

Is Brazil's Prolific Pre-Salt Petroleum Geology a Template for Oil & Gas Exploration in West Africa?

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The Pre-Salt of Brazil – Implications for West Africa

In 2006 a milestone event happened in Brazil which held great significance for West Africa: the discovery of the **Lula** oilfield in the offshore Santos Basin. This field was originally called *Tupi* but was renamed *Lula* after Brazilian President Luiz Inacio Lula da Silva.

But why would a discovery in far away Brazil have significance for West Africa? Geologists have known for many years, on the basis of extensive paleontological research, outcrop and seismic information, that in Early Cretaceous time (135 million years ago), Angola and Brazil were part of Pangea – literally “joined at the hip” – so the geology of both was assumed to be identical.

About 125 - 130 million years ago South America began to separate from Africa and as the continents drifted apart, an extensive rift valley was formed, containing large lakes with abundant organic material that had washed off the adjacent highlands. In Angola, these sediments are known as the Bucomazi formation, an exceedingly rich oil and gas source rock. The rift valleys are similar to the present-day East Africa rift system.

As Africa and South America continued to move apart the sea transgressed into the rift system. Since the area invaded by the sea was still long and narrow, from time-to-time the sea was cut off by adjacent land masses and the water evaporated, leaving behind thick deposits of salt. Further continental separation resulted in the laying down of more thick deposits of marine sediments.

Fast-forward 130 million years, and Brazil is now 7,000 km west of the West Africa coastline. Nonetheless, the discovery of the Lula oilfield in Brazil was truly a milestone event for West Africa. Petroleum geologists quickly recognized the implication that, for example, the Santos Basin deposits could be duplicated in Angola's Kwanza and Namibe Basins, to which they were once juxtaposed. So immediately after the discovery of the Tupi field geologists, on the other side of the Atlantic Ocean were searching through any available geological and geophysical data for Tupi look-alikes.

The well which found the Lula field was **Tupi-1**. It was drilled by Petrobras in the deepwater part of the Santos Basin – in water depths of 2,100 m, with the well drilled a further 5,200 m below the sea floor. The Lula field is in a high pressured, high temperature environment beneath a massive, 2 km thick salt sheet. The cost of Tupi-1 was a staggering \$240 million, but the reward was finding a mega-giant oil field and the opening up of the pre-salt oil play in Brazil.

Accordingly, Lula was the first of the now famous pre-salt oil fields in Brazil, proving that a working petroleum system exists beneath the salt layer of the Santos Basin. The oil source rocks are the organically rich lake shales, the reservoirs are porous microbialitic limestones and dolomites, and the seal above the reservoirs is the thick, impervious salt layer.

Noteworthy is that the Santos Basin was explored for at least two decades for oil and gas in the post-salt sediments. Seismic was not able to penetrate through the thick salt layers therefore Lula might never have been discovered. However, seismic recording and processing technology improved dramatically during the late 1990's and early 2000's and was able to define the sedimentary layers and structures beneath the salt. As wells were drilled beneath the salt, geologists recognized they were dealing with lacustrine, microbialitic carbonates and were able to accurately map the reservoirs using the new seismic and new well data. Accordingly, the discovery of Lula and the follow-up pre-salt fields must be recognized as a true geosciences success story.

According to Petrobras, the field has recoverable reserves of 5.3 billion barrels oil and 6.9 trillion cubic feet of gas. Petrobras (65% working interest) operates the field on behalf of partners BG Group (25%) and Galp Energia (10%). Two FPSOs (Floating Production Storage & Offloading), Lula pilot and Lula NE, are currently producing the Lula field. The wells in Lula are averaging production of 25,000 bopd per well.

An oil field even larger than Lula was discovered in the Santos Basin in 2010. Petrobras, on behalf of the Brazilian regulator Agencia Nacional do Petroleo (ANP) discovered Libra in 2,000 m of water. The discovery well intersected a continuous oil column of 325 m in carbonate rocks below the salt. Test results indicated good quality light oil with 27 degree API. In October, 2013 a consortium of Petrobras (40%), Shell (20%), Total (20%), CNPC (10%) and CNOOC (10%) was awarded a 35-year production sharing contract to develop Libra. The consortium agreed to pay to Brazil's government a signature bonus of \$6.7 billion for the field rights. Shell has described the field as one of the largest deepwater oil accumulations in the world. According to ANP, Libra has the potential of 8 to 12 billion barrels of recoverable oil resources. Libra's total gross peak oil production could reach 1.4 million bopd, according to ANP.

Oil industry analysts such as Wood Mackenzie and IHS have estimated that Brazil's pre-salt volumes could amount to some 20 – 30 billion barrels of recoverable oil, while ANP has stated that that the volumes could be as much as 50 billion barrels.

The impact of the pre-salt discoveries on Brazil has been dramatic: Brazil's oil production is now 2,200,000 bopd of which 700,000 bopd is from the pre-salt fields. Approximately 50% of the pre-salt production is from the Santos Basin and the other 50% is from the Campos Basin. The pre-salt oil production is coming from only about 33 wells which is equivalent to 21,000 bopd per well. Petrobras believes that output from these reservoirs will grow and bring Brazil's overall output to about 4.0 million bopd – nearly double the country's current production.

From an economic view point, the pre-salt production is extremely important for Brazil. The production from Brazil's mature post-salt fields has been declining rapidly. Brazil is approximately oil neutral meaning that its oil consumption is met by its oil production. But had the pre-salt fields not been discovered, then Brazil would have needed to begin importing significant volumes of oil which would have had a serious impact on Brazil's economy.

Angola's Recent Pre-Salt Successes

For petroleum explorers, the deepwater Kwanza Basin has become one of the most exciting basins in the world. A historic event occurred in 2011 with the awarding of 11 pre-salt blocks by Sonangol to BP, Cobalt International, ENI, Total, Repsol, ConocoPhillips, and Statoil.

In 2011, the Danish oil company, Maersk Oil had already embarked on drilling in deepwater Kwanza Basin Block 23 and in early 2012 announced the results of its first well, **Azul-1** drilled specifically to evaluate a pre-salt prospect. The well was drilled in a water depth of 902 m to a depth of 5,330 m. Azul-1 was tested at 3,000 bopd. In the history of Angola's oil industry, this well is historic since it was the first-ever deep water well drilled in the Kwanza Basin which flowed oil from the pre-salt.

The announcement of the Azul-1 oil discovery was shortly followed up by the announcement by Houston, Texas-based Cobalt International Exploration of the success of its first well drilled in Block 21 in the Kwanza Basin, **Cameia-1** which tested high quality oil from the pre-salt. Cameia-1 was drilled in a water

depth of 1,680 m. An extended DST (drill stem test) was performed on Cameia-1 which flowed at a sustained rate of 5,010 bopd of 44 degrees API oil and 14.3 million cubic feet of associated gas per day thus approximately a total of 7,400 barrels of oil-equivalent per day. Cobalt reported that the well confirmed the presence of 360 m of gross continuous oil column with over 75% net-to-gross. No gas-oil nor oil-water was evident on the wireline logs. Cobalt stated that it believed that the well has the potential to produce in excess of 20,000 bopd.

Approximately one year later, Cobalt announced another important pre-salt discovery which was the **Lontra-1** well drilled in Block 20. This well was drilled to a total depth of 4,195 m and penetrated 75 m of high quality reservoir section. The well flowed at a stabilized flow rate of 2,500 barrels per day of condensate and 39.0 million cubic feet of gas per day. According to Cobalt, the flow rates were significantly restricted by the surface test facilities on the drilling rig.

An additional very encouraging well was drilled by Cobalt in the first half of 2014. The **Orca-1** well was drilled in Block 20 to a depth of 3,872 m and intersected 76 m of pay in a section which Cobalt described as having excellent reservoir quality. Orca-1 flowed at a facility-constrained rate of 3,700 bopd and 16.3 million cubic feet of gas per day with minimal drawdown. Cobalt has a 40% working interest in Block 20 and is partnered by Sonangol and BP, each with 30% working interests.

However, as with any oil exploration play worldwide, there have also been some failures. ConocoPhillips reported a dry hole on the western edge of the pre-salt play and most recently Statoil reported two dry holes. Also, Petrobras drilled the **Ogonga-1** well which encountered gas that proved to be entirely CO₂.

The Pre-Salt Beyond Angola – North & South Along the Atlantic Coast

The discovery of the Tupi oil field in Brazil's Santos Basin also led the international oil explorers to look along the entire West Africa margin. Exploration wells focused on extending the pre-salt oil play southwards from Angola have been drilled offshore **Namibia** but without success. These wells, all dry holes, were drilled in the last two years by BP, Petrobras, Repsol and the Brazilian company - HRT Oil & Gas. Oil industry analysts have reported that no salt has been encountered in any wells drilled offshore Namibia and likely that pre-salt oil-generating source rocks are not present in Namibia.

However, exploration in the pre-salt northwards of Angola exploration has met with encouragement beginning in **Gabon**. In 2012, Total announced that the **Diaman-1B** well, the first well to explore in the pre-salt of deepwater Gabon, encountered up to 55 m of gas and condensate pay in pre-salt sandstones thus confirming the existence of a working petroleum system in the pre-salt in deepwater Gabon. The water depth of Diaman-1 was 1,730 m and the drill depth was 5,585 m. Partners in the well included Cobalt and Marathon Oil.

In 2012, in **Congo Brazzaville** the Italian oil company ENI encountered success in the **Nene Marine-1** pre-salt oil discovery. The well was drilled in the shallow waters 17 km off the Congo Brazzaville coastline in a water depth of 24 m. The reservoir is not pre-salt microbialite carbonates similar to the pre-salt oil discoveries of Brazil and Angola but rather is pre-salt sandstones. The discovery was tested at 5,000 bopd of 36 degrees API oil. A third well, Nene Marine-3 drilled 2 km westwards from the discovery well confirmed the hydrocarbons and reservoir continuity. ENI estimates the in-place resources at 1.2 billion barrels of oil and about 1.0 trillion cubic feet of gas. In February, 2014 ENI's upstream chief operating officer, Claudio Descalzi told analysts that the Nene Marine discovery had "cracked the pre-salt code in Congo-Brazzaville" and that further potential will be sought by ENI in a dedicated 2014 exploration program.

Thereafter ENI announced in July, 2014 a significant new pre-salt gas and condensate discovery in the shallow waters of **Gabon**. ENI revealed that the **Nyonie Deep-1** well was located in 28 m of water about 13 km off the coast of Gabon and was drilled to a depth of 4,314 m. The well intersected a 320 m thick hydrocarbon bearing section in a pre-salt clastic sequence of Aptian age (110 million years old). According to ENI, the initial potential in-place resources are 500 million barrels of oil-equivalent.

Lastly, in October, 2014 Shell announced a frontier exploration discovery offshore **Gabon**. The **Leopard-1** well was drilled 145 km off the coast of Gabon in 2,100 m water depth and was drilled to a total depth of 5,063 m. The well encountered a gas column with approximately 200 m of net gas pay in a

pre-salt reservoir. Shell has a 75% interest in the discovery and CNOOC is a partner in the well with 25%.

The recent pre-salt discoveries in Gabon and Congo Brazzaville are encouraging. However, the reservoirs are sandstones so these discoveries are not fully geologically equivalent to the microbialite carbonate reservoirs which are so prolific in Brazil and which have been discovered in Angola.

The Future

As the oil industry keenly watches the success or failure of more drilling in West Africa, everyone is questioning if the success of Brazil's pre-salt oil play will truly be duplicated in West Africa. At this time, it is entirely speculative. More exploration wells are needed. In about two more years, our knowledge of West Africa's pre-salt will be much clearer.

Angola and Brazil have a common cultural heritage due to both countries were colonized by Portugal. Portuguese is the national language of both countries. Will the cultural commonality also extend to a commonality in the pre-salt oil and gas reservoirs? In the case of Angola, more drilling will provide answers to such questions.

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The author much appreciates the support from his employer, Gaffney, Cline & Associates to give this presentation. The author is Holland-born and Canada-raised. He graduated in 1971 with a B.Sc. in Geology from the University of Alberta and in 1981 with a B.A. in Economics from the University of Calgary. He joined the oil industry in 1971 and has 44 years of experience which includes 30 years overseas in Indonesia, Nigeria and Angola. He is a long-term member (about 40 years) of the CSPG. He lives in Luanda, Angola where he is an active member of the boards of directors of the AAPG, SPE, and SPWLA. He also frequently leads geological field trips north of Luanda for oil industry professionals, university students and the public-at-large to study Cretaceous sedimentary rocks and robust seepages of pre-salt oil which occur along the eastern margins of the Kwanza Basin.

