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## **Synopsis of Geology of Ethiopia\***

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### **Physiography**

A first glance at a topographic map of Ethiopia ([Figure 1](#) [from Ethiopian Mapping Authority, 2001]), gives the impression of a mountainous area surrounded by inhospitable deserts and dissected by a northeast-southwest rift trough lowland. Ethiopia has a high central plateau ranging from 6000 to 10,000 ft., with some mountains reaching over 15,000 ft. Temperatures are temperate on the plateau but hot in the desert lowlands.

Ethiopia is considered part of the Horn of Africa and is bordered by Sudan to the west and southwest, Djibouti to the east, Somalia to the east and southeast, Eritrea to the north and northeast, and Kenya to the south.

There are two rainy seasons, February-March and late May through July, but Ethiopia is periodically plagued by drought.

### **Surface Geology**

The Simplified Geologic Map of Ethiopia, [Figure 2](#) (from Ethiopian Geological Survey, Mapping Authority, 1996), presents an area of 1,127,127 square kilometers (435,186 square miles) divided in half by a northeast-southwest-trending rift lined with Tertiary and Quaternary volcanic rocks. The eastern half, the Ogaden Basin, consists of Jurassic, Cretaceous, and Tertiary sedimentary rocks. The sediment outcrops define the Ogaden Basin, a potential hydrocarbon producer. The western half is dominated by Cenozoic volcanic cover but with Jurassic and Cretaceous sedimentary rocks exposed along the western and northern limits, revealing the Blue Nile Basin beneath and the Mekele Outlier to the north ([Figure 3](#)).

Additional potentially prospective areas for oil and/or gas are seen in the flat, Quaternary-age sediment-covered area to the extreme west, known as the Gambela Basin, and to the north in the Afar or Danakil Depression area. Potential exists in the relatively unknown rift valleys to the south along the border with Kenya, i.e., the Omo River valley and Chew Bahir rift valley.

The combination Bouguer Gravity map ([Figure 4](#)), covering Ethiopia, Eritrea, the southern Red Sea, and the southwestern corner of the Arabian Peninsula, supports the interpretation of the sedimentary basin areas.

Precambrian basement rocks, igneous and metamorphic, crop out along the western border with Sudan, along the northeastern, western, and southern boundaries of the Ogaden Basin, and to the extreme north along the border with Eritrea.

### **Plate Tectonics and Paleogeography**

Our universe came into being over 13 billion years ago, followed by the creation of our solar system. Continents on Earth are estimated to have begun forming about 4.5 billion years in the past. Continental crust developed over time and, floating on moving sub-crust, forged cratons which then combined to become continents. The continents have, over the millennia, broken apart, drifted and recombined. The process continues today. The original crust was formed of igneous and metamorphic rocks and the identification of the original supercontinents and of the breakup and reformation into the intermediate stages and today's continents is based on rock type and radiometric age dating.

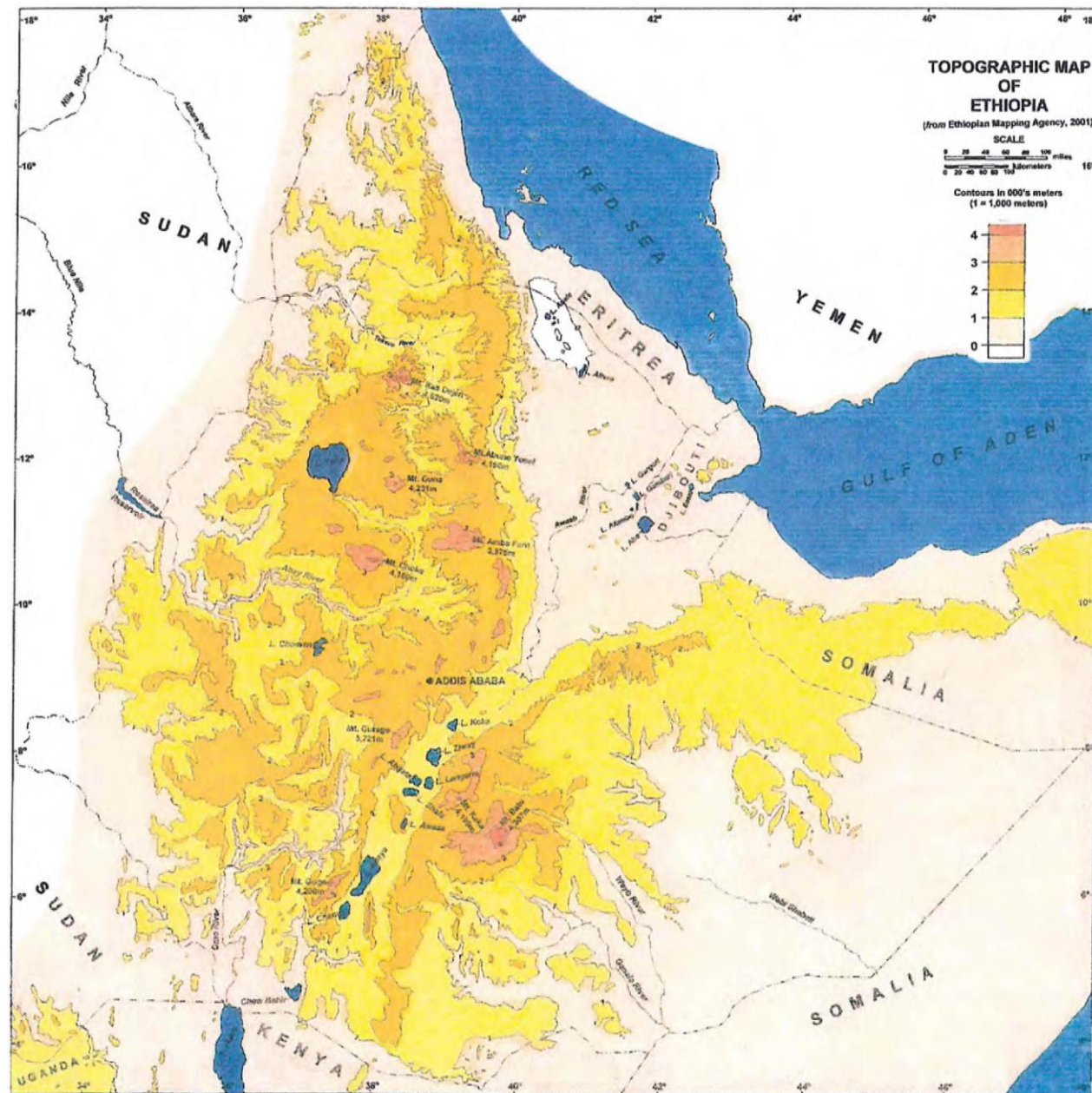
The first identified continent was named Rodinia, believed to have existed from 1.3 billion years ago until 765 million years ago (Ma). Rodinia broke up and intermediate continents Pannotia, Pangaea, Laurentia, Baltica, Siberia, and Gondwana went through breakup, movement, combining and breaking again into today's fragments. Gondwana is the ancient supercontinent of interest to Ethiopia. Gondwana's formation began 950 Ma (Precambrian Proterozoic), continuing until final consolidation about 540-523 Ma (Paleozoic Cambrian).

Extensional rifting within Gondwana occurred during the Late Paleozoic (Late Carboniferous to Permian), through the Triassic, and into the Jurassic. Cannon et al. (1981) stated that continental Karoo deposition was initiated and controlled by major faulting of the Paleozoic/Mesozoic triple-junction rift system developed in East Africa. BEICIP (1985) also concluded that the Ogaden Basin developed as part of a triple-junction rift system during Late Paleozoic-Mesozoic: the Mandera- Lugh Deep, the Calub saddle of the Ogaden Basin, and the Blue Nile rift to the northwest. Thick Karoo sediments filled the rift troughs (Figure 5). These rifts initiated the Mandera-Lugh Basin of southeastern Ethiopia and the Karoo rift hosting the Calub Gas discovery within the Ogaden Basin of Ethiopia. The Karoo Group Calub, Bokh and Gumboro Formations are found only in these grabens.

The separation of Western Gondwana (Africa and Arabia) from the supercontinent Laurentia, which included North America, began about 180 Ma (Early Jurassic), and separated from South America during the Middle Jurassic. Western Gondwana also separated from Eastern Gondwana (India, Sri Lanka, Seychelles, Madagascar, Australia, and Papua-New Guinea) during the Middle Jurassic.

The Atlantic Ocean formed in the gap created by the separation of North and South America from Western Gondwana, whereas the ancestral Tethys Sea developed off Gondwana's east coast as Eastern Gondwana moved away. The waters of the Tethys Sea filled the void and directly affected sedimentation in Ethiopia.

The tectonic development of the Tethys Sea and its influence on Ethiopian geology is illustrated in Figures 6 (Late Carboniferous-Permian) through 19 (Pliocene-Quaternary).





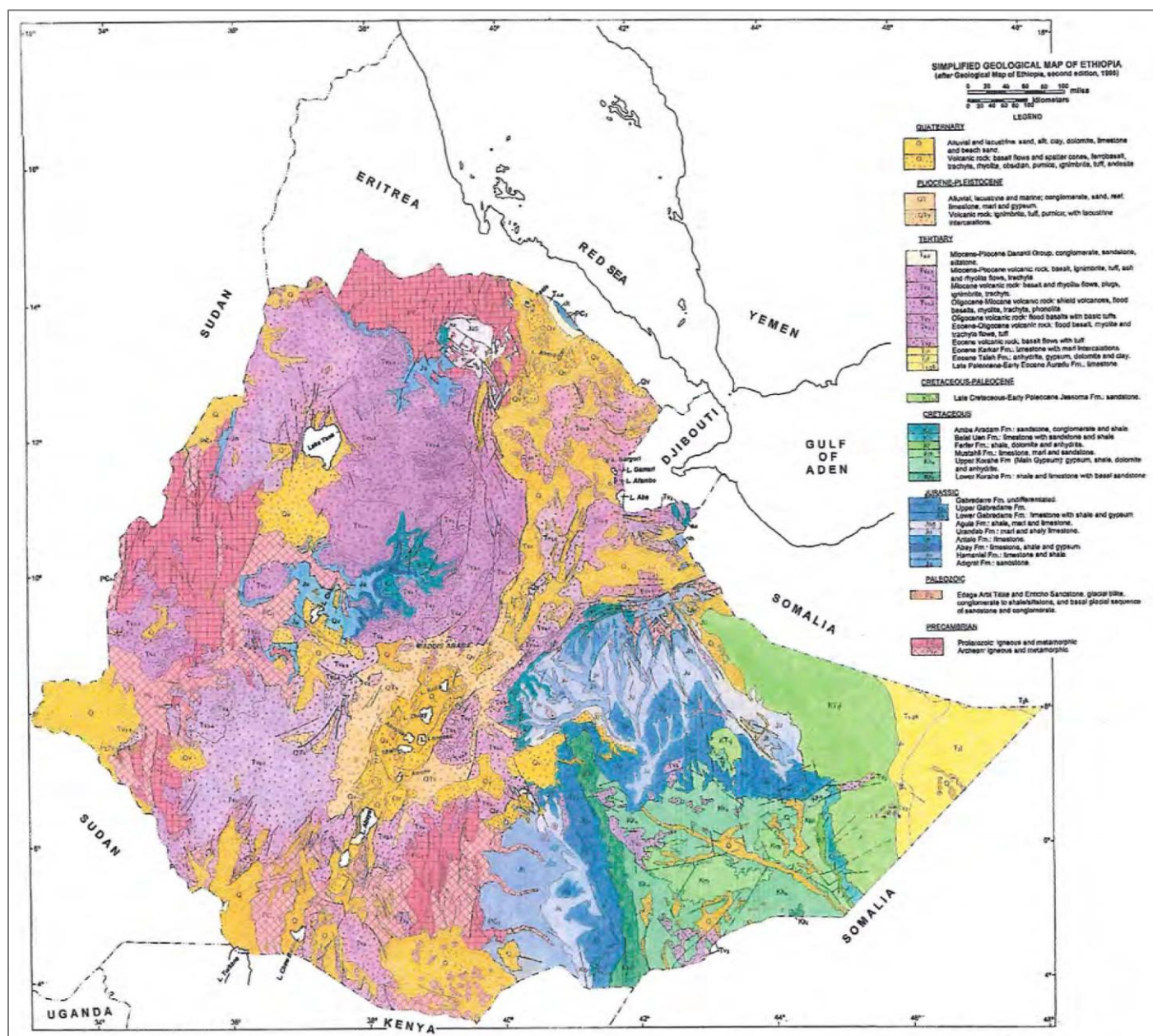


Figure 2. Simplified geologic map of Ethiopia (*from* Geological Map of Ethiopia, second edition, Ethiopian Mapping Authority, 1996).



Figure 3. Sedimentary basins of Ethiopia and Eritrea.

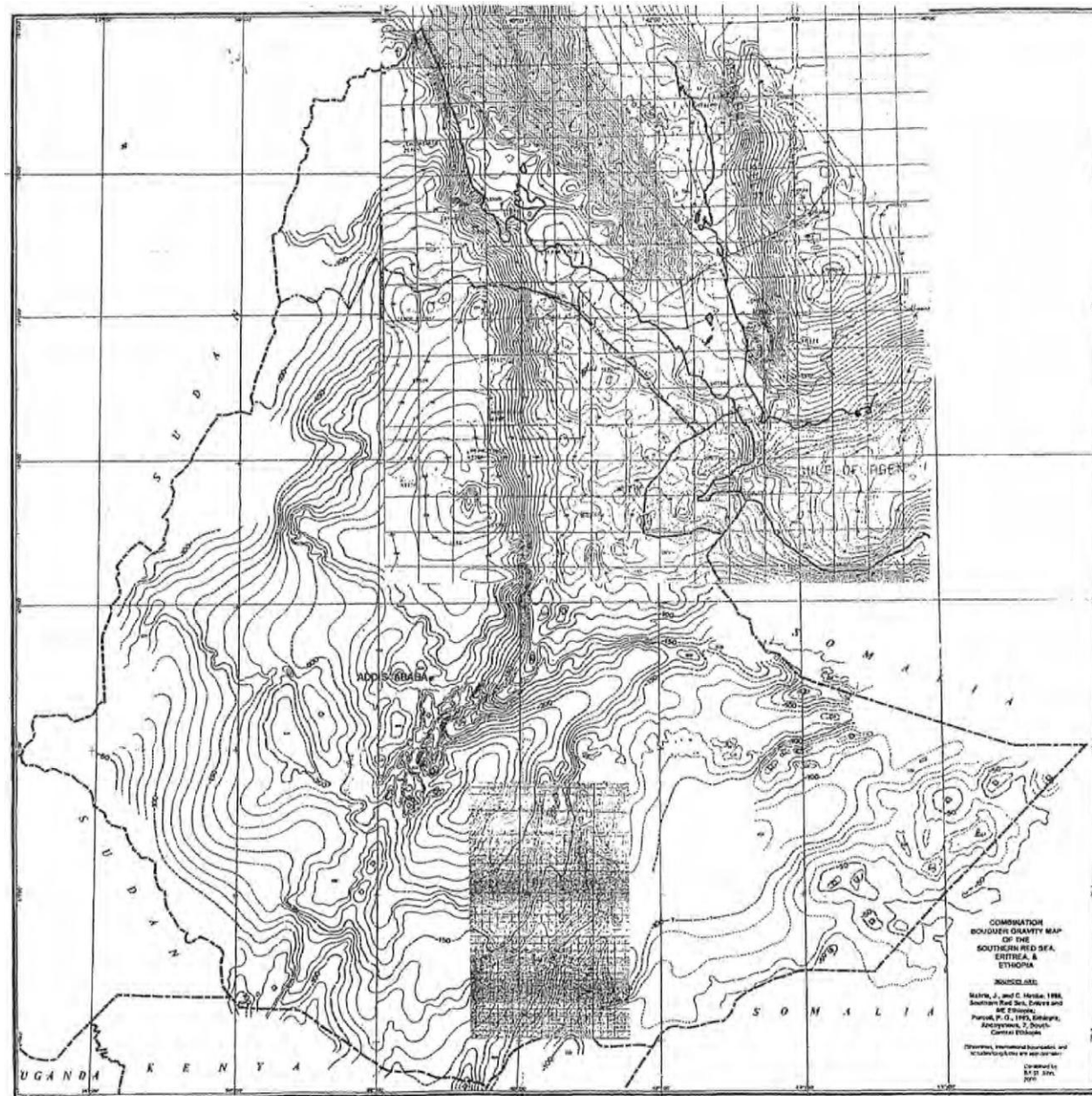


Figure 4. Bouguer Gravity map of Ethiopia, Eritrea, and Red Sea area (from Makris and Henke, 1988; Purcell, 1993).

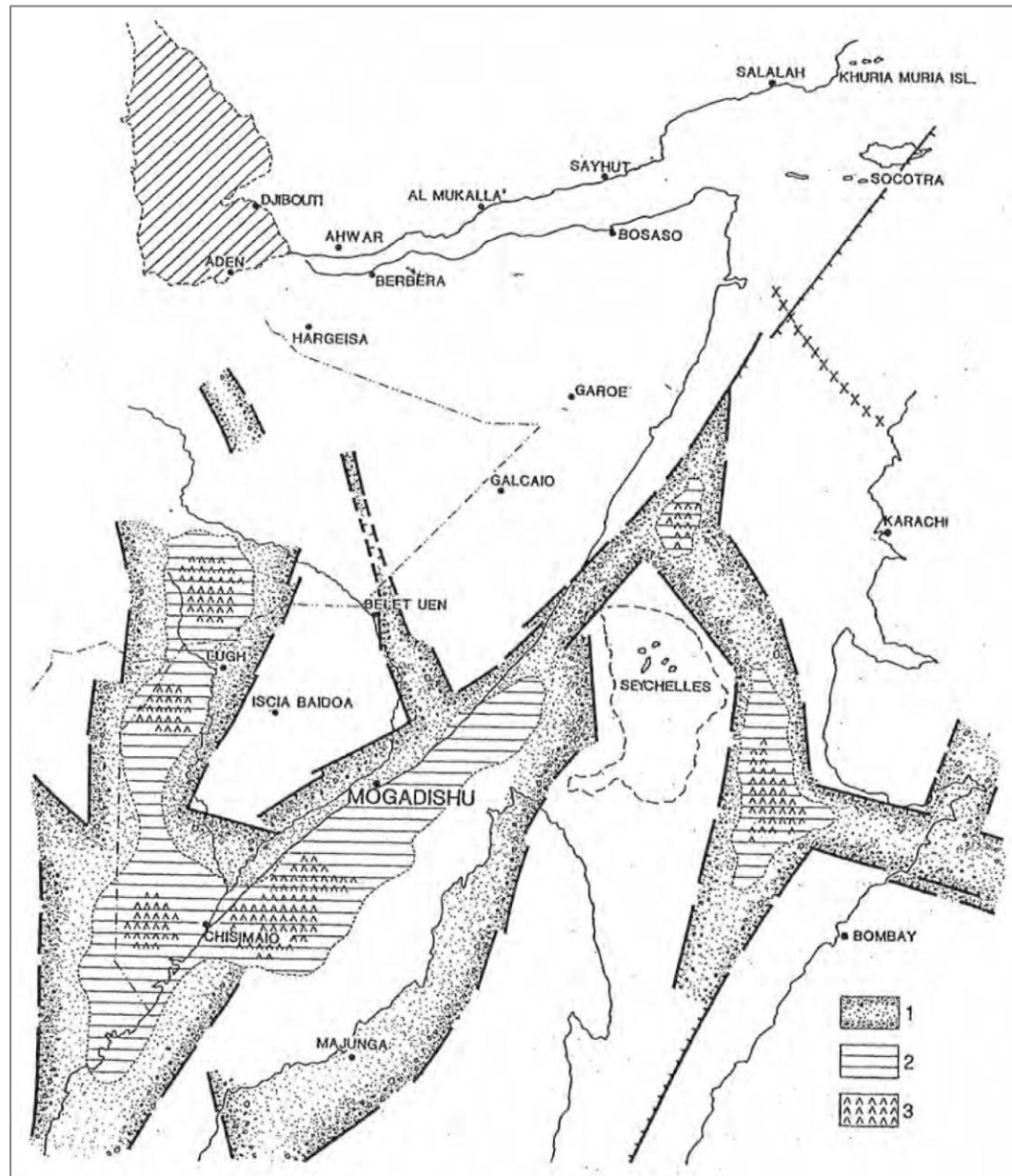


Figure 5. The Karoo rift system in East Africa, Madagascar, Socotra, and India (*after* Bosellini, 1989); only major rifts are shown. Legend: 1) intermontane clastics; 2) water bodies, mainly lacustrine; 3) evaporites.



## **Late Carboniferous-Permian ([Figure 6](#))**

The final assembly of the super-continent Pangaea occurred during this time, with Gondwana to the south and Laurasia to the north. Pangaea was shaped like a vast “C”, facing east, and inside the “C” was the Paleo-Tethys Ocean.

A rift formed along the northeastern shelf of Gondwana. The rift evolved into a spread center, separating the coastal fragment known as “Cimmeria.” The northward-migrating spreading center pushed Cimmeria in front of it, away from Gondwana, replacing the old Paleo-Tethys Ocean with a Neo-Tethys Ocean. The old Paleo-Tethys Ocean crust was being subducted beneath the eastern end of Laurasia.

Continental glaciers covered much of Antarctica- East Africa and West Africa - southern South America. Continental tillites and glacial outwash deposits define the areas of glaciation. The Enticho Sandstone and Edaga Arbi Tillites are what remain of continental glacial deposits in Ethiopia. Except for Cimmeria, Gondwana remained intact with marine incursion beginning between what is now the East African and West Indian coasts.

Pre-breakup extension was occurring and marine invasion was beginning in the resultant developing lows, while rift basins were beginning to form inland. In northeast Africa, including Ethiopia, fluvial-lacustrine sediments sourced from exposed highlands began to fill the rift basins. These include the fluvial Calub sandstones and the siltstone and lacustrine shale of the Bokh Formation.

## **Triassic ([Figure 7](#))**

The Cimmeria block was nearing the eastern Laurasia subduction zone, and little remained of the Paleo-Tethys Ocean. The Tethys Ocean occupied most of the area between Gondwana and Laurasia. Rifting accompanied by spreading and introduction of oceanic crust was beginning to develop a wedge between the Southern Arabian Platform and western India. Continental-to-transitional sediments filled the depression beginning between East Africa and Madagascar.

In East Africa, a fluvial domain dominated. The main deposits are the Gumboro and Adigrat sandstones of the Ethiopia-Somalia Ogaden Basin. Triassic continental sediments occur in the Ogaden and Mandera-Lugh basins of Ethiopia and Somalia. These are considered Karoo equivalent, as are the continental clastic sediments overlain by Adigrat Formation sandstones in the Blue Nile Basin of northwest-central Ethiopia.

## **Early Jurassic Lias ([Figure 8](#))**

Subduction continued along the southern border of Laurasia and the area of the Tethys Ocean continued to shrink. Incipient rifting between East Africa and Madagascar/India continued and marine waters from the north flooded the depressed area. Continental clastic sediments fringed the flooded area and a transitional facies, including the Ethiopia Ogaden Basin Transition unit overlying the Adigrat Formation, filled the center.

### **Middle Jurassic Dogger ([Figure 9](#))**

A major breakup of Pangaea occurred by the close of the Middle Jurassic Dogger. The southern Gondwana limb began to separate in the west with South America separating from West Africa as a spread center and oceanic crust began to appear starting in the south. The still-joined India/Madagascar/Seychelles/Australia/Antarctica plate separated from East Africa with similar spreading center / oceanic crust development.

Off East Africa, a northern spreading center was joined via a north-south transform fault to a southern spreading center. The separation was essentially a north-south motion. The spread centers were the sites of introduction of oceanic crust. The northern spreading center joined the west-east aligned spreading center in the southern Tethys Ocean forming a triple-junction. The Tethys Ocean continued its closing motion with subduction continuing in the north along the southern Laurasia edge.

The Middle Jurassic Dogger was a period of global highstand and transgression. Epicratonic seas spread over north and east Africa, the Arabian platform, and the north India and north Australia cratons.

In Ethiopia, the transgressive Antalo Formation limestone occurs in the Mekele Outlier to the north, in the Blue Nile Basin to the west, and in the Danakil Alps of Eritrea. The equivalent Hamanlei limestone blanketed the Ogaden Basin.

### **Late Jurassic Malm ([Figure 10](#))**

The Arabian plate remained a passive margin with a wide eastern shelf facing the Tethys. Rifting and separation between Arabia/Somalia and India remained active. Marine transgression moved onto the shelves of the separating blocks of Ethiopia/Somalia and Madagascar/Seychelles/India.

To the south, the Tethys Ocean was bounded by the easternmost Gondwana block, consisting of India/Madagascar/Seychelles, and Laxmi/Australia/Antarctica. The waters of the Tethys Ocean penetrated eastern Africa through epicontinental basins.

### **Early Cretaceous Neocomian ([Figure 11](#))**

By the close of the Neocomian, separation between East Africa / Arabia from East Gondwana had ceased. The Davie Ridge, along the transpressive transform fault separating the masses, was firmly established. Closure of the Tethys Ocean into the subduction zone south of Laurasia continued.

The lack of Early Cretaceous coarse siliciclastic deposits in the marine sediments of central Ethiopia and northwestern Somalia indicates the lack of high erosional source areas. In the Blue Nile Basin of northwestern Ethiopia, however, there are siliciclastic limestones and shaly sandstones, deposited (undifferentiated) from supratidal environments into a meandering river system. In the Ogaden Basin of Ethiopia and Somalia, evaporitic conditions led to deposition of the Korahe Formation.

### **Middle Cretaceous Earliest Barremian ([Figure 12](#))**

The spreading and emplacement of new oceanic crust between East Africa / Arabia and Madagascar ceased and moved to the south as the spreading center extended eastward from near the South Africa - Mozambique boundary to separate Madagascar/Seychelles/Laxmi/India from Australia/Antarctica. This marked the beginning of the southern Indian Ocean.

A new north-south-aligned transform fault between eastern Madagascar and western India joined the southern west-east spreading center to a newly developed spreading center between Madagascar and Seychelles/Laxmi/India. This led to the rift basin between Madagascar and the Seychelles and to the straight-line topography of the Madagascar eastern shelf and India's western shelf. It also appears that the transform fault was transpressive, resulting in the uplift of Madagascar's east coast and subsequent westward movement of erosional sediments and uplift of India's west coast, with corresponding eastward movement of erosional products.

In East Africa, uplift and block movement in northern Somalia led to subsidence with deposition of evaporites and marine deposits in eastern Ethiopia. This is represented by the Middle to Upper Korahe Formation.

### **Middle Cretaceous Barremian-Aptian-Albian ([Figure 13](#))**

To the north, subduction of Tethys Ocean crust continued as the Tethyan seaway continued to close. In the south, the transpressive transform fault between Madagascar and Seychelles, Laxmi/India evolved into an oblique spread center accompanied by the introduction of oceanic crust between Madagascar and Seychelles/Laxmi/India. It may be that the new spread center joined the South Indian Ocean spread center at this time to form a triple junction. The southern spreading center between India and Australia/Antarctica continued to be active, and the separation widened.

Coastal clastics cover the Arabian/Somalia shelves, but evaporites occur in eastern Somalia as a 500-km belt known as the Main Gypsum Formation. This unit extends into Ethiopia as the uppermost Korahe Formation. Carbonate platforms developed in east and north Somalia, extending into Ethiopia as the Mustahil and Ferfer formations and grading upwards into the Belet Uen Formation.

### **Late Cretaceous Maastrichtian ([Figure 14](#))**

The Tethys Ocean seaway was rapidly closing as India approached Laurasia from the south while subduction of oceanic crust continued. The spread center separating Madagascar from the Indian plate remained active while a lesser spread center began to separate the still-combined Seychelles/Laxmi Ridge from India proper.

The volcanic-basalt-extrusive Deccan Traps of western India appeared in latest Cretaceous Maastrichtian and continued into the Early Tertiary Danian. The Traps saddled the Cretaceous -Tertiary boundary. It is interpreted that the volcanic flow covered the Seychelles/Laxmi Ridge prior to separation from India. The Deccan Traps resulted from a hot spot or mantle plume that continued to extrude basalt as the Indian plate moved northward, resulting in the formation of the Laccadive basalt ridge upon which carbonates would later develop.

In eastern and northern Ethiopia and central and northwestern Somalia, braided rivers began depositing continental sandstone of the Jessoma Formation. Fluvial Jessoma Sandstone occurs in the Kenya and Somali coastal areas, suggesting flow from the Bur Acaba High. Good reservoir rocks occur in the Upper Maastrichtian continental sandstones.

Initial tectonic activity related to development of the Red Sea rift off Eritrea began in the pre-rift Late Cretaceous with uplift and erosion. A continental siliciclastic deposit accumulated in a NNW-SSE depression in the position of today's southern Red Sea.

### **Paleocene ([Figure 15](#))**

Subduction and reduction of the Tethys Ocean continued into the Paleocene, with the Indian plate approaching the Laurasia subduction zone. Separation of India from Australia and Antarctica was ongoing as spreading continued through the Southern Indian Ocean. Separation was also occurring between East Africa / Madagascar and India via seafloor spreading in the Western Indian Ocean.

Some volcanic activity of the Deccan Traps extended into at least the early Paleocene. At the close of the Paleocene, the original Deccan Trap hot spot had created the base for the Laccadive Archipelago and was continuing in the Maldives to the south as the Indian plate continued its northward drift.

Continental fluvial sandstone deposition of the Jessoma Formation continued into the early Paleocene. The shallow shelf, transgressive Auradu Formation carbonates covered the Jessoma clastics.

### **Eocene ([Figure 16](#))**

By the close of the Eocene, the Tethys Ocean had disappeared, subducted beneath the southern margin of the Eurasian plate. Remnants of the Tethys Ocean are believed to exist today as floors to the Black, Caspian, and Aral Seas. The Indian plate had been subducted and underthrust the Southern Tibet plate, with the resultant uplift creating the Himalayan mountain chain.

Two hot spots remained active. The western one created the Chagos Islands Ridge, and the eastern one was active at the south end of the Ninety-East Ridge. The Southern Indian Ocean spread center had separated Broken Ridge and Kerguelen Ridge or Plateau, introducing oceanic crust between the two. The eastern end of the same spread center had effected a wide separation between Australia and Antarctica. The same Southern Indian Ocean spread center was connected via an oceanic transform fault to an Eastern Indian Ocean spread center, widening the gulf between Southeast Asia/India and Australia.

In the Ogaden Basin of Ethiopia and Somalia, as well as in the Mudugh Basin and Nogal Rift of Somalia, the Eocene is represented by the upper part of the Auradu limestone overlain by the Taleh shallow marine evaporites and carbonates. The Ashangi Trap volcanics extruded from Paleocene through the Oligocene. The Dogali Formation syn-rift deposits of Eocene-Miocene age continental-to- marine sandstone, shale, evaporites and volcanics were laid down on- and offshore Eritrea.

## **Oligocene ([Figure 17](#))**

India was firmly attached to Tibet. The Himalayas were beginning to form, but not to the point of providing huge amounts of clastic sediment to the low above the underthrust northern Indian plate. Continental sediments were being sourced from the south. A deep ocean basin lay off India's northwest coast and the continental cores of Afghanistan and Iran remained separate from the Pakistan/India continental mass. An active subduction zone along the southern Iran/Afghanistan coast would later result in melding of the continental crusts of Iran/Afghanistan with Pakistan/India.

The triple junction spread center in the Southern Indian Ocean remained active with a single northwestern leg extending between India and the Seychelles. The extended leg separated the hot spot basalt ridge of the Laccadives, Maldives and Chagos (now covered with carbonates), to the south side of the spreading center, where the hot spot was creating a carbonate-covered basalt ridge termed the Cargados Carajas Bank. The southwestern leg remained active south of South Africa. The southeastern leg had now widely separated Kerguelen Ridge, or Plateau, from Broken Ridge and the Ninety-East Ridge. The hot spot responsible for creating the Ninety-East Ridge had become inactive. Australia and Antarctica had become separate entities.

Preliminary sag and rifting was developing between northeast Africa and the Arabian plate, and between the Arabian plate and northern Somalia. Some continental rifts formed in the present-day Red Sea area and in the incipient Gulf of Aden. Intensified extension in the Gulf of Aden leading to the separation of the Arabian and African plates started in the late Oligocene. Initiation of the Late Oligocene event led to thick successions of slope deposits such as calciturbidites, debris flows and olistoliths. Oceanic crust was not to appear until the Miocene. The East Africa Rift System was in place with active rifting and extrusion of basalt flows over that part of East Africa, including Ethiopia and Eritrea.

Rifting leading to the formation of the East Africa Rift basins may have started as early as the Eocene; however, the Oligocene is generally accepted as the initiation of the rifting accompanied by volcanic extrusion. Oligocene volcanic rocks occur in the Turkana Basin of Kenya, while Oligocene fluvio-lacustrine sediments occur in the Lokichar and Anza basins. Deltaic sediments developed in the Lamu Basin. Rhyolitic tuffs in the Ethiopian rift yield K/Ar ages between 37 and 31 Ma. In Eritrea, there was minor syn-rift faulting and subsidence from the Paleocene into the Late Oligocene when the first major rifting occurred, leading to the development of the southern Red Sea.

## **Miocene ([Figure 18](#))**

East of Arabia, the remnant Tethys Ocean disappeared beneath Iran/Afghanistan into the Makran subduction zone. The process of collision between Africa/Arabia and southern Europe is estimated to have ceased during the Miocene, at which time the Mediterranean boundaries were defined.

The triple junction spread center of the southern Indian Ocean remained intact and active as the northwestern extension moved beyond the Western Indian Ocean and into the Gulf of Aden. Oceanic crust first appeared in the Gulf of Aden during the Miocene, as it did to the north in the opening of the Red Sea.



Major rifting in the Southern Red Sea caused separation of Arabia from Africa occurred during the Miocene. Offshore Eritrea, there was also deposition of the Habab Formation, an upper marine to deltaic clastic, followed by a significant restricted marine evaporite, the Amber Formation. The East African Rift System remained active and new volcanic flows of Miocene age occur from Eritrea south through Mozambique. Miocene extrusive basalts also occur on the western Arabian platform.

Rifting continued in the southern Ethiopia and northeastern Kenya rift trough. The Ethiopia/Kenya rift valley received fluvio-lacustrine and volcanoclastic sediments, as well as volcanic flows. In the Ethiopian rift area, volcanic rocks are dated as Early to Middle Miocene (17-15 Ma) and Late Miocene (11-11.9 Ma), as are the volcanic flows of the Turkana and Gregory rifts in Kenya ((9-7 Ma). In the Afar area of northern Ethiopia, rhyolites have K/Ar dates of 16-16.3 Ma and 8-13 Ma. The Ogaden Basin of Ethiopia-Somalia and the Mendera Basin of Somalia were sites of uplift and erosion during the Miocene.

### **Pliocene-Quaternary ([Figure 19](#))**

The Pliocene-Quaternary includes the southernmost extension of the continental ice sheet over northern Europe into Asia. Major continental ice sheets covered the Alps of Switzerland and Italy, the Pyrenees along the border between Spain and France, much of the British Islands, and Fennoscandia into Russia. The period of extended freezing cold reduced the precipitation in North and East Africa, Arabia and India resulting in extensive continental deposits in desert-like environments.

The Western Indian Ocean appeared much as it does today. The active triple junction spread center extends from the Gulf of Aden to south of Australia, and south of South Africa west into the Atlantic Ocean. Carbonates dominate deposition on the old hot spot basalt ridges, while the one remaining hot spot or mantle plume continues to be active at Reunion Island.

Pliocene-Recent rifting and volcanic activity occurs even today in the East African Rift Zone with occasional earthquakes along the rift faults and occasional outbursts of volcanic activity. Non-deposition or continental clastics represent the Plio-Pleistocene in the interior Ethiopia basins. In Eritrea, Pliocene Desset Formation alluvial fans are abundant and, in the offshore, are covered by Plio-Pleistocene open-marine Dhunishub Limestone.

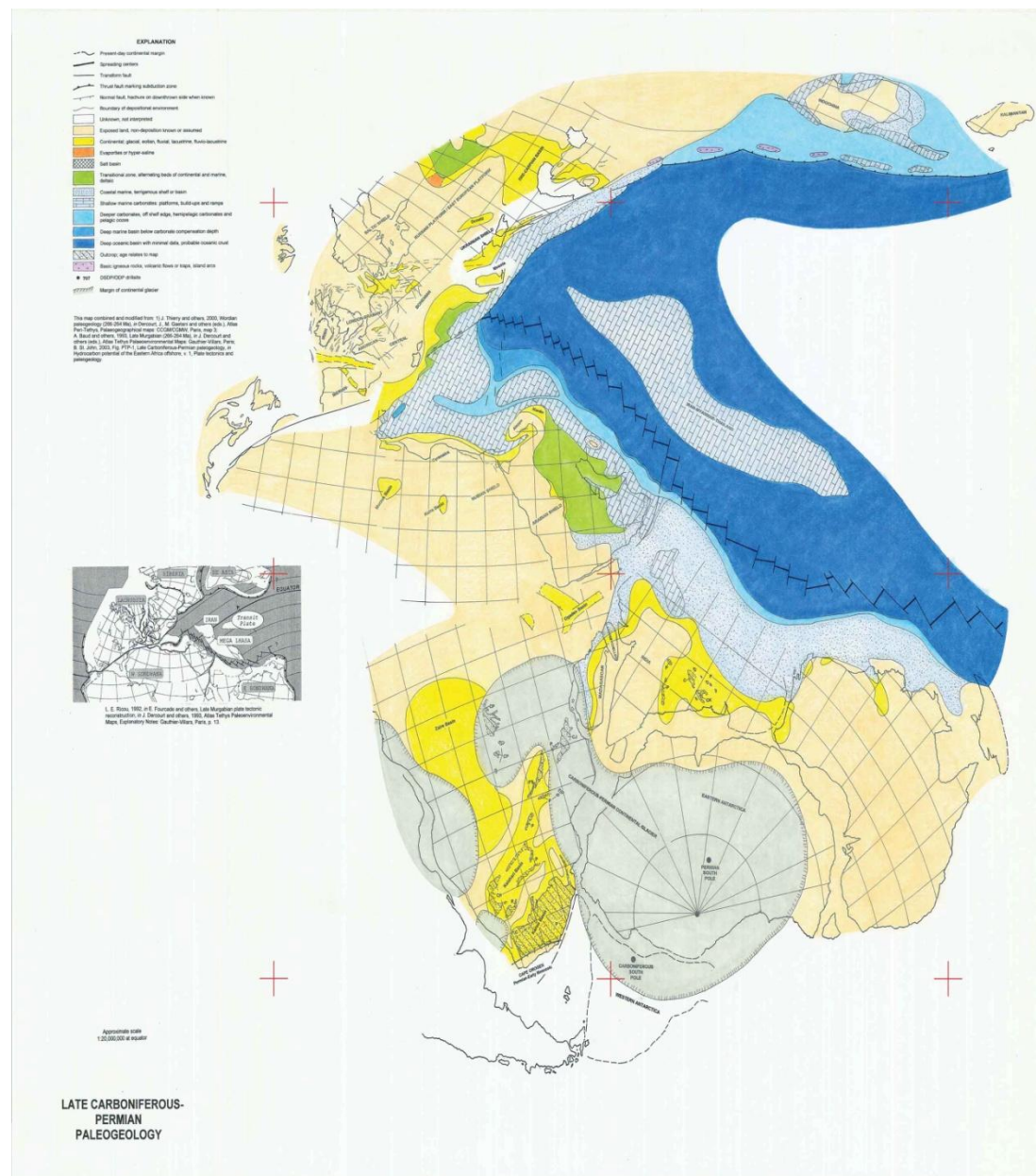
To the east, a major subduction zone consumes Indian Ocean crust beneath Myanmar, and Indonesia to Papua-New Guinea. Western Gondwana (Africa and Arabia) migrated northward from the South Polar region until it collided with Europe during the Middle to Late Eocene (44-41 Ma).

The first stage of rifting in the Gulf of Suez-northern Red Sea began in the Late Oligocene-Early Miocene, accompanied by rifting in the Gulf of Aden at the beginning of the Late Oligocene (~25 Ma). Rifting and crustal extension in the northern Red Sea continued into the Early Miocene, resulting in rotated fault blocks and a marine connection to the north. The Arabian plate began northeastward movement relative to the African plate 10-14 Ma during the Middle Miocene, leading to the development of the southern Red Sea and the Gulf of Aden. Extension by crustal thinning and faulting across the southern Red Sea, including offshore Eritrea, is evident during the Oligocene and Miocene; however,

there is no definitive evidence of oceanic crust prior to the Pliocene. The process of collision between Africa/Arabia and southern Europe is estimated to have ceased, or slowed significantly, during the Miocene, at which time the Mediterranean was closed off.

### **Volcanic Rocks of Ethiopia (from Mengesha Tefera et al., 1996)**

Basalt flows and tuffs within Jurassic and Cretaceous sediments near Dire Dawa and on the southeastern plateau suggest some Mesozoic volcanism, possibly related to the Jurassic mantle plume that uplifted that portion of Africa-Arabia. Much of the surface of Ethiopia is covered by Cenozoic volcanic flows, shield volcanoes, and plugs. The extensive volcanic activity is directly related to the underlying long-term plume, tension and extension; and creation of the Red Sea and Gulf of Aden rifts extending into the East African Rift System via the Afar and Main Ethiopian Rift (MER).

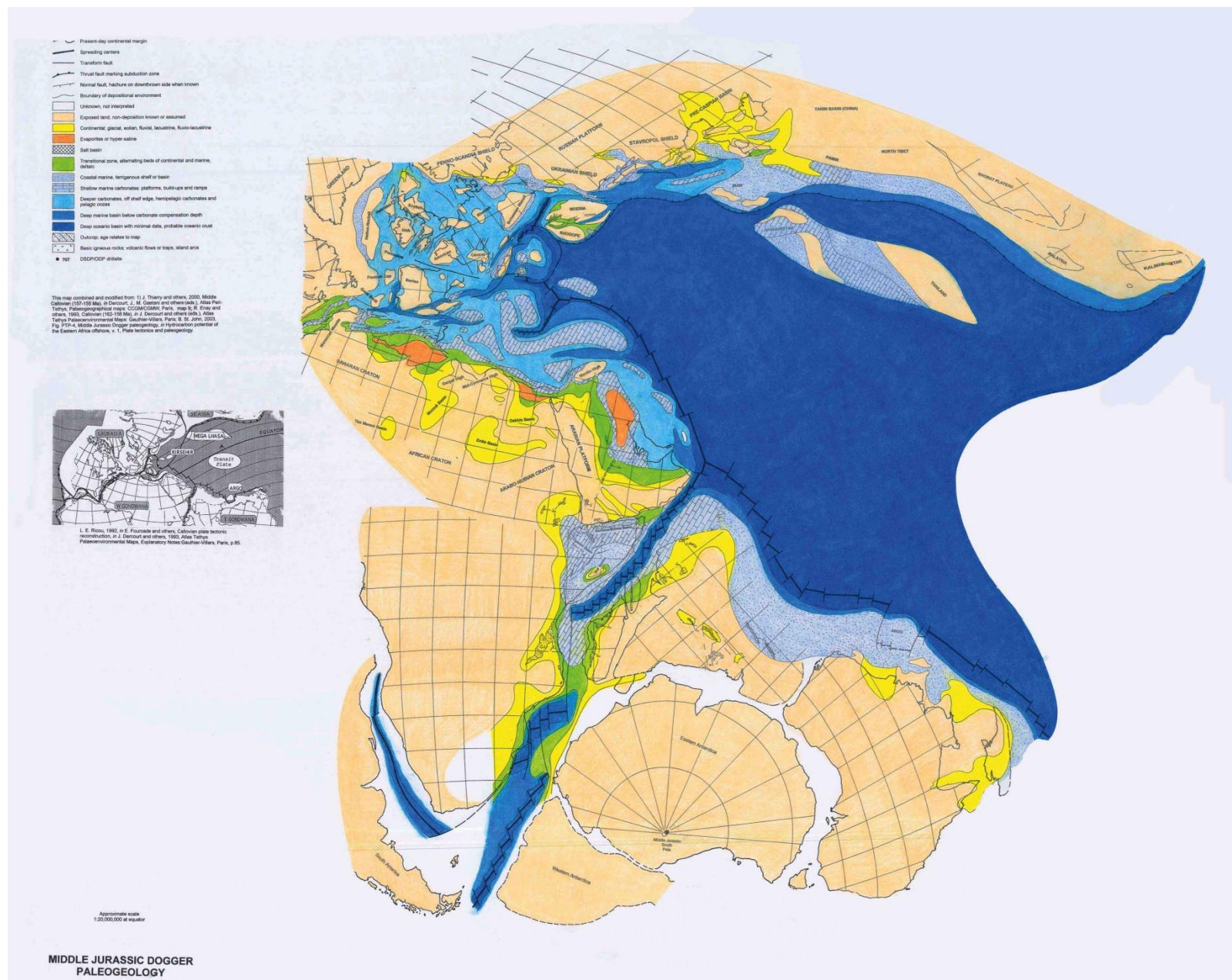
































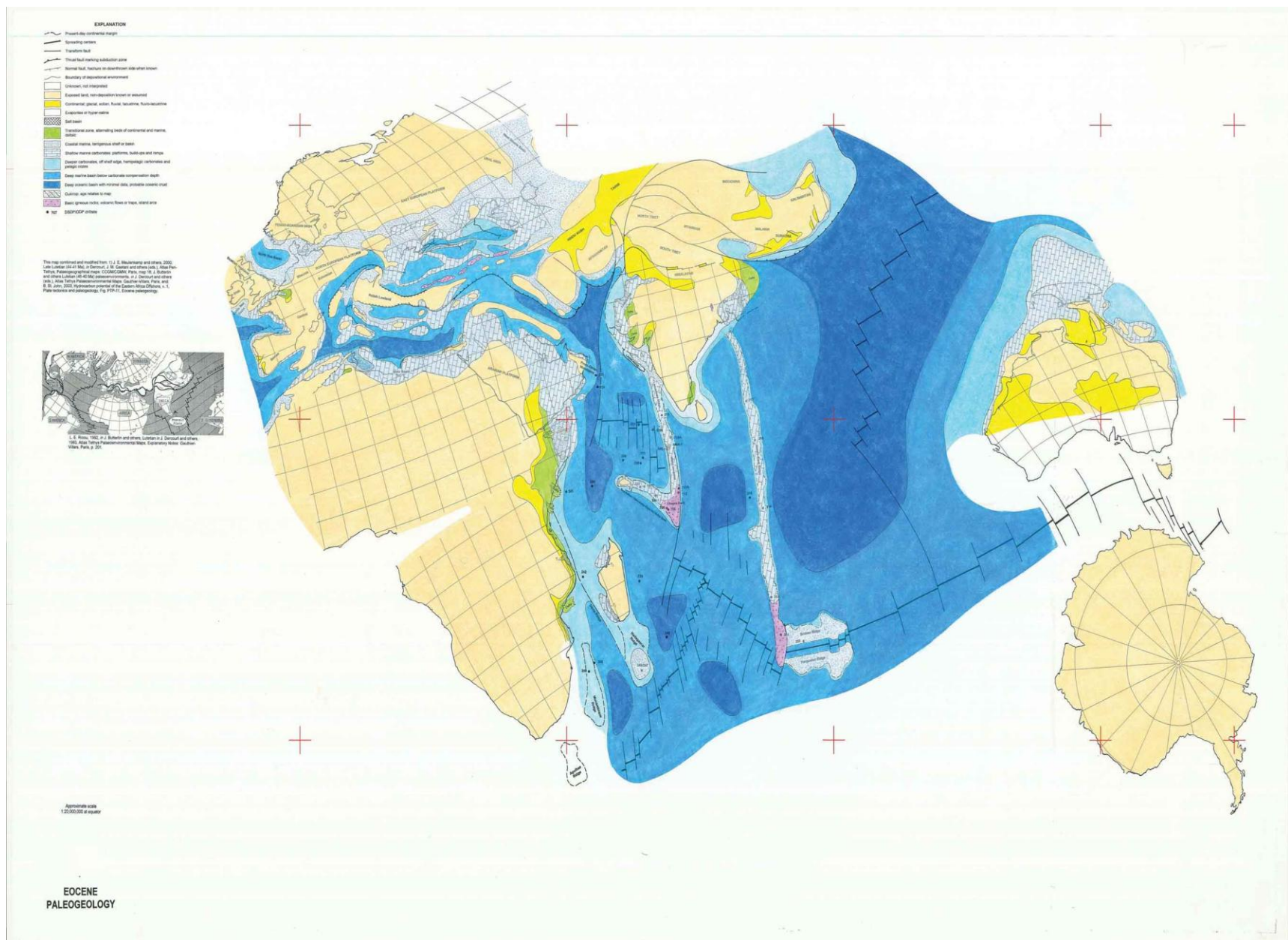


Figure 16. Eocene paleogeography.











## Stratigraphy ([Figure 20](#))

Schematic cross-sections across Ethiopia ([Figure 21](#)) display the relationship of stratigraphic units within the various depositional basins.

### **Precambrian**

The Precambrian contains a wide variety of sedimentary, volcanic, and intrusive rocks which have been metamorphosed to varying degrees (Mengesha Tefera et al., 1996).

#### **Matheos Formation (carbonate)**

In northern Ethiopia, there are many unmetamorphosed sedimentary units grouped or included with the Precambrian rocks by the early mapping geologists. The unmetamorphosed sediments include carbonate and clastic sediments. Some of the carbonate rocks have been folded and are currently mined as dimension stone for production of tiles. The carbonate rocks are algal stromatolitic and appear originally to have been a chicken-wire sabkha evaporite associated with anhydrite.

### **Paleozoic**

#### **Late Carboniferous-Permian**

In north-south-aligned erosional valleys in basement gneiss within the Blue Nile Basin, the Adigrat overlies unconformably about 650m of thick sandstone and shale of fluvial, lacustrine or deltaic origin deposited in cold climatic conditions (Mohr, 1963). Plant debris indicates a Late Carboniferous - Early Permian age.

The exact age of the basal clastic glacial/alluvial section is unknown, but the sediments are older than Jurassic and younger than Precambrian. Although the Edaga Arbi and Enticho have been given the inexact age of Paleozoic-Triassic, restricting the age to Paleozoic (Late Carboniferous- Permian) appears a better fit with the paleogeography of East Africa.

Enticho Sandstone--The basal Enticho Sandstone is unconformable on basement, mostly thick, cross-bedded quartz sandstone. It is present in the Mekele area (no thickness given) and is approximately 50m thick in the Danakil Range (Smewing and McKeown, 1989).

Edaga Arbi Tillites--The Edaga Arbi massive tillites beneath varved shales in north and west Ethiopia represent a glacial environment. The unit is present in the Mekele area and in the Danakil Range (no thickness given).

Buni Limestone--In the escarpment west of the Danakil and unconformably above the glacial sediments, there is exposed about 800m (2500ft) of unfossiliferous thick marine, brown Buni Limestone (Parsons, 1965; Holwerda and Hutchinson, 1968). The Buni Limestone is overlain unconformably by Upper Triassic sandstone.

The Buni Limestone could be age-equivalent to the Karoo Group of the Ogaden Basin. The oldest unmetamorphosed sedimentary rocks of the Dallol, or Danakil Depression have never been considered relative to hydrocarbon potential.

### **Late Carboniferous-Triassic**

Karoo Group--Thick Karoo sediments, Carboniferous to Triassic in age, were deposited in east Africa under continental conditions with limited marine access. The Karoo of east Africa is sandstone, shale, and conglomerate. Sandstones are fluvial and lacustrine, and shales appear to have resulted from channel and floodplain environments. Lacustrine beds are thick, widespread, and considered a hydrocarbon source. Shales in the middle part have been dated palynologically as Late Permian to Early Triassic.

In Ethiopia, the Karoo is subdivided as:

Adigrat (fluvial sandstone): Late Triassic age

Gumboro (fluvial sandstone): Triassic age

Bokh (lacustrine shale; source rock): Late Permian / Early Triassic age

Calub (alluvial fan sandstone; reservoir rock): Late Carboniferous - Permian age

The Karoo Group reaches 5000m in Kenya (Mombasa and Mandera Basin); whereas in the Ethiopian Ogaden Basin, maximum formation thicknesses reach 266.5m (874ft) for the Calub, 445m (1460ft) for the Bokh, and 753m (2470ft) for the Gumboro, a total of 1465m (4804ft) (BEICIP, 1985).

Carboniferous-Permian Calub Sandstone--The type area is the Calub area in the Ogaden Basin. The first penetration was in the Tenneco Calub-1 discovery well. The Calub Sandstone rests unconformably on Precambrian basement rocks. It represents the first fill of the rift valley within the Ogaden Basin. The sandstone beds are predominantly alluvial fan deposits. Calcrete interbeds indicate exposure to high evaporation rates typical of arid or semi-arid conditions.

Late Permian - Early Triassic Bokh Shale--The type locality is the Bokh area in the eastern Ogaden Basin; the Bokh shale was first encountered in the Sinclair Bokh-1 well in 1957. The continental, lacustrine organic shale and silty shale of the Bokh are dominant with minor interbeds of sandstone and dolomite. Contact with over- and underlying formations are conformable and gradual. The fine clastic sediments are believed to have been deposited below wave base in quiet, standing water. Other possible Paleozoic sediments in Ethiopia (Mengesha Tefera et al., 1996) include: Permian sandstone in Illubabor and Kefa; Gura Sandstone in Bale; Middle Abay Tillite; and Waju Sandstone near Hararghe.

### **Mesozoic**

#### **Triassic Gumboro Sandstone**

The type locality is the Gumboro village in the eastern Ogaden Basin near the Bokh well. It was first observed in the Sinclair Gumboro-1 well drilled in 1957. The Gumboro Sandstone is an alluvial, river-deposited sandstone containing abundant land-derived carbonaceous debris. The

Gumboro Sandstone is mainly the result of sandy braided river deposition, where the major sandy unit was deposited at a fast overall rate of sedimentation from flowing rivers.

### **Late Triassic-Early Jurassic**

Adigrat Sandstone--The Adigrat Sandstone type locality is in northern Ethiopia, near the village of Adigrat. It was named by Blanford in 1870 (quoted by Arkell, 1956). It occurs along the margins of the Mekele Outlier (Gebreyohannes, 1989). It also crops out in the Danakil Range of Eritrea and along the western and southern postulated margins of the Blue Nile Basin (Ethiopian Mapping Authority, 1996). The Adigrat is 200-300m thick in the Blue Nile Basin and probably was never deposited farther west than Lake Tana or farther north than Asmara (Bosellini, 1989).

Adigrat Sandstone is the formation name used in Ethiopia and Somalia. Equivalent units in the southern Arabian peninsula are the Kohlan Formation, Lathi Formation in India, Mansa Guda Formation in northern Kenya, and Isalo Group in Madagascar.

The Adigrat Sandstone is exposed overlying basement in the northern Ogaden Basin, and to the south extending into Somalia (Barnes, 1976). It also crops out along northern coastal Somalia. Thickness is variable dependent upon the underlying topography. Adigrat Sandstone thickness averages 122-152m (400-500ft) in the Ogaden, thinning to 46m (150ft) in the northeast, and is about 275m (900ft) thick in the Blue Nile Basin, and 670m (2,200ft) in the Mekele area, according to BEICIP (1985). Smewing and McKeown (1989) report Adigrat measured thickness of 250-350m in the Danakil Range.

Following peneplanation of the Precambrian basement rocks and the rift- filled Late Carboniferous to Triassic glacial and alluvial continental clastic sediments, continental fluvial, lacustrine and deltaic sandstones of the Adigrat began to cover East Africa beginning near the coastline extending to at least western Ethiopia. It resulted from denudation and peneplanation of the remaining highlands. The Adigrat is a typical fluvial succession with braided-stream deposits at the base, point-bar sequences in the middle, and coastal plain to lagoonal sediments at the top. The Adigrat Sandstone is time-transgressive.

Transition Zone--Transition Zone is an informal designation for a thinly interbedded sequence of shales, sandstones, siltstones, silty sandstones, grainy limestones and dolomites, and evaporites between the uppermost Adigrat sandstones and Hamanlei/Antalo limestones. Its age is usually considered Early Jurassic. The Transition Zone marks the change from a continental to a marine environment of deposition and may represent a rise of sea level at the Triassic-Jurassic boundary (Haq et al., 1987). The Transition zone has gas source rock potential (Shigut Geleta, 1997).

### **Early-Late Jurassic**

Hamanlei/Antalo Formations: Limestone and Shale--Continental subsidence, accompanied by a major rise in sea level with resultant major marine transgression and marine deposition during the Middle Jurassic, brought an end to Karoo and Karoo-equivalent deposition in Ethiopia. In places, the Hamanlei Formation lies directly on basement, e.g., in the western Ogaden, in the Harer area, and in the Nogal Uplift of

Somalia. Marine transgressive carbonate-evaporite sediments of the Hamanlei Formation were subsequently overlain by basinal shales and marls of the Uarandab Formation followed by the Gabre Darre Limestone. The Korahe evaporite overlies the Gabre Darre limestone and, in turn, is overlain by the Mustahil Limestone, the Ferfer Evaporite, the neritic Belet Uen Limestone, and the regressive Jessoma Sandstone as the sea retreated southwards. Above the Jurassic, these overlying sediments reflect a regressive sequence.

The Hamanlei Formation of the eastern Ogaden Basin and the Antalo Limestone of the northern Mekele Inlier, Danalik Alps, and western Blue Nile Basin are near age-equivalent and represent a transgressive sea. The original type section of Hamanlei Formation crops out near the village of Hamanlei in the northern Ogaden; however, the outcrop is now known to represent only the Upper Hamanlei limestone (Migliorini, 1956).

The Hamanlei Formation of the Ogaden Basin is subdivided into three lithological units:

- Lower Hamanlei clastic-carbonate mixed facies;
- Middle Hamanlei evaporite, dolostone and limestone; and
- Upper Hamanlei limestone.

*Lower Hamanlei*--The Lower Hamanlei limestone is found only in the Ogaden Basin; however, it is reported (Gebreyohannes, 1989) that a transitional sandy facies in the Blue Nile Basin has been correlated with the Lower Hamanlei. In Somalia, the Meregh Formation correlates with the Lower Hamanlei.

The Lower Hamanlei thickness in the Ogaden Basin decreases from 338.7m (1111ft) at El Kuran-1, to 256.4m (840ft) at Gumboro-1 and 165m (540ft) at XEF-2. The equivalent Lower Abay Formation in the Blue Nile area reaches 183m (600ft) thickness. Several wells in central Somalia have penetrated Lower Hamanlei or equivalents, and in southern Somalia, at Hol-1, the thickness exceeds 1097.5m (3600ft) (BEICIP, 1985).

The Lower Hamanlei reflects open lagoon-marine conditions and beginning development of a carbonate platform in the Ogaden Basin. It thins to the northeast and thickens to the south (Shigut, 1997). The Lower Hamanlei is considered a source rock in the Ogaden Basin.

*Middle Hamanlei*--A distinctive Middle Hamanlei evaporite/carbonate facies separates the Lower Hamanlei from the Upper Hamanlei in the Ogaden Basin. The Middle Hamanlei occurs in both the Ogaden and in the Blue Nile basins. It consists of limestone, dolostone, and evaporites with abundant oolites, algal stromatolites, green algae, foraminifera, echinoids, gastropods, and brachiopods. It is suggested (Migliorini, 1956) that the Middle Hamanlei was deposited under hot climatic conditions adjacent to a gently shelving seafloor.

The Middle Hamanlei thicknesses given in BEICIP (1985) range from 832m (2730ft) at Bodle-1548.8m (1800ft) Calub-1 and 388m (1273ft) at Bokh-1 in the Ogaden, to 222.5m (730ft) of the equivalent Abay Formation in the Blue Nile Basin to a maximum of 1463.4m (4800ft) at the Hol-1 in Somalia.

*Upper Hamanlei*--The Upper Hamanlei of the Ogaden Basin is composed of skeletal and peloidal grainstones and mudstones. The base at places is composed of high-energy oolitic grainstones. The Upper Hamanlei in the Ogaden Basin is overlain by the Uarandab Formation shales and marls; whereas, in the Harer region it is overlain by the regressive Upper Sandstone. The Upper Hamanlei, in all locations, shows an



upward-deepening trend (Shigut, 1997). The Upper Hamanlei is equivalent to the Baidoa Limestone and Shale of Kenya, the Bihen/Sawer Limestone of Somalia, and the Upper Abay Beds mapped in the Blue Nile Basin.

Upper Hamanlei thickness in the Ogaden Basin averages 396-488m (1300-1600ft) with maximum of 544m (1785ft) at Hilala-1 (BEICIP, 1985). Erosion toward the northwest decreases thickness to <152m (500ft). The equivalent Upper Abay in the Blue Nile Basin is composed of 129.5m (425ft) of shale, siltstone, and limestone, with an additional 100.6m (330ft) of marly fossiliferous limestone of the Lower Antalo. A correlative unit in the Somalia Hol-1 is 396m (1300ft) thick. The equivalent Antalo Limestone reaches 670.7m (2200ft) thickness in the Mekele area and >914.6m (3000ft) in the Danakil Range.

Blanford (1870) named the Antalo Limestone for the village near the outcrop in the Mekele area of northern Ethiopia. The Antalo Limestone of the Mekele area overlies the Adigrat Sandstone with a transitional contact. It is a sandy, fossiliferous, neritic limestone, 700-800m thick. Eastward, the Antalo Limestone changes to a coral and biostrome limestone with marl interbeds. Beyth (1972) described the Antalo as a “deepwater limestone” in the Danakil area.

Smewing and McKeown (1989) measured sections in the Danakil Range from 920m to 2650m in thickness. They determined four depositional environments: Antalo A, deposited on a shallow open-marine carbonate shelf with moderate energy; Antalo B, carbonate deposition on a deep muddy shelf; Antalo C, deposited on a muddy, low-energy tidal flat with periodic emergence, lagoonal; and, Antalo D, rapid progradation of a fluvial-deltaic environment over the previous tidal flat. The Antalo Limestone in the Danakil is Middle-Late Jurassic age. Equivalent marly limestones and oolitic skeletal, cherty limestones of the Blue Nile Basin were dated as Middle to Late Jurassic (Arkell, 1956).

Middle Jurassic (Abay Formation)--Abay Formation (Hamanlei equivalent): limestone, shale and gypsum crop out along the Abay River in the Blue Nile Basin. The formation is 580m thick, including a 196m sandy limestone and calcareous sandstone, 257m of gypsum, and 138m of interbedded shale and limestone. The Abay Formation overlies the Adigrat Formation and underlies the Antalo Formation.

Late Jurassic (Uarandab, Agula, and Gabredarre Formations)--The Uarandab Formation is Oxfordian-Kimmeridgian age marl and shaly limestone. The type locality for the Uarandab is the village of the same name located a few miles west of Dega Bur in the eastern Ogaden Basin (Migliorini, 1956). Equivalent units are the Rhamu Shale in northeast Kenya, and the Anole and Gahodleh Fms. in Somalia.

The Uarandab Formation represents an open, deep-marine, low-energy environment with slightly anoxic conditions (Shigut, 1997). It is considered an ideal source rock for hydrocarbons. BEICIP (1985) interpreted the Uarandab Formation to represent a period of quiet tectonic activity with a basinal depositional environment grading westward into a shallow inner shelf environment.

The Uarandab Formation thins northeastward in the Ogaden Basin, with 196.6m (645ft) at the Bodle-1 142m (465ft) at Calub-1. and 115m (376ft) at Gumboro-1. In its type section, it is 55m (180ft) thick. The Uarandab is absent in northeastern Ogaden and Somalia as a result of uplift and erosion at the end of the Jurassic. A 91.5m (300ft)-thick Antalo limestone in the Blue Nile Basin might be correlated to the Uarandab Formation Equivalents are found in Somalia and Kenya.

Agula Formation was deposited during the Late Jurassic Kimmeridgian; the transgressive sea reached its maximum extent in northern Ethiopia, allowing deposition of the Agula shale, marl, limestone, and evaporites. This unit is observed in the vicinity of Mekele and Antalo and occupies only the eastern part of the Mekele Outlier in the central part of the basin. This unit was deposited under semi-arid lagoonal conditions and may correlate with the shaly gypsum unit above the Antalo Limestone in the Danakil Range of Eritrea (Hutchinson and Engels, 1970). Thickness is 60- 250m.

Gabredarre Formation is Kimmeridgian-Portlandian-age limestone and shaly limestone. The type locality is at Kebri Dehar in the eastern Ogaden Basin (Migliorini, 1956). The equivalent unit in the Mendera-Lugh Basin and in southern Somalia is the Uegit Formation; in northern Kenya, the Seir Limestone, the Herreri Shale and Dakacha Limestone. In the Blue Nile Basin, the Gabredarre is correlated with the upper Antalo Limestone and lowermost Amba Aradam Sandstone (BEICIP, 1985).

The Gabredarre Formation represents a gradual shallowing of the sea, resumption of carbonate sedimentation, and the upper disconformity suggests a fall of sea level. Thickness of the Gabredarre is 410m (1345ft) at its type locality, 353.6m (1160ft) at El Kuran, 1259m (850ft) at Shillabo-1, and 164.6m (540ft) at Galadi-1. It is missing in the northeastern Ogaden and Somalia through erosion. The equivalent unit in the Mendera-Lugh Basin, the Uegit Formation, consists of 680m (2230ft) of sandstone, coquina and oolitic limestone and shale. Equivalent units are found in Kenya.

The Gabredarre can be correlated with the upper Antalo Limestone and possibly the lower Amba Aradam Sandstone in the Blue Nile Basin area. In the Mekele and Danakil areas to the north, the upper Antalo Limestone and overlying Agula shale are lateral equivalents of the Gabredarre Formation. The Gawan Formation of northern Somalia, 183-244m (600-800ft) thick, is equivalent to the Gabredarre Formation.

## **Cretaceous**

Korahe Formation--The upper part of the Korahe (aka Gorrahei or Main Gypsum) Formation is gypsum, shale, and dolomite with anhydrite intercalations; lower part is shale and limestone with basal sandstone. Type locality is the village of Korahe in the eastern Ogaden Basin. It represents an inner shelf environment. Near the close of the Jurassic, the sea began to retreat, leaving behind a large evaporite area. This is represented by deposits of the Korahe Formation.

The Korahe interfingers with the Amba Aradam sandstone in the Blue Nile Basin to the west. Equivalent units to the Korahe Formation in the Mekele and Harar areas are 46- 201m (150-660ft) thick and 488m (1600ft) thick in the Blue Nile Basin but reach 1067m (3500ft) in thickness in the Danakil Range (BEICIP, 1985).

Amba Aradam Formation--The Amba Aradam Formation is interbedded fluvial and lacustrine sandstone, conglomerate, and shale. This name is used in the Mekele Outlier, the Eritrean Danakil Range, and possibly the Blue Nile Basin area. It was described by Shumburo (1968). Beyth (1972) quotes 60-200m thickness for Mekele area. There is an angular unconformity separating the underlying Agula Shale from the Amba Aradam Formation in the Red Sea area (BEICIP, 1985), whereas Smewing and McKeown (1989) state that the Amba Aradam

conformably overlies the Antalo Limestone in the Danakil area and reaches a thickness of ~400 m. The top is an erosional surface marked by a lateritic crust 20-30m thick. The unconformable surface is overlain by the volcanics of the Red Series, or the Dogali Formation. The Amba Aradam equivalent was called Upper Sandstone by Kazmin (1975). It is found in Yemen, and is considered equivalent to the Jessoma Sandstone in Somalia.

Mustahil Formation--The Mustahil Formation is an Aptian-Albian limestone and marl, with minor sandstone. The Mustahil Formation, exposed in the Ogaden Basin, consists of alternating fossiliferous limestone, marly limestone, marl and rudist limestone, and was deposited in an inner- to outer-shelf environment. The Mustahil Formation thickness in the Ogaden ranges from 183-244m (600- 800ft).

Ferfer Formation--The Ferfer Formation is Albian-Cenomanian age shale, dolomite, gypsum and anhydrite. The Ferfer Formation is found in a narrow strip in the southeastern Ogaden and extends as far south as Belet Uen in Somalia.

In central Somalia, the sequence passes laterally into the Gumboro Group. The facies is believed to represent a restricted lagoonal environment. Thickness at the type section is 201m (660ft).

Belet Uen Formation--The Belet Uen Formation is Upper Cretaceous limestone with some sandstone and shale. The type section at Belet Uen in Somalia ranges in age from Cenomanian to Turanian and possibly into the Senonian. The upper section in the Ethiopian Ogaden is late Senonian and Maastrichtian, indicating a westward transgression (BEICIP, 1985). Its lower contact is unconformable with older units; however, at its top, it is conformable with the Jessoma Sandstone. Thickness at the type section is 227m (745ft). In general, thickness decreases to the southwest with 415m (1360ft) at XC-3, 367m (1204ft) at the Bokh-1, and 174m (570ft) at XEF-1.

## **Cenozoic**

The following covers the Cenozoic sedimentary units; the Cenozoic volcanic units are described in [Table 1](#).

### **Paleocene**

Jessoma Formation—This Upper Cretaceous-Paleocene sandstone represents a fluvial, shallow- marine depositional environment. Age is based on the age of overlying and underlying sediments. The Jessoma may correlate with beds of the Amba Aradam Sandstone in the Harer area. In northern Somalia, the Jessoma passes eastward into the Tisje Limestone. In central Somalia, the sandy Jessoma passes into fossiliferous limestone of the upper Gumboro Group. Maximum thickness of the Jessoma Sandstone is 427m (1400ft) at the Sinclair XF-5 location in the eastern Ogaden. The unit thins to 307.6m (1009ft) at Galadi-1 213-244m (700-800ft) at Bokh-1 and XEF-2.

### **Late Paleocene-Early Eocene**

Auradu Formation--The Auradu Formation is a transgressive fossiliferous mudstone to dolomitic packstone deposited in an inner- to outer-shelf environment. Maximum thickness in the Ogaden is about 427m (1400ft) at the Bokh-1 and XEF-2; whereas in central Somalia, at the Gira-1 well, a deeper facies reaches 654m (2145ft) thickness.

## **Early-Middle Eocene**

Taleh Formation--The Taleh Formation is lower to middle Eocene evaporitic anhydrite, gypsum, dolomite, cherty limestone, and clay.

## **Middle-Late Eocene**

Karkar Formation--The Karkar Formation is middle to upper Eocene limestone with marly intercalations and clay.

## **Oligocene-Miocene**

The upper Oligocene-Miocene units, Dogali Formation, Red Series, and Danakil Formation, appear the same, but they have different names whether on the Danakil side or along the Red Sea coast. The Dogali Formation of the Eritrean area is composed of lacustrine clastics mixed with nearshore marine clastics, which are interbedded with or intruded by Afar trap volcanics.

Thickness ranges from 300m for the Dogali to possibly 1000m for the Red Series. The Dogali Formation and Red Series rest disconformably on the Amba Aradam Formation. The upper surface appears to be overlain by the Amber Formation (salt) or by Plio-Pleistocene volcanic rocks in the Danakil Depression, or by the Desset Formation along the Red Sea coast.

## **Early-Middle Miocene**

Habab Formation--The Habab Formation is an Eritrean Red Sea sand and shale sequence of up to 1500m thickness deposited in an upper marine to restricted delta environment (BEICIP, 1985; Smewing and McKeown, 1989).

## **Middle-Late Miocene**

Amber Evaporite Group--The Amber Evaporite Group of the Eritrean Red Sea is a restricted marine sequence consisting of massive halite with anhydrite and gypsum layers. The thickness reaches 3000m (10,000ft) (BEICIP, 1985); or 3500-6500m (Smewing and McKeown, 1989).

## **Miocene-Pliocene**

Danakil Group--The Danakil Group (Red Series) is composed of clastics with intercalated submarine basalt flows and lacustrine sediments. In the Danakil, the Red Series is overlain by up to 1200m of halite, gypsum, anhydrite, potash salts, magnesium salts, and shale of Pliocene-Recent age (Smewing and McKeown, 1989).

Desset Formation--The Desset Formation is an Upper Miocene-Pliocene sand and shale sequence with anhydrite and salt layers and carbonate intercalations which unconformably overlies the Dogali and Habab Formations in the Eritrean Red Sea area. The environment is continental or deltaic (BEICIP, 1985; Smewing and McKeown, 1989).



## **Pliocene-Pleistocene**

Omo Group/Hadar Formation--The Omo Group and Hadar Formation are undivided lacustrine and fluvial sand, silt, gravel, and conglomerate deposits in southernmost Ethiopia.

Dhunisub Formation--The Dhunisub Formation is found only in the Eritrean Red Sea area. The lower part is of open marine sands and shales interbedded with marine limestones; the upper part is a carbonate shelf limestone. The thickness is variable, 61-1220m (200ft-4000ft) (BEICIP, 1985). It ranges 150-1400m thick of abundantly fossiliferous reefal limestone resting conformably on the Desset, Habab, and Amber Salt Formations (Smewing and McKeown, 1989).

## **Quaternary**

Rhyolite basalt at base, overlain by alkaline plateau basalt and trachyte, covered with basalt flows, spatter cones, and hyaloclastics, unconformable beneath alluvial and lacustrine deposits of sand, silt, clay, diatomite, limestone, and beach sand.

## **Pleistocene**

Ignimbrite, tuff, pumice, and waterlain pyroclastics, with lacustrine sediment intercalations at the base, are overlain by alluvial, lacustrine and marine conglomerate, sand, clay, reef, limestone, marl and gypsum.

## **Holocene**

Basalt near base is overlain by alluvial, lacustrine and beach sediments. In some areas, basalt at base is overlain by alkaline plateau basalt and trachyte, which in turn are covered with basalt flows, spatter cones and hyaloclastics. These are unconformably overlain by alluvial and lacustrine deposits of sand, silt, clay, diatomite, limestone, and beach sand.

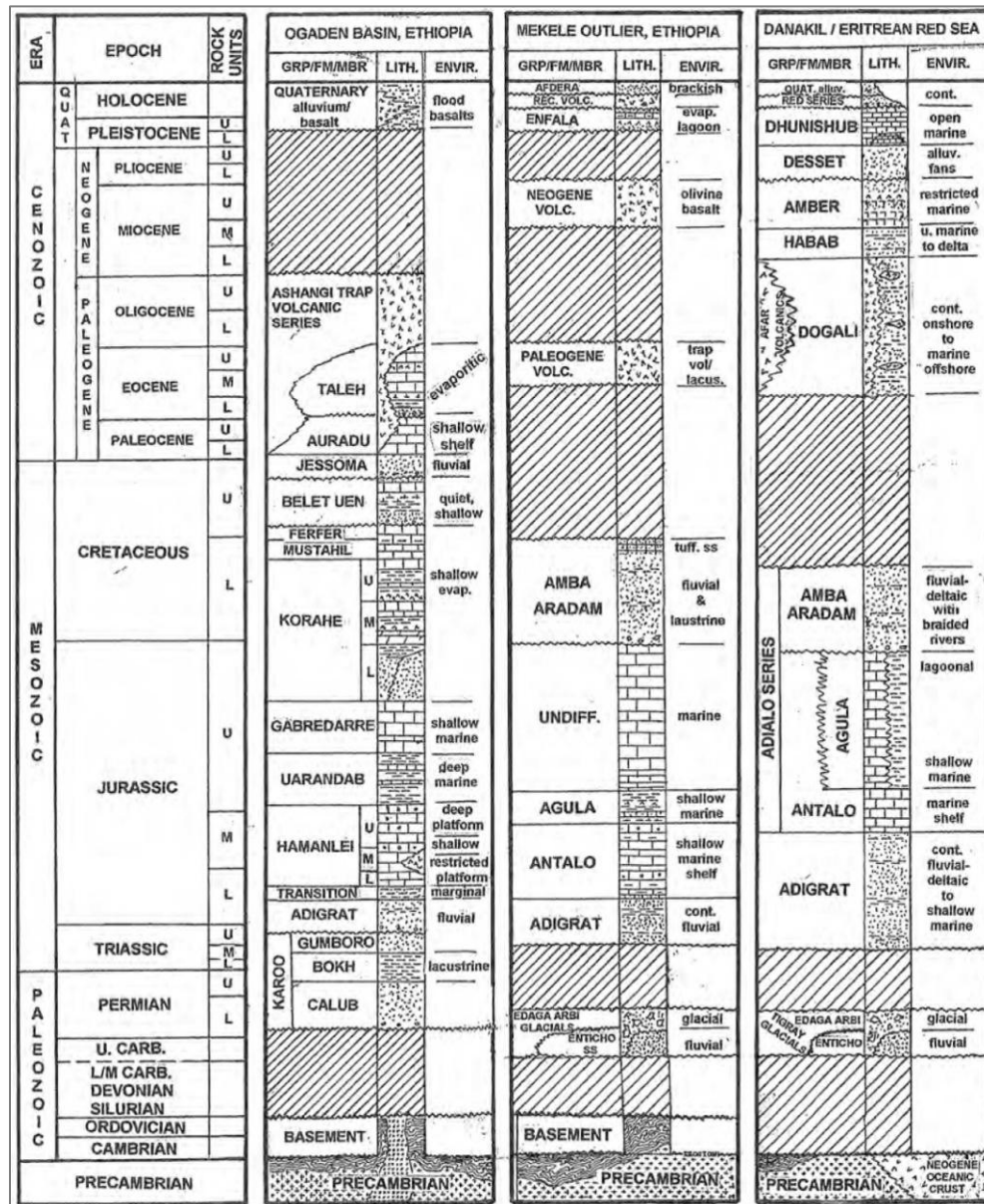


Figure 20. Stratigraphic chart of Ethiopia, Mekele Outlier, and Danakil and the Eritrean Red Sea (after BEICIP, 1985; Beyth, 1972; Gebreyohannes Habtezgi, 1989; Kazmin, 1973; Mengesha Tefera et al., 1996; Shigut Geleta, 1997; Smewing and McKeown, 1989; Tamrat Worku, 1988).

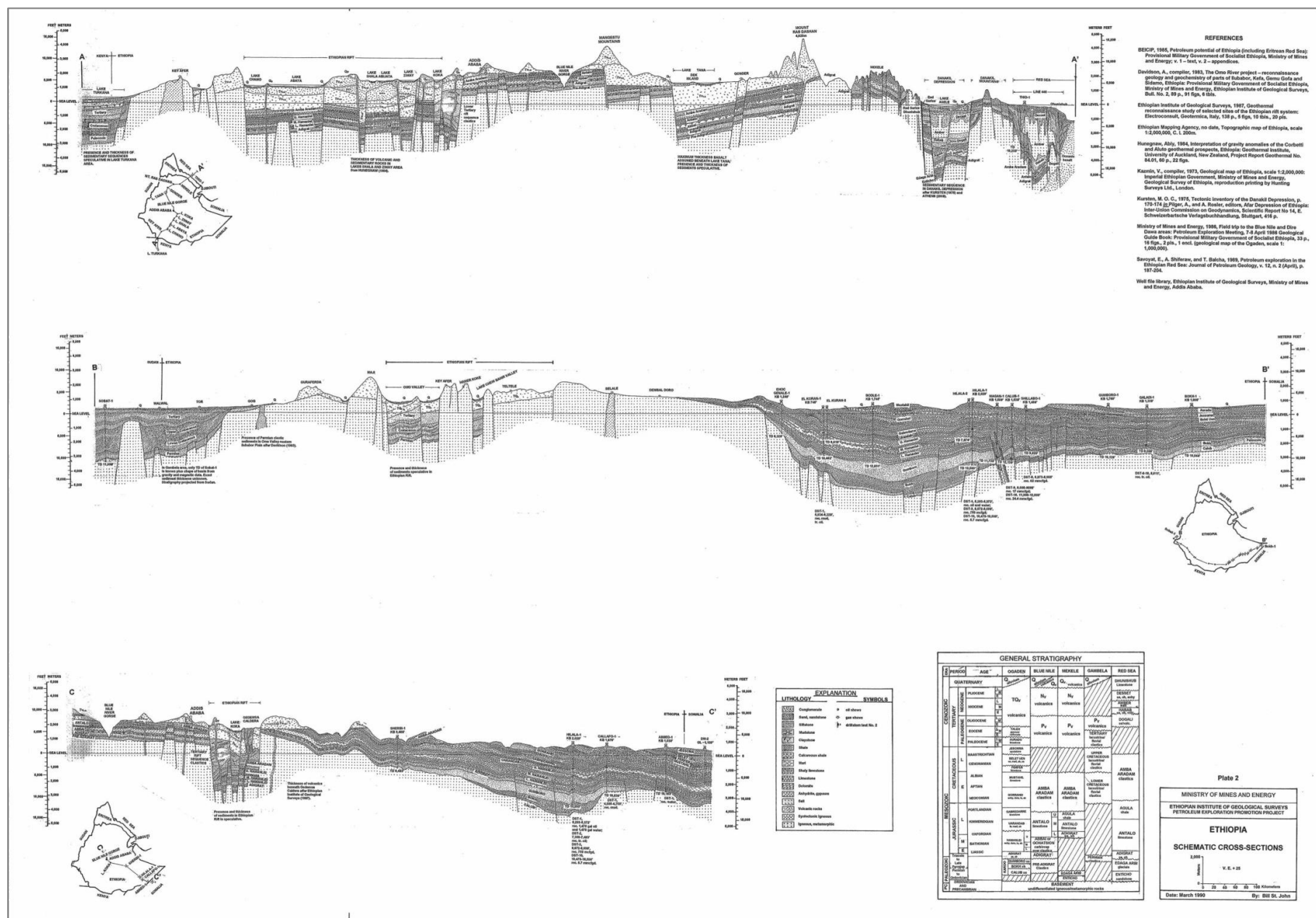


Figure 21. Schematic cross-sections, Ethiopia.

**Table 1**  
**Tertiary Volcanic Rocks**

<b>Grp/Fm/Unit Name</b>	<b>Period</b>	<b>Age Ma</b>	<b>Rock Type</b>	<b>Location</b>	<b>Character/thick (m)</b>
Ashangi/Akobo	Eocene-Oligocene	49-36	alkaline, rhyolite, dolerite, interbed. lacustrine	NW plateau, SW Ethiopia	fissural, flood, sills/dikes; to 1,000m
Jima	L. Eocene-L. Oligocene	42.7-30.5	trachybasalt, rhyolite	SW Ethiopia	100's m's
Aiba	Middle-Late Oligocene	34-28	basalt	NW plateau	200-600m
Arsi/Bale	Oligo-Miocene	34-28	basalt	SE plateau	high peaks
Makonnen	Oligo-Miocene	34.8-23.1	basalt	S and SW Ethiopia	to 700m
Alajae	Oligo-Miocene	36-13	aphyric, rhyolite, Trachyte	NW and SE plateaus	flood basalts
Tarmaber Gussa	Oligo-Miocene	26-16	basalt	Northern NW plateau	shield volcanoes
Adwa	M. Miocene		alkaline plugs and volcanics	NW plateau, SE Ethiopia	high peaks
Teltele/Surma	E. Miocene	21.2-18.2	flood basalts	SW Ethiopia	
Mabla/Arba Guracha	M. Miocene	14-10	rhyolite, ignimbrite	Afar and northern MER	flows and domes; 200m
Tarmaber/Megezez	M. Miocene	16-7		Southern NW plateau	shield volcanoes
Tulu Wolei	L. Miocene	8	trachyte basalt	western Ethiopia	shield volcanoes
Dalala	L. Miocene	8.6	felsic, rhyolite	Afar and Djibouti	interbeds detrital/lacustrine
Afar	Mio-Pliocene	8.4-0.37	stratified	Afar Depression	500-1,500m
Nazret	Mio-Pliocene	9-3	ignimbrite, tuffs, ash flows, domes	MER	200-250m
Chilalo	E. Pliocene	8-4	trachy, alkaline basalt	MER margins	shield volcanoes
Mursi/Bofa	L. Pliocene	4-1.6	flood basalts	north and central MER	80-500m
Bishoftu	Plio-Pleistocene	2.8-2	basalt	MER, south of Addis Ababa	flows and scoria cones
Dino	Pleistocene	1.5	ignimbrite, tuff, pumice, waterlain volcanics	MER	50m

The Quaternary volcanic rocks cover a large geographic range. Alkaline and trachyte basalts occur on the NW and SE plateaus. These are Pleistocene to Recent age and are abundant in the Lake Tana region. Quaternary age basalts occur in the Afar Depression and throughout the MER. Transitional basalts occur along the axis of the Afar Depression. Alkaline olivine fissural basalts are found along the western frontal range of the MER.

Table 1. Tertiary volcanic rocks.



## **History of Ethiopian Petroleum Exploration**

The exploration history of Ethiopia is complicated by its relationship with neighboring Eritrea. The territory of Eritrea, including the offshore Red Sea, has been controlled by various nations and empires over the centuries. Part, or all, of Eritrea has belonged to the Turkish Ottoman Empire, Egypt, combined Britain and Egypt, Italy, and, periodically, Ethiopia.

Following World War II, a United Nations resolution in 1952 joined Eritrea to Ethiopia via a federation which guaranteed Eritrea autonomy and democratic rights. Ethiopia immediately violated these rights, treated Eritrea as a possession, and pressured the members of Eritrea's Parliament into abolishing the Federation in 1962. Emperor Haile Selassie of Ethiopia, following the Federation of 1952, proceeded to issue exploration licenses or concessions on- and offshore Eritrea, which today would be considered in violation of international law. An uprising against the Ethiopian government, which soon evolved into a full-scale civil war, led to the overthrow of the socialist Ethiopian government of Mengistu Haile Mariam in May 1991. Eritrea became an independent state in 1993, totally separate from Ethiopia.

The following section treats the Ethiopian petroleum exploration separately from that of Eritrea.

### **Ethiopia (Table 2)**

Initial exploration for hydrocarbons in the Ethiopian Ogaden Basin was begun around 1920 by Anglo-American, the British arm of the Standard Oil Company of New Jersey. No records of this work are available.

Ethiopian petroleum exploration, excluding Eritrea and the Red Sea, has focused almost exclusively on the Ogaden Basin of southeastern Ethiopia, bordered by Somalia and Kenya. Other sedimentary areas include the Gambela Basin area of southwestern Ethiopia, the Mekele Basin in the north-central, the East African Rift area of the northern Afar region, and possibly a major basalt-covered area, the Blue Nile Basin, extending from Addis Ababa north to Mekele in Tigray, and west to ~37° East. Although little is known of the small, southern rift basins along the Kenya border, Chew Bahir, and the Omo, Kibish and Usno branches of the Turkana rift, they too may hold potential.

Following World War II, Ethiopia feared the British intended to combine the Ogaden area with Greater Somalia. Emperor Haile Selassie decided to grant an American oil company exploration rights in the area, a political act, as Britain would be forced to accept the assignment under the provisions of the Treaty of 1944. Sinclair Petroleum Company was granted a concession covering all of Ethiopia in 1945, including the Ogaden Basin. Sinclair had completed 36 party months of surface geology, 5 months of magnetometer, and 6 months of seismograph work before spudding the first well for oil ever to be drilled in Ethiopia, the Gumboro-1, on 17 May 1949. The well was abandoned 5 May 1950 at the total depth of 10,127 feet. The western, basalt-covered half of their concession was relinquished in 1951.

Sinclair had obtained poor seismic results and focused on drilling surface anticlines, copying successful efforts in Saudi Arabia. Sinclair began the deep wildcat Galadi-1 in 1953, reached total depth of 9081 ft. before plugging back to 8056 ft. in 1954 and testing, unsuccessfully, in 1955. Minor oil was recovered from the Adigrat Formation. Sinclair relinquished the remaining area on 1 March 1957.

It was reported in 1960 that Ethiopia had given an Ogaden concession of 92,675 sq. km., part of the area previously held by Sinclair, to

Gewerkschaft Elwerath of Germany. Partners with Elwerath were Royal Dutch Shell and Standard of New Jersey. Elwerath drilled the dry hole Abred-1 in 1963. Elwerath spudded the Bokh-1 in November 1964 near the Somali border. It reached total depth of 10,044 feet in July 1965 as a dry hole. Seismic and other work, but no drilling, was performed during 1967. Elwerath relinquished their concession on 31 March 1968.

Tenneco obtained a large Ogaden Basin concession from the Ethiopian government in September 1969 and began an airborne magnetometer survey over 10,000 sq. mi. of the block. Tenneco increased the size of its block to 102,628 sq. mi. during 1970. Tenneco, with partners Texaco and Chevron, first drilled the El Kuran-1, which had oil and gas shows. The offsetting El Kuran-2 was a dry hole. The subsequent Calub-1 was a gas discovery (1973). The Hilala-1 tested oil in what was believed to be a commercial discovery, while 5 other wildcats, Magan-1, Callafo-1, Bodle-1, Hilala-1 and Gherbi-1 were dry holes. Subsequent step-outs to the Hilala-1 were considered unsuccessful. The Tenneco group withdrew from Ethiopia in 1976 and relinquished its concession in 1977.

Whitestone and Louisiana Land and Exploration, Inc. (LL&E) obtained an Ogaden concession in 1973. They conducted photogeology, surface geology, and gravity and aeromagnetic surveys but withdrew without drilling in early 1977.

The Voyager Group, composed of the companies Voyager Petroleum Ltd, Polar Bear International Petroleum Ltd., and Cardinal Petroleum Company did photogeology and gravity, but it relinquished its Ogaden Basin permit in 1975 without drilling.

Emperor Haile Selassie was deposed by a military coup in September 1974, resulting in a slowdown in exploration activity. All western petroleum exploration companies operating in Ethiopia relinquished their holdings in 1977 because of the political situation.

In 1978, the Ethiopian government reached an agreement with the Soviet government under which the Soviets offered technical and financial assistance plus participation in exploration and development of petroleum in Ethiopia. The operating group became known as the Soviet Petroleum Exploration Expedition (SPEE). The focal area was the Ogaden Basin, specifically, the Calub Saddle, where 9 wells were drilled in the Calub Gas Field plus 9 nearby exploration wells. The Calub Gas Field wells were drilled and logged, but not cased or completed. The exploration wells were all dry holes. The Soviets withdrew when the Mengistu government was overthrown in 1991.

Chevron acquired 2 blocks with geophysical options in 1982, comprising 30,743 sq. km. in the Gambela area of western Ethiopia, adjacent to its exploration area in Sudan. Chevron ran an aeromagnetic survey in 1982 and a gravity survey in early 1983. Chevron dropped the options on 1 July 1983 after drilling a dry hole on their adjacent Sudan acreage.

The AAPG reported, (1984, v. 69, n. 10, p.1529):

According to Petroconsultants, the Ethiopian government is involved in a joint venture with the USSR. The work is being done in the southeastern part of the country in the region where Tenneco made a gas discovery in 1973.

In 1983, the government inaugurated a \$9.5 million exploration program to promote petroleum industry activity. Funds are being made available through a \$7.0 million loan from the World Bank. The balance is covered by a grant from the United Nations. It is anticipated that the program will include the following: a national oil company will be set up within the Ministry of Mines; a team of legal consultants in Washington will draft a new petroleum law, and a group of accounting consultants in London will rewrite the tax regulations; the French consulting firm, BEICIP, will review all existing geologic and geophysical data in the country; an additional 1000 km of seismic lines will be shot in the Red Sea; a promotion report will be offered to interested

companies in 1984 to highlight areas of interest; and geothermal reconnaissance studies will begin in 1984.

No activity was reported for 1985-1989. Ethiopia Hunt Oil Company (EHOC) acquired a Production Sharing Agreement (PSA) covering 44,000 sq. km. in the Ogaden Basin effective 27 July 1990. Following extensive field geology studies and seismic, EHOC spudded in 1995 the Genale-1, which was a dry hole. EHOC dropped the PSA in 1997.

Maxus Energy obtained a PSA covering 110,798 sq. km. in the easternmost Ogaden in 1990, bordered to the north and south by Somalia. Maxus conducted extensive field geology and seismic, with partners Arco and Deminex, but eventually elected to drop the block without drilling. It might be noted that Maxus operations were plagued with problems believed to result from the influence of nearby lawless Somalia:

1. Helicopter crash with pilot and gravity technician killed (possibly shot down?);
2. Four guards on gravity survey killed, weapons taken;
3. Guard riding on bulldozer shot and killed;
4. Local shot and killed by EPRDF at meeting in Aware; one camel paid to family in compensation;
5. Local given unauthorized ride by Western Geophysical driver; killed while jumping off moving vehicle; Maxus paid compensation;
6. EPRDF guards for seismic crew spotted bandits robbing local truck — one local killed, one EPRDF wounded.
7. Battle between two villages over Maxus/Western jobs resulted in one killed;
8. Guard cleaning gun in camp accidentally shot and wounded local laborer;
9. Incident of ~50 shots and one RPG round fired at Western crew during unauthorized area move.

The eastern Ogaden is populated by ethnic Somalis, many of whom are members of the Ogaden National Liberation Front (ONLF), traditionally hostile to the Ethiopian government. The ONLF is believed to be behind the attack on the Calub Gas Field in which 74 Ethiopian and Chinese oil workers were killed in 2007 (The Economist, February 7<sup>th</sup> 2009, p. 41).

As of May 2009, virtually all hydrocarbon potential areas in Ethiopia have been leased ([Figure 22](#)) via Production sharing Agreements. Petronas holds 8 blocks in the Ogaden Basin and one over the Gambeta area. Additional Ogaden PSA holders include Africa Oil Corporation with 4 blocks, SW Energy with three, Pexco with 3 and Titan Resources with 5. Afar Exploration Company, LLC. acquired a PSA of 6.4 million acres in the Danakil Depression adjacent to the Eritrean border while TransGlobal Petroleum holds the remainder of the Afar rift area. CalValley holds 2 blocks along the western Ethiopia-Sudan border. The deeper portion of the Blue Nile Basin is held by Titan Resources with 4 blocks and Falcon Petroleum with 3. Two blocks, AB8 and AB9, remain open in the Blue Nile Basin.

### **Eritrea** ([Table 3](#))

The Red Sea off Eritrea was long known for its oil seeps along the coast near Massawa and offshore on the Dahlak Islands. An Italian company, Societa Mineraria Dell Africa Orientale, did field work and drilled the dry Bu El Issar-1 in 1921. The Italian firm Agip Mineraria explored the Dahlak Islands 1935-1940; finding oil shows and proving the presence of an evaporite basin. Prior to WWII, the Suri and Adal prospects had been drilled, unsuccessfully, on Dahlak Island. Agip had also proved the existence of thick hydrocarbon-bearing sediments offshore Sudan to the north, suggesting the same prospective section occur offshore Eritrea. Operations ceased during World War II.

During 1953, Ethiopia confirmed the concession assigned to AGIP in Eritrea before the war. The area covered the littoral area from Massawa to the Sudan border plus the offshore Dahlak Islands. Eritrea held the status of home rule but was federated with Ethiopia. AGIP began exploration activity in December 1958 but drilled no additional wells before leaving. The Yugoslavian NAFTAPLIN, under contract to the Ethiopian government, conducted geological, gravity and magnetic investigations in coastal Eritrea and in the onshore Danakil Alps from December 1958 through 1960.

Mobil applied for and in February 1963 was granted, 10,000 sq. mi. in the Red Sea off Eritrea, including a narrow strip of land along the coast. In November 1963, Gulf was granted a similar concession of approximately the same size off southern Eritrea. Both Mobil and Gulf did seismic work during 1964-1965. Esso Exploration Ethiopia joined Mobil in its block during 1966.

Mobil spudded the Red Sea Amber-1 which was declared a dry hole at a total depth of 11,671 feet. The Amber had penetrated approximately 11,000 feet of salt and reached total depth in metamorphic rocks. In 1969, Mobil drilled the unsuccessful B-1 well east of the Amber location. The subsequent Mobil C-1 well encountered pressured gas in a sandstone reservoir at 9874ft, either below the salt or within the salt near its base. The well blew out for 55 days before it could be logged. A relief well, the C-1 A, was spudded at year-end 1969. The C-1 A was abandoned at 5600ft when the C-1 blowout died. Mobil/Esso relinquished 25% of their block 1 January 1970. Mobil was seeking liquid hydrocarbons, and based on the presence of gas only in the C-1 well, and the high geothermal gradient present, concluded the area was gas-prone and dropped their permit by year-end 1970.

During 1966, Baruch-Foster obtained from the Ethiopian government a petroleum concession that was 60% offshore and bordered Gulf's area to the south. It was considered "protective acreage" in the event Gulf was successful.

Following seismic surveys, Gulf spudded the Dhunishub-1. It was declared a dry hole at a total depth of 12,688ft. Gulf spudded the Secca Fawn- 1X, which reached total depth of 11,034ft and was declared a dry hole. Gulf relinquished 30% of its concession at year-end 1969 and the remainder during 1970. Baruch-Foster relinquished its Red Sea acreage during 1970.

Ethiopian Oil/Equitex Petroleum, operating as the Ethiopian Oil Corporation (EOC), received a 2955-sq. mi. on- and offshore block just southwest of the Red Sea Dahlak Islands. In 1971, Ethiopian Oil/Equitex Petroleum applied for 4 blocks totaling about 4115 sq. mi. on- and offshore Massawa and the southern Red Sea of Eritrea, which they never received. General American Oil (GAO) acquired the EOC blocks via farm- in, drilled 2 dry holes during 1973, the J-1 and MN-1, and relinquished the Red Sea blocks in 1974.

The Voyager Group acquired 1 onshore and 2 offshore Eritrea blocks in 1974. Siebens applied for, but never received, part of the relinquished Baruch-Foster area.

Shell Oil Company obtained an offshore Eritrea oil concession in July 1974, and conducted a reconnaissance seismic survey over the area. Shell spudded the offshore Thio-1 19 December 1976. It was declared a dry hole at TD 10,233ft in 1977 and Shell withdrew from the concession.



Eritrea voided all existing contracts when it became independent in 1993. Several small companies have since held licenses; however, the only serious exploration since independence has been by Anadarko which drilled the unsuccessful wells Bulissar-1, Du RigRig-1 and Edd-1.

## **Source-Rock Analysis**

### **Ogaden Basin**

Following extensive literature and oil company reports, research, and sample and core analyses, Shigut (1997) concluded:

1. The Uarandab Shale Formation is a good source rock with oil-prone organic material. It is relatively mature in the western Ogaden and marginally immature at the top in the eastern Ogaden;
2. The uppermost beds of the Upper Hamanlei carbonates are a potential source rock in the eastern Ogaden and in the Mandera-Lugh Basin having oil and/or gas-prone organic matter;
3. The Transition Zone between the Lower Hamanlei and Adigrat Formation has good source rock potential;
4. The Bokh shale is a good gas source.

### **Blue Nile Basin and Mekele Outlier**

The Agula Shale above the Antalo limestone is believed to have source potential (BEICIP, 1985). The Agula Shale is believed equivalent to the Uarandab Shale and uppermost Hamanlei of the Ogaden Basin. The Antalo limestone is a lateral equivalent to the Upper and Middle Hamanlei Limestone of the Ogaden Basin.

Assuming the sediments in the Blue Nile Basin thicken into the gravity low as suggested in the Bouguer gravity map ([Figure 5](#)) and structural fabric map ([Figure 23](#)), source rocks equivalent to those in the Ogaden Basin should exist. Although there is no direct evidence that Karoo-equivalent rocks occur in the Blue Nile Basin, it is known that Upper Carboniferous-Permian clastic glacial deposits, possible reservoir rocks, are present.

### **Mandera-Luah Basin**

In 1987, Amoco drilled core-holes into the Tarbaj oil seep in northern Kenya, within the Mandera-Lugh Basin depression. The “oil” was determined to be biodegraded asphalt that had reached a good maturation stage, probably towards the end of the oil window. The host sediment is a fluvial sandstone whereas the source rock is marine; both are of probable Early Jurassic age.

Shigut (1997) concluded that the uppermost beds of the Upper Hamanlei carbonates are a potential source rock containing hydrocarbon-prone organic matter within the Ethiopian portion of the Mandera-Lugh Basin.

### **Gambela Basin**

The Gambela Basin is an extension of the Sudan Melut Basin, where the source rocks are Cretaceous lacustrine shales.

## **Afar Depression**

The reported gas and condensate blowout from the potash drillhole and observed oily patina on gravel roads indicate the presence of a hydrocarbon source rock. Any source rock is probably within the Desset alluvial/lacustrine clastic sediments.

## **Exploration Plays**

### **Ogaden Basin**

There are three proven hydrocarbon reservoirs present in the Ogaden Basin: the Karoo Group Permian age Calub Sandstone, the Upper Triassic - Lower Jurassic Adigrat Sandstone, and the Lower-Middle Jurassic Hamanlei carbonates. Source rocks include the Permian-Triassic Bokh Shale and the Upper Jurassic Uarandab Shale. Hydrocarbons have been produced from closed structures and possibly from stratigraphically trapped porous zones within the Jurassic limestones.

### **Blue Nile Basin and Mekele Outlier**

BEICIP (1985) concluded that the Blue Nile and Mekele areas are not true sedimentary basins but rather form a single east-dipping monocline. They stated that the Upper Jurassic and Cretaceous are missing in the west, thin in the center, and have minimal burial in the east, making it unlikely for hydrocarbon generation, migration and entrapment.

The Bouguer Gravity Map ([Figure 5](#)) and postulated sediment thicknesses shown on the Structural Fabric Map ([Figure 23](#)) suggest this is not the case. The sediments appear to thicken significantly toward the eastern margin of the basin. Adigrat Sandstone and younger reservoir rocks are known to be present. Potential source rocks are also present, but maturity will depend upon depth of burial, which in turn may depend upon increased thickness of the sedimentary section.

### **Mandera-Lugh Basin**

The Mandera-Lugh extends through much of southern Ethiopia, Kenya, and Somalia. The area along the Ethiopia-Kenya border is filled with up to 8000-10,000m of Karoo and post-Karoo fluvial-continental, lacustrine, and marine sediments. From the Middle to Late Jurassic, the basin formed a slowly subsiding platform basin. Domal structures and associated fault traps are present in the border area. Sandstone drapes and carbonate reefs may have formed over paleotopographic highs.

Undrilled potential for hydrocarbons exists in Jurassic sandstone and carbonate grainstone reservoir rocks, as well as sandstones in the Karoo Group Mansa Guda Formation. Mature Jurassic marine source beds are identified along the border area. Evaporite beds or marine shales present would provide seal.

## **Gambela Basin**

The Gambela Basin of southwestern Ethiopia is the southeast extension of the Melut Basin of eastern Sudan. Melut is a rift basin containing thick nonmarine clastic sediments of Jurassic to Early Cretaceous and Tertiary age. The major oil discovery to date in the Melut Basin is the Great Palogue Field. There are over a dozen lesser discoveries. Source rocks are the Lower Cretaceous lacustrine shales, and reservoir rocks are in the Upper Cretaceous and Paleogene sandstones. Sealing formations are also Late Cretaceous to Paleogene in age. Oil/gas accumulations have occurred in structural anticlines and antithetic normal fault-blocks. Prospects in the Gambela Basin are expected to be similar.

Notes taken from a conversation with Chevron Overseas Africa-Middle East Exploration Manager (1990) state:

1. The Gambela extension of Sudan's Melut Basin was shown by gravity and magnetic data to be shallow, restricted in lateral extent and complicated by near-surface volcanics;
2. As the Gambela concession was taken as protective acreage prior to the drilling of the Sudan Sobot-1, and Sobot-1 was a dry hole, the rationale of holding that concession evaporated.

## **Afar Depression**

The Afar Depression is a Tertiary rift basin filled with evaporites similar to those cropping out in the nearby Dallol Mountains. Prior to WWII, an Italian firm held a potash mining permit in the area and drilled numerous core holes, one of which reportedly suffered a blowout of gas and liquid hydrocarbons. Gravel-topped roadways in the immediate area of the blowout retain an oily patina. Gravity indicates the presence of subsurface salt domes. Prospects should occur in sands over the salt domes or in truncated sand beds on the flanks of the salt domes.

## **Southern Chew Bahir Rift and Extensions of the Kenyan Turkana Rift: Kibish. Omo and Usno Branches**

Little is known of the subsurface of these areas including the thickness or age of sediments. Mengesha Tefera (1996) does note a total of 1190m of Plio-Pleistocene Omo Group sediments in the Ethiopian branches of the Turkana Rift. Shell Oil Company recovered hydrocarbons from a well drilled to the south in Kenya along the western flank of Lake Turkana.

## **Summary**

The geology presented is focused on tectonics and structure, sedimentary stratigraphy, and hydrocarbon potential. Mineral potential and host "hard rocks" are not considered.

The geologic history of Ethiopia traces back to Precambrian Gondwana, the ancient supercontinent. Precambrian rocks include a variety of igneous, volcanic, and sedimentary deposits which have been metamorphosed and intruded to different degrees. Continental migration and breakup during the Paleozoic and Early Mesozoic established fracture zones, while ancient plumes forced surface highs and intervening lows. Separation of Laurentia to the far west and breakup of Gondwana into West and East Gondwana during the Middle Jurassic, accompanied by

the evolving Tethys Sea, changed sedimentary deposition from eroded continental clastics to a transgressive sea moving inland, depositing marine clastic sediments, which in turn would be covered by carbonate and evaporite layers. The interval, Late Carboniferous to Cretaceous-Eocene, was a time of transgression/regression cycles, and predominantly marine sedimentation.

Preliminary sag and rifting between northeast Africa and the Arabian Plate, and between the Arabian Plate and northern Somalia, developed during the Oligocene. Rifts formed in the Red Sea and Gulf of Aden areas. Separation began in the late Oligocene. Rifting within the East Africa Rift System may have originated as early as Eocene, but the Oligocene is marked by initial volcanic activity and is generally accepted as the beginning rift period.

The Miocene marked the end of the Tethys Sea as the collision between Africa/Arabia and southern Europe climaxed and the Mediterranean became closed at both ends. Oceanic crust developed in the Red Sea and in the Gulf of Aden. Miocene volcanic flows covered extensive areas within the East African Rift System, from Eritrea south to Mozambique, including the Main Ethiopian Rift.

Volcanic activity in the rift areas continued through the Pliocene- Quaternary, and until today. The Cenozoic is considered a period of predominantly volcanic activity and deposition with minor amounts of interfingering sediments, mostly lacustrine or shallow marine, including major evaporite deposits.

There have been many shows of oil and/or gas, predominantly gas, in the wells drilled in Ethiopia and surrounding areas. The area is known to be subject to high heat flow from the plumes generating the volcanic extrusions; so gas is to be expected.

The sedimentary section contains numerous documented source rocks: the Permian-Triassic Bokh Shale, the Lower Jurassic Transition Zone, the Middle Jurassic Upper Hamanlei and Antalo carbonates, the Upper Jurassic Uarandab and Agua shales, and possibly Miocene-Pliocene sediments in the Afar Depression and offshore Eritrea.

Reservoir sections occur in all the Ethiopia basins, both in sandstones and limestones.

Exploration plays within Ethiopia include closed structures and domes, and uplifted fault blocks, within Karoo Group Calub sandstone, Triassic- Jurassic Adigrat Sandstone, Jurassic Hamanlei Limestone, and possibly Miocene-Pliocene sandstones. Porosity pinchouts also may occur in the limestones.



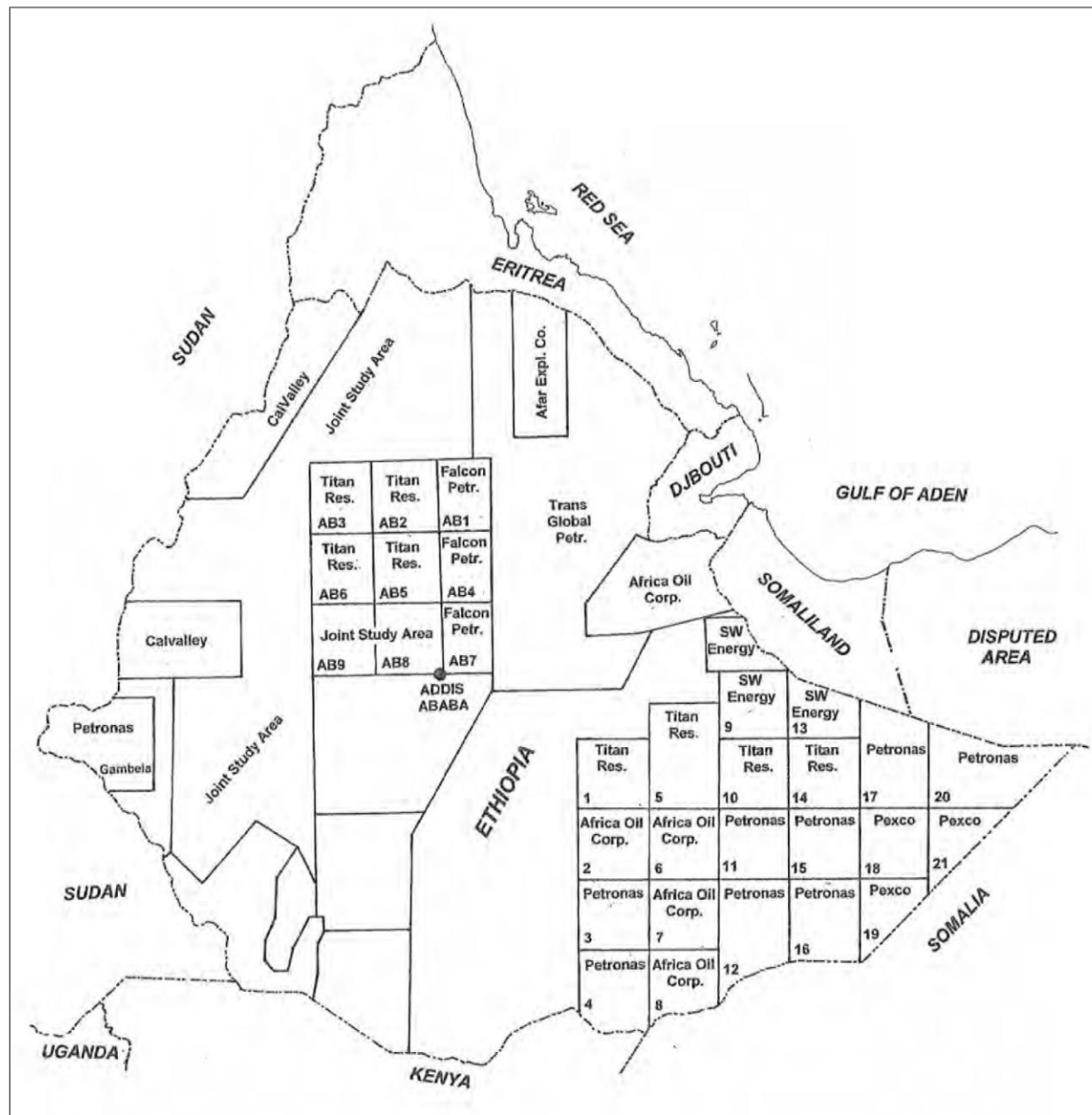


Figure 22. Production Sharing Agreements (PSA) blocks in Ethiopia (as of May, 2009).





Table 2  
EXPLORATION WELLS DRILLED IN ETHIOPIA

(majority of well data from <i>BEICIP</i> , 1985)					
Well	Operator	Total Location	Year	Depth	Results
Gumboro-1	Sinclair	06° 55' 12" N 45° 48' 49" E	1950	10,127'	P&A
XE-3	Sinclair	07° 34' 00" N 46° 33' 30" E	1954	1,010'	Strat. test, P&A
Galadi-1	Sinclair	07° 01' 15" N 46° 25' E	1955	9,086'	P&A with oil/gas shows
XC-3	Sinclair	06° 29' 20" N 46° 17' 00" E	1955	3,996'	Strat. test, P&A
XC-4	Sinclair	06° 20' 30" N 45° 44' 30" E	1955	3,915'	Strat. test, P&A
XD-2	Sinclair	07° 09' 50" N 46° 57' 00" E	1955	230'	Strat. test, P&A
XD-2A	Sinclair	07° 10' 00" N 46° 57' 00" E	1955	1,289'	Strat. test, P&A
XE-4	Sinclair	07° 25' 00" N 46° 01' 10" E	1955	3,592'	Strat. test, P&A
XE-5	Sinclair	07° 16' 00" N 45° 29' 00" E	1955	2,983'	Strat. test, P&A
XF-5	Sinclair	07° 49' 00" N 45° 36' 45" E	1955	4,364'	Strat. test, P&A
XDE-1	Sinclair	07° 30' 10" N 46° 41' 00" E	1956	3,600'	Strat. test, P&A
XE-3A	Sinclair	07° 34' 00" N 46° 33' 30" E	1956	5,989'	Strat. test, P&A
XEF-1	Sinclair	07° 29' 40" N 45° 41' 20" E	1956	5,320'	Strat. test, P&A
GX-2	Sinclair	07° 03' 20" N 46° 23' 45" E	1956	317'	Strat. test, P&A
GX-3	Sinclair	07° 03' 20" N 46° 22' 10" E	1956	3,505'	Strat. test, P&A
GX-4	Sinclair	07° 03' 50" N 46° 23' 30" E	1956	4,519'	Strat. test, P&A
XEF-2	Sinclair	07° 58' 15" N 47° 05' 46" E	1956	5,610'	Strat. test, P&A
Abred-1	Elwerath	05° 30' 02" N 45° 14' 55" E	1963	10,185'	P&A
El Kuran-1	Tenneco	04° 41' 33" N 42° 05' 13" E	1972	10,462'	P&A with oil/gas shows
El Kuran-2	Tenneco	04° 43' 14" N 42° 05' 04" E	1972	6,610'	P&A
Callafo-1	Tenneco	05° 39' 11" N 44° 20' 59" E	1973	10,636'	P&A
Magan-1	Tenneco	06° 06' 11" N 44° 17' 41" E	1973	11,730'	P&A with oil/gas shows
Calub-1	Tenneco	06° 09' 02" N 44° 31' 09" E	1973	12,139'	Gas discovery
Bodle-1	Tenneco	05° 08' 05" N 42° 40' 05" E	1974	12,831'	P&A
Gherbi-1	Tenneco	07° 23' 55" N 41° 26' 00" E	1974	6,483'	P&A
Hilala-1	Tenneco	06° 06' 00" N 43° 54' 05" E	1974	13,503'	Oil/gas discovery
Shillabo-1	SPEE	06° 11' 00" N 44° 44' 00" E	1983	9,514'	P&A
Hilala-2	SPEE	06° 05' 00" N 43° 51' 00" E	1983	7,874'	P&A
Hilala-3	SPEE	not available	1984	7,874'	P&A
South Calub-1	SPEE	not available	1985	5,778'	P&A
FAf-1	SPEE	not available	1985	3,446m	P&A
Magan-2	SPEE	not available	1987	4,306m	P&A
Calub-2	SPEE	06° 09' 04" N 44° 30' 56" E	1987	3,732m	Gas well
Tulli-1	SPEE	not available	1987	4,010m	P&A
Calub-3	SPEE	06° 10' 06" N 44° 31' 55" E	1988	3,690m	Gas well
Calub-4	SPEE	06° 10' 12" N 44° 31' 02" E	1989	3,712m	Gas well
Calub-5	SPEE	06° 09' 12" N 44° 32' 52" E	1989	3,690m	Gas well
Calub-6	SPEE	not available	1989	3,805m	Gas well
Calub-7	SPEE	not available	1989	3,724m	Gas well
Calub-8	SPEE	not available	1991	3,714m	Gas well
Calub-9	SPEE	not available	1990	3,702m	Gas well
Shillabo-2	SPEE	not available	1990	3,425m	P&A
Genale-1	EHOC	not available	1995	1,928m	P&A

(several of the Calub wells are injection wells)

Table 2. Exploration wells drilled in Ethiopia.

Table 3

**EXPLORATION WELLS DRILLED IN THE ERITREAN (FORMERLY  
ETHIOPIAN) RED SEA**

(majority of well data from BEICIP, 1986)

<u>Well</u>	<u>Operator</u>	<u>Year</u>	<u>Total Depth</u>	<u>Results</u>
Bu El Issar-1	Societa Mineraria Dell' Africa Oriental	1921	160m	P&A
Dahlac-1	AGIP	1936	170m	P&A
Suri-1	AGIP	1936- 1940	1,700m	P&A with oil shows
Suri-2	AGIP	1937- 1938	425m	P&A
Suri-3	AGIP	1937- 1938	668m	P&A
Suri-4	AGIP	1938	541m	P&A
Suri-5	AGIP	1937- 1938	312m	P&A
Suri-6	AGIP	1938	559m	P&A
Suri-7	AGIP	1939- 1940	2,503m	P&A
Adal-1	AGIP	1939	804m	P&A with oil shows
Adal-2	AGIP	1939- 1940	2,475m	P&A with oil shows
Ras Shoke-1	AGIP	1936- 1940	603m	P&A
Amber-1	Mobil	1966	11,671'	P&A
Dhunishub-1	Gulf	1966	12,688'	P&A with oil/gas shows
B-1	Mobil	1969	9,726'	P&A
Secca Fawn-1	Gulf	1969	11,034'	P&A with gas shows
C-1	Mobil	1970	9,874'	P&A with gas blowout
C-1A	Mobil	1970	5,600'	Plugged when C-1 died
J-1	EOC/GAO	1973	10,291'	P&A
MN-1	EOC/GAO	1973	9,420'	P&A
Thio-1	Shell	1977	10,233'	P&A
Bulissar-1	Anadarko	1998	4,200m	P&A, with oil shows in shale
Du RigRig-1	Anadarko	1998	2,000m	P&A
Edd-1	Anadarko	1999	3,262m	P&A
Chita-1	Perenco	2005	3,345m	P&A

Table 3. Exploration wells drilled in the Eritrean (formerly Ethiopian) Red Sea.



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(Note: Ethiopian custom is to have one name, the second name being that of the father; therefore, Shigut is the authors name and Geleta is the name of Shigut's father. Some Ethiopians also list a third name, that of the grandfather (if it is politically expedient to do so).

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