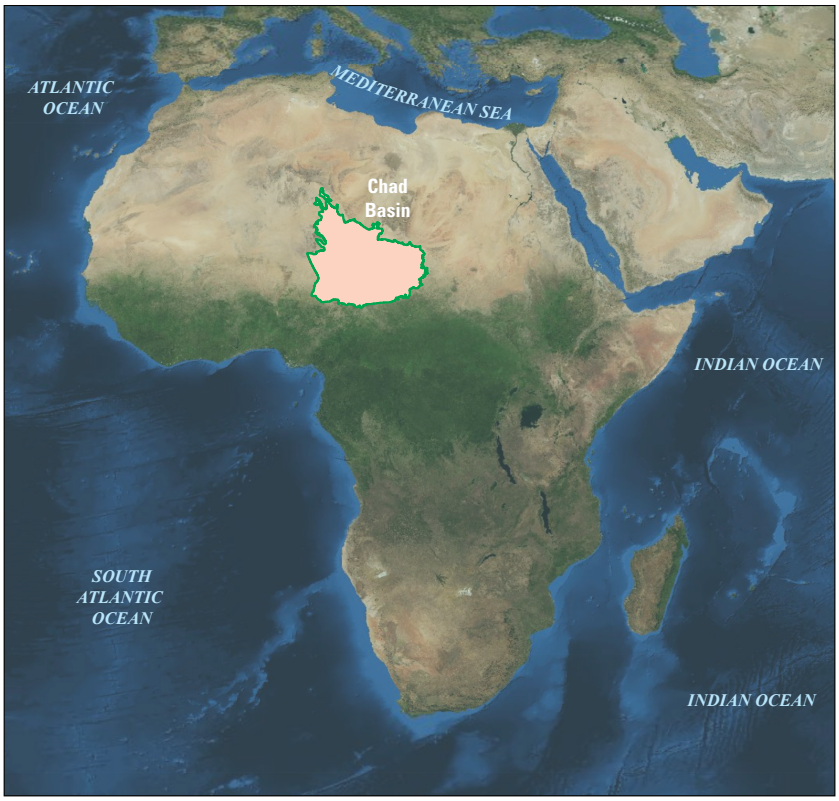
Assessment of Undiscovered Oil and Gas Resources of the Chad Basin Province, North-Central Africa

By Michael E. Brownfield



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Chapter 6 of
Geologic Assessment of Undiscovered Hydrocarbon Resources of Sub-Saharan Africa
Compiled by Michael E. Brownfield

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Abbreviations Used in This Report

km^2	square kilometers
m	meter
mg/g	milligram per gram
AU	assessment unit
TOC	total organic carbon
TPS	total petroleum system
USGS	U.S. Geological Survey

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Abstract

The main objective of the U.S. Geological Survey's National and Global Petroleum Assessment Project is to assess the potential for undiscovered, technically recoverable oil and natural gas resources of the United States and the world. As part of this project, the U.S. Geological Survey completed an assessment of the Chad Basin Province in north-central Africa. The Chad Basin is the largest intracratonic basin in north-central Africa and is characterized by Cretaceous and Tertiary rifting. The province covers an area of approximately 1,145,000 square kilometers and includes parts of Algeria, Cameroon, Chad, Niger, and Nigeria. This assessment was based on data from oil and gas wells and fields, field production records, and published geologic reports.

The Chad Basin Province was assessed because of increased energy exploration and interest in its future oil and gas resource potential. The assessment was based on geology and used the total petroleum system concept. The geologic elements of a total petroleum system consist of hydrocarbon source rocks (source-rock maturation and hydrocarbon generation and migration), reservoir rocks (quality and distribution), and traps for hydrocarbon accumulation. Using these geologic criteria, the U.S. Geological Survey defined the Cretaceous-Tertiary Composite Total Petroleum System with one assessment unit, the Cretaceous-Tertiary Rifts Assessment Unit, encompassing about 415,000 square kilometers. The total petroleum system was defined to include Cretaceous and Tertiary lacustrine and marine source rocks, and the assessment unit contains Cretaceous and Tertiary clastic reservoirs, shale seals, and traps that are mostly structural.

Hydrocarbons were generated from Cretaceous and Tertiary lacustrine and marine source rocks and most likely began in the Late Cretaceous. The generated hydrocarbons migrated into Cretaceous and Tertiary reservoirs. Hydrocarbon traps are generally structural and include tilted faulted blocks, rollover folds, drape anticlines, and reverse-faulted structures. Some inversion features are recognized. Reservoir seals are Lower and Upper Cretaceous shale. Oligocene shale and other Tertiary shale are seals for the Tertiary reservoirs. The sometimes limited lateral extents of fluvial seals have been considered problematic in some areas because of the limited exploration drilling in the province. At the time of the 2010 assessment, the province contained only 58 new-field wildcat wells. Rift-sag and continental analogs were used for assessment of field sizes and numbers because of similar source and reservoir rocks and traps.

In this 2010 assessment, the U.S. Geological Survey estimated mean volumes of undiscovered, technically recoverable conventional oil and gas resources for the Cretaceous-Tertiary Rifts Assessment Unit in the Chad Basin Province. The mean volumes are estimated at 2,315 million barrels of oil, 14,648 billion cubic feet of gas, and 391 million barrels of natural gas liquids. The estimated mean size of the expected largest oil field is 387 million barrels of oil and the estimated mean size of the expected largest gas field is 2,320 billion cubic feet of gas.

Introduction

The main objective of the U.S. Geological Survey's (USGS) National and Global Petroleum Assessment Project is to assess the potential for undiscovered, technically recoverable oil and natural gas resources of the United States and the world (U.S. Geological Survey World Conventional Resources Assessment Team, 2012). As part of this project, the USGS recently completed an assessment of the Chad Basin Province in north-central Africa (fig. 1). The Chad Basin, the largest intracratonic basin in north-central Africa, is characterized by Cretaceous and Tertiary rifting. The province covers an area of approximately 1,145,000 square kilometers (km^2) and includes parts of Algeria, Cameroon, Chad, Niger, and Nigeria. This assessment was based on data from oil and gas wells and fields, field production records (IHS Energy, 2009), and published geologic reports. Figure 2 is a geologic map of north-central Africa showing the Chad Basin Province.

The Chad Basin Province was assessed because of increased exploratory activity and interest in its future potential. The assessment was based on geology and used the total petroleum system concept. The geologic elements of a total petroleum system consist of hydrocarbon source

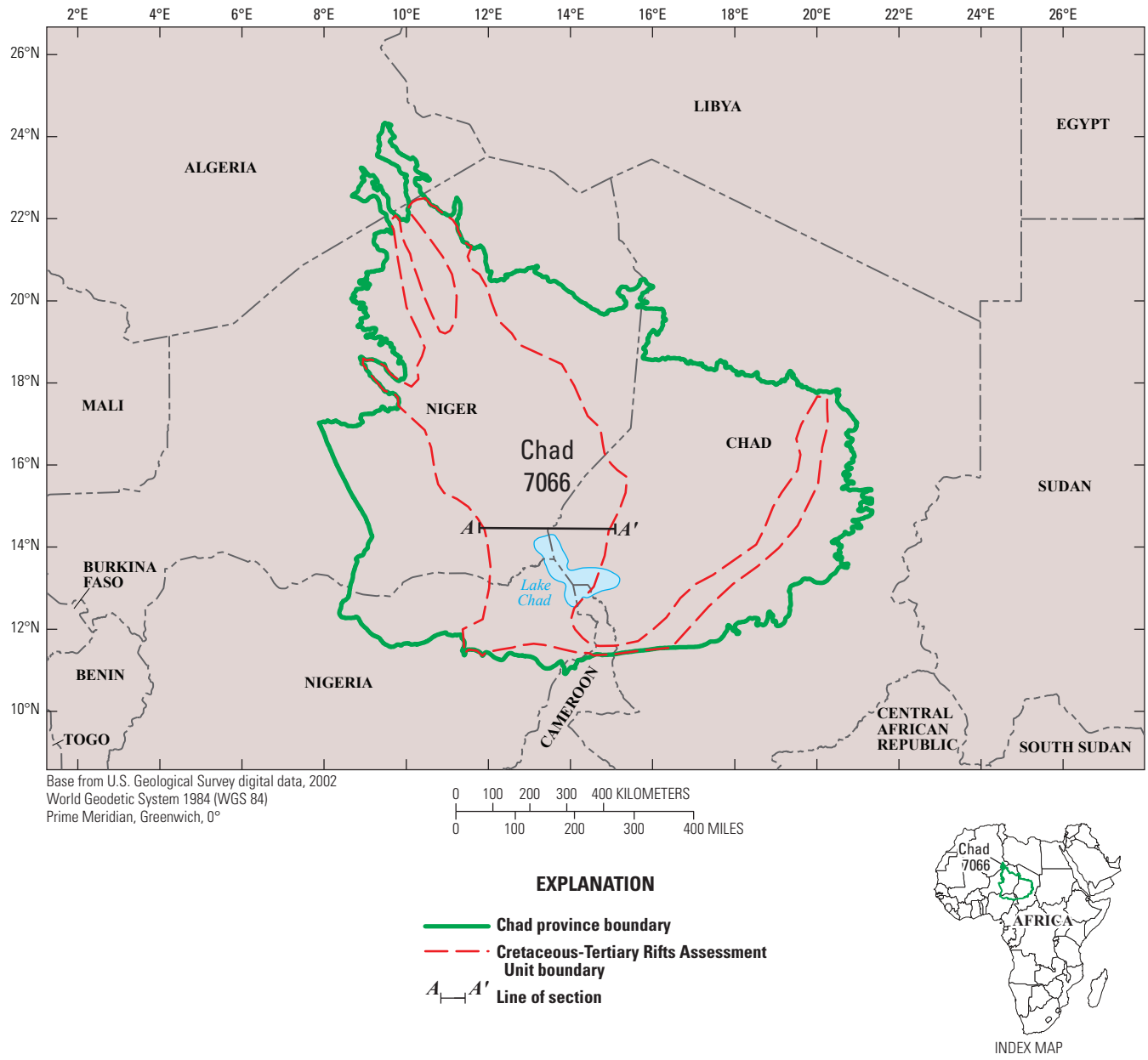

Figure 1. Chad Basin Province and Cretaceous-Tertiary Rifts Assessment Unit. Cross section *A*–*A*′ shown in figure 5.

rocks (source-rock maturation and hydrocarbon generation and migration), reservoir rocks (quality and distribution), and traps for hydrocarbon accumulation. Using these geologic criteria, the USGS defined the Cretaceous-Tertiary Composite Total Petroleum System (TPS) with one assessment unit, the Cretaceous-Tertiary Rifts Assessment Unit (AU) (figs. 1, 2), encompassing about 415,000 km^2. The total petroleum system was defined to include Cretaceous and Tertiary lacustrine and marine source rocks, and the assessment unit contains Cretaceous and Tertiary clastic reservoirs, shale seals, and traps that are primarily structural.

Tectonic History of Chad Basin Province, North-Central Africa

Rifting and the breakup of west Africa and South America began in the Early Cretaceous, creating rift basins (fig. 3) where continental and marine rocks were deposited (Fairhead and Green, 1989; Genik, 1992, 1993). These continental rocks were deposited in the northwest to southeast trending Western African Rift System, reaching thicknesses of 2,000 to 5,500 meters (m) (fig. 4) (Genik, 1993).

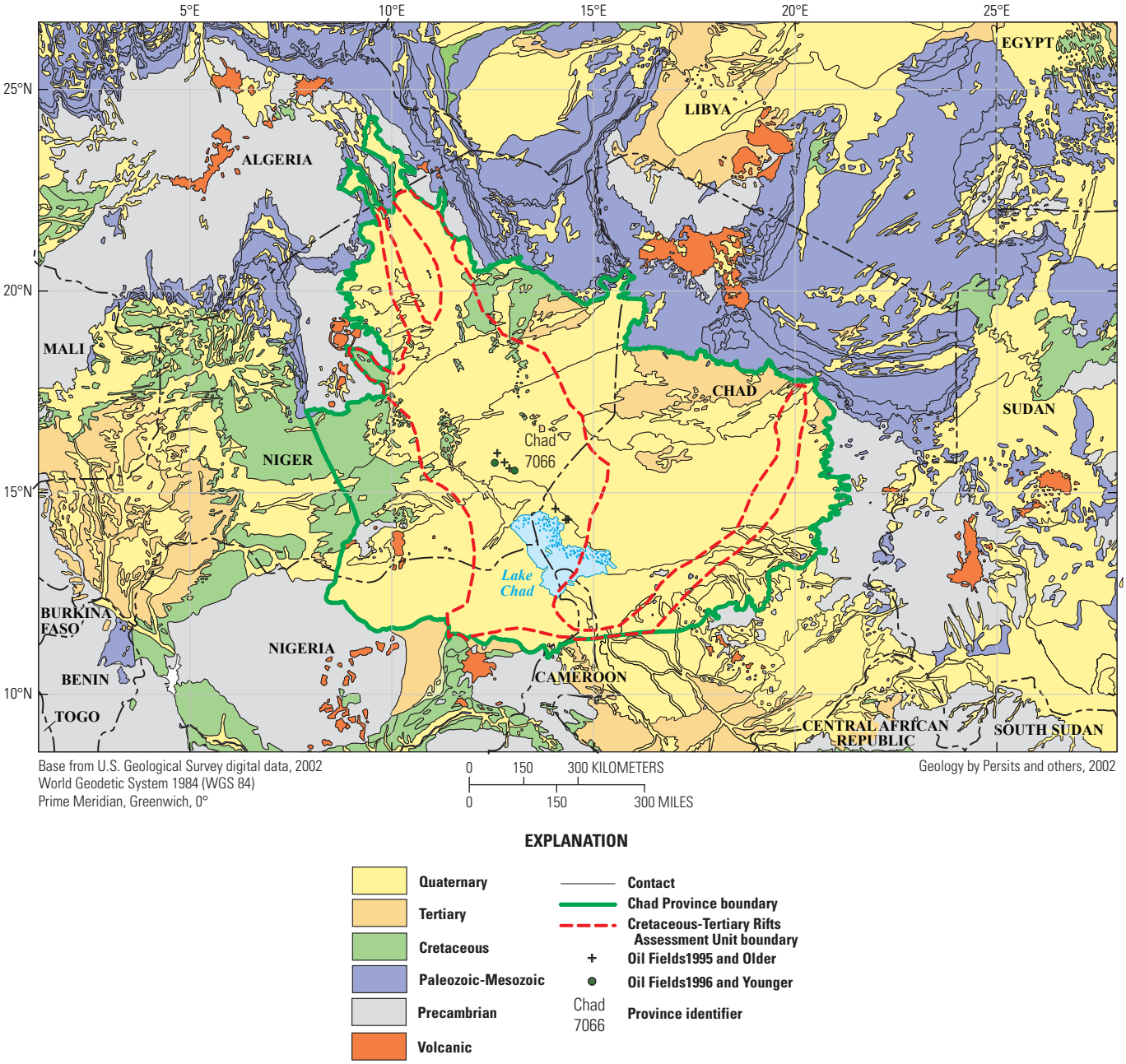

Figure 2. Geology of north-central Africa showing the Chad Basin Province (7066) and the Cretaceous Tertiary-Rifts Assessment Unit (70660101). Modified from Klett and others (1997) and Persits and others (2002).

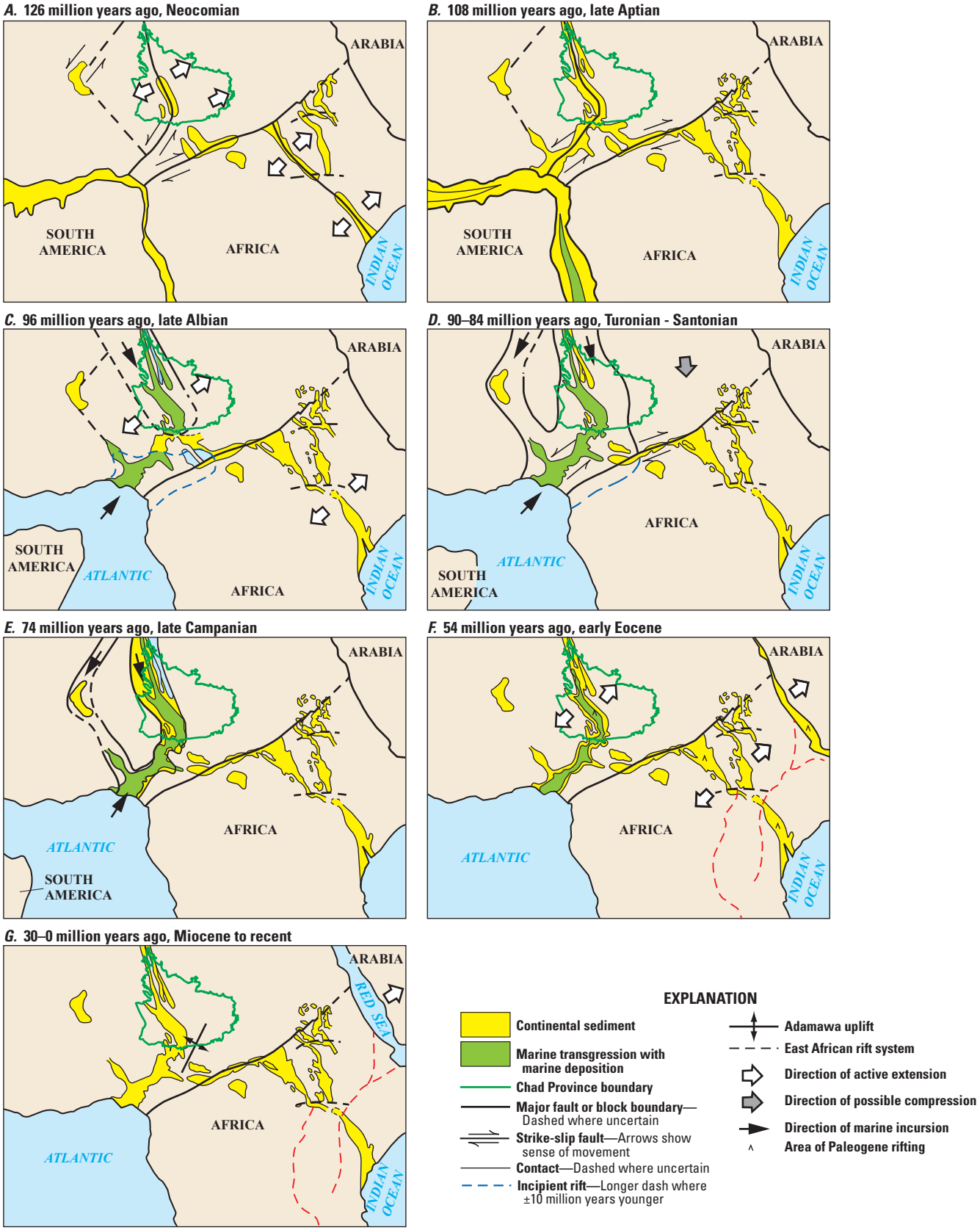

Figure 3. Paleotectonic maps showing the evolution of the west and central African rifts. Approximate location of the Chad Basin Province outlined in red. Modified from Genik (1993).

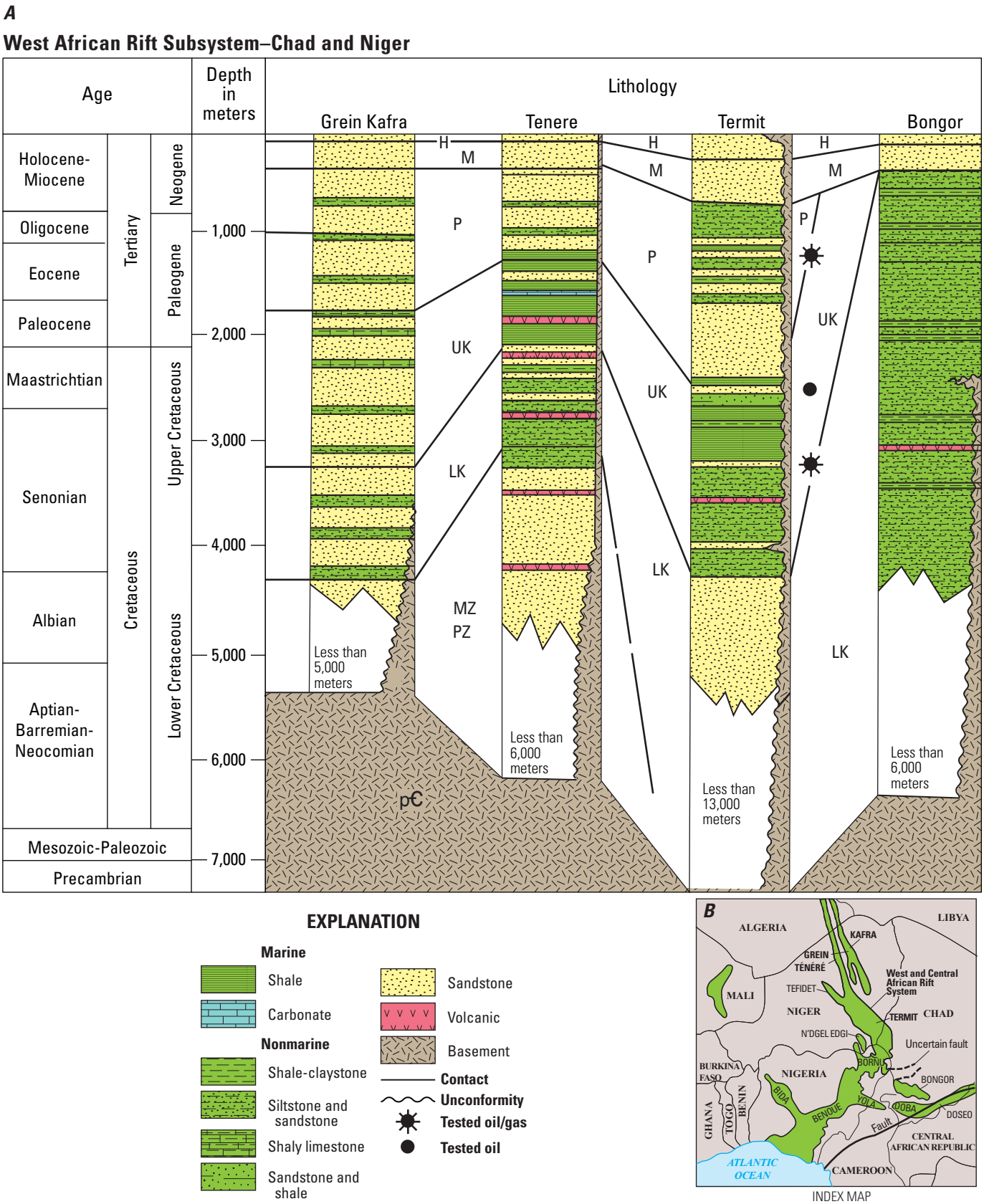

Figure 4. *A,* Stratigraphic columns of selected rift basins in the west African rifts, Chad and Niger. H, Holocene; M, Miocene; P, Paleogene; UK, Upper Cretaceous, LK, Lower Cretaceous; Mz, Mesozoic; PZ, Paleozoic, pC, Precambrian. *B*, Location of rift basins of Chad and Niger and stratigraphic columns shown in 4*A*. Modified from Genik (1992, 1993).

During the Early Cretaceous, fluvial and lacustrine rocks were deposited in the rift basins of the Chad Basin (Genik, 1992, 1993; Zanguina and others, 1998). A regional sag event in the Late Cretaceous (Cenomanian to Maastrichtian) formed a broad basin resulting in a marine transgression in which shallow marine to marginal marine and coastal plain rocks accumulated. During the Late Cretaceous to Oligocene, the last rifting phase occurred in the Chad Basin and thick fluvial and lacustrine rocks were deposited (Genik, 1993).

Gravity modeling of the Chad Basin shows the extent and thickness of the Mesozoic and Cenozoic sedimentary rocks in the rift basins of the Chad Province (Fairhead and Green, 1989). The extent of the rift basin sedimentary rocks was used to define the Cretaceous-Tertiary Rifts Assessment Unit (fig. 2).

Geology

The Cretaceous-Tertiary rift basins are filled with Lower Cretaceous to Neogene sedimentary rocks, ranging in thickness from about 3,000 m to more than 12,000 m (fig. 4), which were deposited in fluvial, lacustrine, and marine environments (Genik, 1992, 1993; Zanguina and others, 1998). The Termit Basin, which is filled with more than 12,000 m of sediment (fig. 5) (Genik, 1993), contains producing oil fields (Mbendi International Services, 2010).

Petroleum Occurrence in Chad Basin Province, North-Central Africa

Source Rocks

The rift basins that traverse Chad are known to contain Cretaceous and Tertiary lacustrine and marine source rocks that have generated hydrocarbons since the Late Cretaceous (Genik, 1993). Primary source rocks for hydrocarbons in the Chad Province are in the Cretaceous lacustrine and marine shale section within the grabens. Source rocks are identified in Lower Cretaceous lacustrine shale, Upper Cretaceous marine shale, and Eocene and Oligocene lacustrine shale. Lower Cretaceous lacustrine shale contains Type I kerogen whose total organic carbon (TOC) content ranges from 1.0 to 14.0 weight percent and averages 2.0 to 3.0 weight percent. Its hydrogen index values are greater than 600 milligrams per gram (mg/g) (Genik, 1993). Late Cretaceous marine source rocks contain Type II and Type III kerogen whose TOC ranges from 0.8 to 1.5 weight percent. Oligocene lacustrine shale contains Type 1 and Type II kerogen with TOC values up to 4.5 weight percent.

Two main types of oil have been identified in the Cretaceous-Tertiary AU: oil with a marine-paralic source, and oil with a lacustrine source (Genik, 1992). Oils of marine origin have American Petroleum Institute (API) gravities greater than 40 API and high gas-to-oil ratios. The oils have low viscosities, moderate wax, and low sulfur values. Oils of lacustrine origin have medium to high API gravities around 35 API. The oils have low gas-to-oil ratios, low viscosities, low sulfur, and high wax contents. Oils in shallower reservoirs have been degraded and exhibit low API gravities and high viscosities (Genik, 1992).

The oil window in the Cretaceous-Tertiary rifts in the Chad Basin is between 2,500 m and 4,000 m depth (Genik, 1993). In the Niger part of the Chad Basin the oil window begins at a depth ranging from 2,200 to 2,900 m (Zanguina and others, 1998).

Reservoirs, Traps, and Seals

The generated hydrocarbons migrated into Cretaceous and Tertiary sandstone reservoirs and mostly into Cretaceous and Tertiary structural traps (Genik, 1993; Warren, 2009). Lower Cretaceous lacustrine sandstone reservoirs are poorly defined in terms of their distribution, net thickness, and reservoir quality because of the limited number of exploration holes in the Cretaceous-Tertiary Rifts AU. At the time of the 2010 assessment, the province contained only 58 new-field wildcat wells.

Lower Cretaceous sandstone reservoirs include stacked fluvial channels and lacustrine-deltaic units (Genik, 1993). Individual reservoir beds are generally less than 5 m thick; however, stacked channels can range up to 20 m thick. Porosities range from 12 to 35 percent in shallow reservoirs and decrease to 10 to 12 percent at depths of 3,000 to 3,500 m (Genik, 1993). Permeabilities range considerably, in Lower Cretaceous units from 3 to 525 millidarcies (mD) and in Upper Cretaceous units from 35 to 500 mD. The Maastrichtian sandstone reservoirs, which are fluvial in origin, have excellent reservoir quality with porosity ranging from 25 to 35 percent (Zanguina and others, 1998). An Upper Cretaceous channel sandstone reservoir in southern Chad has porosities up to 32 percent and permeabilities up to 10 Darcies (Genik, 1993). The limited vertical and lateral extents of the reservoirs influence preservation of possible hydrocarbon.

Fluvial sandstone reservoirs of Eocene age are generally thin, but stacked reservoirs may be as much as several hundred meters thick. Fluvial sandstones are generally of limited lateral extent and are interbedded with thick shale units. Reservoir characteristics are good to excellent; porosities range from 16 to 35 percent and permeabilities average 500 mD (Genik, 1993). Porosity decreases with depth. Vertical and lateral seals may not be present in some areas.

Marine reservoirs include Upper Cretaceous deltaic to tidal sandstone. Reservoir rocks are generally thin bedded and have limited lateral extent. The stacked reservoirs are as much as 70 m thick. Porosities range from less than 10 percent to about 32 percent and permeabilities range from 35 to 500 mD (Genik, 1993). Porosity decreases with depth.

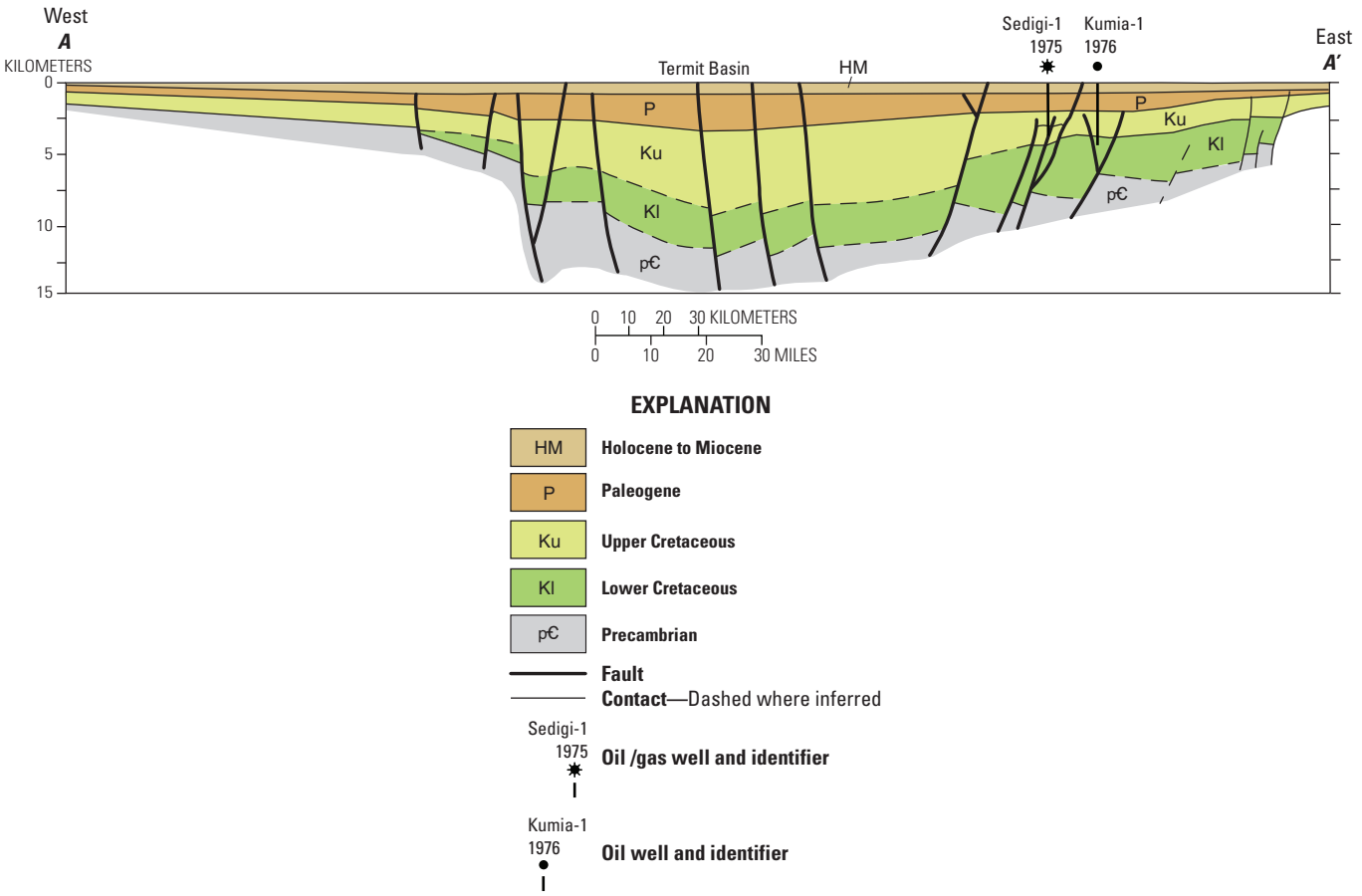

Figure 5. Sedimentary fill of the southern part of the Termit rift basin in the Chad Basin Province, north-central Africa. Line of section shown in figure 1. Modified from Genik (1993).

Hydrocarbon traps, which are generally structural, include tilted faulted blocks, rollover folds, drape anticlines, and reverse-faulted structures. Some inversion features are recognized (Warren, 2009).

In the lacustrine and marine section, Lower and Upper Cretaceous shale act as the hydrocarbon seals. Oligocene shale and other Tertiary shale seal Tertiary reservoirs (Genik, 1993). The lateral extents of fluvial mudstone and shale seals are considered problematic in some areas.

Exploration

Hydrocarbon discoveries and fields are limited to the Cretaceous-Tertiary rift basins of Chad and Niger, and oil and gas shows have been recorded in most of the wells drilled in the assessment unit. At the time of the 2010 assessment, the province contained 8 oil fields: 3 in Chad and 5 in Niger; in addition, 58 new-field wildcat wells had been drilled (IHS Energy, 2009). There are currently no gas fields, but several oil discoveries in the Chad Basin have reported tests that include associated gas. For example, Chad's Sedigi field (125 million barrels of oil) in the Termit rift basin (fig. 5) has an estimated 100 billion cubic feet of associated gas (Mbendi International Services, 2010). In southeastern Niger, 9 oil discoveries and 1 gas discovery have been estimated to be about 500 million barrels of oil equivalent (TG World Petroleum LTD., 2009).

The Cretaceous rifts of the Chad Basin Province remain underexplored despite the discovered oil fields and despite an identified petroleum system with its source rocks, potential reservoirs, and structural targets.

Geologic Model

The geologic model developed for the assessment of conventional oil and gas in the Chad Province and the Coastal Plain and Offshore AU is as follows:

1. Hydrocarbons were generated from Cretaceous and Tertiary lacustrine and marine source rocks. Generation most likely began in the Late Cretaceous.

2. The generated hydrocarbons migrated into Cretaceous and Tertiary reservoirs. Migration paths are generally fault controlled.

3. Hydrocarbon traps are primarily structural and include tilted faulted blocks, rollover folds, drape anticlines, and reverse-faulted structures. Some inversion features have been recognized.

4. Reservoir seals are Lower and Upper Cretaceous shale. Oligocene shale and other Tertiary shale seals the Tertiary reservoirs. The limited lateral extents of fluvial seals are considered problematic in some areas.

5. Rift-sag and continental analogs (Charpentier and others, 2007) were used to estimate field sizes and numbers because their source and reservoir rocks and traps are similar.

An events chart (fig. 6) for the Cretaceous-Tertiary Composite TPS and the Cretaceous-Tertiary Rifts AU summarizes the age of the source, seal, and reservoir rocks and the timing of trap development and generation and migration of hydrocarbons.

Resource Summary

Using a geology-based assessment, the U.S. Geological Survey estimated mean volumes of undiscovered, technically recoverable conventional oil and gas resources for the Cretaceous-Tertiary Rifts AU in the Chad Basin Province (table 1). The mean volumes are estimated at 2,315 million barrels of oil, 14,648 billion cubic feet of gas, and 391 million barrels of natural gas liquids. The estimated mean size of the expected largest oil field is 387 million barrels of oil and the estimated mean size of the expected largest gas field is 2,320 billion cubic feet of gas.

For Additional Information

Assessment results are available at the USGS Central Energy Resources Science Center website: http://energy.usgs.gov/oilgas/ or contact Michael E. Brownfield, the assessing geologist (*mbrownfield@usgs.gov*).

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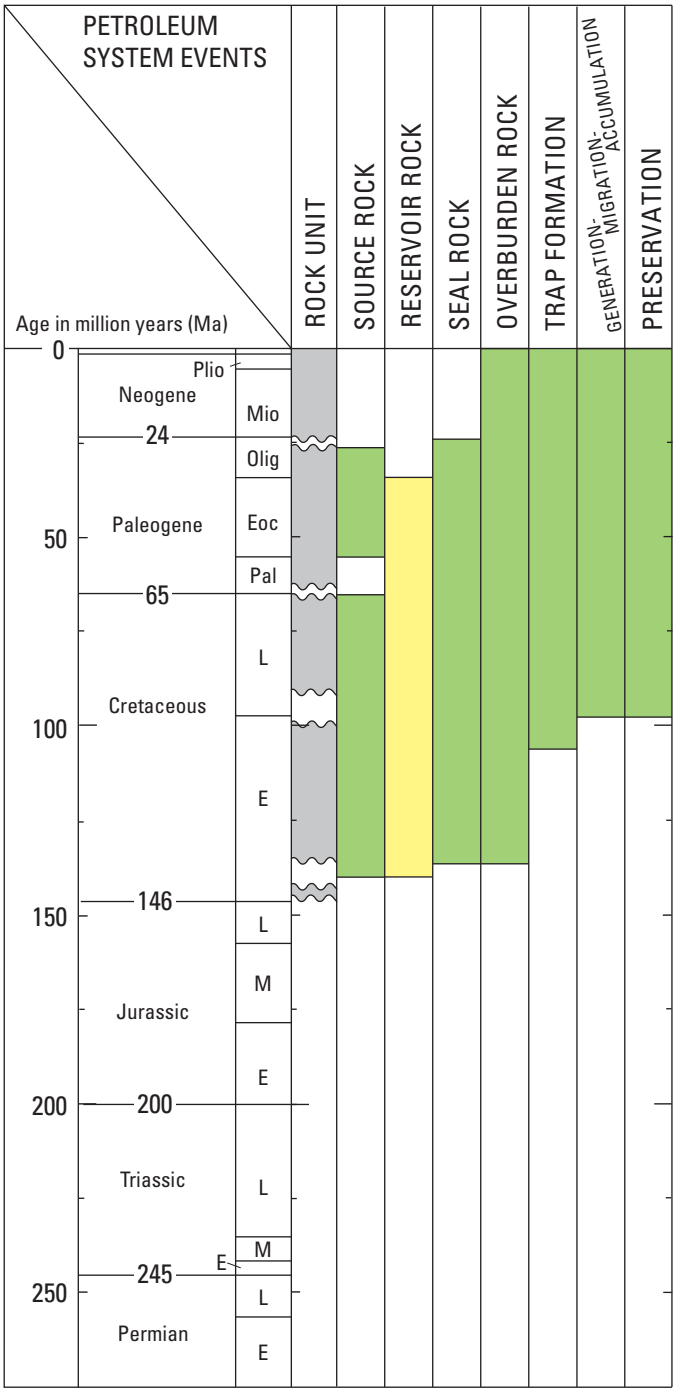

Figure 6. Events chart for the Cretaceous-Tertiary Composite Total Petroleum System (706601) and the Cretaceous-Tertiary Rifts Assessment Unit (70660101). Gray, rock units present; yellow, age range of reservoir rock; green, age ranges of source, seal, and overburden rocks and the timing of trap formation and generation, and migration and preservation of hydrocarbons; wavy line, unconformity. Divisions of geologic time conform to dates in U.S. Geological Survey Geological Names Committee (2010). Ma, million years ago; Plio, Pliocene; Mio, Miocene; Olig, Oligocene; Eoc, Eocene; Pal, Paleocene, L, Late; E, Early; M, Middle.

Table 1. Chad Basin Province assessment results for undiscovered, technically recoverable oil, gas, and natural gas liquids.

[Largest expected mean field size in million barrels of oil and billion cubic feet of gas; MMBO, million barrels of oil. BCFG, billion cubic feet of gas. MMBNGL, million barrels of natural gas liquids. Results shown are fully risked estimates. For gas accumulations, all liquids are included as natural gas liquids (NGL). Undiscovered gas resources are the sum of nonassociated and associated gas. F95 represents a 95 percent chance of at least the amount tabulated; other fractiles are defined similarly. Fractiles are additive under assumption of perfect positive correlation. AU, assessment unit; AU probability is the chance of at least one accumulation of minimum size within the AU. TPS, total petroleum system. Gray shading indicates not applicable]

Total Petroleum Systems (TPS) and Assessment Units (AU)	Field type	Largest expected mean field size	Total undiscovered resources											
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Chad Province–Cretaceous—Tertiary Composite TPS														
Cretaceous-Tertiary Rifts AU	***Oil***	387	794	2,082	4,637	2,315	228	657	1,665	766	6	18	46	21
	Gas	2,320					4,786	12,443	28,002	13,882	125	330	751	570
Total Conventional Resources			**794**	**2,082**	**4,637**	**2,315**	**5,014**	**13,108**	**29,667**	**14,643**	**131**	**348**	**797**	**391**

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