Changing Exploration Focus Paved Way for Success

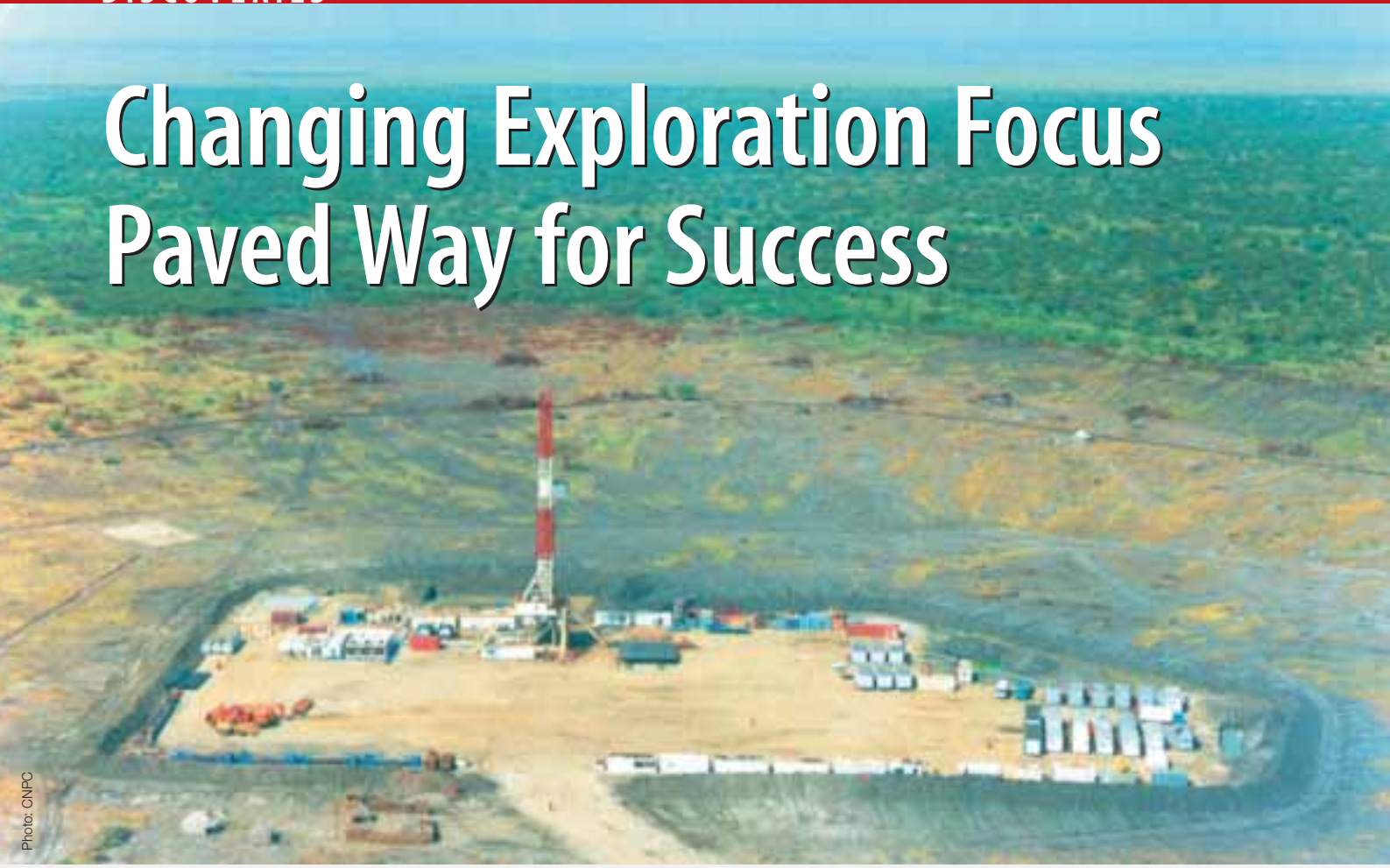

Photo: CNPC

Petrodar Operation Company (PDOC) spudded the wildcat Palogue-1 in the autumn of 2002 following a detailed study of the petroleum system of the Melut Basin. The well ultimately encountered 72.3m of net oil pay in Tertiary (Paleogene) and 9.9m in Cretaceous rocks. Paleogene sandstones constitute the main pay zone, and the interval from 1312 to 1333m was tested at an initial rate of 5,100 bopd. In the deeper pay zone, Cretaceous sandstones were tested at a cumulative rate of 300 bopd. Later the same year, another wildcat found more oil 2.8 km north of Palogue-1. It then became clear that a significant discovery had been made.

After only a few small discoveries in what appeared to be favourable geological conditions, a major study of the petroleum system of the huge, immature basin was conducted. The subsequent well hit oil in Lower Tertiary sandstones, and the discovery was later proven to be a giant (>500 million bbls of recoverable oil) within the prolific Central African Rift.

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The Great Palogue Field in southern Sudan, 650 km to the south from Khartoum, was discovered in 2003 following a major exploration campaign. The field probably contains 2.9 billion barrels of oil, of which an estimated 600 million barrels (20%) are recoverable. It is by far the largest oil field in Sudan, and also one of few giant oil fields discovered in the 21st century.

According to the BP Statistical Review of World Energy 2005, proven reserves in Sudan at the end of 2004 were 900 million m^3 of oil (6.3 billion barrels). Sudan thus ranks as no. 5 in Africa with respect to oil reserves, only behind Libya, Nigeria, Algeria and Angola.

The reserve estimates for Sudan will most likely increase considerably in the years to come, as the prolific Muglad and Melut Basins are both largely underexplored.

Sudan has become a significant oil producer with an average output of more than 330,000 bopd last year. Sudan's bedrock of output is the 300,000 bopd of Nile Blend produced from the Muglad Basin with other fields adding another 30,000 bopd. This year, an extra 80,000 bopd is scheduled to come from block 5a and another 30,000 bopd from block 6, both in the Muglad Basin. Another 150,000 bopd will come from the Great Palogue field at the end of 2006.

Dry wells along the Red Sea

Petroleum exploration in Sudan dates back to the late 1950's when some preliminary investigations were carried out along the Red Sea coast. In 1959, Italy's Agip was granted concessions carrying out seismic surveys and drilling six wells. Following Agip into the Red Sea came Oceanic Oil Company, France's Total, Texas Eastern, Union Texas and Chevron. All yielded nothing for the next fifteen years.

The first successful results were achieved by Chevron in 1974, 120 km southeast of Port Sudan, where dry gas and gas condensate were found. No oil was found, however, and most companies relinquished their concessions in the region.

Exploration for oil in southern and southwestern Sudan began in 1975, when the government of Sudan granted Chevron a concession area of 516,000 km^2 (equivalent to some 90 North Sea quadrants!) in blocks around Muglad and Melut basins. Chevron started geological and geophysical surveys in 1976, and drilled its first well in 1977, which was dry.

The Muglad Basin

In 1979, Chevron made its first oil discovery in the Muglad Basin with Abu Jabra #1, where 8 million barrels were proven.

Chevron's most significant discovery was made in 1980 in the Unity oilfield. Heglig field, which lies 70 km north of Unity field, was discovered in 1982. Chevron estimated total oil reserves of 593 million barrels from the two fields combined.

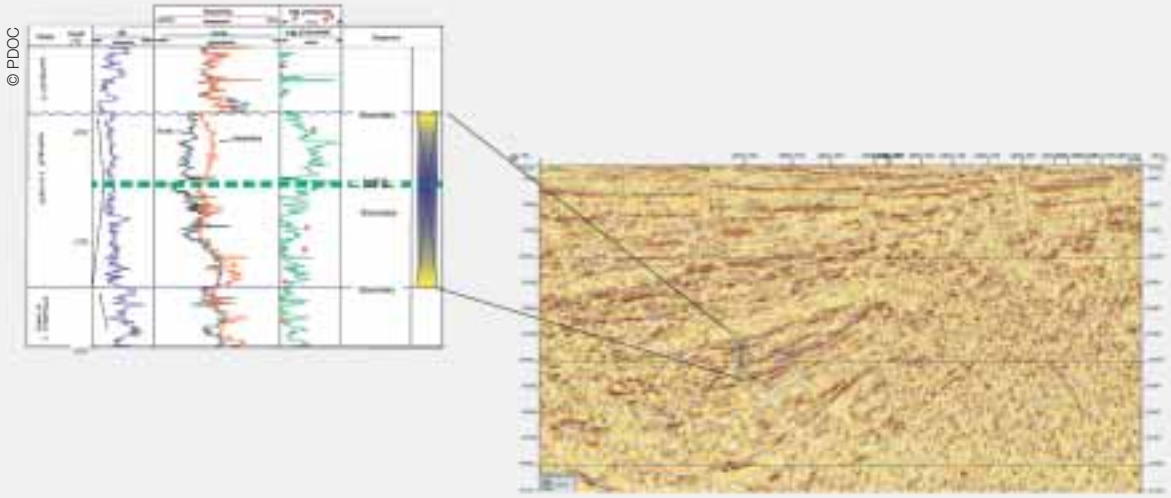
Oil has been produced since 1999 from the Unity and Heglig fields and transported via a 1500 km pipeline to Port Sudan on the Red Sea coast. It has a 250,000 bopd capacity that can be expanded to over 450,000 bopd with additional pump stations. Sudan thus became an oil exporter in August 1999, when the first shipment of oil left Port Sudan.

The Melut Basin

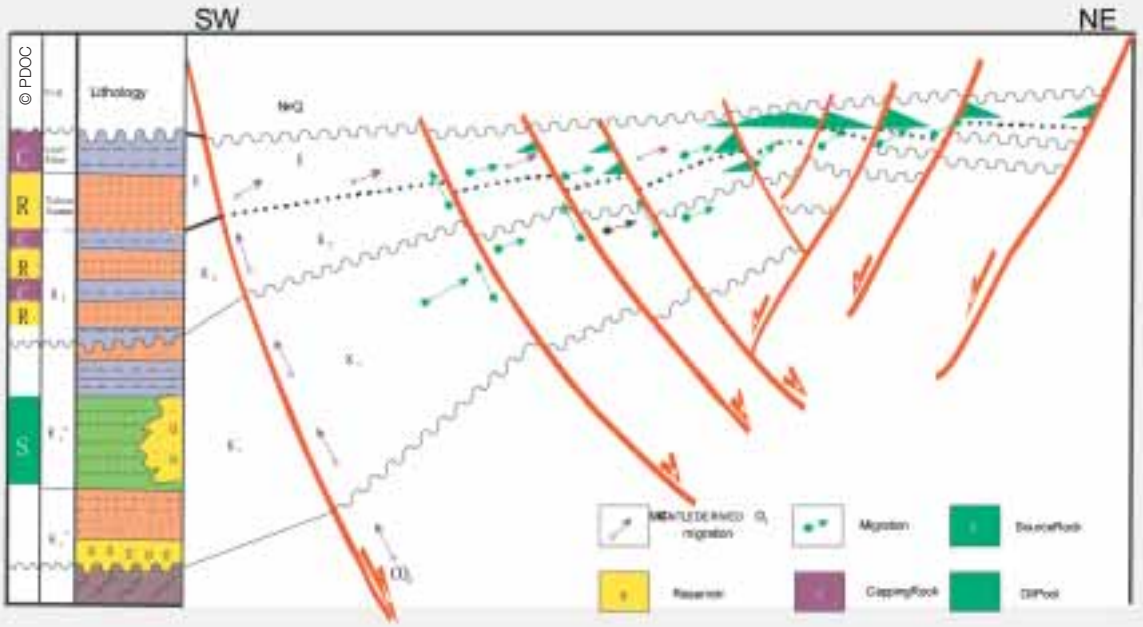
Chevron discovered the Adar-Yale oil field in Block 3 in the Melut Basin, east of the river Nile and some 150 km west of the Sudanese border with Ethiopia, in 1981. Four exploration wells were drilled that all showed flow rates in excess of 1,500 bopd from the **Yabus** Fm sandstones of Paleogene age (compare Geological Time Scale p.12). The field covers an area of about 20 km^2, but the average pay zone is only 2.9m, resulting in 168 million barrels of oil in place. The Adar-Yale oil field was therefore,

The Republic of Sudan

The Republic of Sudan with an area of 2,500,000 km^2 is the largest country in Africa. The scale of the map could be deceiving and may not easily convince you of Sudan's immensity. So then, imagine the entire country of France fitting within the borders of Sudan: five times. From north to south it also equals the US Lower 48 from north to south. The Nile and its tributaries dominate Sudan giving it an overall flat landscape, except where the mountains rise along the Red Sea coast and the western border with Chad. The climate in Sudan is tropical in the south while arid desert conditions prevail in the north. The rainy season is from April to October. Sudan's name derives from the Arabic "bilad al-sudan" which means "land of the blacks." Since independence from Britain in 1956, a north-south war has dominated Sudan's history, pitting Arab Muslims in the northern desert against black Christians and animists in the southern wetlands. Muslim Arabs control the government in Khartoum, but are only about 40 percent of the population. Blacks, or Africans, make up 52 percent of Sudanese, and are most numerous in southern and western Sudan. All the discovered oil and gas fields so far have been made in the interior southern part of the country, including the Muglad and Melut Basins. Pipelines are therefore built all the way to the Red Sea. The Great Palogue Field is located in the Melut Basin in the Upper Nile province, 650 km to the south of Khartoum, the capital of Sudan. The field lies in Block 7, now operated by the Petrodar Operation Company (PDOC), a joint venture between CNODC/CNPC, Petronas, Sudapet, SinoPec and Thani Corporation.



Stratigraphic summary of Lower Cretaceous source rock and corresponding reflection feature on typical seismic section in northern part of Melut Basin.



Hydrocarbon Migration Model

at that time, not considered commercial. However, after Chevron's departure in 1990, the Adar-Yale concession was awarded to Gulf Petroleum Corporation-Sudan (GPC) and it began producing 5,000 bopd in March 1997.

In November 2000, Petrodar Operation Company (PDOC) was established with China National Oil and Gas Exploration and Development Company (CNODC/CNPC) as operator and one of the largest shareholders. Firstly, seismic data was acquired around Adar-Yale oil field, and drilling improved the in place estimates from 168 to 276 million barrels. In 2001, three small oil pools were also discovered south of Adar-Yale oil field, adding another 129 million barrels. To the east of Adar-Yale, several wildcats proved to be dry.

By the turn of the century, the Melut Basin was thus a proven oil province with established production. However, the fields discovered were small and could not be produced with the investment burden of long-distance pipeline construction. PDOC therefore felt the urge to restudy the whole basin with the aim of defining prospects with significant oil potential.

New ideas

The study of the petroleum system in the Melut Basin led to several conclusions that had important implications for the exploration strategy. First of all, based on seismic correlation, it was apparent that the rich Lower Cretaceous source rock interval present in the Muglad Basin and other basins in central Africa, including the prolific Doba Basin in Chad, also was present in the Melut Basin. Moreover, according to the gravity data, the main source kitchen should be present in the northern part of the basin. This then shifted PDOC's exploration focus.

While the main pay zones in the Muglad basin is within the Upper Cretaceous, this stratigraphic interval is lacking in the Melut Basin. The study, therefore, also concluded that sandstones in the Paleogene **Yabus** and **Samma** formations should be the main play of Melut basin, which in consequence shifted the exploration focus from deeper Cretaceous to shallower Paleogene strata.

Two seismic surveys followed. In 2001, five 2D seismic lines with a total length of 103 km were acquired in the western part of the Palogue area. The year after 22 more lines totalling 538 km were acquired. The structural features of the Palogue area then became gradually known. In October

Great Palogue

The Great Palogue Field is located on a huge anticline trending SW-NE with a closure of roughly 80 km² and which is complicated by multiple faults. The closure is defined by faulting and pinch-out of the sandbodies. Each block has a different oil/water contact due to the complexity of the structure and sand continuity. The anticline developed from Late Cretaceous to Miocene.

A thick sequence of Mesozoic to Tertiary fluvial-lacustrine sediments has been penetrated in the Palogue area.

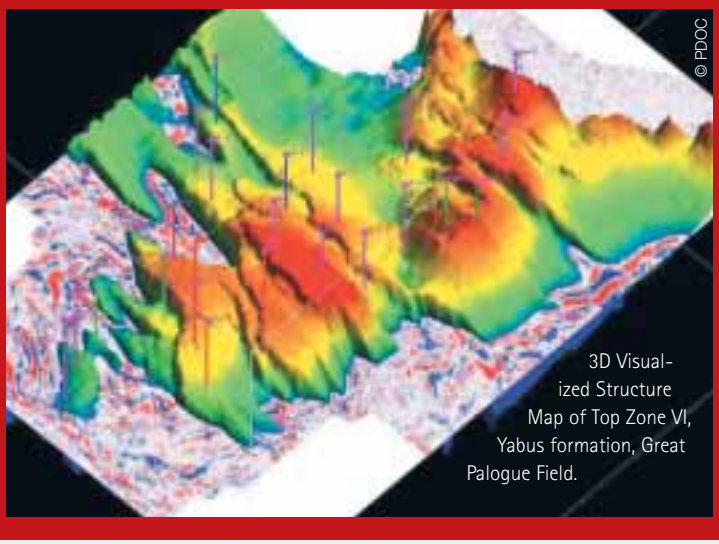
Coarse grained and conglomeratic sandstones of the **Yabus** and **Samma** formations (Paleocene to Oligocene) and the **Galhak** formation (Cenomanian-Santonian), all deposited by meandering rivers and braided rivers, are the main reservoirs. Sandstones in the **Melut** Fm (Upper Cretaceous Campanian-Maastichtian) and **Al Gayger** Fm (Lower Cretaceous Berriasian-Albian) also have favourable reservoir properties, but no discoveries have been made in them yet.

The porosity of lower interval of Yabus formation and Samma formation ranges from 24 to 33%, averaging 29%, while the permeability ranges from 245 to 1583 mD, averaging 643 milliDarcy.

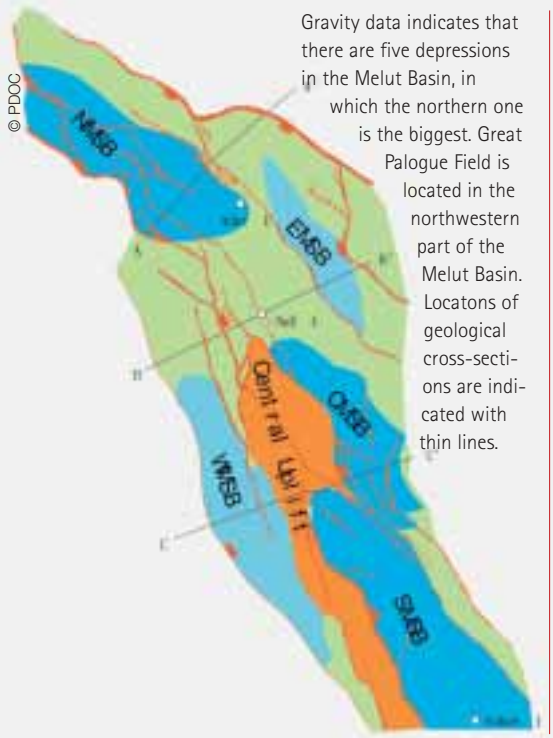
The Miocene section of **Adar** formation is considered the regionally stable seal for the underlying Yabus and Samma reservoirs.

The shales of Galhak Fm (Cenomanian-Santonian) and **Al Renk** Fm (Ablian) display good source potential.

Structure Map of Top Zone VI, Yabus formation, Great Palogue Field.



3D Visualized Structure Map of Top Zone VI, Yabus formation, Great Palogue Field.



Gravity data indicates that there are five depressions in the Melut Basin, in which the northern one is the biggest. Great Palogue Field is located in the northwestern part of the Melut Basin. Locatons of geological cross-sections are indicated with thin lines.

2002, CNODC/CNPC thus proposed to drill wildcat Palogue-1 on the apex in one of the faulted-anticlines.

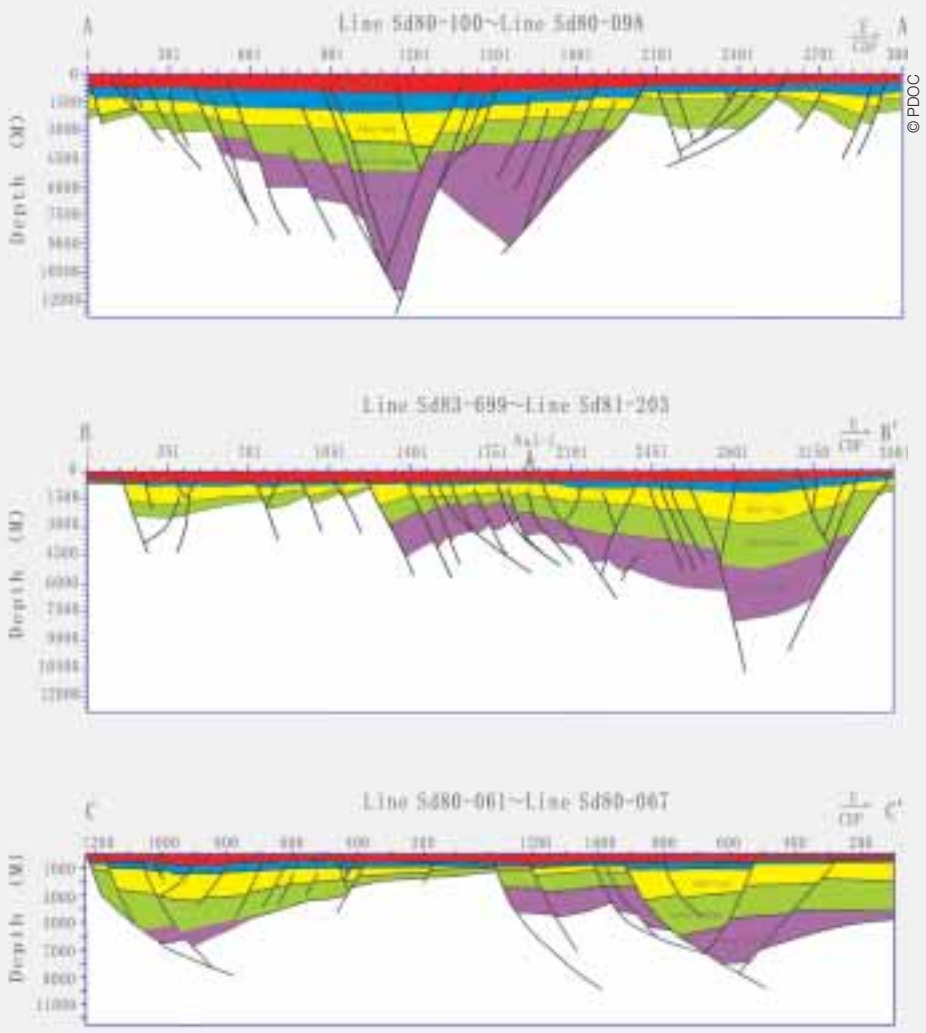
Following the discovery, 308 km² of 3D seismic data and twelve 2D seismic lines with a total length of 431 km were acquired and processed on the main part of the Palogue structure. The 2D seismic grid was later filled in.

Two more wildcats encountered oil in the Paleogene **Yabus** and **Samma** formations and in the Cretaceous **Galhak** formation. Altogether 28 appraisal wells were then designed and drill in succession up to June 2004.

According to the Field Development Plan completed in 2004, 124 developing wells have been designed including the existing 3 wildcats and 28 appraisal wells. The recovery factor is 21%, well spacing is 600 to 800m and peak oil production rate is expected to reach 187,000 bopd 1.5 years after production start-up. The field will use water injection to improve the recovery factor.

The Great Palogue field is expected to start producing in June this year at a rate of around 75,000 bopd, quickly rising to 125,000 bopd and reaching 150,000 bopd by the end of 2006.

Fresh water is more precious than oil and gas in most of Sudan.



Geologic cross-sections in the Melut Basin showing the half-graben structural style. All basins were initiated in the Early Cretaceous, when a series of large NW-SE trending half grabens developed. From Early to Mid Tertiary, periodic pulses of extensional deformation occurred in the north (Tethys and Mediterranean) and the northeast (the Red Sea and the Gulf of Aden). During Late Tertiary times, transtensional reactivation occurred in response to collision along the northern margin of Arabia and cessation of fault activity in the Red Sea.

Oil in the Great Palogue field is mainly medium gravity (20°API to 34°API) and heavy gravity (15°API to 20°API), has a high pour point and high asphaltene as well as wax content. Deeper than 1250m, API gravity decreases with increasing depth. This implies that biodegration and possibly deasphaltizing by CO_2 derived from the upper mantle is entering the basin along the southern boundary fault of the northern Melut Basin.

The Upper Cretaceous Melut formation consists predominantly of massive sandstones interbedded with thin claystones. We consider these rocks to constitute the migration pathway from the source kitchen to the trap.

A Cretaceous rift

Both the Muglad Basin, roughly the size of the North Sea Basin, but with less than 150 exploration wells drilled so far, and the Melut Basin remain largely unexplored. Both basins are part of the huge Cretaceous rift system that extends across central Africa and which also includes the Doba Basin in Chad with significant oil production.

The richness of this rift system is related to the presence of organic-rich lacustrine source rocks deposited during the Lower Cretaceous.

The discovery of the Great Palogue field in the little explored Melut Basin was a result of a belief that both source rocks and reservoir rocks were present. Thorough geological studies using modern exploration technology proved to be successful.

Source, maturation and migration

Lower and Upper Cretaceous shales both have a good source potential in the Melut Basin. Total organic carbon determinations of ditch samples indicate intervals of good to excellent organic content within the lower part of Upper Cretaceous Galhak formation and upper part of Lower Cretaceous Al Renk formation. Results of Rock-Eval pyrolysis indicate that these intervals show variable capabilities for generating oil, mainly from type II kerogen.

Modelling has shown that the deepest part of the northern Melut Basin entered the oil window in the Late Cretaceous. During late Miocene, the Cretaceous source rocks began to generate oil. At this time the deepest part of Melut Basin entered the gas window.

Muslim Arabs make up about 40 percent of the population in Sudan.