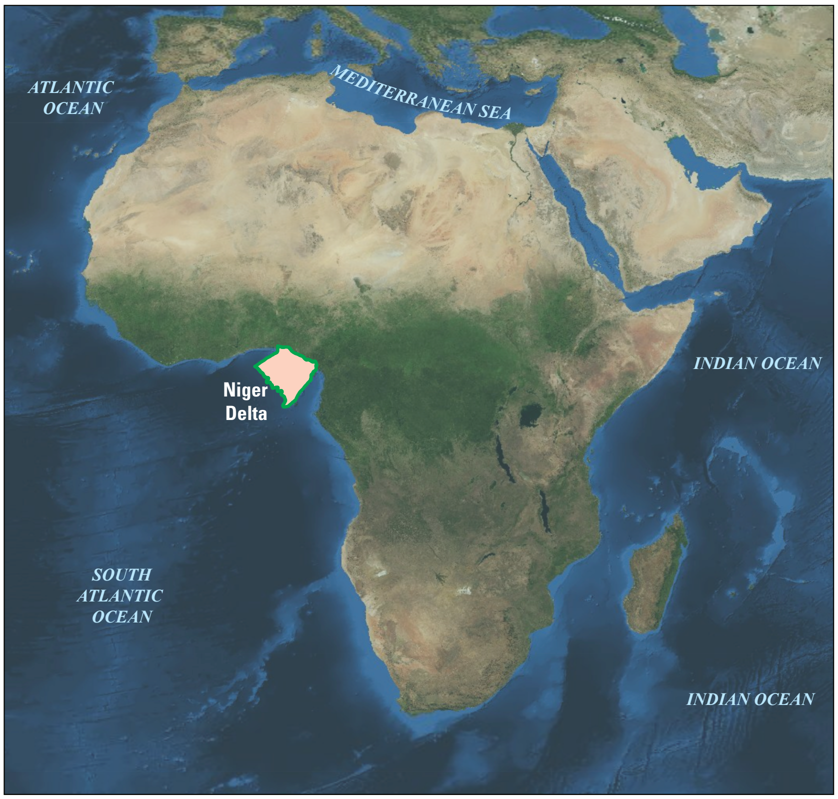
Assessment of Undiscovered Oil and Gas Resources of the Niger Delta Province, Nigeria and Cameroon, Africa

By Michael E. Brownfield



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Chapter 5 of
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Compiled by Michael E. Brownfield

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Abbreviations Used in This Report

ft foot

km kilometer

Assessment of Undiscovered Oil and Gas Resources of the Niger Delta Province, Nigeria and Cameroon, 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 completed an assessment of the Niger Delta Province, an area of about 292,407 square kilometers. This assessment was based on data from oil and gas exploration wells, oil and gas fields, and published geologic reports.

The Niger Delta Province is a priority province for the National and Global Petroleum Assessment Project. 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 Tertiary Niger Delta Total Petroleum System with two assessment units, the Agbada Reservoirs and the Akata Reservoirs Assessment Units, encompassing 99,915 square kilometers and 212,652 square kilometers, respectively. The Agbada Reservoirs Assessment Unit was assessed to a water depth of 200 meters and the Akata Reservoirs Assessment Unit was assessed to 4,000 meters water depth.

Hydrocarbons were generated from Eocene paralic and prodeltic Type II and Type III kerogen, ranging from 1.4 weight percent to 5.2 weight percent total organic carbon, and possibly from Cretaceous marine and lacustrine sources. Generation began in the Eocene and continues to the present. Generation moved progressively from north to south as younger units entered the oil window. Hydrocarbons migrated into Eocene Agbada Formation sandstone reservoirs and traps. Hydrocarbons have also migrated into Akata Formation turbidite sandstones, including lowstand channels, sheet sand, and fans. In the Agbada Assessment Unit, hydrocarbon traps are mostly structural, but stratigraphic traps are also present, whereas in the Akata Assessment Unit traps are mostly related to turbidites. The Eocene marine mudstone and shale rocks are the primary reservoir seals in both Agbada and Akata Assessment Units. The Niger Delta Province is considered mature for oil and gas; therefore, current field histories were used as a partial guide for undiscovered sizes and numbers.

The U.S. Geological Survey estimated mean volumes of undiscovered, technically recoverable conventional oil and gas resources for the Agbada Reservoirs Assessment Unit in the Niger Delta Province at 1,616 million barrels of oil, 9,454 billion cubic feet of gas and 494 million barrels of natural gas liquids. The estimated mean size of the largest oil field that is expected to be discovered is 274 million barrels of oil, and the estimated mean size of the expected largest gas field is 981 billion cubic feet of gas. The estimated mean volumes for the Akata Reservoirs AU are 13,918 million barrels of oil, 48,767 billion cubic feet of gas, and 5,832 million barrels of natural gas liquids; estimated mean sizes of the largest oil and gas fields are 4,119 million barrels of oil and 13,355 billion cubic feet of gas, respectively. For this assessment, a minimum undiscovered field size of 1 million barrels of oil equivalent was used for the Agbada Reservoirs AU and a minimum undiscovered field size of 5 million barrels of oil equivalent was used for the Akata Reservoirs Assessment Unit. 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 of the Niger Delta Province (fig. 1), an area of about 292,407 square kilometers (km^2). This assessment was based on data from oil and gas exploration wells, fields (IHS Energy, 2008), and published geologic reports.

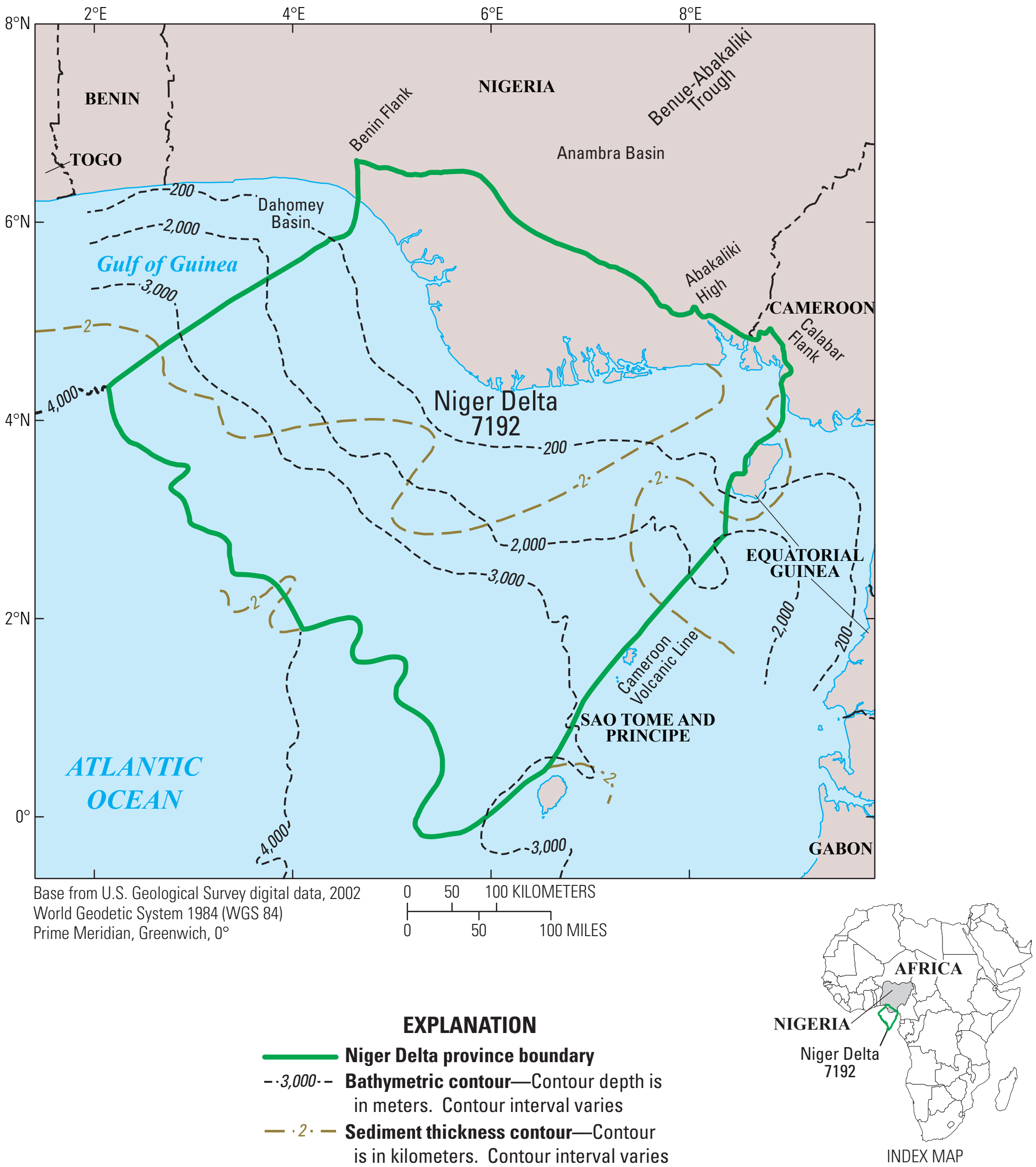

Figure 1. Nigeria and Cameroon, the Niger Delta Province boundary, bounding structural features, and 200-, 2000-, 3000-, and 4000-meter bathymetric contours.

This province was assessed previously as part of the USGS World Assessment 2000 (U.S. Geological Survey World Energy Assessment Team, 2000), resulting in estimated mean undiscovered volumes of 40.5 billion barrels of oil (BBO), 133.7 trillion cubic feet (TCF) of gas, and 6.03 billion barrels of natural gas liquids (BBNGL).

The Niger Delta Province was reassessed because of continued 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 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 Tertiary Niger Delta Total Petroleum System (TPS) with two assessment units, the Agbada Reservoirs Assessment Unit (AU) and the Akata Reservoirs AU (figs. 1, 2), encompassing 99,915 km^2 and 212,652 km^2, respectively. The Agbada Reservoirs AU was assessed to a water depth of 200 m and the Akata Reservoirs AU was assessed to 4,000 meters (m) water depth.

Two previous USGS geologic studies have reported on the potential for undiscovered hydrocarbon resources and described the petroleum system, assessment units,

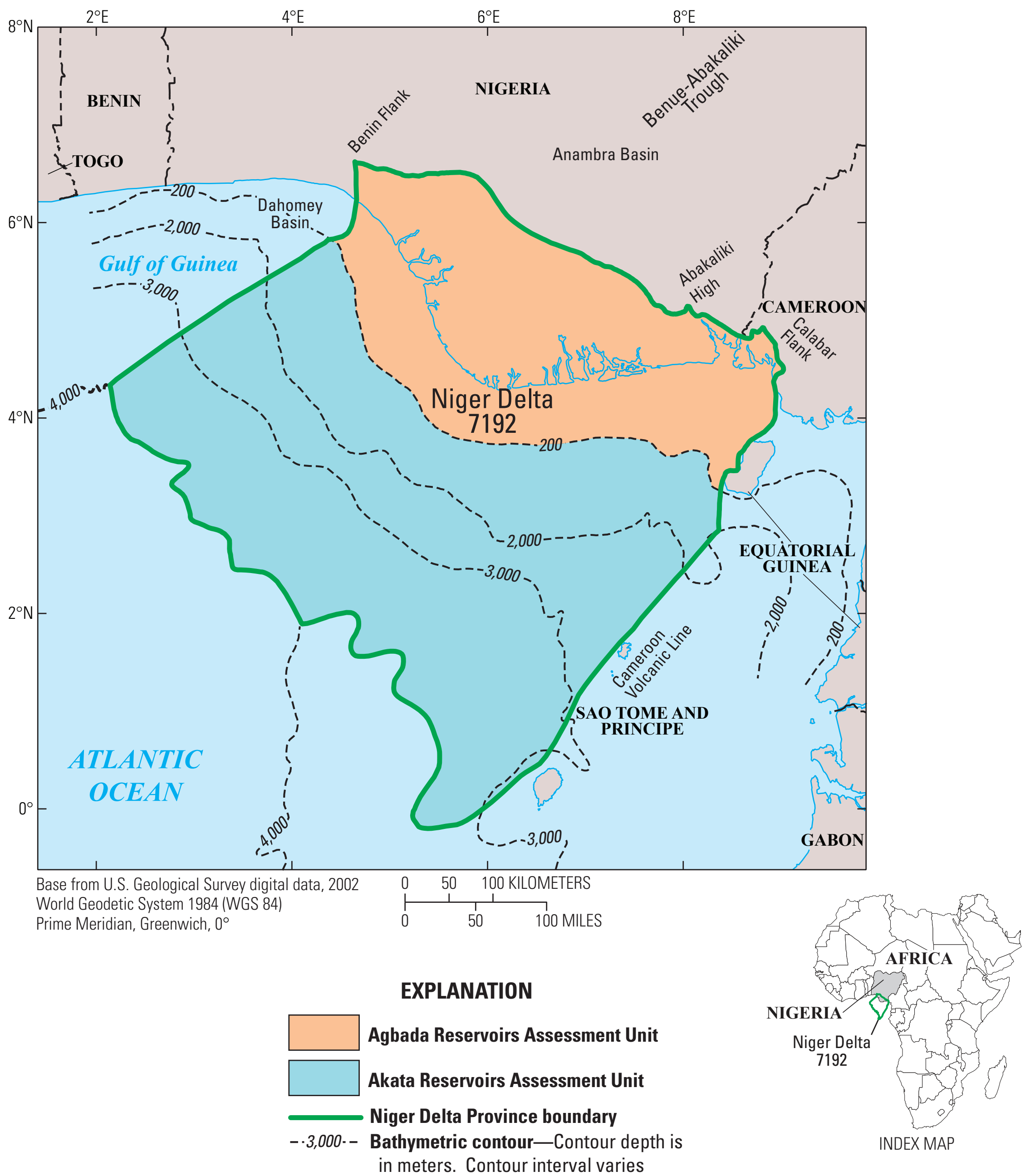

Figure 2. Extent of the Agbada Reservoirs Assessment Unit (71920101) and the Akata Reservoirs Assessment Unit (71920102). The Agbada Reservoirs Assessment Unit overlies the Akata Reservoirs Assessment Unit, in part subaerially.

hydrocarbon source rocks, reservoir rocks, and potential traps for hydrocarbon accumulation for the province (Tuttle, Brownfield, and Charpentier, 1999; Tuttle, Charpentier, and Brownfield, 1999). Geologic maps of west Africa and the Gulf of Guinea are shown in figures 3 and 4.

The northern boundary of the Niger Delta Province is the Benin flank (figs. 1, 2)—an east-northeast trending hinge line south of the West Africa Nigerian Massive Province (figs. 3, 4). The northeastern boundary is defined by Cretaceous outcrops on the Abakaliki High and Calabar Flank—a hinge line bordering adjacent Precambrian rocks in Cameroon terrain (figs. 1, 2). The offshore boundary of the province is defined by the Cameroon volcanic line on the southeast and the eastern boundary of the Dahomey Embayment (fig. 4) to the west. The 2-kilometer (km) sediment thickness contour or the 4000-m bathymetric contour in areas where sediment thickness is greater than 2 km defines the boundary to the south and southwest.

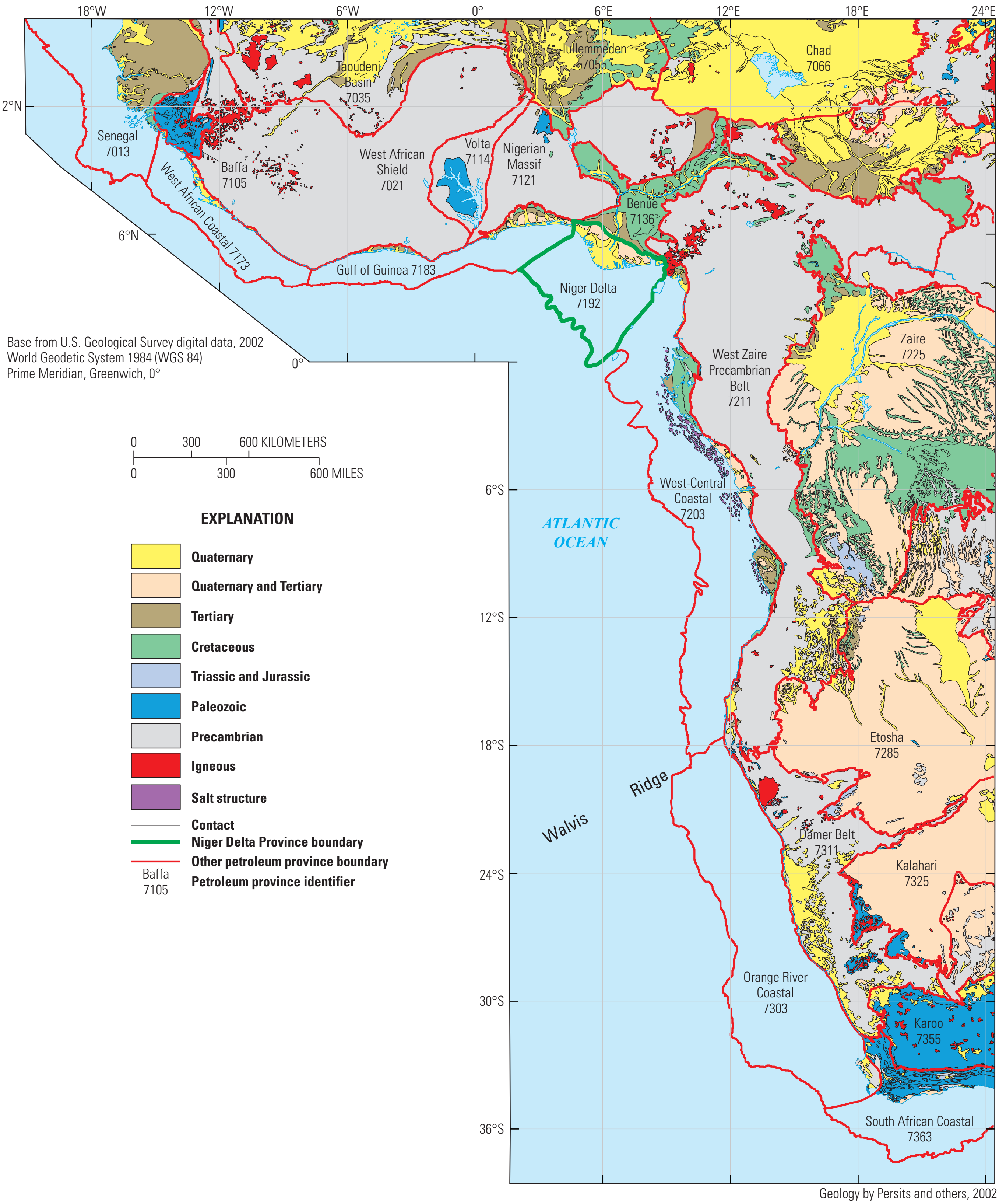

Figure 3. Generalized geology of west Africa (Persits and others, 2002), petroleum province boundaries, and 20 province names and codes as defined by Klett and others (1997).

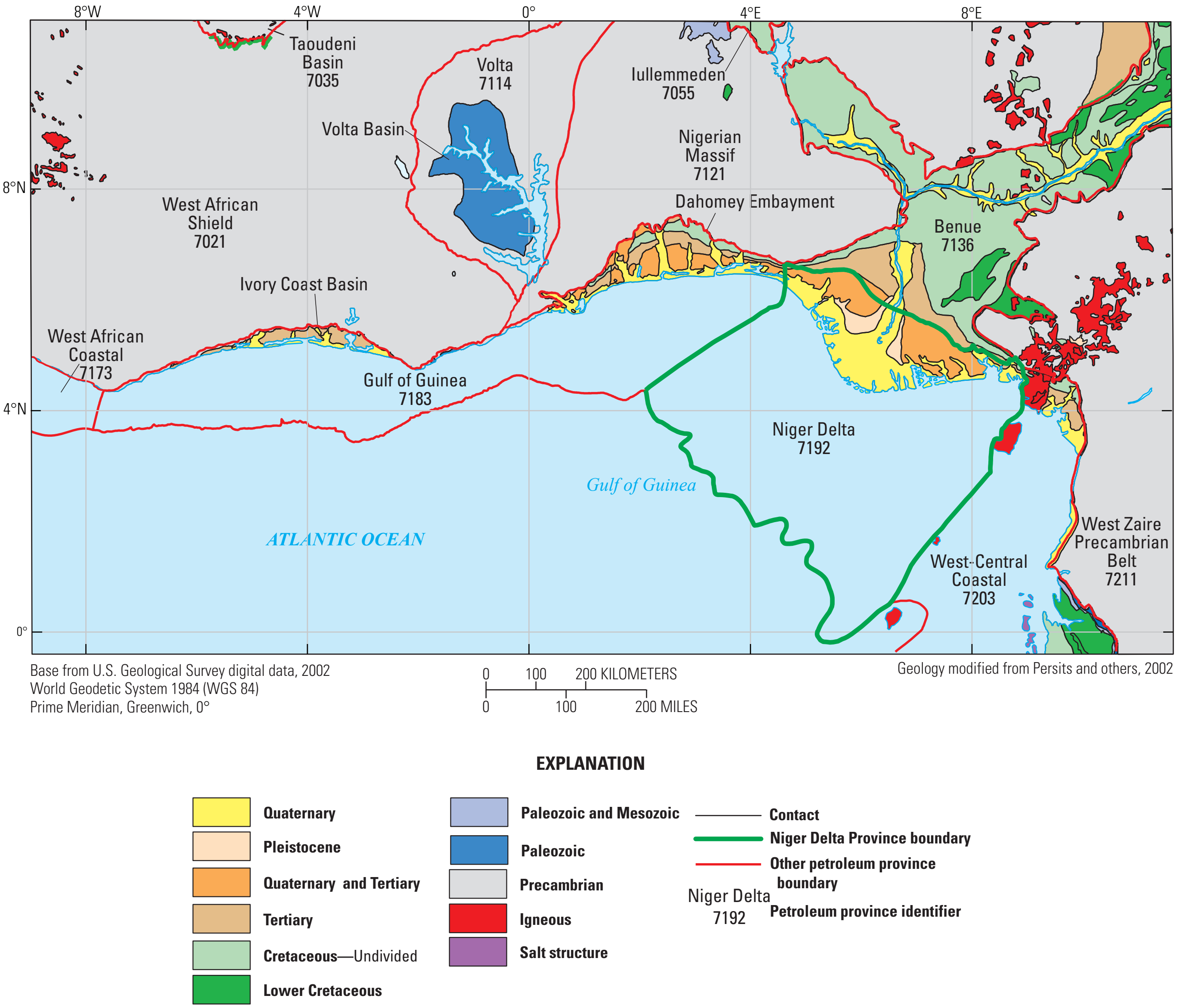

Figure 4. Geology of the Gulf of Guinea and the Niger Delta, Africa, showing 11 provinces.

Geology of the of the Niger Delta Province, Nigeria and Cameroon, Africa

Tectonics

The tectonic framework of the continental margin along the West Coast of equatorial Africa is controlled by Cretaceous fracture zones expressed as trenches and ridges in the deep Atlantic. The fracture-zone ridges subdivide the west African margin into individual basins and, in Nigeria, form the boundary faults of the Cretaceous Benue-Abakaliki Trough (figs. 1, 2), which extends eastward into the west African shield. The trough represents a failed arm of a rift triple junction associated with the opening of the South Atlantic. In this part of the Africa and South America continental margins, rifting started in the Early Cretaceous and persisted into the Late Cretaceous (Genik, 1993). In the Niger Delta area, rifting ended in the latest Cretaceous. Figure 5 shows Early Cretaceous to Holocene paleogeography of west-central Africa and South America. After rifting ceased, gravity tectonism became the primary deformational process. Shale mobility induced internal deformation and occurred in response to two processes (Kulke, 1995). First, loading by higher density delta-front sands in the overlying Agbada Formation induced shale diapirs to form in the underlying poorly compacted and overpressured prodelta and delta-slope clays of the Akata Formation. Second, a lack of basinward support from the under-compacted delta-slope clays of the Akata Formation led to slope instability within the delta complex. Gravity tectonics, which ended before deposition of the Benin Formation, are expressed in complex structures such as shale diapirs, roll-over anticlines, collapsed growth faults, back-to-back features, and steeply dipping, closely spaced flank faults (Doust and Omatsola, 1990; Stacher, 1995).

Depositional History

The Cretaceous section has not been penetrated beneath the Niger Delta Basin, the youngest and southernmost subbasin in the Benue-Abakaliki Trough (figs. 1, 6). Cretaceous rocks deposited in what is now the Niger Delta Basin can be extrapolated only from an exposed Cretaceous section in the next basin to the northeast—the Anambra Basin (fig. 1). From the Campanian through the Paleocene, longshore drift along a shoreline that was concave into the Anambra Basin resulted in tide-dominated deltaic sedimentation during transgressions and river-dominated sedimentation during regressions (Burke, 1972; Reijers and others, 1997). Shallow marine clastic sediment was deposited farther offshore and, in the Anambra basin (fig. 1), is represented by the Albian-Cenomanian Asu River shale, Cenomanian-Santonian Eze Aku and Awgu shales (fig. 7), and Campanian to Maastrichtian Nkporo shale (fig. 8), among others (Reijers and others, 1997). The distribution of Late Cretaceous shale beneath the Niger Delta is unknown.

In the Paleocene, a major transgression began with deposition of the Imo shale in the Anambra Basin to the northeast and the Akata shale in the Niger Delta Basin area to the southwest (fig. 8). In the Eocene, the delta coastline was again influenced by longshore currents, and wave-dominated sedimentation predominated (Burke, 1972; Reijers and others, 1997). At this time, deposition of paralic sediment began in the Niger Delta Basin proper and, as the sediment prograded south, the coastline became progressively more convex seaward. Today, deltaic sedimentation is still wave dominated.

The Tertiary section of the Niger Delta is divided into three formations, representing prograding depositional facies (figs. 7, 8, 9). These formations are the Akata Formation, the Agbada Formation, and the Benin Formation. The three formations were deposited during offlapping clastic-sedimentation cycles that compose the Niger Delta. The deposits resulting from these cycles ("depobelts") are 30–60 km wide and prograde southwestward 250 km over oceanic crust into the Gulf of Guinea (fig. 10) (Whiteman, 1982; Stacher, 1995). They are characterized by synsedimentary listric faulting in response to variable rates of subsidence and sediment supply (Doust and Omatsola, 1990). The interaction of subsidence and supply rates resulted in sedimentation in the depobelts, and when further crustal subsidence of the basin could no longer be accommodated, the focus of sediment deposition shifted seaward and formed a new depobelt (Whiteman, 1982; Doust and Omatsola, 1990). Five major depobelts are generally recognized, each with its own sedimentation, deformation, and petroleum history (Doust and Omatsola, 1990; Tuttle, Brownfield, and Charpentier, 1999). The shorelines shown in figure 10 approximate the depobelt shorelines described by Doust and Omatsola (1990).

The type sections for these formations are described in Short and Stäuble (1967) and summarized in a variety of papers (for example, Doust and Omatola, 1990; Kulke, 1995). The Akata Formation at the base of the delta is of marine origin and is composed of thick shale sections containing potential source rock and turbidite-sand reservoirs in the deeper parts of the delta (figs. 7, 9). Beginning in the Paleocene and continuing to the Holocene, the Akata Formation accreted, during lowstands, when terrestrial organic matter and clays were transported to deep-water areas of the delta. Only the upper part of the formation has

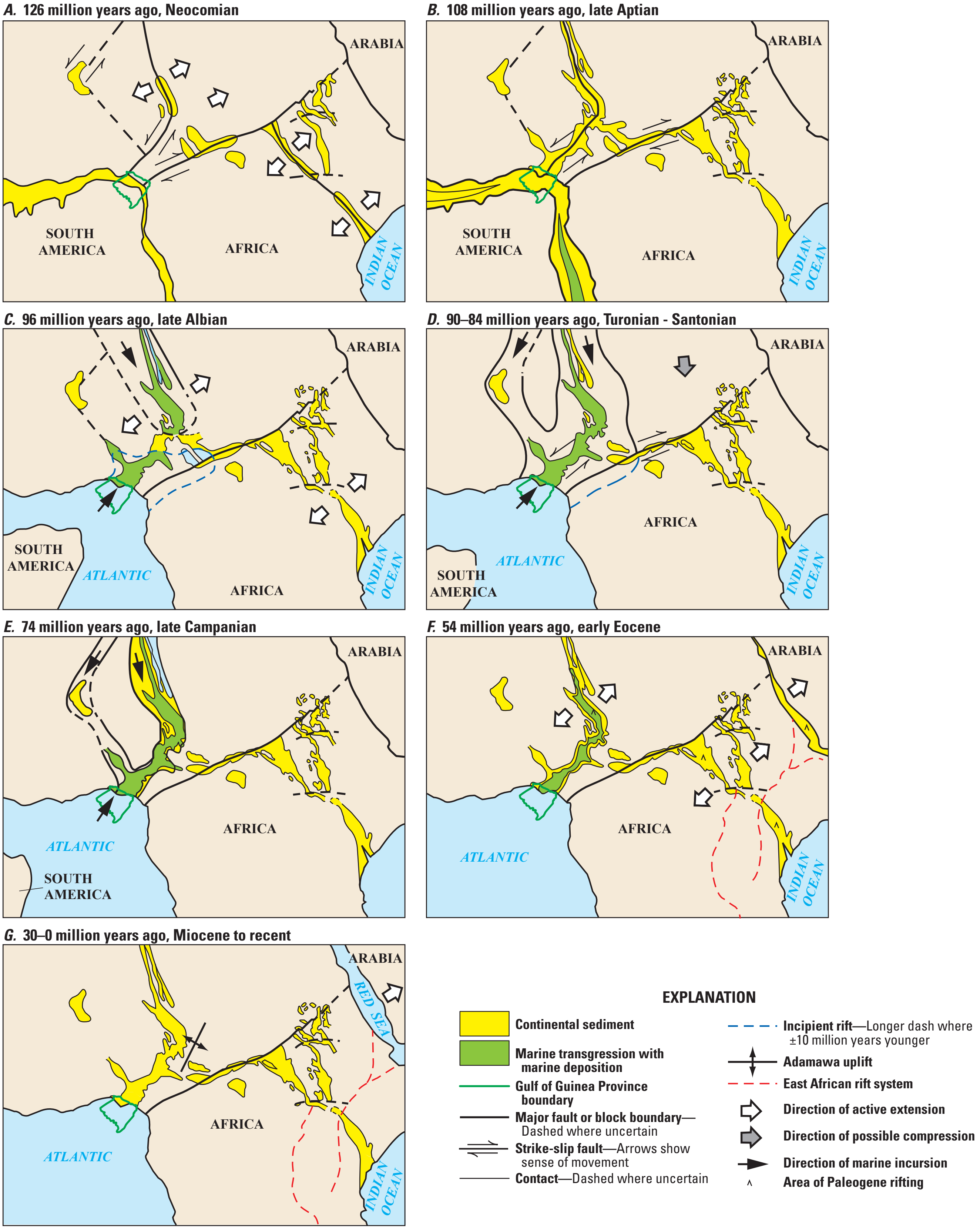

Figure 5. Paleotectonic maps showing evolution of the west Africa and South America continental margins. Niger Delta Province outlined in red. Modified from Genik (1993).

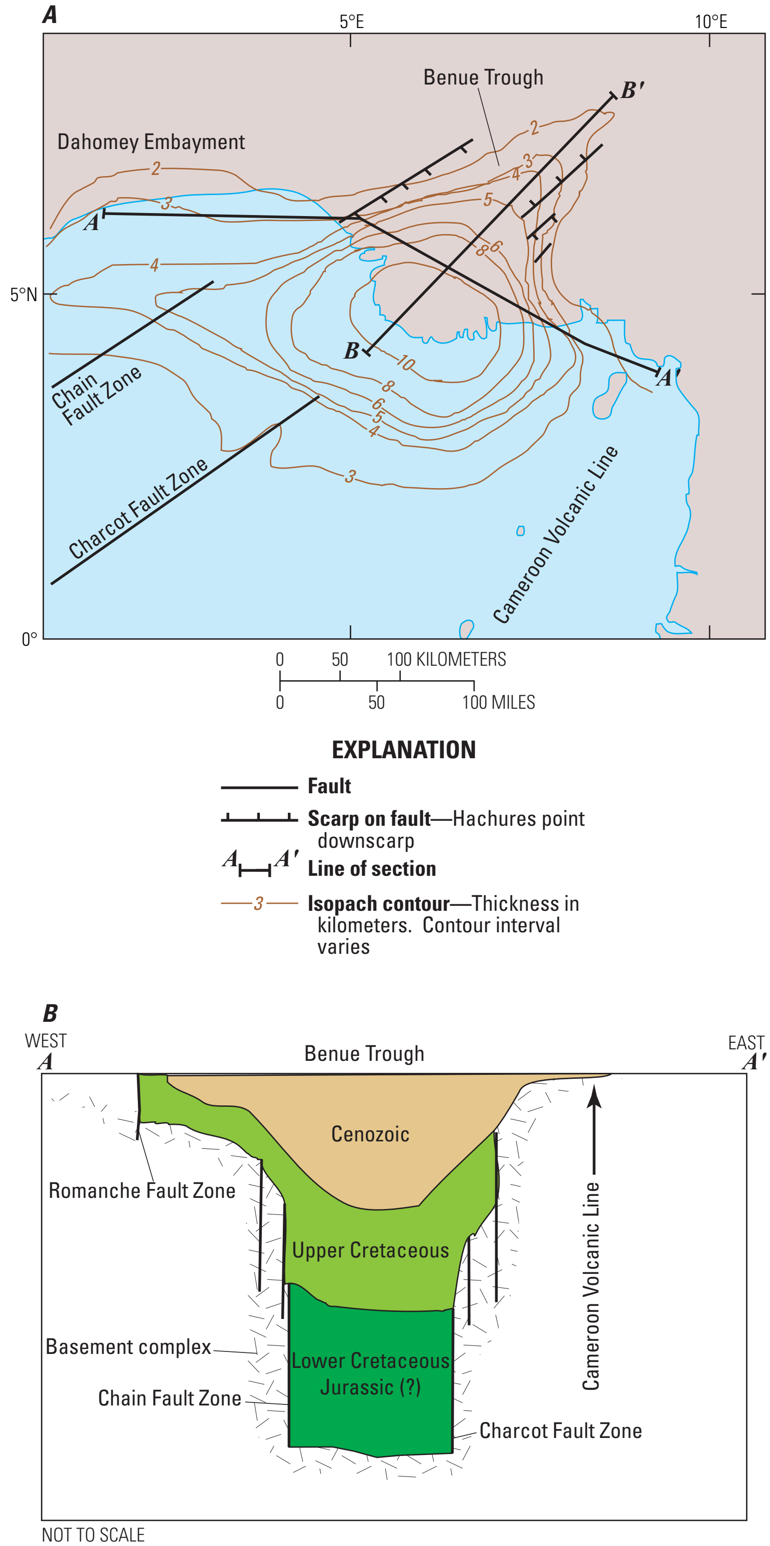

Figure 6. *A*, Isopach map of Niger Delta; isopachs represent total sediment thickness (Kaplan and others, 1994). *B*, Diagrammatic west-east cross section through the Niger Delta region. Modified from Whiteman (1982).

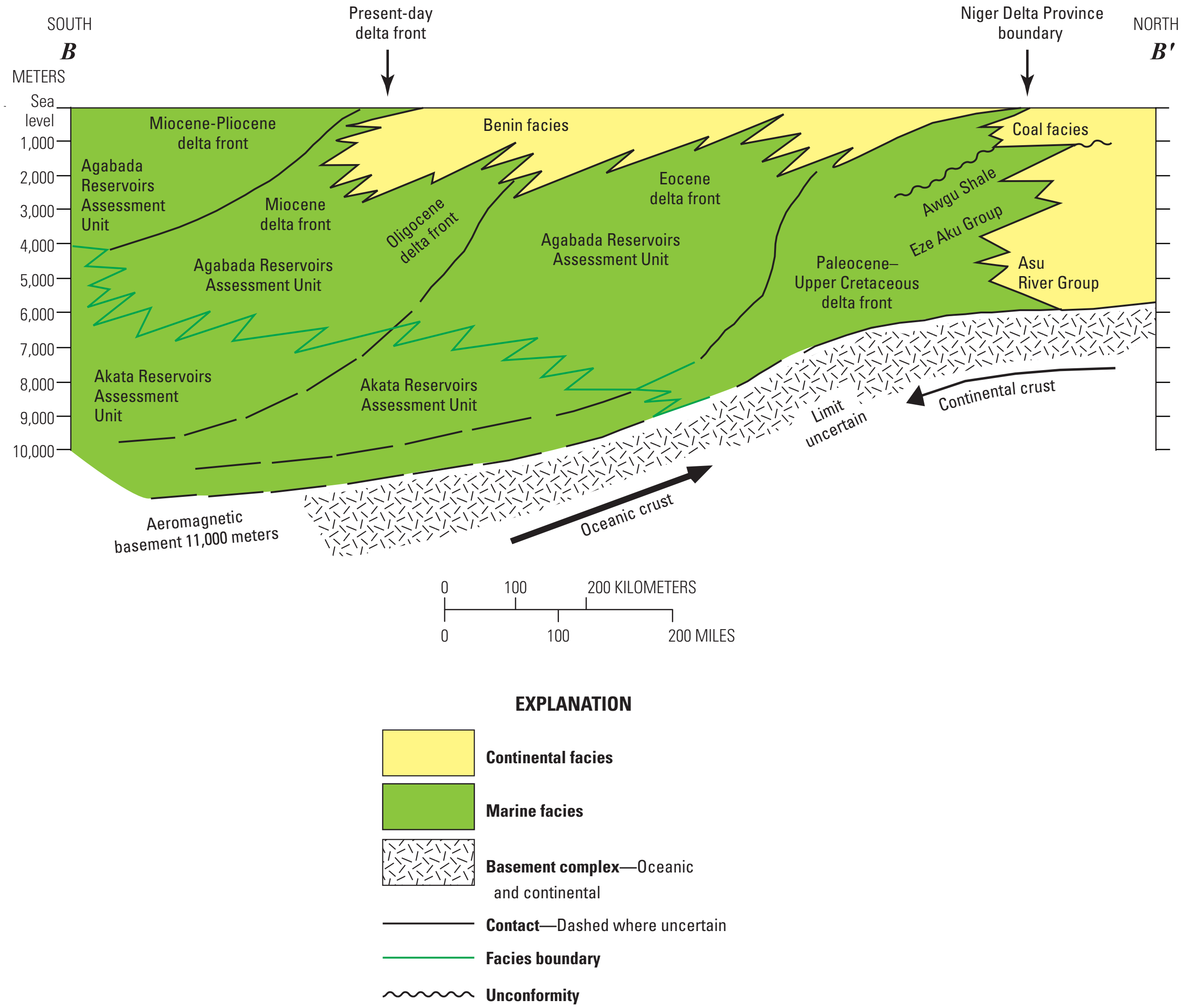

Figure 7. Southwest-northeast cross section (*B*–*B*′ in fig. 6*A*) through the Niger Delta region. Modified from Whiteman (1982).

been drilled. It is estimated that the formation is as much as 7,000 m thick (Doust and Omatsola, 1990). The formation underlies the entire delta, and it is typically overpressured. Turbidity currents likely deposited deep-sea fan sands within the upper Akata Formation during development of the delta. Deposition of the overlying Agbada Formation began in the Eocene and continues into the Holocene (figs. 7, 9). The formation consists of marine, marginal-marine, and nonmarine siliciclastic units more than 3,700 m thick that represent the deltaic portion of the succession (fig. 9). Clastic sediment accumulated in delta-front and fluviodeltaic environments. In the lower Agbada Formation, shale and sandstone beds were deposited in equal proportions; however, the upper portion is mostly sandstone with only minor shale interbeds. The Agbada Formation is overlain by the Benin Formation, a latest Eocene to Holocene deposit of alluvial and upper coastal plain sands that are as much as 2,000 m thick (fig. 7).

Petroleum Occurrence in the Niger Delta Province, Nigeria and Cameroon, Africa

Oil and gas occur throughout the Agbada Formation of the Niger Delta (figs. 1, 2), however, several oil-and-gas-field trends form an oil-rich belt having the largest fields and lowest gas:oil ratios. The belt extends from the northwest offshore area to the southeast offshore and along a number of north-south trends near Port Harcourt (Tuttle, Brownfield, and Charpentier, 1999, fig. 1). The trend corresponds to the transition between continental and oceanic crust and is within the axis of maximum sedimentary thickness (fig. 6). Stacher (1995), using sequence stratigraphy, developed a hydrocarbon-habitat model for the Niger Delta (fig. 11). The

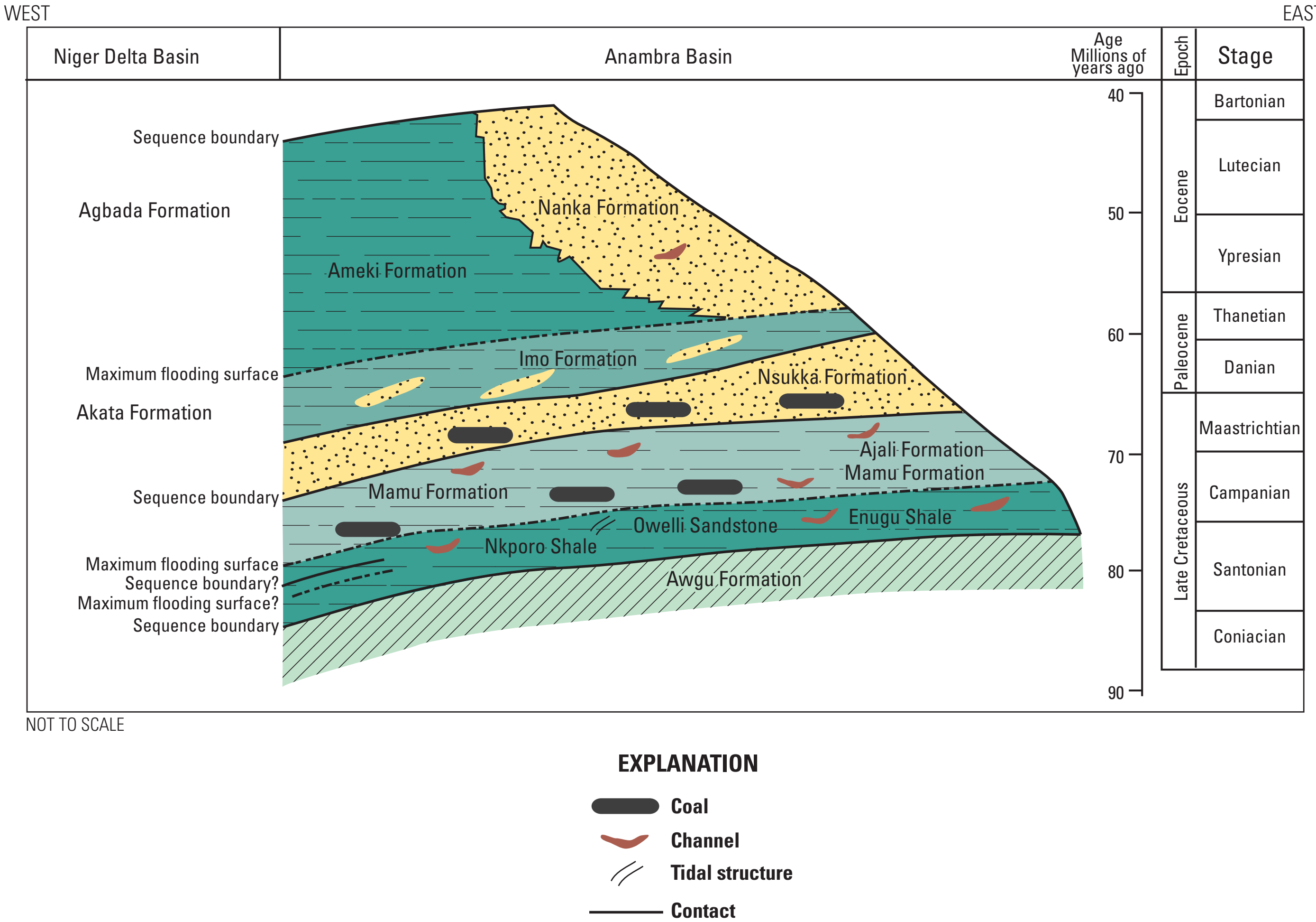

Figure 8. Stratigraphic section of the Anambra Basin (fig. 1) from Late Cretaceous through Eocene and time-equivalent formations in the Niger Delta Basin. Modified from Reijers and others (1997).

model was constructed for the central portion of the delta, including some of the oil-rich belt, and relates deposition of the Akata Formation (assumed lowstand source rock) and the sand-shale units in the Agbada Formation (the reservoirs and seals) to sea level. The Akata Formation shale, which was deposited in deep water during lowstands, is overlain by the Agbada sequences. The Agbada Formation in the central portion of the delta fits a shallow-ramp model with mainly highstand (hydrocarbon-bearing sandstone) and transgressive (sealing shale) system tracts. Faulting in the Agbada Formation provided pathways for petroleum migration and formed structural traps that, together with stratigraphic traps, accumulated hydrocarbons. The shale in the transgressive system tract provided an excellent seal above the sand as well as enhancing clay smearing within fault zones.

The Akata Formation underlies the entire Niger Delta Province (figs. 1, 2). It contains hydrocarbons within sandstone-units-related growth-fault structures, rotated fault blocks within the lower parts of the continental shelf, and stratigraphic traps related to turbidites. The turbidites include channel and ponded sandstone and deep-water clastic fans in the deep-water part of the Niger Delta.

Source Rocks

Several reports have debated the source rock for oil and gas within the Niger Delta (Ekweozor and Okoye, 1980; Lambert-Aikhionbare and Ibe, 1984; Bustin, 1988; Doust and Omatsola, 1990; Tuttle, Brownfield, and Charpentier, 1999; Haack and others, 2000). Source rocks include the interbedded marine shale in the Agbada Formation, the marine Akata shale, and possibly Cretaceous shale (Ekweozor and Okoye, 1980; Lambert-Aikhionbare and Ibe, 1984; Doust and Omatsola, 1990; Stacher, 1995; Tuttle, Brownfield, and Charpentier, 1999; Haack and others, 2000).

Some intervals in the Agbada Formation contain organic carbon contents sufficient to be considered good source rocks (Ekweozor and Okoye, 1980). The source-rock intervals rarely reach thicknesses sufficient to produce a world-class oil province and are immature in parts of the delta (Stacher, 1995). The Akata shale is present in large volumes beneath the Agbada Formation (fig. 7) and is at least volumetrically sufficient to generate enough oil for a world-class oil province such as the Niger Delta (Klett and others, 1997).

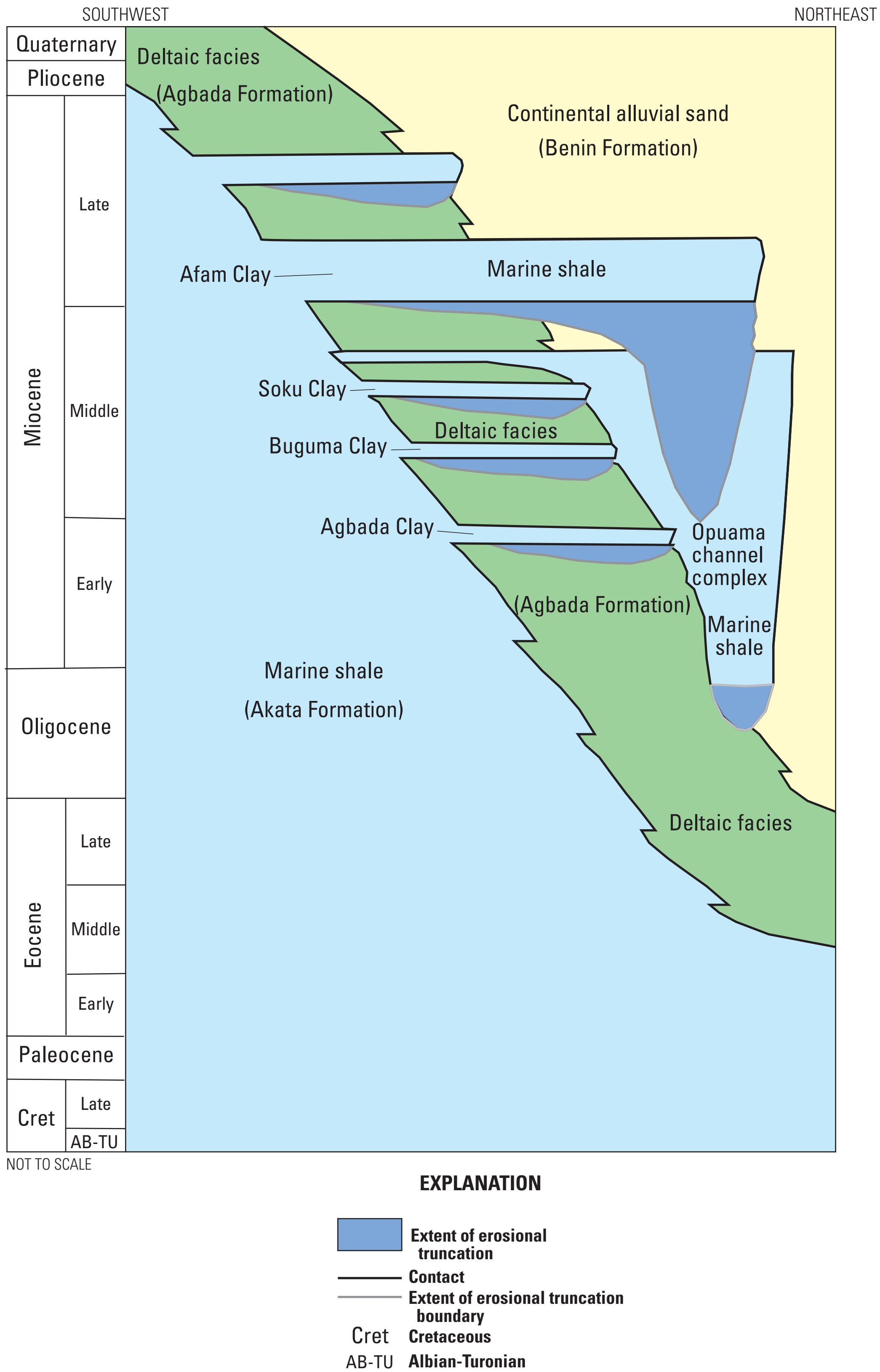

Figure 9. Schematic cross section of the Niger Delta, Africa. Eocene Agbada Formation contains deltaic-sandstone reservoirs and traps. Akata Formation contains turbidite sandstone and lowstand channels, sheet sands, and fans. Modified from Shannon and Naylor (1989) and Doust and Omatsola (1990).

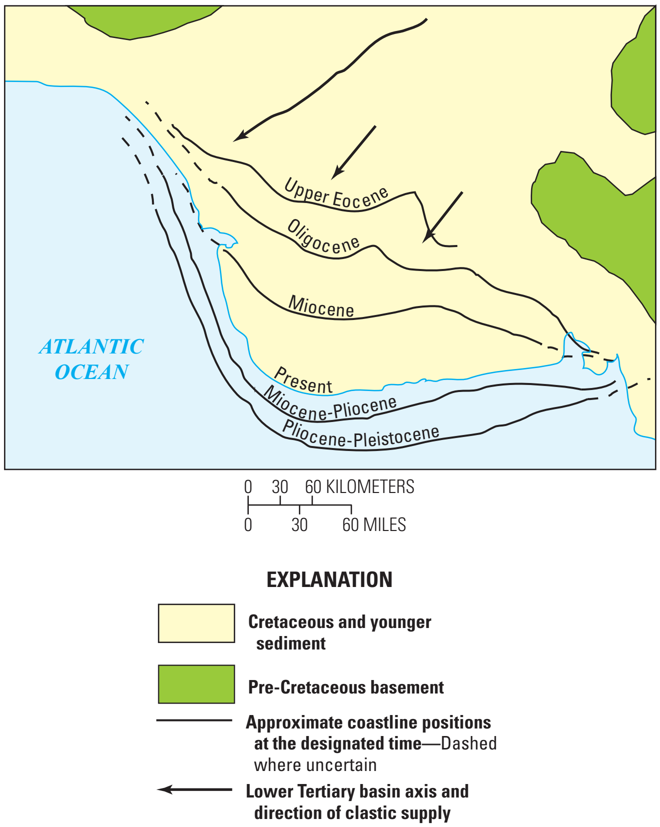

Figure 10. Coastline progradation of the Niger Delta since 35 million years ago (Ma). The delta has advanced seaward more than 200 kilometers and has broadened from a width of less than 300 kilometers to a width of about 500 kilometers. Shorelines approximate the Doust and Omatsola (1990) depobelts. Modified from Whiteman (1982).

Bustin (1988) reported total organic carbon (TOC) analyses of Agbada Formation siltstone and shale samples to be essentially the same, averaging 1.4 to 1.6 weight percent. The TOC content, however, seems to vary with age of the strata—an average of 2.2 weight percent in the late Eocene compared to 0.9 weight percent in Pliocene strata. Bustin (1988) reported that the Eocene TOC average compares well with the averages of 2.5 weight percent and 2.3 weight percent obtained for Agbada-Akata shales in two wells (Udo and Ekweozor, 1988). Ekweozor and Okoye (1980) reported TOC values ranging from 0.4 to 14.4 weight percent in the both onshore and offshore paralic sediments. Nwachukwu and Chukwura (1986) reported values as high as 5.2 weight percent in paralic shales from the western part of the delta. Bustin (1988) concluded that there are no rich source rocks in the delta and that the poor quality of the source rock has been partly offset by its great volume and excellent migration pathways. The oil potential is further increased by permeable interbedded sandstone and rapid hydrocarbon generation and overpressuring resulting from high sedimentation rates.

Some authors have proposed that oil-bearing Cretaceous rocks may be beneath and east of the present Niger Delta (Frost, 1997; Haack and others, 2000). This Cretaceous section has not been drilled owing to its great depth; therefore, no data exist on its source-rock potential. Migration of oil from the Cretaceous into reservoirs in the Agbada Formation would require an intricate fault or fracture network, because the Akata shale reaches a thickness greater than 6,000 m. No data exist to support the existence of such a network. Haack and others (2000) reported rocks and marine kerogen may be present along the Nigerian coastline and offshore. These conclusions are based on oil seeps from Nigerian tar sands within the Dahomey Embayment (fig. 4), source-rock outcrops along the eastern margin of the delta, and geochemical data from wells. These source rocks could be contributors to hydrocarbon accumulations in the deep-water areas of the Niger Delta.

In the northwestern part of the Niger Delta, the oil window lies in the upper Akata Formation and the lower Agbada Formation (fig. 12). To the southeast, the oil window is stratigraphically lower, as much as 4,000 ft below the upper Akata–lower Agbada strata (Evamy and others, 1978). The present day oil-generation window in the Niger Delta is approximately at the 240 °F (115 °C) isotherm.

A burial history chart for the Oben-1 well (fig. 12) in the northern part of the Niger Delta is shown in figure 13. The Akata-Agbada Formation boundary entered the oil window at approximately 0.6 percent R_o in the late Eocene. The Akata-Agbada boundary in this part of the delta is currently at a depth of about 4,300 m, with the upper Akata Formation in the wet-gas-condensate generating zone (vitrinite reflectance greater than 1.2 percent; Tissot and Welte, 1984). The lowermost part of the Agbada Formation entered the oil-generation window sometime in the late Oligocene.

Reservoirs

Oil and gas in the Agbada Reservoirs AU is produced from sandstone and unconsolidated sand primarily found within the Agbada Formation (fig. 9). Known reservoir rocks are Eocene to Pliocene in age, are commonly stacked, and range in thickness from less than 15 m to greater than 45 m (Evamy and others, 1978). The thicker reservoirs likely represent amalgamated bodies of stacked channels (Doust and Omatsola, 1990). Based on reservoir geometry and quality, Kulke (1995) described the most important reservoir types as point bars of distributary channels and coastal barrier bars intermittently cut by sand-filled channels. Edwards and Santogrossi (1990) described the primary Niger Delta reservoirs as Miocene sandstones with as much as 40 percent porosity, 2 darcies permeability, and a thickness of 100 m. The variation in reservoir thickness is strongly controlled by growth faults; the sandstone thickens against the fault within the down-thrown block (Weber and Daukoru, 1975). Porosity typically decreases with depth (Kulke, 1995).

Computer modeling suggests that local fault movements along the shelf edge control the thickness and lithofacies of potential reservoir sand downdip (Tuttle, Brownfield, and

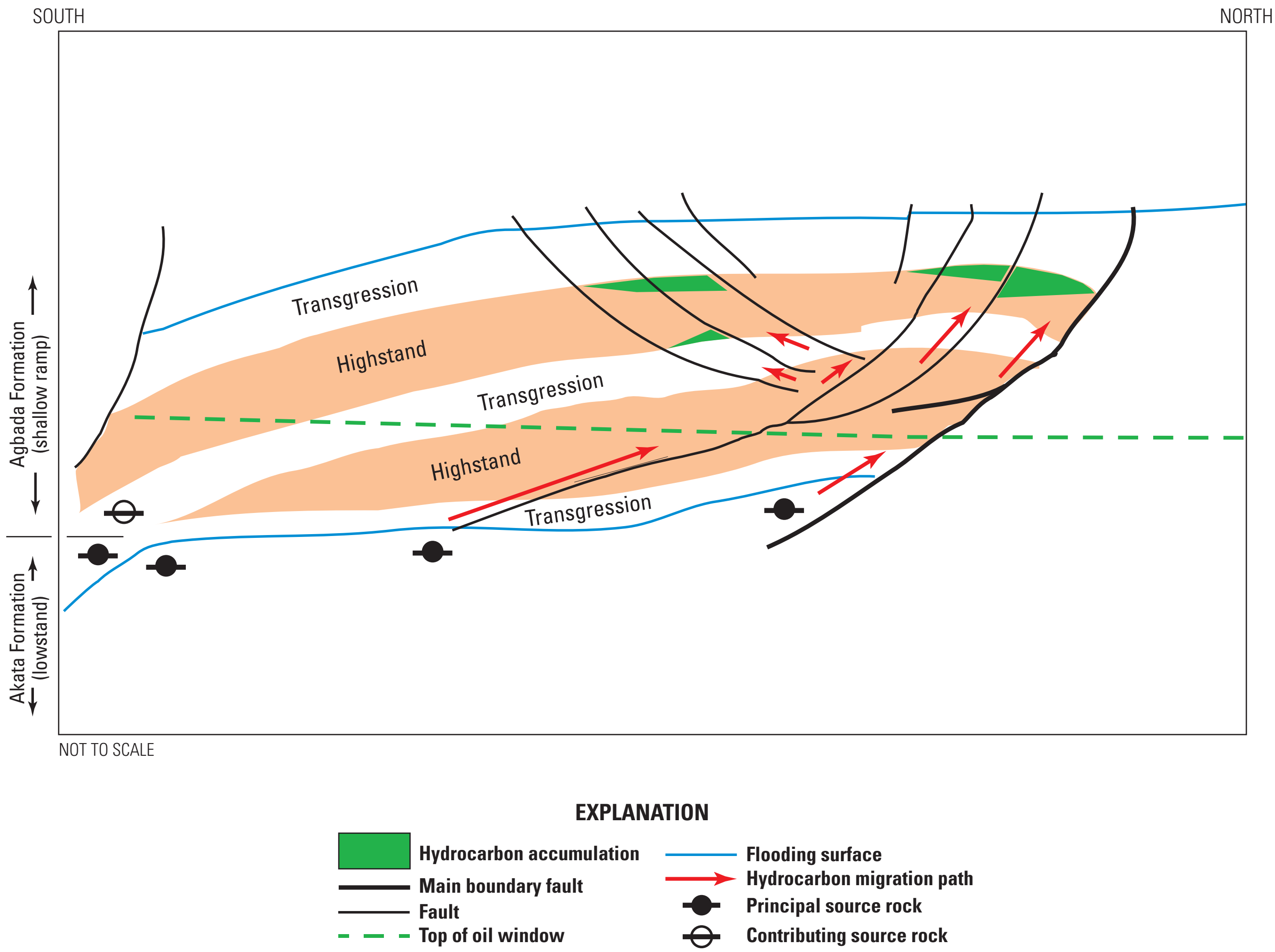

Figure 11. Sequence-stratigraphic model for the central portion of the Niger Delta. Source rock, migration pathways, and hydrocarbon traps mainly related to growth faults, but minor stratigraphic traps present. Hydrocarbon fluids migrated laterally through Agbada Formation sandstone units. The main boundary fault separates megastructures, which represent major breaks in the regional dip of the delta (Evamy and others, 1978). Modified from Stacher (1995).

Charpentier, 1999; their figure 15). The slope-edge fault and reservoir simulation from these experiments are shown in figure 14.

Traps and Seals

Traps in Niger Delta oil and gas fields are mostly structural, although stratigraphic traps are not uncommon (fig. 15). Structural traps developed during synsedimentary deformation of the Agbada paralic sequences (Evamy and others, 1978; Stacher, 1995). Structural complexity increases from north to south within the depobelts in response to increasing instability of the less-compacted, overpressured shale. Doust and Omatsola (1990) described a variety of structural-trapping elements, including those associated with simple rollover structures, clay-filled channels, structures with multiple growth faults, structures with antithetic faults, and collapsed-crest structures (fig. 15).

In the deep-water part of the delta, the primary reservoirs found in Akata Reservoirs AU are mostly stratigraphic and include turbidite sands, lowstand sand bodies, and clastic fans (Beka and Oti, 1995). Structural traps are less common in the deep-water parts of the delta.

The major reservoir seal rocks in the Niger Delta are interbedded shale units within the Agbada and Akata formations. The shale provides three types of seals in the Agbada: clay smears along faults, interbedded strata against which reservoir sands are juxtaposed due to faulting, and vertical seals (Doust and Omatsola, 1990). On the flanks of the delta, major erosional events of early to middle Miocene age formed canyons that are now clay filled (fig. 9). These clays form the top reservoir seals for some highly productive(?) offshore fields (Doust and Omatsola, 1990). Akata shale is the primary seal in the deep-water parts of the delta where turbidites and submarine fans are the primary traps.

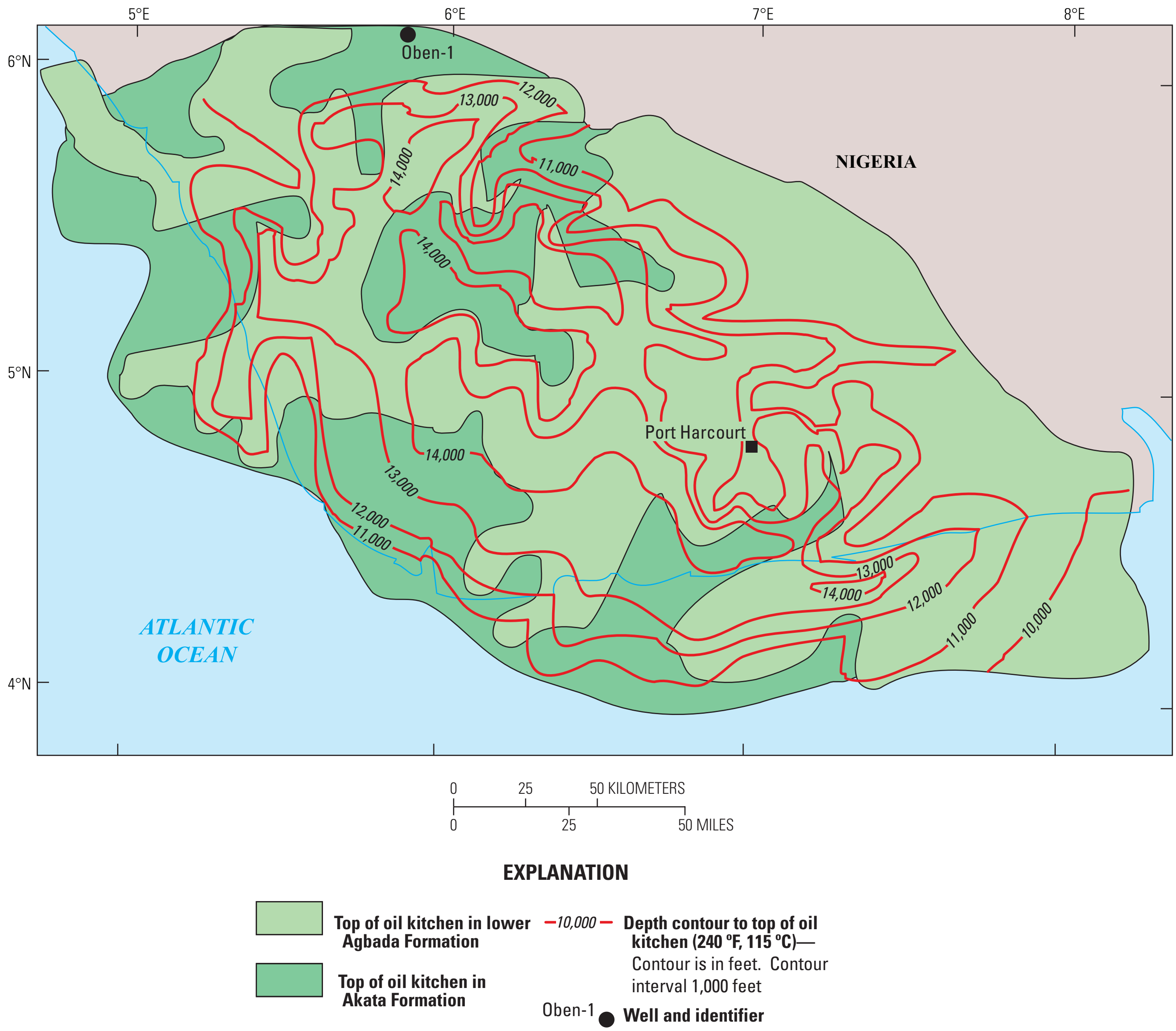

Figure 12. Subsurface depth to top of Niger Delta oil kitchen showing that the entire Akata Formation and a portion of the lower Agbada Formation are in the oil window. Modified from Evamy and others (1978).

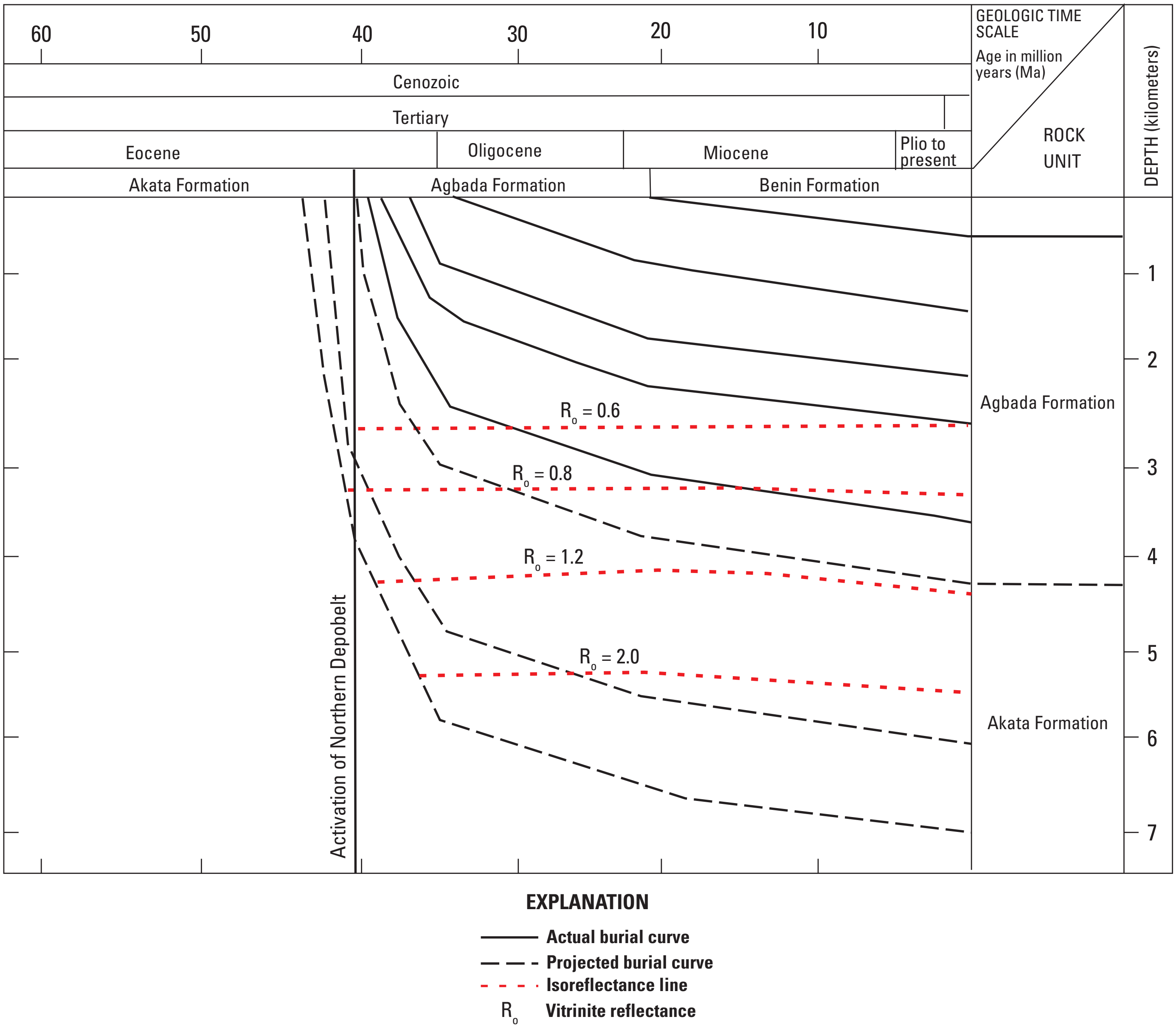

Figure 13. Burial-history chart for the northern portion of the Tertiary Niger Delta (Akata-Agbada). Data from Oben-1 well (fig. 12) in northern depobelt (Doust and Omatsola (1990). Modified from Ekweozor and Daukoru (1994). Plio, Pliocene.

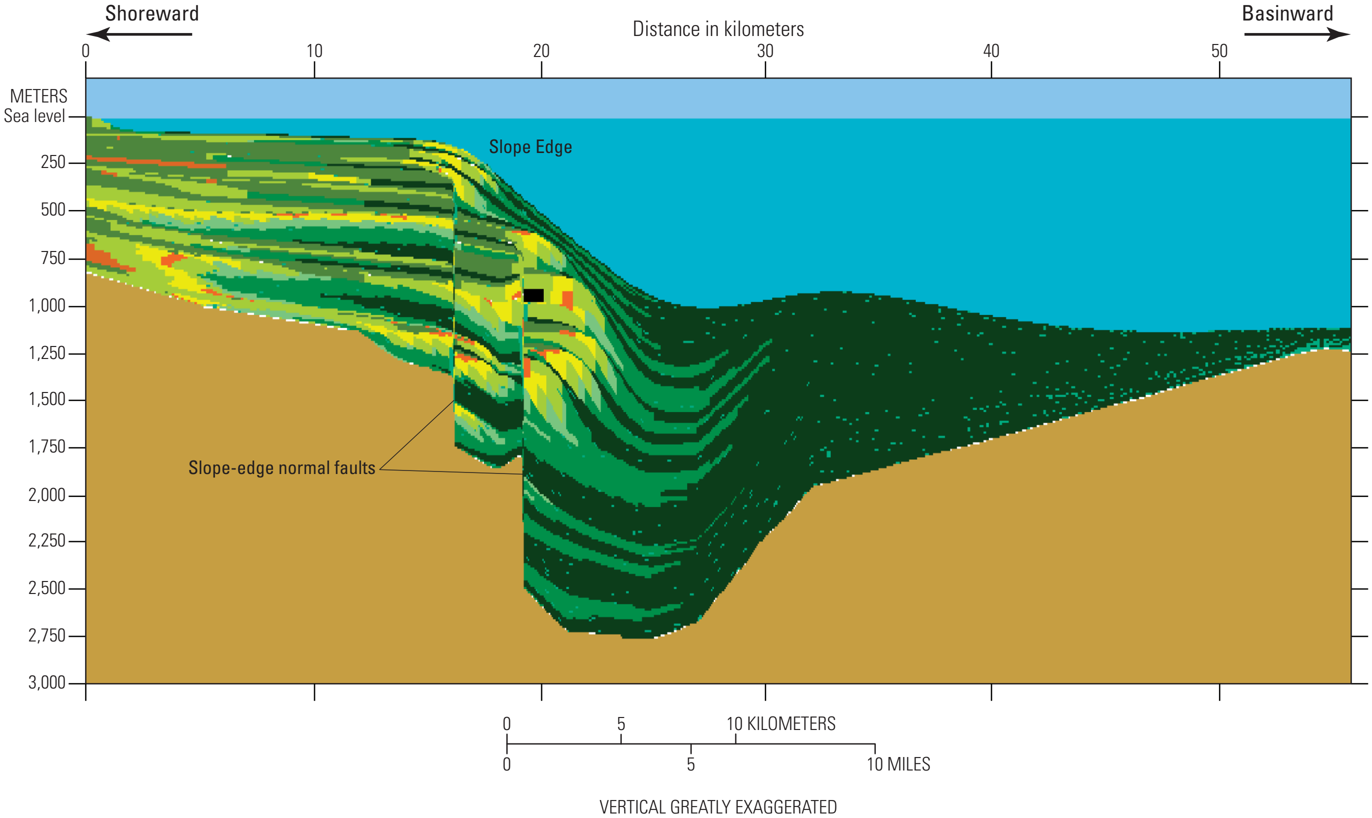

Figure 14. Slope edge normal-fault simulation (2 million years ago (Ma) to present) of the Niger Delta. Orange and yellow, potential hydrocarbon accumulations in sandstone reservoirs. Figure provided by Linda Smith-Rouch (written commun., 1998; Tuttle, Brownfield, and Charpentier, 1999).

Exploration

Between the USGS World Assessment 2000 (U.S. Geological Survey World Energy Assessment Team, 2000) and this assessment (2009), both the Agbada and the Akata Reservoirs AUs added fields. The Agbada added 84 oil fields and 22 gas fields exceeding the minimum assessment size of 1 million barrels of oil equivalent (MMBOE). It now contains a total of 537 oil and 161 gas fields. The Akata Reservoirs AU added 39 new oil fields and 13 new gas fields—the total number of fields in the assessment unit—exceeding the minimum assessment size of 5 MMBOE. In the Agbada Reservoirs AU, the largest grown oil field is about 2.0 BBO and the largest grown gas field is about 8.2 TCF. In the Akata Reservoirs AU, the largest grown oil field is about 1.4 BBO and the largest grown gas field is 8.5 TCF. The Niger Delta Province is considered mature on the basis of its exploration activity.

Producing fields (IHS Energy, 2008) provide evidence for two inferences: the existence of an active petroleum system containing Tertiary source rocks that have produced hydrocarbons most likely since the Eocene, and the migration of hydrocarbons into Tertiary reservoirs.

Geologic Model

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

1. The primary source rock for petroleum is the upper Akata Formation, the marine-shale facies of the delta. Additional hydrocarbon contributions from interbedded marine shale of the lowermost Agbada Formation are possible. Oil and gas were generated from Eocene paralic and prodeltic Type II and Type III kerogen ranging from 1.4 weight percent to 5.2 weight percent total organic carbon and possibly from Cretaceous marine and lacustrine sources. Hydrocarbon generation began in the Eocene and continues to the present. Petroleum generation shifted north to south as progressively younger depobelts entered the oil window.

2. Petroleum migrated into Eocene Agbada Formation sandstone reservoirs and traps. Petroleum also migrated into Akata Formation turbidite sandstone units including lowstand channels, sheet sands, and fans.

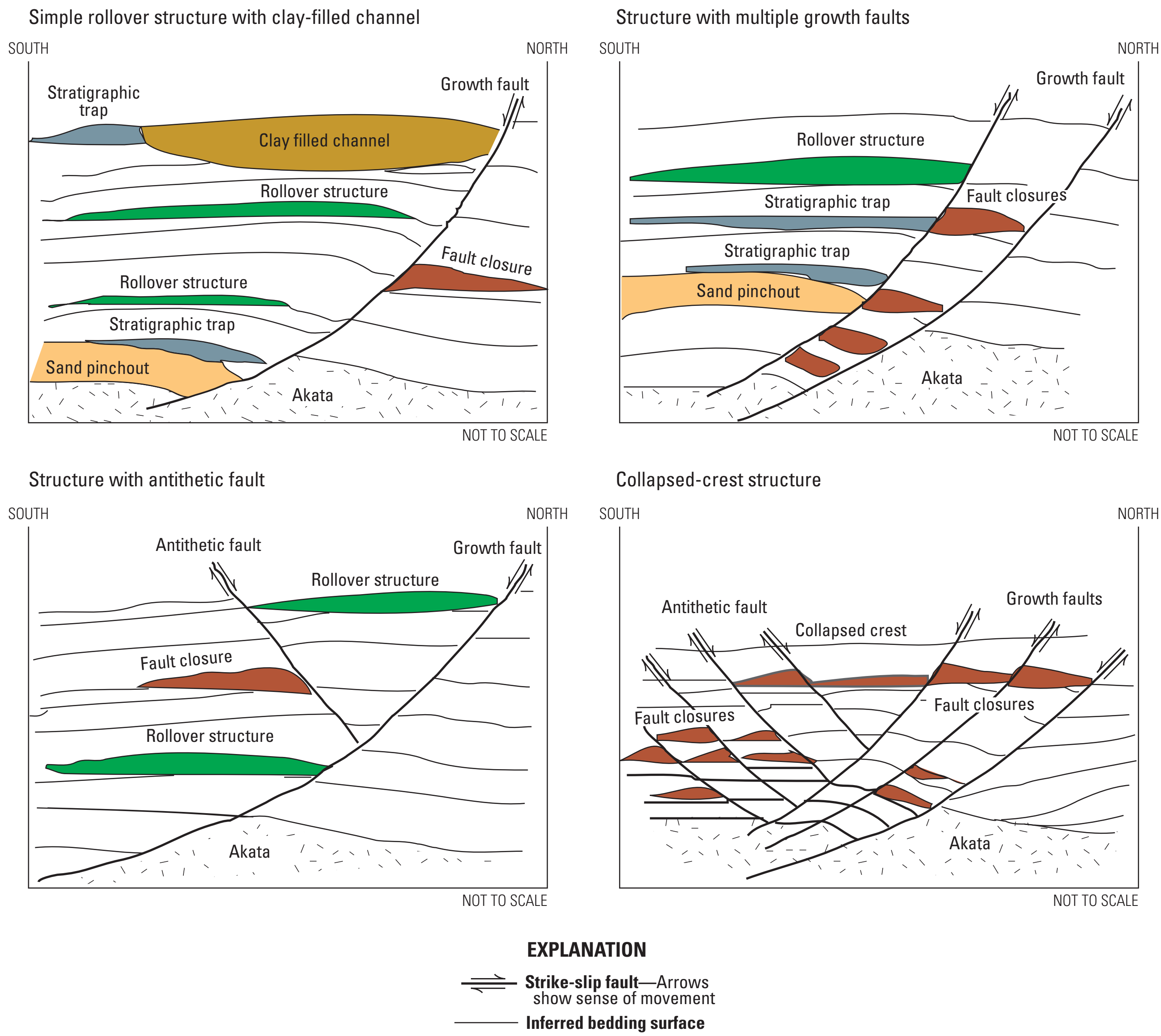

Figure 15. Oil field structures and associated trap types, Niger Delta, Nigeria and Cameroon, Africa. Modified from Doust and Omatsola (1990) and Stacher (1995).

3. Traps are mostly structural in the Agbada Reservoirs AU, but stratigraphic traps are also present. Turbidite traps are the major trapping style in the Akata Reservoirs AU.
4. The Eocene marine mudstone and shale rocks are the primary reservoir seals in both Agbada and Akata assessment units.
5. The Niger Delta is considered mature for oil and gas; therefore, current field histories were used in part to determine the distributions of sizes and numbers of undiscovered fields.

An events chart (fig. 16) for the Tertiary Niger Delta Total Petroleum System and the Agbada Reservoirs and Akata Reservoirs AUs summarizes the age of the source, seal, and reservoir rocks and the timing of trap development, generation, and migration of petroleum.

Resource Summary

The USGS estimated mean volumes of undiscovered, technically recoverable conventional oil and gas resources for the Agbada Reservoirs Assessment Unit in the Niger Delta Province (table 1) at 1,616 million barrels of oil, 9,454 billion cubic feet of gas, and 494 million barrels of natural gas liquids. The estimated mean size of the largest oil field that is expected to be discovered is 274 million barrels of oil, and the estimated mean size of the expected largest gas field is 981 billion cubic feet of gas. The estimated mean volumes for the Akata Reservoirs Assessment Unit (table 1) are 13,918 million barrels of oil, 48,767 billion cubic feet of gas, and 5,832 million barrels of natural gas liquids with estimated mean sizes of the largest oil and gas fields of 4,119 million barrels of oil and 13,355 billion cubic feet of gas, respectively. For this assessment, a minimum undiscovered field size of 1 million barrels of oil equivalent was used for the Agbada Reservoirs Assessment Unit and a minimum undiscovered field size of 5 million barrels of oil equivalent was used for the Akata Reservoirs Assessment Unit. 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*).

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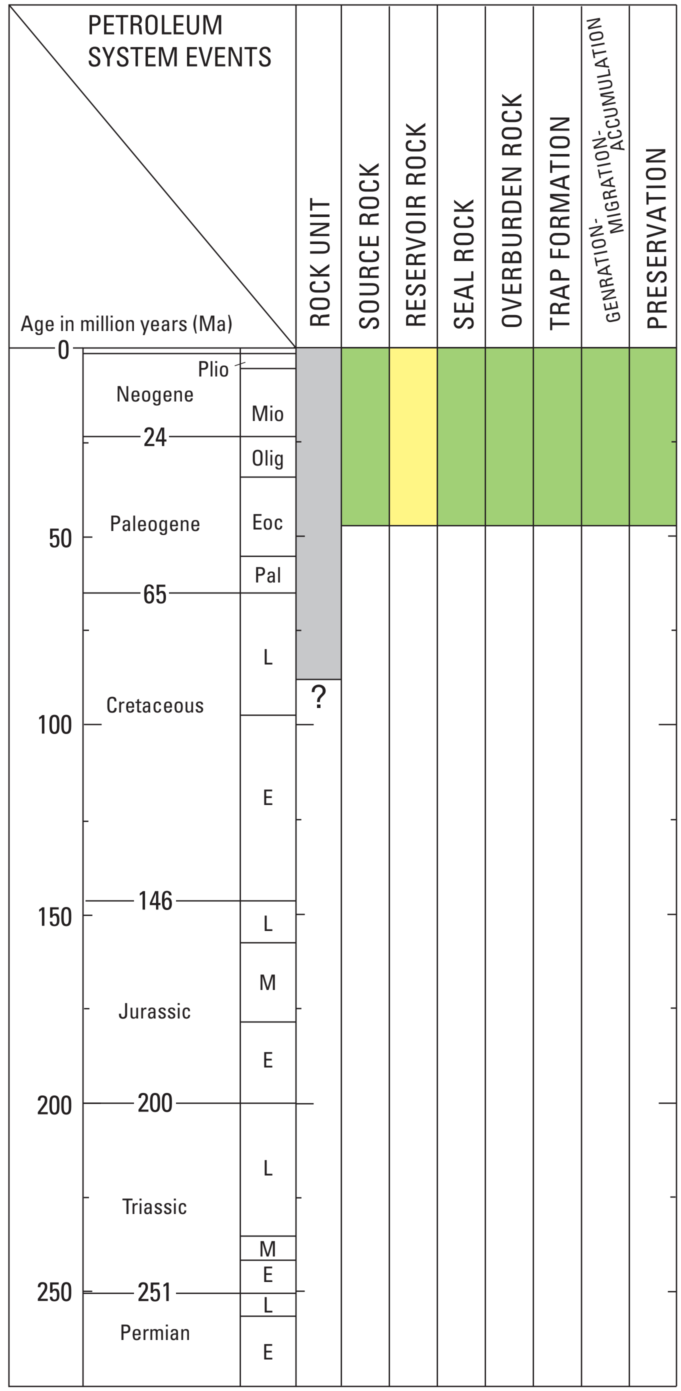


Figure 16. Events chart for the Tertiary Niger Delta Total Petroleum System (719201) and the Agbada and Akata Reservoirs Assessment Units (71920101; 71920102) in the Niger Delta Province, Africa. Gray, rock units present; yellow, age range of reservoir rock; green, age ranges of source, seal, and overburden 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, million years ago; Plio, Pliocene; Mio, Miocene; Olig, Oligocene; Eoc, Eocene; Pal, Paleocene, L, Late; E, Early; M, Middle; ?, uncertain.

Table 1. Niger Delta Province and Agbada and Akata Reservoirs Assessment Units 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. Fractiles are additive under assumption of perfect positive correlation. Gray shading indicates not applicable]

Province, 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
Niger Delta Province—Tertiary Niger Delta TPS														
Agbada Reservoirs AU	Oil	274	526	1,437	3,326	1,616	1,904	5,387	13,011	6,139	65	245	904	339
	Gas	981					751	2,742	7,817	3,315	30	120	397	155
Akata Reservoirs AU	Oil	4,119	4,321	12,271	29,129	13,918	5,432	16,270	45,864	19,779	143	433	1,253	535
	Gas	13,355					5,862	21,723	78,443	28,988	1,030	3,886	14,491	5,297
Total Conventional Resources			**4,847**	**13,708**	**154,081**	**15,534**	**8,949**	**46,122**	**145,135**	**58,221**	**1,268**	**4,684**	**17,045**	**6,326**

References

Beka, F.T., and Oti, M.N., 1995, The distal offshore Niger Delta—Frontier prospects of a mature petroleum province, *in* Oti, M.N., and Postma, G., eds., Geology of deltas: Rotterdam, A.A. Balkema, p. 237–241.

Burke, K., 1972, Longshore drift, submarine canyons, and submarine fans in development of Niger Delta: American Association of Petroleum Geologists Bulletin, v. 56, p. 1975–1983.

Bustin, R.M., 1988, Sedimentology and characteristics of dispersed organic matter in Tertiary Niger Delta—Origin of source rocks in a deltaic environment: American Association of Petroleum Geologists Bulletin, v. 72, p. 277–298.

Doust, Harry, and Omatsola, Ebi, 1990, Niger Delta, *in* Edwards, J.D., and Santogrossi, P.A., eds., divergent/passive margin basins, American Association of Petroleum Geologists Memoir 48: Tulsa, American Association of Petroleum Geologists, p. 201–238.

Edwards, J.D., and Santogrossi, P.A., 1990, Summary and conclusions, *in* Edwards, J.D., and Santogrossi, P.A., eds., Divergent/passive margin basins: American Association of Petroleum Geologists Memoir 48, p. 239–248.

Ekweozor, C.M., and Daukoru, E.M., 1994, Northern delta depobelt portion of the Akata-Agbada(!) petroleum system, Niger Delta, Nigeria, *in* Magoon, L.B., and Dow, W.G., eds., The petroleum system—From source to trap: American Association of Petroleum Geologists Memoir 60, p. 599–614.

Ekweozor, C.M., and Okoye, N.V., 1980, Petroleum source-bed evaluation of Tertiary Niger Delta: American Association of Petroleum Geologists Bulletin, v. 64, p. 1251–1259.

Evamy, B.D., Haremboure, J., Kamerling, P., Knaap, W.A., Molloy, F.A., and Rowlands, P.H., 1978, Hydrocarbon habitat of Tertiary Niger Delta: American Association of Petroleum Geologists Bulletin, v. 62, p. 277–298.

Frost, B.R., 1997, A Cretaceous Niger Delta petroleum system, *in* Extended abstracts, American Association of Petroleum Geologists Bulletin/Brazilian Association of Petroleum Geologists Hedberg Research Symposium, Petroleum System of the South Atlantic Margin, November 16–19, 1997, Rio de Janeiro, Brazil.

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.

Haack, R.C., Sundararaman, P., Diedjomahor, J.O., Xiao, H., Gant, N.J., May, E.D., and Kelsch, K., 2000, Niger Delta petroleum systems, Nigeria, *in* Mello, M.R., and Katz, B.J., eds., Petroleum systems of South Atlantic margins: American Association of Petroleum Geologists Memoir 73, p. 213–231.

IHS Energy, 2008, International petroleum exploration and production database [current through December 2008]: Available from IHS Energy, 15 Inverness Way East, Englewood, CO 80112 USA.

Kaplan, A., Lusser, C.U., and Norton, I.O., 1994, Tectonic map of the world, panel 10: Tulsa, American Association of Petroleum Geologists, scale 1:10,000,000.

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.

Kulke, H., 1995, Nigeria, *in* Kulke, H., ed., Regional petroleum geology of the world. Part II—Africa, America, Australia and Antarctica: Berlin, Gebrüder Borntraeger, p. 143–172.

Lambert-Aikhionbare, D.O., and Ibe, A.C., 1984, Petroleum source-bed evaluation of the Tertiary Niger Delta—Discussion: American Association of Petroleum Geologists Bulletin, v. 68, p. 387–394.

Nwachukwu, J.I., and Chukwura, P.I., 1986, Organic matter of Agbada Formation, Niger Delta, Nigeria: American Association of Petroleum Geologists Bulletin, v. 70, p. 48–55.

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.

Reijers, T.J.A., Petters, S.W., and Nwajide, C.S., 1997, The Niger Delta Basin, *in* Selley, R.C., ed., African basins—Sedimentary basins of the world 3: Amsterdam, Elsevier Science, p. 151–172.

Shannon, P.M., and Naylor N., 1989, Petroleum basin studies: London, Graham and Trotman Limited, p. 153–169.

Short, K.C., and Stäublee, A.J., 1967, Outline of geology of Niger Delta: American Association of Petroleum Geologists Bulletin, v. 51, p. 761–779.

Stacher, P., 1995, Present understanding of the Niger Delta hydrocarbon habitat, *in* Oti, M.N., and Postma, G., eds., Geology of deltas: Rotterdam, A.A. Balkema, p. 257–267.

Tissot, B.P., and Welte, D.H., 1984, Petroleum formation and occurrence: Berlin, Springer-Verlag, 518 p.

Tuttle, M.L., Brownfield, M.E., and Charpentier, R.R., 1999, Tertiary Niger Delta (Akata-Agbada) Petroleum System (701901), Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa, *in* Tuttle, M.L., Charpentier, R.R., and Brownfield, M.E., eds., The Niger Delta Petroleum System; Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa: U.S. Geological Survey Open-File Report 99–50–H, p. 4–44.

Tuttle, M.L., Charpentier, R.R., and Brownfield, M.E., 1999, Assessment of undiscovered petroleum in the Tertiary Niger Delta (Akata-Agbada) Petroleum System (719201), Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa, *in* Tuttle, M.L., Charpentier, R.R., and Brownfield, M.E., eds., The Niger Delta Petroleum System, Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa: U.S. Geological Survey Open-File Report 99–50–H, p. 45–65.

Udo, O.T., and Ekweozor, C.M., 1988, Comparative source rock evaluation of Opuama Channel Complex and adjacent producing areas of Niger Delta: Nigerian Association of Petroleum Explorationists Bulletin, v. 3, no. 2, p. 10–27.

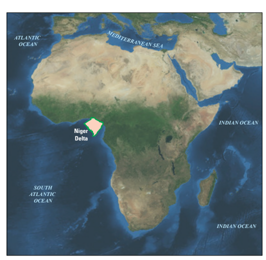
U.S. Geological Survey Geologic Names Committee, 2010, Divisions of geologic time: U.S. Geological Survey Fact Sheet 2010–3059, 2 p. Available at http://pubs.usgs.gov/fs/2010/3059/.

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/.

U.S. Geological Survey World Energy Assessment Team, 2000, U.S. Geological Survey World Petroleum Assessment 2000—Description and Results: U.S. Geological Survey Digital Data Series DDS–60, 4 CD–ROMs. Available at http://pubs.usgs.gov/dds/dds-060/.

Weber, K.J., and Daukoru, E.M., 1975, Petroleum geology of the Niger Delta—World Petroleum Congress, 9th, v. 2, Geology, Proceedings: London, Applied Science Publishers, Ltd., p. 210–221.

Whiteman, A., 1982, Nigeria—Its petroleum geology, resources and potential: London, Graham and Trotman, 394 p.



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