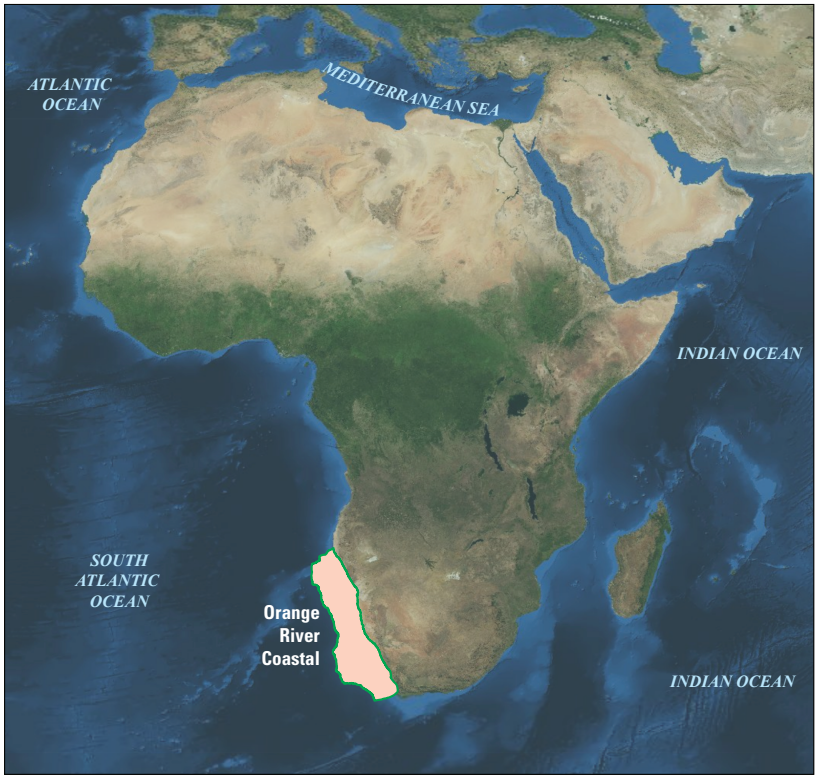
Assessment of Undiscovered Oil and Gas Resources of the Orange River Coastal Province, Southwest Africa

By Michael E. Brownfield



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Chapter 8 of
Geologic Assessment of Undiscovered Hydrocarbon Resources of Sub-Saharan Africa
Compiled by Michael E. Brownfield

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Assessment of Undiscovered Oil and Gas Resources of the Orange River Coastal Province, Southwest 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 completed an assessment of the Orange River Coastal Province, an area of about 743,620 square kilometers that covers the western part of Namibia and northwest part of South Africa. This assessment was based on data from oil and gas exploration wells and published geologic reports.

The Orange River Coastal Province is a priority province for the World Petroleum Assessment because of its recent energy exploration activity and 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 include 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 Offshore Assessment Unit. This assessment unit encompasses 743,620 square kilometers; it includes the offshore part of the province to a water depth of 4,000 meters.

Oil and gas were generated from Barremian-Aptian and Cenomanian-Turonian marine Type II source rocks during burial by as much as 7,000 meters of sediments during the drift–passive margin–stage progradation. Generation most likely started in the Late Cretaceous and continues to the present. Lower Cretaceous Type I lacustrine source rocks may have generated hydrocarbons beginning in the Early Cretaceous. Hydrocarbons migrated into Cretaceous and Cenozoic sandstone reservoirs such as deltaic and nearshore marine sandstone, turbidite sandstones, slope truncations along the present-day shelf and paleoshelf edge, and basin-floor fan reservoirs. Structural traps include growth-fault-related structures and rotated fault blocks within the continental shelf. Cretaceous and Cenozoic mudstone and shale rocks are the primary reservoir seals. Passive margin analog was used for assessment 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 Offshore Assessment Unit in the Orange River Coastal Province at 1,057 million barrels of oil, 27,839 billion cubic feet of gas, and 700 million barrels of natural gas liquids. The estimated mean size of the largest oil field that is expected to be discovered is 247 million barrels of oil, and the estimated mean size of the expected largest gas field is 2,693 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 project, the USGS recently completed an assessment in 2010 of the Orange River Coastal Province, an area of about 743,620 square kilometers (km^2) that covers the western part of Namibia and northwestern part of South Africa (fig. 1). This assessment was based on data from oil and gas exploration wells, discovered fields and published geologic reports.

The Orange River Coastal Province, which is a priority province for the World Petroleum Assessment, was assessed in 2010 because of recent exploration and 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 include 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 Mesozoic Composite Total Petroleum System with one assessment unit, the Offshore Assessment Unit (AU) (fig. 1), encompassing 743,620 km^2 that includes the offshore part of the province to a water depth of 4,000 m.

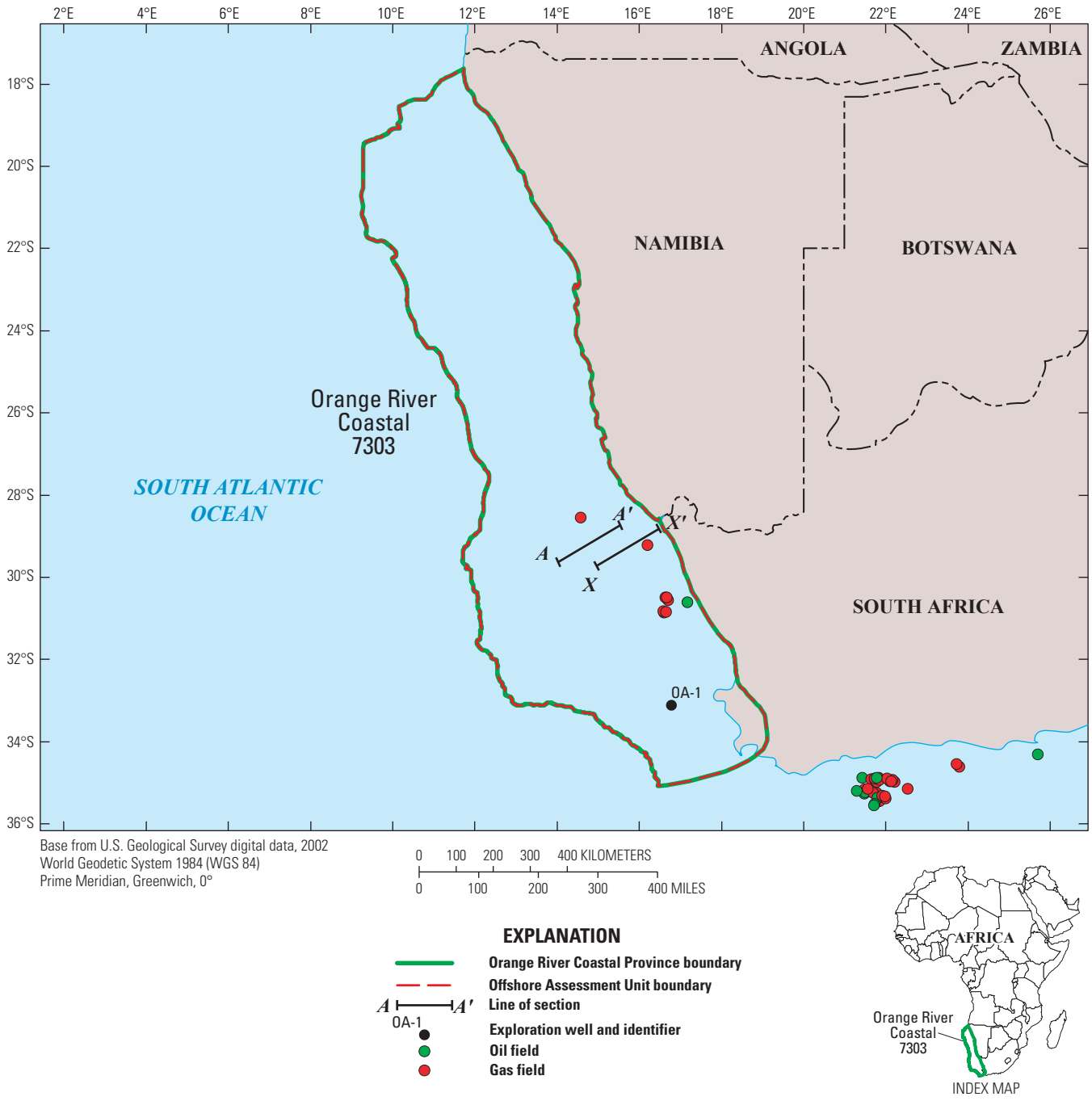

Figure 1. Orange River Coastal Province and the Offshore Assessment Unit, southwest Africa. Exploration well OA-1 drilled by Soekor Energy and Petroleum. (Lines of section *X–X′* and *A–A′*, figs. 6 and 7 respectively).

Tectonic History and Geology of the Orange River Coastal Province, Southwest Africa

A generalized geologic map of west Africa (Persits and others, 2002) showing province boundaries, names, and province codes (Klett and others, 1997) is shown in figure 2. Most of the Orange River Coastal Province in located in the offshore parts of Namibia and northwest South Africa. A map showing the major basins and basement highs for the offshore and onshore parts of the southern part of Africa is shown in figure 3. Today the western margin of southern Africa is a passive-continental margin that formed by the breakup of Gondwana and the subsequent opening of the South Atlantic Ocean during the Late Jurassic to Early Cretaceous (fig. 4) (Muntingh, 1993; Muntingh and Brown, 1993).

The basic geologic framework of the offshore part of the Orange River Coastal Province developed in two major phases (Campher and others, 2009): a syn-rift phase that was initiated during the Jurassic and continued into the Early Cretaceous (figs. 4, 5, 6) resulting in the formation of grabens and half-grabens (figs. 6, 7), and a drift-passive-margin phase that began in the late Hauterivian and continues to the present (figs. 5, 6, 7, 8). The syn-rift stage of the Orange Basin consists of north-south-trending grabens and half grabens containing continental and lacustrine rocks and volcanic intrusions (fig. 5) (Muntingh, 1993). Lacustrine, fluvial, and aeolian facies successions may be interbedded with volcanic rocks. The upper boundary of the syn-rift stage is the Hauterivian rift-drift unconformity, which was succeeded by a transition stage (fig. 6) consisting of a deepening-upward succession of fluvial red beds overlain by sandy marine sediment (Muntingh, 1993; Paton and others, 2007). The Late Cretaceous drift stage was characterized by thermal subsidence of the margins and the initiation of open-ocean circulation. The early Late Cretaceous contains the deepest marine sediment, and the deep marine environments generally shallow upward to the present day (Kuhlmann and others, 2010). The Barremian contains a transitional to marine source rocks, and the basal part of the Aptian marks an anoxic black-shale event (van der Spuy, 2003). The drift stage is characterized by turbidite sedimentation consisting of basin-floor fan, slope fan, and turbidite units containing mainly clastic shale, siltstone, and sandstone (Muntingh, 1993). Figure 6 shows the major unconformities and sequence boundaries in the offshore part of the Orange Basin (Jungslager, 1999; Salomo, 2011). The total thickness of the Mesozoic to Cenozoic drift-passive-margin section is more than 7,000 meters (m) on the outer parts of the continental shelf (fig. 8; Muntingh and Brown, 1993).

Petroleum Occurrence in the Orange River Coastal Province, Southwest Africa

Source Rocks

Four source rock intervals are identified in the Orange River Coastal Province (Muntingh, 1993; Kuhlmann and others, 2010): (1) Upper Jurassic-Neocomian, syn-rift lacustrine source rock and continental (coal and carbonaceous shale) source rocks; (2) Barremian transitional to marine source rocks; (3) Aptian anoxic marine source rocks; and (4) Cenomanian-Turonian drift stage marine source rocks. The known and actively generating oil and gas source rocks, whether in the syn-rift, transitional, or drift units are the major controls on the observed occurrences of petroleum. The predominantly gas-bearing source rocks coincide with the main depocenter of the Orange Basin where the lower Aptian source rocks are in the gas generation window. Oil-prone areas are predicted outside the depocenter, in deeper water, where the lower Aptian source rocks may become more oil prone and possibly located in the oil-generation window. These possibly more oil-prone areas coincide with hypothetical deepwater turbidite sandstone reservoirs. A burial history diagram for the OA-1 drill hole is shown in figure 9; peak generation most likely started in the Late Cretaceous (Jungslager, 1999).

Within the Upper Jurassic to Lower Cretaceous syn-rift section, Hauterivian lacustrine sedimentary units have been reported with oil-prone source rock containing total organic carbon (TOC) as much as 12 weight percent with hydrogen index values greater than 600 mg hydrocarbon/g TOC in the A-J graben (fig. 6; Jungslager, 1999; Paton and others, 2007). Hauterivian lacustrine source rock should be present above the transitional crust in the offshore part of the Orange Basin (Jungslager, 1999). From the Barremian to Early Aptian, rapid deepening of the basin led to the deposition of a marine-transitional source rock within an Aptian anoxic basin. This oil-prone source rock has a potentially large lateral distribution. Paton and others (2007) reported Barremian and Aptian source rock values of 10 weight percent TOC. Davies and van der Spuy (1990) and van der Spuy (2003) measured TOC contents as much as 4 weight percent. They suggest that original TOC contents might have been initially as high as 8 weight percent. This source rock is most likely source interval for the Kudu Gas (Namibia) field. Muntingh (1993) described Turonian source rocks with TOCs as much as 5 weight percent, but its regional presence in the Orange Basin remains speculative. Oil and gas generation most likely began in the Late Cretaceous and continues to the present (Kuhlmann and others, 2011).

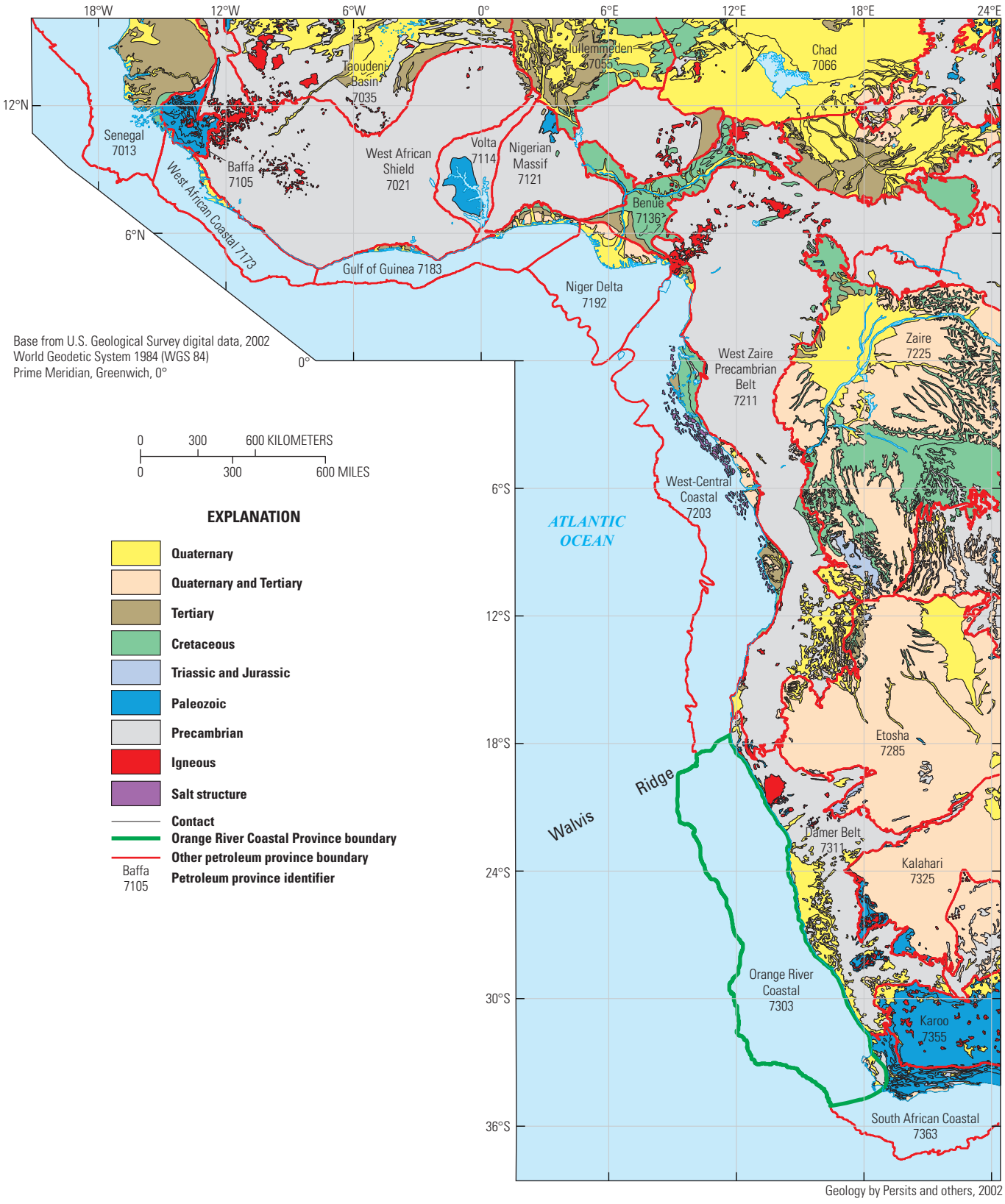

Figure 2. Generalized geology of west Africa (Persits and others, 2002), showing province boundaries and 21 province names and codes as defined by Klett and others (1997).

Figure 3. Major basins and basement highs in southwestern Africa and offshore South Africa. Modified from Campher and others (2009).

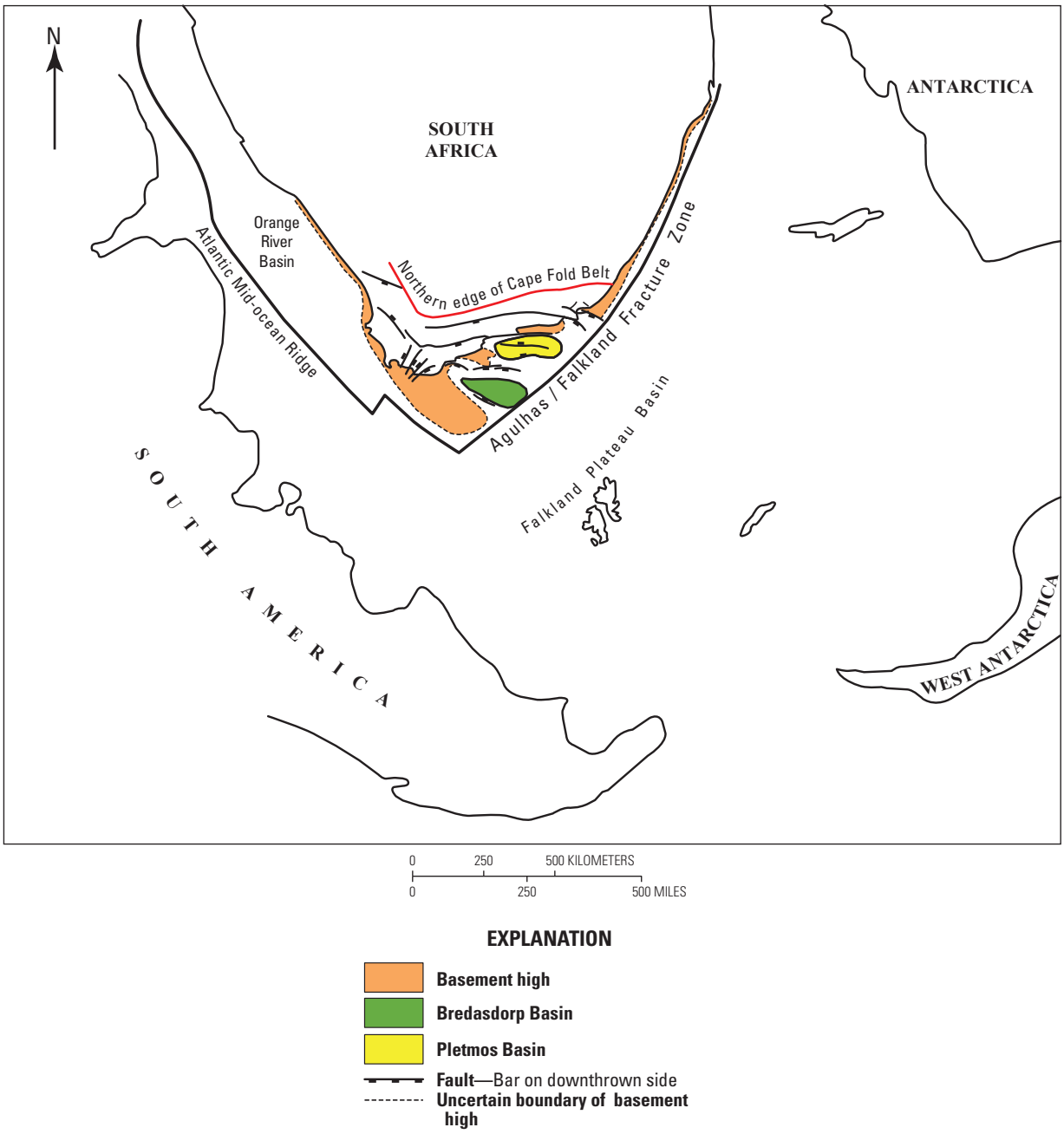

Figure 4. Early Cretaceous reconstruction of Antarctica, South Africa, and South America continental margins. Modified from Muntingh and Brown (1993).

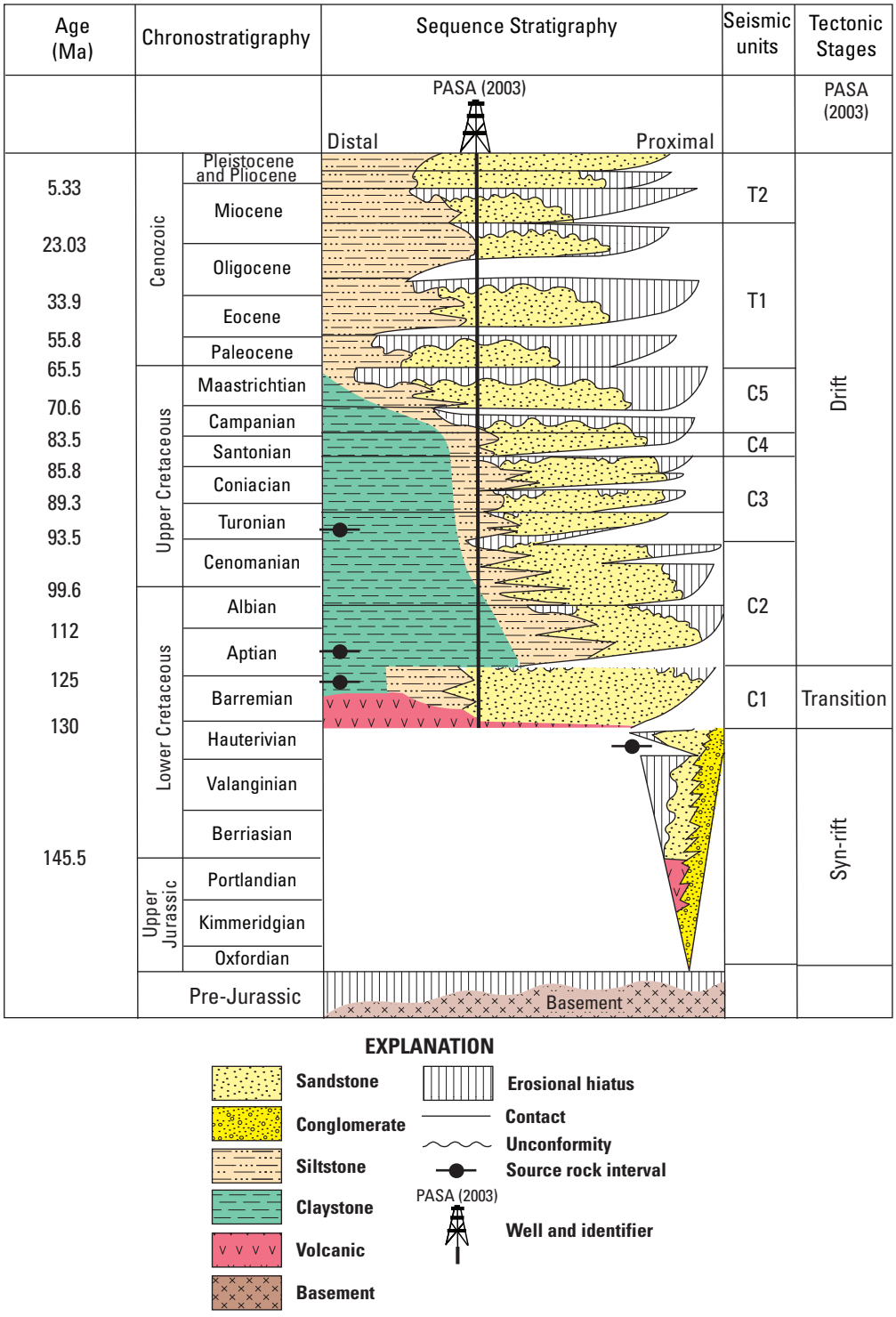

Figure 5. Chronostratigraphy and sequence stratigraphic chart for the Orange River Coastal Province showing seismic horizons and markers and tectonic stages. Three Cretaceous marine source-rock intervals and one Lower Cretaceous lacustrine source-rock interval are present in the province. Seismic reflections from Brown and others (1995) and sequence stratigraphy from Petroleum Agency SA (PASA) (2003). Modified from Kuhlmann and others (2010). Ma, million years ago.

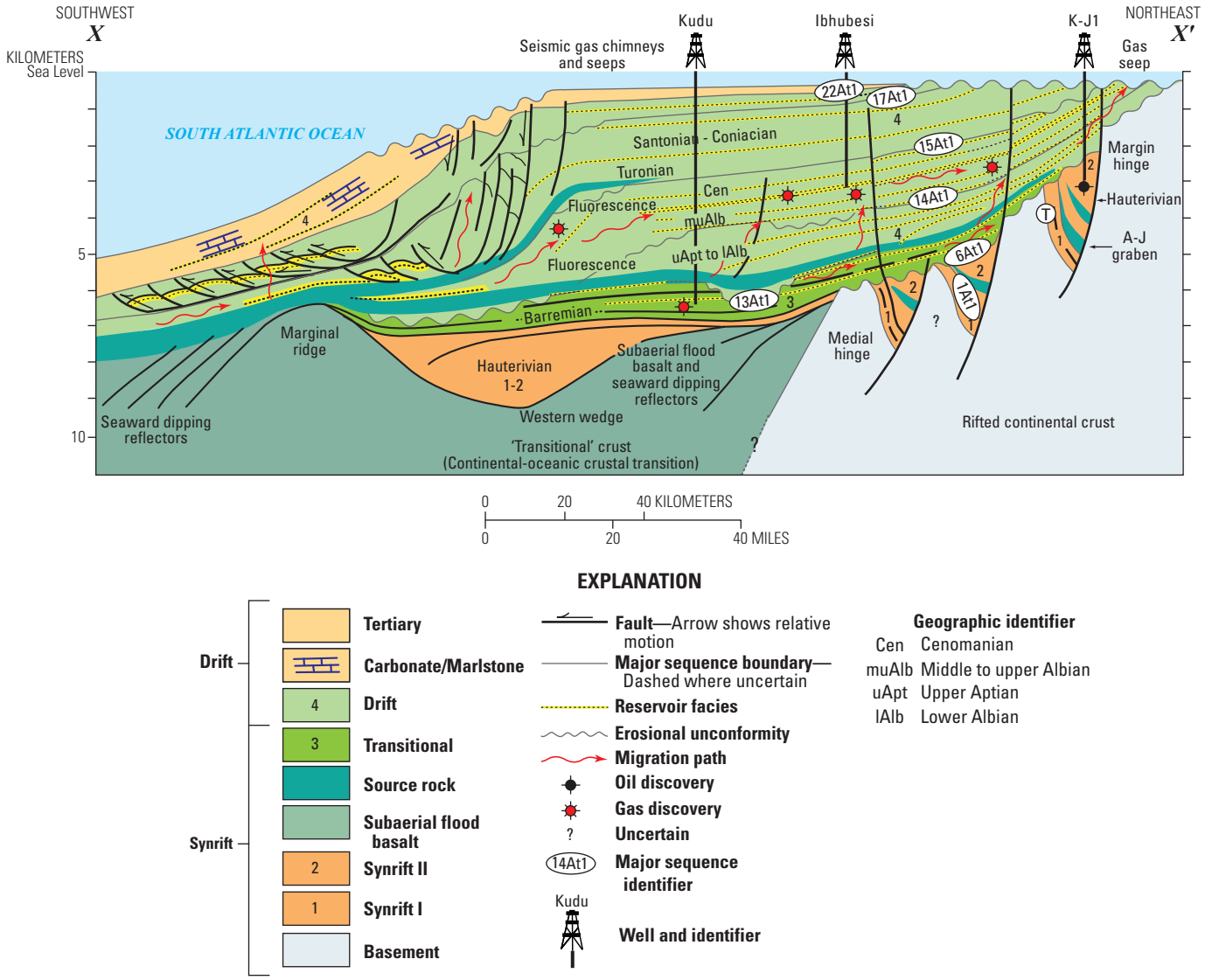

Figure 6. Generalized stratigraphic cross section through the Orange Basin, offshore South Africa. See figure 1 for location. Modified from Jungslager (1999) and Salomo (2011).

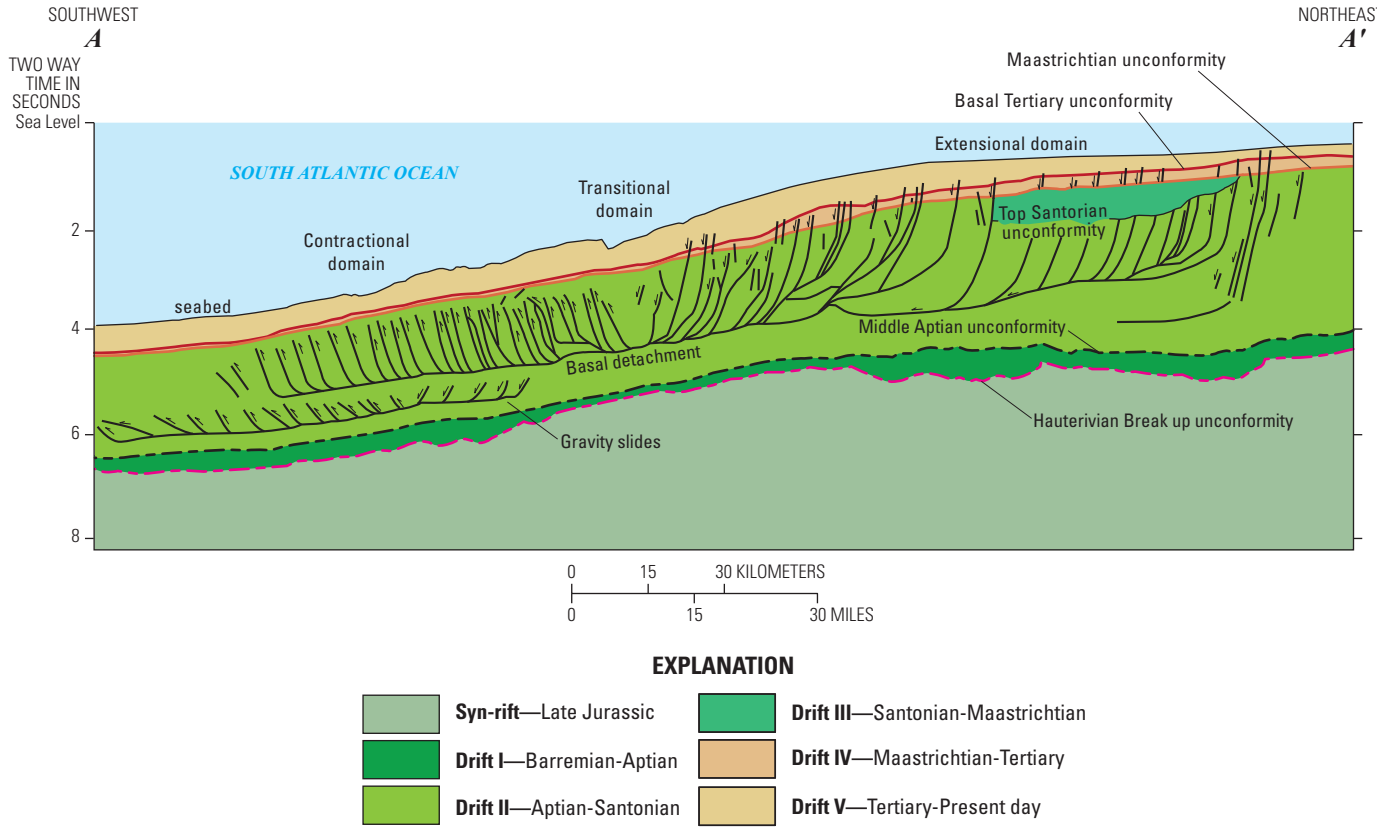

Figure 7. Geoseismic cross section in the Orange Basin, southwestern Africa showing main megasequences and Late Cretaceous gravity-driven slide system (line of section *A–A′*, fig. 1). Modified from De Vera and others (2010).

The Mesozoic Composite TPS was defined to include Mesozoic source rocks containing as much as 10 weight percent total organic carbon (TOC) including Barremian-Aptian source rocks containing Type II kerogen ranging from 4 to as much as 10 weight percent TOC and the Cenomanian-Turonian strata containing Type II kerogen with as much as 5 weight percent TOC.

Reservoirs, Traps, and Seals

The Offshore AU contains Upper Jurassic, Cretaceous, and Cenozoic clastic reservoirs and traps (Muntingh, 1993; Muntingh and Brown, 1993: Jungslager, 1999). Upper Jurassic and Lower Cretaceous syn-rift reservoirs are associated with the grabens and half grabens in the deeper parts of the offshore and the A-J graben (fig. 6) (Jungslager, 1999). Reservoirs in the syn-rift section include fluvio-deltaic and lacustrine sandstone, whereas the drift-passive-margin reservoirs include deltaic and turbidite sandstone. Structural traps include growth-fault-related structures, rotated fault blocks within the continental shelf, and stratigraphic traps include deep-water fans, turbidite sandstones and slope truncations along the present-day shelf and paleoshelf edge (Muntingh, 1993; Muntingh and Brown, 1993). Stratigraphically trapped Barremian aeolian sandstone and Albian-Cenomanian sandstone act as gas reservoirs (fig. 5) for the Kudu Gas (Namibia) field (Jungslager, 1999).

The primary reservoir seals are Cretaceous and Cenozoic marine mudstone and shale (Muntingh, 1993).

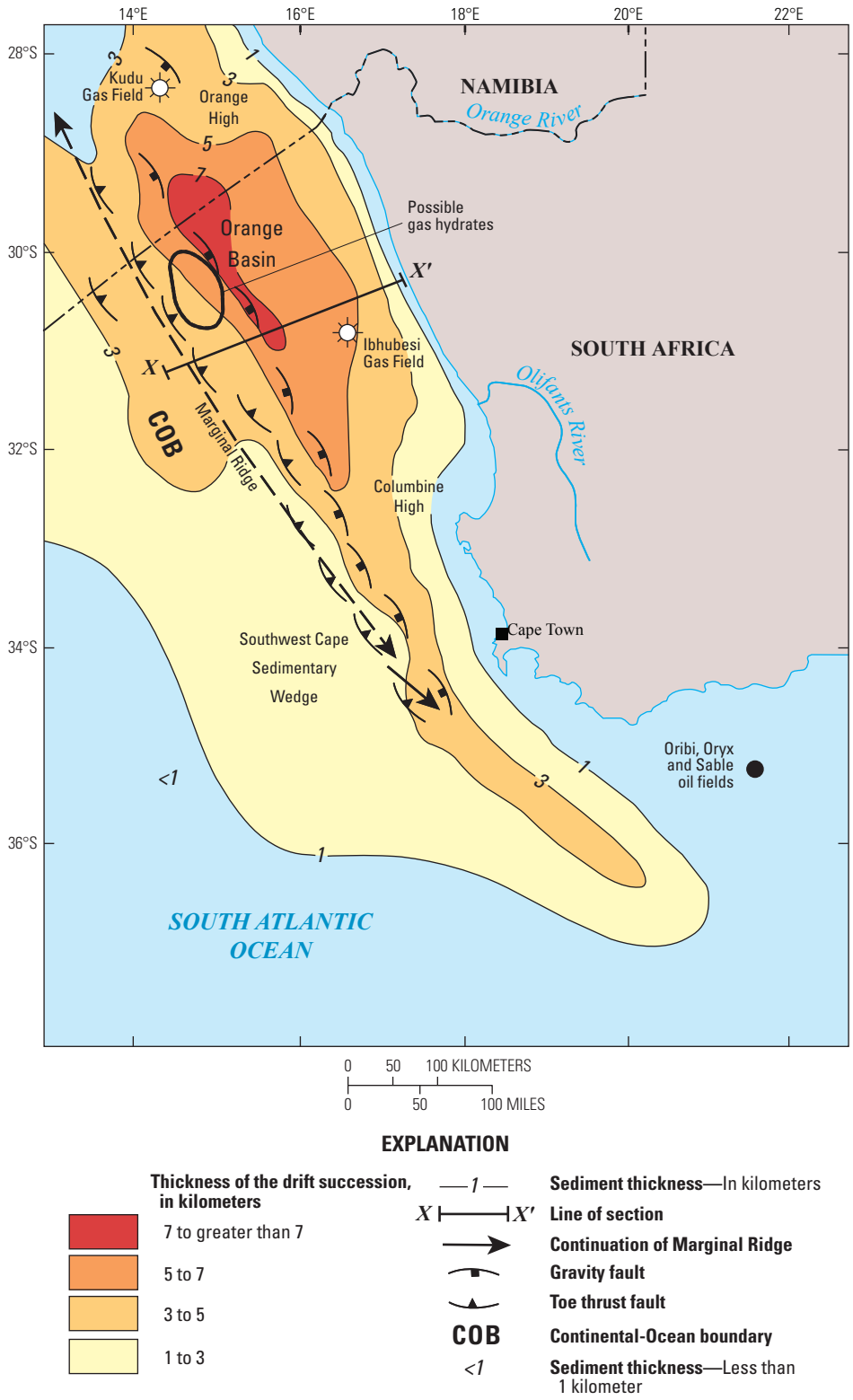

Figure 8. Isopach map showing thickness of drift succession, generally outlining the Orange Basin and the drift-passive-margin section overlying the main Aptian-Barremian source rocks. Large-scale synsedimentary structures are restricted to the distal parts of the basin where probable oil plays are predicted. (Cross section X–X′, fig. 6.) Modified from Jungslager (1999) and Salomo (2011).

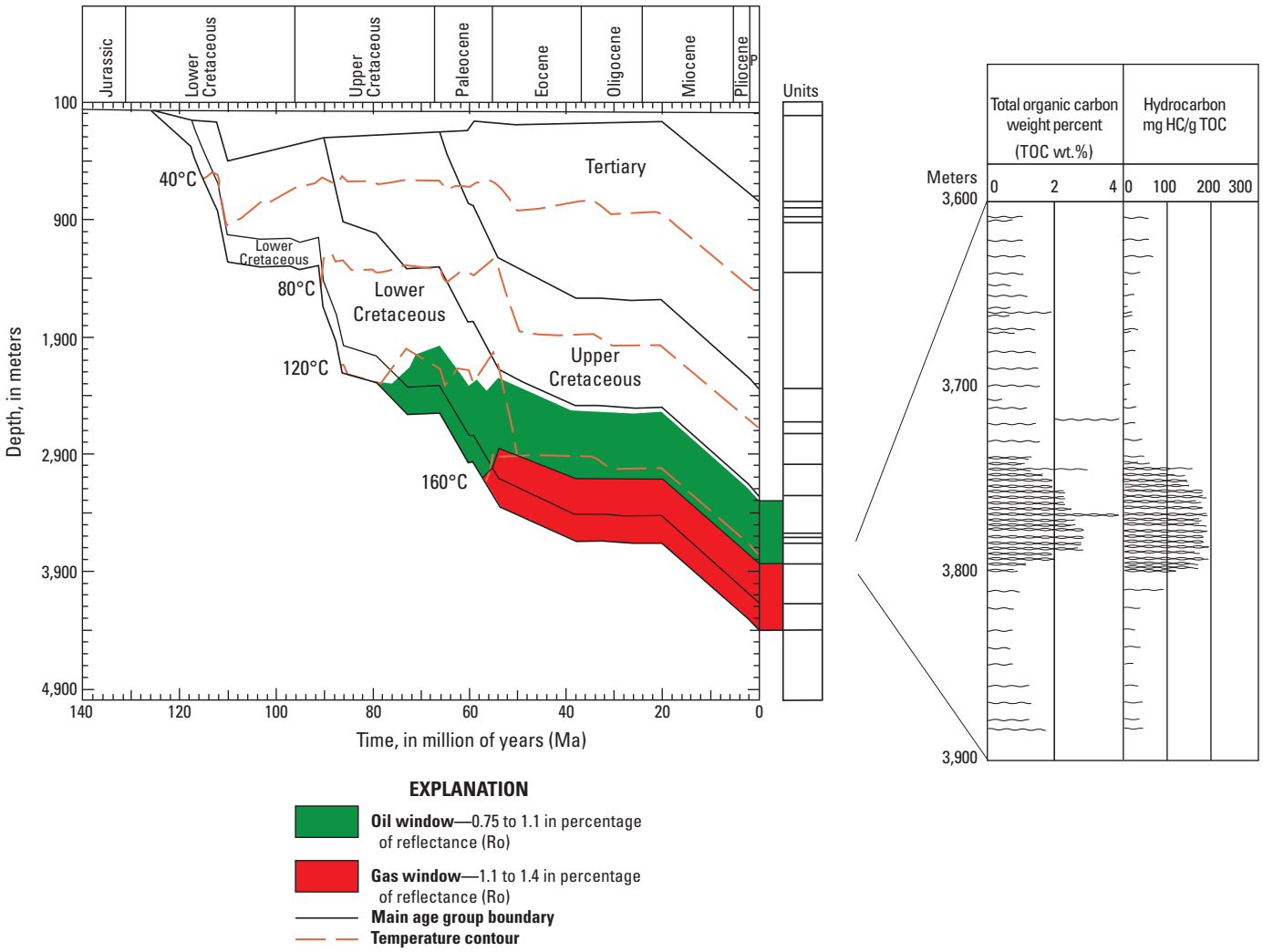

Figure 9. Burial history of the OA-1 drill hole (Soekor Energy and Petroleum), Orange River Coastal Province, South Africa. (Location of drill hole, fig. 1.) Modified from Jungslager (1999). % Ro, percent reflectance; Ma, million years ago; mg HC/g TOC, milligrams hydrocarbon per gram total organic carbon; TOC, total organic carbon; P, Pleistocene.

Exploration

At the time of the 2010 assessment, only eight gas fields exceeding the minimum size of 5 million barrels of oil equivalent and 30 billion cubic feet of gas had been discovered (IHS Energy, 2009). The assessment unit is considered to be underexplored based on its level of exploration activity.

Exploration wells and discovered gas 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 Cenozoic reservoirs.

Geologic Model

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

1. Oil and gas was generated from Barremian-Aptian and Cenomanian-Turonian Type II marine source rocks during progradation and burial by as much as 7,000 m of sediment during the drift–passive-margin stage. Generation most likely started in the Late Cretaceous and continues to the present. Lower Cretaceous Type I lacustrine source rocks possibly generated hydrocarbons beginning in the Lower Cretaceous.

2. Hydrocarbons migrated into Cretaceous and Cenozoic sandstone reservoirs including deltaic and nearshore marine sandstone and continental margin and slope-turbidite sandstones and basin-floor fans.
3. Structural hydrocarbon traps include growth-fault-related structures, rotated fault blocks within the continental shelf. Stratigraphic hydrocarbon traps include deep-water fans, turbidite sandstones, and slope truncations along the present-day shelf and paleoshelf edge.
4. Cretaceous and Cenozoic mudstone and shale rocks are the primary reservoir seals.
5. Passive margin analog (Charpentier and others, 2007) was used for assessment sizes and numbers because of similar source and reservoir rocks and traps.

An events chart (fig. 10) 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 U.S. Geological Survey estimated mean volumes of undiscovered, technically recoverable conventional oil and gas resources for the Offshore AU in the Orange River Coastal Province at 1,057 million barrels of oil, 27,839 billion cubic feet of gas, and 700 million barrels of natural gas liquids (table 1). The estimated mean size of the largest oil field that is expected to be discovered is 247 million barrels of oil, and the estimated mean size of the expected largest gas field is 2,693 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 Christopher J. Schenk, the assessing geologist *(schenk@usgs.gov)*.

Acknowledgments

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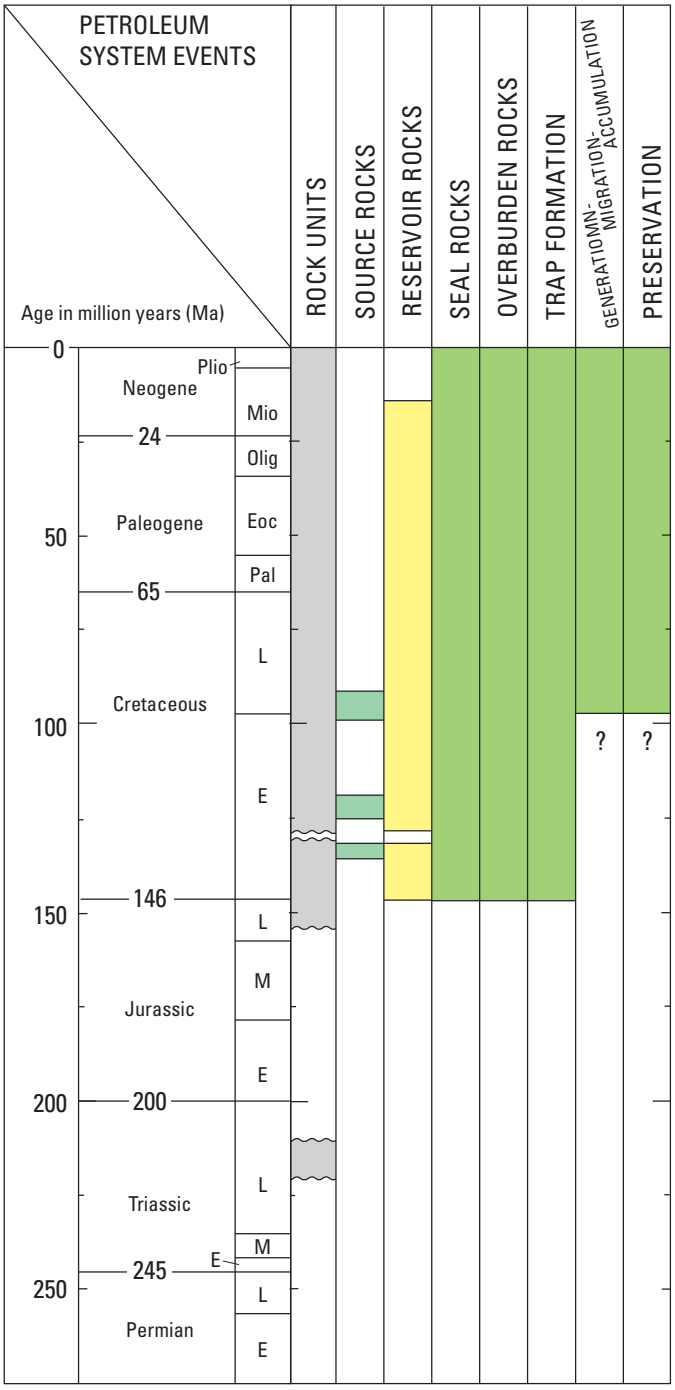

Figure 10. Events chart for the Mesozoic Composite Total Petroleum System (730301) and the Offshore Assessment Unit (73030101) in the Orange River Coastal Province, southwest Africa. Gray, rock units present; yellow, age range of reservoir rock; green, age ranges of source, seal, and overburden rocks 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 Geologic Names Committee (2010). Ma, millions of years ago; E, Early; M, Middle; L, Late; Pal, Paleocene; Eoc, Eocene; Olig, Oligocene; Mio, Miocene; Plio, Pliocene.

Table 1. Orange River Coastal Province and Offshore 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														
Offshore AU	***Oil***	247	410	955	2,044	1,057	937	2,209	4,806	2,458	57	134	293	149
	Gas	2,693					11,988	23,771	44,329	25,381	257	516	970	551
Total Conventional Resources			**410**	**955**	**2,044**	**1,057**	**12,925**	**25,980**	**49,135**	**27,839**	**314**	**650**	**1,263**	**700**

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