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Abstract

The principal research effort for the first six months of Year 2 of the project has been petroleum system characterization. Understanding the burial and thermal maturation histories of the strata in the onshore interior salt basins of the North Central and Northeastern Gulf of Mexico areas is important in petroleum system characterization. The underburden and overburden rocks in these basins and subbasins are a product of their rift-related geohistory. Petroleum source rock analysis and thermal maturation and hydrocarbon expulsion modeling indicate that an effective regional petroleum source rock in the onshore interior salt basins, the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin, was the Upper Jurassic Smackover lime mudstone. The 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. Hydrocarbon generation and expulsion was initiated in the Early Cretaceous and continued into the Tertiary in the North Louisiana Salt Basin and the Mississippi Interior Salt Basin. Hydrocarbon generation and expulsion was initiated in the Late Cretaceous and continued into the Tertiary in the Manila Subbasin and Conecuh Subbasin. Reservoir rocks include Jurassic, Cretaceous and Tertiary siliciclastic and carbonate strata. Seal rocks include Jurassic, Cretaceous and Tertiary anhydrite and shale beds. Petroleum traps include structural and combination traps.

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Introduction

The University of Alabama and Louisiana State University have undertaken 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 deeply buried (below 15,000 ft) in the onshore interior salt basins of the North Central and Northeastern Gulf of Mexico areas. The project is designed to assist in the formulation of advanced exploration strategies for finding and maximizing the recovery from deep natural gas domestic resources at reduced costs and risks and with minimum impact.

The results of the project should serve to enhance exploration efforts by domestic companies in their search for new petroleum resources, especially those deeply buried (below 15,000 ft) natural gas resources, and should support the domestic industry's endeavor to provide an increase in reliable and affordable supplies of fossil fuels.

Executive Summary

The principal research effort for the first six months of Year 2 of the project has been data compilation and petroleum system identification. Understanding the burial and thermal maturation histories of the strata in the onshore interior salt basins of the North Central and Northeastern Gulf of Mexico areas is critical in petroleum system characterization. The underburden and overburden rocks in these basins and subbasins are a product of their rift-related geohistory.

Petroleum source rock analysis and thermal maturation and hydrocarbon expulsion modeling indicate that the Upper Jurassic Smackover Formation served as an effective regional petroleum source rock in the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin. The 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. Lower Cretaceous lime mudstone was an effective local petroleum source rock in the South Florida Basin, and these rocks were possible source beds in the North Louisiana Salt Basin and Mississippi Interior Salt Basin given the proper organic facies. Uppermost Jurassic strata were effective source rocks in Mexico, and thus, were possible source beds in the North Louisiana Salt Basin given the proper organic facies. Lower Tertiary shale and lignite have been reported to have been source rocks in south Louisiana and southwestern Mississippi, but these 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.

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, James, Rodessa, Mooringsport, Paluxy, and Fredericksburg-Washita units, the Upper Cretaceous Tuscaloosa, 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 beds, Lower Cretaceous Pine Island shale, Ferry Lake anhydrite, Mooringsport shale, and Fredericksburg-Washita shale beds, Upper Cretaceous Tuscaloosa shale, Eagle Ford shale, and Selma Chalk beds, and Lower Tertiary Midway shale beds.

Petroleum traps include structural and combination traps in these basins and subbasins. Halokinesis 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.

Project Objectives

The objectives of the study are: to perform resource assessment of the in-place deep (>15,000 ft) natural gas resource of the onshore interior salt basins of the North Central and Northeastern Gulf of Mexico areas through petroleum system identification, characterization and modeling and to use the petroleum system based resource assessment to estimate the volume of the in-place deep gas resource that is potentially recoverable and to identify those areas in the interior salt basins with high potential to recover commercial quantities of the deep gas resource.

The project objectives will be achieved through a 3-year effort. First, emphasis is 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 includes identification of the petroleum systems in these basins and the characterization of the overburden, source, reservoir and seal rocks of the petroleum systems and of the associated petroleum traps. Second, emphasis is on petroleum system modeling. This task includes the assessment of the timing of deep (>15,000 ft) gas generation, expulsion, migration, entrapment and alteration (thermal cracking of oil to gas). Third, emphasis is on resource assessment. This task includes the volumetric calculation of the total in-place hydrocarbon resource generated, the determination of the volume of the generated hydrocarbon resource that is classified as deep (>15,000 ft) gas, the estimation of the volume of deep gas that was expelled, migrated and entrapped, and the calculation of the potential volume of gas in deeply buried (>15,000 ft) reservoirs resulting from the process of thermal cracking of liquid hydrocarbons and their transformation to gas in the reservoir. Fourth, emphasis is on identifying those areas in the onshore interior salt basins with high potential to recover commercial quantities of the deep gas resource.

Experimental

Work Accomplished

Data Compilation—The existing information on the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin (Figure 1) have been evaluated and an electronic database of these data for each basin has been compiled. Eleven (11) cross sections consisting of 141 wells for the North Louisiana Salt Basin have been selected and constructed. The log curves for the wells used in the cross sections have been digitized. Five (5) cross sections consisting of 48 wells for the Mississippi Interior Salt Basin have been prepared. The log curves for the wells used in the cross sections have been digitized. Five (5) cross sections consisting of 18 wells for the Manila and Conecuh Subbasins have been prepared. These log curves for the wells used in the cross sections have been digitized. Subsurface structure and isopach maps have been prepared using the digitized database for the North Louisiana Salt Basin, the Mississippi Interior Salt Basin and the Manila Subbasin and Conecuh Subbasin. Burial history, thermal maturation history, and hydrocarbon profiles have been constructed for key wells in each of these basins.

Source rock geochemical data for the Mississippi Interior Salt Basin and Manila and Conecuh Subbasins have been reviewed and compiled (Tables 1 and 2). Source rock geochemical data for the North Louisiana Salt Basin have been reviewed, and additional samples have been analyzed by GeoChem Laboratories for source rock characterization and analysis (Table 3).

Representative geologic cross sections (Figures 2A, 3A, 4A and 5A), and representative thermal maturity profiles (Figures 2B, 3B, 4B and 5B), representative burial history profiles (Figure 6), representative thermal maturation history (Figure 7) and representative hydrocarbon expulsion profiles (Figure 8) for each of the studied basins and subbasins have been constructed.

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 have been characterized. These components include the underburden, source, reservoir and seal rocks (Figure 9) of these petroleum systems that are associated with the petroleum traps in these onshore interior salt basins. A summary of the Upper Jurassic Smackover petroleum system in each of these basins and subbasins is presented in Figures 10 and 11.

Work Planned

***Petroleum System Modeling*—**Hydrocarbon and deep (>15,000 ft) gas generation, expulsion and migration will be modeled and the timing of entrapment and of the thermal cracking of oil to gas in deeply buried (>15,000 ft) reservoirs in the North Louisiana Salt Basin, the Mississippi Interior Salt Basin, the Conecuh Subbasin and Manila Subbasin will be determined in this task. This task will be initiated and completed in this year of work (Table 4).

***In-Place Assessment*—**This task is designed to volumetrically calculate the total estimated in-place hydrocarbon resource generated and the potential amount of resource that is classified as deep (>15,000 ft) gas in the North Louisiana Salt Basin, the Mississippi Interior Salt Basin, the Manila Subbasin, and the Conecuh Subbasin. This task will be initiated this year and will be completed as part of next year's work effort.

Results and Discussion

Overburden Rocks

The underburden and overburden rocks in these basins and subbasins are a product of their rift-related geohistory. The underburden rocks include pre-rift Paleozoic rocks; syn-rift Triassic graben fill redbeds of the Eagle Mills Formation and Jurassic evaporite deposits of the Werner Formation and Louann Salt; and post-rift nonmarine and marine siliciclastic sediments of the Norphlet Formation. The overburden rocks are Jurassic, Cretaceous and Tertiary post-rift nonmarine and marine siliciclastic, carbonate and evaporite deposits.

Potential Petroleum Source Rocks

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 have been described as serving as source rocks in the North Louisiana Salt Basin, the Mississippi Interior Salt Basin, and the Manila and Conecuh Subbasins (Oehler, 1984; Sassen et al., 1987; Sassen and Moore, 1988; Claypool and Mancini, 1989; Mancini et al., 2003). The Upper Creta-ceous (Cenomanian-Turonian) Tuscaloosa marine shale beds have been reported as serving as source rocks in Mississippi (Koons et al., 1974). The Lower Cretaceous (Albian) Sunniland lime mudstone beds have been described as serving as 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).

From source rock and oil characterization studies and from burial and thermal maturation history modeling, Mancini and Claypool (1989), Mancini et al., (1999), 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 (Figure 3), Mississippi Interior Salt Basin (Figure 4), Manila Subbasin (Figure 5), and Conecuh Subbasin (Figure 6). The Upper Cretaceous Tuscaloosa marine shale beds were an effective local petroleum source rock in parts of the Mississippi Interior Salt Basin and a possible local source bed in the North Louisiana Salt Basin given the proper organic facies but not in the Manila and Conecuh Subbasins. The uppermost Jurassic strata and the Lower Cretaceous lime mudstone and shale beds were possible local source beds in parts of the North Louisiana Salt Basin and Mississippi Interior Salt Basin given the proper organic facies. These beds probably were not source beds in the Manila and Conecuh Subbasins because the proper organic facies do not appear to be present.

Based on this assessment of potential petroleum source rocks in the onshore interior salt basins and subbasins of the north central and northeastern Gulf of Mexico area, only the Upper Jurassic Smackover lime mudstone beds 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).

Smackover Source Rocks and Oils

The 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; Mancini and Claypool, 1989; Mancini et al., 2003). Organic geochemical analyses of the Smackover source beds (Tables 1-3) indicate that the Jurassic oils and many of the Cretaceous oils originated from the organic matter associated with the Smackover lime mudstone beds.

Smackover samples from the lower and middle lime mudstone beds average 0.81% total organic carbon according to Claypool and Mancini (1989). Organic carbon contents of up to 1.54% for the North Louisiana Salt Basin, 9.30% for the Mississippi Interior Salt Basin, and 1.76% for the Manila and Conecuh Subbasins have been measured in these lime mudstone beds (Sassen et al., 1987; Sassen and Moore, 1988). Because much of the Smackover has experienced advanced levels of thermal maturity, the total organic carbon values were higher in the past prior to the generation of crude oil (Sassen and Moore 1988).

The dominant kerogen types in the Smackover are algal (microbial) and microbial-derived amorphous (Oehler 1984; Sassen et al. 1987; Claypool and Mancini, 1989). In updip areas near the paleoshoreline, the Smackover includes herbaceous and woody kerogen (Wade et al. 1987). 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 generation of crude oil from the source rocks in the North Louisiana Salt Basin, Mississippi Interior Salt Basin and Manila and Conecuh Subbasins 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) (Nunn and Sassen 1986; Sassen and Moore 1988). This requires a depth of burial of 3 km or 9,840 ft according to Driskill et al. (1988). Nunn and Sassen (1986) reported that the generation of crude oil was initiated at a depth of 3.5 km or 11,500 ft. The generation of crude oil was determined to have been initiated from basinal Smackover lime mudstone beds in the Early Cretaceous, and the generation and migration of low to intermediate gravity crude oil is interpreted to have continued into Cenozoic time (Nunn and Sassen 1986; Driskill et al. 1988; Sassen and Moore 1988). Updip Smackover lime mudstone beds have been reported to have generated low gravity crude oil beginning in the Late Cretaceous or 20 my later than the basinal lime mudstone (Driskill et al. 1988). At a depth of burial of 5 to 6 km (16,400 to 19,700 ft), the basinal Smackover lime mudstone beds were determined to be over-mature for the generation of crude oil (Nunn and Sassen 1986; Driskill et al. 1988). The low to intermediate gravity crude oils that migrated into reservoirs were subjected to thermal cracking with increasing depth of burial and time (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 (Figures 6 and 7), hydrocarbon generation and maturation trends can be observed. In wells in much of the North Louisiana Salt Basin, the generation of hydrocarbons from Smackover lime mudstone was initiated at 1,829 to 2,896 m (6,000 to 9,500 ft) 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 2,438 to 3,353 m (8,000 to 11,000 ft) during the Early Cretaceous and continued into the Tertiary (Figure 10). In wells in much of the Manila and Conecuh Subbasins, the generation of hydrocarbons from Smackover lime mudstone was initiated at 2,591 to 3,811 m (8,500 to 12,500 ft) during the Late Cretaceous and continued into the Tertiary (Figure 11). 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 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 commenced during the Early Cretaceous and continued into the Tertiary (Figure 8). Initiation of oil expulsion began first in the central portion of the basin in

Early Cretaceous and peaked in mid Early Cretaceous in this area. Hydrocarbon expulsion from Smackover source rock in the Manila and Conecuh Subbasins commenced during the Late Cretaceous and continued into the Tertiary. The hydrocarbon expulsion profiles for the wells are in agreement with the thermal maturation profiles. The timing of commencement of oil expulsion is consistent with the tectonic, depositional, burial and thermal histories of the basins and subbasins. The Smackover hydrocarbon expulsion profiles support an intermediate range (80 km or 50 mi) migration model for Smackover crude oil in that the thermal maturity and hydrocarbon expulsion profiles for wells located in fields producing low gravity crude oil show that the local Smackover source beds, to date, have not reached the thermal maturity level to expel Smackover oil. Smackover hydrocarbon migration into overlying strata was facilitated by vertical migration along faults. Evans (1987), Sassen (1990) and Zimmerman and Sassen (1993) also published information in support of combined long range and vertical hydrocarbon migration in this area.

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 (Figure 9).

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, and Washita-Fredericksburg-Washita limestone; the Upper Cretaceous Tuscaloosa sandstone, Austin sandstone and chalk, Taylor chalk and sandstone, Navarro sandstone and Monroe gas rock chalk; and Lower Tertiary Wilcox sandstone. 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, James limestone, Rodessa sandstone, Mooringsport sandstone, Paluxy sandstone, and Dantzler sandstone; the Upper Cretaceous

Tuscaloosa sandstone, Eutaw sandstone, Selma chalk, and Jackson gas rock; and Lower Tertiary Wilcox sandstone. The petroleum reservoirs in the Conecuh Subbasin include the Upper Jurassic Norphlet sandstone, Smackover limestone and dolostone and Haynesville sandstone; Lower Cretaceous Hosston sandstone, Fredericksburg-Washita sandstone and Dantzler sandstone; and Upper Cretaceous Tuscaloosa sandstone. The petroleum reservoirs in the Manila Subbasin include the Upper Jurassic Norphlet sandstone, Smackover limestone and dolostone and Haynesville sandstone and Upper Cretaceous Tuscaloosa sandstone.

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 (Figure 9).

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 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. These features form the majority of the petroleum traps in these basins and subbasins. Anticlinal structures associated with basement paleotopographic highs are also present.

Conclusions

The principal research effort for the first six months of Year 2 of the project has been data compilation and petroleum system identification. Understanding the burial and thermal maturation histories of the strata in the onshore interior salt basins of the North Central and Northeastern Gulf of Mexico areas is critical in petroleum system characterization. The underburden and overburden rocks in these basins and subbasins are a product of their rift-related geohistory.

Petroleum source rock analysis and thermal maturation and hydrocarbon expulsion modeling indicate that the Upper Jurassic Smackover Formation served as an effective regional petroleum source rock in the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin. The 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. Lower Cretaceous lime mudstone was an effective local petroleum source rock in the South Florida Basin, and these rocks were possible source beds in the North Louisiana Salt Basin and Mississippi Interior Salt Basin given the proper organic facies. Uppermost Jurassic strata were effective source rocks in Mexico, and thus, were possible source beds in the North Louisiana Salt Basin given the proper organic facies. Lower Tertiary shale and lignite have been reported to have been source rocks in south Louisiana and southwestern Mississippi, but these 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.

Reservoir rocks in the North Louisiana Salt Basin, Mississippi Interior Salt Basin, Manila Subbasin and Conecuh Subbasin include Jurassic and Cretaceous siliciclastic and carbonate strata. These reservoir rocks include Upper Jurassic Norphlet, Smackover, Haynesville, and Cotton Valley units, Lower Cretaceous Hosston, Sligo, James, Rodessa, Mooringsport, Paluxy, and

Fredericksburg-Washita units, the Upper Cretaceous Tuscaloosa, Eutaw-Austin, Selma-Taylor/Navarro, and Jackson gas rock-Monroe gas rock units, and the Lower Tertiary Wilcox unit.

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

Petroleum traps include structural and combination traps in these basins and subbasins. Halokinesis 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.

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Table 1. Analyses of potential Smackover source rocks, 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	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	0.3	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.

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 x	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	15,00	--	0.05	--	--	--	--	--	--	--	--	--	--	--	--	--	--
735	Cla	Smk	11,15	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	10,98	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	13,48	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	14,24	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	14,59	94.20	0.05	0.03	0.50	--	40	--	--	--	--	--	--	--	--	--	--
1584	Bal	Smk	16,22	--	0.42	--	--	--	--	Am	2	--	--	--	--	--	--	--	--
2075	Bal	Smk	18,33	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	19,86	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	18,47	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	19,40	95.20	0.88	0.03	0.00	--	3	Am	3+	--	--	--	--	--	--	--	--
1460	Esc	Smk	15,30	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	16,00	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	15,32	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	15,63	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	15,61	97.90	0.17	0.04	0.50	411	11	--	--	--	--	--	--	--	--	--	--
1895	Esc	Smk	15,61	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	14,74	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	15,49	18.40	0.17	0.03	0.50	--	11	--	--	24	6	0.40	34.00	1	1	--	--
3402	Esc	Smk	15,51	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	15,30	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	14,91	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.

Table 3. Organic geochemical analyses of core samples, North Louiaiana Salt Basin.

Sample No.	Well	Parish	Depth (feet)	Unit[1]	TOC[2] (%)	T_{max}[3] (ºC)	S1[4] (mg/g)	S2[5] (mg/g)	S3[6] (mg/g)	PI[7]	PC[8]	HI[9]	OI[10]	TAI[11]	Kerogen[12]
1	George Franklin #1	Richland	11,690.50	Smk	0.16	334	0.06	0.08	0.35	0.43	0.00	50	218	3	Am
2	George Franklin #1	Richland	11,770.00	Smk	0.25	344	0.13	0.09	0.16	0.59	0.02	36	64	3	Am
3	Colvin #2	Lincoln	10,856.00	Smk	0.32	333	0.16	0.15	0.38	0.52	0.03	47	119	3	H
4	McGehee #1	Lincoln	13,439.00	Smk	0.78	286	0.20	0.10	1.10	0.67	0.02	13	141	3+	Am/H
5	McGehee #1	Lincoln	13,602.00	Smk	0.38	314	0.09	0.04	0.36	0.69	0.01	11	95	3+	Am/H
6	Bearden #1	Union	10,170.00	Smk	0.14	288	0.11	0.04	0.16	0.73	0.01	29	114	3-	H
7	B-1 Hamiter	Bossier	10,568.00	Smk	0.19	318	0.13	0.06	0.24	0.68	0.02	32	126	3-	H
8	Waller #1	Claiborne	10,390.00	Smk	0.18	323	0.06	0.04	0.48	0.60	0.01	22	267	3-	Am
9	Sherman #1	Claiborne	10,216.00	Smk	0.24	430	0.20	0.14	0.18	0.59	0.03	58	75	3-	Am/H
10	Dillon Heirs	Caddo	7,015.00	CV	0.41	432	0.32	0.35	1.12	0.48	0.05	85	273	2	Am
11	F. Wappler	Caddo	8,683.00	CV	0.75	370	0.17	0.58	0.54	0.23	0.06	77	72	2+	Am
12	F. Wappler	Caddo	8,793.00	CV	0.62	336	0.09	0.05	0.72	0.64	0.01	8	116	2+	Am/H
13	F. Wappler	Caddo	8,801.00	CV	1.80	441	0.30	2.71	0.42	0.10	0.25	151	23	2+	H
14	F. Wappler	Caddo	9,351.00	CV	0.62	375	0.19	0.20	0.60	0.49	0.03	32	97	2+	H
15	L. Enloe	Claiborne	10,714.00	Smk	0.19	308	0.21	0.10	0.94	0.68	0.03	53	495	3-	H/W
16	Bankston	Franklin	14,656.00	CV	0.35	293	0.17	0.09	0.65	0.65	0.02	26	186	3	Am
17	Davis Bros.	Jackson	10,944.00	Boss	0.46	331	0.14	0.12	0.09	0.54	0.02	26	20	3-	H
18	Davis Bros.	Jackson	12,956.00	Boss	0.43	304	0.10	0.08	0.22	0.56	0.01	19	51	3-	H
19	Davis Bros.	Jackson	12,976.00	Boss	0.61	313	0.11	0.07	0.02	0.61	0.01	11	3	3-	H
20	C. Atkins	Natchitoches	11,203.00	GR	0.10	288	0.09	0.03	0.36	0.75	0.01	30	360	3-	Am
21	Huffman-McNeely	Natchitoches	17,480.00	CV	0.11	325	0.06	0.04	0.18	0.60	0.01	36	164	3+	Am
22	J. Bentley	Rapides	12,911.00	Sligo	0.23	365	0.10	0.10	0.23	0.50	0.02	43	100	3-	Am/H
23	J. Bentley	Rapides	12,948.00	Sligo	0.45	408	0.00	0.07	0.35	0.00	0.01	16	78	3-	Am/H
24	Chicago Mill	Tensas	14,876.00	Hoss	1.69	519	0.04	0.09	0.16	0.31	0.01	5	9	3-	H
25	Chicago Mill	Tensas	15,520.00	Hoss	4.09	524	0.04	0.20	0.05	0.17	0.02	5	1	3-	H
26	Chicago Mill	Tensas	15,560.00	Hoss	0.51	333	0.06	0.06	0.07	0.50	0.01	12	14	3-	H
27	N. Manning	Union	16,016.00	p-salt	0.26	311	0.03	0.03	0.15	0.50	0.00	12	58	3	Am
28	N. Manning	Union	16,057.00	p-salt	0.18	252	0.01	0.00	0.29	1.00	0.00	0	161	3+	Am
29	N. Manning	Union	16,074.00	p-salt	0.13	252	0.01	0.00	0.12	1.00	0.00	0	92	3+	Am
30	Frazier Unit	Webster	10,874.00	Smk	0.24	318	0.18	0.13	0.59	0.58	0.03	54	246	3-	H
31	Frazier Unit	Webster	11,250.00	Smk	0.21	411	0.06	0.10	0.24	0.38	0.01	48	114	3-	H
32	H. Davis	Webster	11,043.00	Smk	0.28	380	0.02	0.03	0.15	0.40	0.00	11	54	3	Am/H
33	H. Davis	Webster	11,243.00	Smk	0.16	305	0.01	0.01	0.15	0.50	0.00	6	94	3	Am
34	CZ 10-11	Winn	13,690.00	CV	0.57	276	0.03	0.03	0.22	0.50	0.00	5	39	3+	Am
35	CZ 10-11	Winn	13,804.00	CV	0.47	252	0.03	0.01	0.21	0.75	0.00	2	45	3+	Am/H
36	CZ 10-11	Winn	13,924.00	CV	0.48	252	0.01	0.01	0.02	0.50	0.00	2	4	3+	Am
37	CZ 10-11	Winn	13,946.00	CV	0.30	354	0.03	0.05	0.13	0.38	0.01	17	43	3+	AM/I
38	CZ 5-7	Winn	15,608.00	Boss	0.28	307	0.02	0.04	0.00	0.33	0.00	14	0	3+	I
39	CZ 5-7	Winn	16,418.00	Boss	0.34	355	0.05	0.07	0.11	0.42	0.01	21	32	3+	I
40	CZ 5-7	Winn	16,431.00	Boss	0.34	329	0.06	0.10	0.37	0.38	0.01	29	109	3+	W/I
41	Pardee	Winn	16,200.00	Boss	0.35	322	0.21	0.29	0.29	0.42	0.04	83	83	3+	Am/I
42	Pardee	Winn	16,400.00	Boss	0.35	328	0.19	0.16	0.16	0.54	0.03	46	46	3+	AM/I

[1] Unit: Smk=Smackover, CV=Cotton Valley, Boss=Bossier, GR=Glen Rose, Hoss=Hosston, p-salt=pre-salt.

[2] TOC=total organic carbon.

[3] T_{max}=temperature index.

[4] S1=free hydrocarbon.

[5] S2=residual hydrocarbon potential.

[6] S3=CO_2 produced from kerogen pyrolysis.

[7] PI=S1/ (S1+S2).

[8] PC=0.083 (S1+S2).

[9] HI=hydrogen index.

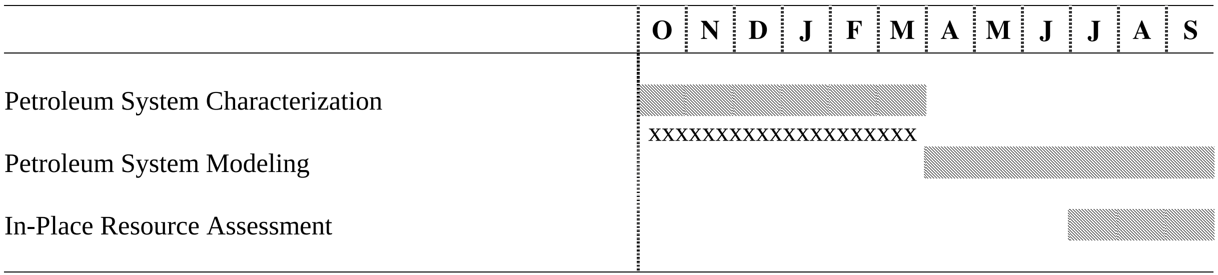
[10] OI=oxygen index.

[11] TAI=thermal alteration index.

[12] Kerogen: AM=amorphous, H=herbaceous, W=woody, I=inertinite.

Table 4

Milestone Chart—Year 2



Work Planned
Work Completed xxx

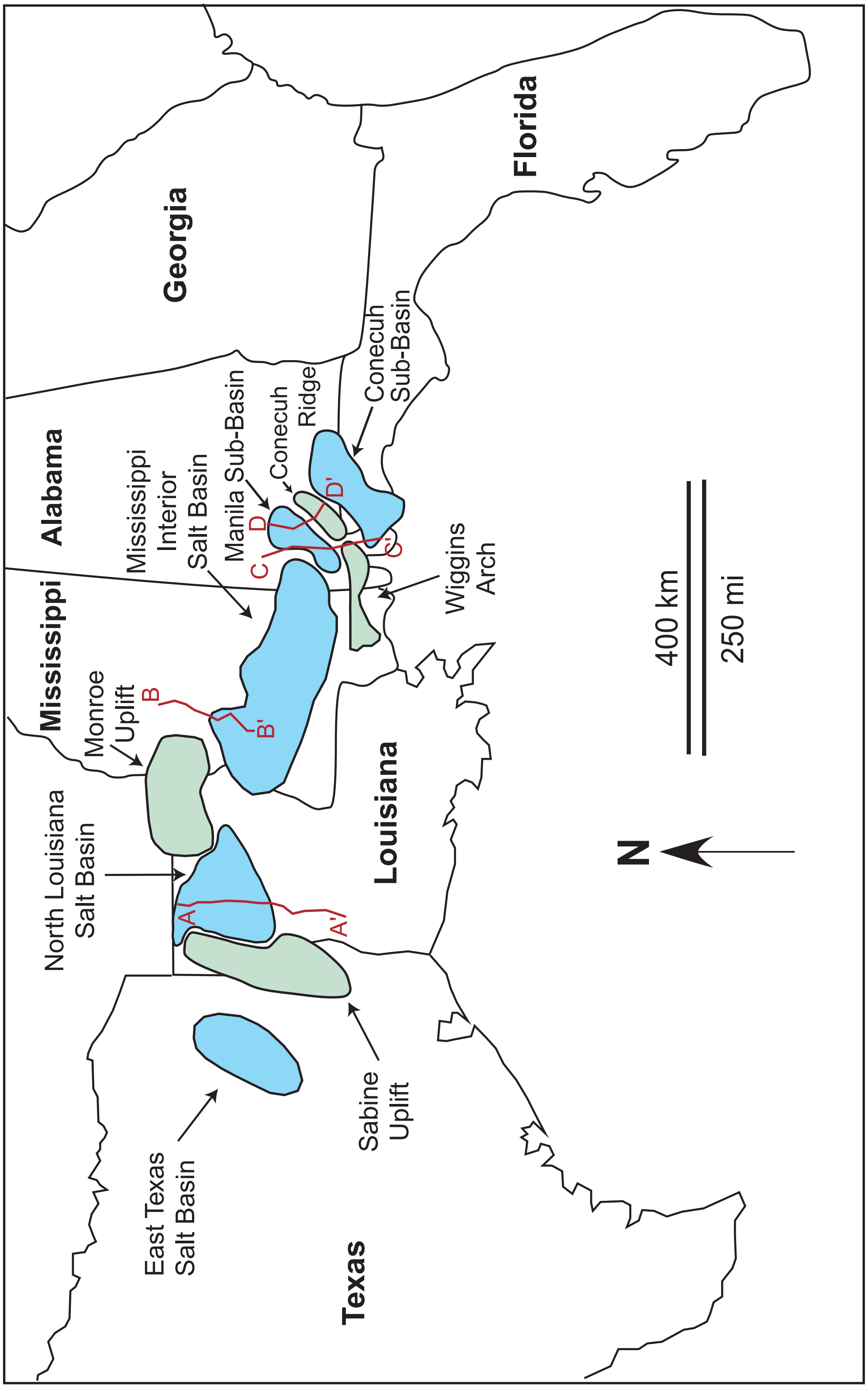


Figure 1. Location map of interior salt basins and subbasins in the north central and northeastern Gulf of Mexico area.

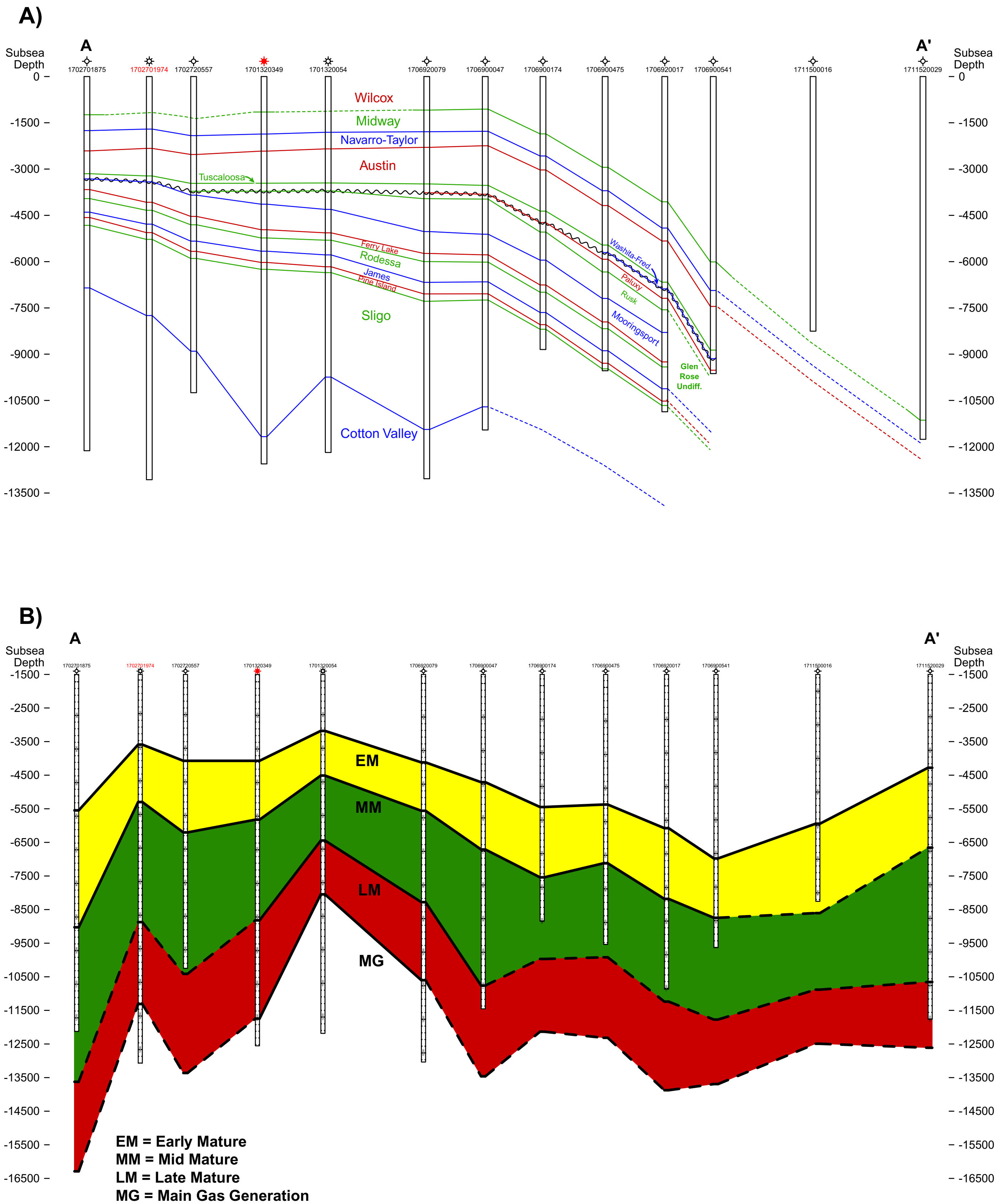


Figure 2. Regional cross section and thermal maturity profile (A-A´) for the North Louisiana Salt Basin: A. Regional cross section and B. Thermal maturity profile at present. See Figure 1 for location of cross section.

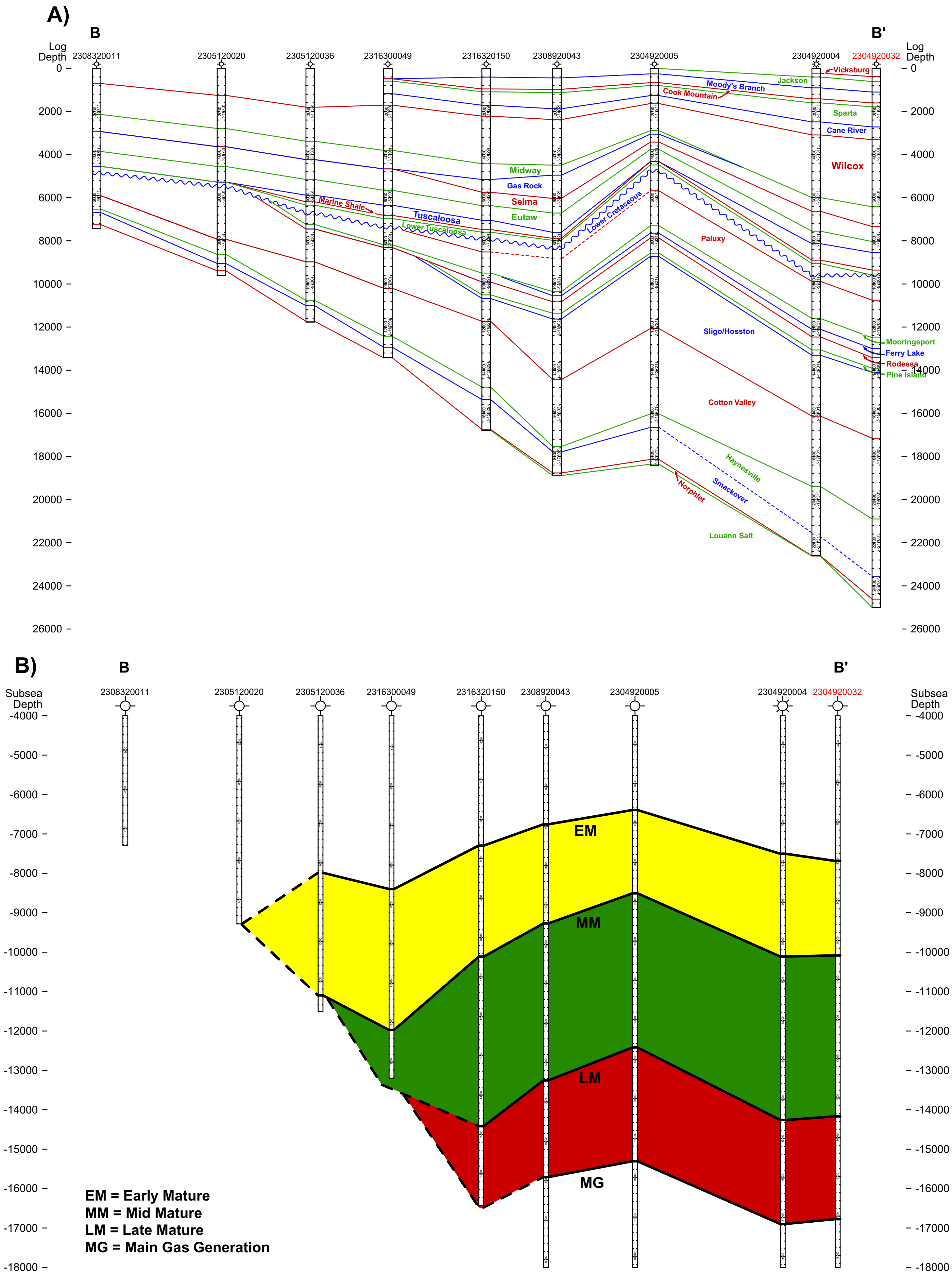


Figure 3. Regional cross section and thermal maturity profile (B-B´) for the Mississippi Interior Salt Basin: A. Regional cross section and B. Thermal maturity profile at present. See Figure 1 for location of cross section.

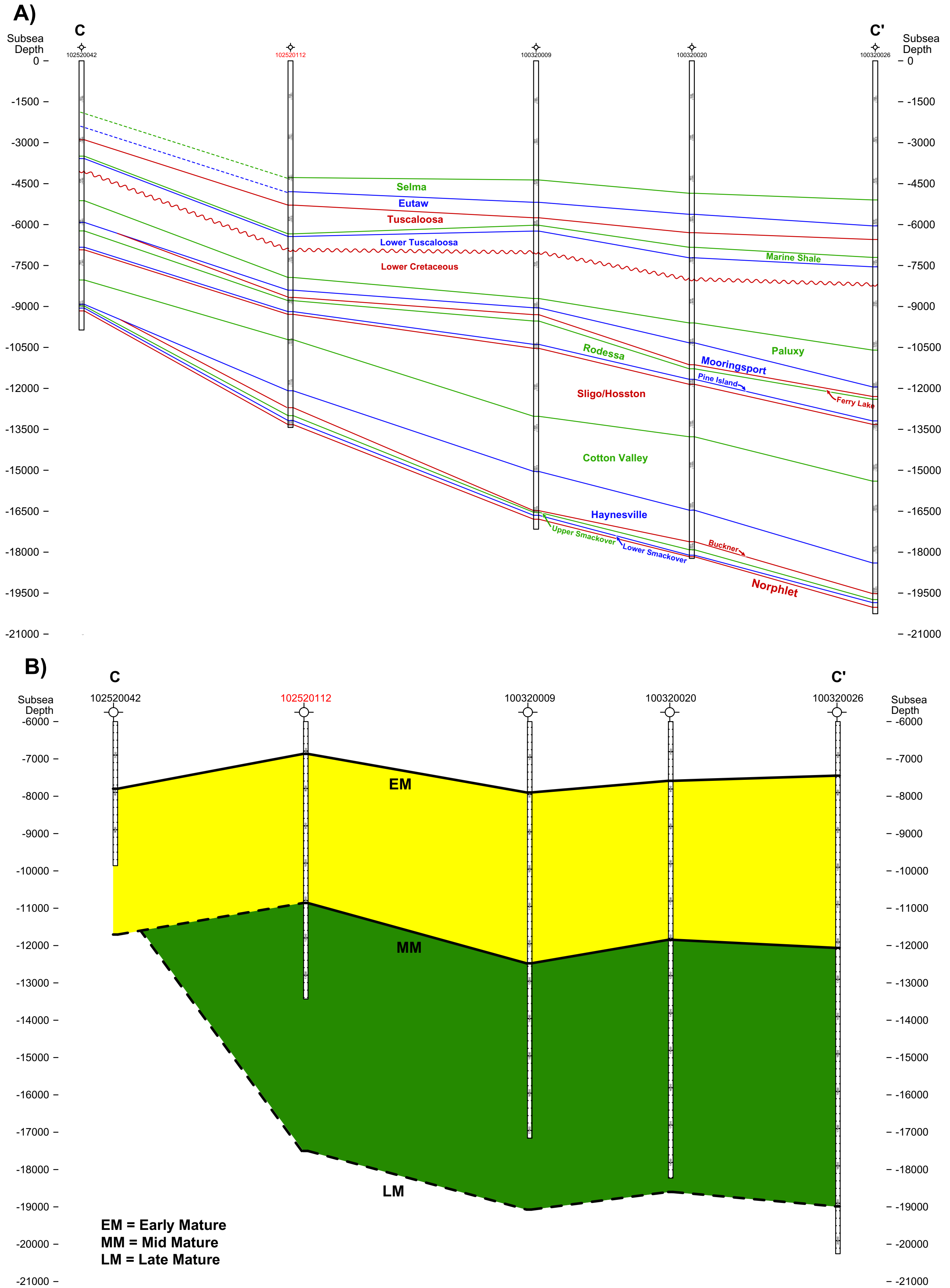


Figure 4. Regional cross section and thermal maturity profile (C-C′) for the Manila Subbasin: A. Regional cross section and B. Thermal maturity profile at present. See Figure 1 for location of cross section.

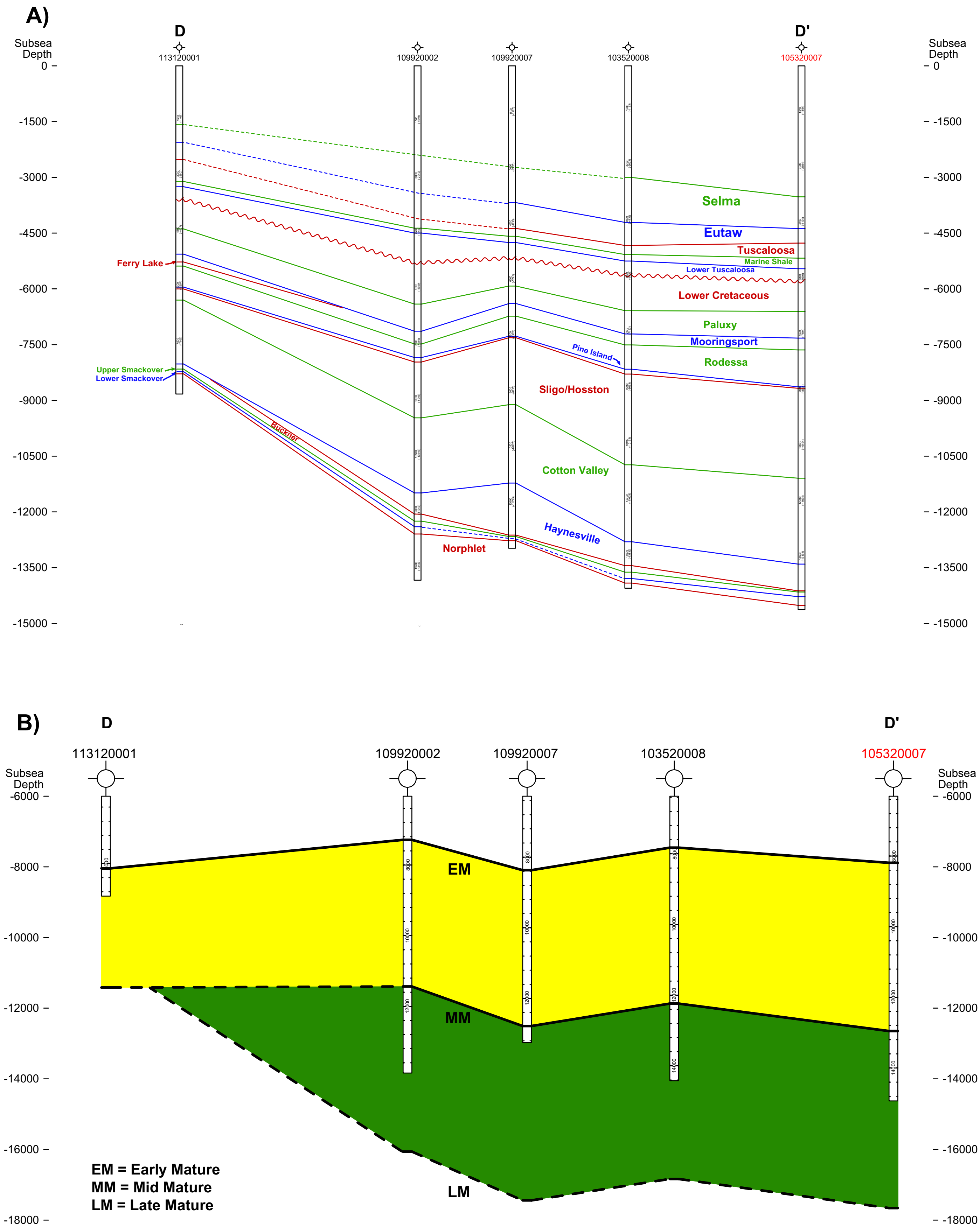


Figure 5. Regional cross section and thermal maturity profile (D-D´) for the Conecuh Subbasin: A. Regional cross section and B. Thermal maturity profile. See Figure 1 for location of cross section.

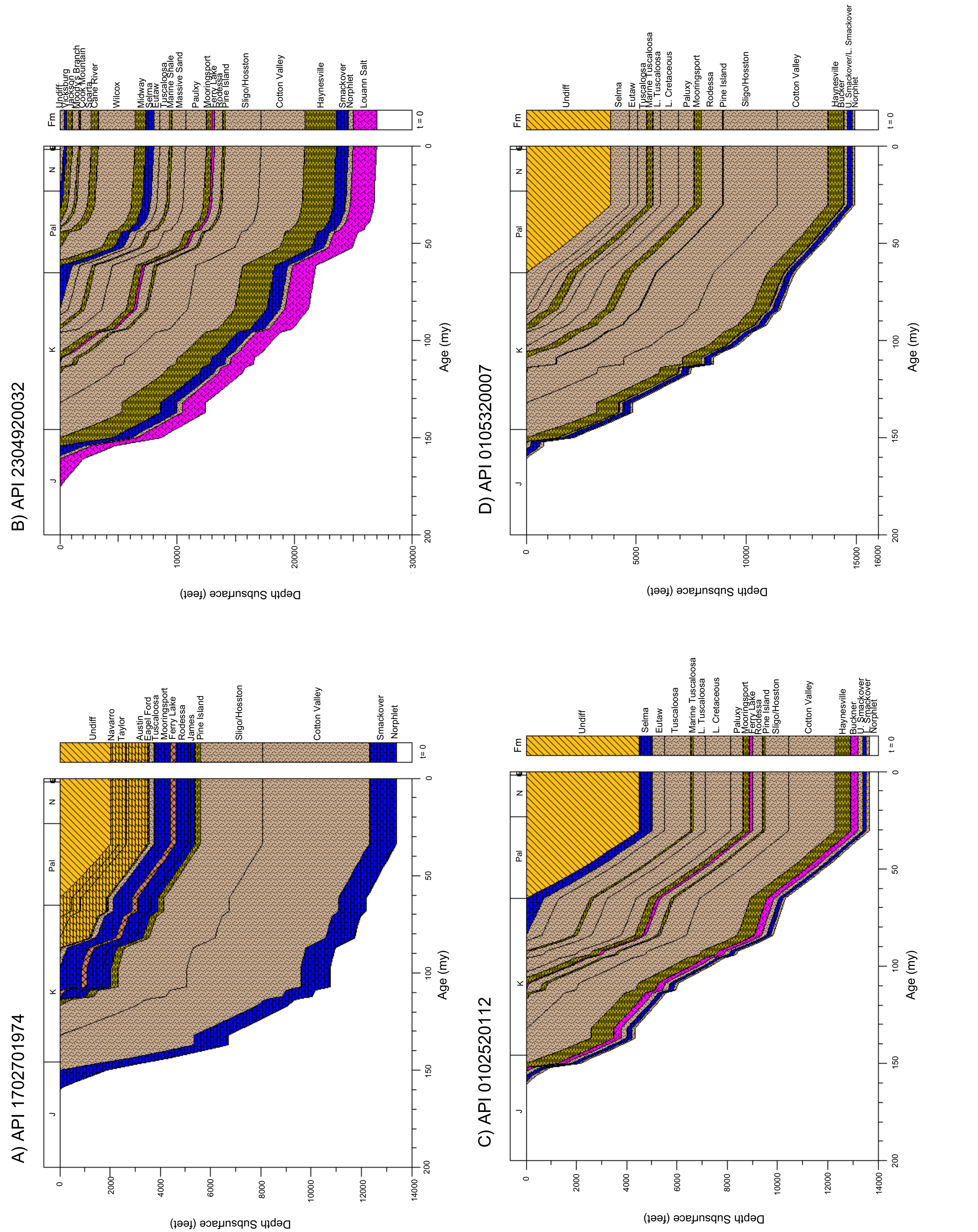


Figure 6. Burial history profiles for wells: A. API Number 1702701974, North Louisiana Salt Basin, B. API Number 23 049 20032, Mississippi Interior Salt Basin, C. API Number 0102520112, Manila Subbasin, and D. API Number 0105320007, Conecuh Subbasin. See Figures 2-5 for location of wells.

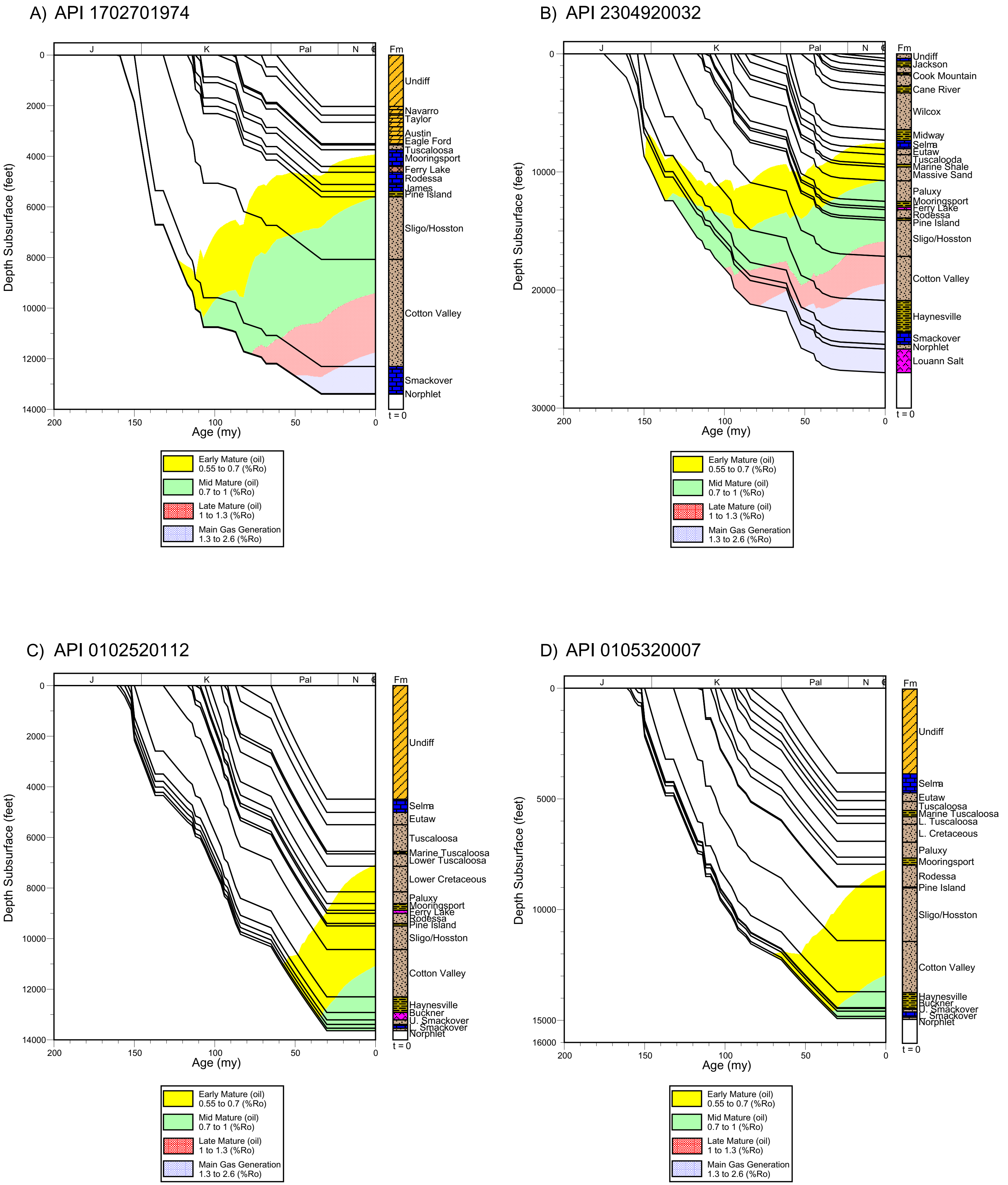


Figure 7. Thermal maturation history profiles for wells: A. API Number 1702701974, North Louisiana Salt Basin, B. API Number 23 049 20032, Mississippi Interior Salt Basin, C. API Number 0102520112, Manila Subbasin, and D. API Number 0105320007, Conecuh Subbasin. See Figures 2-5 for location of wells.

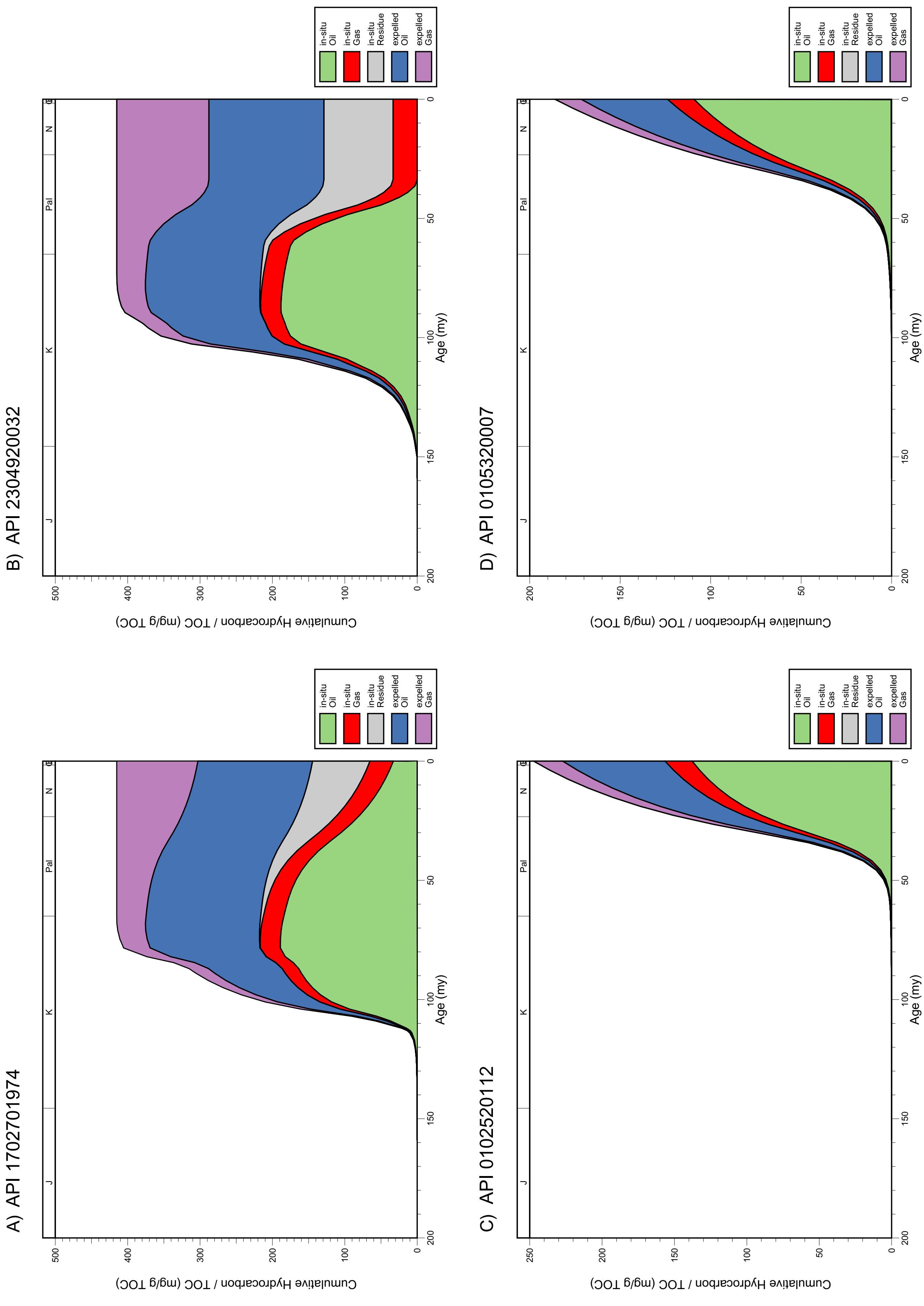


Figure 8. Hydrocarbon expulsion plots for wells: A. API Number 1702701974, North Louisiana Salt Basin, B. API Number 23 049 20032, Mississippi Interior Salt Basin, C. API Number 0102520112, Manila Subbasin, and D. API Number 0105320007, Conecuh Subbasin. See Figures 2-5 for location of wells.

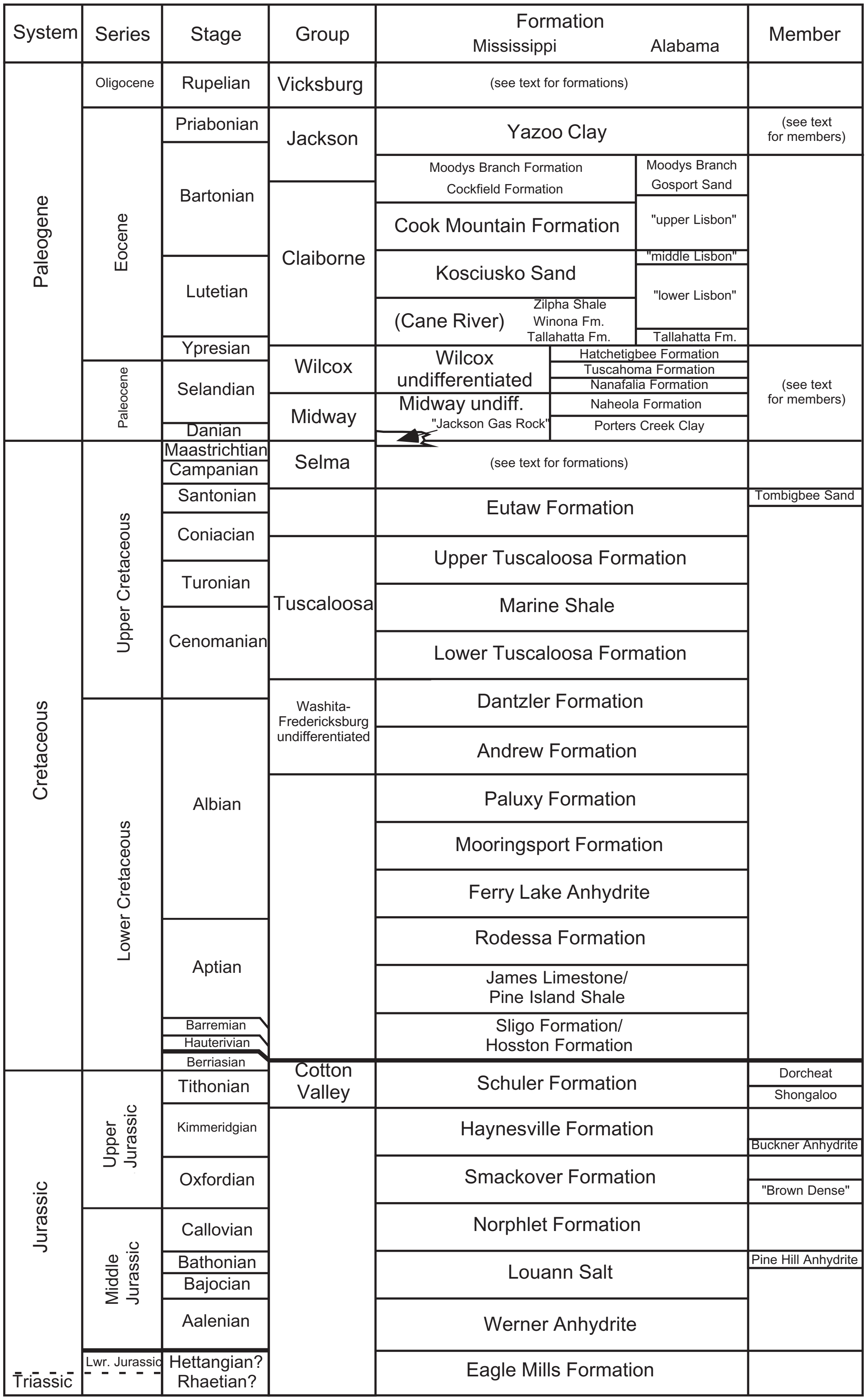


Figure 9. Stratigraphy for the north central and northeastern Gulf of Mexico area.

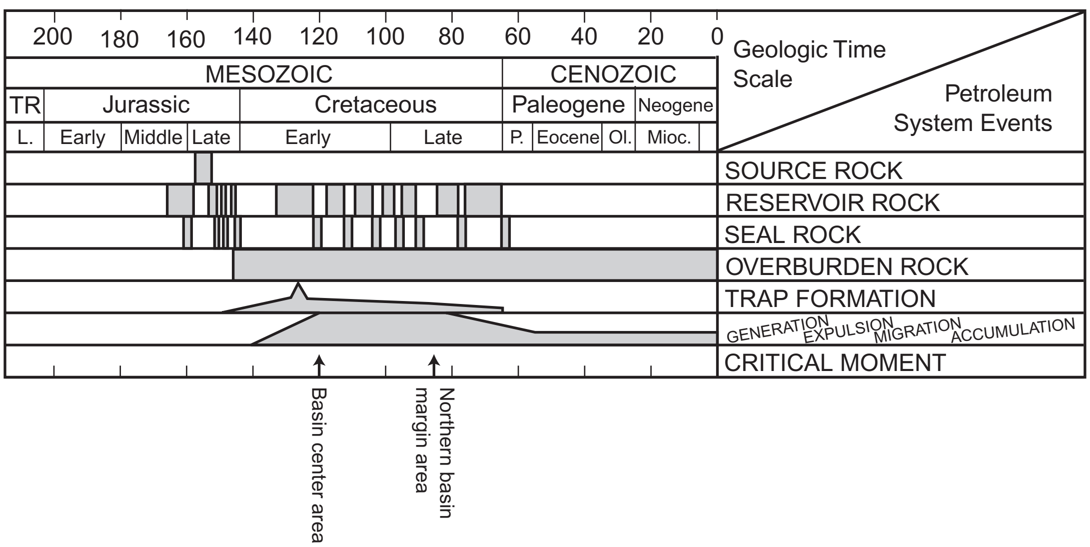


Figure 10. Event chart for Smackover petroleum system, North Louisiana and Mississippi Interior Salt Basins.

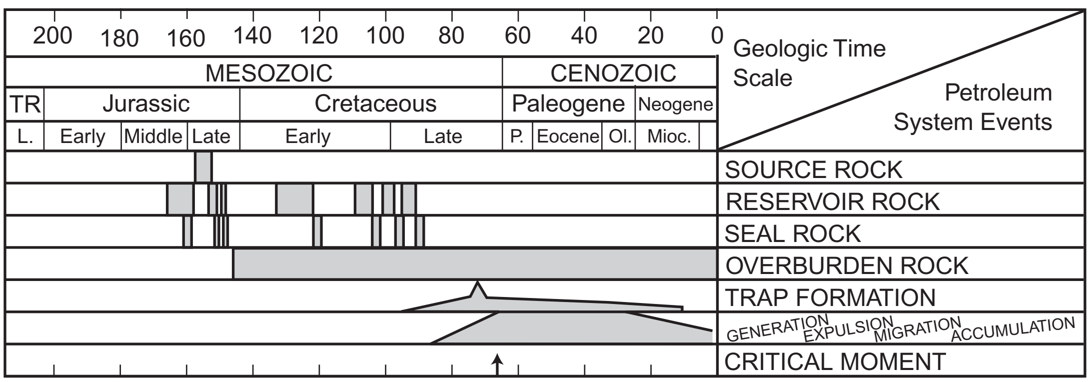


Figure 11. Event chart for Smackover petroleum system, Manila and Conecuh Subbasins.