Cracking a Brasil Nut

Simple Overview of Santos Pre-Salt Geology and Example of a Development

Presentation Structure

- Working with Brasilian data
- Introduction to Santos Basin Pre-Salt
- Santos Basin Stratigraphy and Play
- Barra Velha reservoir components, mineralogy and depositional model
- Barra Velha reservoir quality
- Sapinhoá development
- Santos Pre-Salt performance and growth

Working with Brasilian Data

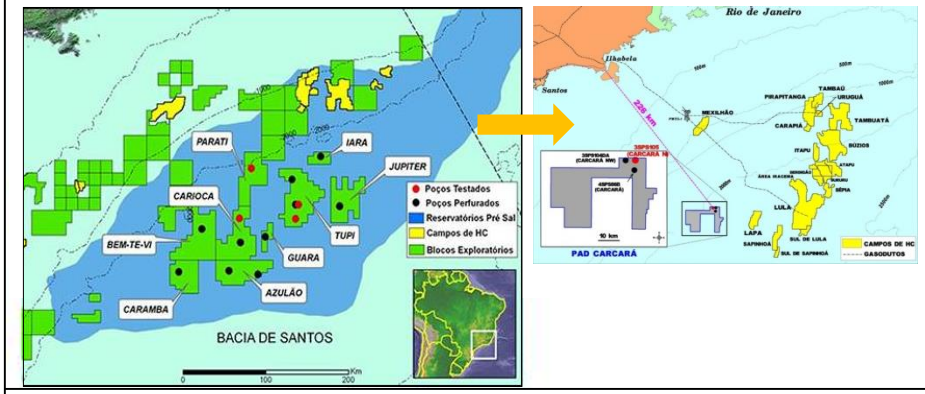
- Well Names
- Field Names

Brasil Data: Well names and numbering

- "Local" names/numbering
  - 1- Exploration e.g 1-SPS-55
  - 3- Appraisal e.g. 3-SPS-82A
  - 4- Step-out appraisal
  - 7- Producer e.g. 7-SPH-16-SPS
  - 8- Injector e.g. 8-SPH-09-SPS
  - 9- Reservoir data acquisition e.g. 9-SPS-95
  - SPS- Sao Paulo state
  - RJS- Rio de Janeiro state
- ANP database names/numbering
  - 3-SPS-69 = 3-BRSA-788-SPS well

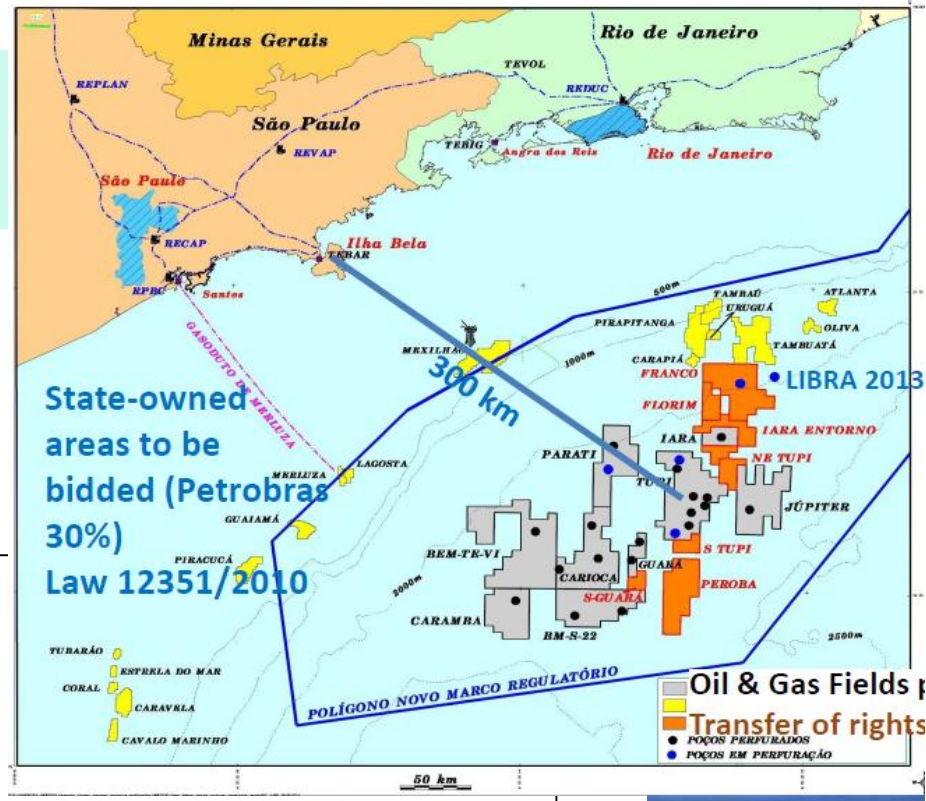
Block and licence names

- Renaming on declaration of commerciality
  - Carioca -> Lapa
  - Guara -> Sapinhoa
  - Tupi -> Lula
  - Iara -> Berbigao, Sururu & Atapu



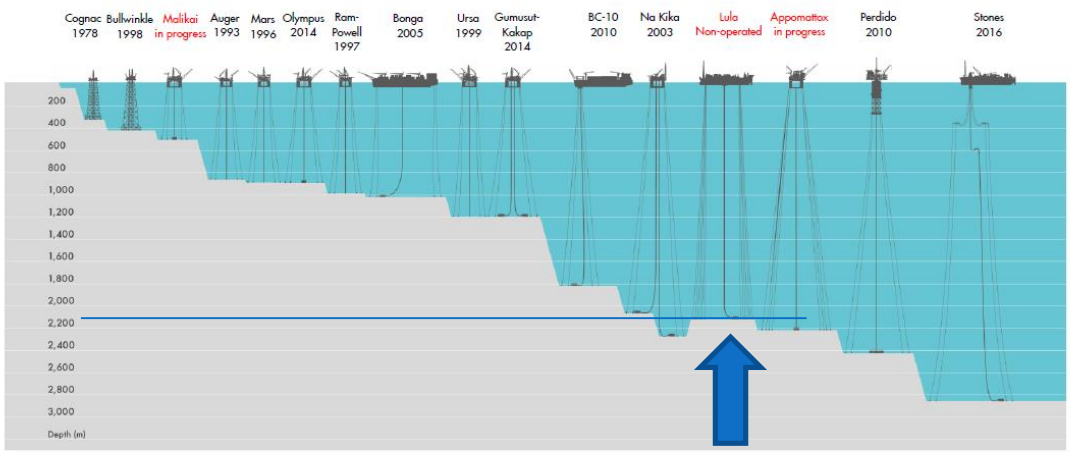
Santos Basin Pre-Salt

- >150 km from shore
  - Lula and Sapinhoá >250 km from shore
- Mainly in water depth >2000 m



Deep water capabilities

- Leading deep water developer
- Success through innovation and leveraging technology
- Brazil in moderate depth



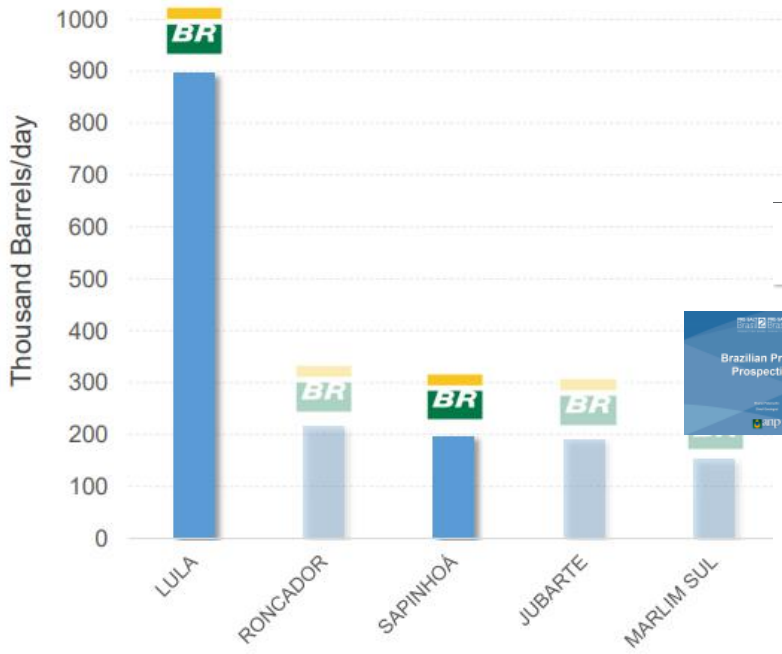
Role of Pre-Salt Reservoir in Brasil Production

Oil Production in Brazil

Importance of Carbonates for Brazil:
Historical Successes and Future Perspectives

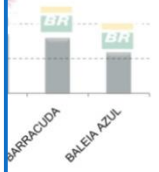
Marina Abelha

2 exclusively Carbonate Reservoirs



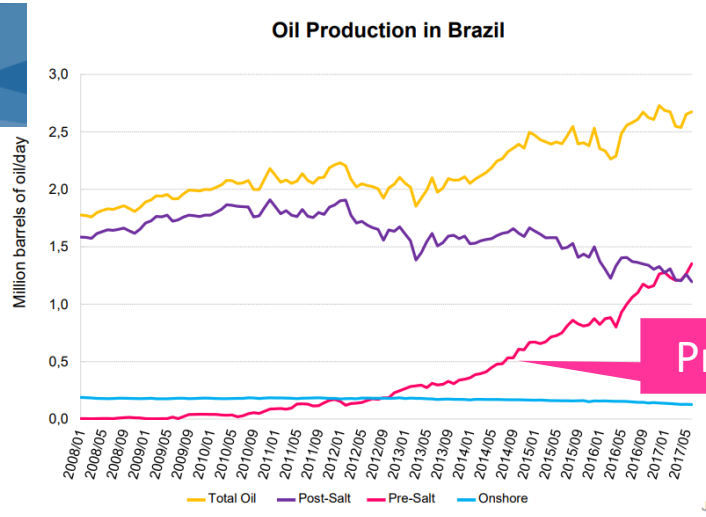
Brazilian Pre-Salt Prospectivity

Sapinhoa



PRE-SALT Brasil 2 PRODUCTION SHARE
PRE-SALT Brasil 3 PRODUCTION SHARE

Production



Pre-Salt

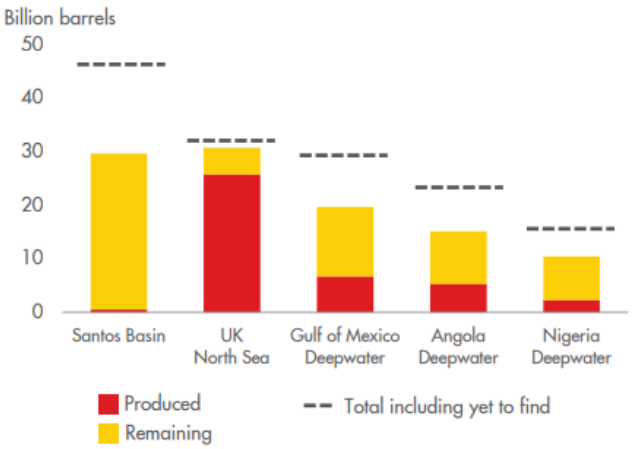
June/2017

Santos Basin Pre-Salt Reservoir

Brazil: Santos Basin

Advantaged portfolio

Industry off-shore resource base[1]



- Santos basin top tier deep water acreage early in life-cycle
- Significant learning curve potential and upside

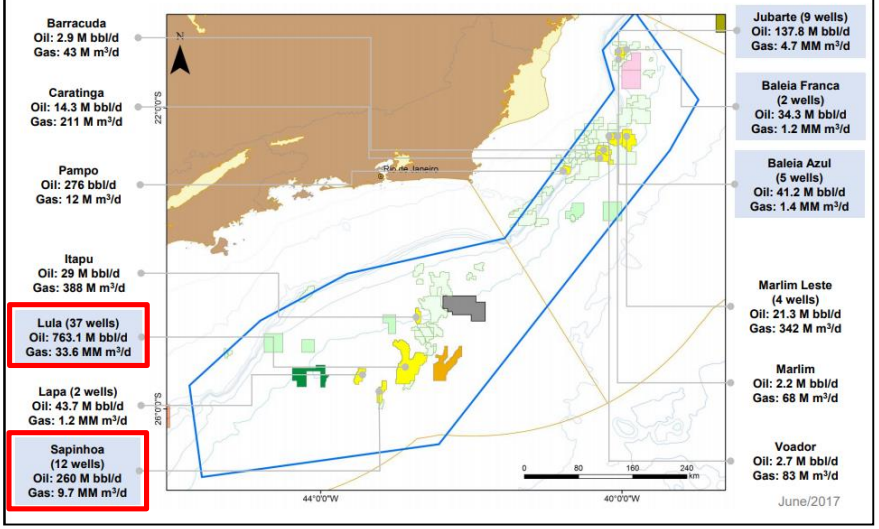
Significant growth and resource potential

[1] Source: Wood Mackenzie Upstream Data Tool August 2016 for the produced / remaining reserves and Exploration Tool March 2016 for the yet to find resource

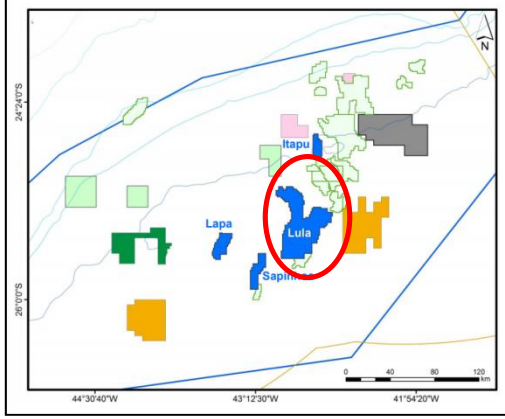
Royal Dutch Shell Shareholder presentation 2016: deepwater-brazil-shareholder-visit-2016

Production

~1.34 million barrels of oil/day



Potential for Giant Oil Fields



Pre-salt fields under development phase:

Buzios
Sepia
Berbigao
Sururu

Libra Accumulation

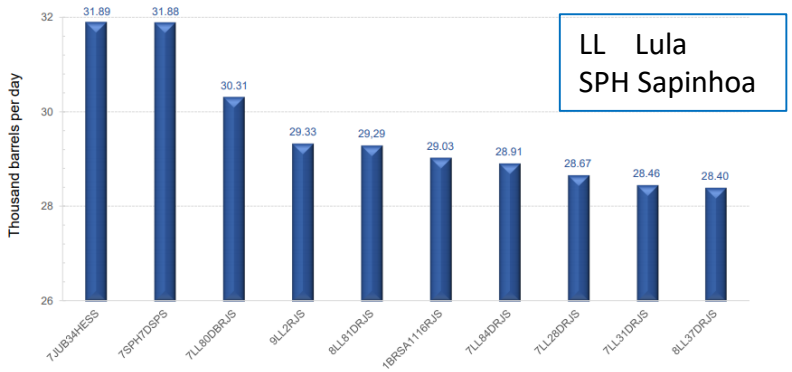
Great prospectivity for oil:
Most part of the recoverable resources are yet to be produced

Oil Field currently under production

Brazilian Pre-Salt Prospectivity

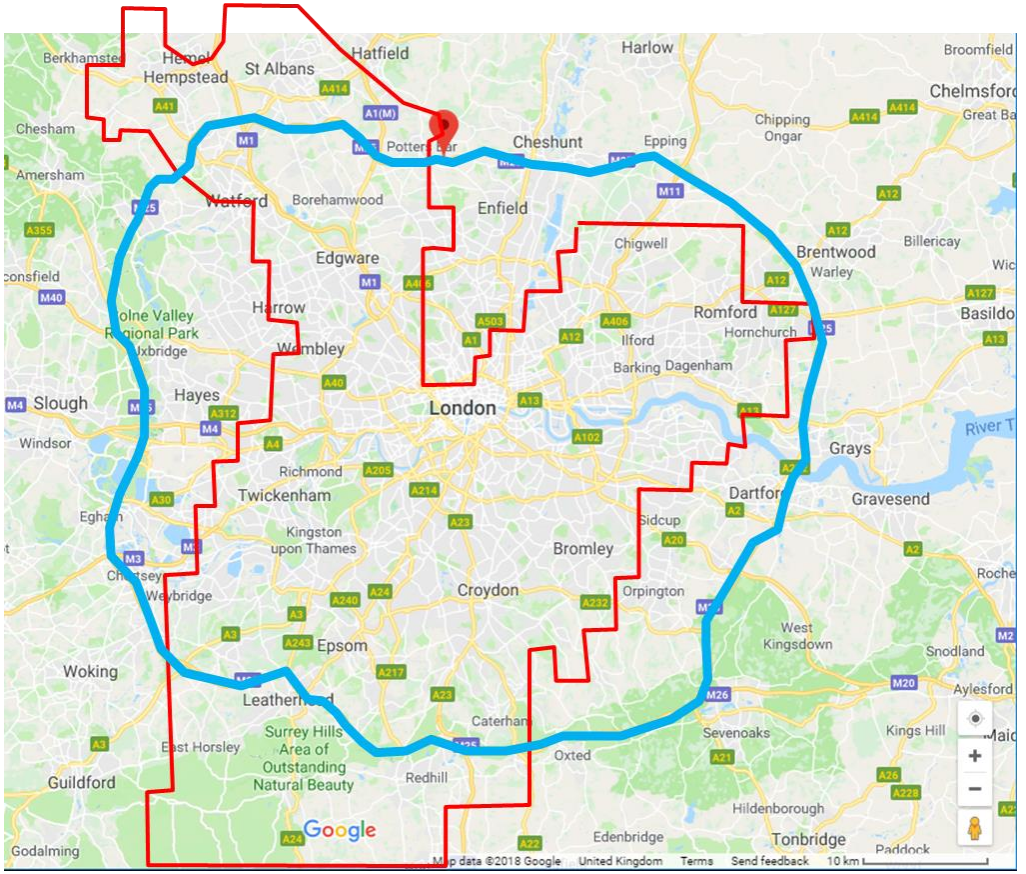
Productivity

10 most productive Pre-Salt wells

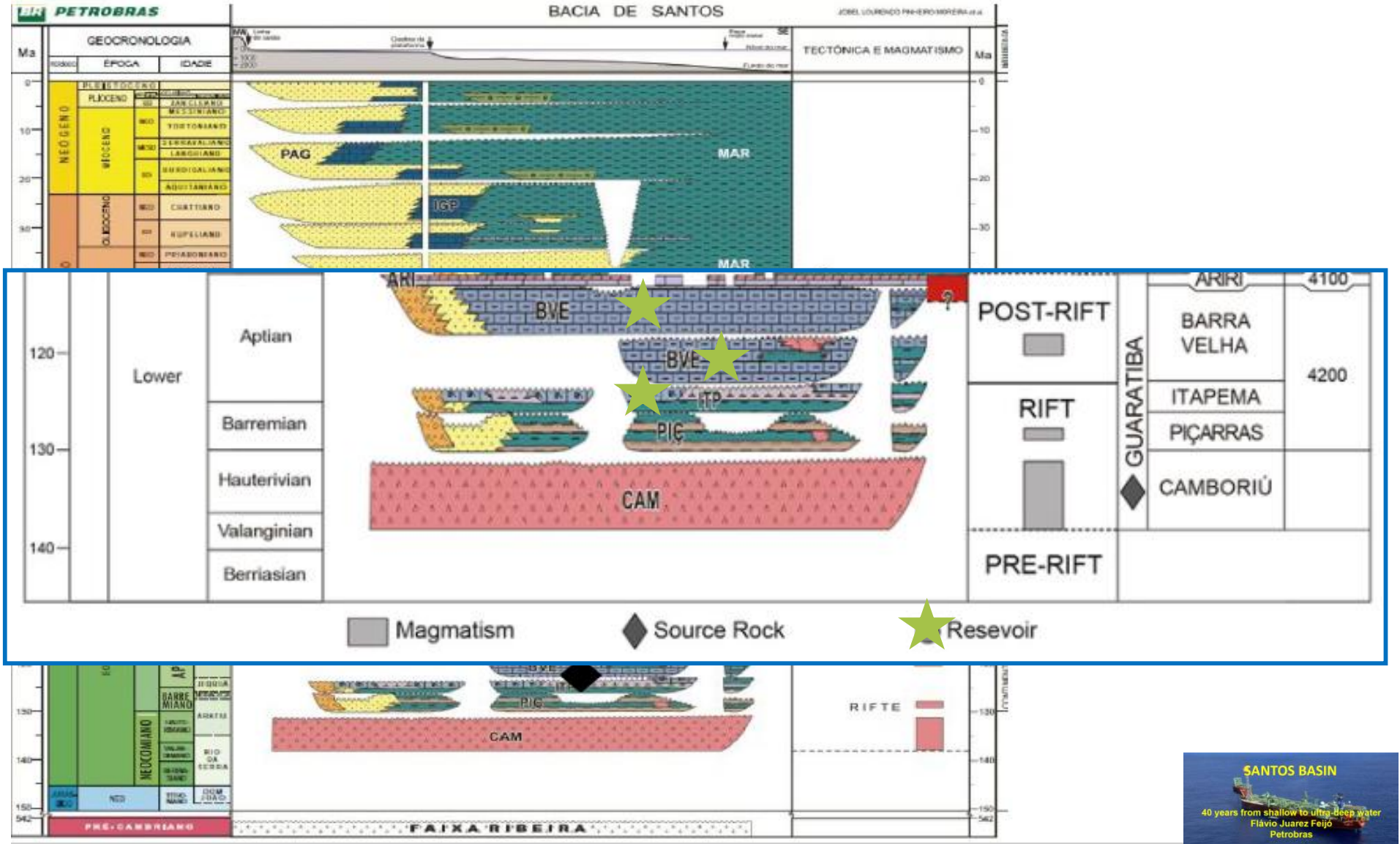


LL Lula
SPH Sapinhoa

June/2017

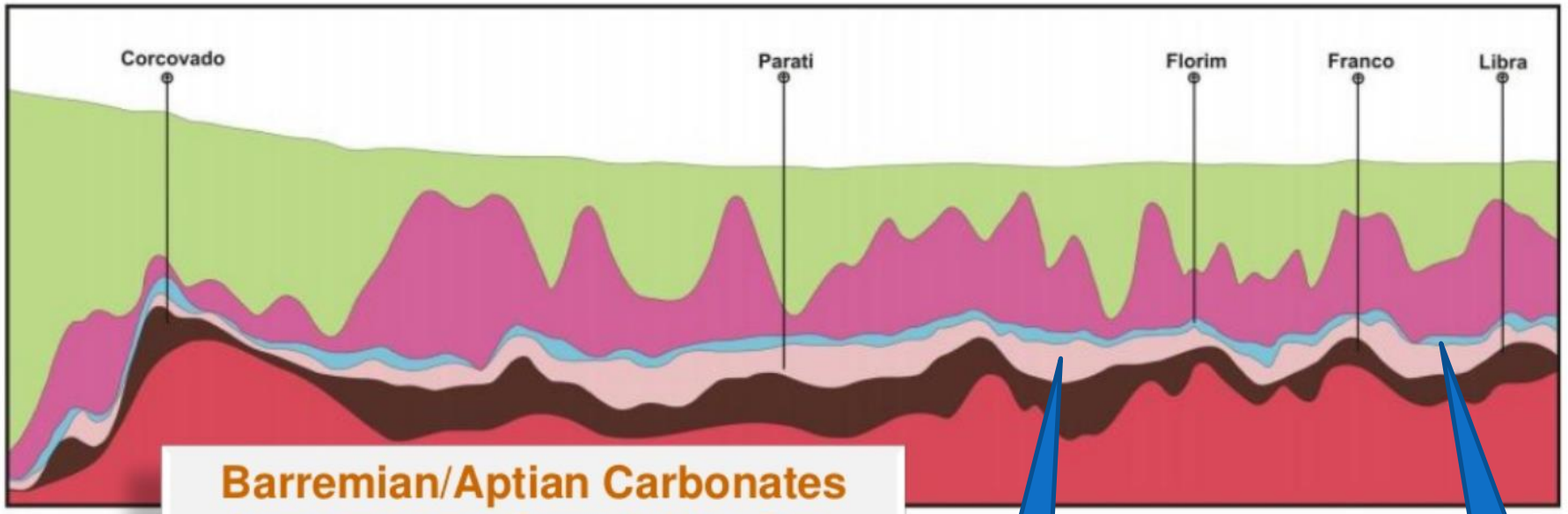


PETROBRAS SANTOS BASIN

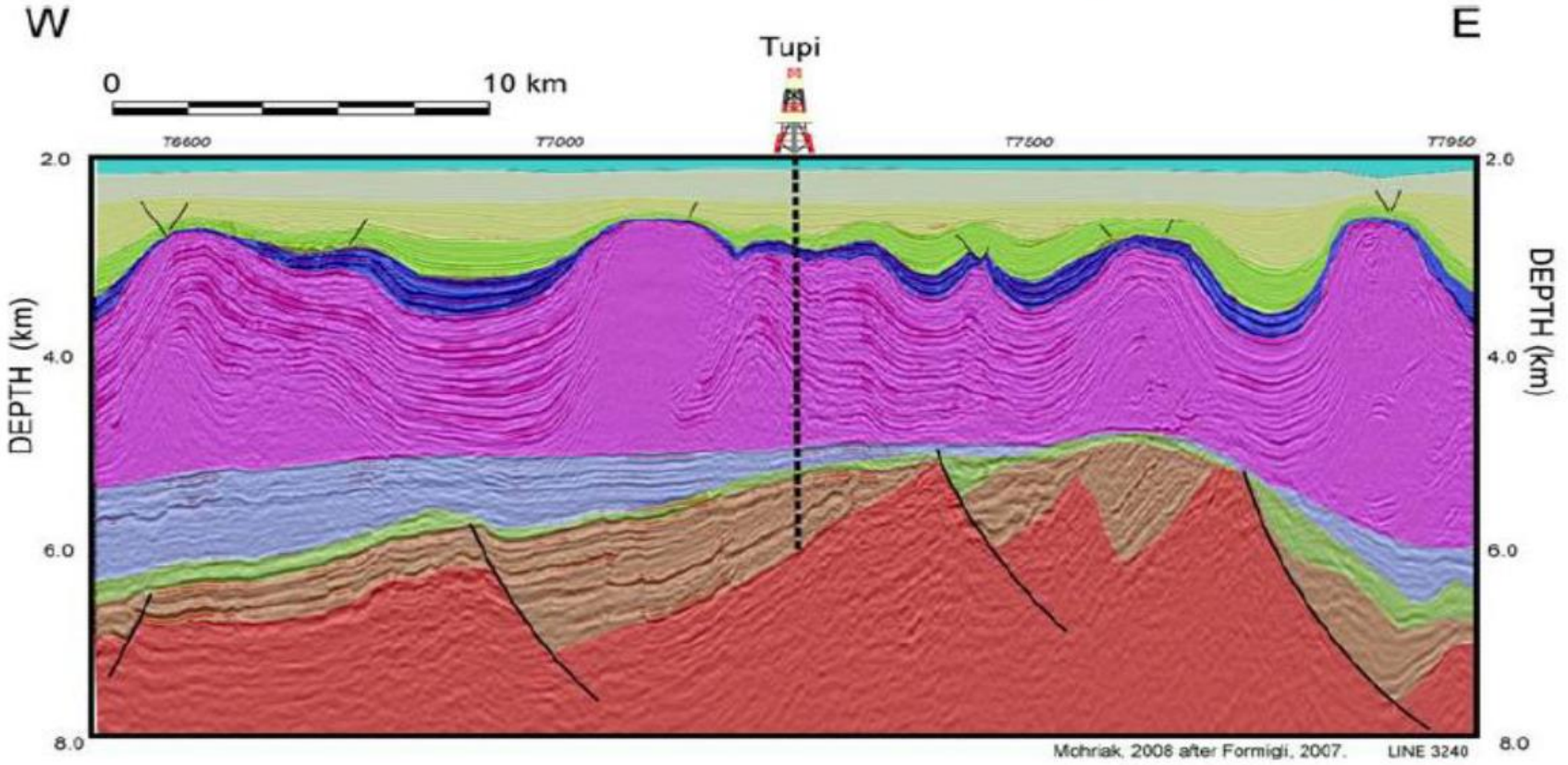


Santos Basin Carbonate Plays

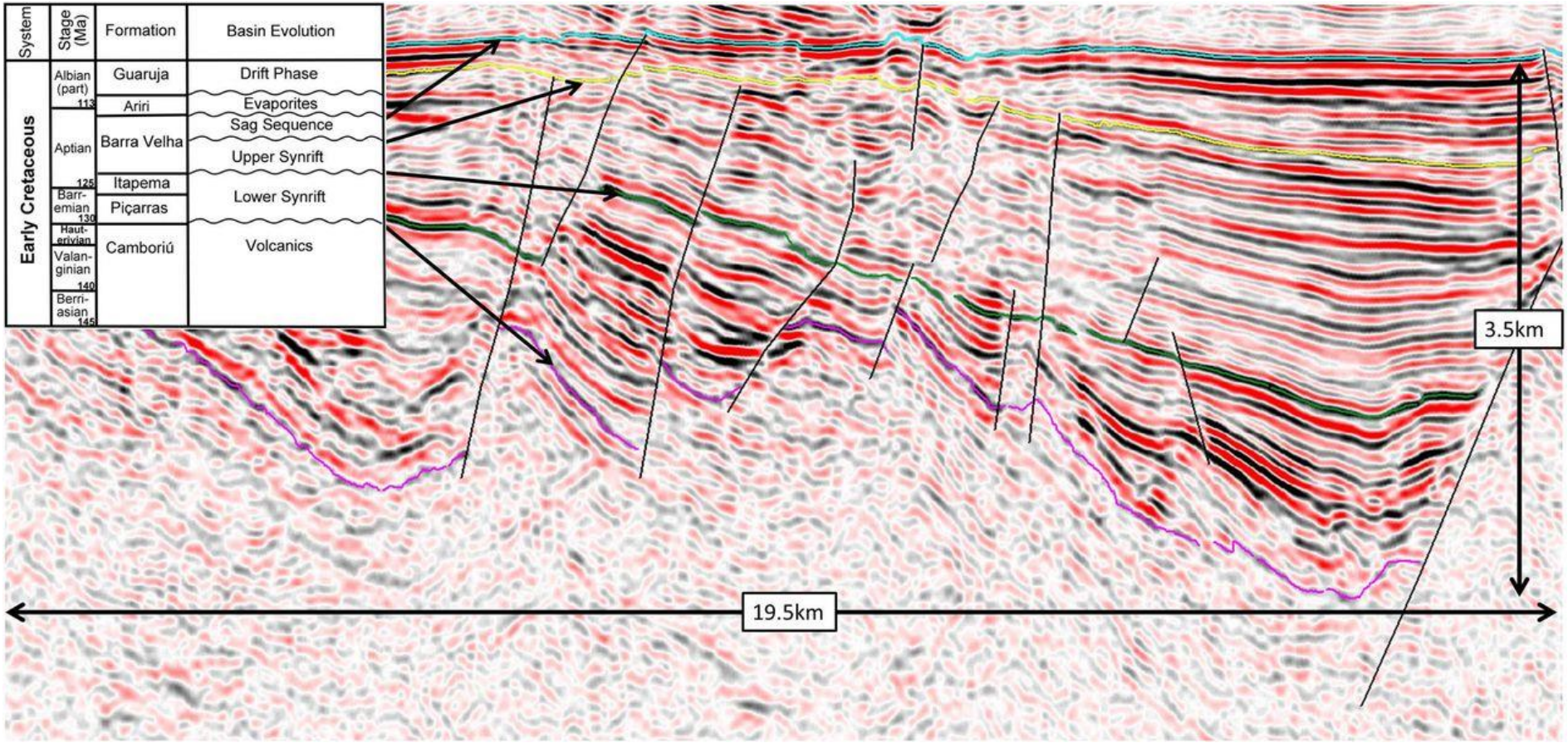
Schematic Geological Section



PETROBRAS TUPI LEAD = LULA (SQUID) FIELD

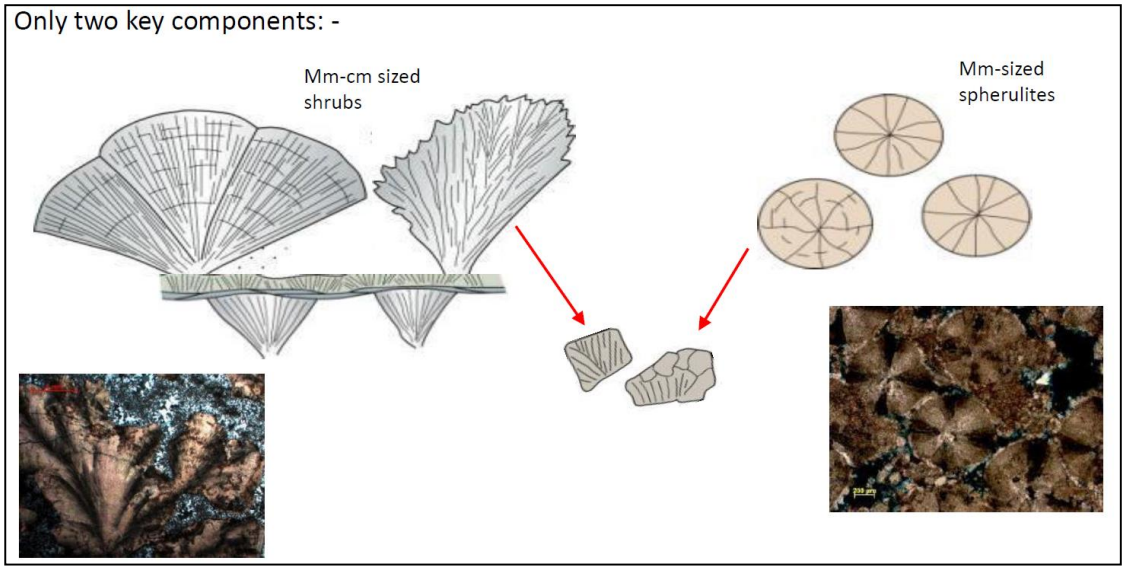


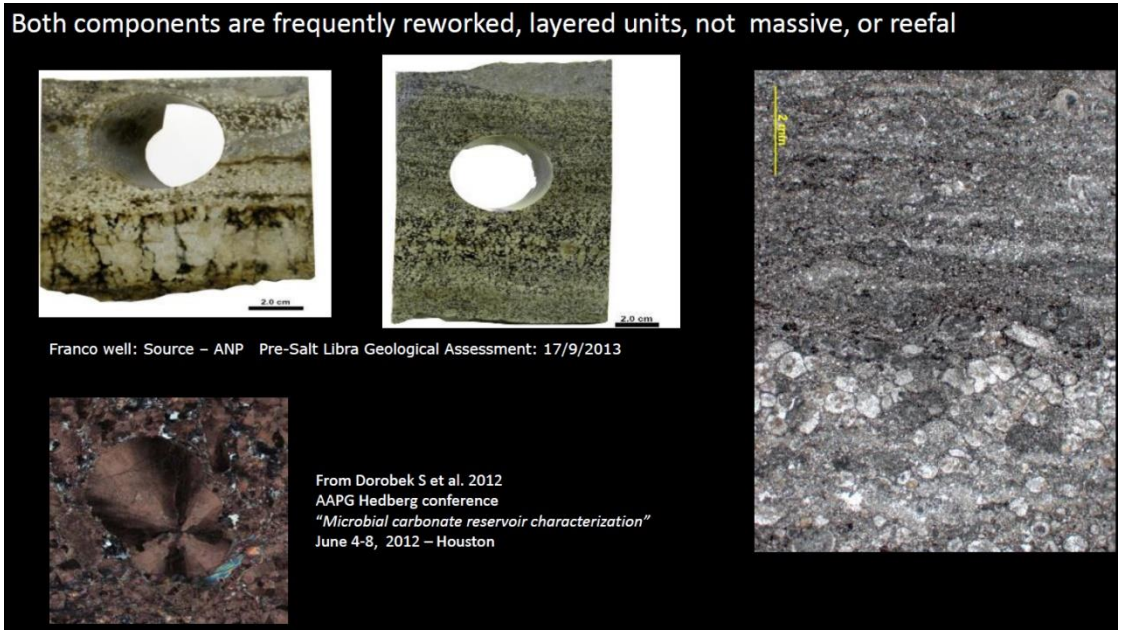
Example Seismic Line



Tectonic setting and stratigraphic architecture of an Early Cretaceous lacustrine carbonate platform, Sugar Loaf High, Santos Basin, Brazil
J. P. Buckley, D. Bosence and C. Elders
Geological Society, London, Special Publications, 418, 175-191, 24 April 2015, https://doi.org/10.1144/SP418.13

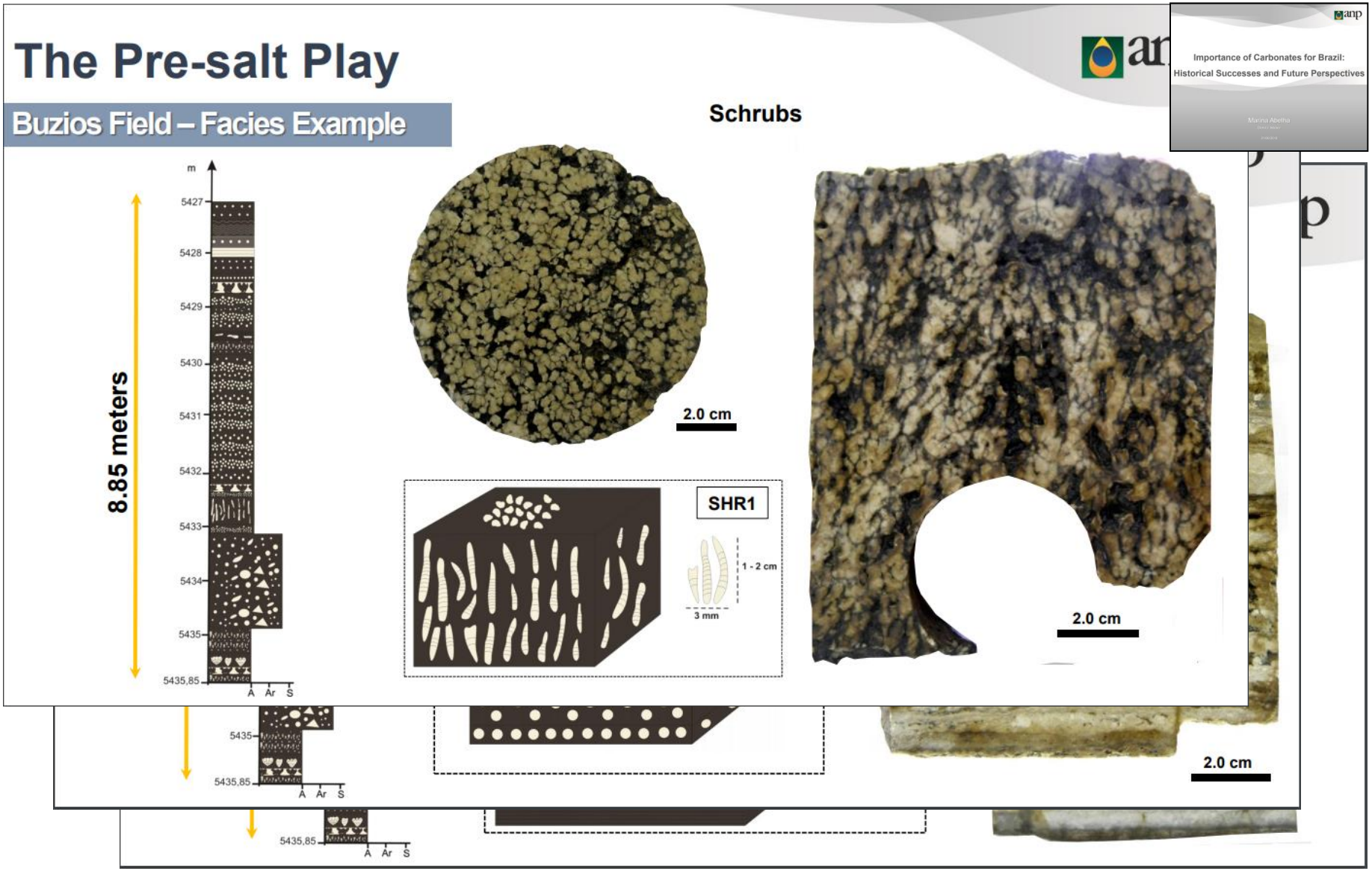
Barra Velha Reservoir Components





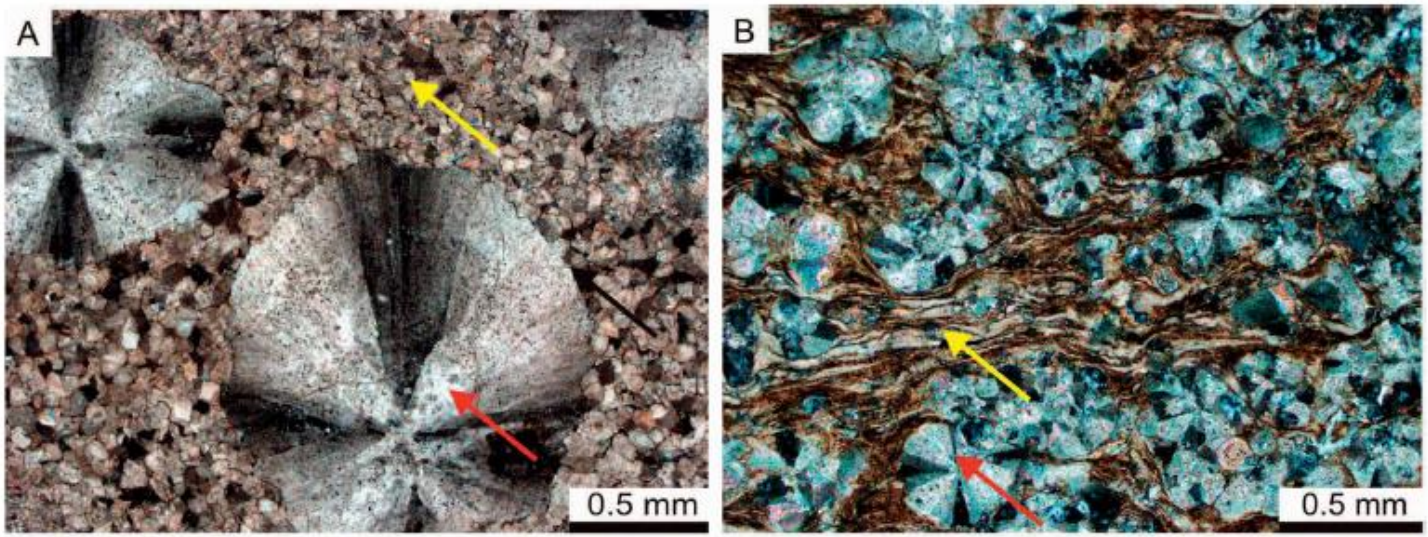
- Microbial macrostructures which resemble classical stromatolites are **rare** (<0.5% of thickness of logged sections)
- No modern lacustrine carbonate systems produce large differentiated platforms and seismic-scale clinoforms
- No analogues are currently known from the geological record of similar lakes

Barra Velha Reservoir Components



Barra Velha Reservoir Mineralogy

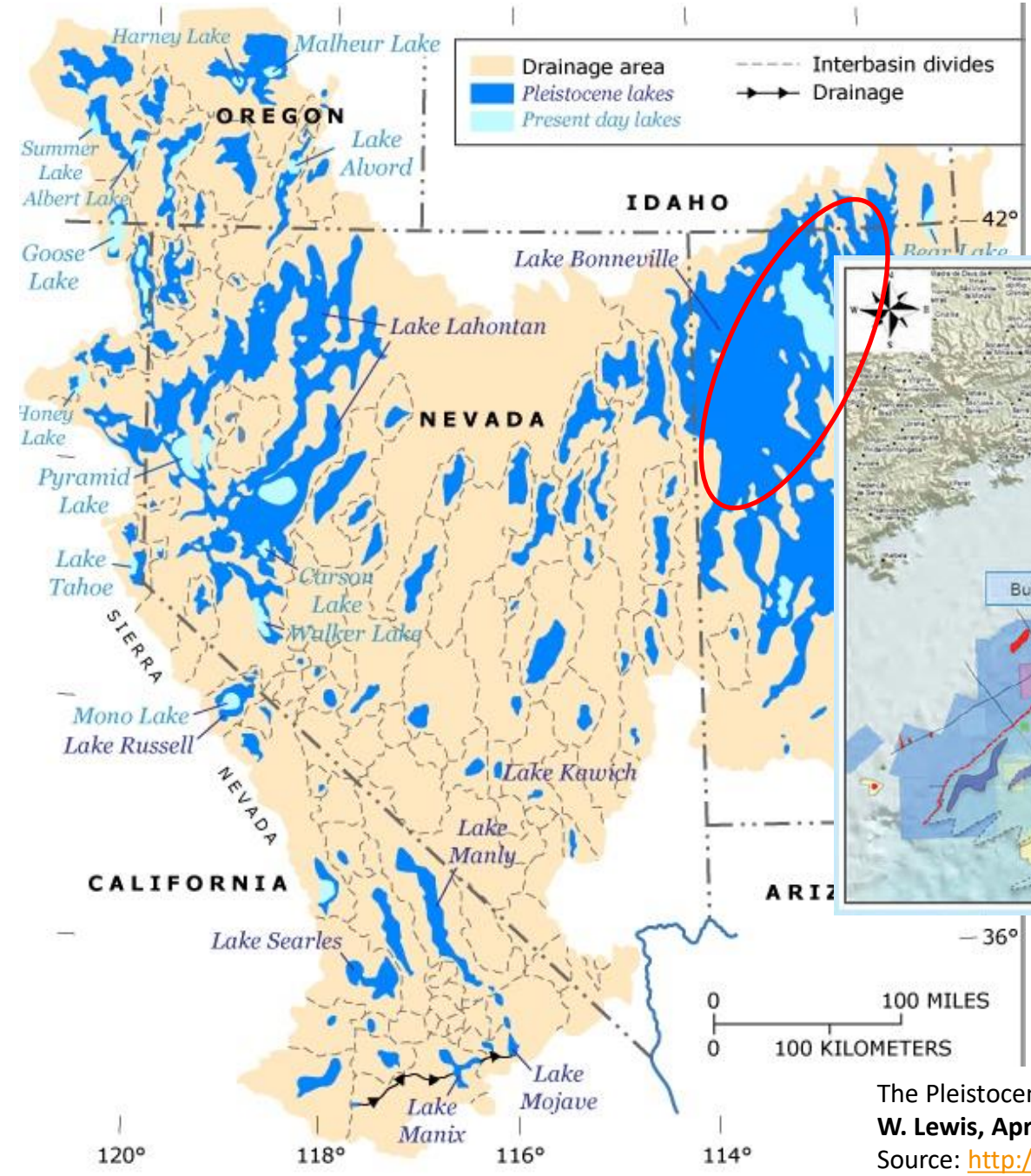
- Calcite
- Dolomite
- Stevensite $Ca_{0.15}Na_{0.33}Mg_{2.8}Fe^{2+}_{0.2}Si_4O_{10}(OH)_2 \cdot 4(H_2O)$
- Quartz

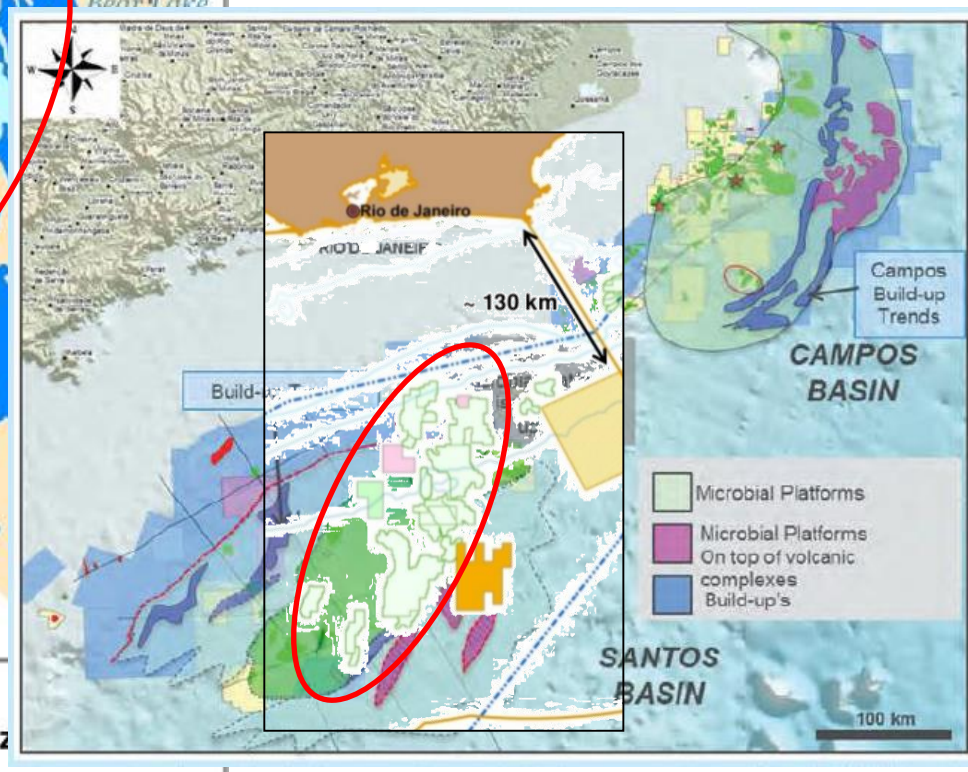


A) Slightly silicified spherulites (red arrow) in a clay matrix replaced by dolomite (yellow arrow) (XPL).
B) Partially silicified spherulites (red arrow), displacing and replacing clay laminae (yellow arrow). Dolomite is interpreted as a result of mimetic replacement of stevensite (XPL).

From: Hertlinger, R. Jr, Zambonato, E. E. and de Ros, L. F., 2017. Influence of Diagenesis on the Quality of Lower Cretaceous Pre-Salt lacustrine Carbonate Reservoirs from Northern Campos Basin, Offshore Brazil. Journal of Sedimentary Research v. 87, p.1285-1313. DOI: http://dx.doi.org/10.2110/jsr.2017.70

How Big Was The Barra Velha Lake?





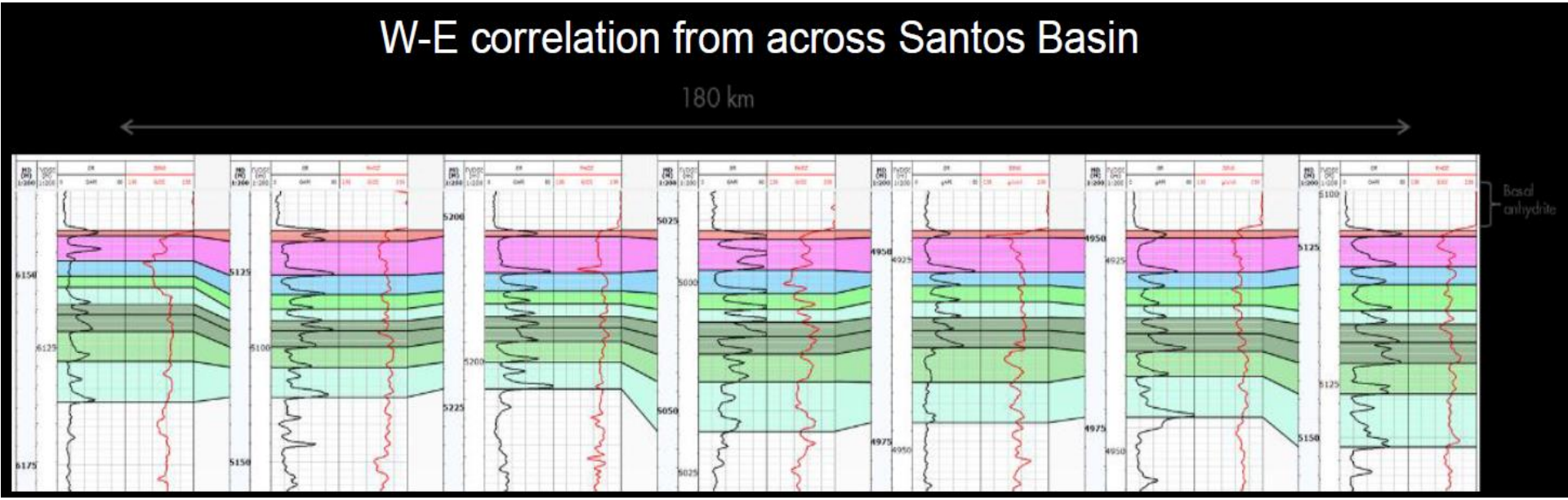
The Pleistocene Great Lakes of Western North America by **Martin W. Lewis, April 16, 2012**
Source: http://www.geocurrents.info/geonotes/the-pleistocene-great-lakes-of-western-north-america#ixzz5AhF0A8bB

How Deep Were The Lakes?

The case for a shallow versus a deep lake with high relief platforms

- Most seismic features attributable to carbonate buildups are not present in the Barra Velha.
  - In most cases the seismic features can be explained by syn- and especially post-Barra Velha faulting, including local inversion, and erosion, rotated onlap geometries
  - Some may even be volcanic in origin including lava deltas
- Long-range correlations using well logs indicate that current relief across the basin did not exist at the time of deposition and is due to post-Barra Velha structuration
- The facies model, supported by geochemical modelling, suggests shallow evaporitic lakes
- Provisional isotopic data suggest the lakes were shallow and evaporitic, with no large water body nearby

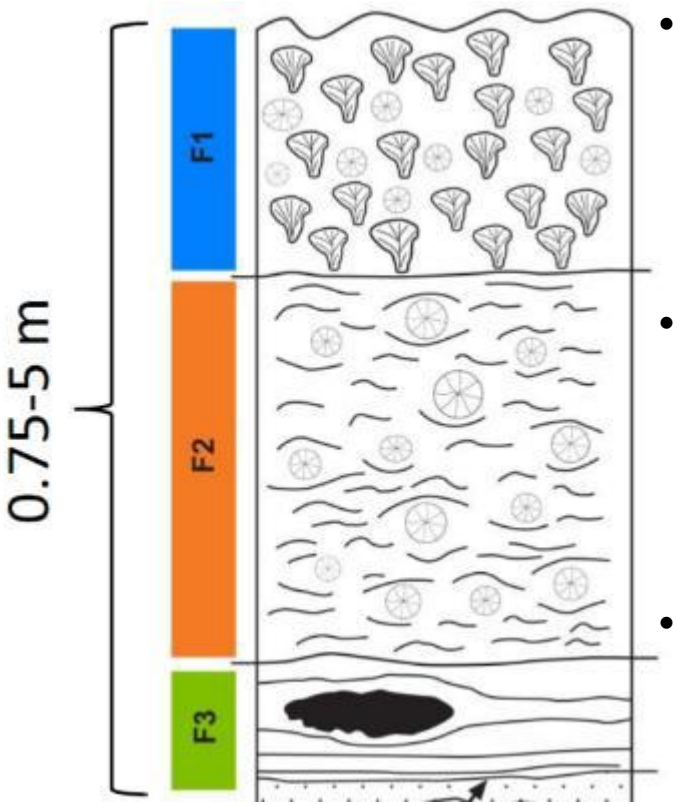
Structural History: Structuration Post-Barra Velha Deposition



- Total thickness of correlated package (so-called “Lula’s fingers”) varies from 20.8 to 28.5 m (mean = 24.3 m).
- 9 gamma-defined cycles (mean thickness 2.7 m) comprise one or more shallowing-upwards cycles defined by basal laminites.
- Cycles are well sampled by core and SWC, and facies are very similar in all wells and include a range of unequivocally shallow-water facies (e.g., microbial laminites and stromatolites).
- Cycles were deposited at same water depth but are now separated by > 1 km vertical relief, indicating significant post-depositional, but pre-salt structuration.

Barra Velha Depositional Model

The facies and the occurrence of cyclothems support a shallow evaporitic lake model - Wright & Barnett 2015

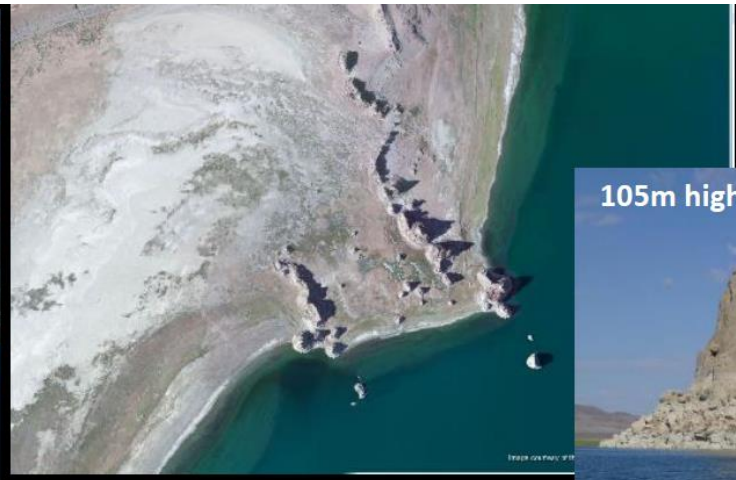


- Facies 1: Calcite shrub cementstones, with Mg-silicates or patchy traces of former Mg-silicates
- Facies 2: Calcite spherulite floatstones, with Mg-silicates or traces of former Mg-silicate matrices
- Facies 3: Laminated calcimudstones with prominent ostracodes and vertebrate debris, early silica nodules

- Reduction of gel precipitation allows rapid growth of calcite crystal shrub framestones by asymmetric growth of spherulites into lake waters
- Evaporation triggers Mg-silicate gel precipitation; pH >9.5. Mg rapidly depleted. = low Mg/Ca. Spherulites grew in Mg-silicate gels, in low densities.
- Flooding phase; reduced alkalinity-salinity allows influx of ostracodes and vertebrates; also triggers silica precipitation as pH drops

From - Wright, V. P. & Barnett, A. J. 2015 An abiotic model for the development of textures in some South Atlantic Early Cretaceous lacustrine carbonates. In Bosence, D. W. J. et al. (eds) Microbial Carbonates in Space and Time: Implications for Global Exploration and Production. Geological Society, London, Special Publications, 418, 209–219.

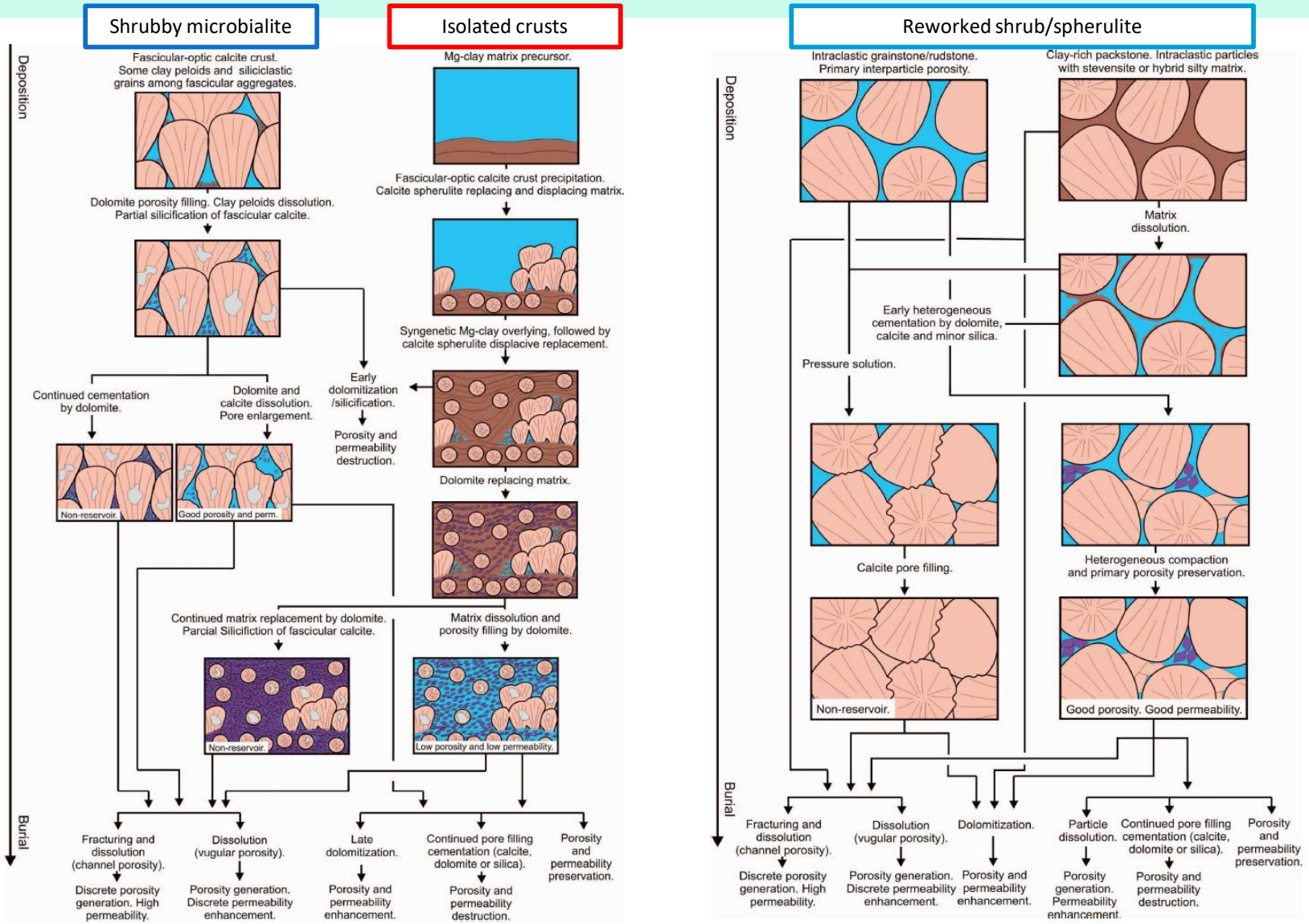
Does the Lake Model Explain Everything? Pyramid Lake, Nevada



1-3km long

Large sub-lacustrine spring mounds develop in perennial lakes – they need the space (depth) in which to grow

Deposition, Diagenesis and Reservoir Quality



From: Hertlinger, R. Jr, Zambonato, E. E. and de Ros, L. F., 2017. Influence of Diagenesis on the Quality of Lower Cretaceous Pre-Salt lacustrine Carbonate Reservoirs from Northern Campos Basin, Offshore Brazil. Journal of Sedimentary Research v. 87, p.1285-1313. DOI: http://dx.doi.org/10.2110/jsr.2017.70

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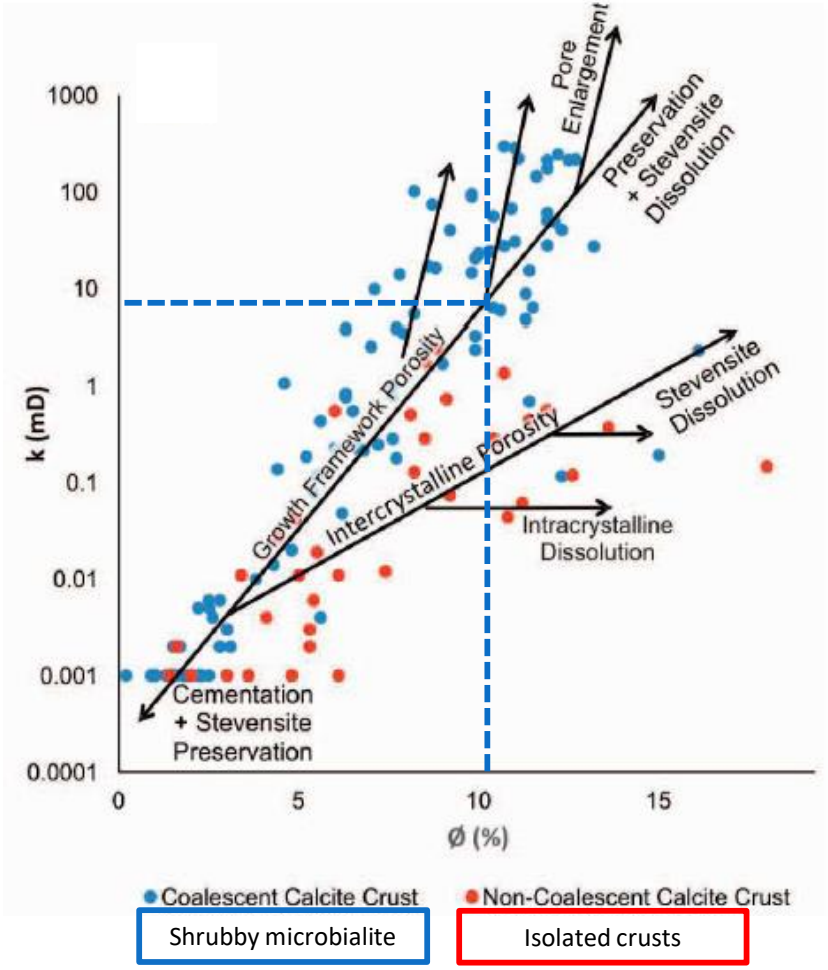

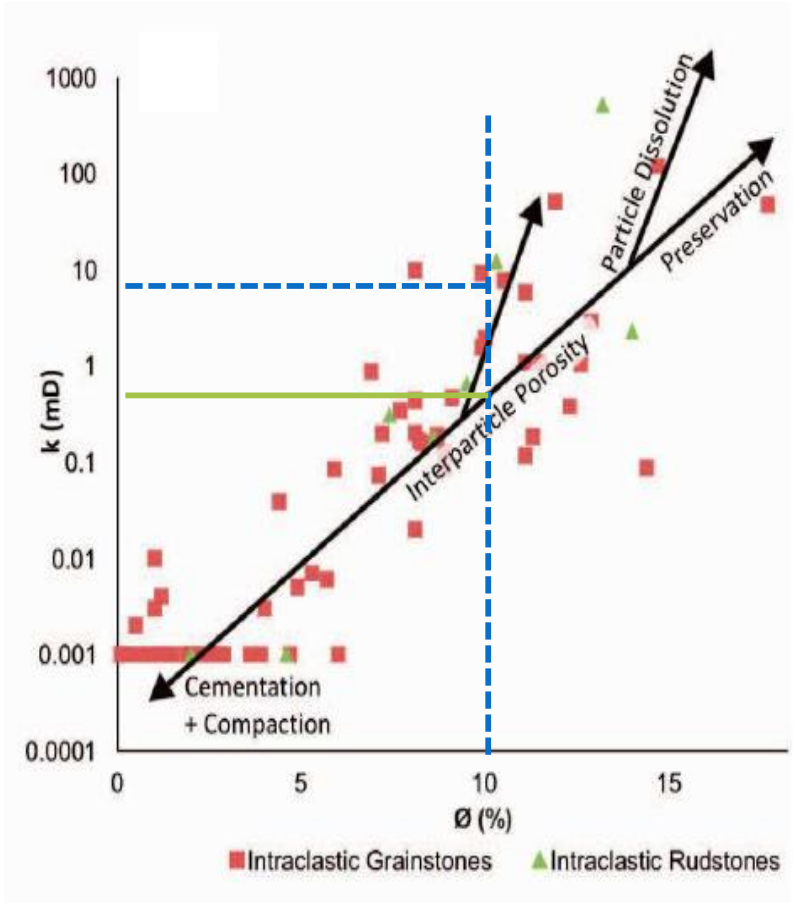

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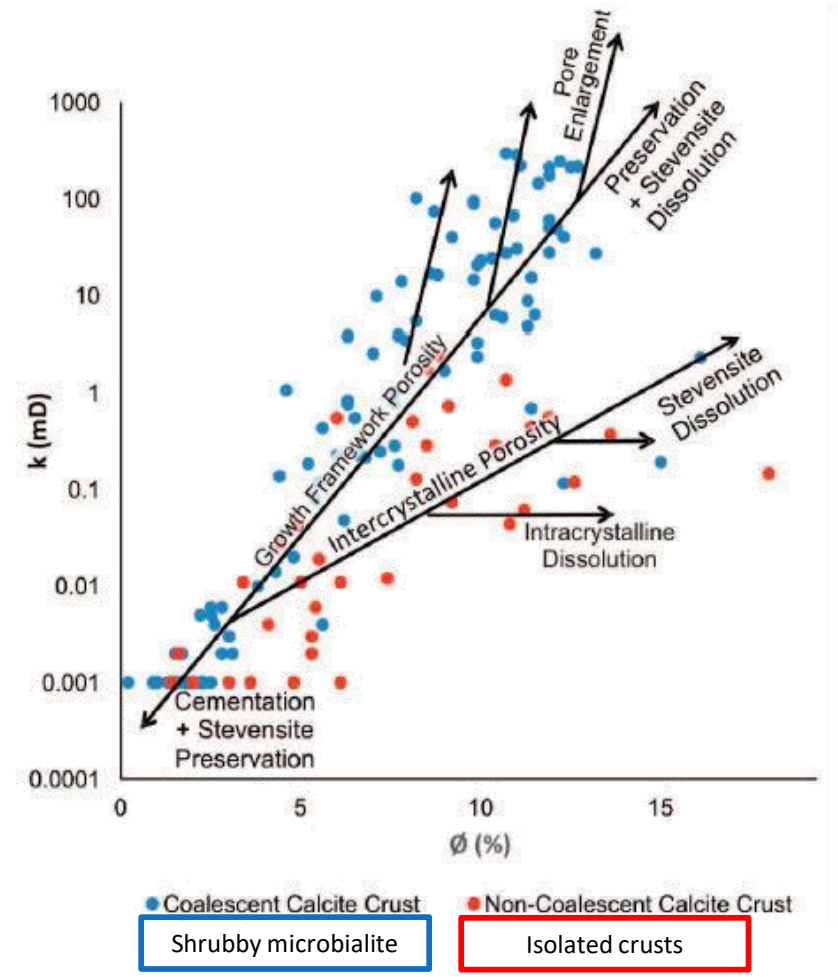
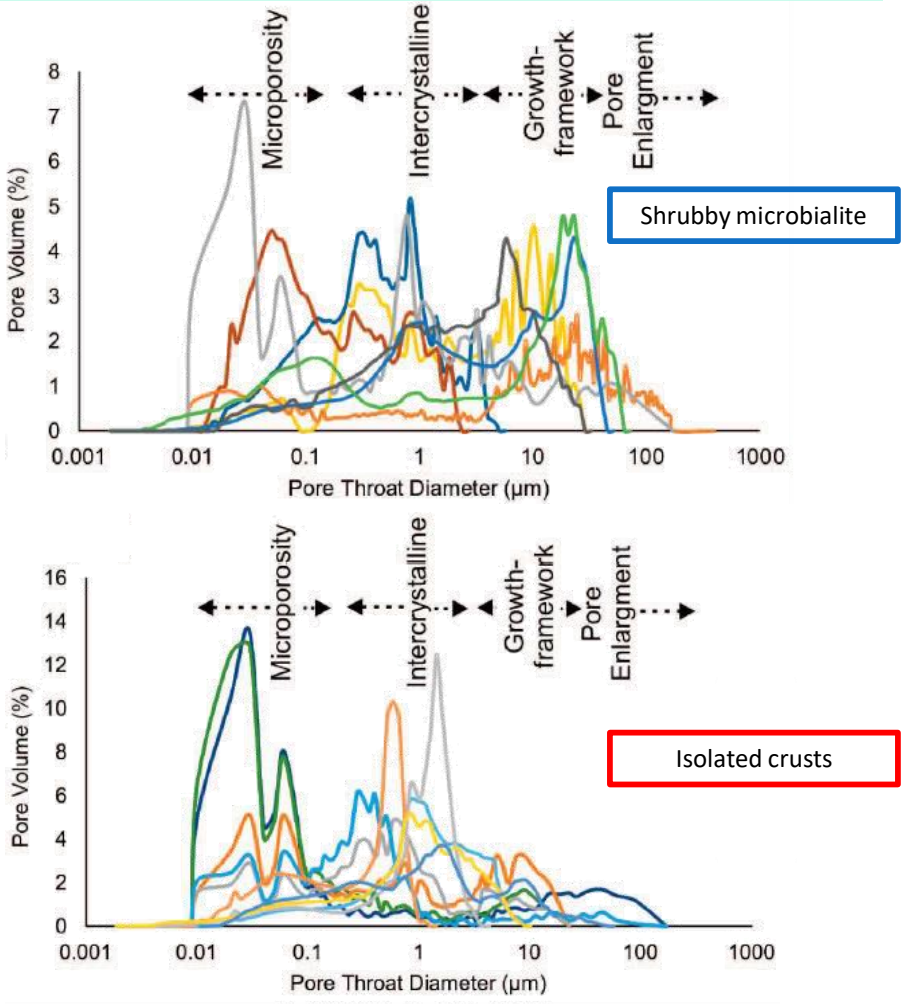
Deposition, Diagenesis and Reservoir Quality

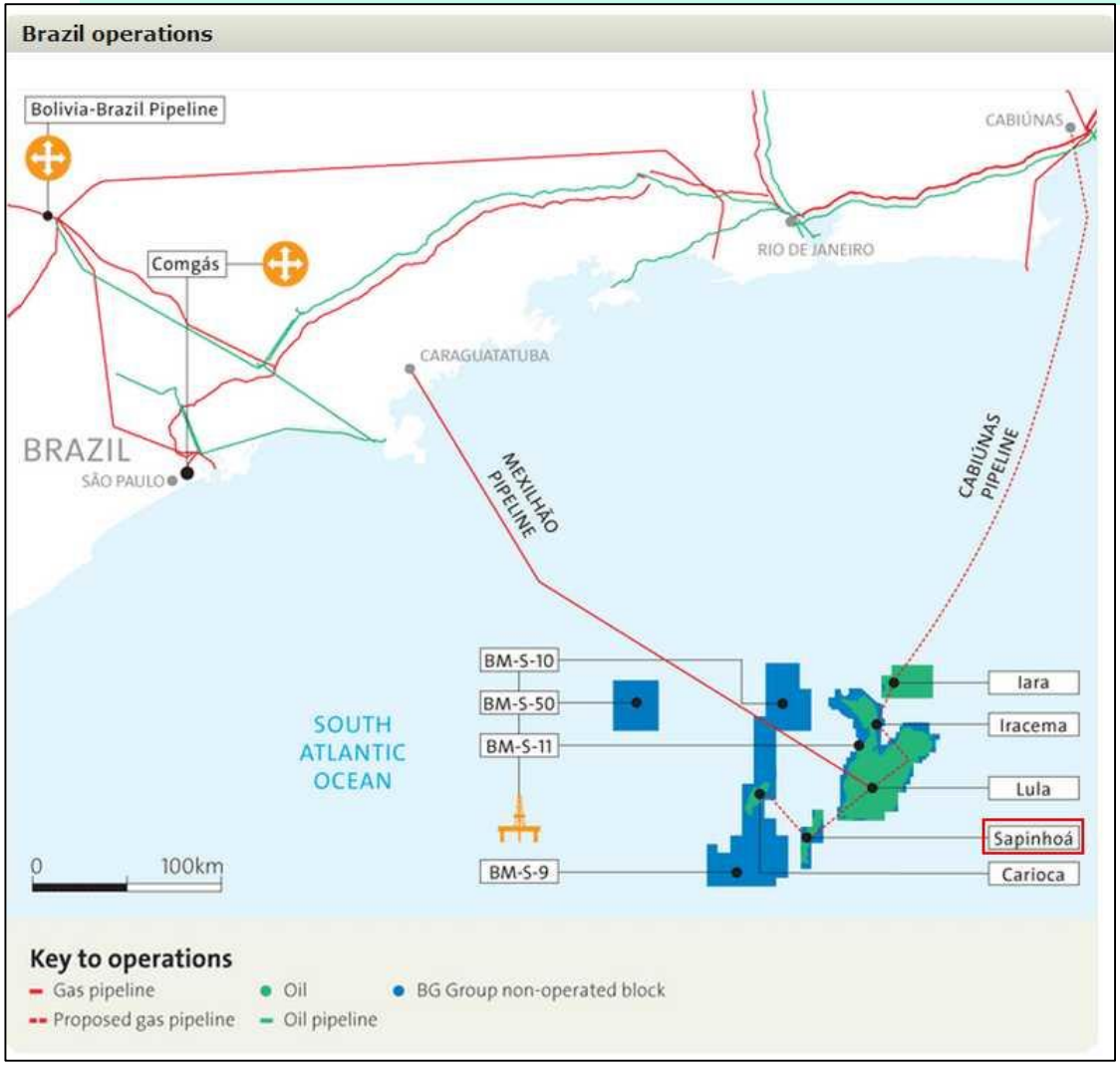




Distribution of pore throats of studied samples and their interpreted relationship with the pore type (each colour represents one sample):

From: Hertlinger, R. Jr, Zambonato, E. E. and de Ros, L. F., 2017. Influence of Diagenesis on the Quality of Lower Cretaceous Pre-Salt lacustrine Carbonate Reservoirs from Northern Campos Basin, Offshore Brazil. Journal of Sedimentary Research v. 87, p.1285-1313. DOI: http://dx.doi.org/10.2110/jsr.2017.70

Sapinhoá Development

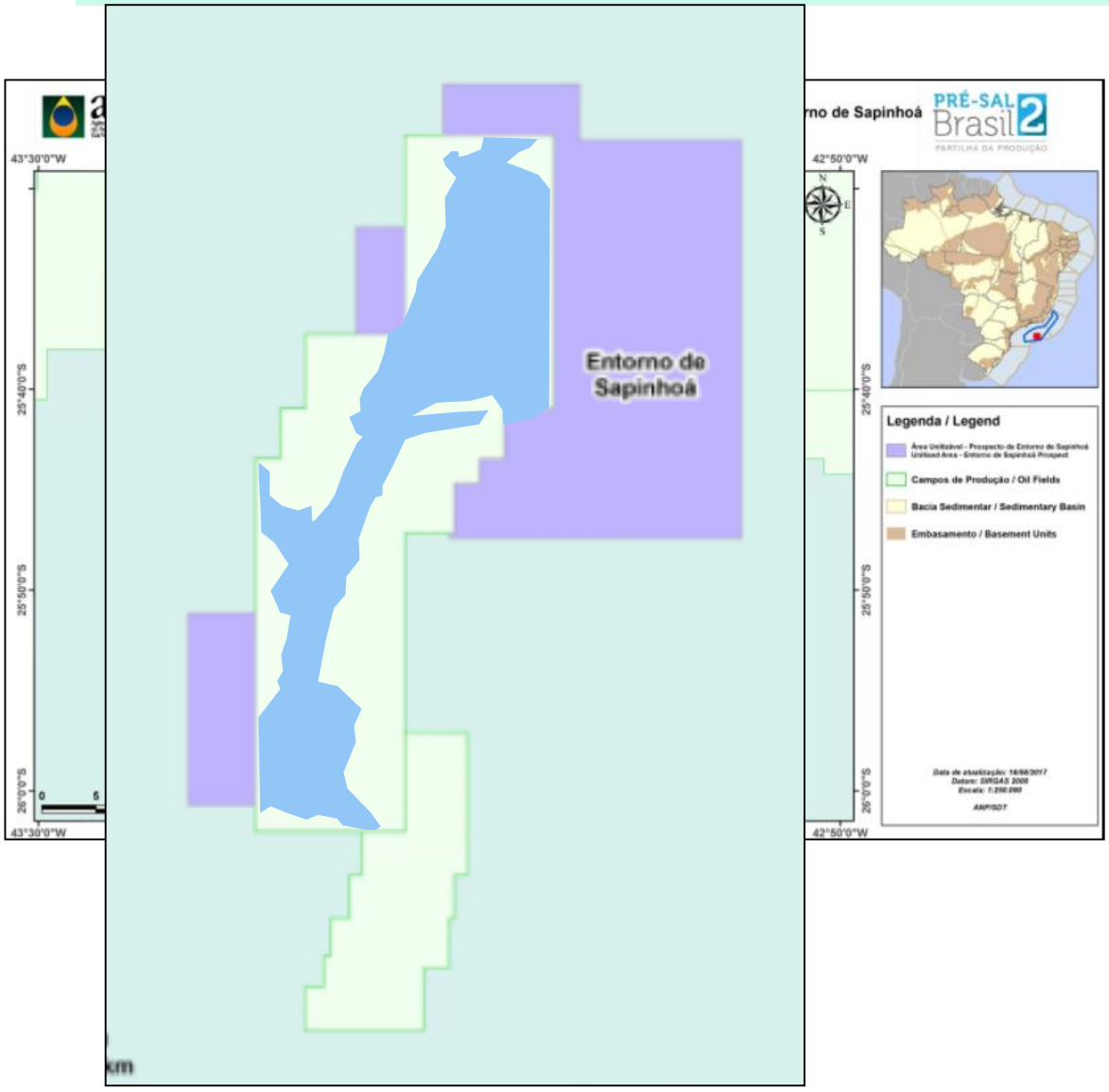


- The Sapinhoá field located in the southern Brazilian Santos Basin, 310 kilometres off the coast of Rio de Janeiro in a water depth of 2,153 m.
- It was discovered in 2008 and originally named Guará field.
- The oil field is operated by Petrobras and owned by Petrobras (45%)
  Repsol Sinopec Brazil (25%)
  and Shell (BG Brasil (30%)).
- The total proven reserves of the Sapinhoá oil field range from 1,100–2,000 million barrels

https://en.wikipedia.org/wiki/Santos_Basin

The porosity of Microbial limestone section is 10-20% and the permeability is 300-3000md.
http://www.searchanddiscovery.com/pdfz/abstracts/pdf/2017/90255aapg/abstracts/ndx_zhang.pdf.html

Sapinhoá Pilot Development



- Sapinhoá structure is a long, relatively straight, asymmetrical NE-SW trending horst defined by faults and fractures
- The depositional model indicated that the reservoirs were deposited on a carbonate platform developed as a shallow water horst and amplitude and impedance analysis indicated that the best reservoir properties correlated with the structural highs

From: Naveiro, J.T. and Haimson, D. 2015. Sapinhoá Field, Santos Basin Pre-Salt: From Conceptual Design to project Execution and Results. OTC-26320-MS

Sapinhoá Pilot Development: timeline from contract award to first oil

Date	Event
2001	BM-S-9 Concession Contract with ANP Seismic data acquisition for BM-S-9 block
2008	Wildcat discovery – 1-SPS-55 (P1S) Appraisal Plan (ANP)
2009	Technical and economic feasibility study approval (Opportunity Evaluation Phase FEL 1 Gate) Process of acquiring environmental licences from the Brazilian Environmental Regulatory Authority (IBAMA)
2010	3-SPS-69 (P1N) appraisal well drilled LOI to FPSO Cidade de Sao Paulo chartering 14 Christmas tree supply contract for BM-S-9
2011	Technical and economic feasibility study approval (Conceptual Phase FEL 2 Gate) 2 appraisal wells drilled (P2S and I1S) P1S EWT Decoupled gathering system contract (steel catenary risers (SCR) on buoy supported risers (BSR)) DECLARATION of COMMERCIALITY (ANP)
2012	Technical and economic feasibility study approval (Basic Engineering Phase FEL 3 Gate) Start of drilling campaign Umbilicals and flexible lines (gathering system) contract Environmental licences authorization Gas pipeline installation FPSO mooring and first well hook-up
2013	Sapinhoá FIRST OIL – 05/01/2013

From: Naveiro, J.T. and Haimson, D. 2015. Sapinhoá Field, Santos Basin Pre-Salt: From Conceptual Design to project Execution and Results. OTC-26320-MS

Sapinhoá Pilot Development

Well Type	Geometry	Completion
Producers	Vertical (6)	Simple (3)
		Selective (1)
		Intelligent (2)
	Directional (2)	Simple (1)
		Intelligent (1)
WAG injector	Vertical (1)	Intelligent(1)
Gas injector	Vertical (1)	Intelligent (1)
Water injector	Vertical (3)	Intelligent (3)

- The first well to be connected to the FPSO, 1-SPS-55, can produce over 25,000 barrels of oil per day.
- Production though will be restricted to 15,000 barrels of oil per day, until the commissioning of natural gas processing and reinjection systems is concluded, which is expected to last 90 days.
- The produced oil, which is of intermediate density (30º API) and high quality, will be transported through tankers.
- The gas not used for reinjection will be transported through the Sapinhoá-Lula-Mexilhão Gas Pipeline to the Monteiro Lobato Gas Treatment Unit (UTGCA), located in Caraguatatuba, on the São Paulo state coast.
- Another 10 wells (five production and five injection) will be interconnected to the platform in the coming months.
- Peak production of 120,000 barrels of oil per day is expected for the first half of 2014.
- The Sapinhoá field is one of the biggest oil fields in Brazil with a total recoverable volume estimated at 2.1bn barrels of oil equivalent (boe)
- It goes into commercial production **four and a half years after it was discovered in July 2008.**

From: Naveiro, J.T. and Haimson, D. 2015. Sapinhoá Field, Santos Basin Pre-Salt: From Conceptual Design to project Execution and Results. OTC-26320-MS

Petrobras Press Release 2013

3-SPS-69 (Guará Norte) EWT

- BG Group said it has started a new extended well test in the Sapinhoá North area of the BM-S-9 concession in the pre-salt Santos Basin marking the delivery of another milestone in the field development plan. The FPSO Cidade de São Vicente was connected to the 3-BRSA-788-SPS well, in water depths of 2140 metres.
- The FPSO will operate in the area for up to six months, gathering technical information on reservoir behaviour and oil flow in the subsea lines, amongst other data. During this initial test phase the well is expected to produce at around 15 000 bopd – as authorised by Brazil's National Agency for Petroleum, Natural Gas and Biofuels.

BG Group Press Release February 2013

Sapinhoá Norte Development

- Production commenced 20 November 2014
- The Cidade de Ilhabela has capacity to process 150,000 barrels of oil per day and 212 million standard cubic feet per day of natural gas.
- Injection capacity 180,000 bpd
- First well, 3-SPS-69, potential for 32,000 bopd
- The oil produced from Sapinhoá is high quality and of medium density (29° API). Gas not used for reinjection will be transferred to shore through the Santos Basin pipeline system.
- The hull was converted from a tanker at the CXG shipyard, in China, while the integration of the process plant modules took place at the Brasa Shipyard, in Niterói (RJ).

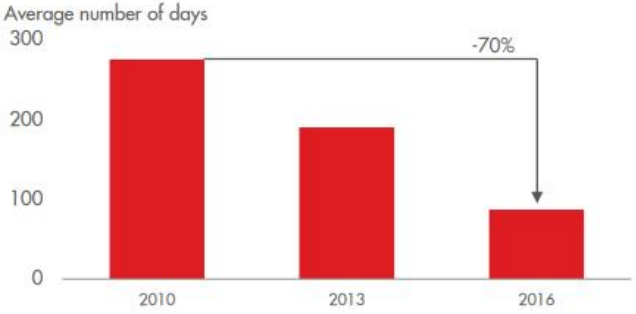
Petrobras Press Release 01 December 2014

Brazil: Santos Basin

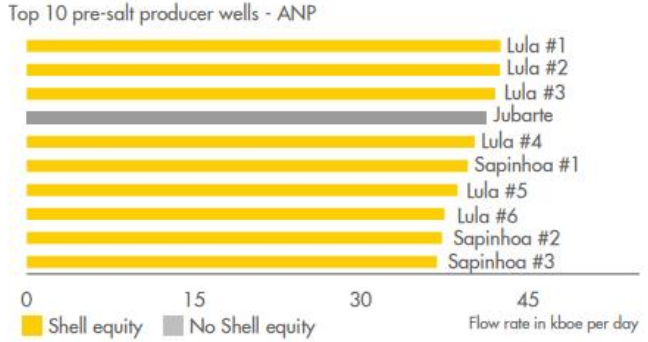
Competitive growth

- Learning curve resulting in significant cost reduction
- Exceptional well productivity
- Low breakeven prices

Drill and complete time



Well performance



Brazil pre-salt breakeven price

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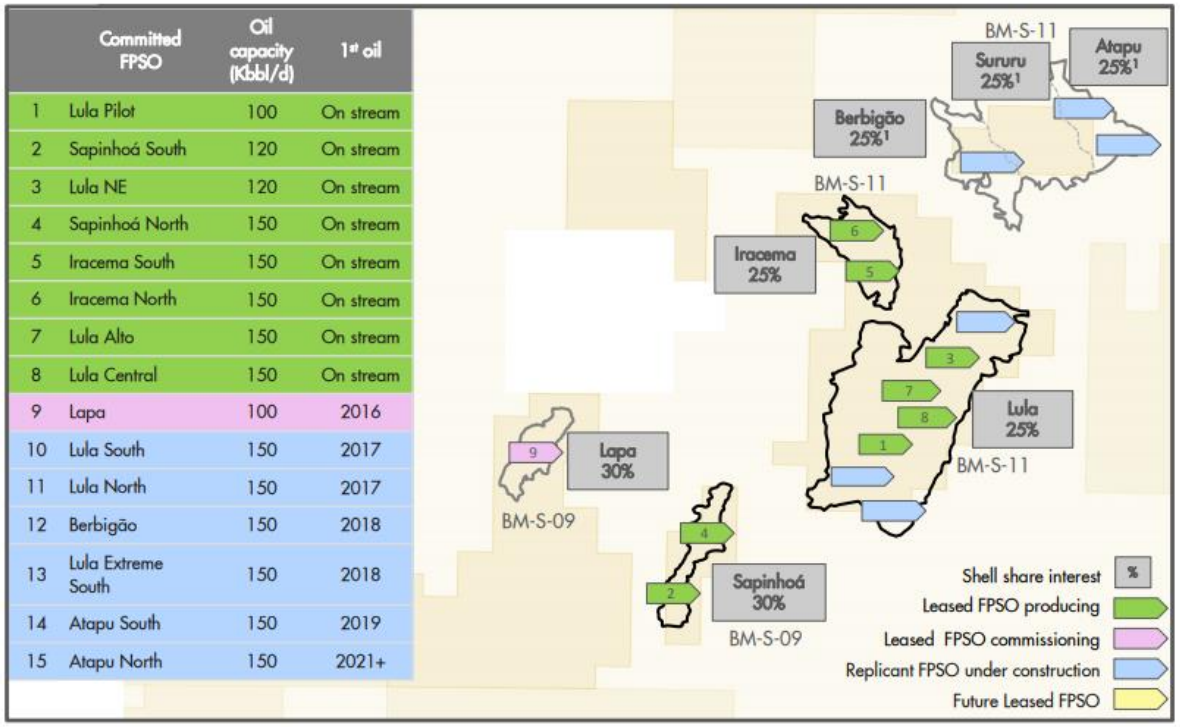
Brazil: Santos Basin

Competitive growth

- Petrobras operated
- Significant development in progress
- Impressive delivery track record

	Committed FPSO	Oil capacity (Kbbl/d)	1st oil
1	Lula Pilot	100	On stream
2	Sapinhoá South	120	On stream
3	Lula NE	120	On stream
4	Sapinhoá North	150	On stream
5	Iracema South	150	On stream
6	Iracema North	150	On stream
7	Lula Alto	150	On stream
8	Lula Central	150	On stream
9	Lapa	100	2016
10	Lula South	150	2017
11	Lula North	150	2017
12	Berbigão	150	2018
13	Lula Extreme South	150	2018
14	Atapu South	150	2019
15	Atapu North	150	2021+



[1] The Berbigão, Sururu and Atapu accumulations are subject to unitisation agreements

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Thank You