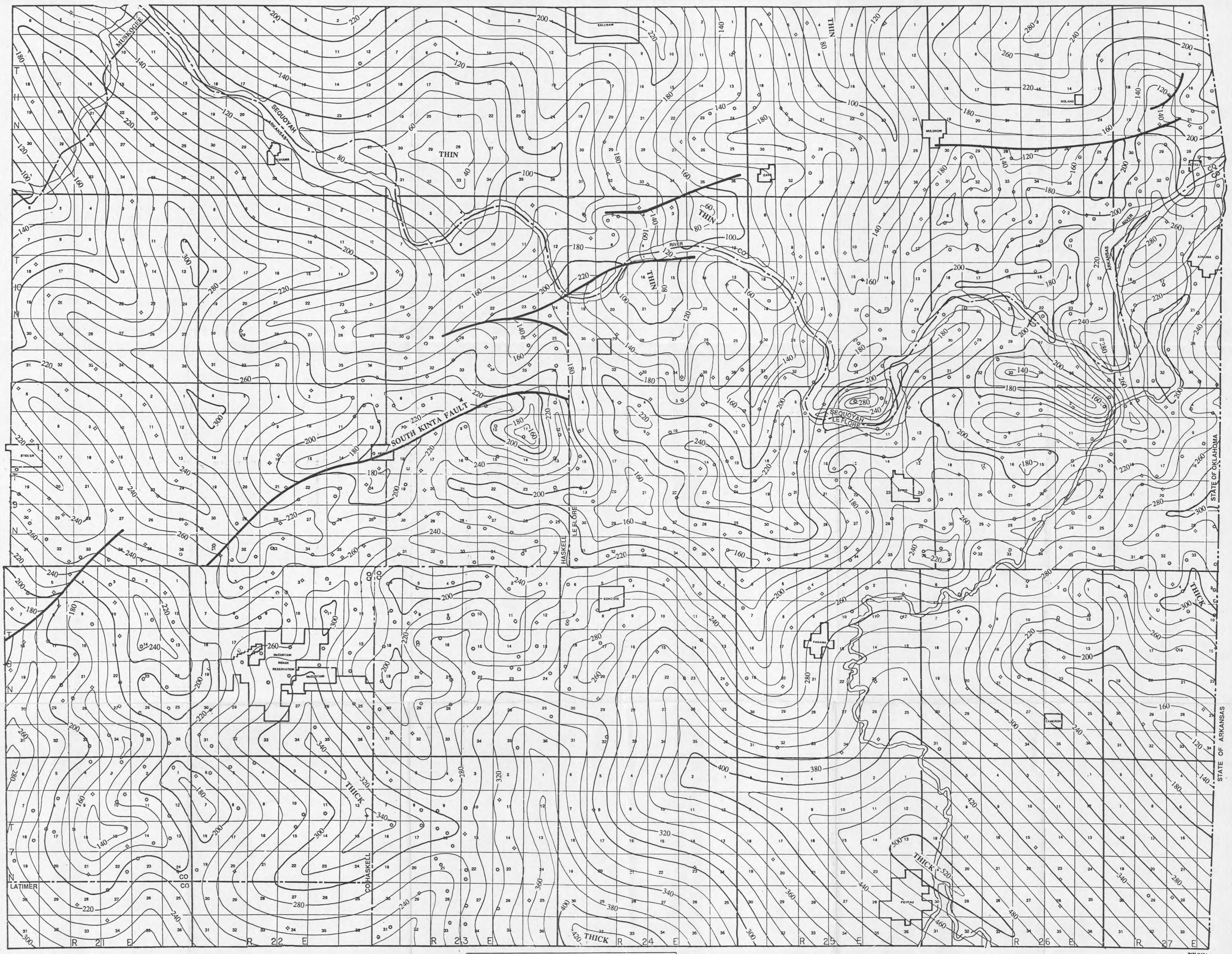


PLATE IV :

UNION VALLEY ISOPACH MAP

(Bottom Cromwell Sandstone-Bottom Wapanucka Limestone)

C.I : 20 FT

2 Miles

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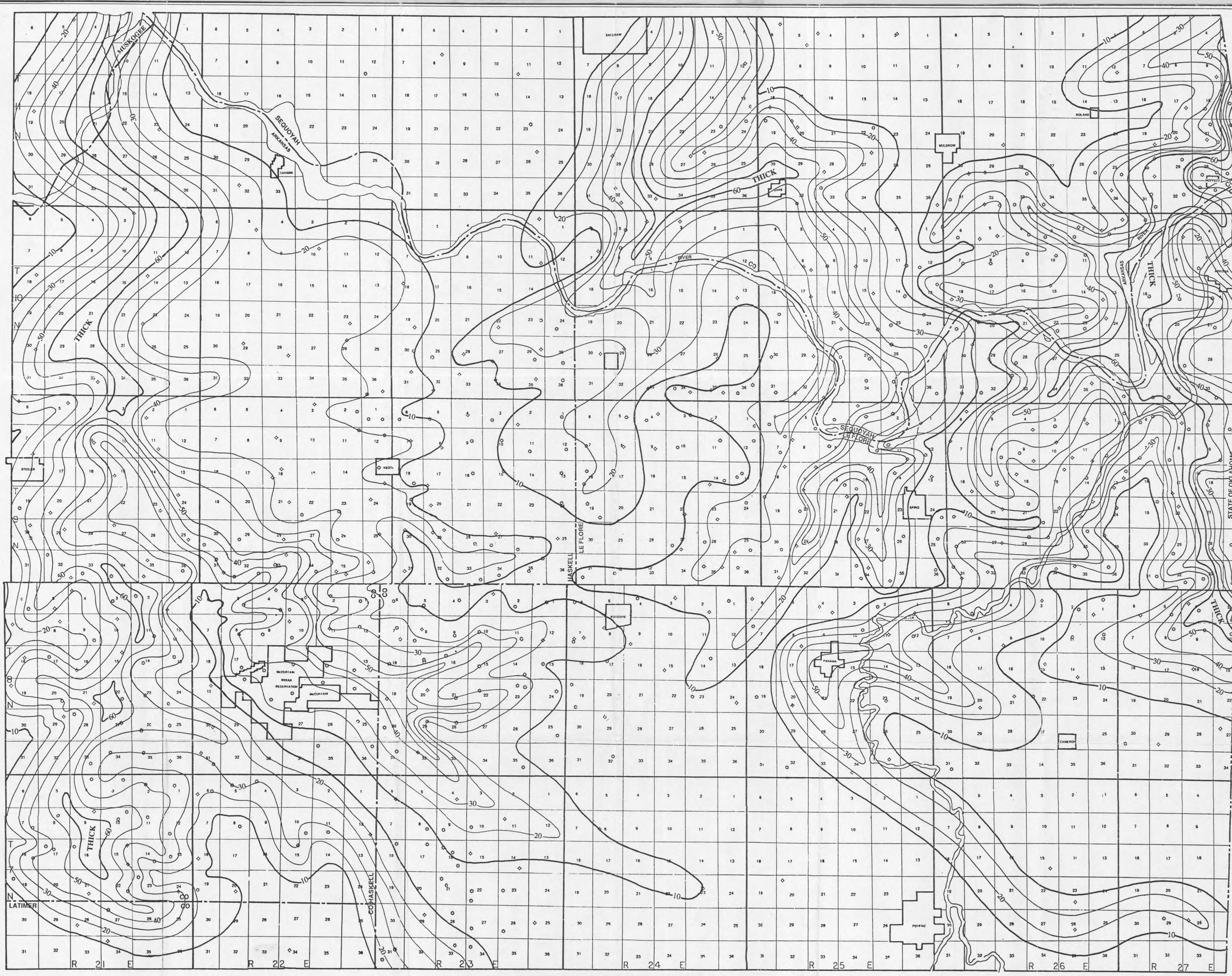

PLATE V :

CROMWELL NET SANDSTONE ISOLITH MAP

C.I. : 10 FT

1:8000

2 Miles

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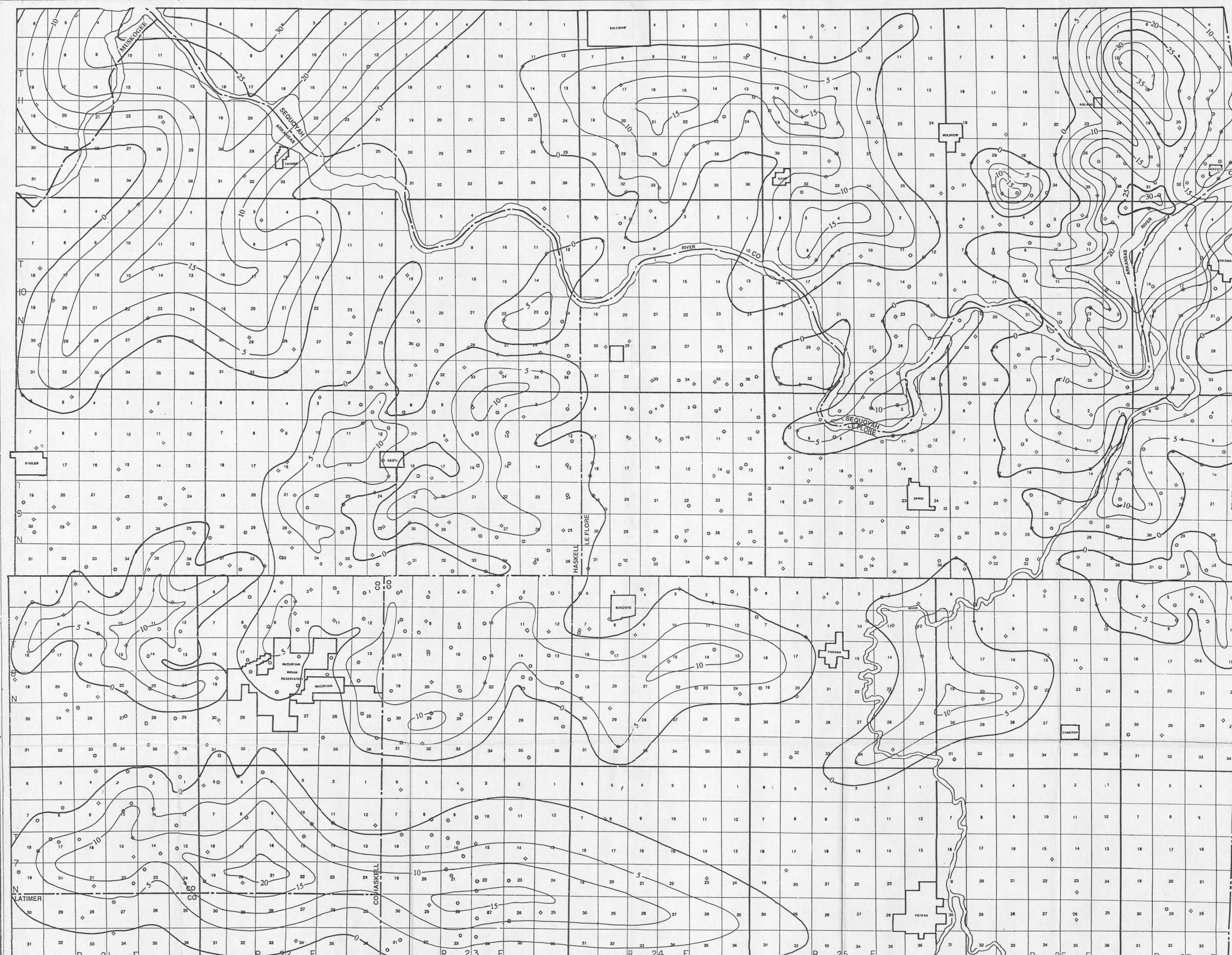
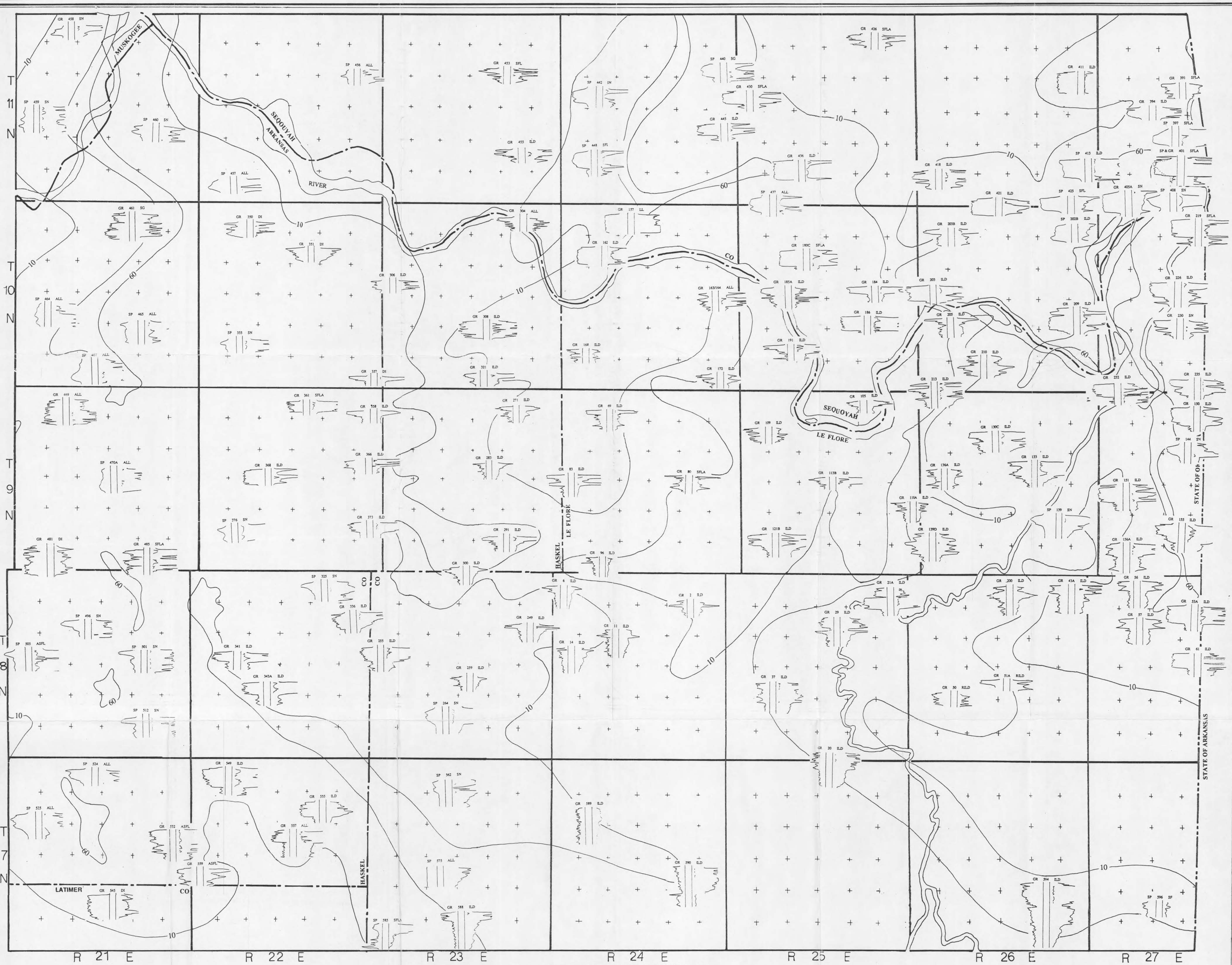


PLATE VI

NET CARBONATE ISOLITH MAP OF UNION VALLEY LIMESTONE

C.I. : 5 FT

2 Miles



Made in USA

PLATE VII :

CROMWELL SANDSTONE LOG MOTIF MAP

2 Miles

GR: Gamma Ray Log; SP: Spontaneous Potential Log; ILD,RILD,DI: Resistivity Induction Log Deep; LL: Laterolog; ALL: Averaged Laterolog; SFL,SF: Shallow Focused Log; ASFL,SFLA: Averaged Shallow Focused Log; SG: Shallow Guard Log.

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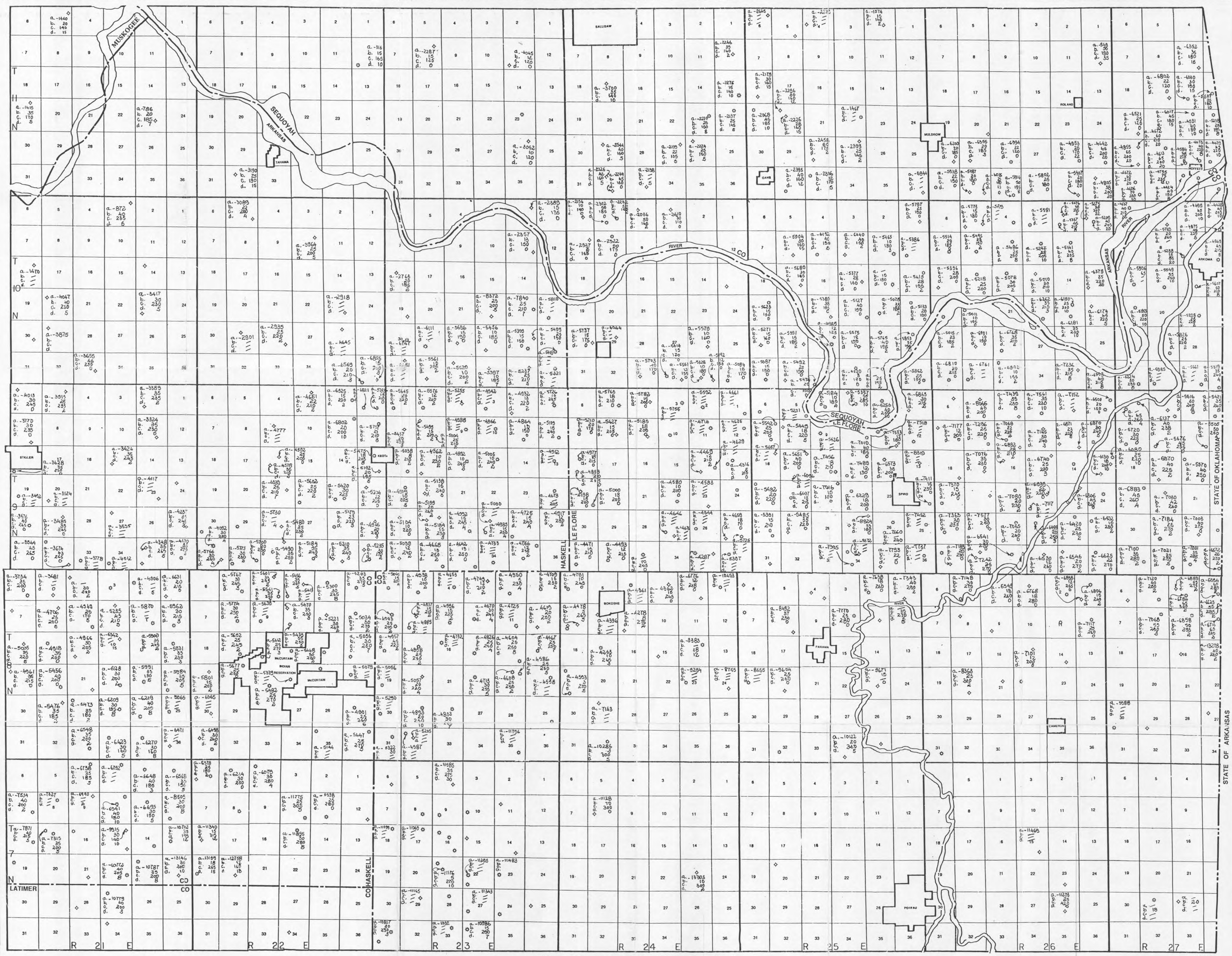

PLATE VIII: BASE MAP

Legend:
a. Top of Wapanucka Limestone Data
b. Cromwell Net Sandstone Isolith Data
c. Union Valley GIS Isopach Data
d. Net Carbonate Isolith of Union Valley Limestone Data

2 Miles

Martin Guy ABOLO | Oklahoma State University | M.S. 1995