Brazil’s Deepwater Pre-Salt Oil Play as a Model for Pre-Salt Oil Exploration in Deepwater West Africa

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Luanda - Angola
This Presentation.....

• This presentation is entirely based on public domain, published information
• No confidential information is in this presentation
• This presentation reflects the personal views of the presenter who accepts responsibility of any errors, omissions or oversights
Sources of Information

• AAPG Bulletins & Explorer magazine
• SPE Journal of Petroleum Technology
• SEG First Break mag., also GeoExPros in 2013
• Offshore Engineer, Oil & Gas Journal, Upstream magazines
• Lentini & all, Petroleum Geoscience bulletin, 2010
• Ian Davison (EarthMoves), PESGB-HGS Joint Africa Meeting, 2011
• Cobalt and Petrobras websites
Info on the presenter Tako Koning:

**Holland-born & Alberta-raised**

- B.Sc. in Geology from University of Alberta (1971) and B.A. in Economics from the University of Calgary (1981)

- 43 years *non-stop* oil industry experience

- Retired from Texaco after 30 years worldwide, also consulted for Tullow Oil and now for Gaffney, Cline & Associates

- Has lived & worked 22 years in Africa - Angola (19 years) and Nigeria (3 years)
Presentation Outline

• Geology of West Africa
• Oil Production of West Africa
• Brazil’s Gigantic Pre-Salt Oil & Gas Discoveries
• Brazil vis-à-vis West Africa’s Pre-Salt: Namibia, Congo Braz, Gabon
• Pre-salt of Angola
• Possible Future of Angola’s Oil
The Golden Triangle for Deepwater Oil & Gas Exploration: The Gulf of Mexico – Brazil & West Africa
### West Africa Oil Production – Current Production in BOPD (Barrels Oil Per Day)

<table>
<thead>
<tr>
<th>Country</th>
<th>Production (BOPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nigeria</td>
<td>2,200,000</td>
</tr>
<tr>
<td>Angola</td>
<td>1,750,000</td>
</tr>
<tr>
<td>Congo Brazzaville</td>
<td>340,000</td>
</tr>
<tr>
<td>Equatorial Guinea</td>
<td>320,000</td>
</tr>
<tr>
<td>Gabon</td>
<td>240,000</td>
</tr>
<tr>
<td>Ghana</td>
<td>110,000</td>
</tr>
<tr>
<td>Chad</td>
<td>100,000</td>
</tr>
<tr>
<td>Cameroon</td>
<td>75,000</td>
</tr>
<tr>
<td>Ivory Coast</td>
<td>30,000</td>
</tr>
<tr>
<td>Congo DRC</td>
<td>25,000</td>
</tr>
<tr>
<td>Mauritania</td>
<td>2,000</td>
</tr>
</tbody>
</table>

**Total 5,192,000 BOPD**

Top 20 Oil Producing Countries

• The following two slides show the top 20 oil producing the countries in the world; these numbers are black oil (crude oil) and not condensate and NGL’s
## Global Oil Production – Top 20

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Production (BOPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Russia</td>
<td>10,500,000</td>
</tr>
<tr>
<td>2</td>
<td>Saudi Arabia</td>
<td>9,500,000</td>
</tr>
<tr>
<td>3</td>
<td>USA</td>
<td>8,800,000</td>
</tr>
<tr>
<td>4</td>
<td>China</td>
<td>4,200,000</td>
</tr>
<tr>
<td>5</td>
<td>Canada</td>
<td>3,300,000</td>
</tr>
<tr>
<td>6</td>
<td>Mexico</td>
<td>2,500,000</td>
</tr>
<tr>
<td>7</td>
<td>UAE</td>
<td>2,400,000</td>
</tr>
<tr>
<td>8</td>
<td>Iraq</td>
<td>2,400,000</td>
</tr>
<tr>
<td>9</td>
<td>Kuwait</td>
<td>2,400,000</td>
</tr>
<tr>
<td>10</td>
<td>Nigeria</td>
<td>2,200,000</td>
</tr>
</tbody>
</table>
Global Oil Production – Top 20

11.) Brazil 2,200,000 BOPD
12.) Venezuela 2,100,000
13.) Iran 2,000,000 - reduced due to sanctions
14.) Norway 1,800,000
15.) Angola 1,750,000
16.) Algeria 1,700,000
17.) Kazakhstan 1,600,000
18.) Libya 1,300,000 - now down to 400,000 bopd
19.) UK 1,200,000
20.) Qatar 1,200,000
Key Points of Presentation

• Brazil’s pre-salt oil and gas discoveries are truly stunning!

• Brazil’s pre-salt could be “duplicated” in West Africa – initial drilling results in Angola and Gabon are encouraging but much more drilling is definitely needed

• Development of Brazil’s pre-salt will be very challenging due to deep water conditions, deep reservoirs, high CO2
• Brazil as a Model for Pre-Salt Exploration in West Africa
Impact of Brazil’s Recent Pre-Salt Mega-Oil Discoveries on Angola’s Oil & Gas Potential

• Major world class pre-salt (sub-salt) oil and gas discoveries have been made since 2006 in the deepwater of Brazil

• Petrobras believe the pre-salt fields could be producing 1.8 MM BOPD by 2020 thereby doubling Brazil’s oil production to 4.0 MM BOPD ((very ambitious target))

• Brazil and Angola were contiguous in Early Cretaceous time

• This play has been minimally evaluated in the deepwater of West Africa
Reconstruction of the South Atlantic Ocean evolution

A: Neocomian to Lower Aptian age

B: Aptian age

C: Albian age

D: Upper Cretaceous age
Geology

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**BRAZIL**  
**AFRICA**

**SALT LAYER**  
**UP TO 2 KM**

**LIMESTONE**

**SYNRAFT SANDS**

**HIGHLY ORGANIC, OIL GENERATING LAKE SHALES**
BRAZIL!!!

• What is happening in the pre-salt of Brazil?????
Brazil’s Pre-salt: An Incredible Geosciences Success Story

• Tupi pre-salt oil field was discovered due to the ability of geophysicists to obtain definitive seismic data beneath the salt and due to geologists to understand the depositional environment of the microbalalite reservoirs
Mega-Oil & Gas Discoveries in Brazil: LULA FIELD (Previously Tupi)

- Tupi Field discovered in 2006 in offshore Santos Basin
- Estimated 5.7 billion barrels recoverable reserves
- Reservoir is in the subsalt in Lower Cretaceous microlithic carbonates and coquinas
- Tupi -1 was on an extended well test and flowing at 23,000 bopd (constrained flow rate), 28 API, 10% CO2
- Subsalt follow-up oil discoveries are Carioca-Sugar Loaf, Jubarte, Iara; also Jupiter discovery called a “giant natural gas field”
Brazil Pre-Salt Oil Production

• Brazil currently producing 2.2 MMBOPD of which >400,000 BOPD is from pre-salt

• Brazil is currently “oil neutral” meaning its oil consumption is met by its current production

• If Tupi was not discovered, then the Brazil would be importing 400,000 BOPD which would have huge economic hardship for Brazil at today’s current oil prices of >$100/barrel
Estimated Extent of Pre-Salt Reservoirs: +/- 800 km length!

The thickness of the salt layer is about 2-3 km in Santos Basin, and is thinning out towards Espírito Santo.
Pre-Salt Discoveries in Santos Basin, Brazil
Libra Pre-Salt Oil Discovery
Libra Pre-Salt Oil Discovery

• Super-giant field with potential of 8 – 12 billion barrels of recoverable oil resources

• Largest pre-salt oil discovery in the prolific Santos Basin, offshore Brazil

• Total gross peak oil production could reach 1.4 million barrels per day

• Companies are Petrobras 40% (operator), Total 20%, Shell 20%, CNPC 10% and CNOOC 10%

Source: TOTAL press release, Oct 21, 2013
Libra Pre-salt Oil Discovery

• Shell describes Libra as “one of the largest deepwater oil accumulations in the world”

• Discovery well 2NP-2A-RJS drilled in 2010 had 326 meters net pay, tested 3,700 BOPD, and ANP indicated it had capacity to produce 30,000 BOPD

• Petrobras-led consortium paid $7.5 billion signature bonus for Libra
LIBRA: @ J. Mann, CGG, 2013, GeoExPro, Oil in syn-rift coquina limestones
Brazil’s Reservoirs Microbalalites

• Question: What are “microbalalites”?

• Answer: These are carbonate rocks (limestones and dolomites) associated with growths of algae known as stromatolites. Next are examples.

• Can be both marine and non-marine; presalt of Brazil are non-marine being continental – lacustrine – lake deposits.
Microbalites - Stromatololites

• Next four slides are of current day stromatololites in Australia and Brazil, marine & lacustrine
Shark Bay, West Australia – Stromatolitic (Algal) Limestones
Shark Bay Microbial Column

Fig. 9. Detail of vertical section of a Shark Bay microbial column from Hamelin Pool, Western Australia, showing coarse and irregular layering. Slab supplied by R. V. Burne.
Thrombolitic stromatolites in the brackish Lake Clifton, Western Australia – from Geoscientist Dec 2009
Stromatolites in the saline Lake Thetis, Western Australia – from Geoscientist Dec 2009
Modern Pre-Salt Reservoir Analogue from shallow water lake in Brazil

Estromatolitos Recentes
Lagoa Salgada, RJ

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Microbalites - Stromatolites

• Next three slides are of Pre-Cambrian stromatolites in Australia and Angola
A columnar stromatolite from the 3.4 billion year old Strelley Pool Group, Pilbara region Australia – from Geoscientist Dec 2009
Southern Angola – PreCambrian Proterozoic Stromatolites
Southern Angola – PreCambrian Proterozoic Stromatololites
Microbalalites - Thrombololites

• Next slide is of algal thrombololites in southern Angola, post-salt Albian age
• Thrombololites are clotted accretionary structures whereas stromatololites are layered algal accretions
Southern Angola – Namibe Basin
Algae Thrombolites
Brazil Pre-Salt Oil & Gas Reservoirs
Geology

• **TOP SECTION**: Microbial carbonates in the sag sequence

• **LOWER SECTION**: Coquinas of the syn-rift sequence
Pre-Salt – Reservoirs
Typical vuggy porosity 9-12%, k 100 mD (Tupi/Lula)
Core & Micrographs of Campos Coquina Reservoir (Upper Rift Section)
Seismic Line (see next slide)

• Next slides shows Petrobras seismic line and then a 300 km long GXT seismic which was published in Lentini et al, 2010
• Note position of Tupi and also Jupiter located 40 km eastwards
• Jupiter has been described as a giant pre-salt gas field with 10 TCF gas and 0.5 billion barrels condensate
Santos Basin NW-SE Regional Seismic Section

The Pre-Salt Play → Basement Highs

Outer High of the Santos Basin
Lentini et al, Petroleum Geoscience 2010

Fig. 11. Regional seismic profiles across offshore Campos and Santos basins, Brazil. In the Santos Basin the onlap fill sequence (OF) is commonly offset from maximum extension (SE) during rifting. From: Lentini & all, 2010, Petroleum Geoscience, Vol 16, pp.217 - 229
Reverse Time Migration section across the Tupi discovery, showing improved definition of base salt and termination of sediments against the salt flanks.

DATA COURTESY: CGG VERITAS MULTI-CLIENT LIBRARY.

Published in Offshore Engineer
CGGVeritas Line Over Tupi – Interpreted by T. Koning
Pre-salt Wells in Brazil

• Outstanding Wells
  - Oil columns up to 400 meter
  - 20,000 to 25,000 BOPD capacity
  - High quality, medium gravity oil

• Challenging Wells
  - 2000 m water depths
  - 7,000 m drill depths
  - Costs of $100 - $150 million
  - High gas CO2 content is a big problem
Pre-salt Wells in Brazil

• April, 1, 2014 Petrobras announced that newly connected SPS-77 well, Spainhao Field, Santos Basin is producing an “excellent” 36,000 BOPD, country’s best performing well to date.
Pre-salt Wells in Brazil

• April, 17, 2014 Petrobras announced that Brazil has achieved 428,000 BOPD from its pre-salt fields
Brazil vis-à-vis West Africa

• Now we look at the correlations between Brazil and West Africa
Symmetric salt basins of equal width on both margins, but thicker salt is present in the downslope Kwanza margin where the allochthonous salt massif reaches 3 km in thickness. The sediments above the allochthonous salt sheet have been uplifted 1.6 km above regional.

Conjugate sections across the Campos and Kwanza basins

Fig. 9. South Atlantic reconstruction at Albian/Cenomanian time (99 Ma) (Scotese 2008) showing distribution of oil and source rock families and their depositional environments. (Modified from Brownfield & Charpentier 2006. Data from Schiefelbein et al. 1999, 2000).

Reconstructions @ Jennifer Greenhalgh, PGS, 2013; note Lula field next to Namibe Basin
@Jacques Biteau et al, Total, 2014

Lower Congo basin
Offshore: 841 wells
Onshore: 158 wells
(Cabinda and FS/FST)

Kwanza basin
Onshore: 171 wells
Offshore: 60 wells

Namibe basin
On/offshore: 0 well

Interior basins
Onshore: 0 well

From: Biteau et al (Total)
EAGE First Break
February 2014
Fig. 13. Regional depth seismic profiles offshore Angola and offshore Gabon. Full, undeformed(?), continental crust is approximately 20–25 km thick and thins to about 5–6 km at the continental–oceanic boundary (COB).
Namibia Pre-Salt

• In 2012 and 2013 dry holes drilled by BP and Petrobras targeting the pre-salt

• HRT drilled 3 dry holes

• No wells drilled in Namibia have found any salt

• My prediction is Namibia will have no pre-salt oil or gas due to lack of pre-salt source rocks
ENI Nene Marine (Congo Brazz) Shallow Water

- ENI discovered in-place resources of 1.2 billion bls oil and 2 TCFG; recoverable resources of 0.7 billion BOE
- Reservoir is pre-salt clastics (*not microbial carbonates*)
- Tested 5,000 bopd 36 deg API
- Two wells now define this discovery

Source: Upstream magazine, World Oil
Gabon – First Deepwater Pre-Salt Hydrocarbon Discovery
Recent Significant Gas Discovery in the Pre-Salt of Deepwater Gabon

- Total & Cobalt discovered 50 – 55 meters net gas pay in pre-salt sandstones successfully proving the existence of a working petroleum system deepwater Gabon; note the was in siliciclastic sandstone and not in carbonates!

- Water depth 1,730 meters, well depth 5,585 meters

- First deepwater well in Gabon targeting the pre-salt
Total Pre-Salt Discovery in Congo Brazaville

- Shallow water – aprox 30 meters W.D.
- One discovery well and one delineation well; delineation well flowed 5,000 bopd
- Reservoir is pre-salt siliciclastic sandstones, *not carbonates*
- Total estimate aprox 700 MMbls recoverable
ANGOLA’S PRE-SALT

• Now we focus on Angola’s pre-salt!!!
Key Milestones in Angola’s Oil & Gas Industry

Sketch Diagram to Explain Libongos Oil Deposit

- Shore line
- Libongos oil saturated outcrops of Pinda carbonates
- Granite outcrop
- Atlantic Ocean
- Tertiary
- Cretaceous Tare
- Pinda rafts
- Pinda
- Salt lakes
- Lacustrine sediments
- Salt
- Oil
- Pre-Cambrian granite

Takokouing April 1, 2013
Dande-4, drilled by Portuguese in 1915 on banks of Dande River, leaking pre-salt oil
Libongos Oil Seeps – Asphalt Deposits and Rivers of Oil!
Pre-salt Bucomazi lacustrine sourced oil seeping out at Libongos, 50 km north of Luanda
Pre-salt Bucomazi lacustrine sourced oil seeping out at Libongos, 50 km north of Luanda

Libongos oil seeps. Here oil has migrated into Pinda-equivalent porous carbonates. This oil has been analyzed by Norsk Hydro and Chevron to be pre-salt oil. The oil-filled Pinda has been eroded exposing it at the surface and creating these oil seeps. Recent (2011 & 2012) pre-salt discoveries in the deepwater Kwanza Basin by Maersk Oil (Azul-1) and Cobalt International Exploration (Cameia-1) has focused attention on these oil seeps since they provide an important data point on the pre-salt of the Kwanza Basin.
ANGOLA 2011 BID ROUND – AWARD OF PRE-SALT BLOCKS

• All blocks are located in the deepwater Kwanza Basin
• Bid round was described as “a historic event in Angola’s oil industry”
• Operators include BP, ENI, ConocoPhillips, Cobalt, Repsol, Total, Statoil
• Blocks were officially awarded in December, 2011
• Chevron, Exxon, Petrobras, Shell & Galp Energia were conspicuous by their absence
Kwanza Basin deepwater drilling
PUBLICALLY ANNOUNCED INFO ON PRE-SALT DRILLING – MAERSK – AZUL-1

• January 14, 2012 MAERSK OIL announced that their first well on deepwater Block 23, AZUL-1 was “mini-tested” indicting a flow capacity of greater than 3,000 BOPD; Maersk viewed the results as “encouraging”

• Azul-1 was the first ever deep water well targeting pre-salt reservoirs in the Kwanza Basin

• Drilled in 920 meters water to a depth of 5,330 meters
• February 9, 2012 COBALT announced that CAMEIA-1 drilled on Block 21 in 1,680 meters (5,500 feet) of water tested at 5,010 barrels of oil per day from pre-salt carbonates
• 360 meters (1,180 feet) of gross pay of which 75% is net pay
• No gas/oil or oil/water contacts encountered
• Well has potential to produce at excess of 20,000 barrels of oil per day
December 1, 2013 COBALT announced that LONTRA-1 was drilled on Block 20 to a depth of 4,195 meters

75 meters (245 feet) of net pay “in a very high quality reservoir section”

Lontra-1 tested at 2,500 barrels per day of condensate and 39 MMcf/gpd; flow rates were restricted by the surface test facilities on the rig

Press reports: 2.2 – 3.8 TCF gas or 900 MMBOE
May 1, 2014 COBALT announced that ORCA-1 was drilled on Block 20 and tested 3,700 bopd and 16.3 MMcfgpd in Upper Sag section

- 76 meters (250 feet) of net oil pay

Cobalt press release stated “Orca is by far the largest and most significant oil discovery in the Kwanza Basin and potentially one of the largest oil fields in Angola”
SLIDES FROM COBALT WEBSITE

• Acknowledgement: Next 8 slides are from Cobalt’s website
~120 million years ago, the Whale Park Complex (Campos Basin, Brazil) and Blocks 20 and 21 (Kwanza Basin, Angola) existed in the same depositional basin and were only 50-100 miles apart.

Our analysis confirms that the Campos and Kwanza Basins share similar Pre-salt histories and characteristics.

We believe the exploration history in the Campos Basin serves as the appropriate analog for Angola’s Kwanza Basin.
Angular’s Emerging Pre-salt Play

- The Cameia-1 and Azul-1 discoveries confirmed a working Pre-salt petroleum system and significantly de-risks the play
  - Now rapidly moving from play risk to prospect specific risk

- Angola’s 2011 Pre-salt License Round successfully completed
  - Broad industry participation by super-majors
  - Cobalt is the operator of Block 20, the most heavily contested block

- Cobalt has the leading position in Angola Pre-salt
  - Operator of three Angola blocks with a 40% working interest in each block
  - Discoveries within or offsetting each block
  - Active exploration drilling program in place for 2012-2013 in each block

Source: The Oil Daily, company press releases
Cameia #1 – An Exceptional Success

Cameia #1 Drill Stem Test Results

- Sustained rate of 5,010 bopd and 14.3 mmcfd (~ 7,500 boed)
- Minimal bottom-hole pressure draw down
- Upon shut-in, bottom-hole pressure reverted to initial state in less than one minute
- Perforated less than 1/3 of reservoir section
- Rate mechanically constrained by surface testing facilities and safety precautions
- Actual flow capacity expected to be several times the tested flow rate (in excess of 20,000 bopd)
- Data indicates a continuous, very thick high quality reservoir saturated with light oil

Cameia Appraisal Program to be initiated immediately

1 Well capability estimate based on Cobalt analysis

Update on Cameia #1 Pre-salt Exploration Discovery

February 2012
# Cameia #1 - Well Results Exceed Expectations

<table>
<thead>
<tr>
<th>Pre-Drill</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Thickness</td>
<td>~1,200 ft. oil column</td>
</tr>
<tr>
<td>(Mean case)</td>
<td>~ 900 ft. Net Pay</td>
</tr>
<tr>
<td></td>
<td>&gt;75% net-to-gross</td>
</tr>
<tr>
<td>Reservoir Quality</td>
<td>Highly permeable and fractured carbonates</td>
</tr>
<tr>
<td>Key Risk</td>
<td></td>
</tr>
<tr>
<td>Oil Quality</td>
<td>44° API</td>
</tr>
<tr>
<td>Key Risk</td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>7,500 - 25,000 Acres¹</td>
</tr>
<tr>
<td>5,000 - 25,000 Acres</td>
<td></td>
</tr>
<tr>
<td>Reservoir Sections</td>
<td>Decided to drill only Pre-salt Carbonate</td>
</tr>
<tr>
<td>Pre-salt Carbonate and Syn-rift Sections</td>
<td>Section²</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cameia discovery significantly de-risks
Angola Pre-salt play

¹ Determination of aerial extent requires follow-on appraisal of Cameia reservoir
² Decision to not drill deeper in this wellbore driven by desire to: 1) preserve the Pre-salt Carbonate reservoir section drilled and 2) accelerate understanding of reservoir by validating log assessment with actual production test

Update on Cameia #1 Pre-salt Exploration Discovery
February 2012
Accelerating the Appraisal of CAMEIA Discovery

CAMEIA #2 appraisal well will be drilled immediately following CAMEIA #1:
- Well location ~2.5 miles from CAMEIA #1
- Well planned up to ~18,000 ft., ~2,000 ft. deeper than CAMEIA #1
- Estimated time to drill 100 to 120 days

CAMEIA #2 results will help better define aerial extent of CAMEIA discovered resources and test deeper Pre-salt (Syn-rift) potential:
- Essential information to advance ongoing development planning
- Invaluable in helping to better quantify facility requirements
Conclusions: Angola

- Angola currently producing 1.75 million barrels per day

- Length of Angola’s pre-salt play is at least about 700 km long, comparable to Brazil’s pre-salt play of 800 km

- Will Angola’s oil production double from 1.75 to 3.5 million barrels of oil per day???
Angola’s Oil Production
1956 - 2014

ANGOLA OIL PRODUCTION BY YEAR (Barrels Oil Per Day)

- Deep Water (>500 feet/ 150 meters water depth)
- Shallow Water (0-500 feet/ 150 meters water depth)
- Onshore (Kwanza Basin and Soyo Area)

Sources: Sonangol Universo magazines, Website - Angola Finance Ministry, 2013 BP World Energy Review
Angola’s Pre-Salt

• Will Angola’s pre-salt oil production “replicate” what will happen in Brazil???

• “You don’t know until you drill. You’ve gotta drill to know what is going on!!!”

• By mid 2015 we will know when many more pre-salt exploration wells are drilled by Statoil, ENI, Repsol, BP, Total, ConocoPhillips.
Conclusions - Angola

• The exploration success rate in Angola in the Tertiary turbidites oil fields in the Lower Congo Basin is about 80%; the pre-salt play has just gotten underway.

• Accordingly, the Angola government has P.S.A.’s where the government “take” is in the range of 80 – 85%, so the government is the major beneficiary of oil and not the oil companies, as it is in Canada and many countries.
Conclusions: Angola

- Oil industry in Angola and West Africa is not a sunset industry – has a bright long-term future
- More oil discoveries will happen in the existing Tertiary turbidite plays
- If Angola’s pre-salt “mirrors” Brazil, then Angola’s oil production could double in about 15 years
Obrigado!

Thank you!