Assessment of Undiscovered Oil and Gas Resources of the Sud Province, Central-East Africa

By Michael E. Brownfield

Click here to return to
Volume Title Page

Chapter 14 of
Geologic Assessment of Undiscovered Hydrocarbon Resources of Sub-Saharan Africa
Compiled by Michael E. Brownfield

Digital Data Series 69–GG

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

Suggested citation:
Brownfield, M.E., 2016, Assessment of undiscovered oil and gas resources of the Sud Province, central-east Africa, *in* Brownfield, M.E., compiler, Geologic assessment of undiscovered hydrocarbon resources of Sub-Saharan Africa: U.S. Geological Survey Digital Data Series 69–GG, chap. 14, 12 p., http://dx.doi.org/10.3133/ds69GG.

ISSN 2327-638X (online)

Contents

Figures

Table

Abbreviations Used in This Report

km^2	square kilometers
m	meter
mD	millidarcy
mg/g	milligrams per gram
AU	assessment unit
D	darcy
HI	hydrogen index
TOC	total organic carbon
TPS	total petroleum system
USGS	U.S. Geological Survey

Assessment of Undiscovered Oil and Gas Resources of the Sud Province, Central-East Africa

By Michael E. Brownfield

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 recently completed an assessment of the Sud Province, an area of approximately 978,800 square kilometers that covers parts of the of Central African Republic, Chad, Ethiopia, and Sudan. This assessment was based on data from oil and gas wells, field production records, and published geologic reports.

The Sud Province was assessed because of increased exploratory activity and interest in its future oil and gas potential. The assessment was geology based 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 Central African Rifts Assessment Unit, encompassing about 848,825 square kilometers, that extends beyond the Sud Province boundary. The assessment unit contains parts of the Central African Republic, Chad, Ethiopia, Kenya, Sudan, and Tanzania.

Hydrocarbons were generated from Cretaceous and Paleogene lacustrine rocks in the rift basins and from Paleogene lacustrine source rocks and possibly from Cretaceous marine source rocks in the Kenyan Anza rift basin. Generation most likely began in the Late Cretaceous and continues to the present. Hydrocarbons migrated into Cretaceous and Paleogene reservoirs and structural traps. Traps include tilted fault blocks, rollover folds, draped anticlines, and reverse-faulted structures. Some inversion features are recognized. Reservoir seals are Cretaceous and Paleogene shale. Rift-sag and continental analogs were used for sizes and numbers because of similar source and reservoir rocks and trapping mechanisms.

The U.S. Geological Survey estimated mean volumes of undiscovered, technically recoverable conventional oil and gas resources for the Central African Rifts Assessment Unit in the Sud Province. The mean volumes are estimated at 7,310 million barrels of oil, 13,218 billion cubic feet of gas, and 353 million barrels of natural gas liquids. The estimated mean size of the largest oil field that is expected to be discovered is 1,112 million barrels of oil, and the estimated mean size of the expected largest gas field is 3,677 billion cubic feet of gas. For this assessment, a minimum undiscovered field size of 1 million barrels of oil equivalent was used. No attempt was made to estimate economically recoverable reserves.

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 in 2012 completed an assessment of the Sud Province (fig. 1), an area of approximately 978,800 square kilometers (km^2) that covers parts of the of Central African Republic, Chad, Ethiopia, and Sudan. This assessment was based on data from oil and gas wells, field production records, and published geologic reports. A geologic map of central-east Africa is shown in figure 2.

The Sud Province was assessed because of increased energy exploration activity and interest in its future oil and gas potential. The assessment was geology based 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 USGS defined the Cretaceous-Tertiary Composite Total Petroleum System (TPS) with one assessment unit, the Central African Rifts Assessment Unit (AU) (fig. 1), encompassing

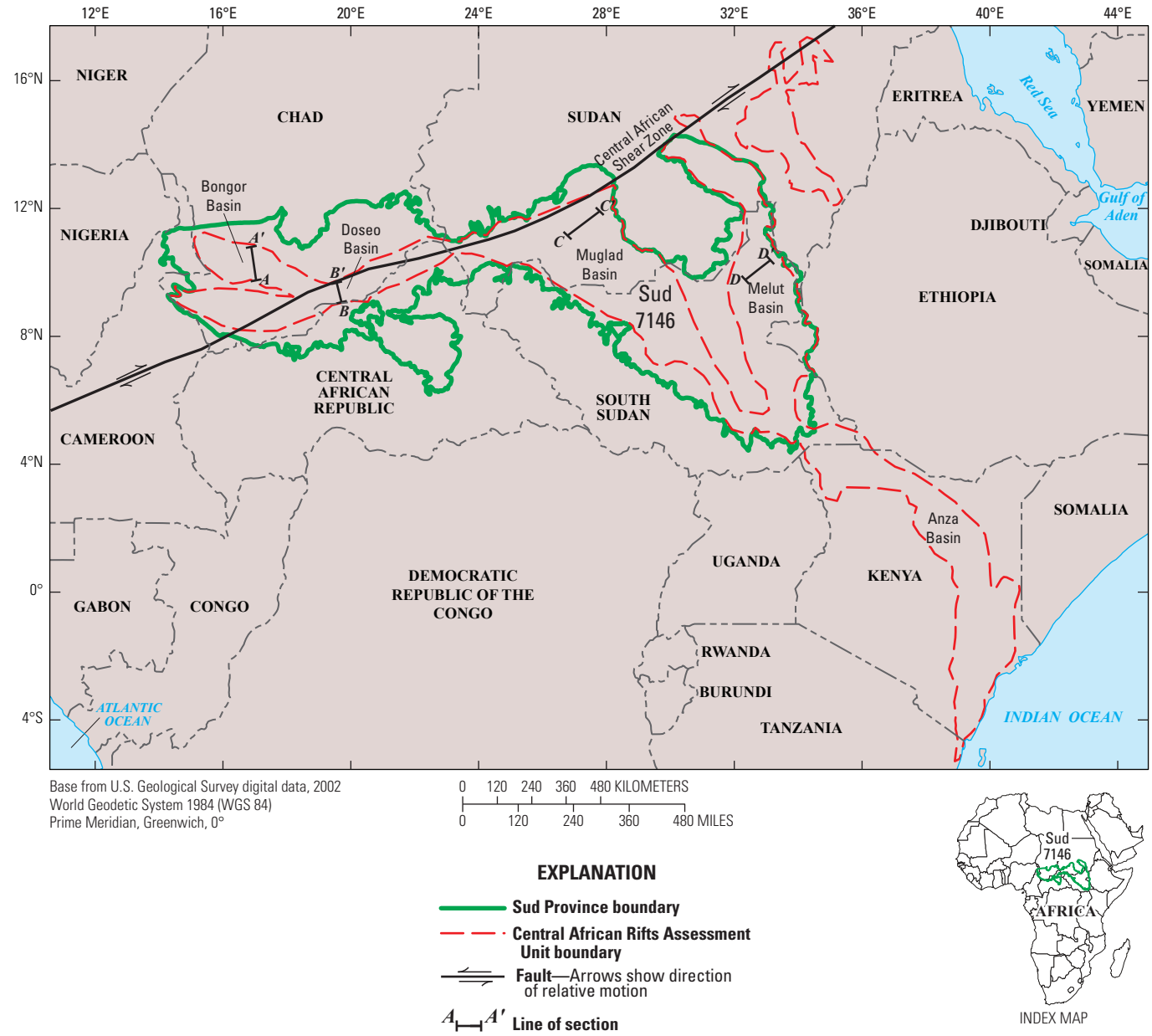

Figure 1. The Sud Province, Central African Rifts Assessment Unit, central-east Africa, and approximate locations of four lines of cross sections (figs. 4, 7).

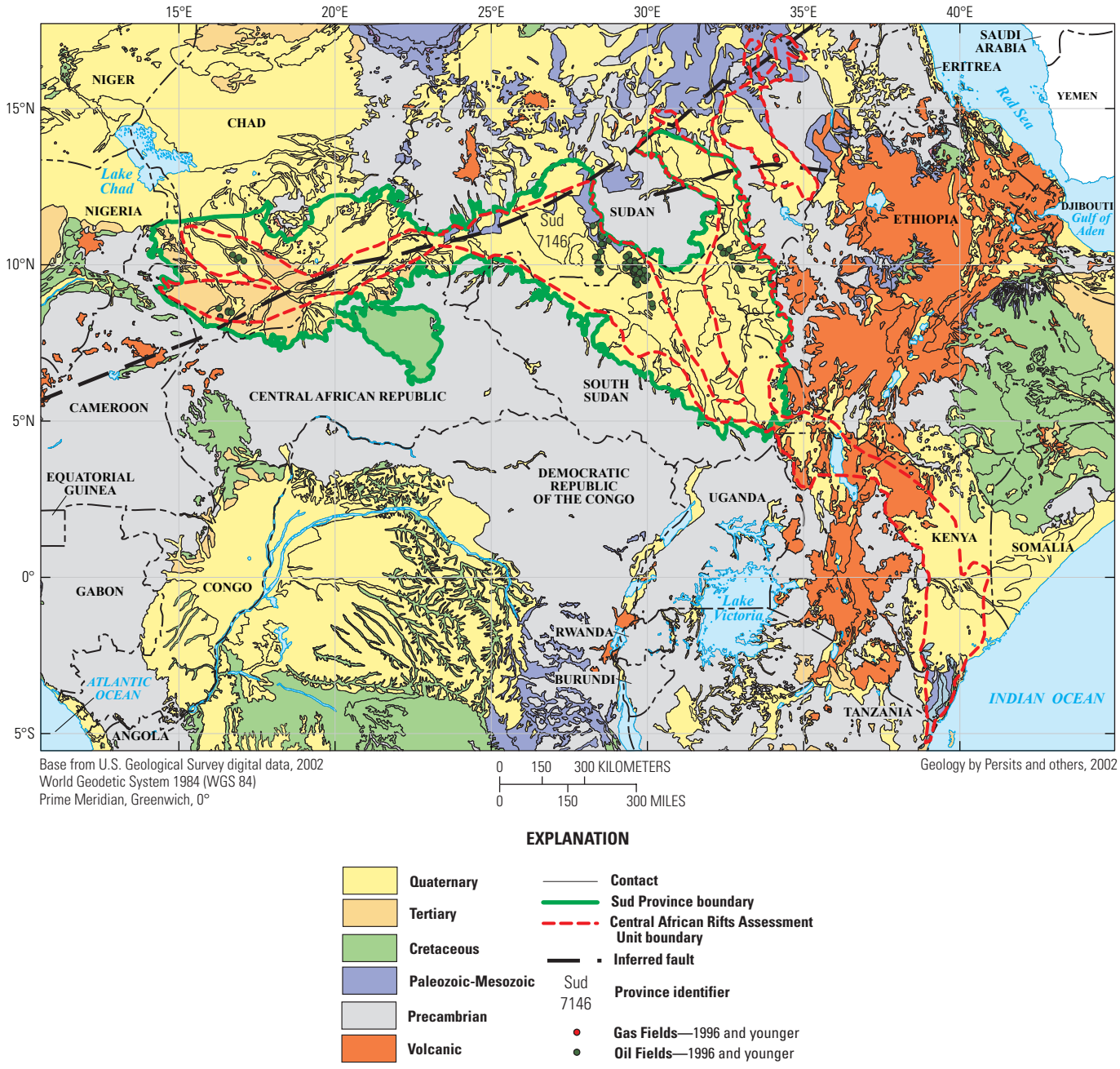

Figure 2. Generalized geology of central-east Africa. For information about geologic units, see Persits and others (2002).

about 848,825 km^2, that extends beyond the USGS-defined Sud Province boundary (Klett and others, 1997). The assessment unit includes parts of the Central African Republic, Chad, Ethiopia, Kenya, Sudan, and Tanzania (fig. 1). The total petroleum system was defined to include Cretaceous and Paleogene lacustrine and marine source rocks, and the assessment unit contains Cretaceous and Paleogene clastic reservoirs, shale seals, and traps that mostly are structural and associated with extensional and transtensional faulting and minor compressional inversion.

Tectonic History and Geology of the Sud Province and Central African Rifts Assessment Unit, Central-East Africa

The Central African Rift system was initiated during the Early Cretaceous, at the commencement of regional northwest-southeast extension and the opening of the South Atlantic Ocean. The rifting continued into the Neogene and can be divided into two major rifting events in the western part and three rifting events in the eastern part. The rift basins of central Africa are linked along the Central African shear zone right-lateral fault system (figs. 1, 3). Several thousand meters of Lower Cretaceous clastic sediment, mostly lacustrine shale, siltstone, and sandstone were deposited during this rifting phase (Genik, 1992, 1993).

The Cretaceous-Tertiary rift basins of the western part of the Sud Province (fig. 1) are transtensional and are filled with Lower Cretaceous to Neogene sedimentary rocks, ranging in thickness from about 3,000 meters (m) to more than 7,500 m (figs. 4, 5), that were deposited in fluvial and lacustrine environments (Genik, 1992, 1993). During the Early Cretaceous the first rifting event allowed deposition of fluvial and lacustrine rocks in rift basins of southern Chad and the Central African Republic (fig. 2). In the Late Cretaceous (Cenomanian to Turonian), a regional rifting event deposited thick continental clastic rocks in the eastern part of the province. During the Late Cretaceous and Paleogene, transtensional faulting and sag events in the western part of the Sud Province led to deposition of fluvial and lacustrine rocks.

The extensional and transtensional rift basins in the eastern part of the Province are filled with Jurassic? to Neogene sedimentary rocks (figs. 6, 7) that range in thickness from 6,000 m to more than 13,000 m; these rocks were deposited in fluvial and lacustrine environments (Mohamed and others, 2000, 2002; Dou and others, 2007). The initial rifting event began in the latest Jurassic and continued through the Early Cretaceous (fig. 3), resulting in the deposition of Lower Cretaceous lacustrine source rocks (figs. 3, 4). The second rifting event began in the Turonian and continued into the Senonian, and the third rifting event occurred during the Paleogene, at the same time that Red Sea rifting began (Mohamed and others, 2000). Each rifting event was followed by a sag event, during which thick continental clastic rocks were deposited (fig. 3).

The central African rift basins are known to contain Cretaceous to Paleogene lacustrine and marine source rocks that have generated hydrocarbons since the Late Cretaceous (Genik, 1992, 1993; Mohamed and others, 2002). Hydrocarbons migrated into Cretaceous and Paleogene reservoirs and structural traps.

Source Rocks

Primary source rocks are Lower and Upper Cretaceous and Paleogene lacustrine rocks, ranging from 2,500 m to 5,000 m thick that were deposited in the rift basins (figs. 5, 6). Lacustrine source rocks range from 1 to more than 5 weight percent total organic carbon (TOC) and average 2 to 3 weight percent TOC; their hydrogen index (HI) values are greater than 600 milligrams per gram (mg/g) in the eastern part of the province (Schull, 1988; Mohamed and others, 2000; Dou and others, 2007). Some analyzed lacustrine samples in the Muglad Basin (fig. 1) had TOC values as much as 9 weight percent TOC and an HI value of about 800 mg/g (Mohamed and others, 2002).

Lacustrine source rocks in the western part of the province range from 1 weight percent TOC to more than 14 weight percent TOC and average 2 to 3 weight percent TOC (Genik, 1993). HI values are greater than 600 mg/g for the lacustrine source rocks.

The depth to the oil generation window in the Cretaceous-Tertiary rifts in the eastern part of the Sud Province averages about 2,050 m and ranges from 1,500 m to 5,300 m (Mohamed and others, 2000, 2002; Dou and others, 2007). In the Chad part of the Sud Province the depth of the oil window ranges from 2,300 m to 5,000 m (Genik, 1993).

Reservoirs, Traps, and Seals

The Cretaceous and Paleogene sandstone reservoirs in the western part of the Central African Rifts AU are generally poorly defined in terms of their distribution and their net thickness. The reservoir quality is fair to good; porosities range from 12 to 32 percent and permeabilities from 10 millidarcies (mD) to 10 darcies (D) (Genik, 1993). These rocks were generally deposited in fluvial environments although some reservoirs contain lacustrine-delta sandstone. Reservoir characteristics are good to excellent in the Cretaceous fluvial sandstone reservoirs in the eastern part of the assessment unit and have excellent reservoir quality; porosities range from 8 to 25 percent and permeabilities are as much as 1,600 mD (Mohamed and others, 2000; Dou and others, 2007).

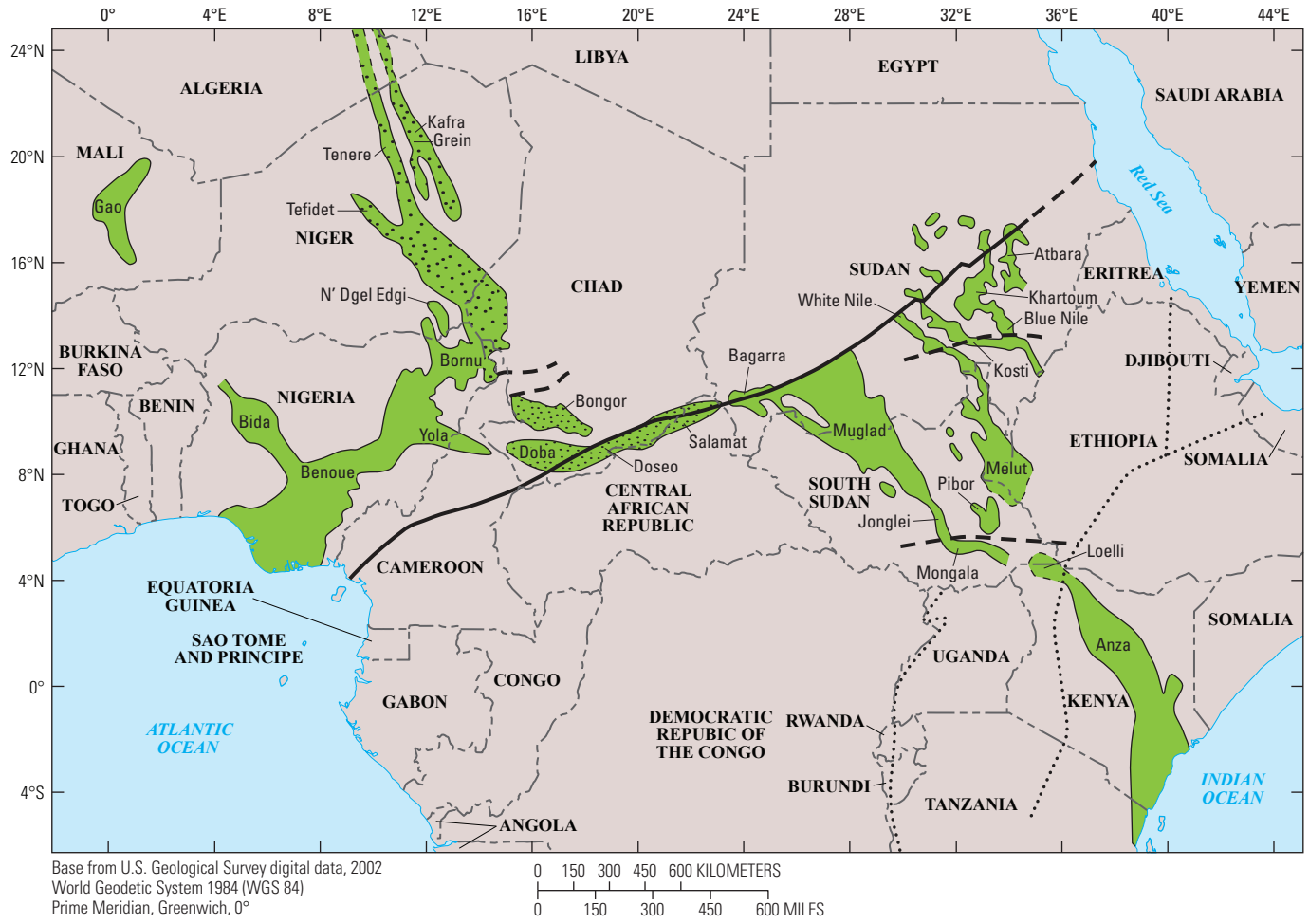

Figure 3. Western and Central African rift system. West African rift subsystem and Central African rift subsystem. Modified from Genik (1993).

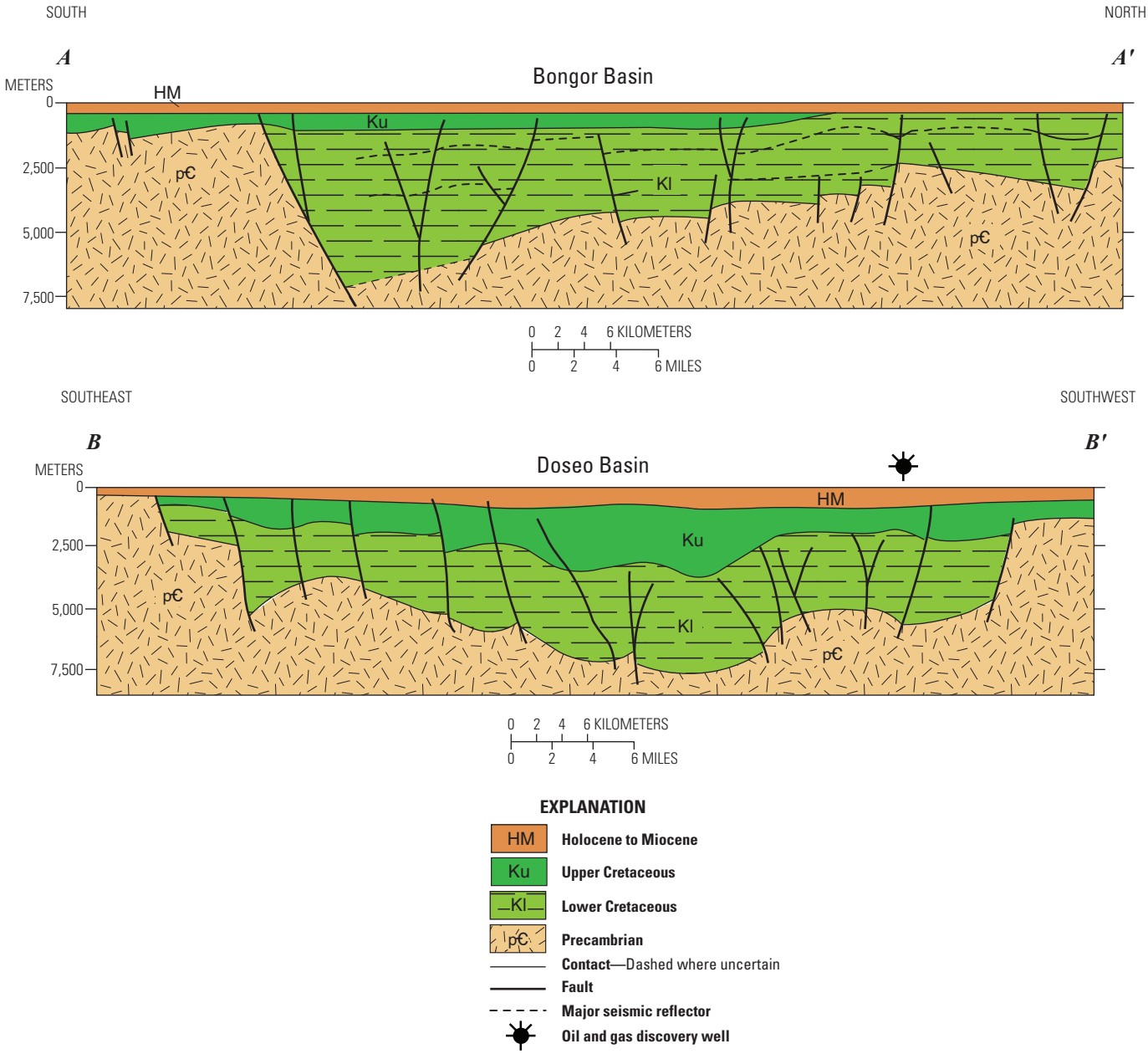

Figure 4. Schematic geologic cross sections of the western part of the Bongor and Doseo Basins, showing sedimentary fill in the western part of the Sud Province, central-east Africa. Lines of cross section *A*–*A*′ and *B*–*B*′ on figure 1. Modified from Genik (1992).

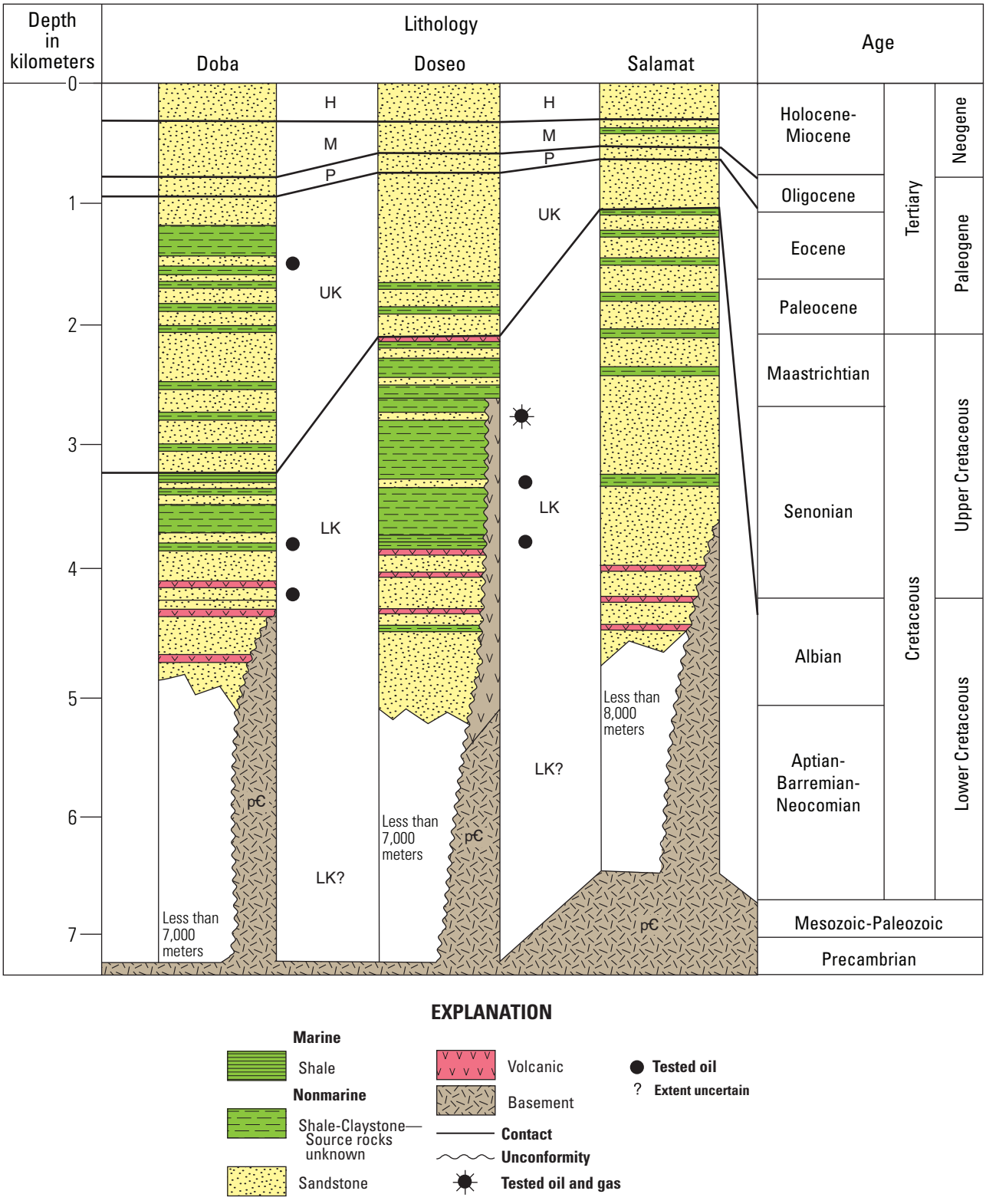

Figure 5. Generalized stratigraphic columns of the Doba, Doseo, and Salamat Basins, Central African Republic and Chad (see fig. 3), central-east Africa. Modified from Genik (1992, 1993). H, Holocene; M, Miocene; Pe, Paleogene; UK, Upper Cretaceous; LK, Lower Cretaceous.

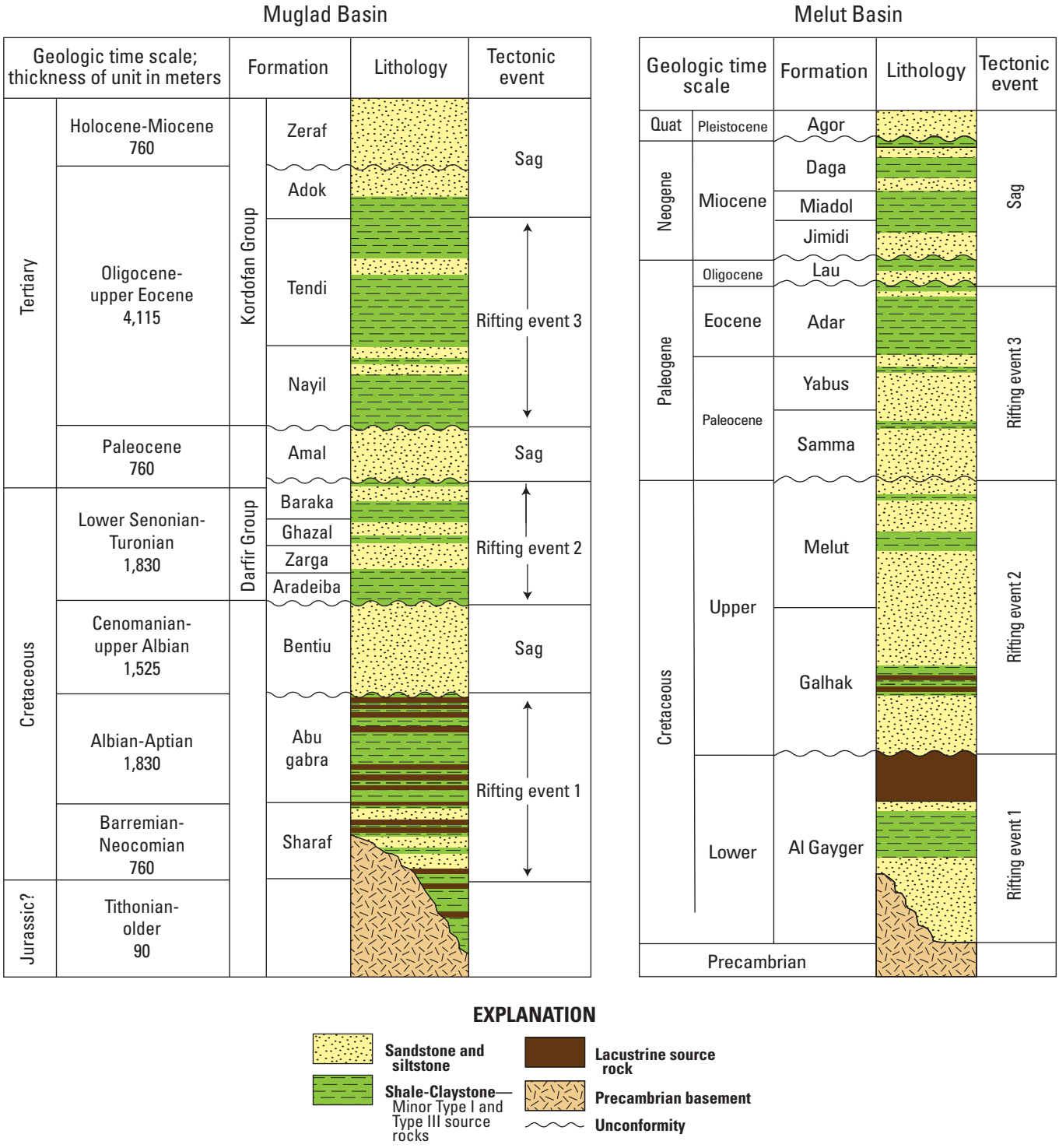

Figure 6. Generalized stratigraphic columns of the Muglad and Melut Basins, southern Sudan (see fig. 3). Modified from Mohamed and others (2000) and Dou and others (2007). Quat, Quaternary.

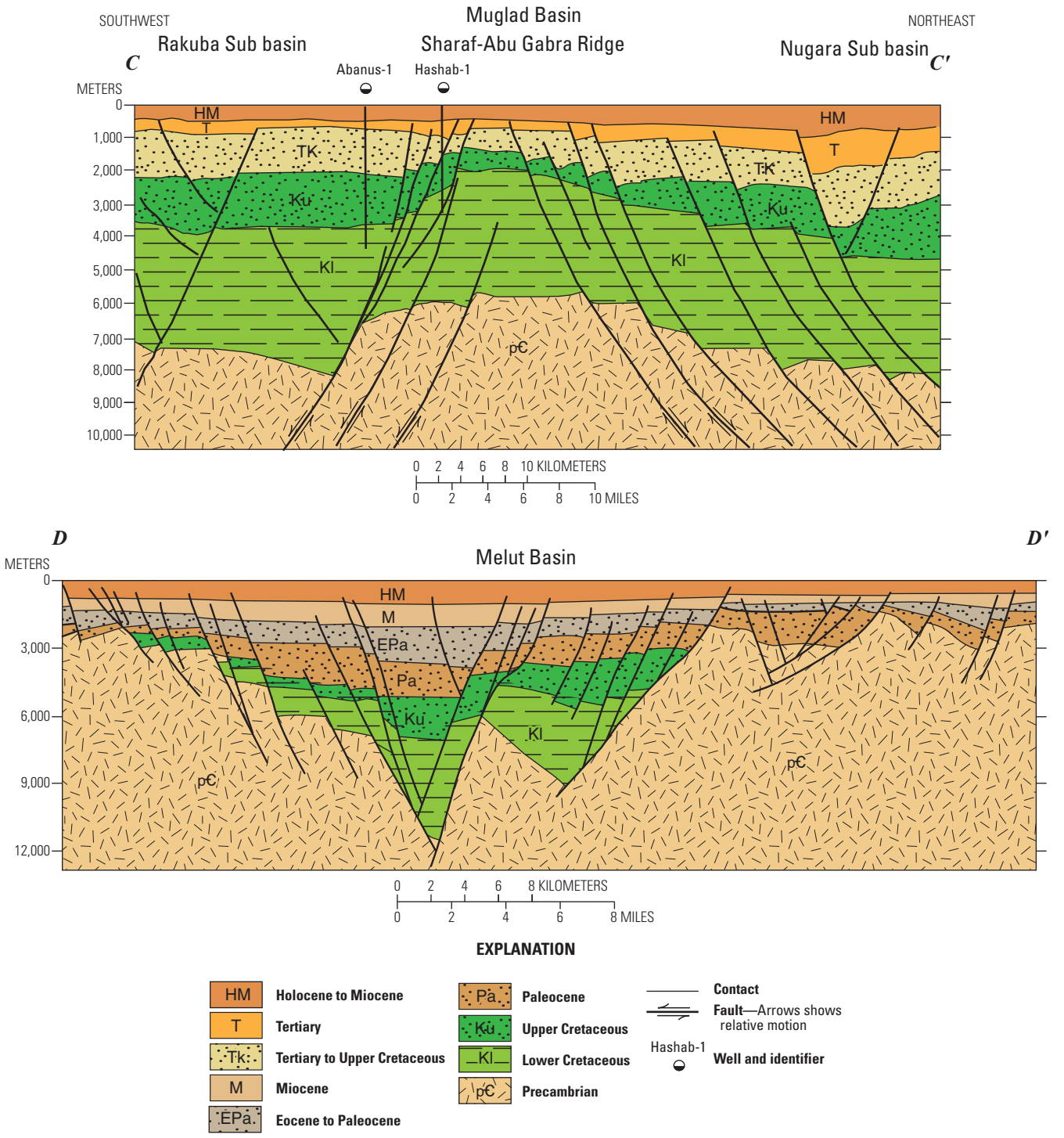

Figure 7. Schematic geologic cross sections of the Muglad and Melut Basins showing sedimentary fill in southern Sudan. Lines of cross section *C*–*C*′ and *D*–*D*′ shown on figure 1. Modified from Mohamed and others (2002) and Dou and others (2007).

Paleogene sandstone reservoirs were deposited in a fluvial environment. The sandstones are generally thin, but stacked reservoirs may be as much as several hundred meters thick. Porosities range from 22.1 to 40.8 percent and average 29 percent (Dou and others, 2007). The Paleogene sandstone reservoirs are interbedded with shale and the reservoir characteristics are good to excellent.

Reservoir seals are Upper Cretaceous and Paleogene shales. The limited lateral extents of fluvial shale seals have been considered a problem in some areas of the assessment unit Genik, 1993).

Traps are generally structural and include anticlines, tilted-fault blocks, rollover folds, drape anticlines, and reverse-faulted structures (Schull, 1988). Some inversion features, such as flower structures, have been recognized (Warren, 2009).

Exploration

At the time of this 2010 assessment, the province contained 113 oil fields—18 in Chad and 95 in Sudan—and is considered to be underexplored on the basis of its exploration activity. The province contains two gas fields, and several discoveries reported associated gas in oil fields (IHS, 2009). The producing oil fields and recent petroleum discoveries are limited to Cretaceous-Tertiary rift basins.

Geologic Model

The geologic model developed for the assessment of conventional oil and gas in the Sud Province and the Central African Rifts AU of central Africa is as follows:

- Rift basins in the Central African Rifts AU are known to contain hydrocarbons. Hydrocarbons were generated from Cretaceous and Paleogene lacustrine rocks in the rift basins in Chad and Sudan. Hydrocarbons were generated from Paleogene lacustrine source rocks and possibly from Cretaceous marine source rocks in the Kenyan Anza rift basin. Generation most likely began in the Late Cretaceous and continues to the present.
- Hydrocarbons migrated into Cretaceous and Paleogene reservoirs and structural traps.
- Hydrocarbon traps are generally structural, such as tilted-faulted blocks, rollover folds, draped anticlines, and reverse-faulted structures. Some inversion features are recognized.
- Seals consist of Cretaceous and Paleogene shale.
- Rift-sag and continental analogs (Charpentier and others, 2007) were used for assessment sizes and numbers because of similar source and reservoir rocks and trapping mechanisms.

Events charts (figs. 8, 9) for the eastern and western parts of the Sud Province and the Central African Rifts AU summarize the age of the source, seal, and reservoir rocks and the timing of trap development and generation and migration of hydrocarbons.

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 Assessment Unit in the Sud Province (table 1). The mean volumes are estimated at 7,310 million barrels of oil, 13,218 billion cubic feet of gas, and 353 million barrels of natural gas liquids. The estimated mean size of the largest oil field that is expected to be discovered is 1,112 million barrels of oil, and the estimated mean size of the expected largest gas field is 3,677 billion cubic feet of gas. For this assessment, a minimum undiscovered field size of 1 million barrels of oil equivalent was used. No attempt was made to estimate economically recoverable reserves.

For Additional Information

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

Acknowledgments

The author wishes to thank Mary-Margaret Coates, Jennifer Eoff, Christopher Schenk, and David Scott for their suggestions, comments, and editorial reviews, which greatly improved the manuscript. The author thanks Wayne Husband for his numerous hours drafting many of the figures used in this manuscript, and Chris Anderson, who supplied the geographic information system files for this assessment.

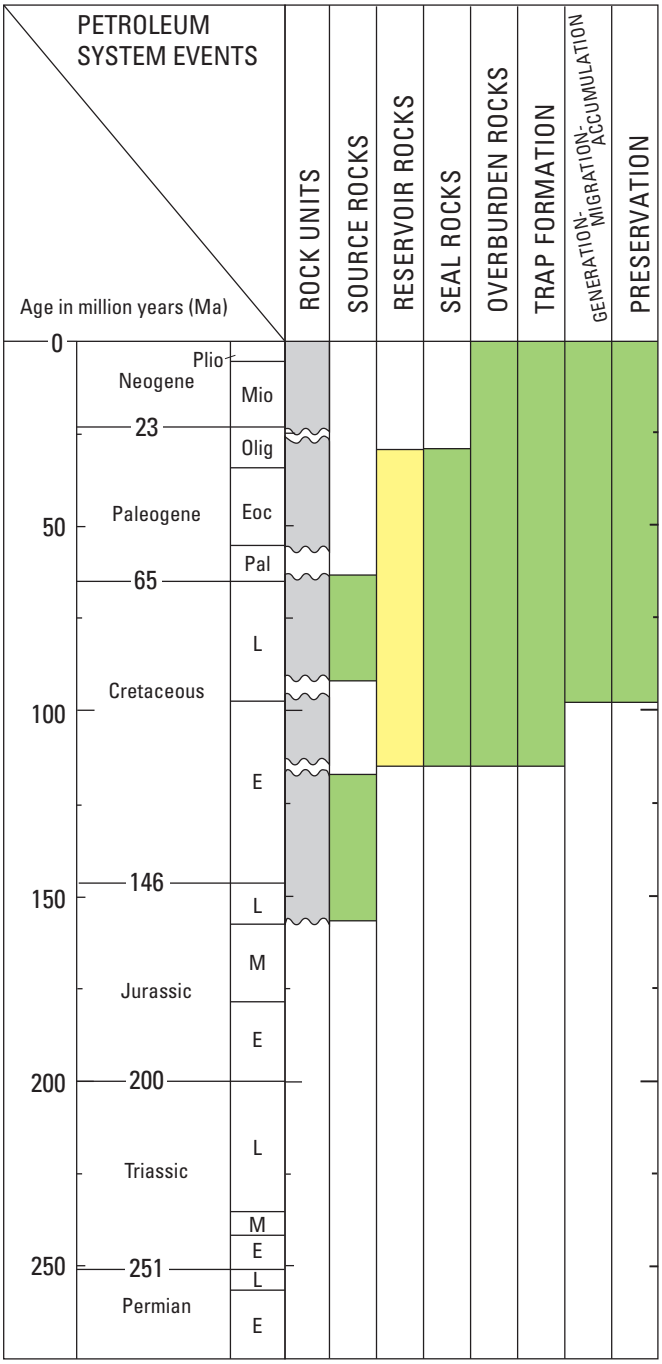

Figure 8. Events chart for the eastern part of the Cretaceous-Tertiary Composite Total Petroleum System (704601) and the Central African Rifts Assessment Unit (70460101). Gray, rock units present; yellow, age range of reservoir rock; green, age ranges of source, seal, and overburden rocks and the timing of trap formation and generation, migration, and preservation of hydrocarbons; wavy line, unconformity. Divisions of geologic time conform to dates in U.S. Geological Survey Fact Sheet 2010–3059 (U.S. Geological Survey Geologic Names Committee, 2010). Ma, million years ago; Plio, Pliocene; Mio, Miocene; Olig, Oligocene; Eoc, Eocene; Pal, Paleocene, L, Late; E, Early; M, Middle.

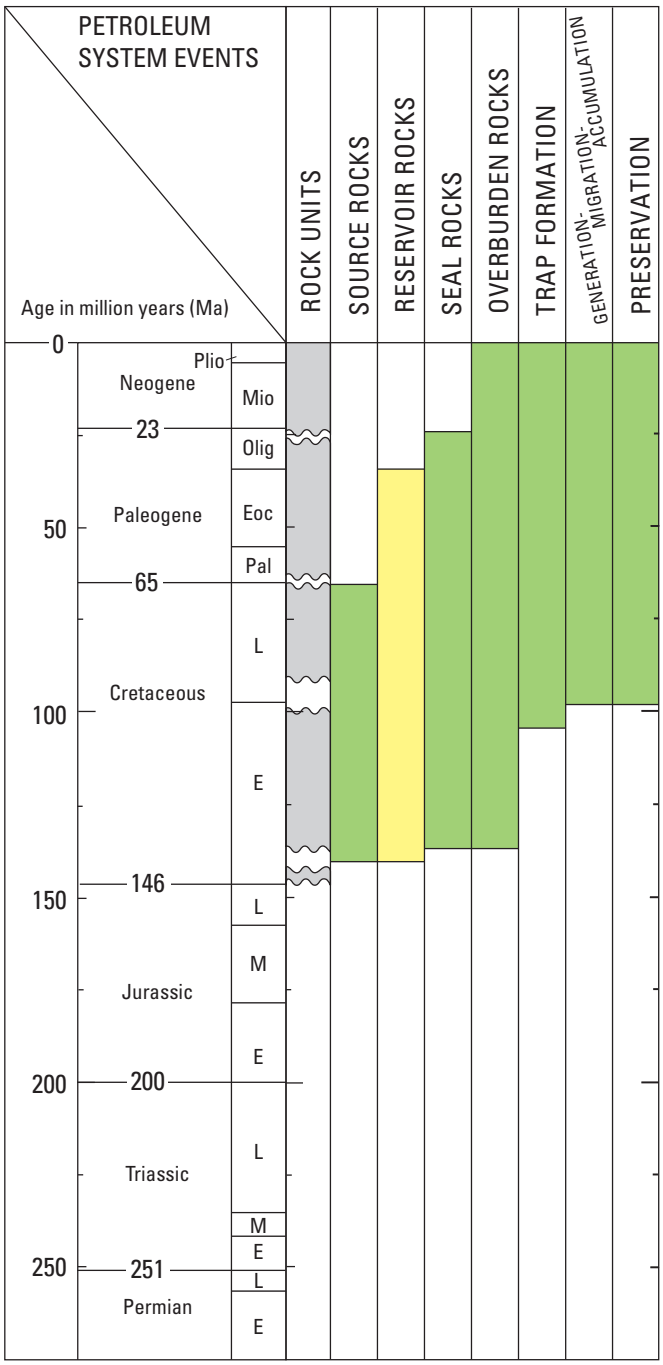

Figure 9. Events chart for the western part of the Cretaceous-Tertiary Composite Total Petroleum System (704601) and the Central African Rifts Assessment Unit (70460101). Gray, rock units present; yellow, age range of reservoir rock; green, age ranges of source, seal, and overburden rocks and the timing of trap formation and generation, migration, and preservation of hydrocarbons; wavy line, unconformity. Divisions of geologic time conform to dates in U.S. Geological Survey Fact Sheet 2010–3059 (U.S. Geological Survey Geologic 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. Sud Province and Central African Rifts Assessment unit 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 the 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
Sud Province-Cretaceous-Cenozoic Composite TPS														
Central African Rifts AU	***Oil***	1,112	3,141	6,809	13,222	7,310	531	1,321	3,169	1,522	14	35	87	41
	Gas	3,677					2,824	9,822	26,776	11,696	73	259	732	312
Total Conventional Resources			**3,141**	**6,809**	**13,222**	**7,310**	**3,355**	**11,143**	**29,915**	**13,218**	**87**	**294**	**891**	**353**

References

Charpentier, R.R., Klett, T.R., and Attanasi, E.D., 2007, Database for assessment unit-scale analogs (exclusive of the United States) Version 1.0: U.S. Geological Survey Open-File Report 2007–1404, 36 p., CD–ROM.

Dou, L., Xiao, K., Cheng, D., Shi, B., and Li, Z., 2007, Petroleum geology of the Melut Basin and the Great Palogue field, Sudan: Marine and Petroleum Geology, v. 24, no. 3, p. 129–144.

Genik, G.J., 1992, Regional framework, structural and petroleum aspects of rift basins in Niger, Chad and the Central African Republic (C.A.R.): Tectonophysics, v. 213, no. 1, p. 169–185.

Genik, G.J., 1993, Petroleum geology of the Cretaceous-Tertiary rifts basins in Niger, Chad, and Central African Republic: American Association of Petroleum Geologists Bulletin, v. 73, no. 8, p. 153–168.

IHS Energy, 2009, International petroleum exploration and production database [current through December 2009]: available from IHS Energy, 15 Inverness Way East, Englewood, Colo. 80112 USA.

Klett, T.R., Ahlbrandt, T.A., Schmoker, J.W., and Dolton, G.L., 1997, Ranking of the world's oil and gas provinces by known petroleum volumes: U.S. Geological Survey Open-File Report 97–463, CD–ROM.

Mohamed, A.Y., Iliffe, J.E., Ashcroft, W.A., and Whiteman, A.J., 2000, Burial and maturation history of the Heglig field area, Muglad Basin, Sudan: Journal of Petroleum Geology, v. 23, no. 1, p. 107–128.

Mohamed, A.Y., Pearson, M.J., Ashcroft, W.A., and Whiteman, A.J., 2002, Petroleum maturation modeling, Abu Gabra–Sharaf area, Muglad Basin, Sudan: Journal of African Earth Sciences v. 35, no. 2, p. 331–344.

Persits, F.M., Ahlbrandt, T.S., Tuttle, M.L., Charpentier, R.R., Brownfield, M.E., and Takahashi, K.I., 2002, Map showing geology, oil and gas fields, and geologic provinces of Africa: U.S. Geological Survey Open-File Report 97–470A, Version 2.0, CD–ROM.

Schull, T.J., 1988, Rift basins of interior Sudan—Petroleum exploration and discovery: American Association of Petroleum Geologists Bulletin, v. 72, no. 10, p. 1128–1142.

U.S. Geological Survey Geologic Names Committee, 2010, Divisions of geologic time: U.S. Geological Survey Fact Sheet 2010−3059, 2 p. Available at http://pubs.usgs.gov/fs/2010/3059/.

U.S. Geological Survey World Conventional Resources Assessment Team, 2012, An estimate of undiscovered conventional oil and gas resources of the world, 2012: U.S. Geological Survey Fact Sheet 2012–3042, 6 p. Available at http://pubs.usgs.gov/fs/2012/3042/.

Warren, M.J., 2009, Tectonic inversion and petroleum system implications in the rifts of central Africa: Frontiers + Innovation, 2009 Canadian Society of Petroleum Geology, Canadian Society of Exploration Geophysicists, and Canadian Well Logging Society Convention, Calgary, May 4–6, 2009, Proceedings, p. 461–464. Available at http://www.cspg.org/documents/Conventions/Archives/Annual/2009/266.pdf. Last accessed March 5, 2012.

Click here to return to
Volume Title Page