

## Exploring in Angola, West Africa for Oil and Gas in Lower Cretaceous Carbonates in the Offshore and Onshore Lower Congo and Kwanza Basins

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Oil was first discovered in Angola in 1955 and the nation's oil production peaked at almost 2.0 million barrels of oil per day (BOPD) in 2010. At that time, Angola was Africa's second largest oil producer after Nigeria. At the peak of production, approximately 1.5 million BOPD was from Tertiary-age turbidite clastics and 500,000 BOPD was from Lower Cretaceous carbonates, primarily the Pinda Formation.

Angola's total oil production has now declined to just over 1.0 million BOPD. The production is approximately 700,000 BOPD from the Tertiary and 300,000 BOPD from the Lower Cretaceous carbonates. One of the most important oil producing reservoirs in Angola has been Lower Cretaceous carbonates. These carbonates include the Toca, Vermelha and Pinda formations of which the Pinda is the most important for oil production.

### **Pinda Carbonates**

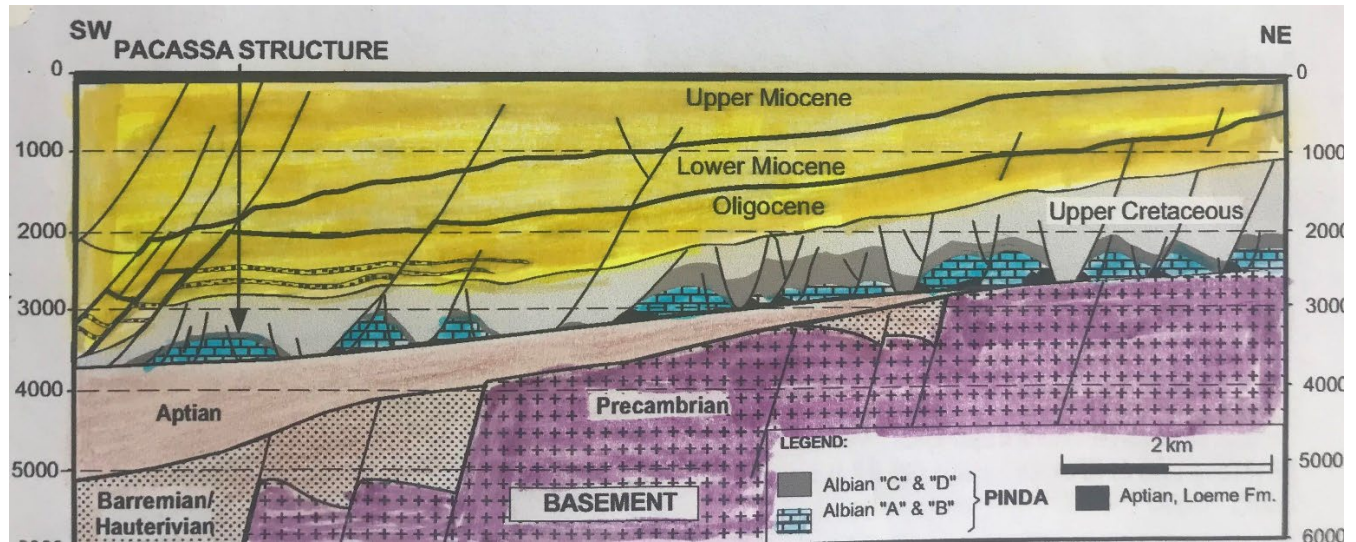
The Pinda Formation consists primarily of shallow marine carbonates deposited on a westward sloping carbonate ramp. The Pinda carbonates include oncoid-oid grainstones, packstones and wackstones which were pervasively dolomitized during multiple dolomitization events.

### **Generalized Structural Geology**

In the Lower Congo Basin, south of the Congo (Zaire) River, the principal structural events which affect the Pinda strata include syn-rift basin architecture, post-rift listric detachment and associated faulting as well as transverse deformation and offset. Northwards oriented listric and antithetic faulting has resulted in a variety of oil-trapping structures including simple rollovers and horst blocks. Salt rafting and down-to-the-basin gravity sliding of Pinda "rafts" resulted in a number of oil fields consisting of blocks of Pinda carbonate with separate oil-water contacts. Indeed, the best example in the world of salt rafting and gravity sliding of carbonates is clearly displayed in the onshore and offshore Lower Congo Basin of Angola (Jackson, M.P.A., & Talbot, C.J., 1991). Examples of this unique style of salt tectonics is shown in Figure 1 covering Elf-legacy Block 3 and Figure 2 which is focused on Texaco-legacy Block 2.

Shallow water Block 3 in the Lower Congo Basin was initially explored by Paris-based Elf Petroleum resulting in the discovery of some major Lower Pinda-reservoired oil fields. These include Palanca, Punja, Impala, Pacassa and Bufalo. The French oil company Total became

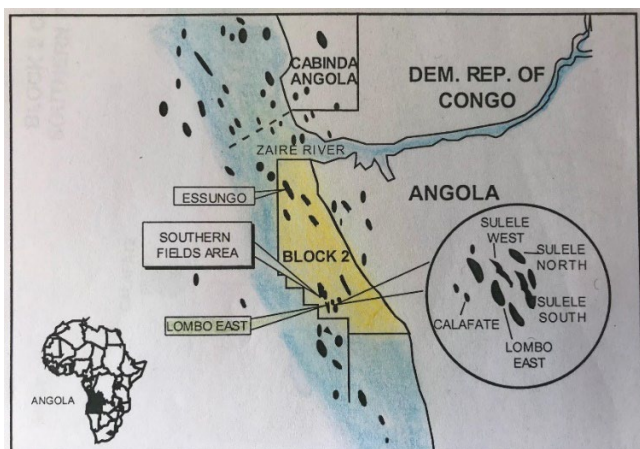
operator when Elf was acquired by Total. Operatorship was eventually taken over by the state oil company Sonangol.



**Figure 1.** Cross-section through Block 3 showing salt tectonic “turtle back” structures which have resulted from down-to-the basin gravity sliding. Note the Pacassa raft which is a major Pinda oil field. From: Eichenseer et al, 1999.

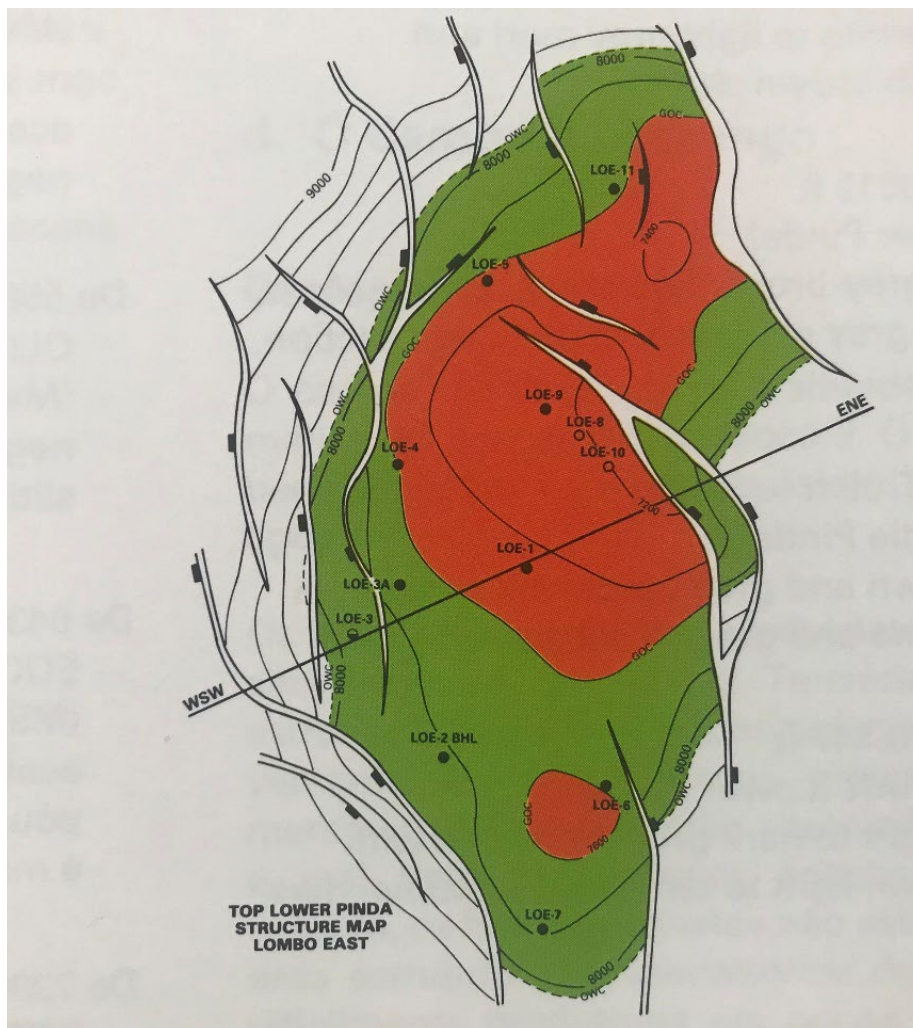
### Lombo East Oil Field (legacy Texaco operated Block 2/85)

The Lombo East field is located in 35 m of water 30 km offshore. Lower Cretaceous fluvial sandstones and conglomerates onlap basement and are overlain by thin Aptian anhydrites. Sandy Aptian-Albian dolomites occur above the anhydrite beds which become progressively less sandy higher up in the sequence. Near the top of the dolomite is a high energy carbonate shoal facies wherein the hydrocarbons are trapped.

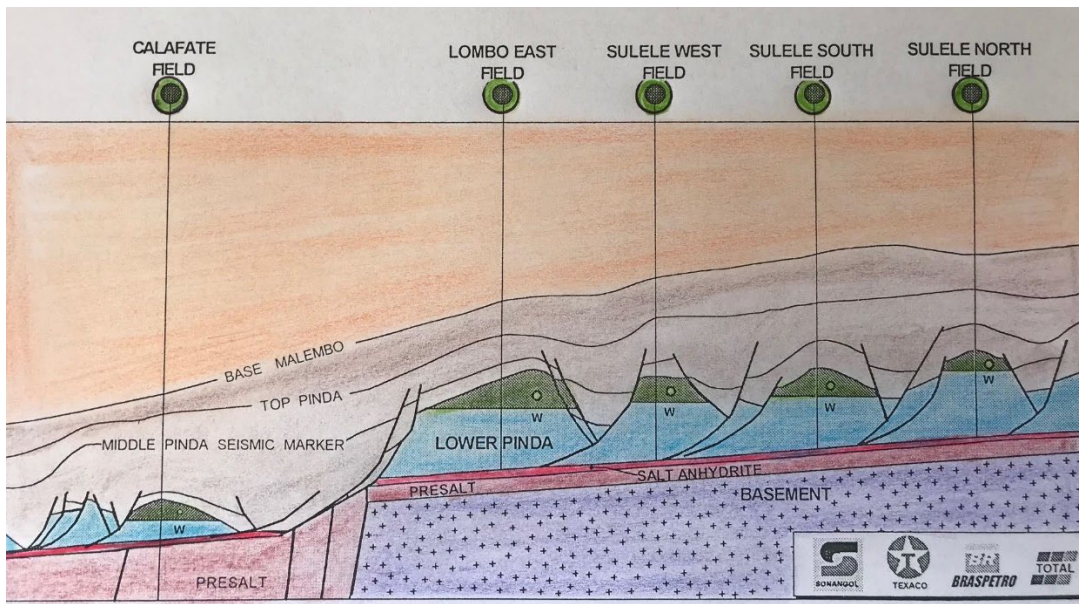


**Figure 2.** Location of the Lombo East oil field. From: Koning, T., and De Deus, G., 1997

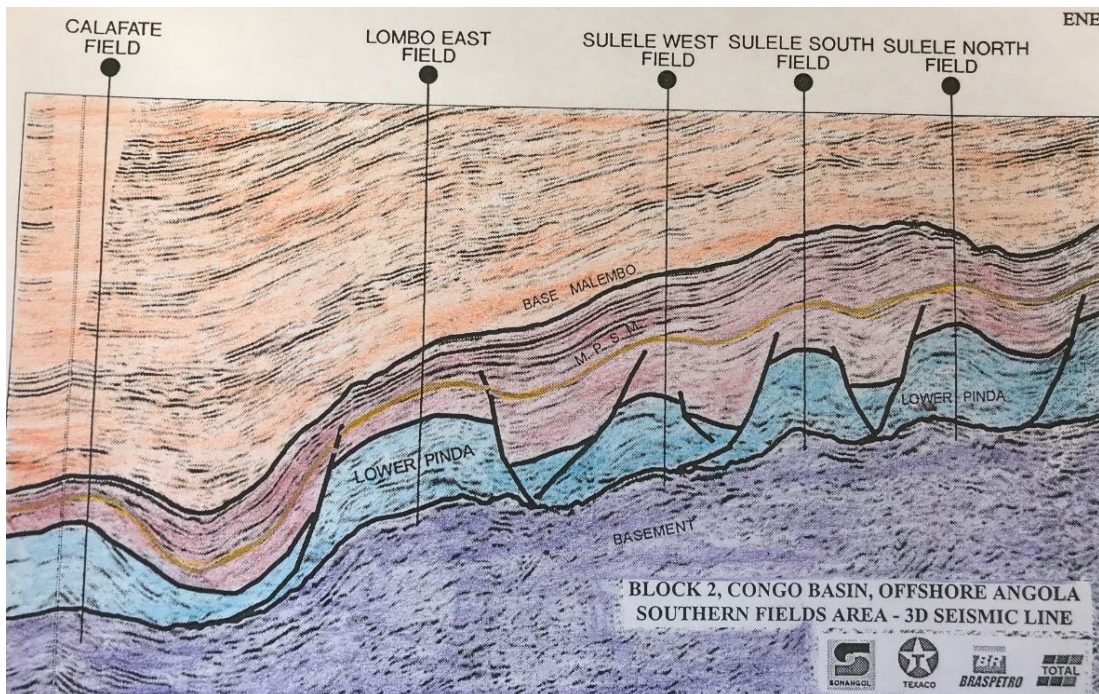
Regional subsidence and localized structuring formed the Lombo East carbonate raft. The reservoir consists of fine to coarse crystalline vugular dolomite with 15 to 20% porosity. The oil gravity is 40 degrees API. The field occurs within a 1,600-acre closure with vertical relief of about 250 m and an oil column of 130 m. The reservoir is overlain and sealed by thick impermeable Albian limestones and silty, tight dolomites. The Lombo East field was discovered by Texaco in 1984 and by the year 2000 had produced about 110 million barrels of oil. The Lombo East-1 discovery well was followed by 9 additional wells by the year 2000 and reached a maximum production of 33,000 BOPD in 1996. In the year 2000 the field was producing about 17,000 BOPD. Due to limited published information, more up-to-date oil production data is not available. For more information on the Lombo East oil field, the reader is referred to Koning & De Deus, 1997, Koning, Pierobom & De Deus, 1998 and Koning & De Deus, 2000.



**Figure 3.** Lombo East oil field, offshore Lower Congo Basin. Top Lower Pinda Structure Map. From: Schlumberger, 1991.



**Figure 4.** Cross section through the Pinda oil fields in Block 2/85. Note the down-to-the basin “rafted” blocks of Pinda carbonate. Each is an oil field with separate oil-water contacts. From: Koning, T. and De Deus, G., 1997.



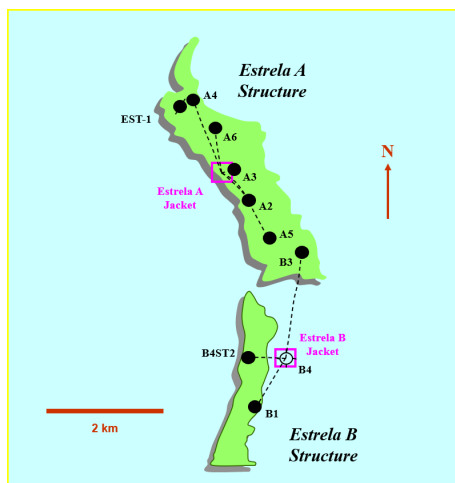
**Figure 5.** 3D seismic line through Block 2/85. From: Koning, T. and De Deus, G., 1997.

## Estrela Oil Field (legacy Texaco operated Block 2)

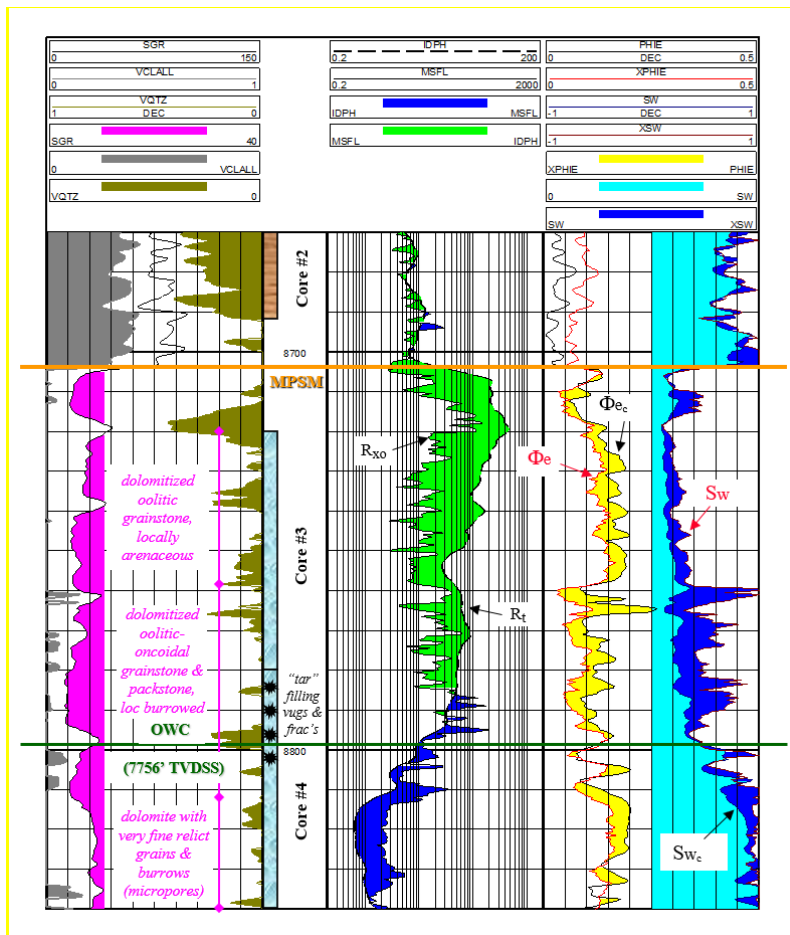
The Estrela field, discovered in 1990, is located offshore Angola Block 2/85 within the northern Lower Congo Basin. The 37 degrees API crude is produced from Albian age Pinda carbonate shelf edge shoals. The field comprises two independent closures, which share a common spill point. Elongate, curvilinear-shaped reservoir fault blocks, termed A and B, are the result of basinward listric faulting and lesser shoreward compensatory displacement.

The Middle Pinda prospective reservoir sequence comprises high energy, oolite-oncolite precursor grainstones interbedded with less prospective lime mudstones. These sequences, particularly the grainstones have undergone partial dolomitization, followed by later dissolution of remnant calcareous allochems. The resulting interconnected moldic pore system is pervasive across stacked shoaling cycles. A 3D reservoir model was built for the Estrela field through an iterative process involving detailed geophysical interpretation of dipping dolomite layers truncated by an overlying erosional unconformity, multi-well log evaluation, and simulation to history match field performance.

The Estrela-1 discovery well encountered over 15 m of porous, oil-bearing dolomite on the northwest flank of the field. Net oil pay thickness within the developed concession area averages 67 m reaching a maximum of 140 m. In year 2000, a total of 8 wells were flowing at a combined rate of about 17,000 BOPD. Ultimate cumulative reserves are estimated to be above 50 million barrels of oil. Well control and 3D seismic mapping indicate a saddle between the respective closures, coincident with listric fault interaction and a change in regional structural grain. Geochemical correlation of crude oils samples confirms that the northern Estrela A and southern Estrela B hydrocarbon accumulations lie in distinctly separate reservoir compartments despite the common spill point. Smithard et al, 2000 is the primary source for information herein on the Estrela oil field as well as Koning & Smithard, 2004 and Koning, 2004.



**Figure 6.** Estrela oil field.  
From: Smithard et al, 2000.



**Figure 7.** Log analysis of the Estrela-B1 development well, Middle Pinda oil producing level. From: Smithard et al, 2000.

The Block 2/85 fields such as Lombo East, Tubarao, Sulele West, and Sulele South were likely all connected by a common, low-porosity aquifer and are all normally pressured. This contrasts with the Block 3 fields which are contained in wholly rafted and separate blocks with no common aquifer. In contrast to the Block 2/85 fields, the Block 3 fields are slightly over-pressured.

In Block 2/85, the first oil discovery was in 1975 with the Essungo oil field which had production from Tertiary deepwater sandstones. Thereafter 19 Pinda carbonate oil fields were discovered by Texaco and its partners Sonangol, Total and Braspetro. Oil production peaked at 110,000 BOPD in 1997. This production was entirely from the Pinda carbonates except for minor production from Tertiary sandstones in the Essungo oil field. By the year 2000, production had declined to approximately 70,000 BOPD. Ultimate oil production from Block 2/85 is estimated at 250 to 300 million barrels of oil.

## **Takula Oil Field, Offshore Cabinda (operated by Chevron)**

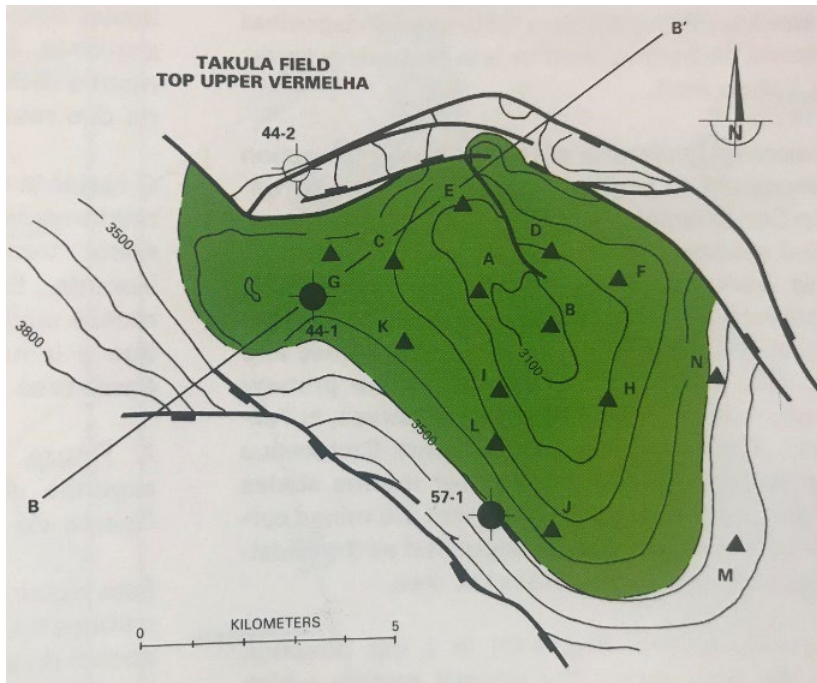
The Takula oil field in the shallow waters of the Lower Congo Basin is one of the most important oil fields in the Chevron operated Block 0. Oil is produced from the Vermelha, Pinda and Toca Formations.

The lowest producing formation is the Toca which is a carbonate which is up to 130 m thick and with limited aerial extent. Porosity and permeability are diagenetic and probably the result of sub-aerial or phreatic zone exposure. Porosities average between 16% and 20% and permeabilities can be over 600 md locally. The Toca underlies the Loeme salt and is an example of a pre-salt oil field in Angola.

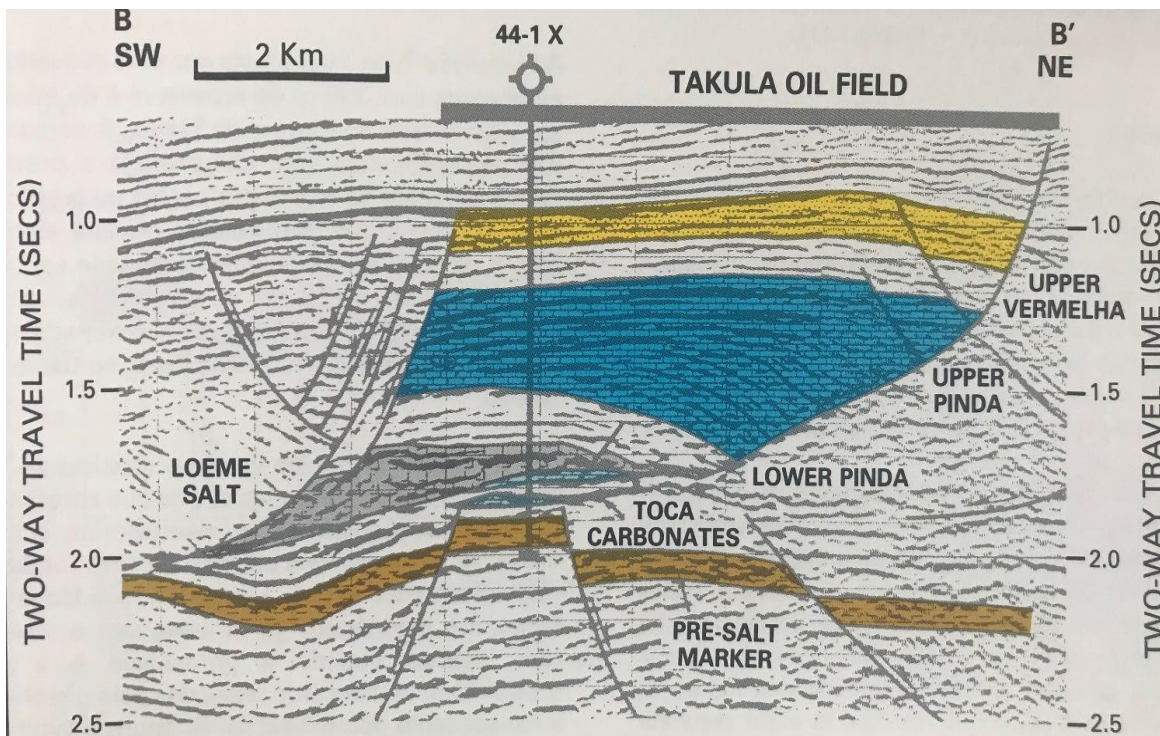
Overlying the Loeme salt is the Pinda Formation. Its structure and stratigraphy were influenced by the growth of listric normal faults soling into the Loeme salt decollement zone. The Pinda consists of intercalated calcareous and quartzose shelf sandstones, dolomites and shales deposited on a broad carbonate shelf. It is a secondary reservoir in the Takula field.

The reservoir sandstone of the Vermelha formation was deposited in a nearshore and beach environment in Cenomanian time. Foreshore, shoreface, and lagoonal sedimentary facies are evident from core and log work. Growth faulting and a eustatic sea level balance provided an environment for the deposition of this stacked sequence of sandstones and shales. The Vermelha sandstones are the primary reservoir, holding the bulk of the oil reserves in the Takula field. The sandstones are quartzose, very fine to coarse grained, clean, consolidated to poorly consolidated. Porosities averaged 25% and as high as 35%. Permeability averages about 1 darcy. These sandstones grade laterally into well cemented dolomitic sandstones with porosities of approximately 10%. The remainder of the Upper Cretaceous section are predominantly transgressive marine shales which act as good seals.

In 1998, 28 million barrels of oil had been produced from the Toca in the Takula field. At the same time, cumulative oil production of 21 million barrels had recovered from the Pinda Formation. The Vermelha was on production at approximately 140,000 BOPD. Information provided herein about the Takula field is from the Schlumberger Well Evaluation Conference held in 1991 in Luanda, Angola. No updated published oil production data is available to include herein.



**Figure 8.** Takula oil field, offshore Cabinda.  
 Top Upper Vermelha Structure Map. From: Schlumberger,  
 1991.

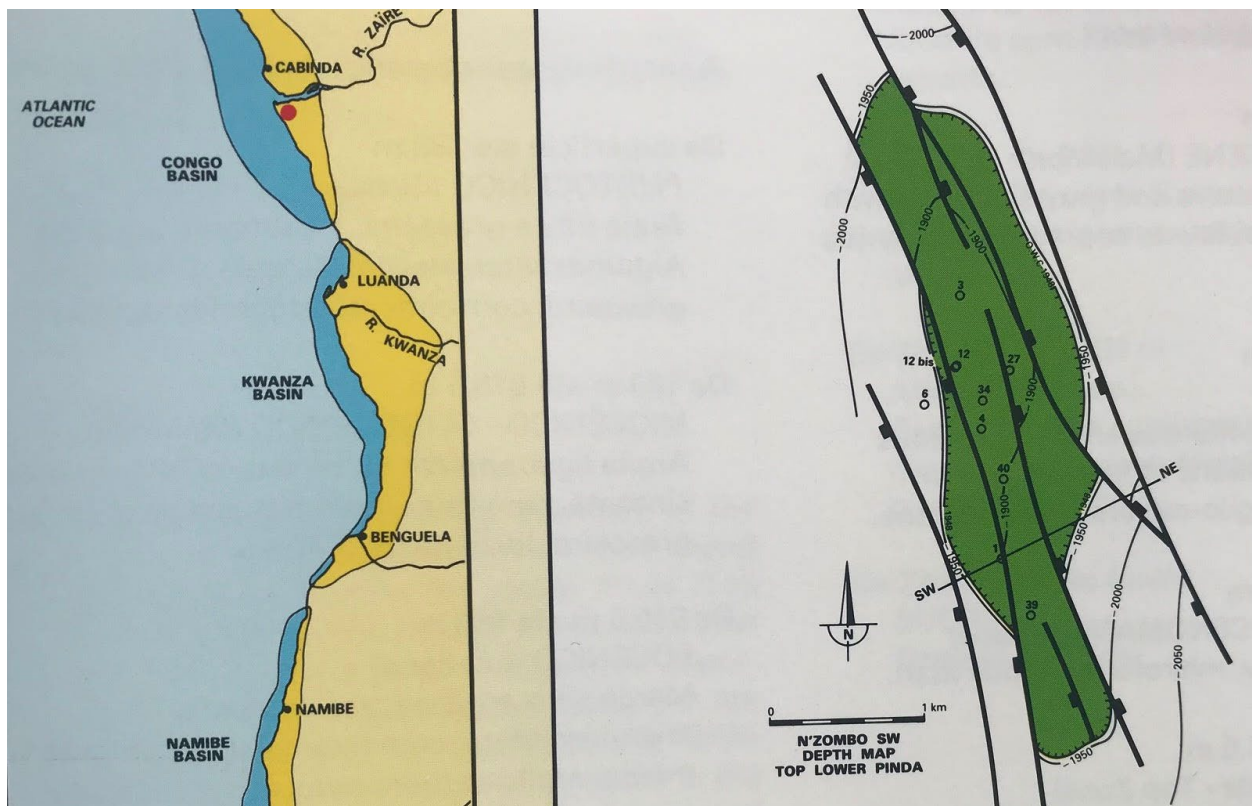


**Figure 9.** Seismic line across the Takula oil field. From: Schlumberger, 1991.

## N'Zombo Southwest Oil Field, Onshore Lower Congo Basin (legacy operator Petrofina)

This oil field was found in 1973 near the coastline of northern Angola. The exploration well NZ-1 encountered three oil-bearing zones in the Pinda formation. The N'Zombo structure is fault-bounded to the east and west with a crestal anticlinal closure. The three oil zones are separated from each other by marly facies within the Pinda which serves as cap rocks. Clays from the Bucomazi Formation are the source of the oil in the Pinda reservoirs.

In 1989 the Lower Pinda was producing at 143 BOPD, Middle Pinda producing 340 BOPD and production of 490 BOPD was flowing from the Upper Pinda (Schlumberger, 1991). This is a small field with ultimate oil production likely in the order of only 10 million barrels of oil.



**Figure 10.** Location of the N'Zombo Southwest oil field and depth map to the top of the Lower Pinda. From: Schlumberger 1991.

## Tobias Oil Field, Onshore Kwanza Basin (legacy operator Petrofina)

History of Exploration and Production in the Onshore Kwanza Basin

The onshore Kwanza Basin was the first basin in Angola to have undergone oil exploration and development. The first-ever well to be drilled for oil was in 1915 in the valley of the Dande River

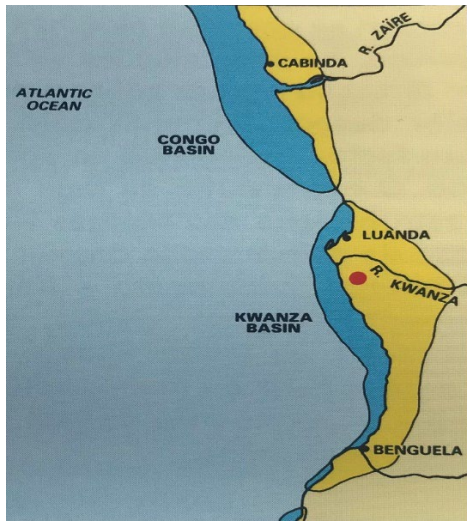
about 40 km northeast of Luanda. Oil exploration occurred sporadically for the next four decades with no commercial success. The Belgium-based oil company Petrofina was the most active of the oil companies in the basin and drilled Angola's first commercial oil discovery at Benfica, near Luanda in 1955. Oil production commenced in the same year and eventually 80 million barrels of oil were produced from the onshore Kwanza Basin. The oil was delivered through a small diameter pipeline to the Petrofina refinery in Luanda. Maximum production was in 1988 when 18,000 BOPD was achieved. About half of this oil was from 8 fields which produced from Pinda-equivalent carbonates, called the Binga Formation in this basin, and the other half was from Miocene sands in the Quenguela North field.

Due to escalation of Angola's civil war and the danger of attacks by the rebel faction UNITA, in 1998 Petrofina stopped producing oil and terminated all its field developments in the onshore Kwanza Basin and the onshore Lower Congo Basin. Consequently, many small oil fields, almost entirely Binga carbonates, remain unproduced or under-produced and eventually the fields fell into a state of disrepair. In the past decade, a few bid rounds have taken place where several blocks were available for acquisition. Sonangol and some smaller international oil companies and small Angolan oil companies are interested in rejuvenating the old oil fields using modern oil field technology. The Angolan companies have included Somoil, Simples Oil, Tusker Energy and Mineral One according to Costa, 2021. Edmonton, Alberta-based MTI Energy have also obtained operatorship and non-operatorship in a number of blocks in the onshore Kwanza and onshore Lower Congo Basins.

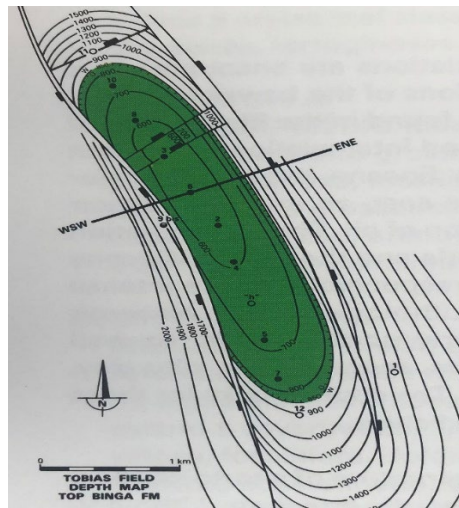
#### Re-development of the Tobias Oil Field

The most high-profile event in the onshore Kwanza Basin has been the drilling of two wells in the Tobias oil field in 2023 by Sonangol and London-based Corcel Plc. This has resulted in a much-heightened interest by oil companies in the onshore Kwanza Basin.

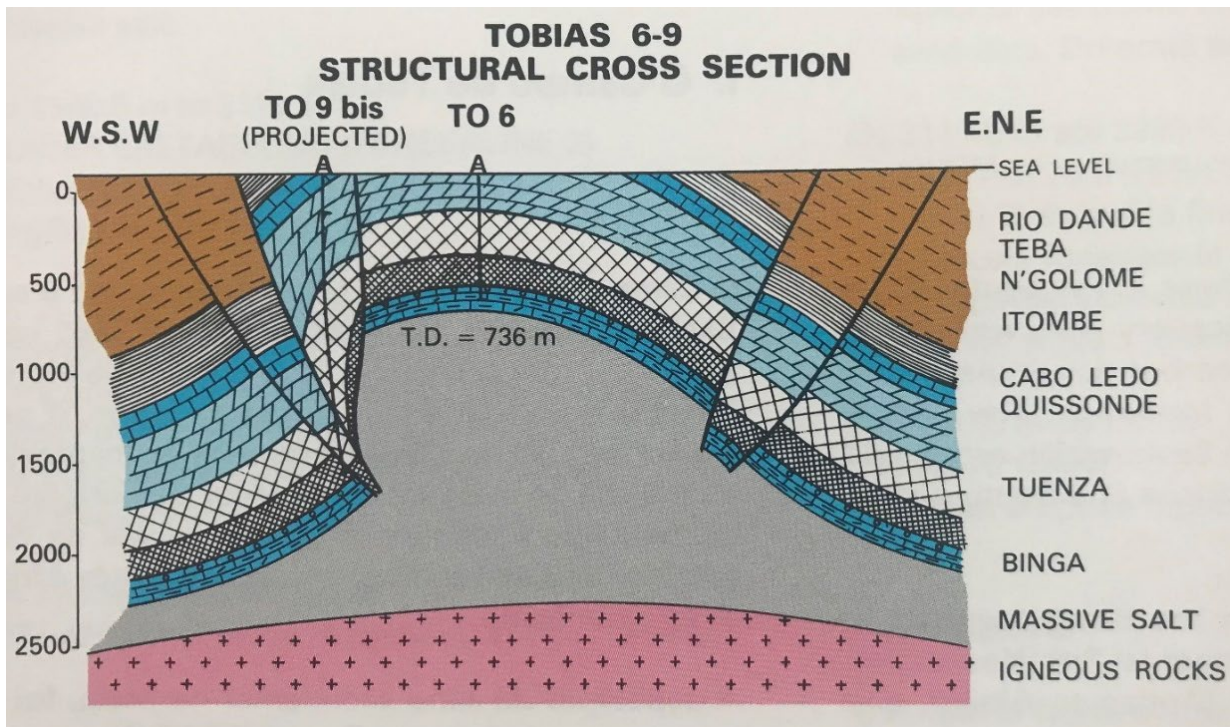
The Tobias field is situated onshore in the southern area of the Kwanza Basin. The field consists of 12 historic vertical wells drilled in the 1960s and 1970s by Petrofina. The discovery well, Tobias-2 was drilled in 1961 and discovered oil in the limestones of the Binga Formation. Tobias is structurally a deformed anticline approximately 8 km long and 1 km wide. The Binga in Tobias is a low porosity limestone with an average of 2.0% porosity but locally the matrix porosity can be in the order of 14%, according to a 1983 Schlumberger publication. Production is possible mainly because of the intense faulting and fracturing resulting from the folding of this structure. The Tuenza evaporites serve as the caprock.



**Figure 10.** Location of the Tobias oil field. From: Schlumberger, 1991.



**Figure 11.** Tobias. Binga structure map. From: Schlumberger, 1991.



**Figure 12.** Structural cross-section across the Tobias oil field, onshore Kwanza Basin. From: Schlumberger, 1991.

Oil in the Tobias field has a density of 31 degrees API. The top of the reservoir is at a depth of 520 m (1,710 ft). The initial oil column was 350 m (1,150 ft) and the bottom hole pressure was 53kg/cm<sup>2</sup>. Due to the intense natural fractures in the Binga, the initial oil production was high at

12,000 BOPD by solution gas drive (Schlumberger, 1983). However, production dropped rapidly, and water injection was necessary to maintain production. Prior to Tobias being abandoned by Petrofina, the field reached peak production of 17,500 BOPD and produced a total of 29 million barrels of oil.

London-based and AIM-listed Corcel Plc has a 20% working interest (18% net) in Block KON-11 which is operated by Sonangol. Corcel is an Angolan – Brazilian oil and gas company focused on onshore upstream development as well as mining and mineral resources development. Corcel also has a 22.5% working interest in Kwanza Basin Block KON-12 and 31.5% in KON-16.

Corcel announced that the companies (Sonangol and Corcel) began drilling in September 2023 in the Tobias oil field. Tobias-13 was drilled at a downdip location from historic production and reached its target depth of 959 m. The full Binga reservoir section of about 120 m was encountered in the well as prognosed and intersected 80 m of Binga reservoir with several potentially productive zones in multiple intervals. Corcel stated that the results of Tobias-13 confirm the ability to reactivate production through an early production system (“EPS”) and implies significant hydrocarbon potential remaining.

Tobias-14 was drilled directly after Tobias-13 to its target depth of 781 m. In a December 28, 2023 press release, Corcel said that Tobias-14 was located at the top of the Tobias anticlinal structure and is an offset to the largest historic producer in the field, Tobias-4 which produced 12,580 BOPD at its peak, albeit penetrating only the first 8 meters of the reservoir. Tobias-14 encountered a full Binga reservoir section of about 80 m with identical zones encountered as in Tobias-13 and had oil shows throughout. Tobias-14 drilling encountered highly fractured oolitic limestones in the reservoir with good primary porosity values in the range of 4 – 14%. Corcel believes that the porosity is enhanced by the extensive, naturally fractured carbonate system. Initial pressure readings support Corcel’s predrill thesis that the reservoir has returned to its original pressure values through active recharge of the system. Tobias-14 found no presence of water despite Tobias-4 watering out at the end of its production life. Corcel believes that this indicates the field has fully re-equilibrated.

Sonangol and Corcel believe the results will allow them to restart production via an early production system (EPS). The companies plan are preparing to test the Tobias-13 and Tobias-14 wells which will determine formation pressures and ultimately the flow rates. Various companies and oil industry analysts are closely watching the oil industry media for announcements on the Tobias wells testing program. If favorable results are achieved, then this would send out the message that there is positive life left in the other old oil fields in the Kwanza Basin. This could start a stampede of companies exploring for oil in similar fields in the basin or indeed focus on rank exploration.

One year ago, Corcel’s share price was 0.25 pence per share. The news from recent drilling has resulted in the share price quadrupling to the current price of 1.0 pence.



Managers and executives of Sonangol and the Angolan National Agency for Petroleum, Gas and Biofuels (ANPG) visiting the Tobias oil field. Photograph from ANPG, September 1, 2023, published in Energy Voice, December 29, 2023.

### **Current Pinda Formation Exploration and Production in Angola**

Due to limited publicly available data about ongoing exploration and production activity in Angola, the following review is generalized. Chevron as operator of Block 0, offshore Cabinda is maintaining an active Pinda oil fields development. The Pinda oil fields in Block 2 (former Texaco operated) and Block 3 (former Elf-Total operated) is now operated by the state oil company Sonangol P&P. An Angola oil company Somoil has also been involved in further developments in these fields. Somoil has now re-branded as Etu Energies and is operator of Block 2/05.

Recently, a London-based oil exploration company, Afentra Plc has acquired working interests in Blocks 3/05 and 3/05A in the offshore Lower Congo Basin which include Pinda fields which were producing 22,000 BOPD at year end 2023.

Active and ongoing acreage bid rounds are being held for open blocks in the onshore Lower Congo and onshore Kwanza Basins.

The oil industry in Angola is now very mature with production on a steady decline. However, a high level of interest remains in Angola for both the major international oil companies (IOCs) as well as the smaller explorers such as Afentra. The Canadian oil company MTI Energy is an example of a small international oil company which is active as operator and non-operator in the onshore Lower Congo Basin as well as the onshore Kwanza Basin. TotalEnergies have announced plans to produce up to 80,000 BOPD from two oil, gas and condensate fields discovered in Lower Cretaceous pre-salt microbial carbonates in the deepwater Kwanza Basin.

Furthermore, ExxonMobil is drilling a rank exploration well in the heretofore totally undrilled Namibe Basin in southern Angola.



**Figure 7.** Angola's oil production from 1995 – 2023 has been on a steady decline since 2010 from 2.0 million BOPD to the current 1.1 million BOPD, representing a 50% decline in the past 13 years. From: OPEC, 2023.

#### Natural gas in Angola

For almost five decades, any natural gas found in Angola belonged to the state since gas was not included in the contracts. Also, during those years, there was no market for gas. However, the situation regarding gas radically changed in 2013 when the US\$ 9.0 billion Chevron-operated LNG plant (“Angola LNG”) near the town of Soyo, northern Angola commenced production. The gas for the Soyo plant is associated gas from oil produced in the prolific Miocene and Oligocene turbidite oil fields in the deepwater Lower Congo Basin. The gas was sourced from deepwater oil fields in blocks which included Block 15 operated by ExxonMobil, Block 17 operated by TotalEnergies and Block 18 operated by BP. This was followed by connecting the Angola LNG

plant to Blocks 0 and 14, operated by Chevron, Block 31 operated by BP and Block 32 operated by TotalEnergies. Angola LNG will also develop and produce non-associated gas from dedicated gas discoveries within Blocks 1 and 2. Lower Cretaceous carbonates, such as the Quiluma and Maboqueiro gas fields could be delivered via the subsea pipeline network to the Soyo LNG plant.

For at least five decades, any gas discovered belonged to the state. This stopped any companies from deliberately exploring for gas in Angola. However, the petroleum legislation was then altered in 2017 to include gas. Accordingly, now gas discoveries potentially can be commercialized and connected with Angola LNG or if sufficiently large, could be produced through a standalone floating LNG plant.

It is the view of this author that a combination of favorable geology, application of leading-edge technology and some good old-fashioned luck could have Angola's declining production turning around and making Angola again as one of Africa's top oil producers.

## Acknowledgements

As author of this extended abstract, I wish to mention that I worked in Angola from 1995 – 1999 on a rotational basis (month in & month out) and from 2000 – 2015 as a resident in Luanda. During my first decade in Angola, I was with Texaco and much involved with development of Pinda oil fields in shallow water Block 2/85. In my second decade in Angola, I was a consultant for Tullow Oil and Gaffney Cline & Associates.

While with Texaco, I worked as Block 2/85 Manager Assets Development with an excellent team of geologists, geophysicists and reservoir engineers who contributed to our knowledge of the Pinda reservoirs. Due to the passage of time, I am unable to remember all the names of my team members. Co-workers included geologists Jim Brandon, Eric Hussey, Mike Kisucky, Martin Sirovs, Luis Cayolla, Jim Collins, Mark Smithard, geophysicist Elizabeth Halliday, and reservoir engineers Edwin Sa and Bill Arnold. They all made large contributions to our understanding of the Pinda reservoirs and the subsequent significant oil production.

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