Geologic Assessment of Undiscovered Conventional Oil and Gas Resources in the Lower Paleogene Midway and Wilcox Groups, and the Carrizo Sand of the Claiborne Group, of the Northern Gulf Coast Region

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By Peter D. Warwick

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U.S. Department of the Interior
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## Conversion Factors

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Geologic Assessment of Undiscovered Conventional Oil and Gas Resources in the Lower Paleogene Midway and Wilcox Groups, and the Carrizo Sand of the Claiborne Group, of the Northern Gulf Coast Region

By Peter D. Warwick

Abstract

The U.S. Geological Survey (USGS) recently conducted an assessment of the undiscovered, technically recoverable oil and gas potential of Tertiary strata underlying the onshore areas and State waters of the northern Gulf of Mexico coastal region. The assessment was based on a number of geologic elements including an evaluation of hydrocarbon source rocks, suitable reservoir rocks, and hydrocarbon traps in an Upper Jurassic-Cretaceous-Tertiary Composite Total Petroleum System (TPS) defined for the region by the USGS. Five conventional assessment units (AUs) were defined for the Midway (Paleocene) and Wilcox (Paleocene-Eocene) Groups, and the Carrizo Sand of the Claiborne Group (Eocene) interval including: (1) the Wilcox Stable Shelf Oil and Gas AU; (2) the Wilcox Expanded Fault Zone Gas and Oil AU; (3) the Wilcox-Lobo Slide Block Gas AU; (4) the Wilcox Slope and Basin Floor Gas AU; and (5) the Wilcox Mississippi Embayment AU (not quantitatively assessed).

The USGS assessment of undiscovered oil and gas resources for the Midway-Wilcox-Carrizo interval resulted in estimated mean values of 110 million barrels of oil (MMBO), 36.9 trillion cubic feet of gas (TCFG), and 639 million barrels of natural gas liquids (MMBNGL) in the four assessed units. The undiscovered oil resources are almost evenly divided between fluvial-deltaic sandstone reservoirs within the Wilcox Stable Shelf (54 MMBO) AU and deltaic sandstone reservoirs of the Wilcox Expanded Fault Zone (52 MMBO) AU. Greater than 70 percent of the undiscovered gas and 66 percent of the natural gas liquids (NGL) are estimated to be in deep (13,000 to 30,000 feet (ft)), untested distal deltaic and slope sandstone reservoirs within the Wilcox Slope and Basin Floor Gas AU.

Introduction

A primary mission of the U.S. Geological Survey (USGS) Energy Program is to conduct geologically based assessments of the undiscovered, technically recoverable quantities of oil and gas that have the potential to be added to the proved reserves in the United States. As part of the National Oil and Gas Assessment Project, these assessments are based on an integration and analysis of geologic elements such as hydrocarbon source rocks (source-rock maturation, hydrocarbon generation and migration), reservoir rocks (sequence stratigraphy and petrophysical properties), and hydrocarbon traps (trap formation and timing) within a total petroleum system (TPS) framework (Magoon and Dow, 1994; Schmoker and Klett, 2005; U.S. Geological Survey National Assessment Review Team, 2006). The last USGS assessment of the entire Gulf of Mexico coastal region was completed in 1995 (Schenk and Viger, 1996a,b; U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995). Since 1995, assessments of parts of the Jurassic and Cretaceous intervals in the Gulf coastal region were reported by Condon and Dyman (2006), Dyman and Condon (2006), and Pitman and others (2007). Recent USGS assessments in the Gulf of Mexico coastal region are updates of previous USGS assessments of the interval (Schenk and Viger, 1996a,b), and have focused on undiscovered resources in Paleogene and Neogene strata (Dubiel and others, 2007; Warwick and others, 2007a), and Jurassic and Cretaceous stratigraphic intervals (Dubiel and others, 2011).

In 2007, the USGS assessed undiscovered, technically recoverable conventional oil and gas resources and continuous coalbed gas resources in Cretaceous, Paleogene, and Neogene strata underlying the U.S. Gulf of Mexico Coastal Plain and State waters (figs. 1 and 2). State waters include those areas within 3 nautical miles of the coastline, except in Texas where State waters are within 9 nautical miles of the coastline. Thirty-three conventional assessment units for the Paleogene to Neogene interval were identified and assessed by the USGS (table 1). Four Cretaceous to Paleogene continuous (coalbed gas) assessment
units were also assessed. The results of the assessment of the conventional and continuous resources can be found in USGS Fact Sheets by Dubiel and others (2007) and Warwick and others (2007a). The purpose of this paper is to describe the geological concepts, models, TPS, and assessment units developed for the 2007 assessment of the remaining technically recoverable oil and gas resources to be found in the onshore and State water portion of the lower Paleogene Midway (Paleocene) and Wilcox (Paleocene to Eocene) Groups, and the Carrizo Sand of the Claiborne Group (Eocene) stratigraphic section in the Gulf of Mexico coastal region (figs. 1 and 2). For descriptive purposes the Midway and Wilcox Groups and the Carrizo Sand of the Claiborne Group will collectively be referred to as the lower Paleogene assessment interval in this paper.

The Gulf of Mexico Basin is one of the major hydrocarbon-producing areas of the world (Nehring, 1991; Horn, 2003). The U.S. Energy Information Administration estimates that in 2004, about 19 percent of the Nation’s producible gas reserves and about 6 percent of the Nation’s oil reserves were found in onshore Gulf of Mexico reservoirs (Budzik, 2006). For a recent summary of the offshore reserves in the Federal outer continental shelf of the Gulf of Mexico region, refer to Crawford and others (2006) and French and others (2006). The recent onshore discovery of coalbed gas in Cretaceous and Paleocene strata identifies new petroleum systems not recognized in previous USGS assessments for the Gulf of Mexico coastal region.

### Regional Geologic and Structural Setting

The Gulf of Mexico Basin is a generally circular structural and topographic depression that contains up to 60,000 ft of strata ranging in age from Late Triassic to Holocene (Ewing, 1991a; Nelson and others, 2000). The structural and stratigraphic setting of the northern Gulf of Mexico Coastal Plain has been well documented by previous studies (Murray, 1961; Salvador 1991; Ewing, 1991a; Caò and others, 1993; Zimmerman, 1995; Hosman, 1996; Galloway and others, 2000; Stephens, 2001). Figure 1 shows the major structural features of the U.S. onshore region of the Gulf of Mexico Coastal Plain. Strata in the Gulf of Mexico coastal region generally dip into the basin, except where local deformation occurs around structural uplifts, subbasins, faults, and folds. At different depths across the basin, strata exhibit overpressure and abnormal temperature conditions that can complicate hydrocarbon production (Dickinson, 1953; Riggs and others, 1991; Leftwich, 1993; Leftwich and Engelder, 1994; Engelder and Leftwich, 1997; Hunt and others, 1998; Flemings and others, 2000).

#### Table 1. Assessment units of the 2007 U.S. Geological Survey assessment of Tertiary strata of the northern Gulf Coast.

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Structural Setting

The lower Paleogene Wilcox Group crops out around the northern edge of the Gulf of Mexico Basin (fig. 3). Structural contours drawn on the top of the Wilcox Group show that Wilcox strata dip southward at variable rates into the basin. The dip rate is gentle near the outcrop belt and within the Mississippi embayment and is moderate to substantial near the present-day coastline. Note that the southern boundary of the Mississippi embayment is somewhat arbitrary as shown on figure 3. A major increase in the rate of dip is observed as the Wilcox Group crosses over the Lower Cretaceous shelf margin which roughly lies between the -5,000 and -10,000 ft contours on figure 3.

The local structure of these lower Paleogene sedimentary units is influenced by flow of the Jurassic Louann Salt (fig. 2) and movement along local and regional fault systems. A detailed discussion of the structural setting of the lower Paleogene strata can be found in Ewing (1991a) and Salvador (1991). Maps showing the location of salt structures in the Gulf of Mexico Basin are found in Ewing and Lopez (1991) and Lopez (1995). Evacuation and allochthonous flow of the Louann Salt due to sedimentary loading has had a dramatic influence on the petroleum geology of the Gulf of Mexico Basin (Ewing, 1991a, b; McBride, 1998; McBride and others, 1998; Stover and others, 2001). In particular, the growth and emplacement of salt diapirs leads to the creation of complex structures which serve as petroleum migration pathways and traps (Halbouty, 1979). Stratigraphic units around salt dome margins are faulted by salt intrusion, creating fault traps, and are dragged upwards at the salt-rock contact, creating combination traps and accentuating stratigraphic traps. In the salt basins, diapirs frequently are aligned on major growth-fault trends suggesting that preexisting domes influence the initiation of faults and tend to control their location (Winker, 1982).

Stratigraphy and Depositional Systems

The lower Paleogene assessment interval is composed of the Midway and Wilcox Groups, and the Carrizo Sand of the Claiborne Group (fig. 2). The Midway Group is primarily composed of marine shale that is interbedded with a few local sandstone and limestone beds (Galloway and others, 1991, 2000). The unit was first defined by Harris (1894) from exposures at Midway Landing, southwest Alabama. The Midway Group is usually undifferentiated in the subsurface, however, locally multiple subunits of the Midway Group have been defined (table 2). Some oil and gas production does occur from Midway sand-rich intervals in southern Texas (such as the Poth sand, see table 3) (Palmer, 1954; Hopf, 1965, 1967, 1986a, b; Nehring, 1991). Because of the low number of Midway fields (9 fields, Nehring Associates, Inc., 2006), and limited production, the Midway Group is combined with the Wilcox Group and Carrizo Sand to form one lower Paleogene assessment interval.

The Wilcox Group is the primary oil and gas producer for the lower Paleogene assessment interval, with more than 1,200 known oil and gas fields (Nehring Associates, Inc., 2006). Thickness of the Wilcox Group ranges from less than 1,000 ft near the outcrop to over 7,000 ft in the Rio Grande embayment of south Texas (figs. 1 and 4). The Wilcox Group is composed of fluvial and deltaic coal-bearing facies consisting of sandstone, siltstone, mudstone, claystone, limestone, and coal intervals that become dominated by marine facies beyond the Lower Cretaceous shelf margin (Galloway and others, 1991, 2000). Recent exploration south of the modern outer continental shelf in the deep-water areas of the Gulf of Mexico indicates that thick sand-rich facies extend several hundred miles into the deepest part of the basin (Meyer and others, 2005). The Wilcox Group has multiple stratigraphic names and subunits that are used across the basin (table 2). In addition, table 3 lists informal field names and numerous driller’s terms for the lower Paleogene assessment interval.


The basal Carrizo Sand of the Claiborne Group (fig. 2) was combined with the Wilcox and Midway Groups to form the lower Paleogene assessment interval primarily because the Carrizo interval is usually included with the Wilcox Group in drilling history and reservoir unit databases (IHS, 2005a, b; Nehring Associates, Inc., 2006). The Carrizo Sand crops out in Mexico, Texas, and Louisiana, and disconformably overlies the upper part of the Wilcox Group (Stenzel, 1940; Harris, 1962; Breyer, 1997). Galloway and others (2000) describe the Carrizo Sand as a late Wilcox-type delta-building sequence that was located primarily in south Texas. However, other studies have recognized the Carrizo Sand as a prominent subsurface sand-rich interval across much of the Gulf coastal region (Baker, 1979; Coates and others, 1980; Hamlin, 1983; Stoudt and others, 1990; Bellamy and Breyer, 2002).
Table 2. Alternate formal group, formation, or member names for the Midway and Wilcox Groups, and the Carrizo Sand of the Claiborne Group.

[States where these names are used are in parentheses. Data from U.S. Geological Survey (2008) National Geologic Map Database, Geolex: http://ngmdb.usgs.gov/Geolex/. Asterisks (*) indicate usage by the U.S. Geological Survey. Other usages by State geological surveys]

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<td>Berger Formation of Wilcox Group (Ark.*)</td>
<td>Cow Bayou Formation of Wilcox Group (La.)</td>
</tr>
<tr>
<td>Caldwell Knob Member of Rockdale Formation of Wilcox Group (Tex.)</td>
<td>Detonti Sand of Wilcox Group (Ark.*)</td>
</tr>
<tr>
<td>Calvert Bluff Formation of Wilcox Group (Tex.)</td>
<td>Dolet Hills Formation of Wilcox Group (La.*)</td>
</tr>
<tr>
<td>Carrizo Sand of Claiborne Group (Ark.<em>, La.</em>, Tex.*)</td>
<td>Fearn Springs Formation of Wilcox Group (Miss.)</td>
</tr>
<tr>
<td>Carrizo Formation of Wilcox Group (Tex.)</td>
<td>Fearn Springs Member of Nanafalia Formation (Miss.*)</td>
</tr>
<tr>
<td>Converse Formation of Wilcox Group (La.)</td>
<td>Flour Island Formation of Wilcox Group (Mo.<em>, Tenn.</em>)</td>
</tr>
<tr>
<td>Cow Bayou Formation of Wilcox Group (La.)</td>
<td>Fort Pillow Sand of Wilcox Group (Mo.<em>, Tenn.</em>)</td>
</tr>
<tr>
<td>Detonti Sand of Wilcox Group (Ark.*)</td>
<td>Hall Summit Formation (La.)</td>
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</tbody>
</table>
Table 3. Some informal production unit and field names used for the lower Paleogene assessment interval.

([Lower Paleogene production unit names from IHS Energy Group (2005b) and Nehring Associates, Inc. (2006). Abbreviations: La., Louisiana; Miss., Mississippi; S., south; Tex., Texas]

<table>
<thead>
<tr>
<th>Lower Paleogene production unit name</th>
<th>Assessment interval</th>
<th>References</th>
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<tbody>
<tr>
<td>4600 SD</td>
<td>Upper Wilcox (Miss.)</td>
<td>Dockery (2001)</td>
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<tr>
<td>Armstrong sand</td>
<td>Lower Wilcox (Miss.)</td>
<td>Holden (1951); Williams (1969)</td>
</tr>
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<td>Ashley sand</td>
<td>Lower Wilcox (Miss.)</td>
<td>Williams (1969)</td>
</tr>
<tr>
<td>Atman</td>
<td>Lower Wilcox (Miss.)</td>
<td>Williams (1969)</td>
</tr>
<tr>
<td>Baker</td>
<td>Lower Wilcox (Miss.)</td>
<td>Williams (1969)</td>
</tr>
<tr>
<td>Bartosh (Bartosch Sand)</td>
<td>Lower Wilcox (Tex.)</td>
<td>Palmer (1954); Hargis (2000)</td>
</tr>
<tr>
<td>Campbell</td>
<td>Lower Wilcox</td>
<td>Williams (1969); Corcoran and others (1994)</td>
</tr>
<tr>
<td>Carrizo</td>
<td>Upper Wilcox</td>
<td>Hargis (2000)</td>
</tr>
<tr>
<td>Carrizo Wilcox</td>
<td>Upper Wilcox</td>
<td>Hargis (2000)</td>
</tr>
<tr>
<td>Deville Sand</td>
<td>Lower Wilcox (La Salle, La.)</td>
<td>Location and depth could be lower Wilcox; see Eversull (1984)</td>
</tr>
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<td>Falcon</td>
<td>Wilcox(? Escobas field(?)</td>
<td>Meyerhoff and Braddock (1998)</td>
</tr>
<tr>
<td>Foster</td>
<td>Lower Wilcox (Miss.)</td>
<td>Williams (1969)</td>
</tr>
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<td>Freewoods</td>
<td>Lower Wilcox (Miss.)</td>
<td>Williams (1969)</td>
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<td>French Fork</td>
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<td>Location and depth could be lower Wilcox; see Eversull (1984)</td>
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<td>Hinnant Upper</td>
<td>Upper Wilcox (S. Tex.)</td>
<td>Bornhauser (1979)</td>
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<td>Hirsch</td>
<td>Lower Wilcox (S. Tex.)</td>
<td>Hargis (2000)</td>
</tr>
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<td>Lower Wilcox (S. Tex.)</td>
<td>Long (1986)</td>
</tr>
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<td>Lobo1</td>
<td>Lower Wilcox (S. Tex.)</td>
<td>Long (1986)</td>
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<tr>
<td>Lobo6</td>
<td>Lower Wilcox (Hirsch, S. Tex.)</td>
<td>Long (1986)</td>
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<td>Luling</td>
<td>Upper Wilcox (S. Tex.)</td>
<td>Hargis (2000)</td>
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<td>Mackhank</td>
<td>Upper Wilcox (S. Tex.)</td>
<td>Hargis (2000)</td>
</tr>
<tr>
<td>Massive 2 sand (massive sand[?])</td>
<td>Upper Wilcox (S. Tex.)</td>
<td>Hargis (2000)</td>
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<td>Mckittrick</td>
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<td>Miller</td>
<td>Lower Wilcox</td>
<td>Glawe and Echols (1997)</td>
</tr>
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<td>Minter A</td>
<td>Lower Wilcox (Miss.)</td>
<td>Williams (1969)</td>
</tr>
<tr>
<td>Nichols</td>
<td>Lower Wilcox (Miss.)</td>
<td>Glawe and others (1999); Williams (1969)</td>
</tr>
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<td>Pearline</td>
<td>Lower Wilcox (Miss.)</td>
<td>Williams (1969)</td>
</tr>
<tr>
<td>Poth sand</td>
<td>Midway (Tex.)</td>
<td>Palmer (1954); Hopf (1965, 1967)</td>
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<td>Reagan</td>
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<td>Lower Wilcox (S. Tex.)</td>
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<td>Slick</td>
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<td>Hargis (2000)</td>
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<td>Steinhauser</td>
<td>Carrizo</td>
<td>Ryman (1954)</td>
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<td>Stewart B</td>
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<td>Williams (1969)</td>
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<td>Tew Lake</td>
<td>Lower Wilcox</td>
<td>Glawe and Echols (1997)</td>
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<td>Walker</td>
<td>Lower Wilcox (Miss.)</td>
<td>Williams (1969)</td>
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<tr>
<td>Wilcox</td>
<td>Upper and lower Wilcox</td>
<td>Galloway and others (1991)</td>
</tr>
<tr>
<td>Wilcox 1</td>
<td>Upper Wilcox (Miss., La.)</td>
<td>Williams (1969); location and depth projects to be lower Wilcox; see Eversull (1984)</td>
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<td>Wilcox 2</td>
<td>Upper Wilcox (Miss.)</td>
<td>Williams (1969)</td>
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<td>Wilcox A</td>
<td>Upper Wilcox (Tex., La.)</td>
<td>Schenk and Viger (1995b, Play 4722)</td>
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<tr>
<td>Wilcox B</td>
<td>Upper Wilcox (La.)</td>
<td>Schenk and Viger (1995b, Play 4723)</td>
</tr>
<tr>
<td>Yakey Sand</td>
<td>Lower Wilcox (La.)</td>
<td>Echols and Goddard (1992)</td>
</tr>
</tbody>
</table>
Assessment Methodology

The methodology used for the Gulf coastal region conventional assessment units follows Charpentier and Klett (2005), Klett and others (2005), and Schmoker and Klett (2005). The methodology used for the continuous assessment units is described in Cook (2005), Crovelli (2005), Klett and Schmoker (2005), and Schmoker (2005). Peer reviews of the USGS oil and gas assessment methodology, as well as links to the above references can be found at the following web page: http://energy.cr.usgs.gov/oilgas/noga/methodology.html.

Assessment Unit and Petroleum System Concepts

In this report, assessment units (AUs) replaced the play concept that was applied for the 1995 USGS national assessment (Schenk and Viger, 1996a,b; U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995). The application of the AU concept is part of the petroleum system approach (described below) to resource assessments (Magoon and Dow, 1994). An AU is “a mappable part of a TPS in which discovered and undiscovered oil and gas accumulations constitute a single relatively homogeneous population such that the methodology of resource assessment is applicable” (Klett, 2004, p. 599). In other words, an AU is comprised of a three-dimensional volume of rock, which contains discovered and undiscovered hydrocarbon resources that are relatively similar in terms of their geological occurrence, exploration strategy, and risk characteristics (Ahlbrandt, 2000). Using AUs in place of the play concept may not necessarily result in quantitative differences in the volumes of undiscovered resources (Klett, 2004), but it supplies a common basis for resource assessment methodology within the USGS (Condon and Dyman, 2006). The petroleum system approach to resource assessment (Magoon and Dow, 1994) includes an analysis of “genetically related petroleum generated by a pod or by closely related pods of mature source rock” (Condon and Dyman, 2006). The AUs defined for the assessment of the lower Paleogene strata of the Gulf of Mexico coastal region are mappable subunits of the Upper Jurassic-Cretaceous-Tertiary Composite TPS (Warwick and others, 2007b). The term “composite” indicates that hydrocarbons were generated from more than one source rock, in this case the Jurassic Smackover Formation, the Cretaceous Eagle Ford Formation, and the Paleogene Wilcox Group and Sparta Sand (fig. 2). The composite TPS includes all of the geologic elements such as source, reservoir, seal, and overburden rocks, which control the processes of generation, migration, and trapping of hydrocarbon resources (Magoon and Dow, 1994; Klett, 2004). A map of the outline of the Upper Jurassic-Cretaceous-Tertiary Composite TPS of the Gulf of Mexico Basin consists of the total geographic extent of source and reservoir rocks (fig. 5).

Data Sources, Discovery History Analysis, and Forecast Period

The primary well and field production data used in the USGS assessment of the Gulf of Mexico Tertiary strata are proprietary commercial datasets of the IHS Energy Group (2005a,b) and Nehring Associates, Inc. (2006). Data from these commercial databases are subject to proprietary constraints, and the USGS may not publish, share, or serve any data from these databases. However, derivative representations in the form of graphs and summary statistics can be prepared and presented for each assessment unit. The IHS production database includes oil and gas production data for wells, leases, or producing units (collectively called “entities” in these databases). The IHS oil and gas wells database includes individual well data (including data for dry holes) such as well identification, locations, and information on penetrated and producing formations. Oil and gas field databases include location, geologic characterization, and oil and gas production data for domestic oil and gas fields and reservoirs (U.S. Geological Survey National Assessment Review Team, 2006). The USGS, however, cannot verify the accuracy, completeness, or currency of data reported in these commercial databases.

Interpretations of the lower Paleogene petroleum geology presented in this report are based on discovery history analysis of the spatial distribution of wells and known hydrocarbon reservoirs within a geographic information system (GIS). Spatial locations of lower Paleogene wells from IHS Energy Group (2005a,b), and hydrocarbon reservoirs from Nehring Associates, Inc. (2006) were examined using Esri software ArcMap 9.1. Other geologic data used in this assessment include the locations of Wilcox Group outcrop (Schruben and others, 1997; Warwick and others, 1997, 2002), major structural features of the Gulf of Mexico Basin (Ewing and Lopez, 1991), faults (Ewing and Lopez, 1991), salt (Ewing and Lopez, 1991; Lopez, 1995), geochemical data (Hood and others, 2002), Cenozoic depositional systems and shelf margins (Galloway and others, 2000), regional cross sections (Dodge and Posey, 1981; Bebout and Gutierrez, 1982, 1983; Eversull, 1984; Galloway and others, 1994), lower Paleogene isopach and structure maps (constructed from proprietary data contained in the IHS and Nehring databases), oil and gas field executive reference maps (Geomap, 1995a-e), and tectonic maps (Ewing and others, 1990). As an example of the spatial analysis, separation of lower Paleogene production well and reservoir data into AUs with different geologic characteristics (for example, stable shelf versus expanded fault zone) was completed through an evaluation of discovered reservoir depths, porosity-permeability-pressure-temperature characteristics, and reservoir thicknesses, in comparison with the
Elements of the Petroleum System

The Gulf of Mexico Basin is one of the world’s most important petroleum provinces (Nehring, 1991; Horn, 2003). As such, an abundance of research has been directed at understanding the generation, migration, and trapping of its hydrocarbon resources (Koons and others, 1974; Laplante, 1974; Nunn and Sassen, 1986; Evans, 1987; Sassen and Moore, 1988; Sassen and others, 1988; Walters and Dusang, 1988; Sassen, 1990; Thompson and others, 1990; Gregory and others, 1991; Price, 1991; McDade and others, 1993; Zimmerman and Sassen, 1993; Echols and others, 1994; Wagner and others, 1994; Wescott and Hood, 1994; Losh, 1998; Zimmerman, 1999; Nelson and others, 2000; Fillon, 2001; Gatenby, 2001; Hood and others, 2002; Lewan, 2002; Cathles, 2004; Mancini and others, 2006; among many others). Collectively, these workers have demonstrated that Gulf of Mexico Basin hydrocarbons are sourced from a number of stratigraphic intervals and that organic matter maturation and the generation and migration of hydrocarbon resources from a particular source interval are dependent on location within the basin. Most oils trapped in lower Paleogene strata are interpreted to be derived from the lower Tertiary stratigraphic intervals (fig. 6) (McDade and others, 1993; Hood and others, 2002). As described earlier, the conventional hydrocarbon resources contained in the approximately 1,250 known lower Paleogene reservoirs across the study area are considered to be part of the Upper Jurassic-Cretaceous-Tertiary Composite TPS that was defined for this assessment (fig. 5). Timing of the various elements of the Upper Jurassic-Cretaceous-Tertiary Composite TPS, which includes the stratigraphic position of major source rocks and the generation and accumulation of hydrocarbons in the lower Paleogene, are summarized in the events chart presented in figure 7.

Source Rocks and Thermal Maturation

Multiple source rock intervals (fig. 2) in the Gulf of Mexico Basin have been identified and discussed by numerous authors (Laplante, 1974; Evans, 1987; Sassen and Moore, 1988; Walters and Dusang, 1988; Jones, 1990; Price and Clayton, 1990; Sassen, 1990; Nehring, 1991; Price, 1991; Comet, 1992; Thompson and Kennicutt, 1992; McCrady and others, 1993; Zimmerman and Sassen, 1993; Echols and others, 1994; Wescott and Hood, 1994; Losh, 1998; Zimmerman, 1999; Nelson and others, 2000; Fillon, 2001; Gatenby, 2001; Hood and others, 2002; Lewan, 2002; Cathles, 2004; Mancini and others, 2006). The primary source rock intervals for Meso- and Cenozoic strata of the northern, onshore Gulf of Mexico coastal region are organic-rich shale and limestone/marl of the Eagle Ford (Turonian) and Smackover (Oxfordian) Formations (numbers 3 and 8 on fig. 6) and mudstone, claystone, and coaly intervals of the Wilcox Group (Paleocene-Eocene), with some contributions from interbedded shales of the Sparta Sand in the lowermost Claiborne Group (Eocene) (fig. 2 and number 2 on fig. 6) (Wenger and others, 1990; Price, 1991; McCrady and others, 1993; Hood and others, 2002).

For the current assessment, regional Wilcox Group thermal maturity data were obtained from the literature and unpublished databases to improve definitions of source rock maturity and distribution (Warwick, 2006; Dennen and others, 2010; Pitman and Rowan, 2012). Coal from the Wilcox Group ranges in coal rank from lignite at the outcrop to high volatile C bituminous at depths of about 1,675 m (~5,500 ft) (Warwick and others, 2006, 2008). For the thermal maturation modeling studies (Rowan and others, 2007; Pitman and Rowan, 2012) an average approximate total organic carbon (TOC) in weight percent for Wilcox source rocks was obtained from more than 1,000 outcrop and drill-hole samples; average TOC was determined to be 1.4 weight percent (fig. 8). The average is based on non-coaly samples (TOC values <10 percent) and samples with TOC values above a minimum value of 0.5 percent (fig. 8). Coal-rich samples with high TOC were excluded because they were over-represented in the database and the low TOC values were excluded because they did not have source rock potential. Wilcox mean vitrinite reflectance values (%Ro mean; n ≈ 450 samples) range from about 0.3 percent updip near the outcrop, to more than 1.5 percent at elevations lower than about 15,000 ft below sea level in south Texas (fig. 9). Locally, %Ro values exceed 4.0 percent in south Texas (Dow and others, 1988; Dennen and others, 2010) possibly due to updip fluid circulation along faults or other undefined geologic phenomena. Regional trends in the vitrinite reflectance data suggest that gradients of Wilcox maturity versus elevation are not as great in the northeastern part of the basin (Arkansas, Louisiana, and Mississippi) as they are in the southwest (Texas), thereby...
implying a general increase in Wilcox maturity towards the south (fig. 10). However, a general elevation to %Ro relationship, expressed as the y-intercept on figure 9, was used to generate a regional contour map of expected vitrinite reflectance on the structural top of the Wilcox Group (fig. 11). The Wilcox %Ro map (fig. 11) was mathematically derived from the structural contour map of the top of the Wilcox Group (fig. 3) using the y-intercept equation from figure 9 and a commercial mapping and well-log management software package. These mean %Ro data and the maturity map (fig. 11) were used to calibrate burial history models, which constrain the oil and gas generating capacity of Wilcox source rocks in the northern part of Gulf of Mexico Basin (Warwick, 2006; Rowan and others, 2007; Pitman and Rowan, 2012) (fig. 12). Figure 12 shows burial history models for two wells in northeastern and south Texas. The Wilcox strata in well 3-10 in northeastern Texas are still in the oil generation window, whereas well 21-13 in south Texas completed oil generation at about 20 Ma (mega-annum) (early Miocene). This relationship supports the general increase in Wilcox maturity towards the south as shown in figure 10.

### Migration of Hydrocarbons

Conventional oil and gas resources found in the shallow, immature section of the lower Paleogene in the Gulf of Mexico Coastal Plain are thought to have originated from updip or vertical migration of hydrocarbons produced from thermally mature source beds (Evans, 1987; Sassen, 1990; Price, 1991; Zimmerman and Sassen, 1993; Echols and others, 1995). Hydrocarbon migration in this area is illustrated by a diagram from Sassen (1990) that shows both vertical and updip oil and gas migration from mature Smackover, Eagle Ford, and Wilcox-Sparta source rocks in southern Louisiana (fig. 13). Updip migration of oil and gas from mature Wilcox-Sparta Sand source rocks is responsible for the shallow large oil accumulations in lower Paleogene strata in northeastern Louisiana and adjoining areas of southwestern Mississippi (Sassen, 1990). The updip migration of hydrocarbons may also be the best explanation for shallow oil and gas accumulations in the lower Paleogene subsurface of Texas; however, oil accumulation in lower Paleogene strata is less common in Texas. The importance of vertical migration of hydrocarbons should not be ignored. Hydrocarbons derived from any of the major Gulf Coast source rock intervals are liable to move vertically along the numerous conduits associated with the growth faults and salt domes (fig. 13). Echols and others (1995) argued that vertical hydrocarbon migration along faults is the dominate mechanism for charging shallow lower Paleogene reservoirs in northern Louisiana. Recent work by Warwick and others (2008) and McIntosh and others (2010) has shown that Wilcox Group coal beds may also serve as a source rock for biogenic gas generation, and isotopic data suggest that this biogenic gas is probably the source of much of the conventional gas produced from the Wilcox in northern Louisiana. This may also be the case in other parts of the basin where shallow accumulations of gas occur in the lower Paleogene.

### Table 4. Lower Paleogene Gulf Coast assessment results.

<table>
<thead>
<tr>
<th>Total Petroleum Systems (TPS) and Assessment Units (AU)</th>
<th>Field Type</th>
<th>Oil (MMBO)</th>
<th>Gas (BCFG)</th>
<th>NGL (MMBNGL)</th>
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<tbody>
<tr>
<td></td>
<td>F95</td>
<td>F50</td>
<td>F5</td>
<td>Mean</td>
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<tr>
<td>Wilcox Stable Shelf Oil and Gas AU (50470116)</td>
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<td>12</td>
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<td></td>
<td>Gas</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Wilcox Expanded Fault Zone Gas and Oil AU (50470117)</td>
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<td>18</td>
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<td>95</td>
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<tr>
<td></td>
<td>Gas</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Wilcox Slope and Basin Floor Gas AU (50470118)</td>
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<td>0</td>
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<tr>
<td></td>
<td>Gas</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Wilcox-Lobo Slide Block Gas AU (50470119)</td>
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<td>4</td>
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<tr>
<td></td>
<td>Gas</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total conventional resources</td>
<td></td>
<td>31</td>
<td>102</td>
<td>215</td>
</tr>
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Reservoir Rocks, Traps, and Seals of the Lower Paleogene Assessment Interval

Midway Group

Limited oil and gas production occurs from sand-rich intervals in the Midway Group in southern Texas (for example, the Poth sand; Palmer, 1954; Hopf, 1965, 1967, 1986a,b; Nehring, 1991) and in Mississippi (for example, the Clayton Formation; Warner and Moody, 1991). Because of the low number of Midway fields (9 fields, Nehring Associates, Inc., 2006), the Midway Group was combined with the Wilcox Group and Carrizo Sand of the Claiborne Group to form the lower Paleogene assessment interval. According to Nehring Associates, Inc. (2006), known resources (produced and reported reserves) from Midway Group reservoirs range from 325 to 2,280 million barrels of oil (MMBO) and 1,000 to 1,079 million cubic feet of gas. Midway Group hydrocarbon reservoirs are sandstone and the traps are a combination of structural and stratigraphic. Generally, traps are formed by growth faults, faulted anticlines, salt diapirs, and deltaic sandstone pinch outs.

Wilcox Group

The majority of oil and gas produced from the lower Paleogene assessment interval in the onshore Gulf Coastal region is from the Wilcox Group. Nehring Associates, Inc. (2006) identified 1,218 reservoirs that are associated with the Wilcox Group (see tables 2 and 3 for some reservoir names). Like the Midway Group, the Wilcox reservoirs are sandstone, and the traps are a combination of structural and stratigraphic. Traps are formed by growth faults, faulted rollover anticlines, salt diapirs, and fluvial and deltaic sandstone pinch outs.

Many studies have described Wilcox reservoir quality (Grubbs, 1953; Berg, 1979; Straccia, 1981; McBride and others, 1991; Goddard and others, 2002; Dutton and Loucks, 2007, 2008, 2010). In a typical example, Straccia (1981) describes the characteristics of Wilcox sandstone reservoirs of the Rosita gas field (fig. 14) that produce abundant gas from highly faulted reservoirs at depths of 9,500 to 15,300 ft. Reservoir quality varies according to rock type and degree of deformation, with porosity ranging from 8 to 25 percent and permeability ranging from 0.02 to 0.5 millidarcies (md). Goddard and others (2002) indicated that in the Livingston oil and gas field of southeastern Louisiana (fig. 15) the best reservoir quality is located within the uppermost 10 to 16 ft of a thick (40 to 70 ft) sandstone interval, where fine to very fine grained silty sandstone has porosity and permeability averaging 24 percent and 290 md, respectively. Porosity and permeability decrease toward the base of the sandstone interval. Two intra-reservoir impermeable hard layers were identified as barriers to vertical fluid movement in the reservoir. In general, Wilcox porosity and permeability decrease with depth (McBride and others, 1991), however, recent work by Dutton and Loucks (2007, 2008, 2010) indicates that an increase of microporosity by feldspar dissolution at depths greater than 19,500 ft may help to maintain some porosity and permeability for ultradep reservoirs. For additional discussions of individual Wilcox Group field characteristics, refer to Williams (1969), Galloway and others (1983), and Kosters and others (1989).

Carrizo Sand

In general, the Carrizo Sand has similar reservoir characteristics as those described above for the Wilcox Group. Because of the relatively few Carrizo Sand reservoirs (24) identified in the Nehring Associates, Inc. (2006) database, and because the Carrizo is generally included in Wilcox field completions, the unit was assessed as part of the lower Paleogene assessment interval (fig. 2). For a discussion of Carrizo Sand reservoir characteristics refer to Hamlin (1983, 1988), McBride and others (1991), and Enos and Kyle (2002). Examples of Carrizo Sand fields are discussed by Greenberg and Swinbank (1998).

Resource Assessment

In October of 2006, the USGS Gulf Coast Tertiary Assessment team met at the USGS offices in Denver, Colorado, to review the petroleum geology of the Tertiary stratigraphic interval for the onshore and State waters portion of the U.S. Gulf of Mexico Coastal Plain. The Paleogene strata were assessed by a team led by P.D. Warwick, whereas the Neogene strata were assessed by a team led by R.F. Dubiel. The results of the Tertiary assessment are contained in Dubiel and others (2007). Five assessment units (AUs) were established for the lower Paleogene assessment interval and are described below. The AUs include: Wilcox Stable Shelf Oil and Gas (50470116), Wilcox Expanded Fault Zone Gas and Oil (50470117), Wilcox Slope and Basin Floor Gas (50470118), Wilcox-Lobo Slide Block Gas (50470119), and Wilcox Mississippi Embayment (50470147) (fig. 16).
The AU numbering system was established by the USGS to facilitate petroleum resource assessment (U.S. Geological Survey, 2000). The unique number assigned to the Upper Jurassic-Cretaceous-Tertiary Composite TPS is 504701, of which “5” denotes the region (North America), “047” denotes the province (Western Gulf), and “01” denotes the TPS. Recent assessment studies in the Gulf region (Condon and Dyman, 2006; Dyman and Condon, 2006; Pitman and others, 2007) also are considered to be part of the Upper Jurassic-Cretaceous-Tertiary Composite. A review of the geologic model used to define the assessment units is presented below. Digital versions of the AU boundary lines are available for download at the following USGS Energy Resources Program website: https://energy.usgs.gov/OilGas/AssessmentsData/NationalOilGasAssessment/USBasinSummaries.aspx?provcode=5047.

In January 2007, the Paleogene and Neogene Gulf of Mexico assessment teams met in Denver to present to a USGS review panel a thorough analysis of all the available geologic data, petroleum exploration data, and petroleum development data for each AU. The result of the meeting was to arrive at consensus data values used for estimating the remaining hydrocarbon resources in each assessment unit (appendixes 1–4). Among these values were estimates of the sizes and numbers of undiscovered oil and gas accumulations, based on a tabulation of existing field and well records provided by Timothy Klett (written commun., 2007). The default minimum accumulation size that has potential for additions to reserves is 0.5 million barrels of oil equivalent (MMBOE) (Schmoker and Klett, 2005). Additional data compiled or calculated in appendixes 1 to 4 for each assessment unit to aid in the final estimate of undiscovered resources include gas to oil ratios, natural gas liquids to gas ratios, API gravity, sulfur content, and drilling depth. Additionally, allocations of undiscovered resources were calculated for Federal, State, and private lands and for various ecosystem regions. Table 4 summarizes the technically recoverable undiscovered resource results for each of the four assessed AUs and a total for the lower Paleogene. The Wilcox Mississippi Embayment AU was not quantitatively assessed.

**Geologic Model**

For the assessment of Paleogene strata (lower and upper parts), the USGS used a generalized structural and stratigraphic model to better define the various AUs for the Gulf of Mexico Coastal Plain (figs. 16 to 19). Each of the twenty-one assessed Paleogene AUs (four in Wilcox, six in the Claiborne, six in the Jackson/Vicksburg, and five in the Frio/Anahuac; figs. 2 and 17) has a well-defined zone of extensional growth faults where stratigraphic units have been greatly expanded (Ewing, 1990, 1991a,b). In general, growth faults were active during sedimentation. The primary factor that defines the onset of coastal plain expansion for a particular stratigraphic unit is the location of the shelf margin of the underlying stratigraphic unit (fig. 17). For example, the northwest boundary of the Wilcox expansion zone is defined by the underlying Lower Cretaceous shelf margin (fig. 17). The expansion zones for the younger stratigraphic intervals (Claiborne to Frio) were defined using a combination of the fault zone data of Ewing (1990, 1991a,b) and the paleo-shelf margins defined by Galloway and others (2000).

In the most simplistic interpretation of the model, three AUs (updip, middip, and downdip) were defined for each of the assessed stratigraphic intervals (the Wilcox, Claiborne, Jackson, and Vicksburg Groups; and the Frio, Hackberry, and Anahuac Formations) (fig. 18). Some of the stratigraphic intervals were further subdivided into upper and lower parts (table 1).

**Stable Shelf**

In the updip, stable shelf AU, relatively shallow reservoirs (mostly at a depth <8,000 ft) are characterized by minimal expansion due to growth faulting, and primarily consist of highstand and transgressive systems tracts including regional fluvial-deltaic complexes, delta mouth and barrier bars, shelf sandstones, and incised valley fill (AU 1, fig. 18). Reservoir facies may have high and predictable lateral continuity. Stratigraphic expansion is absent or minor and reservoir intervals are thin in AU 1 when compared to those in the middip AU (AU 2, fig. 18). Traps generally occur as faulted traps or roll-over anticlines against reactivated growth faults which flatten out in the underlying strata. Less frequent are back barrier sandstone pinchout stratigraphic traps. Reservoirs are normally pressured, usually produce both oil and gas by pumping, and eventually typically have a high water cut. In the Gulf of Mexico Coastal Plain, this AU constitutes a mature exploration and production trend, with few remaining undiscovered fields and little potential for field growth by infill development wells. Exploration in the updip stable shelf AU is very mature and production trends produce both oil and gas from reservoirs with normal temperature and pressure depth gradients. Based on thermal modeling studies (Rowan and others, 2007; Pitman and Rowan, 2012), Paleogene strata in the stable shelf AU are generally thermally immature, indicating that oil and gas produced in the area probably migrated from deeper mature source rocks (fig. 13). This interpretation is supported by production data from IHS Energy Group (2005a) and Nehring Associates, Inc. (2006).
**Expanded Fault Zone**

The mid dip, expanded fault zone AU exhibits the maximum amount of expansion for each of the assessed stratigraphic intervals (AU 2, fig. 18). The stratigraphic intervals in the expansion zone thicken to their maximum extent due to syndepositional growth faulting. The mid dip AU consists mostly of deltaic and marine highstand and lowstand systems tract sedimentary strata. Reservoir intervals in the mid dip AU range from thin to thick, and hydrocarbon exploration and production trends are characterized as mature to frontier. Reservoir pressure gradients range from normal to high due to the overpressured zones at depth. Based on production data (IHS, 2005a; Nehring Associates, Inc., 2006) and thermal modeling studies (Rowan and others, 2007; Pitman and Rowan, 2012), Paleogene strata in the mid dip expansion AU are generally mature to overmature with respect to oil and gas generation, indicating that some oil and predominately gas is produced from the AU.

In plan view, the expanded fault zone AU occurs over a relatively narrow area of the coastal plain, bracketing the contemporary shelf edge basinward of the stable shelf (fig. 16). Reservoirs are characterized by maximum stratigraphic expansion over syndepositional growth faults. Cumulative reservoir thickness increases greatly (fig. 18), although the thickness of individual sands is not necessarily greater than in the stable shelf environment. Reservoir sands are deep (mostly 8,000 to 12,000 ft) and consist of highstand and lowstand systems tracts including delta mouth and front facies, incised valley fill, outer shelf storm retreat sands, and upper slope sands occurring in turbidite and debrite deposits and slump blocks. Reservoir facies generally have low and unpredictable lateral continuity because of stratigraphic and structural complexities. Traps are associated with the ubiquitous contemporary growth faults, including rollover anticlines and upthrown and downthrown fault closures. Reservoirs are overpressured, remaining in hydrostatic isolation since their rapid deposition, and produce both non-associated gas and condensate by natural flow. Fields are highly compartmentalized and have a wide range of areal extents compared to those of the stable shelf (Galloway and others, 1983; Kosters and others, 1989; Bebout and others, 1992). In the Gulf coastal plain region, this AU constitutes late mature to frontier exploration and production trend with a high likelihood for new discoveries and excellent potential for development wells within existing fields.

**Slope and Basin Floor**

The downdip slope and basin floor AU occurs downdip of the expanded fault zone and is characterized by minimal to moderate expansion of reservoir sands due to their distal position with respect to contemporaneous shelf edge growth faulting (AU 3, fig. 18). Reservoir sands are deep (mostly >12,000 ft) and consist of distal highstand and lowstand systems tracts including slope turbidite fans, slope apron fans, shelf slump sands, incised valley fill, and blanket sand deposits on the basin floor (AU 3, fig. 18). Reservoir facies are laterally continuous, but their locations are hard to predict or project from shallower updip strata or depositional environments. Traps include stratigraphic pinchouts at sand body margins, complicated by structural offset resulting from growth faults, which sole out from the overlying expansion zone (fig. 18, fault zone 3). Reservoirs are likely to be overpressured, high-temperature, and produce nonassociated gas and condensate. For the lower Paleogene interval, this AU constitutes a hypothetical exploration and production trend with very high potential for new discoveries.

The downdip, slope and basin floor AU (AU 3, fig. 18) shows minor to no fault-related expansion and consists mostly of deltaic and marine distal highstand and lowstand systems tract sedimentary rocks. Reservoir intervals are thin to moderate when compared to the reservoir intervals in AU 2 (fig. 18). The slope and basin floor AU is defined as a frontier to hypothetical hydrocarbon production area due to the lack of drilling and production data from the area. Recent deep drilling (conducted mostly after the 2007 resource assessment) to Paleogene reservoirs in the Federal and State waters of Louisiana have proven the existence of petroleum charge and reservoirs in the Wilcox, Claiborne, Vicksburg, and Frio intervals beneath previously established Neogene pay horizons (Moffat, 2010; Enomoto, 2014). In these discoveries, reservoirs are under high temperature and pressure conditions due to deep burial. Based on thermal modeling studies (Rowan and others, 2007; Pitman and Rowan, 2012), Paleogene strata in the downdip expansion AU are likely to be overmature with respect to oil and gas generation, indicating that gas is the predominate hydrocarbon in the AU.

**Consequence of Progradation**

Each assessed Paleogene interval (fig. 2), consists of a period of dominant progradation into the Gulf of Mexico, a period of regional highstand and deposition of transgressive shale and thin marine sands, or a combination of the two periods. During dominantly progradational periods, deposition occurred in stable shelf environments on the landward margin of the basin, in expanded fault zone environments and slightly beyond at the contemporary shelf edge, and in slope and basin floor environments basinward of the contemporary shelf edge (fig. 18). This motif is repeated in each of the progradational clastic sequences, resulting in a systematic stepping-out of the three environments into the Gulf during deposition of each overlying
stratigraphic sequence. Within individual stratigraphic intervals (for example, the Wilcox or Claiborne Groups) the boundaries between the structural-depositional environments are time-transgressive (fig. 19). For example, the shelf margin gradually advances basinward, in effect bringing stable shelf structural-depositional environments over the previously deposited expansion zone within the same stratigraphic package (the Wilcox or Claiborne Group). In other words, the real boundaries between the structural-depositional environments overlap in plan view, and overlap in the depth range of reservoirs. For the purposes of the assessment and for the analysis of exploration and production history of individual AUs, this has the unintended consequence of misplacing discovered reservoirs which lie near the structural-depositional boundary between the stable shelf and expanded fault zone environments. Thus, characteristics of two AUs may be unintentionally grouped and assessed as one dataset.

Wilcox Stable Shelf Oil and Gas (AU 50470116)

The Wilcox Stable Shelf Oil and Gas Assessment Unit (figs. 16 and 20) extends from the approximate updip limit of Wilcox outcrop (Schruben and others, 1997) downdip to the Lower Cretaceous shelf margin as defined by Galloway and others (2000). IHS (2005a) data show shallow gas production within the outcrop zone of the Wilcox, so the shallow outcrop areas were included in the AU. The AU extends mainly across southeastern Texas, eastern Texas, and northern Louisiana, but also extends into Arkansas, Mississippi, and Alabama where local Wilcox production is present. The eastern boundary of the AU is the eastern boundary of the USGS Louisiana-Mississippi Salt Basin Province (fig. 16; U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995). The southwestern boundary of the AU is the United States-Mexico border. The downdip extent of the AU is the approximate updip boundary of the Wilcox expansion zone (fig. 17; Ewing, 1990). The AU includes the Paleocene-Eocene Midway and Wilcox Groups, and the Carrizo Sand of the lowermost Claiborne Group (Eocene) (fig. 2).

Wilcox Stable Shelf Oil and Gas Assessment Unit reservoir-size and (or) field-size data (from Nehring Associates, Inc., 2006) (fig. 20) show that oil and gas accumulations above the minimum cutoff sizes of 0.5 MMBO and 3 BCFG, respectively, are distributed throughout middip and downdip parts of the AU. Oil reservoirs are more common in northeastern Louisiana and southeastern Mississippi. Sassen (1990), Wenger and others (1994), and Hood and others (2002) indicated that Wilcox oil and gas production in this area is primarily derived from lower Tertiary marine source rocks that in some places is mixed with oil and gas derived from Upper Cretaceous marine source rocks (figs. 6 and 13). In Texas, gas reservoirs are more common in the downdip areas of the AU (fig. 20); however, oil is more prevalent in the shallow, updip parts of the AU. Wilcox petroleum produced from Texas is suggested by several studies to be primarily derived from lower Tertiary terrestrial source rocks (fig. 6). Interestingly, the downdip parts of the AU in northeastern Texas and central and southern Louisiana have few reservoirs and (or) fields that meet the minimum accumulation cutoff requirements for the assessment.

The Wilcox Stable Shelf Oil and Gas AU is a mature exploration area, where more than 45,000 drill holes have penetrated the Wilcox interval within the AU boundaries (IHS, 2005b). Geographic information system files that illustrate the density of drilling and production for the Wilcox Stable Shelf Oil and Gas AU can be downloaded from the USGS Energy Resources Program Gulf Coast website at: https://energy.usgs.gov/OilGas/AssessmentsData/NationalOilGasAssessment/USBasinSummaries.aspx?provcode=5047.

For the purposes of the assessment, an analysis of accumulation discovery year and accumulation size is helpful to predict the potential sizes and numbers of undiscovered accumulations of both gas and oil for each AU. Figures 21 and 22 show the results of both discovered oil and gas accumulations for the Wilcox Stable Shelf Oil and Gas AU shown on figure 20. The discovered accumulations have been divided into thirds, based on the year of discovery, and a median size is indicated for each discovery third. Expected undiscovered minimum, median, and maximum field sizes are shown on the right of each plot for an undetermined time in the future. For both oil and gas, maximum undiscovered accumulation sizes are expected to decrease, however, undiscovered median accumulation sizes are not expected to decline significantly from the present value (figs. 21 and 22). Input data for the AU can be found in appendix 1 of this report.

The results of the assessment for the Wilcox Stable Shelf Oil and Gas AU are given on table 4. The estimate mean technically recoverable undiscovered resources for the AU are as follows: 54 MMBO; 472 BCFG; and 15 MMBNGL.

Wilcox Expanded Fault Zone Gas and Oil (AU 50470117)

The updip limit of the Wilcox Expanded Fault Zone Gas and Oil AU is defined by the updip boundary of the Wilcox expansion zone (fig. 17; Ewing, 1990), and the trace of the Lower Cretaceous shelf margin as defined by Galloway and others (2000) (fig. 17). The downdip boundary is approximately the updip boundary of the Claiborne expansion zone (Ewing, 1990), and the trace of the upper Wilcox shelf margin (Galloway and others, 2000) (fig. 17). The AU narrows towards the eastern boundary, which is formed by the Louisiana State/Federal water boundary (fig. 16). The southwestern boundary is the northernmost extent of the Wilcox-Lobo slide-block deformation as defined by the seismic interpretations of Anderson and
Fiduk (2003). The AU includes the Paleocene-Eocene Midway and Wilcox Groups, and the Carrizo Sand of the lowermost Claiborne Group (fig. 2).

Wilcox Expanded Fault Zone Gas and Oil AU reservoir-size and (or) field-size data (from Nehring Associates, Inc., 2006) (fig. 23) shows that oil and gas accumulations above the minimum cutoff sizes of 0.5 MMBO and 3 BCFG, respectively, are most abundant in the Texas portion of the AU. Wilcox petroleum (primarily gas) produced from Texas is suggested to be sourced from lower Tertiary terrestrial source rocks (Sassen, 1990; Wenger and others, 1994; and Hood and others, 2002) (fig. 6). The updip parts of the AU in Texas and areas in central Louisiana may not be adequately explored or they have few reservoirs that meet the minimum accumulation cutoff requirements for the assessment.

The Wilcox Expanded Fault Zone Gas and Oil AU is a moderately mature exploration area, with more than 2,500 dry holes that penetrated the Wilcox interval within the AU boundaries and approximately 500 oil or gas reservoirs and (or) fields identified (IHS, 2005b; Nehring Associates, Inc., 2006). Geographic information system files that illustrate the density of drilling and production for the Wilcox Expanded Fault Zone Gas AU can be downloaded from the USGS Energy Resources Program Gulf Coast website at: https://energy.usgs.gov/OilGas/AssessmentsData/NationalOilGasAssessment/USBasinSummaries.aspx?provcode=5047.

For the purposes of the assessment, an analysis of accumulation discovery year and accumulation size is helpful to predict the potential sizes and numbers of undiscovered accumulations of both gas and oil for each AU. Figures 24 and 25 show the results of discovered oil and gas accumulations for the AU. The discovered accumulations have been divided into thirds, based on the year of discovery and the median discovered accumulation size is indicated for each discovery third. Expected undiscovered minimum, median, and maximum field sizes are shown on the right of each plot for an undetermined time in the future. For both oil and gas, maximum accumulation sizes are expected to decrease, however, undisclosed median accumulation sizes are not expected to decline significantly (figs. 24 and 25). Input data for the AU can be found in appendix 2 of this report. The expected reservoir depths for undiscovered oil reservoirs range from 6,000 to 15,000 ft, and the expected gas reservoir depth for undiscovered gas reservoirs range from 6,000 to 20,000 ft.

The results of the assessment for the Wilcox Expanded Fault Zone Gas and Oil AU are given on table 4. The estimated mean technically recoverable undiscovered resources for the AU are as follows: 52 MMBO; 2,498 BCFG; and 75 MMBNGL.

**Wilcox-Lobo Slide Block Gas (AU 50470119)**

The northeastern and northwestern boundaries of the Wilcox-Lobo Slide Block Gas AU (figs. 26 and 27) were drawn to include the area of lower Tertiary slide block deformation as defined by the seismic interpretations of Anderson and Fiduk (2003) (fig. 27). The downdip, southeastern boundary is based on limited (or sparse) proprietary seismic data that show diminished lower Tertiary slide-block deformation styles towards the modern Texas coast. The AU also includes the lower Wilcox Lobo structural and depositional basin that has been described by Adams (1993), Schenk and Viger (1996b), and Stricklin (1996). The southwestern boundary of the AU is the United States-Mexico border. The AU includes the Paleocene-Eocene Midway and Wilcox Groups, and the Carrizo Sand of the lowermost Claiborne Group (fig. 2).

Wilcox-Lobo Slide Block Gas Assessment Unit reservoir-size and (or) field-size data (from Nehring Associates, Inc., 2006) (fig. 26) show that gas and a few oil reservoirs above the minimum cutoff sizes of 3 BCFG and 0.5 MMBO, respectively, are distributed throughout the updip half of the AU. The downdip, southeastern half of the AU is relatively unexplored and has no established production. Wilcox petroleum produced from the Wilcox-Lobo Slide Block Gas AU is suggested to be generated from lower Tertiary terrestrial source rocks (fig. 6) (Wenger and others, 1994; Hood and others, 2002).

The updip northwestern half of the Wilcox-Lobo Slide Block Gas AU is a well explored area, with more than 800 drill holes that penetrated the Wilcox interval (IHS, 2005b). However, relatively few (<75) wells have been drilled to test the Wilcox interval in the downdip part of the AU. With the exception of the structural deformation style of the AU (fig. 27), reservoir characteristics of the updip part of the AU are similar to those described above for the Wilcox Expanded Fault Zone Gas and Oil AU. The reservoir characteristics of the updip areas of the AU are thought to be similar to those for the Wilcox Slope and Basin Floor Gas AU. Geographic information system files that illustrate the density of drilling and production for the Wilcox-Lobo Slide Block Gas AU can be downloaded from the USGS Energy Resources Program Gulf Coast website at: https://energy.usgs.gov/OilGas/AssessmentsData/NationalOilGasAssessment/USBasinSummaries.aspx?provcode=5047.

For the purposes of the assessment, an analysis of accumulation discovery year and accumulation size is helpful to predict the potential sizes and numbers of undiscovered accumulations of both gas and oil for each AU. Figures 28 and 29 show the results of both discovered oil and gas accumulations for the Wilcox-Lobo Slide Block Gas AU. For oil, there are only five oil accumulations in the AU, and these have been divided into two groups (halves) based on the accumulation discovery year (fig. 28). The median discovered accumulation size is indicated for each discovery half. Expected undiscovered minimum, median, and maximum accumulation sizes are shown on the right of the plot for an undetermined time in the future that will use current recovery technologies. Maximum undiscovered oil accumulation sizes are expected to maintain their sizes, whereas the median...
undiscovered oil accumulation size is expected to decline (fig. 28). For gas, the discovered accumulation sizes have been divided into thirds, based on the year of discovery (fig. 29). The median discovered accumulation size is indicated for each discovery third. Expected undiscovered minimum, median, and maximum field sizes are shown on the right of the plot for an undetermined time in the future. Both the maximum and median undiscovered accumulation sizes are expected to be maintained at present values for an undetermined time in the future (fig. 29). Input data for the AU can be found in appendix 3 of this report.

The results of the assessment for the Wilcox-Lobo Slide Block Gas AU are given on table 4. The estimated mean technically recoverable undiscovered resources for the AU are as follows: 4 MMBO; 7,521 BCFG; and 126 MMBNGL.

Wilcox Slope and Basin Floor Gas (AU 50470118)

The updip extent of the Wilcox Slope and Basin Floor Gas AU (fig. 30) is the approximate updip boundary of the Claiborne expansion zone (figs. 16 and 17; Ewing, 1990), and the trace of the upper Wilcox shelf margin defined by Galloway and others (2000). The eastern boundary of the AU is the Louisiana State/Federal water boundary. The southwestern boundary is the United States-Mexico border. The downdip boundary is the Texas-Louisiana State/Federal water boundary. The AU includes the Paleocene-Eocene Midway and Wilcox Groups, and the Carrizo Sand of the lowermost Claiborne Group (fig. 2).

There are only two reservoir-size and field-size data points in the Wilcox Slope and Basin Floor Gas AU (Nehring Associates, Inc., 2006) (fig. 30). These gas accumulations are on the updip margin of the AU and are probably an extension of the Wilcox Expanded Fault Zone Gas and Oil AU described above. The AU is a frontier exploration area, with only about 180 drill holes that penetrate some portion of the Wilcox interval within the AU boundaries (IHS, 2005b). Geographic information system files that illustrate the density of drilling and production for the Wilcox Slope and Basin Floor Gas AU can be downloaded from the USGS Energy Resources Program Gulf Coast website at: https://energy.usgs.gov/OilGas/AssessmentsData/NationalOilGasAssessment/USBasinSummaries.aspx?provcode=5047.

Because very little production has occurred in the Wilcox Slope and Basin Floor Gas AU, an analysis of accumulation discovery year and accumulation size is not possible. Recent exploration and discoveries of Wilcox gas in the deep, offshore part of the basin indicate that several thousand feet of Wilcox strata, containing thick (~1,000 ft) intervals of Wilcox sandstone-dominated reservoirs are preserved in the distal parts of the basin (Meyer and others, 2005, 2007). Analysis of reservoir quality in the deep (>19,000 ft) onshore Wilcox interval suggests the presence of sandstone reservoirs that maintain some porosity and permeability (Dutton and Loucks, 2007, 2008, 2010). Given the probable widespread occurrence of sandstone reservoirs in slope and basin floor Wilcox environments, and the limited deep drilling information from the AU, the USGS assessment team reports a broad range of uncertainties for the resource potential for the Wilcox Slope and Basin Floor Gas AU (table 4). Input data for the AU can be found in appendix 4 of this report. The expected reservoir depths for undiscovered oil range from 6,000 to 15,000 ft, and for gas reservoirs expected depths range from 13,000 to 30,000 ft.

The results of the assessment for the Wilcox Slope and Basin Floor Gas AU are given on table 4. The mean technically recoverable undiscovered resources for the AU are as follows: 26,398 BCFG; and 423 MMBNGL.

Wilcox Mississippi Embayment (AU 50470147)

The Wilcox Mississippi Embayment AU extends northward from the Wilcox Stable Shelf Oil and Gas AU and the Louisiana-Mississippi Salt Basin Province boundary (fig. 16) to the updip extent of Wilcox-age strata that crop out on the margins of the Mississippi embayment. Cushing and others (1964) presented a detailed discussion of the geology of the Mississippi embayment and Coleman and Pratt (2015) have reviewed the petroleum potential of the Reelfoot rift and overlying sediments of the northern part of the Mississippi Embayment AU (fig. 1). The AU includes the Paleocene-Eocene Midway and Wilcox Groups, and the Carrizo Sand of the lowermost Claiborne Group (fig. 2). This AU was not formally assessed by the USGS because of the low resource potential for hydrocarbons in the area (Dubiel and others, 2007).

Comparison of Results of the Lower Paleogene Assessment with other 2007 U.S. Geological Survey Tertiary Assessments

The summary graphs of the Gulf Coast region (fig. 31) show the results of all USGS 2007 assessed undiscovered oil and gas resources in the Gulf Coast region (total of 22,689 MMBOE). Figure 31A illustrates the results of the lower Paleogene AUs, whereas figure 31B shows the results of the Tertiary stratigraphic AUs. The Wilcox Stable Shelf Oil and Gas AU contains the most undiscovered oil and the least amount of undiscovered gas resources of all the assessed AUs in the lower Paleogene assessment interval. The Wilcox Expanded Fault Zone Gas and Oil AU contains similar amounts of undiscovered oil as might be found in the updip Wilcox Stable Shelf Oil and Gas AU, and significantly more gas than found in the shallow parts for the basin.
The Wilcox-Lobo Slide Block Gas AU contains the second greatest undiscovered accumulations of gas and the third greatest accumulation of undiscovered oil in comparison to the other lower Paleogene AUs. The assessment results for the Wilcox Slope and Basin Floor Gas AU indicates that the AU is dominated by gas and is estimated to hold about one third (or 26.4 trillion cubic feet) of the undiscovered gas resources for all of the Wilcox assessed intervals. Of the assessed total of undiscovered conventional resources in the Gulf Coast Tertiary (22,689 MMBOE), the Wilcox and Neogene AUs contain more than 50 percent of the remaining resources, 30.4 percent and 23.2 percent, respectively (fig. 31B).

Summary

The U.S. Geological Survey (USGS) recently conducted an assessment of the undiscovered, technically recoverable conventional oil and gas resources in Paleogene sediments underlying the U.S. Gulf of Mexico Coastal Plain and State waters. For purposes of the assessment, an Upper Jurassic-Cretaceous-Tertiary Total Petroleum System (TPS) was defined for the entire Gulf of Mexico Basin. Paleogene strata were divided into the following stratigraphic study intervals and assessed accordingly: (1) Wilcox Group (including the Midway Group and the basal Carrizo Sand of the Claiborne Group; Paleocene-Eocene); (2) Claiborne Group (Eocene); (3) Jackson and Vicksburg Groups (Eocene-Oligocene); and (4) Frio and Anahuac Formations (Oligocene). Based on a generalized structural and stratigraphic model, each assessed Paleogene stratigraphic interval was subdivided into an updip, stable shelf assessment unit (AU); a middip, expanded fault zone AU; and a downdip, slope and basin floor AU. A significant controlling factor for the location of the middip expansion zone AU is the location of underlying, stratigraphically older shelf margins. Using the geology-based assessment methodology, the USGS assessed a mean of 36.9 trillion cubic feet (or 6,148 MMBOE) of undiscovered, technically recoverable natural gas; a mean of 110 million barrels of undiscovered, technically recoverable oil; and a mean of 0.6 billion barrels of undiscovered, technically recoverable natural gas liquids in the Midway and Wilcox Groups and the Carrizo Sand of the Claiborne Group. A significant portion of these undiscovered resources (26.4 trillion cubic feet of gas, or 4,400 MMBOE) is estimated to occur in the Wilcox Slope and Basin Floor Gas AU.

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Figures 1–31
**Figure 2.** Generalized stratigraphic section of the northern Gulf of Mexico Coastal Plain showing gas (red triangles) and oil (green circles) occurrences, potential shale source rocks (blue boxes), and potential coal source rocks (red stars). Numbered intervals refer to the major Paleogene and Neogene, and coalbed gas assessment intervals assessed by the U.S. Geological Survey in 2007 including: (1) lower Paleogene (Midway, Wilcox, and Carrizo Sand) reported in this chapter, (2) Claiborne, (3) Jackson and Vicksburg, (4) Frio, Anahuac, and Hackberry, (5) Miocene, (6) Plio-Pleistocene, (C1) Olmos-Escondido coalbed gas, (C2) Wilcox coalbed gas, and (C3) Cretaceous-Tertiary coalbed gas. Abbreviations: Holo., Holocene; L., Lower; Mid., Middle; Pal., Paleocene; Plei., Pleistocene; Tri., Triassic; Quat., Quaternary; Up., Upper. Vertical lines represent an unconformity; wavy line, disconformity; jagged line, interfingering; dashed line, uncertain (modified from Salvador and Quezada Muñeton, 1991; Nehring, 1991; Humble Geochemical Services and others, 2002; and Warwick and others, 2007b). The time scale follows Palmer and Geissman (1999) and U.S. Geological Survey Geologic Names Committee (2007, 2010).
Figure 3. Structure contour map for the top of the Wilcox Group. The map is based on more than 42,000 wells where the top of the Wilcox Group has been determined from the IHS database (IHS Energy Group, 2005b). Structure contours have been extended to beyond the coastal areas by using control points based on depths to the top of the Wilcox from regional cross sections and seismic lines (Ewing, 1991a; Salvador, 1991). Recent, ultra-deep Wilcox wells in the outer continental shelf have not been incorporated into this map. The contours have been smoothed to remove the local effect of uplifts associated with salt structures. Outcrops of the Wilcox Group are from Warwick and others (1997).
Figure 4. Generalized isopach map of the Wilcox Group (modified from Barker and others, 2009). Outcrop geology from Warwick and others (1997); Lower Cretaceous (K) shelf margin is from Galloway and others (2000).
Figure 5. Upper Jurassic-Cretaceous-Tertiary Composite Total Petroleum System (TPS) for the Gulf of Mexico Basin. Refer to Warwick and others (2007b) for a discussion on how the TPS boundary was drawn.
Figure 6. Map showing the ages and distribution of trapped petroleum from correlated source rocks in the northern Gulf of Mexico region. The complex two-dimensional pattern of the source rock ages, depositional setting, salinity, and sulfur content was derived from oil geochemistry data and suggests numerous three-dimensional petroleum systems are in the region. "Intermediate" denotes a depositional environment that is transitional between marine and terrestrial; "centered on" denotes primary interval (modified from Wenger and others, 1994; Hood and others, 2002; and Warwick and others, 2007b).
Figure 7. Events chart summarizing the major elements of the Upper Jurassic-Cretaceous-Tertiary Composite Total Petroleum System (TPS) of the northern Gulf of Mexico Basin. This events chart shows the Midway-Wilcox-Carrizo Sands AUs of the TPS. To show all AUs of the TPS would require a more complex chart. The critical moment is defined as the point in time (marked by arrow) that best represents the generation, migration, and accumulation of most of the hydrocarbons in the Upper Jurassic-Cretaceous-Tertiary Composite TPS (modified from Condon and Dyman, 2006).

Abbreviations: E, Early; Fm., Formation; L, Late; M, Middle; Ma, mega-annum; Olig., Oligocene; P, Pleistocene; Paleo., Paleocene; Po, Pliocene; Quat., Quaternary; Triassic.
Figure 8. Sequential plot of Wilcox Group total organic carbon (TOC) content data in weight percent obtained from more than 1,000 outcrop and drill-hole samples. The averages for all samples and for samples with less than 10 percent TOC and greater than 0.5 percent TOC are shown. Data are from Dennen and others (2010).
Figure 9. Wilcox Group mean vitrinite reflectance (%Ro) values plotted by sample elevation. Data are from Dennen and others (2010).

\[ y = -10908\ln(x) - 13501 \]

\[ R^2 = 0.5173 \]
Figure 10. Regional trends in the mean vitrinite reflectance (%Ro) data suggesting that gradients of Wilcox maturity versus elevation are not as great in the northeastern part of the basin (Arkansas, AR; Louisiana, LA; and Mississippi, MS) as they are in the southwest (Texas, TX). This implies a general increase in Wilcox maturity towards the south. Data are from Dennen and others (2010).
Figure 11. Present-day thermal maturity model for the top of the Wilcox Group. The map was mathematically derived from the structural contour map of the top of the Wilcox Group (fig. 3) using the y-intercept equation for the best-fit curve of vitrinite reflectance and elevation shown on figure 9. Outcrop geology from Warwick and others (1997).
Figure 12. Burial history curves for two Wilcox wells in Texas where mean vitrinite reflectance (%Ro) and bottom-hole-temperature (BHT) data were available. The green shaded area in A and B represents the oil window for the Wilcox, defined by transformation ratios (TR). The onset, peak, and end of oil generation in the Wilcox, are represented by 1 percent, 50 percent, and 99 percent TR curves, respectively. The curves were calculated using kinetic parameters for the Wilcox listed in Rowan and others (2007, table 4). The 0.5 %Ro contour represents the onset of gas generation from Type III kerogen. A, Well 3-10; B, Well 21-13; and C, locations of burial history models discussed in Rowan and others (2007). Solid green squares indicate wells for which BHT data were available and black circles show locations of %Ro data from the Wilcox Group. The Lower Cretaceous shelf edge is shown for reference (Ewing and Lopez, 1991, plate 2). Red circles show locations of Wells 3-10 and 21-13. Abbreviations: ft, feet; km, kilometers; L, lower; M, middle; U, upper.
Figure 13. Migration pathways of oil and gas in southern Louisiana. A, Line of cross section showing geologic framework, stratigraphic units, source rocks, and proposed migration pathways. B, Map showing location of cross section in A (red line). Modified from Sassen (1990). Abbreviations: km, kilometers; mi, miles.
Figure 14. Petroleum geology of the Rosita field that produces from the Wilcox Group in south Texas. A. Location map. B. Generalized cross section illustrating the major faults and sandstones in the Rosita field. C, Structure contour map of the “R” sand and location of the cross section in B. D, Grain size, composition, and bedsets of part of the middle “V” sand in the Shell Stegal 1A well (location of well shown on C). Modified from Straccia (1981). Abbreviations: f, fine; ft, feet; km, kilometer; m, medium; max, maximum; s, silt; vf, very fine.
Figure 15. Petroleum geology of the Livingston field that produces from the Wilcox Group in southeastern Louisiana. 

**A.** Location map. **B.** Depositional model for Wilcox Group barrier island sandstone deposits in the Livingston field (modified from Reinson, 1984; and Goddard and others, 2002). **C.** Structure contour map of the “1st Wilcox Sand”, Livingston field. An east-west structural trend and a slight rollover toward the northern east-trending fault can be observed. **D.** Geophysical log from the well with an arrow shown on C. From Goddard and others (2002).

Abbreviations: ϕ, porosity; K, permeability; md, millidarcies; ft, feet.
Figure 16. Assessment units (AUs) and their boundaries for the lower Paleogene (Midway-Wilcox-Carrizo Paleocene-Eocene) stratigraphic intervals (fig. 2). The U.S. Geological Survey Region 6 Province boundaries (heavy black lines) are from the U.S. Geological Survey National Oil and Gas Resource Assessment Team (1995). See text for a discussion of how the AU boundaries were determined. Abbreviations: TPS, total petroleum system.
Figure 17. Generalized cross section showing Tertiary expansion zones across the south Texas Gulf of Mexico Coastal Plain (modified from Ewing, 1991b; and Warwick and others, 2007b). Abbreviations: km, kilometers; mi, miles.
Figure 18. Model used to define assessment units (AUs) in the U.S. Geological Survey assessment of Paleogene strata in Gulf of Mexico onshore and State water areas. Assessment unit 1 (AU 1) defines the stable shelf structural area (shown by the blue stratigraphic unit); AU 2 defines the main unit expansion and thickening zone (shown by the blue stratigraphic unit); and AU 3 is composed of sediments deposited in slope and basin floor depositional environments (shown by the blue stratigraphic unit). Modified from Swanson and others (2013).

AU 1: Mostly highstand and transgressive systems tracts; unit expansion is absent or minor (in blue stratigraphic unit); thin reservoir intervals; very mature exploration and production trend; normal temperature and pressure gradient.

AU 2: Mostly highstand and lowstand systems tracts; major fault extension and unit expansion (in blue stratigraphic unit); thin to thick reservoir intervals; mature to frontier exploration and production trend; normal and high pressure; normal to high temperature gradient.

AU 3: Mostly distal highstand and lowstand systems tracts; minor to no unit expansion (in blue stratigraphic unit); thin to moderate reservoir intervals; frontier to hypothetical production trend; probably high temperature and pressure gradient.
Figure 19. Stacked reservoirs and assessment units (AUs) in the Gulf Coast Tertiary assessment model showing the offset and overlapping character of the assessment units through time and the advance of the shelf margin basinward (see fig. 17).
Figure 20. Wilcox Stable Shelf Oil and Gas Assessment Unit (AU), showing oil and gas accumulations (reservoirs) that existed at the time of the assessment. Field and reservoir data are from Nehring Associates Inc. (2006). Outcrop geology from Warwick and others (1997). Abbreviations: BCFG, billion cubic feet of gas; MMBO, million barrels of oil; TPS, Total Petroleum System.
Figure 21. Plot of grown oil accumulation size versus discovery year for the Wilcox Stable Shelf Oil and Gas Assessment Unit (AU). Also shown are the expected sizes of future oil accumulations. Data from Nehring Associates Inc. (2006) and T.R. Klett (written commun., 2006). Abbreviations: MMBO, million barrels of oil.
Figure 22. Plot of grown gas accumulation size versus discovery year for the Wilcox Stable Shelf Oil and Gas Assessment Unit (AU). Also shown are the expected sizes of future gas accumulations. Data from Nehring Associates Inc. (2006) and T.R. Klett (written commun., 2006). Abbreviations: BCFG, billion cubic feet of gas.
Figure 23. Wilcox Expanded Fault Zone Gas and Oil Assessment Unit (AU), showing oil and gas accumulations. Field and reservoir data from Nehring Associates Inc. (2006). Outcrop geology from Warwick and others (1997). Abbreviations: BCFG, billion cubic feet of gas; MMBO, million barrels of oil; TPS, Total Petroleum System.
Figure 24. Plot of grown oil accumulation size versus discovery year for the Wilcox Expanded Fault Zone Gas and Oil Assessment Unit (AU). Also shown are the expected sizes of future oil accumulations. Data from Nehring Associates Inc. (2006) and T.R. Klett (written commun., 2006). Abbreviations: MMBO, million barrels of oil.
Figure 25. Plot of grown gas accumulation size versus discovery year for the Wilcox Expanded Fault Zone Gas and Oil Assessment Unit (AU). Also shown are the expected sizes of future gas accumulations. Data from Nehring Associates Inc. (2006) and T.R. Klett (written commun., 2006). Abbreviations: BCFG, billion cubic feet of gas.
Figure 26. Wilcox-Lobo Slide Block Gas Assessment Unit (AU), showing oil and gas accumulations. Field and reservoir data from Nehring Associates Inc. (2006). Outcrop geology from Warwick and others (1997). Abbreviations: BCFG, billion cubic feet of gas; MMBO, million barrels of oil.
Figure 27. Structural characteristics of the Wilcox-Lobo Slide Block Gas Assessment Unit (AU). A, Regional location map and location of seismic section lines. B, Drawing of east-west oriented Line A across the Wilcox detachment and “raft” structures. C, Line B showing extension of Cretaceous strata associated with “raft” structures. Modified from Fiduk and Hamilton (1995); Anderson and Fiduk (2003). Abbreviations: ft, feet; m, meters.
Figure 28. Plot of grown oil accumulation size versus discovery year for the Wilcox-Lobo Slide Block Gas Assessment Unit (AU). Also shown are the expected sizes of future oil accumulations. Data from Nehring Associates Inc. (2006) and T.R. Klett (written commun., 2006). Abbreviations: MMBO, million barrels of oil.
Figure 29. Plot of grown gas accumulation size versus discovery year for the Wilcox-Lobo Slide Block Gas Assessment Unit (AU). Also shown are the expected sizes of future gas accumulations. Data from Nehring Associates Inc. (2006) and T.R. Klett (written commun., 2006). Abbreviations: BCFG, billion cubic feet of gas.
Figure 30. Wilcox Slope and Basin Floor Gas Assessment Unit (AU), showing gas accumulations. Field and reservoir data from Nehring Associates Inc. (2006). Outcrop geology from Warwick and others (1997). Abbreviations: BCFG, billion cubic feet of gas; TPS, Total Petroleum System.
Figure 31. U.S. Geological Survey Gulf Coast assessment results. A, Results for all lower Paleogene undiscovered, technically recoverable conventional oil, gas, and natural gas liquids. B, Results for all Tertiary undiscovered, technically recoverable conventional oil, gas, and natural gas liquids (Dubiel and others, 2007). The percentages shown are of the Gulf Coast Tertiary total of 22,689 MMBOE and are by major assessment intervals and lower Paleogene assessment units. Abbreviations: AUs, Assessment Units; MMBOE, million barrels of oil equivalent; NGL, natural gas liquids.
Appendix 1. Input Data Form for the Wilcox Stable Shelf Oil and Gas Assessment Unit (50470116)

Input data form in appendix 1 for evaluating the Wilcox Stable Shelf Oil and Gas Assessment Unit (50470116). [Abbreviations: accum., 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; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; NGL, natural gas liquids; no., number]
Appendix 2.  Input Data Form for the Wilcox Expanded Fault Zone Gas and Oil Assessment Unit (50470117)

Input data form in appendix 2 for evaluating the Wilcox Expanded Fault Zone Gas and Oil Assessment Unit (50470117). [Abbreviations: accum., 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; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; NGL, natural gas liquids; no., number]
Appendix 3. Input Data Form for the Wilcox-Lobo Slide Block Gas Assessment Unit (50470119)

Input data form in appendix 3 for evaluating the Wilcox-Lobo Slide Block Gas Assessment Unit (50470119). [Abbreviations: accum., 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; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; NGL, natural gas liquids; no., number]
Appendix 4. Input Data Form for the Wilcox Slope and Basin Floor Gas Assessment Unit (50470118)

Input data form in appendix 4 for evaluating the Wilcox Slope and Basin Floor Gas Assessment Unit (50470118). [Abbreviations: accum., accumulations; AU, assessment unit; bcfg, billion cubic feet of gas; bliq/mmcf, barrels of liquid per million cubic feet of gas; bngl/mmcf, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; NGL, natural gas liquids; no., number]