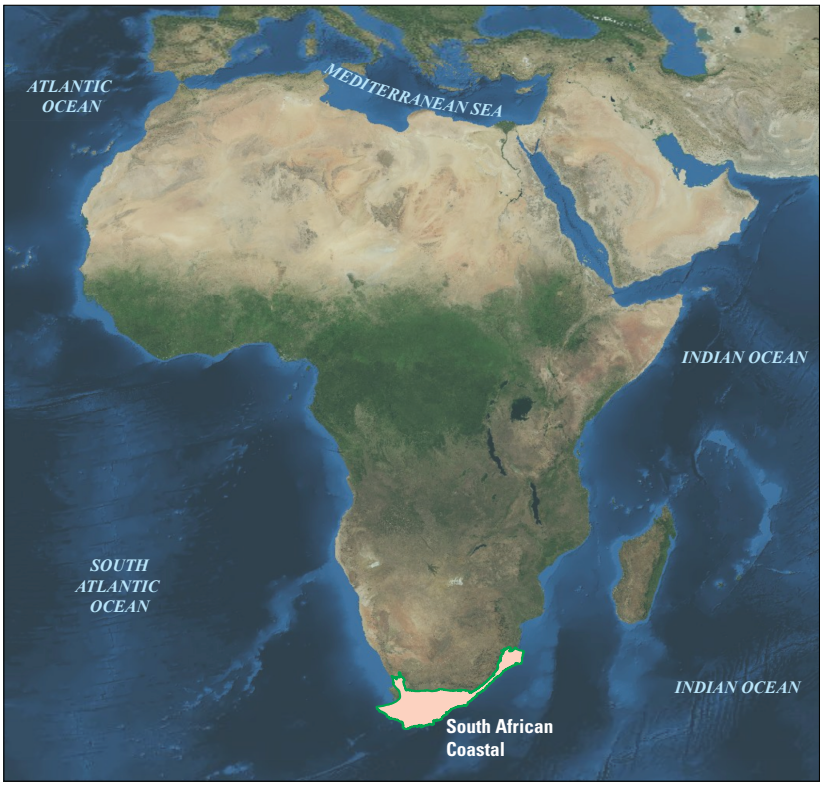
Assessment of Undiscovered Oil and Gas Resources of the South African Coastal Province, Africa

By Michael E. Brownfield



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Chapter 9 of
Geologic Assessment of Undiscovered Hydrocarbon Resources of Sub-Saharan Africa
Compiled by Michael E. Brownfield

Digital Data Series 69–GG

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

Suggested citation:
Brownfield, M.E., 2016, Assessment of undiscovered oil and gas resources of the South African Coastal Province, 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. 9, 9 p., http://dx.doi.org/10.3133/ds69GG.

ISSN 2327-638X (online)

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Abbreviations Used in This Report

km^2	square kilometer
m	meter
Ma	million years ago
AU	assessment unit
TOC	total organic carbon
TPS	total petroleum system
USGS	U.S. Geological Survey

Assessment of Undiscovered Oil and Gas Resources of the South African Coastal Province, Africa

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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 recently completed an assessment of the South African Coastal Province, an area of about 367,550 square kilometers that covers part of the offshore and southern onshore of South Africa. This assessment was based on data from oil and gas exploration wells, producing fields, and published geologic reports.

The South African Coastal Province was assessed because of increased 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 Mesozoic Composite Total Petroleum System with one assessment unit, the Mesozoic-Cenozoic Reservoirs Assessment Unit), encompassing 212,652 square kilometers, which includes the offshore part of the province to a water depth of 4,000 meters.

Oil and gas were generated from Lower Cretaceous marine Type II source rocks usually containing 2.0 to 4.28 weight percent total organic carbon (some samples contained more than 5 percent) and from possible Upper Jurassic syn-rift lacustrine Type I source rocks that contained at least 3 weight percent total organic carbon. Generation of hydrocarbons from lacustrine sources began in the Early Cretaceous; from Lower Cretaceous marine sources it began in the latest Cretaceous and most likely continues today. Hydrocarbons migrated into Cretaceous reservoirs and to traps such as reservoirs related to Upper Jurassic syn-rift grabens and half grabens and facies traps typical of rifts. Lower Cretaceous syn-rift transgressive and regressive stratigraphic sandstone traps may also be present. Reservoir and traps are also related to post-rift (drift) growth-fault-related structures, rotated fault blocks within the continental shelf, deep-water fans, turbidite units, and slope truncations along the present-day shelf and paleoshelf edge. The Cretaceous marine mudstone and shale rocks are the primary reservoir seals. Passive-margin analog was used for assessment field sizes and numbers because of similar source and reservoir rocks and traps.

The U.S. Geological Survey estimated mean volumes of undiscovered, technically recoverable conventional oil and gas resources for the Mesozoic-Cenozoic Reservoirs Assessment Unit in the South African Coastal Province at 2,129 million barrels of oil, 35,964 billion cubic feet of gas, and 1,115 million barrels of natural gas liquids. The estimated mean size of the largest oil field that is expected to be discovered is 340 million barrels of oil, and the estimated mean size of the expected largest gas field is 2,937 billion cubic feet of gas. For this assessment, a minimum undiscovered field size of 5 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 program, the USGS recently completed an assessment of the South African Coastal Province (fig. 1) (Klett and others, 1997), an area of about 367,550 square kilometers (km^2) that covers part of southern offshore and onshore regions of South Africa. This assessment was based on data from oil and gas exploration wells, producing fields (IHS Energy, 2009), and published geologic reports.

The South African Coastal Province was assessed because of increased interest in its future oil and gas resource potential. The assessment was geology based and used the total petroleum system concept. The geologic elements of a total petroleum system are 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 a Mesozoic Composite Total Petroleum System (TPS) with one assessment unit, the Mesozoic-Cenozoic Reservoirs Assessment Unit (AU) (fig. 1), encompassing 212,652 km^2 that includes the offshore part of the province to a water depth of 4,000 meters (m). The assessment unit is divided into several basins by faults and areas of shallow basement (figs. 2, 3).

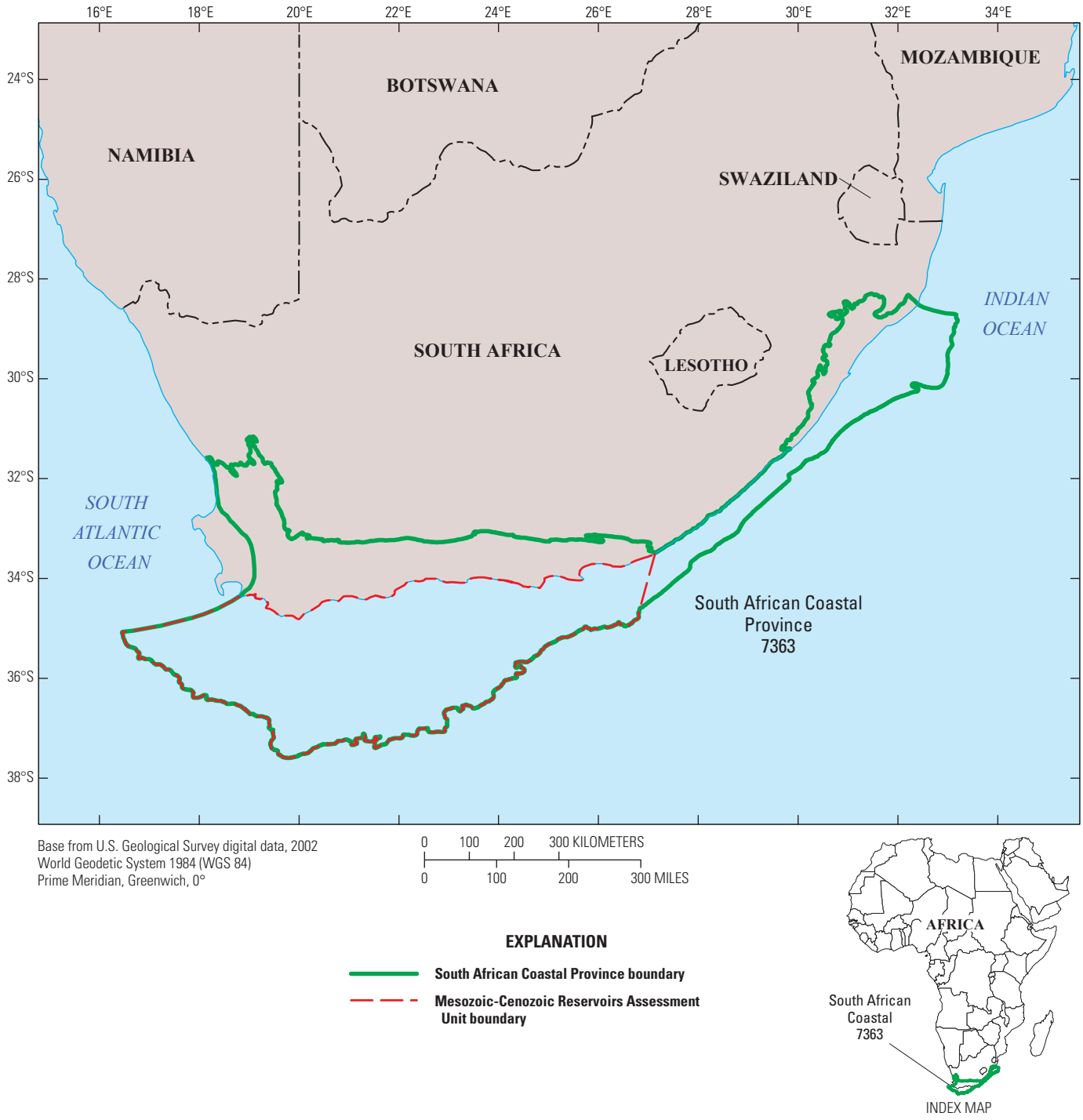


Figure 1. South African Coastal Province and Mesozoic-Cenozoic Reservoirs Assessment Unit, South Africa.

Figure 2. Major basins and basement highs in the offshore part of South Africa and the southern part of Africa. Modified from Campher and others (2009).

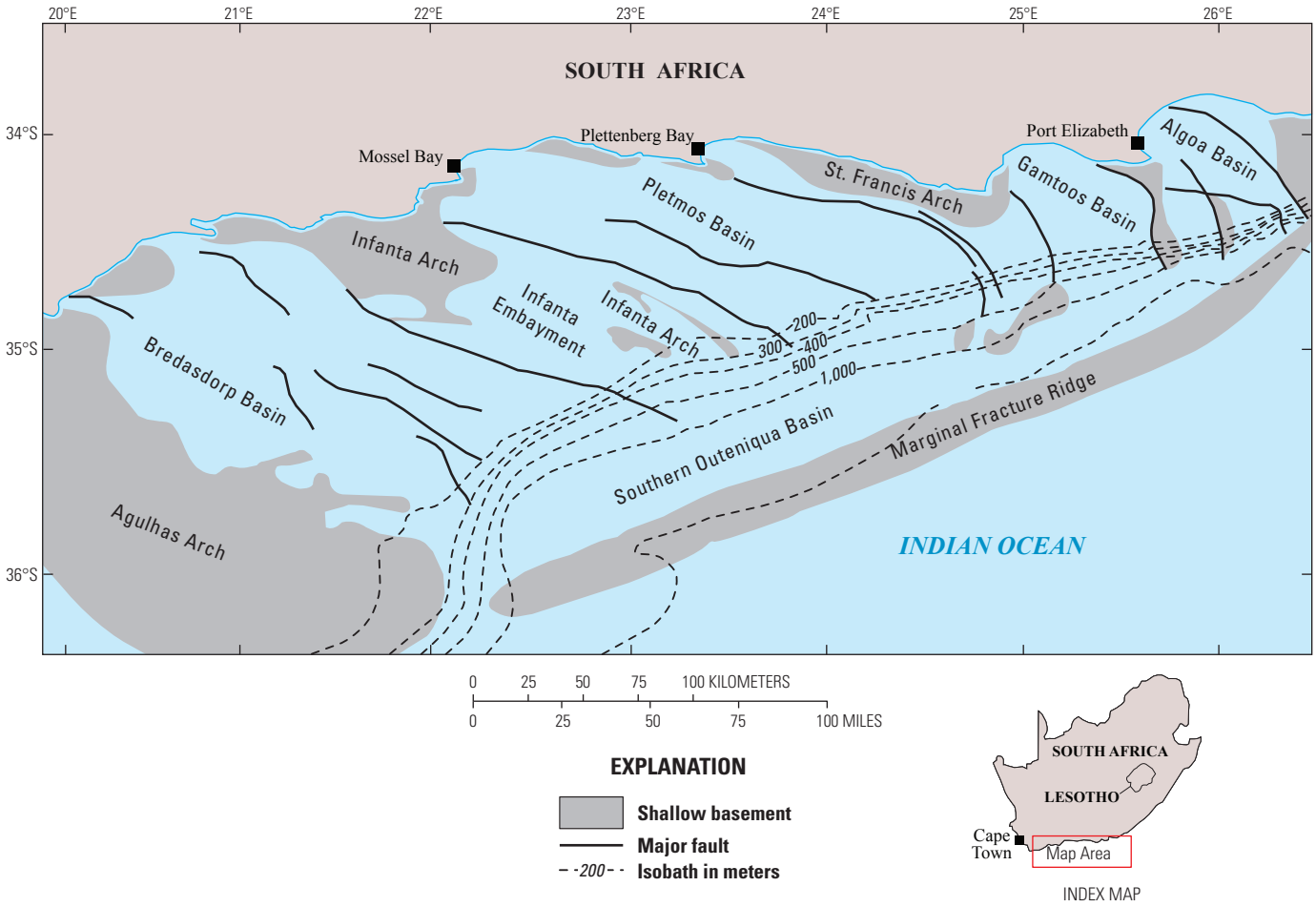


Figure 3. Offshore basins of South Africa. Modified from Madyibi and others (2009).

Tectonic History and Geology of South African Coastal Province, Africa

The offshore part of the South African Coastal Province developed in two phases: a syn-rift phase initiated during the Jurassic and continued into the Early Cretaceous that formed grabens and half-grabens; a transform-drift phase began in the late Albian and a passive-margin phase began in the Neogene that continues to the present (Davis, 1997; McMillan and others, 1997; Petroleum Agency SA, 2009). Regional uplift, extension, microplate formation and rotation, rifting, and volcanism began in the southern part of Africa during the Lower Jurassic (Davis, 1997). During the Late Jurassic to Early Cretaceous syn-rift phase several offshore graben basins formed, into which lacustrine sediments were deposited (figs. 2, 3). Transtensional movement developed along the Agulhas-Falkland fracture zone during the Late Cretaceous as the Falkland Plateau Basin moved westward (fig. 4); that movement continued to the Albian (fig. 5). The south Atlantic Ocean opened during the Lower Cretaceous, as is documented by the Lower Cretaceous break-up unconformity (fig. 5) (Madyibi and others, 2009). The main source rocks lie above the break-up unconformity. Thermal subsidence and major sea-level changes occurred during the Late Cretaceous. Regional sag during the Miocene resulted in a period of hot-meteoric-water flushing in the eastern and central part of the Bredasdorp Basin (fig. 4), which may have discouraged the preservation of hydrocarbons in the reservoirs (Davis, 1997).

The total thickness of the Mesozoic to Cenozoic stratigraphic section is more than 5,000 m on the outer parts of the continental shelf (fig. 6).

Petroleum Occurrence in South African Coastal Province, Africa

Source Rocks

The Mesozoic Composite TPS was defined to contain Jurassic through Turonian rocks: Middle to Upper Jurassic lacustrine source rocks containing 1.0 to 3.7 weight percent total organic carbon (TOC); Cretaceous marine source rocks, including Aptian strata containing Type II kerogen ranging from 2.0 to 4.3 weight percent TOC; and (3)

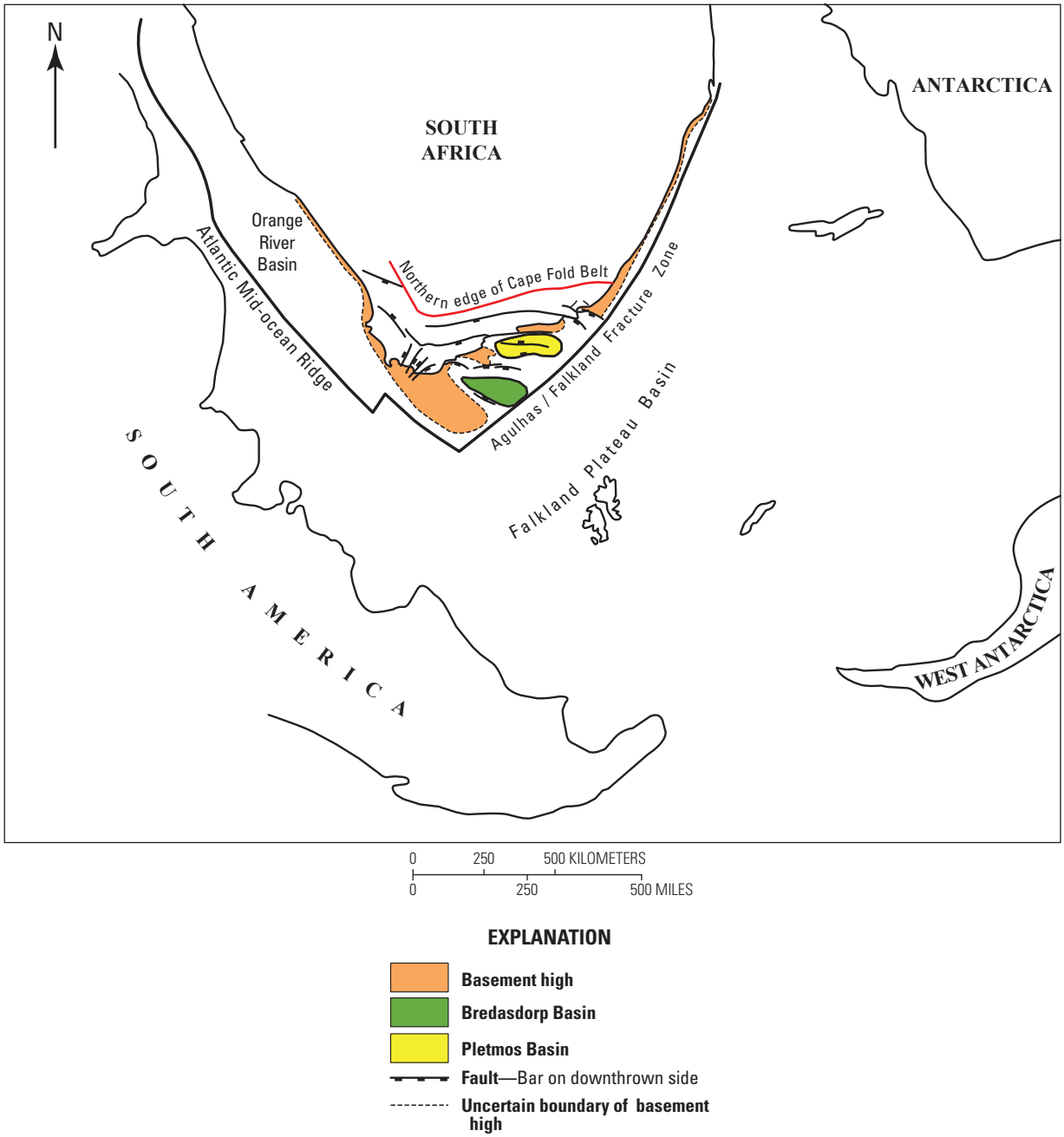


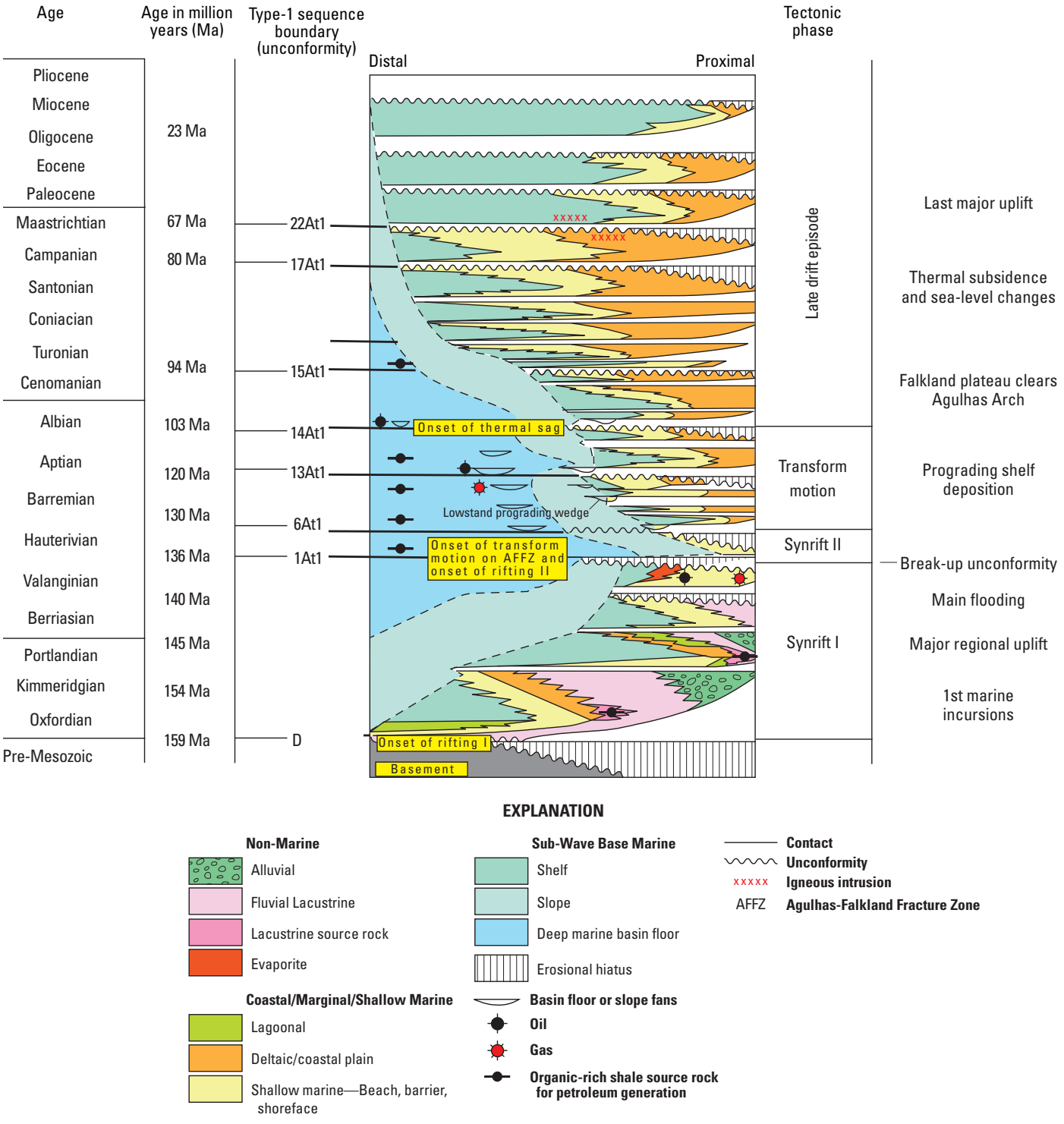
Figure 4. Early Cretaceous reconstruction of Antarctica, South Africa, and South America continental margins. Modified from Muntingh and Brown (1993).

Cenomanian-Turonian strata containing Type II kerogen ranging from 1.0 to 3.0 weight percent TOC (fig. 5; Davis, 1997; van der Spuy, 2003; Madyibi and others, 2009).

Hydrocarbon generation from Upper Jurassic syn-rift sources most likely began in the Early Cretaceous, whereas generation of the early post-rift sources (Barremian to Aptian) began in the Late Cretaceous (Davis, 1997). Post-rift (Turonian) source rocks are just within the oil generation window (0.4 to 0.7 percent R_o) in parts of the offshore and are likely generating oil today. Petroleum generation seems to have ceased at about 69 to 35 million years ago (Ma) owing to the removal at least 800 m of Maastrichtian to early Paleogene sediment; it then resumed (about 10–12 Ma) with the addition of more sediment and continues today (Davis, 1997; Madyibi, 2009).

Reservoirs, Traps, and Seals

The Mesozoic-Cenozoic Reservoirs AU contains Cretaceous and lower Paleogene clastic reservoirs (fig. 6) (Davis, 1997). Syn-rift reservoirs may be present in Jurassic and Lower Cretaceous section in grabens and half grabens in the deeper parts of the offshore. Traps (fig. 6) are mostly



EXPLANATION

Non-Marine
- Alluvial
- Fluvial Lacustrine
- Lacustrine source rock
- Evaporite

Coastal/Marginal/Shallow Marine
- Lagoonal
- Deltaic/coastal plain
- Shallow marine—Beach, barrier, shoreface

Sub-Wave Base Marine
- Shelf
- Slope
- Deep marine basin floor
- Erosional hiatus

Basin floor or slope fans

Oil

Gas

Organic-rich shale source rock for petroleum generation

Contact

Unconformity

xxxxx **Igneous intrusion**

AFFZ **Agulhas-Falkland Fracture Zone**

Figure 5. Sequence stratigraphic framework of the Bredasdorp Basin, South Africa. Modified from Madyibi and others (2009).

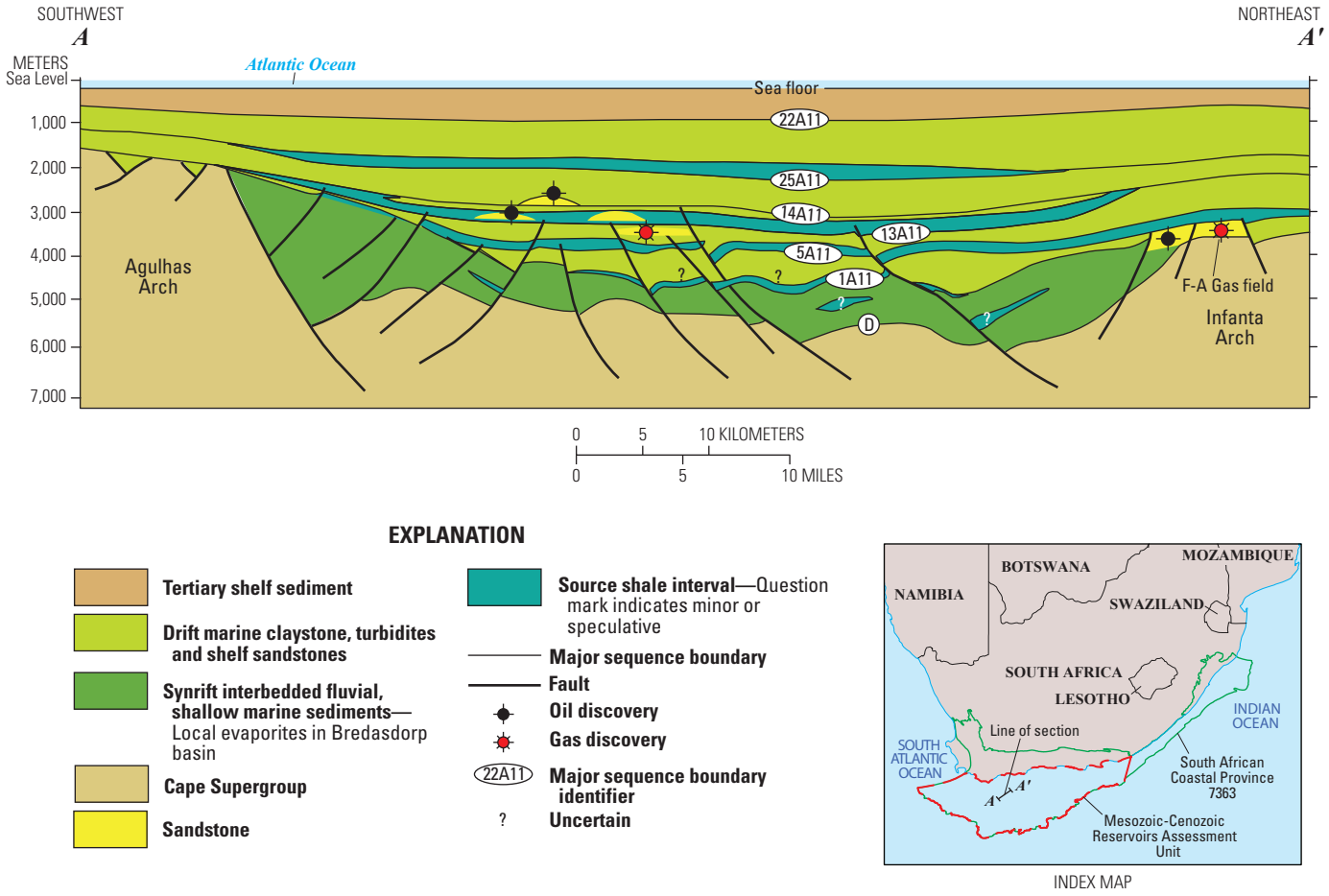


Figure 6. Schematic southwest to northeast cross section showing major faults, hydrocarbon discoveries, source rocks, and major sequence boundaries in the Bredasdorp Basin. Modified from Davies (1997).

associated with growth-fault-related structures, rotated fault blocks within the continental shelf, deep-water fans, turbidite units, slope truncations along the present-day shelf and paleoshelf edge, and Cretaceous and Paleogene stratigraphic pinch-outs along the southern margin of the assessment unit (Davis, 1997; Madyibi and others, 2009; Petroleum Agency SA, 2009). The primary reservoir seals are Cretaceous and Paleogene marine mudstones and shales.

Exploration

At the time of this 2011 assessment, only 183 exploration wells had been drilled since 1969. Those wells discovered 7 oil and 17 gas accumulations exceeding the minimum size of 5 million barrels of oil equivalent and 30 billion cubic feet of gas. The Mesozoic-Cenozoic Reservoirs AU is considered to be underexplored given its past exploration activity. The largest grown oil field is about 37 million barrels of oil and the largest grown gas field is about 1.6 trillion cubic feet. The oil and gas fields are located in the Bredasdorp Basin and Infanta Embayment (figs. 3, 6).

Exploration wells and discovered accumulations on the continental shelf and upper slope (IHS Energy, 2009) provide evidence for the existence of an active petroleum system containing Cretaceous marine source rocks that have produced hydrocarbons most likely since the Late Cretaceous, and for the migration of hydrocarbons into Cretaceous and Paleogene reservoirs.

Geologic Model

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

1. Oil and gas were generated from Lower Cretaceous marine Type II rocks containing 2.0 to 4.28 weight percent TOC; some samples contained TOC values greater than 5 weight percent. Oil and gas may have been generated from the Upper Jurassic lacustrine Type I organic material (TOC at least 3 weight percent). Generation from syn-rift lacustrine sources began in the Early Cretaceous, and from Lower Cretaceous marine sources began in the latest Cretaceous and are most likely generating hydrocarbons today.

2. Hydrocarbons migrated into Cretaceous sandstone reservoirs such as turbidite units.
3. Hydrocarbon traps are mostly associated with growth-fault-related structures, rotated fault blocks within the continental shelf, deep-water fans, turbidite units, slope truncations along the present-day shelf and paleoshelf edge, and Cretaceous and Paleogene stratigraphic pinch-outs along the southern margin of the assessment unit.
4. Cretaceous marine mudstone and shale rocks are the primary reservoir seals.
5. Passive-margin analog (Charpentier and others, 2007) was used for assessment of field sizes and numbers because of similar source, reservoir rocks, and traps.

An events chart (fig. 7) for the Mesozoic Composite TPS and the Mesozoic-Cenozoic AU summarizes the age of the source, seal, and reservoir rocks and the timing of trap development, generation, and migration of hydrocarbons.

Resource Summary

Using a geology-based assessment, the USGS estimated mean volumes of undiscovered, technically recoverable conventional oil and gas resources for the Mesozoic-Cenozoic Reservoirs Assessment Unit in the South African Coastal Province at 2,129 million barrels of oil, 35,964 billion cubic feet of gas, and 1,115 million barrels of natural gas liquids (table 1). The estimated mean size of the largest oil field that is expected to be discovered is 340 million barrels of oil, and the estimated mean size of the expected largest gas field is 2,937 billion cubic feet of gas. For this assessment, a minimum undiscovered field size of 5 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.

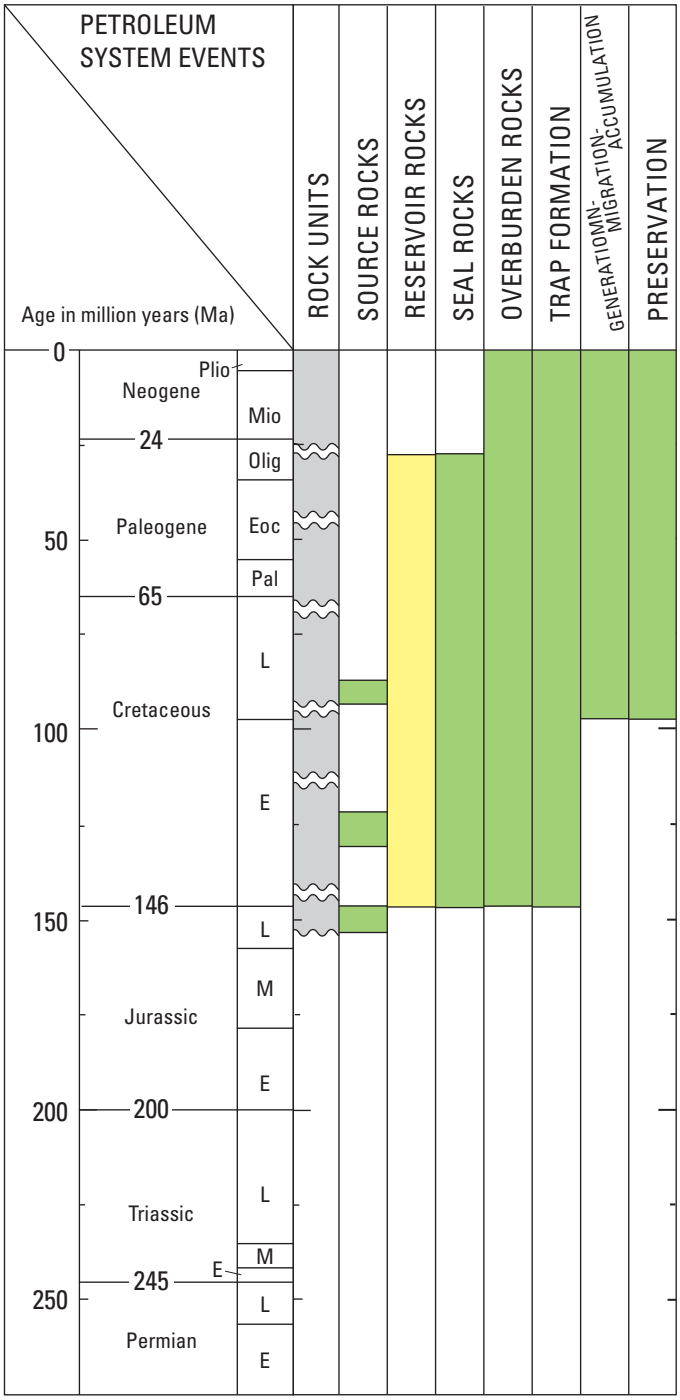


Figure 7. Events chart for the Mesozoic Composite Total Petroleum System (736301) and the Mesozoic-Cenozoic Reservoirs Assessment Unit (73630101) in the South African Coastal Province, west Africa. Gray, rock units present; yellow, age range of reservoir rocks; green, age ranges of source and overburden rocks, 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 Geologic Names Committee (2010). Ma, thousands of years ago; Plio, Pliocene; Mio, Miocene; Olig, Oligocene; Eoc, Eocene; Pal, Paleocene, L, Late; E, Early; M, Middle.

Table 1. South African Coastal Province and Mesozoic-Cenozoic Reservoirs Assessment Unit 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
West-Central Coastal Province–Melania–Gambia TPS														
Mesozoic-Cenozoic Reservoirs AU	*Oil*	340	924	1,984	3,851	2,129	1,209	2,728	5,657	2,995	32	74	155	81
	Gas	2,937					15,915	30,931	57,024	32,969	496	968	1,794	1,034
Total Conventional Resources			**924**	**1,984**	**3,851**	**2,129**	**17,124**	**33,659**	**62,681**	**35,964**	**528**	**1,042**	**1,949**	**1,115**

References

Campher, C.J., di Primio, R., Kuhlmann, G., van der Spuy, D., and Domoney, R., 2009, Geological modeling of the offshore Orange Basin, west coast of South America: American Association of Petroleum Geologists Search and Discovery article 10191 (2009), 21 p.

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.

Davies, C.P.N., 1997, Hydrocarbon evolution of the Bredasdorp Basin, offshore South Africa—From source to reservoir: Stellenbosch, South Africa, University of Stellenbosch, Ph.D. dissertation, 1123 p.

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.

Madyibi, Lihle, di Primio, Rolando, Smith, G.C., Kuhlmann, Gesa, and Anka, Zahie, 2007, Evidence of petroleum system evolution of the southern Bredasdorp Basin, South Africa–A multi-dimensional approach: AAPG International Conference and Exhibition, Cape Town, South Africa, October 26–29, 2008, American Association of Petroleum Geologists Search and Discovery article 10197 (2009).

McMillan, I.K., Brink, G.J., Broad, D.S., and Maier, J.J., 1997, Late Mesozoic sedimentary basins off the south coast of South Africa, *in* Selley, R.C., ed., Sedimentary basins of the world—African basins: Amsterdam, Elsevier Science B. V., p. 319–376.

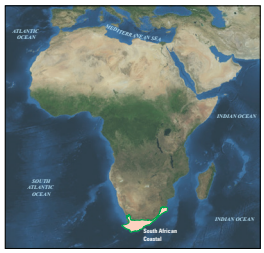
Muntingh, A., and Brown, L.F., Jr., 1993, Sequence stratigraphy of petroleum plays, post-rift Cretaceous rocks (lower Aptian to upper Maastrichtian), Orange Basin, western offshore, South Africa, *in* Weimer, Paul, and Posamentier, H.W., eds., Siliciclastic sequence stratigraphy—Recent developments and applications: American Association of Petroleum Geologists Memoir 58, p. 71–98.

Petroleum Agency SA (PASA), 2009, Republic of South Africa western Bredasdorp Basin: Available at http://www.petroleumagencysa.com/index.php/petroleum-geology-resources/brochures, 4 p. Accessed January 24, 2013.

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/.

van der Spuy, David, 2003, Aptian source rocks in some South African Cretaceous basins, *in* Arthur, T.J., MacGregor, D.S., and Cameron, N.R., eds., Petroleum geology of Africa—New themes and developing technologies: Geological Society, London, Special Publications 207, p. 185–202.



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