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GEOSCIENCES CHALLENGERS TO DEVELOP AND PRODUCE PRE-SALT FIELDS, OFFSHORE SE BRAZIL

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ABSTRACT

According to the Petrobras´ Strategic Plan 2020, in the next 10 years, Petrobras´ oil production will reach 5,4 Kboe/d, twice today's production, and almost triple today´s Brazilian gas production (from 384 Kboe/d to 1,109 Kboe/d). A significant part of this production increment will come from the Pre-Salt Oil Province, which typically presents important volumes of associated gas. The gas-associated Lula oil field, one of the largest fields of the Pre-Salt Province, has a high GOR (> 200 m3/m3), reinforcing the importance of these province for the future of Brazilian gas production.

After successfully testing two wells, PETROBRAS, as the operator of Block BMS-11 (Santos Basin), and partners BG and PETROGAL, announced Tupi discovery in the Pre-salt province of Santos Basin by November 2007. An extended well test program (EWT) was initiated to acquire reservoir dynamic information from May 2009 up to the end of 2010. The official commerciality declaration of this area, now named as Lula field (including Lula and Cernambi areas) was informed to the National Petroleum Agency of Brazil in December 2010, after drilling and testing additional wells and analyzing the EWT data. Since 2010, a production pilot is in progress in Lula field, anticipating more robust reservoir information for the definitive production systems. This strategy, frequently used by PETROBRAS production development projects, consists of development in phases: EWT, Production Pilot, and Definitive System.

Pre-Salt reservoirs are lacustrine carbonates, mostly microbialites, deposited during the Sag- and Rift-Phase (Aptian), and coquinas of the Rift-Phase (Barremian), formed during the South Atlantic Gondwana break-out. They are located at more then five km depth below sea level, at ultra deep water (around 2,2 km), and under a two km thick layer of evaporites. The main geoscience reservoir challenges to develop these areas are related to (1) geological model: understanding the origin and characterize the rock-system itself, (2) describing and representing reservoir rock heterogeneities, (3) imaging seismically reservoir rocks and fluids, (4) and the definition of the production strategy: analyzing the impact of heterogeneities for different production strategies, including placing the wells at optimum locations according to each production strategy (predicted water flood at some areas or WAG at other areas).

To overcome these difficulties, Petrobras set up a large R&D program internally and with Brazilians and international universities, research centers and service companies. The major geosciences research trends, mainly related to reservoir geology and geophysics, actually on development to accomplish these challengers, are discussed on this paper.

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INTRODUCTION

Petrobras' wildcat drilled in 2006 at the offshore ultra-deep water (2000 m water depth) Santos Basin tested a completely new exploratory concept for this relatively unexplored and large east Brazilian offshore basin. For many years, Petrobras discovered and explored heavy oil in post-salt turbidite sandstones, mainly in deep and ultra-deep waters in Campos basin.

The Pre-Salt Brazilian Petroleum Province discovered at Santos Basin brought a new scenario for the oil industry in this country. New potential oil reserves and strong increasing production perspectives for Petrobras, partners and eventually for the country demanded a totally new planning to face the associated challengers.

The Pre-salt discoveries of Santos Basin represent discovery of huge volumes of light oil of 28 to 30 degrees API. Only in Lula field, PETROBRAS and partners initially estimated, in December 2007, recoverable volume of 5 to 8 Bboe, with high gas content, and close to the most important consuming centers in Southeastern Brazil (Beltrão *et al.,* 2009). At December 2010, after several additional wells drilled, an EWT program concluded and a Production Pilot beginning, the consortium maintained oil reserve estimates very close to the original ones, declaring commerciality to the Brazilian National Petroleum Agency with total estimates of 8,3 Bboe (including 6,5 Bboe for the Lula area - Tupi Lead, and 1,8 Bboe for the Cernambi area - Iracema Lead).

THE BRAZILIAN PRE-SALT OIL PROVINCE

The Brazilian Pre-salt geologic unit stretched for 800 km along Brazilian southeast offshore areas, covering from Espírito Santo to Santa Catarina States, and encompassing the three of the most petroleum prolific sedimentary basins of Brazil: Espirito Santo, Campos and Santos basins (Figure 1).

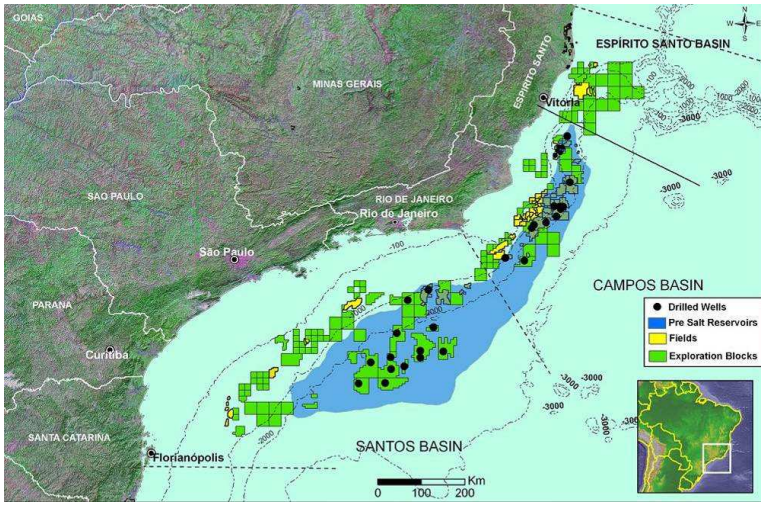

Figure 1 – Estimated occurrence of Pre-Salt rocks (dark blue) in the South-Eastern Brazilian sedimentary basins and the exploratory blocks and former oil fields discovered in these basins. PETROBRAS MAGAZINE, Edition 56 (2009).

In this paper, the geosciences challengers of the pre-salt Brazilian reservoirs are explored and the efforts to overcome these difficulties are described.

GEOLOGY OF THE PRE-SALT RESERVOIRS

Pre-Salt reservoirs are shallow lacustrine carbonates, mostly microbialites, deposited during the Sag- and Rift-Phase (Aptian), and coquinas of the Rift-Phase (Barremian), formed during the South Atlantic Gondwanaland break-out, and marking the beginning of the South Atlantic Ocean opening (Figure 2).

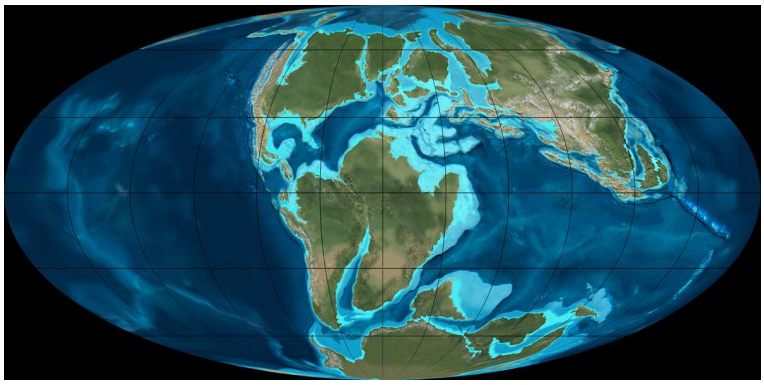

Figure 2 – Gondwana physiographic land distribution at the Aptian (123-113 million years ago) during the Sag Phase of the Santos basin Pre-Salt deposition. (from http://jan.ucc.nau.edu/~rcb7/mollglobe.html)

The first wildcat well drilled in the Pre-Salt area was located at the External High, a prominent structural elevated feature offshore Santos Basin. This well discovered oil (2006) at Lower Cretaceous layers, below the Aptian Salt Formation.

Partially dolomitic, the microbial carbonates from the tectonic sag phase seem to be nearly flat in seismic sections, and well data indicate high vertical ciclicity in permeability. Formation tests in sag carbonates have presented very high flow rates with no indication of barriers (Beltrão *et al., 2009)*.

RESERVOIR GEOSCIENCES CHALLENGERS

According to Beltrão et al (2009) one of the geologic challenges in reservoir technology in Pre-salt of Santos Basin is to describe and represent reservoir fluids and rock heterogeneities. The knowledge about reservoir properties at the moment is incipient, and the main challenge now is to build the best models, projects and predictions with the available data-set.

Microbial carbonates reservoir rocks are not common in world record. One of the initial research tasks is to identify possible analogs aiming the understanding of the rock-forming and depositional controls, of the geobodies geometries, and the mapping of reservoir-rock heterogeneities in all scales, indications of how the flow will behave according to the main controls.

Many geological stratigraphic units from different geologic ages and some recent depositional environments were studied to capture this knowledge. As

examples of these studies, it is mentioned the investigation of depositional controls of recent sedimentary analog environments as the area of Shark Bay, Western Australia and the small coastal, salty lakes of the northwest Rio de Janeiro State (Figure 3). Also, the study of world-class outcrops in the Cretaceous lacustrine microbial carbonates of the Yacorite Fm., Balbuena Group, at Salta, Argentina, and the Neo-Proterozoic Nama Group, Namibia, and the Pre-Cambrian carbonate rocks in Brazil (Figure 4), as wells as, published studies of carbonate rocks of Neo-Proterozoic at Chapada Diamantina Bahia, Brazil (Srivastava and Rocha, 1999).

Figure 3 – Picture form the Lagoa Salgada recent microbial structures, coastal northwest area of Rio de Janeiro State, Brasil. Environments like this are used to identify depositional controls, facies distribution and sediments heterogeneity mapping as analogs for real reservoirs at the Pre-Sal oil province.

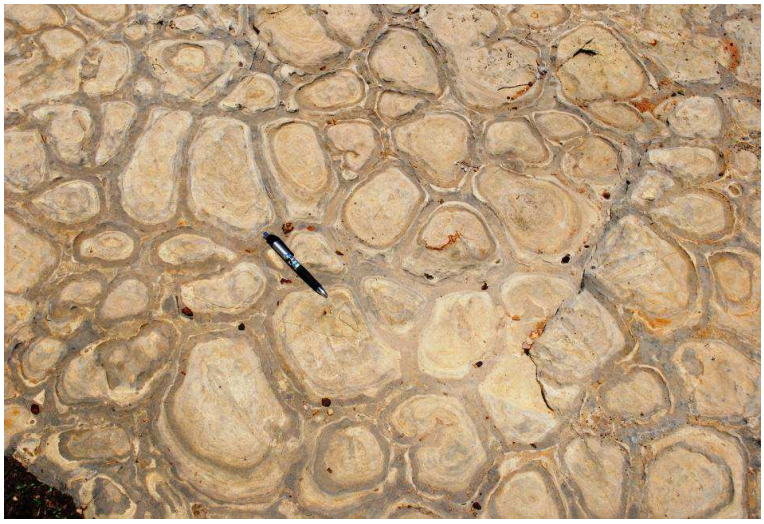

Figure 5 – Exposure of the Neo-Proterozoic stromatolitic carbonates outcropping in northeastern Brazil.

As examples of the importance of the reservoir heterogeneities, the reservoir-rock vertical and horizontal permeability anisotropy ratio may be decisive information

for well design definition. If very low vertical to horizontal permeability ratios prevail, for example, horizontal wells may not be indicated. In this situation, it is possible that their performance may be close to vertical wells, and for economic and operational reasons, vertical wells may be more indicated. A strong effort is being carried in order to get information about Kv/Kh ratios at different scales and using different techniques, including geologic models, petrophysical information, tracers, production logs and pressure data in production pilot and other appraisal wells.

Other important information is placing properly structural elements (faults and fractures) and describing and understanding properly their flow properties, both from seismic and well data, structural analysis, geomechanical modeling and flow models. Important decisions have to be made with that information: how to place the wells with respect to structural features, close to them or far away? Although they may guarantee high initial flow rates, they may represent risk of early water breakthrough, with high impact in water-flooding and other EOR procedures. Special attention is dedicated to structural elements. For the same reasons, geological unconformities within the carbonates rocks are being analyzed in detail to unveil possibly permeability anisotropies.

Seismic data is a major tool for Pre-Salt reservoir studies and mapping. Major structures can be recognized and mapped but imaging of reservoir heterogeneities as facies changes has to be improved.

Carbonate high velocity rocks and the presence of thick and heterogeneous evaporates on top of the microbial rocks are complexities to the seismic methodology of reservoir studies when medium and small scale heterogeneities need to be recognized and mapped.

Following Beltrão et alli (2009), structural complexity of the top of the salt, as well as internal structural heterogeneities within the thick salt layers, may result in non homogeneous spread of seismic energy through the Pre-salt reservoir. The consequence may be a non homogeneous illumination of the reservoir (Figure 6). Seismic modeling has been widely used to better understand this phenomena and to orient new seismic acquisitions, including method of acquisition, direction, parameters, etc (Alves, et al., 2009; Bulcão et al., 2011; Boechat et al; 2007).

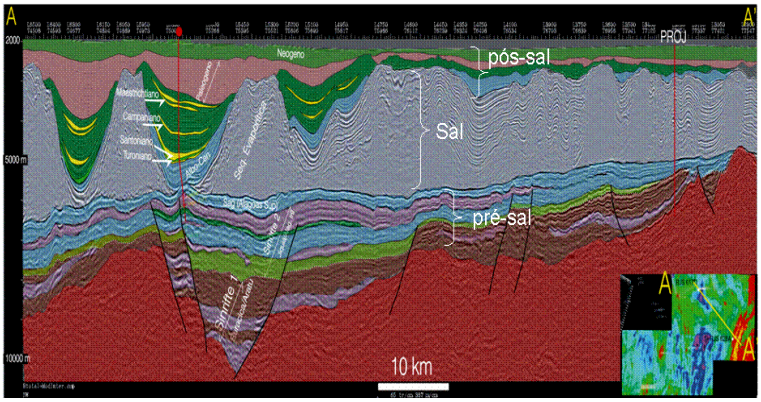

Figure 6 – Seismic line at the Pre-Salt Oil Province in Santos Basin. From Formigli 2007 presentation "Pre-Salt Reservoirs Offshore Brazil: Perspectives and Challenges" Source: www.petrobras.com.br

Certainly, reprocessing old seismic data, or acquiring and processing new data are important steps to produce the best reservoir images, improve mapping of petrophysical reservoir properties and, eventually help the identification of reservoir properties and fluid contacts.

In the sequence of geological reservoir challengers, there are many issues associated to geoengineering and reservoir engineering matters. The Extended Well Test programs at some Pre-Salt fields as well as Pilot Production Systems planned for the areas should bring many strategic information for the production development final definition, as the option for water-flood and WAG injection performance for sweep efficiency, recognition of continuity of high permeable layers, hydraulic connectivity throughout the reservoir, injectivity behavior, permeabilbity anisotropy, etc.

First oil from the Pre-salt Santos basin Petroleum Province was produced in May 2009, starting an extended well test program for reservoir evaluation performance purpose. Other EWT's are now in progress to get production information, and one Production Pilot is in progress in Lula Field to get strategic insights from the reservoir production performance.

The Pre-Salt production challengers are a formidable task that the Petrobras and its partners are facing. This scenario demands sometimes the use of present day technology in the limit, and other times, adaption and development of technologies specific for such conditions. PETROBRAS has organized its research structure to face these technological challenges, including the creation of a technological program – PROSAL – focused on Pre-salt objectives, involving the hole company R&D technologic system and many different areas to support this effort.

At the moment, Petrobras and partners invest in the static reservoir data gathering (sedimentologic and stratigraphic models, seismic studies) and in the dynamic models (well extended tests and pilot production system in Tupi) and laboratory studies to reduce uncertainties and subsurface risks.

A strong and comprehensive technologic network was also formed with Brazilian and foreign universities and research institutions around the world to support some of the developments and investigations.

GAS PRODUCTION STRATEGIES FOR THE PRE-SALT AREA

According to recent headlines news in Brazil, natural gas used for industrial, commercial e and gas-fueled car consumption increase 10 % in the first semester of 2011. Actually, Brazilian gas consumption system is supported by the domestic production and gas imported from Bolivia and imported LNG. In the next future, Pre-Salt gas production is expected to get an important role in this scenario.

in the next 10 years, Petrobras´ oil production will reach 5,4 Kboe/d, twice today's production, and almost triple today's Brazilian gas production (from 384 Kboe/d to 1,109 Kboe/d). A significant part of this production increment will come from the Pre-Salt Oil Province, which typically presents important volumes of

associated gas. The gas-associated Lula oil field, one of the largest fields of the Pre-Salt Province, has a high GOR (200 m3/m3), reinforcing the importance of these province for the future of Brazilian gas production. Petrobras and partners are also performing research and studies to deal with future Pre-Salt gas production, as GNL, GTL or GNC.

The Pre-Salt production will have to deal with contaminants. According to Beltrão et al.(2009) there his between 8-12% of CO2 contaminant in Tupi Field. The issue of capture and sequestration of CO2 at the Pre-Salt fields is other challenger that Petrobras and partners are considered as mandatory and a great opportunity to improve the recovery factor using CO2 in the WAG system in the miscible CO2 to improve oil characteristics (lowering oil viscosity). According to Beltrão et al (2009), EOR performance is also being evaluated in fluid flow simulations (gas flood and 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.

In summary, following Beltrão et al (2009), a very important issue for future decision about EOR is that the local market is strongly demanding natural gas. The high gas-oil ratio brings opportunities in EOR which are closely linked to environmental restrictions and market demands. One possibly complex challenge will be the separation of CO2 form natural gas in offshore conditions. The development of compact processing floating units for CO2 separation will be critical in defining the future of EOR in the Pre-salt of Santos Basin. If such plants could not be developed in time, at least at the production begging, CO2 may be injected in the reservoir together with natural gas.

Pre-Sal production strategy will considered the opportunity with existing infrastructure is the Santos basin (Figure 7). The Mexilhão Gas Field gas pipe is considered as a possible opportunity for Pre-Salt gas exportation. The gas exporting scenarios are under analysis nowadays in Petrobras and partners offices.

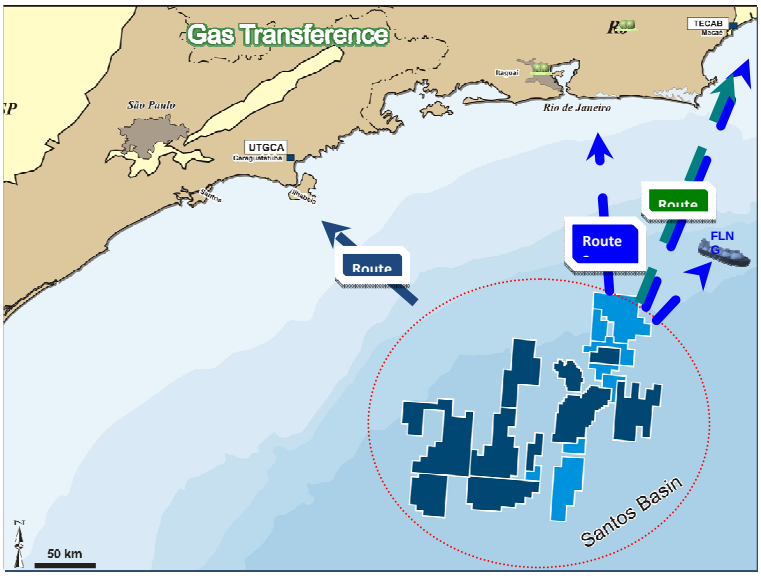

Figure 7 – Pre-Salt Santos Basin Oil province production infrastructure scenario for gas exportantion. Source: José Formigli, Petrobras, Oral Presentation at Offshore

Technology Conference, 2011 – "Updated information on the Pré-Salt Development offshore Brazil: Material results leads to a bright future".

CONCLUSIONS

Pre-Salt Oil Province in off-shore Southeast Brazil is a complete revolution in Petrobras and partners manner of seen their futures. Probably, this situation is of such magnitude that can even change future Brazilian economy context in the next decades.

There are many different scientific and technologic challengers to be overcome in order to succeed and develop the Pre-Salt oil province but the most important was summarized by Petrobras engineer Antonio Pinto (2011, cited in TN Petroleo): the reduction of the geologic uncertainties. To drill high productivity wells, necessary to guarantee economic projects in ultra deep water scenario, besides engineering concerns, the conceptual reservoir model must be tested and continuously refined. The main, large scale heterogeneities in rock properties, as well as smaller scale, internal reservoir heterogeneities, must be represented. They are the geosciences challengers facing the involved companies to succeed to the next step in this complex development of the Pre-Salt province.

These are also the basic requirements to place these very expensive wells in the best reservoir portions, to choose the best well concept – including geometry, spacing and completion strategy, and finally, optimizing the production strategy. It is mandatory to develop conceptual and numerical reservoir models to deal with all scales of heterogeneities that may impact decisively primary production, water-flood strategies and EOR methods.

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