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Ethiopia on the Cusp

A guest article by **Jane Whaley, Editor in Chief, GEO ExPro Magazine**

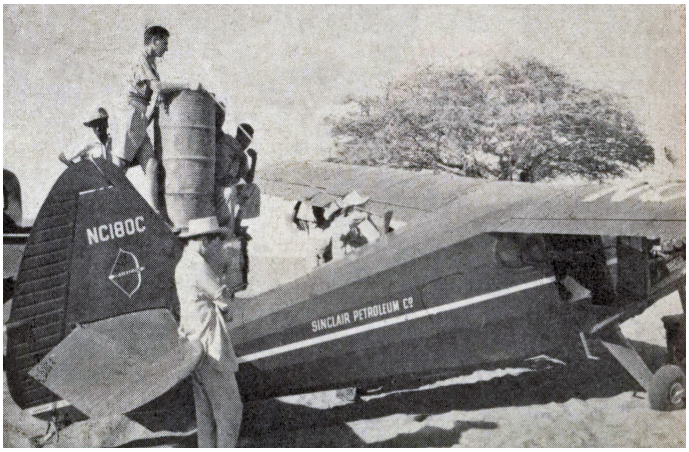
GEO ExPro GEOSCIENCE & TECHNOLOGY EXPLAINED

A country that has long held fascination in the west, Ethiopia is rich in history and culture as well as minerals, but after 100 years of hydrocarbon exploration it is only now close to commercial oil and gas production.

Ethiopia is situated in the Horn of Africa at the northern end of the East African Rift System (EARS), a proven hydrocarbon hunting ground, and is located near successful oil and gas provinces in Yemen, Kenya and South Sudan - but has yet to yield similar riches. One of the fastest growing economies in the world, with a population of over 100 million, Ethiopia has a growing critical need for power supplies, given that 50% of the population and 25% of the health clinics lack access to electricity. While some power is supplied by hydropower, the rest is dependent on imported coal and oil. The production of proven oil and gas reserves and the discovery of new resources are national imperatives, along with development of other energy sources.

Century of Exploration History

East African O&G exploration actually began in Ethiopia, in 1921, when Anglo American's expedition to 'Abyssinia' arrived and conducted several local geological surveys amid controversy and intrigue over who held and could award the concessions. The first systematic petroleum exploration was by AGIP in the late 1930s, predominantly in the northern and eastern Ogaden, before WWII disrupted exploration. In 1945 Sinclair Petroleum obtained an exploration license covering all Ethiopia, undertaking surface mapping before spudding the first oil well in the country, Gumboro-1, on 17 May 1949, which proved to be dry. The company drilled a series of 'structural' holes looking for regional structures – a technique successful in Saudi Arabia but which failed to identify any Ghawar-type structures in the Ogaden Basin. The 1955 Galadi well had encouraging oil shows in the Jurassic and Triassic.



Sinclair supply plane, 1948.

After Sinclair left in 1956, more companies entered the arena and 43 wells were drilled in the Ogaden Basin between 1950 and 1995, the high point being the Tenneco's discovery of the country's first two fields: Calub (1973) and Hilala (1974). There were also good oil shows in 1972 in the El Kuran wells in the south-west part of the Ogaden Basin.

The military coup in 1974 which overthrew Emperor Haile Selassie was followed by years dominated by civil unrest and war with neighbouring Somalia, although extensive geophysical prospecting and appraisal drilling was carried out by Russian organisations. US companies Hunt Oil and Maxus arrived in 1990 and explored for several years, with Hunt drilling the Ganale-1 well in the SW Ogaden. As the oil

price surged early in the 21st century, interest in Ethiopia revived. Petronas began work in the Gambela Basin in 2003, later expanding into Ogaden, and by 2009 it was reported that virtually all areas thought to have potential had been leased; over 30 blocks, with up to ten companies involved. At the time of writing at least five companies have leases in the country, predominantly in the Ogaden Basin.

Rifting Dominates Sedimentation

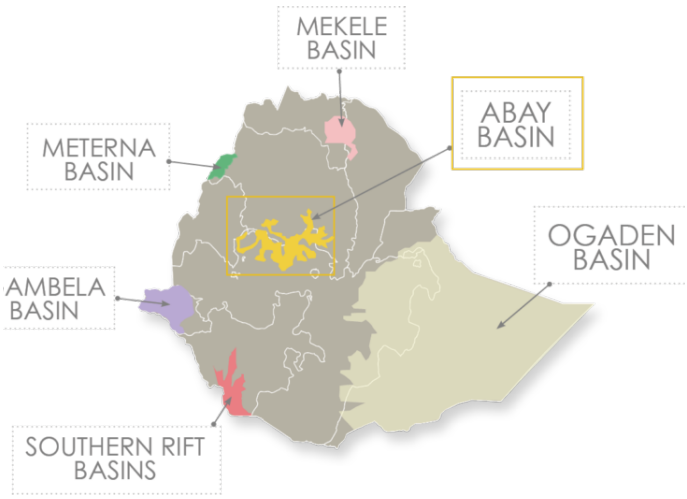
Ethiopia is underlain at depth by Precambrian rocks of the Afro-Arabian Shield, much of which are covered by Permian to Paleogene glacial and marine sediments, with some Tertiary volcanics. The Main Ethiopian rift (MER), a segment of the EARS, is an active continental rift zone dominated by extensional faulting running north-east to south-west through the centre of the country. It was initiated in Early Miocene times, about 20 million years ago.

To the south and east of the MER lies the Ogaden Basin, consisting of Jurassic, Cretaceous and Tertiary sedimentary rocks, with Precambrian basement exposed on the uplifted northern and western margins. Extensional rifting from Late Palaeozoic to early Triassic developed a triple-junction rift system in East Africa, including the Ogaden system region, into which were deposited thick layers of continental sediments.

View an accompanying diagram here.

The Geological Survey of Ethiopia have outlined six sedimentary basins covering a significant proportion of the country. These are the Ogaden, Abay (Blue Nile), Mekele, Metema, Gambela and Southern Rift basins.

Location of basins with hydrocarbon potential in Ethiopia. Source: Ministry of Mines and Petroleum.



Ogaden Basin Petroleum Systems

Occupying an area of about 350,000 km^2 in the south-eastern part of the country and extending into Somalia and Kenya, the Ogaden is by far the largest and the best explored of Ethiopia's basins. It developed as part of a Permo-Triassic Karoo Rift triple-junction overlain by a Jurassic – Cretaceous sag basin, with up to 10,000m of Palaeozoic to Tertiary clastic and thick marine carbonate fill. The basin is divided into eastern and western sub-basins by the north-west to south-east trending Marda Fault.

Several proven and potential source rocks have been identified. The gas-condensate in the Calub and Hilala fields is sourced from the thick Permo-Triassic Bokh lacustrine shale, which rests unconformably on Precambrian basement. Black argillaceous marls and shales interbedded in the evaporitic and carbonate Jurassic Middle Hamanlei Formation and the Transition Series leading into the Lower Hamanlei are also thought to be potential hydrocarbon sources. The Late Jurassic Uarandab Formation, comprising up to 200m of marl, shale and interbedded mudstone, is a proven source rock with TOC values of ~3% in the Somali Ogaden Basin. It is thought to be relatively mature in the western Ogaden and marginally immature in the east.

View an accompanying diagram here.

Good potential reservoirs in the Ogaden Basin include the Triassic Adigrat Sandstone, the basal unit of the Mesozoic transgression across the Horn of Africa and the main reservoir unit in the Calub and Hilala fields. It consists of over 100m of sandstones with intercalations of shales, dolomites and marls and has good permeability and porosity. It underlies the Lower-Middle Jurassic Hamanlei Formation, the upper part of which yielded 32° oil in Hilala-1. The basal Permian Calub Formation, composed of fluvial medium- to coarse-grained sandstones, is also a reservoir in the Calub field. These reservoirs are expected to be sealed predominantly within the same range of sediments.

Source and reservoir rocks can be closely associated in the Ogaden Basin in areas where faults provide for abrupt facies changes between horst and graben areas, so lateral migration, possibly initiated by palaeo uplift, may help source reservoirs. There is potential across the basin for a variety of both structural and stratigraphic trapping mechanisms, including

low-amplitude anticlines, pinch-outs, fault blocks, oolitic limestones, dolomite lenses and carbonate reefs.

Understanding the age, rifting pattern and basin development in the Ogaden Basin is crucial. To date, only the Triassic-Jurassic plays have really been investigated and the deeper Karoo rifting is poorly understood, both structurally and stratigraphically, as are the Jurassic rifts interpreted in the Adigala area on the northern basin margin.

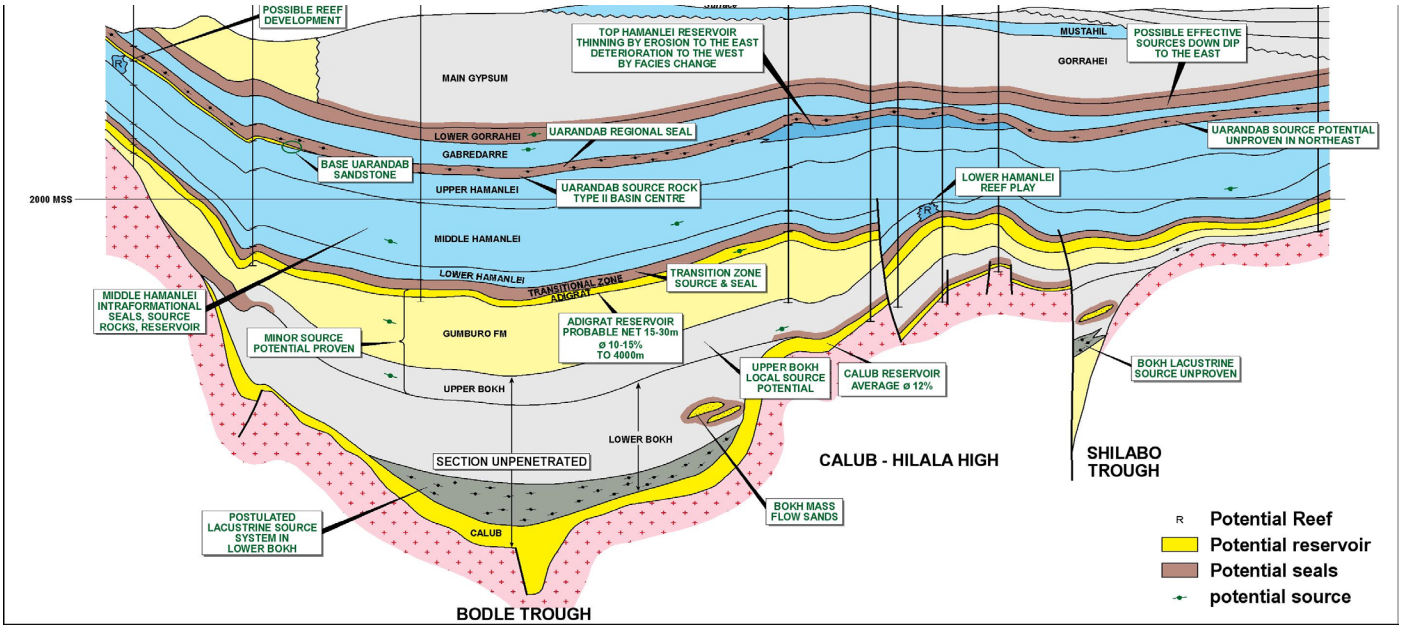
Ogaden Basin Discoveries

As previously mentioned, the first discoveries in Ethiopia were Calub, located 1,200 km south-east of Addis Ababa, and Hilala, 80 km further west. These were found by Tenneco, with partners Texaco and Chevron. Several other wells drilled by the group in the same area were unsuccessful and they relinquished the concession in 1977. A number of companies have since held interests in the blocks containing these discoveries. In the 1980s, the USSR Petroleum Exploration Expedition undertook geophysical studies and drilled further wells on both the Calub and Hilala fields and conducted successful production tests on several Calub wells. After they withdrew in 1991, the Calub Gas and Oil Corporation commissioned ZPEB of China to conduct a well completion programme on the fields. Several other companies held interest in the area but no progress was made until Petronas was awarded the blocks in 2006; after drilling several appraisal wells, they relinquished them in 2010.

In 2013 Chinese company Poly GCL was awarded these blocks and undertook further seismic investigations, drilling several wells. Estimates of reserves at Calub vary from 1.4 Tcf to 2.7 Tcf, and Poly GCL's discovery of the nearby Dohar field reportedly added 3 Tcf to reserves available for development, suggesting that combined reserves in the area could be 6 - 8 Tcfg recoverable. In 2016 Poly GLC announced plans to build an 830 km pipeline from the Calub and Hilala fields to a planned treatment plant at the Red Sea port of Djibouti, in order to export the gas to China.

Poly GCL also discovered good quality oil reserves, estimated at 337 MMbo in-place, in the Hilala block and in June 2018, the first barrel of crude oil was produced - a major milestone for the country. Poly GCL reported daily production of 350-450 bo and is considering building a small mobile oil refinery in the Ogaden, looking to supply the local market, potentially saving Ethiopia substantial costs in imported furnace oil.

In 2014 New Age Petroleum had significant shows in El Kuran-3 on the south-western edge of the Ogaden Basin, on a large anticlinal feature drilled by Tenneco in the early 1970s, about 250 km south-west of Calub and Hilala. The oil is located in Jurassic fractured carbonates and the gas is within sands in the ?Permo-Triassic Gumburo Formation. As well as looking at small-scale local projects, New Age has contracted with Poly GCL to export gas via their pipeline to Djibouti.



Ogaden Basin cross-section showing plays. Source: Ministry of Mines & Petroleum

The Ethiopian Rift

The section of the MER lying in the south-west of Ethiopia on the border with Kenya – the Southern Rift Basins, comprising the north-south striking Omo and Chew Bahir sub-basins – is also considered prospective. Rift development began during late Oligocene to early Miocene and has continued periodically to the present day. By analogy with associated basins in northern Kenya with proven major oil deposits, the Omo and Chew Bahir Basins could contain up to 3,500m of Tertiary deposits, possibly with Jurassic-Cretaceous rift sediments.

Organic-rich oil shale occurs in Tertiary grabens in the northern part of the Southern Rift Basins, where hydrocarbon generation could be facilitated by high thermal activity related to volcano-tectonic episodes throughout the Tertiary. Oil slicks have been recorded in lakes in the Ethiopian Rift but analysis elsewhere in the EARS indicates that slicks often originate from recent shallow organic-rich sediment so their presence does not guarantee a working hydrocarbon system.

Tullow Oil moved north from its EARS successes in Kenya and Uganda to test play continuation into Ethiopia. Several wells drilled between 2012 - 2014 had gas and oil shows, proving a working petroleum system, but no discoveries were made. Sabisa-1 in the Omo Sub-basin, along a major basinal fault trend and structurally similar to significant Tullow discoveries in the Lokichar Basin, encountered reservoir quality sands and a potentially sealing thick shale section, but yielded only oil and heavy gas shows; it is thought the trapping mechanism was poor. Tullow's next well in the sub-basin, Tultule-1, on a horst block structure 4 km east of Sabisa, was also dry, with only minor gas shows. Tullow also drilled a number of unsuccessful wells in the Chew Bahir Basin, before relinquishing the permits in 2014.

At the northern end of the MER is the 150,000 km^2 Afar rift complex, believed to be a triple junction of the Red Sea, Gulf of Aden and the MER. It is relatively unexplored but according to New Age Petroleum there are a number of known Jurassic oil seeps in the region. It is thought to have fluvio-lacustrine sediments ranging in age from Miocene to Quaternary in grabens within the rift complex. According to the Ministry of Mines recent mapping indicates source and reservoir rocks, but the thermal maturity of these is unknown.

New Age Energy acquired the Adigala block in the south-east corner of the Afar close to the border with Somalia in 2008. This acreage covers the interpreted Jurassic Adigala Rift, thought to be analogous to the petroliferous Yemen rift basins across the Gulf of Aden to the north. The company successfully acquired 910 km of 2D seismic data and identified a number of high impact exploration leads below the surface volcanics.

The Unexplored North

Like the Ogaden, the Abay and Mekele Basins are thought to be intracontinental rift basins formed as a result of extensional stresses induced by the break-up of Gondwana.

The 63,000 km^2 Abay or Blue Nile Basin in the central north-western plateau of Ethiopia is a north-west to south-east trending erosional basin containing 3,000m of Late Palaeozoic - Mesozoic sediments, including continental clastics and marine carbonates, evaporites, black shales and mudstones. These sediments cover a vast area of the Ethiopian Plateau but are hidden below thick Trap Series basalts except where exposed by erosion in the Abay Gorge. The basin remains unexplored by the drill bit, but analysis of a seep in the north-eastern margin of the basin suggests the presence of mature oil source rock of marine origin.

It is thought that the stratigraphic units in the Abay Basin are similar in age and lithology to those encountered in the Ogaden wells. The most significant potential source is probably the shaley interbeds in the Upper Jurassic Antolo limestone, correlatable with the Ogaden's Uarandab Formation, while the Jurassic Upper Sandstone offers the best reservoir potential. The laterally restricted limestone of the Antolo Formation and the Early Jurassic Adigrat Sandstone may also provide reservoirs.

Trapping mechanisms are expected to be structural horsts and tilted fault blocks, along with stratigraphic traps. Exploration challenges in the Abay Basin include breached reservoirs, plus difficult terrain in the gorge area and the cover of volcanics elsewhere.

In the north, close to the Eritrean border, Jurassic and Cretaceous sedimentary rocks are exposed in the 8,000 km^2 Mekele Basin, a downthrown portion of the Abay Mesozoic

basin. About 2,000m of Jurassic and Cretaceous fluvio-lacustrine to marine sediments are postulated in this area, where there has been no subsurface exploration. Source rock potential is again suggested in the transgressive Antalo Formation limestone, particular in the east, where the upper layers contain mudstone and brown shales. This is equivalent to part of the oil-prone Madbi Formation of Yemen, as is the Agula Shale. Source maturity is considered a significant exploration risk. The Adigrat Sandstone occurs along the margins of the Mekele Basin and is considered a potential reservoir. It is up to 600m thick and consists of medium-to-coarse-grained sandstone with silt, clay and shale. There is also potential in the sand-dominated Upper Cretaceous Amba Aradam Formation.

The Western Basins

The 17,500 km^2 Gambela Basin in the far west of Ethiopia is the south-eastern extension of the Melut Basin (White Nile Rift) of South Sudan, where over 600 MMbo has already been discovered. Sources could be Lower Cretaceous lacustrine shales, up to 1,800m thick. The main reservoirs are Upper Cretaceous and possibly Paleogene sandstones in Tertiary rifts, where sealing formations are also expected. Total sediment fill is up to 8,000m.

In 1982 Chevron acquired two blocks in this basin and conducted aeromagnetic and gravity surveys that proved Gambela to be an extension of the Melut Basin, though restricted in lateral extent and complicated by near-surface volcanics. It dropped the acreage after drilling a dry well in its adjacent Sudanese acreage. Petronas acquired the blocks in 2003 and drilled the first well in the basin in 2006, which proved to be dry, as was the second, raising concerns about the presence of mature source rock at this south-western end of the MER.

In 2012 South West Energy, (the first Ethiopian oil and gas exploration company), took over. It processed 17,906 kms of FTG, magnetic and Lidar data, which ascertained top of basement and other horizons and estimated 9,000m of sediment. It outlined two regional structural trends; one is Cretaceous, analogous with the Melut Basin; the other comprises Tertiary basins similar to those found in the EARS in Kenya. The company has identified a number of potential leads and suggests an estimated total resource potential over 2 Bbo.

The small Metema Basin on the north-west border with Sudan is possibly a continuation of the sedimentary sequence exposed in the Abay Basin. It may be part of a rift zone or trough extending from the Ogaden through the Abby Basin to Sudan but to date little is known about it.

Alternative Sources of Energy

Because of the active tectonic and volcanic processes associated with the MER, Ethiopia has plenty of opportunities for harnessing geothermal energy, and the geothermal resource potential is estimated to be 4,200–11,000 MW. Investigating geothermal energy in Ethiopia has been ongoing since the early ‘70s and over 20 possible prospects have been identified in the Ethiopian section of the MER, where geothermal manifestations include hot grounds, mud pools, mineral-enriched hot springs and pools, fumaroles and geysers.

Aluto geothermal well steaming in 2019. Source: Peter Purcell

The only geothermal plant is in the Aluto Langano geothermal field in the central rift area, associated with the dormant Aluto volcano complex. A pilot plant with 7.3 MW capacity was built in 1998 but operational problems limited output. Production ceased in 2018 but there are now plans to rebuild and start producing electricity in the near future. The country also plans to develop two 500-MW plants at nearby Corbetti and at Tulu Moye, south of Addis Ababa.

Ethiopia potentially has substantial oil shale reserves, predominantly in the northern Tigray

region, where they are probably contained in Upper Palaeozoic sediments left after Cretaceous erosion. Thick shale horizons occur in other parts of the country but very little research has been undertaken on this potential to date.

Ethiopia has some of the richest potential for hydropower in Africa, distributed across eight major basins with an exploitable hydropower potential of 45,000 MW. At the moment it has harnessed about 10% of that, but the huge Grand Renaissance Hydroelectric Project under construction could increase that capacity by 6,000 MW. This vast dam on the Blue Nile is nearing completion but is highly controversial, as it will control the flow of the Nile through Sudan and Egypt, so both countries are vehemently opposed to it.

Below: The Grand Renaissance Dam in July 2020. Source: Hailefida/Wikipedia

Welcoming Exploration

The Ethiopian Ministry of Mines is keen to welcome more oil and gas exploration companies to the country to help provide energy for the fast growing economy, which is primarily based on agriculture, export-led manufacturing and large-scale infrastructure projects. It is currently updating its petroleum legislation to make it more investor friendly.

A beautiful, friendly and fascinating country on the cusp of becoming an oil producer, Ethiopia is looking forward to welcoming further investment in its oil and gas industry.

Many thanks to Peter Purcell, P&R Geological Consultants Pty Ltd., for all his help with this article.

Jane Whaley will be moderating the Africa Independents Forum at Africa Oil Week (1-5 November 2021, Cape Town, South Africa). Learn more and register here.

Please click here to access references for this piece.