Report Title

Resource Assessment of the In-Place and Potentially Recoverable Deep Natural Gas Resource of the Onshore Interior Salt Basins, North Central and Northeastern Gulf of Mexico

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Disclaimer

Abstract

The objectives of the study were: (1) to perform resource assessment of the thermogenic gas resources in deeply buried (>15,000 ft) natural gas reservoirs of the onshore interior salt basins of the north central and northeastern Gulf of Mexico areas through petroleum system identification, characterization and modeling; and (2) to use the petroleum system based resource assessment to estimate the volume of the deep thermogenic gas resource that is available for potential recovery and to identify those areas in the interior salt basins with high potential for this thermogenic gas resource.

Petroleum source rock analysis and petroleum system characterization and modeling, including thermal maturation and hydrocarbon expulsion modeling, have shown that the Upper Jurassic Smackover Formation served as the regional petroleum source rock in the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin. Thus, the estimates of the total hydrocarbons, oil, and gas generated and expelled are based on the assumption that the Smackover Formation is the main petroleum source rock in these basins and subbasins.

The estimate of the total hydrocarbons generated for the North Louisiana Salt Basin in this study using a petroleum system approach compares favorably with the total volume of hydrocarbons generated published by Zimmermann (1999). In this study, the estimate is 2,870 billion barrels of total hydrocarbons generated using the method of Schmoker (1994), and the estimate is 2,640 billion barrels of total hydrocarbons generated using the Platte River software application. The estimate of Zimmermann (1999) is 2,000 to 2,500 billion barrels of total hydrocarbons generated. The estimate of gas generated for this basin is 6,400 TCF using the Platte River software application, and 12,800 TCF using the method of Schmoker (1994). Barnaby (2006) estimated that the total gas volume generated for this basin ranges from 4,000 to 8,000 TCF. Seventy-five percent of the gas is estimated to be from late cracking of oil in the source rock. Lewan (2002) concluded that much of the

thermogenic gas produced in this basin is the result of cracking of oil to gas in deeply buried reservoirs. The efficiency of expulsion, migration and trapping has been estimated to range from 0.5 to 10 percent for certain basins (Schmoker, 1994: Zimmerman, 1999).

The estimate of the total hydrocarbons generated for the Mississippi Interior Salt Basin is 910 billion barrels using the method of Schmoker (1994), and the estimate of the total hydrocarbons generated is 1,540 billion barrels using the Platte River software application. The estimate of gas generated for this basin is 3,130 TCF using the Platte River software application, and 4,050 TCF using the method of Schmoker (1994). Seventy-five percent of the gas is estimated to be from late cracking of oil in the source rock. Claypool and Mancini (1989) report that the conversion of oil to gas in reservoirs is a significant source of thermogenic gas in this basin.

The Manila and Conecuh Subbasins are oil-prone. Although these subbasins are thermally mature for oil generation and expulsion, they are not thermally mature for secondary, non-associated gas generation and expulsion. The gas produced from the highly productive gas condensate fields (Big Escambia Creek and Flomaton fields) in these subbasins has been interpreted to be, in part, a product of the cracking of oil to gas and thermochemical reduction of evaporite sulfate in the reservoirs (Claypool and Mancini, 1989).

The areas in the North Louisiana and Mississippi Interior Salt Basins with high potential for deeply buried gas reservoirs (>15,000 ft) have been identified. In the North Louisiana Salt Basin, these potential reservoirs include Upper Jurassic and Lower Cretaceous facies, especially the Smackover, Cotton Valley, Hosston, and Sligo units. The estimate of the secondary, non-associated gas generated from cracking of oil in the source rock from depths below 12,000 feet in this basin is 4,800 TCF. Assuming an expulsion, migration and trapping efficiency of 1 to 5%, 48 to 240 TCF of gas is potentially available. The final recoverable gas is some percent of this estimated thermogenic gas resource based on the recovery factor for the specific reservoir. To date, some 29 TCF of gas have been produced from this basin. Also, the thermogenic gas, whether generated from late secondary cracking of oil to gas in the source rock or from oil to gas conversion in deeply buried reservoirs, migrated updip into shallower reservoirs, including the Monroe gas rock at depths of some 2,000 feet.

In the Mississippi Interior Salt Basin, the potential area for deeply buried gas reservoirs includes Upper Jurassic and Lower Cretaceous facies, especially the Norphlet, Smackover, Haynesville, Cotton Valley, Hosston, and Sligo units. The estimate of the secondary, non-associated gas generated from cracking of oil in the source rock from depths below 16,500 feet in this basin is 2,350 TCF. Assuming an efficiency of 1 to 5%, 23.5 to 117.5 TCF of gas is potentially available. The final recoverable gas is some percent of this estimated thermogenic gas resource based on the recovery factor for the specific reservoir. To date, some 13 TCF of gas have been produced from this basin. Also, this thermogenic gas, whether generated from late secondary cracking of oil to gas in the source rock or from oil to gas conversion in deeply buried reservoirs, which migrated updip into shallower reservoirs, including the Jackson gas rock at depths of some 2,000 feet.

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Introduction

The University of Alabama and Louisiana State University undertook a cooperative 3-year, advanced subsurface methodology resource assessment project, involving petroleum system identification, characterization and modeling, to facilitate exploration for a potential major source of natural gas that is in deeply buried (below 15,000 ft) reservoirs in the onshore interior salt basins of the north central and northeastern Gulf of Mexico areas. The project was designed to assist in the formulation of exploration strategies for identifying deeply buried natural gas reservoirs in domestic basins.

Executive Summary

The objectives of the study were: (1) to perform resource assessment of the thermogenic gas resources in deeply buried (>15,000 ft) natural gas reservoirs of the onshore interior salt basins of the north central and northeastern Gulf of Mexico areas through petroleum system identification, characterization and modeling; and (2) to use the petroleum system based resource assessment to estimate the volume of the deep thermogenic gas resource that is available for potential recovery and to identify those areas in the interior salt basins with high potential for this thermogenic gas resource.

Petroleum source rock analysis and petroleum system characterization and modeling, including thermal maturation and hydrocarbon expulsion modeling have shown that the Upper Jurassic Smackover Formation served as the regional petroleum source rock in the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin. Previous studies have indicated that Upper Cretaceous Tuscaloosa shale was

an effective local petroleum source rock in the Mississippi Interior Salt Basin and a possible local source bed in the North Louisiana Salt Basin given the proper organic facies; that Lower Cretaceous lime mudstone was an effective local petroleum source rock in the South Florida Basin and a possible local source bed in the North Louisiana Salt Basin and Mississippi Interior Salt Basin given the proper organic facies; that uppermost Jurassic strata were effective petroleum source rocks in Mexico and were possible local source beds in the North Louisiana and East Texas Salt Basins given the proper organic facies; and that Lower Tertiary shale and lignite were petroleum source rocks in south Louisiana and southwestern Mississippi. In this study, Lower Tertiary beds were found not to have been subjected to favorable burial and thermal maturation histories required for petroleum generation in the North Louisiana, Mississippi Interior Salt Basins, and Manila and Conecuh Subbasins. The burial and thermal maturation histories for Upper Cretaceous Tuscaloosa beds were found to be favorable for oil generation locally in the Mississippi Interior Salt Basin. Organic-rich facies in Lower Cretaceous strata were not identified in this study. The Upper Jurassic Bossier beds have possible potential as a local source rock in the North Louisiana Salt Basin. The estimates of the total hydrocarbons, oil, and gas generated and expelled are, therefore, based on the assumption that the Smackover Formation is the main petroleum source rock in these basins and subbasins.

The estimate of the total hydrocarbons generated for the North Louisiana Salt Basin in this study using a petroleum system approach compares favorably with the total volume of hydrocarbons generated published by Zimmermann (1999). In this study, the estimate is 2,870 billion barrels of total hydrocarbons generated using the method of Schmoker (1994), and the estimate is 2,640 billion barrels of total hydrocarbons generated using the Platte River software application. The estimate of Zimmermann (1999) is 2,000 to 2,500 billion barrels of total hydrocarbons generated. The estimate of gas generated for this basin is 6,400 TCF using the Platte River software application, and 12,800 TCF using the method of

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The Manila and Conecuh Subbasins are oil-prone. Although these subbasins are thermally mature for oil generation and expulsion, they are not thermally mature for secondary, non-associated gas generation and expulsion. The gas produced from the highly productive gas condensate fields (Big Escambia Creek and Flomaton fields) in these subbasins has been interpreted to be, in part, a product of the cracking of oil to gas and thermochemical reduction of evaporite sulfate in the reservoirs.

Petroleum reservoir rocks in the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin include Jurassic, Cretaceous and Tertiary siliciclastic and carbonate strata. These reservoir rocks include Upper Jurassic Norphlet, Smackover, Haynesville, and Cotton Valley units; Lower Cretaceous Hosston, Sligo, Pine Island, James, Rodessa, Ferry Lake, Mooringsport, Paluxy, Fredericksburg-Washita and Dantzler units; the Upper Cretaceous Tuscaloosa/Eagle Ford, Eutaw-Austin, Selma-

Taylor/Navarro, and Jackson gas rock-Monroe gas rock units; and the Lower Tertiary Wilcox unit.

Petroleum seal rocks in these basins and subbasins include Upper Jurassic Smackover lime mudstone, Buckner anhydrite, Haynesville shale, and Cotton Valley shale; Lower Cretaceous Pine Island shale, Ferry Lake anhydrite, Mooringsport shale, and Fredericksburg-Washita shale; Upper Cretaceous Tuscaloosa shale, Eagle Ford shale, and Selma chalk; and Lower Tertiary Midway shale.

Petroleum traps include structural and combination traps in these basins and subbasins. Salt movement is the principal process that formed these traps, producing a complex array of salt structures. These structures include peripheral salt ridges, low relief salt pillows, salt anticlines and turtle structures, and piercement domes. Structures associated with basement paleotopographic highs are also present.

The areas in the North Louisiana and Mississippi Interior Salt Basins with high potential for deeply buried gas reservoirs (>15,000 ft) have been identified. In the North Louisiana Salt Basin, these potential reservoirs include Upper Jurassic and Lower Cretaceous facies, especially the Smackover, Cotton Valley, Hosston, and Sligo units. The estimate of the secondary, non-associated gas generated from cracking of oil in the source rock from depths below 12,000 feet in this basin is 4,800 TCF. Assuming an expulsion, migration and trapping efficiency of 1 to 5%, 48 to 240 TCF of gas is potentially available. The final recoverable gas is some percent of this estimated thermogenic gas resource, based on the recovery factor for the specific reservoir. To date, some 29 TCF of gas have been produced from this basin. Also, the thermogenic gas, whether generated from late secondary cracking of oil to gas in the source rock or from oil to gas conversion in deeply buried reservoirs, migrated updip into shallower reservoirs, including the Monroe gas rock at depths of some 2,000 feet.

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Project Objectives

The objectives of this study were: (1) to perform resource assessment of the thermogenic gas resource in deeply buried (>15,000 ft) natural gas reservoirs of the onshore interior salt basins of the north central and northeastern Gulf of Mexico areas through petroleum system identification, characterization and modeling; and (2) to use the petroleum system based resource assessment to estimate the volume of the deep thermogenic gas resource that is available for potential recovery and to identify those areas in the interior salt basins with high potential for this deep thermogenic gas resource.

The project objectives were achieved through a 3-year effort. First, emphasis was on petroleum system identification and characterization in the North Louisiana Salt Basin, the Mississippi Interior Salt Basin, the Manila Subbasin and the Conecuh Subbasin of Louisiana, Mississippi, Alabama and Florida panhandle. This task included identification of the petroleum systems in these basins and the characterization of the underburden, overburden, source, reservoir and seal rocks of the petroleum systems and of the associated petroleum traps. Second, emphasis was on petroleum system modeling. This task included the assessment of the timing of thermogenic gas generation, expulsion, migration, entrapment and alteration (thermal cracking of oil to gas). Third, emphasis was on resource assessment. This task included the estimation of the hydrocarbon resource generated, the assessment of the generated hydrocarbon resource that was classified as thermogenic gas, the estimation of thermogenic gas that was expelled, and potentially migrated and entrapped, and the assessment of the potential volume of gas in deeply buried (>15,000 ft) reservoirs resulting from the process of thermal cracking of liquid hydrocarbons and its transformation to gas in the reservoir. Fourth, emphasis was on identifying those areas in the onshore interior salt basins with high potential for deeply buried gas reservoirs.

Experimental

Data Compilation—The existing information on the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin (Figure 1) were evaluated and an electronic database was compiled for the basins and subbasins. Eleven (11) cross sections consisting of 140 wells for the North Louisiana Salt Basin were selected and constructed (Figures 2-13). The locations for the cross sections and wells used correspond to those published by Eversull (1984). The log curves for the wells used in the cross sections were digitized. This work was performed in conjunction with our companion DOE study of the North Louisiana Salt Basin (2006). Five (5) cross sections consisting of 48 wells for the Mississippi Interior Salt Basin were prepared (Figures 14-19). The log curves for the wells used in the cross sections were digitized. This work was an update of our previous study of the Mississippi Interior Salt Basin (1999, 2000, 2001). Five (5) cross sections consisting of 18 wells for the Manila and Conecuh Subbasins were prepared for this study (Figures 20-25). The log curves for the wells used in the cross sections were digitized. Subsurface structure and isopach maps were prepared using the digitized database for the North Louisiana Salt Basin, the Mississippi Interior Salt Basin, the Manila Subbasin, and the Conecuh Subbasin (Figures 26-37). Burial history, thermal maturation history, and hydrocarbon expulsion profiles were constructed for key wells in each of these basins.

Source rock geochemical data for the Mississippi Interior Salt Basin (Table 1) and Manila and Conecuh Subbasins (Table 2) were reviewed and compiled. Source rock geochemical data for the North Louisiana Salt Basin were reviewed, and additional samples were analyzed by GeoChem Laboratories and Baseline Resolution (Table 3) for source rock characterization and analysis. Selected samples were analyzed for stable isotopes (carbon, oxygen) by Paul Aharon and his students for this study (Table 4).

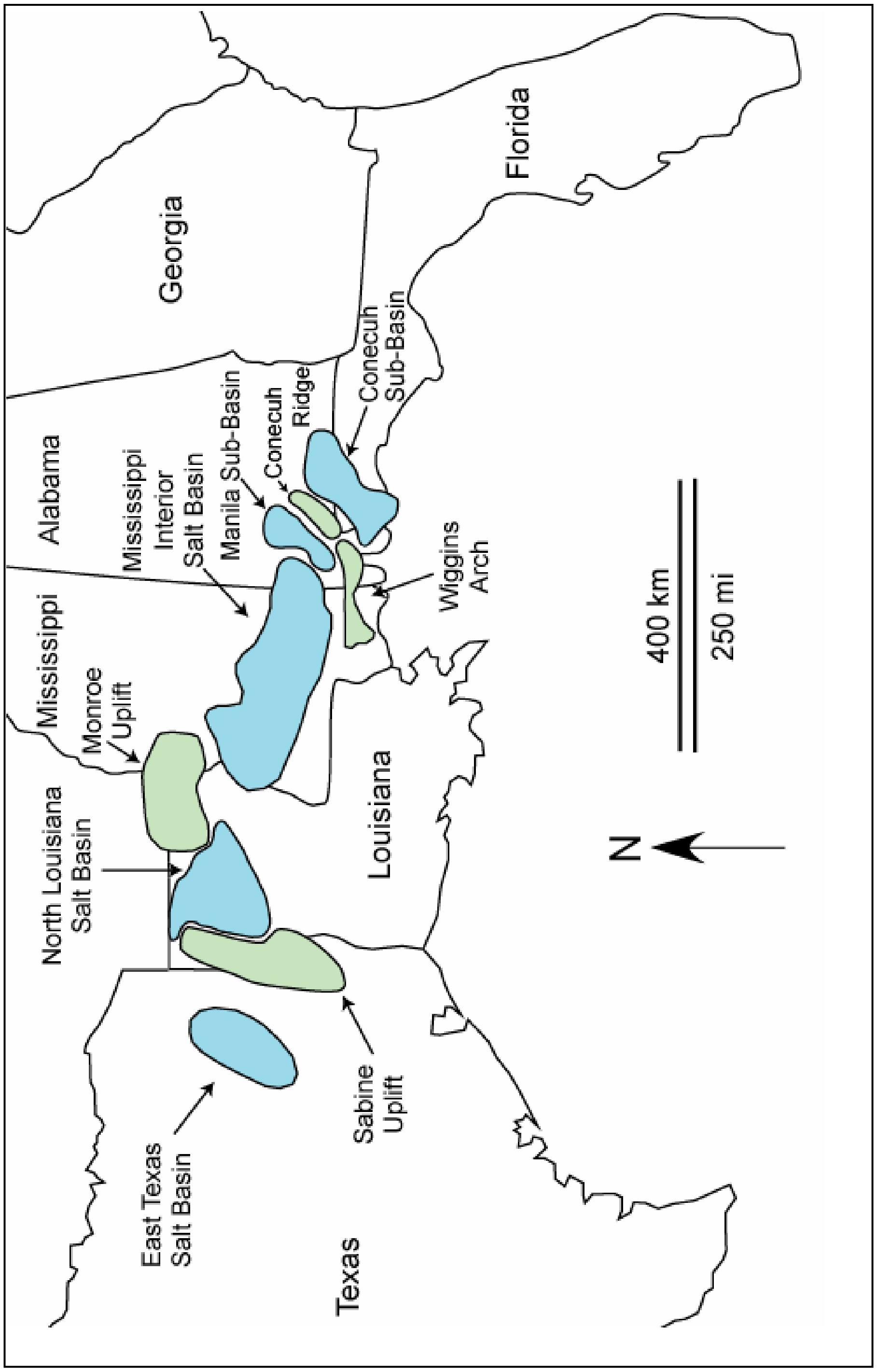


Figure 1. Location map of interior salt basins and subbasins in the north central and northeastern Gulf of Mexico area (modified from Mancini et al., 2006).

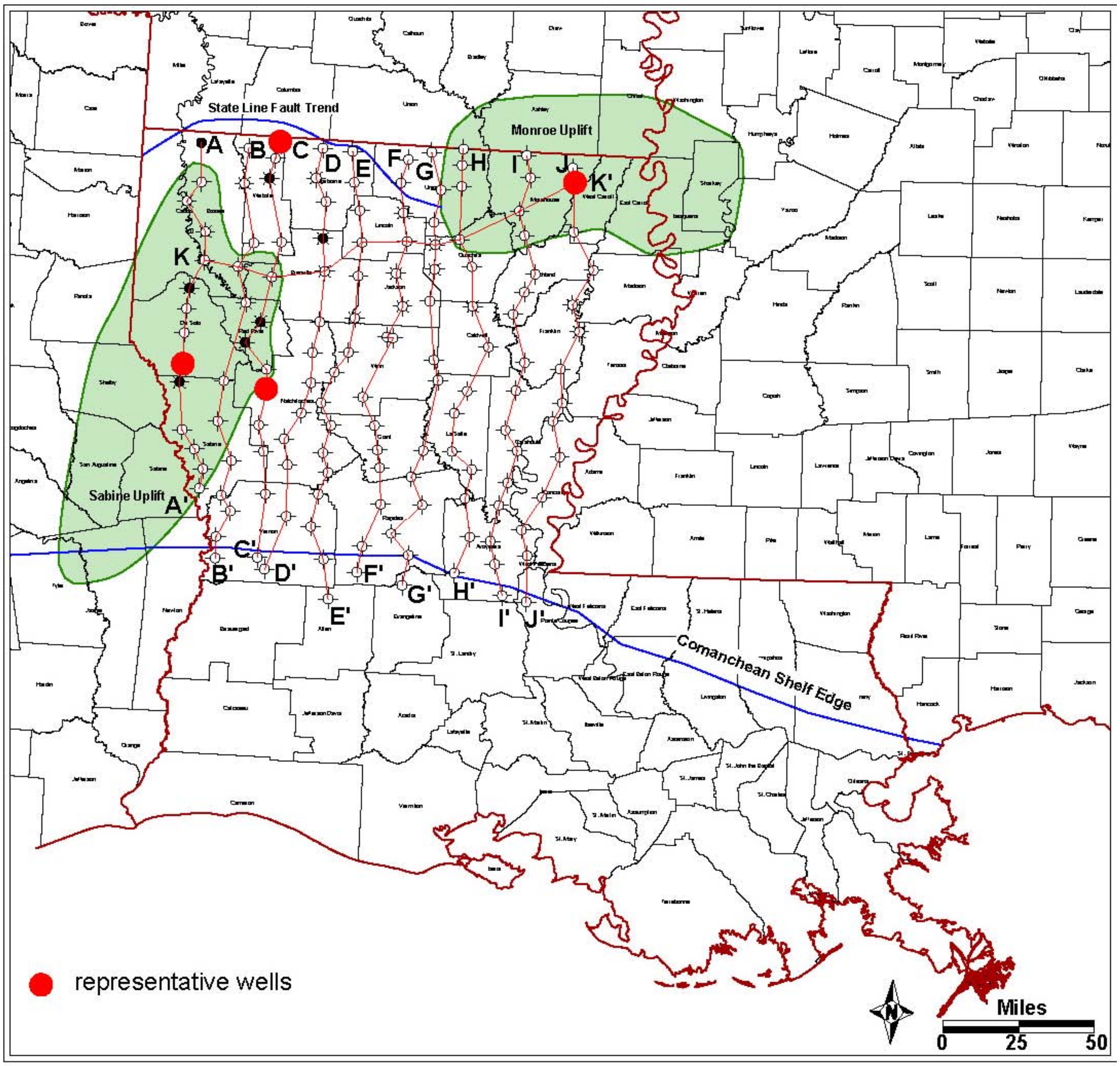


Figure 2. Index map showing locations of cross sections and wells for the North Louisiana Salt Basin (after Eversull, 1984).

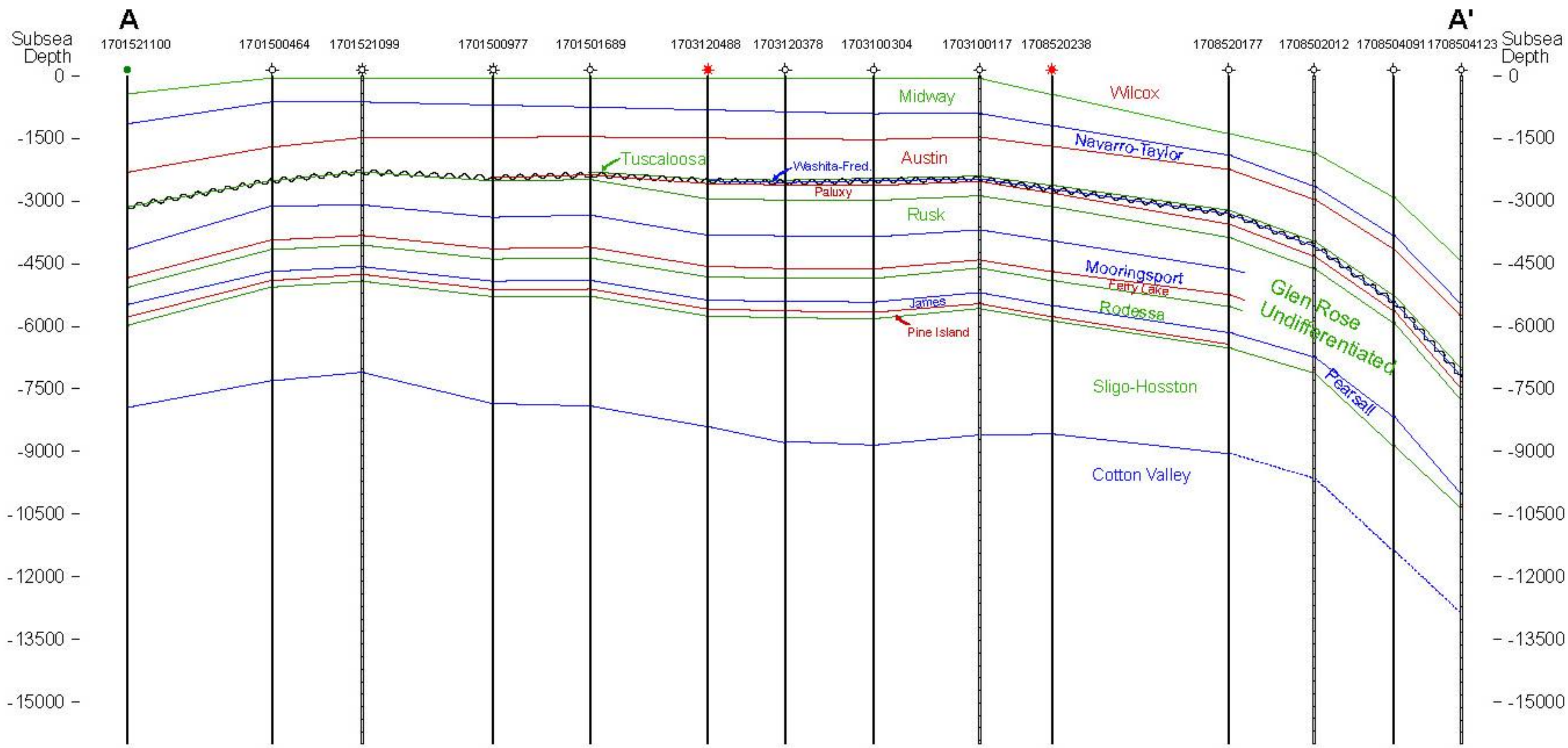


Figure 3. Cross section A-A' for the North Louisiana Salt Basin, modified from Mancini et al. (2006). See Figure 2 for location of cross section.

VE: 22X

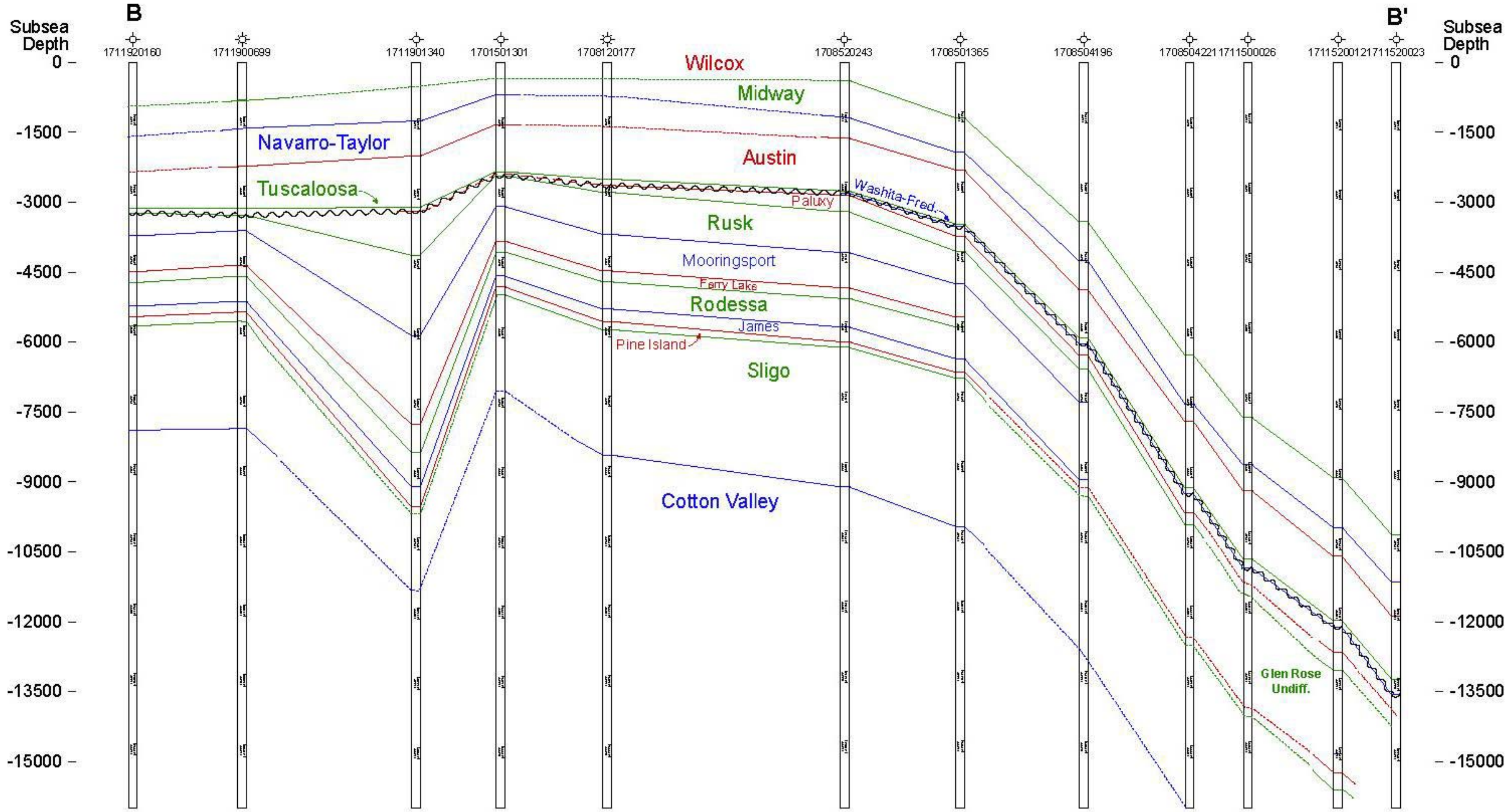


Figure 4. Cross section B-B' for the North Louisiana Salt Basin, modified from Mancini et al. (2006). See Figure 2 for location of cross section.

VE: 30X

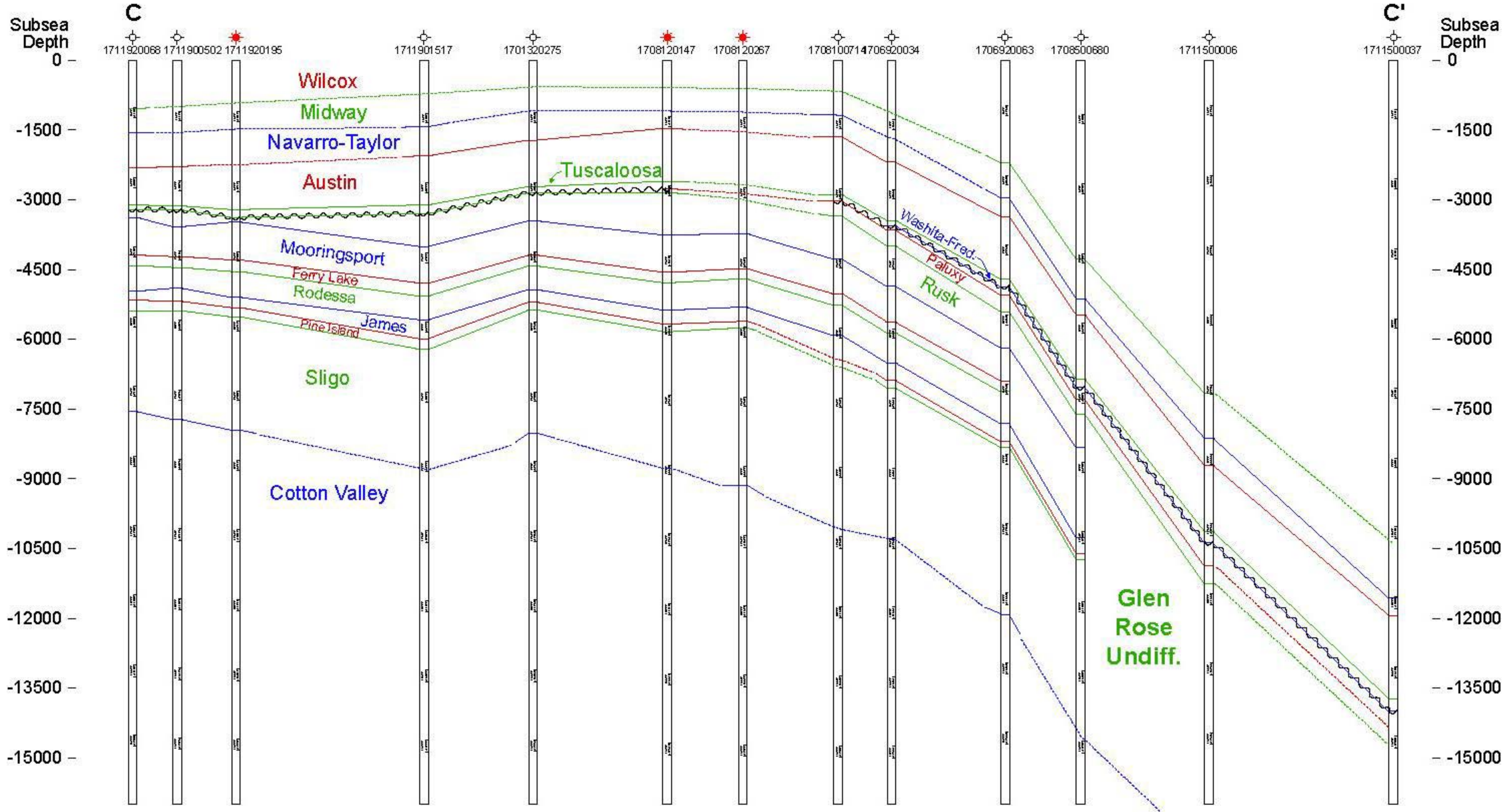


Figure 5. Cross section C-C' for the North Louisiana Salt Basin, modified from Mancini et al. (2006). See Figure 2 for location of cross section.

VE: 29X

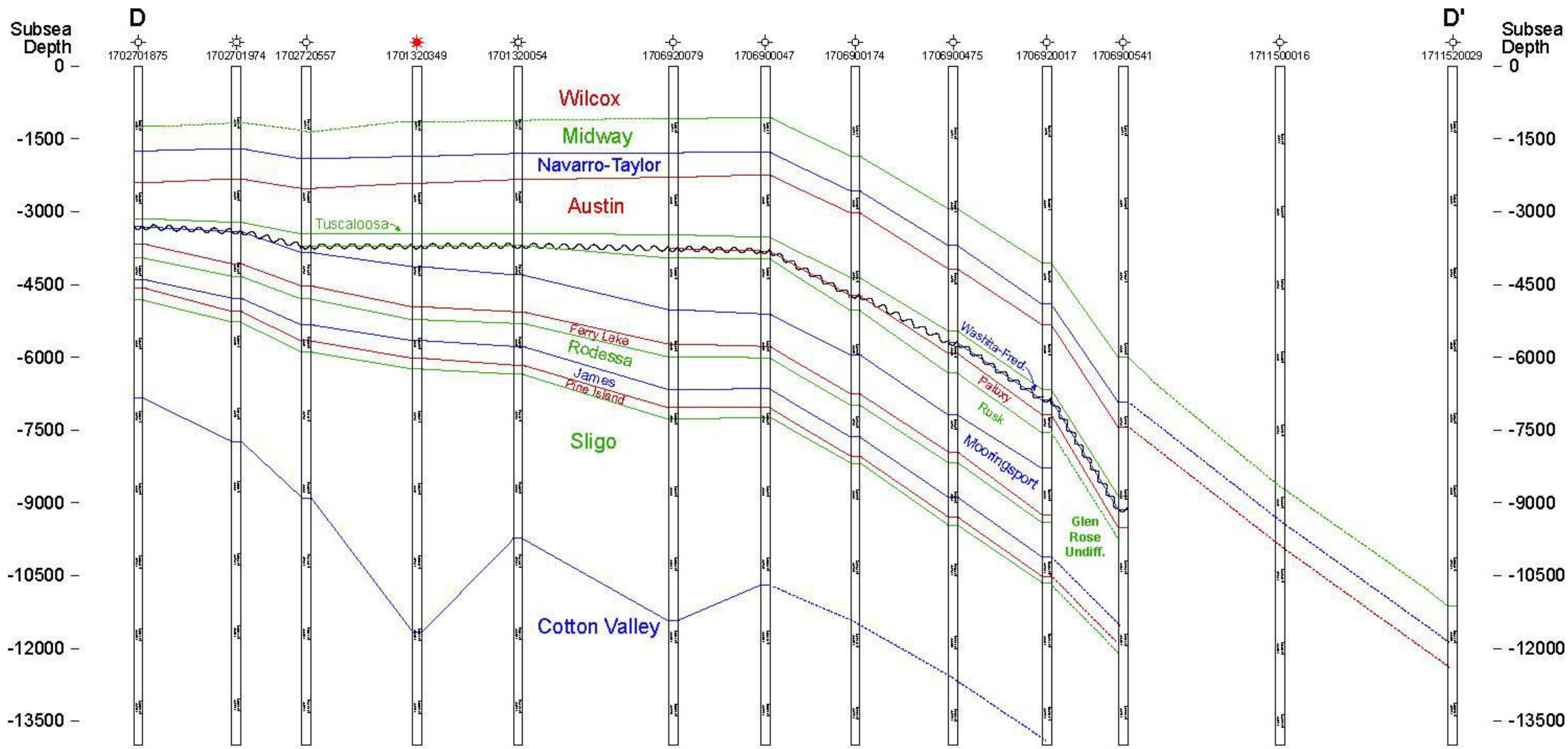


Figure 6. Cross section D-D' for the North Louisiana Salt Basin, modified from Mancini et al. (2006). See Figure 2 for location of cross section.

VE: 32X

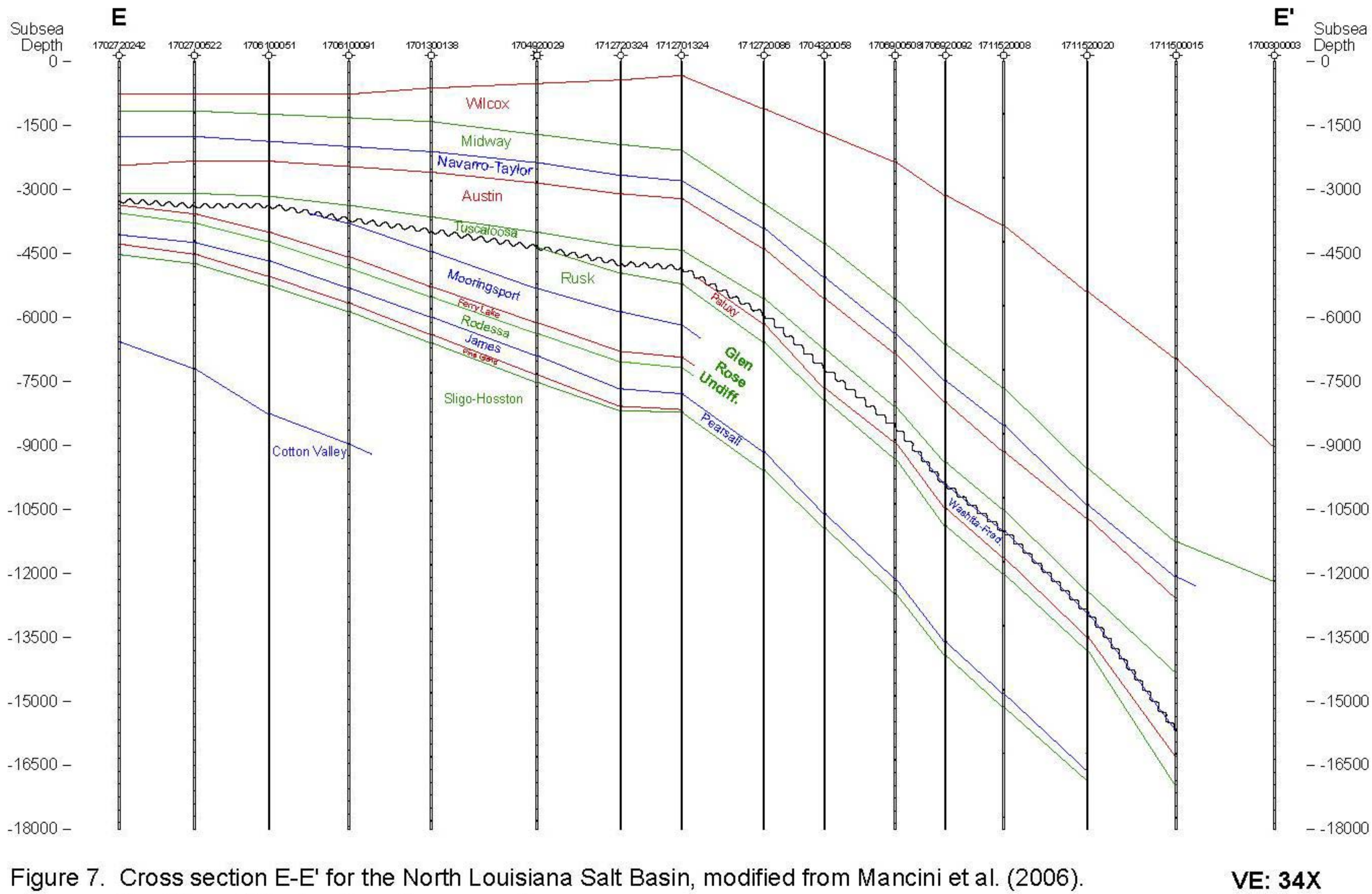


Figure 7. Cross section E-E' for the North Louisiana Salt Basin, modified from Mancini et al. (2006). See Figure 2 for location of cross section.

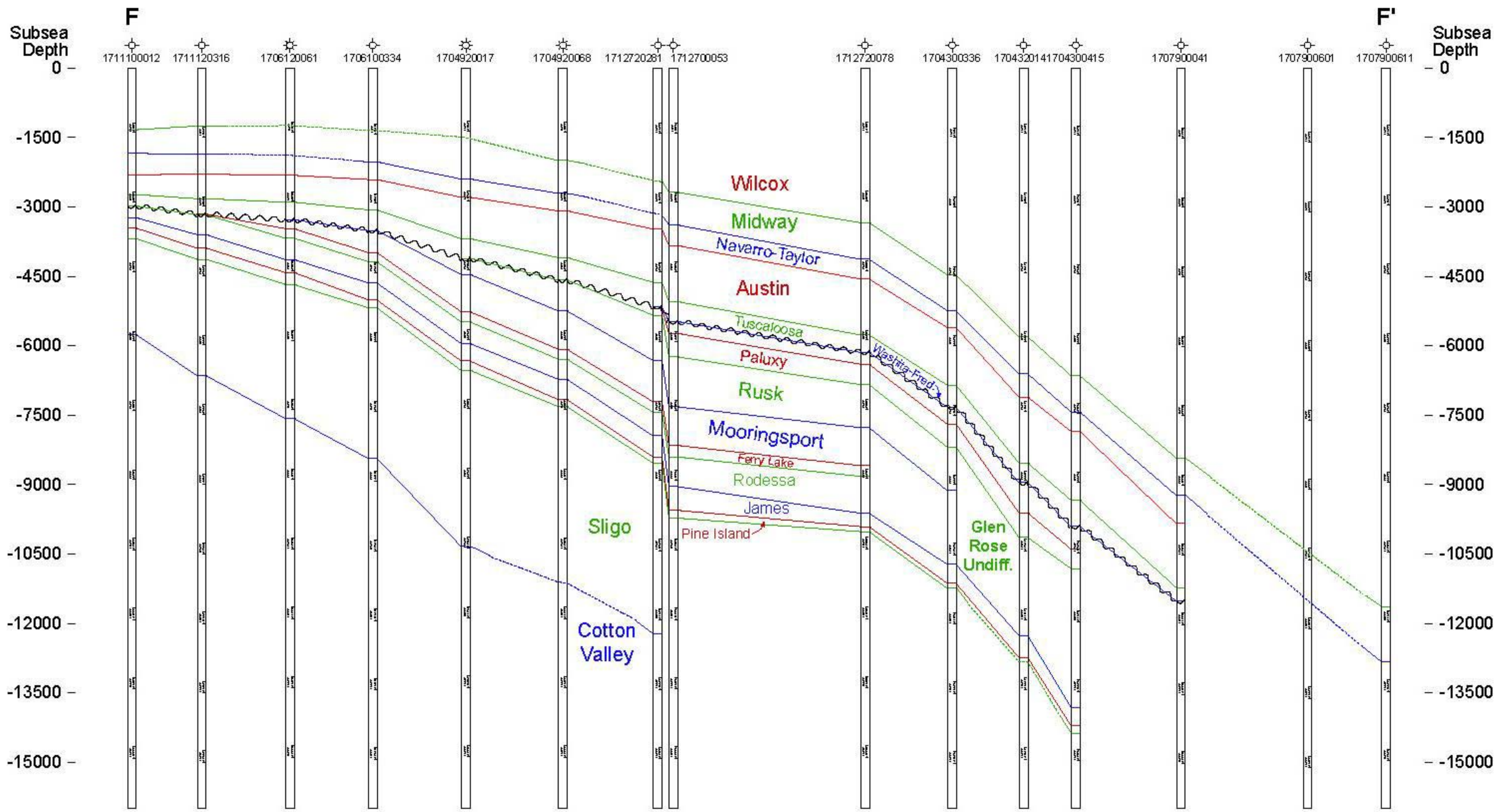


Figure 8. Cross section F-F' for the North Louisiana Salt Basin, modified from Mancini et al. (2006). See Figure 2 for location of cross section.

VE: 32X

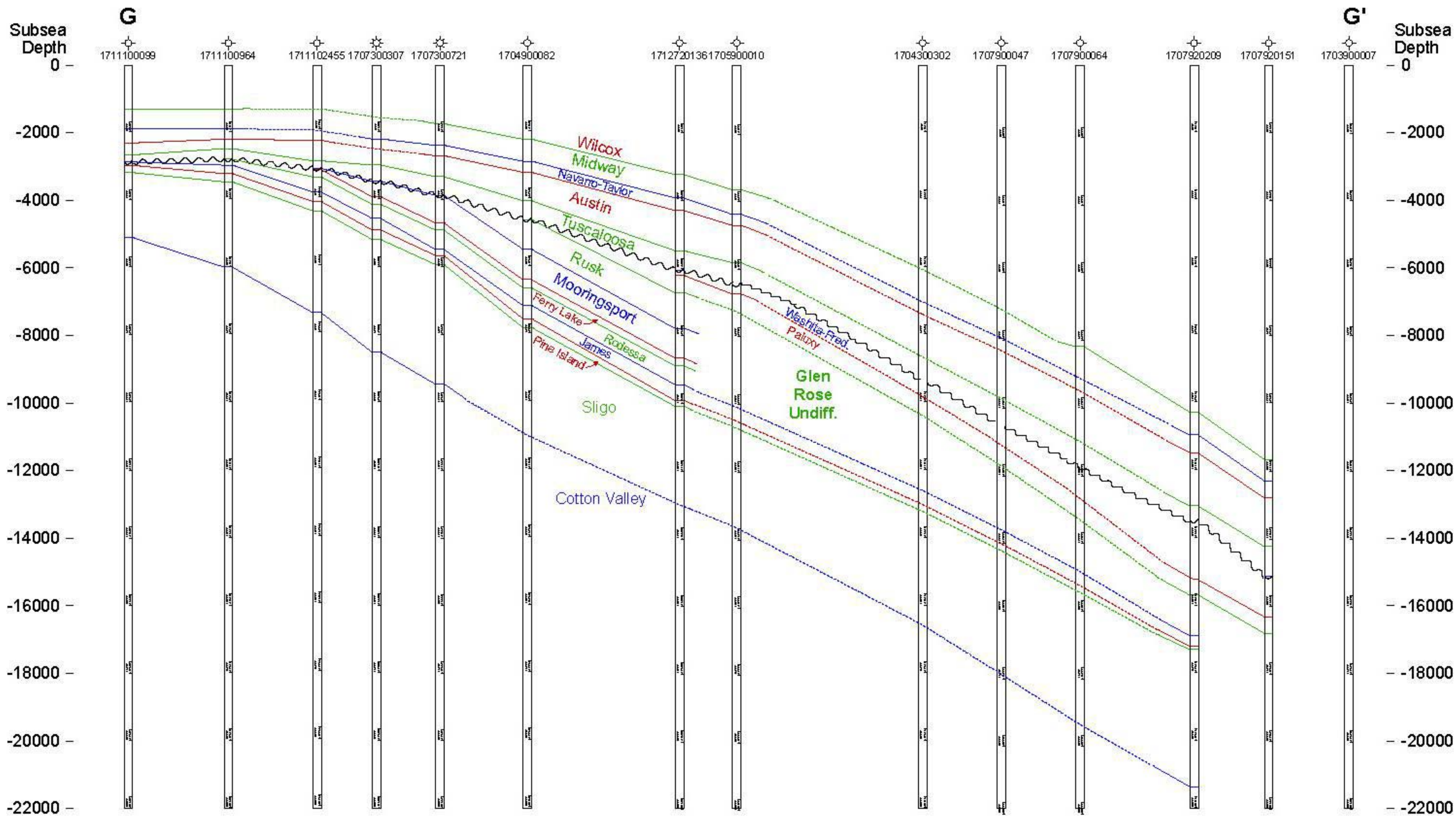


Figure 9. Cross section G-G' for the North Louisiana Salt Basin, modified from Mancini et al. (2006). See Figure 2 for location of cross section.

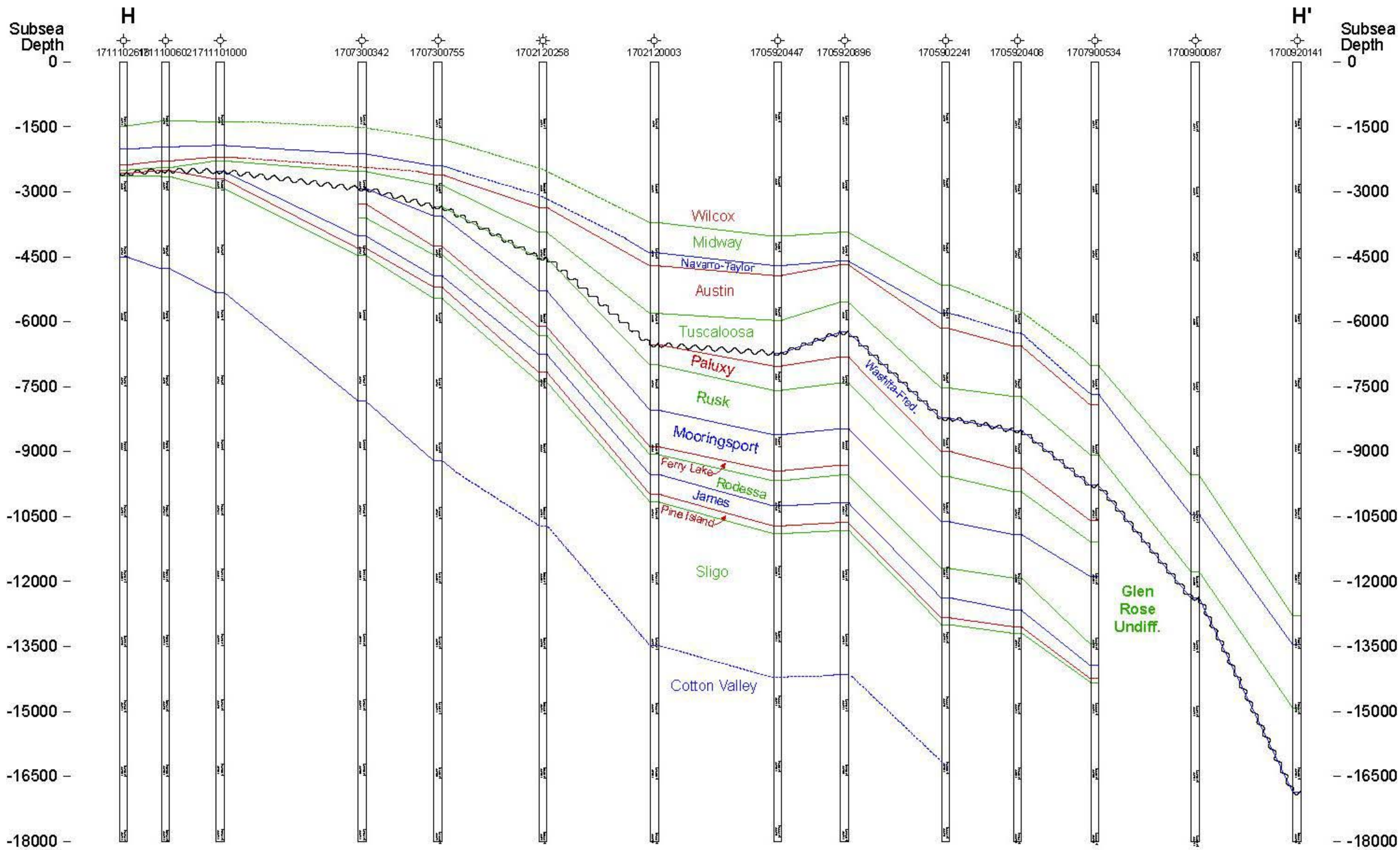
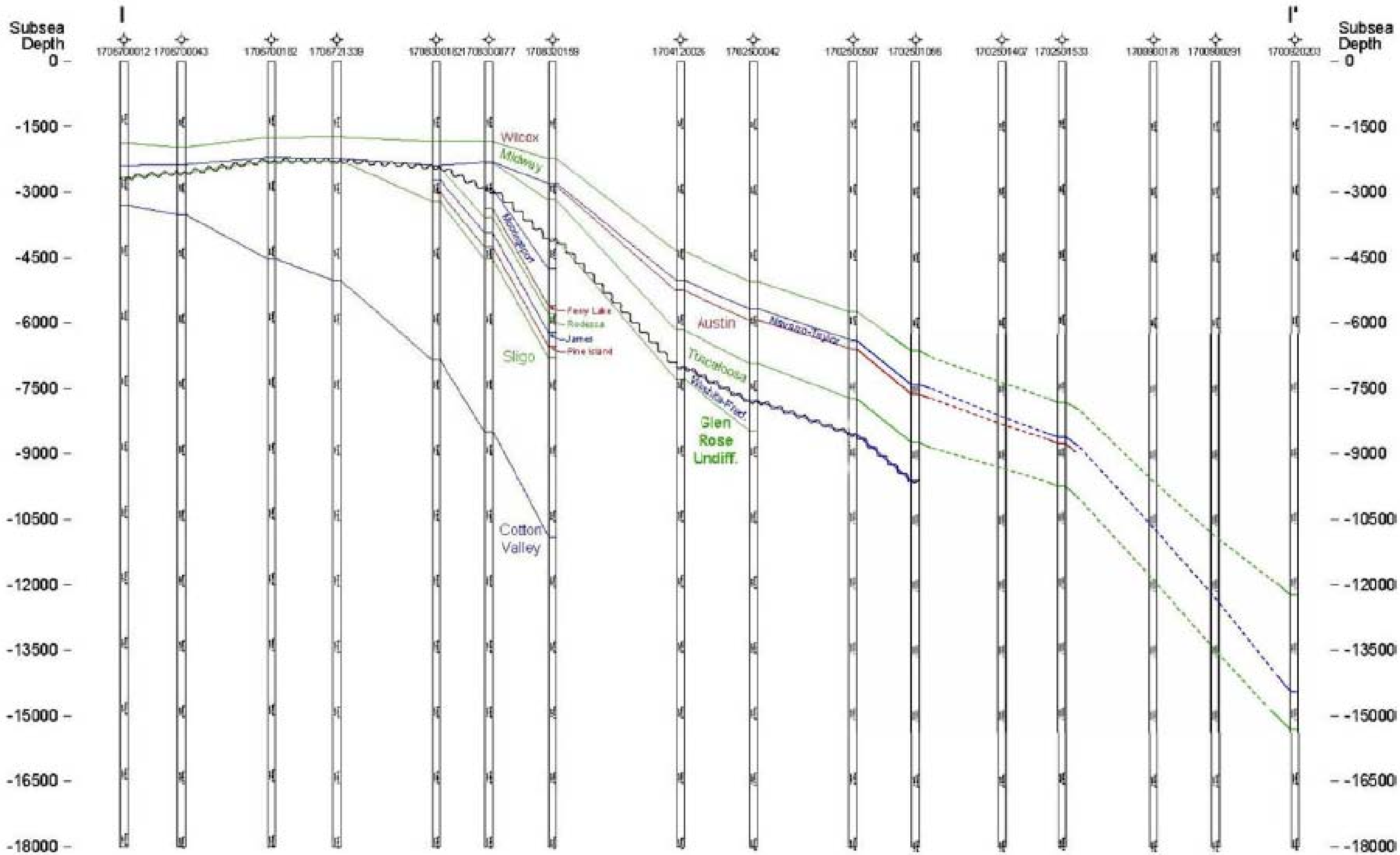


Figure 10. Cross section H-H' for the North Louisiana Salt Basin, modified from Mancini et al. (2006). See Figure 2 for location of cross section.



VE: 31X

Figure 11. Cross section I-I' for the North Louisiana Salt Basin, modified from Mancini et al. (2006). See Figure 2 for location of cross section.

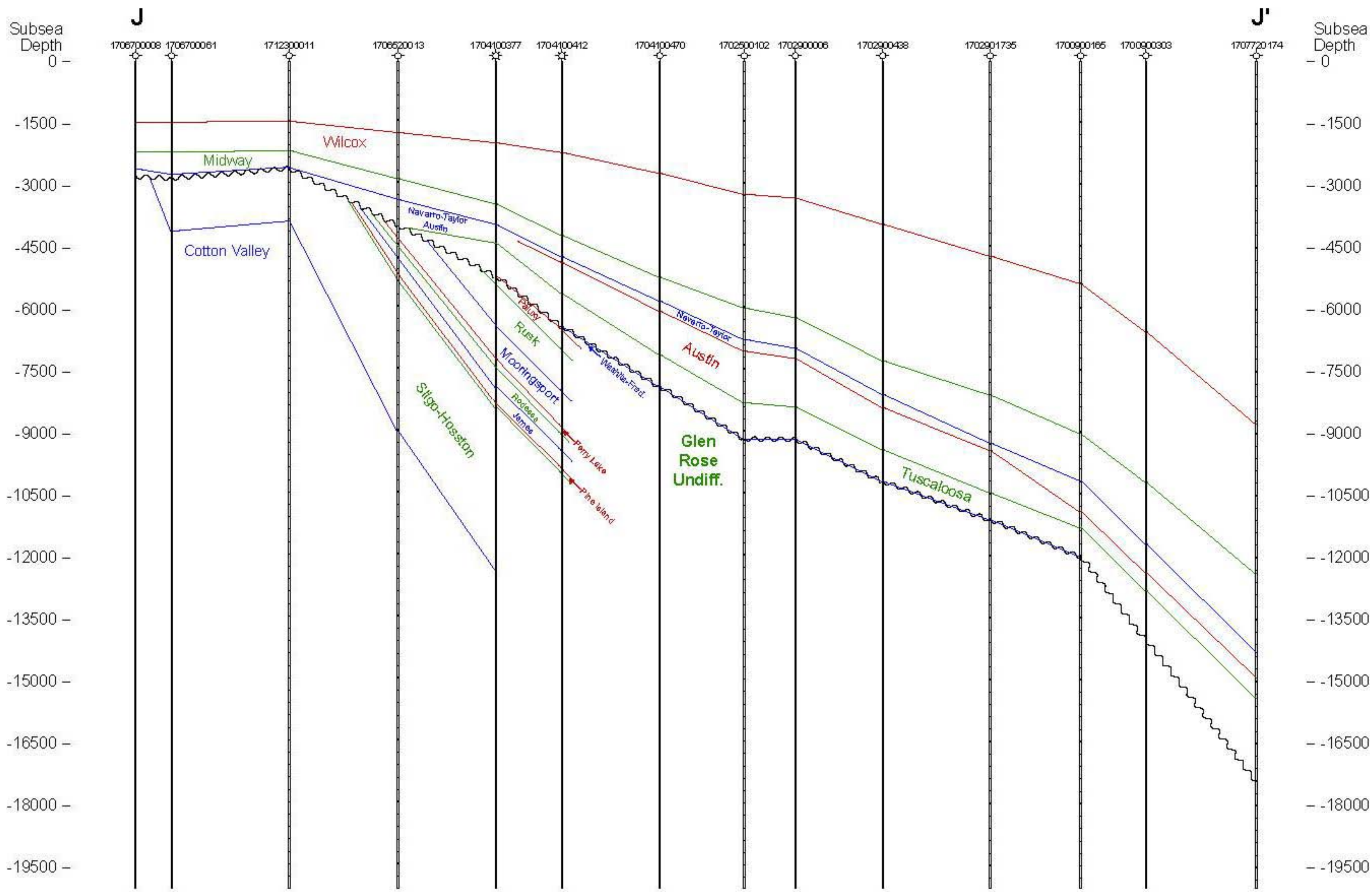


Figure 12. Cross section J-J' for the North Louisiana Salt Basin, modified from Mancini et al. (2006). See Figure 2 for location of cross section.

VE: 30X

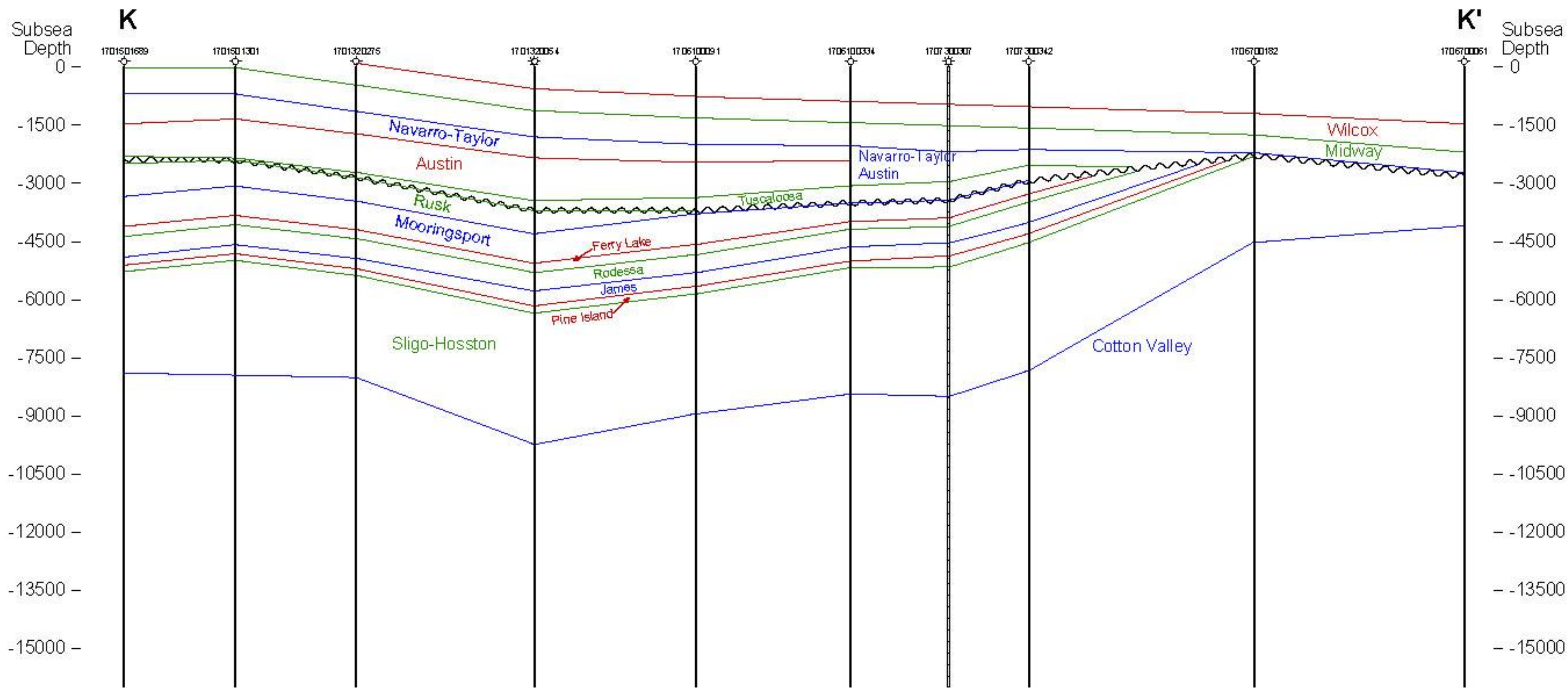


Figure 13. Cross section K-K' for the North Louisiana Salt Basin, modified from Mancini et al. (2006). See Figure 2 for location of cross section. **VE: 22X**

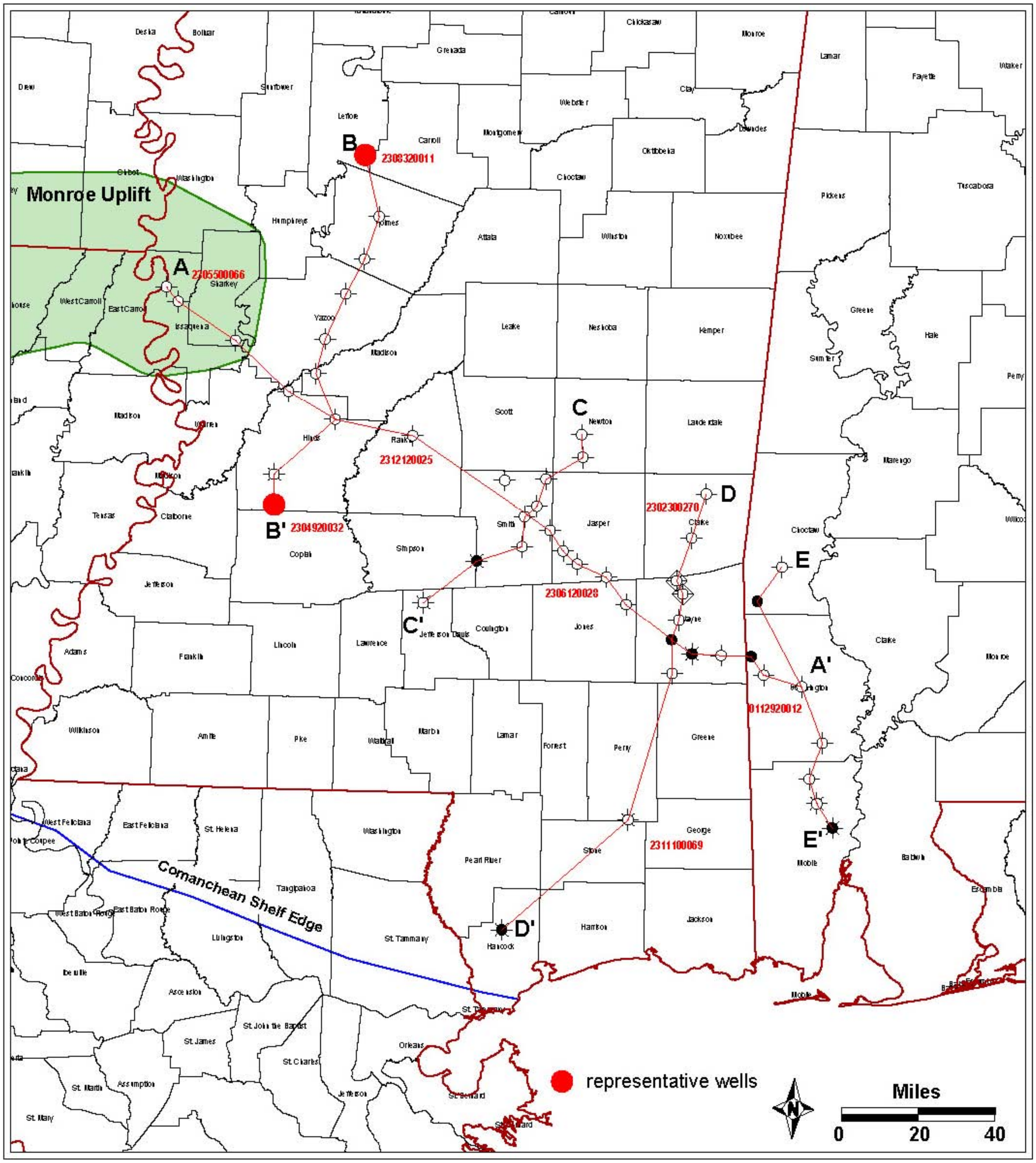


Figure 14. Index map showing locations of cross sections and wells for Mississippi Interior Salt Basin (after Mancini et al., 2003)

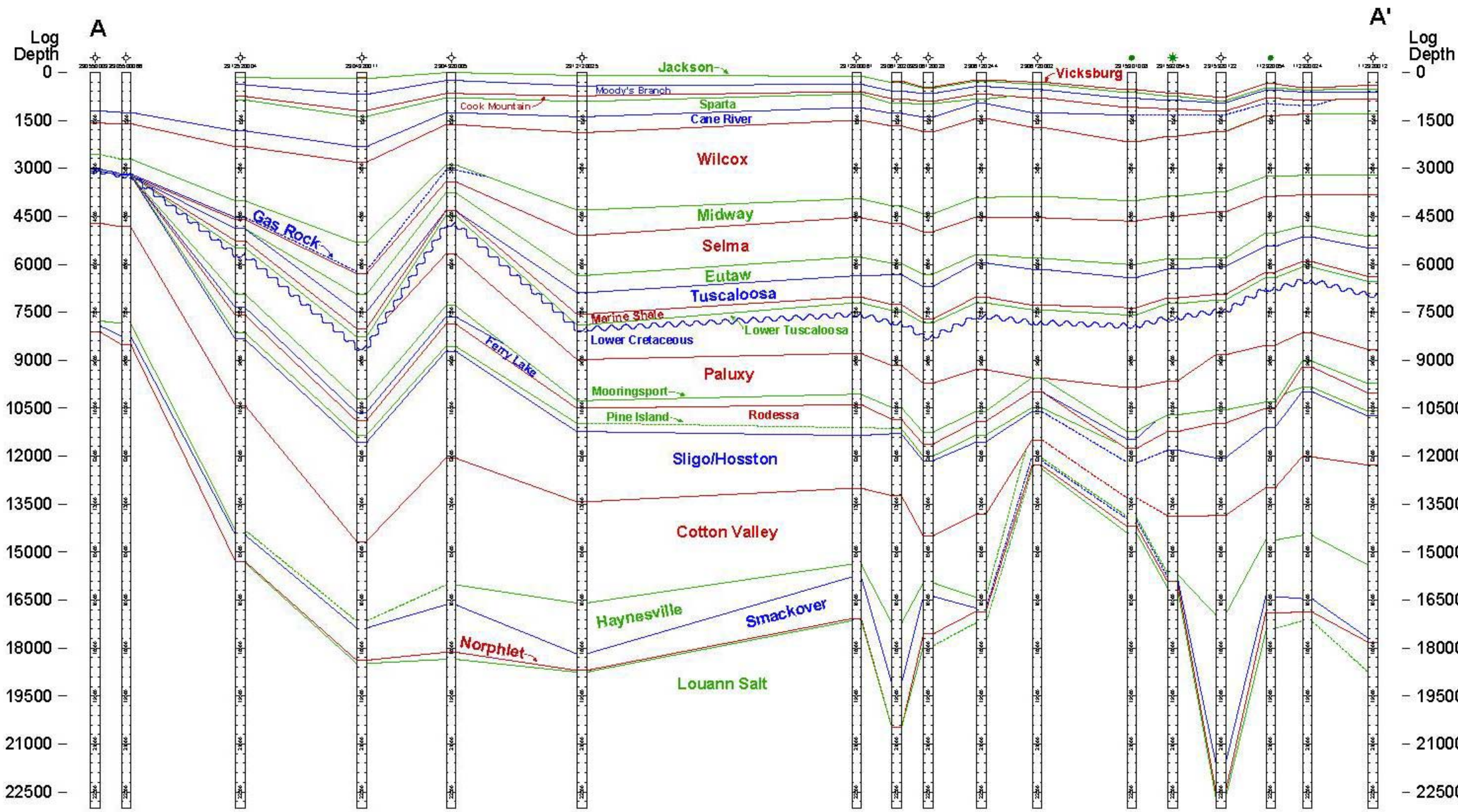


Figure 15. Cross section A-A' for the Mississippi Interior Salt Basin, modified from Mancini et al. (2003). See Figure 14 for location of cross section.

VE: 28X

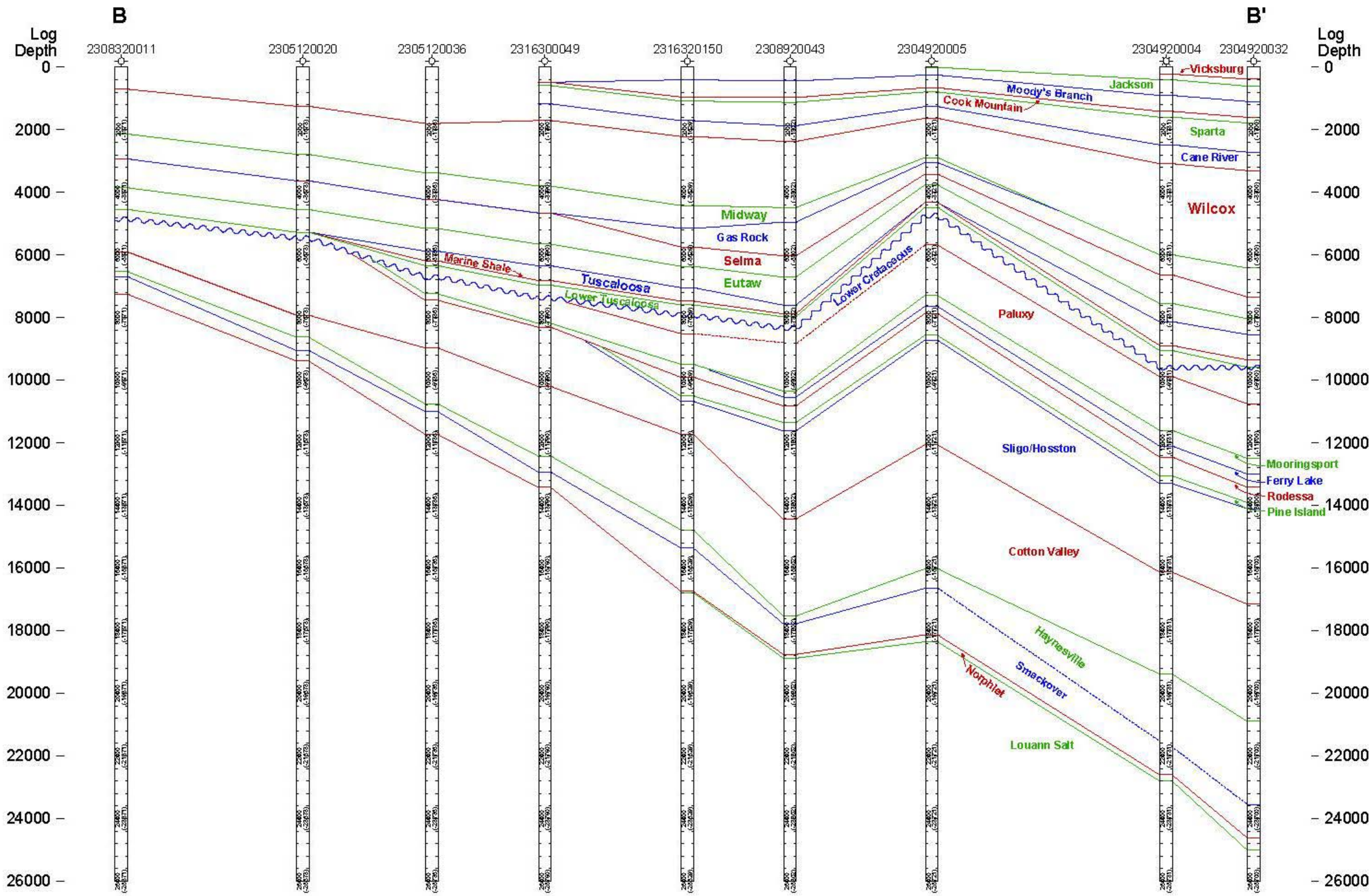


Figure 16. Cross section B-B' for the Mississippi Interior Salt Basin, modified from Mancini et al. (2003). See Figure 14 for location of cross section.

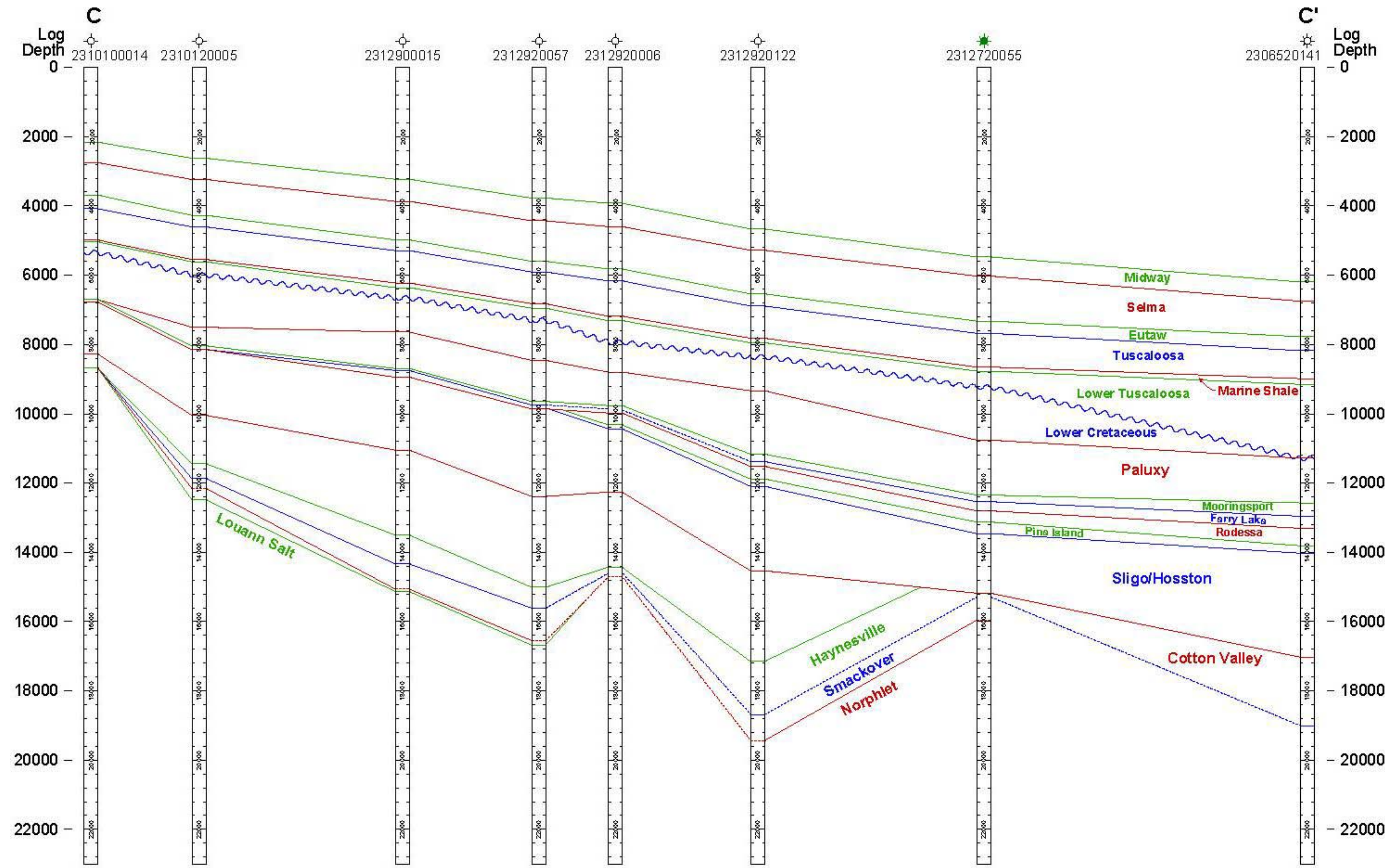


Figure 17. Cross section C-C' for the Mississippi Interior Salt Basin, modified from Mancini et al. (2003). See Figure 14 for location of cross section.

VE: 14X

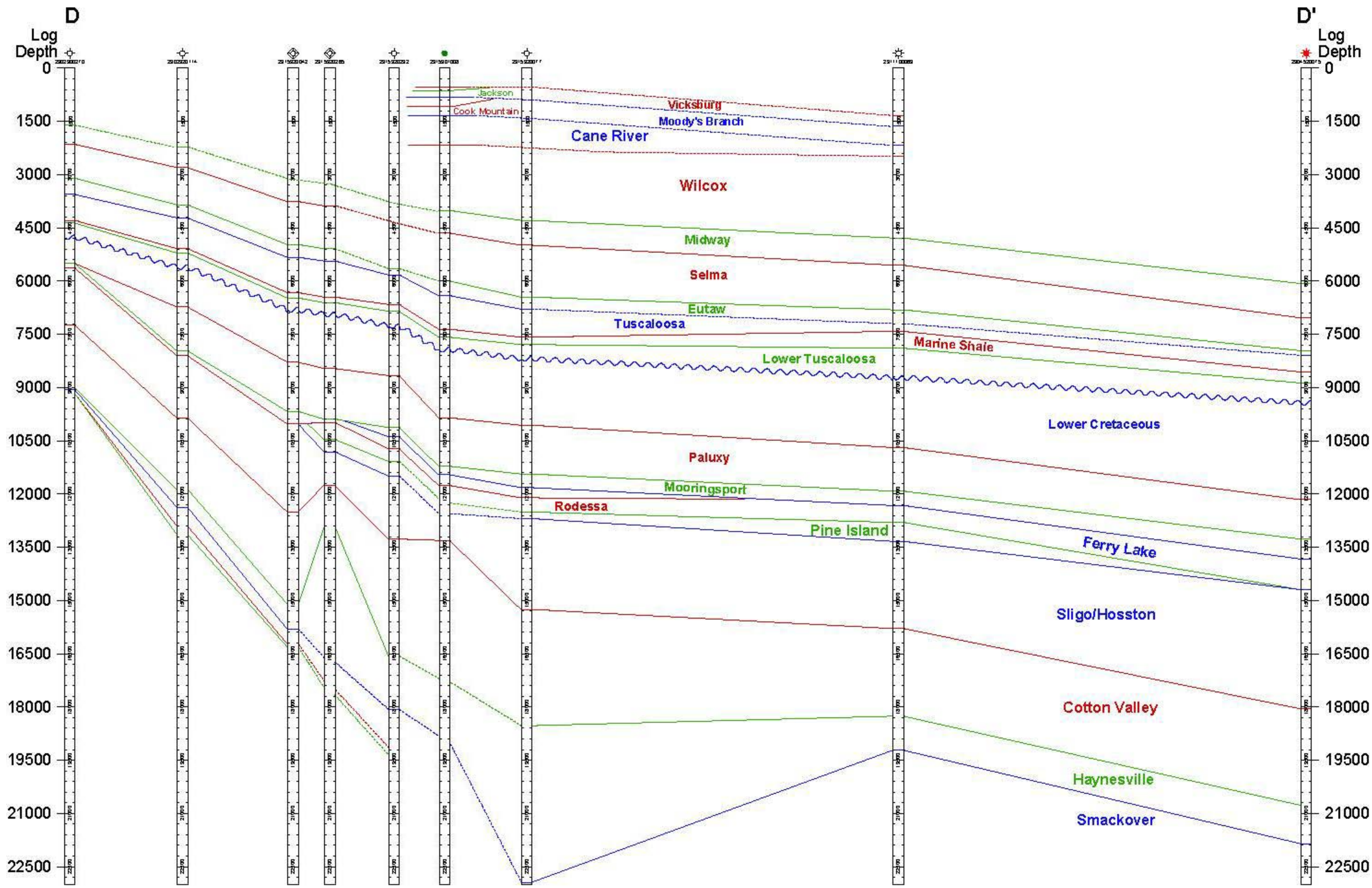


Figure 18. Cross section D-D' for the Mississippi Interior Salt Basin, modified from Mancini et al. (2003). See Figure 14 for location of cross section.

VE: 20X

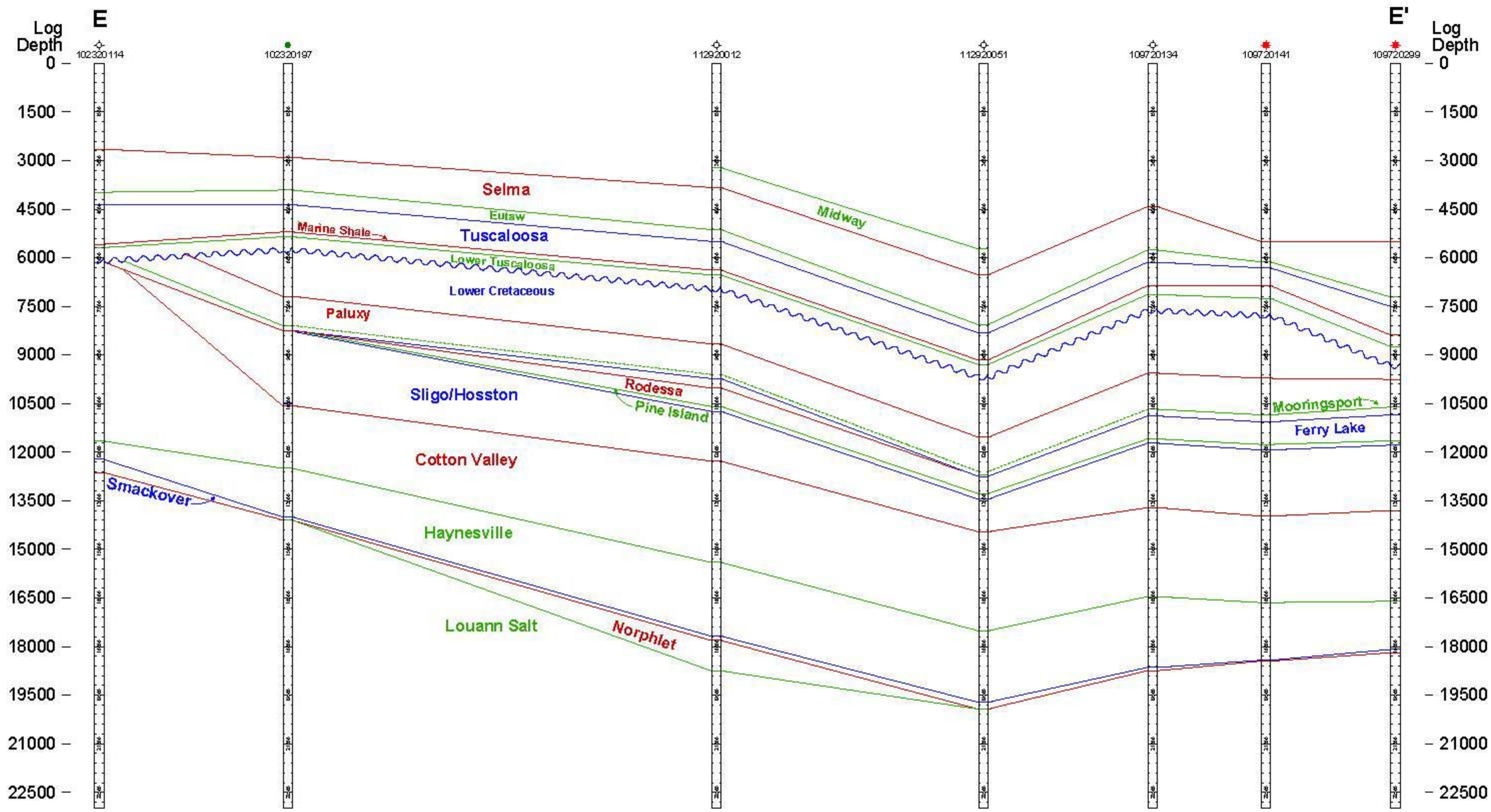


Figure 19. Cross section E-E' for the Mississippi Interior Salt Basin, modified from Mancini et al. (2003). See Figure 14 for location of cross section.

VE: 10X

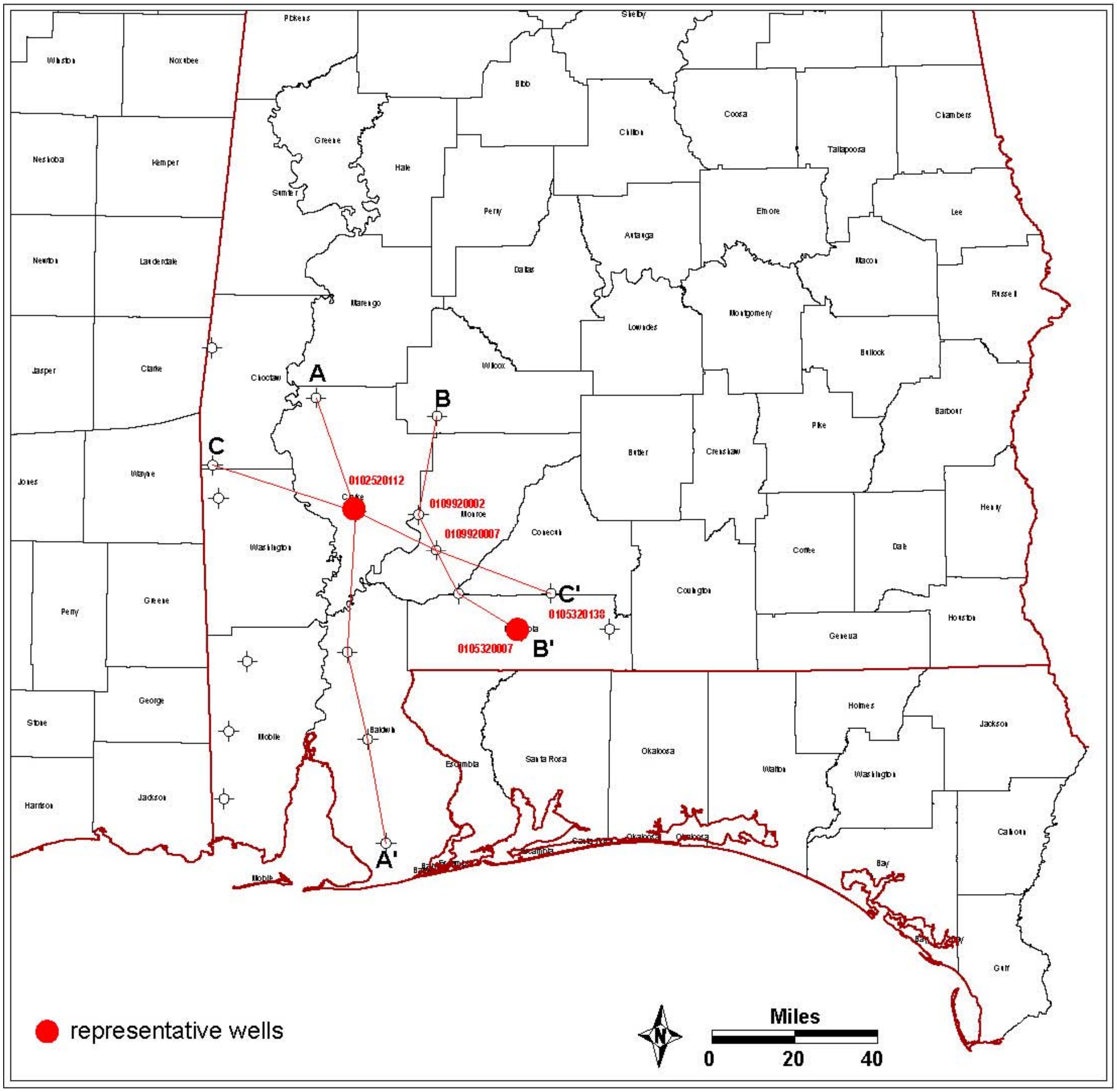


Figure 20. Index map showing locations of cross sections and wells for the Manila and Conecuh Subbasins.

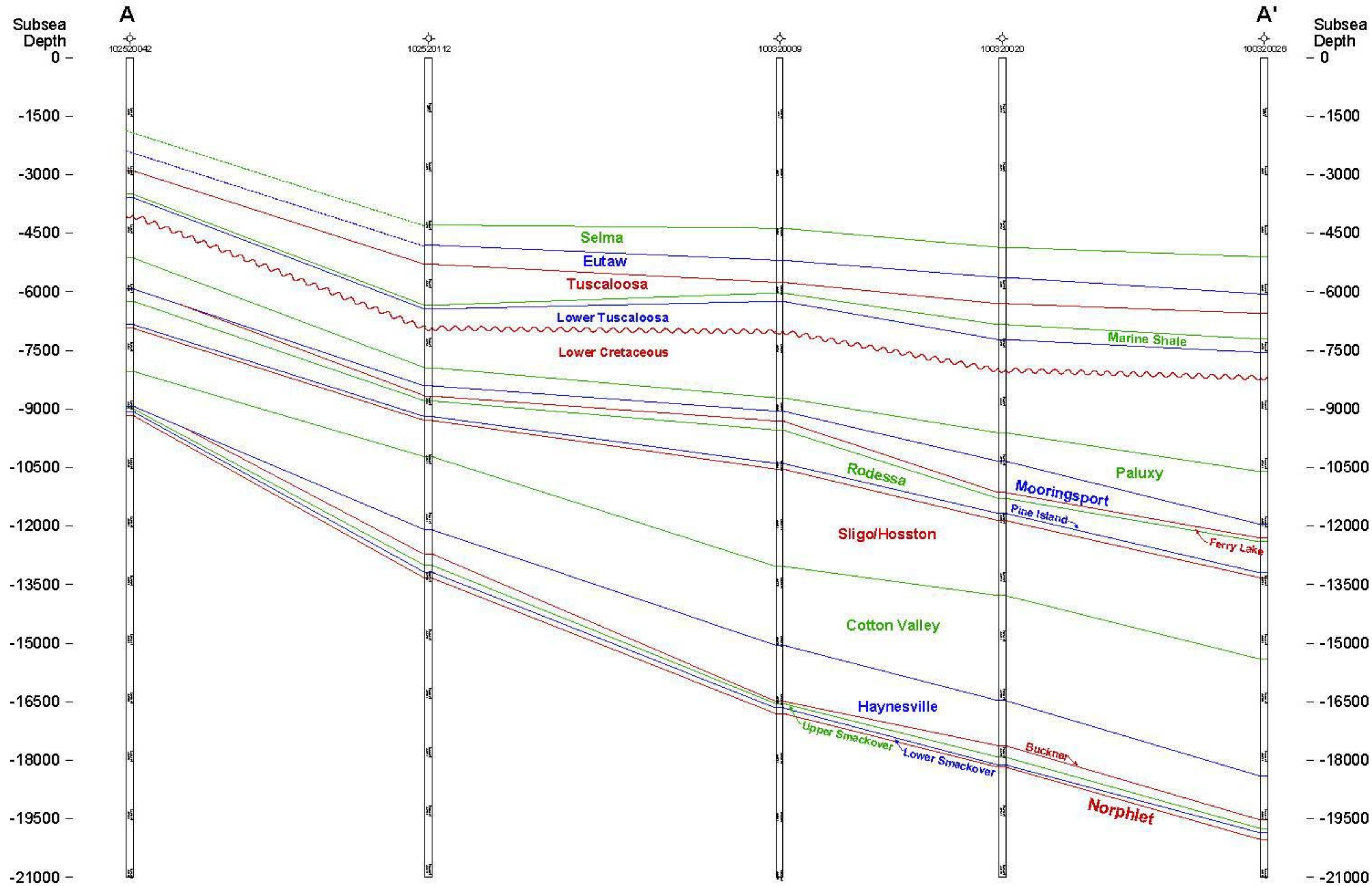


Figure 21. Cross section A-A' for the Manila and Conecuh Subbasins. See Figure 20 for location of cross section. VE: 24X

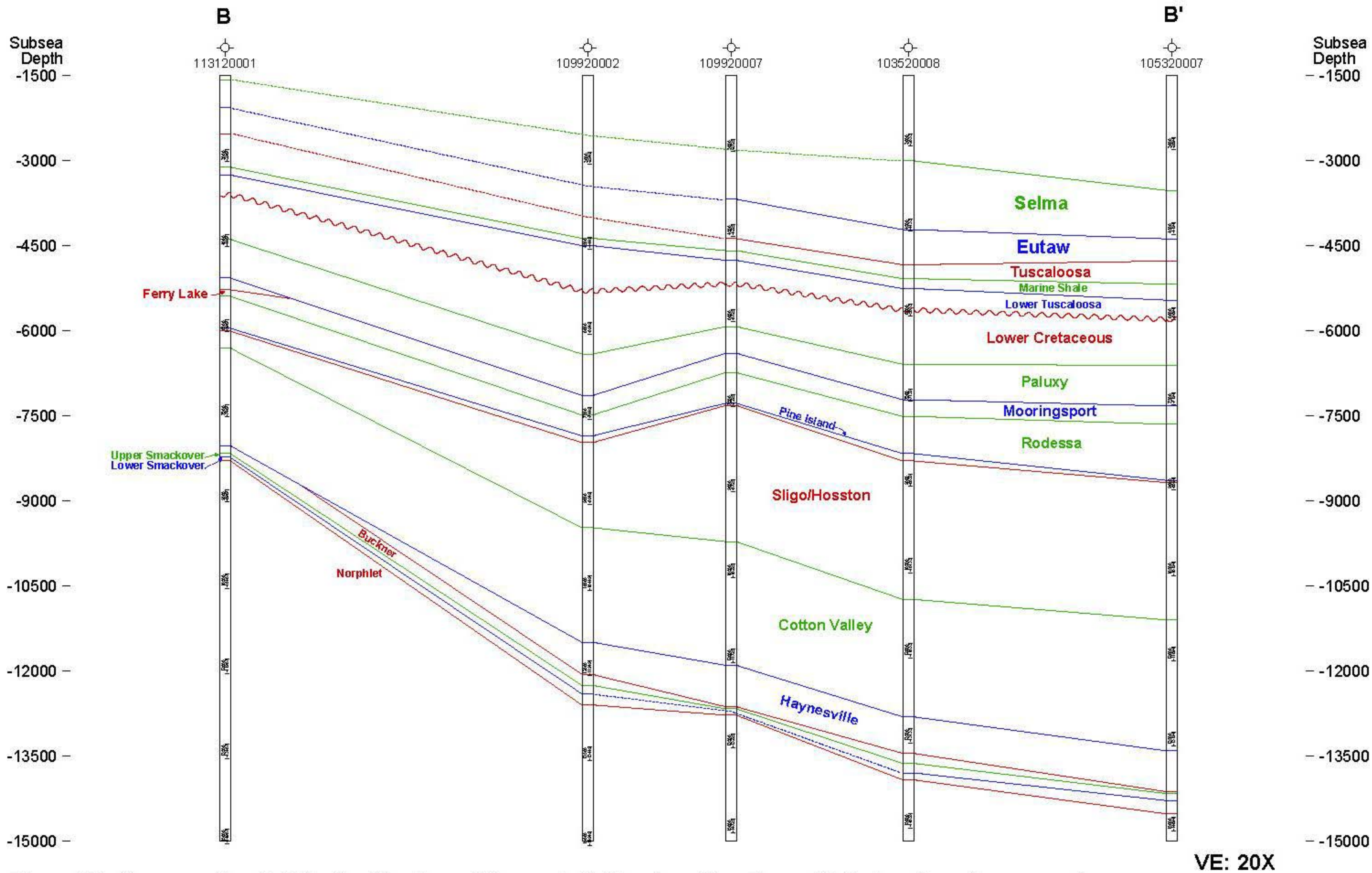


Figure 22. Cross section B-B' for the Manila and Conecuh Subbasins. See Figure 20 for location of cross section.

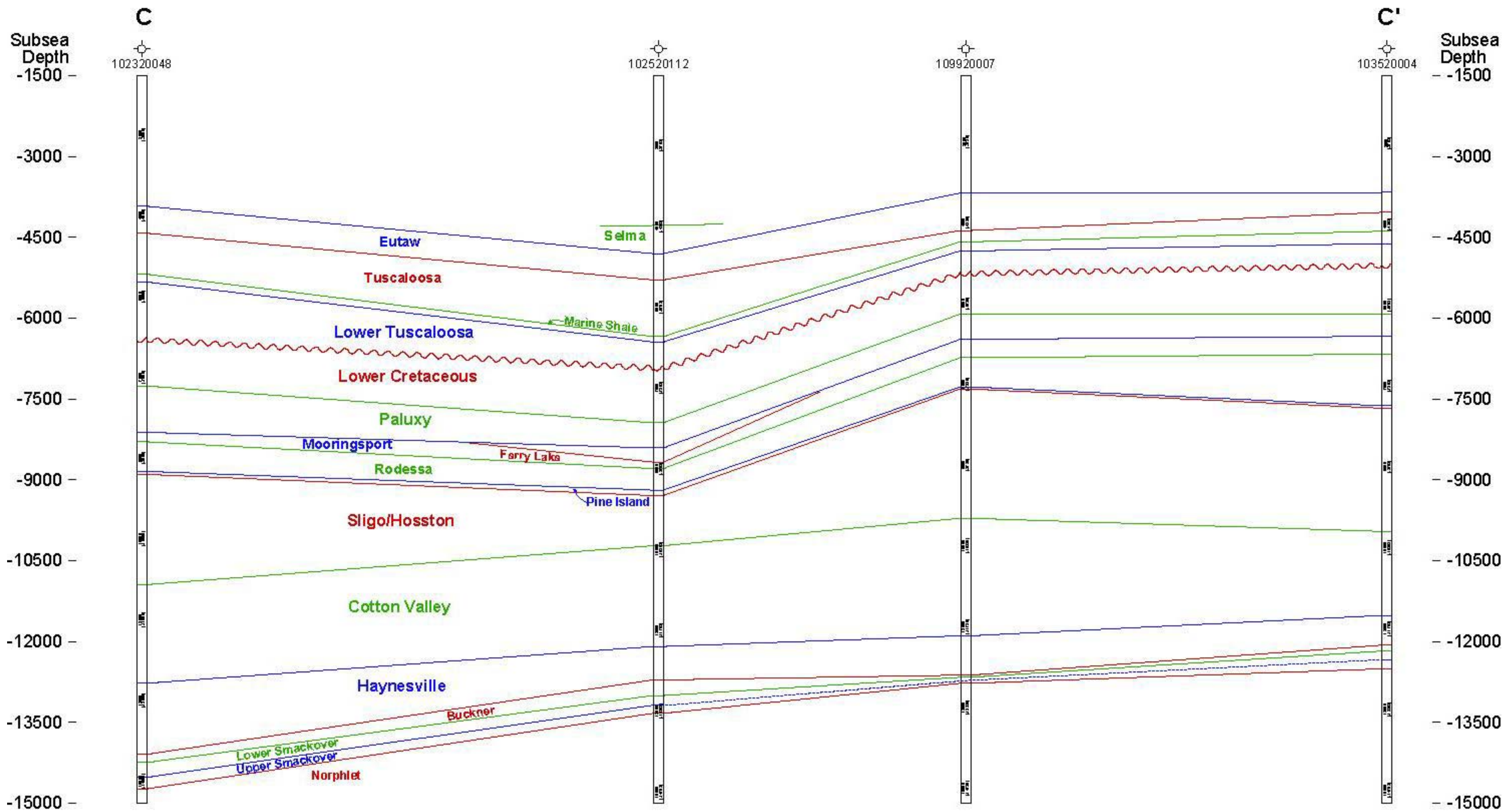


Figure 23. Cross section C-C' for Manila and Conecuh Subbasins. See Figure 20 for location of cross section.

VE: 21X

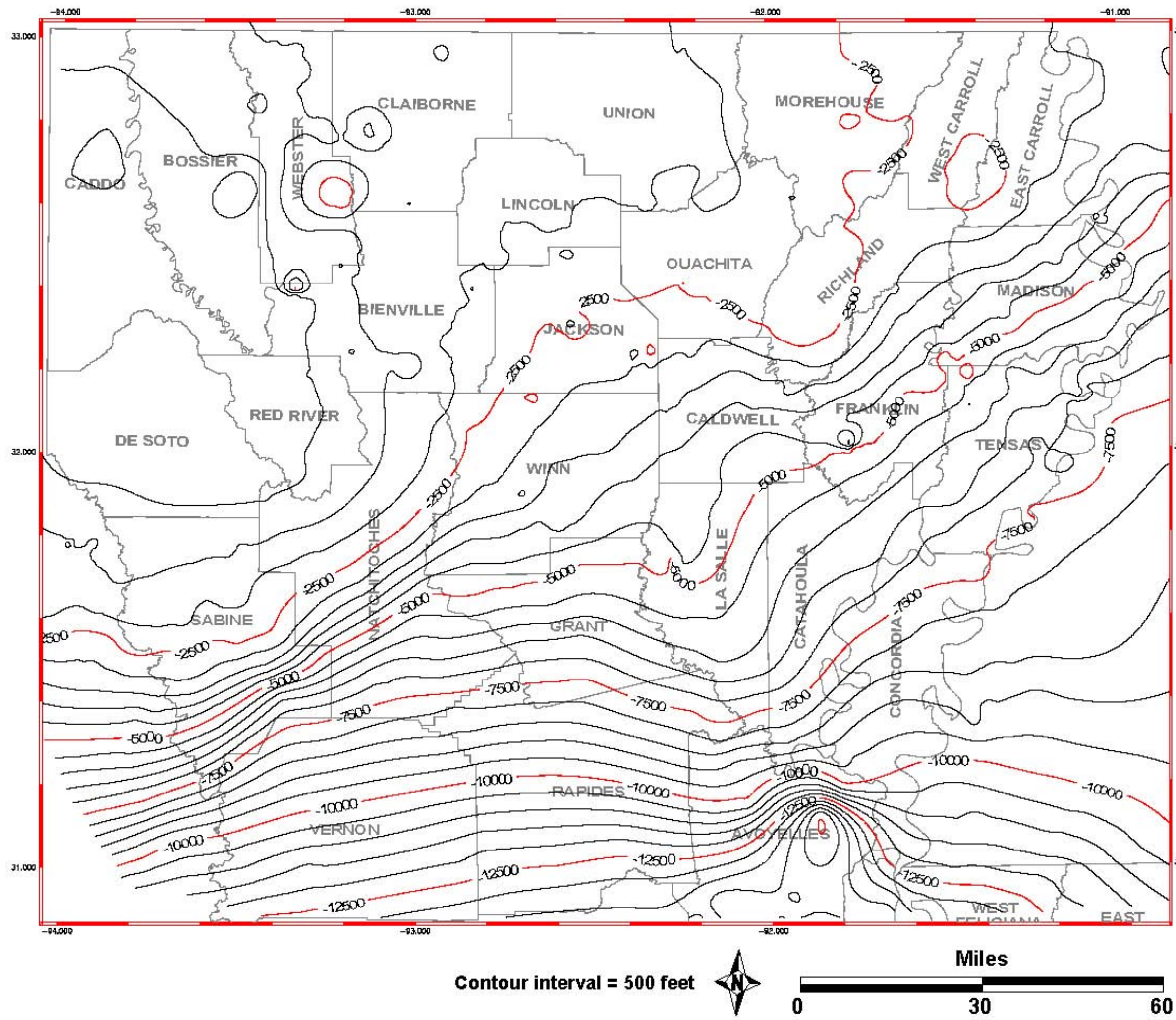


Figure 24. Structural contour map on top of the Upper Cretaceous, North Louisiana Salt Basin. Prepared by R. Zimmerman.

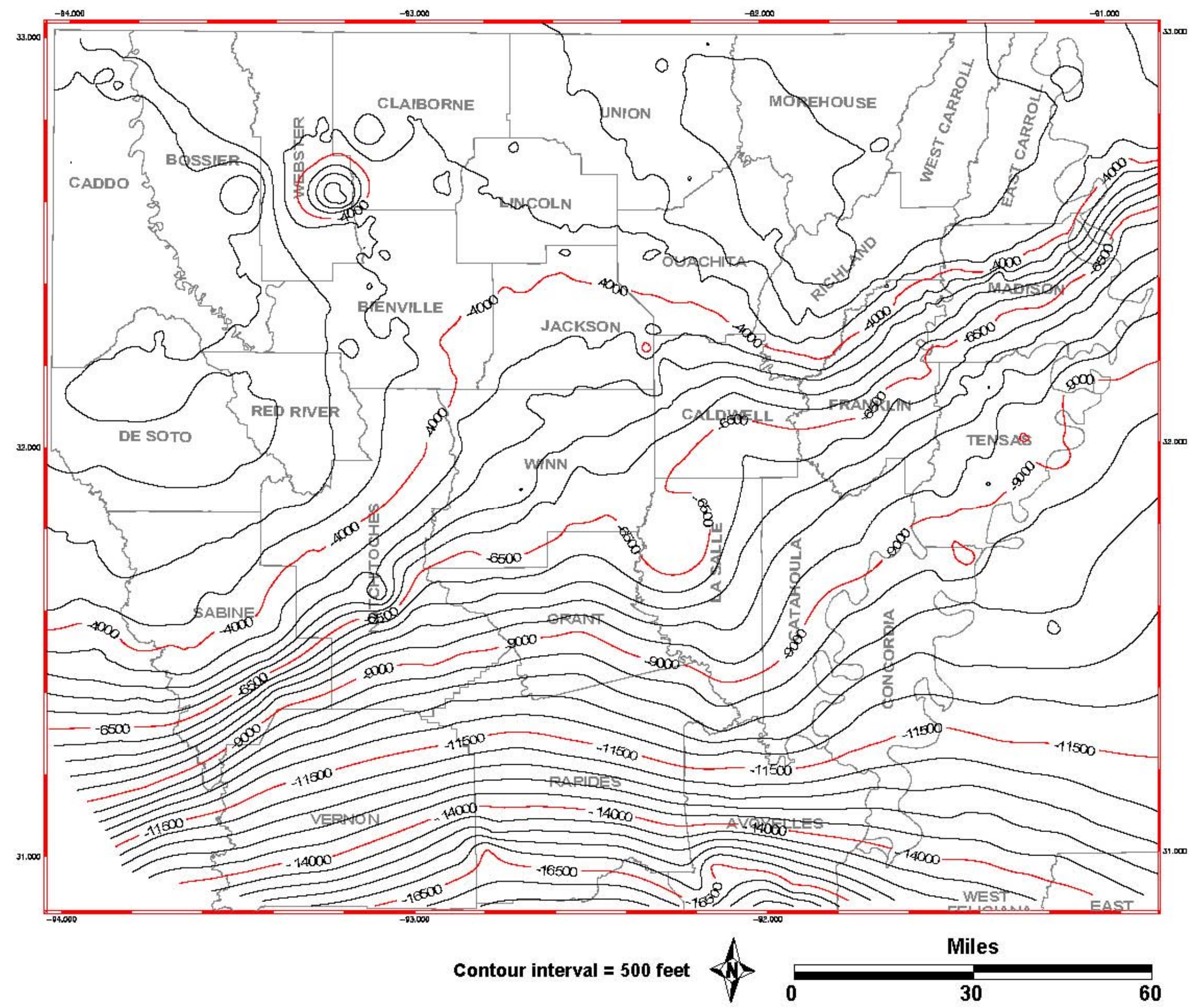


Figure 25. Structural contour map on top of the Lower Cretaceous, North Louisiana Salt Basin. Prepared by R. Zimmerman.

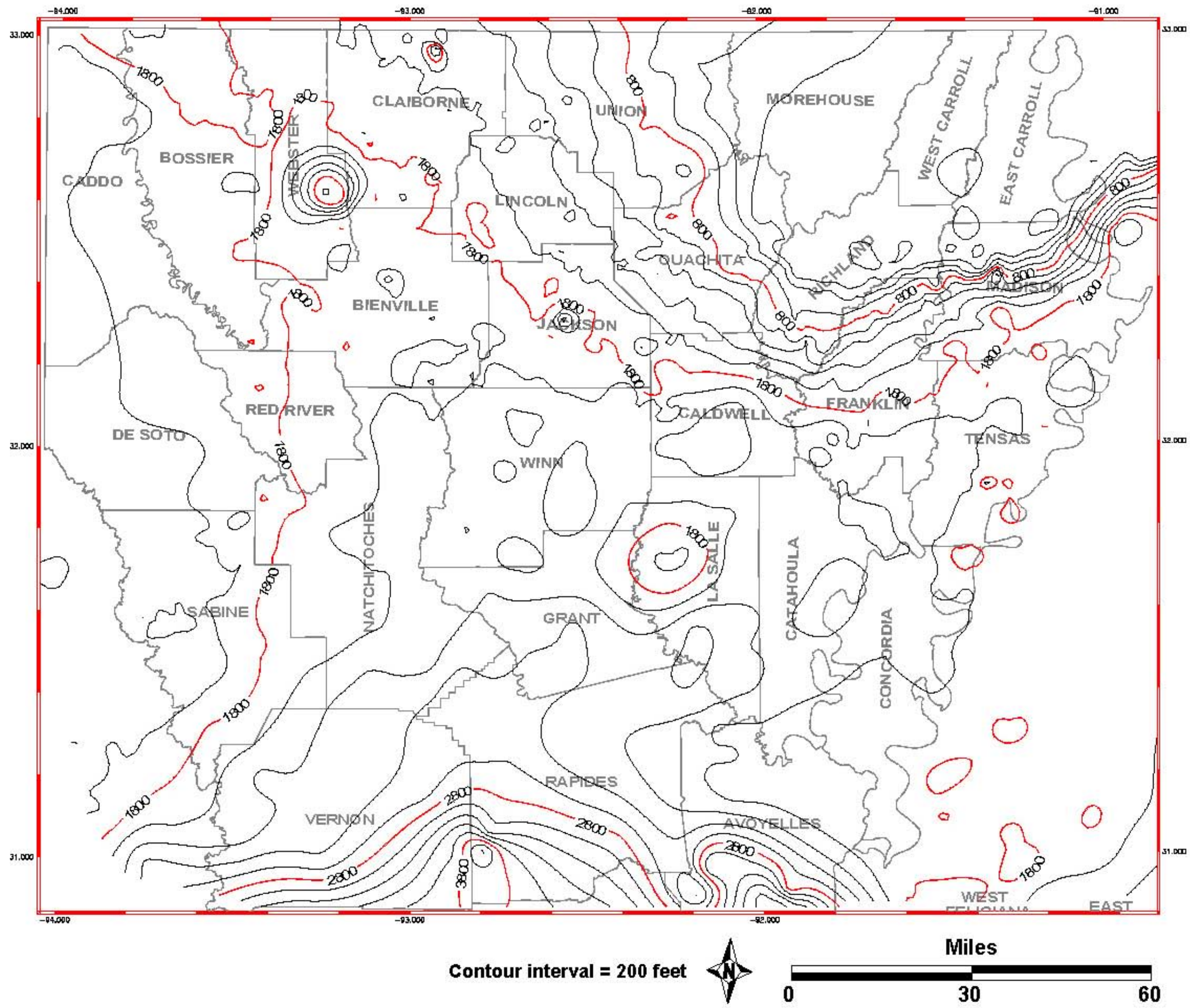


Figure 26. Isopach map of the interval from the top of the Lower Cretaceous to the top of the Upper Cretaceous, North Louisiana Salt Basin. Prepared by R. Zimmerman.

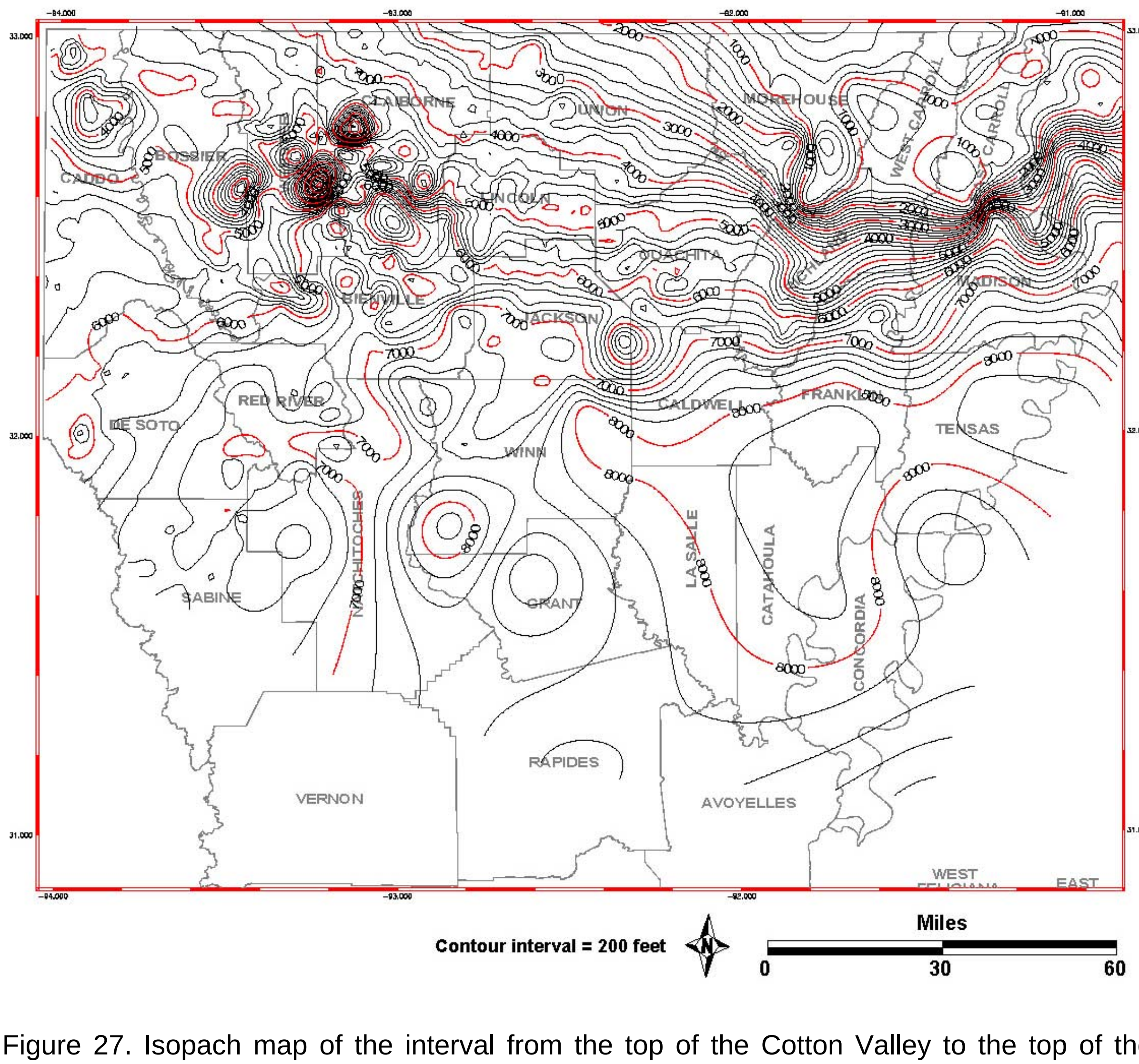


Figure 27. Isopach map of the interval from the top of the Cotton Valley to the top of the Lower Cretaceous, North Louisiana Salt Basin. Prepared by R. Zimmerman.

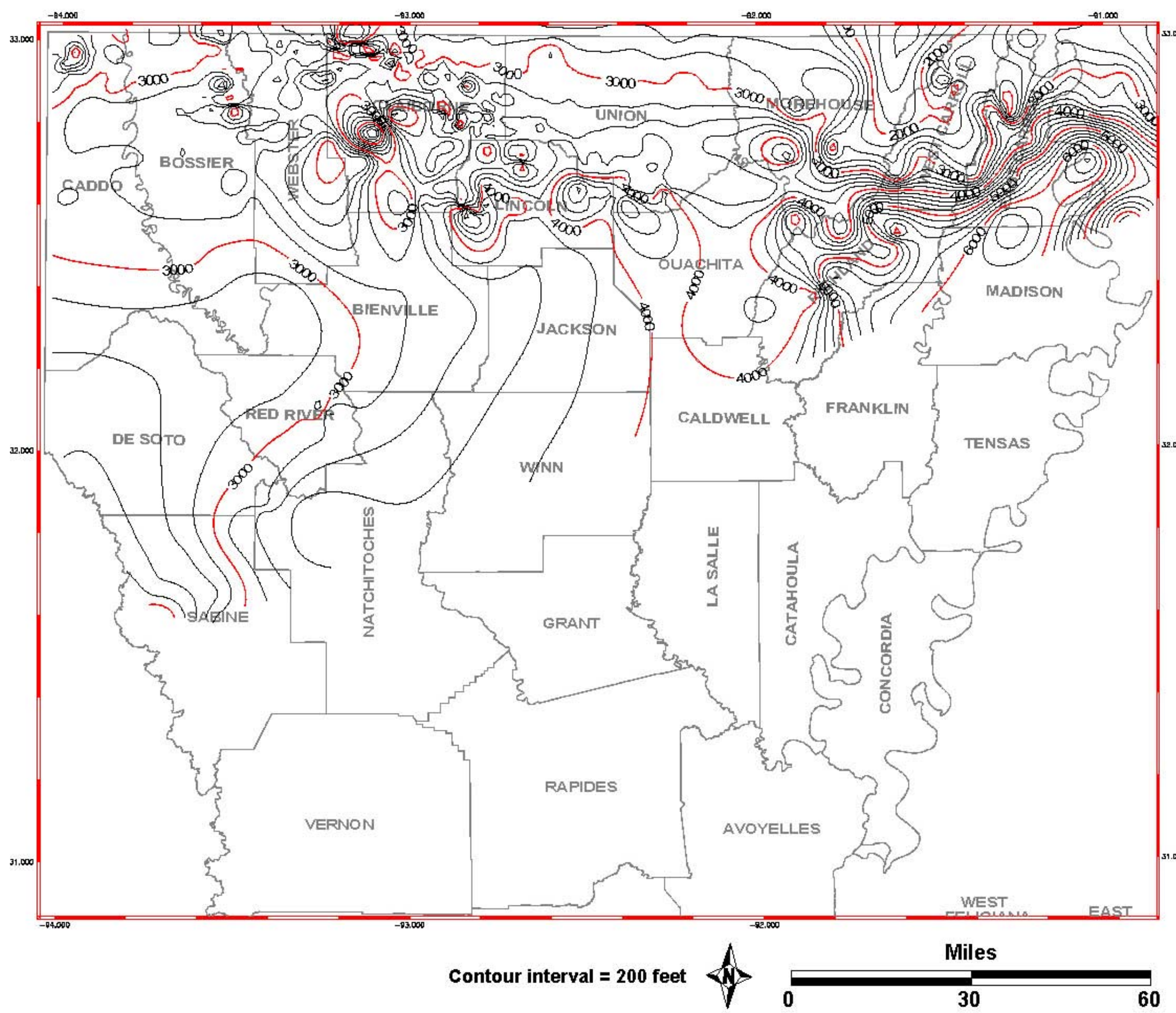


Figure 28. Isopach map of the interval from the top of the Smackover to the top of the Cotton Valley, North Louisiana Salt Basin. Prepared by R. Zimmerman.

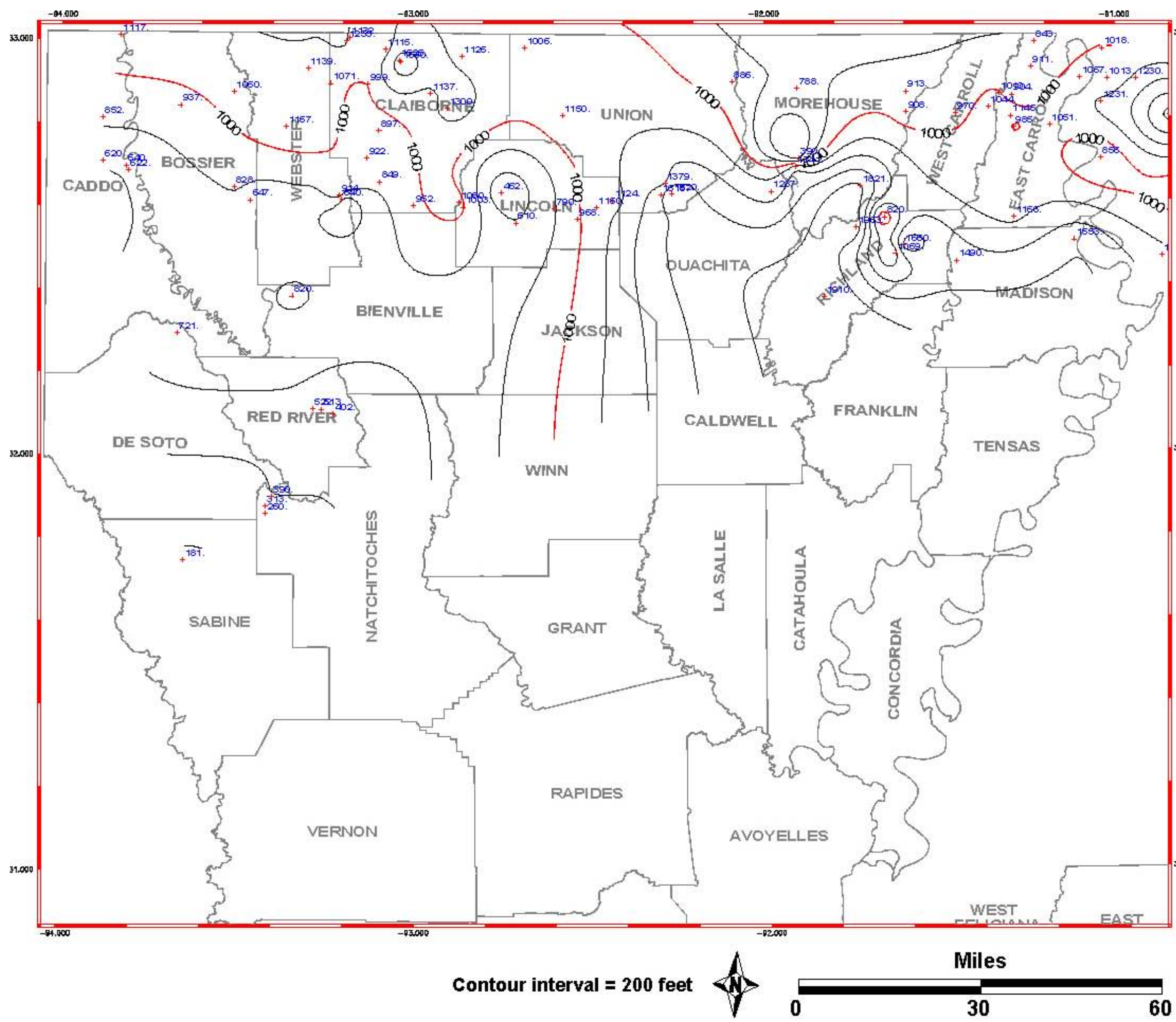


Figure 29. Isopach map of the interval from the top of the Louann Salt to the top of the Smackover, North Louisiana Salt Basin. Prepared by R. Zimmerman.

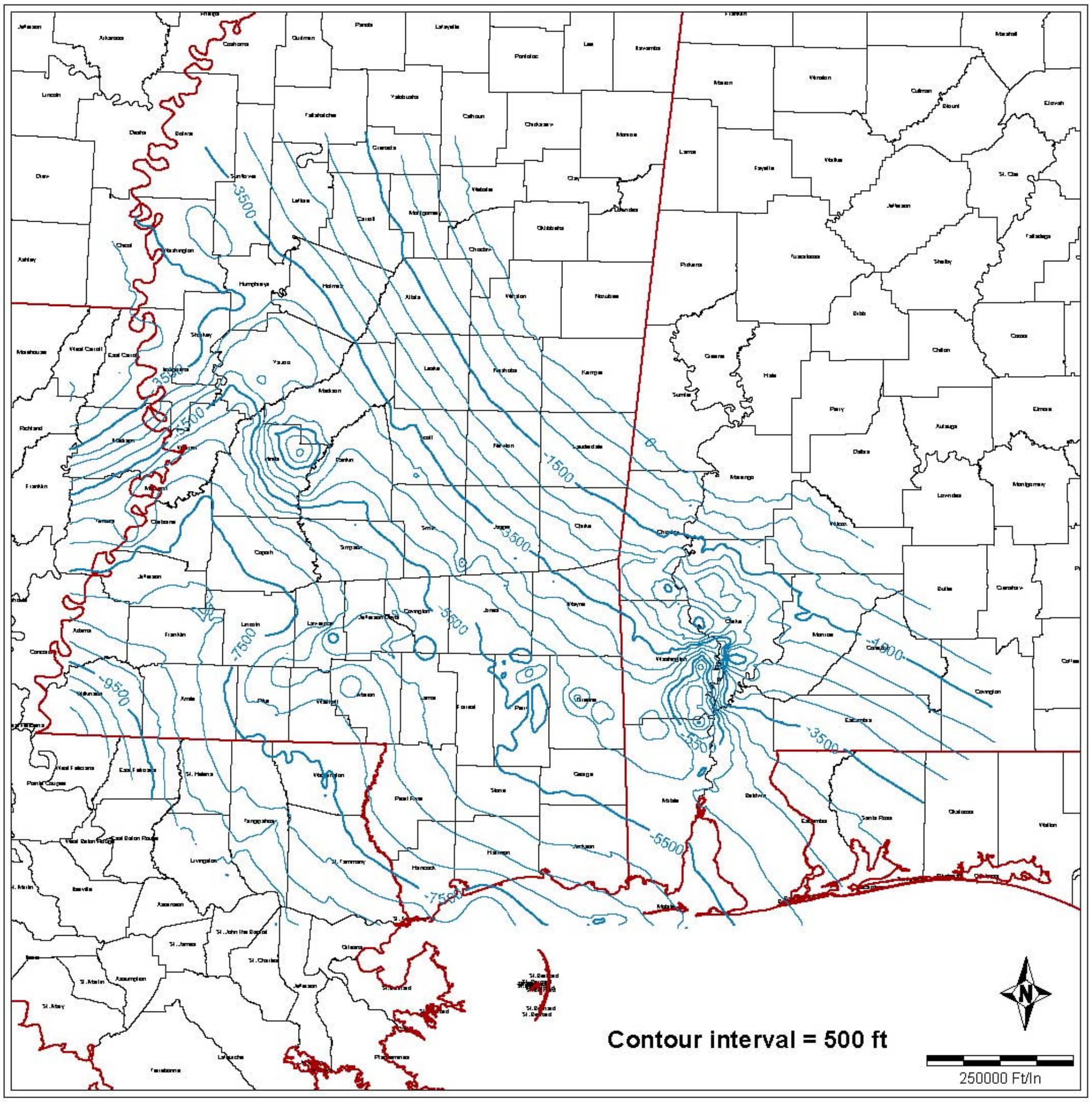


Figure 30. Structure contour map on top of the Upper Cretaceous, Mississippi Interior Salt Basin and Conecuh and Manila Subbasins. Prepared by P. Li.

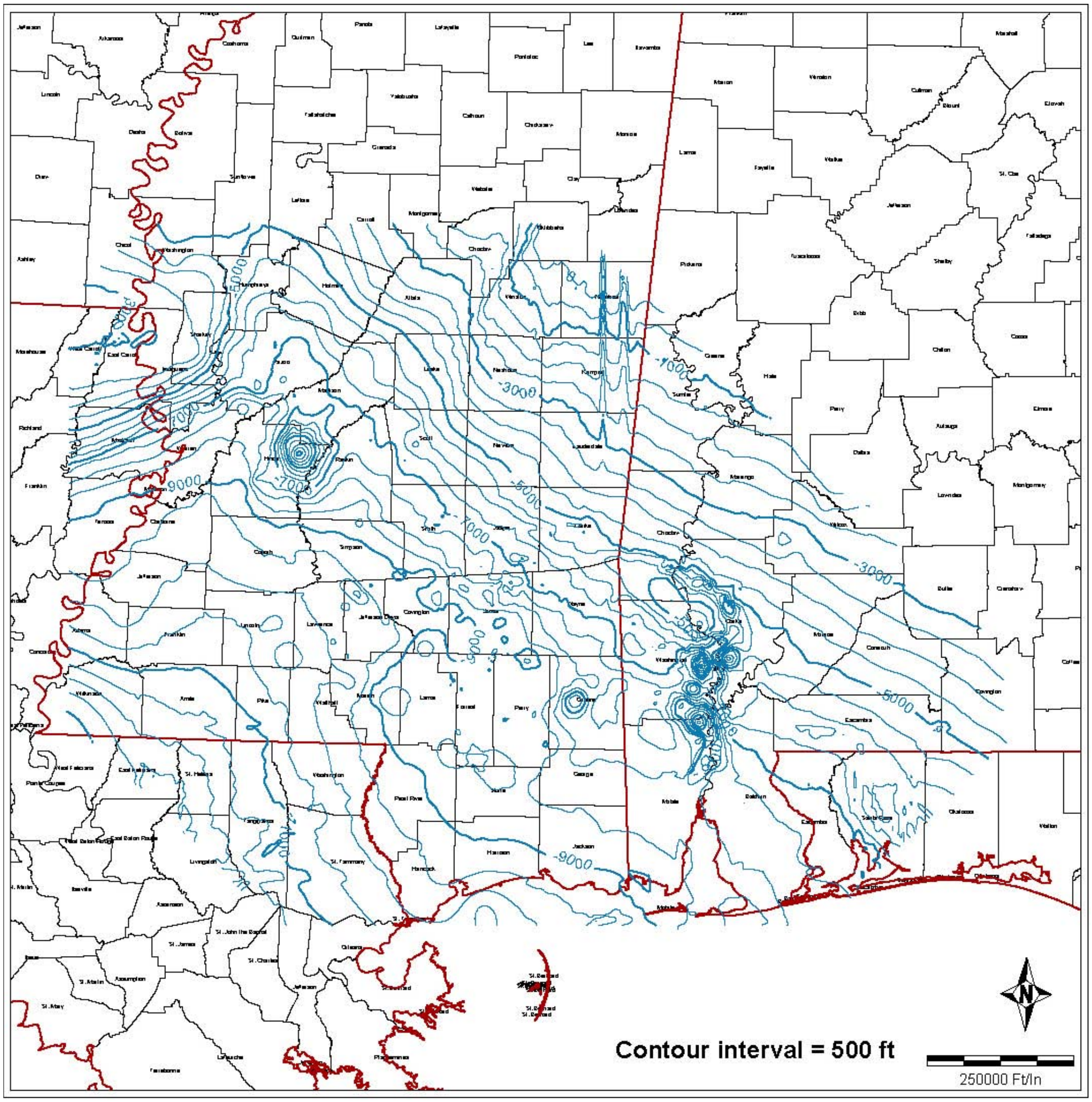


Figure 31. Structure contour map on top of the Lower Cretaceous, Mississippi Interior Salt Basin and Conecuh and Manila Subbasins. Prepared by P. Li.

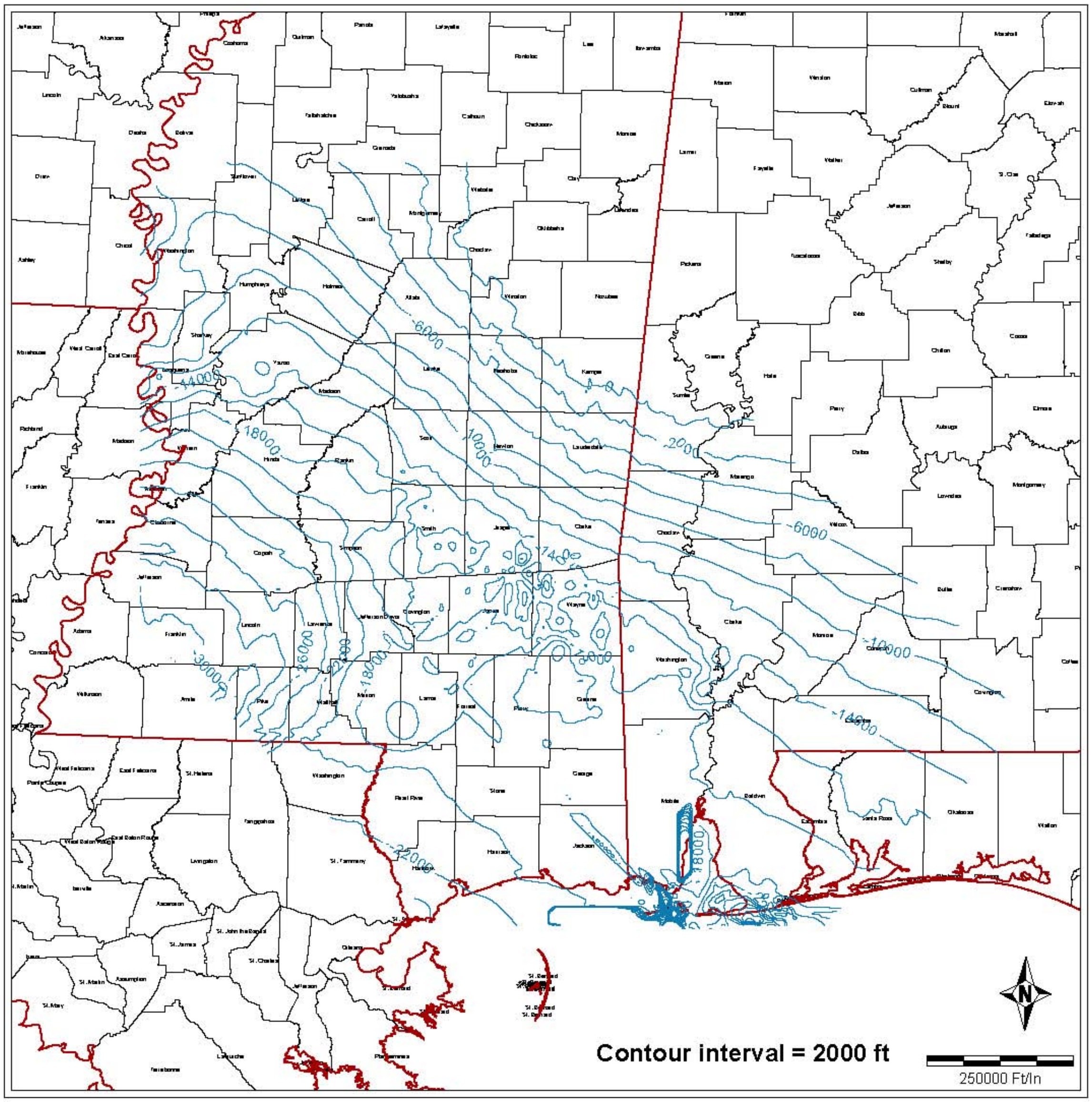


Figure 32. Structure contour map on top of Smackover Formation. Mississippi Interior Salt Basin and Conecuh and Manila Subbasins Prepared by P. Li.

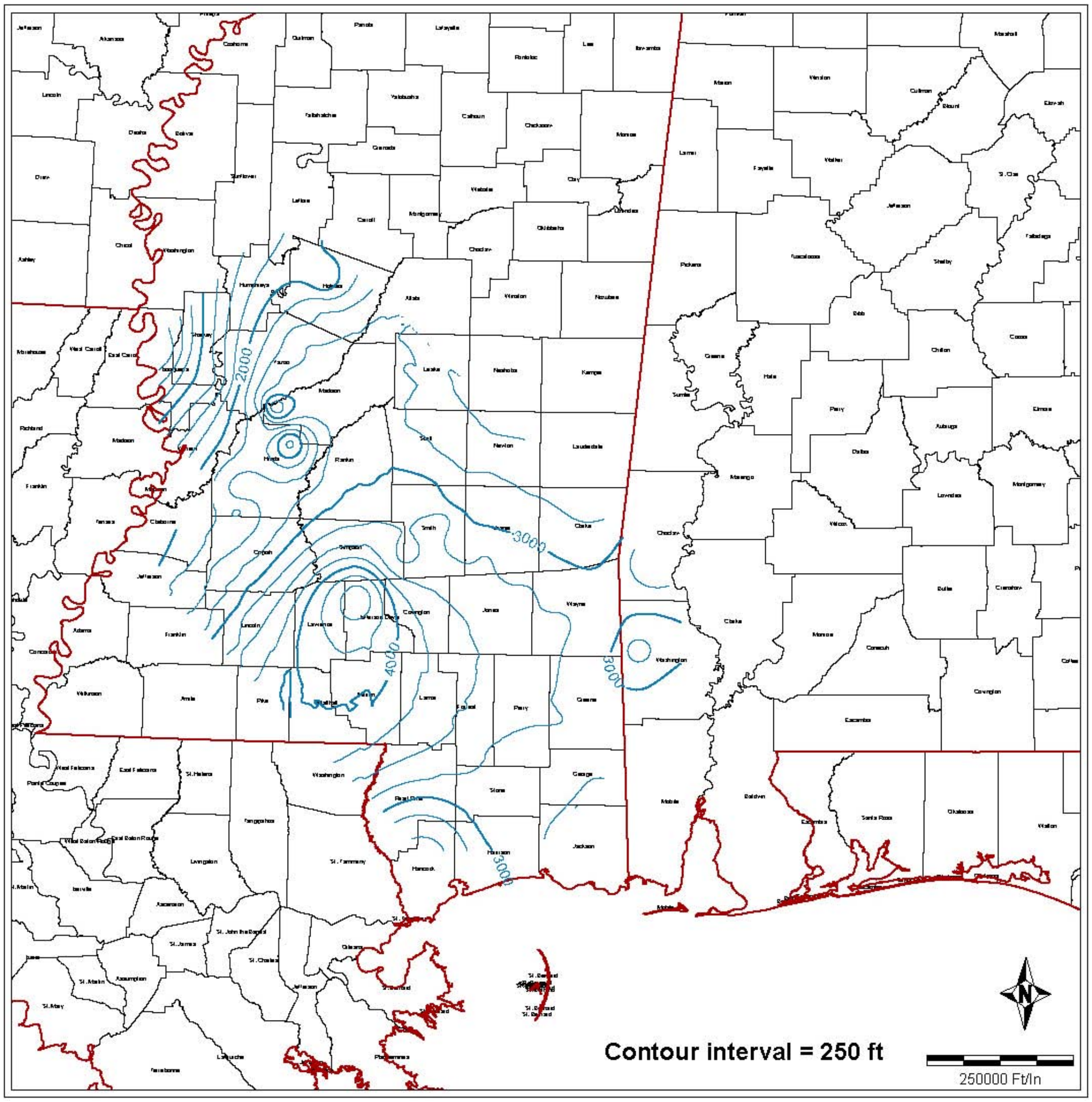


Figure 33. Isopach map of the interval from top of the Lower Cretaceous to the top of the Upper Cretaceous, Mississippi Interior Salt Basin. Prepared by P. Li.

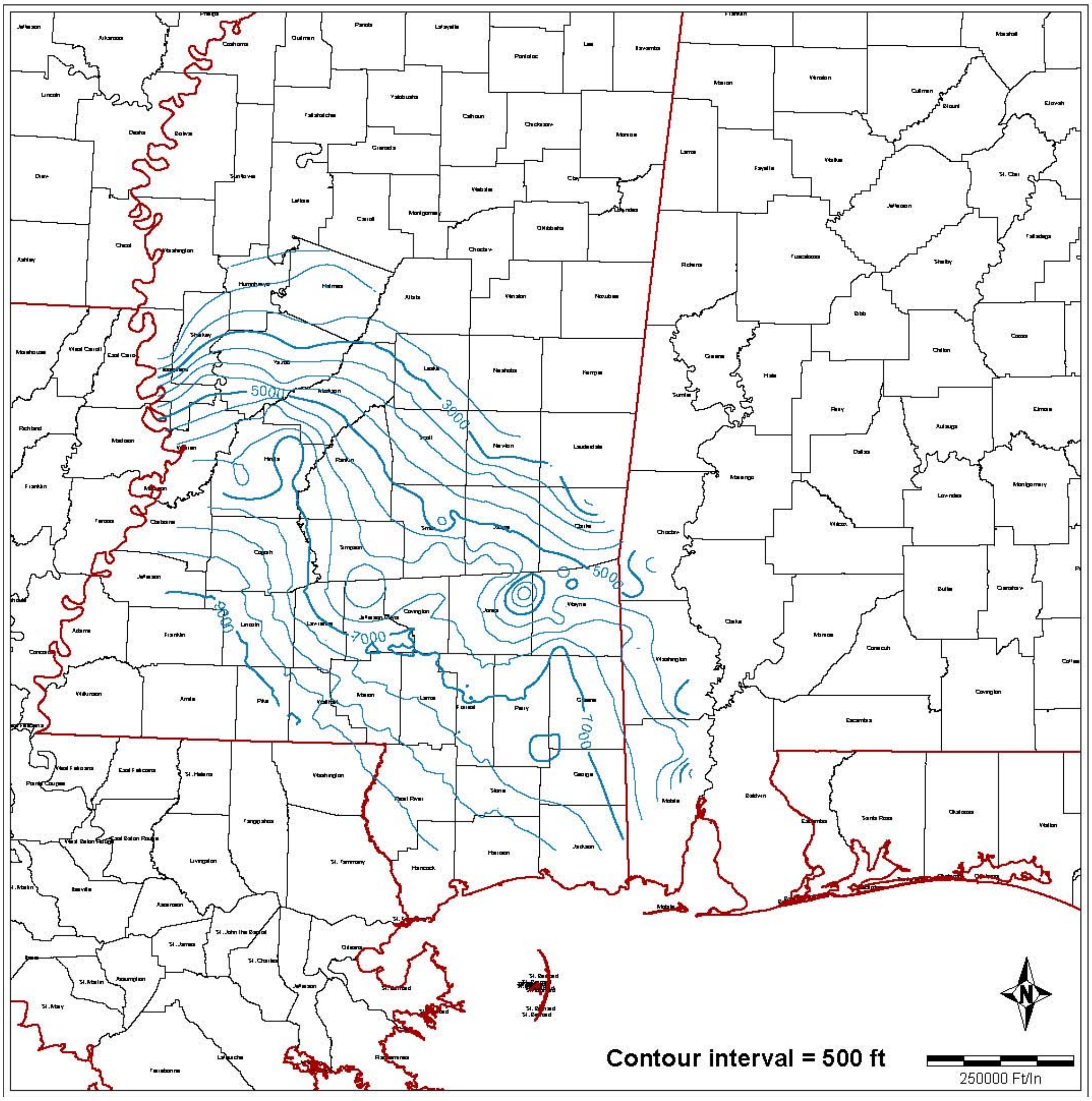


Figure 34. Isopach map of the interval from top of the Cotton Valley to the top of the Lower Cretaceous, Mississippi Interior Salt Basin. Prepared by P. Li.

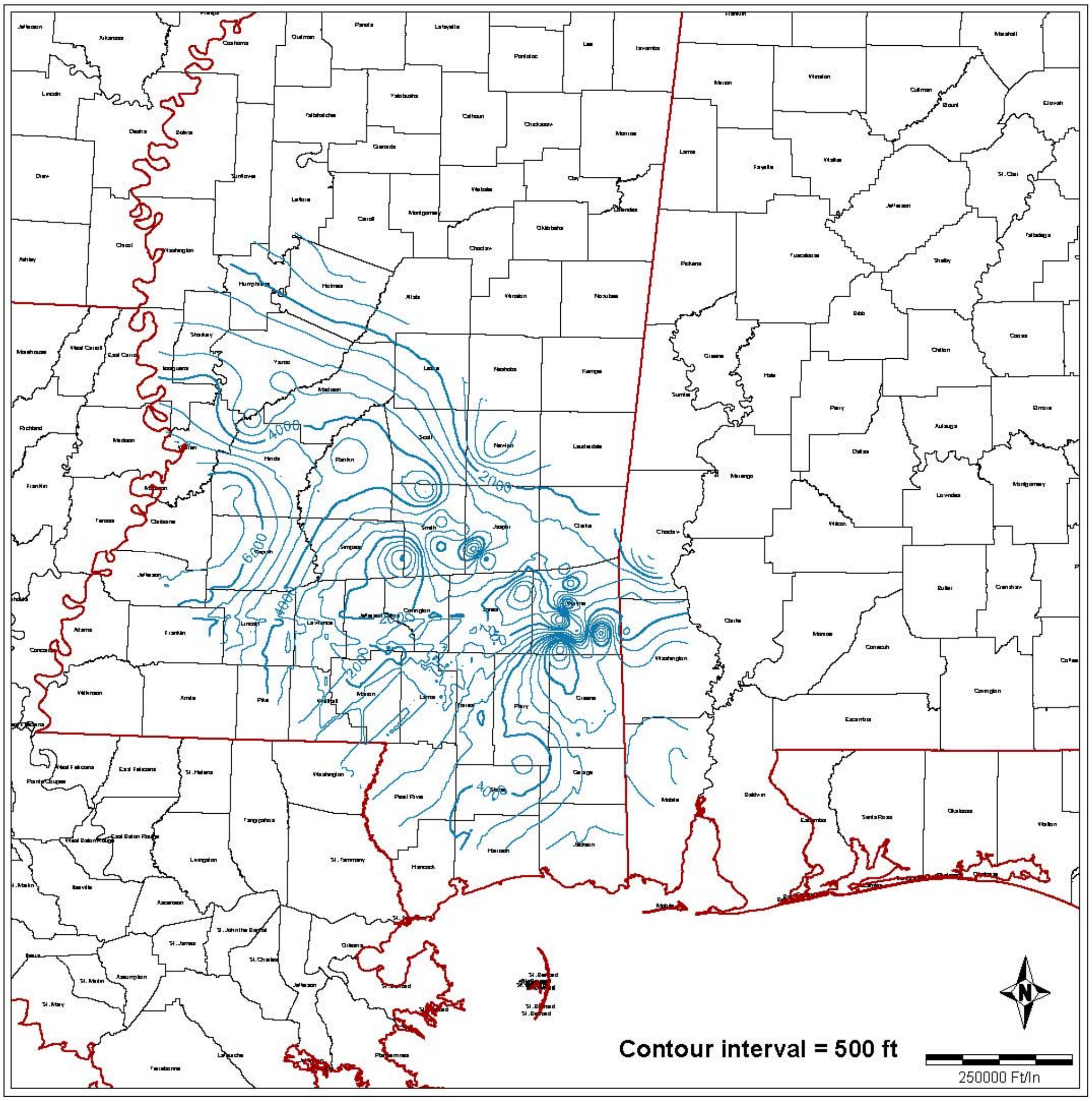


Figure 35. Isopach map of the interval from top of the Smackover to the top of the Cotton Valley, Mississippi Interior Salt Basin. Prepared by P. Li.

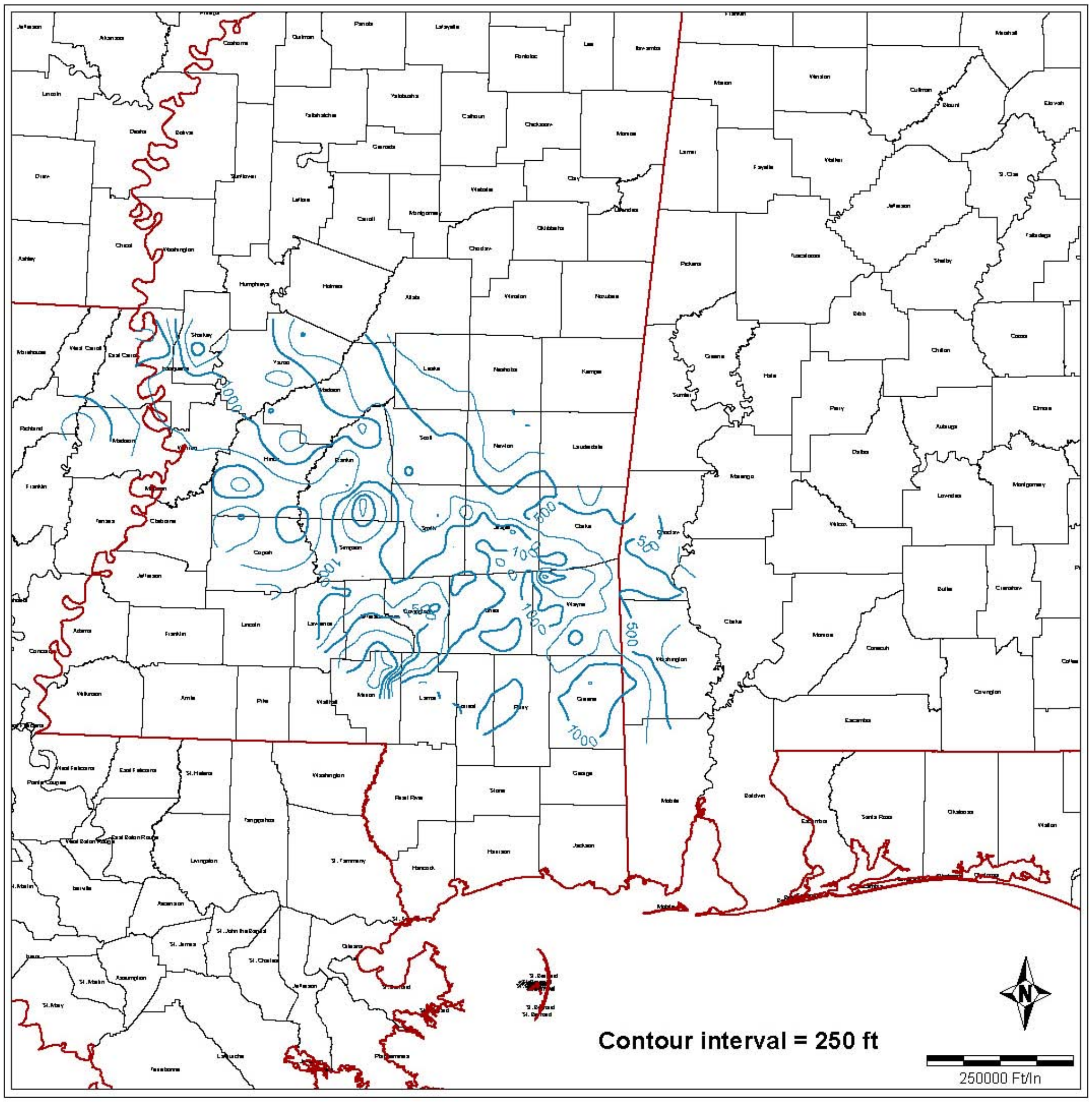


Figure 36. Isopach map of the interval from top of the Norphlet to the top of the Smackover, Mississippi Interior Salt Basin. Prepared by P. Li.

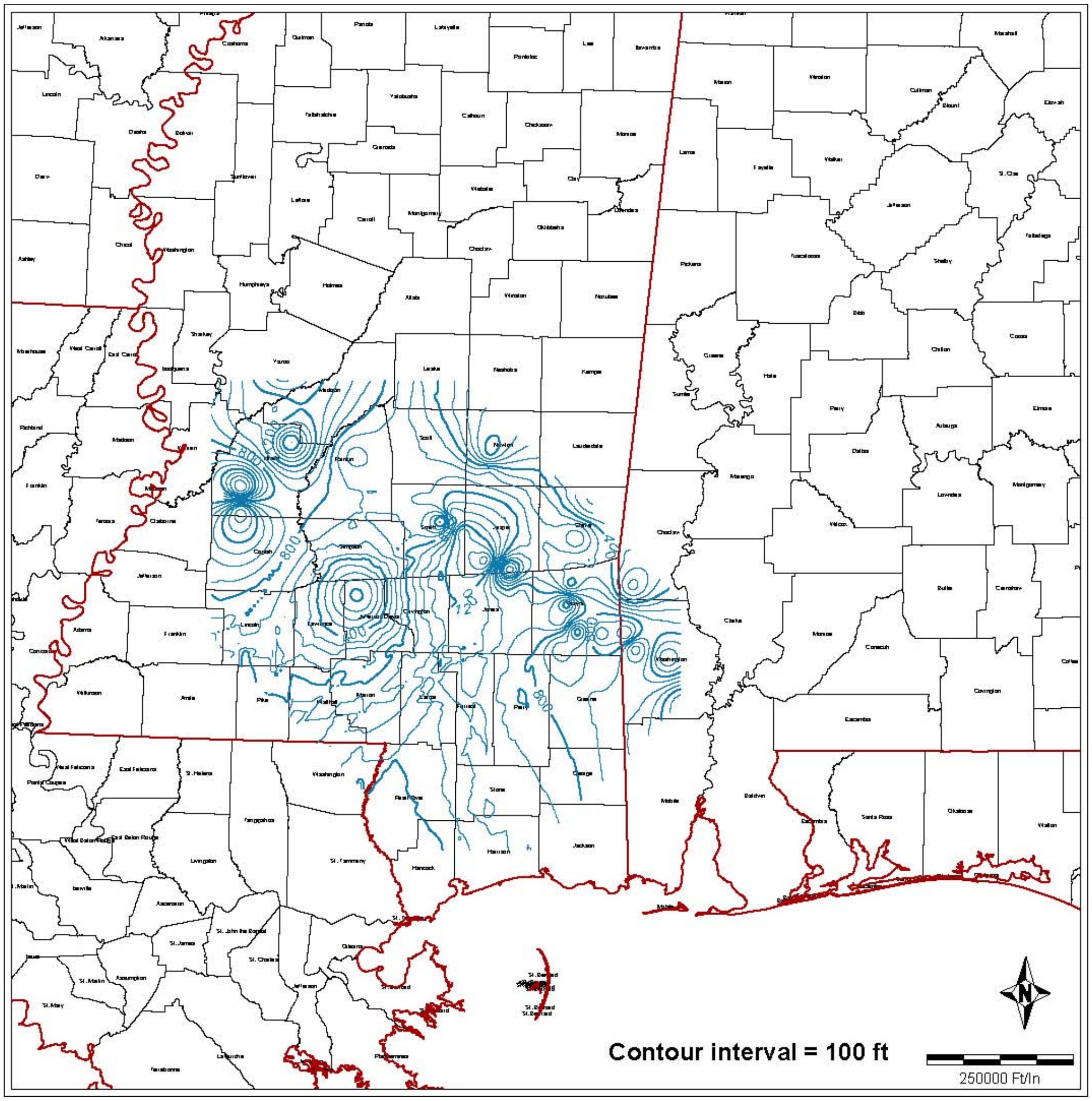


Figure 37. Isopach map of the interval from top of the Louann Salt to the top of the Smackover, Mississippi Interior Salt Basin. Prepared by P. Li.

Table 1. Organic Geochemical Analyses of Core Samples, Mississippi Interior Salt Basin*.

Well Name	County/State[1]	Depth (feet)	TOC (wt%)	Kerogen[2]	$\%R_o$[3]	T_{max} (°C)[4]	HI[5]
Weissinger Lumber #1	Issaquena+	8,451	0.36	Am/Al	2	430	66
Flora Johnson #1	Newton+	11,775	0.26	Am/Al	0.55	431	134
Masonite 25-14	Clarke +	14,586	0.24	Am/Al	0.9	429	91
USA Rubie Bell #1	Scott+	14,902	0.48	Am/Al	0.9	431	137
Bishop-Cooley #1	Wayne+	15,541	1.35	Am/Al	1.5	427	27
R. M. Thomas #1	Smith+	16,554	0.27	Am/Al	1.5	432	62
Grief Bros. #1	Jasper+	17,015	0.44	Am/Al	0.55	433	54
McFarland #1	Jones+	19,865	0.28	Am/Al	1.5	410	25
Crain et al. 1-4	Rankin+	20,179	0.24	Am/Al	2	420	50
Crown Zellerbach #1	Simpson+	23,981	4.55	Am/Al	2	367	23
Jackson #1	Choctaw++	10,532	0.30	Am/Al	0.45	--	--
Bolinger 3-4	Choctaw++	10,610	0.07	Am/Al	0.45	--	42
Stewart 6-5	Choctaw++	12,245	0.24	Am/Al	0.45	--	22
Britton #1	Washington++	16,101	0.08	Am/Al	1.5	--	12
Chatom 2-01	Washington++	16,167	0.19	Am/Al	1.5	--	10
Foster 10-6	Washington++	19,359	0.25	Am/Al	1.5	--	4

[1]State: +Mississippi, ++Alabama.
[2]Kerogen: Am=Amorphous, Al=Algal (microbial).
[3]$\%R_o$: Vitrinite reflectance ($\%R_o$) was determined by converting TAI values to R_o values using the conversion chart of Geochem Laboratories
[4]T_{max}: temperature index.
[5]HI: hydrogen index.

*Data from Mancini et al. (2003).

Table 2. Organic Geochemical Analyses of Core Samples, Manila and Conecuh Subbasins*.

Well Permit No.	County/ Area[1]	Rock Unit[2]	Depth (feet)	Car-bonate (%)	Organic Carbon (%)	S1+S2 Yield (mg/g)	Trans-forma-tion Ratio	Temp Max Yield (°C)	H Index	Kero-gen Type[3]	TAI 1-5 Scale	Bitu-men (ppm)	Hydro-car-bons (ppm)	HC/ org C[4]	Satu-rate/ Aro-matic Ratio	Pris-tane/ Phy-tane	CPI	$\delta^{13}C$ Satu-rate (%)	$\delta^{13}C$ Aro-matic (%)
355	Esc	Tus	5,814	2.30	1.18	1.11	0.05	416	89	Am(Al)	2-	634	338	2.90	3.50	>1	>1	-26.40	-24.50
427	Esc	Tus	6,080	51.00	2.63	7.38	0.02	431	273	Am(Al)	2-	1,440	630	2.10	1.90	>1	>1	-26.30	-25.30
2182	Cla	Tus	5,271	15.60	2.75	7.75	0.01	415	277	Am(Al)	2-	1,050	540	2.00	2.30	<1	>1	-26.20	-24.60
3299	Bal	Hay	15,002	--	0.05	--	--	--	--	--	--	--	--	--	--	--	--	--	--
735	Cla	Smk	11,155	85.10	0.29	0.28	0.46	425	51	Am(Al)	2-	395	164	5.60	3.60	>1	1	-27.40	-24.30
1438	Cla	Smk	10,980	99.00	0.11	0.08	0.12	426	63	Am(Al)	2-	48	28	2.50	2.80	1	>1	-27.50	-26.80
3648	Cla	Smk	13,488	59.20	0.28	0.27	0.19	433	78	Am(Al)	2	235	164	5.90	3.30	>1	>1	-26.50	-24.60
1352	Mon	Smk	9,221	--	0.04	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1592	Mon	Smk	14,245	75.00	0.54	0.47	0.17	433	72	Am	2+	449	266	4.90	2.10	<1	>1	-24.00	24.90
4673	Mon	Smk	14,596	94.20	0.05	0.03	0.50	--	40	--	--	--	--	--	--	--	--	--	--
1584	Bal	Smk	16,225	--	0.42	--	--	--	--	Am	2	--	--	--	--	--	--	--	--
2075	Bal	Smk	18,335	89.20	0.49	0.30	0.43	--	34	Am	3-	327	322	6.60	16.10	1	1	-26.40	-25.90
2587	Bal	Smk	19,860	95.80	0.20	0.04	0.25	--	15	Am(Al)	3+	37	27	1.40	5.20	<1	1	-27.80	-25.50
2621	Bal	Smk	18,470	78.60	1.17	0.10	0.20	506	6	Am	3	97	52	0.40	3.00	1	1	26.90	-25.90
2915	Bal	Smk	19,409	95.20	0.88	0.03	0.00	--	3	Am	3+	--	--	--	--	--	--	--	--
1460	Esc	Smk	15,304	87.90	0.33	0.27	0.58	455	36	--	--	382	215	6.50	4.40	<1	1	-25.80	-24.50
1674	Esc	Smk	16,003	84.50	0.32	0.08	0.37	424	15	Am	2+	127	81	2.50	3.30	1	1	-25.90	-25.50
1766	Esc	Smk	15,326	98.30	0.26	0.19	0.44	--	42	Am(Al)	2+	119	118	4.60	5.30	>1	1	-26.70	-24.80
1770	Esc	Smk	15,637	90.70	0.99	0.95	0.44	444	54	Am	2+	823	617	6.20	7.10	<1	1	-24.60	-22.10
1837	Esc	Smk	15,619	97.90	0.17	0.04	0.50	411	11	--	--	--	--	--	--	--	--	--	--
1895	Esc	Smk	15,611	87.10	0.91	0.64	0.34	448	46	Am(Al)	2+	428	323	3.50	7.30	>1	1	-24.30	-22.40
2041	Esc	Smk	14,742	76.70	1.35	1.61	0.38	431	74	Am	2	1,410	1,110	8.20	6.20	<1	<1	-23.60	-22.80
2991	Esc	Nor	15,496	18.40	0.17	0.03	0.50	--	11	--	--	24	6	0.40	34.00	1	1	--	--
3402	Esc	Smk	15,514	77.70	1.05	0.52	0.42	440	28	--	--	581	411	3.90	6.50	>1	1	-25.10	-24.20
3900	Esc	Smk	15,301	90.70	0.91	0.63	0.47	446	37	Am	2+	489	365	4.00	11.20	>1	<1	-22.90	-21.40
4395	Esc	Nor	14,914	1.00	0.07	0.11	0.30	--	114	--	--	69	49	7.00	4.70	>1	<1	-29.00	-25.10

[1]County: Bal=Baldwin, Cla=Clarke, Esc=Escambia, Mon=Monroe.

[2]Unit: Tus=Tuscaloosa, Hay=Haynesville, Smk=Smackover, Nor=Norphlet.

[3]Kerogen: Am=Amorphous, Al=Algal (microbial).

[4]HC/org C=hydrocarbon/organic carbon.

*Data from Claypool and Mancini (1989).

Table 3. Organic geochemical analyses of potential source rocks, North Louisiana Salt Basin.

Sample no.	Well	Parish	Depth (ft)	Unit[1]	TOC (%)	Kerogen[2]	TAI	$\%R_o$	Tmax[3] (°C)	S1[4] (mg/g)	S2[5] (mg/g)	S3[6] (mg/g)	PI[7]	PC[8]	HI[9]	OI[10]
*1	George Franklin #1	Richland	11,690.50	Smk	0.16	Am	3.3	1.45	334	0.06	0.08	0.35	0.43	0.00	50	218
*2	George Franklin #1	Richland	11,770.00	Smk	0.25	Am	3.4	1.54	344	0.13	0.09	0.16	0.59	0.02	36	64
*3	Colvin #2	Lincoln	10,856.00	Smk	0.32	H	3.2	1.37	333	0.16	0.15	0.38	0.52	0.03	47	119
*4	McGehee #1	Lincoln	13,439.00	Smk	0.78	Am/H	3.6	1.71	286	0.20	0.10	1.10	0.67	0.02	13	141
*5	McGehee #1	Lincoln	13,602.00	Smk	0.38	Am/H	3.6	1.71	314	0.09	0.04	0.36	0.69	0.01	11	95
*6	Bearden #1	Union	10,170.00	Smk	0.14	H	3.0	1.22	288	0.11	0.04	0.16	0.73	0.01	29	114
*7	B-1 Hamiter	Bossier	10,568.00	Smk	0.19	H	2.8	1.07	318	0.13	0.06	0.24	0.68	0.02	32	126
*8	Waller #1	Claiborne	10,390.00	Smk	0.18	Am	2.8	1.07	323	0.06	0.04	0.48	0.60	0.01	22	267
*9	Sherman #1	Claiborne	10,216.00	Smk	0.24	Am/H	2.8	1.07	430	0.20	0.14	0.18	0.59	0.03	58	75
*10	Dillon Heirs	Caddo	7,015.00	CV	0.41	Am	2.4	0.80	432	0.32	0.35	1.12	0.48	0.05	85	273
*11	F. Wappler	Caddo	8,683.00	CV	0.75	Am	2.5	0.86	370	0.17	0.58	0.54	0.23	0.06	77	72
*12	F. Wappler	Caddo	8,793.00	CV	0.62	Am/H	2.5	0.86	336	0.09	0.05	0.72	0.64	0.01	8	116
*13	F. Wappler	Caddo	8,801.00	CV	1.80	H	2.5	0.86	441	0.30	2.71	0.42	0.10	0.25	151	23
*14	F. Wappler	Caddo	9,351.00	CV	0.62	H	2.5	0.86	375	0.19	0.20	0.60	0.49	0.03	32	97
*15	L. Enloe	Claiborne	10,714.00	Smk	0.19	H/W	3.0	1.22	308	0.21	0.10	0.94	0.68	0.03	53	495
*16	Bankston	Franklin	14,656.00	CV	0.35	Am	3.5	1.62	293	0.17	0.09	0.65	0.65	0.02	26	186
*17	Davis Bros.	Jackson	10,944.00	Boss	0.46	H	2.9	1.14	331	0.14	0.12	0.09	0.54	0.02	26	20
*18	Davis Bros.	Jackson	12,956.00	Boss	0.43	H	3.0	1.22	304	0.10	0.08	0.22	0.56	0.01	19	51
*19	Davis Bros.	Jackson	12,976.00	Boss	0.61	H	3.1	1.29	313	0.11	0.07	0.02	0.61	0.01	11	3
*20	C. Atkins	Natchitoches	11,203.00	GR	0.10	Am	2.9	1.14	288	0.09	0.03	0.36	0.75	0.01	30	360
*21	Huffman-McNeely	Natchitoches	17,480.00	CV	0.11	Am	3.7	1.80	325	0.06	0.04	0.18	0.60	0.01	36	164
*22	J. Bentley	Rapides	12,911.00	Sligo	0.23	Am/H	3.1	1.29	365	0.10	0.10	0.23	0.50	0.02	43	100
*23	J. Bentley	Rapides	12,948.00	Sligo	0.45	Am/H	3.1	1.29	408	0.00	0.07	0.35	0.00	0.01	16	78
*24	Chicago Mill	Tensas	14,876.00	Hoss	1.69	H	3.1	1.29	519	0.04	0.09	0.16	0.31	0.01	5	9
*25	Chicago Mill	Tensas	15,520.00	Hoss	4.09	H	3.1	1.29	524	0.04	0.20	0.05	0.17	0.02	5	1
*26	Chicago Mill	Tensas	15,560.00	Hoss	0.51	H	3.1	1.29	333	0.06	0.06	0.07	0.50	0.01	12	14
*27	N. Manning	Union	16,016.00	p-salt	0.26	Am	3.4	1.54	311	0.03	0.03	0.15	0.50	0.00	12	58
*28	N. Manning	Union	16,057.00	p-salt	0.18	Am	3.7	1.80	252	0.01	0.00	0.29	1.00	0.00	0	161
*29	N. Manning	Union	16,074.00	p-salt	0.13	Am	3.8	1.89	252	0.01	0.00	0.12	1.00	0.00	0	92
*30	Frazier Unit	Webster	10,874.00	Smk	0.24	H	2.9	1.14	318	0.18	0.13	0.59	0.58	0.03	54	246
*31	Frazier Unit	Webster	11,250.00	Smk	0.21	H	3.0	1.22	411	0.06	0.10	0.24	0.38	0.01	48	114
*32	H. Davis	Webster	11,043.00	Smk	0.28	Am/H	3.2	1.37	380	0.02	0.03	0.15	0.40	0.00	11	54
*33	H. Davis	Webster	11,243.00	Smk	0.16	Am	3.4	1.54	305	0.01	0.01	0.15	0.50	0.00	6	94
*34	CZ 10-11	Winn	13,690.00	CV	0.57	Am	3.7	1.80	276	0.03	0.03	0.22	0.50	0.00	5	39
*35	CZ 10-11	Winn	13,804.00	CV	0.47	Am/H	3.7	1.80	252	0.03	0.01	0.21	0.75	0.00	2	45
*36	CZ 10-11	Winn	13,924.00	CV	0.48	Am	3.7	1.80	252	0.01	0.01	0.02	0.50	0.00	2	4
*37	CZ 10-11	Winn	13,946.00	CV	0.30	Am/I	3.7	1.80	354	0.03	0.05	0.13	0.38	0.01	17	43
*38	CZ 5-7	Winn	15,608.00	Boss	0.28	I	3.7	1.80	307	0.02	0.04	0.00	0.33	0.00	14	0
*39	CZ 5-7	Winn	16,418.00	Boss	0.34	I	3.8	1.89	355	0.05	0.07	0.11	0.42	0.01	21	32
*40	CZ 5-7	Winn	16,431.00	Boss	0.34	W/I	3.8	1.89	329	0.06	0.10	0.37	0.38	0.01	29	109
*41	Pardee	Winn	16,200.00	Boss	0.35	Am/I	3.7	1.80	322	0.21	0.29	0.29	0.42	0.04	83	83
*42	Pardee	Winn	16,400.00	Boss	0.35	Am/I	3.7	1.80	328	0.19	0.16	0.16	0.54	0.03	46	46
**43	REF. #1	Bienville	5,819.00	Rodessa	0.46	Am	2.9	1.14	413	0.04	0.17	0.39	0.19	0.02	37	85
**44	REF. #1	Bienville	7,547.00	Hoss	0.17	Am	3.2	1.37	333	0.03	0.02	0.10	0.60	0.00	12	59
**45	Southern Nat Gas #2	Bienville	10,802.00	CV	0.43	H	3.4	1.54	423	0.11	0.04	0.46	0.73	0.01	9	107
**46	Lawhorn Amoco #1	Bienville	10,774.00	CV	1.25	H	2.3	0.74	479	0.06	0.23	0.27	0.20	0.02	18	22
**47	Wheless #1	Claiborne	11,866.00	Smk	0.32	H	2.7	1.00	378	0.14	0.09	0.20	0.60	0.02	28	62
**48	Bob #1	Claiborne	10,707.00	Smk	0.36	H	2.8	1.07	452	0.04	0.07	0.08	0.36	0.01	19	22
**49	Expl Ipco #1	De Soto	10,364.00	CV	0.48	W/I	2.7	1.00	473	0.11	0.18	0.15	0.37	0.02	38	31
**50	Davis #1	Jackson	11,188.00	CV	0.31	Am/H	2.5	0.86	394	0.07	0.04	0.05	0.63	0.01	13	16

Table 3. Organic geochemical analyses of potential source rocks, North Louisiana Salt Basin (continuation).

**51	Parnell #1	Lincoln	9,127.00	CV	0.60	H	2.4	0.80	436	0.31	0.60	0.57	0.34	0.08	100	95
**52	James #1	Lincoln	10,443.00	CV	0.12	H	3.2	1.37	412	0.05	0.03	0.23	0.62	0.01	25	192
**53	Crown-Zellerbach #1	Natchitoches	13,421.00	Smk	0.09	H	3.7	1.80	361	0.36	0.31	0.43	0.54	0.06	344	478
**54	Godfrey "B" #1	Natchitoches	13,305.00	Smk/Nor	1.80	H	3.7	1.80	341	0.94	0.28	0.66	0.77	0.10	16	37
**55	Terzia F. C. #1	Ouachita	10,193.00	CV	1.65	H	2.4	0.80	450	0.41	0.82	0.29	0.33	0.10	50	18
**56	Webb #1	Ouachita	9,620.00	CV	0.20	Am/H	2.3	0.74	429	0.10	0.18	0.09	0.35	0.02	90	45
**57	Kennedy #2	Ouachita	9,915.00	CV	0.76	Am/H	2.4	0.80	443	0.21	0.96	0.17	0.18	0.10	127	23
**58	Teer #1	Red River	14,060.00	Smk/Nor	1.22	H/I	3.8	1.89	418	0.94	0.29	0.27	0.77	0.10	24	22
**59	Sample #1	Red River	9,676.00	CV	0.45	H	2.7	1.00	410	0.19	0.23	0.15	0.45	0.03	51	33
**60	Sample #2	Red River	9,911.00	CV	0.29	H	2.7	1.00	431	0.09	0.13	0.14	0.40	0.02	45	48
**61	Green #1	Union	10,683.00	Smk	0.08	H	3.0	1.22	378	0.04	0.12	0.18	0.25	0.01	150	225
**62	Green #1	Union	10,825.00	Smk	0.12	H	3.7	1.80	400	0.02	0.09	0.46	0.17	0.01	75	383
**63	Phillip #1	Webster	10,290.00	CV	1.07	H	2.7	1.00	455	0.28	0.71	0.29	0.28	0.08	66	27
**64	Phillip #1	Webster	10,640.00	CV	0.25	H/I	2.7	1.00	450	0.05	0.15	0.10	0.25	0.02	60	40
**65	Huffman-Mcneely #1	Natchitoches	7,685.00	Austin	0.26	H	2.5	0.86	433	0.24	2.45	0.41	0.09	0.22	942	158
**66	Huffman-Mcneely #1	Natchitoches	9,747.00	Moor	1.00	H/I	2.7	1.00	437	0.05	0.10	0.13	0.32	0.01	10	13
**67	Huffman-Mcneely #1	Natchitoches	11,771.00	James	0.17	H	2.7	1.00	349	0.01	0.00	0.13	1.00	0.00	_ _	76
**68	Huffman-Mcneely #1	Natchitoches	15,507.00	Sligo	0.23	H	3.2	1.37	369	0.04	0.04	0.07	0.49	0.01	17	30
**69	English #2	Bossier	9,382.00	CV	0.29	I	2.5	0.86	439	0.04	0.15	0.11	0.20	0.02	52	38
**70	English #2	Bossier	9,432.00	CV	0.32	H	2.5	0.86	443	0.08	0.40	0.14	0.16	0.04	125	44
**71	English #2	Bossier	11,136.00	Boss	0.55	W/I	2.7	1.00	515	0.08	0.23	0.24	0.26	0.03	42	44
**72	English #2	Bossier	11,168.00	Boss	0.91	Am/H	2.7	1.00	498	0.25	0.25	0.40	0.50	0.04	27	44
**73	First Bank #1	Bossier	11,108.00	Boss	0.35	W/I	2.9	1.14	482	0.06	0.11	0.17	0.34	0.01	31	49
**74	First Bank #1	Bossier	11,173.00	Smk	0.47	W/I	2.9	1.14	381	0.09	0.13	0.00	0.40	0.02	28	_ _
**75	First Bank #1	Bossier	11,178.00	Smk	0.80	W/I	2.9	1.14	515	0.11	0.33	0.00	0.25	0.04	41	_ _
***76	Fee Gas #1	Union	9,887.00	Smk	0.08	_ _	_ _	_ _	422	0.04	0.03	0.34	0.57	0.01	37	425
***77	Fee Gas #1	Union	9,901.00	Smk	0.12	_ _	_ _	_ _	385	0.02	0.02	0.17	0.50	0.00	17	142
***78	Fee Gas #1	Union	9,911.00	Smk	0.06	_ _	_ _	_ _	280	0.01	0.00	0.22	1.00	0.00	_ _	367
***79	Aycock #1	Richland	2,692.00	Arka	0.05	_ _	_ _	_ _	376	0.01	0.00	0.35	1.00	0.00	_ _	700
***80	Aycock #1	Richland	7,894.00	Smk	0.09	_ _	_ _	_ _	330	0.03	0.01	0.13	0.75	0.00	11	144
***81	Jackson #1	West Carrol	2,726.00	Arka	0.06	_ _	_ _	_ _	412	0.03	0.08	0.20	0.27	0.02	133	333
***82	GH Cooper #1	East Carrol	7,077.00	Smk	0.07	_ _	_ _	_ _	350	0.02	0.01	0.24	0.66	0.02	14	343
***83	GH Cooper #1	East Carrol	7,093.00	Smk	0.06	_ _	_ _	_ _	318	0.03	0.04	0.20	0.43	0.02	67	333
***84	GH Cooper #1	East Carrol	7,107.00	Smk	0.09	_ _	_ _	_ _	366	0.01	0.05	0.15	0.17	0.02	56	167
***85	Hope Fee #1	Morehouse	5,972.50	Smk	0.18	_ _	_ _	_ _	434	0.03	0.05	0.29	0.38	0.03	28	161
***86	Hope Fee #1	Morehouse	6,116.50	Smk	0.33	Lip	2.2	0.63	433	0.08	0.25	0.43	0.24	0.06	76	130
***87	Hope Fee #1	Morehouse	6,210.50	Smk	0.48	Lip	2.2	0.60	420	1.19	0.70	0.39	0.63	0.09	146	81
***88	Hope Fee #1	Morehouse	6,304.50	Smk	0.38	Lip	2.3	0.66	432	0.19	0.43	0.25	0.31	0.06	113	66
***89	Hope Fee #1	Morehouse	6,530.50	Smk	0.84	Lip	2.3	0.70	434	0.32	1.43	0.52	0.18	0.16	170	62
***90	Hope Fee #1	Morehouse	6,609.50	Smk	1.47	Lip	2.3	0.69	436	0.51	3.12	0.35	0.14	0.29	212	24
***91	Hope Fee #1	Morehouse	6,649.50	Smk	1.41	Lip	2.0	0.51	431	0.61	4.85	0.36	0.11	0.43	344	26
***92	Hope Fee #1	Morehouse	6,725.50	Smk	0.31	Lip	_ _	_ _	431	0.10	0.17	0.52	0.37	0.06	55	168
***93	Smith #1	Claiborne	10,808.00	Smk	0.40	Lip	3.0	1.03	470	0.10	0.14	0.64	0.42	0.06	35	160
***94	Smith #1	Claiborne	10,836.00	Smk	0.29	Lip	3.0	0.99	358	0.08	0.05	0.68	0.61	0.06	17	234
***95	Smith #1	Claiborne	10,866.00	Smk	3.02	Vit	2.5	0.85	448	1.62	1.12	0.6	0.59	0.14	37	20
***96	Smith #1	Claiborne	10,875.00	Smk	3.30	Vit	2.6	0.89	446	1.69	1.63	0.64	0.51	0.19	49	19
***97	Smith #1	Claiborne	10,899.00	Smk	8.42	Vit	2.5	0.83	450	1.63	3.12	0.89	0.34	0.33	37	11
***98	Smith #1	Claiborne	10,920.00	Smk	0.54	Lip	2.6	0.91	453	0.16	0.20	0.77	0.45	0.08	37	143
***99	Lowery #1	Union	10,661.00	Smk	1.23	Lip	2.6	0.90	448	0.79	1.16	0.84	0.41	0.17	94	68
***100	Lowery #1	Union	10,666.00	Smk	0.88	Lip	2.7	0.94	448	0.47	0.68	0.54	0.41	0.10	77	61
***101	Lowery #1	Union	10,676.00	Smk	1.00	Lip	2.7	1.02	447	0.61	0.77	0.49	0.44	0.10	77	49
***102	Manville Forest #1	Webster	11,494.00	Smk	0.64	Vit	3.2	1.23	450	0.13	0.14	0.42	0.48	0.05	22	66
***103	Manville Forest #1	Webster	11,567.00	Smk	0.37	Lip	3.4	1.47	439	0.08	0.05	0.27	0.62	0.03	14	73
***104	Manville Forest #1	Webster	11,618.00	Smk	0.49	Lip	3.4	1.47	422	0.09	0.04	0.48	0.69	0.04	8	98
***105	Waller #1	Claiborne	10,313.00	Smk	0.32	Lip	3.0	1.03	436	0.11	0.15	0.34	0.42	0.04	47	106

Table 3. Organic geochemical analyses of potential source rocks, North Louisiana Salt Basin (continuation).

***106	Waller #1	Claiborne	10,484.00	Smk	0.27	Lip	3.0	1.04	434	0.12	0.04	0.26	0.75	0.02	15	96
***107	Yates A1	Claiborne	10,410.00	Smk	0.42	Lip	2.2	0.59?	448	0.30	0.21	0.22	0.59	0.04	50	52
***108	Yates A1	Claiborne	10,476.00	Smk	0.22	Lip	3.0	1.03	429	0.06	0.01	0.22	0.86	0.02	5	100
***109	Turner #1	Claiborne	10,175.00	Smk	0.11	Lip	_ _	_ _	399	0.07	0.06	0.2	0.54	0.02	55	182
***110	Turner #1	Claiborne	10,254.00	Smk	0.14	Lip	2.3	0.70	333	0.09	0.07	0.17	0.57	0.02	50	121
***111	Rockhold #1	Claiborne	9,893.00	Smk	0.34	Lip	2.5	0.79	455	0.07	0.07	0.48	0.50	0.05	21	141
***112	Rockhold #1	Claiborne	9,928.00	Smk	0.45	Lip	2.5	0.78	445	0.12	0.29	0.49	0.29	0.06	64	109
***113	Barrett #1	Union	10,549.00	Smk	0.22	_ _	_ _	_ _	448	0.08	0.03	0.24	0.73	0.02	14	109
***114	Barrett #1	Union	10,575.00	Smk	0.12	_ _	_ _	_ _	359	0.04	0.00	0.65	1.00	0.05	_ _	542
***115	Elliot #1	Union	10,140.00	Smk	0.18	Lip	2.2	0.60	320	0.08	0.01	0.14	0.89	0.01	6	78
***116	Elliot #1	Union	10,310.00	Smk	0.13	_ _	_ _	_ _	256	0.05	0.00	0.22	1.00	0.02	_ _	169
***117	Elliot #1	Union	10,333.00	Smk	0.23	_ _	_ _	_ _	455	0.07	0.10	0.37	0.41	0.04	43	161
***118	Farris #1	Union	10,265.00	Smk	0.11	Lip	_ _	_ _	367	0.13	0.09	0.22	0.59	0.03	82	200
***119	Exxon #1	Union	8,522.00	Smk	0.12	Lip	_ _	_ _	331	0.04	0.01	0.36	0.80	0.03	8	300
***120	Parther Est #1	Claiborne	11,837.00	Smk	0.48	Lip	3.2	1.22	425	0.20	0.08	0.56	0.72	0.05	17	117
***121	Parther Est #1	Claiborne	11,947.00	Smk	0.53	Lip	3.2	1.27	441	0.18	0.12	0.15	0.60	0.02	23	28
***122	Gray Estate #1	Claiborne	10,278.00	Smk	0.22	Lip	2.6	0.85	432	0.08	0.07	0.23	0.53	0.02	32	105
***123	Gray Estate #1	Claiborne	10,306.00	Smk	0.28	Lip	2.5	0.82	390	0.09	0.02	0.15	0.82	0.01	7	54
***124	Bell #1 "B"	Claiborne	10,920.00	Smk	0.20	Lip	_ _	_ _	315	0.08	0.00	0.22	1.00	0.02	_ _	110
***125	Gibson A-1	Claiborne	11,140.00	Smk	0.24	Lip	_ _	_ _	422	0.13	0.13	0.16	0.51	0.02	54	67
***126	Gibson A-1	Claiborne	11,156.00	Smk	0.27	Lip	_ _	_ _	442	0.23	0.10	0.26	0.70	0.03	37	96
***127	Northcott #2	Bossier	11,530.00	Smk	0.21	Lip	2.2	0.56?	457	0.11	0.11	0.16	0.50	0.02	52	76
***128	Tinsley #1	Claiborne	11,817.00	Smk	1.17	Lip	3.1	1.17	491	0.18	0.31	0.41	0.36	0.06	26	35
***129	Tinsley #1	Claiborne	11,835.00	Smk	1.07	Lip	3.2	1.22	349	2.19	0.74	0.62	0.75	0.11	69	58
***130	Norman Dowling #1	Lincoln	12,642.00	Smk	1.03	Vit/Lip	3.4	1.49	403	7.10	1.05	0.74	0.87	0.15	102	72
***131	Norman Dowling #1	Lincoln	12,649.00	Smk	0.60	Vit/Lip	3.5	1.59	363	0.94	0.29	0.34	0.76	0.05	48	57
***132	Colvin #1	Lincoln	11,119.00	Smk	0.34	Lip	3.0	1.03	408	0.09	0.06	0.22	0.60	0.02	18	65
***133	Colvin #1	Lincoln	11,166.00	Smk	0.16	Lip	3.1	1.11	425	0.05	0.05	0.29	0.50	0.03	31	181
***134	Copeland "A"	Webster	11,288.00	Smk	0.81	Lip	3.0	1.04	492	0.11	0.25	0.4	0.30	0.05	31	49
***135	Copeland "A"	Webster	11,338.00	Smk	0.34	Lip	3.1	1.16	415	0.05	0.02	0.24	0.72	0.02	6	71
***136	Hearn "A"#1	Webster	11,558.00	Smk	0.46	Lip	3.1	1.19	367	0.11	0.02	0.1	0.84	0.01	4	22
***137	Hearn "A"#1	Webster	11,580.00	Smk	0.37	Lip	3.2	1.24	386	0.09	0.10	0.21	0.47	0.03	27	57
***138	Alston "A" #1	Webster	11,586.00	Smk	1.11	Vit	3.2	1.21	484	0.21	0.28	0.11	0.42	0.03	25	10
***139	Alston "A" #1	Webster	11,622.00	Smk	0.42	Lip	3.3	1.32	457	0.08	0.14	0.24	0.36	0.03	33	57
***140	Hearn "C"	Webster	11,930.00	Smk	0.94	Lip	3.2	1.20	514	0.18	0.21	0.16	0.46	0.03	22	17
***141	B #1	Webster	10,979.00	Smk	0.30	Lip	3.4	1.42	329	0.54	0.01	0.25	0.98	0.02	3	83
***142	B #1	Webster	11,095.00	Smk	0.30	Lip	3.6	1.63	283	0.06	0.00	0.11	1.00	0.01	_ _	37

1Unit: Smk=Smackover, Nor=Norphlet, CV=Cotton Valley, Boss=Bossier, GR=Glen Rose, Hoss=Hosston, p-salt=pre-salt, Moor=Mooringsport, Arka=Arkadelphia.
2Kerogen: Am=amorphous, H=herbaceous, W=woody, I=inertinite, Lip=Liptinite, Vit=Vitrinite.
GeoChem Laboratories Inc. and Baseline Resolution Inc. use different classification of visual kerogen.
3Tmax=temperature index.
4S1=free hydrocarbon.
5S2=residual hydrocarbon potential.
6S3=CO2 produced from kerogen pyrolysis.
7PI=S1/ (S1+S2).
8PC=0.083 (S1+S2).
9HI=hydrogen index.
10OI=oxygen index.
*****All data by GeoChem Laboratories Inc..
******TOC, Kerogen type, and TAI data by GeoChem Laboratories Inc., Rock Pyrolysis data by Baseline Resolution Inc..
*******All data by Baseline Resolution Inc..

Table 4. Stable Carbon and Oxygen Isotope Analysis.*

Well Name	Formation	$\delta^{18}O$ (‰VPDB)	$\delta^{13}C$ (‰VPDB)
Crosby et ux #8 lower case unit AL	Tuscaloosa	-7.18	0.82
Wall et al. #3-9 AL	Tuscaloosa	-6.12	1.35
Myrick Estate Gas Unit 802 #1 AL	Smackover	-0.6	1.98
Mary Higgins Unit 26-4 #1 AL	Smackover	-10.05	3.51
US Steel Unit 1-11 #1	Smackover	-1.43	2.69
Huxford 27-11 #1 AL	Smackover	0.16	4.07
Blacksher Co. 7-12 # 1 AL	Smackover	1.52	4.92
USA Rubie Bell #1 MS	Smackover	-2.66	4.31
Crown Zellerbach #1 MS	Smackover	-7.63	2.25
Bishop-Cooley #1 MS	Smackover	-0.54	4.23
PAN AM Well # H. A. Davis LA	Smackover	-3.83	3.41
PAN AM Well # H. A. Davis LA	Smackover	-5.26	3.12
PAN AM Frazier Unit LA	Smackover	-5.02	0.69
PAN AM Frazier Unit LA	Smackover	-4.34	3.01
PAN AM Well # L. Enloe LA	Smackover	-5.53	2.67
PAN AM Green #1 LA	Smackover	0.31	2.25

*Analysis performed by Paul Aharon and Students

***Petroleum System Identification*—**Three active petroleum source rocks have been reported from the onshore north central and northeastern Gulf of Mexico area. The Upper Jurassic (Oxfordian) Smackover lime mudstone beds (Figures 38-39) have been described as serving as source rocks in the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin (Sassen et al., 1987; Claypool and Mancini, 1989; Mancini et al., 2003). The Upper Cretaceous (Cenomanian-Turonian) Tuscaloosa marine shale beds have been reported as local source rocks in Mississippi (Koons et al., 1974). The Lower Cretaceous (Albian) Sunniland lime mudstone beds have been described as local source rocks in south Florida (Palacas, 1978; Palacas et al., 1984). In addition, Sassen (1990) reported that Lower Tertiary (Paleocene/Eocene) Midway, Wilcox, and Sparta shale beds are source rocks in southern Louisiana, and that Paleocene/Eocene Wilcox lignite beds may be a petroleum source in southwestern Mississippi. Upper Jurassic (Tithonian) shale and carbonate beds are source rocks in Mexico (Mancini et al., 2001), and Upper Jurassic Bossier shale beds have been described as potential source rocks in the East Texas Salt Basin by Ridgley et al. (2006).

From source rock and oil characterization studies, and from burial and thermal maturation history modeling, Claypool and Mancini (1989), Mancini et al. (1999, 2003), and the results from this work have shown that the Paleocene/Eocene shale and lignite beds have not been subjected to favorable burial and thermal maturation histories required for petroleum generation in the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin. The Upper Cretaceous Tuscaloosa marine shale beds were an effective local petroleum source rock in parts of the Mississippi Interior Salt Basin, but not in the North Louisiana Salt Basin, Manila Subbasin, and Conecuh Subbasin. The uppermost Jurassic beds are possible source beds in parts of the North Louisiana Salt Basin. In this study, organic-rich facies in Lower Cretaceous strata were not identified in these basins and subbasins.

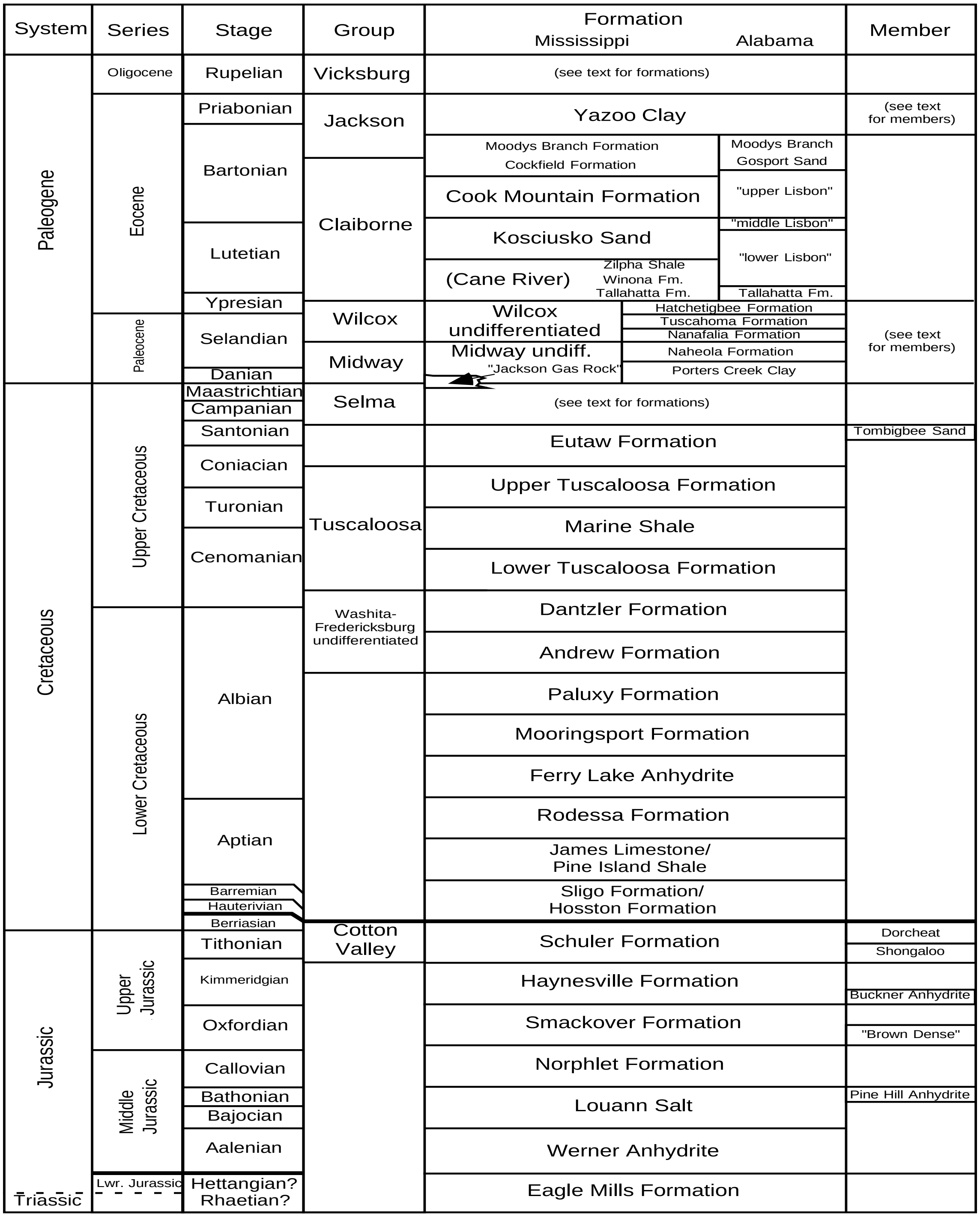


Figure 38. Stratigraphy for the north central and northeastern Gulf of Mexico area.

System	Series	Stage	Group	Stratigraphic Units: Louisiana	Stratigraphic Units: Mississippi	Stratigraphic Sequences
Cretaceous	Upper Cretaceous	Maastrichtian	Navarro	Arkadelphia Formation*	Prairie Bluff Chalk**	Sequence 11
				Nacatoch Formation	Ripley Formation	Sequence 10
				Saratoga Formation		
		Campanian	Taylor	Marlbrook Formation		
				Annona Formation	Demopolis Chalk	
				Ozan Formation		
		Santonian	Austin	Brownstown Formation	Mooreville Chalk	Sequence 9
		Coniacian		Tokio Formation	Eutaw Formation	
		Turonian	Eagle Ford	Eagle Ford	Upper Tuscaloosa Fm	Sequence 8
		Cenomanian	Tuscaloosa	Tuscaloosa Formation	Lower/Middle Tuscaloosa Fm	
			Washita	upper Washita	upper Washita	Sequence 7
	Lower Cretaceous	Albian		lower Washita	Dantzler Formation	Sequence 6
			Fredericksburg	Goodland Formation	Andrew Formation	
				Paluxy Formation	Paluxy Formation	Sequence 5
			Trinity	Rusk Formation/ Mooringsport Formation	Mooringsport Formation	
				Ferry Lake Anhydrite	Ferry Lake Anhydrite	
		Aptian		Rodessa Formation	Rodessa Formation	
				Bexar Formation	Bexar Formation	
				James Limestone	James LS / Donovan ss	Sequence 4
				Pine Island Shale	Pine Island Shale	
		Barremian		Sligo Formation	Sligo Formation	
		Hauterivian / Valanginian / Berriasian		Hosston Formation	Hosston Formation	
Jurassic	Upper Jurassic	Tithonian	Cotton Valley	Knowles / Dorcheat	Schuler Formation / Dorcheat	Sequence 3
				Schuler Fm / Shongaloo	Shongaloo	
		Kimmeridgian		Haynesville Formation / Gilmer Limestone	Haynesville Formation / Buckner Anhydrite	Sequence 2
		Oxfordian		Smackover Formation	Smackover Formation	Sequence 1
				Norphlet Formation	Norphlet Formation	

*Monroe Gas Rock ** Jackson Gas Rock

Rodessa, Ferry Lake, Mooringsport and Rusk = Glen Rose

Pine Island, James and Bexar = Pearsall

Bossier is part of Cotton Valley

Figure 39. Upper Jurassic and Cretaceous sequence stratigraphy for the North Louisiana and Mississippi Interior Salt Basins.

Based on this assessment of potential petroleum source rocks, only the Upper Jurassic Smackover lime mudstone beds, therefore, were determined to be an effective regional petroleum source rock. Further, organic geochemical analyses, including C_{15+} chromatograms and biomarker data of the oils produced from Upper Jurassic, Lower Cretaceous and Upper Cretaceous reservoirs have shown that the oils produced from the Upper Jurassic, Lower Cretaceous and many of the Upper Cretaceous reservoirs were generated from organic matter that accumulated and was preserved in association with the Smackover lime mudstone beds (Koons et al., 1974; Claypool and Mancini, 1989; Mancini et al., 2001). Therefore, only the Smackover lime mudstone beds are used in this study as effective petroleum source rocks in the North Louisiana and Mississippi Interior Salt Basins and Manila and Conecuh Subbasins.

Petroleum System Characterization—The various components of each of the petroleum systems determined to be active in the North Louisiana Salt Basin, the Mississippi Interior Salt Basin, the Manila Subbasin and the Conecuh Subbasin were characterized. These components include the underburden, overburden, source, reservoir and seal rocks (Figure 40-41) of these petroleum systems that are associated with the petroleum traps in these onshore interior salt basins. In this study, the petroleum system as described by Magoon (1987, 1988) and Magoon and Dow (1994) is used.

Petroleum System Modeling--Representative thermal maturity profiles, representative burial history profiles, representative thermal maturation history and representative hydrocarbon expulsion profiles for each of the studied basins and subbasins have been constructed (Figures 42-84). These burial history profiles, thermal maturation history profiles, and hydrocarbon expulsion profiles were modified from the profiles published as the result of our DOE study of the North Louisiana Salt Basin (2006) and of our DOE study of

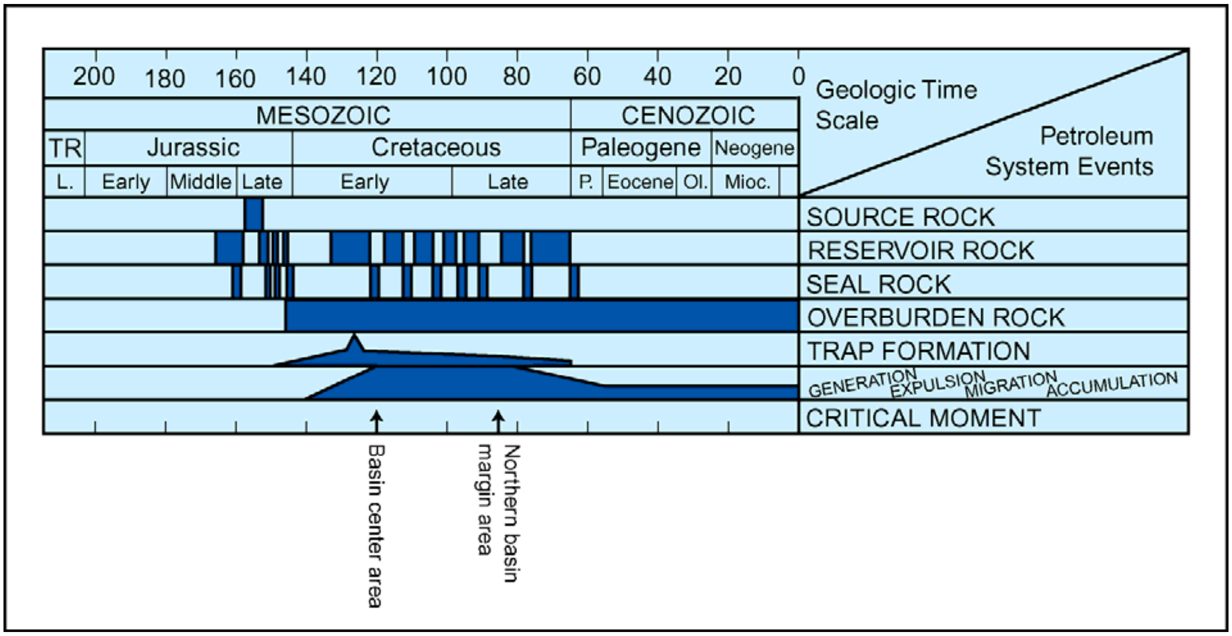


Figure 40. Event chart for Smackover petroleum system, North Louisiana and Mississippi Interior Salt Basins (modified from Mancini et al., 2003).

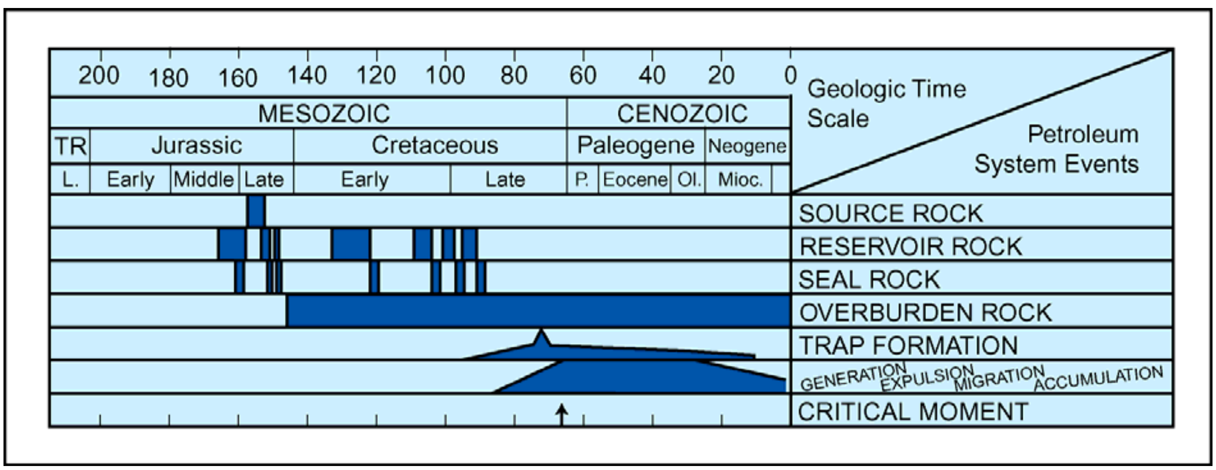


Figure 41. Event chart for Smackover petroleum system, Manila and Conecuh Subbasins.

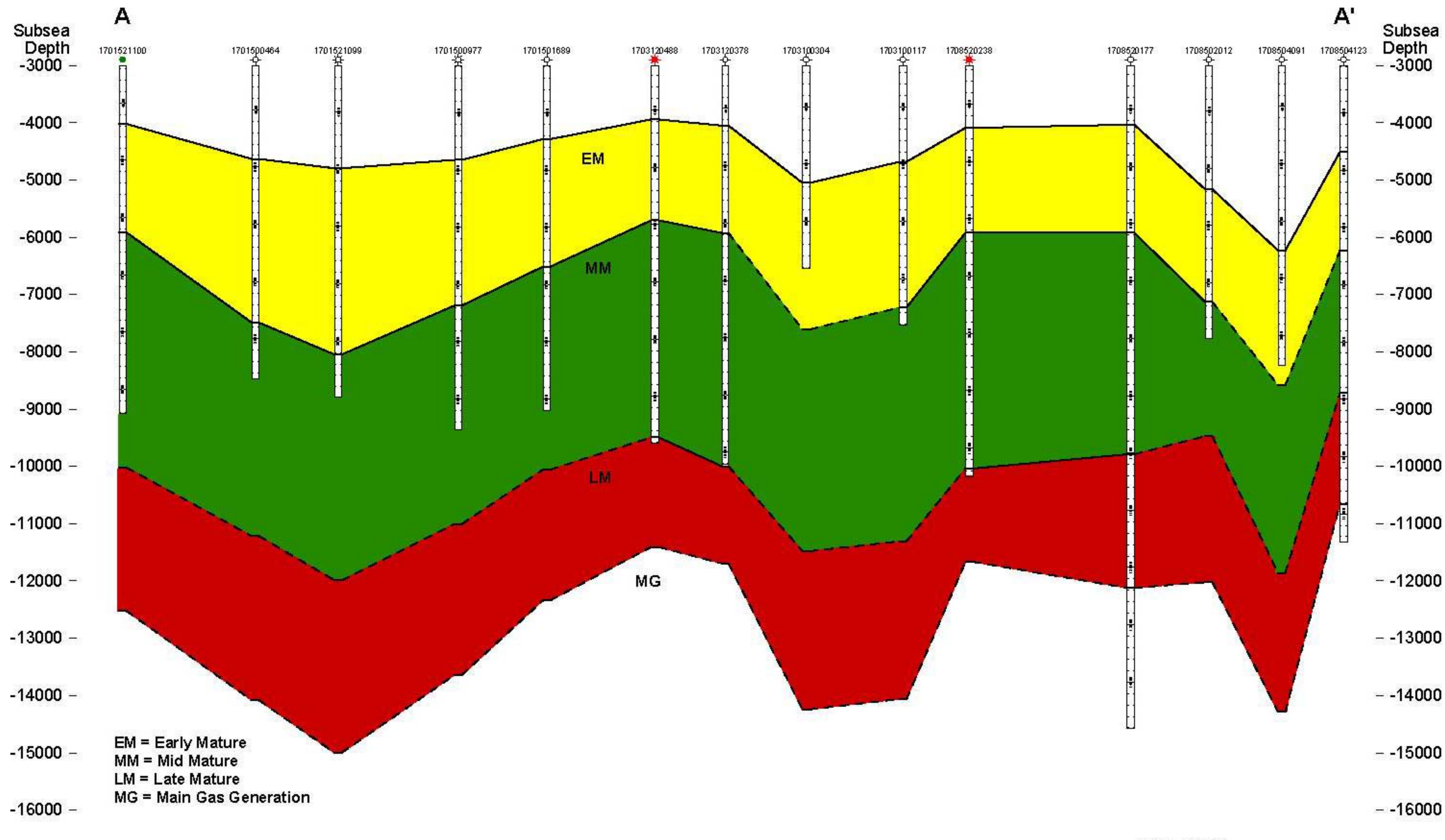


Figure 42. Thermal maturity profile A-A' for the North Louisiana Salt Basin, Location in Figure 2.

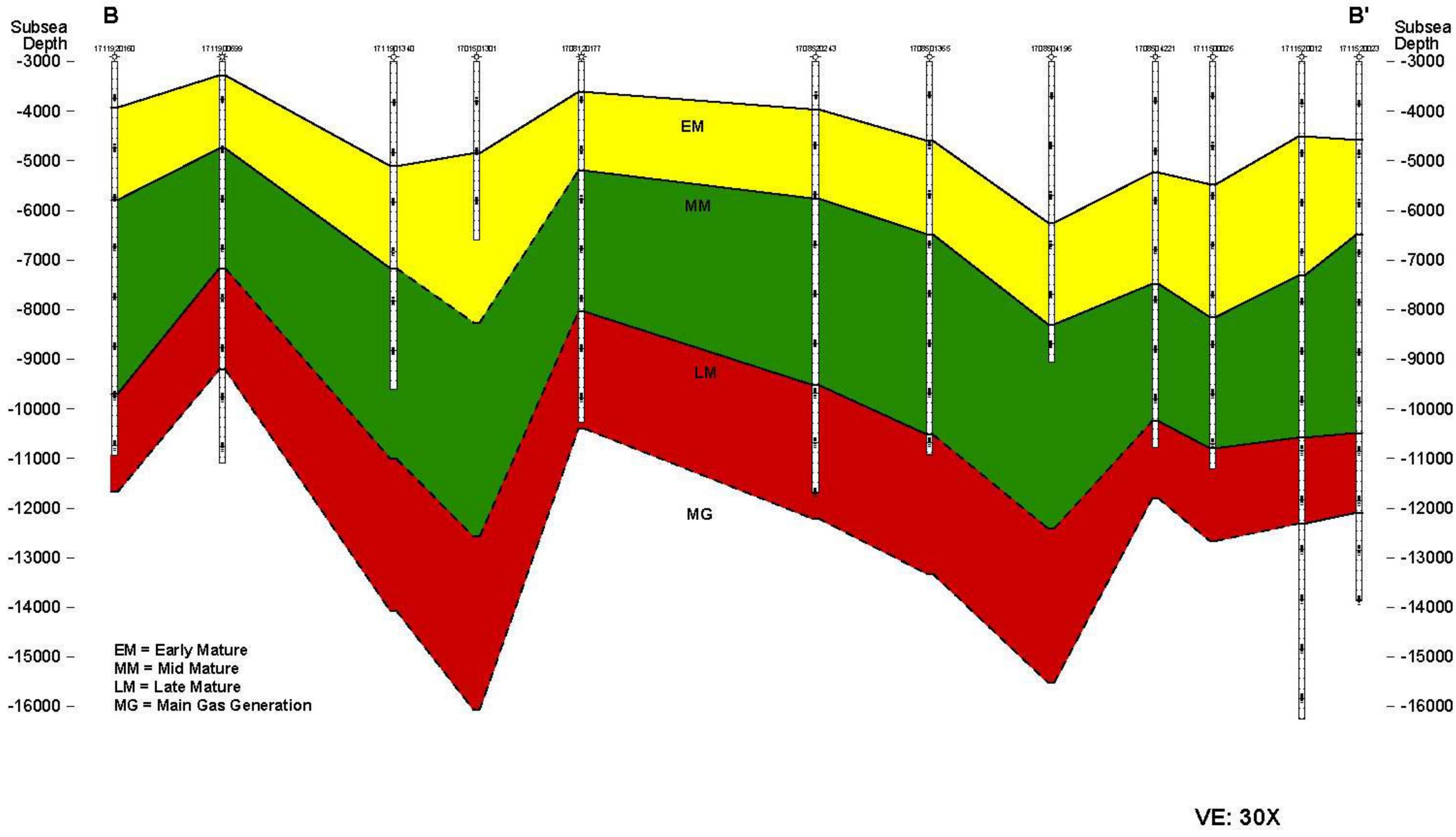


Figure 43. Thermal maturity profile B-B' for the North Louisiana Salt Basin. Location in Figure 2.

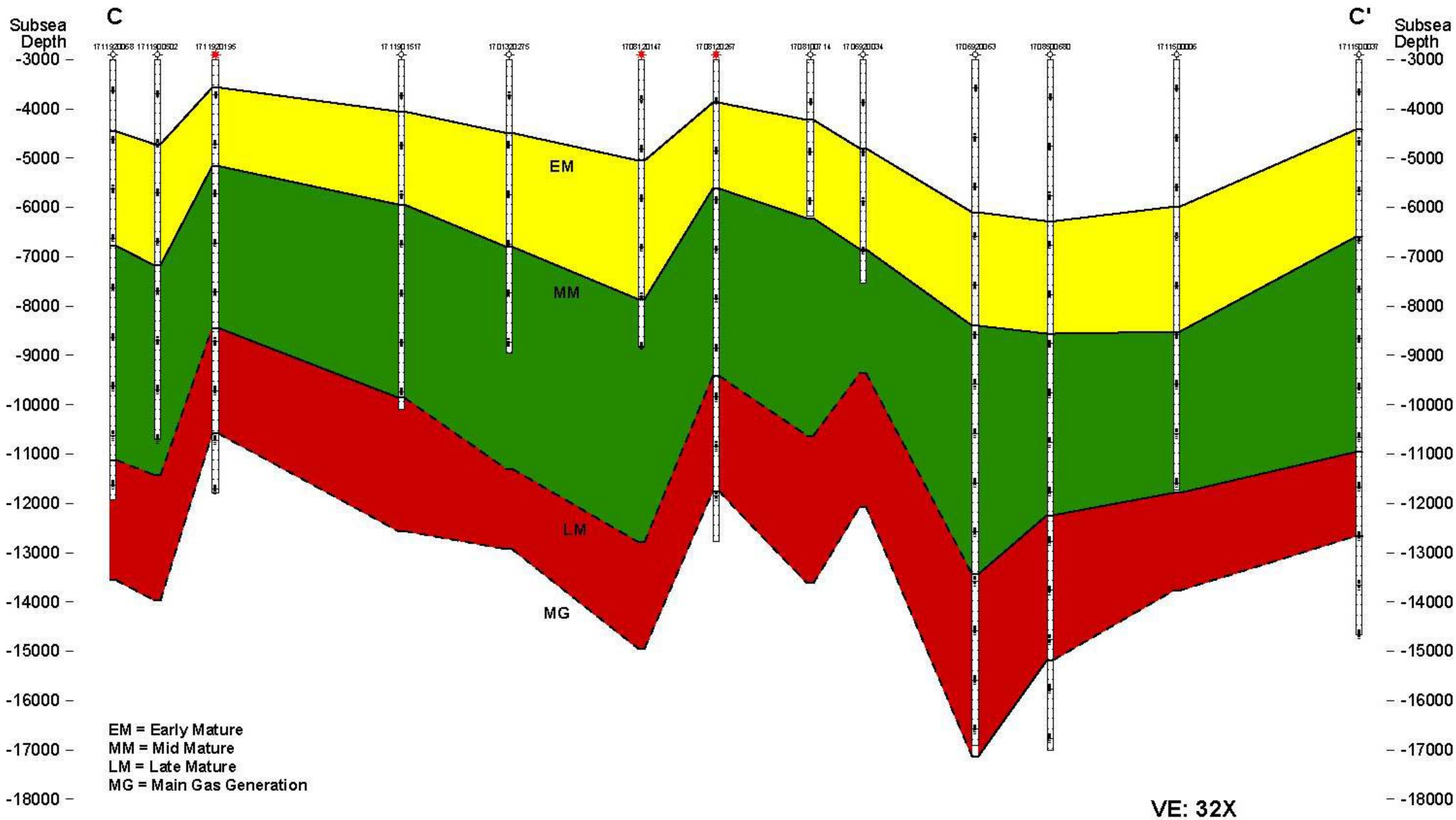


Figure 44. Thermal maturity profile C-C' for the North Louisiana Salt Basin. Location in Figure 2.

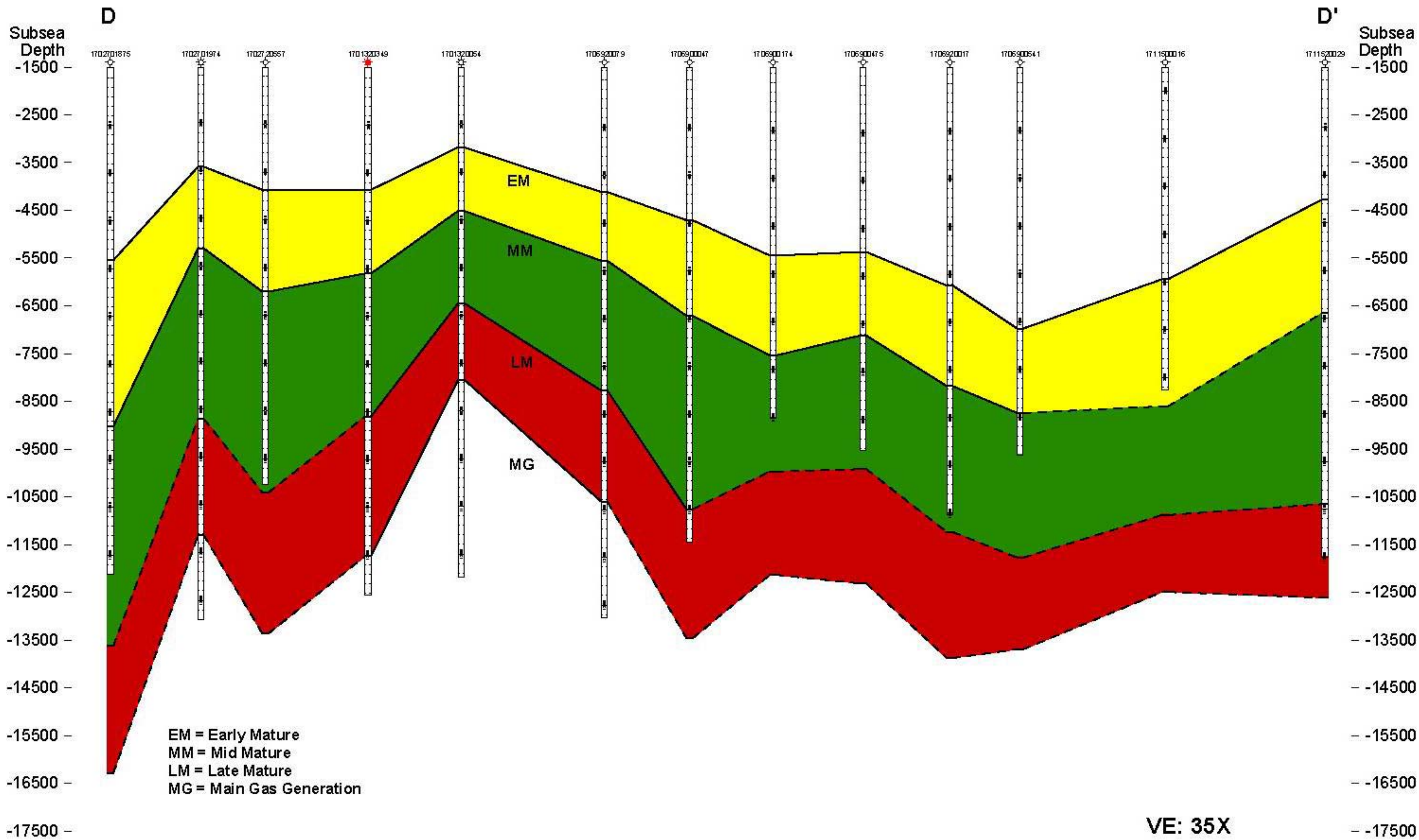


Figure 45. Thermal maturity profile D-D' for the North Louisiana Salt Basin. Location in Figure 2.

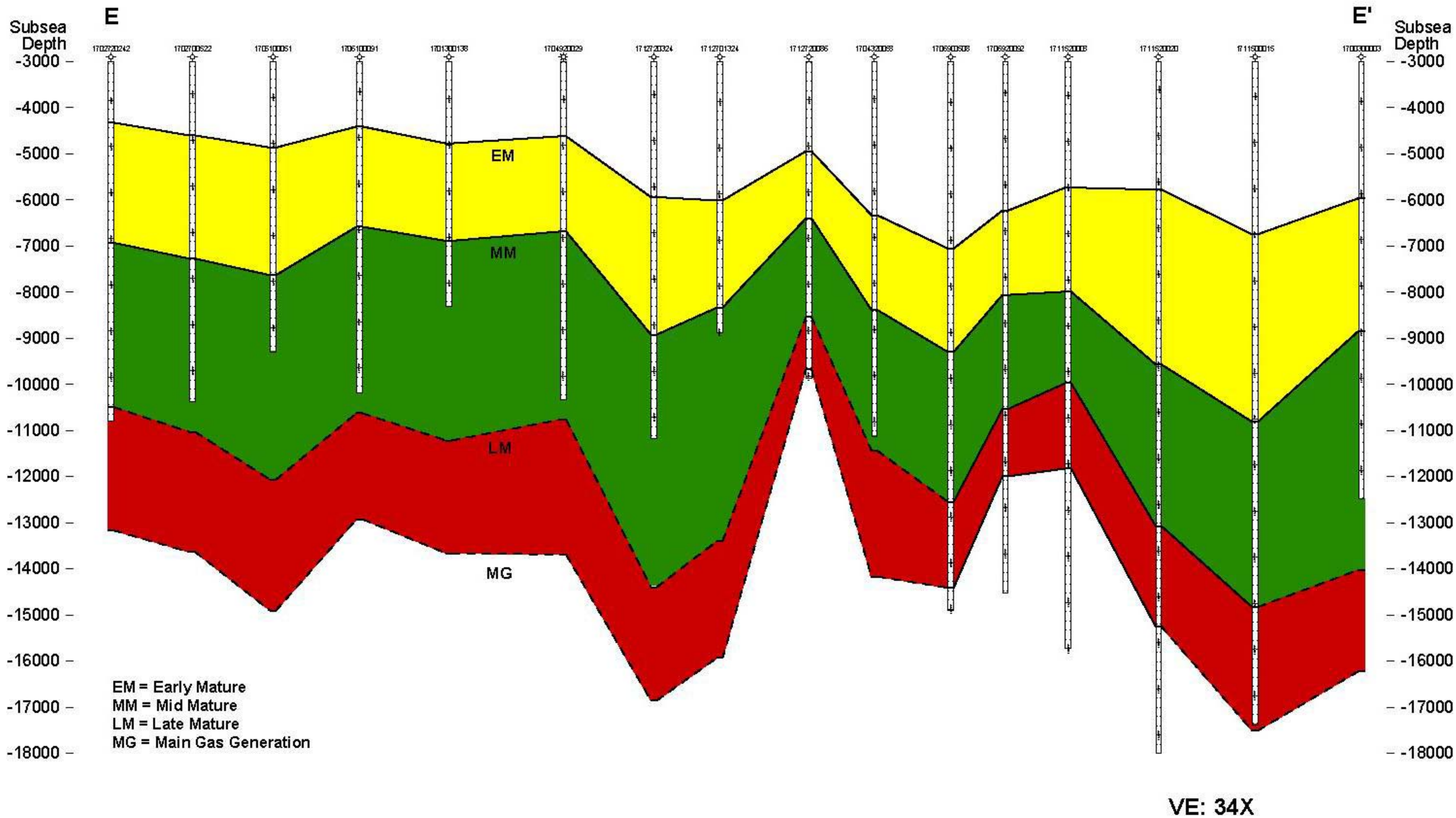


Figure 46. Thermal maturity profile E-E' for the North Louisiana Salt Basin. Location in Figure 2.

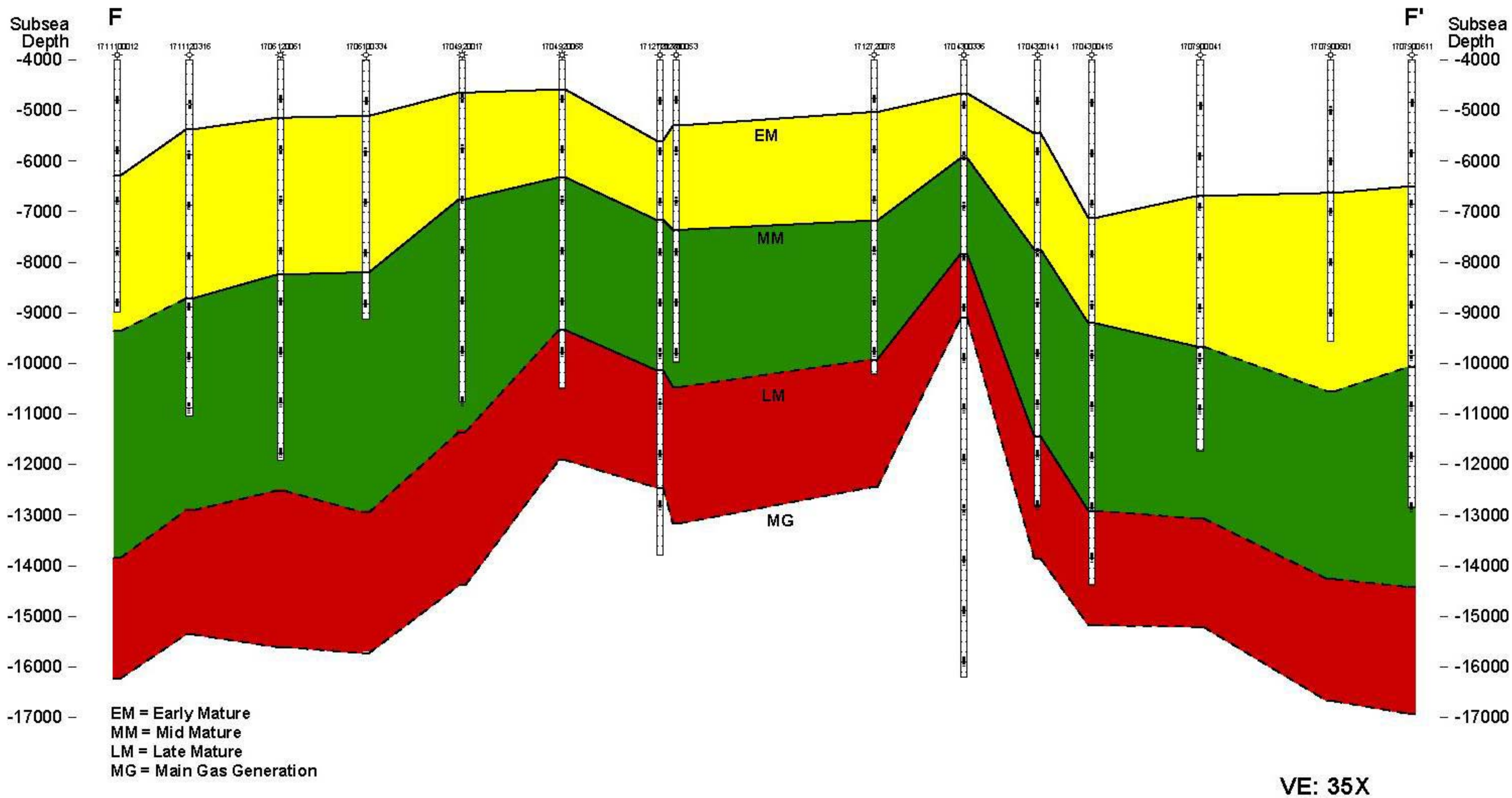


Figure 47. Thermal maturity profile F-F' for the North Louisiana Salt Basin. Location in Figure 2.

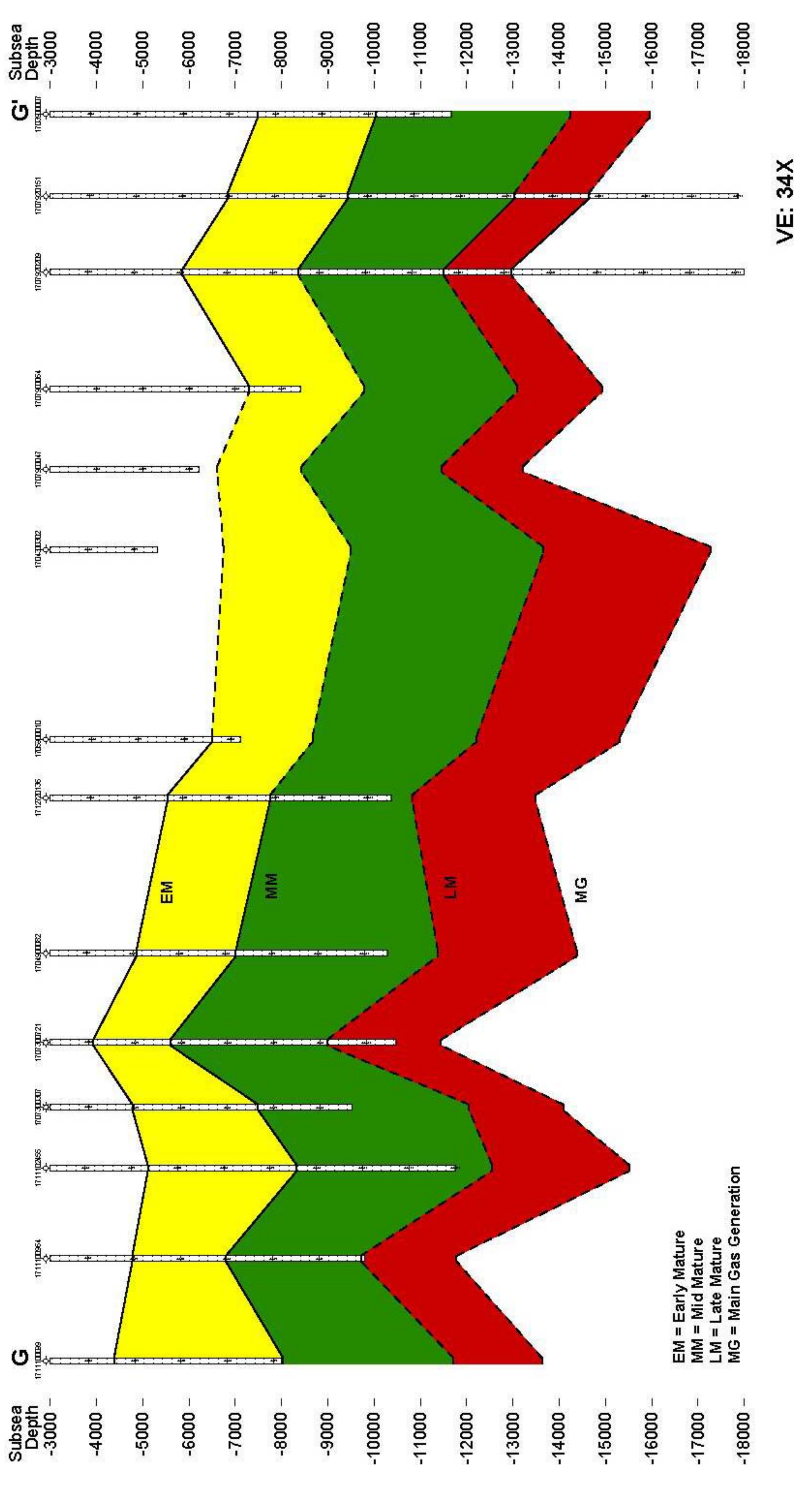


Figure 48. Thermal maturity profile G-G' for the North Louisiana Salt Basin. Location in Figure 2.

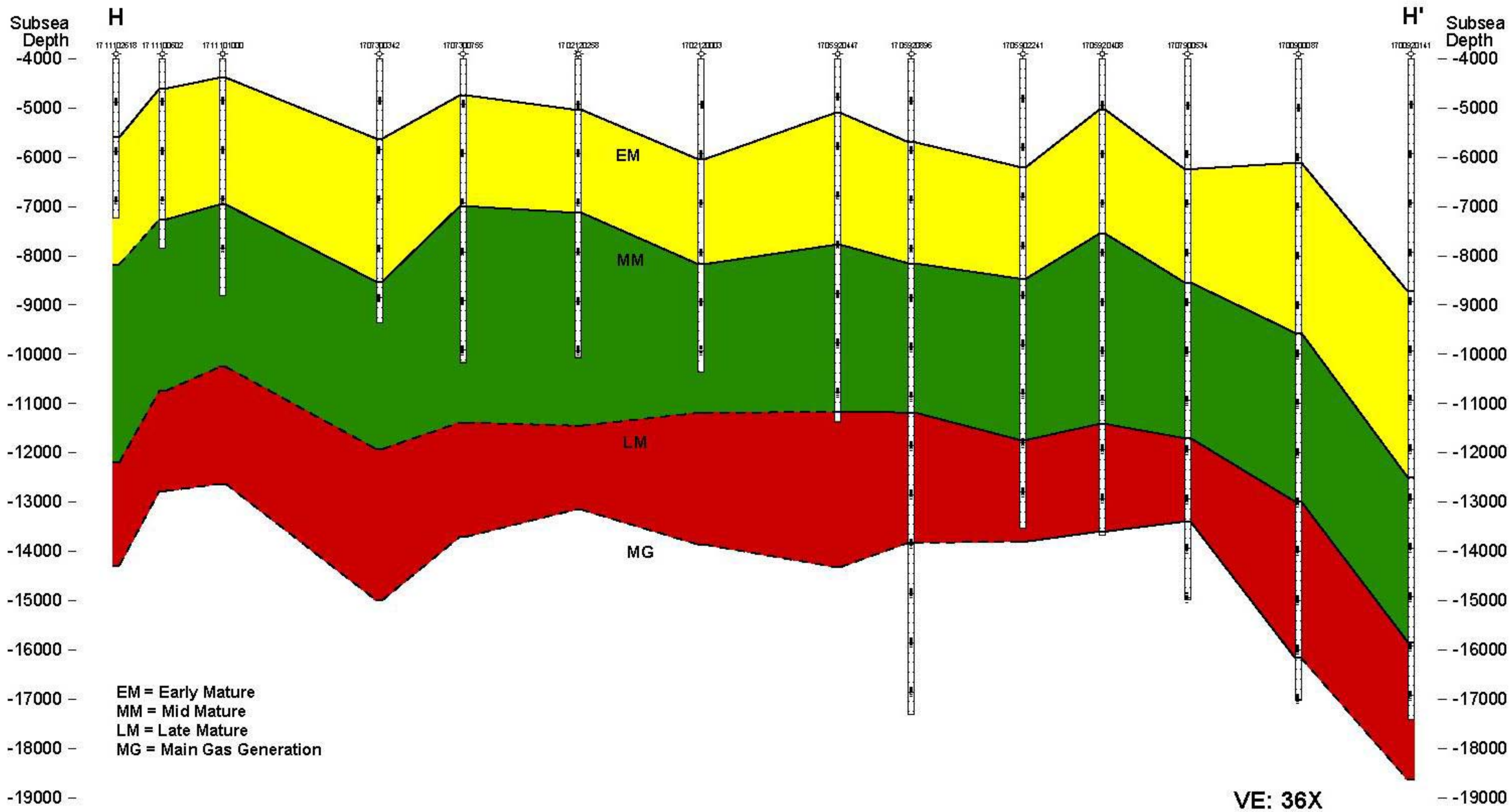


Figure 49. Thermal maturity profile H-H' for the North Louisiana Salt Basin. Location in Figure 2.

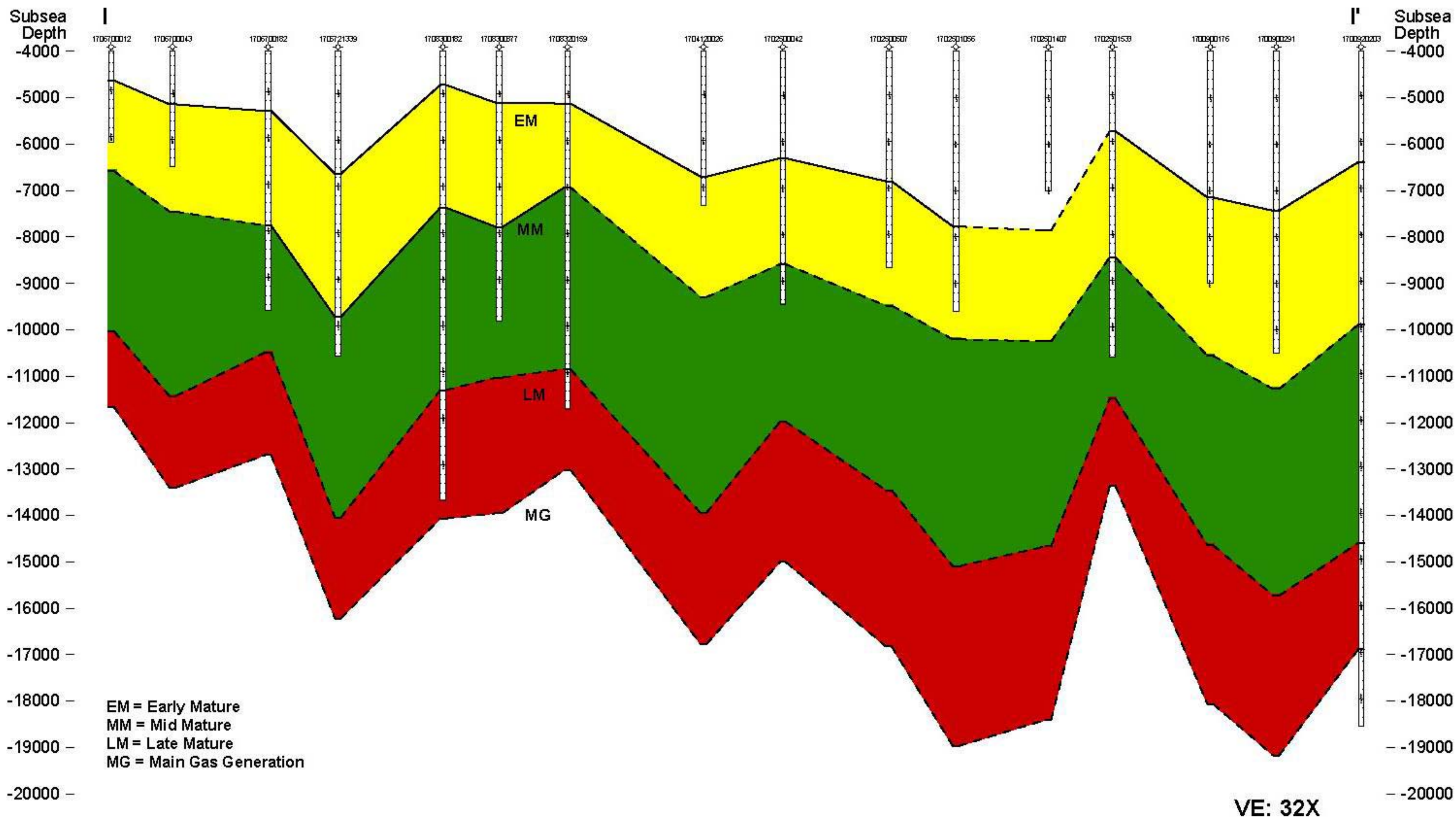


Figure 50. Thermal maturity profile I-I' for the North Louisiana Salt Basin. Location in Figure 2.

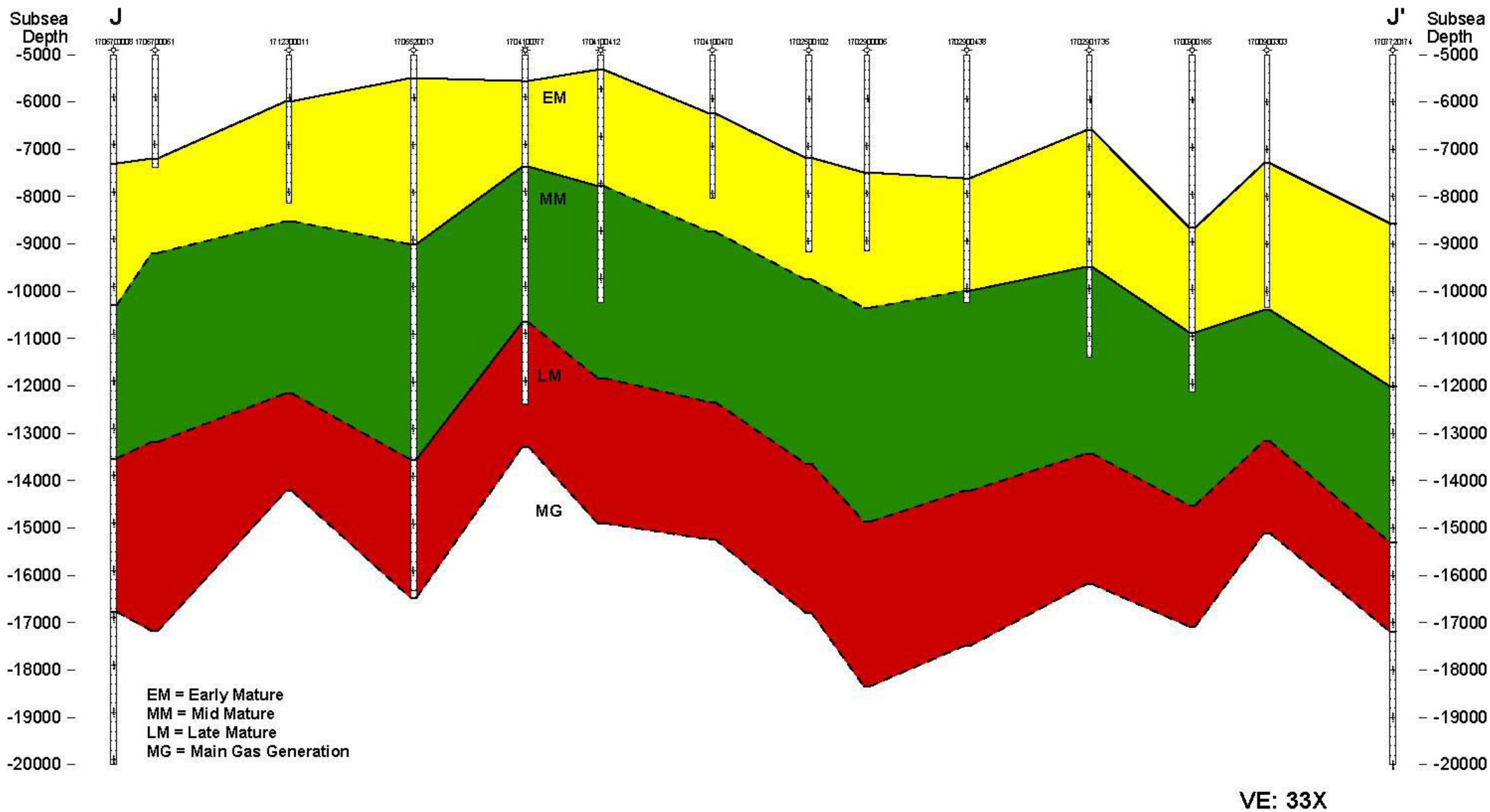


Figure 51. Thermal maturity profile J-J' for the North Louisiana Salt Basin. Location in Figure 2.

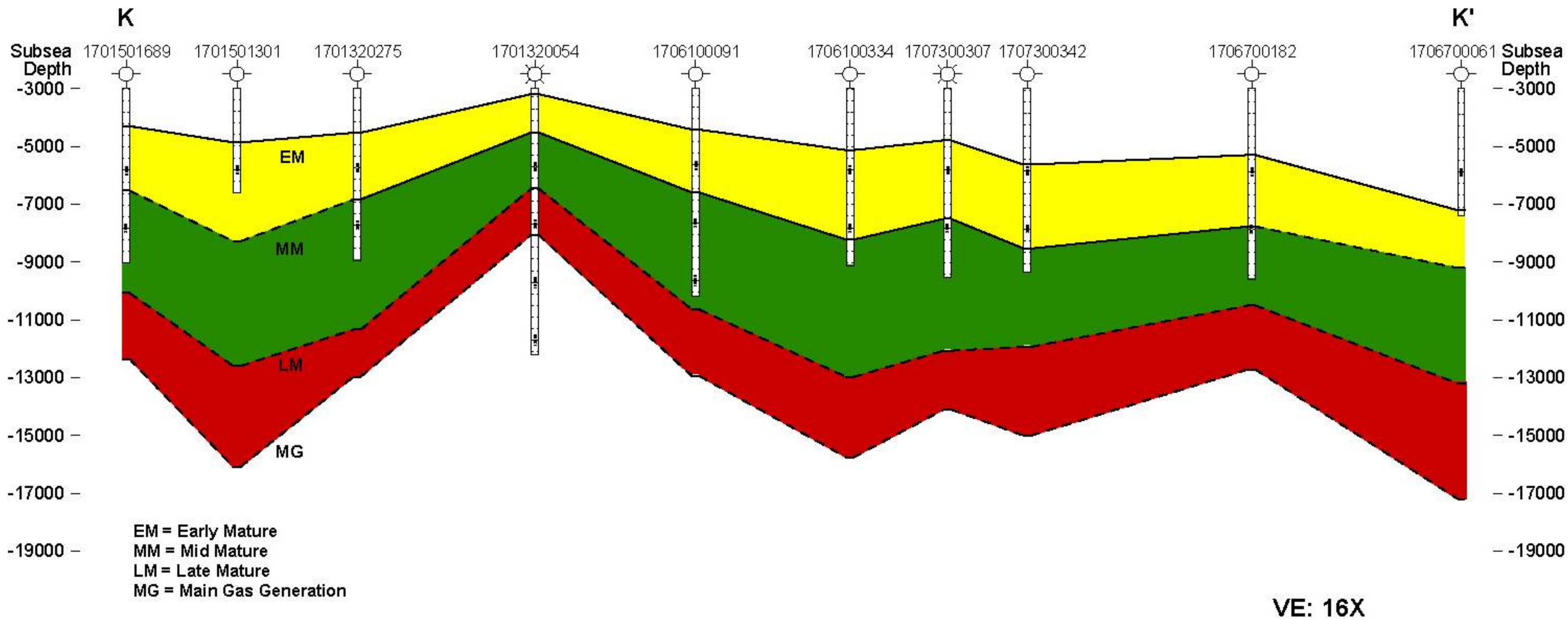


Figure 52. Thermal maturity profile K-K' for the North Louisiana Salt Basin. Location in Figure 2.

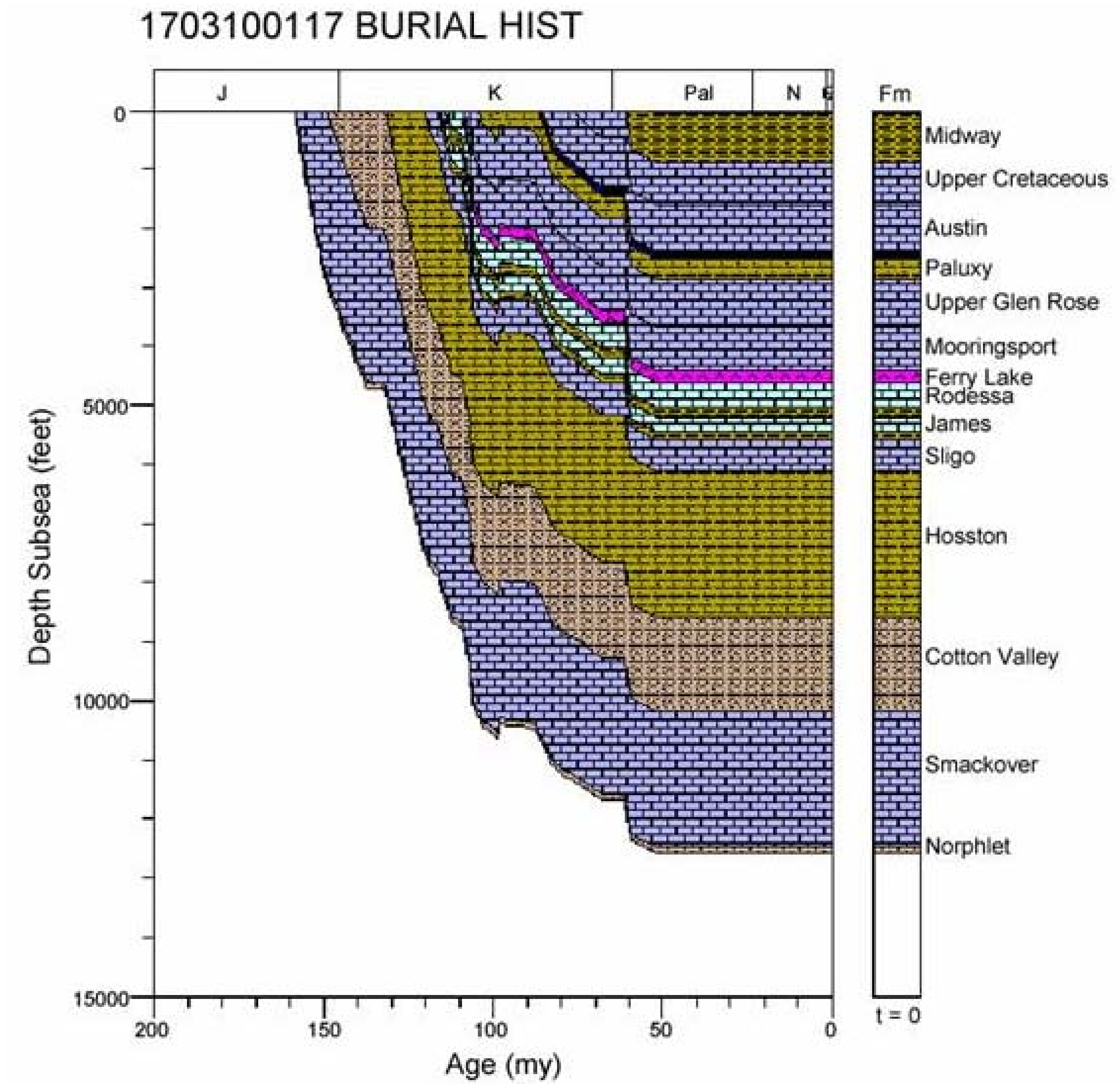


Figure 53. Sabine Uplift, North Louisiana Salt Basin, burial history profile, modified from Mancini et al. (2006).

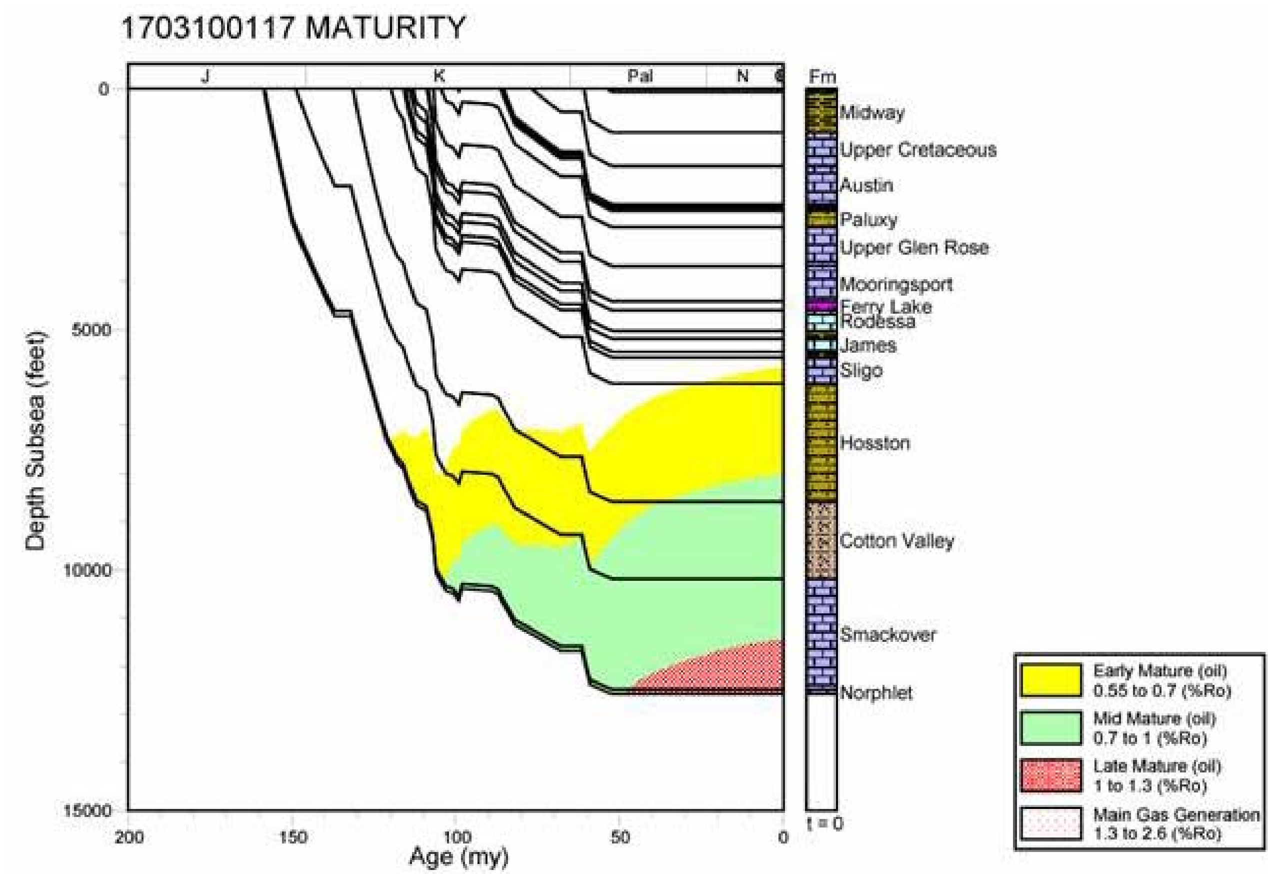


Figure 54. Sabine Uplift, North Louisiana Salt Basin, thermal maturation history profile, modified from Mancini et al. (2006).

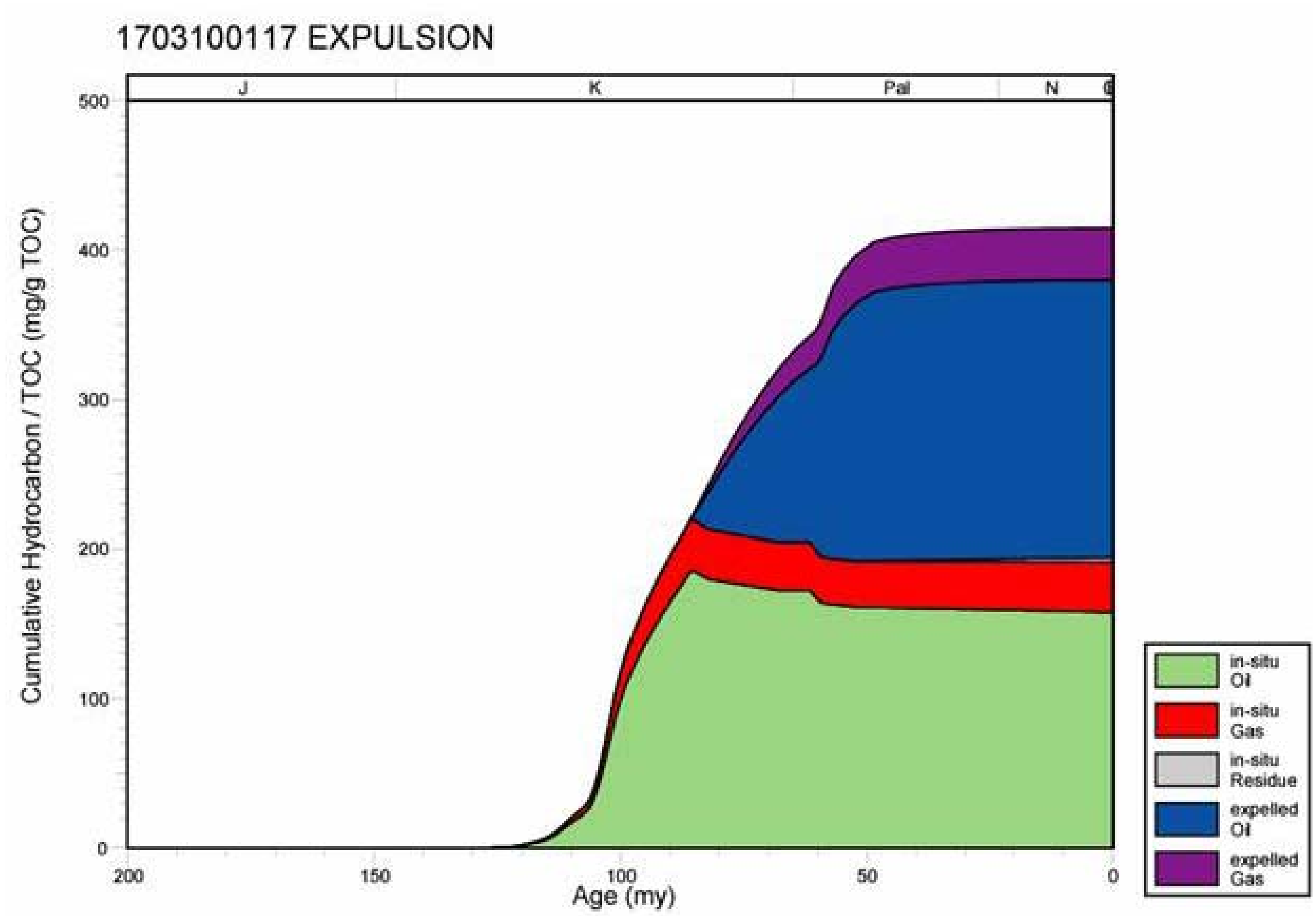


Figure 55. Sabine Uplift, North Louisiana Salt Basin, hydrocarbon expulsion plot, modified from Mancini et al. (2006).

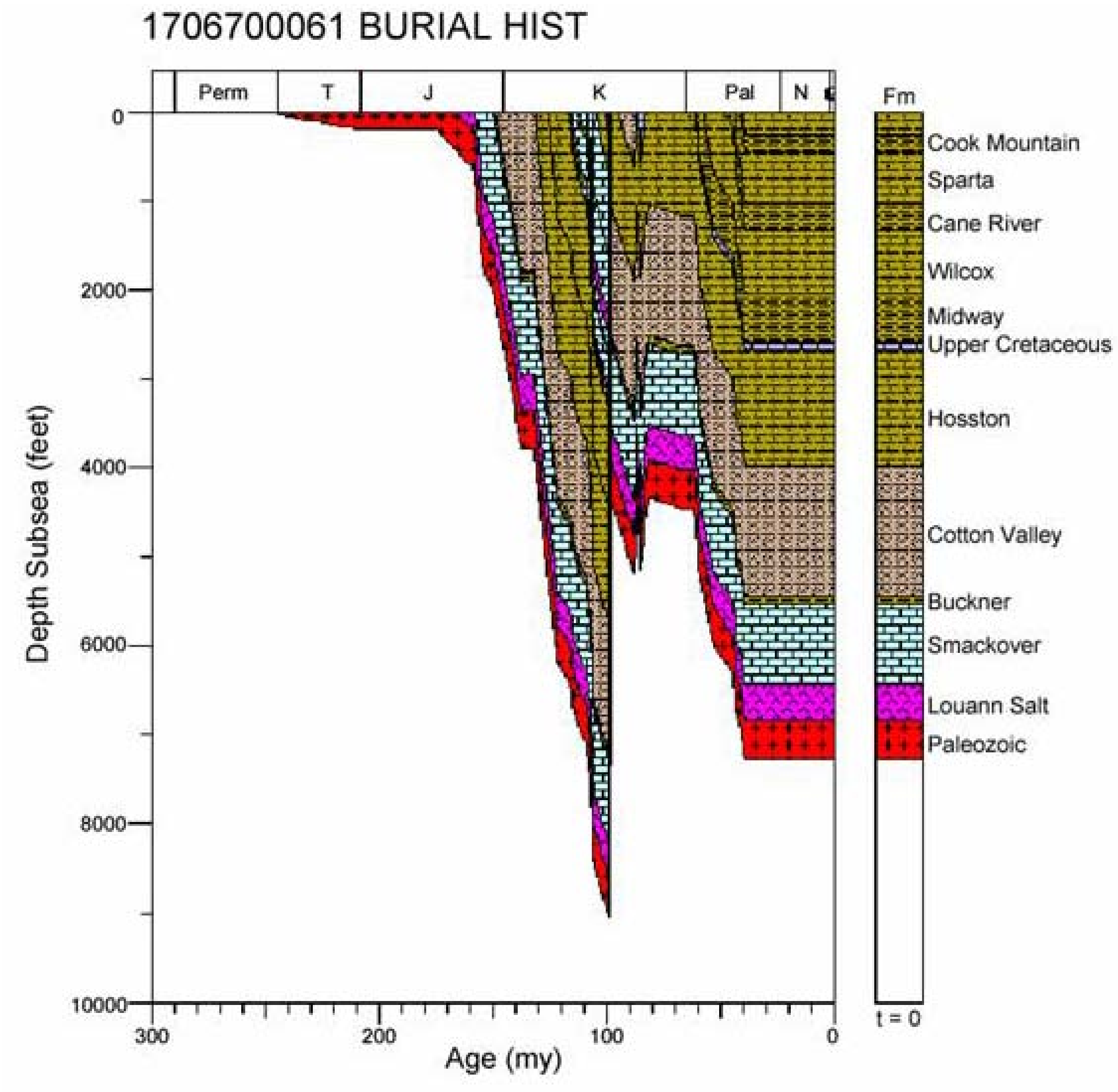


Figure 56. Monroe Uplift, North Louisiana Salt Basin, burial history profile, modified from Mancini et al. (2006).

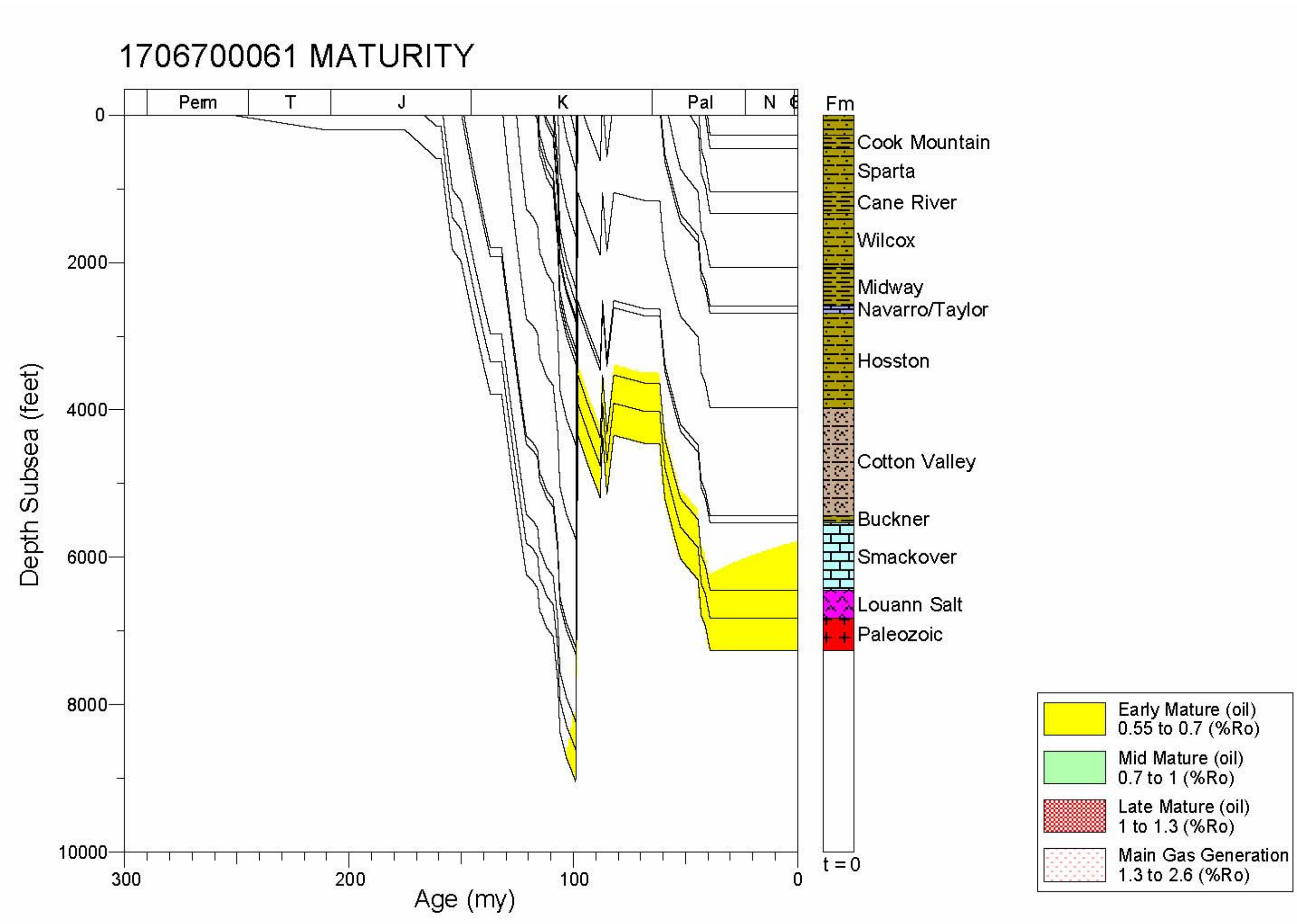


Figure 57. Monroe Uplift, North Louisiana Salt Basin, thermal maturation history profile, modified from Mancini et al. (2006).

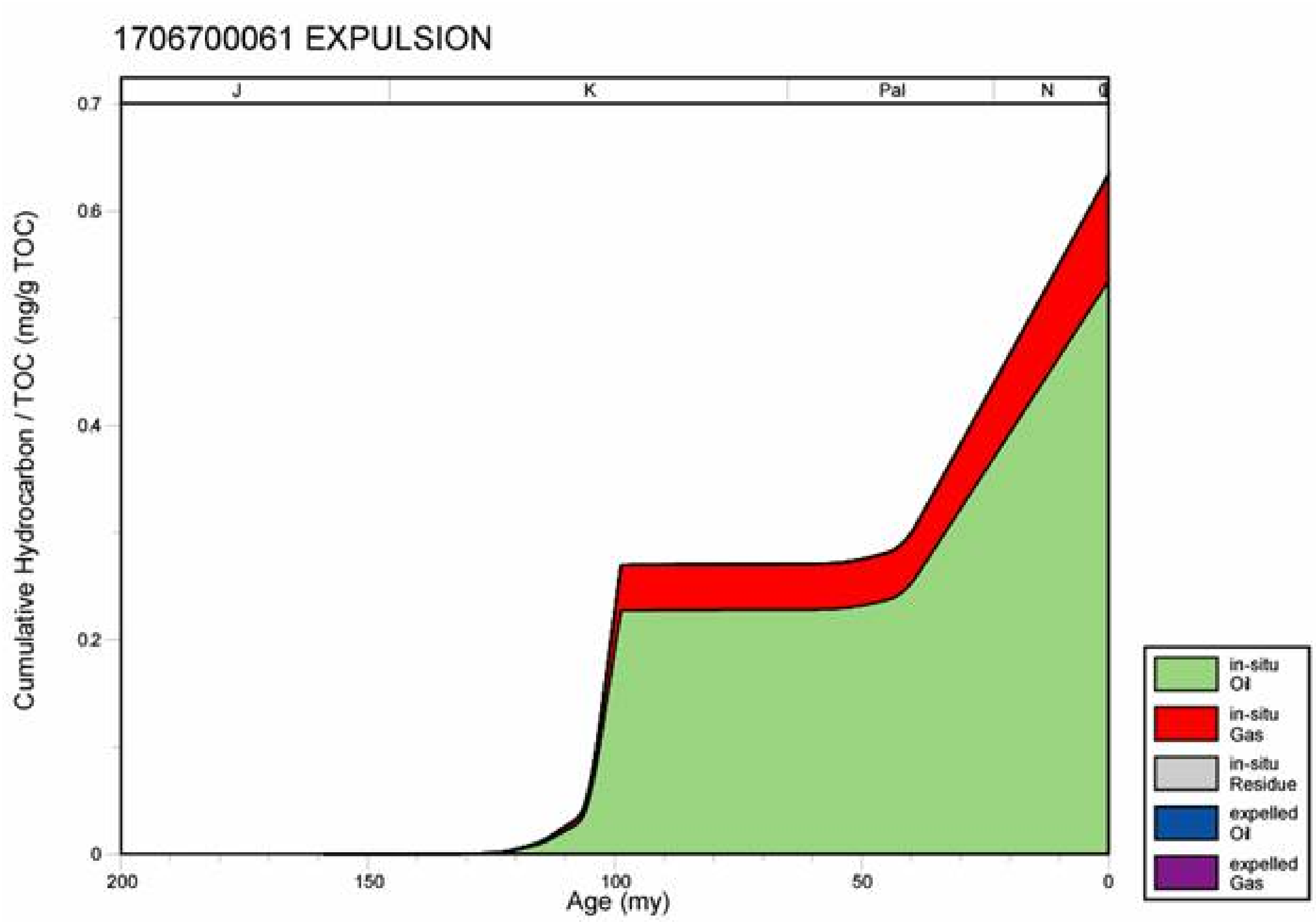


Figure 58. Monroe Uplift, North Louisiana Salt Basin, hydrocarbon expulsion plot, modified from Mancini et al. (2006).

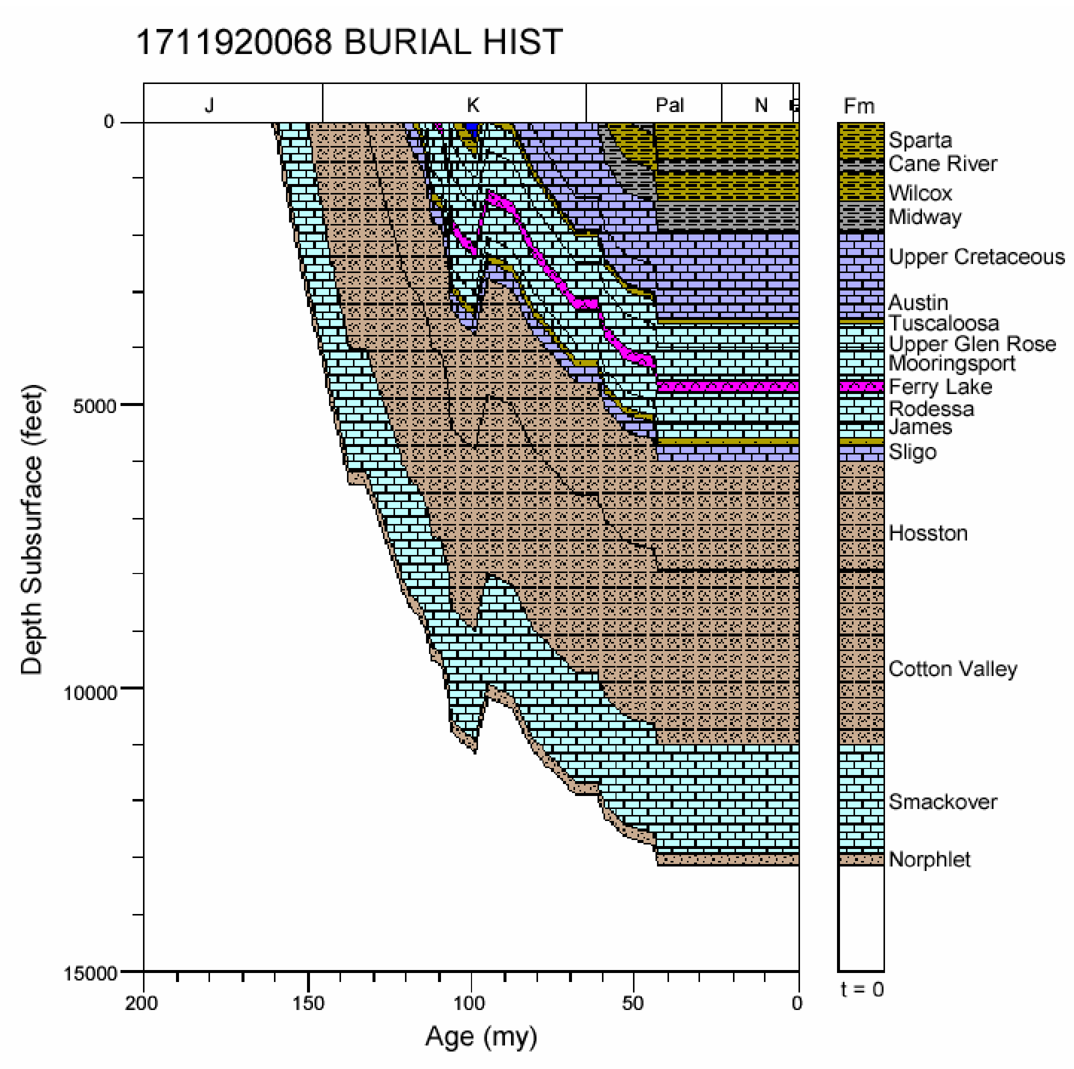


Figure 59. Updip North Louisiana Salt Basin, burial history profile, modified from Mancini et al. (2006).

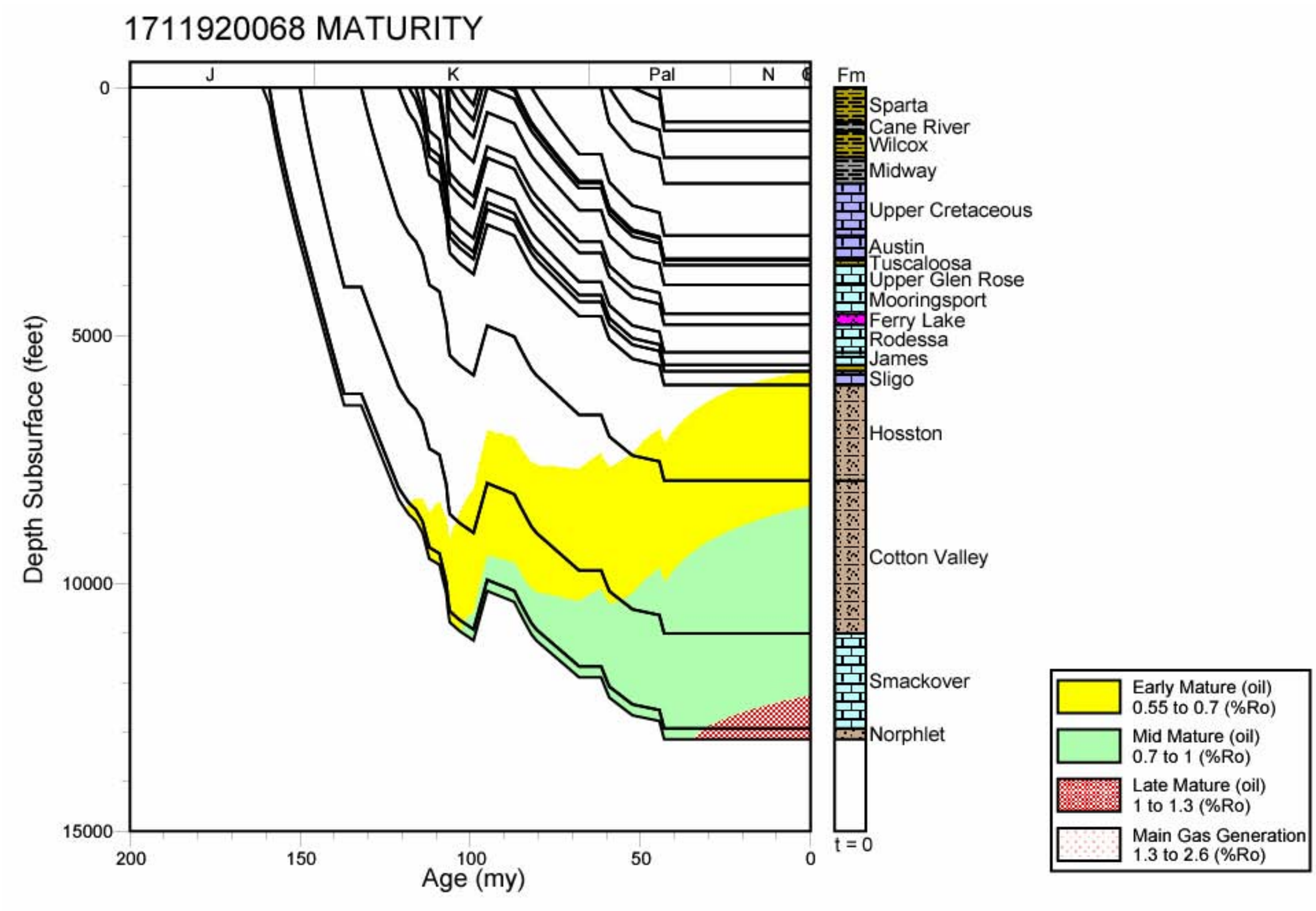


Figure 60. Updip North Louisiana Salt Basin, thermal maturation history profile, modified from Mancini et al. (2006).

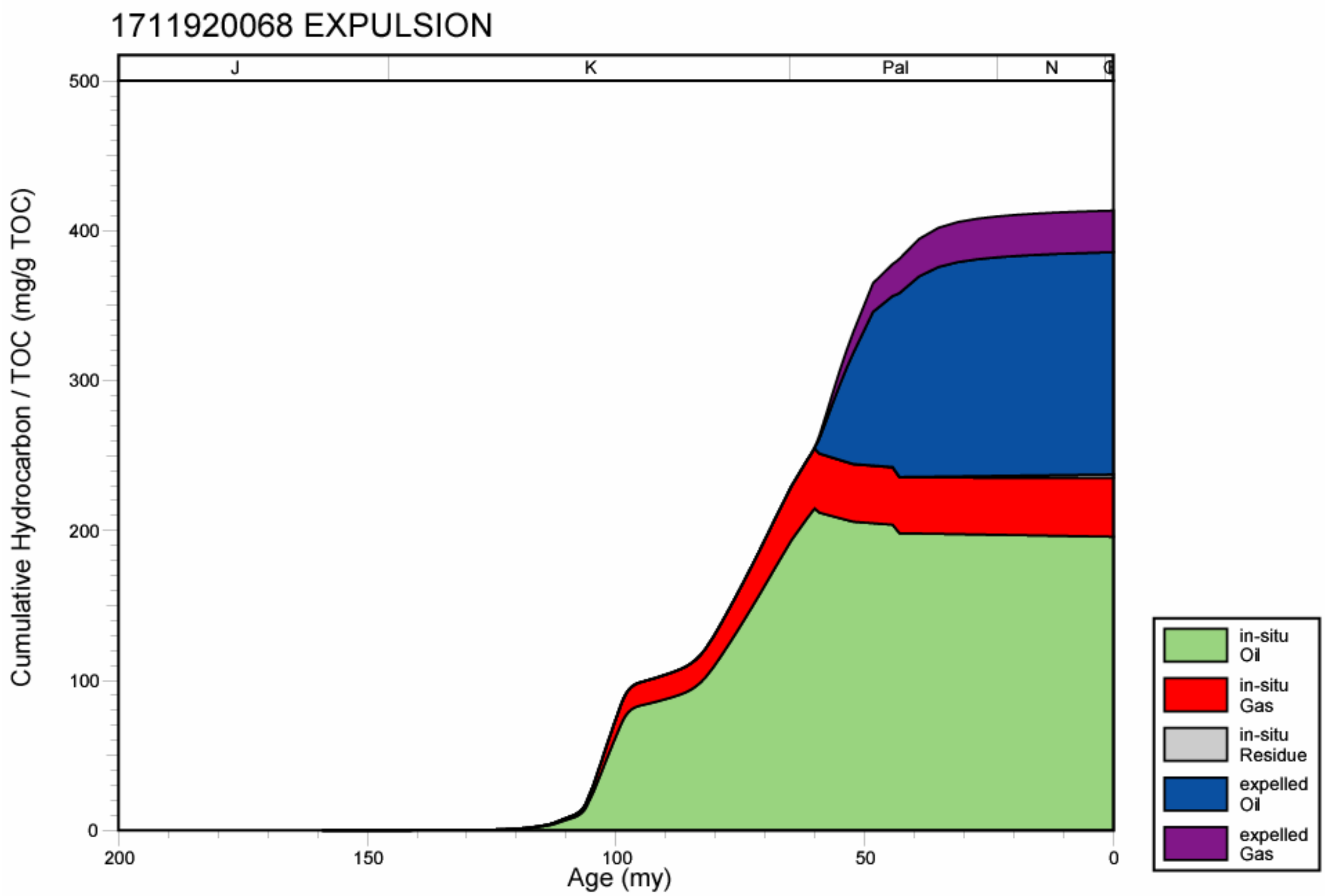


Figure 61. Updip North Louisiana Salt Basin, hydrocarbon expulsion plot, modified from Mancini et al. (2006).

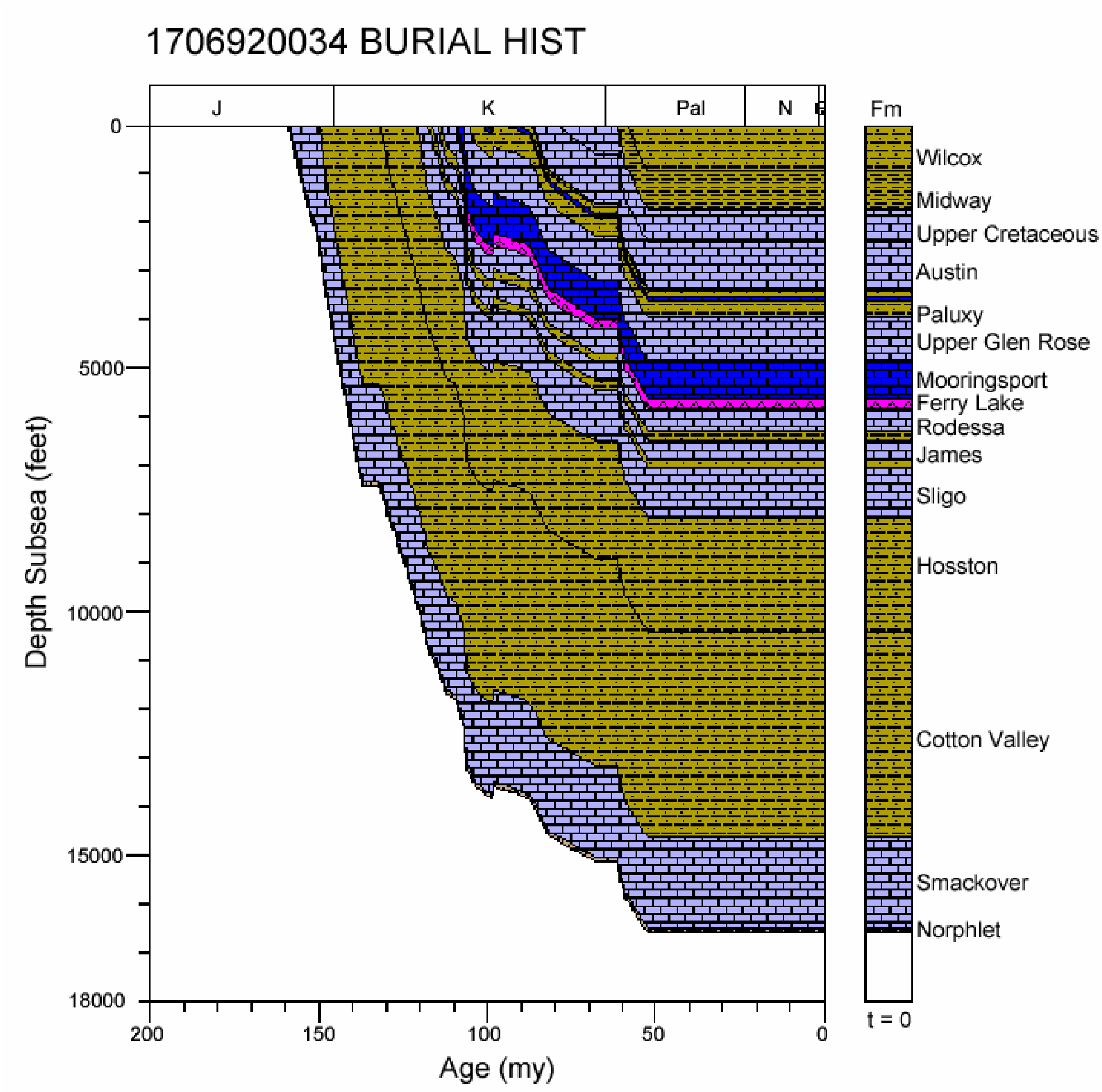


Figure 62. Downdip North Louisiana Salt Basin, burial history profile, modified from Mancini et al. (2006).

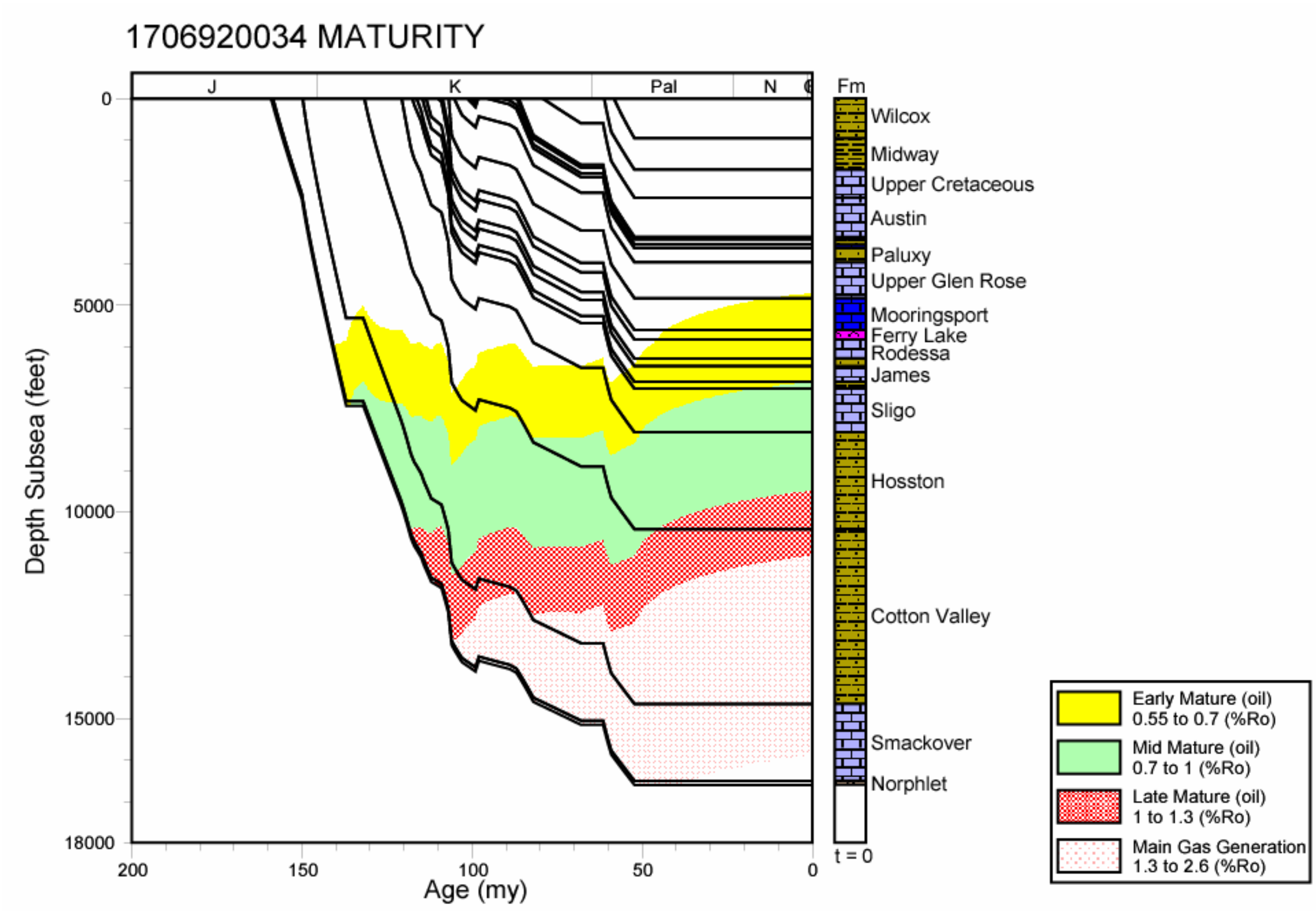


Figure 63. Downdip North Louisiana Salt Basin, thermal maturation history profile, modified from Mancini et al. (2006).

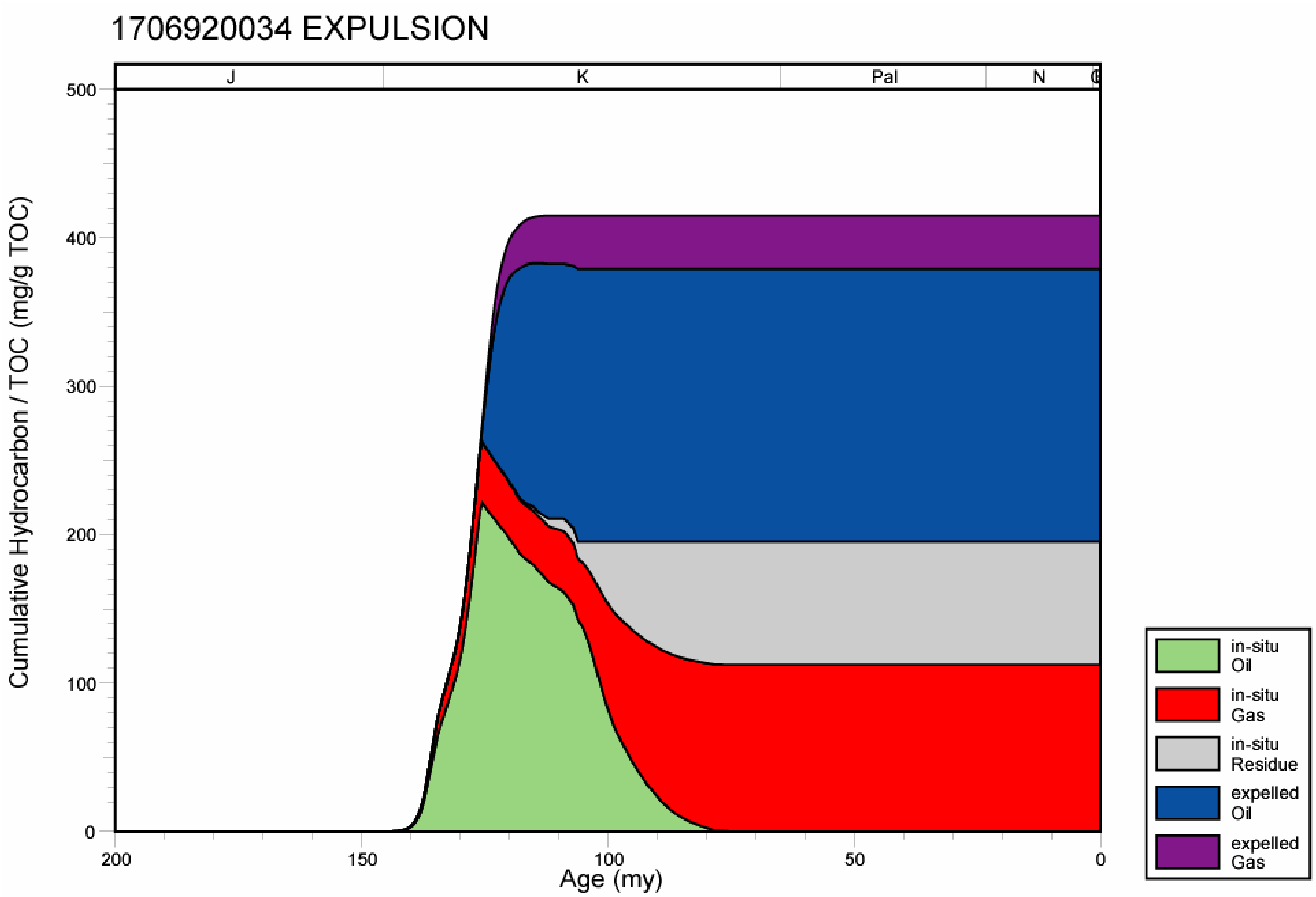


Figure 64. Downdip North Louisiana Salt Basin, hydrocarbon expulsion plot, modified from Mancini et al. (2006).

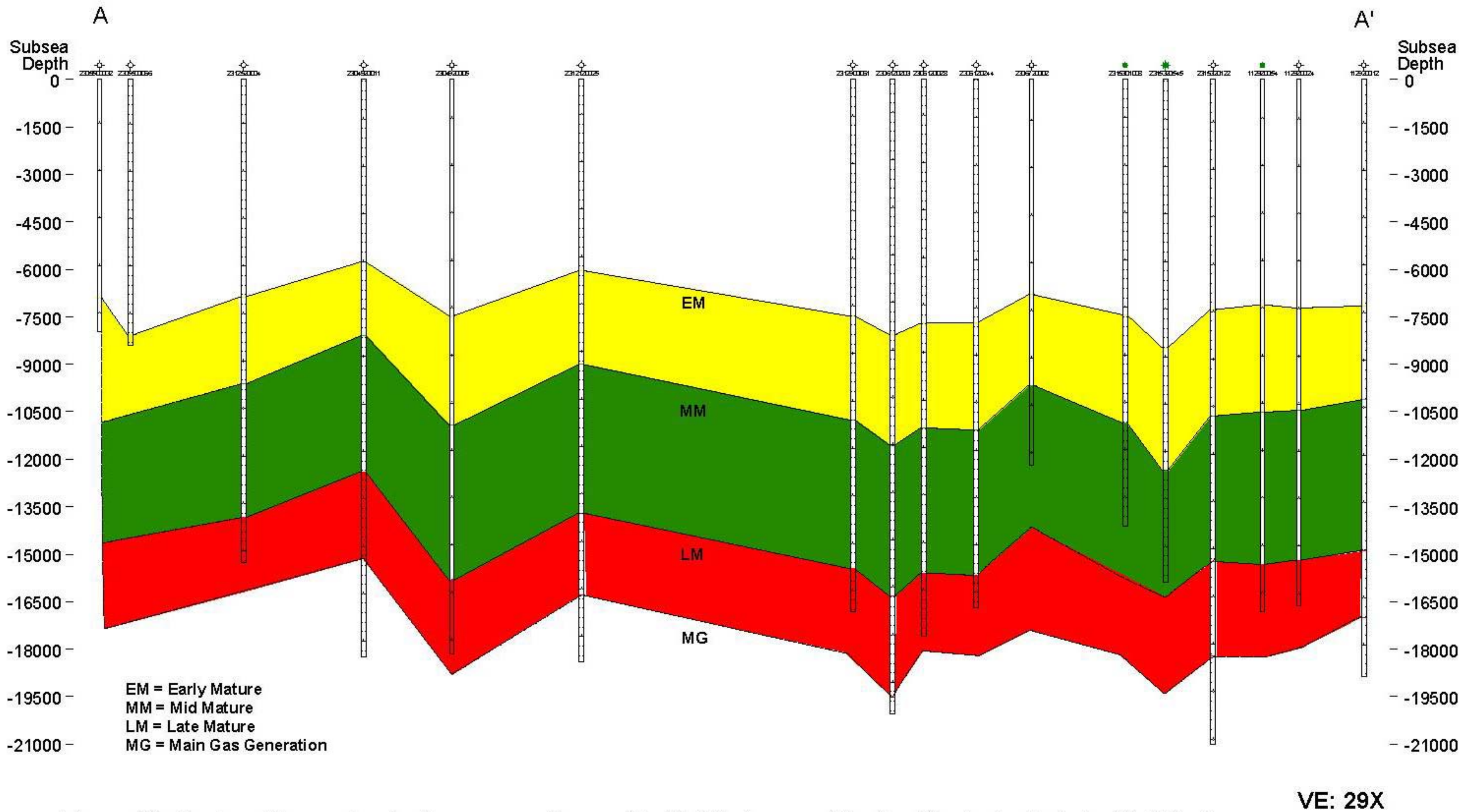


Figure 65. Regional thermal maturity cross section profile (A-A') at present for the Mississippi Interior Salt Basin, modified from Mancini et al. (2003). Location in Figure 14.

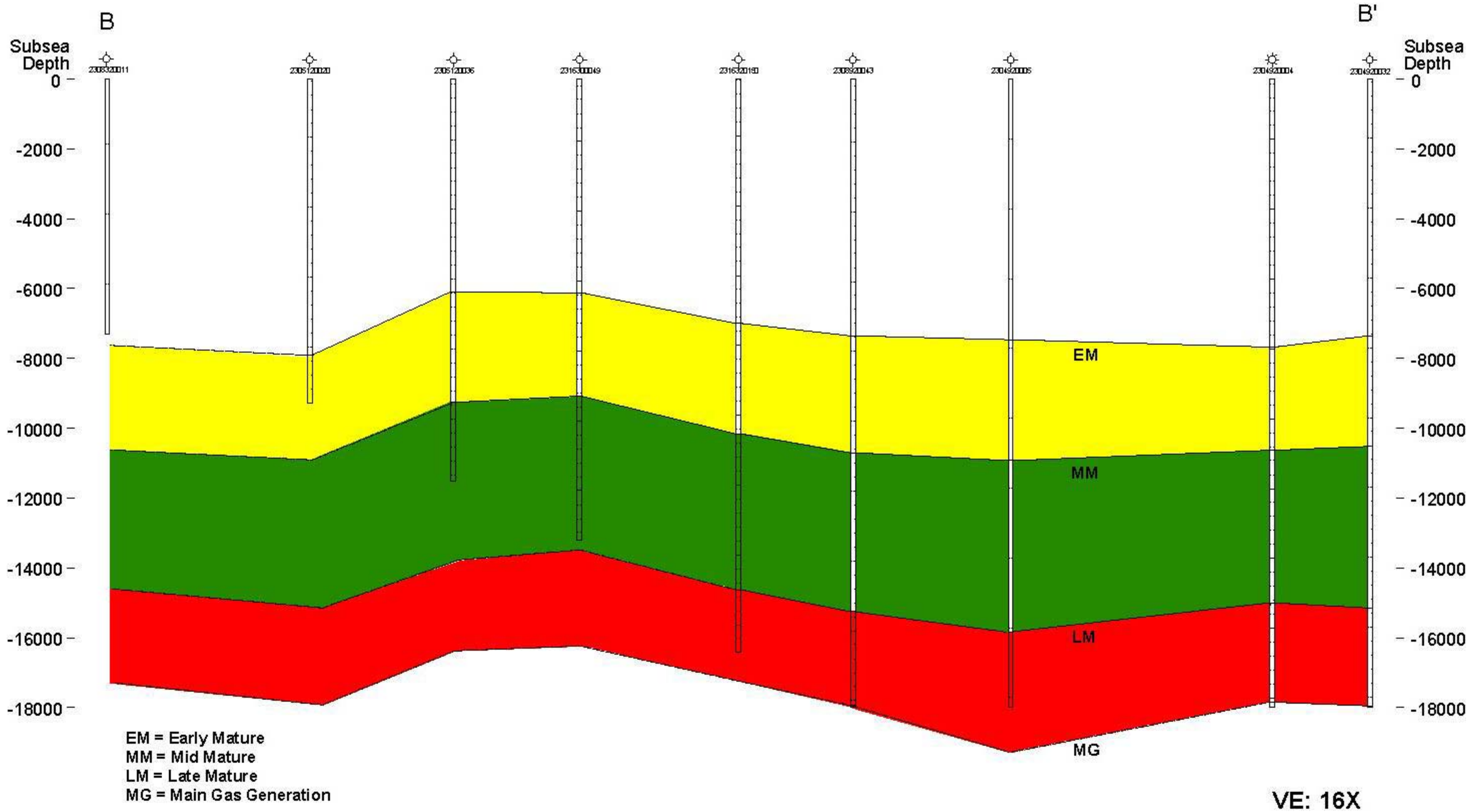


Figure 66. Regional thermal maturity cross section profile (B-B') at present for the Mississippi Interior Salt Basin, modified from Mancini et al. (2003). Location in Figure 14.

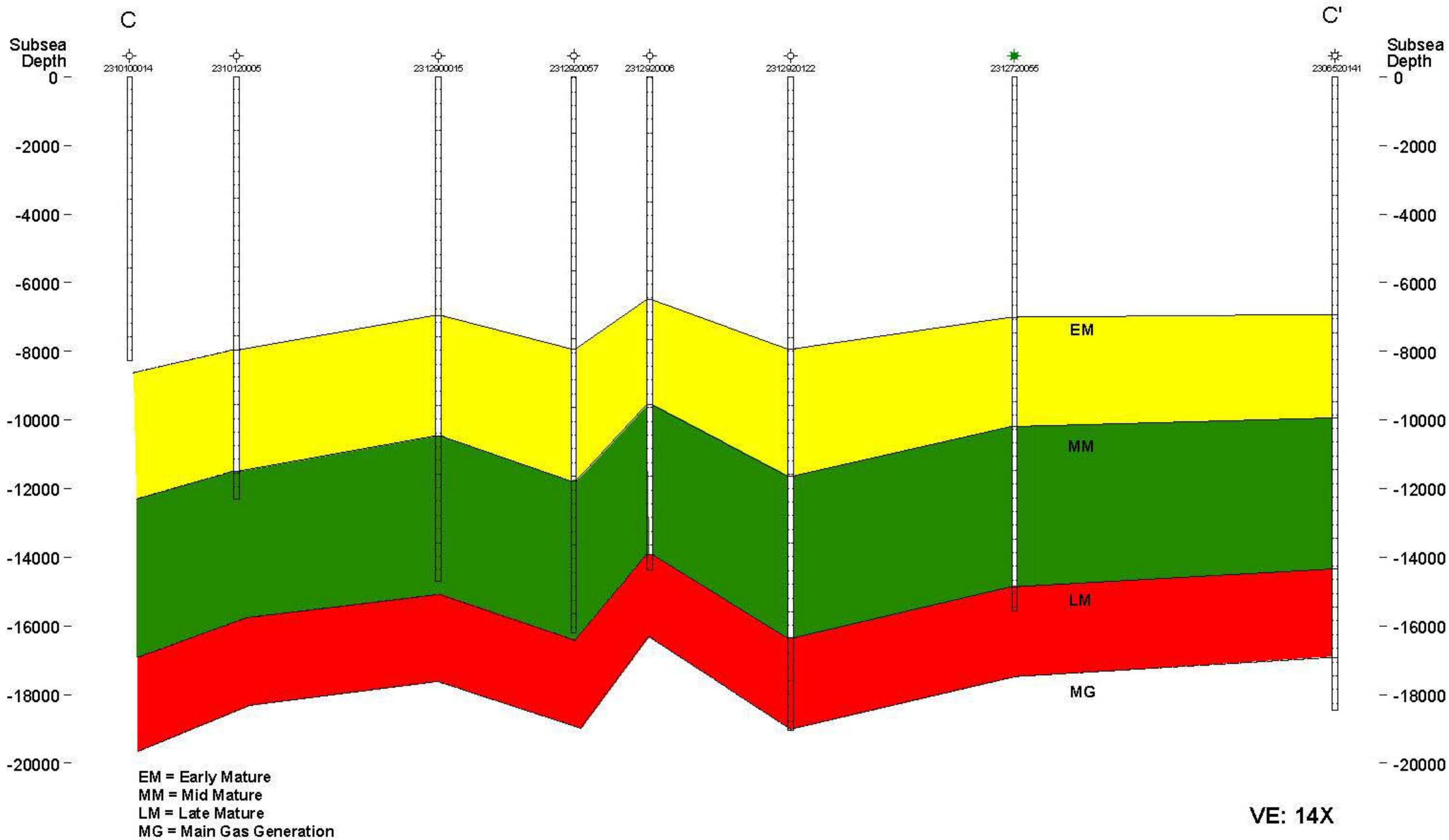


Figure 67. Regional thermal maturity cross section profile (C-C') at present for the Mississippi Interior Salt Basin, modified from Mancini et al. (2003). Location in Figure 14.

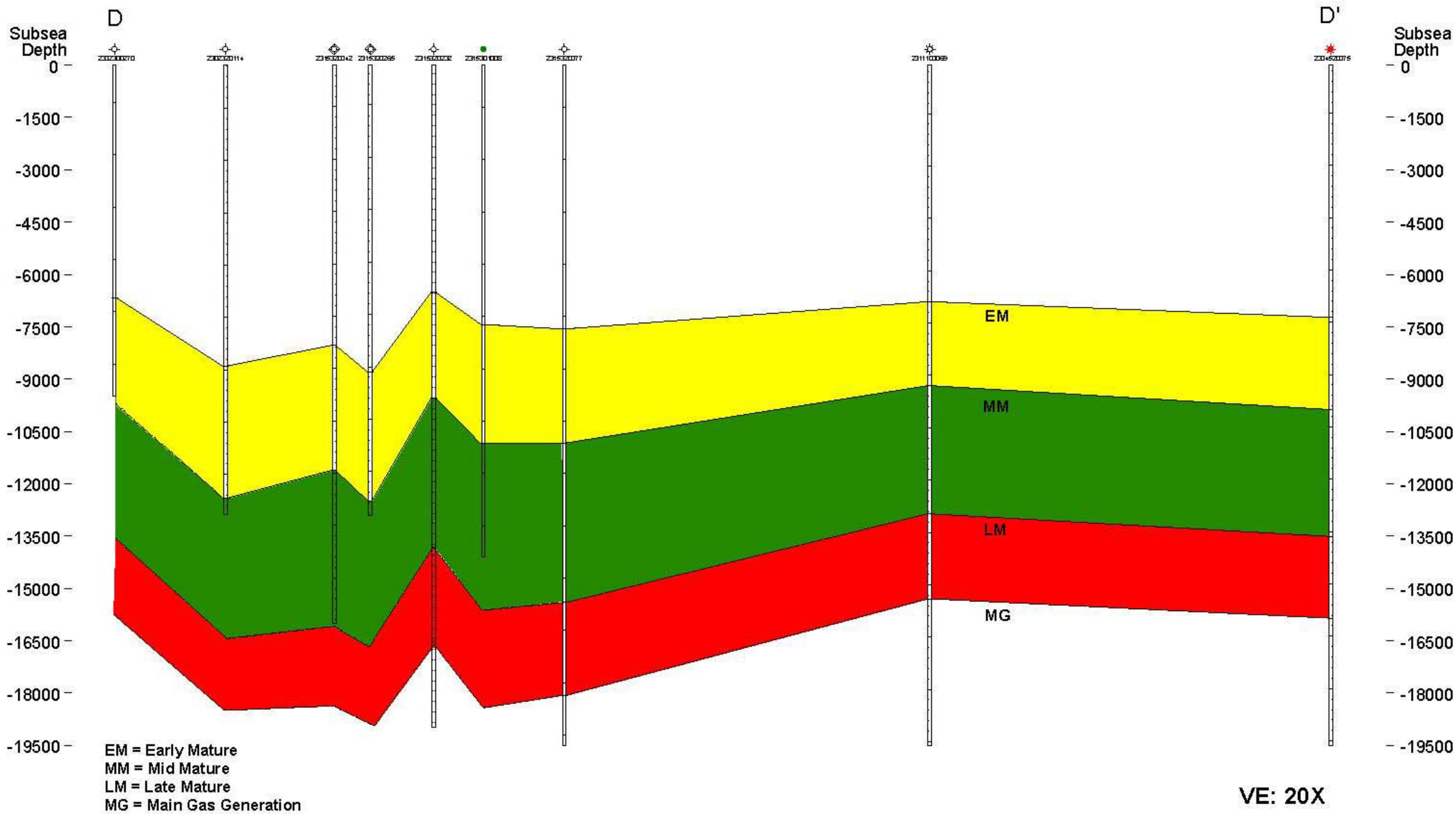


Figure 68. Regional thermal maturity cross section profile (D-D') at present for the Mississippi Interior Salt Basin, modified from Mancini et al. (2003). Location in Figure 14.

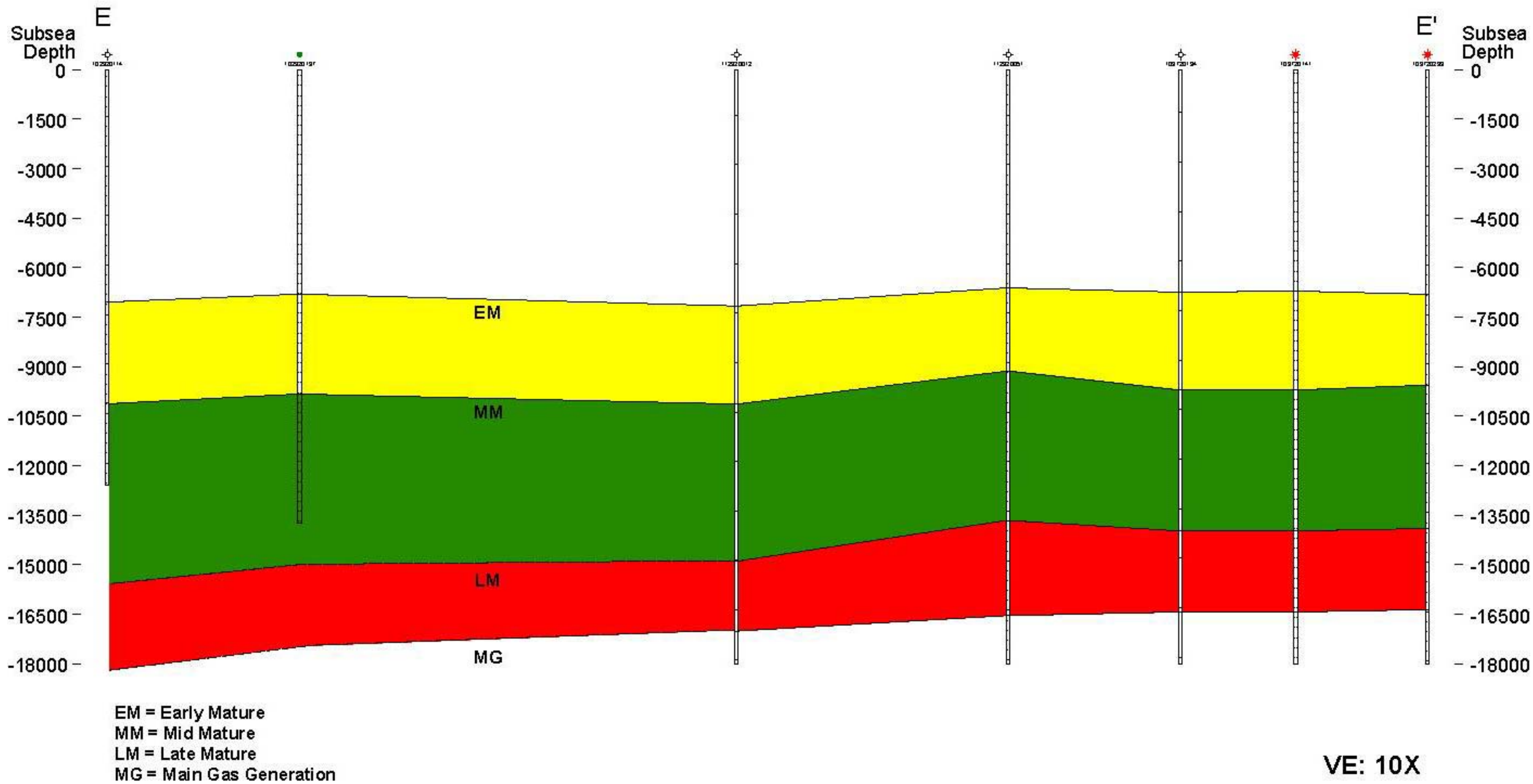


Figure 69. Regional thermal maturity cross section profile (E-E') at present for the Mississippi Interior Salt Basin, modified from Mancini et al. (2003). Location in Figure 14.

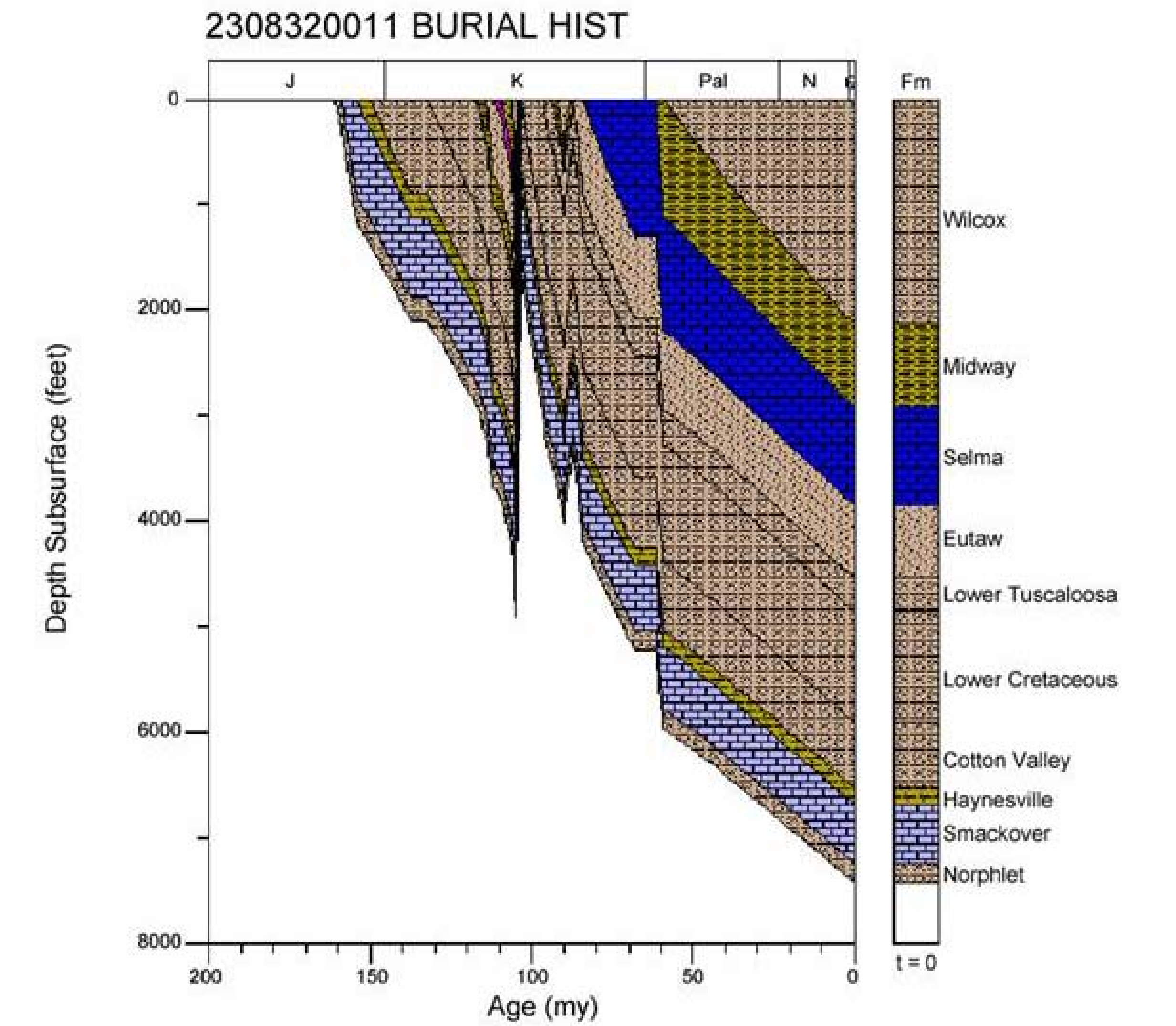


Figure 70. Updip Mississippi Interior Salt Basin, burial history profile, modified from Mancini et al. (2003).

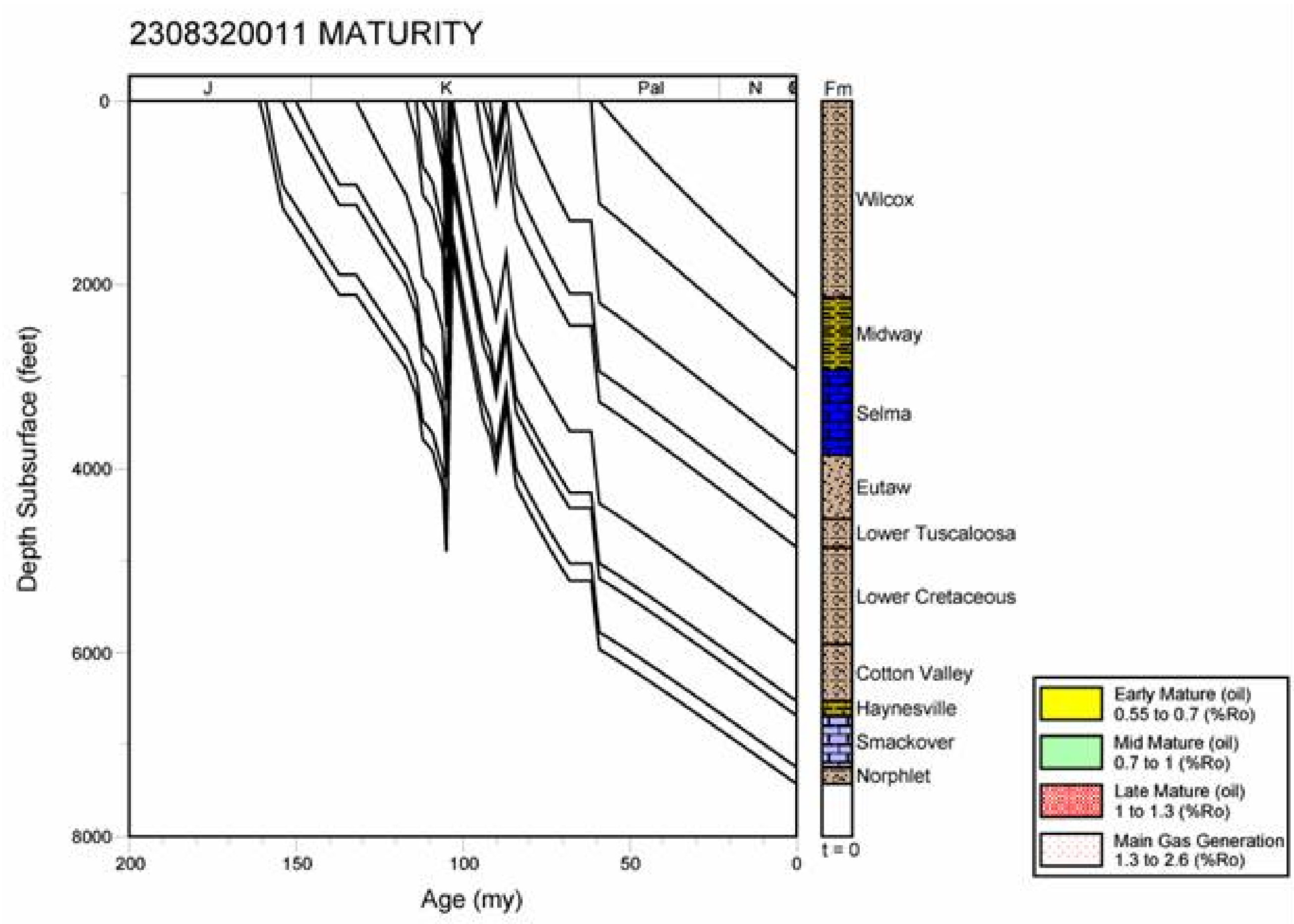


Figure 71. Updip Mississippi Interior Salt Basin, thermal maturation history profile, modified from Mancini et al. (2003).

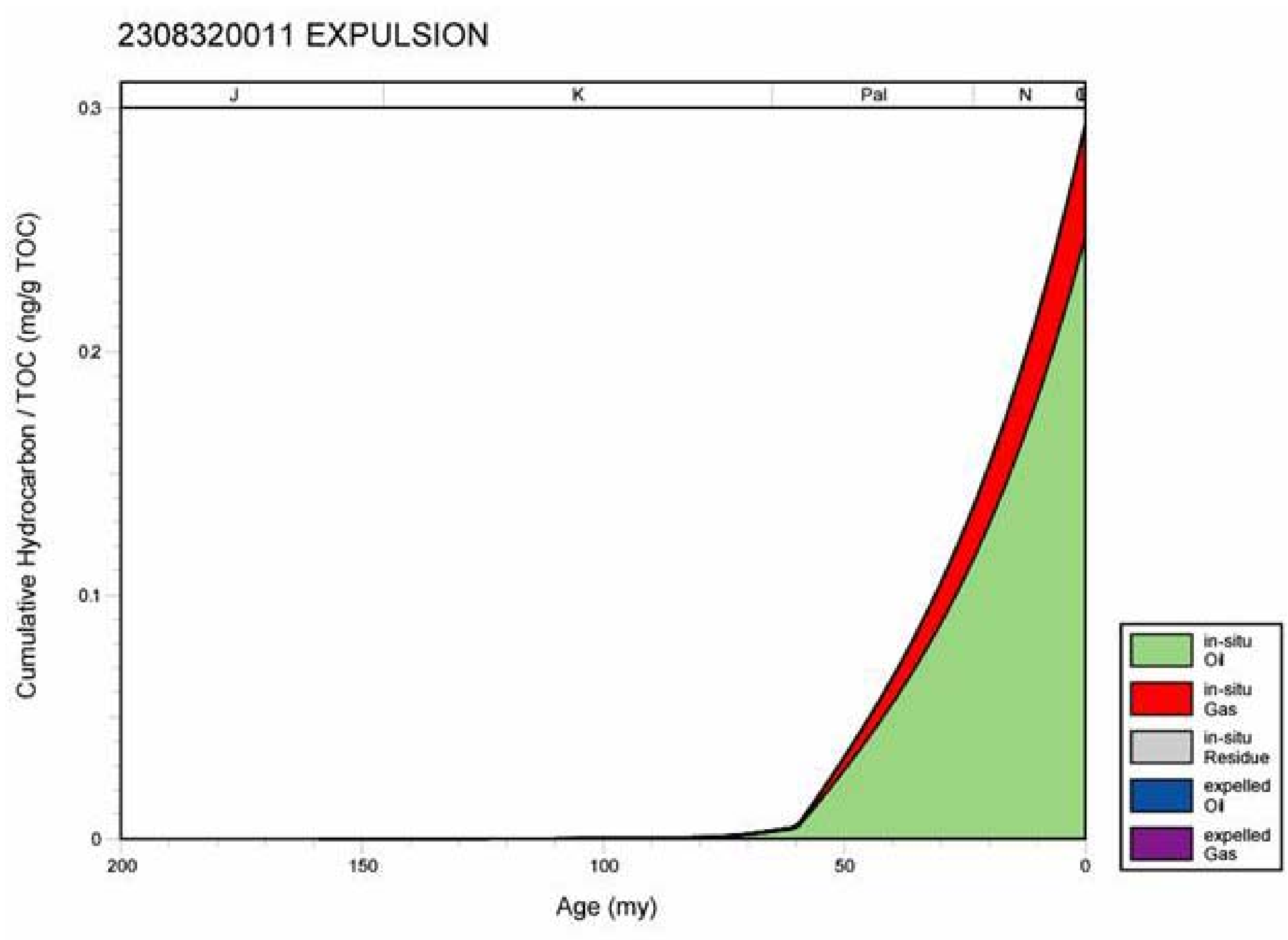


Figure 72. Updip Mississippi Interior Salt Basin, hydrocarbon expulsion plot, modified from Mancini et al. (2003).

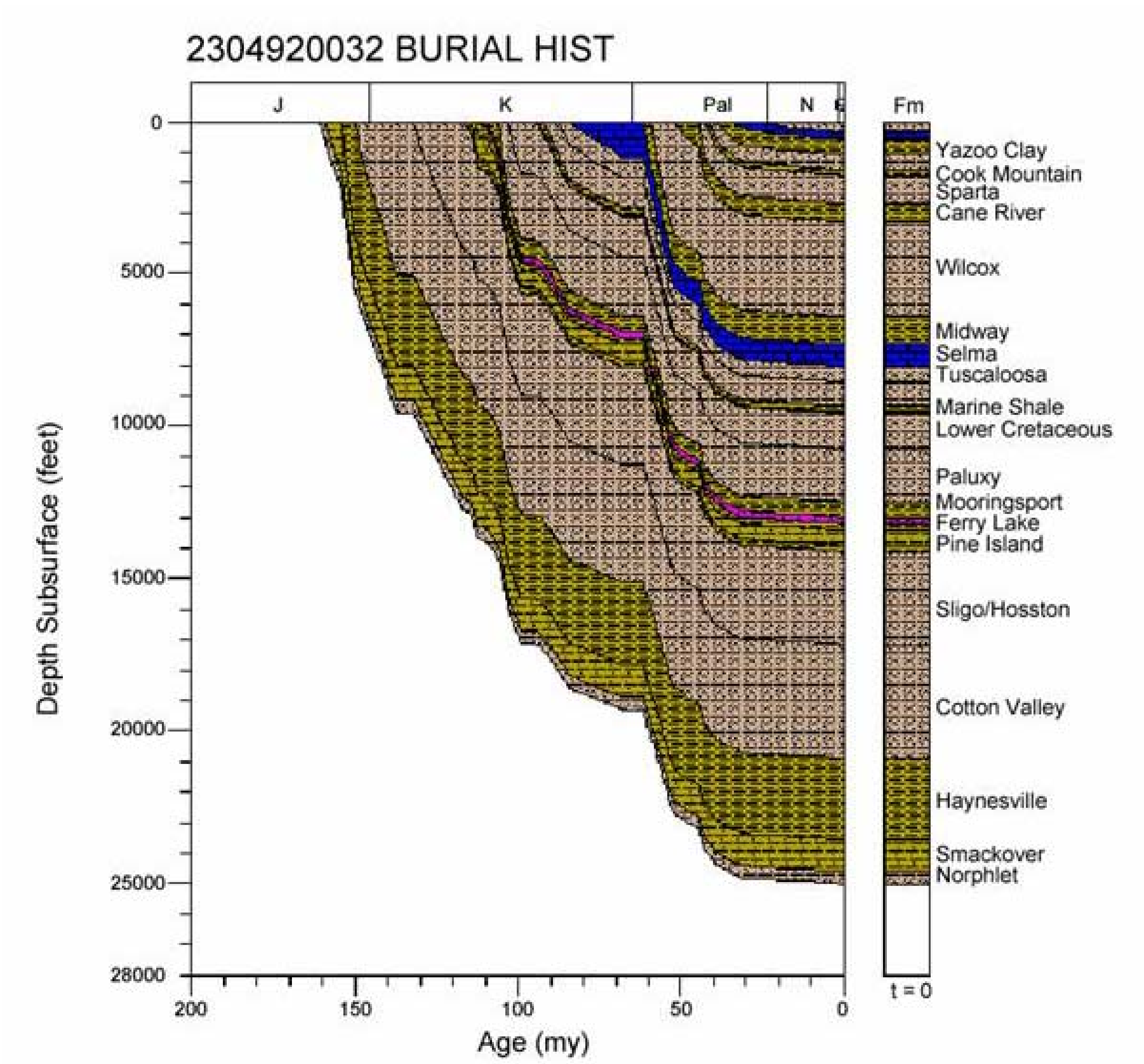


Figure 73. Downdip Mississippi Interior Salt Basin, burial history profile, modified from Mancini et al. (2003).

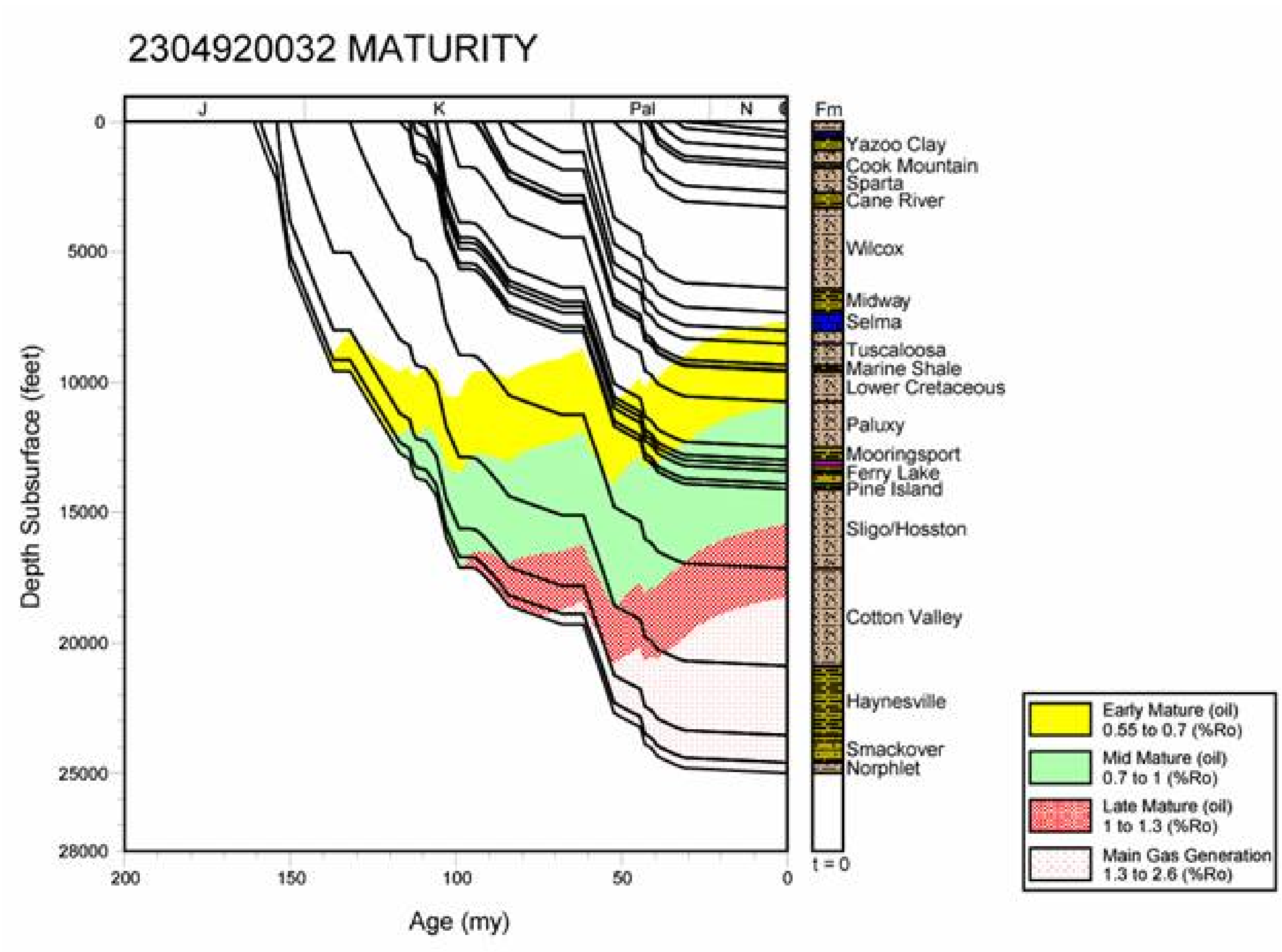


Figure 74. Downdip Mississippi Interior Salt Basin, thermal maturation history profile, modified from Mancini et al. (2003).

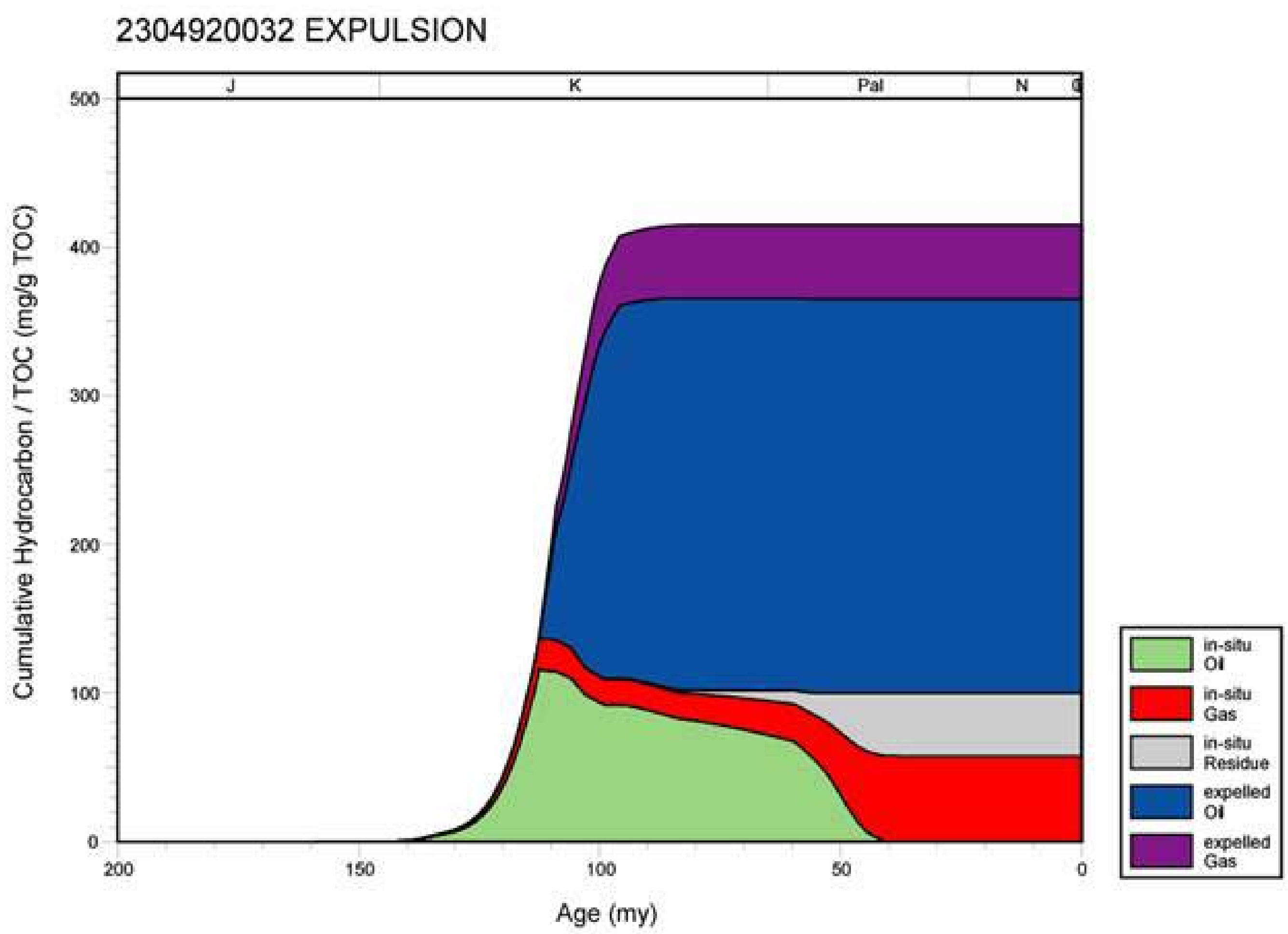


Figure 75. Downdip Mississippi Interior Salt Basin, hydrocarbon expulsion plot, modified from Mancini et al. (2003).

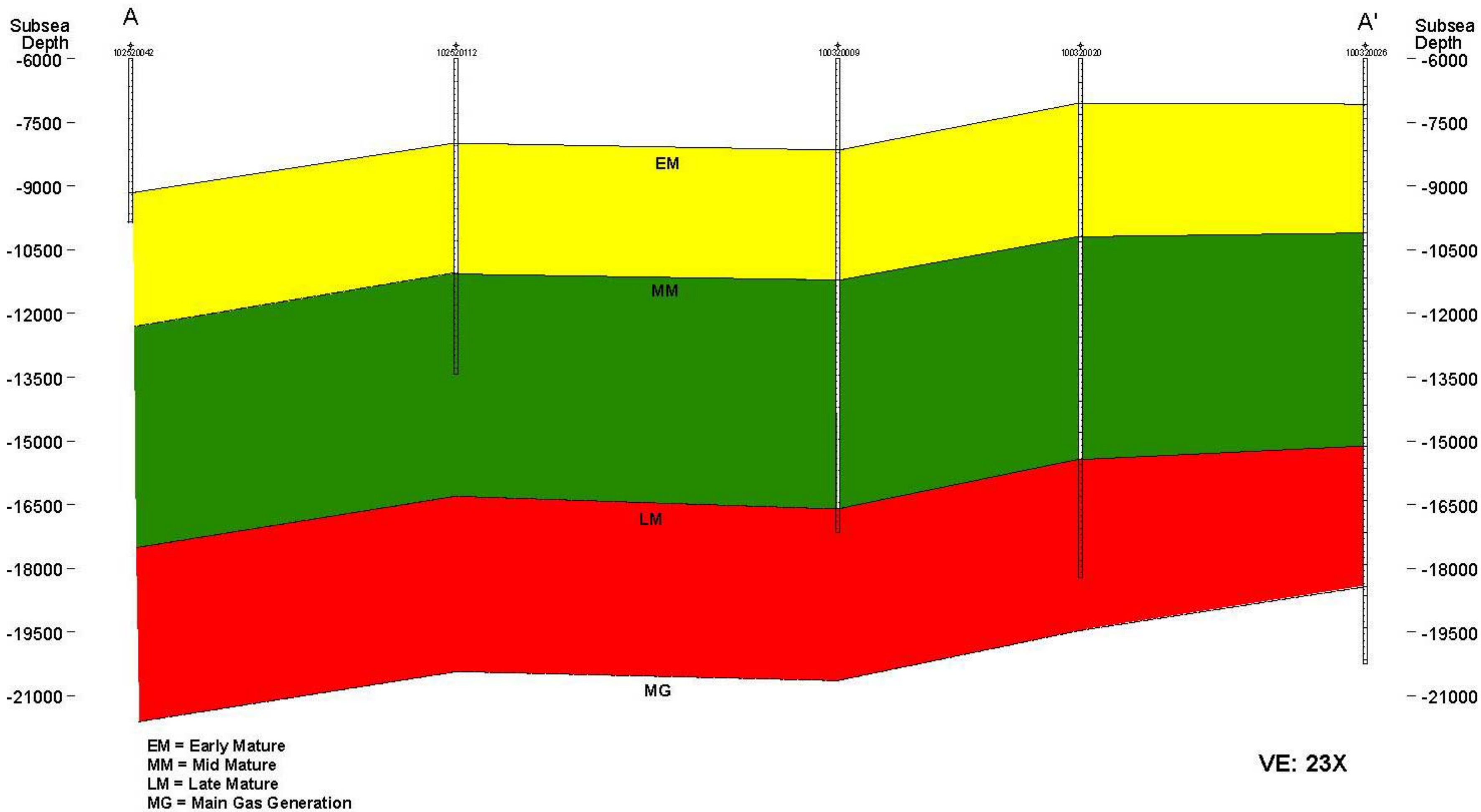


Figure 76. Regional thermal maturity cross section profile (A-A') at present for the Manila and Conecuh Subbasins. Location in Figure 20.

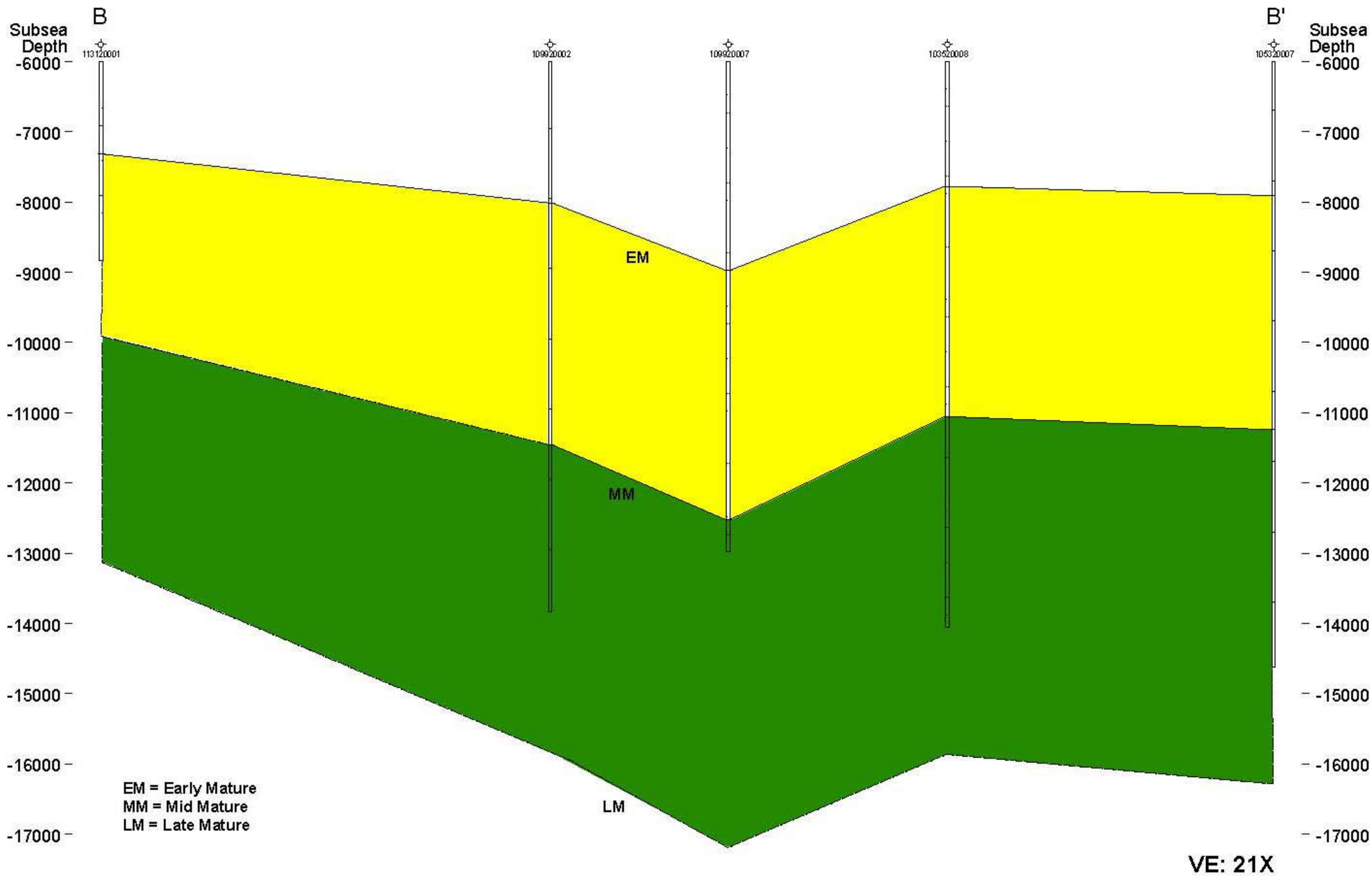


Figure 77. Regional thermal maturity cross section profile (B-B') at present for the Manila and Conecuh Subbasins. Location in Figure 20.

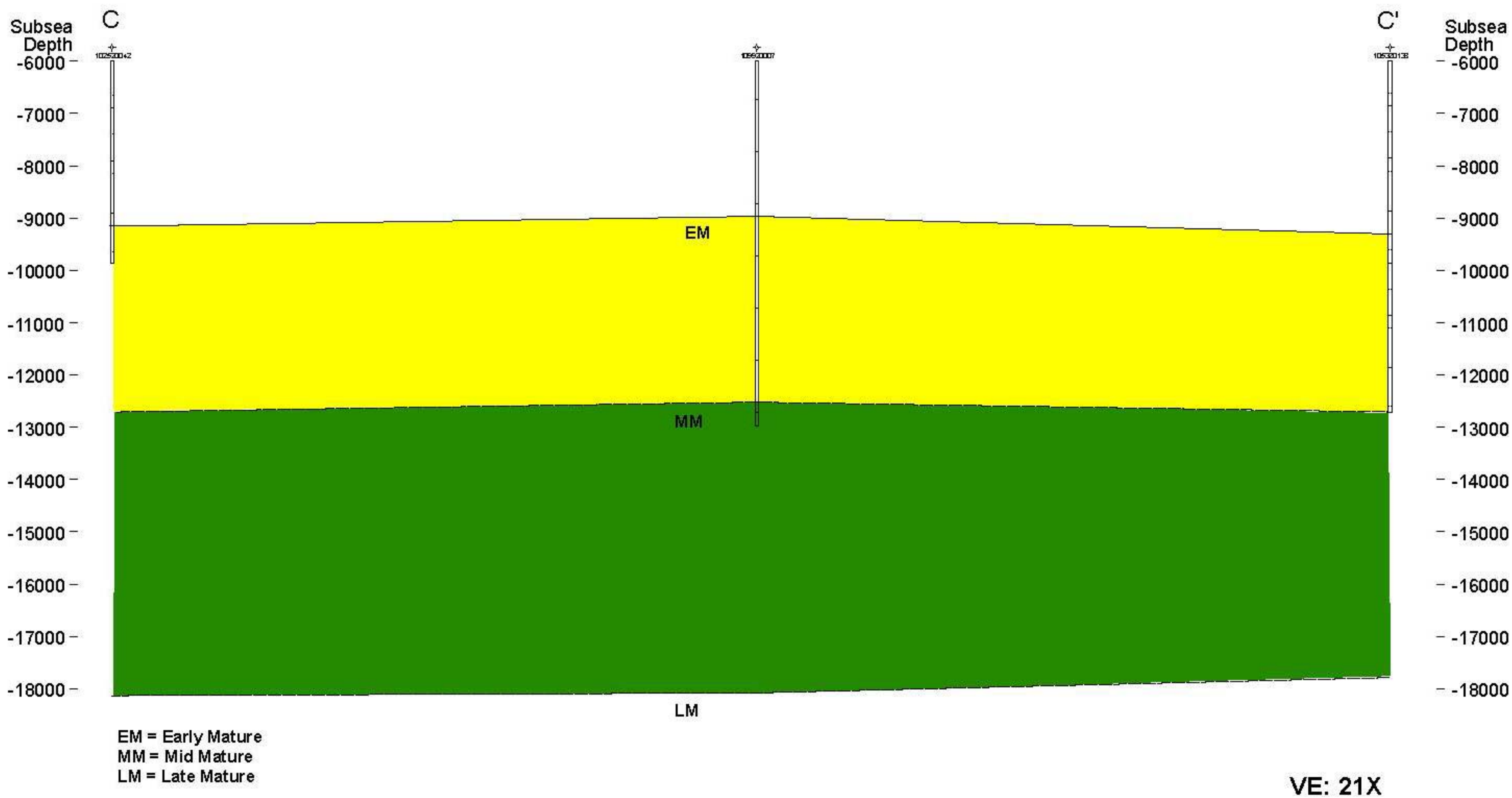


Figure 78. Regional thermal maturity cross section profile (C-C') at present for the Manila and Conecuh Subbasins. Location in Figure 20.

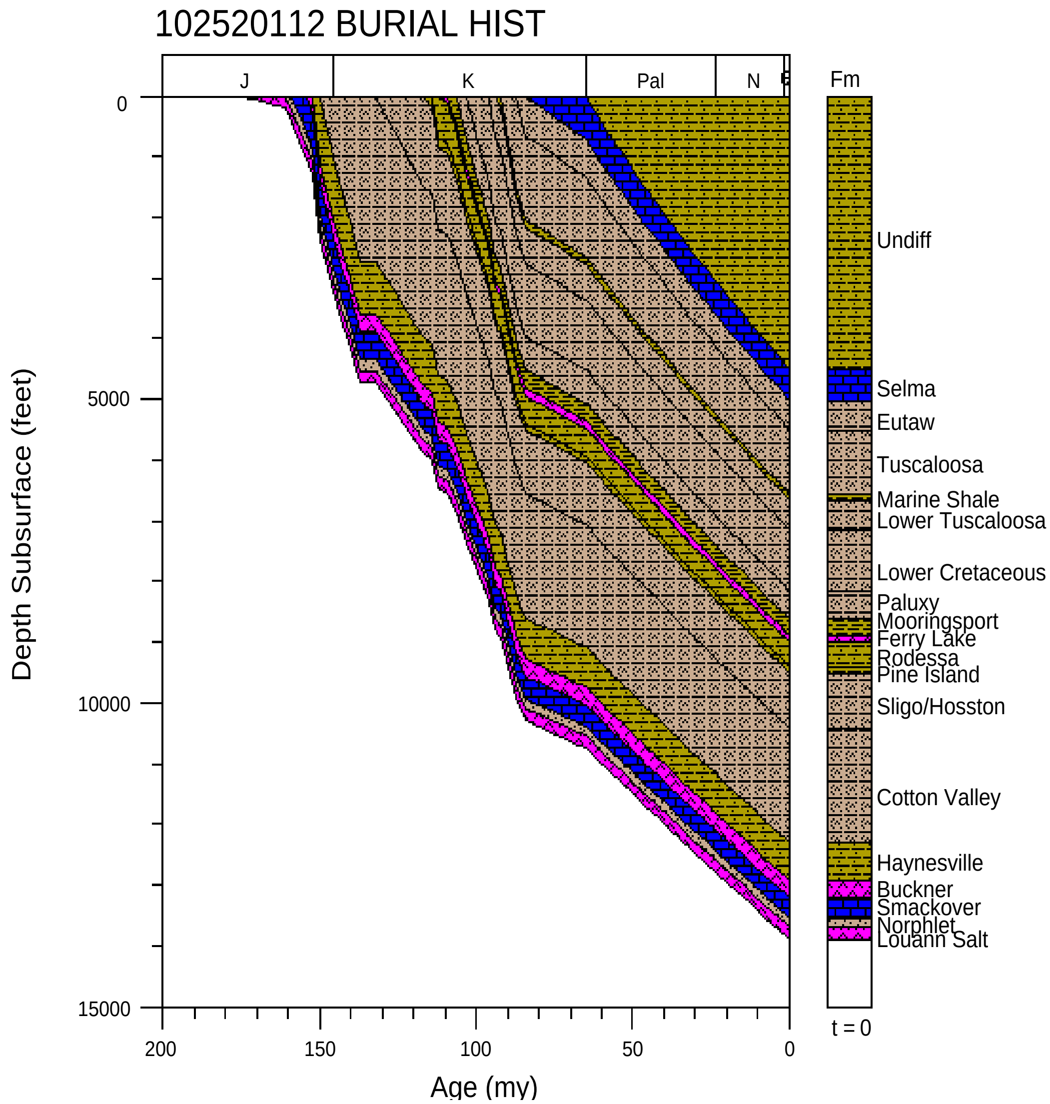


Figure 79. Manila Subbbasin, burial history profile.

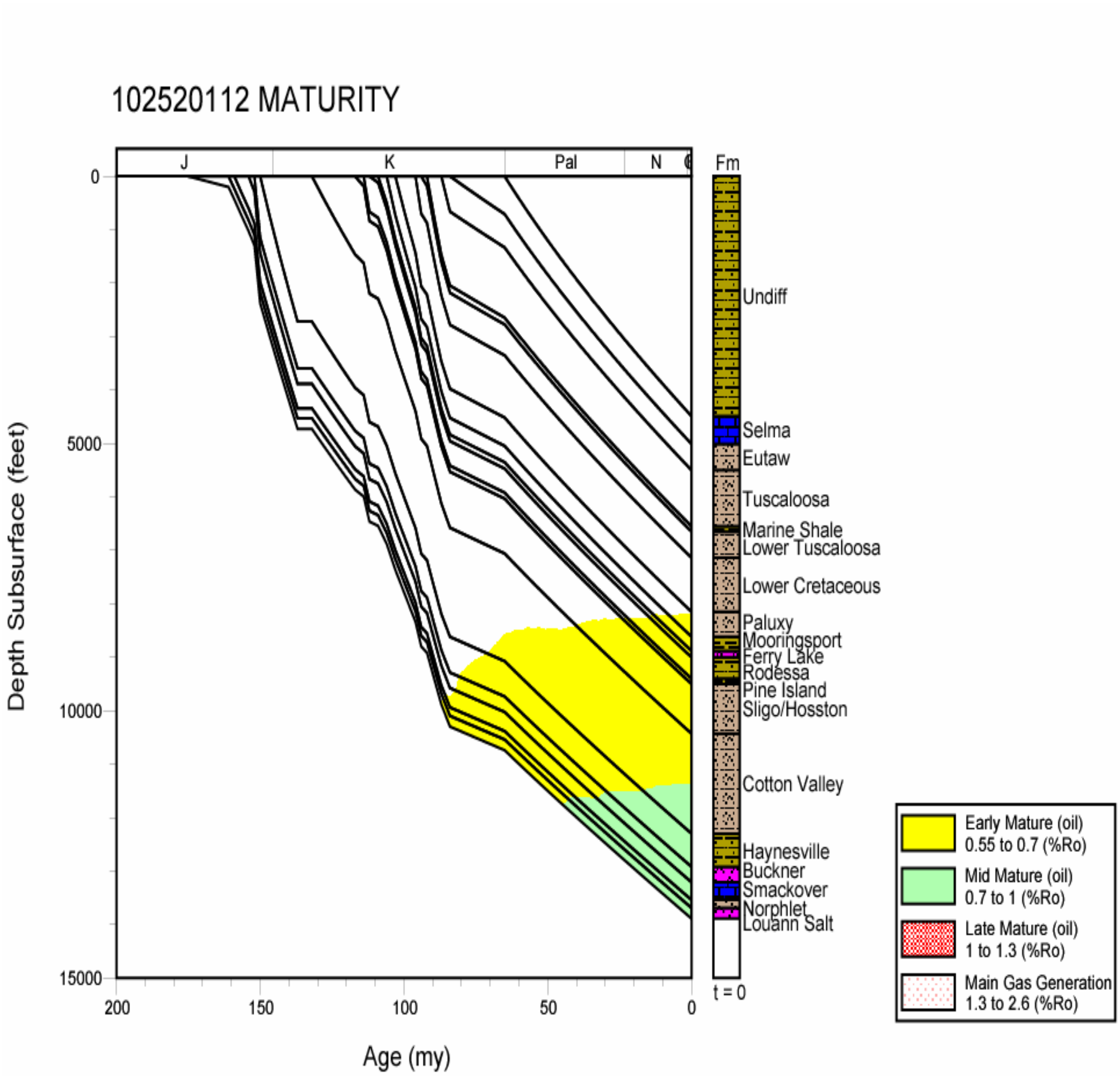


Figure 80. Manila Subbasin, thermal maturation history profile.

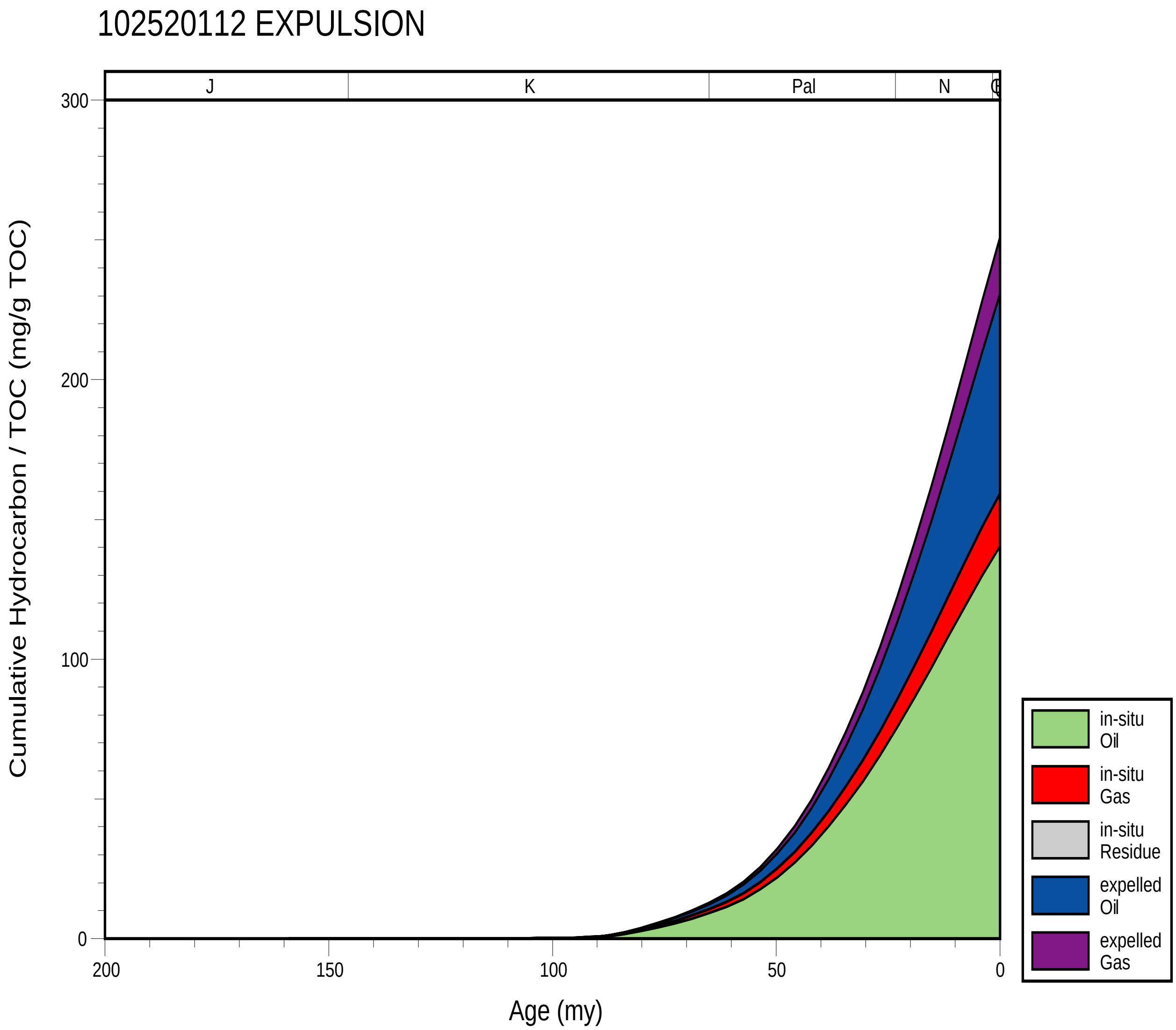


Figure 81. Manila Subbasin, hydrocarbon expulsion plot.

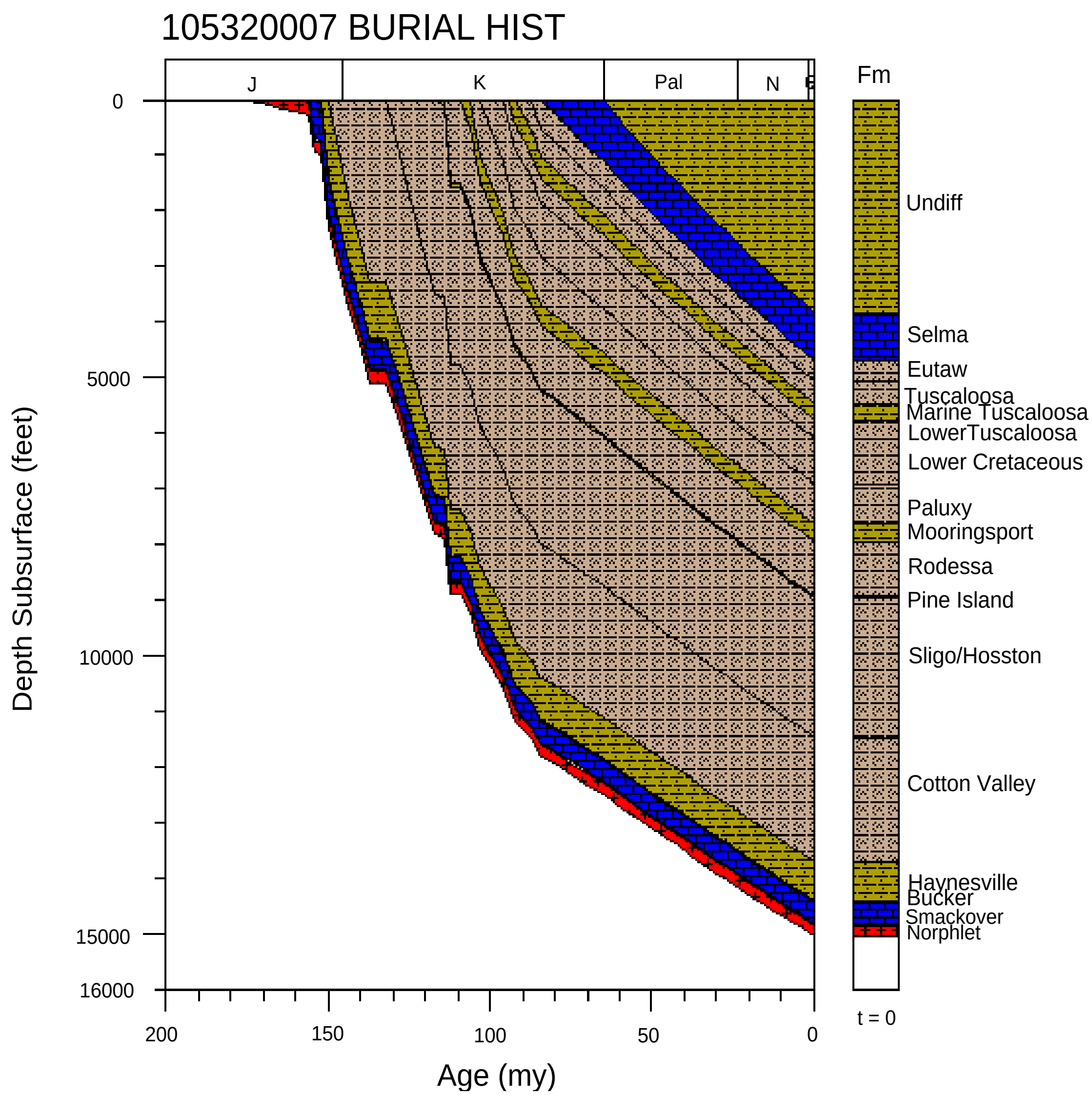


Figure 82. Conecuh Subbasin, burial history profile.

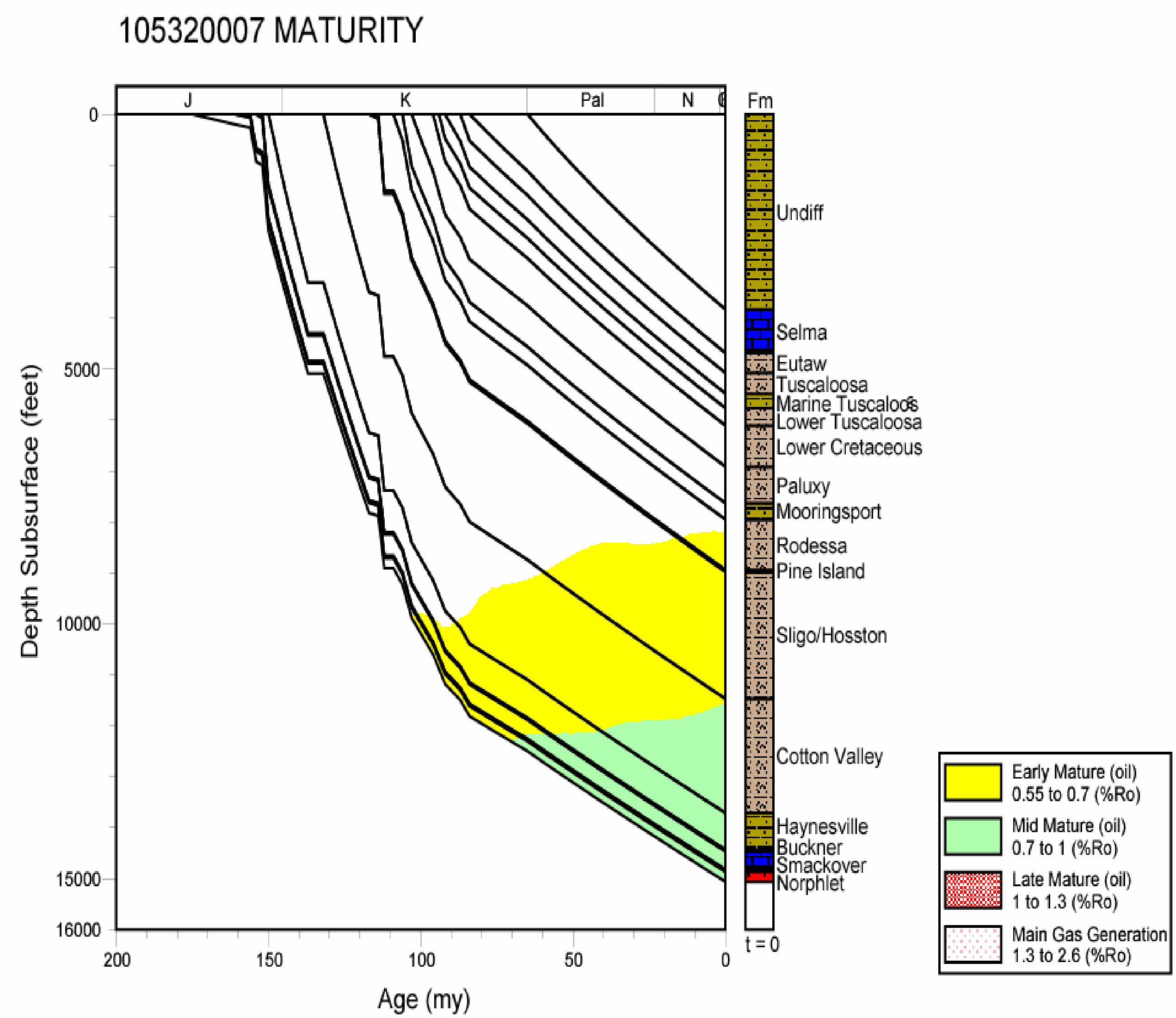


Figure 83. Conecuh Subbasin, thermal maturation history profile.

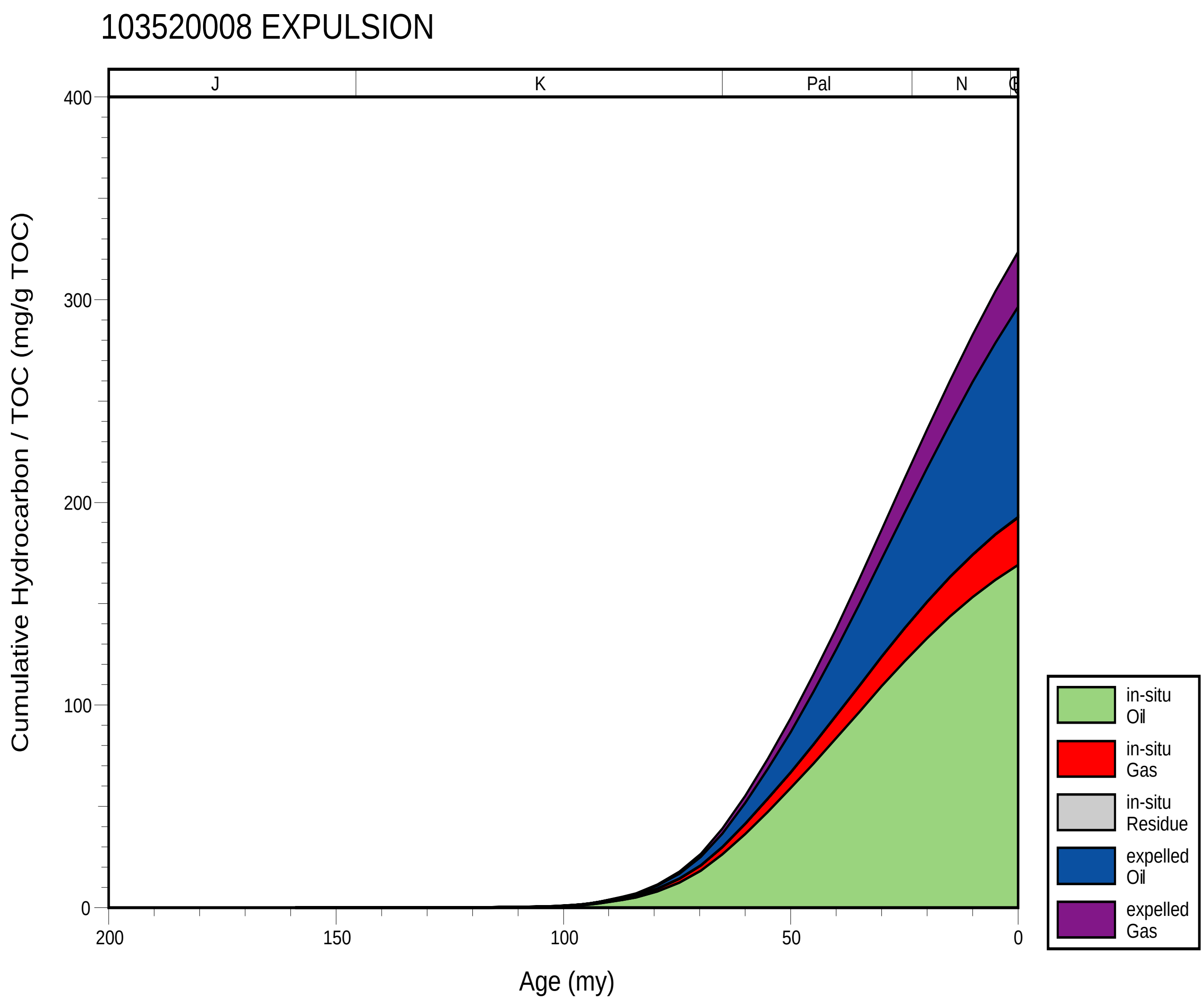


Figure 84. Conecuh Subbasin, hydrocarbon expulsion plot.

the Mississippi Interior Salt Basin (1999, 2000, 2001). This refined petroleum system modeling is based on the methodologies established by Roger Barnaby at LSU. His methodologies include procedures for estimating the amount of erosion, the amount of sediment compaction, the lithologies of the stratigraphic units, the thermal conductivities of the rock units, the present-day heat flow, the paleoheat flow, the original percent of total organic carbon in the source rocks, and the percent of oil saturation of the source rock. Hydrocarbon migration and the timing of hydrocarbon entrapment were assessed from previous studies (Figure 85). Thermal cracking of oil to gas was evaluated. A summary of the Upper Jurassic Smackover petroleum system in each of these basins and subbasins is presented in Figures 40 and 41. The timing of hydrocarbon generation, expulsion and migration in these basins and subbasins as published previously by Mancini et al. (2003) has been modified based on the refined petroleum system modeling. Hydrocarbon and thermogenic gas generation and expulsion were modeled. The hydrocarbon migration modeling is being further modified using a new software application by Petromod ®.

In-Place Resource Assessment—Total oil and natural gas production was obtained from the State of Louisiana for the North Louisiana Salt Basin (Table 5 and 6), from the States of Mississippi and Alabama for the Mississippi Interior Salt Basin (Tables 7 and 8), from Alabama (Table 9) for the Manila Subbasin (Table 10) and from the States of Alabama (Table 8) and Florida (Table 11) for the Conecuh Subbasin (Table 12). This production information is important in estimating the potential thermogenic gas in deeply buried (>15,000 ft) reservoirs in the North Louisiana Salt Basin, the Mississippi Interior Salt Basin, the Manila Subbasin, and the Conecuh Subbasin.

Estimates of the hydrocarbons generated in the North Louisiana Salt Basin, the Mississippi Interior Salt Basin, the Manila Subbasin and the Conecuh Subbasin and estimates of the potential amount of this resource that is classified as thermogenic gas for

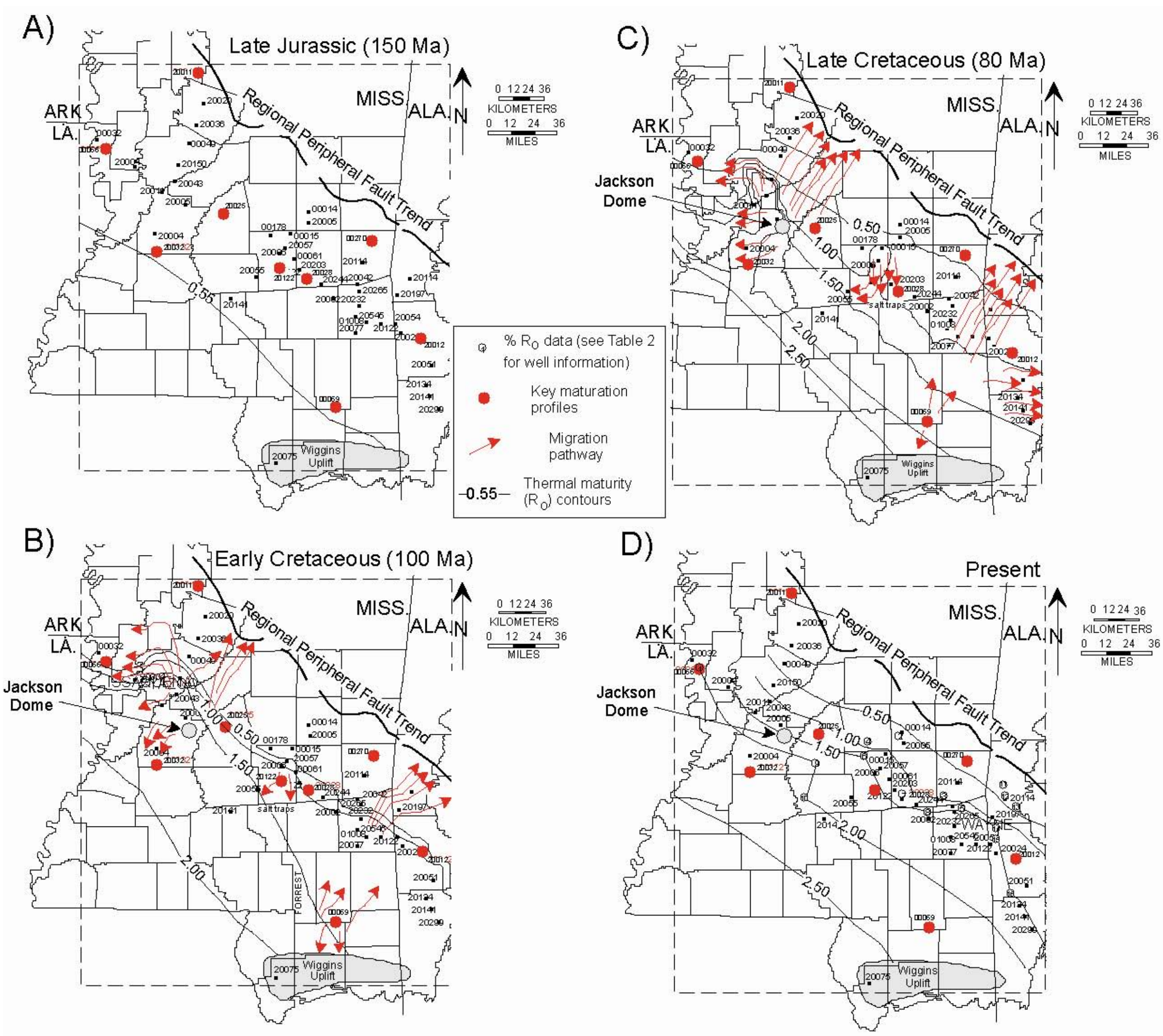


Figure 85. Maps of Smackover-sourced hydrocarbon migration across the Mississippi Interior Salt Basin (modified from Mancini et al., 2003).

Table 5. North Louisiana Salt Basin Oil & Gas Cumulative Production. *

Parish	Principal Reservoirs	Oil (Bbls)	Gas (Mcf)	GOR
Basin				
Webster	Ozan/Rodessa	204,138,070	3,696,121,592	18,106
Bienville	Sligo/Hosston	10,493,461	2,305,281,498	219,687
Claiborne	Nacatoch/Ozan/Sligo /Cotton Valley/Smackover	469,423,557	2,543,033,078	5,417
Red River	Tuscaloosa/Paluxy/Rodessa /Hosston	357,855	82,575,256	230,751
Natchitoches	Nacatoch/Sligo	81,200,000	834,000,000	10,270
Lincoln	Pine Island/Cotton Valley	31,224,187	2,272,668,985	72,786
Jackson	Hosston/Cotton Valley	2,336,084	375,328,103	160,665
Total		**799,173,214**	**12,109,008,512**	**15,152**
Sabine Uplift				
Caddo	Nacatoch	558,172,394	2,453,412,364	4,395
Bossier	Nacatoch/Lower Cretaceous	193,947,248	3,724,351,375	19,203
De Soto	Nacatoch/Paluxy	101,628,063	1,654,755,934	16,282
Total		**853,747,705**	**7,832,519,673**	**9,174**
Monroe Uplift				
Union	Nacatoch	19,687,968	193,987,271	9,853
Morehouse	Cotton Valley	201,005	3,798,739	18,899
Ouachita	Monroe Gas Rock	44,038	7,452,904,183	169,238,026
	Cotton Valley/Hosston/Sligo	40,698,299	766,122,977	18,824
Total		**60,631,310**	**8,416,813,170**	**138,820**
	Total of all parishes	**1,713,552,229**	**28,358,341,355**	**16,549**

* by LSU, D. Goddard

Table 6. North Louisiana Salt Basin Oil & Gas Cumulative Production by Reservoir.*

Reservoir	Oil (Bbls)	Gas(Mcf)	Depth (ft)
Tertiary			
Wilcox	**228,200**	**89,342**	1,500-5,788
Upper Cretaceous			
Monroe Gas Rock (Navarro)	44,038	7,452,904,183	2,000-2,500
Nacatoch (Navarro)	758,374,196	4,431,274,239	300-2,200
Ozan/Buckrange (Taylor)	265,037,353	1,007,534,243	1,712-2,900
Tokio/Blossom (Austin)	128,817,273	1,718,406,462	2,400-3,104
Tuscaloosa/Eagle Ford	3,971,873	75,601,381	2,460-9,700
Total	**1,156,658,414**	**14,686,838,117**	
Lower Cretaceous			
Fredericksburg	1,643,190	34,409,159	2,296-9,800
Paluxy	6,206,760	88,408,279	2,400-4,162
Mooringsport/Ferry Lake	312,309	1,171,999	4,218-4,850
Rodessa/Hill/Kilpatrick	198,858,232	5,615,080,804	3,000-5,000
James	12,409	2,869,335	3,800-9,571
Pine Island	8,745,072	545,229,418	4,000-7,000
Sligo/Pettet	140,715,109	3,557,065,945	3,000-8,000
Hosston	12,896,970	1,641,948,296	4,000-13,700
Total	**369,390,051**	**11,486,183,235**	
Upper Jurassic			
Cotton Valley	114,348,835	2,223,486,076	3,705-14,500
Haynesville	13,923,298	152,081,744	9,452-10,747
Smackover	33,800,601	271,765,406	8,605-11,600
Total	**162,072,734**	**2,647,333,226**	
Others	**25,388,311**	**130,564,541**	
Total of all reservoirs	**1,713,552,229**	**28,949,980,194**	

***** Table based on information from International Oil Scout Association, Yearbook 2002. The production data reported for each field was assigned to the main reservoir. In this Yearbook, the total field production could include some production from other reservoirs producing in the field.
Reservoir depths determined by D. Goddard.

Table 7. Mississippi Interior Salt Basin Oil & Gas Cumulative Production.*

ReservoIr	Oil (Bbls)	Gas(Mcf)	GOR
Tertiary			
Wilcox	**273,753,647**	**198,084,956**	**724**
Upper Cretaceous			
Selma/Jackson Gas Rock	39,205,424	224,393,889	5,724
Eutaw	301,449,711	1,754,506,272	5,820
Upper Tuscaloosa	26,338,415	19,226,238	730
Lower Tuscaloosa	610,702,463	1,805,166,543	2,956
Total	**977,696,013**	**3,803,292,942**	**3,890**
Lower Cretaceous			
Dantzler	783,201	72,450,931	92,506
Washita-Fredericksburg	56,943,318	255,821,157	4,493
Paluxy	56,544,588	568,991,732	10,063
Mooringsport	11,633,767	215,885,662	18,557
Ferry Lake	7,381	8,175	1,108
Rodessa	235,162,019	341,331,628	1,451
James	902,320	80,356,905	89,056
Pine Island	543,856	676,027	1,243
Sligo	30,927,220	157,859,597	5,104
Hosston	54,887,990	995,065,210	18,129
Total	**448,335,660**	**2,688,447,024**	**5,997**
Upper Jurassic			
Cotton Valley	106,461,276	146,163,240	1,373
Haynesville	6,421,491	349,786,844	54,471
Smackover	522,979,535	4,069,721,819	7,782
Norphlet	12,664,335	331,269,443	26,158
Total	**648,526,637**	**4,896,941,346**	**7,551**
Others (including Tuscaloosa production from Louisiana)	**872,883,419**	**1,277,775,162**	**1,464**
Total of all reservoirs	**3,221,195,376**	**12,864,541,430**	**3,994**

***** by UA

Table 8. Mississippi Interior Salt Basin Oil & Gas Cumulative Production by Reservoir.*

Reservoir	Oil (Bbls)	Gas(Mcf)	Depth (ft)**
Tertiary			
Wilcox	**273,753,647**	**198,084,956**	1,307-3,863
Upper Cretaceous			
Selma/Jackson Gas Rock	39,205,424	224,393,889	2,145-7,035
Eutaw	301,449,711	1,754,506,272	3,100-8,030
Tuscaloosa	947,040,878	2,460,392,781	4,365-9,545
Total	**1,287,696,013**	**4,439,292,942**	
Lower Cretaceous			
Dantzler	783,201	72,450,931	3,095-9,695
Washita-Fredericksburg	56,943,318	255,821,157	4,744-9,695
Paluxy	56,544,588	568,991,732	5,677-12,160
Mooringsport	11,633,767	215,885,662	5,502-13,270
Ferry Lake	7,381	8,175	7,346-13,830
Rodessa	235,162,019	341,331,628	7,112-13,413
James	902,320	80,356,905	8,133-13,900
Pine Island	543,856	676,027	8,133-13,900
Sligo	30,927,220	157,859,597	8,343-14,692
Hosston	54,887,990	995,065,210	8,740-15,223
Total	**448,335,660**	**2,688,447,024**	
Upper Jurassic			
Cotton Valley	106,461,276	146,163,240	4,713-18,050
Haynesville	6,421,491	349,786,844	6,528-20,890
Smackover	522,979,535	4,069,721,819	6,685-23,553
Norphlet	12,664,335	331,269,443	7,247-24,606
Total	**648,526,637**	**4,896,941,346**	
Others	**562,883,419**	**641,775,162**	
Total of all reservoirs	**3,221,195,376**	**12,864,541,430**	

* Production data from State Oil and Gas boards of Mississippi and Alabama.
**Depth to the top of the Formation (Mancini et al., 1999).

Table 9. Alabama Oil and Gas Cumulative Production by Reservoir.*

Reservoir	Oil (Bbls)	Gas (Mcf)	Depths(ft)
Tertiary			
Miocene	0	140,049,784	1,200-3,600
Upper Cretaceous			
Selma	2,145,085	0	2,600
Eutaw	12,620,913	5,745	3,200-3,800
Tuscaloosa	30,187,182	851,222	5,300-6,200
Total	**44,953,180**	**856,967**	
Lower Cretaceous			
Lower Cretaceous	1,424	136	8,500
Dantzler	176,036	7,245	6,600-7,100
Washita/Fredricksburg	1,820,140	78,263	7,800-8,200
Paluxy	167,463	243	8,300-8,700
Rodessa	167,426,752	15,142,921	10,000-10,800
Hosston	849,150	67,232	8,900-10,000
Total	**170,440,965**	**15,296,040**	
Upper Jurassic			
Cotton Valley	1,015,955	0	8,800-10,200
Haynesville	27,212,560	39,200,467	11,100-14,200
Smackover	306,760,497	1,788,681,246	10,500-18,600
Smackover/Norphlet	77,124,095	422,223,389	18,000-18,200
Norphlet	20,079,623	2,710,652,138	12,200-22,200
Total	**432,192,730**	**4,960,757,240**	
Total of all reservoirs	**647,586,875**	**5,116,960,031**	

* Production data and reservoir depths from State Oil and Gas Board of Alabama.

Table 10. Manila Subbasin Oil & Gas Cumulative Production.*

County	Reservoirs	Oil (Bbls)	Gas (Mcf)	GOR
Baldwin	Dantzler/Washita-Fredericksburg/Paluxy	2,212,819	86,984	39
	Smackover	2,579,846	2,238,794	868
Clarke	Tuscaloosa	8,916,844	0	0
	Smackover	3,542,563	1,320,934	373
Monroe	Haynesville/Smackover/Norphlet	32,598,550	51,093,438	1,567
Total		**49,850,622**	**54,740,150**	**1,098**

*by UA

Table 11. Florida Oil and Gas Cumulative Production by Reservoir.*

Reservoir	Oil (Bbls)	Gas (Mcf)	Detph (ft)
Upper Jurassic			
Smackover	414,233,000	548,713,000	15,200-15,500
Norphlet/Smackover	58,135,000	60,843,000	15,800
Total	**472,368,000**	**609,556,000**	

*Production from State Oil and Gas Board of Florida.

Table 12. Conecuh Subbasin Oil & Gas Cumulative Production.*

County	Reservoirs	Oil (Bbls)	Gas (Mcf)	GOR
Conecuh	Haynesville/Smackover/Norphlet	6,399,695	7,662,395	1,197
Covington	Cotton Valley/Haynesville/Smackover	3,563,883	48,742	14
	Hosston	870,845	67,232	77
Escambia (AL)	Tuscaloosa	21,542,952	856,043	40
	Haynesville/Smackover/Norphlet	148,395,921	1,346,218,232	9,072
Escambia/Santa Rosa (Florida)	Smackover/Norphlet	472,368,000	609,556,000	1,290
Total		**653,141,296**	**1,964,408,644**	**3,008**

*by UA (including Big Escambia Creek and Flomaton fields) the North Louisiana and Mississippi Interior Salt Basins also were made. This assessment involves estimating the amount of the gas resource that is generated directly from the source rock both during the oil generation process and from late cracking of the oil stored in the source rock. The method of Schmoker (1994) and the use of petroleum system software applications of Platte River were used in the estimation of the total hydrocarbons and the thermogenic gas generated and expelled in the North Louisiana and Mississippi Interior Salt Basins. The petroleum source rocks in the Manila and Conecuh Subbasins have not reached the level of thermal maturation for cracking the oil stored in the source rocks. Listed below are the results of these determinations. These results were compared to the research results of Zimmerman (1999) and Mancini et al. (2003).

1. North Louisiana Salt Basin (by LSU, Roger Barnaby)

   a. Schmoker (1994) method for determining the total mass of hydrocarbons (oil and gas) generated.

   Total mass Smackover = (2.66×10^{13} m^3 volume Smackover) × (2.5 g/cm^3 average density) × (1×10^6 cm^3/m^3) = 6.65×10^{19} g.

   At 1% TOC, total mass of organic carbon = $0.01 \times (6.65 \times 10^{19}$ g$) = 6.65 \times 10^{17}$ g.

   Smackover original hydrocarbon index (HI_0) = 300 to 650 mg HC/g TOC, immature lower Smackover reported by Sassen and Moore (1998).

   Smackover present-day hydrocarbon index (HI_p) = 6 to 58 mg HC/g TOC, average HI_p = 34 mg HC/g TOC, data from this study.

Total mass of hydrocarbons generated per unit mass of organic carbon = (HI_0 – HI_p) = (650 – 34) = 616 mg HC/g TOC.

Total mass of hydrocarbons generated = 616 mg HC/g TOC × (6.65 × 10^{17} g TOC) × (10^{-6} kg/mg) = 4.1 × 10^{14} kg.

Converted to barrels of 25^o API oil = (4.1 × 10^{14} kg × 7 bbls/1,000 kg) = 2,870 × 10^9 barrels.

b. Platte River software method for determining the total volume of hydrocarbons (oil and gas) generated.

Estimates using the Platte River (BasinView) software are comparable, ranging from 2.5 to 3.8 × 10^{14} kg (depending on heat flow).

Converted to barrels of 25°API oil = (3.8 × 10^{14} kg × 7 bbls/1,000 kg = 2,640 × 10^9 bbls.

c. Schmoker (1994) method for determining the oil and gas volumes generated.

To subdivide the total hydrocarbon volume into oil and gas volumes using the method of Schmoker (1994) requires knowledge of the GOR. The average GOR for North Louisiana area (1943 to 2004 production) = 12,300 ft^3gas/bbl oil (Figure 86). This average GOR does not include the anomalous gas production from the Monroe Gas Rock. The average GOR for North Louisiana Salt Basin including the Monroe Gas Rock is 16,549 ft^3gas/bbl oil, as shown in Table 5.

Weight fraction gas (assuming 25^o API oil)

= [12,300 ft^3gas × (1 kg gas/48.7 ft^3)]

÷ [12,300 ft^3gas × (1 kg gas/48.7 ft^3) + 1 bbl oil × (1,000 kg/7 bbls oil)]

= 252.6 kg ÷ (252.6 + 142.9 kg) = 0.64.

Weight fraction oil (assuming 25° API oil) = (1.0 – 0.64) = 0.36.

Total gas generated = 0.64 × (4.1 × 10^{14} kg) × (48.7 ft^3/1 kg gas) = 1.28 × 10^{16} ft^3 = 12,800 TCF.

Total oil generated = 0.36 × (4.1 × 10^{14} kg) × (7 bbls oil/1,000 kg) = 1,030 × 10^9 bbls.

d. Platte River software for determining the volume of oil and gas generated.

The Platte River (BasinView) software model, using the input parameters of TOC = 1%, rift heat flow model with a late Cretaceous event, indicates that 1,715 × 10^9 bbls total oil and 6,400 TCF total gas were generated in north Louisiana (Figures 87 and 88). This yields a GOR of 3,732, which is lower than production statistics.

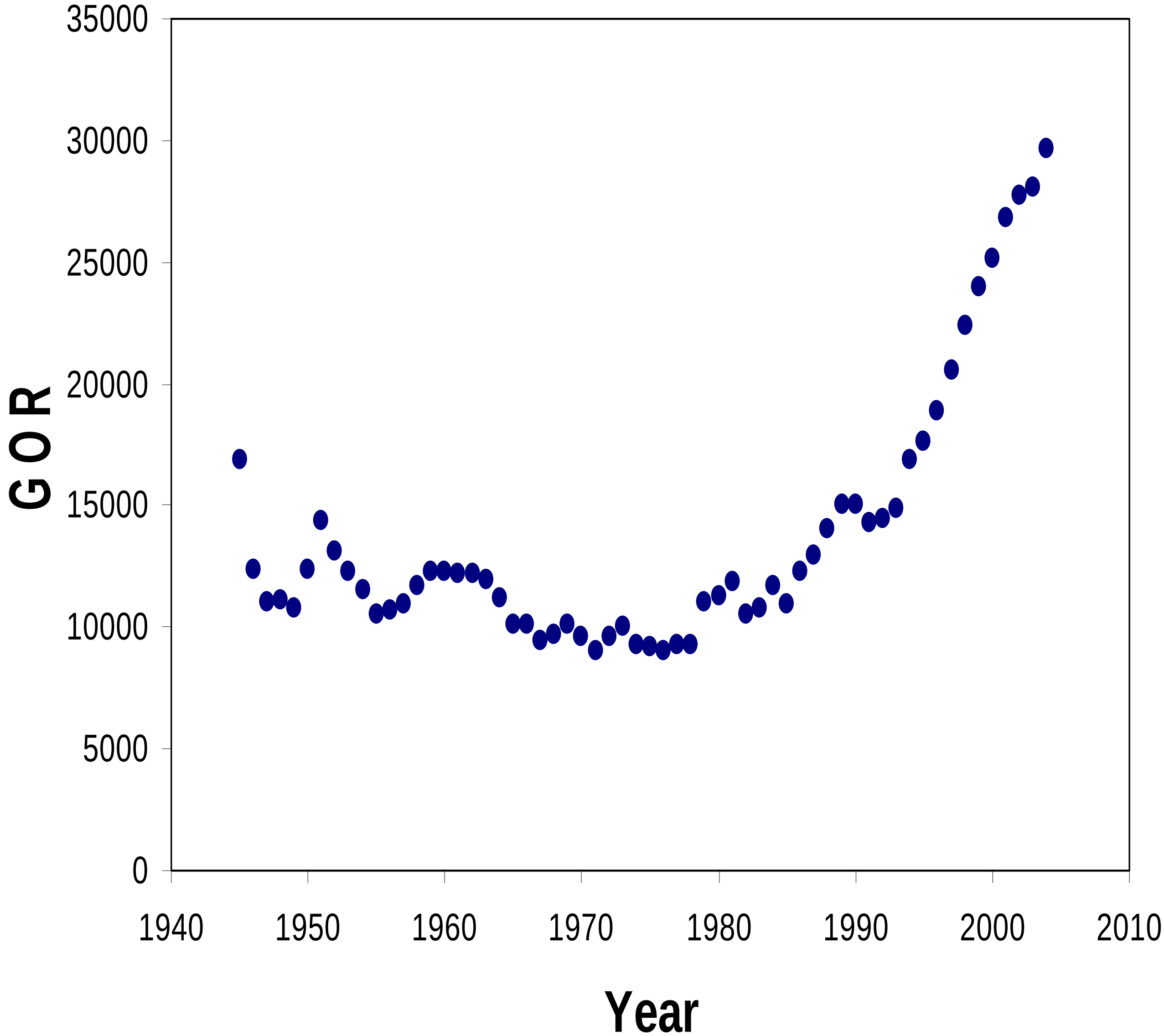
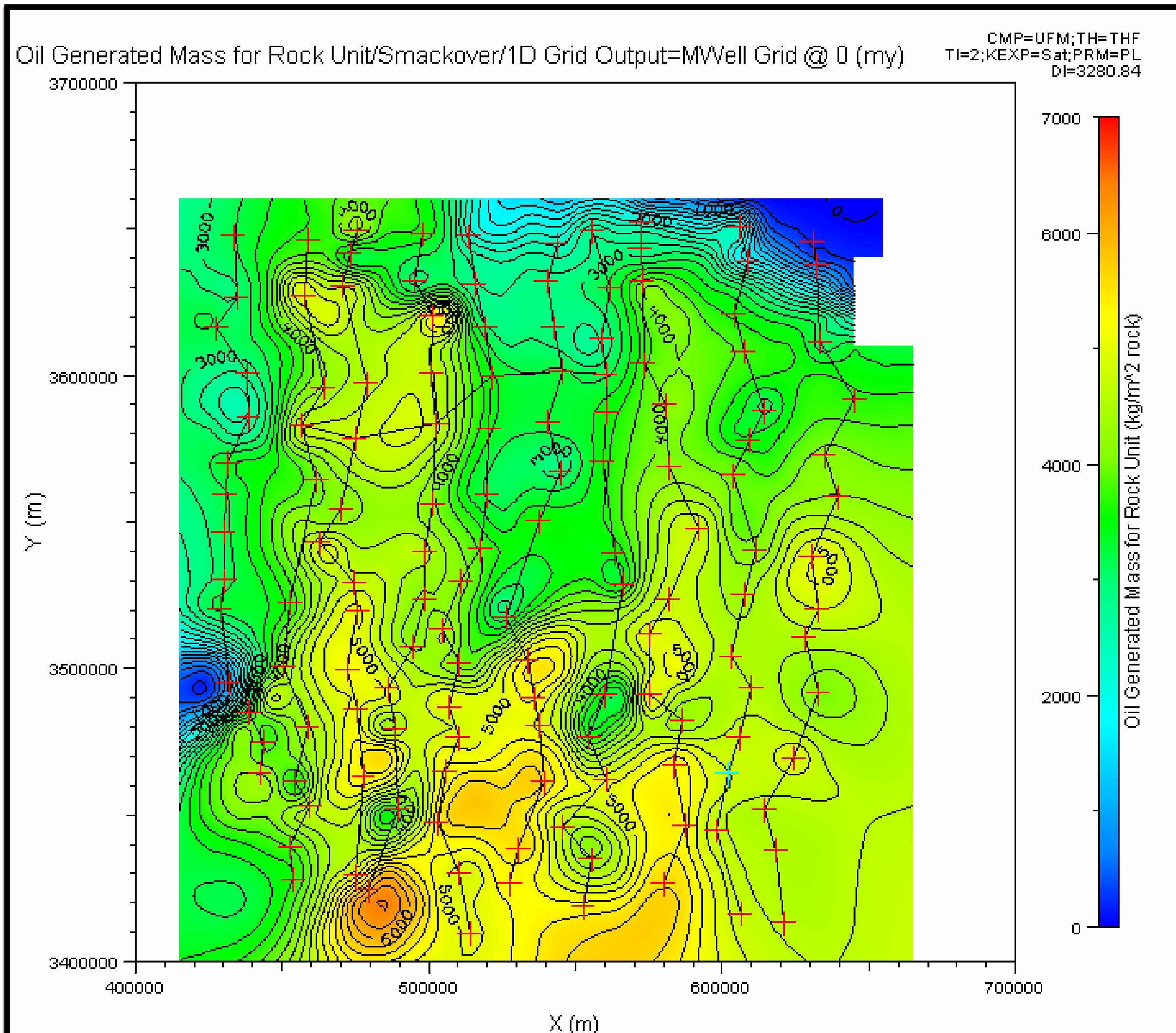


Figure 86. Gas to oil ratio (GOR) for North Louisiana area, production period 1943-2004. Average of 12,300 ft^3gas/bbl oil. By R. Barnaby.



Total = 2.5 x 10e14 kg at 7 bbl oil/1,000kg (25° API) = 1,715 x 10e9 bbls

1% TOC, rift paleoheat flow with late K event

Figure 87. Platte River software (BasinView) model of total oil generated in North Louisiana. By R. Barnaby.

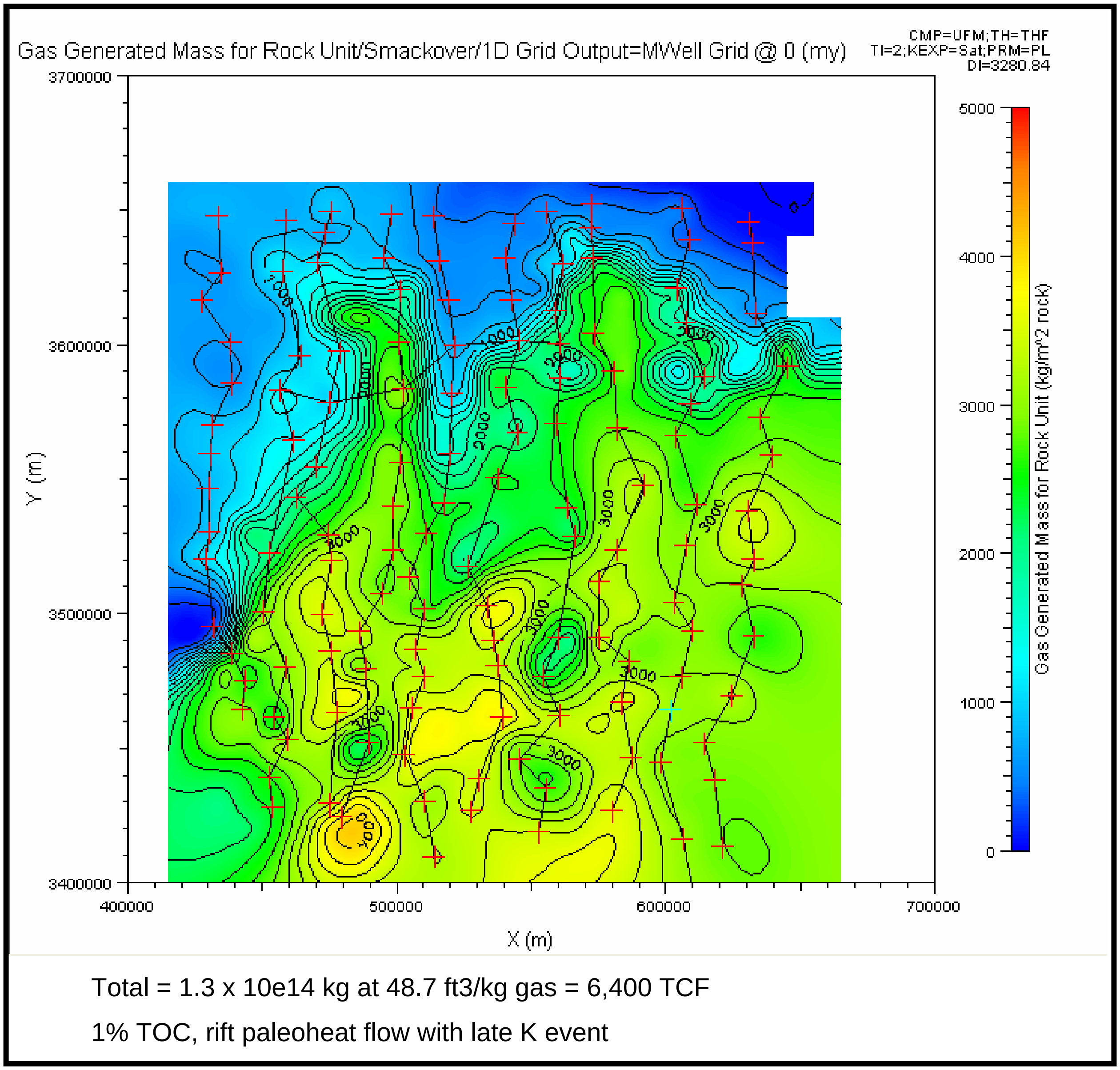


Figure 88. Platte River software (BasinView) model of total gas generated in North Louisiana. By R. Barnaby.

e. Total estimated in place deep gas resource generated (> 12,000 ft).

Modeling indicates that primary associated gas was generated coeval with oil, secondary, non-associated gas was generated later from thermal cracking of oil where the Smackover source rocks were buried to the gas window (Figure 89). For downdip locations, the burial history indicates that the base of the Smackover began to exceed 12,000 ft depths at 119 Ma and 15,000 ft depths at approximately 106 Ma; the top of the downdip Smackover exceeded 12,000 ft depths at 108 Ma and 15,000 ft depths at approximately 90 Ma (Figure 90). Figure 91 shows the present-day distribution of Smackover buried deeper than 15,000 ft. Thermogenic generation, thus initiated during the late Early Cretaceous in downdip locations and continues to the present day.

From consideration of the generated gas distribution with Smackover structure, the volume of gas generated from secondary cracking in the source rock is 4,800 TCF out of a total 6,400 TCF (Figure 92). By this estimate, deep thermogenic gas represents approximately 75% of the total gas generated. However, this total volume of deep thermogenic gas was generated at depths below 12,000 ft. In addition, much of the thermogenic gas has migrated and is entrapped in reservoirs shallower than 15,000 ft.

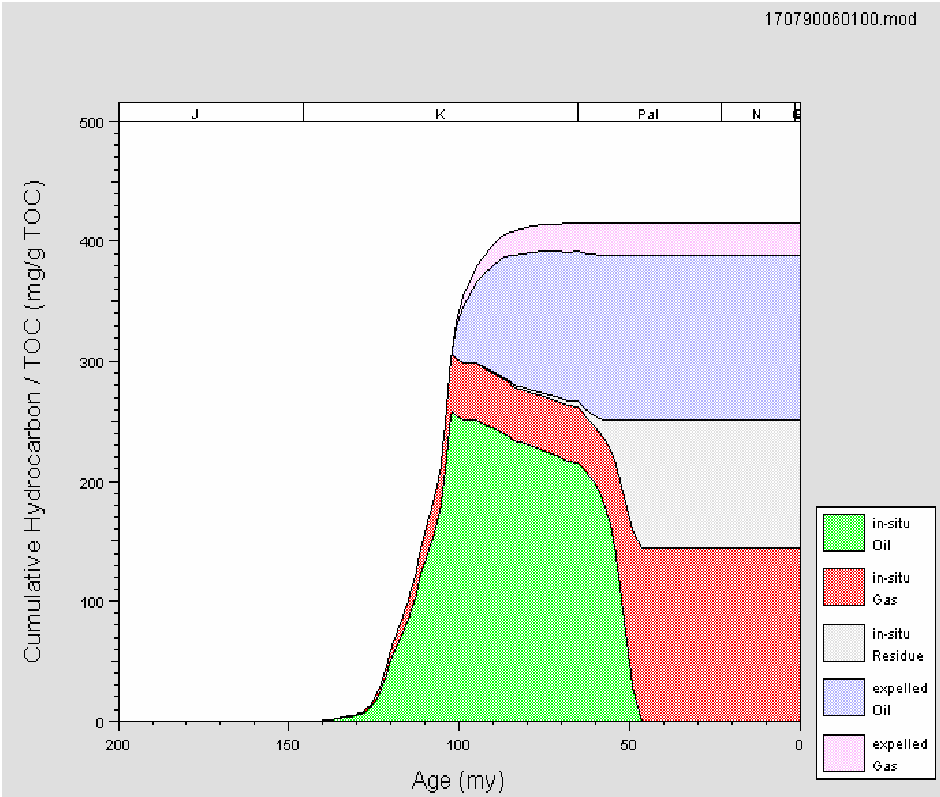
The efficiency of expulsion, migration and trapping has been estimated to range from 0.5 to 10 percent for various basins (Schmoker, 1994; Zimmerman, 1990). Assuming an efficiency of 1 to 5%, 48 to 240 TCF of gas is potentially available. To date, some 29 TCF of gas have been produced from this basin.

2. Mississippi Interior Salt Basin (by UA, Peng Li)

a. Schmoker (1994) method for determining the total mass of hydrocarbons generated.

Area of the basin: 5.18×10^{10} m^2.

Average thickness of lower Smackover: 115.65 m.



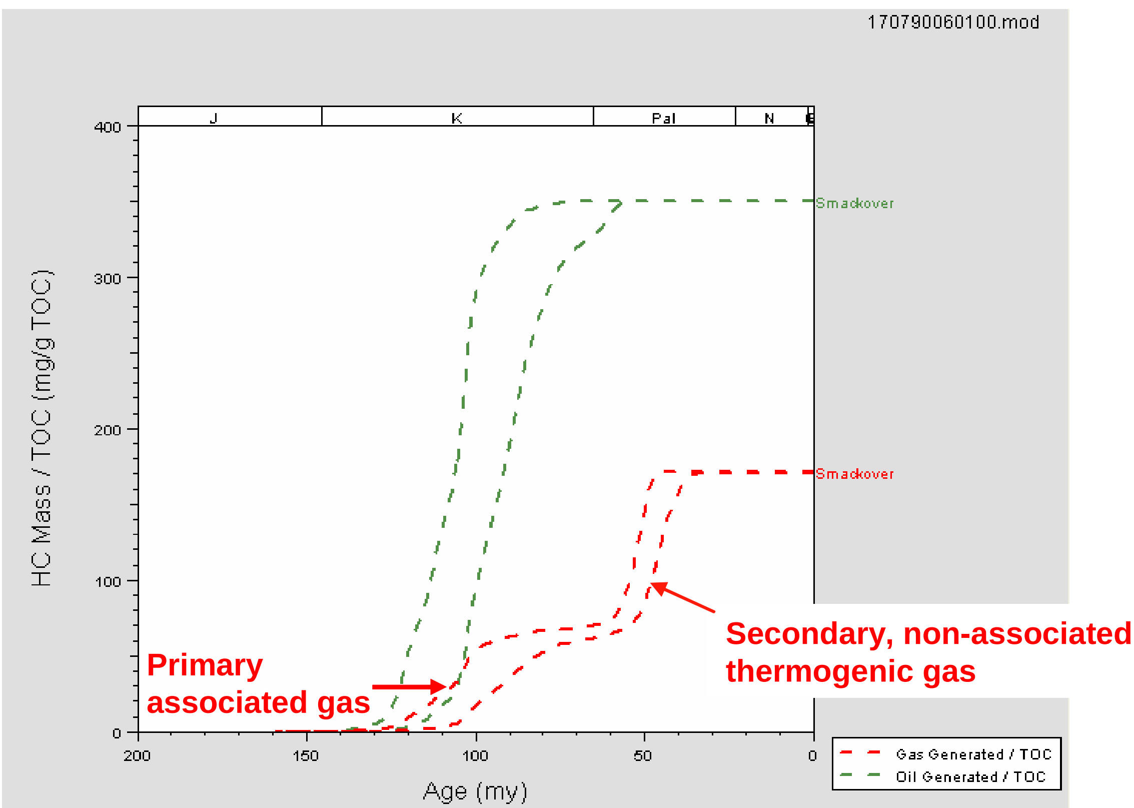


Figure 89. Gas generation and expulsion in North Louisiana area. Average GOR 12,300. By R. Barnaby.

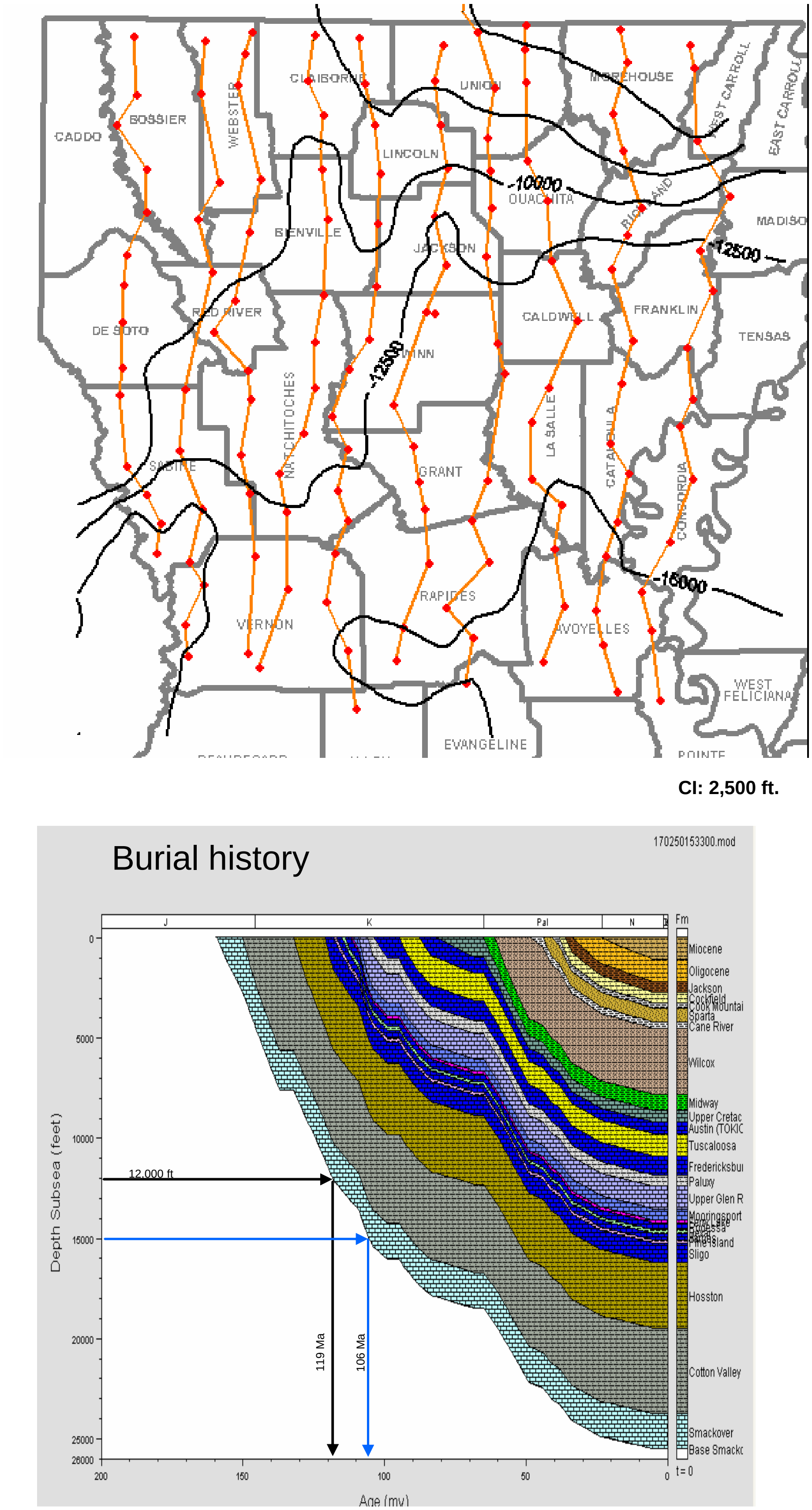


Figure 90. Modeling of top of Smackover burial By R. Barnaby.

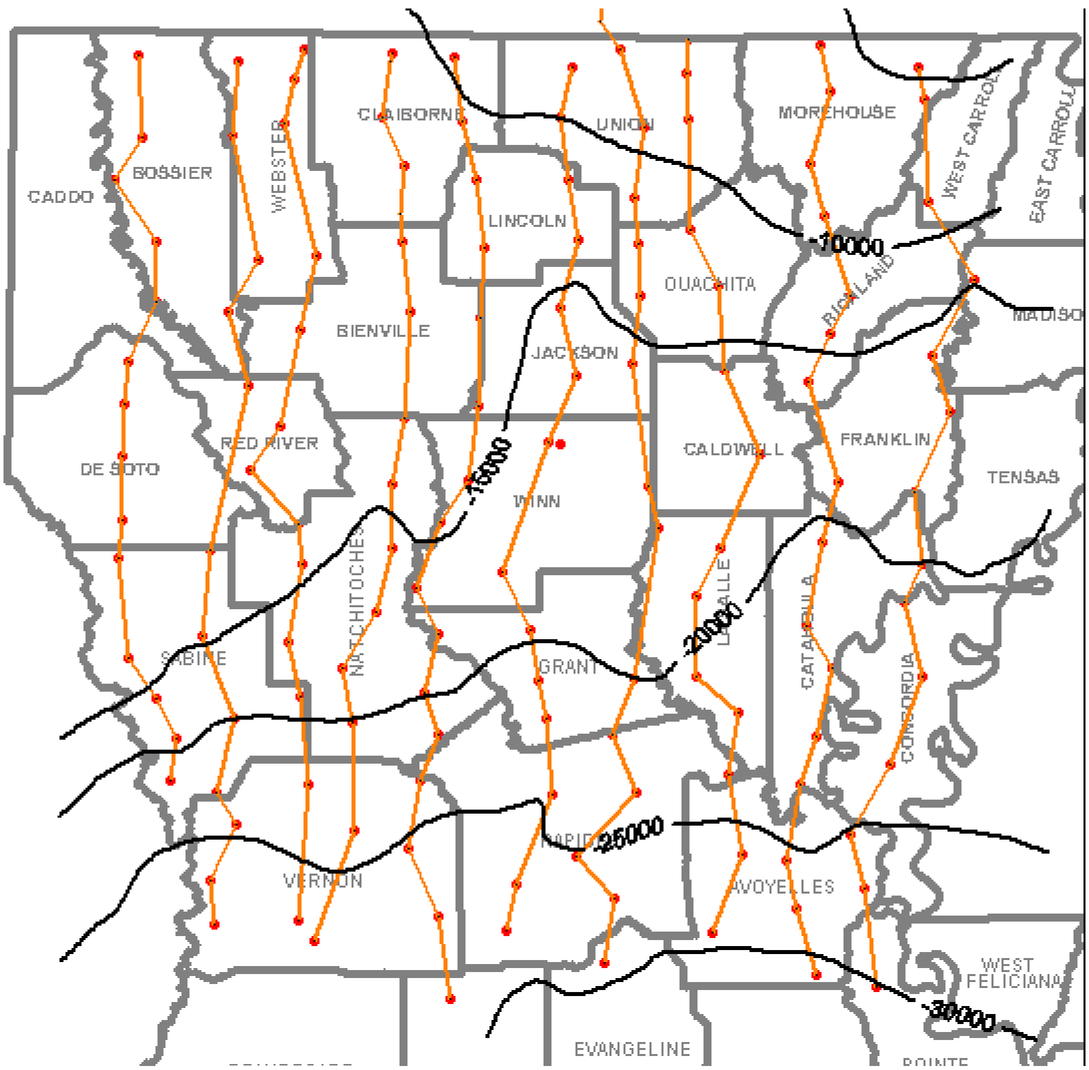


Figure 91. Depth of top of Smackover at present day. By R. Barnaby.

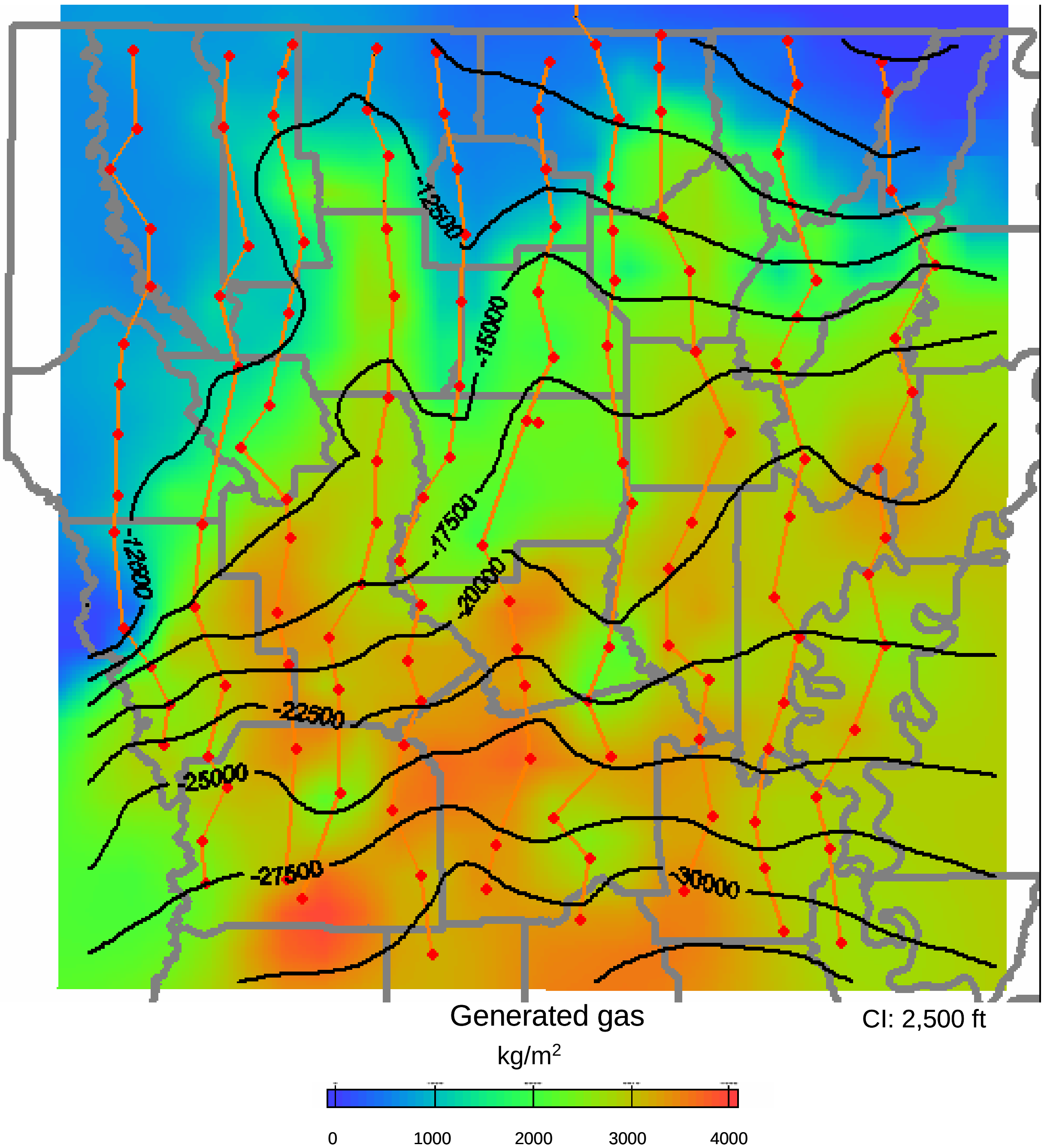


Figure 92. Smackover structure (contours) and generated gas (color fill). By R. Barnaby.

Total mass of lower Smackover = (5.99×10^{12} m^3 volume Smackover) × (2.5 g/cm^3 average density) × (1×10^6 cm^3/m^3) = 1.50×10^{19} g.

At 1.5% TOC, total mass of organic carbon = 0.015 × (1.50×10^{19} g) = 2.25×10^{17} g.

Smackover original hydrocarbon index (HI_0) = 300-650 mg HC/g TOC, with immature lower Smackover reported by Sassen and Moore (1998).

Smackover present-day hydrocarbon index (HI_p) = 4 to 137 mg HC/g TOC, average HI_p = 51 mg HC/g TOC reported by Mancini et al. (2003).

Total mass of hydrocarbons generated per unit mass of organic carbon = ($HI_0 - HI_p$) = (650 – 51) = 599 mg HC/g TOC.

Total mass of hydrocarbons generated = 599 mg HC/g TOC × (2.25×10^{17} g TOC) × (10^{-6} kg/mg) = 1.3×10^{14} kg.

Converted to barrels of 25° API oil = (1.3×10^{14} kg × 7 bbls/1,000 kg) = 910×10^9 barrels.

b. Platte River software method for determining the total volume of hydrocarbons (oil and gas) generated.

Using the Platte River software, a total hydrocarbon generated mass of 2.2×10^{14} kg (1,540 $\times 10^9$ bbls) from Lower Smackover source rocks in the Mississippi Interior Salt Basin is determined.

c. Schmoker (1994) method for determining the oil and gas volumes generated.

The average GOR for the Mississippi Interior Salt Basin is 3,994 (Table 7).

Weight fraction gas (assuming 25^o API oil)

= [3,994 ft^3 gas × (1 kg gas/48.7 ft^3)]

÷ [3,994 ft^3 gas × (1 kg gas/48.7 ft^3) + 1 bbl oil × (1,000kg/7 bbls oil)]

= 82.0 kg ÷ (82.0 kg + 142.9 kg)

= 0.36.

Weight fraction oil (assuming 25^o API oil) = (1.0 – 0.36) = 0.64.

Total gas generated = 0.36 × (1.3 × 10^{14} kg) × (48.7 ft^3/ 1 kg gas) = 4,050 × 10^{12} ft^3

= 4,050 TCF.

Total oil generated = 0.64 × (1.3 × 10^{14} kg) × (7 bbls oil/1,000g) = 580 ×10^9 bbls.

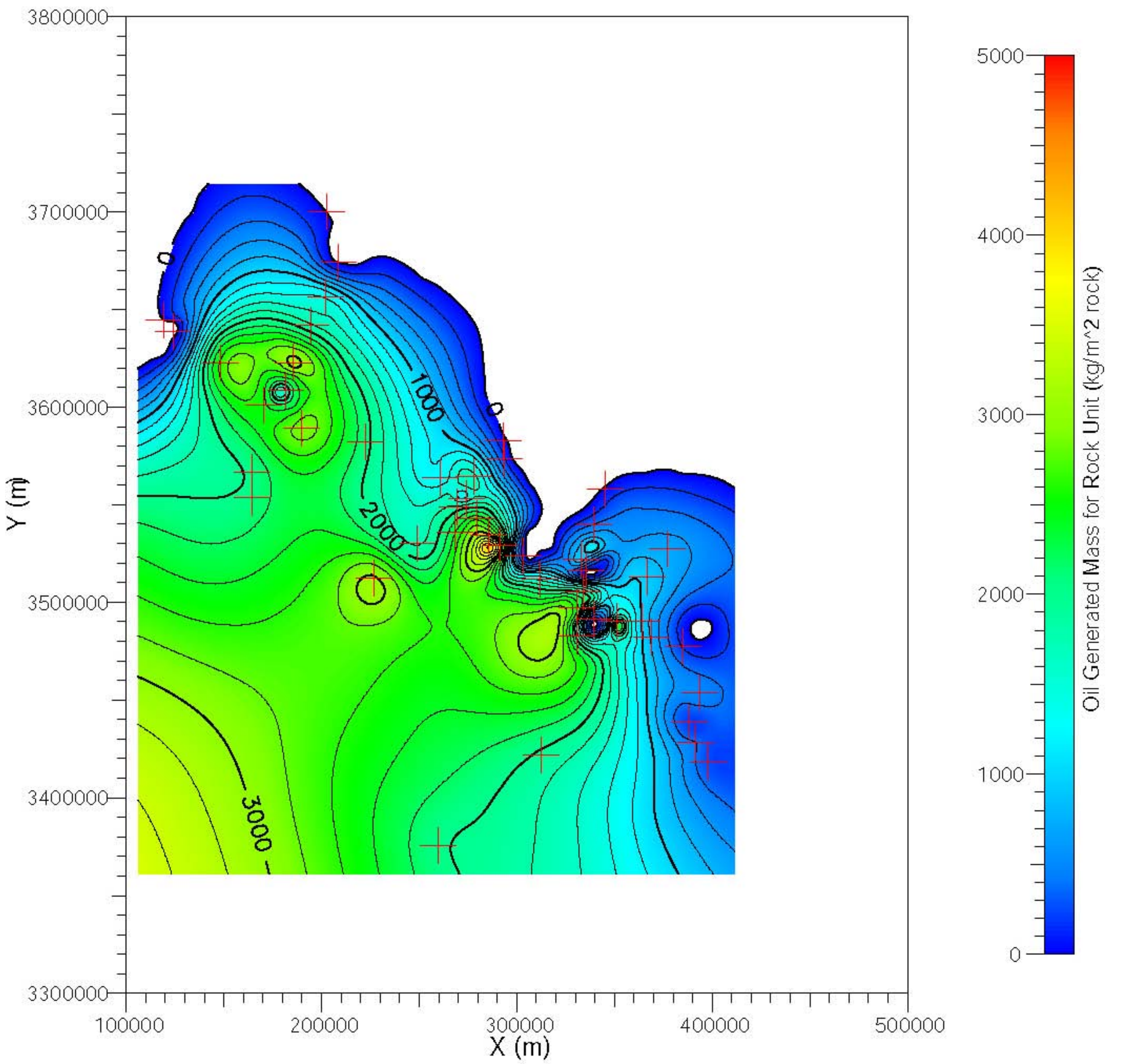
d. Platte River software method for determining the oil and gas volumes generated.

Using the Platte River software, a volume of 1,090 ×10^9 bbls total oil and 3,130 TCF of gas was generated in the Mississippi Interior Salt Basin (Figures 93 and 94), which yields a GOR of 2,872.

e. Total estimated in place deep gas resource generated ($\geq$16,500 ft).

From consideration of the generated gas distribution with the Smackover structural contour map (Figure 32), a volume of gas generated deeper than 16,500 ft is approximately 2,350 TCF out of a total of 3,130 TCF. By this estimate, deep secondary, non-associated gas represents seventy five percent of the total generated gas.

Assuming an expulsion, migration and trapping efficiency of 1 to 5%, a volume of 23.5 to 117.5 TCF of gas is potentially available. To date, some 13 TCF of gas have been produced from this basin.



TOC = 1.5 %, transient heat flow model

Figure 93. Platte River software model of total generated oil from the Smackover in the Mississippi Interior Salt Basin. By P. Li.

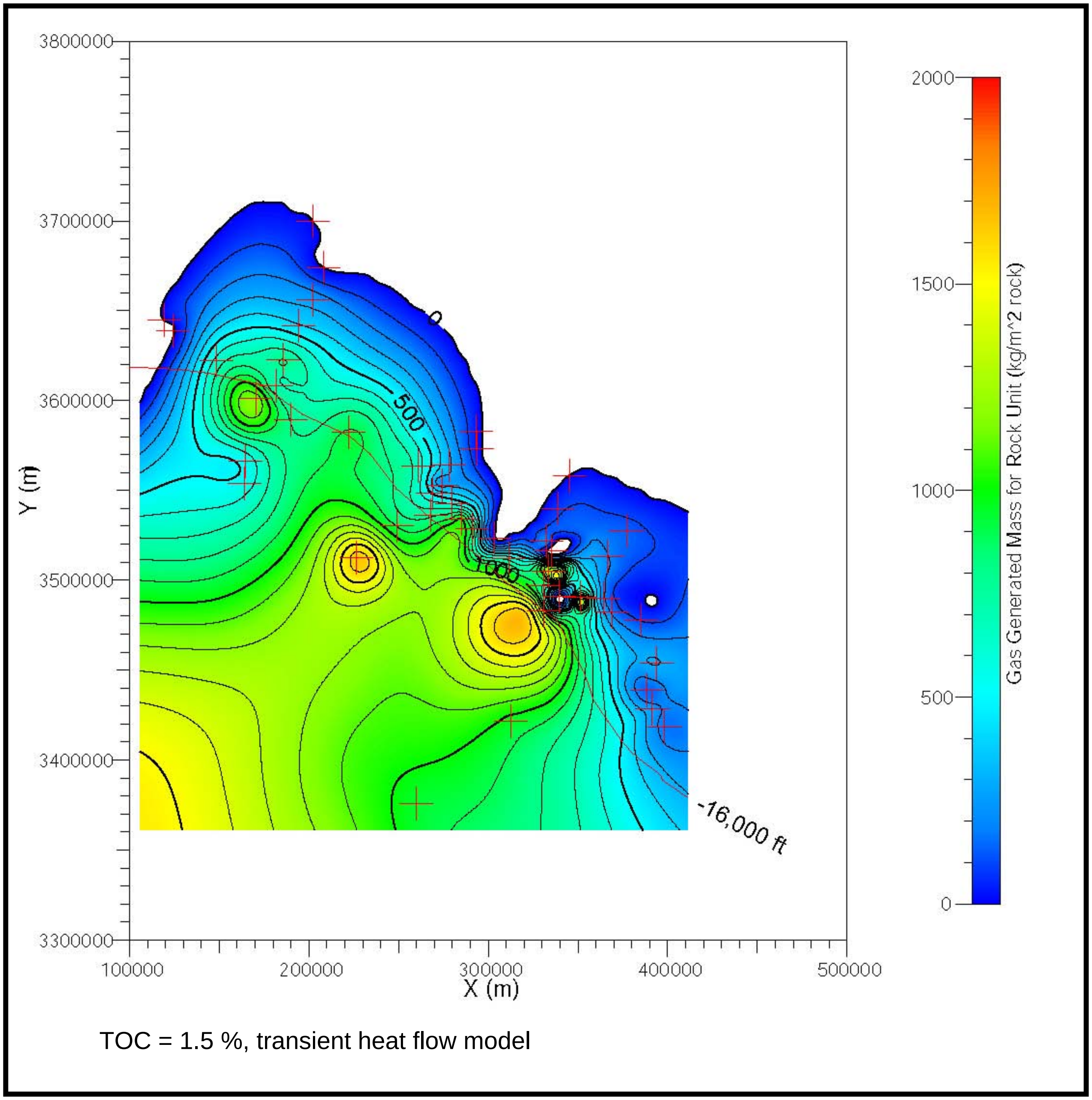


Figure 94. Platte River software model of total generated gas from the Smackover in the Mississippi Interior Salt Basin. By P. Li.

3. Manila Subbasin (by UA, Peng Li)

a. Schmoker (1994) method for determining the total mass of hydrocarbons (oil and gas) generated.

Area of the basin: 4.95×10^9 m^2.

Average thickness of lower Smackover: 47.73 m.

Total mass of lower Smackover = (2.36×10^{11} m^3 volume Smackover) × (2.5 g/cm^3 average density) × (1×10^6 cm^3/m^3) = 5.9×10^{17} g.

At 2% TOC, total mass of organic carbon = 0.02 × (5.9×10^{17} g) = 1.18×10^{16} g.

Smackover original hydrocarbon index (HI_0) = 300-650 mg HC/g TOC, immature lower Smackover reported by Sassen and Moore (1998).

Smackover present-day hydrocarbon index (HI_p) = 40 to 230 mg HC/g TOC, average HI_p = 87 mg HC/g TOC reported by Wade et al. (1987) and Claypool and Mancini (1989).

Total mass of hydrocarbons generated per unit mass of organic carbon = (HI_0 – HI_p) = (300 – 87) = 213 mg HC/g TOC, with a minimum HI_0 value used because terrestrially derived kerogen is present in the lower Smackover of the Manila Subbasin.

Total mass of hydrocarbons generated = 213 mg HC/g TOC × (1.18×10^{16} g TOC) × (10^{-6} kg/mg) = 2.5×10^{12} kg.

Converted to barrels of 25° API oil = (3.5×10^{12} kg × 7 bbls/1,000 kg) = 17.5×10^9 barrels.

b. Platte River software method for determining total hydrocarbons (oil and gas) generated.

Using the Platte River software, a total hydrocarbon generated mass of 0.9×10^{12} kg (6.31×10^{9} bbls) from lower Smackover source rocks in the Manila Subbasin is determined.

c. Schmoker (1994) method for determining oil and gas volumes generated.

The average GOR for the Manila Subbasin is 1,098 (Table 10).

Weight fraction gas (assuming 25^{o} API oil)

$= [1{,}098\ ft^3\ gas \times (1\ kg\ gas/48.7\ ft^3)]$

$\div [1{,}098\ ft^3\ gas \times (1\ kg\ gas/48.7\ ft^3) + 1\ bbl\ oil \times (1{,}000kg/7\ bbls\ oil)]$

$= 22.5\ kg \div (22.5\ kg + 142.9\ kg)$

$= 0.14$.

Weight fraction oil (assuming 25^{o} API oil) = (1.0 – 0.14) = 0.86.

Total gas generated $= 0.14 \times (2.5 \times 10^{12}\ kg) \times (48.7\ ft^3/\ 1\ kg\ gas) = 17.05 \times 10^{12}\ ft^3$

= 17.05 TCF.

Total oil generated $= 0.86 \times (2.5 \times 10^{12}\ kg) \times (7\ bbls\ oil/1{,}000\ kg) = 15 \times 10^{9}$ bbls.

d. Platte River software method for determining oil and gas volumes generated.

Using the Platte River software, a volume of 5.32×10^{9} bbls total oil and 6.9 TCF of gas was generated in the Manila Subbasin (Figures 95 and 96), which yields a GOR of 1,320.

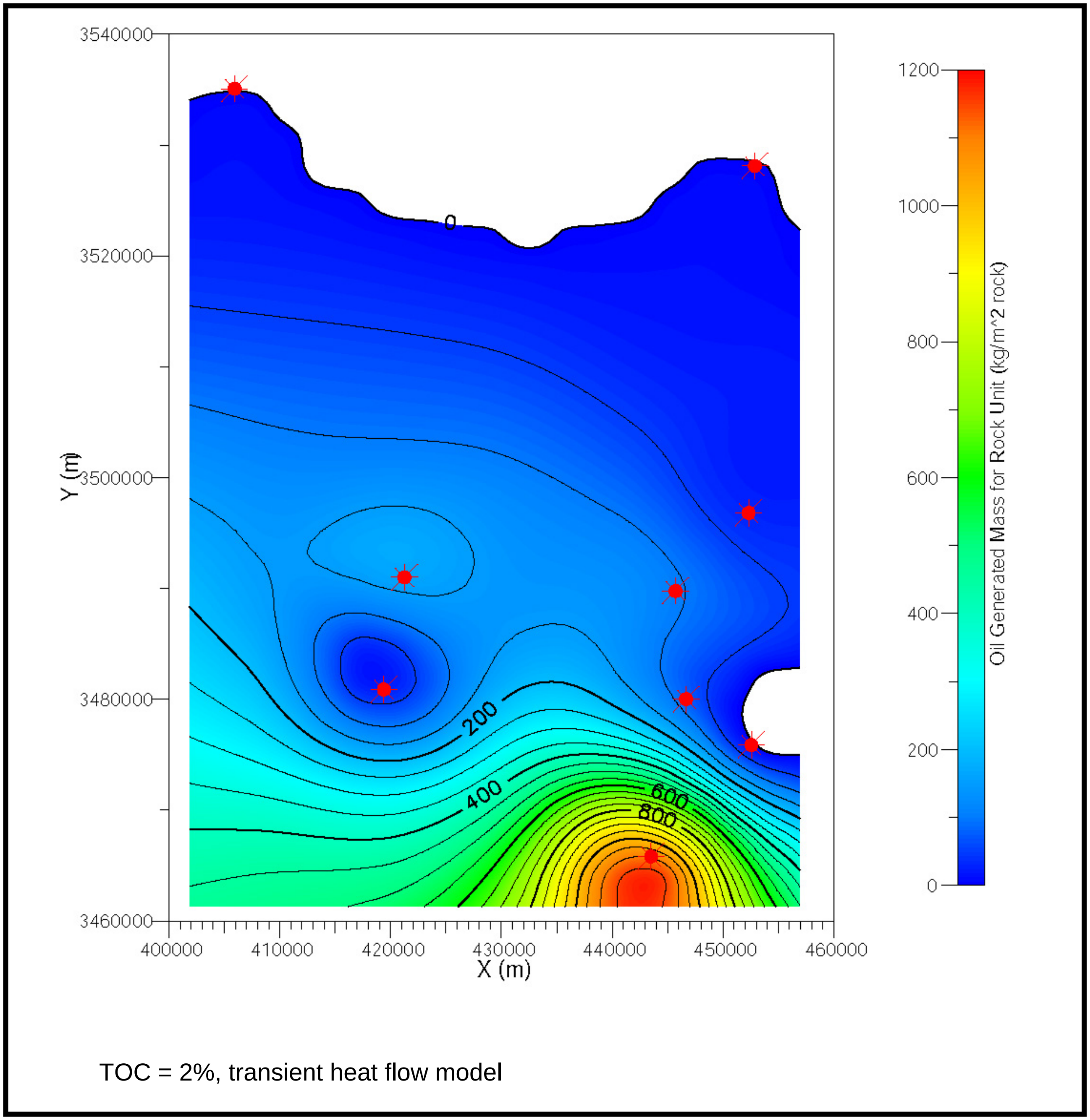


Figure 95. Platte River software model of total generated oil from the Smackover in the Manila Subbasin. By P. Li.

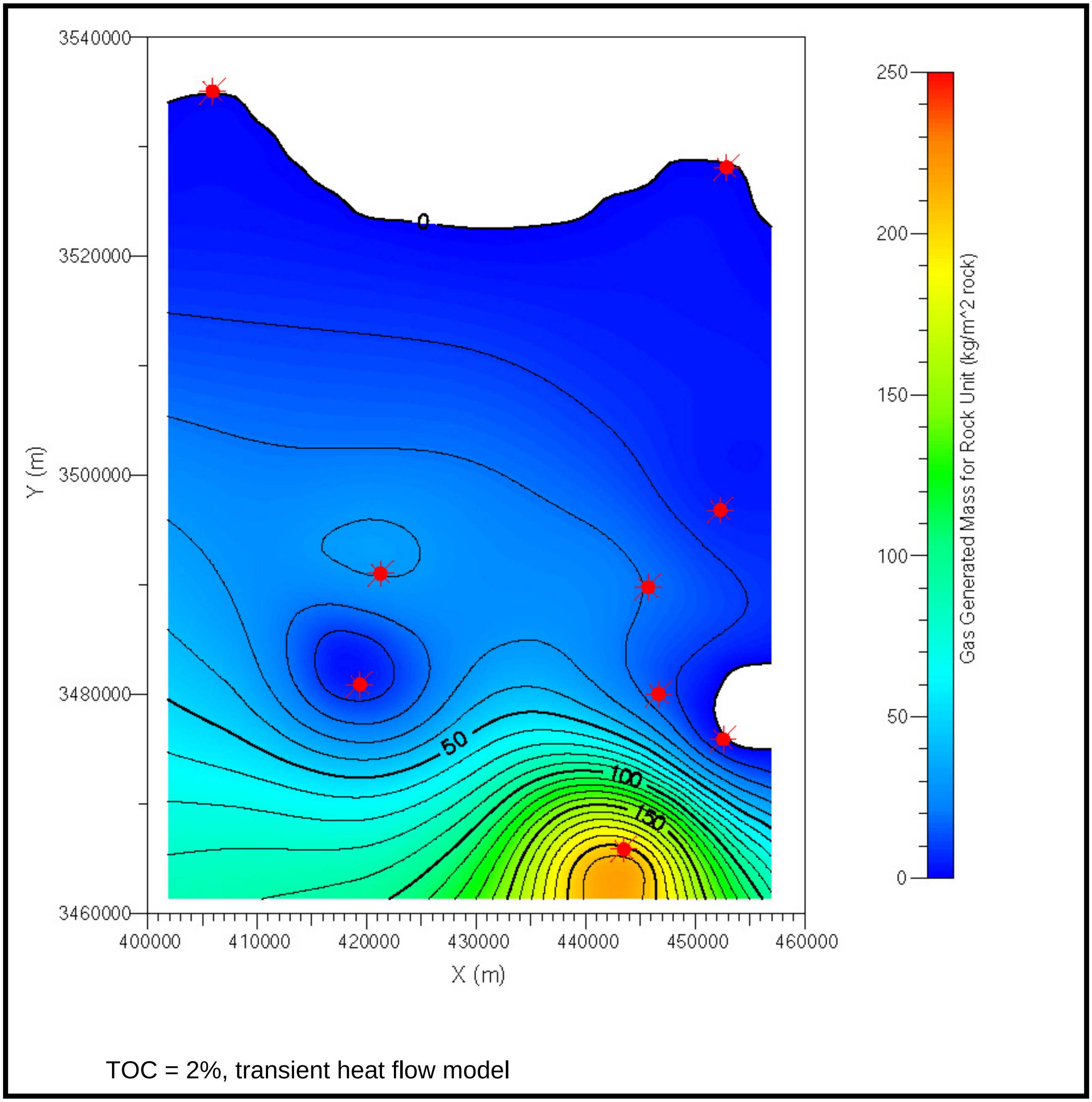


Figure 96. Platte River software model of total generated gas from the Smackover in the Manila Subbasin. By P. Li.

4. Conecuh Subbasin (by UA, Peng Li)

a. Schmoker (1994) method for determining the total mass of hydrocarbons (oil and gas) generated.

Area of the basin: 1.30×10^{10} m^2.

Average thickness of lower Smackover: 45.53 m.

Total mass of lower Smackover = (5.92×10^{11} m^3 volume Smackover) × (2.5 g/cm^3 average density) × (1×10^6 cm^3/m^3) = 1.48×10^{18} g.

At 1.5% TOC, total mass of organic carbon = 0.015 × (1.48×10^{18} g) = 2.22×10^{16} g.

Smackover original hydrocarbon index (HI_0) = 300-650 mg HC/g TOC, immature lower Smackover reported by Sassen and Moore (1988).

Smackover present-day hydrocarbon index (HI_p) = 3 to 114 mg HC/g TOC, average HI_p = 35 mg HC/g TOC reported by Claypool and Mancini (1989).

Total mass of hydrocarbons generated per unit mass of organic carbon = (HI_0 – HI_p) = (650 – 35) = 615 mg HC/g TOC.

Total mass of hydrocarbons generated

= 615 mg HC/g TOC × (2.22×10^{16} g TOC) × (10^{-6} kg/mg) = 1.4×10^{13} kg.

Converted to barrels of 25^o API oil = (1.4×10^{13} kg × 7 bbls/1,000kg) = 98×10^9 barrels.

b. Platte River software method for determining total hydrocarbons generated.

Using the Platte River software, a total hydrocarbon generated mass of 1.1×10^{13} kg (75×10^{9} bbls) from lower Smackover source rocks in the Conecuh Subbasin is determined.

c. Schmoker (1994) method for determining oil and gas volumes generated.

The average GOR for the Conecuh Subbasin (minus the production from Big Escambia Creek and Flomaton fields is 1,284 (Table 14).

Weight fraction gas (assuming 25^{o} API oil)

= [1,284 ft^3 gas × (1 kg gas/48.7 ft^3)]

÷ [1,284 ft^3 gas × (1 kg gas/48.7 ft^3) + 1 bbl oil × (1,000 kg/7 bbls oil)]

= 26.4 kg ÷ (26.4 kg + 142.9 kg)

= 0.16.

Weight fraction oil (assuming 25^{o} API oil) = (1.0 – 0.16) = 0.84.

Total gas generated = $0.16 \times (1.4 \times 10^{13}$ kg) × (48.7 ft^3/ 1 kg gas) = 109×10^{12} ft^3

= 109 TCF.

Total oil generated = $0.84 \times (1.4 \times 10^{13}$ kg) × (7 bbls oil/1,000kg) = 82×10^{9} bbls.

d. Platte River software method for determining oil and gas volumes generated.

Using the Platte River software, a volume of 59×10^{9} bbls total oil and 108 TCF of gas was generated in the Conecuh Subbasin (Figures 97 and 98), which yields a GOR of 2,565.

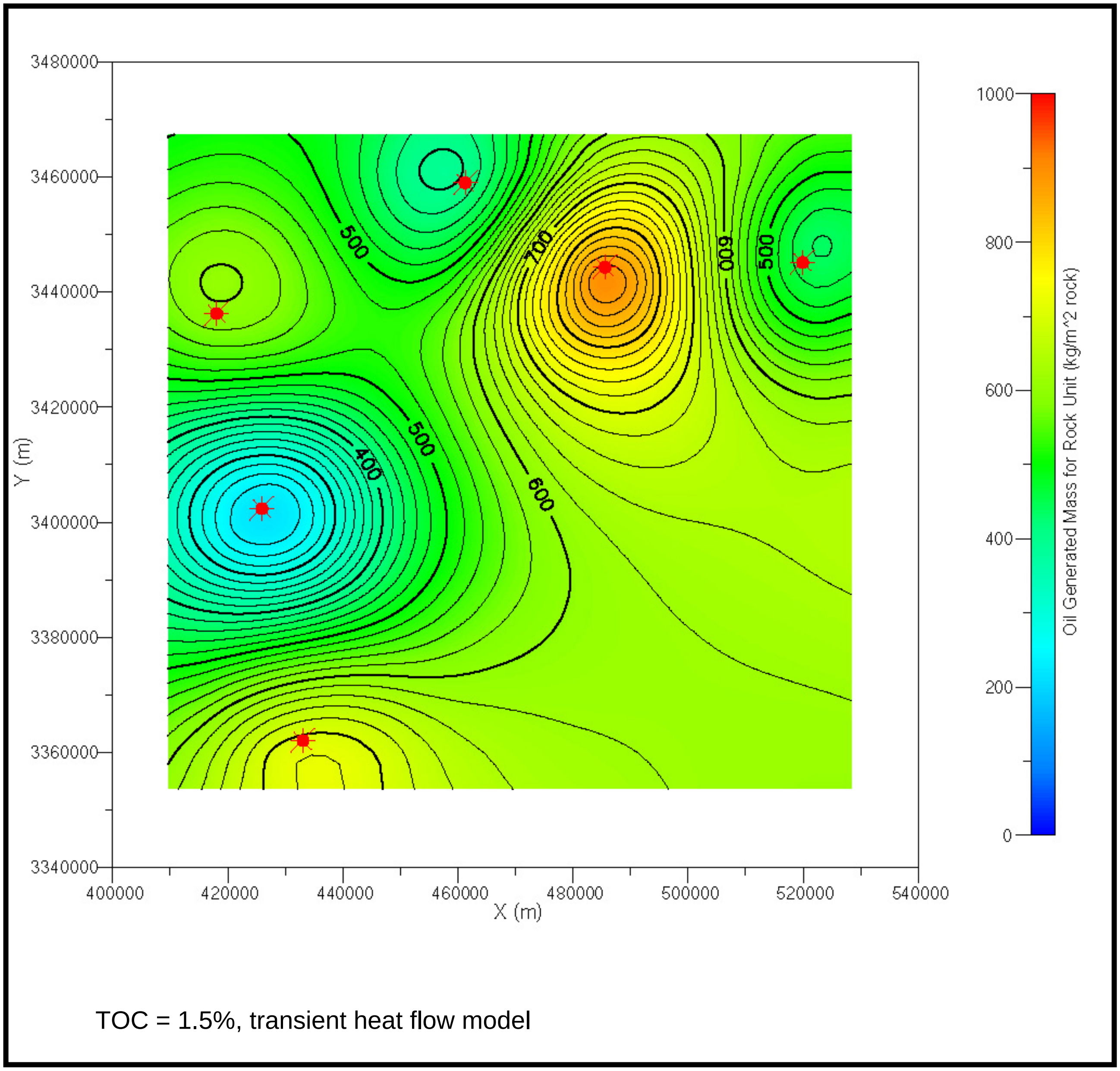


Figure 97. Platte River software model of total generated oil from the Smackover in the Conecuh Subbasin. By P. Li.

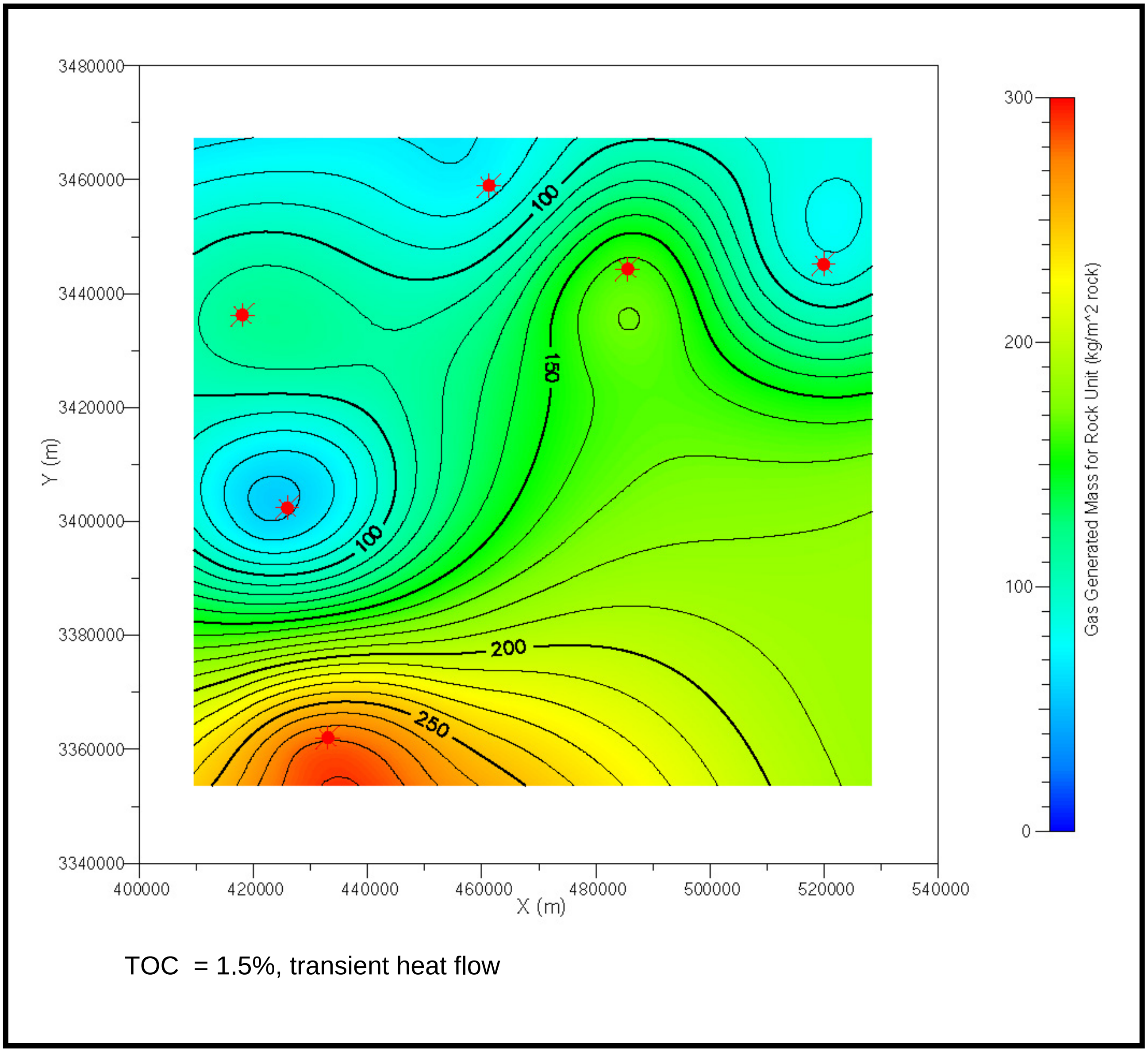


Figure 98. Platte River software model of total generated gas from the Smackover in the Conecuh Subbasin. By P. Li.

Potentially Recoverable Deep Gas Resource—The amount of the generated total hydrocarbon resource and of the thermogenic gas resource in the North Louisiana and Mississippi Interior Salt Basins that was expelled, was estimated using the Platte River software applications. The methods of Mackenzie and Quigley (1988), Zimmerman et al. (1999), and Waples (1984) were evaluated, and we elected to use the Platte River software for these estimations. Using Platte River petroleum system software, the total mass of hydrocarbons expelled in the interior salt basins is as follows.

1. North Louisiana Salt Basin (by LSU, Roger Barnaby)

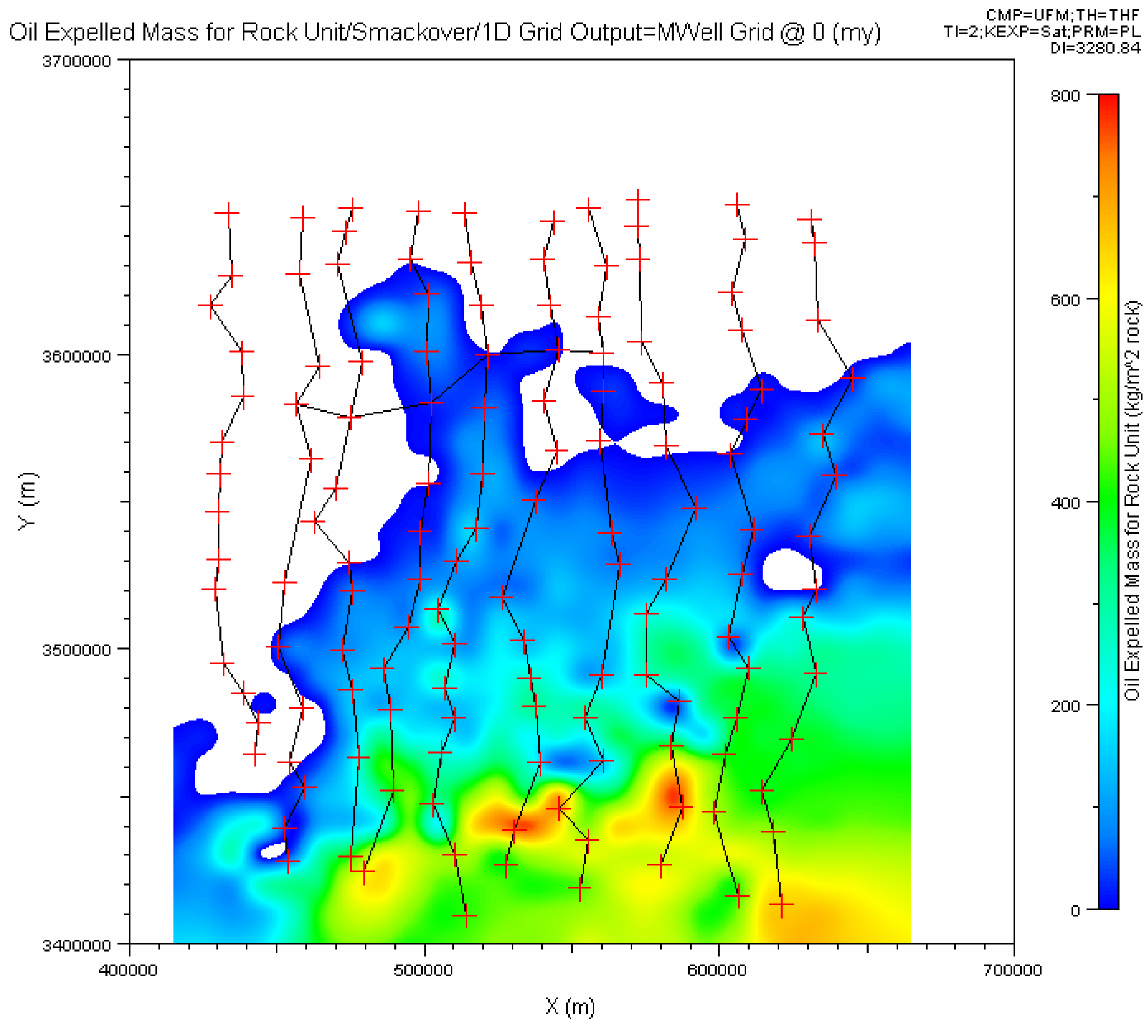
   a. Using the Platte River software (BasinView model) and a saturation threshold of 0.2, a volume of 400 TCF of gas and 180×10^9 bbls of oil were expelled (Figures 99a and 100a). If only expelled gas and oil are considered, 400 TCF of gas are expelled along with 180×10^9 bbls of oil, which does not significantly change the GOR. Using a saturation threshold of 0.1, a volume of 1,280 TCF of gas and 970×10^9 bbls of oil were expelled (Figures 99b and 100b), which yields a GOR of 1,319.

   b. Consideration of the expelled gas distribution with the Smackover structural contours (Figure 101) indicates that all of the expelled secondary, non-associated gas was expelled at depths > 12,000 ft.

2. Mississippi Interior Salt Basin (by UA, Peng Li)

   a. Volume of generated hydrocarbon resource that was expelled.

   Using Platte River software and a saturation threshold of 0.1, a volume of 442×10^9 bbls oil and 843 TCF gas (Figures 102 and 103) was expelled, which yields a GOR of 1,907.



Total = 26 x 10e12 kg at 7 bbl oil/1,000kg (25° API) = 180 x 10e9 bbl
TOC = 1%, saturation threshold = 0.2, rift heat flow w/ K event

Figure 99a. Platte River software (BasinView) model of total expelled oil in North Louisiana. By R. Barnaby.

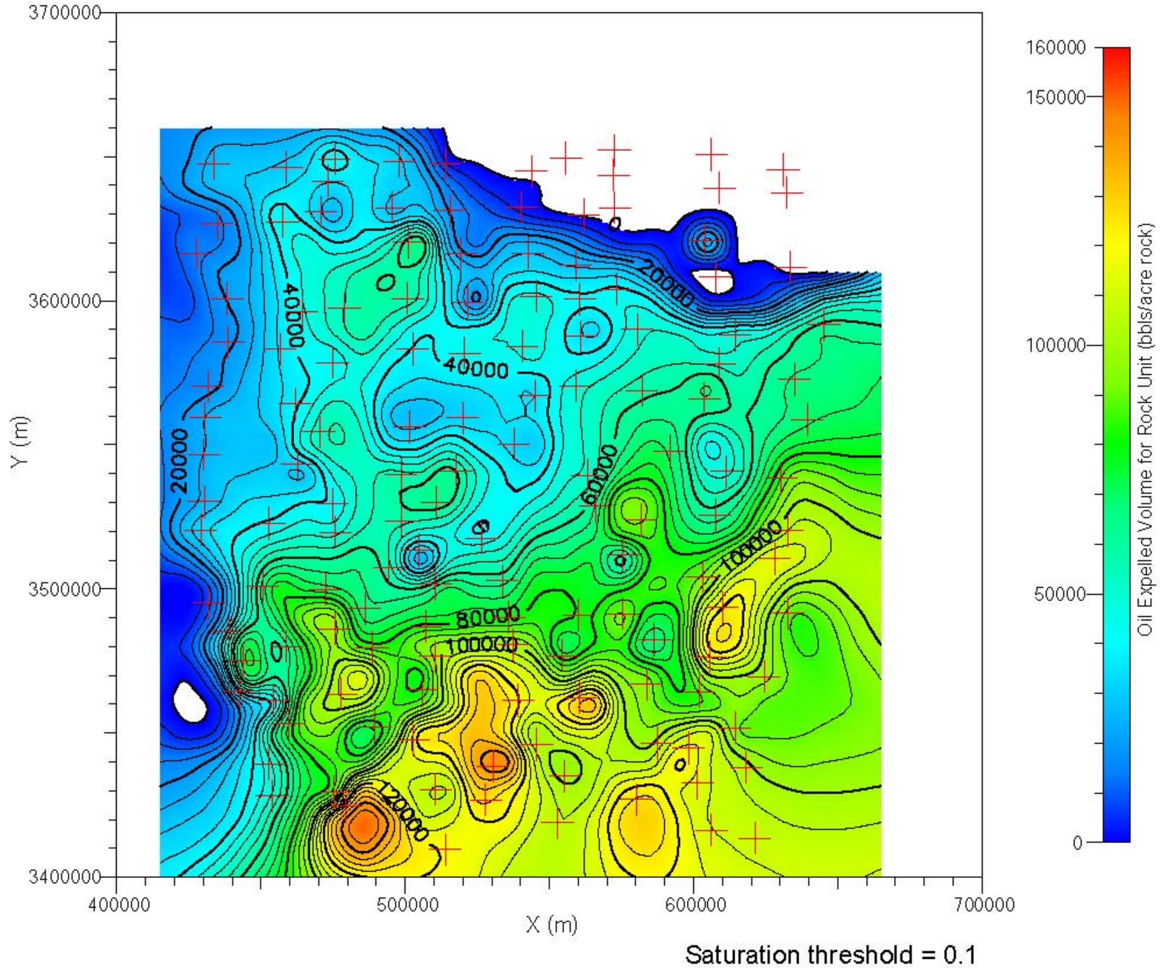
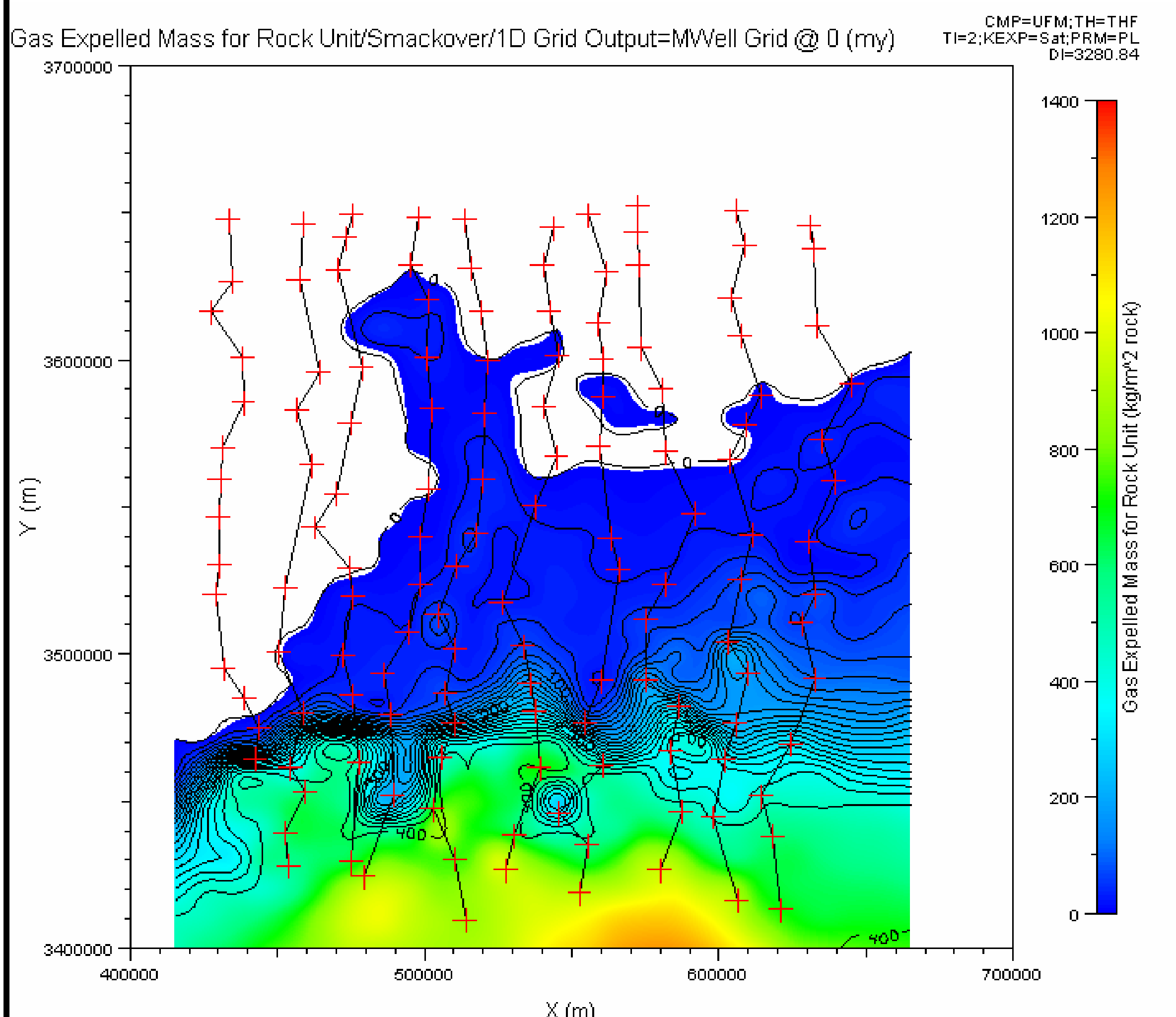


Figure 99b. Platte River software model of total expelled oil in North Louisiana. By P. Li.



Total = 8.2 x 10e12 kg at 48.7 ft3/kg gas = 400 TCF
TOC = 1%, saturation threshold = 0.2, rift heat flow w/ K event

Figure 100a. Platte River software (BasinView) model of total expelled gas in North Louisiana. By R. Barnaby.

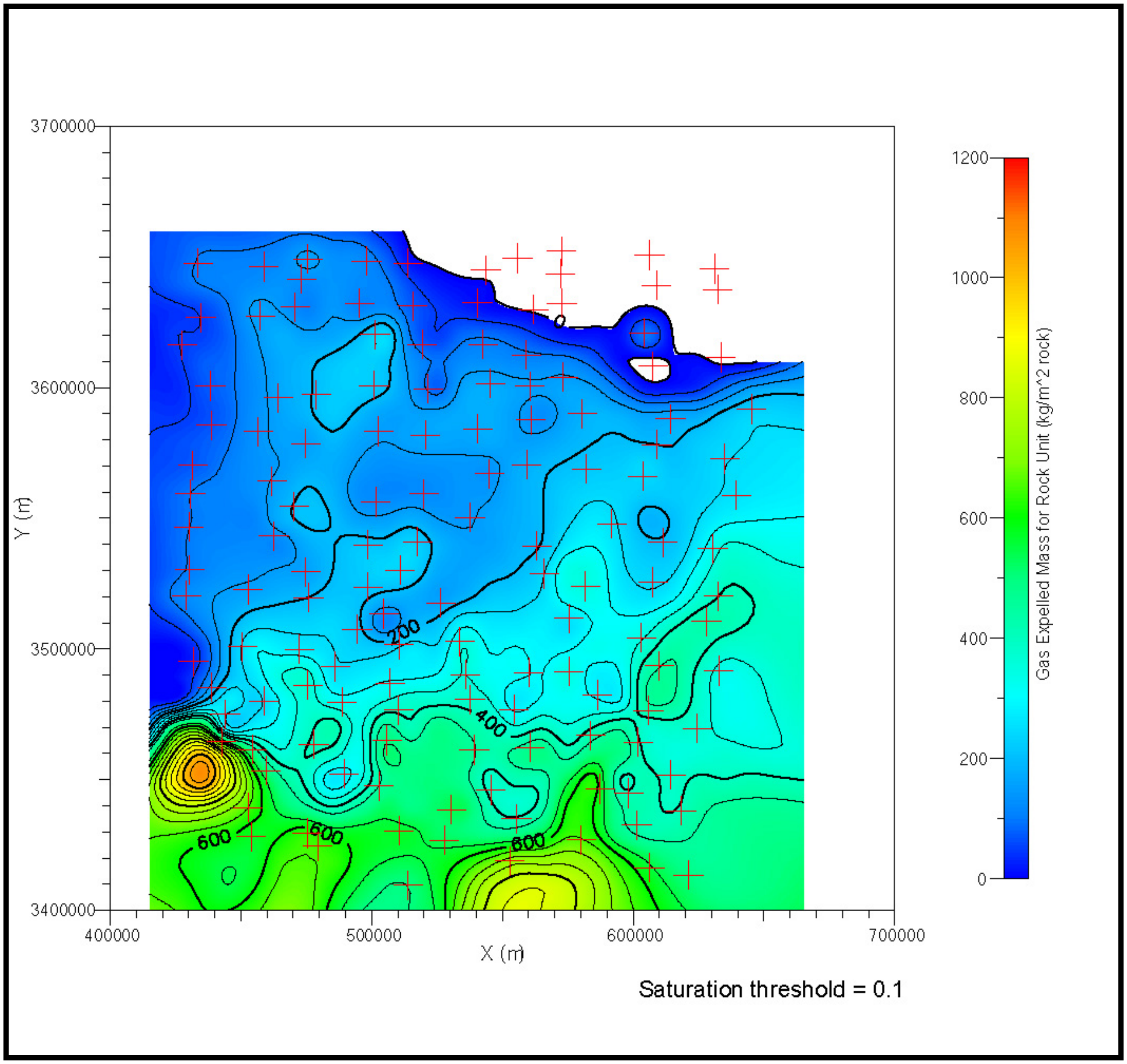


Figure 100b. Platte River software model of total expelled gas in North Louisiana. By P. Li.

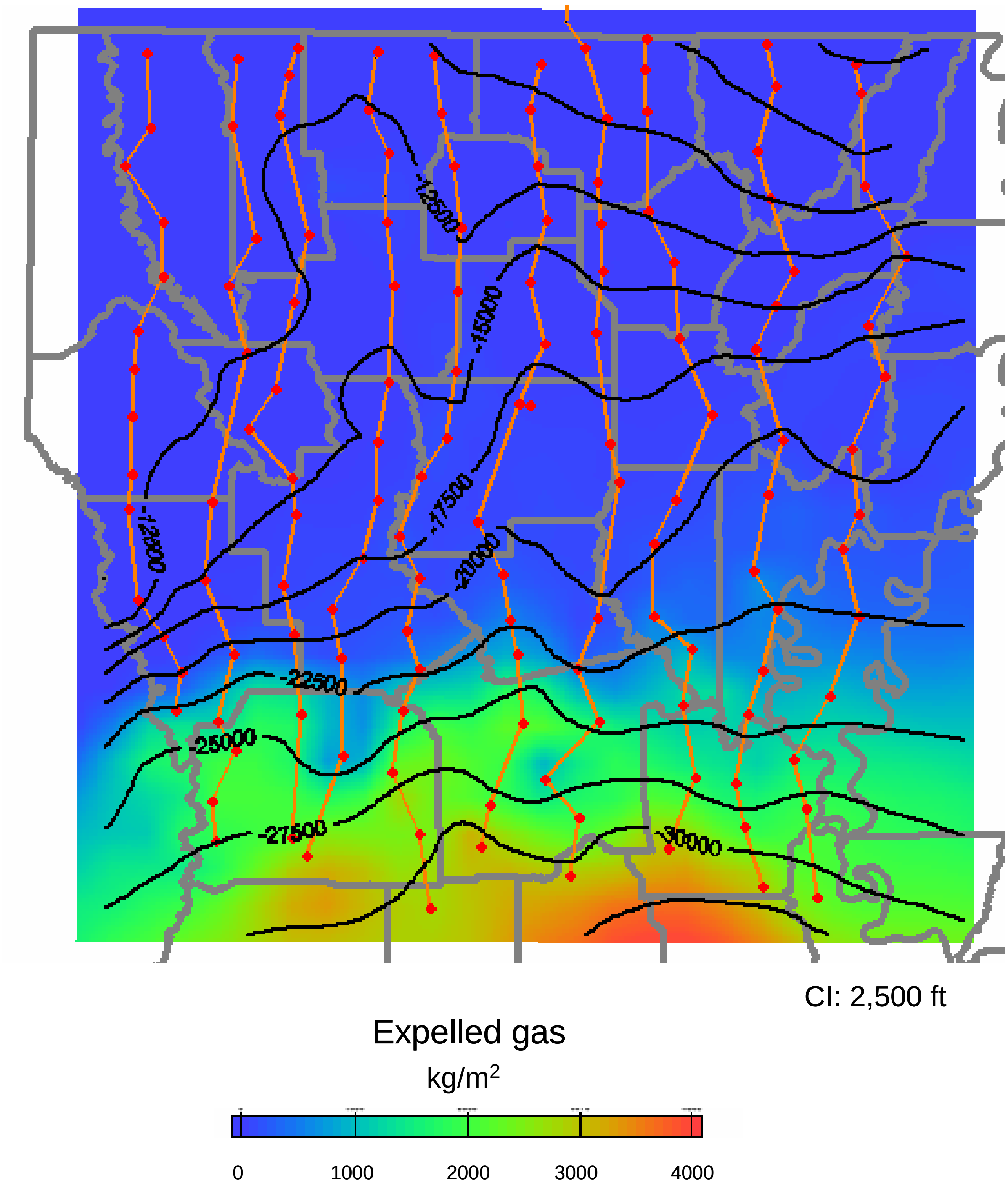


Figure 101. Platte River software (BasinView) model of total gas and depth of expulsion, as shown on Smackover structure map. By R. Barnaby.

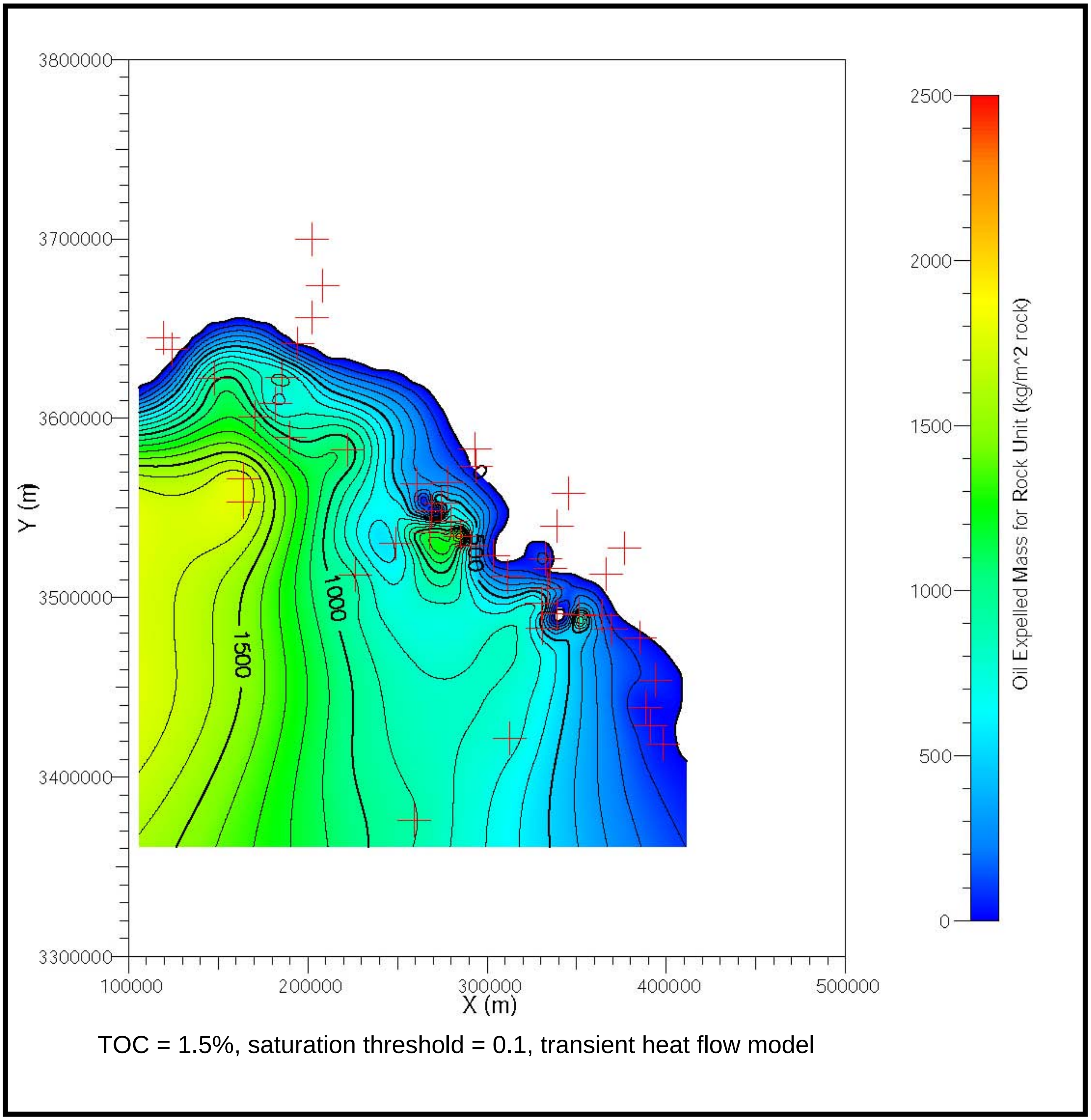


Figure 102. Platte River software model of total expelled oil from the Smackover in the Mississippi Interior Salt Basin. By P. Li.

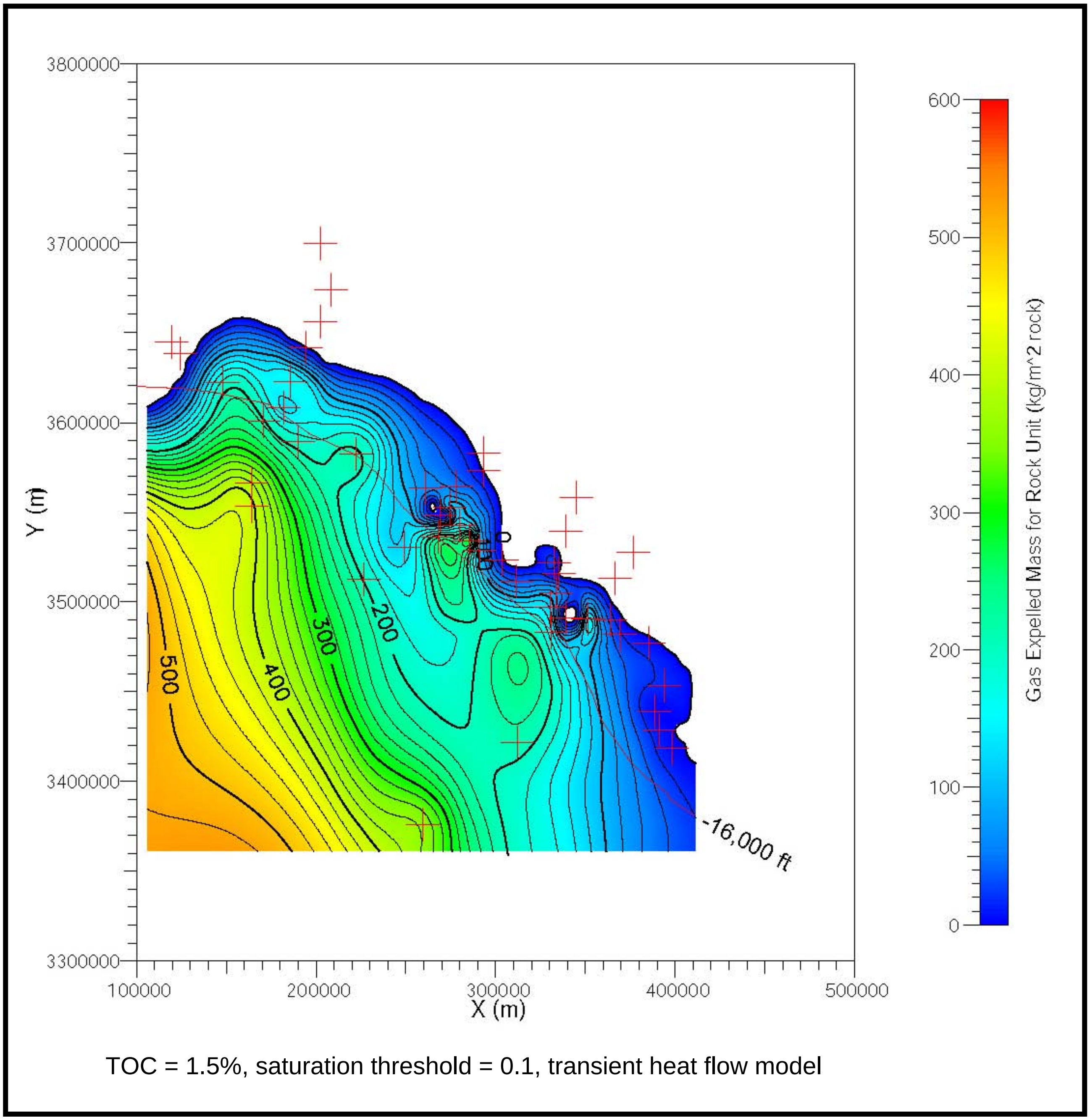


Figure 103. Platte River software model of total expelled gas from the Smackover in the Mississippi Interior Salt Basin. By P. Li.

b. Volume of the generated deep gas resource that was expelled

Consideration of the expelled gas distribution with the Smackover structural contour (Figure 32) indicates that 75% of expelled gas (632 TCF) was expelled at depths greater than 16,500 ft and is, therefore, considered secondary, non-associated gas.

3. Manila Subbasin (by UA, Peng Li)

A volume of 1.44×10^9 bbls total oil and 1.9 TCF gas was expelled (Figures 104 and 105), which yields a GOR of 1,319.

4. Conecuh Subbasin (by UA, Peng Li)

A volume of 31×10^9 bbls total oil and 40 TCF gas was expelled (Figures 106 and 107), which yields a GOR of 1,290.

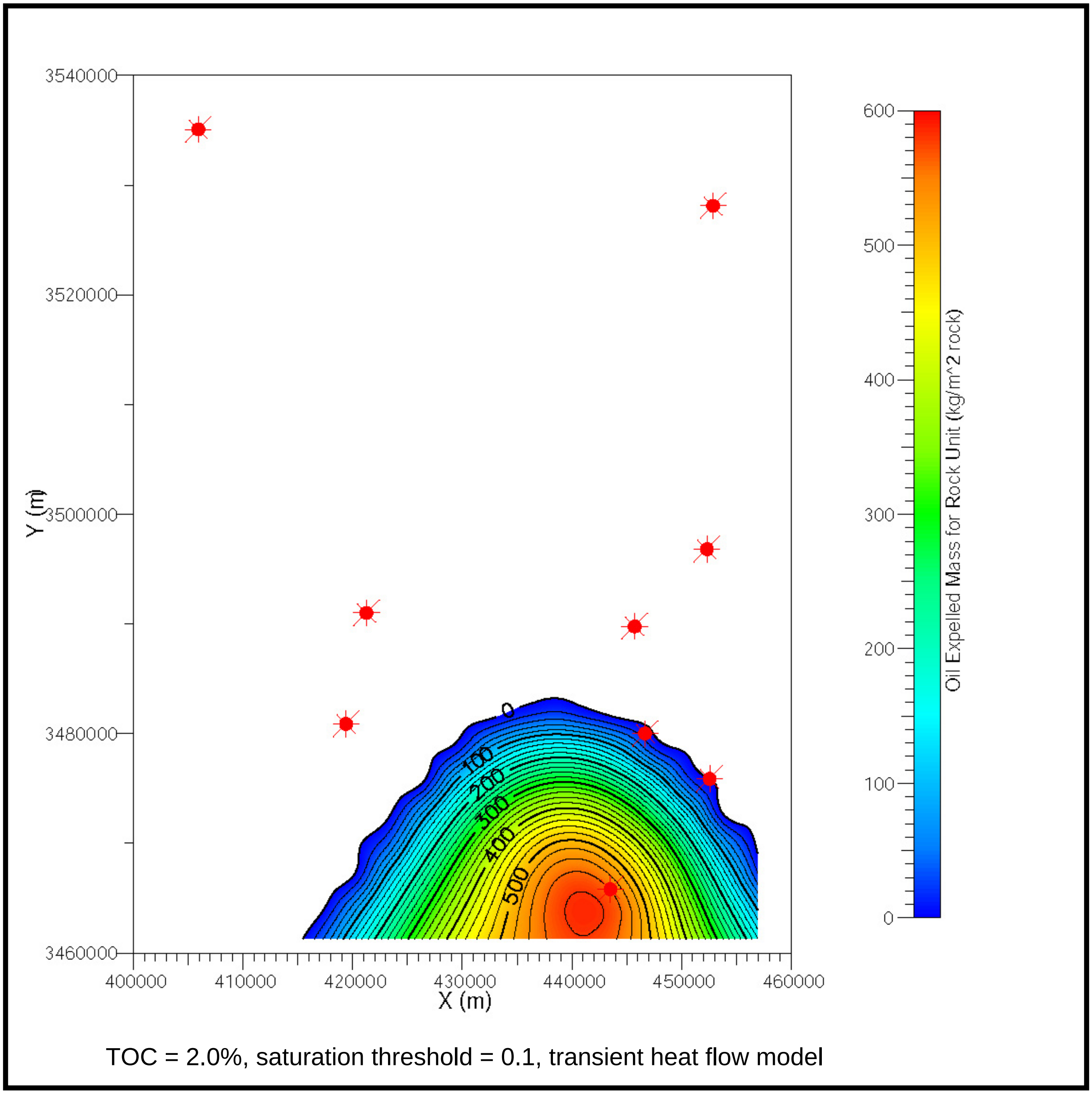
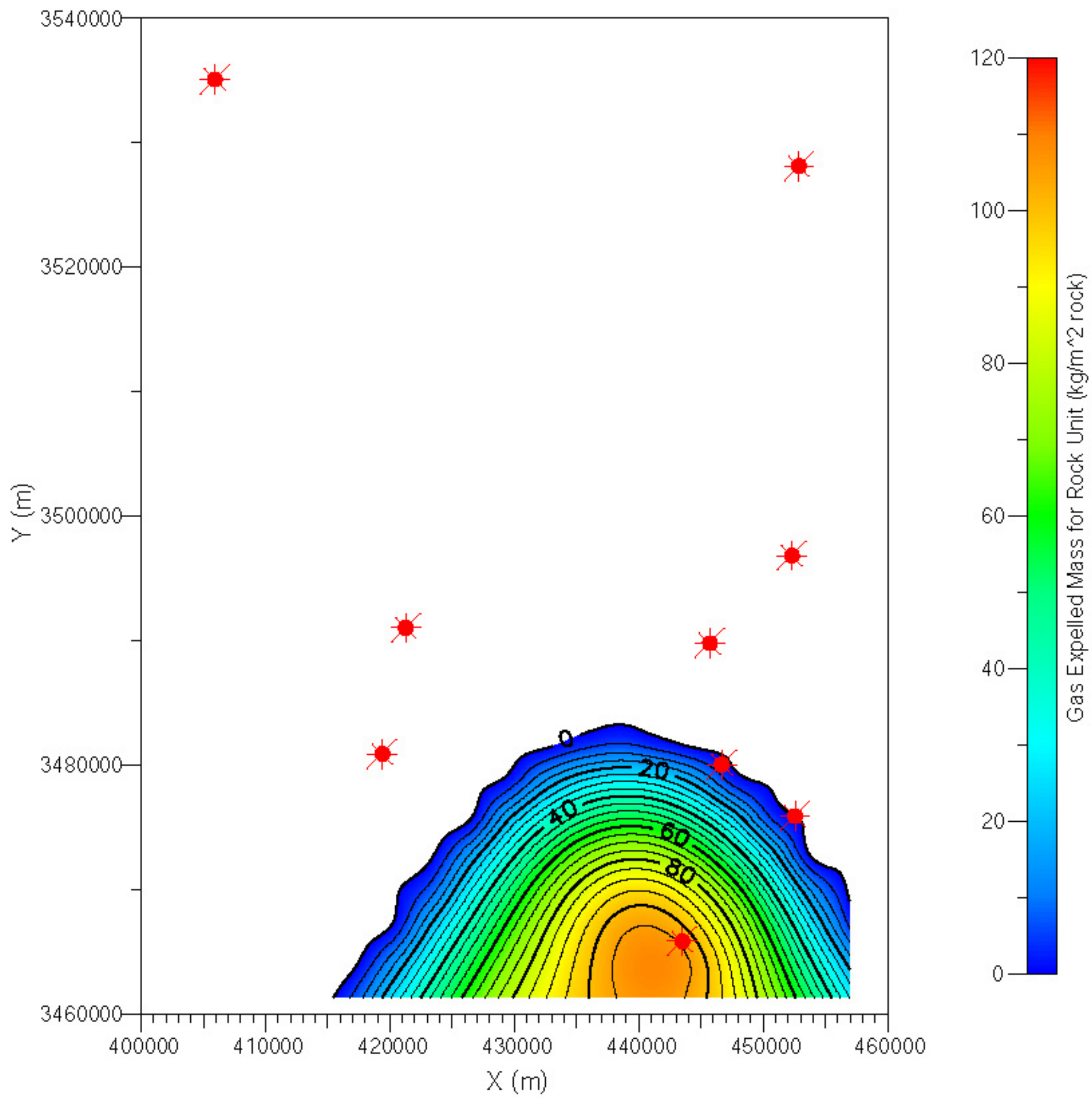


Figure 104. Platte River software model of total expelled oil from the Smackover in the Manila Subbasin. By P. Li.



TOC = 2.0%, saturation threshold = 0.1, transient heat flow model

Figure 105. Platte River software model of total expelled gas from the Smackover in the Manila Subbasin. By P. Li.

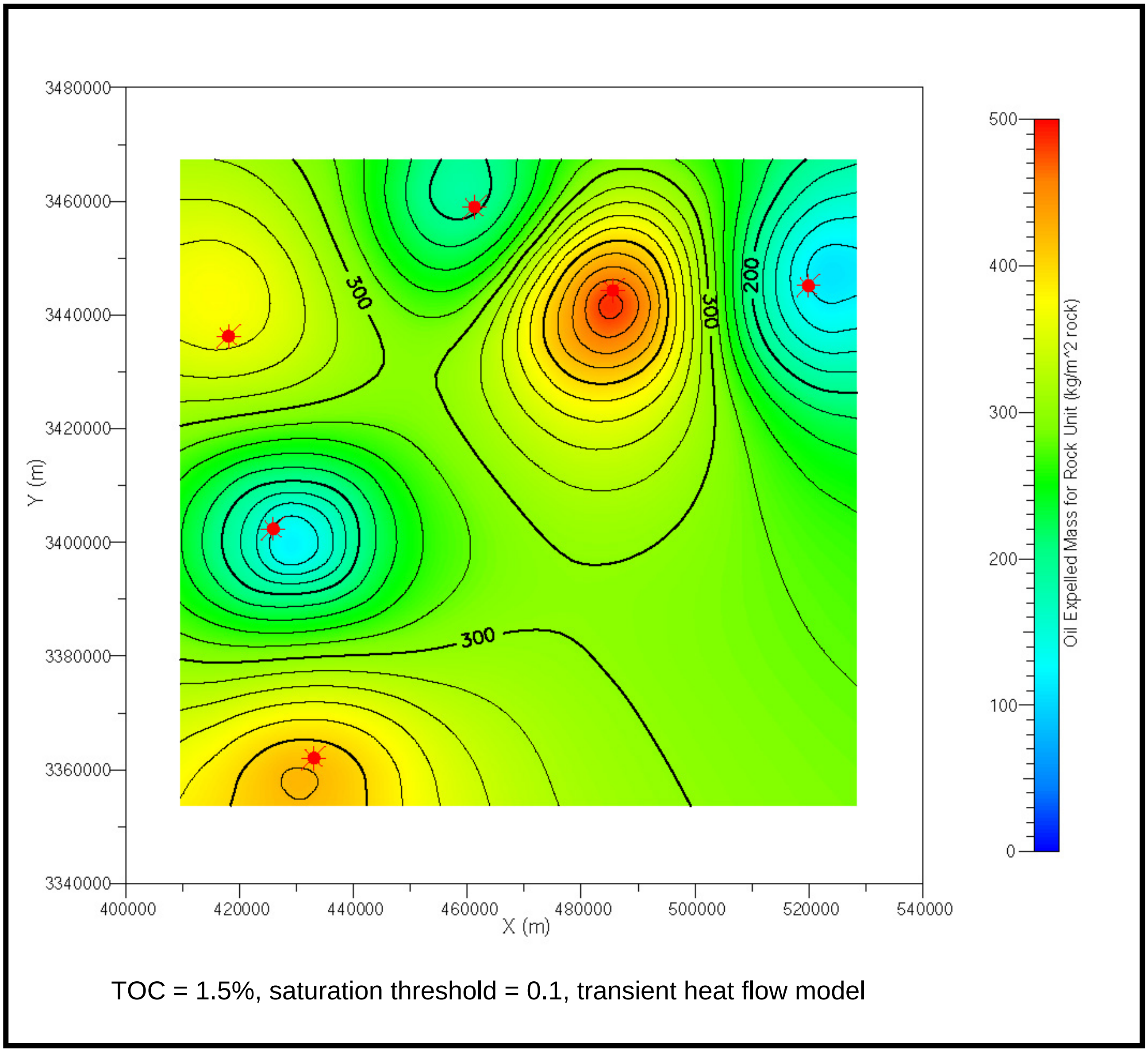
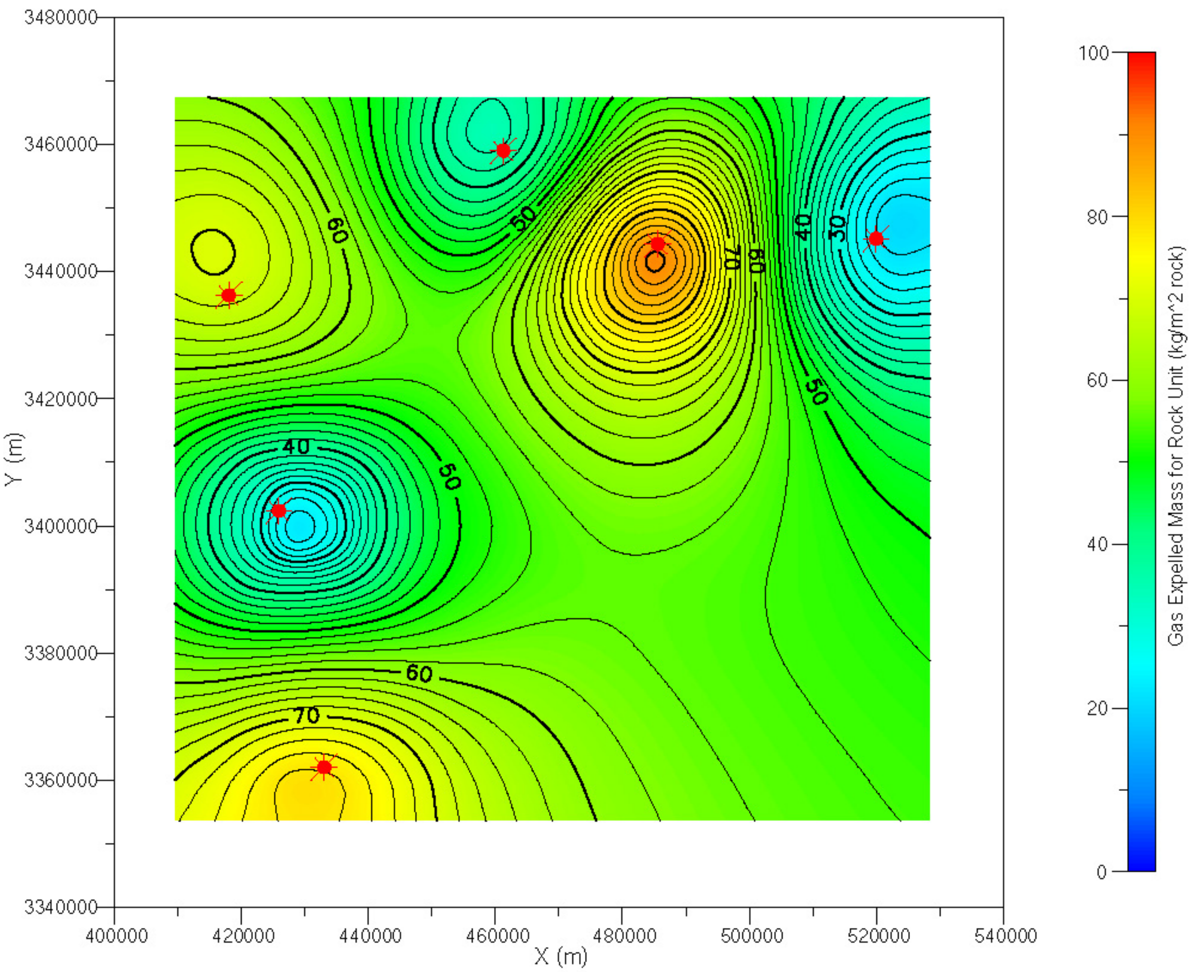


Figure 106. Platte River software model of total expelled oil from the Smackover in the Conecuh Subbasin. By P. Li.



TOC = 1.5%, saturation threshold = 0.1, transient heat flow model

Figure 107. Platte River software model of total expelled gas from the Smackover in the Conecuh Subbasin. By P. Li.

Oil Converted to Gas Assessment—The potential volume of gas in deeply buried reservoirs as a result of thermal cracking of entrapped liquid hydrocarbons being converted to gas in the reservoirs was evaluated for the North Louisiana and Mississippi Interior Salt Basins and for the Manila and Conecuh Subbasins using the methodology of Claypool and Mancini (1989). This evaluation was performed because Lewan (2002) concluded from his study of the North Louisiana and Mississippi Interior Salt Basins that a significant part of the gas in these basins is a product of the cracking of oil to gas in the deeply buried reservoirs. He based this conclusion primarily upon the presence of GOR's greater that 1,500 scf/bbl in these basins. Also, Claypool and Mancini (1989) reported that the conversion of oil to gas with depth in reservoirs in the Manila and Conecuh Subbasins was common. These authors also found that the gas produced from the highly productive gas condensate fields (Big Escambia Creek and Flomaton fields) was a result of thermochemical reduction of evaporite sulfate in the reservoirs. Production from these fields includes a high percent of carbon dioxide and hydrogen sulfide. Also, the condensates from these fields are enriched in isotopically heavy sulfur, which supports this interpretation. Therefore, the production from Big Escambia Creek and Flomaton fields is not included in the evaluation of the Conecuh Subbasin. The results of this evaluation are shown in the Figures 108 and 109 and Tables 13 and 14.

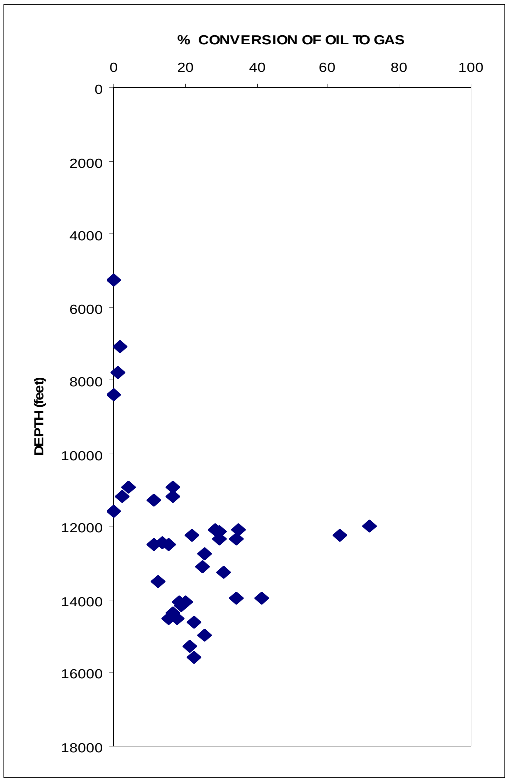


Figure 108. Gas-oil ratios calculated as percent conversion of oil to gas, Manila Subbasin.

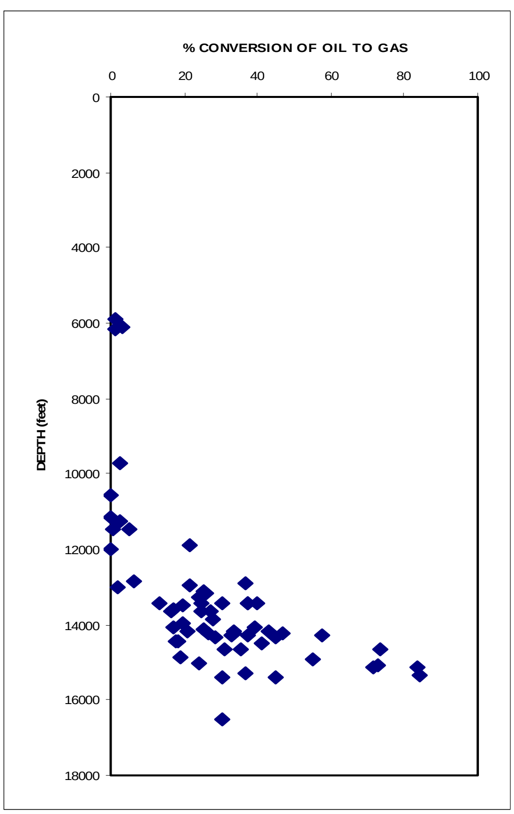


Figure 109. Gas-oil ratios calculated as percent conversion of oil to gas, Conecuh Subbasin.

Table 13. Field production and GOR in Manila Subbasin.

County	Field	Oil (Bbls)	Gas(Mcf)	GOR	% conv. to gas
Monroe	Baileys Creek	76,630	33,651	439	12.6
	Drewry	163,905	22,709	139	4.4
	East Corley Creek	204,493	275,063	1,345	30.7
	East Frisco City	166,384	139,531	839	21.6
	Frisco City	2,124,714	3,333,677	1,569	34.0
	Jones Mill	1,888,609	2,262,332	1,198	28.3
	Little River	127,958	133,931	1,047	25.6
	Little River Lake	1,540,006	1,108,606	720	19.1
	Lovetts Creek	225,832	224,057	992	24.6
	Megargel	63,139	29,503	467	13.3
	Mineola	610,896	536,672	878	22.4
	Monroeville	885,962	525,723	593	16.3
	North Excel	1,343,026	7,092,869	5,281	63.5
	North Frisco City	15,144,208	24,490,888	1,617	34.7
	North Monroeville	2,320,424	1,390,046	599	16.5
	North Wallers Creek	112,148	62,039	553	15.4
	Ollie	247,292	1,911,556	7,730	71.8
	Palmers Crossroads	412,908	248,132	601	16.5
	South Ollie	27,053	34,527	1,276	29.6
	South Uriah	50,842	39,427	775	20.3
	South Vocation	76,739	120,517	1,570	34.1
	Southeast Frisco City	860,450	1,097,420	1,275	29.6
	Southwest Excel	314,415	173,755	553	15.4
	Southwest Monroeville	9,487	0	0	0.0
	Uriah	306,052	205,498	671	18.1
	Vocation	2,283,806	4,947,492	2,166	41.6
	Wallers Creek	987,247	644,450	653	17.7
	West Monroeville	23,925	9,367	392	11.4
Clarke	Barlow Bend	28,089	29,451	1,048	25.6
	South Carlton	8,916,844	0	0	0.0
	Pace Creek	201,881	13,419	66	2.1
	Stave Creek	3,312,593	1,278,064	386	11.3
Baldwin	Blacksher	2,425,698	2,113,197	871	22.3
	Horseneck Creek	154,148	125,597	815	21.1
	Hubbard's Landing	1,726,205	66,945	39	1.3
	Latham	321,828	20,039	62	2.0
	Tensaw Lake	164,786	0	0	0.0
Total		**49,850,622**	**54,740,150**	**1,098**	**26.5**

Table 14. Field production and GOR in Conecuh Subbasin.

County	Field	Oil (Bbls)	Gas(Mcf)	GOR	% conv. to gas
Conecuh	Barnett	598,369	1,197,630	2,001	39.7
	East Barnett	1,630,844	1,836,379	1,126	27.0
	Juniper Creek	43,302	26,821	619	16.9
	Little Cedar Creek	2,124,719	1,791,226	843	21.7
	North Barnett	1,178,734	1,577,615	1,338	30.6
	Northeast Barnett	510,973	914,892	1,790	37.1
	Northwest Range	230,290	246,089	1,069	26.0
	Robbins Branch	11,090	0	0	0.0
	Southwest Range	71,374	71,743	1,005	24.8
Covington	Camp Creek	394,618	0	0	0.0
	Mobley Creek	48,133	7,730	161	5.0
	North Rome	2,382,224	0	0	0.0
	Pleasant Home	870,845	67,232	77	2.5
	South Copeland Creek	58,254	4,815	83	2.6
	Teel Creek	173,906	4,228	24	0.8
	West Falco	506,748	31,969	63	2.0
Escambia	Appleton	2,719,899	4,801,500	1,765	36.7
	(1) Big Escambia Creek	62,113,004	973,442,643	15,672	83.8
	Big Spring Creek	391,987	268,453	685	18.4
	Broken Leg Creek	376,644	239,357	635	17.3
	Burnt Corn Creek	10,911	9,038	828	21.4
	Canaan Church	840,671	999,440	1,189	28.1
	Catawba Springs	246,164	174,442	709	18.9
	Chavers Creek	2,566,193	3,557,799	1,386	31.3
	Chitterling Creek	204,668	548,771	2,681	46.9
	Dean Creek	149,942	69,708	465	13.3
	East Huxford	265,393	172,228	649	17.6
	East Robinson Creek	24,900	52,745	2,118	41.1
	Fanny Church	14,202,061	35,628,079	2,509	45.2
	(2) Flomaton	15,620,791	252,247,469	16,148	84.2
	Foshee	3,710,867	142,372	38	1.2
	Gravel Hill Church	1,069,508	1,291,619	1,208	28.4
	Hall Creek	480,422	458,052	953	23.9
	Hanberry Church	99,844	60,364	605	16.6
	Hickory Branch	561,328	116,437	207	6.4
	Huxford	2,069,040	3,440,385	1,663	35.4
	Jernigan Mill Creek	93,793	352,925	3,763	55.3
	Little Escambia Creek	34,071,409	45,271,730	1,329	30.4
	Little Rock	1,026,527	8,333,584	8,118	72.8
	Narrow Gap Creek	196,574	156,956	798	20.8
	North Robinson Creek	316,023	487,811	1,544	33.7
	North Smiths Church	35,701	39,715	1,112	26.8
	Northwest Appleton	753,382	765,703	1,016	25.1
	Northwest Hall Creek	99,738	150,460	1,509	33.2
	Northwest Smiths Church	446,785	1,122,290	2,512	45.2
	Osaka	2,291,247	244,339	107	3.4
	Perdido	420,237	554,050	1,318	30.2
	Pollard	13,823,466	402,867	29	0.9
	Robinson Creek	476,742	860,234	1,804	37.2
	Sizemore Creek Gas	170,000	1,313,336	7,726	71.8
	Sizemore Creek Oil	206,520	362,176	1,754	36.6
	Smiths Church	102,153	853,915	8,359	73.3
	South Burnt Corn Creek	1,026,545	754,532	735	19.5
	South Dean Creek	212,352	387,068	1,823	37.5
	South Gravel Hill Church	21,662	22,447	1,036	25.4
	South Wild Fork Creek	22,836	93,804	4,108	57.5
	Southwest Canaan Church	910,682	2,111,974	2,319	43.3
	Wallace	11,164	11,266	1,009	24.9
	West Appleton	1,338,783	1,302,560	973	24.2
	West Canaan Church	935,891	1,834,067	1,960	39.2
	West Foshee	1,717,372	66,465	39	1.3
	West Huxford	507,955	779,015	1,534	33.5
	Wild Fork Creek	979,097	718,085	733	19.4
Florida	Jay area	472,368,000	609,556,000	1,290	29.8
Subtotal	**Minus (1) and (2)**	**575,407,501**	**738,718,532**	**1,284**	**29.7**
Total		**653,141,296**	**1,964,408,644**	**3,008**	**49.7**

Evaluation

1. North Louisiana Salt Basin (by UA, Peng Li)

   From the production data in the North Louisiana Salt Basin, the GOR of the basin is 16,549, which can be converted to some 85% based on conversion of oil to gas in the reservoirs. Thus, 825 $\times 10^9$ bbls of expelled oil was potentially thermally cracked to gas in the reservoirs, which generated potentially 5,740 TCF of gas. If the production from the Monroe gas rock is excluded, the GOR of the basin is 12,300, which can be converted to some 80% based on conversion of oil to gas in the reservoir. Thus 776 x 10^9 bbls of expelled oil was potentially thermally cracked to gas in the reservoirs, which potentially generated 5,399 TCF of gas.

2. Mississippi Interior Salt Basin (by UA, Peng Li)

   From the production data in the Mississippi Interior Salt Basin, the GOR of the basin is 3,994, which can be converted to some 57% based on conversion of oil to gas in the reservoirs. Thus, 252 $\times 10^9$ bbls of expelled oil was potentially thermally cracked to gas in the reservoirs, which generated potentially 1,753 TCF of gas.

3. Manila Subbasin (by UA, Peng Li)

   From the production data in the Manila Subbasin, the GOR of the subbasin is 1,098, which can be converted to some 28% based on conversion of oil to gas in the reservoirs. Thus, 0.4 $\times 10^9$ bbls of expelled oil was thermally cracked to gas in the reservoirs, which generated potentially 2.78 TCF of gas.

4. Conecuh Subbasin (by UA, Peng Li)

   From the production data in the Conecuh Subbasin, the GOR of the subbasin is 1,284, which can be converted to some 30% based on conversion of oil to gas in the reservoirs. Thus, 9.3 $\times 10^9$ bbls of expelled oil was thermally cracked to gas in the reservoirs, which generated potentially 64.7 TCF of gas. Including the production from the Big Escambia and Flomaton fields, the GOR of the Subbasin is 3,008, which can be converted to some

50% based on conversion of oil to gas in the reservoir. Thus, 15.5 × 10^9 bbls of expelled oil was thermally cracked to gas in the reservoirs, which generated potentially 107.8 TCF of gas.

Identification of Undiscovered and Underdeveloped Deep Gas Reservoirs—The areas in the North Louisiana and Mississippi Interior Salt Basins with high potential for deeply buried gas reservoirs have been identified using the petroleum system and resource assessment studies.

The petroleum system studies of the Manila and Conecuh Subbasins indicate that these subbasins are thermally mature for oil generation and expulsion, but not thermally mature for secondary, non-associated gas generation and expulsion. The gas condensate found in fields of these subbasins at depths of 15,000 to 18,500 feet in Upper Jurassic Smackover and Norphlet reservoirs is a product of a combination of cracking of oil to gas and/or thermochemical reduction of evaporite sulfate in the reservoirs (Figures 110 and 111).

In the North Louisiana Salt Basin, several parishes have high potential for deeply buried gas reservoirs (Figure 110). The deep thermogenic gas is expected to be found in Upper Jurassic Smackover and Cotton Valley facies, and Lower Cretaceous Hosston and Sligo facies at depths of 15,000 to greater than 20,000 feet (Figures 110 and 112).

In the Mississippi Interior Salt Basin, several counties have high potential for deeply buried gas reservoirs at depths of 15,000 to greater than 25,000 feet (Figures 110 and 113). These reservoirs include Upper Jurassic Norphlet, Smackover, Haynesville and Cotton Valley facies and Lower Cretaceous Hosston and Sligo facies.

The reservoir characteristics and parameters of these units are expected to be similar to those of the units in discovered fields in these basins. Potential petroleum reservoirs include fluvial-deltaic, eolian, nearshore, shoreline, marine bar, shallow shelf and deep water sandstone facies, and carbonate shoal, shelf, reef, and slope facies. Reservoir parameters described below are, in part, from Goddard in Mancini et al. (2006).

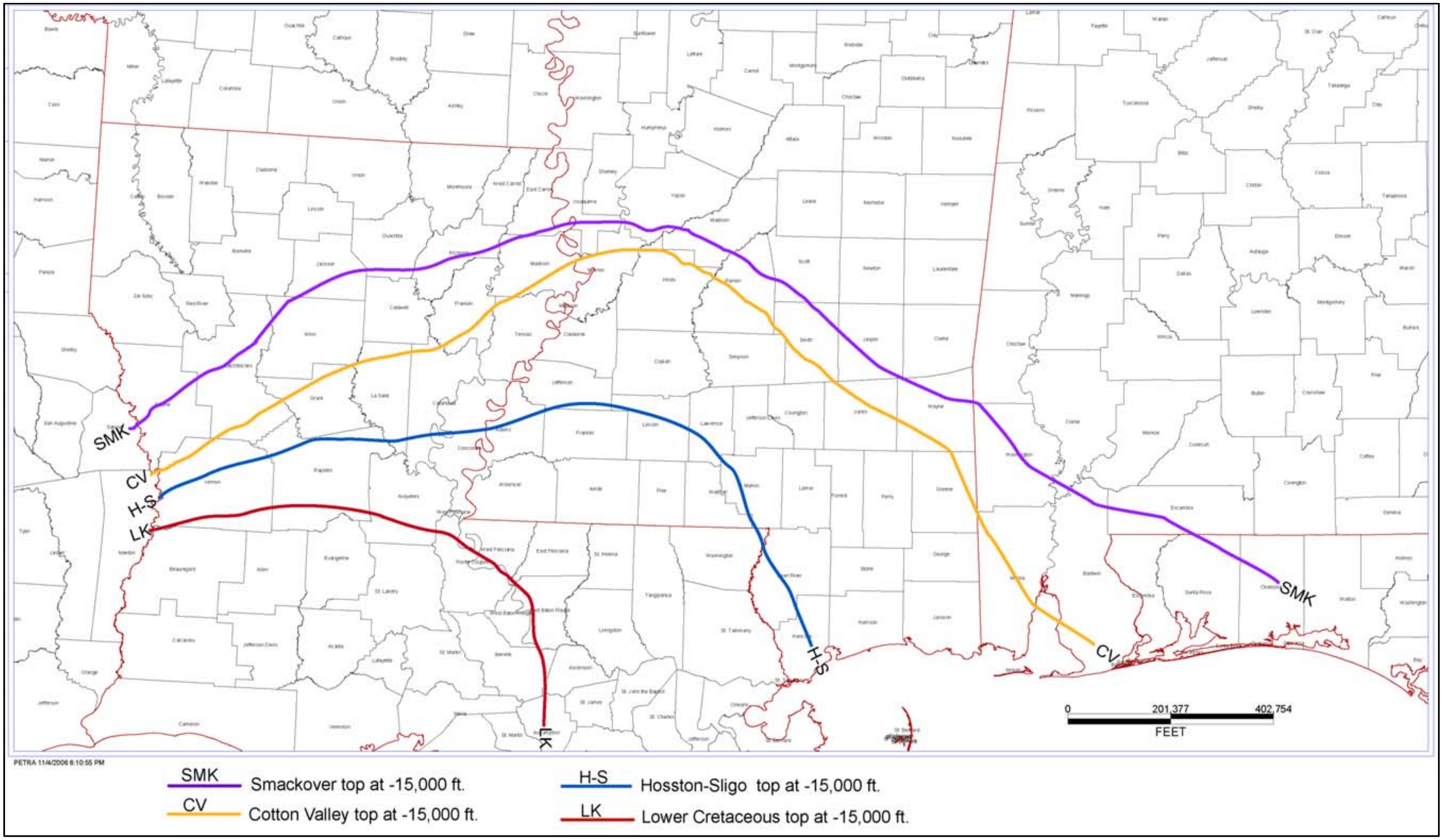


Figure 110. Map for North Louisiana and Mississippi Interior Salt Basins and Manila and Conecuh Subbasins, showing the reference depth of 15,000 ft to the top of Smackover (SMK), Cotton Valley (CV), Hosston-Sligo (H-S), and Lower Cretaceous (LK) stratigraphic levels.

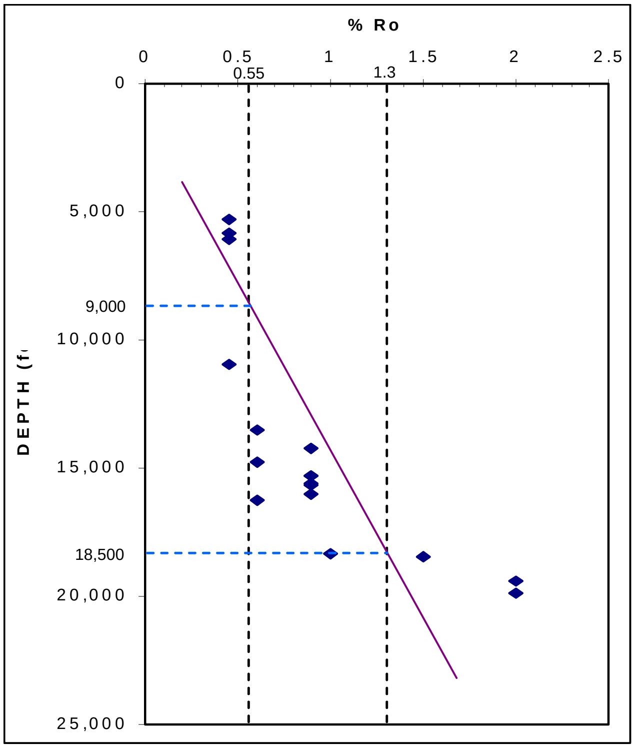


Figure 111. Maturity profile for the Manila and Conecuh Subbasins.

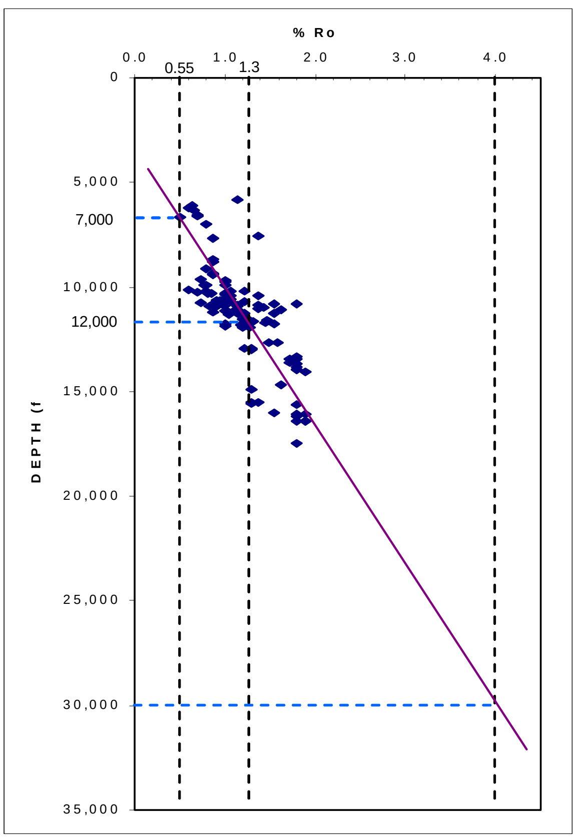


Figure 112. Maturity profile for the North Louisiana Salt Basin.

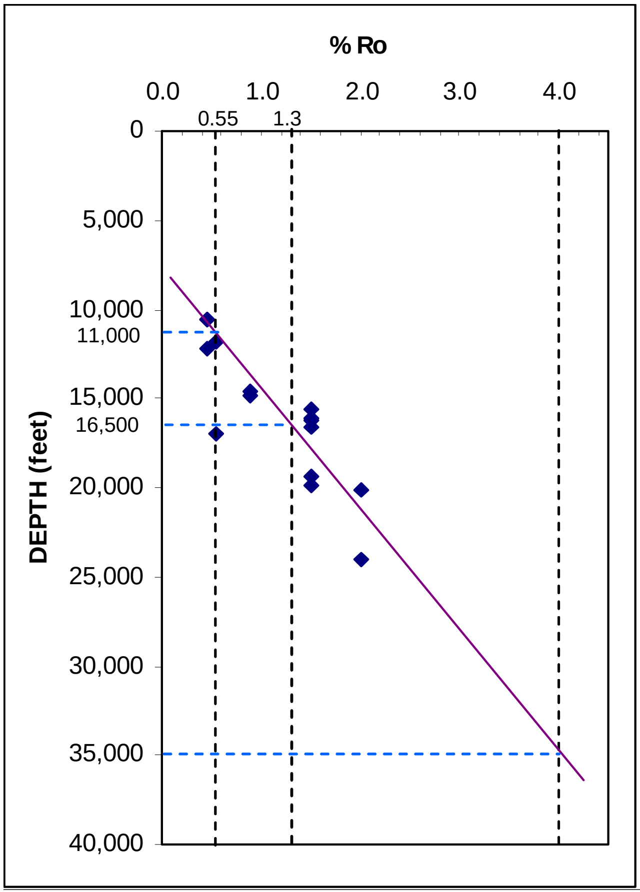


Figure 113. Maturity profile for the Mississippi Interior Salt Basin. Data from Table 1, excluding the well from Issaquena County because this well is located in the Monroe Uplift.

Upper Jurassic Norphlet alluvial and fluvial, eolian dune and interdune, and marine sandstones are reservoirs in the Mississippi Interior Salt Basin. Porosities average 20% with permeabilities of 300 md in this basin.

Upper Jurassic Smackover peritidal, nearshore, shoal and reef limestones and dolostones are reservoirs in the North Louisiana and Mississippi Interior Salt Basins. Porosities are 2 to 28% with permeabilities of 1 to 100 md in the North Louisiana Salt Basin.

Upper Jurassic Haynesville fluvial, eolian, beach and marine sandstones and nearshore and reef limestones and dolostones are reservoirs in the North Louisiana and Mississippi Interior Salt Basins. Porosities are of 9 to 16% with permeabilities of 50 to 400 md in the North Louisiana Salt Basin.

Upper Jurassic/Lower Cretaceous Cotton Valley fluvial-deltaic, nearshore and barrier bar sandstones and nearshore and reefal limestones are reservoirs in the North Louisiana and Mississippi Interior Salt Basins. Porosities are of 9 to 18% with permeabilities of 1 to 300 md in the North Louisiana Salt Basin.

Lower Cretaceous Hosston fluvial-deltaic, tidal, nearshore and deeper water sandstones are reservoirs in the North Louisiana and Mississippi Interior Salt Basins. Porosities are of 3 to 17% with permeabilities of 1 to 300 md in the North Louisiana Salt Basin.

Lower Cretaceous Sligo nearshore, shelf and reef limestones are reservoirs in the North Louisiana and Mississippi Interior Salt Basins. Porosities are of 16 to 20% with permeabilities of 9 to 100 md in this basin.

Lower Cretaceous Pine Island nearshore marine sandstones are reservoirs in the North Louisiana and Mississippi Interior Salt Basins. Porosities are of 10 to 15% with permeabilities of 10 to 200 md in the North Louisiana Salt Basin.

Lower Cretaceous James nearshore, shelf and reefal limestones are reservoirs in the North Louisiana and Mississippi Interior Salt Basins. Porosities are of 10 to 15% with permeabilities of 0.1 to 100 md in the North Louisiana Salt Basin.

Lower Cretaceous Donovan fluvial sandstones are reservoirs in the Mississippi Interior Salt Basin. Porosities are of 10 to 16% with permeabilities of 0.5 to 75 md in this basin.

Lower Cretaceous Rodessa nearshore, shelf and reef limestones are reservoirs in the North Louisiana Salt Basin. Porosities are of 10 to 26% with permeabilities of 10 to 650 md in this basin. In the Mississippi Interior Salt Basin, Rodessa marginal marine and nearshore sandstones are reservoirs. Porosities average 16% with permeabilities of 150 md in this basin.

Lower Cretaceous Mooringsport marine shelf limestones are reservoirs in the North Louisiana Salt Basin, porosities are of 10 to 20% with permeabilities of 10 to 500 md. In the Mississippi Interior Salt Basin, Mooringsport marine shelf and reefal limestones and marginal marine and nearshore sandstones are reservoirs. Porosities average 16% with permeabilities of 150 md in this basin.

Lower Cretaceous Paluxy fluvial, nearshore and shelf sandstones are reservoirs in the Mississippi Interior Salt Basin. Porosities average 16% with permeabilities of 150 md in this basin. Paluxy nearshore sandstones are reservoirs in the North Louisiana Salt Basin. Porosities are of 10 to 30% with low permeabilities in this basin.

Lower Cretaceous Fredericksburg marine shelf limestones of the Goodland Formation are reservoirs in the North Louisiana Salt Basin, and Andrew marine shelf limestones are reservoirs in the Mississippi Interior Salt Basin. Porosities are of 20 to 30% with low permeabilities in the North Louisiana Salt Basin.

Lower Cretaceous Dantzler fluvial-deltaic sandstones are reservoirs in the Mississippi Interior Salt Basin. Porosities average 25 to 30% with permeabilities of 50 to 150 md in this basin.

Upper Cretaceous Tuscaloosa fluvial, coastal and marine shelf sandstones are reservoirs in the North Louisiana and Mississippi Interior Salt Basins. Porosities are of 25 to 30% with permeabilities of 200 to 2,000 md in the North Louisiana Salt Basin.

Upper Cretaceous Eutaw tidal, nearshore and marine shelf sandstones are reservoirs in the Mississippi Interior Salt Basin. Porosities average 27% with permeabilities of 0.1 to 4000 md in this basin.

Upper Cretaceous Tokio, Ozan and Nacatoch nearshore sandstones are reservoirs in the North Louisiana Salt Basin. Porosities are 20 to 33% with permeabilities of 100 to 2,500 md in this basin.

Upper Cretaceous Annona and Saratoga marine shelf chalks are reservoirs in the North Louisiana Salt Basin. Porosities are of 20 to 33% with permeabilities of 100 to 2,500 md in this basin.

Upper Cretaceous Selma marine shelf chalks and Woodruff sandstones are reservoirs in the Mississippi Interior Salt Basin. Porosities are 18% with low permeabilities in this basin.

Upper Cretaceous Monroe Gas Rock marine shelf sandy chalks are reservoirs in the North Louisiana Salt Basin. Porosities are 5 to 25% with permeabilities of 500 md.

Technology Transfer

Workshop

A workshop was held in Tuscaloosa, Alabama on November 8, 2006, on the results of this project. The workshop was sponsored by the Eastern Gulf Region of the Petroleum Technology Transfer Council.

Publications

Reprints of the papers published in the Gulf Coast Association of Geological Societies (GCAGS) Transactions can be obtained by contacting GCAGS at www.gcags.org and reprints of the papers published by the East Texas Geological Society (ETGS) can be obtained at www.easttexasgeo.com.

Barnaby, R., 2006, Modeling the burial and thermal history, organic maturation, and oil expulsion of the North Louisiana petroleum system, Gulf Coast Association of Geological Societies Transactions v. 56, p. 23-25.

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Li, P., 2006, Modeling of thermal maturity history of strata in the North Louisiana Salt Basin area, Gulf Coast Association of Geological Societies Transactions v. 56, p. 439-454.

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<u>Presentations</u>

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Mancini, E.A., Goddard, D.A., Obid, J.A. and Ramirez, V.O., Characterization of Jurassic and Cretaceous facies and petroleum reservoirs in the interior salt basins, central and eastern Gulf Coastal Plain, East Texas Geological Society Gulf Symposium, Tyler, November 16, 2006.

Results and Discussion

The estimate of hydrocarbons generated for the North Louisiana Salt Basin in this study using a petroleum system approach compares favorably with the total volume of hydrocarbons generated published by Zimmermann (1999). In this study, the estimate is 2,870 billion barrels generated using the method of Schmoker (1994), and the estimate is 2,640 billion barrels generated using the Platte River software application (Table 15). The estimate of Zimmermann (1999) is 2,000 to 2,500 billion barrels generated.

The estimate of gas generated for this basin is 6,400 TCF using the Platte River software application and 12,800 TCF using the method of Schmoker (1994). Seventy-five percent of the gas is secondary, non-associated gas and is from late cracking of oil to gas in the source rock. Lewan (2002) concluded that much of the thermogenic gas produced in this basin is the result of cracking of oil to gas in deeply buried reservoirs. The efficiency of expulsion, migration and trapping has been estimated to range from 0.5 to 10 percent for various basins (Schmoker, 1994: Zimmerman, 1999).

The estimate of the hydrocarbons generated for the Mississippi Interior Salt Basin is 910 billion barrels using the method of Schmoker (1994), and the estimate is 1,540 billion barrels using the Platte River software application. The estimate of gas generated for this basin is 3,130 TCF using the Platte River software application and 4,050 TCF using the method of Schmoker (1994). Seventy-five percent of the gas is secondary, non-associated gas and is from late cracking of oil to gas in the source rock. Claypool and Mancini (1989) report that the conversion of oil to gas in reservoirs is a significant source of thermogenic gas in this basin.

The Manila and Conecuh Subbasins are oil-prone. Although these subbasins are thermally mature for oil generation and expulsion, they are not thermally mature for secondary, non-associated gas generation and expulsion. The gas produced from the highly productive gas condensate fields (Big Escambia Creek and Flomaton fields) in these

Table 15. Comparison of Hydrocarbon Conversion and Expulsion Volumes.

Method	NLSB			MISB		Manila		Coneuch	
	Generation			Generation		Generation		Generation	
Schmoker (1994)	hydrocarbon (bbls)	2870×10^9		hydrocarbon (bbls)	910×10^9	hydrocarbon (bbls)	17.5×10^9	hydrocarbon (bbls)	98×10^9
	Oil (bbls)	1030×10^9		Oil (bbls)	580×10^9	Oil (bbls)	15×10^9	Oil (bbls)	82×10^9
	Gas (TCF)	12,800		Gas (TCF)	4,050	Gas (TCF)	17.05	Gas (TCF)	109
Platte River Software	Generation			Generation		Generation		Generation	
	hydrocarbon (bbls)	$2,640\times10^9$		hydrocarbon (bbls)	$1,540\times10^9$	hydrocarbon (bbls)	6.31×10^9	hydrocarbon (bbls)	75×10^9
	Oil (bbls)	$1,715\times10^9$		Oil (bbls)	$1,090\times10^9$	Oil (bbls)	5.32×10^9	Oil (bbls)	59×10^9
	Gas (TCF)	6,400		Gas (TCF)	3,130	Gas (TCF)	6.9	Gas (TCF)	108
	Expulsion			Expulsion		Expulsion		Expulsion	
		S.T. = 0.2	S.T. = 0.1		S.T. = 0.1		S.T. = 0.1		S.T. = 0.1
	Oil (bbls)	180×10^9	970×10^9	Oil (bbls)	442×10^9	Oil (bbls)	1.44×10^9	Oil (bbls)	31×10^9
	Gas (TCF)	400	1,280	Gas (TCF)	843	Gas (TCF)	1.9	Gas (TCF)	40

* S.T.: saturation threshold

subbasins has been interpreted to be a product of the cracking of oil to gas and thermochemical reduction of evaporite sulfate in the reservoirs (Claypool and Mancini, 1989).

The apparent gas-prone nature of the North Louisiana Salt Basin and particularly the Monroe Uplift area has been of study by previous workers, including Zimmerman and Sassen (1993) and Lewan (2002). Lewan (2002) states that most of the gas produced from reservoirs in the North Louisiana Salt Basin is a product of the conversion of oil to gas in deeply buried reservoirs in this basin. These researchers agree that the source of the gas produced from reservoirs in the Monroe Uplift area is the lower Smackover beds. These authors also concur that the gas is thermogenic in origin and that the timing of igneous activity, erosion, and migration play an important role in the presence of the large volume of gas in this area.

Underburden and Overburden Rocks-According to Mancini et al. (2003), the characteristics of the underburden and overburden strata in these basins and subbasins are a result of their rift-related geohistory. The underburden rocks include Paleozoic rocks (pre-rift); Triassic graben fill redbeds of the Eagle Mills Formation and Jurassic evaporite deposits of the Werner Formation and Louann Salt (syn-rift); and nonmarine and marine siliciclastic sediments of the Norphlet Formation (post-rift) (Mancini et al., 2003). The overburden strata are Upper Jurassic, Cretaceous and Cenozoic nonmarine and marine siliciclastic, carbonate and evaporite deposits (post-rift) (Mancini et al., 2003).

Petroleum Source Rocks (Smackover Lime Mudstone)-Upper Jurassic organic rich and laminated Smackover lime mudstone beds are the petroleum source rocks for most of the oils in these onshore interior salt basins and subbasins (Oehler, 1984; Sassen et al., 1987; Claypool and Mancini, 1989; Mancini et al., 2003). Organic geochemical studies of the Smackover source beds indicate that the Jurassic oils and many of the Cretaceous oils originated from the organic matter associated with the Smackover lime mudstone beds. Our work confirms that Smackover lime mudstone is the major petroleum source rock in the onshore interior salt basins and subbasins.

Smackover samples from the lime mudstone beds average 0.81% total organic carbon according to Claypool and Mancini (1989). Organic carbon contents of up to 8.42% for the North Louisiana Salt Basin have been determined from this study (Table 3) and organic carbon contents of up to 9.30% for the Mississippi Interior Salt Basin have been reported by Sassen and Moore (1988). Much of the Smackover has experienced advanced levels of thermal maturity; therefore, the total organic carbon values were higher in the past prior to the generation of crude oil (Sassen and Moore 1988).

The main kerogen types in the Smackover are microbial and microbial-derived amorphous (Oehler 1984; Sassen et al. 1987; Claypool and Mancini, 1989). The Smackover includes herbaceous and woody kerogen in updip areas near the paleoshoreline (Wade et al. 1987). The dominant kerogen types in the North Louisiana Salt Basin are amorphous (microbial) and herbaceous. In the center areas of basins, Smackover samples exhibit thermal alteration indices of 2 to 4 (Oehler 1984; Sassen et al. 1987; Claypool and Mancini, 1989). These values represent an equivalent vitrinite reflectance (Ro) of 0.55 to 4.0% (Sassen and Moore 1988). The thermal alteration indices for the North Louisiana Salt Basin are chiefly in the 3 range.

The generation of crude oil from the source rocks in the Mississippi Interior Salt Basin has been interpreted to have been initiated at a level of thermal maturity of 0.55% Ro (435°C T_{max}; 2 TAI) and concluded at a level of thermal maturity of 1.5% Ro (470°C T_{max}; 3 TAI) by Nunn and Sassen (1986) and Sassen and Moore (1988). Nunn and Sassen (1986) report that the petroleum limit for thermogenic (dry) gas is at the level of 4.0 % Ro. According to Driskill et al. (1988), this requires a depth of burial of 9,840 ft. Nunn and Sassen (1986) reported that the generation of crude oil was initiated at a deeper depth of 11,500 ft in this basin. Generation of oil was interpreted to have initiated from downdip or basinal Smackover lime mudstone beds in the Early Cretaceous, and generation and migration was determined to have continued into Cenozoic time (Nunn and Sassen 1986; Driskill et al. 1988; Sassen and Moore 1988). Smackover lime mudstone beds in updip areas have been reported to have generated oil starting in the Late Cretaceous or 20 my later than the downdip or basinal lime mudstone (Driskill et al. 1988). At a depth of burial of 16,400 to 19,700 ft, the downdip or basinal Smackover lime mudstone beds were determined to be over-mature for the generation of oil (Nunn and Sassen 1986; Driskill et al. 1988). The oils that migrated into reservoirs were subjected to thermal cracking with increasing depth of burial (Sassen and Moore 1988; Claypool and Mancini 1989).

From burial history and thermal maturation history profiles for wells in the North Louisiana Salt Basin, Mississippi Interior Salt Basin and Manila and Conecuh Subbasins, hydrocarbon generation and maturation trends have been observed. For this study, initiation of oil and associated gas was at a Ro level of 0.55%, and the commencement of essentially only thermogenic gas generation was at a Ro level of 1.3%. Cessation of thermogenic gas generation was at a Ro level of 4.0%. In wells in much of the Northern Louisiana Salt Basin, the generation of hydrocarbons from Smackover lime mudstone was initiated at 6,000 to 8,500 feet during the Early Cretaceous and continued into the Tertiary. In wells in much of the Mississippi Interior Salt Basin, the generation of hydrocarbons from Smackover lime mudstone was initiated at 8,000 to 11,000 feet during the Early Cretaceous and continued into the Tertiary. The main difference in the geohistories of the North Louisiana Salt Basin and the Mississippi Interior Salt Basin is the elevated heat flow the strata in the North Louisiana Salt Basin experienced in the Cretaceous due primarily to the reactivation of upward movement, igneous activity, and erosion associated with the Monroe and Sabine Uplifts. The Jackson Dome in the Mississippi Interior Salt Basin is a similar phenomenon, but the effects of this igneous intrusion are more limited with respects to area.

In wells in much of the Manila and Conecuh Subbasins, the generation of hydrocarbons from Smackover lime mudstone was initiated at 8,500 to 11,000 ft. during the Late Cretaceous and continued into the Tertiary. The thermal maturation profiles for wells located updip or along the updip margins of the basins and subbasins indicate that the Smackover source rocks in this area are thermally immature to mature and did not generate significant quantities of oil throughout much of this area, whereas, wells located in the centers of the basins and subbasins are late mature to overmature.

Hydrocarbon expulsion from Smackover source rocks in the North Louisiana Salt Basin and the Mississippi Interior Salt Basin began during the Early Cretaceous and continued into the Tertiary. Commencement of oil expulsion began first in the southern (downdip) portion of these basins in Early Cretaceous and peaked in late Early Cretaceous. Hydrocarbon expulsion from Smackover source rock in the Manila and Conecuh Subbasins was initiated during the Late Cretaceous and continued into the Tertiary. The hydrocarbon expulsion profiles are consistent with the thermal maturation profiles. The timing of the commencement of oil expulsion is a product of the tectonic, depositional, burial and thermal histories of the basins and subbasins. Smackover hydrocarbon migration was probably of an intermediate range (80 km or 50 mi), for thermal maturity and hydrocarbon expulsion profiles for wells located in fields producing low gravity crude oil show that the local Smackover source beds have not reached the thermal maturity level to expel Smackover oil (Mancini et al., 2003). Hydrocarbon migration into overlying strata was probably facilitated by vertical migration along faults as discussed by Evans (1987), Sassen (1990) and Zimmerman and Sassen (1993).

Petroleum Reservoir Rocks-Petroleum reservoir rocks of the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin include Jurassic, Cretaceous and Tertiary siliciclastic and carbonate strata (Figures 38 and 39).

Petroleum reservoir rocks in the North Louisiana Salt Basin include the Upper Jurassic Smackover limestone, Haynesville (Buckner) sandstone and limestone, and Cotton Valley (Schuler) sandstone and limestone; the Lower Cretaceous Hosston sandstone, Sligo limestone, Pine Island sandstone, James limestone, Rodessa limestone, Ferry Lake limestone, Mooringsport limestone, Paluxy sandstone, and Fredericksburg limestone; the Upper Cretaceous Tuscaloosa/Eagle Ford sandstone, Austin sandstone and chalk, Taylor chalk and sandstone, Navarro sandstone and Monroe gas rock chalk; and Lower Tertiary Wilcox sandstone (Table 6). The petroleum reservoirs in the Mississippi Interior Salt Basin include the Upper Jurassic Norphlet sandstone, Smackover limestone and dolostone, Haynesville sandstone, and Cotton Valley (Schuler) sandstone; the Lower Cretaceous Hosston sandstone, Sligo sandstone, Pine Island sandstone, James limestone, Rodessa (Donovan) sandstone, Ferry Lake beds, Mooringsport sandstone, Paluxy sandstone, Washita-Fredericksburg beds and Dantzler sandstone; the Upper Cretaceous Tuscaloosa sandstone, Eutaw sandstone, Selma chalk, and Jackson gas rock; and Lower Tertiary Wilcox sandstone (Table 8). The petroleum reservoirs in the Conecuh Subbasin include the Upper Jurassic Norphlet sandstone, Smackover limestone and dolostone and Haynesville sandstone and Cotton Valley sandstone; Lower Cretaceous Hosston sandstone; and Upper Cretaceous Tuscaloosa sandstone (Table 12). The petroleum reservoirs in the Manila Subbasin include the Upper Jurassic Norphlet sandstone, Smackover limestone and dolostone and Haynesville sandstone; Lower Cretaceous Paluxy sandstone, Washita-Fredericksburg beds and Dantzler sandstone; and Upper Cretaceous Tuscaloosa sandstone (Table 10).

Petroleum Seal Rocks-Petroleum seal rocks in the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin include Jurassic, Cretaceous, and Tertiary anhydrite and shale beds.

Petroleum seal rocks in the North Louisiana Salt Basin include the Upper Jurassic Buckner anhydrite and Cotton Valley (Bossier) shale; the Lower Cretaceous Pine Island shale, Bexar shale, Ferry Lake anhydrite, and Paluxy shale; the Upper Cretaceous Eagle Ford shale; and the Lower Tertiary Midway shale. Petroleum seal rocks in the Mississippi Interior Salt Basin include Upper Jurassic Smackover limestone, Buckner anhydrite, Haynesville shale and Cotton Valley shale; Lower Cretaceous Pine Island shale, Bexar shale, Ferry Lake anhydrite, Mooringsport shale, and Dantzler shale; Upper Cretaceous Tuscaloosa shale, Eutaw shale and Selma chalk; and Lower Tertiary Midway shale. Petroleum seal rocks in the Manila Subbasin and Conecuh Subbasin include Upper Jurassic Smackover limestone, Buckner anhydrite, Haynesville shale and Upper Cretaceous Tuscaloosa shale and Eutaw shale.

Petroleum Traps-Structural or combination traps characterize the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin. Movement of the Jurassic Louann Salt has produced a complex array of structures. These structures include peripheral salt ridges; low relief salt pillows, salt anticlines and turtle structures; and piercement domes (Mancini et al., 2003). These features form the majority of the petroleum traps in these basins and subbasins; however, anticlinal structures associated with basement paleotopographic highs are also present (Mancini et al., 2003).

Identification of Deeply Buried Gas Reservoirs-According to Puckett et al. (2000) potential undiscovered reservoirs in the Mississippi Interior Salt Basin are subsalt Triassic Eagle Mills sandstone facies and Lower Cretaceous carbonate facies of the James, Rodessa, Mooringsport and Andrew formations. Lower Cretaceous sandstone facies of the

Hosston, Paluxy and Dantzler formations and Upper Cretaceous Eutaw and Tuscaloosa sandstone facies are potential underdeveloped reservoirs in this basin.

In this study, Upper Jurassic and Lower Cretaceous facies have been identified as having high potential for the deeply buried gas reservoirs in the Mississippi Interior Salt Basin. The specific facies includes Upper Jurassic continental, marginal marine and shallow and deep marine siliciclastic facies of the Norphlet, Haynesville and Cotton Valley and marine carbonate facies of the Smackover; and Lower Cretaceous continental, marginal marine and shallow and deep marine facies of the Hosston and Sligo in several counties in southern Mississippi (Figure 110). Based on petroleum system characterization and modeling in this study, deep thermogenic gas should be preserved in these potential reservoirs to depths below 25,000 feet in the Mississippi Interior Salt Basin (Figure 113). This thermogenic gas, whether generated from late secondary cracking of oil to gas in the source rock or from oil to gas conversion in the deeply buried reservoirs, migrated updip in to shallower buried reservoirs, including the Jackson gas rock at depths of some 2,000 feet.

According to Mancini et al. (2006), potential undiscovered reservoirs in the North Louisiana Salt Basin are subsalt Triassic Eagle Mills sandstone facies and deeply buried Upper Jurassic sandstone and limestone facies. Potential underdeveloped reservoirs include Lower Cretaceous sandstone and limestone facies and Upper Cretaceous sandstone facies. The Upper Jurassic units account for 20% of the current cumulative oil production and 38% of the current cumulative gas production in the Mississippi Interior Salt Basin (Tables 7 and 8), and only account for some 10% of the current cumulative oil and gas production in the North Louisiana Salt Basin (Tables 5 and 6) (Mancini et al., 2006). Zimmerman and Goddard (2001) identified Hosston deep water sandstone facies as having high potential as deep gas reservoirs in the southern part of the North Louisiana area. The USGS in 2002 assessed Hosston and Cotton Valley sandstone facies as having potential as undiscovered conventional oil and gas reservoirs in the onshore interior salt basins of the northern Gulf of Mexico area. Based on petroleum system characterization and modeling in this study, deep thermogenic gas should be preserved in these potential reservoirs to depths below 20,000 feet in the North Louisiana Salt Basin (Figure 112). This thermogenic gas, whether generated from late secondary cracking of oil to gas in the source rock or from oil to gas conversion in the deeply buried reservoirs, migrated updip in to shallower buried reservoirs, including the Monroe gas rock at depths of some 2,000 feet. The depositional and diagenetic histories of these strata in the North Louisiana Salt Basin are interpreted to be similar to those of the Mississippi Interior Salt Basin. Potential facies in the North Louisiana Salt Basin that have high potential for deeply buried gas reservoirs include Upper Jurassic and Lower Cretaceous sandstone facies of the Cotton Valley and Hosston units and limestone facies of the Smackover and Sligo units in several parishes of central Louisiana (Figure 110).

Conclusions

The objectives of the study were: (1) to perform resource assessment of the thermogenic gas resources in deeply buried (>15,000 ft) natural gas reservoirs of the onshore interior salt basins of the north central and northeastern Gulf of Mexico areas through petroleum system identification, characterization and modeling; and (2) to use the petroleum system based resource assessment to estimate the volume of the deep thermogenic gas resource that is available for potential recovery and to identify those areas in the interior salt basins with high potential for this thermogenic gas resource.

Petroleum source rock analysis and petroleum system characterization and modeling, including thermal maturation and hydrocarbon expulsion modeling, have shown that the Upper Jurassic Smackover Formation served as the regional petroleum source rock in the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin. Previous studies have indicated that Upper Cretaceous Tuscaloosa shale was an effective local petroleum source rock in the Mississippi Interior Salt Basin and a possible local source bed in the North Louisiana Salt Basin given the proper organic facies; that Lower Cretaceous lime mudstone was an effective local petroleum source rock in the South Florida Basin and a possible local source bed in the North Louisiana Salt Basin and Mississippi Interior Salt Basin given the proper organic facies; that uppermost Jurassic strata were effective petroleum source rocks in Mexico and were possible local source beds in the North Louisiana and East Texas Salt Basins given the proper organic facies; and that Lower Tertiary shale and lignite were petroleum source rocks in south Louisiana and southwestern Mississippi. In this study, Lower Tertiary beds were found not to have been subjected to favorable burial and thermal maturation histories required for petroleum generation in the North Louisiana, Mississippi Interior Salt Basins, and Manila and Conecuh Subbasins. The burial and thermal maturation histories for Upper Cretaceous Tuscaloosa beds were found to be favorable for oil generation locally in the Mississippi Interior Salt Basin. Organic-rich facies in Lower Cretaceous strata were not identified in this study. The Upper Jurassic Bossier beds have possible potential as a local source rock in the North Louisiana Salt Basin. The estimates of the total hydrocarbons, oil, and gas generated and expelled are, therefore, based on the assumption that the Smackover Formation is the main petroleum source rock in these basins and subbasins.

The estimate of the total hydrocarbons generated for the North Louisiana Salt Basin in this study using a petroleum system approach compares favorably with the total volume of hydrocarbons generated published by Zimmermann (1999). In this study, the estimate is 2,870 billion barrels of total hydrocarbons generated using the method of Schmoker (1994), and the estimate is 2,640 billion barrels of total hydrocarbons generated using the Platte River software application. The estimate of Zimmermann (1999) is 2,000 to 2,500 billion barrels of total hydrocarbons generated. The estimate of gas generated for this basin is 6,400 TCF using the Platte River software application, and 12,800 TCF using the method of

Schmoker (1994). Barnaby (2006) estimated that the total gas volume generated for this basin ranges from 4,000 to 8,000 TCF. Seventy-five percent of the gas is estimated to be from late cracking of oil in the source rock. Lewan (2002) concluded that much of the thermogenic gas produced in this basin is the result of cracking of oil to gas in deeply buried reservoirs. The expulsion, migration and trapping efficiency has been estimated to range from 0.5 to 10 percent for certain basins (Schmoker, 1994: Zimmerman, 1999).

The estimate of the total hydrocarbons generated for the Mississippi Interior Salt Basin is 910 billion barrels using the method of Schmoker (1994), and the estimate of the total hydrocarbons generated is 1,540 billion barrels using the Platte River software application. The estimate of gas generated for this basin is 3,130 TCF using the Platte River software application, and 4,050 TCF using the method of Schmoker (1994). Seventy-five percent of the gas is estimated to be from late cracking of oil in the source rock. Claypool and Mancini (1989) report that the conversion of oil to gas in reservoirs is a significant source of thermogenic gas in this basin.

The Manila and Conecuh Subbasins are oil-prone. Although these subbasins are thermally mature for oil generation and expulsion, they are not thermally mature for secondary, non-associated gas generation and expulsion. The gas produced from the highly productive gas condensate fields (Big Escambia Creek and Flomaton fields) in these subbasins has been interpreted to be, in part, a product of the cracking of oil to gas and thermochemical reduction of evaporite sulfate in the reservoirs.

Petroleum reservoir rocks in the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin include Jurassic, Cretaceous and Tertiary siliciclastic and carbonate strata. These reservoir rocks include Upper Jurassic Norphlet, Smackover, Haynesville, and Cotton Valley units; Lower Cretaceous Hosston, Sligo, Pine Island, James, Rodessa, Ferry Lake, Mooringsport, Paluxy, Fredericksburg-Washita and Dantzler units; the Upper Cretaceous Tuscaloosa/Eagle Ford, Eutaw-Austin, Selma-

Taylor/Navarro, and Jackson gas rock-Monroe gas rock units; and the Lower Tertiary Wilcox unit.

Petroleum seal rocks in these basins and subbasins include Upper Jurassic Smackover lime mudstone, Buckner anhydrite, Haynesville shale, and Cotton Valley shale; Lower Cretaceous Pine Island shale, Ferry Lake anhydrite, Mooringsport shale, and Fredericksburg-Washita shale; Upper Cretaceous Tuscaloosa shale, Eagle Ford shale, and Selma chalk; and Lower Tertiary Midway shale.

Petroleum traps include structural and combination traps in these basins and subbasins. Salt movement is the principal process that formed these traps, producing a complex array of salt structures. These structures include peripheral salt ridges, low relief salt pillows, salt anticlines and turtle structures, and piercement domes. Structures associated with basement paleotopographic highs are also present.

The areas in the North Louisiana and Mississippi Interior Salt Basins with high potential for deeply buried gas reservoirs (>15,000 ft) have been identified. In the North Louisiana Salt Basin, these potential reservoirs include Upper Jurassic and Lower Cretaceous facies, especially the Smackover, Cotton Valley, Hosston, and Sligo units. The estimate of the secondary, non-associated gas generated from cracking of oil in the source rock from depths below 12,000 feet in this basin is 4,800 TCF. Assuming an expulsion, migration and trapping efficiency of 1 to 5%, 48 to 240 TCF of gas is potentially available. The final recoverable gas is some percent of this estimated thermogenic gas resource, based on the recovery factor for the specific reservoir. To date, some 29 TCF of gas have been produced from this basin. Also, the thermogenic gas, whether generated from late secondary cracking of oil to gas in the source rock or from oil to gas conversion in deeply buried reservoirs, migrated updip into shallower reservoirs, including the Monroe gas rock at depths of some 2,000 feet.

In the Mississippi Interior Salt Basin, the potential area for deeply buried gas reservoirs includes Upper Jurassic and Lower Cretaceous facies, especially the Norphlet, Smackover, Haynesville, Cotton Valley, Hosston, and Sligo units. The estimate of the secondary, non-associated gas generated from cracking of oil in the source rock from depths below 16,500 feet in this basin is 2,350 TCF. Assuming an efficiency of 1 to 5%, 23.5 to 117.5 TCF of gas is potentially available. The final recoverable gas is some percent of this estimated thermogenic gas resource based on the recovery factor for the specific reservoir. To date, some 13 TCF of gas have been produced from this basin. Also, this thermogenic gas, whether generated from late secondary cracking of oil to gas in the source rock or from oil to gas conversion in deeply buried reservoirs, which migrated updip into shallower reservoirs, including the Jackson gas rock at depths of some 2,000 feet.

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