

Frontier with high expectations

Mozambican authorities have good reasons to be optimistic when embarking on a new exploration campaign. Seeps of oil and gas are well documented at several localities in the Rovuma Basin, and potential source rocks are considered to be present throughout the area. Good quality reservoir rocks with high porosity have also been identified during a recent onshore mapping project.

The 2nd round

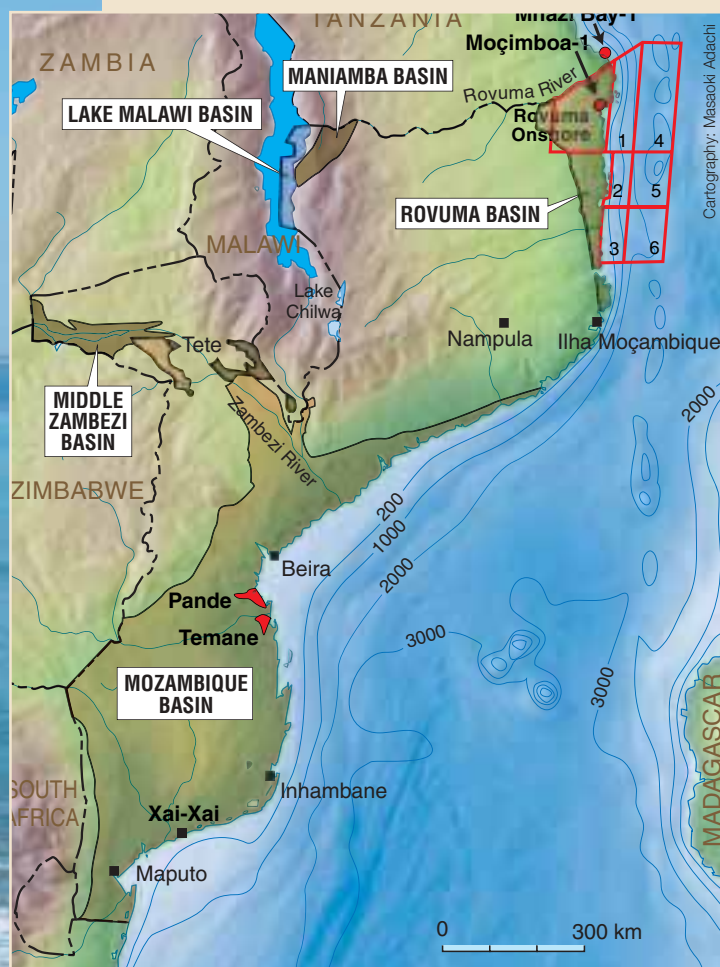
Instituto Nacional de Petróleo (INP) closed the Mozambique Second Licensing round on the 31st of January 2006.

This round focused on the onshore and offshore Rovuma Basin in northern Mozambique. The areas on offer extend from the border with Tanzania in the North, to the port city of Nacala in the South.

INP has reported that seven applications have been received covering all blocks in the round (both onshore and offshore). Three com-

panies have applied for the onshore acreage (Artumas, Petrobras and Rockover), while six companies have applied for the offshore blocks (Anadarko, Artumas, ENI, Norsk Hydro, Petrobras and Petronas). Block 1 was the most sought after, with four applications. Recently, the offshore Rovuma Basin Areas 2 and 5 were licensed to Norsk Hydro.

The evaluation of the bids has started and it is anticipated that license awards will be made by June 2006 (<http://www.inp-rovuma.com/>).



Mozambique, located in southeast Africa, has a 2,500 km coastline with the Indian Ocean and a wide coastal plain that varies in width from 150 to 600 km. The major part of the country consists of undulating plateaus. Mountainous areas occur along the border with Zimbabwe. Precambrian rocks underlie approximately half of the country, mainly in the north and northwest. Karoo sediments (Permian-Triassic) occur in small areas of northern and northwestern Mozambique and Karoo volcanics are exposed in the Lebombo Mountains, close to the border with South Africa. Mesozoic to Cenozoic sediments underlie large parts of southern and central Mozambique (the Mozambique Basin) and northeastern Mozambique (Rovuma Basin).

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European explorers had visited the Rovuma Basin long before the petroleum industry became attracted to the area. Dr. David Livingstone (1813-1873), the Scottish doctor and missionary who is considered one of the most important European explorers of Africa, explored the River Rovuma in 1859 and discovered Lake Chilwa in Malawi. We presume he was as fascinated by the quiet beauty of the landscape of this region as we were during our recent mapping efforts in the same area.

In 1866 Livingstone again travelled along the River Rovuma. This time he was aiming for Lake Tanganyika (reached in 1869) and later ventured further to discover the source of the Nile. Nothing was heard from Livingstone, and his welfare became a matter of international concern. When staying in a village along Lake Tanganyika in 1870, Livingstone was met by a rescue party led by Henry Morton Stanley,

who is said to have greeted the explorer with the famous remark, "Dr. Livingstone, I presume?"

The Rovuma Basin

For the last 3 years geologists from Norway, Great Britain and Mozambique have been working in northern Mozambique for the purpose of mapping the 160,000 km² area at a scale of 1:250 000. Last summer the team also studied, onshore, the sedimentary rocks onshore the Rovuma Basin, which is now going to be actively explored for oil and gas. The findings support the high expectations, but also document some of the major uncertainties for success in the exploration of this frontier area.

The Rovuma Basin is about 400 km long and 160 km wide and is centred on the Rovuma Delta near the border between Mozambique and Tanzania. The basin extends both onshore and offshore, cover-

View towards the Indian Ocean from the Cabo Delgado lighthouse, with raised reefs and an inner wave cut carbonate platform exposed at low tide.

Photo: Morten Smelror



BGS geologist John Powell studying poorly sorted sandstones along the beach section at Ponta Vermelha, near Moçimboa da Praia.

ing over 70,000 km² of northeastern Mozambique, approximately the same size as the Viking Graben of the North Sea.

The Rovuma Basin belongs to the East African passive margin system. The basin history is directly linked to the progressive break-up of southern Gondwana, and the sedimentary succession of the basin can be divided into five tectono-stratigraphic mega-sequences reflecting the different break-up stages: These are as follows:

- 1) The first stage was Pre-rift during the Permo-Triassic; these sequences are poorly known in the basin, but are expected to be equivalent to the Karoo succession with continental clastics, possibly containing coal-beds.
- 2) Syn-rift sediments comprising predominantly continental clastic sediments deposited in a series of half-grabens during the Triassic to Early Jurassic. A period with southerly migrating marine influence led to the deposition of evaporites in the northern parts of the basin.

- 3) An early drift phase in the Mid Jurassic-Mid Cretaceous during which restricted shallow-marine limestone and marine clastics were deposited on the western platform of the evolving ocean. As Madagascar separated southeastwards from the African mainland during the Middle Jurassic, a passive margin developed. An extensive carbonate platform developed before it gradually became covered by prograding Upper Jurassic to Middle Cretaceous marine clastics. As much as 3 km of sediments may have been accumulated in the deepest part of the Rovuma Basin.
- 4) During the Mid-Cretaceous to Paleogene late drift phase the platform areas became depositional sites for open marine marls and argillaceous limestones.
- 5) The final phase is marked by deltaic progradation from the Oligocene to the present. In the Oligocene, the East African Rift System experienced uplift and

doming, and the Rovuma Delta system began to form. During the succeeding period from mid-Tertiary to Recent, the development of this delta system continued and a thick, eastwardly prograding clastic wedge accumulated in the northern Rovuma Basin.

Petroleum systems

Potential hydrocarbon plays in the Rovuma Basin include traps in pre-rift fault blocks (Phase 1), stratigraphic traps in Middle-Upper Jurassic shelf-edge carbonates and Middle-Upper Cretaceous sands (Phase 4). Younger plays include stratigraphic traps in Lower Tertiary basin-floor fans and structural traps associated with deltaic growth faults in Oligocene-Miocene deltaic sands (Phase 5), as proven by the Mnaazi-Bay 1 discovery in the Tanzanian sector. There is also interest in potential structural traps for Upper Jurassic-Lower Cretaceous sand reservoirs on the Ibo High (Phase 3).

Potential source rocks are considered to be present in the syn-rift and early drift sequence throughout the basin, but little has been documented. Analyses of the several seeps encountered in the basin point to two distinct types of oils, proving active petroleum systems. These are interpreted as having been derived from source rocks of Jurassic (Phase 2 synrift?) or older age.

The Rovuma Basin system contains several intervals of good quality reservoir rocks. The pre-late drift continental deposits (pre-Lower Cretaceous) found onshore in the northwest Rovuma Basin are generally expected to show mostly low net-to-gross ratios due to diagenesis, but the contemporaneous paralic and shallow marine clastics towards the east and southeast are expected to have fair to good reservoir potential, with moderate to minor reduction of porosity. The Aptian-Albian succession comprises reservoir sands of good quality. The main reservoir unit in the Moçimboa-1 well comprises channel sandstones deposited towards the proximal part of a turbidite fan.

The recent onshore mapping program has documented that similar turbidite sandstone systems are present over larger areas to the south in the Rovuma Basin. Similar to the Aptian-Albian fans found in the onshore parts of the basin, good reservoir units are expected in Upper Cretaceous-Lower Tertiary fan systems in the offshore domain. Good quality reservoir rocks are also proven in the delta plain and slope

Hydro awarded two blocks

In February, an Exploration and Production Concession (EPC) Contract for Areas 2 and 5 in the Rovuma Basin offshore Mozambique was signed between the government of the Republic of Mozambique, the national oil company Empresa Nacional de Hidrocarbonetos de Moçambique (ENH) with 10 % and Norsk Hydro Oil and Gas Mozambique (operator) with 90%.

Areas 2 and 5 cover approximately 14,500 km² immediately to the east and north of Pemba, the provincial capital of the Cabo Delgado Province. Water depths in the areas range from shallow to more than 2,000m. Following implementation of the contract the first priority will be to complete an environmental impact assessment prior to conducting initial seismic operations.



Photo: Ola Magne Seathar

Morten Smelror, senior author of this article, studies hydrocarbon seeps in Tertiary sandstones at Wimbe Beach. The seeps lie below the high water mark and are mostly heavily biodegraded.

and pro-delta sandstones in the Upper Tertiary Rovuma Delta. The Mnazi Bay-1 well drilled in Tanzania just north of the Mozambican border in 1982 tested gas rates up to 14mmcf/d from Oligocene sands of the Rovuma Delta Complex.

More than petroleum

Mozambique is a developing country with one of the highest population growth rates in Africa. Years of civil war, droughts and floods have severely impeded" foreslår justert til "Mozambique is one of the world's poorest countries with one of the highest economical growth rates in Africa. Years of fight for independence, civil war, droughts and floods have severely impeded the development of the country, but twelve years after the end of the civil war, inflation is under control and the country is gradually being rebuilt. However, according to UN statistics, 38% of the population still lives on less than US \$1 per day.

The country has a large natural resource potential. At present, the economy is largely based on agriculture, fisheries, tourism and transport and only a small percentage of the total mineral resource is currently being exploited. Mozambique has potential for mining for coal, titanium, minerals and gold, as well as a range of less exotic products that are all essential for basic development,- such as building stones, aggregates and fertilizer minerals. Since the end of the civil war increasing amounts of gold, gemstones, marble and graphite, as well as coal, have been mined. World-class titanium-rich sands were discovered inland, near -Xai, about 250 km north of

Exploration history

Exploration for hydrocarbons in Mozambique goes back to 1904 when the early explorers discovered thick sedimentary strata in the onshore basins. In the earliest years, however, poor technology and lack of funds halted those early exploration attempts.

After the termination of the 2nd World War, international oil companies moved into Mozambique and carried out extensive exploration, mainly onshore but with limited activity offshore. In 1961, Gulf Oil discovered the **Pande Gas** field in the Mozambique Basin (present reserves are 3.5 Tcf). The small gas discovery, **Búzi**, 50 km southwest of Beira was discovered in 1962 and the **Temane** field in 1967 (present reserves 1.2 Tcf). Exploration activity declined in the early 1970's due to political unrest.

New activity was established in the Mozambique Basin in the early 1980's with the creation of Empresa Nacional de Hidrocarbonetos de Moçambique (ENH). In the following years extensive work was carried out to map and appraise the Pande Field. A breakthrough was made in 1993 when it became clear that the Pande Field could be mapped using direct hydrocarbon indicators (DHI) from seismic data and it turned out that there was a giant bright spot at the top of the reservoir. The method was later also used to map the Temane field with good result.

An extensive drilling campaign conducted by the South-African oil company Sasol in 2003, which included exploration and production wells in the Pande/Temane Block, allowed the expansion of gas reserves, including additional reserves in the **Inhassoro Gas Field** that was also discovered during this campaign.

Gas from the Temane field was put on stream in 2004, most of the gas being exported to Secunda in South Africa via a 865 km long gas pipe line.

Exploration in the Rovuma Basin started 25 years ago when CGG in 1980 acquired a total of 15,211 km of aeromagnetic data. The following year approximately 1,000 km of seismic were shot by Geco in the offshore Rovuma Basin as part of their larger survey covering the northern part of the Mozambique continental margin. These data were acquired in preparation for the 1983-licensing round, in which Shell and Esso were awarded the onshore portion of

the Rovuma Basin.

In 1986, the onshore **Mocimboa-1** well drilled by Esso encountered strong gas shows in Albian sandstones. Due to drilling problems the well was plugged and abandoned untested. The license was relinquished later that year, and this is the only well drilled onshore in the Mozambican part of the Rovuma Basin. Exploration activities in the Tanzanian part of the Basin have resulted in the AGIP-Amoco **Mnazi Bay-1** gas discovery, which is currently being planned developed. Further north of the Rovuma Basin by the Mafia Basin is the AGIP **Songo-Songo** gas discovery, which started production in June 2004. This was drilled just north of the Mozambican border in 1982 and tested gas at rates up to 14 mmcf/d from Oligocene sands of the Rovuma Delta Complex.

During the 1980s 2,100 km onshore seismic, 300 km offshore seismic, gravity data, and 15,000 km aeromagnetic data was acquired.

Interest in the Mozambique part of the Rovuma Basin was renewed in the 1990's. This was largely in response to the political stability that had been achieved following some 20 years of civil war. In 1994 Mozambique Petroleum NL acquired 3,800 km of new seismic, and in 1998 Western Atlas was contracted by Lonrho de Rovuma Petroleum (Lonropet) to acquire 3,200 km of 2D offshore seismic data. Lonropet had received a seven years contract (from 1995) to the exploration rights both onshore and offshore.

In March 2000 the first Mozambique Licensing Round was announced, offering 14 blocks, mainly in the Mozambique Basin covering the shallow and deep Zambezi area.

Having received seven applications in the 2nd licensing round, Mozambique is again entering a new era in their efforts to find commercial quantities of hydrocarbons.



Photo: Morten Smelror

Coral exposed on the raised carbonate platform at Ponta Uifundo.



Photo: Terje Thorsnes

Small traditional fishing boats at Tandauganhui Village.

Maputo. Small-scale mining for gold has attracted many thousands of miners and migrant workers, and the International Labour Organization (1999) estimates the number of people involved in small-scale mining in Mozambique at up to 700,000.

Mozambique is also considered to have major potential for hydroelectric power, in addition to Cabora Bassa, one of three large dams on the Zambezi river system. This is Africa's second largest dam and the largest power-producing barrage on the continent. The dam began to fill in 1974 and the lake has reached a maximum length and width of approximately 250 and 38 km.

Development of the Petroleum Sector

Until 1995 both the responsibilities for commercial and governmental functions linked to hydrocarbon exploration and exploitation in Mozambique had been placed within the National oil company Empresa Nacional de Hidrocarbonetos de Moçambique (ENH). In order to split the commercial and governmental functions the National Directorate for Coal and Hydrocarbons (NDCH) was set up under the administrative control of the Ministry of Mineral Resources and Energy.

In May 2002 the Norwegian Petroleum Directorate (NPD) signed an agreement with the National Petroleum Institute in Mozambique, with the objective of assisting the development of the petroleum sector in Mozambique. In 2005 the NDCH was converted to an autonomous body, Instituto Nacional de Petróleo (INP), under

the new Ministry of Mineral Resources. INP still have all governmental functions previously held by NDCH, except the responsibilities of coal.

Norwegian support to the development of the petroleum sector in Mozambique started as early in 1983. During the first years the main focus was on commercialization of the Mozambican gas resources and assistance in promoting Mozambican exploration acreage. From 2002 to 2005, experts from NPD provided assistance with

the assessment of discovered resources, licencing of new acreage (including the Rovuma Basin), petroleum data management, and supervision of the large Pande/Temane Natural Gas Project. Through the last project most of the gas is now brought to markets in South Africa via an 865 km long pipeline, as well as some gas to local markets in Mozambique. Further institutional support and cooperation between INP and NPD is planned over the next three years.

Onshore mapping

During the last three years the Geological Survey of Norway, the British Geological Survey and the National Directorate for Geology (DNG) in Mozambique have jointly conducted a project aimed at mapping the bedrock in Northern Mozambique. The Norwegian engineering consultancy company, Norconsult, which has long experience of work in Africa, is the lead agency in the consortium. The fieldwork was completed in 2005.

The project is financed by the Nordic Development Fund, as part of a comprehensive program for mineral resource development under the overall management of the World Bank. The main contract covers an area equivalent to 18 single-degree map-sheets at a scale of 1:250,000, and selected sheets at 1:50,000, in an area of 160,000 km². The maps form a basis for assessing the mineral resource potential of the country. They are the property of Mozambique's Ministry for Mineral Resources, which will be responsible for their release to industry and for their broader use in resource management.

"The bedrock in northern Mozambique is mainly Precambrian, formed ca. 1,100 million years ago. There are gold diggings in the northwestern part of the field area and

extraction of marble as dimension stone, garnet and semi-precious stones in other areas. Both Tanzania to the north and South Africa to the west have diamond mines," says project manager Ron Boyd, NGU.

"Kimberlite, which is the right sort of host-rock for diamonds, has been found in northern Mozambique, but no diamonds as yet, and a great deal of work needs to be done before we know if the country has potential for economic deposits of diamonds," Boyd adds.

During the 2005 field season the team from NGU/BGS/DNG covered the Cabo Delgado Province, which includes the Rovuma Basin on the northeast coast. Here, the sedimentary succession dips very gently (3°) from the west towards the coast, and small exposures of the sedimentary formations are found along roadsides, streams, smaller cliffs, in local quarries, and along the coastal shoreline to the very east. The results from the mapping program and follow-up analyses are expected to constrain the lithostratigraphy, and provide new insight on the chronology and mineralogy of the sedimentary formations of the Rovuma Basin.



Photo: Terje Thorsnes

Mapping of early rift-conglomerates and sandstones west of Ngapa.



Photo: Morten Smeier

Preparation and packing of samples at the Motoro Field Camp.