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Geologic Assessment of Undiscovered Conventional Oil and Gas Resources in the Albian Clastic and Updip Albian Clastic Assessment Units, U.S. Gulf Coast Region

Open-File Report 2016–1026

U.S. Department of the Interior
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Abbreviations

AU	Assessment Unit
BCFG	Billion cubic feet of gas
CFG/BO	Cubic feet of gas per barrel of oil
F	Fractile, in percent
Ma	Mega-annum, or millions of years before present
mD	Millidarcies
MMBNGL	Million barrels of natural gas liquids
MMBO	Million barrels of oil
n	Size of sample set
NGL	Natural gas liquids
NOGA	National Oil and Gas Assessment
R_o	Vitrinite reflectance, in percent
TOC	Total organic carbon
TPS	Total Petroleum System
USGS	U.S. Geological Survey

Geologic Assessment of Undiscovered Conventional Oil and Gas Resources in the Albian Clastic and Updip Albian Clastic Assessment Units, U.S. Gulf Coast Region

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Abstract

U.S. Geological Survey National Oil and Gas Assessments (NOGA) of Albian aged clastic reservoirs in the U.S. Gulf Coast region indicate a relatively low prospectivity for undiscovered hydrocarbon resources due to high levels of past production and exploration. Evaluation of two assessment units (AUs), (1) the Albian Clastic AU 50490125, and (2) the Updip Albian Clastic AU 50490126, were based on a geologic model incorporating consideration of source rock, thermal maturity, migration, events timing, depositional environments, reservoir rock characteristics, and production analyses built on well and field-level production histories. The Albian Clastic AU is a mature conventional hydrocarbon prospect with undiscovered accumulations probably restricted to small faulted and salt-associated structural traps that could be revealed using high resolution subsurface imaging and from targeting structures at increased drilling depths that were unproductive at shallower intervals. Mean undiscovered accumulation volumes from the probabilistic assessment are 37 million barrels of oil (MMBO), 152 billion cubic feet of gas (BCFG), and 4 million barrels of natural gas liquids (MMBNGL). Limited exploration of the Updip Albian Clastic AU reflects a paucity of hydrocarbon discoveries updip of the periphery fault zones in the northern Gulf Coastal region. Restricted migration across fault zones is a major factor behind the small discovered fields and estimation of undiscovered resources in the AU. Mean undiscovered accumulation volumes from the probabilistic assessment are 1 MMBO and 5 BCFG for the Updip Albian Clastic AU.

Introduction

The U.S. Geological Survey (USGS) National Oil and Gas Assessment (NOGA) for the U.S. Gulf Coast region includes the States of Texas, Louisiana, Mississippi, Alabama, and parts of Arkansas and Florida. Assessments have been conducted in multiple stages grouped by the age of the geologic formations investigated. The Jurassic and Cretaceous NOGA for the Gulf Coast region contains 24 conventional and 10 continuous resource assessment units (AUs) (Dubiel and others, 2011). This report focuses on an estimate of undiscovered oil and gas resources in conventional sand and siltstone reservoirs of Lower Cretaceous Albian age, approximately 97.5 to 113 Ma (mega-annum) (Salvador and Quezada Muñeton, 1991). The USGS NOGA team employs a probabilistic assessment methodology discussed in Charpentier and Klett (2005), Klett and Schmoker (2005), and Schmoker and Klett (2005), based on the total petroleum system (TPS) framework of Magoon and Dow (1994). Previous USGS assessments of the entire U.S. Gulf Coast region were completed in 1995 (Schenk and Viger, 1995a,b; U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995). This report is an update to the 1995 assessment where five plays described clastic units in the Albian formations; they were the following: (1) Glen Rose/Rodessa Updip Oil 4932, (2) Glen Rose/Rodessa Salt Basin Gas 4933, (3) Paluxy Updip Oil 4934, (4) Paluxy Downdip Gas 4935, and to some extent (5) Salt Domes 4901 (Schenk and Viger, 1995a,b).

This report discusses the USGS NOGA results for two Albian clastic AUs and the use of exploration history, geologic models, and reservoir properties to populate the inputs used in probabilistic assessment calculations. The Albian Clastic Assessment Unit (50490125) consists of Early Cretaceous late Aptian to Albian clastic rocks that include the Washita and Fredericksburg Groups and the Rodessa, Rusk, Mooringsport, Paluxy, Dantzler, and their equivalent formations (fig. 1). These rocks are generally associated with updip regions of the northern Gulf Coastal plain as well as regressive infilling fluvial facies (Mancini and others, 2008). Petroleum production is primarily from porous sands in structural and stratigraphic combination traps associated with salt bodies and stratigraphic traps along updip fault zone grabens.

The Updip Albian Clastic Assessment Unit (50490126) consists of the same reservoir formations as the Albian Clastic AU. These rocks occupy the Gulf Coastal plain updip of the Mexia, Talco, Southern Arkansas, Pickens, Quitman, and Gilbertown fault zones that approximately indicate the landward limit of Jurassic Louann Salt in the Gulf Coastal plain subsurface. Though stratigraphic traps are present, a potential absence of mature source rocks and restricted updip hydrocarbon migration across the major fault zones has limited production of hydrocarbons (Hager and Burnett, 1960).

Total Petroleum System Framework

Discussion of the geology, production history, and assessed undiscovered hydrocarbon resources of the Albian Clastic AUs is presented within the conceptual framework of the TPS (Magoon and Dow, 1994). A TPS is a mappable entity encompassing genetically-related petroleum accumulations that were generated by one or many related pods of mature source rock. The TPS includes all of the geologic elements related to the processes of generation, migration, entrapment, and preservation of petroleum. Within this framework exists individual AUs; these are known or postulated oil and gas accumulations sharing common geologic properties such as source rock, migration pathway, timing, trapping mechanism, and hydrocarbon type, all occurring within the TPS boundary (Magoon and Dow, 1994).

Data Sources

Hydrocarbon exploration in the U.S. Gulf Coast region has a long and prolific history that has produced significant amounts of primary geologic data. Well data and production information from commercial proprietary databases (Nehring Associates, Inc., 2009; IHS Energy Group, 2009a,b) were primary sources of assessment data used herein. Well-level information such as production, depths, and locations, are primarily from IHS Energy Group (2009a,b), but are also from previously published materials used to perform mapping analyses of subsurface extent, depth, and thickness for the AUs. Summarized reservoir level production histories from Nehring Associates, Inc. (2009), and supplemented by IHS Energy Group (2009a,b) well production and wildcat drilling data, were the major source of oil and gas production data for discovery analysis. Depositional environment and facies analysis by Nunnally and Fowler (1954), Forgotson (1963), and Mancini and Puckett (2000) were essential to the development of the geologic model employed in this assessment. Thermal maturation analyses based on vitrinite reflectance, total organic carbon content, and modeling studies from Oehler (1984), Sassen and Moore (1988), Claypool and Mancini (1989), Wescott and Hood (1994), Lewan (2002), and Hood and others (2002), provided essential timing information required by the TPS-based assessment method.

Upper Jurassic-Cretaceous-Tertiary Composite Total Petroleum System

The Upper Jurassic-Cretaceous-Tertiary Composite TPS is a composite of multiple TPSs that together encompass source rock, migration paths, traps, and reservoir formations for discovered and undiscovered oil and gas accumulations in the Gulf of Mexico Basin (Warwick and others, 2007). All resources in the Albian Clastic and Updip Albian Clastic Assessment Units are part of this composite TPS. USGS NOGA assessments determine undiscovered resources within the onshore and State Waters areas; Federal offshore areas are not included in this assessment. However, this political distinction does not affect the geology-based TPS boundary that extends into various Federal and international territories to the south. The northern Gulf Coastal region including The Upper Jurassic-Cretaceous-Tertiary Composite TPS boundary and the U.S. onshore and State Waters portion of the TPS are shown in figure 2.

Source Rocks

The Upper Jurassic-Cretaceous-Tertiary Composite TPS contains multiple source rocks for hydrocarbons present in the Mesozoic and Tertiary reservoirs (fig. 3). Three of the major source rock intervals are (1) Upper Jurassic Smackover Formation, (2) Upper Cretaceous Eagle Ford/Woodbine/Tuscaloosa Formations, and (3) the Eocene Wilcox and Claiborne Formations (Hood and others, 2002; Evans, 1987; Wescott and Hood, 1994; Sassen and Moore, 1988; Lewan, 2002). There is disagreement on specific source intervals, methods of identification, and spatial distribution within the basin; however, it is clear that there are multiple source intervals in the TPS that have generated the hydrocarbons found in the Gulf of Mexico Basin. Specific discussion of the sources of hydrocarbon reservoirs in Albian clastic AUs is provided later in this report.

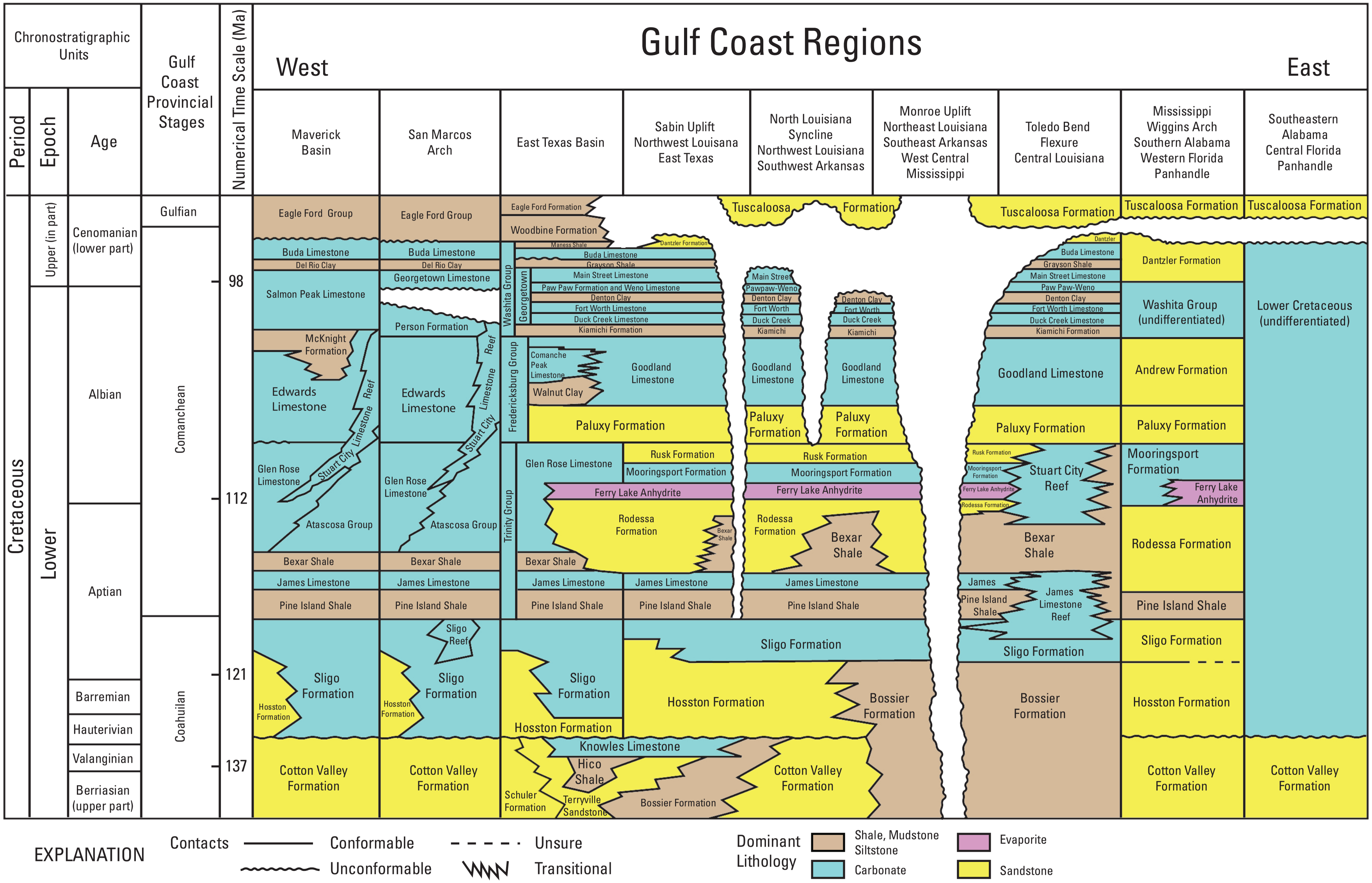

Figure 1. Stratigraphic column for the U.S. Gulf Coast region. Formations assessed in this report are located on this stratigraphic column; however, not all member names from the text are labeled here. The figure is based on the American Association of Petroleum Geologists Gulf Coast regional correlation chart (2002), and modified with information from Ambrose and others (2009); Anderson (1980); Anderson (1989); Chenault and Lambert (2005); Mancini and others (2008); Salvador (1991); Salvador and Quezada Muñeton (1991); Smith and others, (2000); and Zahm and others (1995).

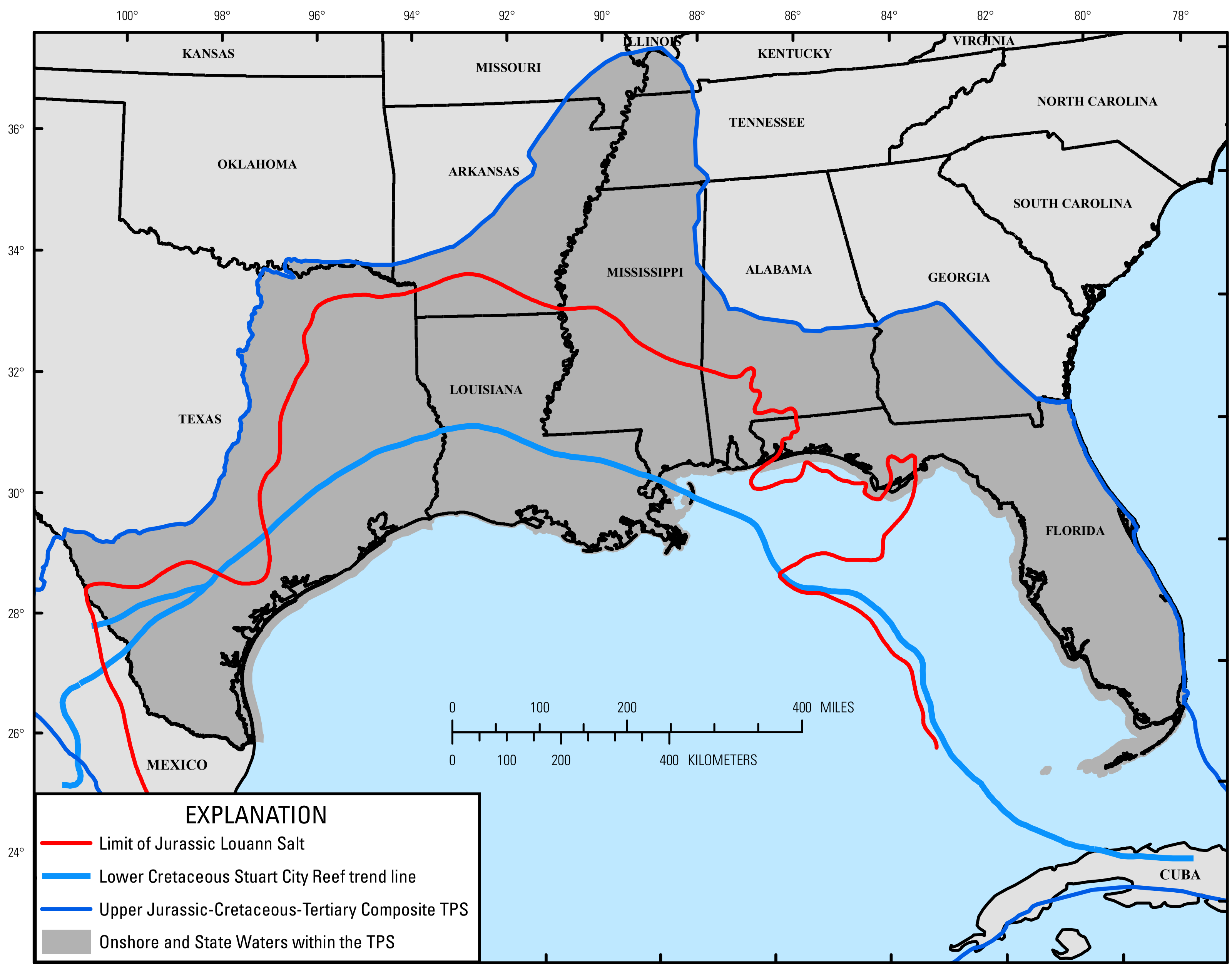

Figure 2. Map showing the boundaries of the Upper Jurassic-Cretaceous-Tertiary Composite TPS (Warwick and others, 2007) in the U.S. Gulf Coast region and the onshore and State Waters area within the purview of this assessment. The updip extent of Jurassic Louann Salt and the Stuart City Reef trend are from Ewing and Lopez (1991).

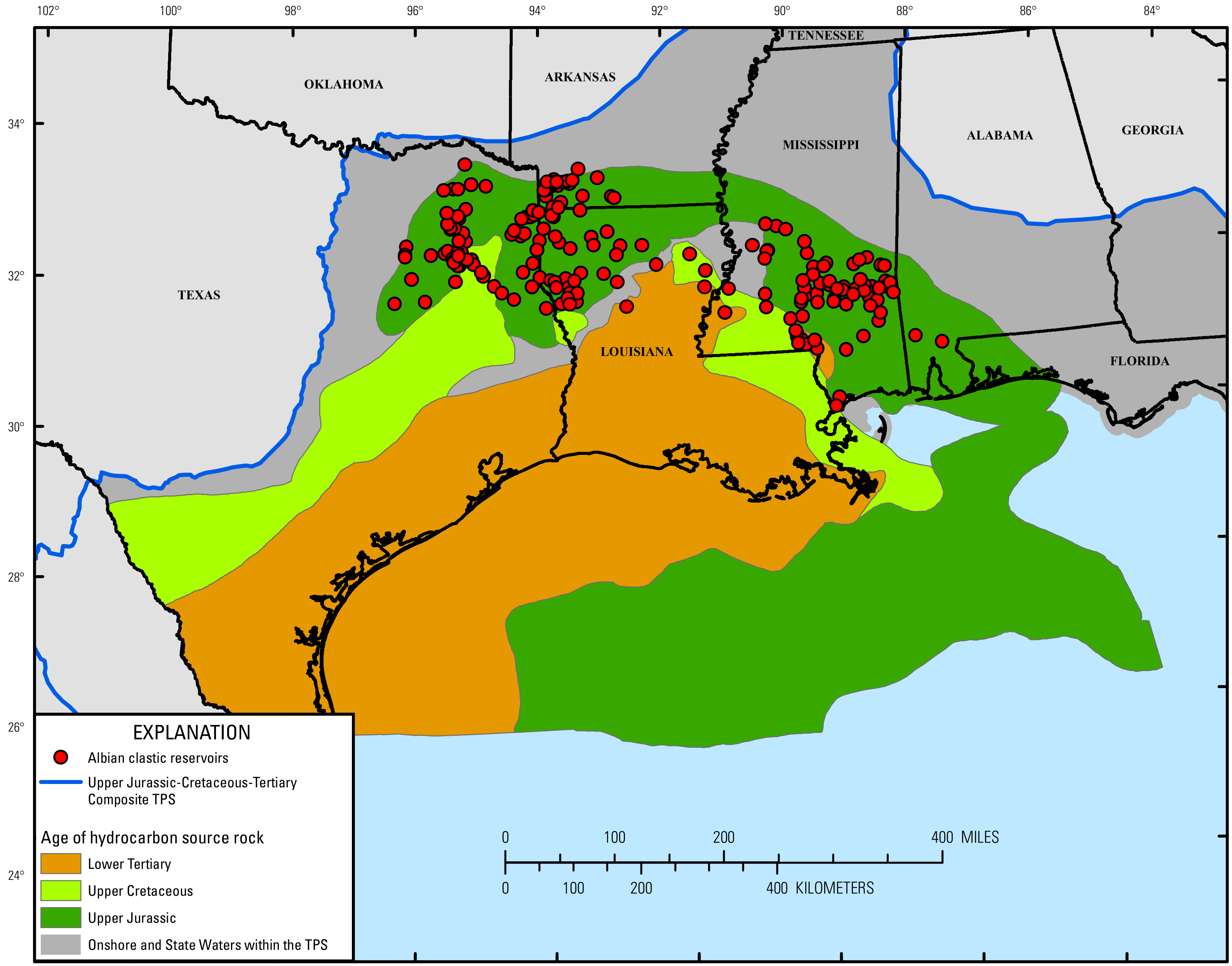

Figure 3. Map showing reservoir oil age across the U.S. Gulf Coast region modified and generalized from Hood and others (2002). Red colored points indicate the approximate locations of Albian age clastic reservoirs (Nehring Associates, Inc., 2009). Upper Jurassic-Cretaceous-Tertiary Composite TPS from Warwick and others (2007).

Albian Clastic Reservoir Rocks

The Albian age clastic reservoir rocks described in this chapter refer specifically to formation and member-level sand and silt lithologies dominant within the Lower Cretaceous section, from the latest Aptian through Albian. These include the Washita and Fredericksburg Groups, and Rodessa, Rusk, Mooringsport, Paluxy, Dantzler, and equivalent formations (fig. 1). A representative cross section through southwestern Arkansas to northwestern Louisiana modified from Stoudt and others (1990) shows the stratigraphic relationship between Albian clastic formations (fig. 4).

Depositional Environment

The Early Cretaceous in the Gulf of Mexico Basin was a time of relative tectonic calm as post Pangaean rifting of the basin during the early Mesozoic had ceased (Yurewicz and others, 1993). Transgression and regression of sea level, and to a lesser extent, surface changes caused by Jurassic Louann Salt movement were the dominant forces behind depositional patterns across the basin during this time. Detailed facies analysis of outcrops in northeast Texas, and well log and core interpretation from Louisiana and Mississippi, provided the majority of published information for Albian clastic depositional environments. Clastic sediments from the Rodessa through Washita and Fredericksburg Groups were sourced predominantly from the Ouachita-Arbuckle Mountains and Appalachian Mountains, generally in the eastern U.S. Gulf Coast region, with lesser material coming from the Texas highlands (Caughey, 1977; Seni, 1981). During this period, much of what is currently eastern and southern Texas was a large stable carbonate shelf with limited clastic deposition; the exception is the Paluxy Formation, a progradational sandy unit sourced from the north (Forgotson, 1963).

Rodessa Formation

During latest Aptian and early Albian time, Rodessa Formation sediments were deposited in a basinward thickening wedge (Forgotson, 1963). Eastern sourced fluvial and nearshore shallow marine coarse clastics and red silts are found in eastern Louisiana, Mississippi, and Alabama. In the west, where the Rodessa is referred to as the Lower Glen Rose Formation, a restricted marine stable shelf with low clastic input favored carbonate deposition with pulses of land-derived clay-rich sediments (Pittman, 1985). The varied lithologies of the Rodessa Formation lend themselves to numerous location-specific member names. On the Sabine Uplift and East Texas Basin, named subsurface clastic members within the Rodessa include the Hill, Gloyd, Dees, Kilpatrick, Young, and Jeter Sands, all with specific localized characteristics (Kitchens, 1950; Howard, 1951; Berryhill and others, 1968). With the exception of the discussion in the reservoir characteristics section of this report, members of this formation are referred to as Rodessa.

Rusk Formation

The Rusk (or Mooringsport) Formation was deposited after the Ferry Lake Anhydrite, a Rodessa shelf lagoon evaporite that formed after high salinities and restricted circulation led to gypsum precipitation (Pittman, 1985; Petty, 1995). The western edge of Rusk deposition is mostly carbonate, the northern edge includes shallow marine sand and shales, while to the east in Mississippi and Alabama, fluvial and deltaic clastics prograded basinward towards the end of the period of Rusk deposition (Forgotson, 1963). According to Forgotson (1963), the lack of variation in beds in the central area of Rusk deposition around northeast Texas and northwest Louisiana suggested a calm, offshore neritic environment.

Paluxy Formation

Across the U.S. Gulf Coast region, the Paluxy Sandstone is recognized as a progradational sand associated with fluvial and marginal marine depositional environments (Caughey, 1977; Mancini and Puckett, 2000). In the East Texas Basin, a northern fluvial system, a central deltaic system, and a western strandplain system are described by Caughey (1977). Mancini and Puckett (2000) interpreted the Paluxy and underlying Rusk in the Mississippi Interior Salt Basin as a single highstand systems tract deposit, with continuous deposition where sediment supply outpaced relative sea level rise.

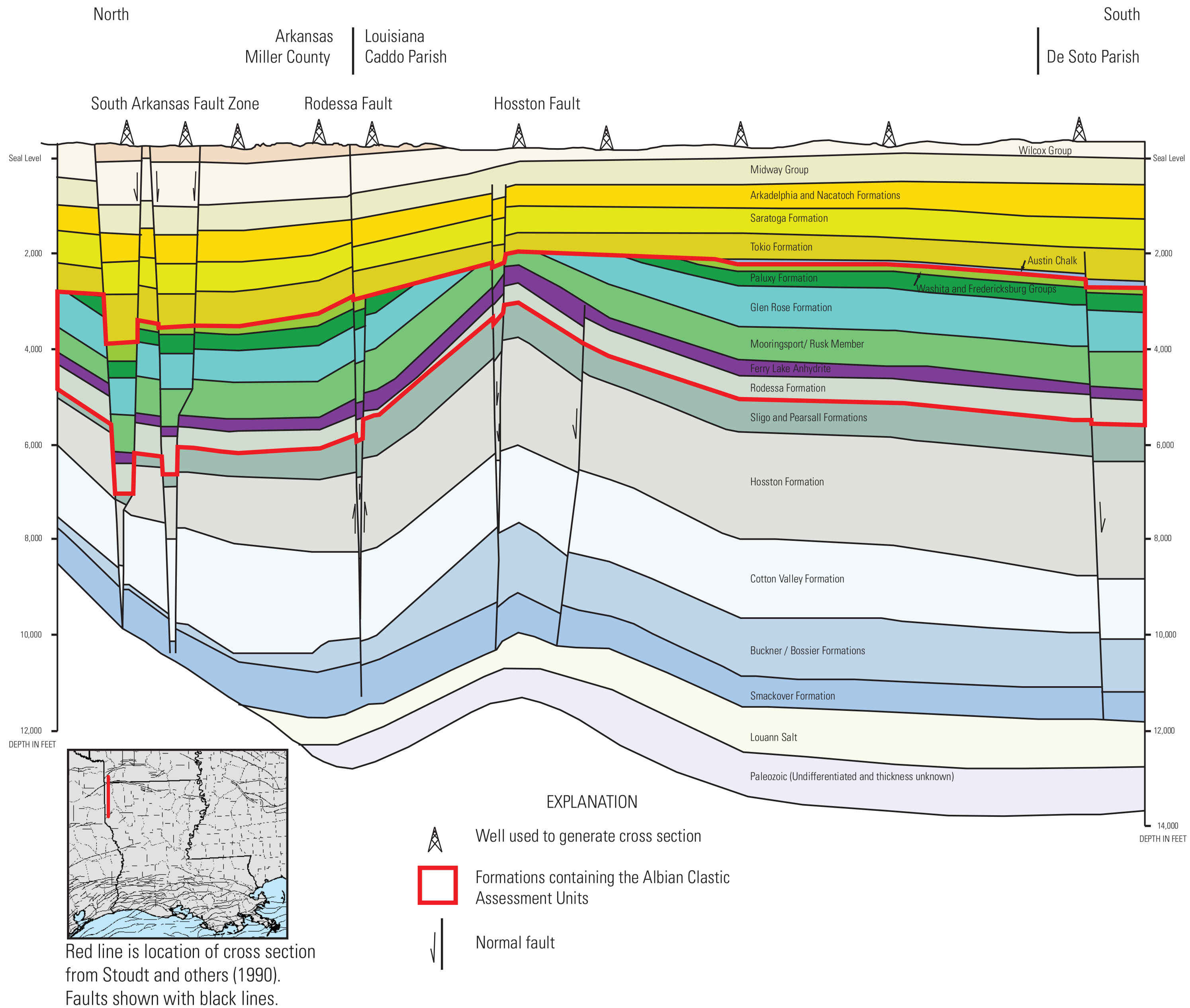

Figure 4. A representative north to south cross section of Jurassic, Cretaceous, and Tertiary formations from southwestern Arkansas to northwestern Louisiana. Generalized and modified from Stoudt and others (1990). The red outline shows formations included in this chapter.

Washita and Fredericksburg Groups

In the western U.S. Gulf Coast region, the Washita and Fredericksburg Groups are generally lagoon carbonates; however, to the east they include a full range of limestones, shales, mudstones, and sands (Nunnally and Fowler, 1954). Sands increase upsection, the sand-rich Washita and Fredericksburg section is called the Dantzler Formation in Mississippi. Mancini and Puckett (2000) viewed the Dantzler as the highstand systems tract for a depositional sequence beginning on top of the Paluxy and including the entire undifferentiated Washita and Fredericksburg section.

Reservoir Rock Characterization

Rodessa Formation

The Rodessa Formation contains various trangressive and regressive lithologies ranging from shale and limestone, to siltstone and sandstone. In Mississippi, Devery (1982) described the Rodessa as red and gray shale; white, fine-grained sandstone; and light-gray limestone. To the south, lithology changes to dark-gray, oolitic limestone; gray shale; and anhydrite stringer. Local and regional member names based on geologic characteristics differentiate the various reservoirs. At the base of the formation, the Dees Sand is deposited amongst limestones that are also productive; the sand is 0 to 50 feet thick with an average productive interval of 20 feet at the Rodessa Field on the northern edge of the Sabine Uplift (Howard, 1951). The Gloyd, the next member up section, exhibits three units; the upper and lower of which are limestones, while the middle unit, often called the Mitchell, is a sand and shale with average net sand pay thickness of 20 to 30 feet (Kitchens, 1950; Howard, 1951). Other sandstones, such as the Hill and Neugent, are composed of fine sands and shales and have net pays around 10 feet locally on the Sabine Uplift. Over all, in 100 Rodessa clastic reservoirs evaluated in this study, average porosity was 17.5 percent and permeability averaged 159 millidarcies (mD) (Nehring Associates, Inc., 2009).

Rusk Formation

In central Texas, Rusk-Mooringsport depositional time favored a lagoon type carbonate depositional environment; across the western U.S. Gulf Coast region carbonate facies from this time are called the Upper Glen Rose Formation. To the east, the Rusk and Mooringsport are similar to the Rodessa, a mix of red and gray shale, fine-grained sandstone, and some varicolored mudstone with red and white limestone nodules. To the south, carbonate and shale increase (Devery, 1982). Nehring Associates, Inc. (2009) reported 17 Rusk and Mooringsport reservoirs containing greater than 0.5 MMBO oil (or greater than 3 BCFG gas), the minimum size considered in USGS assessments, with average porosity of 17 percent and permeability of 110 mD similar to the Rodessa, and net pay thickness averaging 20 feet.

Paluxy Formation

In the Mississippi Salt Basin, the Paluxy consists of fine-to coarse-grained micaceous sandstone interbedded with calcareous shale. Generally, the middle section contains mostly sand, while the upper and lower sections contain abundant shale (Mancini and Puckett, 2000). Nunnally and Fowler (1954) noted that recognition of the Paluxy interval in central Mississippi is difficult due to the numerous sands in the Rusk and Rodessa up and down section of the Paluxy, but recognition is facilitated to the south by the transition of Rusk and Rodessa sands to carbonate and shale facies while the Paluxy Sandstone is still present. Structure on top of the Paluxy Formation shows its relatively shallow depth in many of the major basins and uplifts of the U.S. Gulf Coast region (fig. 5) and rapid deepening to the south. Paluxy reservoir properties are favorable to conventional production with average porosities of 21 percent and permeabilities of 559 mD (n=116) (Nehring Associates, Inc., 2009). Gross formation thickness in east Texas and the Sabine Uplift area averages 400 feet (Rogers, 1968; Seni, 1981; Amis, 1950), while in the Mississippi Interior Salt Basin thicknesses around 1,000 feet are common (Mancini and others, 2008). Nunnally and Fowler (1954) cited maximum thicknesses of 1,448 feet in Forrest County, Mississippi, at depths of 12,000 feet. Producing sands in the Paluxy are often limited to one or two local intervals; average thicknesses of individual pay sands range from 10 to 50 feet, with an overall average of 30 feet (Amis, 1950; Kitchens, 1950; Balkey, 1989; Griffin, 1989; Nehring Associates, Inc., 2009).

Washita and Fredericksburg Groups

Similarly to the Rusk Formation, the Washita and Fredericksburg units are predominantly limestones in the west and clastics and shales in the east. All major clastic fields in the Washita and Fredericksburg Groups reservoirs are located in the central to northern Mississippi Interior Salt Basin (Nehring Associates, Inc., 2009). Dantzler Formation rocks are uppermost Washita Group in age and consist of micaceous and carbonaceous, red to gray and light-green sandstones. They are medium to very fine grained with varying porosity (Nunnally and Fowler, 1954). The Washita and Fredericksburg Groups and Dantzler Formation reservoirs average 18 percent porosity and 190 mD permeability and have an average reservoir pay thickness of 25 feet (n=34) (Nehring Associates, Inc., 2009).

Total Petroleum System Elements of the Albian Clastic Reservoirs

Source Rock and Thermal Maturity

Previous thermal modeling and geochemical studies indicate that the Jurassic Smackover Formation is the main source of hydrocarbons found in Albian and most other Lower Cretaceous reservoirs across the northern Gulf. The Smackover Formation consists of intertidal to subtidal ramp carbonates such as carbonaceous mudstones, ooids, wackstones, packstones, and grainstones deposited during a major Jurassic marine transgression in the Gulf (Mancini and others, 1999). Sassen and others (1987) cited carbon isotopic evidence linking crude oil in the Mississippi Interior Salt Basin to laminated lime mudstones in the Upper Smackover Formation. Monroe Uplift gas has been suggested to be sourced by the Smackover Formation (Zimmerman and Sassen, 1993) and also the Tuscaloosa Formation (Evans, 1987).

Thermal maturity modeling by Wescott and Hood (1994) in the East Texas Basin and by Lewan (2002) across the U.S. Gulf Coast region demonstrated that Jurassic source rocks are mature throughout, Lower Cretaceous rocks are mature in localized areas, and Upper Cretaceous Turonian rocks are generally immature except in the southern part of the U.S. Gulf Coast region far from current Albian production. According to Lewan (2002), burial history curve modeling using hydrous-pyrolysis kinetic parameters suggested that in the updip “interior” basin Smackover rocks generated oil from 121 to 99 Ma while Upper Cretaceous Turonian rocks have generated negligible oil. In the down dip modern day onshore coastal area of the basin, Smackover oil generation began later, occurring from 94 to 76 Ma, and Turonian source rocks generated oil from 35 to 21 Ma.

A map of the age of reservoir oils across the region by Hood and others (2002) shows various pods of Upper Jurassic and Lower Cretaceous oils, but also Upper Cretaceous oils in regions of Albian production (fig. 3). This is in contradiction to Lewan (2002) and Wescott and Hood (1994) who predicted that the Upper Cretaceous is immature in these areas. Upper Cretaceous sourced oils may be restricted to the southern coastal section of the U.S. Gulf Coast region as well as localized parts of the East Texas Basin and the eastern Mississippi Interior Salt Basin (Wescott and Hood, 1994; Lewan, 2002).

Lewan (2002) modeled vitrinite reflectance values, a percent reflectance measurement (R_o) that indicates the thermal maturity of organic materials for Smackover source rocks. Assuming the underlying assumptions of the model are correct, Smackover source rocks range from lows of 1.24 percent R_o, indicating oil preservation in the North Louisiana Salt Basin and northeastern Mississippi Interior Salt Basin, to highs of 4.89 percent R_o, indicating that cracking to gas is complete in the southwestern Mississippi Interior Salt Basin (fig. 6). Sassen and others (1987) noted that Jurassic oils from the Mississippi Interior Salt Basin that have migrated vertically through fractures to shallower depths, mature much more slowly, and can persist at shallow depths, well after the source formation leaves the oil window to pass into the gas window.

Total organic carbon (TOC) measurements, another measure of the hydrocarbon source potential of an organic-bearing rock, show that the Smackover exhibits a wide range of potential. Claypool and Mancini (1989) described Lower and Middle Smackover carbonate mudstones averaging 0.81 percent TOC. Total organic carbon contents of 0.5 to 2.52 percent with an average of 0.48 percent were reported by Oehler (1984) in 22 samples from Mississippi, Alabama, and Florida. But according to Sassen and Moore (1988) TOC values were higher in the past prior to the generation of crude oil, this may explain relatively low TOC values present in the Smackover today.

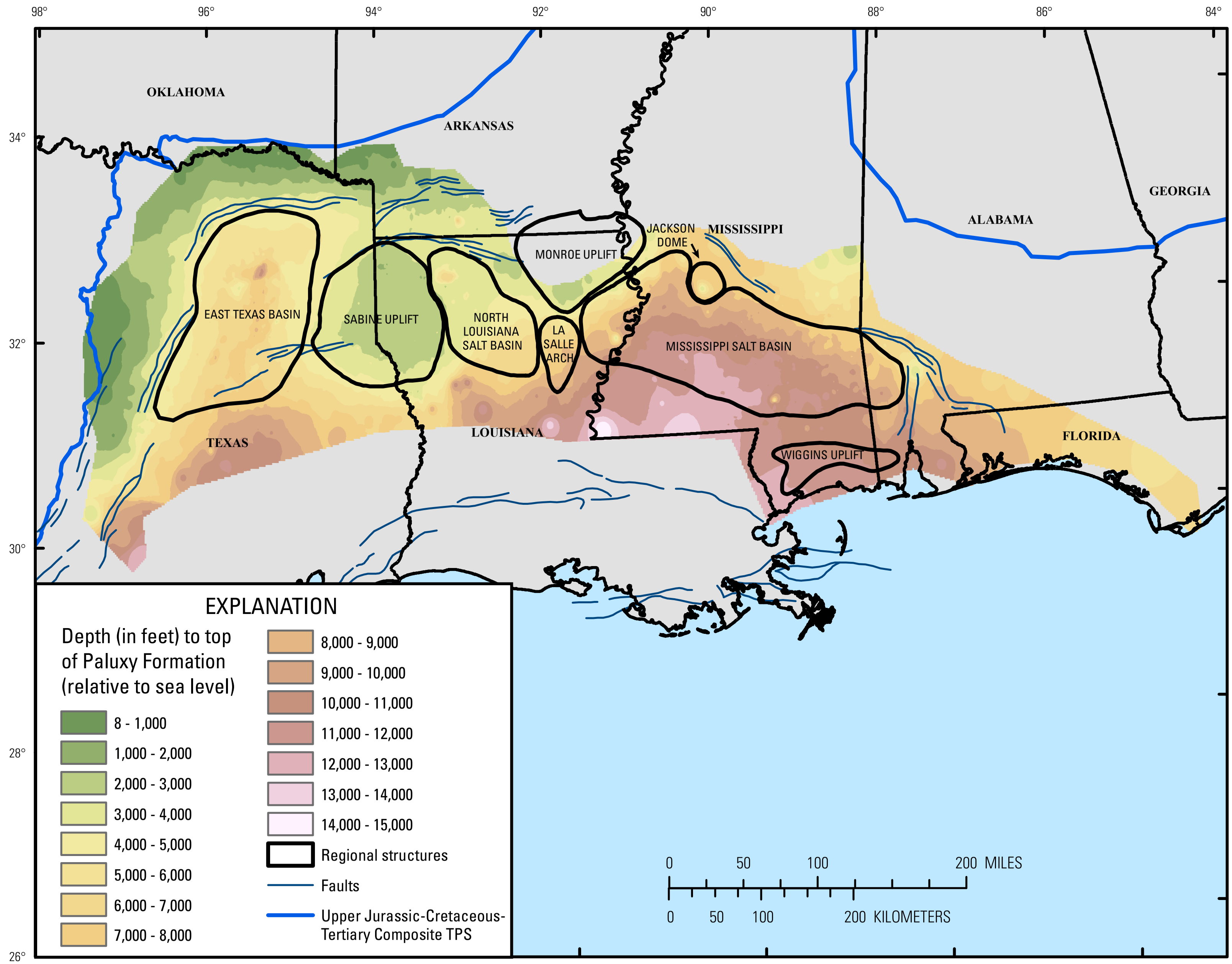

Figure 5. Map showing depth from surface to top of the Paluxy Formation from well penetration depths (IHS, 2009b). Major structural uplifts and basins, and major faults are provided for context (Ewing and Lopez, 1991).

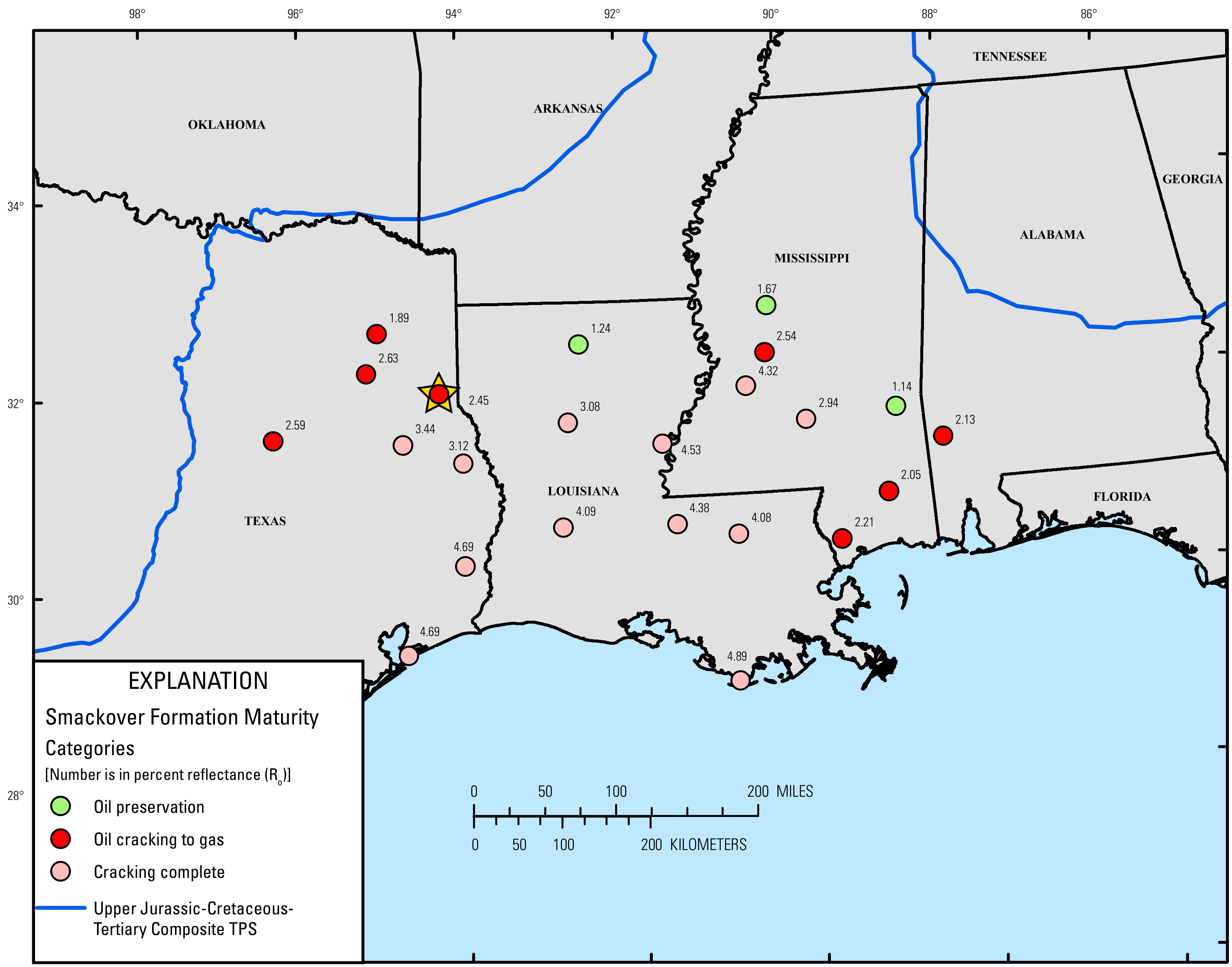

Figure 6. Map showing modeled vitrinite reflectance (% R_o) values across the U.S. Gulf Coast region for the Jurassic Smackover Formation (Lewan, 2002). The starred well in Panola County, Texas, was used to generate the representative burial history model.

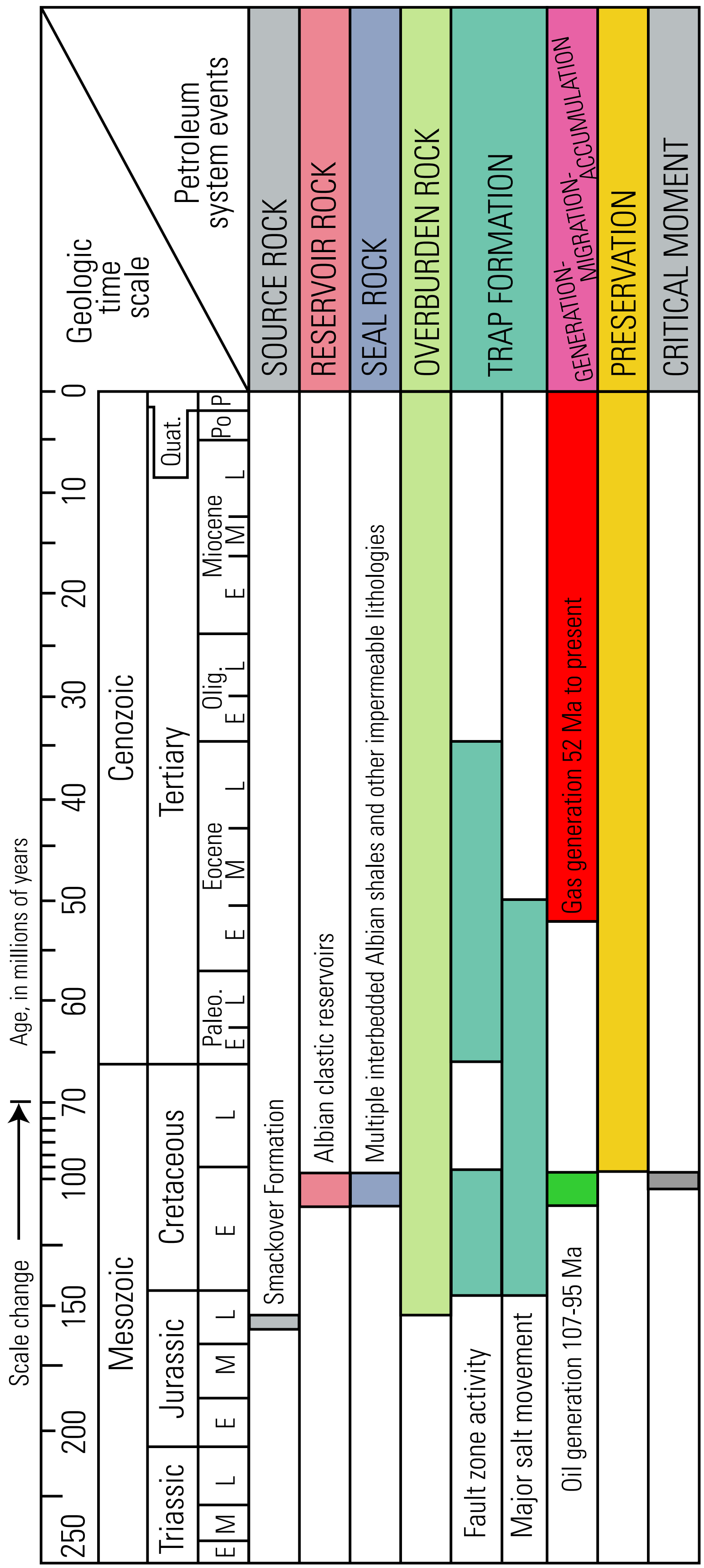

Figure 7. Events chart for Smackover Formation hydrocarbons in Albian clastic reservoirs. Abbreviations: E, Early; M, Middle; L, Late; Ma, mega-annum; Olig., Oligocene; Paleo., Paleocene; Po, Pliocene; P, Pleistocene.

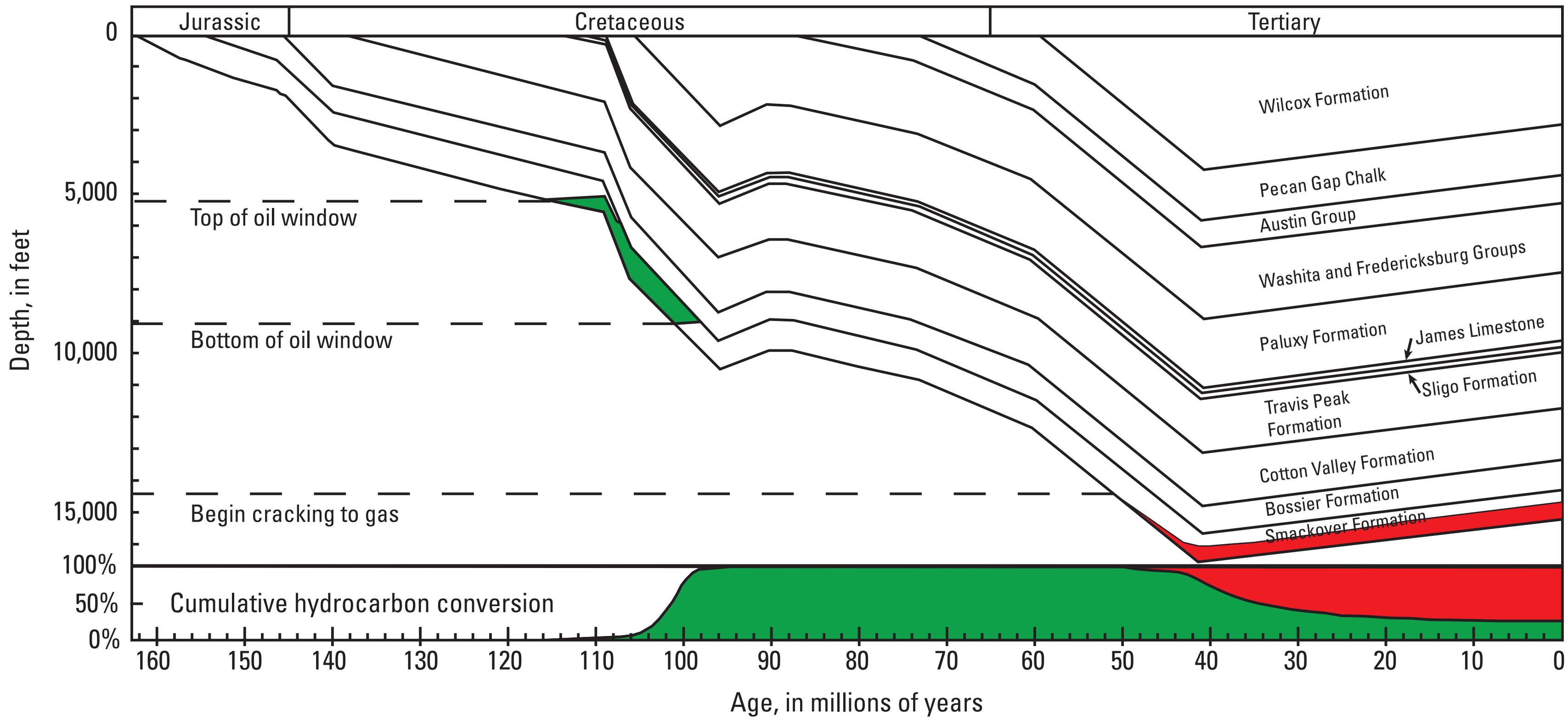

Figure 8. Burial history diagram from a representative well in Panola County, Texas, generated from data in Lewan (2002). Green represents period of oil generation, red represents period of gas formation from hydrocarbon cracking. See starred well location in figure 6.

Hydrocarbon Migration

The migration of predominantly Upper Jurassic oils up section and into Jurassic and Cretaceous reservoirs requires a substantial vertical movement of hydrocarbons. Wescott and Hood (1994) note that the vertical migration required to connect source to reservoir in the East Texas Basin could only be achieved through movement along faults. East Texas Basin production is associated with faulting and two potential methods of migration via faults are possible: (1) migration occurs under overpressured conditions where pressure makes fractures transmissive to fluids until the pressure is relieved by the fluid moving into a reservoir above the previous compartment, and (2) transmissive fault planes allow the movement of fluids across the fault and between porous units until a trap is reached (Wescott and Hood, 1994). Both of these methods of migration favor the occurrence of hydrocarbons in single reservoirs rather than multiple stacked ones. In both the East Texas Basin (Wescott and Hood, 1994) and the Mississippi Interior Salt Basin (Evans, 1987), the majority of producing fields have only one charged reservoir, though the few largest fields are often faulted stacked reservoirs. Explanations differ for the reservoir charging between the two authors, but when considering the migration path of Smackover Formation oil specifically, both explanations support a fault migration mechanism. Invoking faulting, Sassen and others (1987) also cite vertical migration into Lower Cretaceous reservoirs and lateral migration of Smackover oils into Upper Smackover reservoirs in the western Mississippi Interior Salt Basin.

Traps and Seals

Hydrocarbon trapping mechanisms in Albian clastic reservoirs are generally associated with faulting caused by salt movement; however, the actual physical barrier retaining the hydrocarbons may be fault offsets or stratigraphic pinch outs, or a combination of both (Nehring Associates, Inc., 2009). The mixture of shale and sand in Albian depositional environments provide ample sealing potential on fault offsets as less permeable intervals are put in contact with a reservoir facies. Structural traps are common in the peripheral fault zones of the U.S. Gulf Coast region; for example, at Talco Field in the East Texas Basin (fig. 5), a down-dropped block in the Talco Fault Zone graben places low-permeability Washita Group silts and muds against Paluxy Sandstone (dipping away from the fault), producing a hydrocarbon trap stretching for 15 miles along the fault plane (Shelby, 1949). Fault zones like the Talco, Mexia, and Pickens appear to be barriers to lateral migration with little production updip or within the complex central grabens of these peripheral fault zones. In addition, produced fault zone waters are dissimilar in geochemistry to those of down dip producing reservoirs (Shelby, 1949).

Non-structural sealing is common to Albian fluvial, deltaic, and marginal marine environments as lenticular sands pinch out against flood plain shales. Stratigraphic trapping elements in combination-trap fields, such as the Ann McKnight Field in the East Texas Basin, exhibit lateral trapping via facies changes in the fluvial channel sands of the Paluxy B sand, and faulting provides updip structural closure (Balkey, 1989).

Timing of Events

Understanding the TPS components and relative timing are keys to predicting the presence of hydrocarbons in an assessed reservoir, and allows for estimation of the size and number of accumulations. A summary figure, called an events chart, places elements of the TPS in one graphic and uses a temporal axis to indicate timing and interaction of the elements. Figure 7 shows a generalized events chart for emplacement and preservation of hydrocarbons in Albian clastic formations based on burial depths modeled from Lewan (2002) for a well in Panola County, Texas (fig. 6; see starred well location). Thermal maturity in the northern Gulf of Mexico is variable; nevertheless, this chart shows a representative timing of oil generation for the assessed area. The source rock row in the events chart shows the deposition of the Smackover Formation during the Late Jurassic. Deposition of the Albian reservoir rocks and their intermingling and overriding seals occurred at approximately 112 Ma. The Smackover was buried deeply enough to start oil generation at approximately 107 Ma and finish oil generation at 95 Ma (figs. 7 and 8) (Lewan, 2002). Movement of Jurassic Louann Salt began prior to deposition of Albian reservoir formations and resulted in peripheral and intra-basinal fault zones. Faulting continued through deposition of reservoir formations, producing trapping structures immediately after and (or) concurrently with deposition. Selecting an interval for oil preservation is complicated for the same reasons as selecting a period of generation. According to thermal models, depending on the location, Smackover source rocks are in phases of (1) oil preservation, (2) oil cracking to gas, and (3) oil cracking completion. With the exception of the north central area, the Smackover has transitioned out of the oil preservation window and entered the gas window at approximately 50 Ma (fig. 8). The critical moment for the representative burial depth model well location in Panola County, Texas, is approximately 102 Ma (figs. 7 and 8). At this time, generation had reached a peak rate, migration had begun, and Albian reservoirs and traps were in place.

Implications of the timing of hydrocarbon migration into trapping structures in the northern Gulf of Mexico are evident in the production characteristics of some of the region's sub-basins. The Sabine Uplift produces gas, but produces very little oil. Lewan (2002) suggested that the timing of uplift explains the lack of oil. In the Sabine Uplift area, thermal modeling indicated that

Smackover Formation oil generation occurred between 121 to 99 Ma. When uplift began at 94 Ma, most oil was lost due to erosion of the reservoirs. However, as post-uplift fine-grained sediments were deposited on the Sabine, a re-established hydrocarbon seal was present to trap gas generated around 52 Ma when the remaining crude oil cracked to gas and migrated (Lewan, 2002).

Hydrocarbon Production

Cumulative production combined with known reserves from Albian clastic reservoirs is approximately 1,280 MMBO and 2,990 BCFG (Nehring Associates, Inc., 2009); these totals are 8.8, and 5.2 percent, respectively, of all U.S. Gulf Coast Cretaceous oil and gas. In terms of all U.S. Gulf Coast onshore production, these volumes are 2.8 and 0.7 percent, respectively, of cumulative production and known reserves of oil and gas (Nehring Associates, Inc., 2009). Reservoir type is consistent across Albian formations with roughly 1.5 to 2 times more oil reservoirs than gas reservoirs. Using a 20,000 cubic feet gas per barrel of oil (CFG/BO) cut-off ratio to designate reservoir type, a total of 153 discovered oil reservoirs have over 0.5 MMBO in combined cumulative production and known reserves, and 73 gas reservoirs over 3 BCFG are present in Albian clastics of the U.S. Gulf Coast region (Nehring Associates, Inc., 2009). A long-known general trend of updip oil and downdip gas production fits the thermal maturity models of Lewan (2002), Wescott and Hood (1994), and Evans (1987) that predict gas generation from the cracking of oil at greater depths. Among the Albian clastic reservoirs, oil from Paluxy Sandstone accounts for roughly 60 percent of all cumulative production, while Rodessa reservoirs are responsible for 34 percent, and the Rusk, Washita, Fredericksburg, and the Dantzler account for 6 percent. Gas production shows greater equality between the Paluxy and Rodessa at 38 and 46 percent, respectively (Nehring Associates, Inc., 2009). Since 1991, only 14 reservoirs of the minimum size considered in USGS assessments (0.5 MMBO and 3 BCFG) have been discovered in the Albian clastic formations. Wildcat drilling activity remains steady and accounts for approximately 30 percent of the drilling activity during the 1940s to 1980s (figs. 9 and 10).

Future Exploration Models

Higher resolution exploration tools may image smaller traps, pinch-outs, and faults perpendicular to known migration routes that may contain undiscovered Albian hydrocarbon accumulations. Considering the accumulation model put forth by Evans (1987) and Wescott and Hood (1994) that only one reservoir receives the majority of the hydrocarbons in each trap, future discoveries may occur through deeper exploration on structures that have failed to produce at shallow depths. Further exploration of stratigraphic traps also has some potential; however, these traps have been historically associated with structures, some of which have already been targeted.

Assessment of Conventional Undiscovered Resources in the Albian Clastic Reservoirs of the U.S. Gulf Coast Region

The USGS NOGA of clastic Albian formations in the United States onshore and State Waters of the Gulf of Mexico, included two conventional oil and gas AUs, both of which include sandstone and siltstone lithologies from the Rodessa, Rusk, Paluxy, and Washita and Fredericksburg Groups and their equivalents. The assessment was conducted following the methodology outlined by Charpentier and Klett (2005), Klett and Schmoker (2005), and Schmoker and Klett (2005), with the goal to provide the U.S. Congress, State and local partners, and the public with a probability distribution-based estimate of undiscovered oil and gas resources in Albian clastic formations.

Assessment Units

Albian Clastic Geologic Model

The Albian clastic reservoir formations are grouped into two geographically distinct composite assessment units. The properties that make them potential reservoirs for hydrocarbons are summarized in a geologic model for the Albian clastics that includes prograding fluvial, deltaic, and nearshore clastic deposition along a passive and sometimes embayed margin. A detailed description of the geologic model properties for each formation within the assessment units is provided in the previous sections. The model is a concept for the origin and hydrocarbon accumulation potential of these formations that is constructed from depositional environment distributions, reservoir properties, and similar TPS concepts. The Albian clastic geologic model describes sand and silt lithologies from multiple formations with relatively high porosity and permeability that are potential reservoirs.

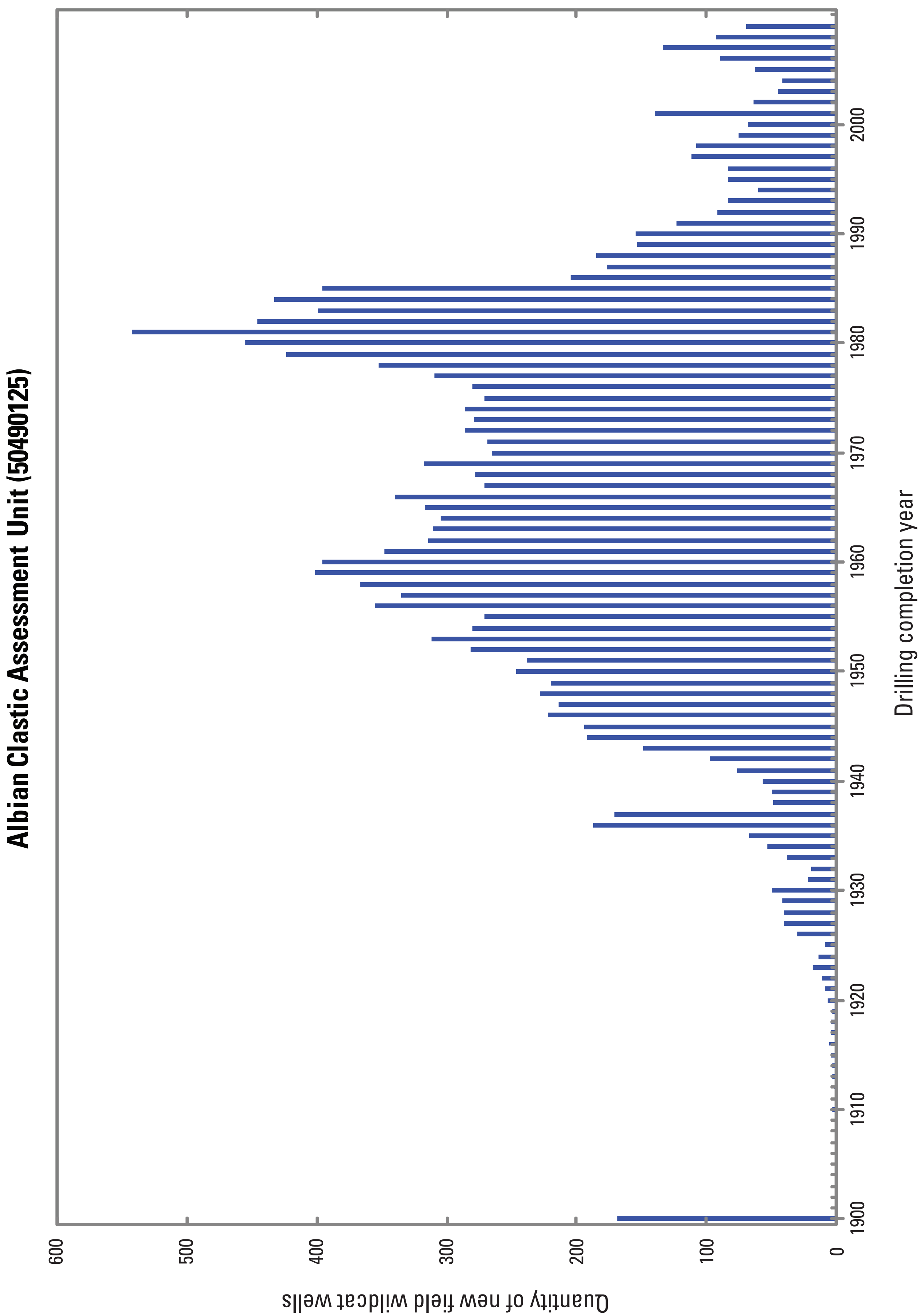

Figure 9. Graph of wildcat wells that penetrate Albian clastic reservoirs in the Albian Clastic Assessment Unit (50490125) from 1900 to 2009 (IHS, 2009b).

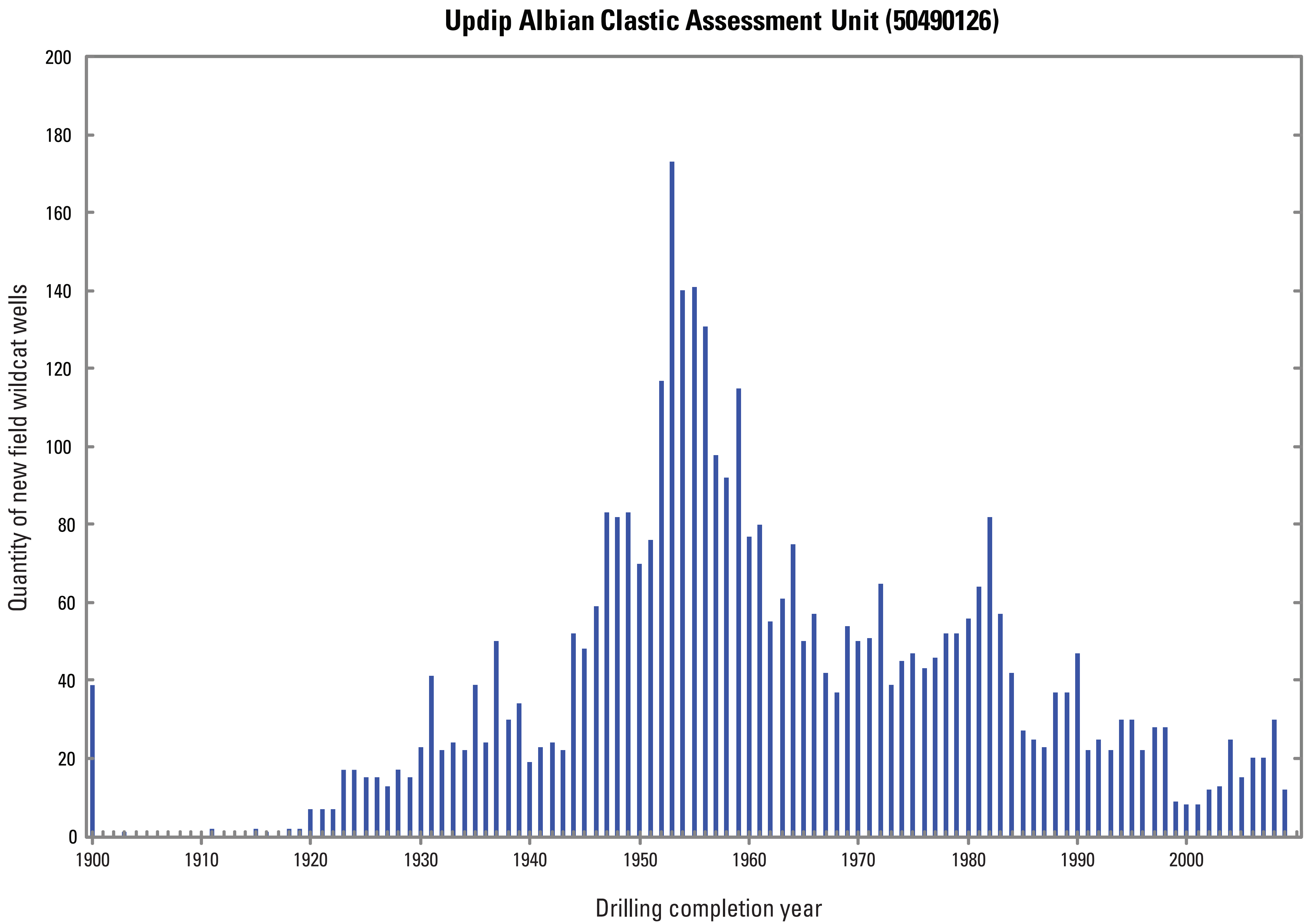

Figure 10. Graph of wildcat wells that penetrate Albian clastic reservoirs in the Updip Albian Clastic Assessment Unit (50490126) from 1900 to 2009 (IHS, 2009b).

These units form both structural and stratigraphic traps, the former occurring predominantly along major fault systems and salt bodies, and the latter occurring as fluvial channel to flood plain lithologic pinch-outs. These reservoirs are sourced primarily from the Jurassic Smackover Formation, requiring significant vertical migration, suggesting that faults are the main source of migration (Wescott and Hood, 1994).

Albian Clastic Assessment Unit (50490125)

The Albian Clastic AU (50490125) extends roughly from the Lower Cretaceous Stuart City Reef trend line in the south, to the updip extent of Jurassic Louann Salt to the north and east (fig. 11). This AU contains nearly all discovered Albian clastic reservoirs. Albian clastic reservoirs in the U.S. Gulf Coast region have been heavily explored. Approximately 100 wildcat wells were drilled on average per year for the recent 15-year period from 1994 to 2009, down from over 300 wildcats per year from 1950 to 1985 (IHS, 2009b) (fig. 9). No new major (>0.5 MMBO or >3 BCFG) reservoirs have been discovered since the late 1990s.

Boundaries

Boundaries for the Albian Clastic AU (50490125) are based on source rock extents, depositional environments, unconformities, and reef trends (figs. 2 and 11). In the south, the boundary extends 10 miles down dip of the Stuart City Reef (Ewing and Lopez, 1991) to include Albian sediments that may have bypassed the reef. The southeastern boundary is the State Waters boundary 3 miles offshore of Louisiana, Mississippi, and Alabama, and 10 miles offshore of Florida. A short linear western boundary line near the Edwards Plateau of central Texas serves as an approximate boundary between carbonate deposition and clastic deposition in Albian reservoirs (Nehring Associates, Inc., 2009). The northwestern, northern, and northeastern margins of the assessment unit, extending from central Texas to western Alabama, follow the Mexia, Talco, Pickens, and Gilbertown Fault Zones (Ewing and Lopez, 1991). These fault zones were produced by the gravitational movement of underlying Louann Salt, for example, gliding over salt décollement zones, collapse over salt pillows, and salt withdrawal below downthrown blocks (Jackson, 1982). Oil and gas exploration has targeted structures associated with salt movement, therefore, the AU boundary encompasses discovered Albian hydrocarbon production. Major U.S. Gulf Coast structural features such as the East Texas Basin, North Louisiana Salt Basin, and Mississippi Salt Basin, and uplifts such as the Sabine Uplift, Monroe Uplift, La Salle Arch, Jackson Dome, and Wiggins Uplift are all included within the AU (fig. 11). Erosion of Albian sediments during the middle Cenomanian on the Monroe Uplift in northeastern Louisiana restricts the extent of the AU to the areas where the assessed lithology is still present as determined by formation tops (IHS, 2009b).

Assessment Form Inputs

Inputs for the probabilistic undiscovered resource calculation are provided on the assessment forms in appendix 1. Risking factors for hydrocarbon charge, reservoir rocks, and the proper timing, were all assigned values of 1.0 due to the existence of Albian production across the basin.

The estimated sizes of undiscovered oil accumulations in the AU were based on past discoveries due to the consideration that the type and size of exploration targets in the future will be similar to those of the past; a new model for conventional exploration in fluvial deltaic systems is not expected. Due to the maturity of exploration in the AU, the minimum field size input was set at the lowest value considered by the USGS methodology, a value of 0.5 MMBO. The selection of a median value of 1 MMBO was based on the downward trend in median field size discoveries over time by separating past production into thirds (fig. 12). A maximum size input of 25 MMBO was selected because it is similar to the size of the largest accumulation found during the last third of new accumulations discovered from 1963 to 1996 (fig. 12). In recognition of the decades elapsed since that large discovery was made, it seems unlikely that larger accumulations will be discovered.

The number of undiscovered oil accumulations remaining in the AU is based on the rate of new discoveries and the amount of wildcat drilling. With no discoveries since the late 1990s (fig. 12) and decreased wildcatting within the last 15 years (fig. 9), a minimum input of 1 undiscovered accumulation was chosen. Twenty undiscovered accumulations at the mode represent a foreseeable future where only half of the discoveries made in the last 40 years are expected. A maximum of 50 undiscovered accumulations requires major exploration for minimum-sized accumulations; accumulations that are not currently an economic priority.

Size and number estimates for undiscovered gas accumulations follow the same logic used for oil accumulations. Accumulations of around 3 BCFG, the USGS minimum cut-off, were commonly discovered in the 1980s to 1990s (Nehring Associates, Inc., 2009) making 3 BCFG the appropriate minimum (fig. 13). A median size of 6 BCFG is predicted following the downward trend in median sizes for each third of discovered gas production from 56 to 13 to 10 BCFG. Just as in the maximum oil accumulation expected, a maximum of 65 BCFG matches the greatest discovered gas accumulation size during the most recent third (fig. 13).

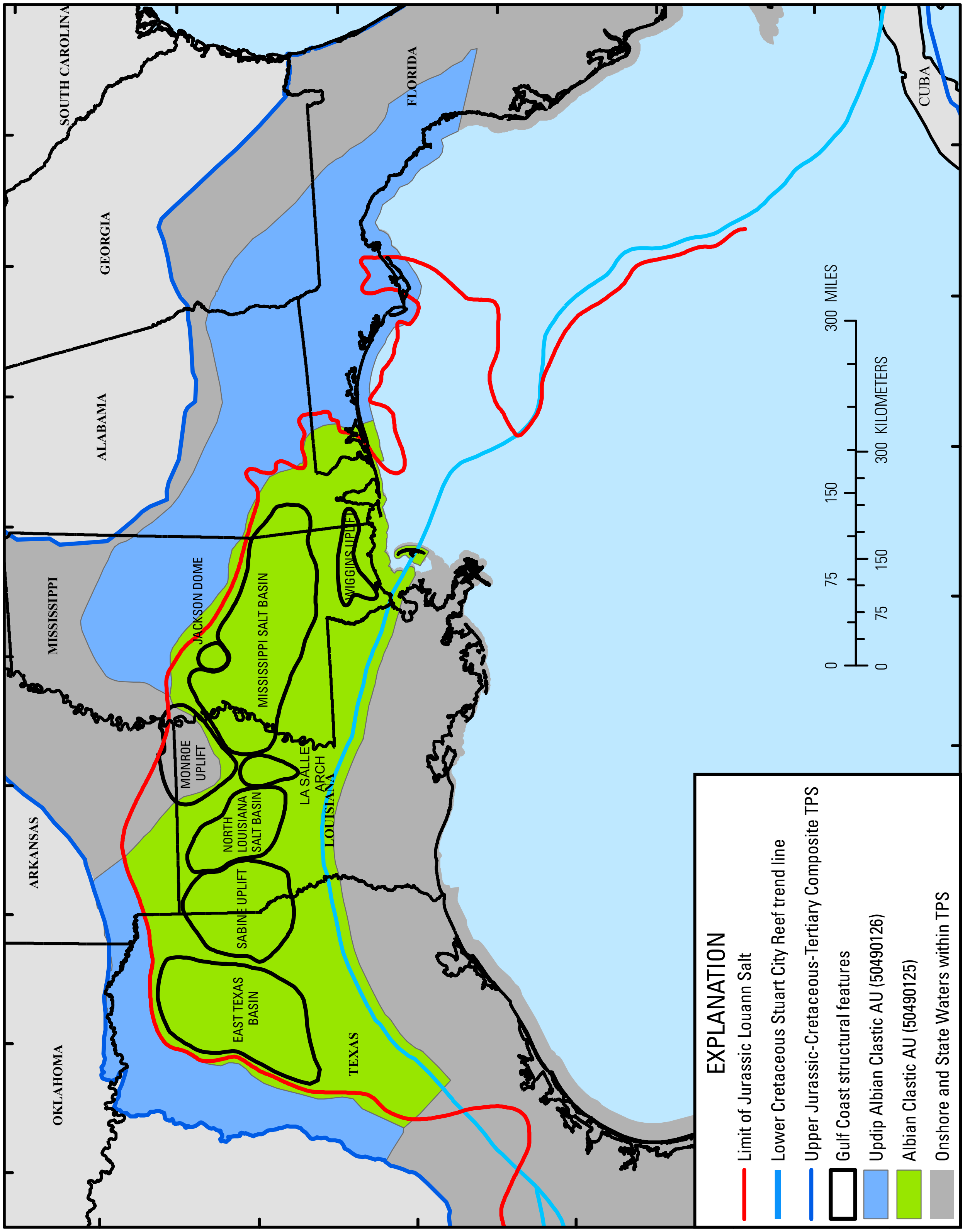

Figure 11. Map showing the geographic extent of the Albian Clastic (50490125) and Updip Albian Clastic (50490126) assessment units including the boundaries of the Upper Jurassic-Cretaceous-Tertiary Composite TPS and the onshore and State Waters area within the purview of this assessment (Warwick and others, 2007). The updip extent of Jurassic Louann Salt and the Stuart City Reef trend line are from Ewing and Lopez (1991); U.S. Gulf Coast region structural features are also from Ewing and Lopez (1991).

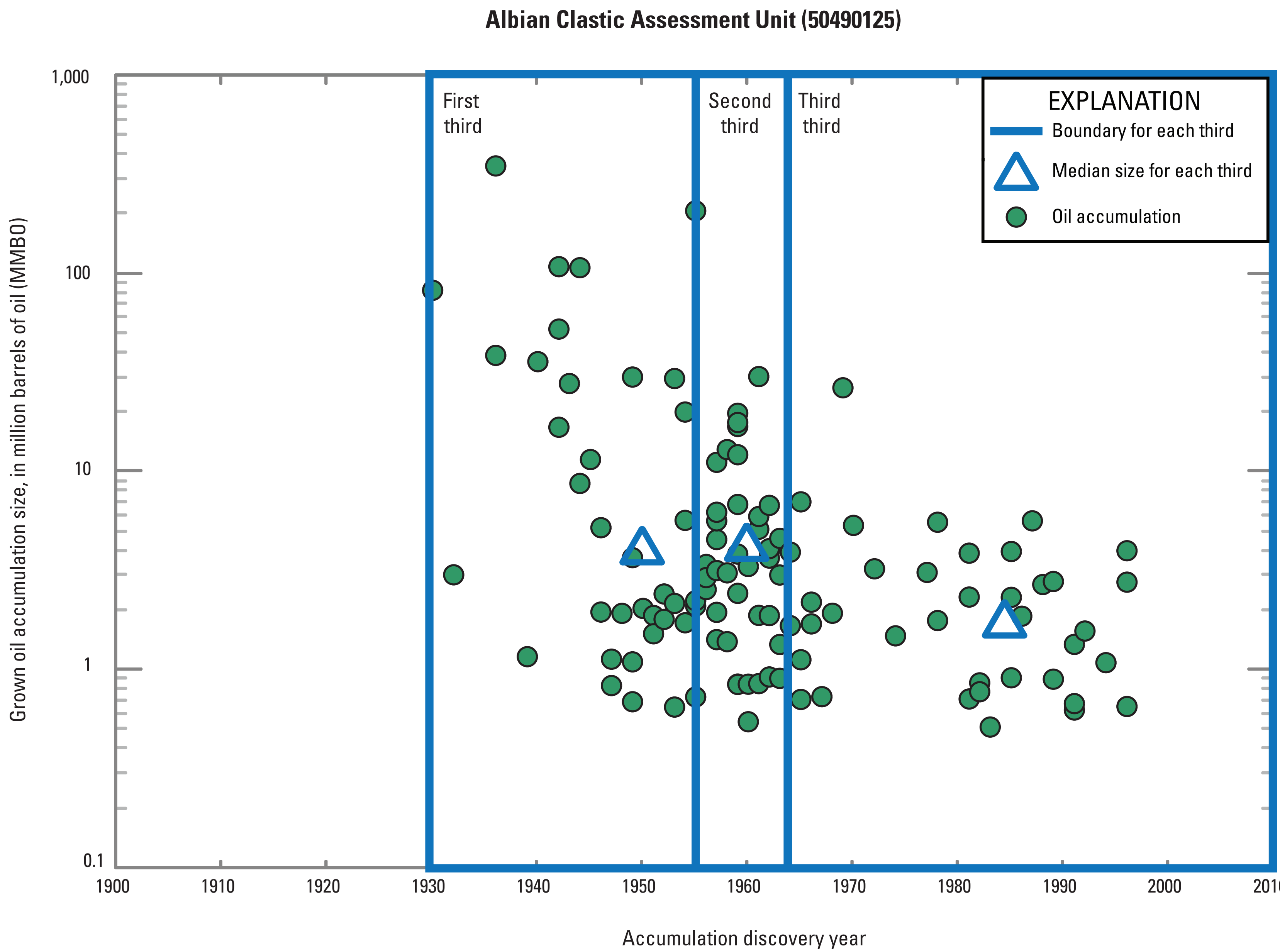

Figure 12. Graph showing the size and discovery year for oil fields greater than 0.5 million barrels of oil (MMBO) of cumulative production and reserves (Nehring Associates Inc., 2009). Grown volumes are projected accumulation sizes based on extension, revision, improved recovery efficiency, and additions of new pools or reservoirs (Klett and others, 2011). Data are separated into thirds by the number of fields, with the median size per third of production marked with a triangle. Circles represent individual fields.

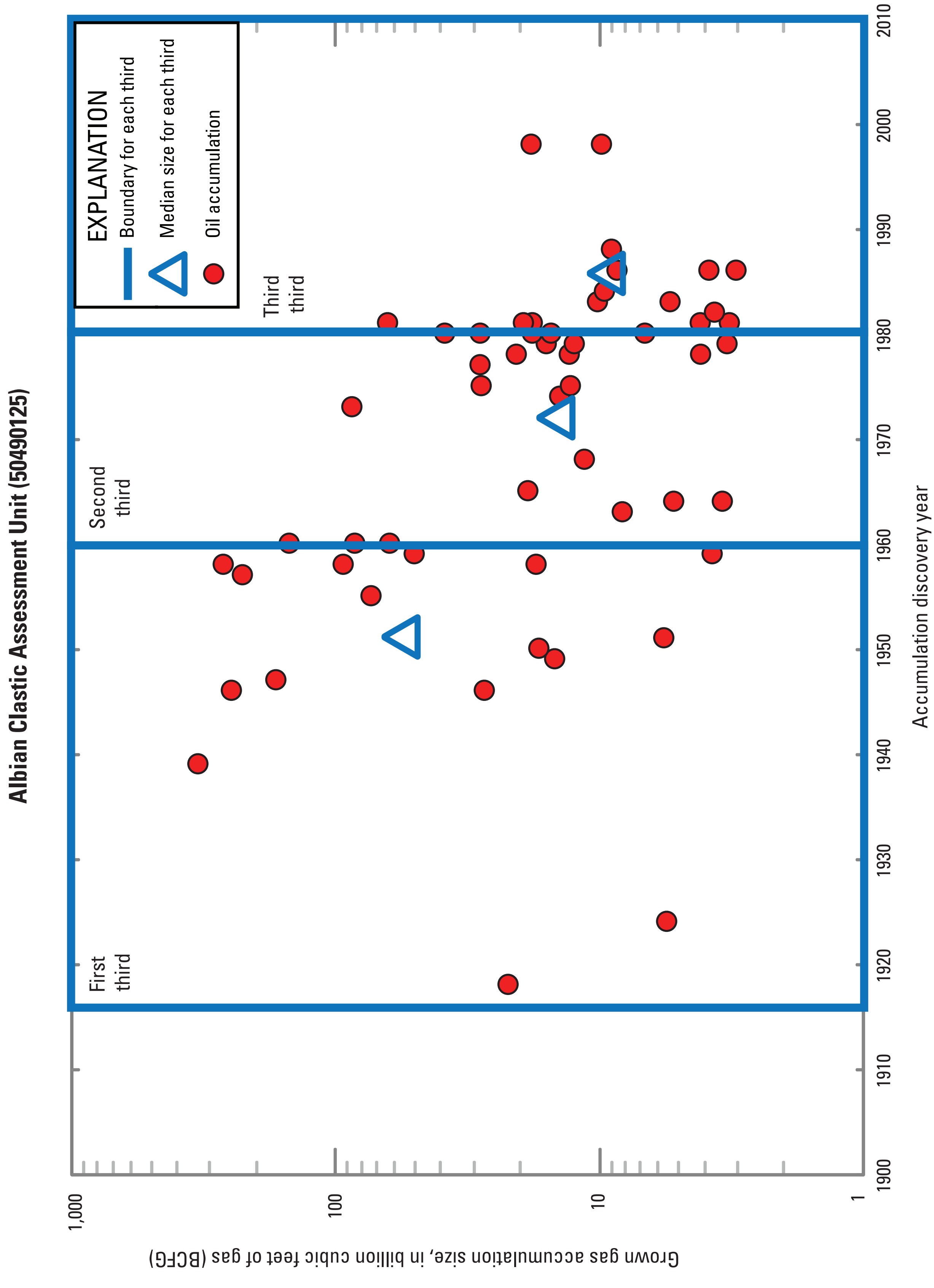

Figure 13. Graph showing the size and discovery year for gas fields greater than 3 billion cubic feet of gas (BCFG) of cumulative production and reserves (Nehring Associates Inc., 2009). Grown volumes are projected accumulation sizes based on extension, revision, improved recovery efficiency, and additions of new pools or reservoirs (Klett and others, 2011). Data are separated into thirds by number of fields, with the median size per third of production marked with a triangle. Circles represent individual fields.

A lack of discoveries since 1998 motivated an input minimum of 1 undiscovered accumulation. The two most recent gas discoveries are 10 and 20 BCFG. Considering the USGS minimum size of 3 BCFG, there are presumably smaller remaining accumulations between 3 and 10 BCFG; therefore, a mode of 15 was selected. Thirty accumulations as a maximum assumes thorough exploration for smaller gas fields at current drilling depths as well as deeper exploration.

Calculated Results

Undiscovered resources for the Albian Clastic AU (50490125) were generated probabilistically using the methodology specified by Charpentier and Klett (2005), Klett and Schmoker (2005), and Schmoker and Klett (2005), with the inputs discussed in the previous section. Table 1 includes the results of these calculations. Oil resources from the Albian Clastic AU were estimated to range from 11 to 69 MMBO at fractiles of 95 percent and 5 percent, respectively, with a mean of 37 MMBO. Gas resources of 39 to 207 BCFG with a mean of 119 BCFG were estimated in gas accumulations, and associated gas resources of 9 to 67 BCFG with a mean of 33 BCFG are estimated in oil accumulations. Natural gas liquids resources of 0 to 3 MMBNGL with a mean of 1 MMBNGL were estimated from oil accumulations, and 1 to 6 MMBNGL with a mean of 3 MMBNGL were estimated from gas accumulations (table 1).

Updip Albian Clastic Assessment Unit (50490126)

The Updip Albian Clastic AU (50490126) extends northward from the northern border of the Albian Clastic AU (50490125) in the west and northward from the Florida State Waters boundary line in the east (fig. 11). Peripheral fault zone barriers and a lack of structural features for trapping combine to reduce the chance of hydrocarbon accumulation in this AU. However, the existence of one 0.64 MMBO field in this AU suggests the possibility of (1) oil migration across peripheral fault zones, or (2) small pods of mature source rock updip of the current mapped extent. Heavy oil produced at I&L Field in Red River County Texas, north of the East Texas Basin, is assumed to be sourced from within the peripheral fault zones; however, it was apparently able to migrate a short distance updip through the bounding graben systems of the fault zone. Wildcat activity in the AU reached a peak in the 1950s with 173 wells drilled in 1953 (fig. 10). Over the last 15 years, wildcat completions are down tenfold, though exploration has continued at a low rate (IHS, 2009b).

Boundaries

The Updip Albian Clastic AU (50490126) is essentially an updip extension of the depositional environments and unconformities that partially defined the boundaries of the Albian Clastic AU (fig 11). The northern limit of the AU is marked by the Upper Jurassic-Cretaceous-Tertiary Composite TPS line in the northwest (Warwick and others, 2007) and the limit of Albian clastic units due to erosion in the northeast (Forgotson, 1957). Applin and Applin's (1944) investigation of drill hole data in Florida's subsurface was used to find Albian clastic sediments and create the eastern boundary of the AU in Florida.

Assessment Form Inputs

Unlike the Albian Clastic AU, the Updip Albian Clastic AU probably did not receive charge from source rocks over much of its area. Inhibition of cross-fault migration at peripheral fault zones increases the risk for proper charge to reservoir formations. However, some Smackover oils migrated through the fault zones, although infiltration of ground water to the shallowing reservoirs updip can degrade the oil. In light of these considerations, the probability of adequate charge has been set at 0.5; probabilities associated with reservoir rock characteristics and timing of events still are favorable to hydrocarbon accumulations and were given probabilities of 1.0. The total multiplicative probability for the AU is 0.5 (appendix 2).

Because there is only one historical field with production above the minimum size for consideration (I&L Field, Red River County, Texas) there is no production history to analyze. Therefore, the estimated numbers and sizes of undiscovered oil and gas accumulations were based on an updip projection of trends seen in Albian clastic reservoir production basinward of the peripheral fault zones. The minimum size of 0.5 MMBO was selected to indicate that large discoveries are not expected. A median of 1 MMBO and maximum of 5 MMBO also reflect charge limitations above the peripheral fault zones. However, the selected median is larger than the 0.64 MMBO from the one productive field in this AU; this is due to the potential for undiscovered accumulations in the State Waters of Florida and other eastern areas where migration across fault zones may occur and (or) where migration routes may have been more direct. For the charge limitations stated above, the number of undiscovered oil accumulations was estimated to be small, with 1 accumulation at the mode, and 1 and 3 accumulations at the minimum and maximum, respectively.

Estimated undiscovered gas accumulation occurrence in the AU is impacted from both the charge issue and low thermal maturity in the Smackover at these shallower depths. Albian gas reservoirs generally are located in the downdip sections of the U.S. Gulf Coast region, far from the boundaries of this AU. Long migration paths or local increases in the thermal gradient would be required to bring gas to the western and central parts of the AU; however, the eastern section of the AU in the Florida Panhandle could be charged by local deep source rock prone to gas generation. These limitations affect the number of accumulations estimated, not their sizes. Sizes for undiscovered gas accumulations could range from the USGS minimum value of 3 BCFG up to a maximum of 30 BCFG, though a median of 6 BCFG is in line with values from the Albian Clastic AU. The limited potential for updip gas is reflected in a minimum, mode, and maximum number of undiscovered gas accumulations of 1, 1, and 2, respectively.

Calculated Results

Undiscovered resources for the Updip Albian Clastic AU (50490126) were generated in the same manner as those for the Albian Clastic AU (table 1). Oil resources from the Updip Albian Clastic AU are estimated to range from 0 to 3 MMBO with a mean of 1 MMBO. Gas resources of 0 to 15 BCFG with a mean of 4 BCFG are estimated in gas accumulations, and associated gas volumes of 0 to 3 BCFG with a mean of 1 BCFG in oil accumulations. Natural gas liquids resources were determined not to be present due to a lack of existing production in Albian formations.

Table 1. Total undiscovered resource assessment results for the Albian Clastic and Updip Albian Clastic Assessment Units of the U.S. Gulf Coast region USGS NOGA (Dubiel and others, 2011).

[Abbreviations: AU, Assessment Unit; BCFG, billion cubic feet of gas; F, fractile (in percent); MMBNGL, million barrels of natural gas liquids; MMBO, million barrels of oil; TPS, Total Petroleum System; —, not applicable]

Assessment Unit (AU)	Field Type	Total Undiscovered Resources											
		Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
		F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Upper Jurassic-Cretaceous-Tertiary Composite TPS (504901)													
Albian Clastic AU (50490125)	Oil	11	35	69	37	9	31	67	33	0	1	3	1
	Gas	—	—	—	—	39	116	207	119	1	3	6	3
Updip Albian Clastic AU (50490126)	Oil	0	1	3	1	0	0	3	1	0	0	0	0
	Gas	—	—	—	—	0	3	15	4	0	0	0	0

Summary

The Albian sand and siltstone reservoirs in this report represent two of the 34 AUs assessed for undiscovered oil and gas resources in the Jurassic and Cretaceous formations of the U.S. Gulf Coast region USGS NOGA project. The USGS NOGA team employed a probabilistic assessment methodology based on a TPS framework to estimate undiscovered hydrocarbon resources reservoired in specific assessment units. Two Albian clastic assessment units were assessed using discovery analysis, a geologic model of Albian depositional environments, and reservoir properties to determine inputs for the probabilistic calculation. The Albian Clastic AU (50490125) encompasses current productive Albian reservoirs in the U.S. Gulf Coast region. Combined cumulative production and known reserves from Albian clastic reservoirs is approximately 1,280 million barrels of oil (MMBO) and 2,990 billion cubic feet of gas (BCFG) (Nehring Associates, Inc., 2009); these totals are 8.8 percent of all U.S. Gulf Coast Cretaceous oil and 5.2 percent of gas. In terms of all U.S. Gulf Coast onshore production, these volumes are 2.8 percent of oil, and 0.7 percent of gas (Nehring Associates, Inc., 2009). Future exploration in these heavily produced formations will rely on high resolution subsurface imaging and deeper drilling depths to find smaller accumulations of oil and gas. The Updip Albian Clastic AU (50490126) is an under-explored area; however, restricted migration pathways result in a reduced probability of hydrocarbon charge. This probably explains the small amount of hydrocarbons produced to date. Considered together, conventional prospects for undiscovered accumulations in Albian clastic reservoirs are relatively low.

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Appendix 1. Basic Input Data for the Albian Clastic Assessment Unit

Basic input data form in appendix 1 for the Albian Clastic Assessment Unit (50490125). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 6, 4–09–03). [Abbreviations: accums., accumulations; AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; bo/mmcfg, barrels of oil per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; F, fractile (in percent); m, meters; min., minimum; mmboe, million barrels of oil equivalent; mmbo, million barrels of oil; NGL, natural gas liquids, no., number.]

Appendix 2. Basic Input Data for the Updip Albian Clastic Assessment Unit

Basic input data form in appendix 2 for the Updip Albian Clastic Assessment Unit (50490126). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 6, 4–09–03). [Abbreviations: accums., accumulations; AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; bo/mmcfg, barrels of oil per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; F, fractile (in percent); m, meters; min., minimum; mmboe, million barrels of oil equivalent; mmbo, million barrels of oil; NGL, natural gas liquids, no., number.]

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