Reservoir Management: Dealing with Critical Diversity in the Pre-Salt Reservoirs

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SESSION C • Conquering the Frontiers of the Future

Outline

- Preamble & Objectives
- Main Characteristics: Geological, Fluid, Rock-Fluid
- Recovery Rate
- Field Development
- Production
- 3D Seismic Monitoring
- Growth of Production
- Conclusions

Preambule & Objectives

- All data presented have been published by the mentioned companies
- Tackling some of the key challenges in forecasting uncertainties of oil & gas production on Pre-Salt reservoirs
- Experience in Brazilian Pre-Salt Reservoirs with Some Observations valid for other Provinces such as Angola

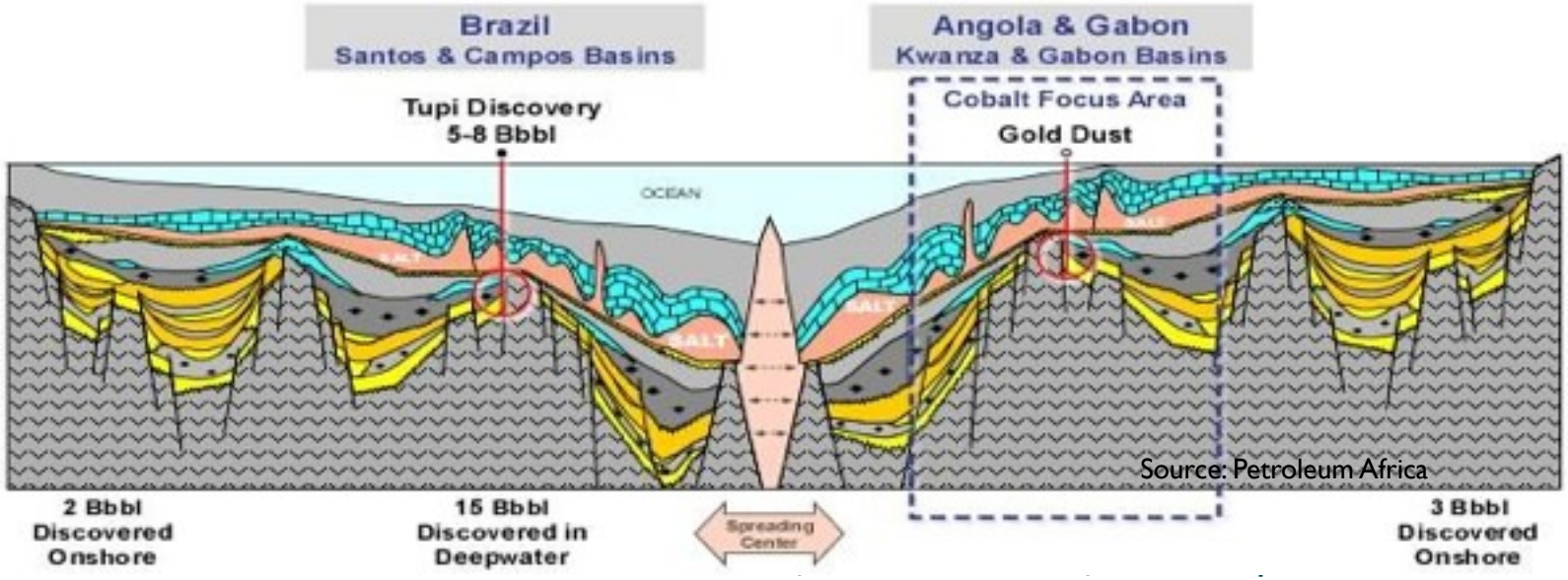
Main Characteristics

- "Some of the most relevant uncertainty are (Moczydlower et al. (2012):
  - the quality and the heterogeneity degree of each reservoir zone, …
  - compositional grading of the fluids,
  - performance of different EOR methods,
  - presence of fractures affecting the flow".

From Petrobras website

Geological Characteristics

- Pre-Salt reservoirs are geological formation on the continental shelves off the coast of Africa & Brazil (Beasley et al., 2010)
- Around 160 million years ago, separation of continental superstructure Gondwana



Source: Petroleum Africa

Geological Characteristics

- The rifting created the conditions necessary for the deposition of sediments &, as sea water filled the space between them, a low energy & high salinity environment, propitious to the development of bacteria colonies, was formed (carbonate rocks), on which oil accumulated

Geological Characteristics

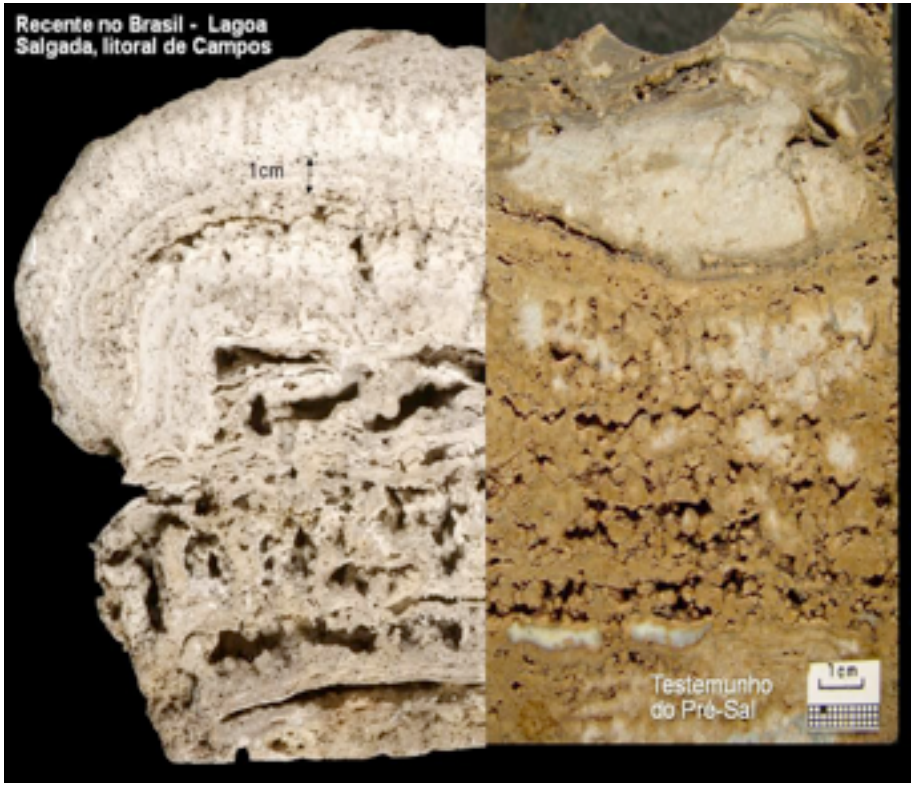
- Tectonic reconstructions made across the southern South Atlantic Ocean indicate a diversity of rift & drift basin characteristics on the conjugate margins
- Different stratigraphic & structural entities
- Close source rocks in both areas
- But some differences have been noticed (Mello et al., 2012)

Geological Characteristics

- The properties of sedimentary rocks change continuously during burial due to diagenetic processes
- Prediction of porosity, permeability, thermal conductivity, seismic & rock mechanical properties requires understanding of diagenetic processes

Geological Characteristics

- Diagenesis processes are mainly due to fluid circulations & compaction with chemical reactions involving dissolution & precipitation of minerals reservoir formation combined with its in-filling (Virgone et al., 2013)



Geological Characteristics

- Petrobras has derived a well-defined operational strategy that includes:
  - after the initial exploration wells, extended Well Testing phase aimed at refining reservoir knowledge (Formigli et al., 2009) allowing to confirm good geological characteristics

Fluid Characteristics

- Most oil has pre-salt origin, but in some cases the salt slips and opens way to the oil, which them accumulates in the post-salt rocks
- Even with same origin, 2 oils have differences:
  - post-salt case, bacteria may consume the lighter part
  - pre-salt oil, high reservoir of rocks such as coquinas and vulcaniclastics, allied with temperature above 80°C sterilizes the oil and preserves its qualities
- Basin modeling studies would allow forecasting of CO2 concentrations in different reservoirs

Rock-Fluid Characteritics

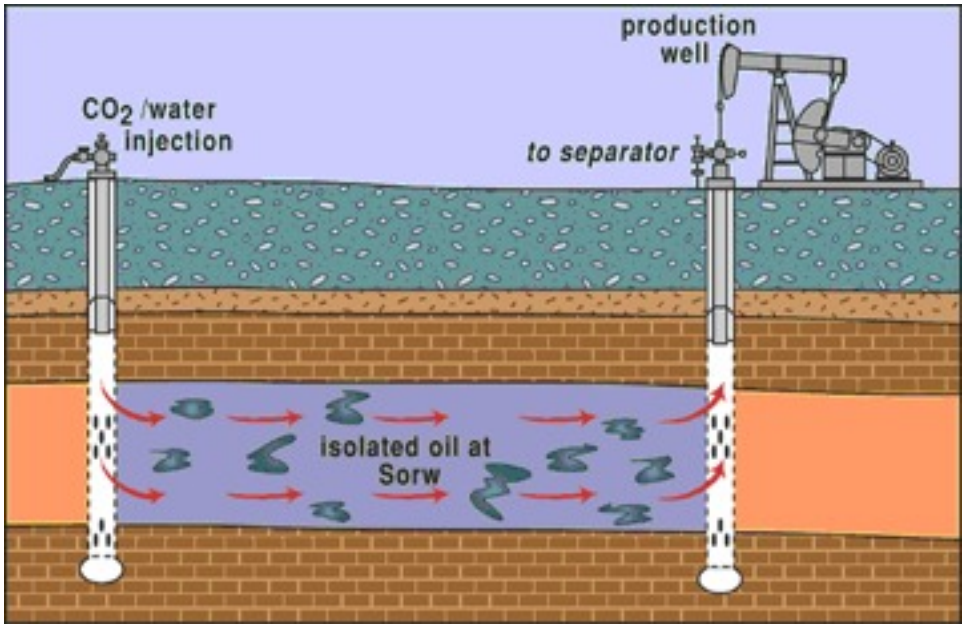
- When injecting CO2 in carbonates, one of the critical aspects is to understand the chemical reactions occurring between the CO2, the in-situ water & the carbonate matrix (Rodrigues, Nunes, Guérillot, D.R., 2012)
- Examples taken from CO2 injection for EOR purposes and/or CO2 storage will be usefull to forecast if these reactions will occur or not: this may have important issues for prediction Well injectivities and productivities

Recovery Rate

- Different recovery methods such as:
  - Waterflooding
  - Gas injection
  - Combining such recovery processes in same or different wells can be envisioned
- Objectives will be to:
  - Maintain the pressure,
  - Reduce the residual oil and gas saturations,
  - Optimize the vertical and horizontal sweep efficiency

Recovery Rate

- Re-injection of the CO2 rich gas will combine:
  - CO2 EOR advantages (Pizarro & Branco, 2012)
  - CO2 storage avoiding global warming concerns (de Almeida et al., 2010)



Field Development

- According to Beltrão et al (2009),
  - EOR performance is also being evaluated in fluid flow simulations (gas flood & WAG)
  - Preliminary results are indicating excellent results of these methods, considering gas miscibility
  - In the Tupi production pilot, gas injectivity is going to be tested, as well as WAG
  - A very important issue for future decision about EOR is that the local market is strongly demanding natural gas
  - High gas-oil ratio brings opportunities in EOR

Field Development

- Drilling through the rock and salt to extract the pre-salt oil and gas is very expensive
- Implementation of pilots that are small-scale production units designed to evaluate the best production strategy
  - Lula incorporates the first pilot unit in the Santos basin pre-salt to evaluate the production efficiency of several well designs, completion options and injection strategy

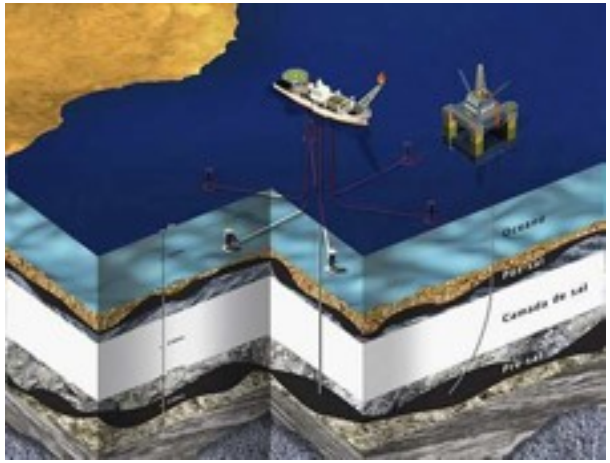
Production

- Most of pre-salt fields are situated a long distance from the shore: between 150 and 300 kilometers leading to logistical challenges:
  - life support & offshore operations optimization
  - gas transportation back to shore
    - pipelines
    - LNG transported using FPSO or FSO

Production

- Flow Assurance: WAX, Asphaltene, Hydrates to be studied (de Assis et al., 2013)
- Well construction, casing materials, flow lines, etc.

From Bruno Domingos/Reuters



From Petrobras website

3D Seismic Monitoring

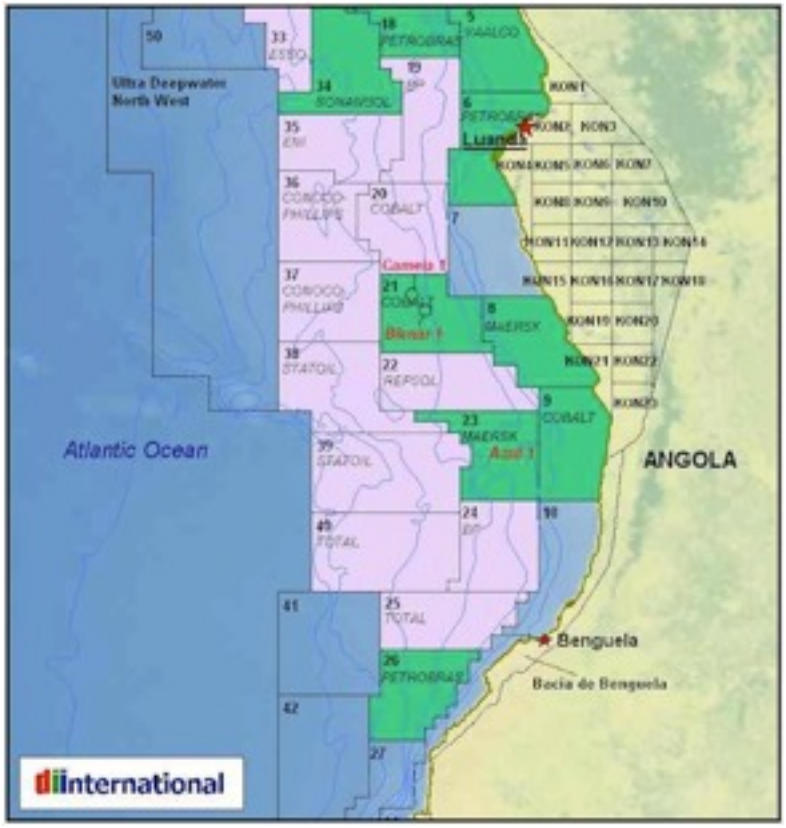
- For a sustainable oil field development strategy and considering the well spacing, early implementation of a 3D geophysical monitoring would be most probably a good investment
- Recent modeling studies demonstrated its feasibility (Glauber, Nunes & Guérillot, 2012)

Growth of Production

- Jan. 2013, Brasilian Pre-salt production was approx.
  - 264,000 bpd of oil, 8.9 million cubic meters of gas
- grows:
  - 9.35% in Jan. / Dec. ’12, 75.23% in Jan ’12/Jan ’13
- Petrobras business plans (2011-2015) forsees that the Santos pre-Salt Cluster area alone wil produce over half Million boe/d in 2015 & over 1,1 Million boe/d in 2020 (Petrobras shares only)

Growth of Production

- US Geological Survey has estimated that pre-salt formations in Angola could contain up to 30 Bbo



Conclusions

- Pre-salt reservoirs production is growing rapidly
- Many challenges involves important investments but also high reservoir engineering expertise for optimizing its overall rate of recovery
- Experiences gained in Brasil should be very useful for pre-salt reservoirs West Africa

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