DEPOSITIONAL SETTING, FACIES, AND PETROLEUM GEOLOGY OF BOATWRIGHT SANDSTONES (SRINGER GROUP) IN PARTS OF CADDO, CANADIAN, AND BLAINE COUNTIES, OK

By

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CHAPTER I

INTRODUCTION

Sandstones in the Springer Group are some of the highest volume gas and gas-condensate wells in the Anadarko Basin. As reported by Andrews (2001). Springer sandstone reservoirs in the Anadarko Basin have produced in excess of 3.8 trillion cubic feet of gas (TCFG) and 200 million barrels of liquids (MMBL) through 1999 (Andrews, 2001). Individual wells produce up to 20 billion cubic feet of gas (BCFG). Recently available core and continued drilling for Springer sandstone gas has increased the data set size and fostered a need to identify depositional environments, distribution patterns, and facies relationships of Springer sandstones to enhance petroleum exploration efforts. The primary purpose of this investigation is to (1) identify facies patterns and their distribution, (2) interpret depositional environments, (3) characterize petroleum accumulation within the Boatwright sandstones and (4) establish a preliminary sequence stratigraphic framework for the Boatwright interval. The Boatwright is a parastratigraphic unit of the Springer Group, a clastic dominated succession of shale and sandstones of the upper Mississippian Subsystem, Carboniferous System. Data used in this study are derived from approximately 1200 wells drilled within the southeastern Anadarko Basin.

Objectives

Specific objectives of this research include: 1) generation of a well-log based cross section network to establish a stratigraphic framework, 2) creation of a structural contour map, 3) core description and calibration to wireline logs, 4) establish core-calibrated wireline log electrofacies, 5) mapping the distribution of electrofacies, 6) interpretation of depositional environments, 7) and petrographic analysis of thin-sections from core to determine detrital constituents, authigenic materials, and porosity type.

Study Area

The study area is located in the southeastern portion of the Anadarko Basin in parts of Canadian, Blaine, and Caddo counties, Oklahoma. The study area includes part of the petroliferous accumulation referred to as the Watonga-Chickasha trend and contains numerous well penetrations, a number of cores, and is actively being drilled for oil and natural gas. The area of investigation (Figure 1) consists of sixteen townships; T. 10 N. through T. 13 N., and R. 9 W. through R. 12 W.

Methods

Multiple cross sections were generated from available electric well logs within the thesis area to establish depositional dip and estimate depositional setting. The cross sections transect the thesis area from east to west and from north to south. Wireline log signatures for specific stratigraphic markers were established. For instance, a characteristic "hot shale" separates the Britt from the Cunningham intervals within the Springer Group. This hot shale served as the marker bed used to create a structural contour map that depicts the subsurface structural attitude of the Springer Group within the mapping area. The structural contour map was generated using sea level as the datum. Publicly available core from wells drilled within the study area were described,

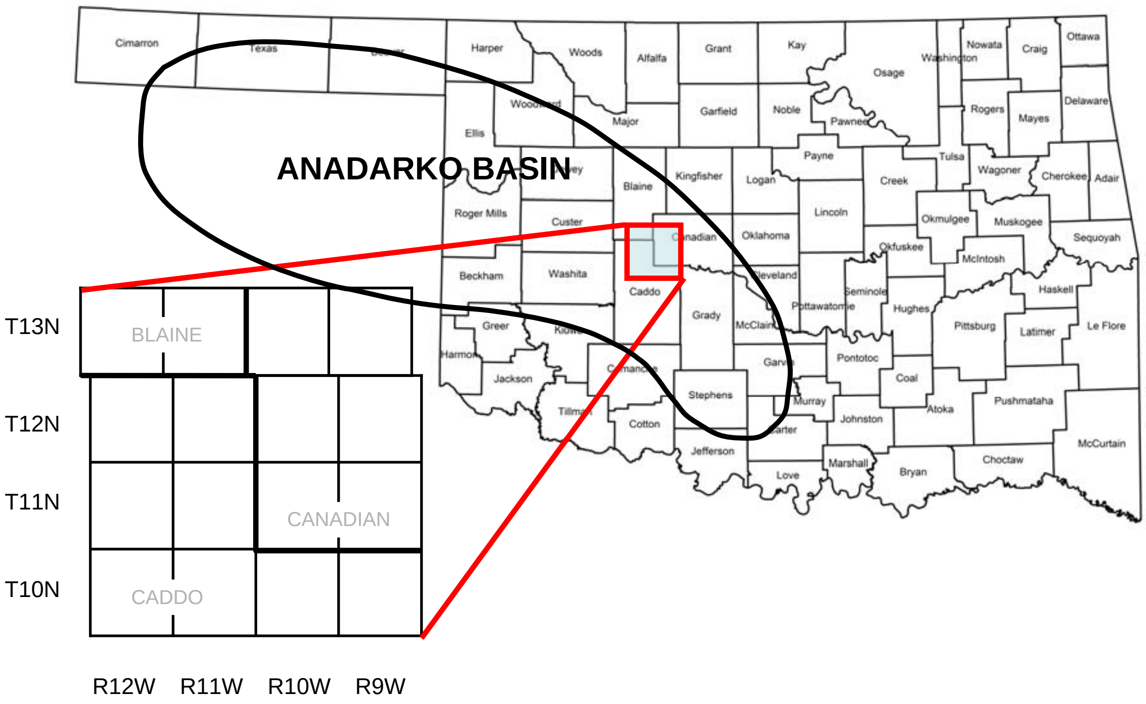


Figure 1. Location of study area within the southeastern part of the Anadarko Basin.

log calibrated, sampled for thin sections, and photographed. Electrofacies were established using gamma-ray log curve signatures and core-calibrated wireline logs. These electrofacies represent the various depositional facies recognized within the Boatwright interval. Electrofacies signatures were interpreted for each well and then incorporated into a color coded map of their distribution. Petrographic analysis of thin sections was accomplished using a research petrographic microscope. Samples were point-counted to determine the type and relative abundance of detrital constituents, authigenic materials, and porosity. Finally, all data was integrated to establish depositional models and to predict the spatial distribution of facies favorable to trapping oil and gas.

Literature Review

To date, no published studies have specifically focused on interpreting the depositional environments and reservoir genesis in the Boatwright Sandstone. The Springer Group and Goddard Formation have been studied for over 80 years. Goldston (1922) was the first to use the name Springer when describing the lowermost members of his “Glenn Formation.” Tomlinson (1929) raised the Springer to the rank of formation and also separated it from the underlying Caney Formation in the Ardmore Basin, Oklahoma. Wallace (1953) correlated surface exposures from the Golden Trend area to the east and Knox pool to the south with the Chitwood area of southeastern Grady County. Wallace with this study defines the 4 units Cunningham, Britt, Spiers, and Boatwright sandstones. Wallace (1953) describes the stratigraphic relationships of sandstones within the Springer and applied the names Cunningham, Britt, Spiers, and Boatwright in descending order. Accordingly, Wallace identifies the shale beneath the

Boatwright as the Goddard Shale. Westheimer (1956) provides a distinction between the Goddard Shale and the Caney Shale by stating that the Goddard is a soft shale overlying the hard and siliceous Caney shale at the type locality within the Goddard Ranch of Johnson County, Oklahoma. Elias (1956) differentiates the Caney and Goddard based on lithologic and paleontologic data collected at the Goddard Ranch. The boundary between the Goddard and Caney is considered the lower boundary of the Springer Group. Weaver (1958) constructed a multi-basin correlation that separated the Mississippian and Lower Pennsylvanian strata in the central United States based on clay mineralogy. Weaver concluded that the entire Springer interval in the Anadarko Basin is Mississippian. This work helped identify the upper boundary of the Springer Group. Peace (1964) examined correlations of the Springer Group across 8 counties (Caddo, McClain, Garvin, Stephens, Comanche, Jefferson, Murray, and Carter Counties) and proposed that the Springer Group be separated into two formations that include the Goddard Formation and Springer Formation (restricted). The Boatwright Sandstone, as described by Peace (1964), is the lowermost sandstone in the Springer interval and is commonly found in the northern half of the study area (Caddo Co.). Straka (1972) used conodont evidence to determine the aged of the Goddard and Springer Formations of the Ardmore Basin, Oklahoma. Straka proposed that the term “Noble Ranch Group” be used to identify everything from the top of the Caney Shale to the base of the Primrose (Morrowan). Davis (1974) discussed both “Springer” and “Morrow” discoveries and gas reserve development in Blaine and Canadian Counties, OK. Davis (1974) identified the “Old Woman Channel” in southeastern Blaine and northwestern Canadian Counties, but did not assign it to a stratigraphic interval. Clement (1974) presents a case history of geoseismic modeling of

Morrow-Springer distributary channel sandstones of the same “Old Woman Channel” discussed by Davis (1974). Clement identifies this channel-like sandstone as the basal Springer sandstone. The primary focus of this study was R.10W. and T.13N. Peace (1964) assigned the name Boatwright to the basal Springer sandstone of Caddo County. Clement (1974) described the basal Springer sandstone in Canadian County as a deltaic distributary channel and concluded that deposition took place under deltaic to transitional shallow-marine conditions for the basal Springer sandstone. Davis (1974) and Clement (1974) both state the importance of the “Old Woman Channel” as a high volume hydrocarbon producer. Haiduk (1987) used well logs, core, and thin sections to interpret depositional environments of the Britt Sandstone and identified fluvial, deltaic, and shelf environments within the Springer Group in Caddo and Canadian Counties. Peace (1989) recognized northeast to southwest trending features believed to represent a fluvio-deltaic depositional system within the Springer Group. Rice (1993) determined the depositional environments, described the petrology, and discussed the compartmentalization of Cunningham and Britt sandstones in southern Caddo and northern Comanche counties. Smith & Hendrickson (1996) established regional correlations of the Springer and Chester Groups. Andrews (2001) published a regional overview of the Springer gas play, combined and summarized much of the previous work on the Springer, and mapped the general distribution of the Cunningham, Britt, and Boatwright sandstones. Although the Springer Group has been a focus of study for a number of years, most work has focused on the Cunningham and Britt sandstones. This study proposes to analyze the Boatwright Sandstone interval in the context of a sequence stratigraphic framework and integrate all data to interpret depositional environments.

CHAPTER II

STRUCTURAL FRAMEWORK

Regional Tectonic Setting

The area of investigation is located in the southeastern portion of the Anadarko basin (Figure 1). The Anadarko basin is an asymmetric cratonic basin that extends from south-central Oklahoma into the Texas Panhandle. The Anadarko Basin, which is the deepest basin of the cratonic interior in the United States, is a petroleum rich, mature basin that contains as much as 40,000 feet of Paleozoic sediment and strata. The Anadarko Basin is bound by the Wichita-Amarillo uplift to the South, the Nemaha Uplift to the East, the Cimarron arch to the West, and the Hugoton embayment to the North (Figure 2). The basin assumed present configuration during late Mississippian through Pennsylvanian time due to compressive stresses associated with the Pennsylvanian orogeny. Boundary normal faults of the Southern Oklahoma Aulacogen were reactivated to produce both vertical and transcurrent movements that resulted in a complex system of paired basins and uplifts that include the Anadarko, Ardmore, Hollis, and Marietta basins (Davis, 1989). An early phase of subsidence for the Anadarko Basin began during the Mississippian (Garner and Turcotte, 1984). Structural features found within the Anadarko basin include normal faults, reverse faults, left-lateral strike slip faults, anticlines, and synclines that are mostly of Pennsylvanian age.

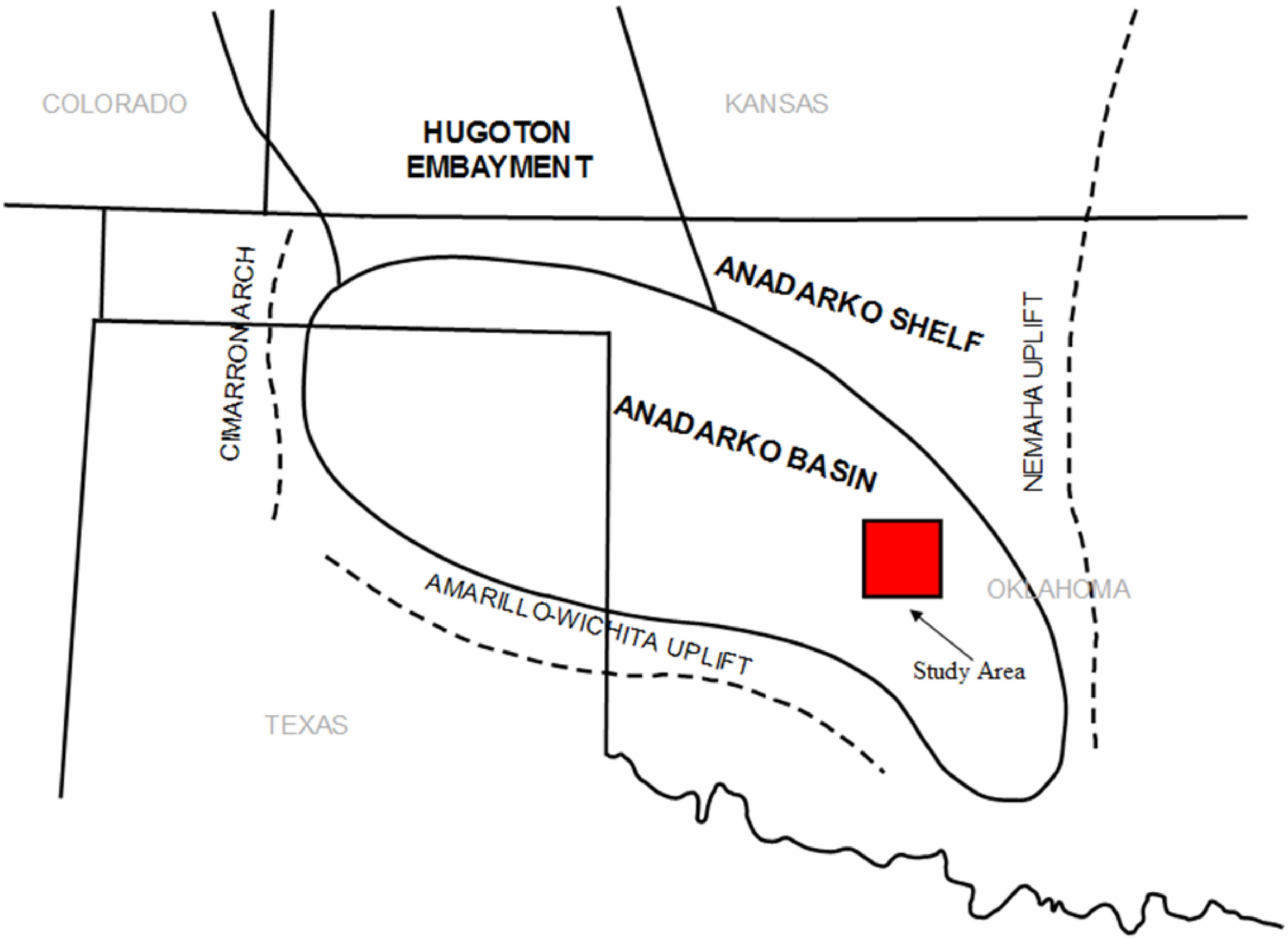


Figure 2. Tectonic features within part of the southern Midcontinent Region showing the location of the Anadarko Basin and study area.

Local Structural Geology

Interpretations of the local structural geology were derived from contour mapping of the Britt Hot Shale marker. The purpose for generating the structural contour map was to identify local structural anomalies and to illustrate the dip orientation of Springer Group strata. The structure map shows a southwest, homoclinal dip of 2°-3° across the study area. One fault was identified at the map contour interval. This fault is an East-West trending normal located in T.11N., R.10W. that has a maximum displacement of approximately 250 feet. Figure 3 depicts structural features that are detectable at the selected contour interval.

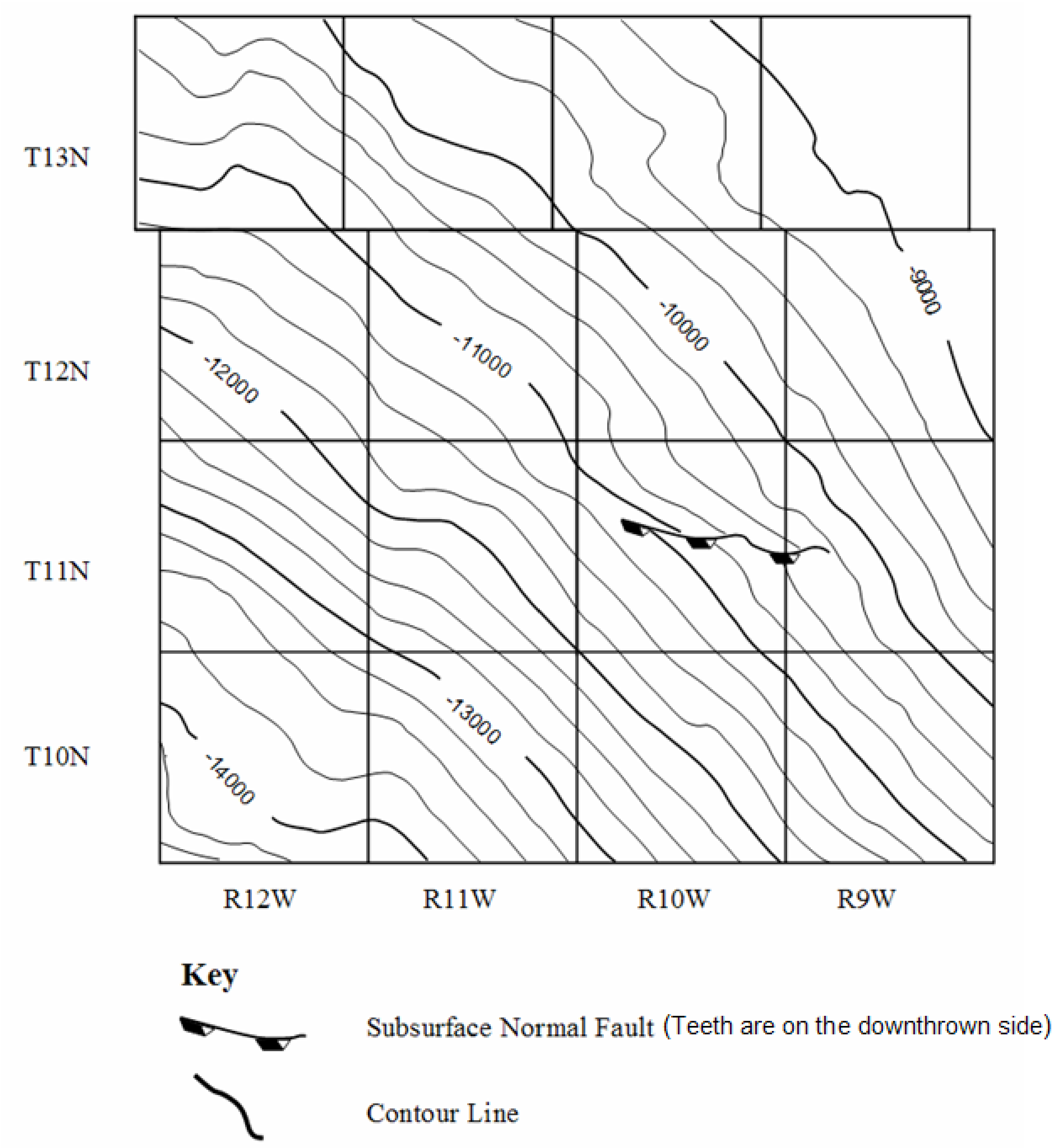


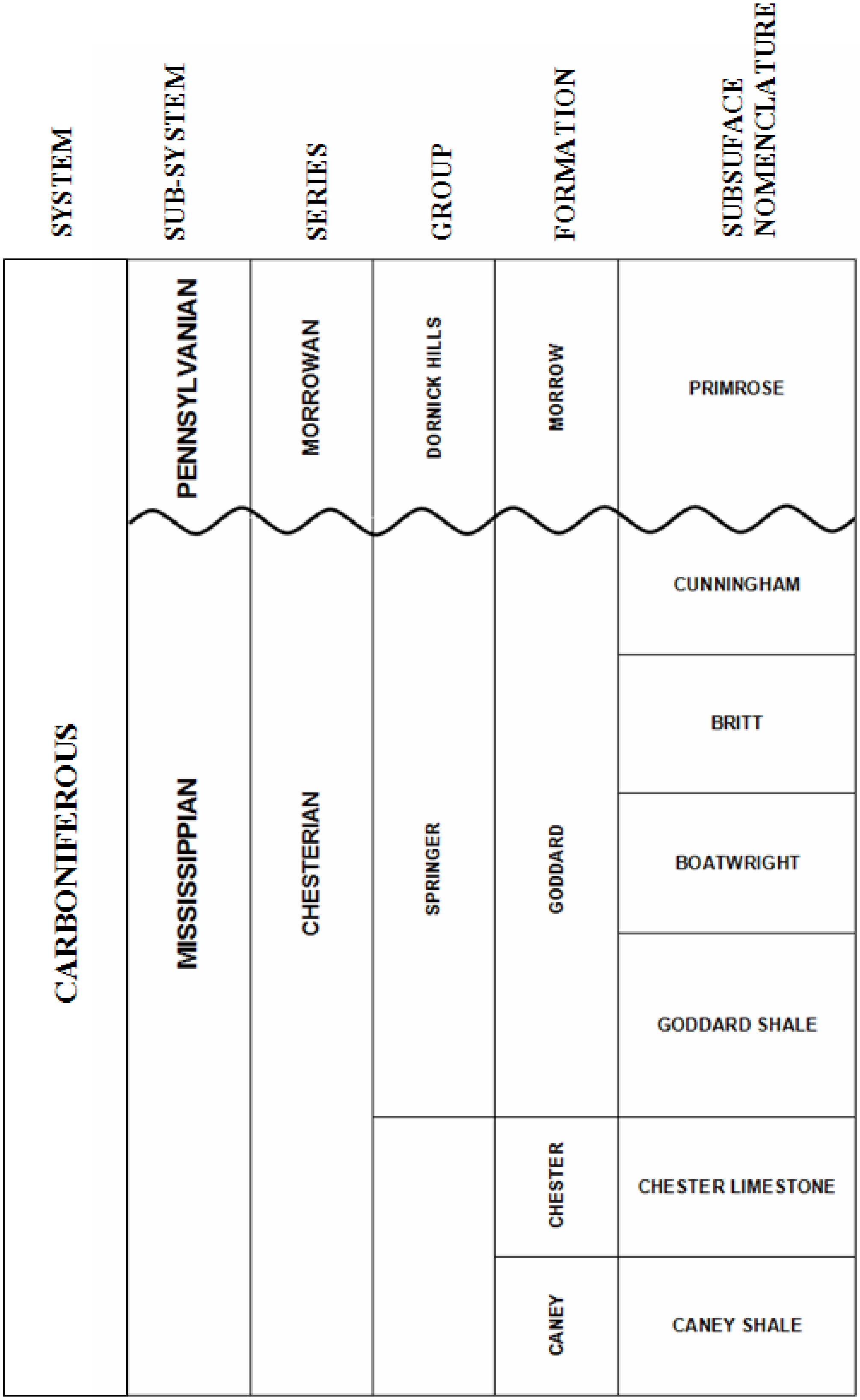
Figure 3. Structural contour map on top of the Britt Hot Shale. Contour interval is 250 feet. Datum is sea level.

CHAPTER III

STRATIGRAPHIC FRAMEWORK

Introduction

The Boatwright is a member of the Goddard Formation of the Springer Group. The Springer Group is a clastic dominated, basinward-thickening, succession of shale and sandstones in the Chesterian Series of the upper Mississippian Subsystem, Carboniferous System. The Springer Group incorporates all strata below the base of the "Morrow Formation" and above the top of the Caney or Chester Formation (Peace, 1989). The Springer Group contains the Boatwright, Britt, and Cunningham, parastratigraphic units in ascending order (Figure 4). Within the study area, the base of the Springer Group is marked by the Chester Limestone. The Springer Group marks a change in sediment type as Mississippian deposition changes from carbonated-dominated deposition to clastic-dominated. This change is evident on wire line logs (Figure 5) and is noted by the underlying Chester carbonate (1270 feet) subjacent to the Springer Group (11695 -12070 feet) and the sandstone-rich Morrow Formation (< 11695 feet) above. Next, the Goddard Shale consists of a thick accumulation of shale that overlies the Chester Limestone. The Boatwright Sandstone overlies the Goddard Shale and represents the first progradation of Mississippian proximal siliciclastic facies into the study area. A regionally extensive "Boatwright Hot Shale" marker separates the Boatwright interval from the Britt. The Britt overlies the "Boatwright Hot Shale" and is a sandstone/shale package. A regionally



SYSTEM	SUB-SYSTEM	SERIES	GROUP	FORMATION	SUBSURFACE NOMENCLATURE
CARBONIFEROUS	PENNSYLVANIAN	MORROWAN	DORNICK HILLS	MORROW	PRIMROSE
	MISSISSIPPIAN	CHESTERIAN	SPRINGER	GODDARD	CUNNINGHAM
					BRITT
					BOATWRIGHT
					GODDARD SHALE
				CHESTER	CHESTER LIMESTONE
				CANEY	CANEY SHALE

Figure 4. Stratigraphic nomenclature for Mississippian and Lower Pennsylvanian in the Southeastern Anadarko Basin (Modified from Weaver, 1958; Tomlinson & McBee, 1959; Haiduk, 1987; Peace, 1989)

extensive “Britt Hot Shale” marker represents the upper contact separating the Cunningham from the Britt. The Cunningham is sandstone/shale package that overlies the Britt interval. The first leftward deflection of the conductivity curve below correlatable lower Morrow sandstone units that is greater than 650 milliohms marks the top of the Springer (Haiduk, 1987). This marker represents the uppermost limit of the Cunningham and the lowermost limit of the Morrow (Figure 5).

Method for Determining Stratigraphic Position of Boatwright

The Boatwright Sandstone has been cited by previous authors as the lowermost sandstone within the Springer Group. Haiduk (1987) presented evidence of a “Boatwright Marker” separating the Boatwright interval from the Britt. This thin shale marker is called the “Boatwright Hot Shale” and has an anomalously high gamma ray signature (> 150 API units) that is regionally traceable (Figure 5). Previously calibrated well logs, used in conjunction with previous studies allowed for accurate identification and delineation of the Boatwright Hot Shale on well logs. All sandstones in the interval below this marker and above the Chester Limestone are the primary focus of this study.

Cross-Section Network

A network of four West to East trending and two North to South trending stratigraphic cross-sections were constructed within the study area (Figure 6). These cross sections were used: 1) to ensure reliable correlations, 2) to illustrate the wireline log character of the various facies within the Boatwright, and 3) to establish a regional stratigraphic framework. The reference datum for each of the cross-sections is the “Britt Hot Shale” marker.

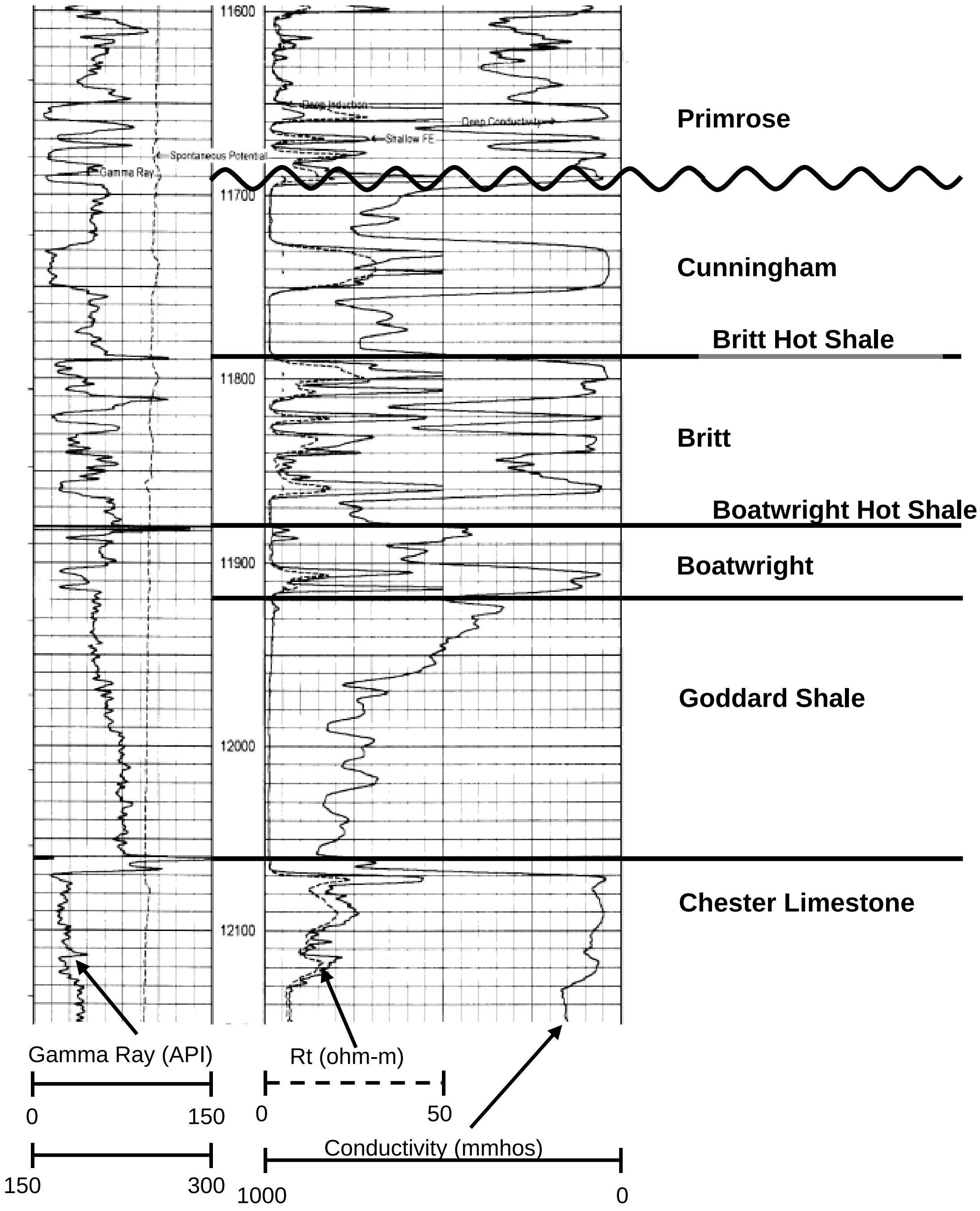


Figure 5. Wireline log characterization of the Springer interval and portions of the Morrow and Chester interval in the eastern Anadarko basin. Well Log from the Chesapeake, Dronberger No. 1-2. Section 2, T.11.N, R.10W., Canadian County, Oklahoma.

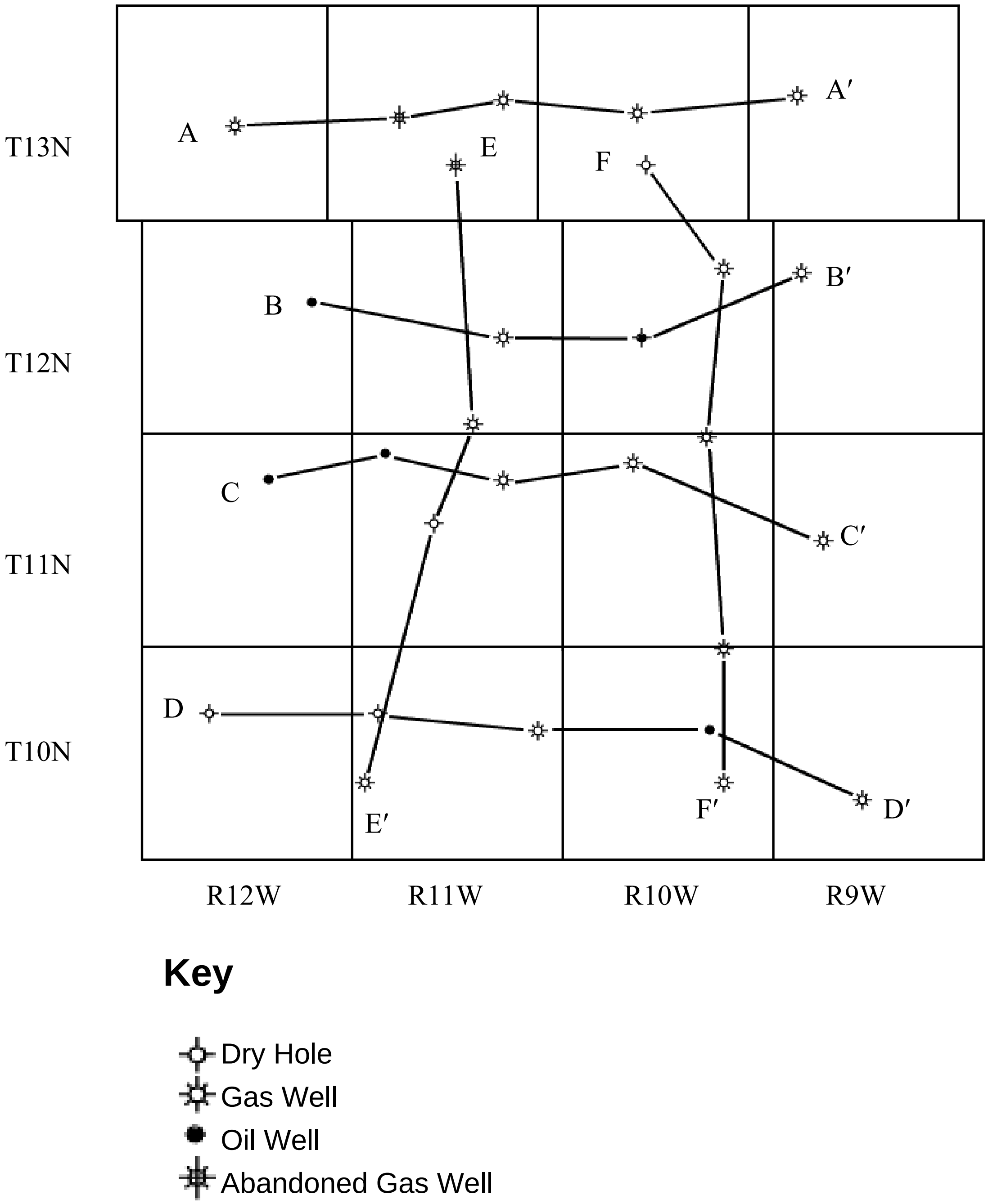


Figure 6. Map showing location of cross sections within the study area that were used to establish a stratigraphic framework for the Boatwright interval.

CHAPTER IV

DEPOSITIONAL FACIES

Introduction

Selley (1978) defines sedimentary facies as “a mass of rock which can be defined and distinguished from others by its geometry, lithology, sedimentary structures, paleocurrent pattern, or fossils. Also, Moore (1949) defines sedimentary facies as “an aerially restricted part of a designated stratigraphic unit which exhibits characters significantly different from those of other parts of the unit.” Thus, facies are established based on distinguishing characteristics for genetically related strata. Facies separation in the Boatwright was determined on the basis of gamma-ray log signature geometry, core determined lithology, and distribution. Gamma-ray log signatures were assigned facies names based on their correlation to core, curve geometry and changes in intensity. These were grouped based on log symmetry and termed ‘electrofacies.’ The gamma-ray log signature was evaluated from wireline logs for all available wells drilled within the study area. Lithology was determined based on wireline log characteristics, core, and bit cuttings. The distribution of electrofacies was determined by integration of mapping and multiple cross sections.

Lithology and Core Description

Lithology was determined using evidence from wireline log characteristics, core, and bit cuttings. The two lithologies frequently recognized in the Boatwright were sandstone and shale. These two lithologies were found to vary vertically and laterally across the study area.

Sandstone was recognized on wireline logs using the following criteria: low gamma-ray reading indicating minimal clay content (≤60 API units); high value of density-porosity (>6%); and separation between the deep and shallow resistivity curves (indicating permeability). Shale was recognized with the following criteria: high gamma-ray reading indicating elevated clay content (>60 API units); low resistivity reading (<5 ohm-m); and no separation between deep and shallow resistivity curves (indicating no permeability).

Descriptions of bit cuttings are typically recorded during the drilling of a well and are termed mudlogs. Numerous mudlogs provided by Unit Petroleum were reviewed. Sandstone and shale were the only lithologies recorded in lithological descriptions of bit cuttings for the Boatwright interval. Descriptions of bit cuttings corroborated the interpretation of lithology inferred from wireline log analysis.

Multiple wells throughout the study area were reported as being cored and a number of these wells cored Springer Group sedimentary rocks. Three of these cored wells sampled strata equivalent to the Boatwright including the Gamble Gas Unit No. 1, the Ellison Unit No. 1, and the Troy Smith No. 1. These cores, which were available to the public at the Oklahoma Geological Survey (OPIC) core facility located in Norman, OK, were obtained and analyzed. All three cores were described, photographed, and sampled for thin sectioning. The location of the cored wells can be seen in Figure 7.

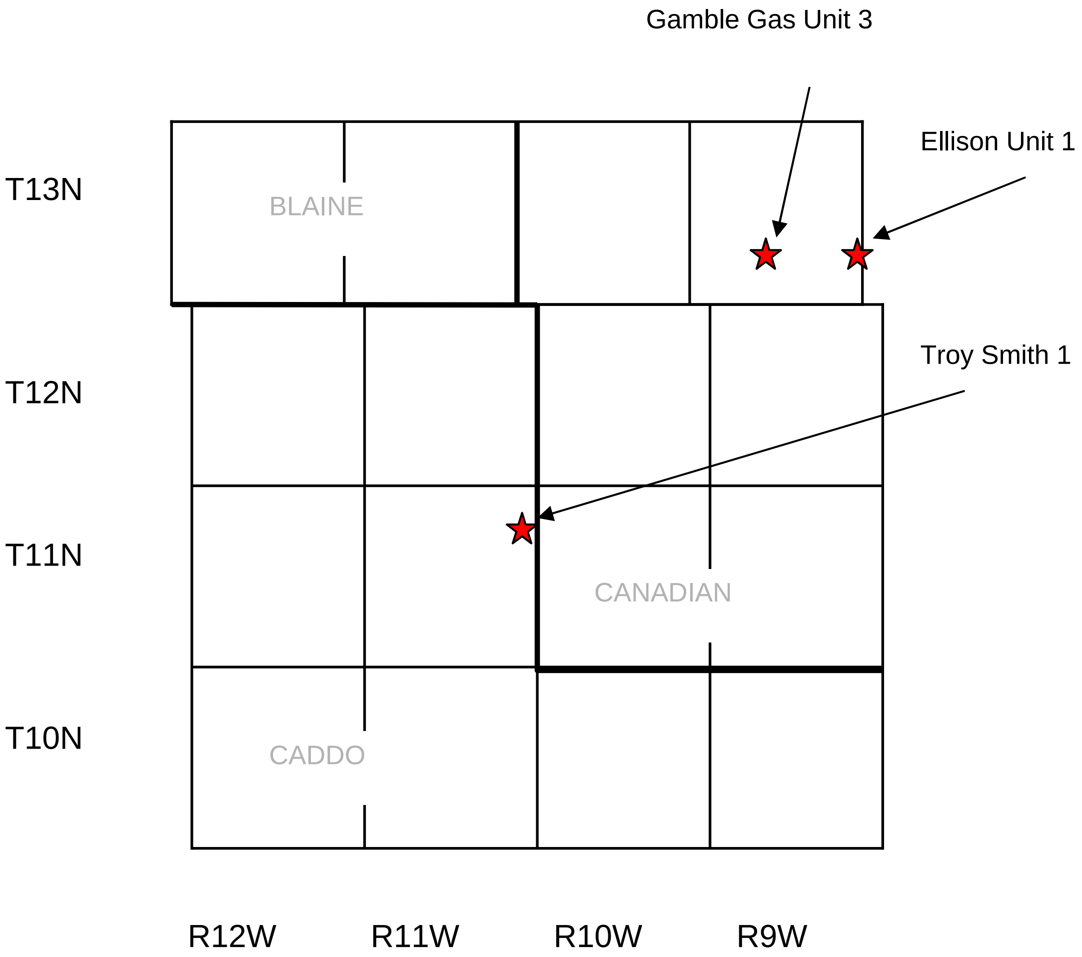


Figure 7. Location of wells that were cored in the Boatwright interval.

Magnolia Petroleum, Troy Smith No. 1

The Troy Smith no. 1 was drilled and cored by Magnolia Petroleum in 1959. This well is located in section 12 of T.11N., R.11W. The cored interval is from 12,969 to 13,077 feet reported depths and represents 12,973 to 13,081feet on wireline logs, a difference of 4 feet. The interval of core described includes the Boatwright interval from 12,999 to 13,077 feet (reported cored depths) (Figure 8). The core is dominated by shale, but does contain an 8 foot thick section of the Boatwright Sandstone. The Goddard Shale represents the lower 46 feet of core from 13,077 to 13,031 feet and is a black to dark gray, highly indurated shale with occasional silt lenses. The Boatwright Sandstone, which represents the next 8 feet of core, (13,031 to 13,023 feet) is a white, fine-grained, sandstone with planar laminations, and a speckled salt & pepper appearance (Figure 9). The upper and lower contact of this sandstone could not be identified due to the fragmented nature of the core. Pieces of core were placed in separate bags consisting of five foot intervals, which prohibited characterizing the nature of contacts. The Boatwright Sandstone displays a blocky log signature on the Spontaneous Potential (SP) curve and in this area is recognized as being part of the sheet sandstone facies discussed later in this chapter. This sandstone was sampled for thin sectioning at 13,028 feet. The final 25 feet of the Troy Smith core consists of black to gray shale with occasional siltstone lenses, pyrite lenses, and siderite concretions.

Amoco Production Co., Gamble Gas Unit No. 3

The Gamble Gas Unit No. 3 was drilled and cored by Amoco Production Co. in 1994. This well is located in section 28 of T.13N., R.9W. The cored interval is from 10,474 to 10,642 feet reported depths and represents 10,477 to 10,645 feet on wireline

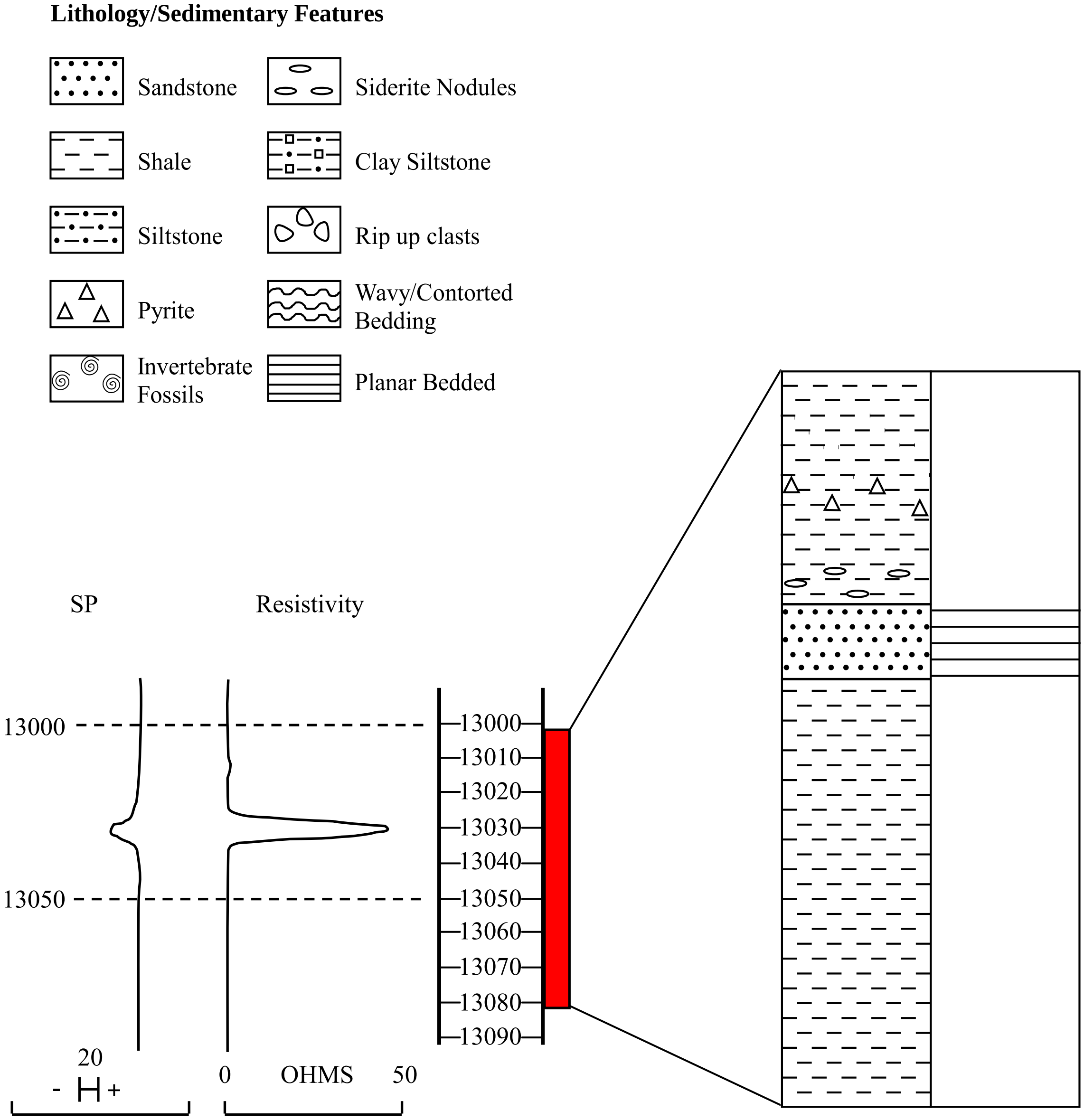


Figure 8. Generalized schematic of the Magnolia Petroleum, Troy Smith No. 1, showing core lithology, sedimentary features, and accessory mineralization. Also shown is the simplified representation of the spontaneous potential and resistivity curves across the sampled interval.

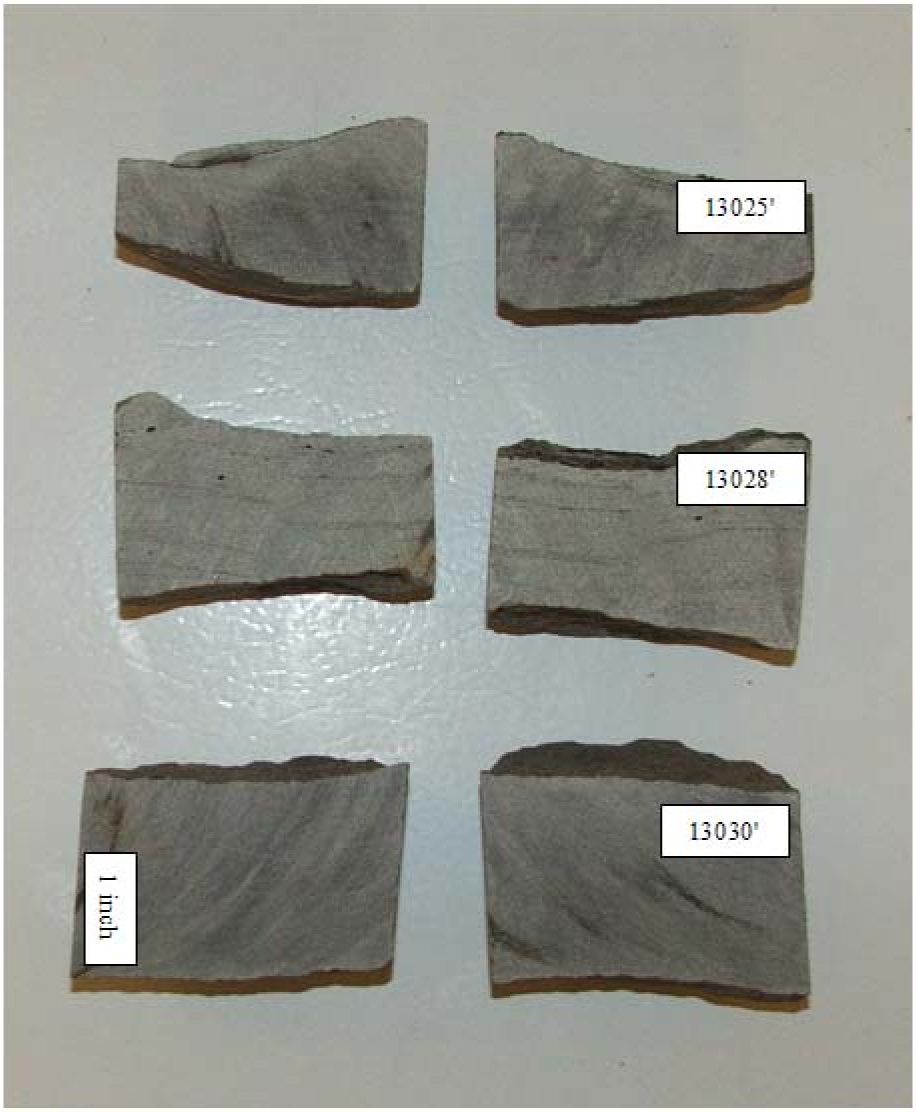


Figure 9. Photograph of selected pieces of core considered to be representative of the Boatwright Sandstone. The samples are fine-grained sandstone with planar laminations. Magnolia Petroleum, Troy Smith No. 1, Caddo Co., OK.

logs, a difference of 3 feet. The interval of core described for this study is from 10,504 to 10,642 feet reported cored depths (Figure 10). This core is also dominated by shale and contains very little sandstone development. The Goddard Shale represents the lower 102 feet of core from 10,642 to 10,540 feet and is a black, fissile, shale with occasional pyrite lenses, siderite concretions, and invertebrate marine fossils. The Boatwright section contains two thin sandstones that display a coarsening upward signature (CUS) on the gamma-ray log curve. These two sandstones are gray with planar laminations and are each 2 feet thick with 3 feet of shale between (Figure 11). The lower contact for this CUS is gradational in core and the upper contact is sharp. The uppermost sandstone was sampled for thin sectioning at 10,534 feet. This sandstone is recognized as being apart of the sheet sandstone facies discussed later in this chapter. Overlying these sandstones are the Boatwright shale and Britt shale which consists of black to gray, laminated, shale. The separation between Boatwright shales and Britt shales is not identifiable in core. A total of 13 feet of shale overlies the Boatwright sandstones. Above this shale is a 3 foot section of Britt sandstone that is white, fine-grained, with planar laminations and has a sharp contact with the shale below. Finally, the sandstone gradationally grades into a siltstone and represents the final 13 feet of described core and is gray with planar laminations.

Pan American, Ellison Unit No. 1

The Ellison Unit No. 1 was drilled and cored by Pan American in 1967. This well is located in section 25 of T.13N., R.9W., three miles east of the Gamble Gas Unit no.3. Unfortunately, Boatwright sandstones were removed by erosion and were not present. The core contains the Goddard Shale, which in turn is unconformably overlain by

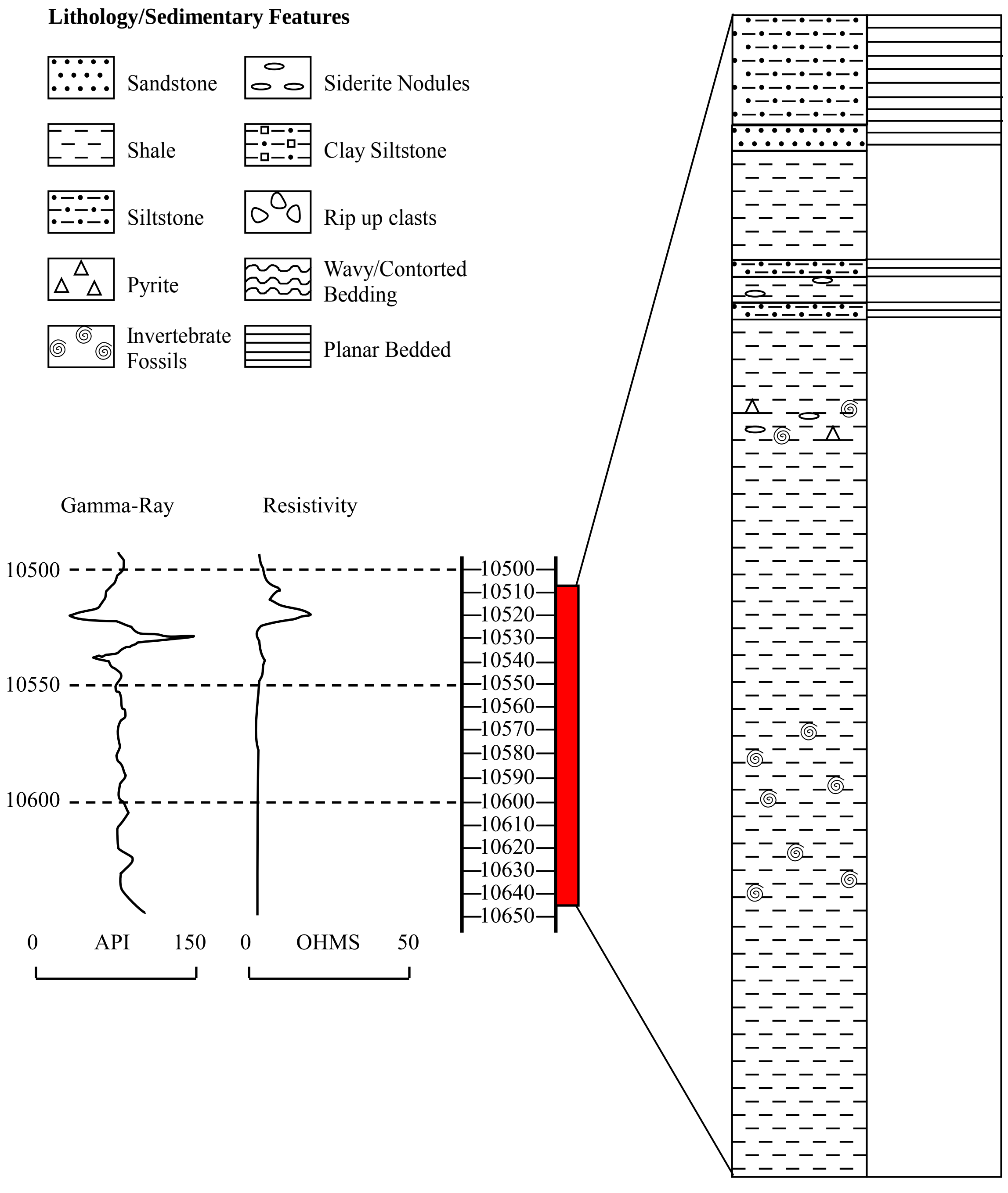


Figure 10. Generalized schematic of the Amoco Production Company, Gamble Gas Unit No. 3, showing core lithology, sedimentary features, and accessory mineralization. Also shown is the simplified representation of the gamma-ray and resistivity curves across the sampled interval.

Figure 11. Photograph of selected section of the cored Boatwright Sandstone. Core consists of very fine-grained sandstone with planar laminations. Amoco Production Co., Gamble Gas Unit No. 3, Canadian Co., OK.

Morrow sandstones. The Ellison Unit No. 1 contains the erosional contact between the Goddard Shale and overlying Morrow that is recognized in cross section. The cored interval in the Ellison Unit No. 1 well is from 10,106 to 10,244 feet reported depths and represents approximately the same depth on well log. Descriptions for this core are limited to 10,154 to 10,165 feet (Figure 12). The Goddard Shale represents the lower 6 feet of core from 10,165 to 10,159 feet and is a black, highly indurated shale (Figure 13). Next, a 2 foot thick siltstone overlies the shale beneath. This siltstone is gray colored, and contains a high amount of clay, and represents the erosional contact between the Goddard Shale and Morrow Formation. The nature of the contact between the Goddard Shale and the overlying Morrow siltstone is unknown due to pore core quality. A sharp change in conductivity curve (1100 mmhos to 400 mmhos) evident on well log (Figure 5) corresponds with the erosional contact between the Morrow and Goddard. Finally, 3 feet of siltstone overlie the clayey siltstone beneath. This siltstone is gray with contorted bedding and contains rip up clasts of the Goddard Shale.

Electrofacies

Previous studies and authors have identified the relationship between electrofacies signature and environment of deposition. Selley (1998) associated log response profiles and environments of deposition (Figure 14). Three common log motifs are evident in Boatwright sandstones: fining upward sequence (FUS), blocky, and coarsening upward signature (CUS). The associated environments of deposition are identified as well, but it is important to note that wireline log responses alone are not diagnostic of particular environments. However, when log-based geometry is combined with core data and aerial distribution, interpretations are possible. Electrofacies classification for the Boatwright

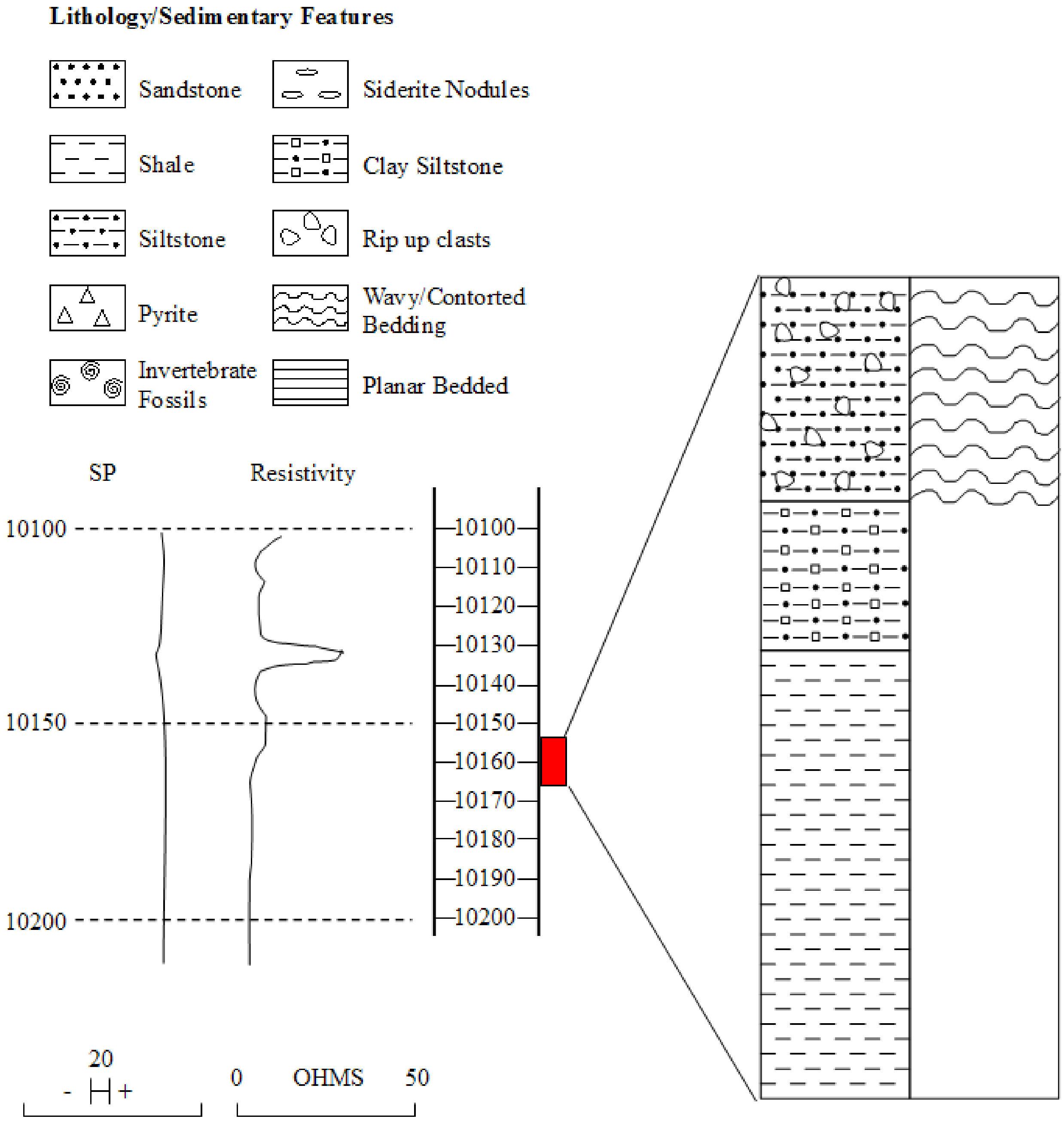


Figure 12. Generalized schematic of the Pan American, Ellison Unit No. 1, showing core lithology, sedimentary features, and accessory mineralization. Also shown is the simplified representation of the spontaneous potential and resistivity curves across the sampled interval.

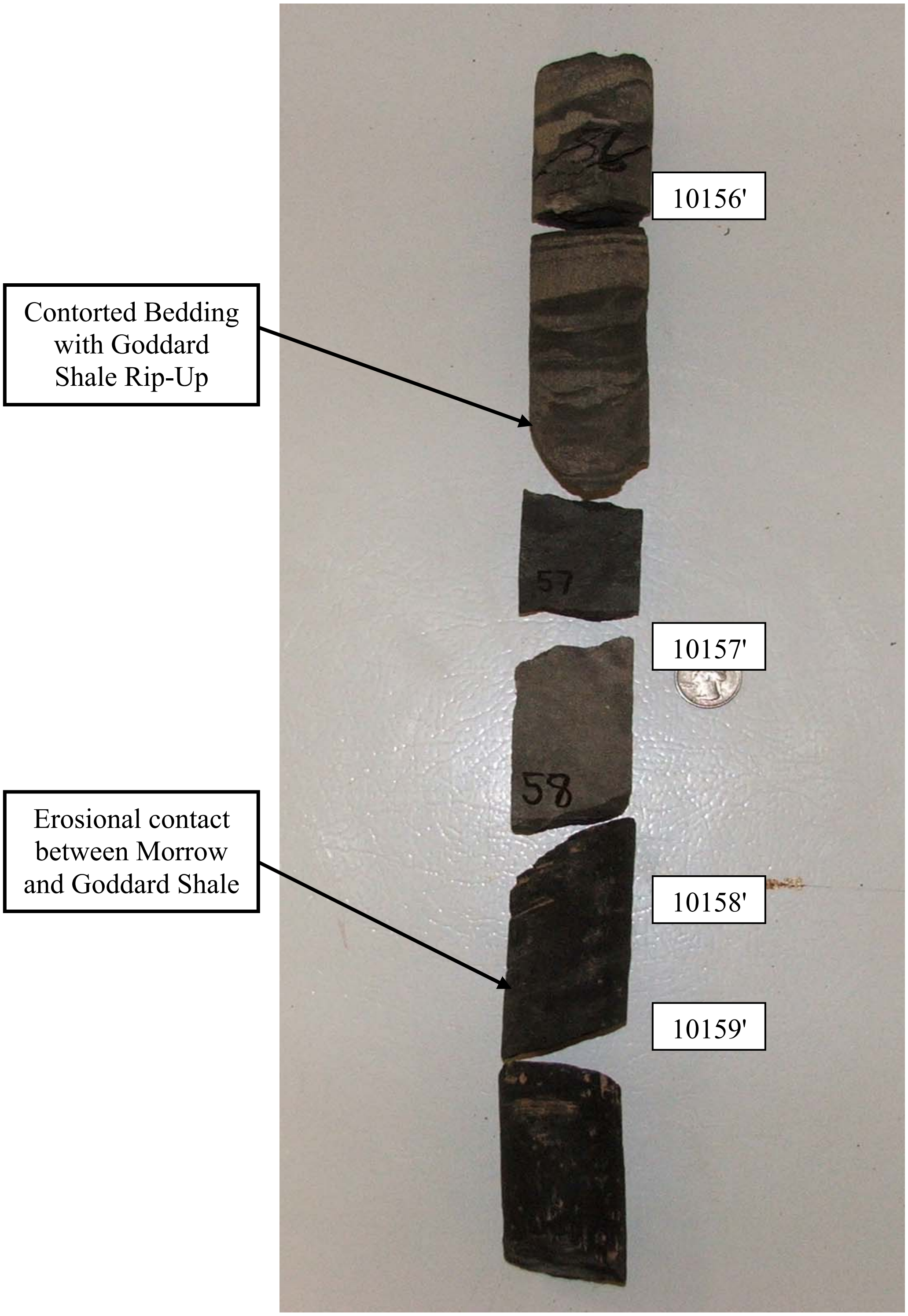
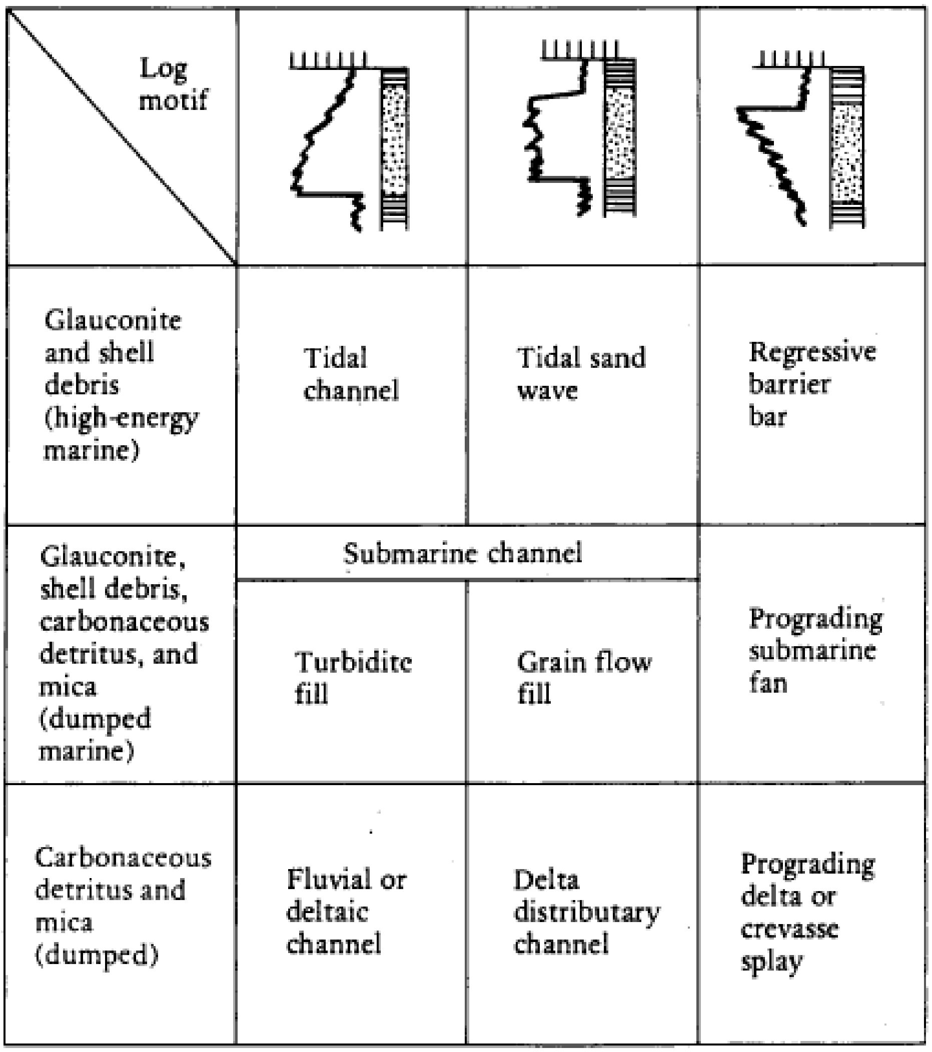


Figure 13. Photograph of selected section of the cored Boatwright interval. Core consists of black shale overlain by siltstones. Pan American, Ellison Unit No. 1, Canadian Co., OK. Quarter for scale.



Log motif			
Glauconite and shell debris (high-energy marine)	Tidal channel	Tidal sand wave	Regressive barrier bar
Glauconite, shell debris, carbonaceous detritus, and mica (dumped marine)	Submarine channel		Prograding submarine fan
	Turbidite fill	Grain flow fill	
Carbonaceous detritus and mica (dumped)	Fluvial or deltaic channel	Delta distributary channel	Prograding delta or crevasse splay

Figure 14. Diagram showing three common electrofacies signatures and their associated environments of deposition from Selley (1998).

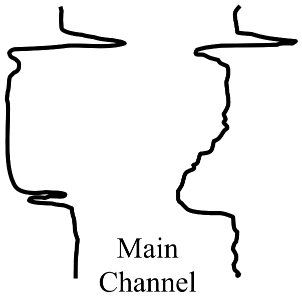
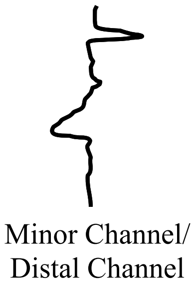
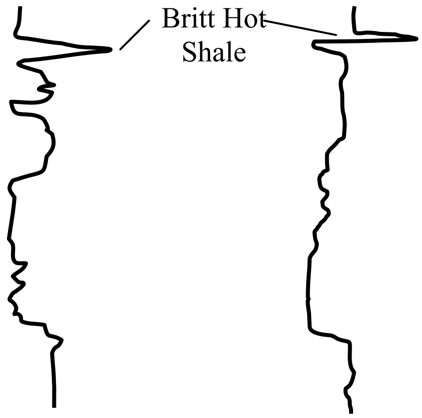
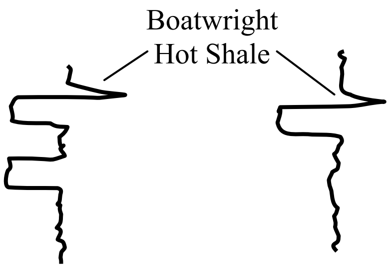
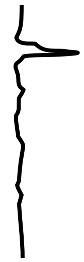
Facies Character	**Electrofacies Signature**	**Description**
Distributary Channel	 	FUS Sandstone to thick blocky Sandstone
Valley-Fill Sandstone (Britt Member)		Erosional Sandstone Fill with missing Boatwright Hot Shale
Sheet Sandstone		Stacked blocky Sandstones
Marine Shale		Shale with high gamma-ray reading

Figure 15. Chart displaying gamma-ray curve (log response signature) for electrofacies identified within the study area.

Sandstone was based on core-calibrated gamma-ray log geometry. Multiple electrofacies were identified and observed within the study area (Figure 15). The distributary channel facies is a sandstone that exhibits a blocky to FUS log character. Environments of deposition for this log character include fluvial and deltaic distributary (Figure 14). The valley-fill sandstone facies also exhibits a blocky to FUS log character. Environments of deposition exhibiting this log character are considered fluvial. This facies has an obvious erosional nature as evidenced by the missing Boatwright hot shale marker (Figure 14). Sandstones of this character occur in a position that suggests the sand body filled a channel that eroded the Boatwright hot shale. The sandstone identified as the sheet sandstone facies exhibits a blocky log character (Figure 14). Environments of deposition associated with this log character include nearshore to beach and delta margin. Finally, the marine shale facies exhibits no change in log character or geometry. This facies is recognized as containing shale and is evident in Figure 15.

Distribution of Electrofacies

Available wireline logs for wells that penetrated the Boatwright were examined and electrofacies signatures were identified for each well. Next, a color was assigned to each electrofacies and each well was colored accordingly based on the characteristic wireline log response. Next, a color-coded map was constructed displaying the distribution of electrofacies within the study area (Figure 16).

Distributary channel facies, shown in orange, are limited to the northeastern portion of the study area. The distribution of distributary channel sandstones is not continuous, the pattern is based on sandstone bodies found in isolated wells; these have a north-south to northeast-southwest trends. The discontinuous nature of this sandstone

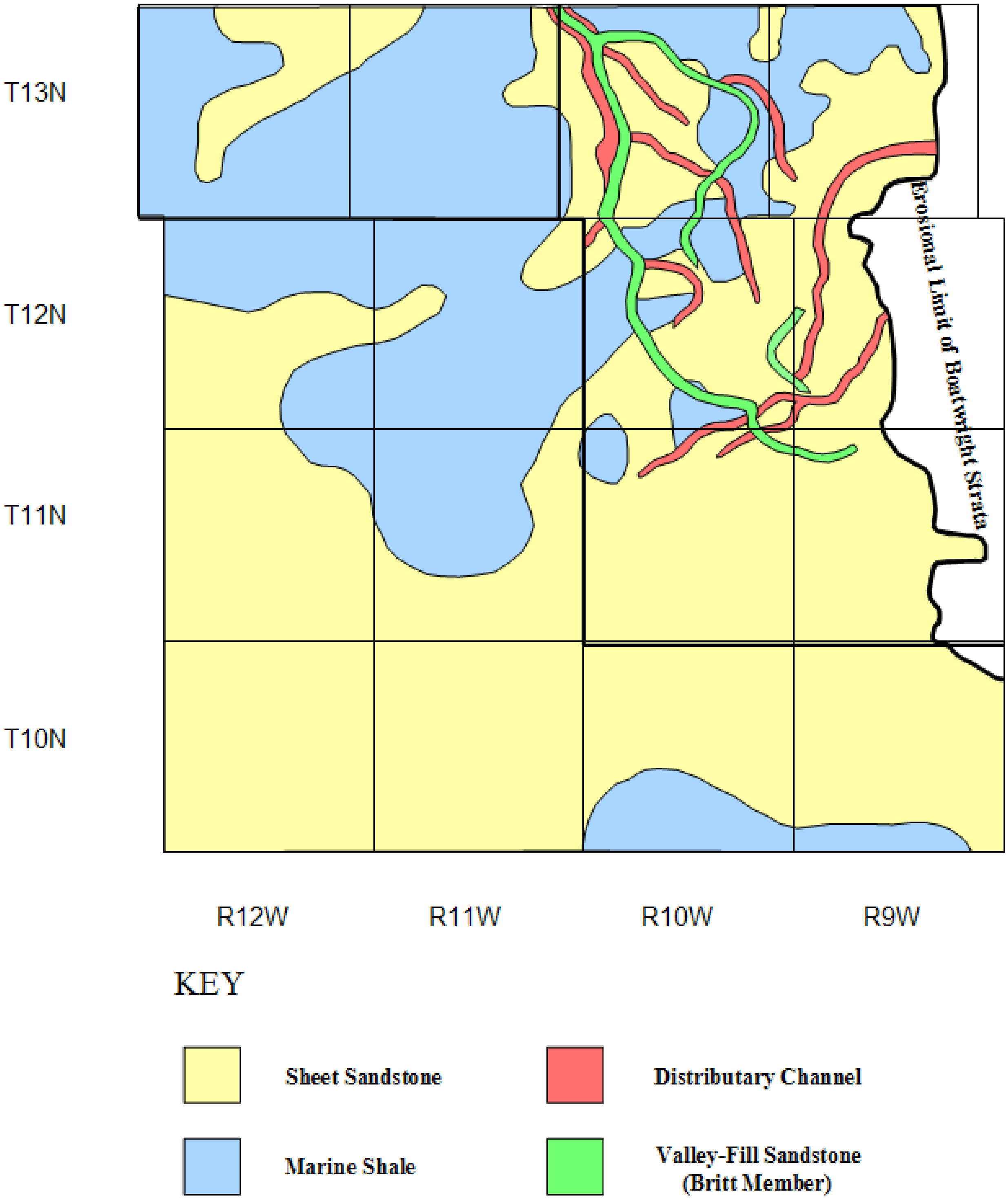


Figure 16. Aerial distribution of Boatwright and Britt (valley filling sandstone) electrofacies within the study area.

can be seen on well logs of closely spaced wells (Figure 17).

Valley filling sandstones that occur where the Boatwright marker is absent are limited to the northeast portion of the study area. The color green was used to depict this sandstone. This sandstone is found in discontinuous bodies and has a general north-south trend. The erosive nature of this sandstone is recognized on well log through the missing Boatwright hot shale (Figure 18).

Sheet sandstone facies exist throughout the study area. The color yellow was used to depict this sandstone. This sandstone/stacked sandstones have a broad aerial distribution pattern. The stacked nature of these sandstones is recognizable in wireline logs of multiple wells (Figure 19).

Marine shale facies occur throughout the study area and the color blue was used to depict shale. The marine shale facies is composed entirely of mudrock and is void of sandstone.

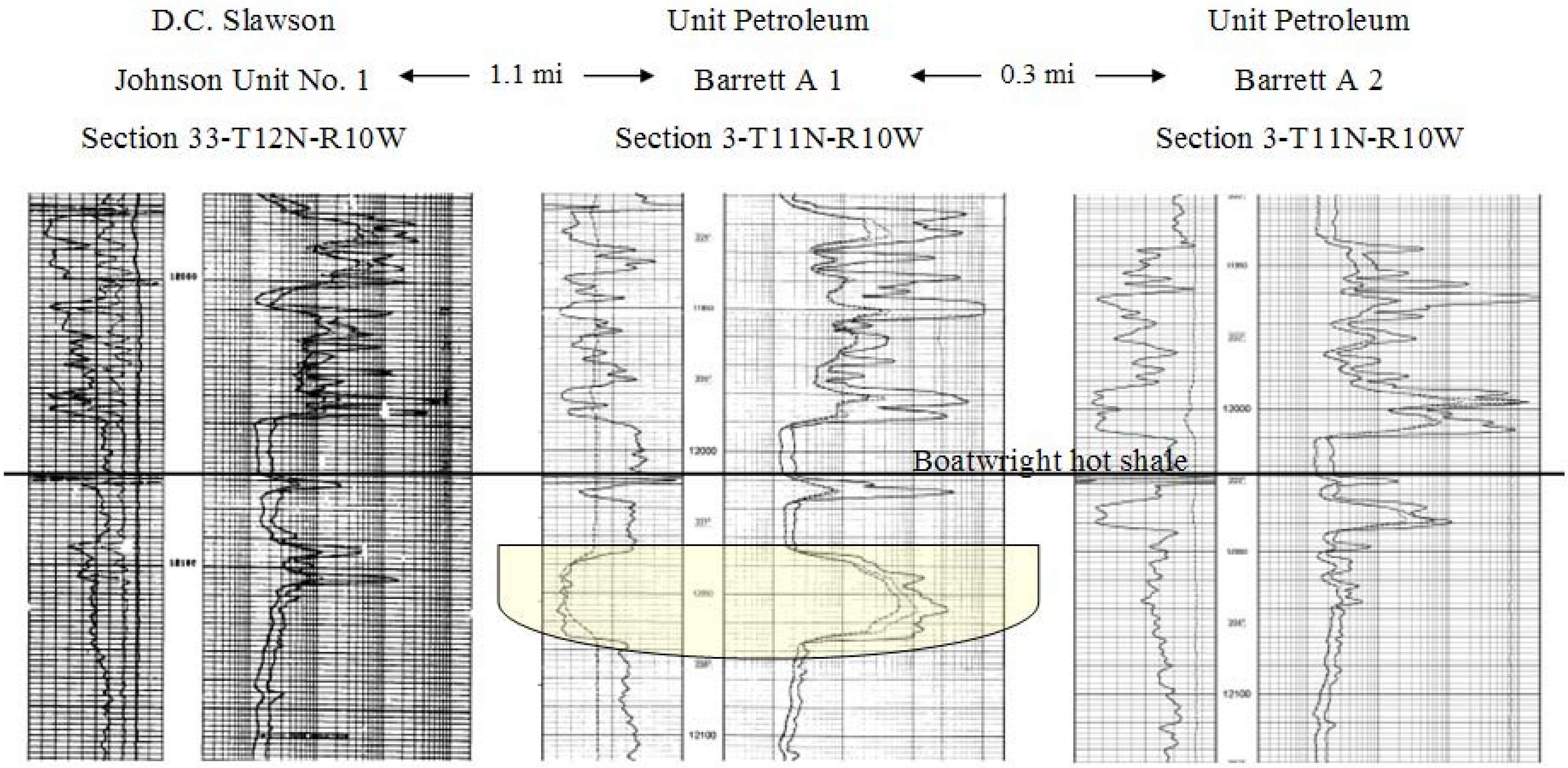


Figure 17. Three well cross section illustrating distributary channel facies in the Unit Petroleum Co., Barrett A 1. Boatwright hot shale as datum. Distance between wells shown in miles (mi).

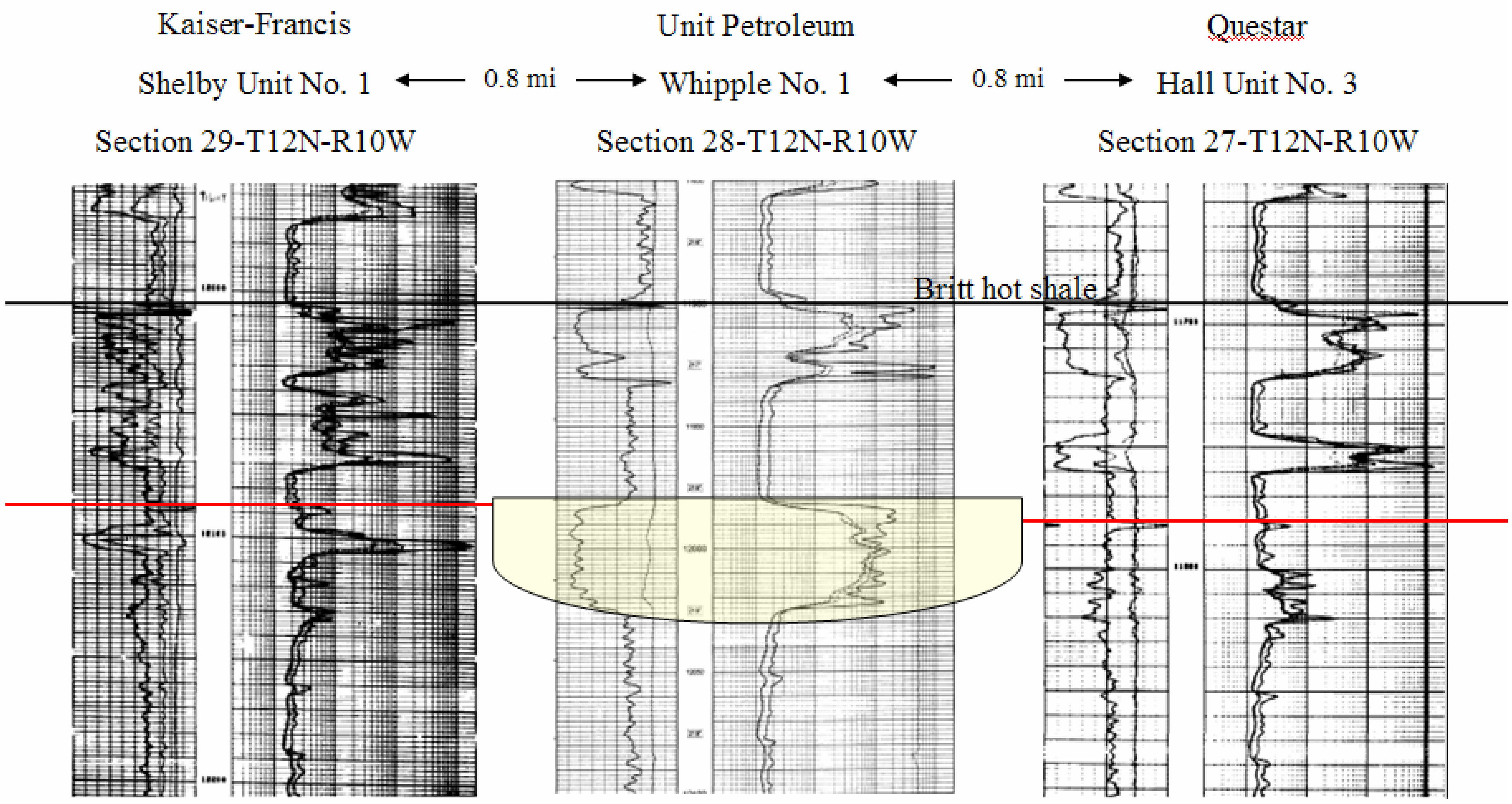


Figure 18. Three well cross section illustrating Valley-Fill Sandstone facies in the Unit Petroleum Co., Whipple No.1. Britt hot shale as datum. Boatwright hot shale shown as red line. Distance between wells shown in miles (mi).

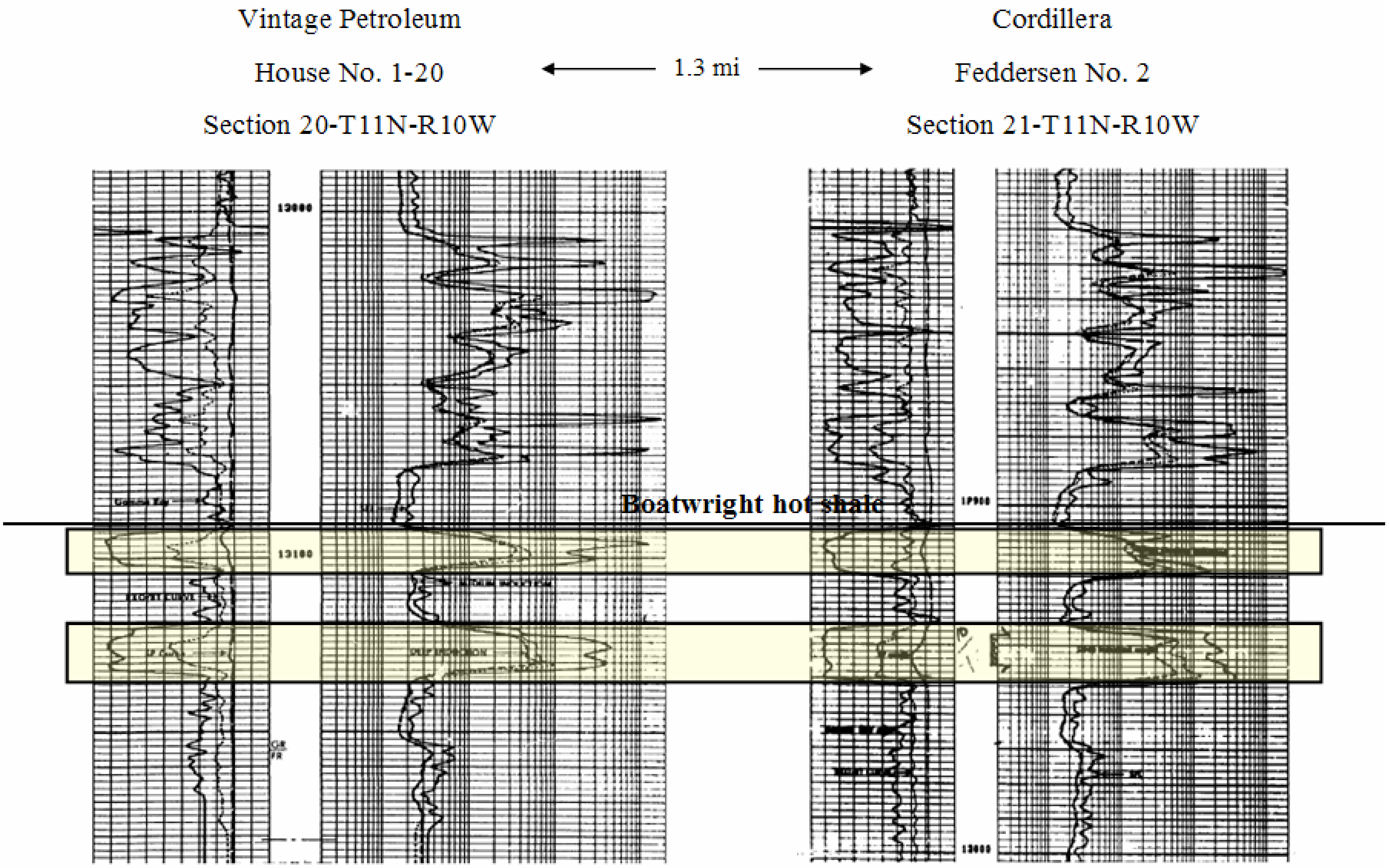


Figure 19. Two well cross section illustrating sheet sandstone facies. Boatwright Hot Shale as datum. Distance between wells shown in miles (mi).

CHAPTER V

DEPOSITONAL SETTING

Introduction

The Boatwright, as stated before, is an informal member of the Goddard Formation, Springer Group. The Springer Group sandstones have been the focus of study for many years. Haiduk (1987) illustrated the existence of a deltaic complex during Britt sand deposition with a parent fluvial system (Old Woman Channel) feeding this delta from the north. Haiduk (1987) also described offshore bar sandstones, representing deposition in a shallow marine environment. These offshore bars were deposited in a shelf setting. Boatwright sands were deposited prior to Britt sands during a transitional time when the shelf and basin areas began to subside at different rates. Peace (1989) suggests that a low differential in subsidence rates during the Early to Middle Mississippian created a broad gentle slope from the shelf to the basin. However, this setting changed during Late Mississippian time. The very distinct shelf and basin facies seen in the Upper Mississippian (Chesterian) section are the result of a rapid increase in basin subsidence relative to shelf subsidence (Peace, 1989). Accordingly, the Boatwright sandstone overlies the Goddard Shale and represents the first transport of sand and depository proximal facies during the Chesterian Series. The basinal area to the distant south began to subside and proximal facies encroached into the thesis area from the north. Fluvial systems delivered sediment to the study area that would ultimately be dispersed and re-worked by marine currents. In conclusion, the Boatwright sands were deposited on a low-gradient shelf setting that subsided during deposition. Boatwright sandstone deposition was influenced by both fluvial and shallow marine processes.

Fluvial Systems

Fluvial systems are the principal means for delivering sediment to the coastline. Fluvial systems deliver water and sediment from high relief areas to low relief areas. Schumm (1977) defines the fluvial system as having three parts (Figure 20): zone 1 is the drainage basin from which sediment and water are derived; zone 2 is the major river channel; zone 3 is the area of deposition or sediment sink. These three zones together make up a dynamic process-response system where any change in one system may effect another.

Depositional environments within fluvial systems include alluvial fans, rivers, and incised valleys. Alluvial fans form as streams flow from areas of high relief onto more gentle slopes. The coarse sediment load from these streams is deposited as alluvial fans. Alluvial fans often develop at the base of a mountainous region or in areas of active tectonic uplift. Rivers form when multiple streams coalesce. Rivers typically flow across coastal plains while being fed water and sediment from smaller tributaries. Rivers are divided into four types, based on channel morphology: meandering; braided; straight; and anastomosing. Finally, incised valleys are fluvially eroded features that are typically larger than a single channel. Zaitlin, Dalrymple, and Boyd (1994) define an incised valley as a “fluvially-eroded, elongate topographic low that is typically larger than a single channel form, and is characterized by an abrupt seaward shift of depositional facies across a regionally mappable sequence boundary at its base. The fill typically begins to

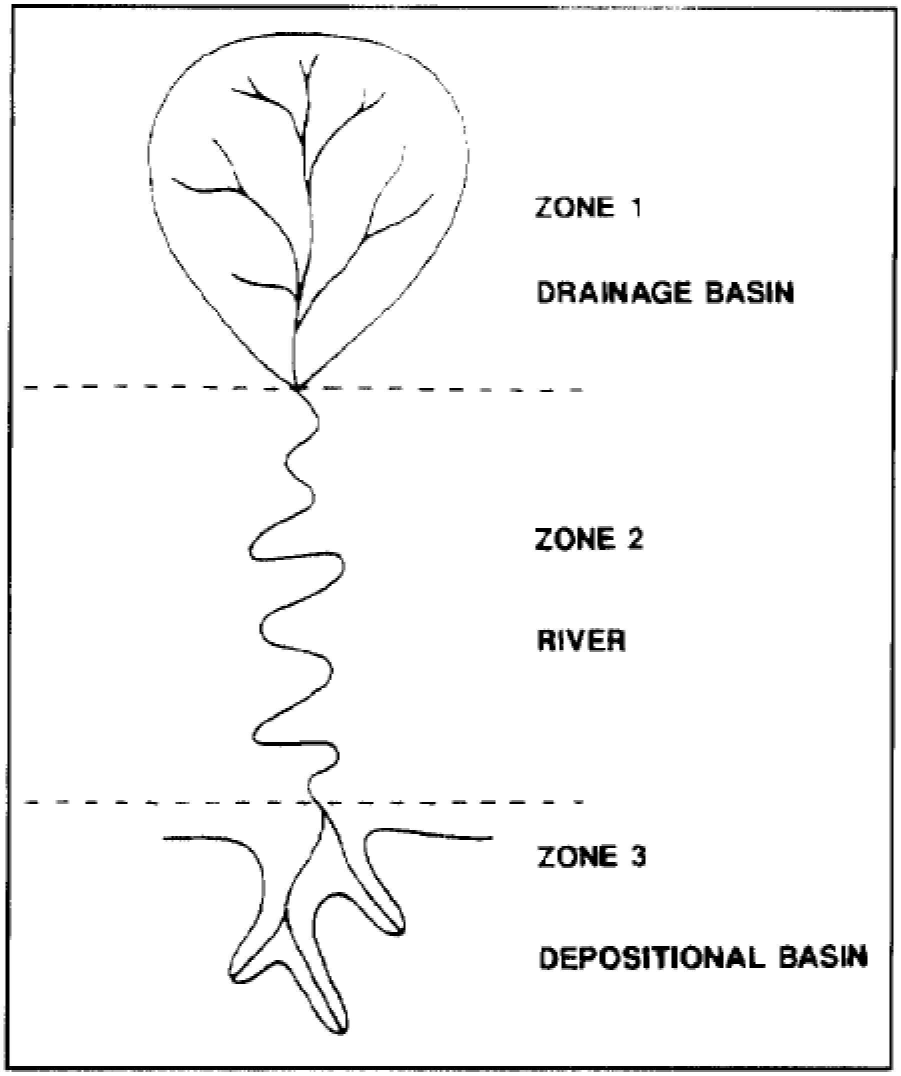


Figure 20. Idealized model of a fluvial system as defined by Schumm (1977).

accumulate during the next base level rise, and may contain deposits of the following transgressive highstand or subsequent seal-level cycles." The "Old Woman Channel" within the thesis area is considered an incised valley. This channel is recognized as the Valley Filling Sandstone facies (Britt Member) in Figure 16.

Shelf Systems

The shelf is defined as the area between the coastline and the deep ocean. Shelf sedimentation is controlled by sediment supply, the hydraulic regime, sea-level fluctuations, tectonic influences, climate, and biological and chemical factors. Sediments delivered to the coastline are modified by oceanic processes such as waves, tides, longshore currents, and storms. A diagrammatic cross section of the shallow shoreline setting showing the foreshore to offshore is illustrated in Figure 21.

Model for Boatwright Deposition

The Springer Group marks a change from carbonate-dominated deposition to clastic-dominated deposition. Specifically, the Boatwright interval contains the lowermost sandstones within the Springer Group and thus contains the first evidence of sand deposition. Sandstone bodies are persistent in the Boatwright interval throughout the study area and were recognized in both well logs and core. The Boatwright, as proposed in this study, represents two cycles of regressive-transgressive couplets in response to basin subsidence and sea-level fluctuation.

The effects of sea-level fluctuation on the stratigraphic record are better understood when interpreted within a sequence stratigraphic framework. Sequence stratigraphy provides processes and mechanisms that explains the succession of facies as they relate to changing sea level through time. Sea-level fluctuation and basin

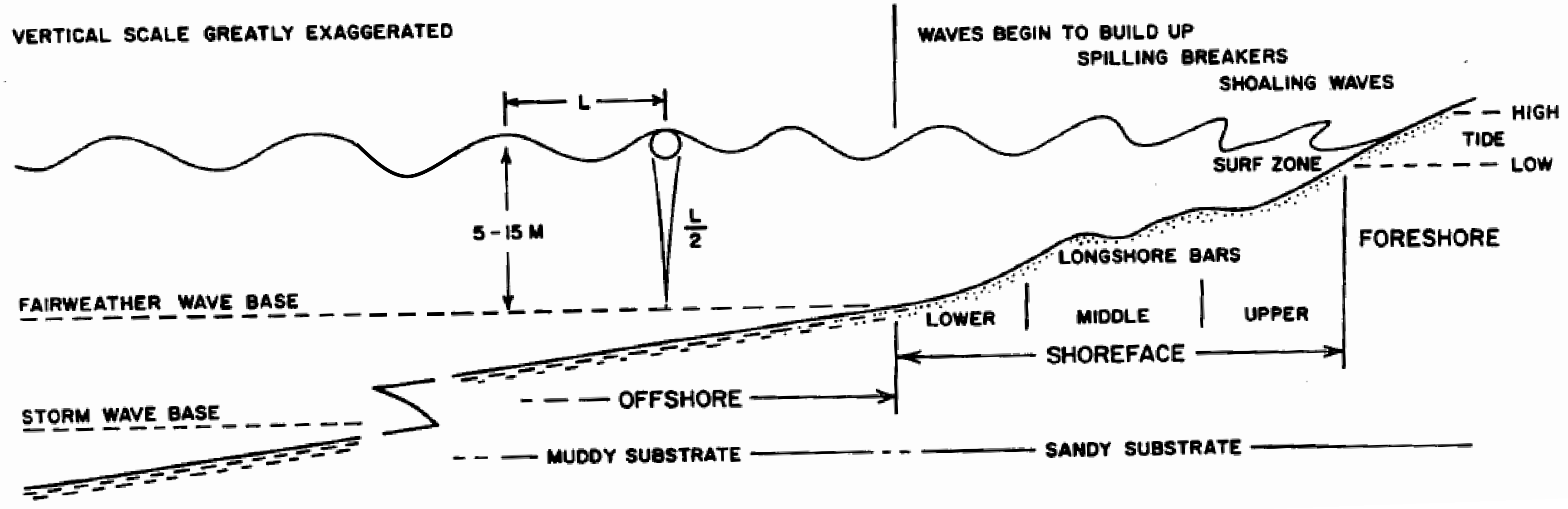


Figure 21. Shoreline to shallow marine profile identifying foreshore, shoreface and offshore areas, and fairweather wave base by Walker & Plint(1992).

subsidence are the two major influences recognized as affecting Boatwright sedimentation. For this reason, the facies distribution, stratigraphic stacking pattern, and depositional environment are integrated to explain the sequential effects of sea-level change and basin subsidence on Boatwright deposition. The two transgressive sheet sands served as horizons for reconstructing the sea-level history of the Boatwright Sandstone. Transgressive shelf sand sheets provide regionally correlatable horizons that can serve as reliable stratigraphic datums in basin reconstructions and determination of sea-level history (McBride et al., 2004).

The Boatwright experienced two cycles of regression and transgression in response to sea-level fluctuations. The first encroachment of proximal (fluvial) facies into the thesis area is believed to be the result of a basinward shift in the shoreline. The paleogeographic orientation of the shoreline was northwest to southeast. Thus, the shoreline shifted in a southwesterly direction. This event represents a relative drop in sea-level and marks the first regression during Boatwright deposition. Two mechanisms can produce the relative drop in sea level: regional-tectonic uplift or eustacy (Van Wagoner et al., 1991). It is believed that fluvial systems prograded into the thesis area from the east and delivered sand and mud. The sandstones and associated facies representing the first regression are not preserved in the stratigraphic record within the study area. Post-depositional erosion removed all evidence of such a fluvial system by the truncation of the Springer interval. Evidence of the first transgression is preserved in the form of the lowermost sheet sandstone, which is believed to be composed of re-worked sediment delivered into the basin during the initial regression. These sediments were re-distributed during the ensuing transgression and deposited with rising sea level during the landward migration of the coastline. The first sheet sandstone facies is widespread, uniformly thick (15-18 feet), with marine shale overlying it. The marine shale overlying the lowermost sheet sandstone represents flooding and marine transgression. As the shoreline advanced in a northeasterly direction the first sheet sand was deposited. Following deposition of marine mud overlying the first sheet sandstone, the second regression is marked by distributary channel facies (Figure 17). It is in this facies that the first evidence of channel development is seen. These sandstones are stratigrahically equivalent to or lower in the section with respect to the first sheet sandstone. The first sheet sandstone is always absent when distributary channel sandstones are present. Based on these observations, it becomes apparent that the base of the sandstone is an erosive event. The distributary channel eroded through the first sheet sandstone, but the second sheet sandstone is often preserved (Figure 19). Therefore, this channel-filling sand was deposited after the first sheet sand, but before the second sheet sand. The isolated and elusive aerial distribution of the distributary channel sandstones combined with their electrofacies character and erosive characteristics seen in cross sections help to identify these sandstones as preserved fluvial lowstand deposits of the second regression. These distributary channels transported sediment from north to south and from northeast to southwest as the shoreline retreated in a southwesterly direction. Accordingly, the final transgression follows deposition of the lowstand deposits. The shoreline shifts landwards (northeast) and marine processes re-work and re-distribute the sediment delivered by the fluvial system of the second regression. This transgressive system deposited the second sheet sandstone as widespread, and uniformly thick (12-15 feet), with a superjacent thin marine shale. This thin marine shale is the “Boatwright Hot

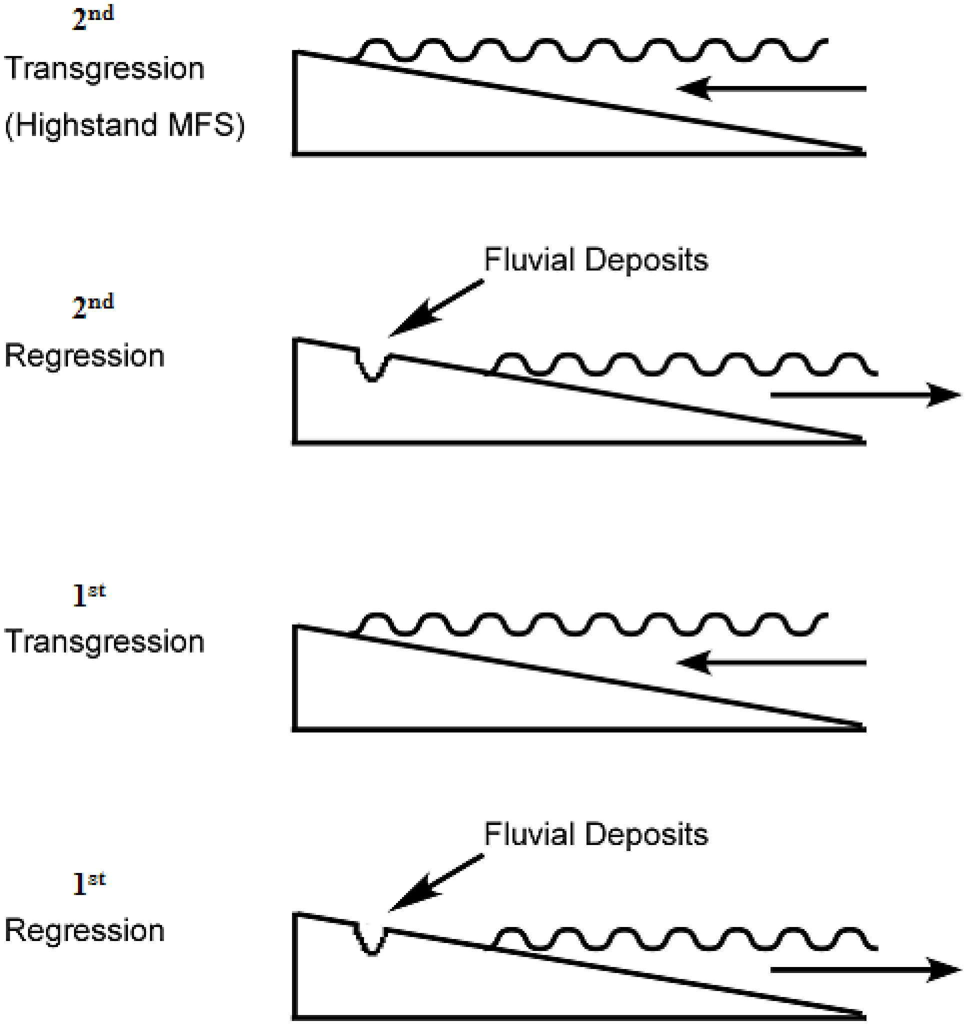


Figure 22. Depositional model for Boatwright development showing relative sea-level change within a shelf setting. Vertical scale for shelf is greatly exaggerated.

Shale" and indicates a highstand maximum flooding surface (MFS) and maximum transgression. This thin shale marks the maximal stage of the final transgression of the Boatwright interval. Figure 22 depicts the sequential sea-level response model for Boatwright sandstone development.

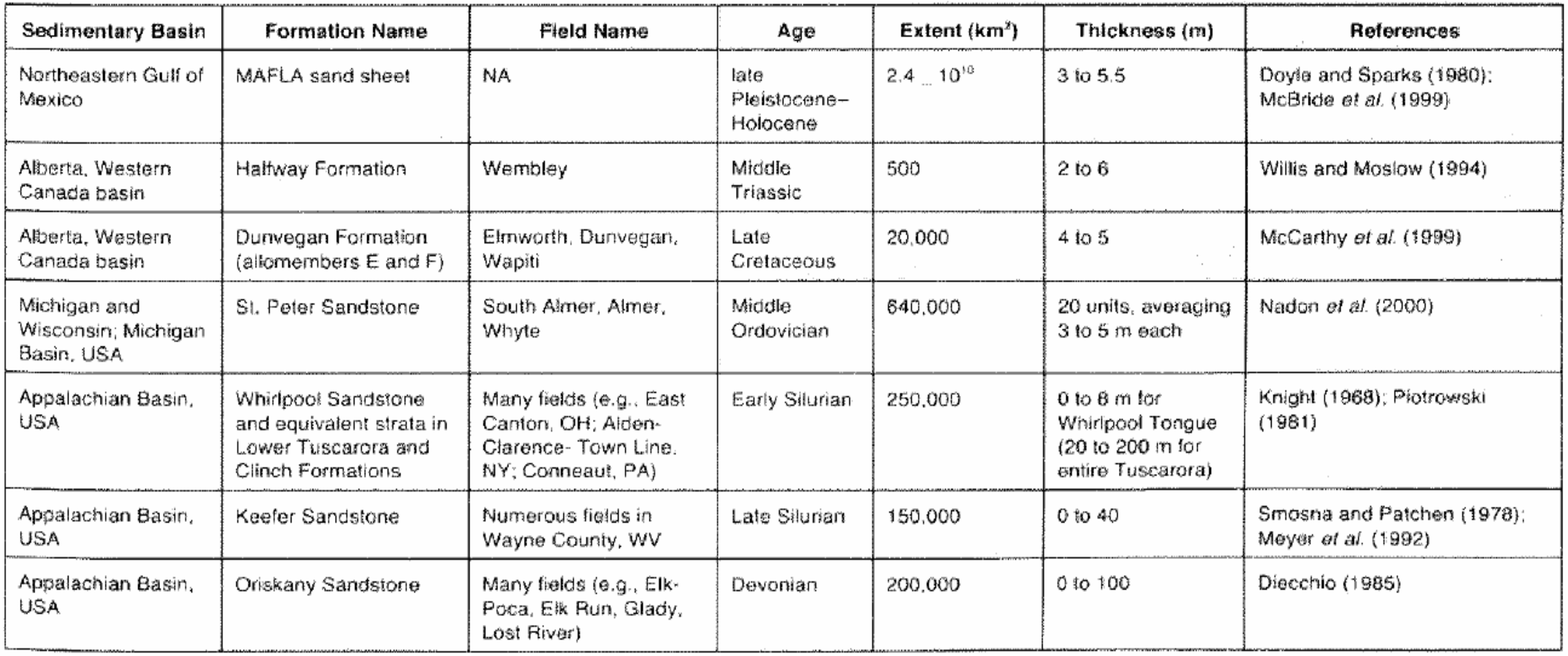
Modern and Ancient Analogs

A challenge to many subsurface studies is identifying modern environments that exhibit similar characteristics as the ancient sandstones being studied. The Boatwright is no exception. Fluvial and shelf systems are well documented in both modern and ancient environments. The challenge is finding a modern analog that exhibits similar distribution patterns, thickness, lithology, and sedimentary features. A modern analog can help identify environments of deposition and the processes that contributed to sediment accumulation. Fortunately, modern environments have been identified that have characteristic similarities to those evident in Boatwright sandstones.

The majority of Boatwright sandstones are classified as sheet sandstones because they are widely distributed, of uniform thickness, and overlain by shales containing marine invertebrate fauna. The spatial relationship of these sandstones to channel filling ones is evidence that these are transgressive sheet sandstones. Transgressive deposits are recognized in both modern and ancient deposits. Specifically, sands deposited during transgression with a broad aerial distribution of uniform thickness are recognized in Pleistocene sediments of the Gulf Coast.

The Mississippi-Alabama-Florida (MAFLA) shelf sand sheet is a quartz sand of uniform thickness that covers an extensive area and serves as a modern-day analog for shallow marine sandstones deposited under regional transgression (McBride et al., 2004).

Several factors influenced the development of this sheet sand. During the postglacial rise and present highstand in sea level, the eastern two-thirds of the Gulf Coast shelf has been sediment starved, enabling additional reworking of the shelf sands during the passage of strong cold fronts and hurricanes. This cyclic re-working has accumulated a nearly uniform thickness of clean, multicyclic quartz sand known as the Mississippi-Alabama-Florida (MAFLA) shelf sand sheet (McBride et al., 2004). This sand is a Pleistocene age deposit that shares similar characteristics with the Boatwright sheet sandstones. These similar characteristics include distribution patterns, thickness, lithology, and sedimentary features. The MAFLA sand sheet and Boatwright sheet sandstones have a broad aerial distribution. The MAFLA sand sheet covers 24,000 km^2 of area and the Boatwright sheet sandstones cover an area of approximately 520 km^2. Both are quartz-rich sand deposits with uniform thickness. The lowermost Boatwright sheet sandstone is 15-18 feet thick and the uppermost sheet sandstone is 12-15 feet thick. Accordingly, the MAFLA sheet sand is 10-15 feet thick on average. More specifically, the MAFLA sheet sand and the uppermost Boatwright sheet sandstone are strikingly similar. Aside from the similar thickness and distribution patterns, both are capped by a maximum flooding surface. The flooding surface for both marks the maximal transgression within their respective stratigraphic units. Finally, Boatwright sandstones exhibit limited sedimentary features present in other transgressive deposits. The only sedimentary feature recognized for Boatwright sandstones in core were low-angle planar laminations. Examples of other transgressive deposits with planar laminations include the Halfway Formation of Alberta and the St. Peter Sandstone of the Michigan Basin. Other analogs for Boatwright sandstones can be found in Paleozoic rocks of the United States and Canada. Figure 23 is



Sedimentary Basin	Formation Name	Field Name	Age	Extent (km^2)	Thickness (m)	References
Northeastern Gulf of Mexico	MAFLA sand sheet	NA	late Pleistocene–Holocene	$2.4 \_ 10^{10}$	3 to 5.5	Doyle and Sparks (1980); McBride *et al.* (1999)
Alberta, Western Canada basin	Halfway Formation	Wembley	Middle Triassic	500	2 to 6	Willis and Moslow (1994)
Alberta, Western Canada basin	Dunvegan Formation (allomembers E and F)	Elmworth, Dunvegan, Wapiti	Late Cretaceous	20,000	4 to 5	McCarthy *et al.* (1999)
Michigan and Wisconsin; Michigan Basin, USA	St. Peter Sandstone	South Almer, Almer, Whyte	Middle Ordovician	640,000	20 units, averaging 3 to 5 m each	Nadon *et al.* (2000)
Appalachian Basin, USA	Whirlpool Sandstone and equivalent strata in Lower Tuscarora and Clinch Formations	Many fields (e.g., East Canton, OH; Alden-Clarence- Town Line, NY; Conneaut, PA)	Early Silurian	250,000	0 to 8 m for Whirlpool Tongue (20 to 200 m for entire Tuscarora)	Knight (1968); Piotrowski (1981)
Appalachian Basin, USA	Keefer Sandstone	Numerous fields in Wayne County, WV	Late Silurian	150,000	0 to 40	Smosna and Patchen (1978); Meyer *et al.* (1992)
Appalachian Basin, USA	Oriskany Sandstone	Many fields (e.g., Elk-Poca, Elk Run, Glady, Lost River)	Devonian	200,000	0 to 100	Diecchio (1985)

Figure 23. Modern and ancient analogs of sand-rich shallow-marine facies from North America by McBride et al., (2004).

a table depicting formations with transgressive deposits and similarities to the Boatwright sandstones. These formations are widely distributed across geologic time and basins.

The MAFLA sand sheet appears to have developed in the offshore to lower shoreface in a shelf setting based on its positioning within the Gulf of Mexico. It is proposed that the Boatwright sandstones were deposited in a similar environment. For sand sheets of this size to develop a large area is required and this area encompasses a significant portion of the offshore but not extending to the shelf break. Therefore, Boatwright sands were deposited in a shallow marine shelf setting.

Discussion

Thus far, proposed depositional environments and facies for the Boatwright Sandstone have been discussed, but the driving mechanisms behind the development of these sandstones have been given little consideration. Both basin subsidence and sea-level fluctuations are proposed as influencing Boatwright deposition. The more influential of the two is believed to be sea-level cyclic fluctuation. The frequency of sandstone development in association with recognized flooding surfaces leads to the inference that the relative sea-level changes were high frequency in nature. Van Wagoner et al. (1991) attributed eustacy as the driving mechanism behind higher-frequency sequence development. Eustacy is most commonly attributed to the expansion and contraction of glaciers. Much research over the past 70 years have focused on the subject of glacioeustatic change due to the expansion and contraction of glaciers in the Paleozoic. Rygel et al. (2008) has composed a comprehensive literature review illustrating the magnitude of glacioeustatic fluctuations throughout the Carboniferous and Permian. The compiled work of this study depicts very clearly a change in glacial activity through the Chesterian. Early Chesterian is depicted as a distinctly non-glacial period with eustatic fluctuations less than 25 meters. Mid-Chesterian is characterized as a moderately active glacial period with eustatic fluctuations 10-30 meters in magnitude. The late Chesterian and remaining Mississippian is characterized as having experienced moderate to large glacioeustatic fluctuations of 20-100 meters. Based on this evidence, the driving mechanism behind the cyclic changes in sea-level for Boatwright development appears to be glaciation. Moderate to large glacioeustatic fluctuations of the late Chesterian appear to be responsible for the proposed depositional cycles that shifted from lowstand erosion and valley incisement to transgressive sheet sands and ultimately maximum transgression with a MFS.

CHAPTER VI

PETROLEUM RESERVOIR PROPERTIES

Introduction

The purpose of this chapter is to describe the composition of the Boatwright Sandstone including detrital framework grains, authigenic minerals, and the types of porosity. Accordingly, identifying porosity types and understanding trapping mechanisms necessary for petroleum accumulation are also important. Thin sections from two cored wells and porosity logs from multiple wells were evaluated to determine components, porosity type and trapping mechanisms.

Methods

Thin sections were made of samples from selected intervals to determine the detrital and authigenic constituents in Boatwright sandstones. First, samples for thin sectioning were cut into 24 x 40 mm billets. These samples were vacuum-impregnated with stained epoxy and mounted to frosted slides. Next, the samples were ground to approximately 30 micron thickness for petrographic analysis. Finally, thin sections were examined using a petrographic microscope and photographed. The Troy Smith core was sampled at 13,028' core depth and represents 13,032' on well log. The Gamble Gas Unit core was sampled at 10,534' core depth and represents 10537' on well log.

Accordingly, productive Boatwright wells were identified and porosity logs were analyzed. Productive porosity thresholds were identified based on the lowest porosity values required to produce large quantities of hydrocarbons. Maps of Oklahoma producing fields published by the Oklahoma Geological Survey (Boyd, 2002) were examined to identify productive fields within the study area.

Detrital Constituents

Boatwright sandstones are quartzitic, with a fair amount of siliceous detrital matrix and trace amounts of muscovite and biotite. Quartz is the dominate detrital grain in the Amoco, Troy Smith No. 1 sample and siliceous matrix was abundant (Figure 24). Quartz dominated the Gamble Gas Unit sample (Figure 25). The detrital framework of Boatwright sandstones consists of 99-100 percent monocrystalline quartz. These sandstones classify as quartz arentites based on the ternary classification of Folk (Figure 23).

Quartz

Monocrystalline quartz dominates both samples and accounts for 99-100% of the detrital framework. Plutonic quartz is the only variety recognized in thin section. Plutonic quartz was recognized on the basis of low birefringence under crossed polarization, monocrystalline appearance, and straight extinction.

Siliceous Detrital Matrix

Siliceous detrital matrix is composed of silt-sized quartz grains. This constituent was found in both samples, but was more abundant in the Troy Smith sample. It is believed that the salt and pepper appearance of the Boatwright Sandstone in the Troy Smith No. 1 is the result of siliceous detrital matrix.

Authigenic Constituents

The primary authigenic constituent in Boatwright sandstones is calcite. Calcite

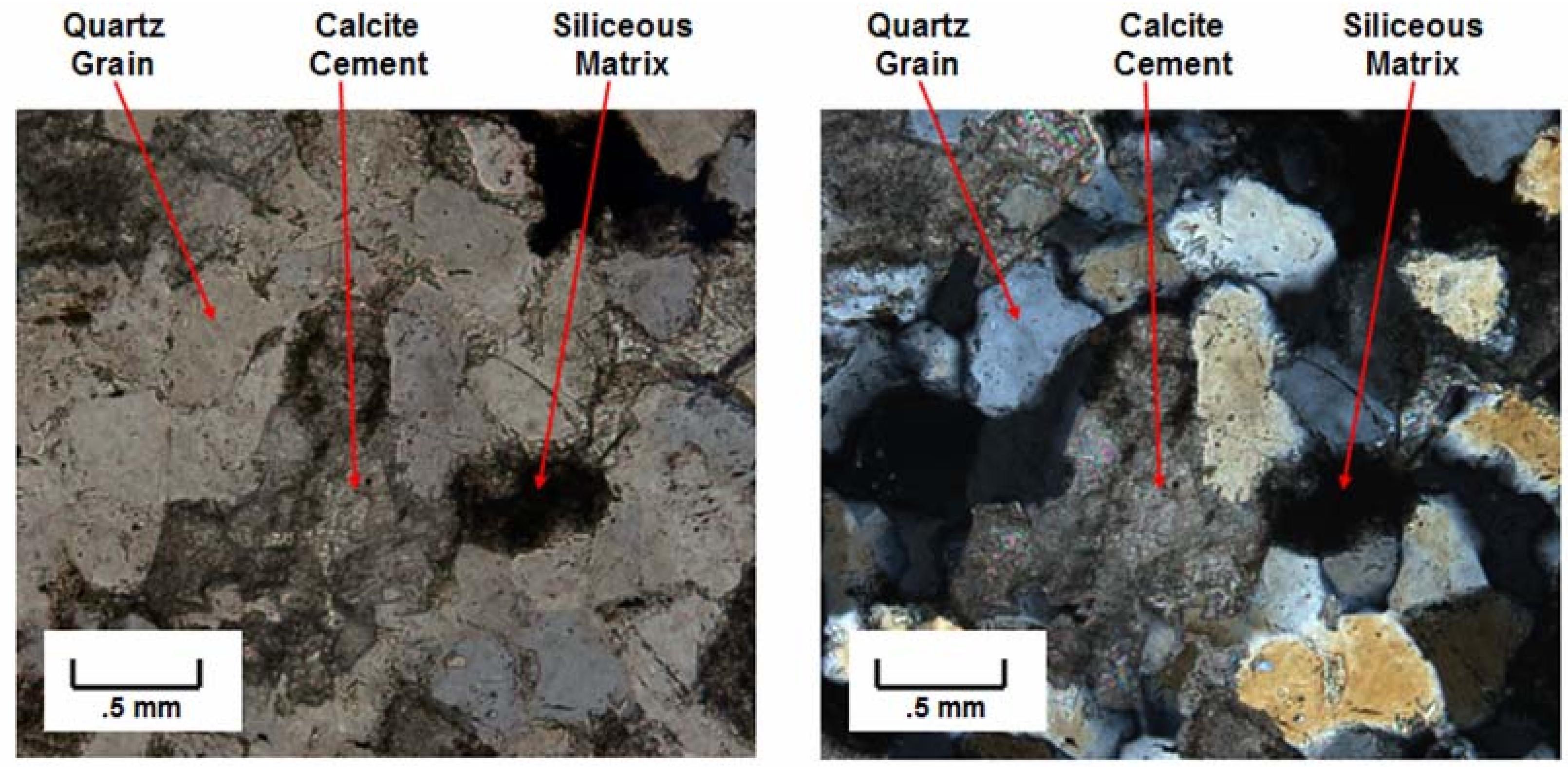


Figure 24. Thin section photographs of Boatwright Sandstone in the Troy Smith well. Photo on the left is plane polarized light and the photo on the right is cross polarized light with both at 10X magnification. Quartz grain, calcite cement, and siliceous matrix are identified with arrows.

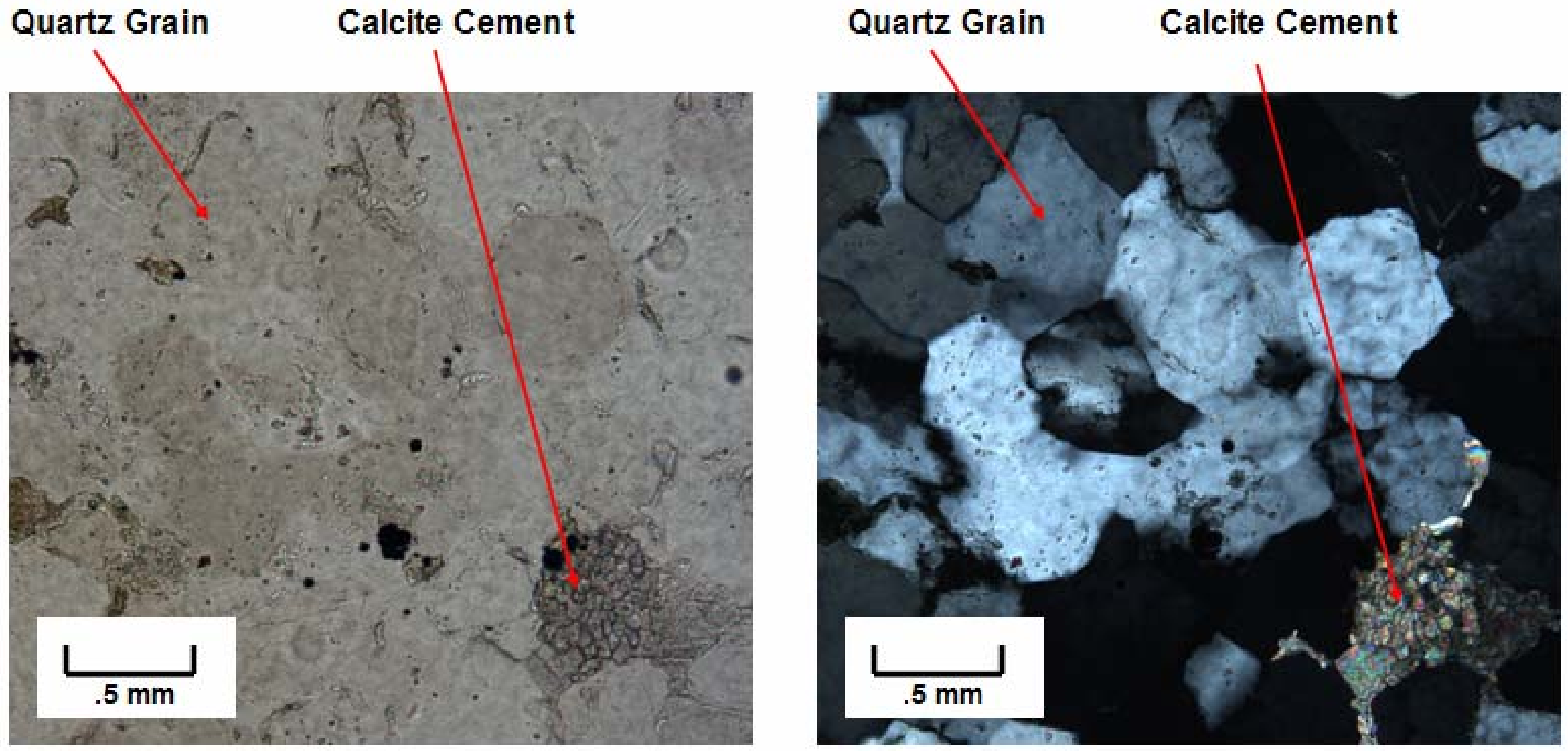


Figure 25. Thin section photographs of Boatwright Sandstone in the Gamble Gas Unit well. Photo on the left is plane polarized light and the photo on the right is cross polarized light with both at 10X magnification. Quartz grain and calcite cement are identified with arrows.

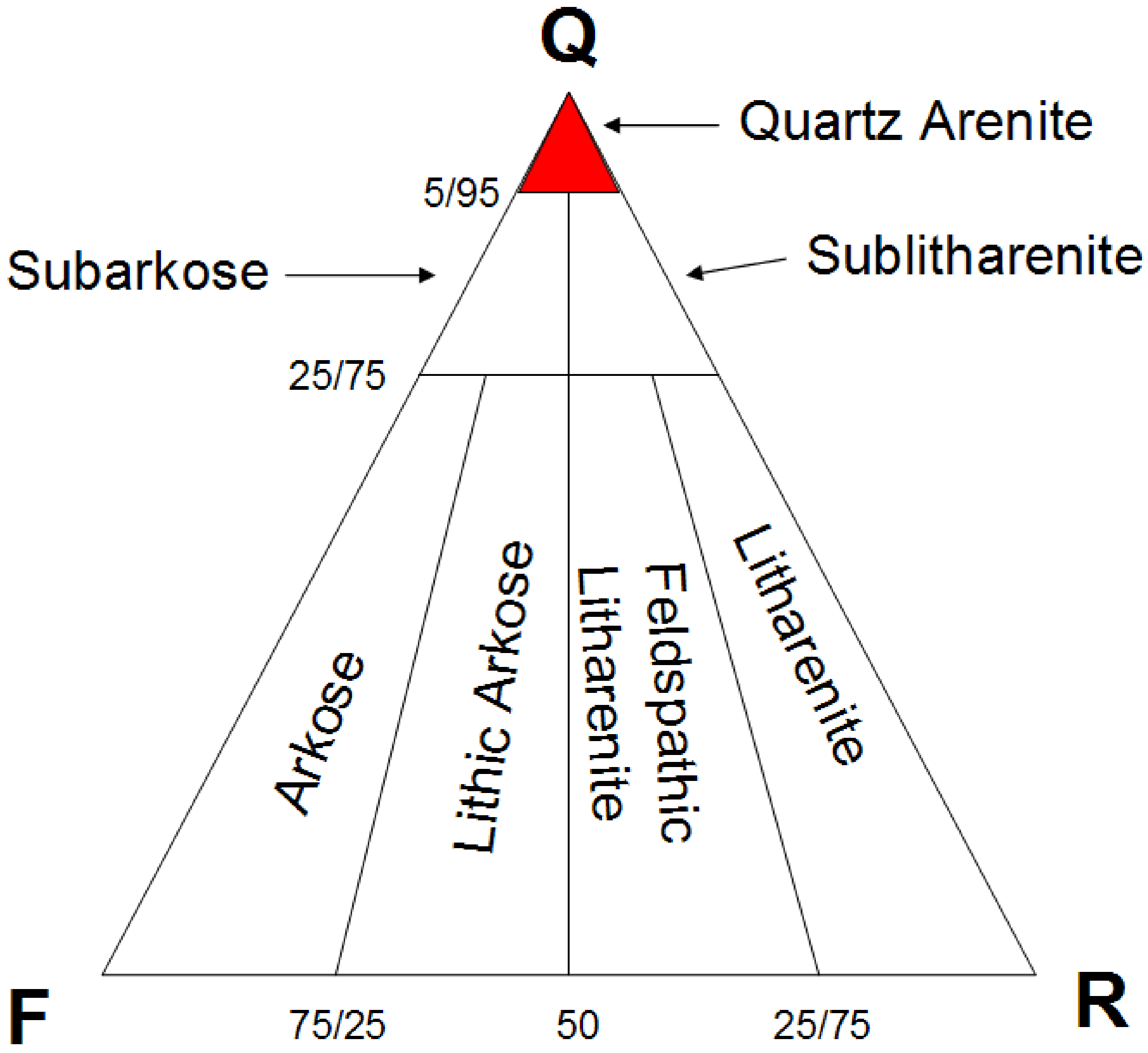


Figure 26. QRF Folk (1974) sandstone classification diagram for the Boatwright sandstones. Boatwright sandstones are classified as quartz arenites. Quartz, rock fragments, and feldspars comprise the three corners of the classification.

occurs in thin section in both poikilotopic and blocky forms. These varieties of calcite formed shortly after burial and filled virtually all primary porosity. A secondary constituent is quartz cement in the form of syntaxial quartz overgrowths.

Porosity

Porosity in the thin sections of the Boatwright sandstones is minimal. Conventional hydrocarbon accumulations occur in sedimentary rocks with sufficient porosity to store petroleum. Based on production history of Boatwright gas wells, the productive threshold for Boatwright sandstones is identified as being 6 percent porosity by volume. No significant amounts of porosity were recognized in thin section. All primary porosity was filled with calcite and secondary porosity was non-existent. Calcite occludes nearly all primary porosity. It is believed that secondary porosity developed through dissolution of calcite. Secondary porosity is believed to be the porosity type responsible for hydrocarbon storage.

Production

Boatwright sandstones produce large quantities of hydrocarbons, most of which are natural gas and condensate. Within the study area a total of 8 gas fields, one oil and gas, and one oil field exist (Figure 27). Boatwright sandstones are prominent producing zones in the Watonga-Chickasha Trend that encompasses almost the entire eastern half of the study area. An average Boatwright well produces ~2.5 BCFG (Andrews, 2001). This makes the Boatwright a high-volume gas producer and an attractive drilling target.

Trapping Mechanisms

A trap is defined as “the place where oil and gas are barred from further movement” (Levorsen 1967). Two types of traps widely recognized for trapping

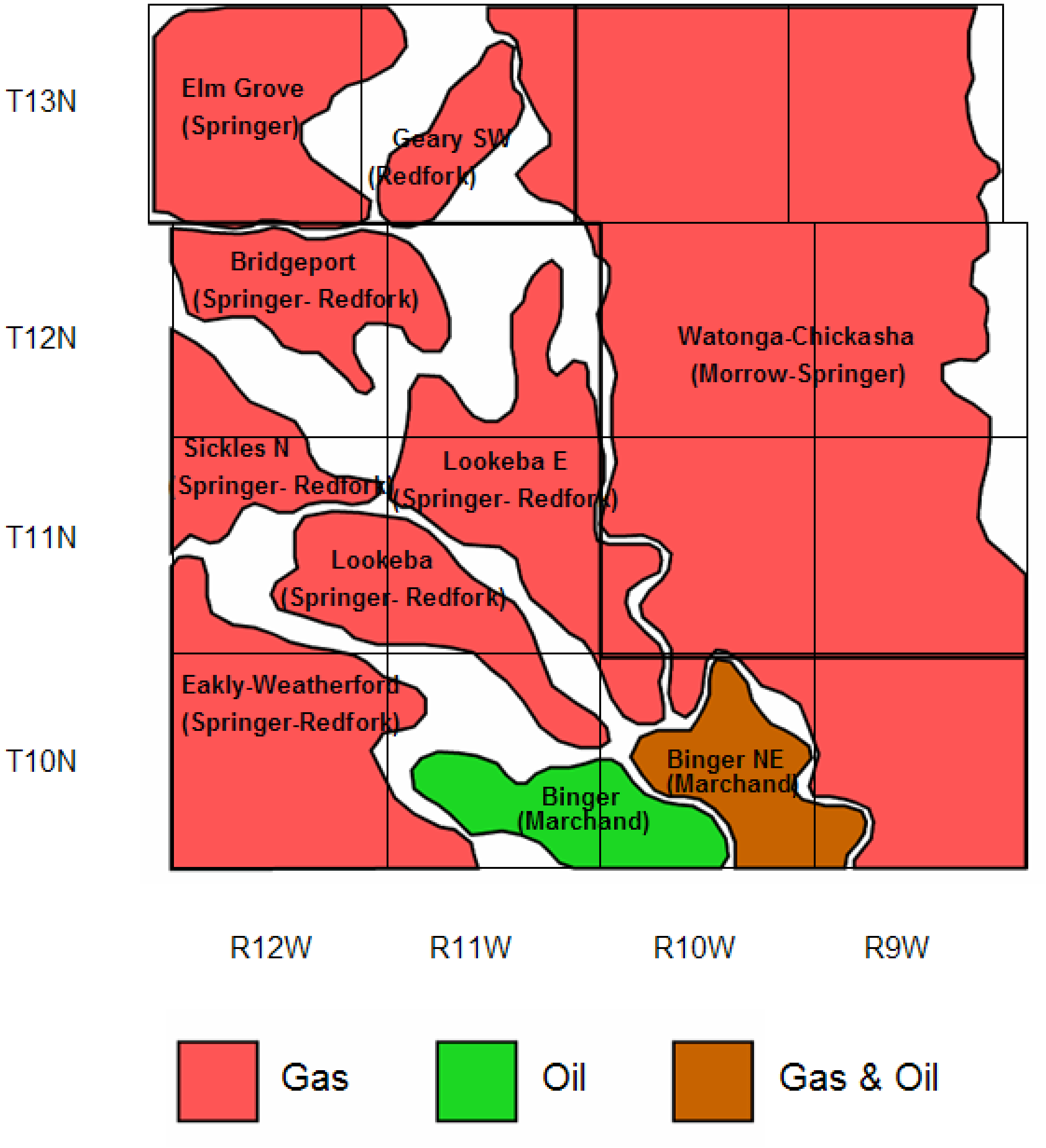


Figure 27. Location of gas and oil fields along with producing horizons within the study area from Boyd (2002).

hydrocarbons are structural traps and stratigraphic traps. Structural trapping occurs when sedimentary strata has been deformed. Stratigraphic trapping occurs due to depositional characteristics of the reservoir rock. The primary trapping mechanism for Boatwright sandstones is stratigraphic. Levorsen defines a stratigraphic trap as "one in which the chief trap-making element is some variation in the stratigraphy, or lithology, or both, of the reservoir rock, such as a facies change, variable local porosity and permeability, or an up-structure termination of the reservoir rock, irrespective of the cause"(Levorsen, 1967). For Boatwright sandstones a facies change, variable porosity, and up-structure termination all exist as trapping elements within the study area. The eastern limit of the transgressive sheet sandstone facies represents the up-structure termination of a massive Boatwright sandstone gas reservoir (Figure 28). The eastern limit of the Watonga-Chickasha Trend is closely related to the eastern limit of the Boatwright transgressive sheet sandstone facies. This sandstone becomes progressively structurally higher to the East and eventually becomes truncated due to an erosional angular unconformity beneath Pennsylvanian sedimentary strata. Gas migrated to the up dip limits of these sandstones and was sealed off by the by the overlying Pennsylvanian shale creating an up-structure termination of the reservoir rock. Channel sandstone facies are high-volume gas producing reservoirs. These sandstone bodies are isolated and sealed by the overlying Boatwright Hot Shale and represent a facies change trapping element. Finally, Boatwright Sandstone wells can be productive in isolated cases where the only trapping element appears to be development of porosity. These isolated wells produce gas from zones containing transgressive sheet sandstone facies. In conclusion, the facies changes, variable porosity, and up-structure termination of Boatwright Sandstones defines the

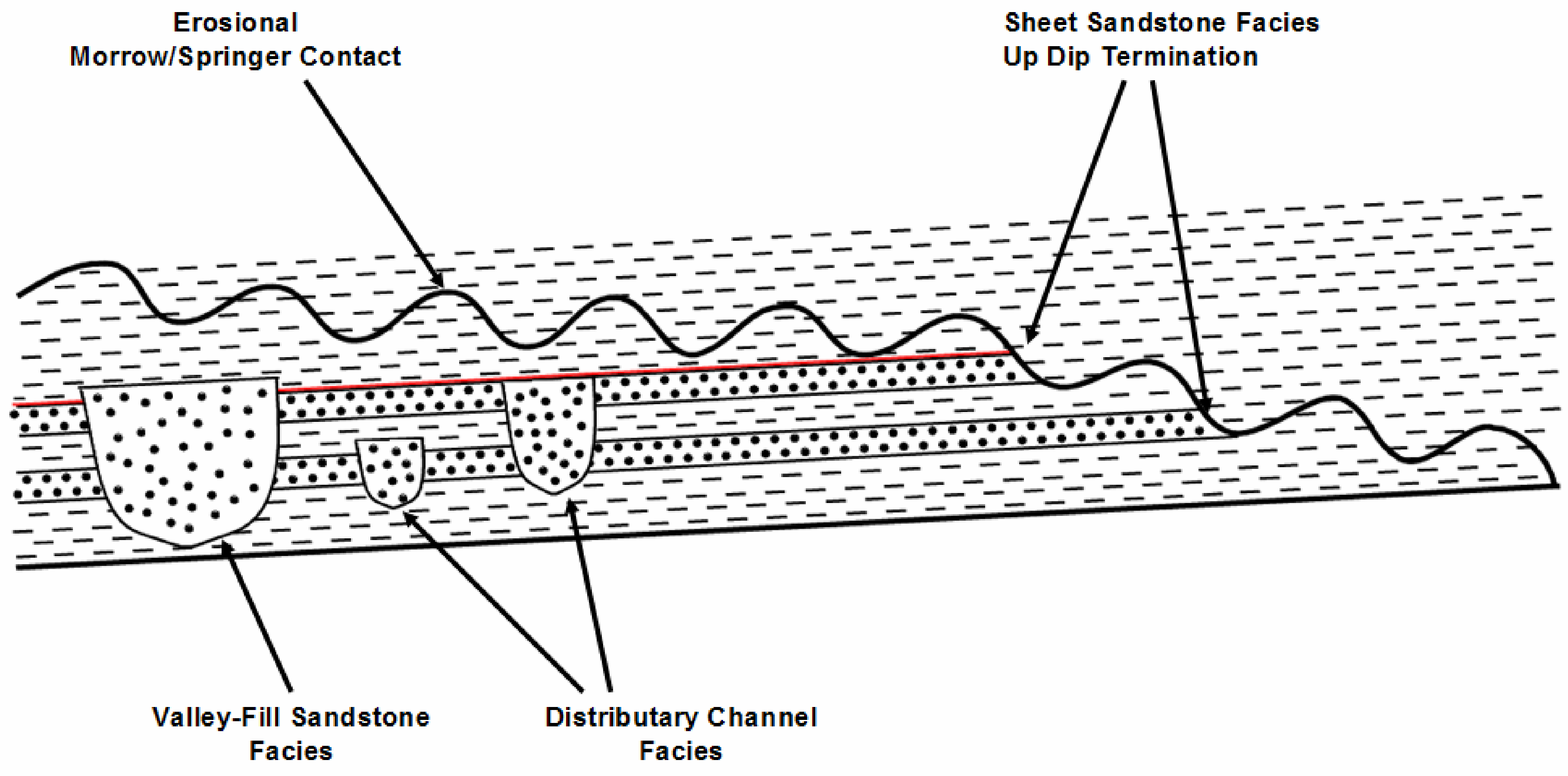


Figure 28. Diagrammatic illustration of the major trapping mechanisms. Boatwright Hot Shale shown as red line. Lowermost sheet sandstone is the first sheet sandstone and the uppermost sheet sandstone is the second.

three elements responsible for trapping hydrocarbons.

"Old Woman Channel" Characteristics and Production

Wells containing the valley filling sandstone facies (Britt Member) make for excellent stratigraphic hydrocarbon traps. This facies contains a high volume hydrocarbon producing trend known as the "Old Woman Channel" (OWC). The discovery well for this channel sandstone was the Pan American Co. Lyon No. 1 well located in section 19 of T.14N.,R.10W., Canadian County, OK. This well was drilled in 1966. In October 1967, an exploratory well in Blaine County named the Old Woman No. 1 was completed in the same channel trend by Pan American Exploration. This subsequent well was such a high-volume producer that the channelized trend was named the Old Woman Channel. The Old Woman No. 1 well has produced over 25 BCFG and 572,000 barrels of oil and is still producing. Within the study area wells penetrating the OWC have produced 17.5 BCFG and 210,000 barrels of oil from 12 wells. This brings the average per well to 1.46 BCFG and 17,500 barrels of oil.

The OWC was introduced earlier and described by previous authors as a deltaic distributary channel. Clement (1974) describes this sandstone as being the basal Springer Sandstone. While this is true, observations of this study identify OWC as belonging to the Britt interval. Due to the depth of the OWC, the Boatwright Hot Shale marker was eroded prior to sand deposition. This erosion of the Boatwright Hot Shale marker bed makes the channel-filling sandstone younger than Boatwright Hot Shale. Haiduk (1987) illustrates the existence of a deltaic complex existing during Britt sandstone deposition with a parent fluvial system (Old Woman Channel) feeding this delta from the north. The

OWC enters the study area in the far northeast corner of T.13N. and R.11W. and continues south through the study area until terminating in T.11N. and R.9W. O'Donnell and Haiduk (1987) stated that the "Old Woman" Sandstone is mappable for more than 30 miles with sandstones bodies being .5 miles wide and 50-70 feet thick. Boatwright distributary channel facies are mapped directly adjacent to the OWC as seen in Figure 16. Wells with interpreted Boatwright distributary channel facies and Boatwright Hot Shale are located within a few hundred feet (surface distance) from wells containing the valley-fill sandstone facies. This is evidence to support the idea that a passageway for sediment transport existed for both Boatwright and Britt fluvial deposits. This passageway appears to be a valley and the Britt sandstones appear to be preserved incised valley fill deposits. The OWC fits the criteria for an incised valley fill deposit. The OWC is mappable for a long distance (30 miles), making it larger than a single channel. It is a fluvially eroded topographic low due to the deep incision of up to 70 feet. An abrupt change in depositional facies is evident by the fluvial (inferred) OWC sandstone juxtaposed on the Boatwright marine shale. Furthermore, the OWC erodes through a regional maker (Boatwright Hot Shale) making it a sequence boundary. This boundary represents a fourth or fifth order level sequence boundary and a minor unconformity that depicts the base of the Britt sequence and the top of the Boatwright sequence.

CHAPTER VII

CONCLUSIONS

Several conclusions were formulated as a result of the examination of the Boatwright interval in the study area. These conclusions are outlined below and address many aspects of Boatwright deposition including setting, structural attitude, depositional environment, sandstone distribution, sequence stratigraphy, rock properties, and oil and gas production.

1. Strike is approximately northwestward. Dip is to the southwest at 2°-3°.

2. One fault was identified in the study area. This fault has an east-west trend, is located in T.11W., R.10W., and a displacement of approximately 240 feet.

3. Four electrofacies were identified using core and wireline log properties: (1) distributary channel, (2) valley fill sandstone (Britt member), (3) sheet sandstone, and (4) marine shale.

4. Boatwright sheet sands were deposited on a shallow Mississippian shelf and are encased in mud with a normal marine invertebrate fauna.

5. The MAFLA sand sheet in the Gulf Coast area serves as a modern analog to the development of Boatwright transgressive sheet sandstones.

6. Sheet sands were deposited during transgression in the offshore to lower shoreface areas and preserved as sheet sandstone facies.

7. Formation of Boatwright sandstones occurred through two cycles of regression and transgression in response to basin subsidence and sea-level fluctuations.

8. Distributary channel sands were likely deposited during early transgression phase of cycles.

9. Marine shale represents advanced transgression with the Boatwright Hot Shale, a maximum flooding surface.

10. Sea-level changes responsible for Boatwright depositional cycles appear to be related primarily to glacially-induced eustatic sea-level changes.

11. Boatwright sandstones are classified as quartz arenites. Calcite cement is an important authigenic component that occludes primary porosity. Secondary porosity development is the primary porosity type and responsible for hydrocarbon storage.

12. The Old Woman Channel sandstones represent fill within an incised valley that eroded the Boatwright hot shale. The spatial relationship requires the OWC fill to be part of the Britt cycle and the base of the OWC a sequence boundary that separates the Britt cycle from the underlying Boatwright cycle.

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APPENDIX A

PLATES

Plate 1. Cross Section A to A' (see supplemental file 1)

Plate 2. Cross Section B to B' (see supplemental file 2)

Plate 3. Cross Section C to C' (see supplemental file 3)

Plate 4. Cross Section D to D' (see supplemental file 4)

Plate 5. Cross Section E to E' (see supplemental file 5)

Plate 6. Cross Section F to F' (see supplemental file 6)


A
CHAPARRAL ENERGY
ANDY PAYNE
1-21
T13N R12W S21
CONTINENTAL OIL CO
WOMAN GOING UP HILL
1
T13N R11W S17
MUSTANG PRODUCTION COMPANY
WEIMERS UNIT
1-14
T13N R11W S14
PROSPECTIVE INVESTMENT & TRADING
HART
1
T13N R10W S16
WARD
HOLMAN FARMS UNIT
1
T13N R9W S17
A'
12180
12240
12300
12360
12420
12480
12540
12600
12660
12720
12780
11220
11280
11340
11400
11460
11520
11580
11640
11700
11760
11820
11100
11160
11220
11280
11340
11400
11460
11520
11580
11640
10860
10920
10980
11040
11100
11160
11220
11280
11340
11400
10140
10200
10260
10320
10380
10440
10500
10560
10620
10680
BRITT_HS [JDC]
BOATWRIGHT_HS [JDC]
CHST_LM [JDC]
GAMMA RAY
RESISTIVITY
CONDUCTIVITY
CALIPER
POROSITY
CORRECTION
BULK DENSITY
SPONTANEOUS-POTENTIAL


B
NOBLE
CARPENTER-STATE
1
T12N R12W S14
CARBON ECONOMY
JAQUES
1
T12N R11W S23
MICH WISC PIPE LINE
LEDFORD
1
T12N R10W S21
CHESAPEAKE OPERATING INCORPORATED
MATTHIES TRUST
1-8
T12N R9W S8
B'
BRITT_HS [JDC]
BOATWRIGHT_HS [JDC]
CHST_LM [JDC]


C
APACHE CORP
BUELL /A/
1
T11N R12W S10
DOMINION
MORELOCK
1
T11N R11W S6
SUNRISE EXPL
ELSIE HOLLIS
1-11
T11N R11W S11
UNIT
BUXTON
2
T11N R10W S4
DOMINION
HOEHNER
1-20
T11N R9W S20
C'
BRITT_HS [JDC]
BOATWRIGHT_HS [JDC]
13800 13860 13920 13980 14040 14100 14160 14220 14280 14340
12960 13020 13080 13140 13200 13260 13320 13380 13440 13500 13560
12900 12960 13020 13080 13140 13200 13260 13320 13380 13440
12060 12120 12180 12240 12300 12360 12420 12480 12540 12600
11460 11520 11580 11640 11700 11760 11820 11880 11940 12000
TGS
SIMULTANEOUS COMPENSATED NEUTRON-FORMATION DENSITY


D
D'
CHAMPLIN
CLAY HENRY
1-17
T10N R12W S17
15240 15300 15360 15420 15480 15540 15600 15660 15720 15780
SANGUINE LTD
RHOADS
1
T10N R11W S18
14880 14940 15000 15060 15120 15180 15240 15300 15360 15420
RAMSEY PROP MGMT INC
PHIFER
1-13
T10N R11W S13
13980 14040 14100 14160 14220 14280 14340 14400 14460 14520
NADEL & GUSSMAN
KISSINGER
1
T10N R10W S14
13140 13200 13260 13320 13380 13440 13500 13560 13620 13680 13740
TECHNICAL ENERGY SER
KELLY UNIT `B`
3
T10N R9W S28
12480 12540 12600 12660 12720 12780 12840 12900 12960 13020
BRITT_HS [JDC]
BOATWRIGHT_HS [JDC]


E
E'
PHILLIPS PETRLM CO
SEITTER /A/
1
T13N R11W S27
WARD PET CORP
HINTON TOWNSITE
1-34
T12N R11W S34
WOODS PET CORP
SENN UNIT
1
T11N R11W S16
CHEVRON TEXACO
LARSON
30-1
T10N R11W S30
BRITT_HS [JDC]
BOATWRIGHT_HS [JDC]
11400
11460
11520
11580
11640
11700
11760
11820
11880
11940
12720
12780
12840
12900
12960
13020
13080
13140
13200
13260
13440
13500
13560
13620
13680
13740
13800
13860
13920
13980
14040
15300
15360
15420
15480
15540
15600
15660
15720
15780
15840
15900
SPONTANEOUS-POTENTIAL
RESISTIVITY
GAMMA RAY
CALIPER
NEUTRON POROSITY INDEX %
DENSITY POROSITY INDEX %
CONDUCTIVITY
POROSITY
BULK DENSITY

F

QUESTAR EXPLORATION & PRODUCTION CO
LECK
3
T13N R10W S28

CHESAPEAKE
DELANA MARY E
1-11
T12N R10W S11

CHESAPEAKE
DRONBERGER
1-2
T11N R10W S2

IRON SIGHTS OPER
BLACKBURN /A/
1
T10N R10W S2

COTTON PET CORP
DUNCAN
A-1
T10N R10W S26

F'

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Abstract: Primary objectives of this study were to examine the depositional setting and establish sandstone facies, distribution, and petroleum geology for the Boatwright sandstones. Depositional setting was determined from cross-section generation, core analysis, and core-correlated wireline electrofacies. All data were integrated to explain the petroleum geology of the hydrocarbon-bearing zones.

Boatwright sand deposition occurred in a shelf setting and is characterized as two cycles of regression to transgression in response to basin subsidence and sea-level fluctuations. Glacially-induced sea-level change is proposed as a possible mechanism for Boatwright depositional pattern. Tectonism is also a possible mechanism for Boatwright deposition. Distributary channel, sheet sandstone, valley-fill sandstone, and marine shale facies are proposed for the Boatwright interval. The Boatwright hot shale represents maximum flooding during the Boatwright cycle. The boundary between the Boatwright and overlying Britt cycle is placed at the erosional surface beneath the Old Woman Channel. Boatwright sandstones are high volume petroleum reservoirs that trap due to facies changes, variable porosity, and up-structure termination of sandstone.

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