Hydrocarbon Generating Potential: Jurassic Cotton Valley – Bossier Group, North Louisiana Salt Basin

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ABSTRACT

Geological/geochemical evaluation of Upper Jurassic Cotton Valley – Bossier core samples from the North Louisiana Salt Basin (NLSB) indicates that fine-grained rocks associated with these units are thermally mature and represent petroleum source rock that generated and expelled mostly gas and some oil. These findings are based on source rock characterization of samples from wells within the NLSB, Vernon Field, Jackson Parish, using total organic carbon (TOC), Rock-Eval pyrolysis, and visual kerogen data.

The data indicate that these rocks at their present maturity level have low to moderate TOC contents and Type III kerogen. Original kerogen types in the immature stage, as assessed by kerogen petrography, were mainly gas-prone Type III and some oil-and gas-prone Type II/III. The principal macerals are partly oxidized, unstructured amorphous organic matter (liptinite) and vitrinite in varying proportions. Amorphous material was derived from degraded marine algal and humic matter (higher plant material). Visual kerogen data support the predominantly gas-prone nature of the source rocks. Vitrinite reflectance (R_o) values (0.94% to 2.62%) and thermal alteration indices (TAI) (2.8 to 3.7) suggest that these source rocks entered the late oil window to main gas maturity window and thus have generated mostly gas with some oil. Thin section petrography of geochemically analyzed intervals documents the following rock types: muddy fine-grained sandstone, laminated fine-grained sandstone, sandy mudstone, and silty mudstone. These combined analytical results indicate that abundant woody organic material of continental origin was deposited in offshore areas in association with fine siliciclastic sediments in a marine prodelta environment during Jurassic time. The thickness and widespread deposition of predominantly gas-prone rocks within the NLSB and their high thermal maturity led to sourcing of mainly gas with some oil in overlying Jurassic and Cretaceous reservoirs, particularly in the Bossier and Cotton Valley.

Goddard, D. A., E. A. Mancini, M. Horn, and S. C. Talukdar, 2008, Hydrocarbon generating potential: Jurassic Cotton Valley – Bossier Group, North Louisiana Salt Basin: Gulf Coast Association of Geological Societies Transactions, v. 58, p. 305-325.

INTRODUCTION

Little published information is available regarding the organic geochemistry, thermal maturity, and hydrocarbon source potential of fine-grained rocks of the Cotton Valley – Bossier Group in the North Louisiana Salt Basin (NLSB). Such geochemical studies have traditionally focused on the Smackover Formation that has always been considered the principal source rock for hydrocarbons in the NLSB. One study of the Ruston Field (Herrman et al., 1991) suggested that gas in Cotton Valley sandstone reservoirs was likely sourced from Cotton Valley Group mudstones/shales, despite a lack of geochemical information from the producing reservoir rock. Other private studies regarding this topic may exist, but if so those results have not been made available to the public. Furthermore, drill cores, which are required for geochemical analyses of the fine-grained rocks that are of interest in the NLSB, are few in number. For economic reasons, coring is usually limited to reservoir sandstones and limestones, not mudstones.

By comparison, a number of publications address sand reservoirs of the Bossier Formation of the East Texas Basin (ETB) where production from sandy intervals has been prolific (Chaouche, 2006; Emme and Stancil, 2002; Ewing, 2001; Norwood and Brinton, 2001; Williams et al., 2001; White et al., 1999; Westcott and Hood, 1993). Geochemical studies were recently reported regarding hydrocarbon source potential in the ETB for the Bossier interval (Ridgeley et al., 2006; Fishman, 2006). Although the Bossier Shale in the NLSB is less sand-prone than its ETB equivalent, information about the ETB Bossier is helpful for understanding Bossier geochemistry and source potential in the NLSB.

This study is a small part of a regional petroleum systems project funded by the U.S. Department of Energy (DOE). Results of this regional study have been published in a number of papers during the last few years (Mancini et al., 2008, 2007, 2005; Li, 2006; Barnaby, 2006). In keeping with the objectives of a geochemical study of the Cotton Valley – Bossier Group, with emphasis on the Bossier Shale in the NLSB, samples were selected at varying depths within the few wells that had whole cores in the zones of interest. The main objectives of this study were to (1) determine the thermal maturity and sourcing potential of these Jurassic rocks in the NLSB, (2) explain the origin of the hydrocarbons found in the Cotton Valley sandstone reservoirs and shallower reservoirs (Hosston and Sligo), (3) try to determine whether or not the naturally fractured fine-grained rocks pertaining to the Bossier interval are also potential gas reservoirs, and (4) use the results of this study for source/reservoir rock correlation comparisons with data from regional studies in adjacent areas.

METHODS

Samples of Cotton Valley – Bossier rocks in the NLSB for geochemical analyses were collected from cored wells made available by the Texas Bureau of Economic Geology core research center in Houston, Texas (Table 1). The sampled wells were drilled in Union (Pan Am Venzina), Jackson (Amoco Davis), and Winn (Exxon Pardee and Amoco CZ 5-7) parishes (Fig. 1). Using electric logs to determine the stratigraphic tops of interest and to be sure the cored intervals were within the Cotton Valley – Bossier Group; detailed correlations were performed (Fig. 2). After confirming that the cores were indeed within the interval of interest, 18 samples from four wells were selected for geochemical analyses (Table 1). In addition, Anadarko Petroleum Corporation has produced gas from Cotton Valley sandstone reservoirs in Vernon Field (Jackson Parish) for several years. Some of the Anadarko wells were cored, and the cores made available for sampling for this study (Table 2; Fig. 3). Four wells were correlated, and six samples for analysis were selected from cores taken in shale zones within the Cotton Valley and Bossier (Fig. 4).

To constrain stratigraphic positions of study samples and to observe the thickness of the Bossier shale in the NLSB, north-south and west-east regional stratigraphic cross sections were constructed using several selected wells (Figs. 5A and 5B). These correlations show that Bossier thickness increases from north to south and ranges from 350 ft (110 m) in the north to over 2000 ft (600 m) to the south, and averages approximately 1000 ft (300 m) within the NLSB (Tables 3 and 4). Bossier shale thickness also increases in an easterly direction (Fig. 5B).

The following techniques were used in the analysis of the samples: (1) total organic carbon (TOC) and Rock-Eval pyrolysis were completed on 26 samples, (2) visual kerogen analysis techniques were employed for vitrinite reflectance and kerogen typing of 11 regional samples (at the time of writing, the authors were still wait-

Table 1. Cotton Valley – Bossier Group wells in NLSB selected for analyses.

(Ser#) & API#	Operator / Well Name	(Louisiana Parish) Core Interval	Depth (ft)
(162291)	AMOCO Davis Bros. 29-2	(Jackson)	10,944
170492011000		Bossier Fm.	10,945
			10,948
			12,804
			12,956
			12,976
(164798)	AMOCO CZ 5-7	(Winn)	15,601
171272082000		Bossier Fm.	15,608
			16,413
			16,418
			16,431
			16,432
(166680)	EXXON Pardee	(Winn)	16,195
171272085700		Bossier Fm.	16,200
			16,400
(107545)	PAN AM Venzina Green 1	(Union)	9347
171110003800		Bossier Fm.	9357
			9372

ing for six R_o analyses from the Vernon Field) (Table 5), and (3) thin section petrographic analysis was performed on five shale samples from three wells.

TOTAL ORGANIC CARBON (TOC) AND ROCK-EVAL PYROLYSIS

TOC and Rock-Eval results are posted in Table 5. TOC values range from 0.11% to 0.5%, which according to classic interpretation of TOC in shale, indicate that the quantity of organic matter is poor (Peters, 1986; Jarvie, 1991). The S_1 (0.02-0.21) and S_2 (0.04-0.43) parameters show correspondingly low values. The S_2 versus TOC diagrams (Figs. 6A and 6B) are one technique that can be used to compare analyzed samples and to help determine their petroleum generation potential (Langford and Blanc-Valleron, 1990). Because of the low S_2 and TOC values the samples plot below the HI 200 line and mainly in the III and IV fields of the diagrams.

The hydrogen index (HI), ranging from 11 to 147, and the oxygen index (OI), ranging from 0 to 109, when plotted on the HI versus OI diagram suggest that the rocks are mostly gas generative, typical of those with type III kerogen (Fig. 7). Interference by mineral matrix in these argillaceous clay-rich rocks is possibly responsible for such low HI and OI values (Peters, 1986; Langford and Blanc-Valleron, 1990). This may result from adsorption of the pyrolytic organic compounds onto the matrix of such minerals as illite, montmorillonite, and kaolinite. The type III kerogen is most prone to this problem (Peters, 1986). For this reason, the estimate of thermal maturity of the organic matter of these rocks using pyrolysis techniques alone can be misleading. Therefore, kerogen petrography was also performed in order to constrain the assessment of sourcing potential.

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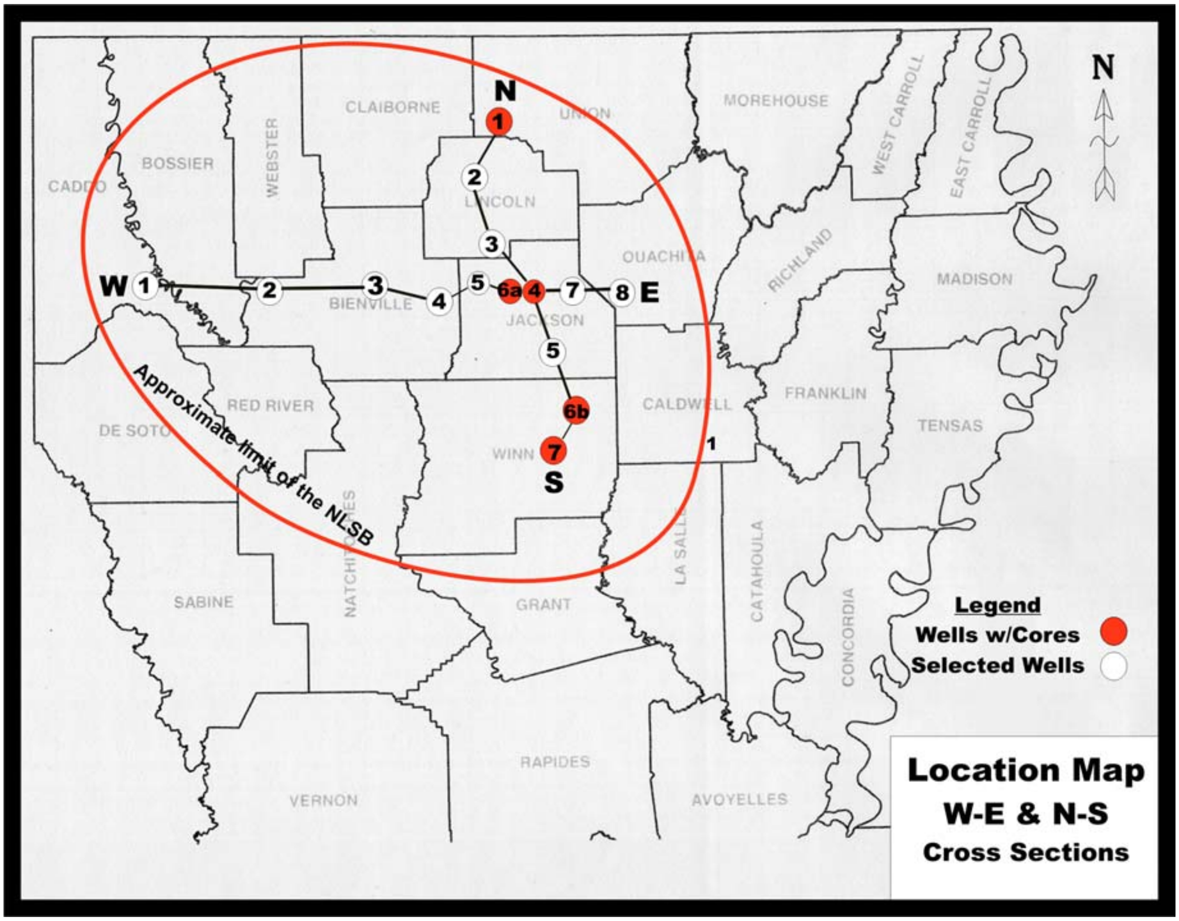

Figure 1. Regional map showing the north-south and west-east cross sections with cored (red) and selected wells (white) that penetrate the Cotton Valley – Bossier Group within the NLSB.

Four Bossier shale samples were analyzed from two wells in the Vernon Field, Jackson Parish (Fisher 16-1 and Davis Bros 29-2). The results obtained are similar to other Bossier samples analyzed in the NLSB and lie within the type III range on the TOC versus S_2 plot (Figs. 6A and 6B). On the HI versus OI diagram, they plot within the gas-prone area as well (Fig. 7).

In two other Vernon Field wells, shale layers within the Cotton Valley interval were also sampled (Stewart Harrison and Beasley 9-2). The TOC, S_1, S_2, and T_{max} values in the samples are considerably higher than those of the Bossier shales (Table 5). Such values indicate that their generative potential is very good (Peters, 1986; Jarvie, 1991). They plot with the Bossier and Haynesville samples on the HI versus OI diagram (Fig. 7) and with high TOC of 4.5 on the TOC versus S_2 diagram (Fig. 6A).

KEROGEN PETROGRAPHY

Vitrinite reflectance (R_o) has been used successfully by petroleum geochemists for several years as an indicator of organic maturation in sedimentary rocks (Senftle and Landis, 1991). In this study, this technique, in combination with Rock-Eval pyrolysis, allowed us to assess the quality and maturity of the kerogen present in the Cotton Valley – Bossier Group strata. When the results of the kerogen analyses are plotted on the $\%R_o$ versus

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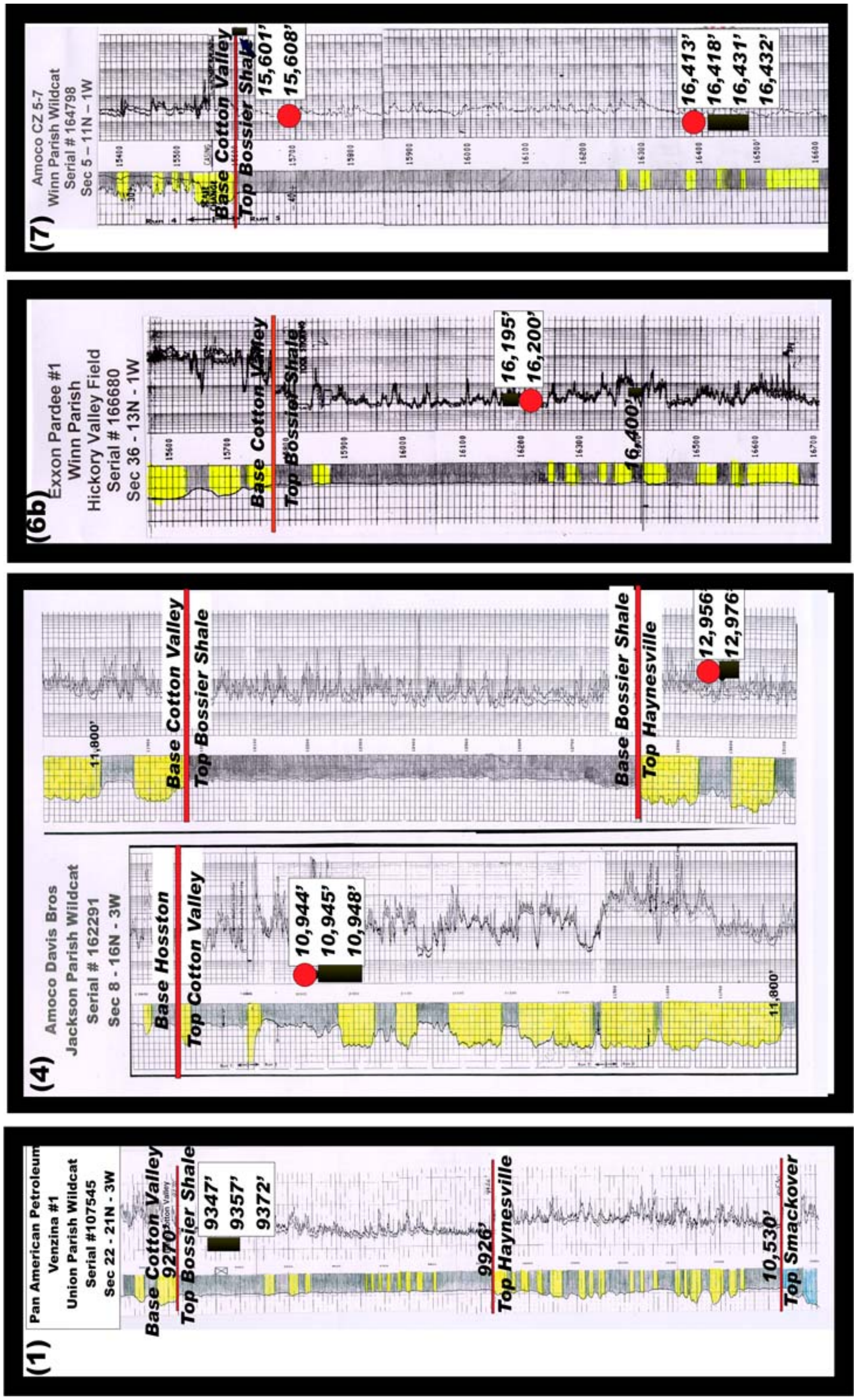

Figure 2. Electric logs from cored wells in the NLSB with major stratigraphic boundaries (Cotton Valley, Bossier, and Haynesville) and depths for samples analyzed and thin section micrographs (red circles).

Table 2. Cotton Valley – Bossier Group samples in Vernon Field selected for analyses.

Ser# / API#	Operator	Well	Field	Sec	TWP	RGE	Parish	Sample Depth (ft)
224274 1704920332	Anadarko	Fisher 16-1	Vernon	16	16N	02W	Jackson	13,175 13,770
226742 1704920390	Anadarko	Davis Bros. 29-2	Vernon	29	16N	02W	Jackson	14,035 15,120
231813 1704920649	Anadarko	Beasley 9-2	Vernon	9	16N	02W	Jackson	11,348
232316 1704920665	Anadarko	Stew.-Harr. 34-2	Vernon	34	16N	03W	Jackson	11,805

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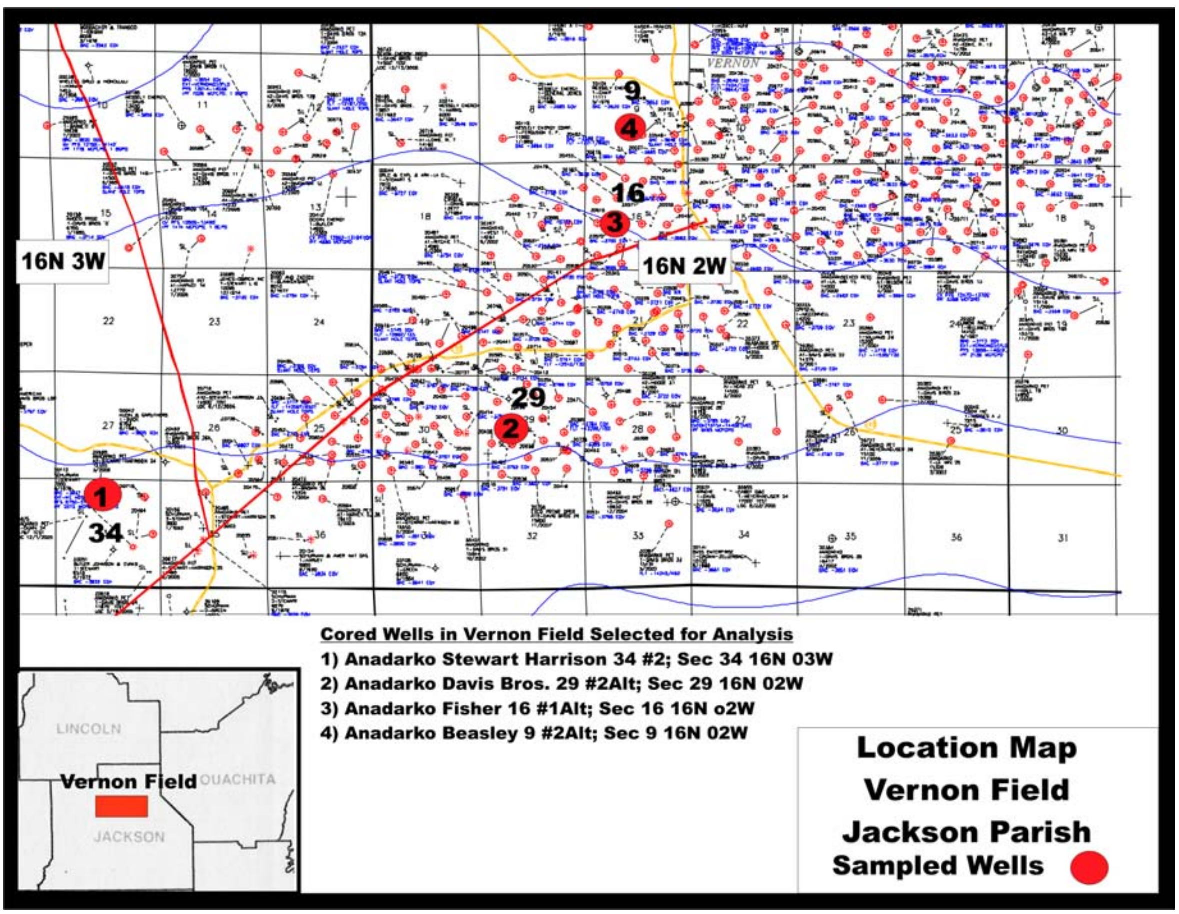

Figure 3. Map of Vernon Field, Jackson Parish, with sampled wells 1, 2, 3, and 4 highlighted in red.

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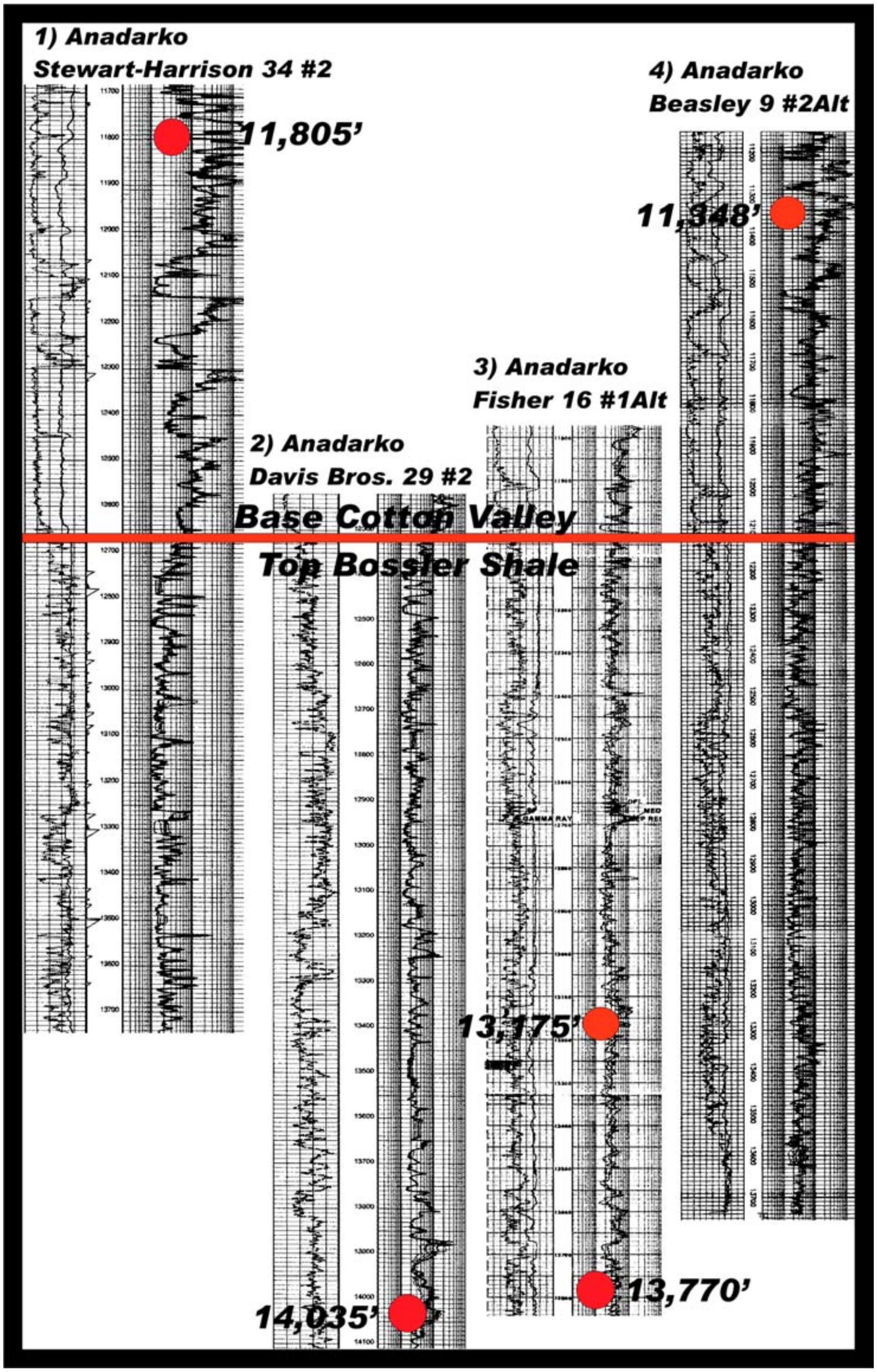

Figure 4. Electric logs for wells selected from Vernon Field, Jackson Parish, showing depths where samples chosen for analysis and thin section micrographs (red circles). The Anadarko Davis Bros. 29 #2Alt sample at 15,120 ft (4609 m) depth is not shown at the scale of the electric logs.

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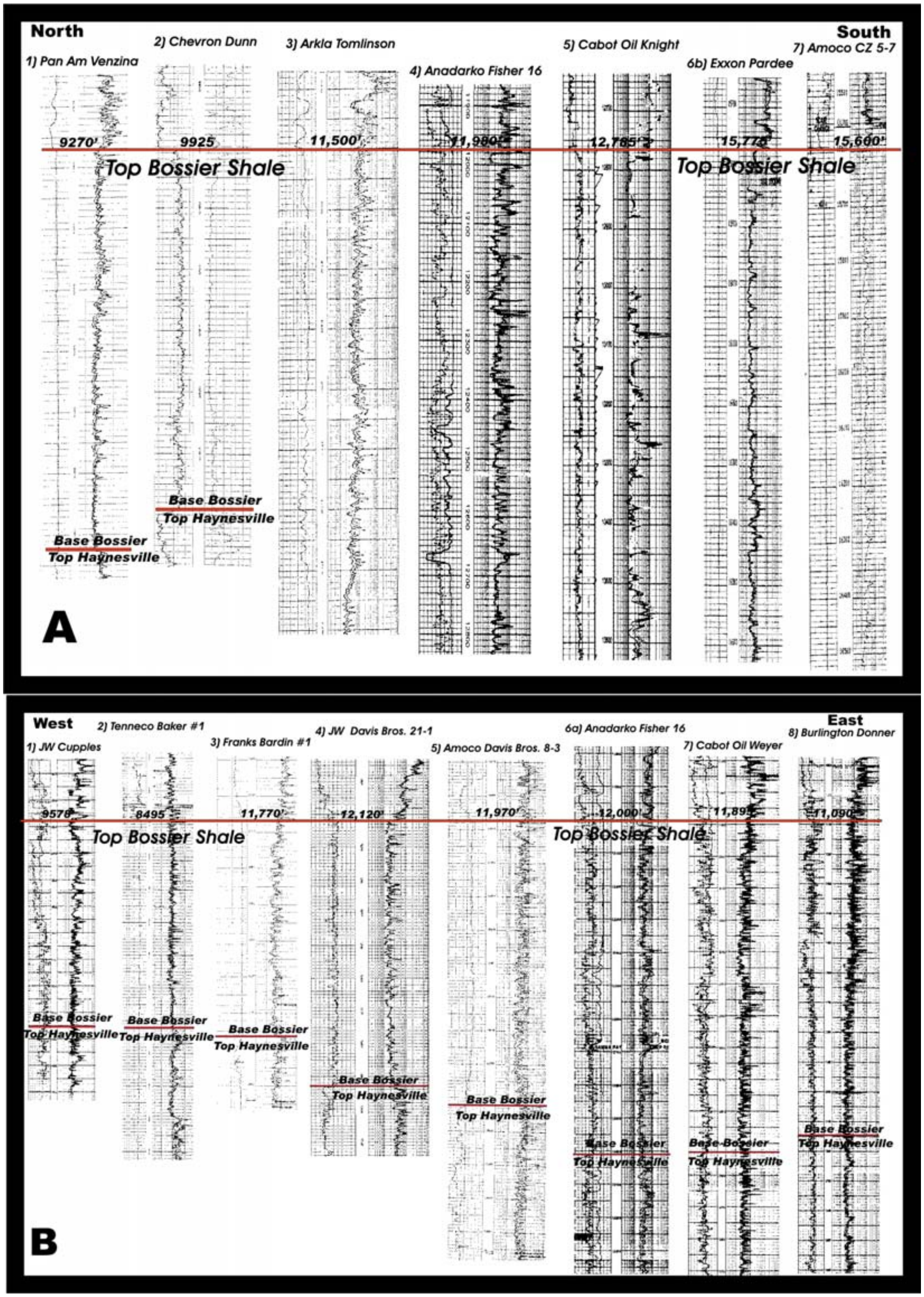

Figure 5. (A) North-south stratigraphic cross section showing the cored wells together with other wells that penetrate the Cotton Valley – Bossier Group, and (B) west-east stratigraphic cross section showing the cored wells together with other wells that penetrate the Cotton Valley – Bossier Group.

depth plot (Fig. 8) and correlated with other common organic maturation parameters (Senftle and Landis, 1991), the data fall primarily in the principal zone of gas formation. The principal macerals observed with the visual kerogen analysis (liptinite, vitrinite, and minor amounts of inertinite and humic debris) confirm the results of the plots. These all originate from land plants and tend to mature along the type III kerogen pathway, indicating that they are gas-prone (Peters and Cassa, 1994).

Results from the visual kerogen analyses are shown in Figures 9 and 10, with observed values for each of the following wells.

Well Amoco Davis (Figs. 9A and 9B): Organic matter (OM) in the shales consists of abundant amounts of partially oxidized amorphous material and associated with little humic debris. The rocks are petrographically similar in that they contain 80-90% structured lipids and only 5-10% vitrinite and inertinite. The %R_o is from 1.73-1.76% with TAI values of 3.5-3.7, indicating a good initial potential for gas generation. The sample generated gas.

Well Exxon Pardee (Fig. 9C): OM consists mainly of highly oxidized amorphous material. The shale contains 60% liptinite, 30% vitrinite, and 10% inertinite. Average %R_o is 2.06 and the very dark brown color of the spores and pollen suggests a TAI of 3.7-3.8. These kerogens could generate gas.

Well Amoco CZ 5-7 (Fig. 9D): OM consists of abundant partially oxidized amorphous material and is approximately 30% liptinite, 60% vitrinite, and 10% inertinite. Average %R_o is 2.62 and the very dark brown color suggests TAI values of 3.7-3.8. This is indicative of high gas-prone source rocks that generated gas.

Well Pan Am Venzina (Figs. 10A and 10B): OM in this sample consists of abundant partially oxidized amorphous material. Liptinite content is high (70-85%), with smaller amounts of vitrinite (10-20%) and inertinite (5-10%). The average %R_o for these shales is 0.94; the dark brown color of the spores suggests TAI values of 2.8-3.0. They can be considered mostly oil-prone source rocks and could source minor amounts of gas.

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THIN SECTION PETROGRAPHY

Five samples from three wells in the NLSB were selected for petrographic analysis. The samples were selected within fine-grained intervals of the Cotton Valley – Bossier Group where geochemical analyses were performed. Their mineralogical assemblages were described in detail. Thin section micrographs (Fig. 11) of these samples are shown at depth on the Figure 2 electric logs.

Table 3. Wells used to construct the north-south stratigraphic cross section.

Operator	Well	Field	Sec	TWP	RGE	Parish	Top Bossier (ft)	Base Bossier (ft)
1) Pan Am	Venzina	Bernice	22	21N	03W	Union	9270	9930
2) Chevron Oil	Eliza Lewis Dunn	Hico-Knowles	31	20N	03W	Lincoln	9925	10,495
3) Arkla Explo	Tomlinson 1	Clay	10	17N	03W	Lincoln	11,780	n/a
4) Anadarko	Fisher 16-2	Vernon	16	16N	02W	Jackson	11,980	13,000
5) Cabot Oil	Knight et al.	Clear Branch	01	14N	02W	Jackson	12,785	14,890
6b) Exxon	Pardee 1	East Sikes	36	13N	01W	Winn	15,775	17,310
7) Amoco Prod	CZ 5-7	Wildcat	05	11N	01W	Winn	15,600	n/a

Table 4. Wells used to construct the west-east stratigraphic cross section.

Operator	Well	Field	Sec	TWP	RGE	Parish	Top Bossier (ft)	Base Bossier (ft)
1) JW Operating	Cupples 18-12	Elm Grove	03	16N	13W	Caddo	9578	10,160
2) Tenneco Oil	Baker 1	Lake Bistineau	12	16N	10W	Bienville	8495	9120
3) Franks & Broy	Bardin 1	Bear Creek	08	16N	06W	Bienville	11,770	12,365
4) J-W Operating	Davis Bros. 21-1	Driscoll	21	16N	04W	Bienville	12,120	12,930
5) Amoco Prod.	Davis Bros. 8-31	Vernon	08	16N	03W	Jackson	12,005	12,725
6a) Anadarko Petr.	Fisher 16-1	Vernon	16	16N	02W	Jackson	12,000	13,013
7) Cabot Oil & Gas	Weyerh Co. 15-1	Vernon	15	16N	01W	Jackson	11,895	?
8) Burlington Res.	Donner 13-1	Cheniere Creek	13	16N	02E	Ouachita	11,000	?

North Louisiana Salt Basin Wells

(1) Amoco Davis Bros.

10,944 ft (3340 m) (Fig. 11A): Muddy fine-grained sandstone with clasts of modally 0.006 in (0.15 mm) angular quartz. Most of the rock is at least partially clast supported with interstitial yellow-brown mud (transmitted light) and calcite. The matrix consists of yellow-brown mud composed of clay and suspended clay-size particles of quartz. Accessory clasts (<1%) include fossil fragments, plagioclase feldspar, alkali feldspar, apatite, and zircon. Secondary minerals are calcite and pyrite.

12,956 ft (3950 m) (Fig. 11B): Mudstone that is uniformly matrix supported, consisting of clay, silt, and smaller size (0.0025 in [0.06 mm]) quartz and silt and smaller white mica; quartz and mica particles occupy about 10% volume. The majority of the rock is of clay, stained brown by organic material. Larger clasts of plant tissue occupy less than about 1% volume and are mostly replaced by pyrite (opaque), though some remain intact (translucent). The secondary component is pyrite.

(2) Amoco CZ 5-7

15,608 ft (4760 m) (Fig. 11C): Brown mudstone with about 1% fine quartz sand (about 0.004 in [0.1 mm] size). The mud fraction is a 50/50 mix of clay and silt-size quartz and accessory minerals. Variations in this proportion range from about 60% quartz silt to about 15% quartz silt and define millimeter-scale laminations. Accessory minerals are mostly white mica (0.5%) with only one grain of zircon in the entire thin section. Secondary phases are pyrite (5%) and carbonate that occurs in lesser amounts as porosity fill and isolated crystals in pores.

16,418 ft (5000 m) (Fig. 11D): Fine sandy mudstone with about 1% fine quartz sand in a brown mudstone matrix of about 40% silt-size quartz and 60% clay. The fine sand fraction tends to be concentrated in bands

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Table 5. Analytical results of total organic carbon, Rock-Eval pyrolysis, and vitrinite reflectance (R_o) of Cotton Valley, Bossier, and Haynesville cores in the NLSB.

Well	Sample	Sample Depth (ft)	TOC Wt.%	S1 mg/g	S2 mg/g	S3 mg/g	Tmax	HI	OI	S1/TOC	OI	TAI	%Ro
AMOCO DAVIS	Cotton V.	10,944	0.46	0.14	0.12	0.09	331	26	20	30	0.54		
AMOCO DAVIS	Cotton V.	10,945	0.25	0.04	0.04	0.12	442	17	46	17	0.49		
AMOCO DAVIS	Cotton V.	10,948	0.11	0.02	0.04	0.11	424	35	98	18	0.33		
AMOCO DAVIS	Haynesville	12,956	0.43	0.1	0.08	0.22	304	19	20	43	0.56	3.5-3.7	1.73
AMOCO DAVIS	Haynesville	12,976	0.61	0.11	0.07	0.02	313	11	3	18	0.61	3.5-3.7	1.77
AMOCO CZ 5-7	Bossier	15,601	0.27	0.04	0.06	0.13	375	21	50	15	0.42		
AMOCO CZ 5-7	Bossier	15,608	0.28	0.02	0.04	0	307	14	0	7	0.33		
AMOCO CZ 5-7	Bossier	16,413	0.23	0.04	0.05	0.14	379	22	58	18	0.45		
AMOCO CZ 5-7	Bossier	16,418	0.34	0.05	0.07	0.11	355	21	32	15	0.42		
AMOCO CZ 5-7	Bossier	16,431	0.34	0.06	0.1	0.37	329	29	109	18	0.38	3.7-3.8	2.62
AMOCO CZ 5-7	Bossier	16,432	0.28	0.05	0.09	0.15	375	31	55	18	0.37		
EXXON PARDEE	Bossier	16,195	0.19	0.18	0.27	0.12	370	147	62	96	0.39		
EXXON PARDEE	Bossier	16,200	0.35	0.21	0.29	0.29	322	83	83	60	0.42		
EXXON PARDEE	Bossier	16,400	0.35	0.19	0.16	0.16	328	46	46	54	0.54	3.7-3.8	2.06
VENZINA	Bossier	9347	0.50	0.06	0.26	0.44	442	52	88	12	0.19	2.8-3.0	0.91
VENZINA	Bossier	9357	0.45	0.19	0.43	0.22	451	94	48	41	0.30	2.8-3.0	0.96
VENZINA	Bossier	9372	0.39	0.10	0.24	0.32	449	62	83	26	0.29	2.8-3.0	0.96
STEWART-HARRISON	Cotton V.	11,805	2.80	0.26	0.52	0.19	491	19	7	9	0.33	3.0-3.2	1.07
FISHER 16-1	Bossier	13,175	0.51	0.17	0.09	0.57	406	18	112	33	0.65	3.3-3.5	1.72
FISHER 16-1	Bossier	13,770	0.56	0.16	0.16	0.13	436	29	23	29	0.50	3.3-3.5	1.89
DAVIS BROS. 29-2	Bossier	14,035	0.68	0.87	0.44	0.49	359	65	72	128	0.66	3.5-3.7	1.94
DAVIS BROS. 29-2	Bossier	15,120	0.75	0.53	0.32	0.50	360	42	66	70	0.62	3.7-3.9	2.28
BEASLEY 9-2	Cotton V.	11,348	4.46	1.31	2.20	0.47	464	49	11	29	0.37	3.3-3.5	1.43

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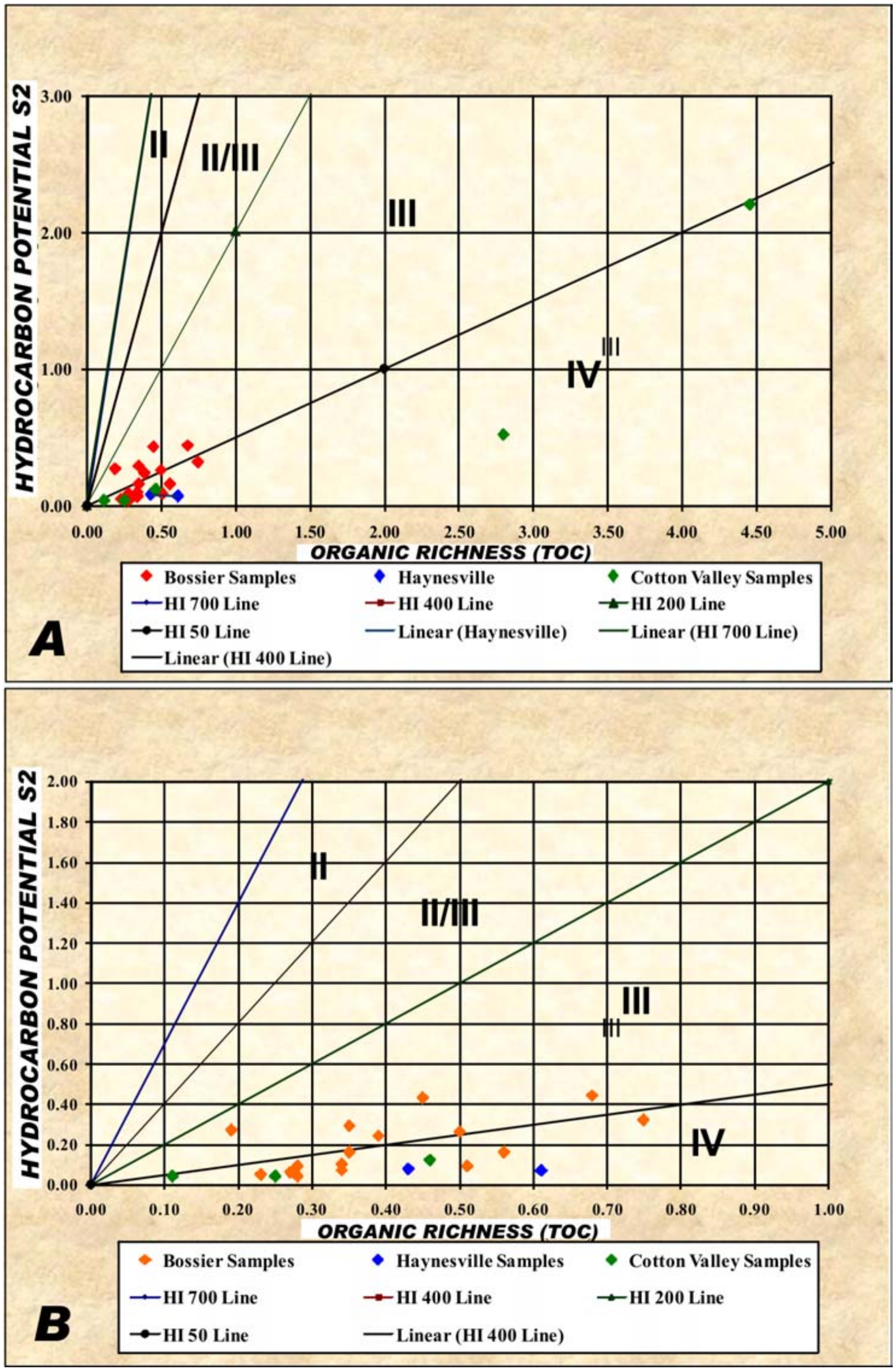

Figure 6. (A) Plot of TOC versus S_2 scaled from TOC 0.00 to 5.00 in order to show a Cotton Valley sample with a TOC of 4.5. (B) Expanded version of (A) with TOC from 0.00 to 1.00. The majority of the NLSB wells analyzed plot below the HI 200 line and lie in the III and IV fields, with TOCs ranging from 0.1 to 0.6 wt. %.

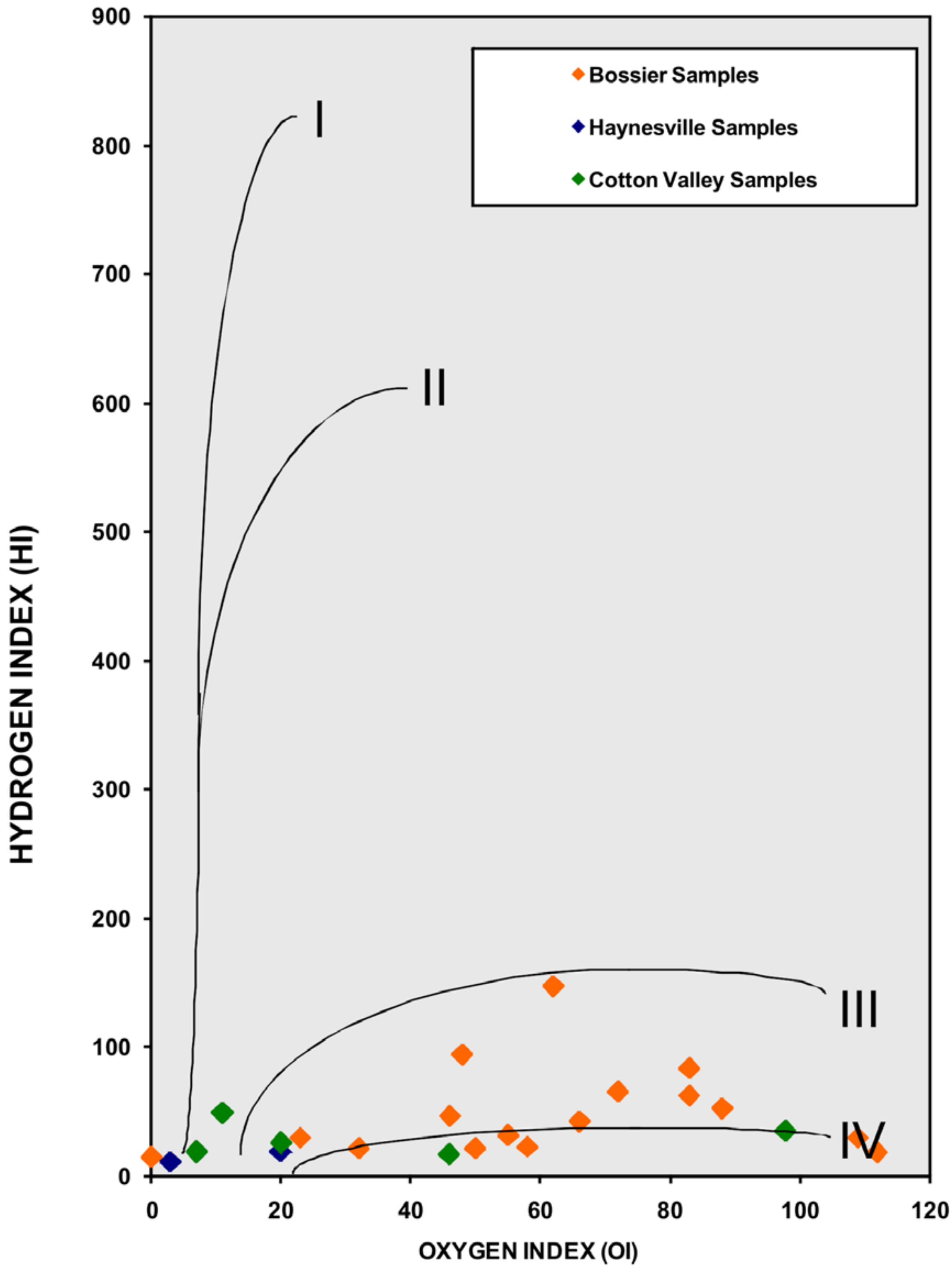

Figure 7. HI versus OI diagram. The majority of data plot between the III and IV field, indicating they are mostly gas generative rocks. Haynesville and some Cotton Valley samples tend to be more oil prone.

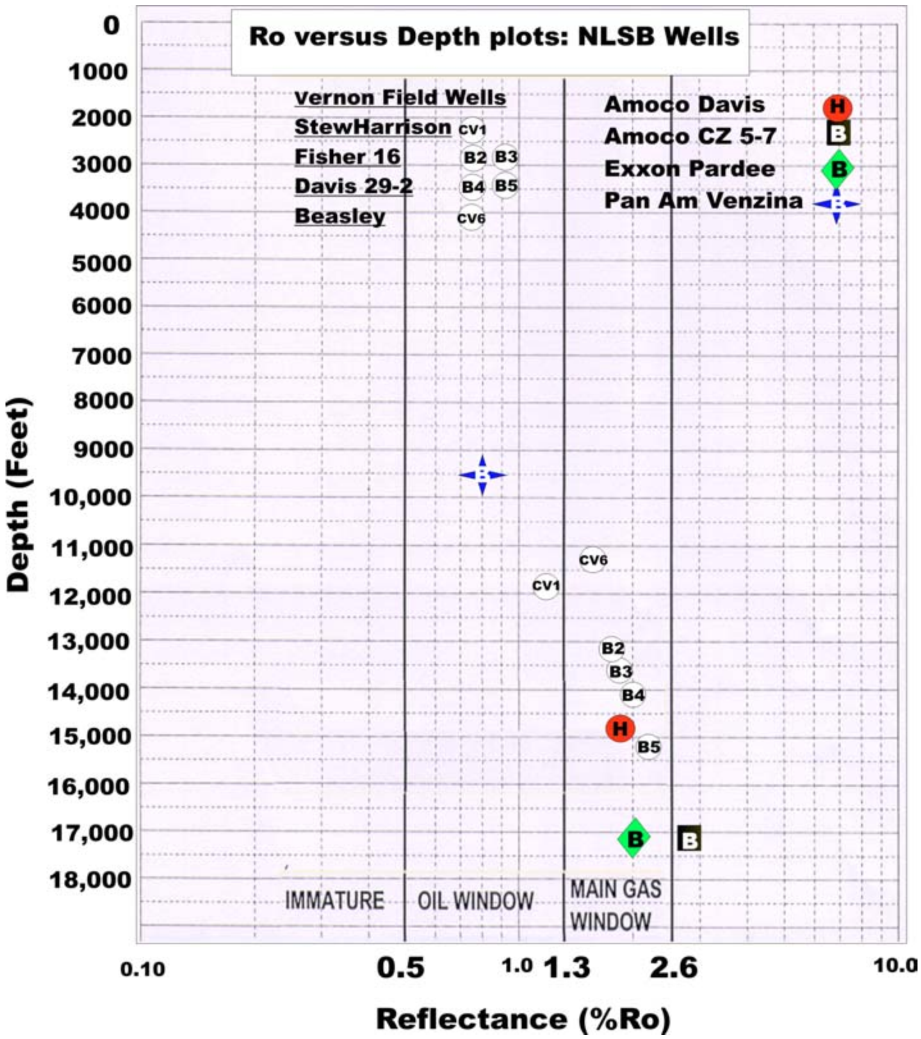

Figure 8. R_o versus depth plot. $\%R_o$ of the analyzed samples increases with depth, placing them within the main gas window. CV = Cotton Valley, B = Bossier, and H = Haynesville.

yielding a laminated structure, but fine sand grains occur throughout the mud-dominated areas. Accessory minerals are white mica (about 0.5%) and traces of amount zircon. Fossil fragments, including Textularid-type foraminifera, and plant fragments occur in trace amounts (<0.1%). Secondary phases are pyrite (3%) and carbonate that is mainly calcite occupying intergranular pore space.

(3) Exxon Pardee

16,200 ft (4940 m) (Fig. 11E): Laminated fine quartz sandstone, muddy fine sandstone, and fine sand mudstone. The sandstone portion is colorless, clast supported of modal 0.004 in (0.1 mm) quartz grains with interstitial calcite and minor clay-based mud. The mudstone portion hosting 0.004 in (0.1 mm) size quartz grains (3%) is brown color consisting of clay-rich mud with silt size quartz. Accessory clasts include trace colorless mica flakes and zircon grains. Large fossil fragments (3%-5%) tend to be clustered. Secondary components are calcite (10%-20%) and pyrite (5%).

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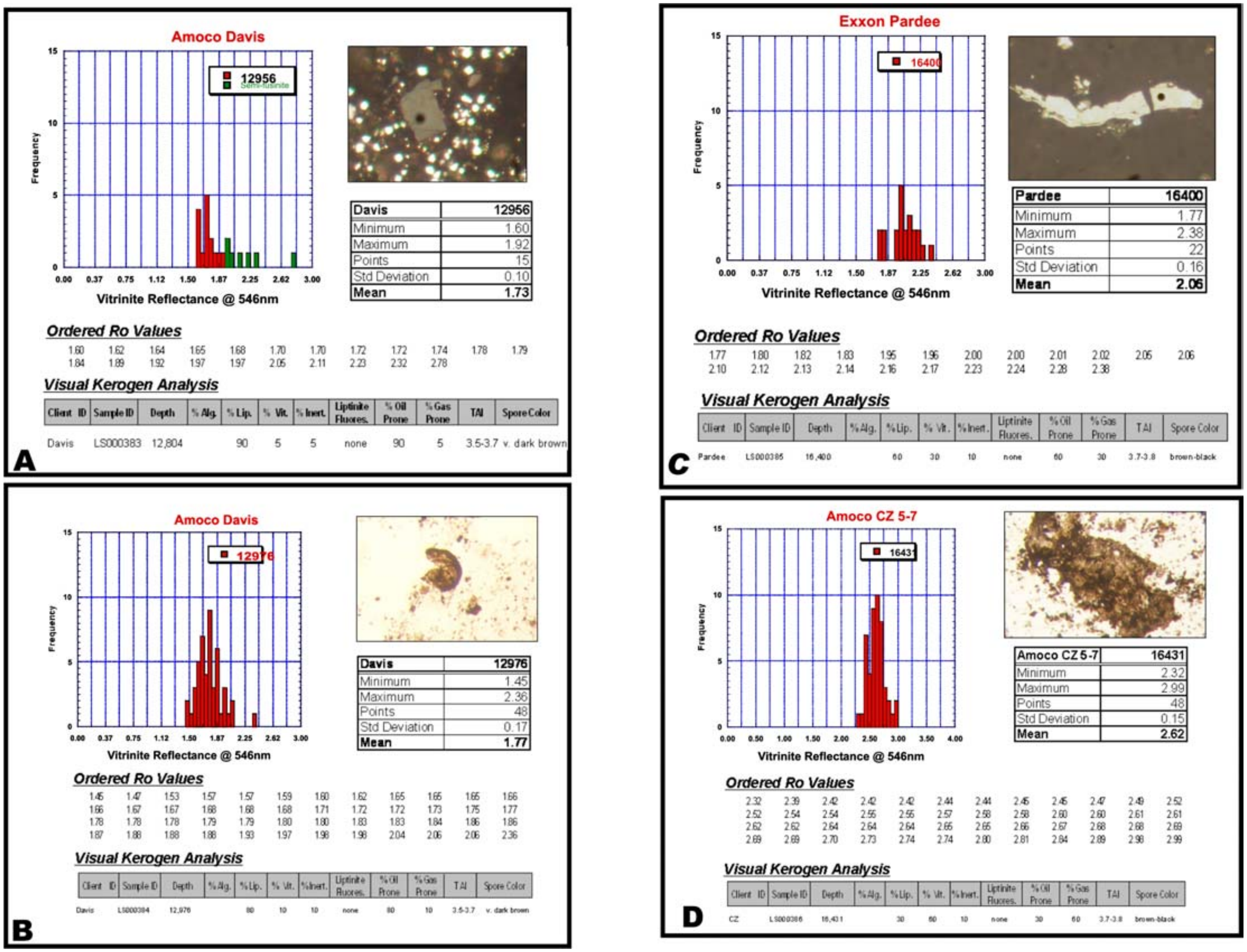
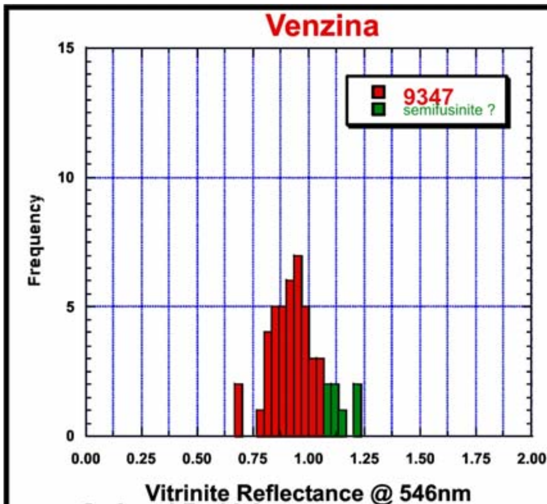
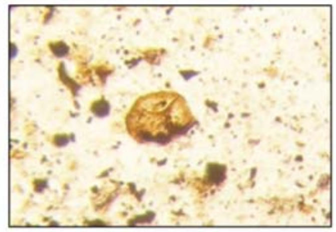


Figure 9. Visual kerogen analyses of samples from the Amoco Davis well sampled at depths of (A) 12,956 ft (3950 m) and (B) 12,976 ft (3955 m), from the (C) Exxon Pardee well sampled at a depth of 16,400 ft (4999 m), and from the (D) Amoco CZ 5-7 well at a depth of 16,431 ft (5008 m).





Venzina	9347
Minimum	0.70
Maximum	1.06
Points	41
Std Deviation	0.09
Mean	**0.91**

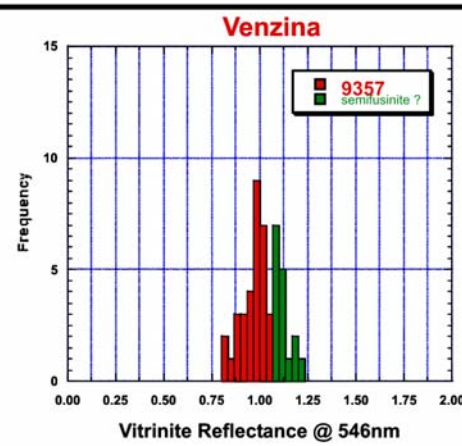
Ordered Ro Values

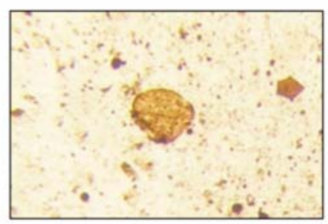
0.70	0.70	0.78	0.80	0.80	0.80	0.80	0.84	0.85	0.85	0.86	0.86
0.87	0.89	0.90	0.90	0.90	0.91	0.91	0.93	0.93	0.93	0.93	0.94
0.94	0.94	0.95	0.95	0.95	0.95	0.97	0.97	0.97	0.98	0.99	1.01
1.03	1.03	1.04	1.05	1.06	1.09	1.09	1.11	1.12	1.16	1.20	1.21

Visual Kerogen Analysis

Client ID	Sample ID	Depth	% Alg.	% Lip.	% Vit.	% Inert.	Liptinite Fluores.	% Oil Prone	% Gas Prone	TAI	Spore Color
Venzina	LS000380	9,347		80	10	10	yel-orange	80	10	2.8-3.0	dark brown

A





Venzina	9357
Minimum	0.81
Maximum	1.05
Points	32
Std Deviation	0.06
Mean	**0.96**

Ordered Ro Values

0.81	0.83	0.85	0.88	0.90	0.90	0.92	0.93	0.93	0.94	0.95	0.95
0.95	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	1.00	1.00
1.01	1.02	1.02	1.02	1.03	1.04	1.05	1.05	1.07	1.07	1.07	1.09
1.09	1.09	1.09	1.10	1.10	1.10	1.10	1.12	1.16	1.17	1.18	1.21

Visual Kerogen Analysis

Client ID	Sample ID	Depth	% Alg.	% Lip.	% Vit.	% Inert.	Liptinite Fluores.	% Oil Prone	% Gas Prone	TAI	Spore Color
Venzina	LS000381	9,357		70	20	10	yel-orange	70	20	2.8-3.0	dark brown

B

Figure 10. Visual kerogen analysis of two samples from the Pan Am Venzina well at depths of (A) 9347 ft (2849 m) and (B) 9372 ft (2857 m).

Vernon Field

Six samples from four wells in the Vernon Field, Jackson Parish, were selected for petrographic analysis. Locations of samples illustrated with photomicrographs (Fig. 12) are shown on the correlated electric logs (Fig. 4).

(1) Anadarko Davis 29-2

14,035 ft (4280 m) (Fig. 12A): Calcareous black shale, dark brown silt and very fine sand size quartz (10%-40%) supported by a matrix of dark brown clay dominated mud. Accessory clasts include trace amounts of colorless mica and very sparse amount of apatite crystals and fresh feldspar grains. Fossil shell fragments occupy about 2% by volume and include tests of bivalves and foraminifera. Secondary components are calcite as infill of pore spaces and as replacement of fossil tests and pyrite (8%).

15,120 ft (4610 m) (Fig. 12B): Fossiliferous black shale with a silt component consisting primarily of quartz smaller than 0.002 in (0.05 mm). Accessory clasts are mainly filaments of organic tissue (3%) and fossil shell fragments (3%). Fossils include bivalve shell fragments up to 0.40 in (1 cm) breadth. Secondary components are calcite and pyrite (15%). Calcite occurs as pore space fill and in replacement of fossil tests.

(2) Anadarko Fisher 16-1

13,175 ft (4020 m) (Fig. 12C): Brownish gray, calcareous muddy fine sandstone, colorless with streaks of brown tint. Primary component is very fine sand (0.004 in [0.1 mm]) and coarse silt size quartz cemented with calcite and calcite plus clay mix and clay. Trace amounts of fossil tests include uniserial foraminifera. Secondary components are calcite and pyrite (20%) as 0.0004 in (0.01 mm) framboids individually dispersed, clustered and in aggregates.

13,770 ft (4200 m) (Fig. 12D): Gray, very fine-grained quartz sandstone with clay, colorless and brown tint in thin section. Texture is grain supported, consisting of 0.004 in (0.1 mm) size quartz grains, with interstitial clay cement. Primary assemblage is quartz, with clay the most abundant accessory component, serving as a cementing agent through much of the rock, with trace amounts of fresh feldspar, apatite inclusions in some quartz grains, and colorless mica. Fossil tests are absent. Secondary components are pyrite (3%) individually disbursed as well as clustered and in aggregates as large as 0.004 in (0.1 mm) and trace amounts of calcite.

(3) Anadarko Stewart-Harrison 34-2

11,805 ft (3600 m) (Fig. 12E): Black shale with fine sand, dark brown, mostly fine mud with <1% silt size (0.002 in [0.05 mm]) quartz, and supported muddy fine sand consisting of approximately 0.008 in (0.2 mm) quartz with interstitial clay-rich mud. Filaments of organic tissue, partially pyritized, occupy approximately 10% of the volume. The secondary component is primarily pyrite in partial replacement of organic tissue fragments and as framboids of 0.0008 in (0.02 mm) individually dispersed and in aggregates.

(4) Anadarko Beasley 9-2

11,348 ft (3460 m) (Fig. 12F): Fossiliferous black shale, very dark brown (almost opaque) in thin section. Laminations are manifested by concentrations of silt size (0.002 in [0.05 mm]) quartz occupying 5% versus trace amounts by volume, correlative with alternating concentrations of fossil shell fragments. Fossil tests appear to be mainly fragments of bivalve shells nominally 0.02 in (5.0 mm) in breadth, with some as large as 0.04 in (1.0 cm), and occupy about 10% of the rock. Pyrite is the dominant secondary phase and occurs as 0.002 in (0.05 mm) framboids (5%) jacketed by about 0.0004 in (0.01 mm) rim of calcite. Calcite mainly occurs as replacement of fossil shell fragments and as fill in cleavage parallel fractures.

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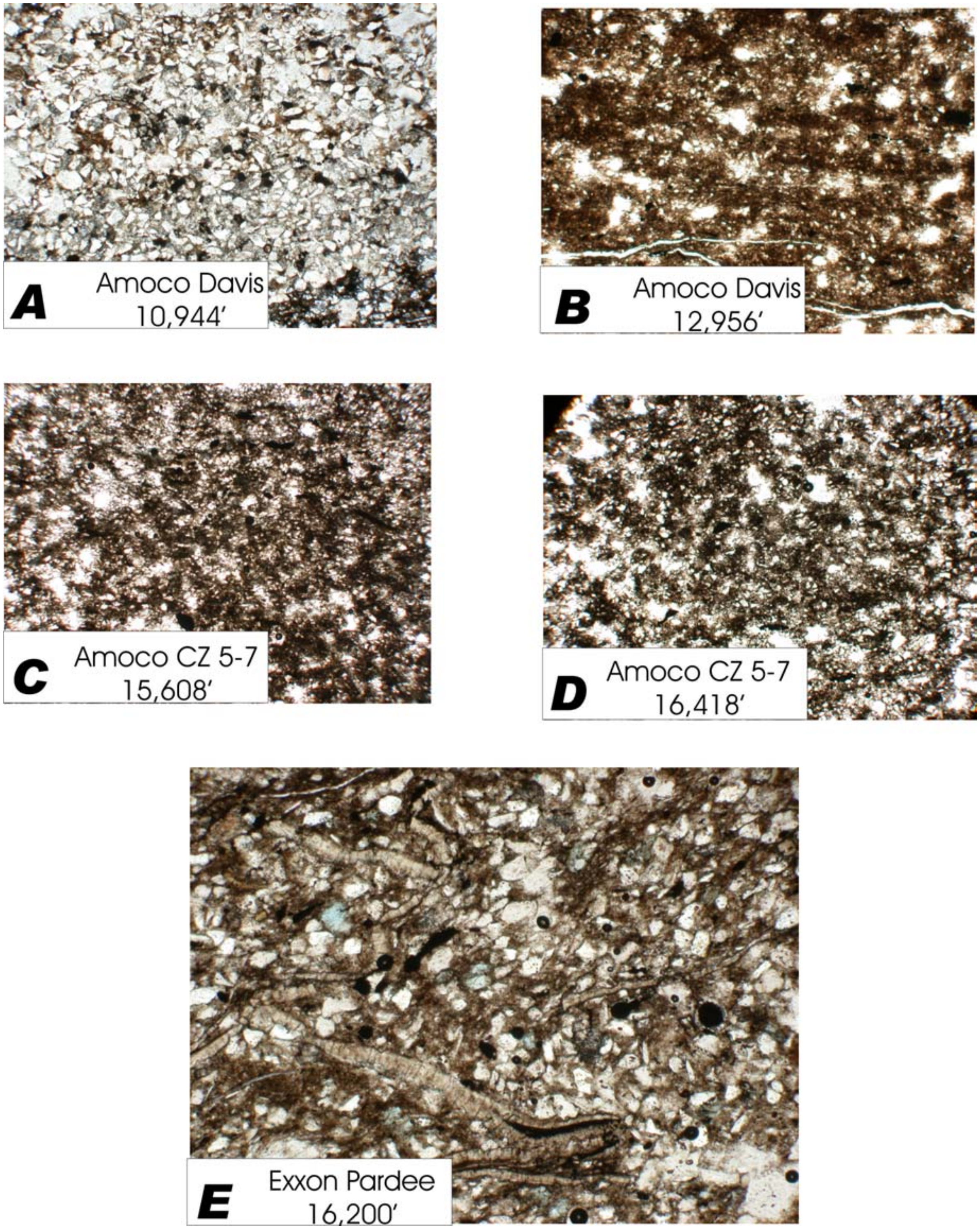

Figure 11. Selected thin section micrographs of samples analyzed in wells: (A-B) Amoco Davis Bros., (C-D) Amoco CZ 5-7, and (E) Exxon Pardee in the NLSB.

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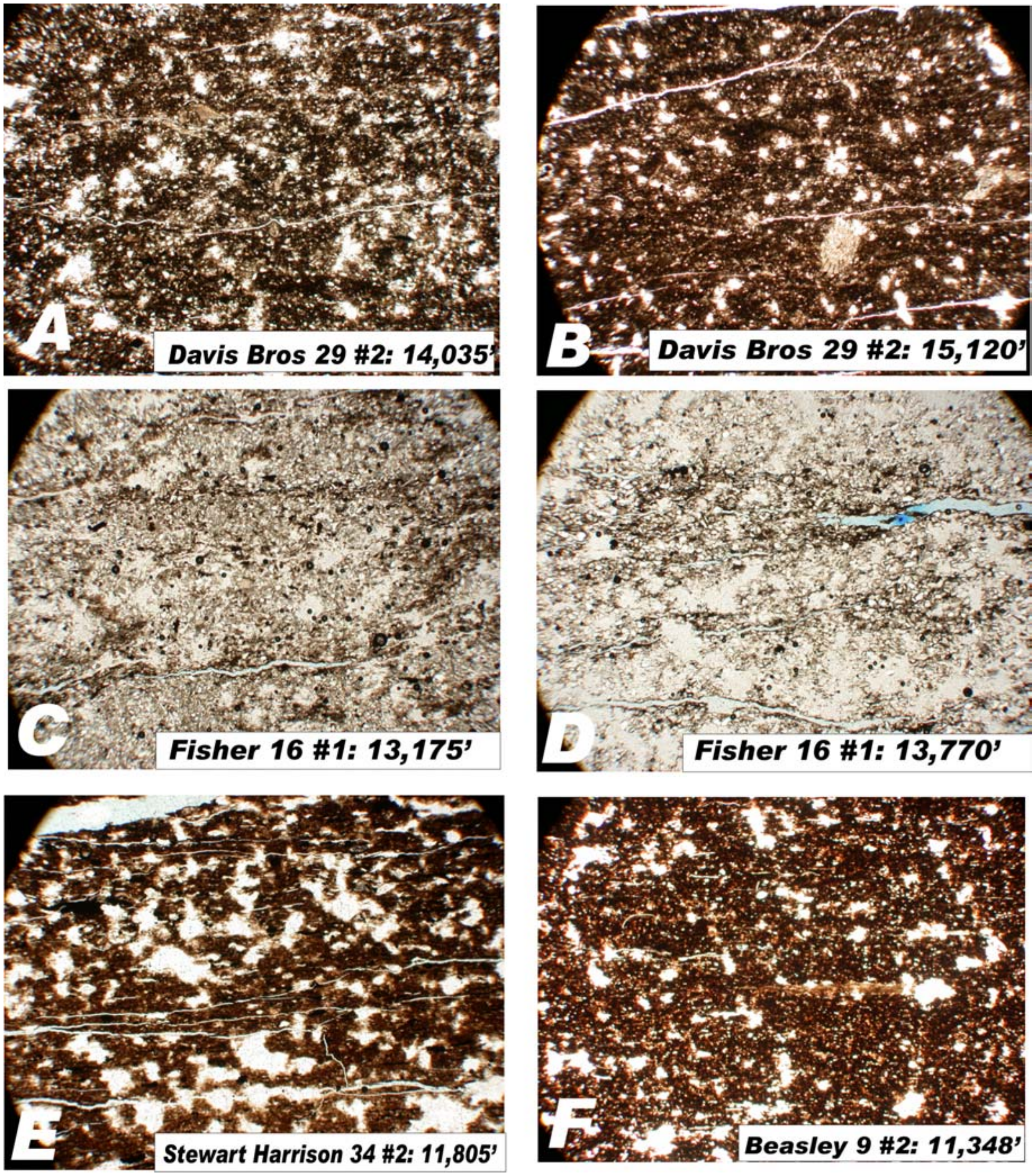

Figure 12. **Selected thin section micrographs of samples analyzed in wells: (A-B) Davis Bros. 29-2, (C-D) Fisher 16-1, (E) Stewart Harrison 34-2, and (F) Beasley 9-2, in Vernon Field, Jackson Parish.**

CONCLUSIONS

Regionally, within the North Louisiana Salt Basin and in the area of Vernon Field, Jackson Parish, core samples from the Cotton Valley – Bossier Group, permitted us to evaluate their thermal maturity and sourcing potential. Results of the Rock-Eval, and TOC analyses indicate that the samples contain gas-prone type III kerogen, and the visual kerogen analysis confirm that their organic matter commonly consists of finely dispersed, oxidized amorphous material and vitrinite in varying proportion. Vitrinite particles presented $\%R_o$ values that range from 0.91 to 2.62, indicating oil and gas generating maturity windows. The vitrinite particles (woody material of continental origin) made its way offshore and deposited within fine clastic sediments in a marine prodelta environment during Jurassic time. The rocks are capable of sourcing some oil and mostly gas to the Cotton Valley sandstone reservoirs as well as shallower Lower Cretaceous Hosston and Sligo reservoirs. Results of the TOC and pyrolysis analyses on shale samples taken in the Cotton Valley interval from wells in the Vernon Field, Jackson Parish, indicate that they also have good hydrocarbon generative potential.

Although the measurements of TOC data indicate that the quantity of organic matter in the Bossier strata are not abundant, their thickness and widespread deposition allows them to be good source rocks for the petroleum accumulations found in the overlying Jurassic and Cretaceous reservoirs. The Bossier shale interval can also be considered a potential shale gas reservoir as a result of this study.

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