The Construction of Predictive Model to Reductions in Time and Cost of the Appraisal / Exploratory Well*

Enrique Estrada[1], Michelle Celestino[1], and Angelo Lima[1]

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[1]Halliburton, Rio de Janeiro, Rio de Janeiro, Brazil (Enrique.Estrada@Halliburton.com)

Abstract

The deep-water project has been the focus of an extensive exploration campaign in four years ago; since one of the pre-salt exploratory block in Brazil located in the Santos Basin. The challenges in post-salt and salt was minimized with the used of suite from SDL (lithofact) where the cutting samples had a great performance identified mineralogy and elements, Gas Fact and Gamma spectral combined with LWD (Gamma rays, Resistivity, Sonic and resonance). The more valuable was X-Rays Diffraction (XRD) and X-Rays Fluorescence (XRF) from SLD and excellent solutions like MSE (Mechanical Specific Energy) that provide geostoping information (top the reservoir) and Creep Control for proactive MSE to avoid the salt fluency and reduce the risk stuck pipe. For the mechanical properties, it was necessary to generate the elastic properties for the salt column using the logs of the well drilled and calibrate them with the drilling events observed during the drilling. Information collected from the wells of different characteristics of the same basin to correlate them with the results of the geomechanical curves and drilling events. These results showed that it is possible to identify at least four different sectors in the same basin, each of which has different response to drilling complexity. For another hand, the reservoir rock presented low rate penetration due to hard and abrasive carbonate mixed rocks, severe loss of fluids by caves, cavern (Karst) that generated bad hole conditions (Washout) that complicate the evaluation and cementation stage, spending more time that planned. Geology knowledge is also an important tool to help predict potential drilling problems in the salt section and pre-salt. The previous experience in formation evaluation of the reservoir rocks in different sedimentary models like microbial platforms, complex build up and mixed platform with volcanic

influence; were used in many wells to corroborate all the results. The highlight of this new predictive risk model; should be applied to many other pre-salt fields in the Santos Basin.

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AAPG Latin America & Caribbean Region

BRAZIL 2019 Geosciences Technology Workshop

Co-hosted by ABGP Associação Brasileira de Geólogos do Petróleo

The construction of predictive model to reductions in time and cost of the appraisal / exploratory well

Enrique Estrada, Micheli Celestino and Angelo Lima

Halliburton

Agenda

- Introduction to Giant Pre-salt Carbonate

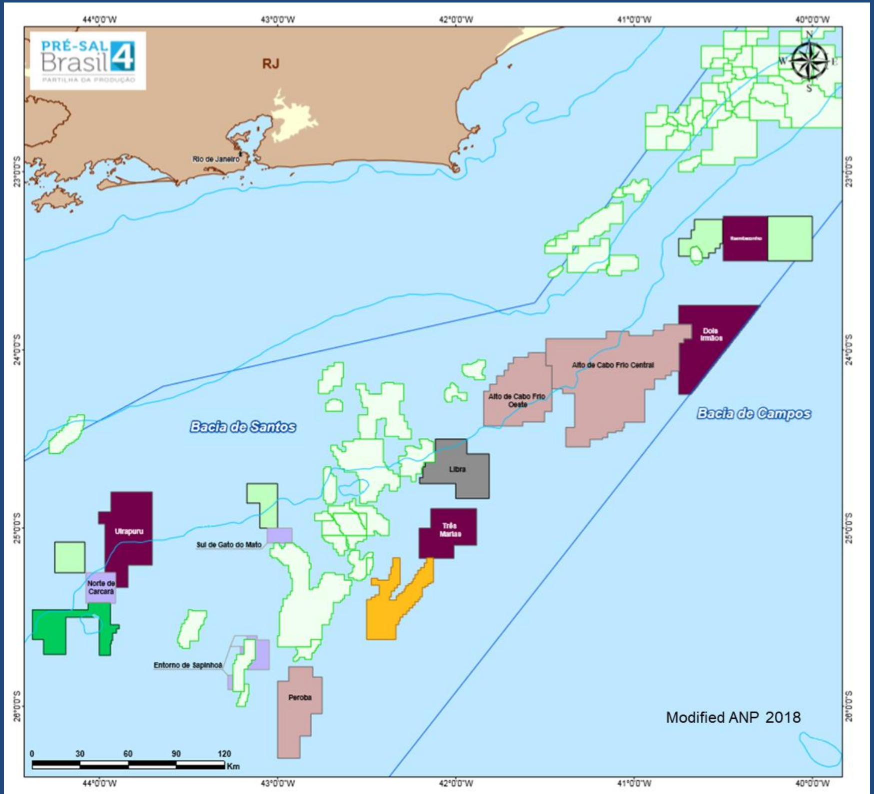
    Post-salt & Salt Challenges (stuck pipe, salt creep and loss of fluid)

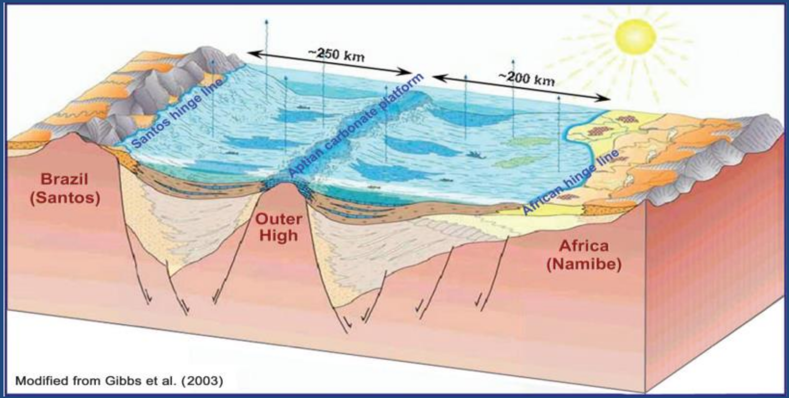
    Pre-salt Challenges (low rate penetration, abrasive rock and loss of fluid)

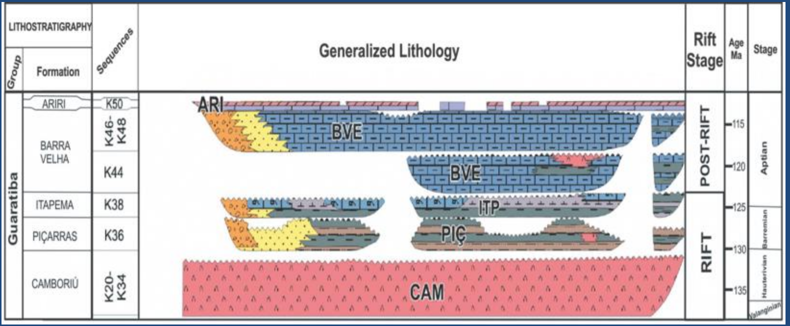
    Summary of Technologies for FE in Pre-Salt Carbonate

- The construction of predictive model to reductions in time and cost of the appraisal / exploratory well.

The Giant Pre -Salt Province Brazil (Santos + Campos Basins)

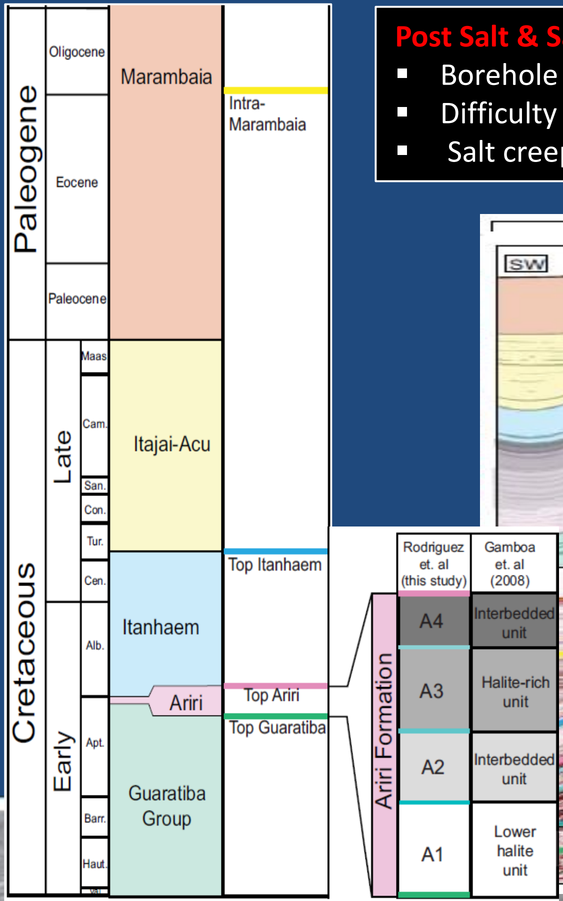






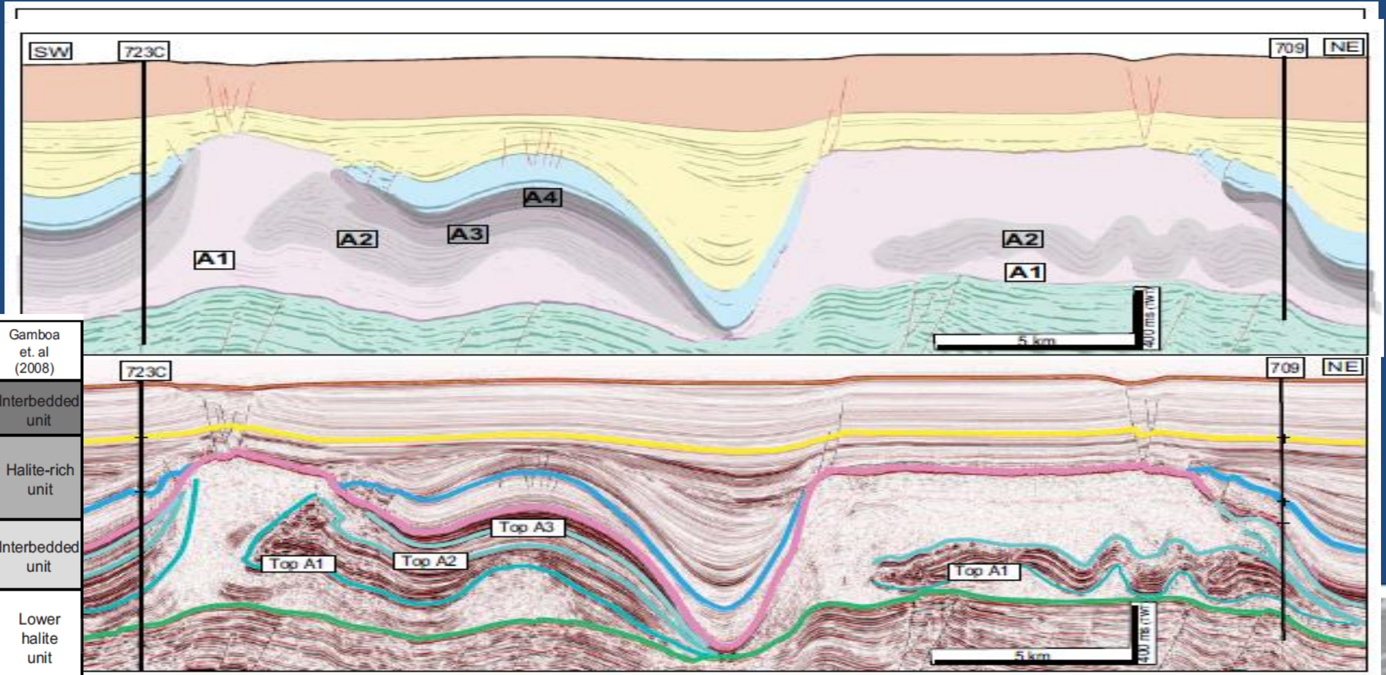
(Modified from Moreira et al., 2007.)

Challenges: Post Salt, Salt Carbonate



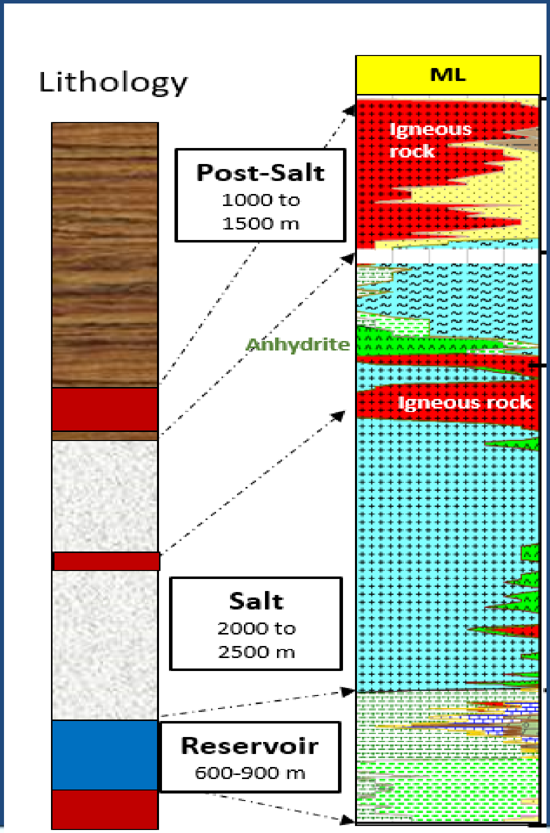
Post Salt & Salt Challenges

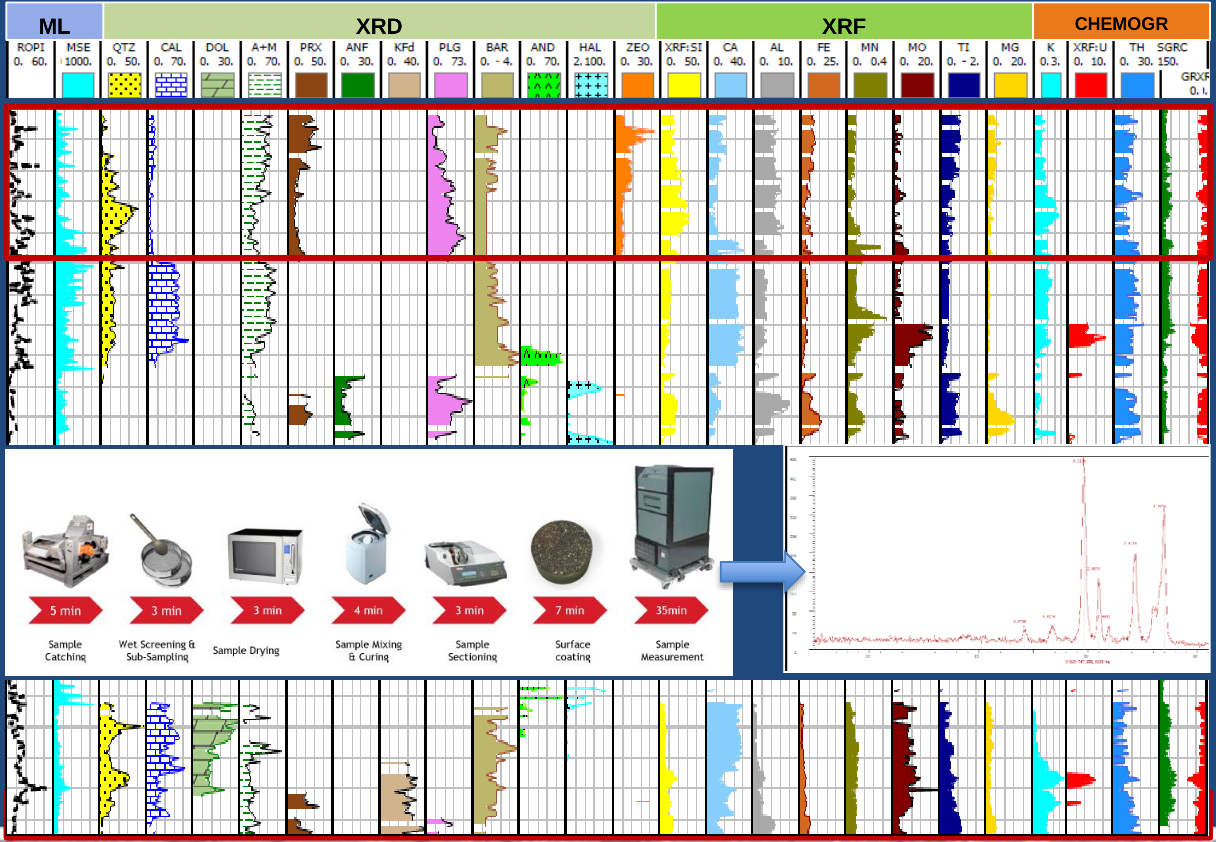
- Borehole instability and High torque and vibration during drilling.
- Difficulty to maintain the trajectory through the salt due to hard rock intercalations (igneous rock)
- Salt creep, and the risk of stuck pipe.



(Rodriguez et al., 2018)

Challenges: Post Salt, Salt and Pre Salt Carbonates





Elemental Analysis XRF and Identification Minerals XRD

Challenges: Vibrations, Salt Fluency and Stuck Pipe. Creep Control

ECD/ OBG Percentage Ratio X Well Signals

Levels	ECD X OBG Ratio (%)	Well Occurrences	Alert colors
I	90 a 85%	Drilling without Vibrations	Green
II	85 a 84%	Small oscillations in surface parameters	Yellow
III	84 a 82%	Rising Vibrations Stick Slips	Red
IV	82 a 80%	Stuckpipes Threats and Occurrence	Purple

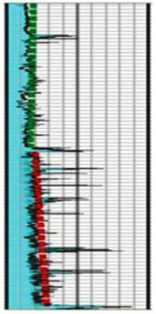
B — Reactive - WITHOUT CREEP CONTR

MW-ECD X OBG Ratio

(Drilled **reactive way** x Proposed Creep Control **proactive way**)

CREEP CONTROL REACTIVE

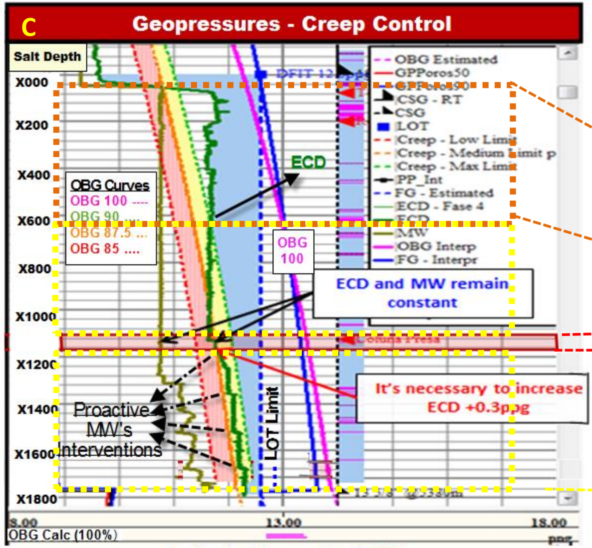
Salt Depth (m)	MW (ppg) Drilled Well	MW Proposed By Creep Control Methodology	ECD Drilled Well	ECD 85% from OBG (Ideal, Goal)	Diff. Creep Control	ECD X OBG Ratio Drilled Well	Control Level
X750	11.3	11.20	11.59	11.49	0.10	85.90%	I
X850	11.3	11.30	11.57	11.57	0	85.00%	I
X950	11.3	11.35	11.59	11.64	0.05	84.60%	II
X1050	11.3	11.39	11.62	11.71	0.09	84.20%	II
X 1150	11.3	11.51	11.58	11.79	-0.21	83.20%	III
X1250	11.3	11.57	11.57	11.84	-0.27	82.70%	III
X1350	11.3	11.60	11.61	11.91	-0.30	82.50%	III
X1450	11.3	11.67	11.6	11.97	-0.37	81.90%	IV
X1550	11.3	11.76	11.56	12.02	-0.46	81.20%	IV
X1600	11.5	11.75	11.79	12.04	-0.25	82.90%	III
X1640	11.6	11.77	11.88	12.05	-0.17	83.60%	III



MSE Indicator

MW X ECD X OBG 85% (From Lima et al., 2016)

C

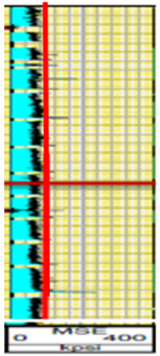


Estimated Fluence Limit: 87%

D — Proactive - CREEP CONTROL

CREEP CONTROL PROACTIVE

Salt Depth (m)	MW (ppg) Drilled Well (With MPD)	ECD Drilled Well	ECD 87% from OBG (Ideal, goal)	Diff. Creep Control Margin	ECD X OBG Ratio Drilled Well	Control Level
X100	10.8	11.76	10.79	0.97	94.84%	I
X300	10.8	11.63	10.99	0.64	92.08%	I
X500	10.8	11.70	11.18	0.52	91.05%	I
X700	10.8	11.60	11.34	0.26	88.96%	II
X900	10.8	11.67	11.50	0.17	88.28%	II
X1100	10.8	11.64	11.65	-0.01	86.95%	III
X1300	11.1	12.01	11.81	0.20	88.50%	II
X1500	11.2	12.10	11.97	0.13	87.94%	II
X1700	11.7	12.30	12.11	0.19	88.36%	II
X1725	11.7	12.30	12.13	0.17	88.24%	II

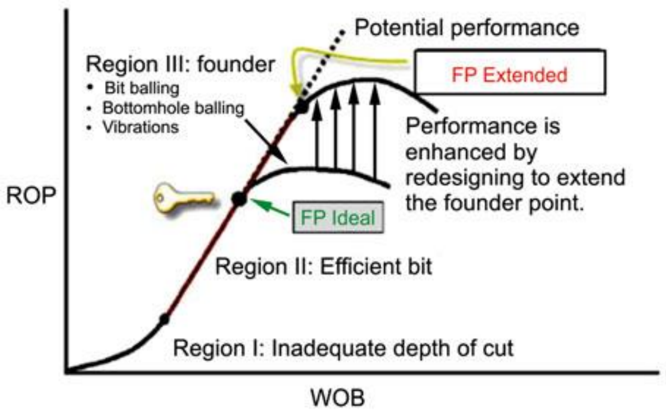


MSE Indicator

MW X ECD X OBG 87%

(From Lima et al., 2016)

Salt Solutions – MSE (Mechanical Specific Energy)

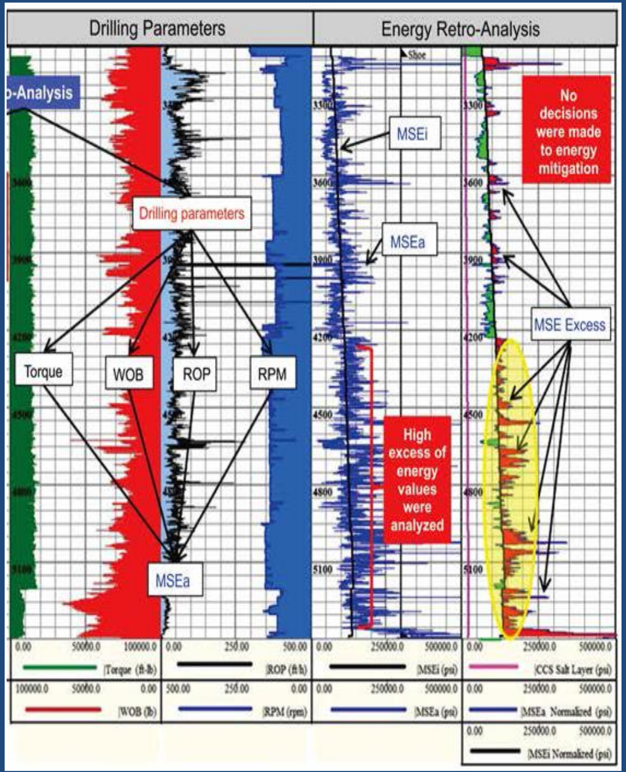


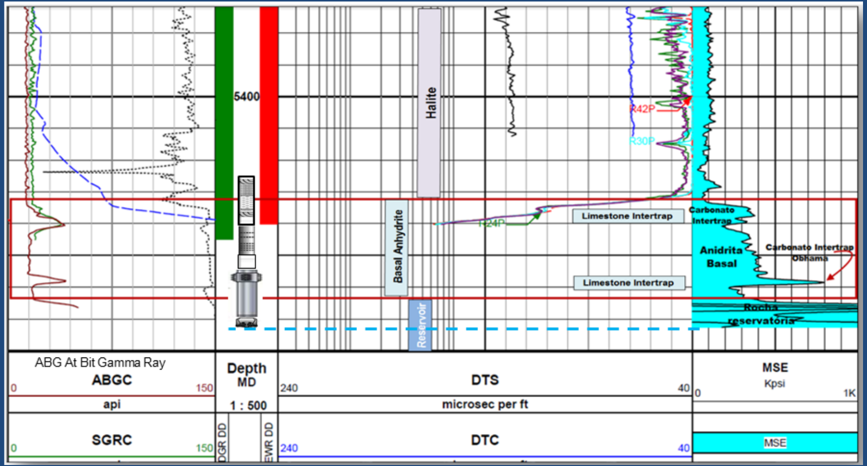
(modified from Dupriest and Koederitz, 2005)

$$MSE \approx \frac{\text{Input Energy}}{\text{Output ROP}}$$

MSE Input Energy: RPM, WOB and Torque

- MSE – Drilling Optimization
- MSE – Salt Mobility (Creep control)
- MSE – Lithology ID
- MSE – Geostop





(From Lima et al., 2016)

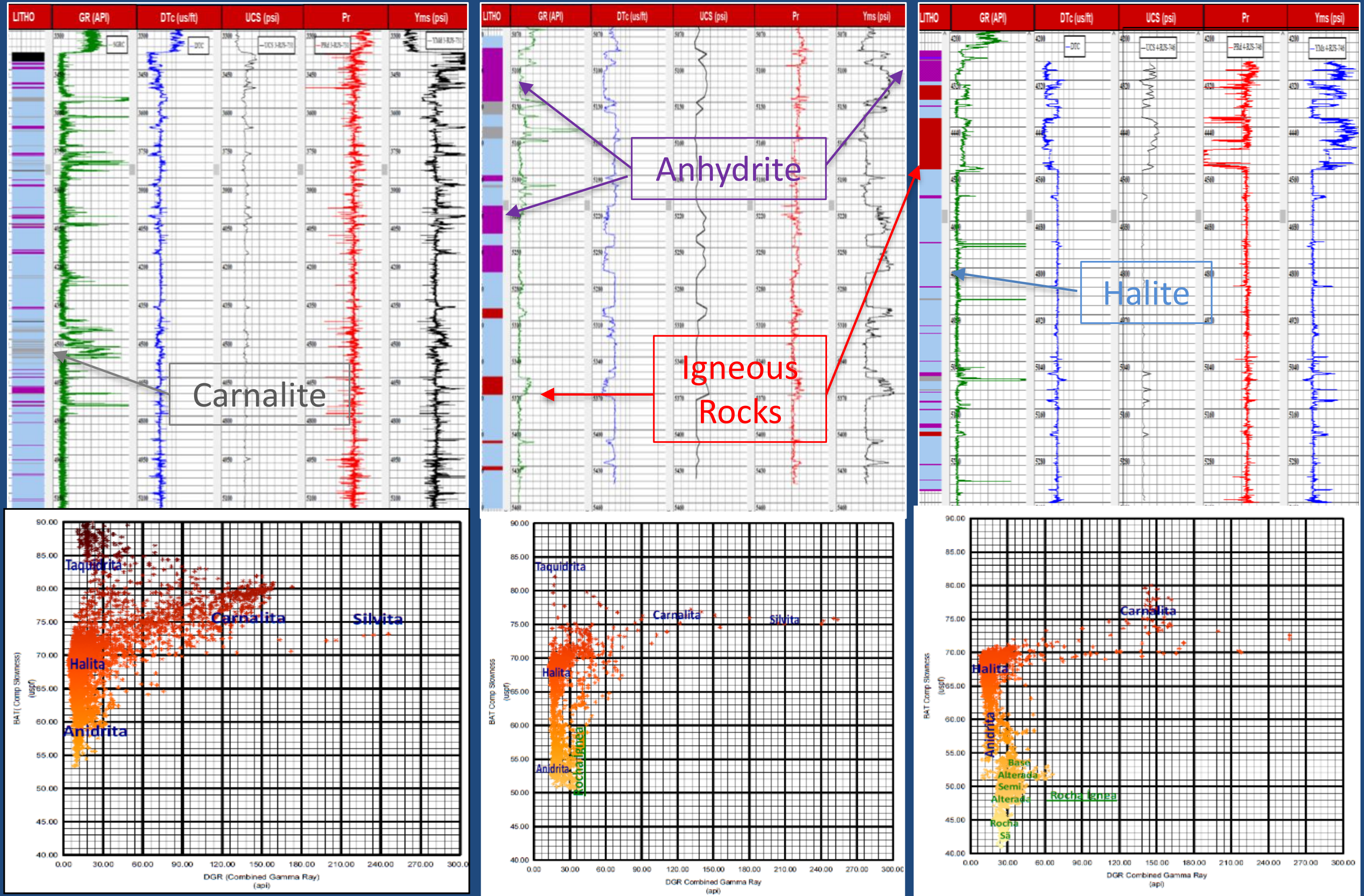
Geomechanics parameters

- Gamma ray
- DTC (sonic)
- UCS
- Modulo Poison
- Modulo Young

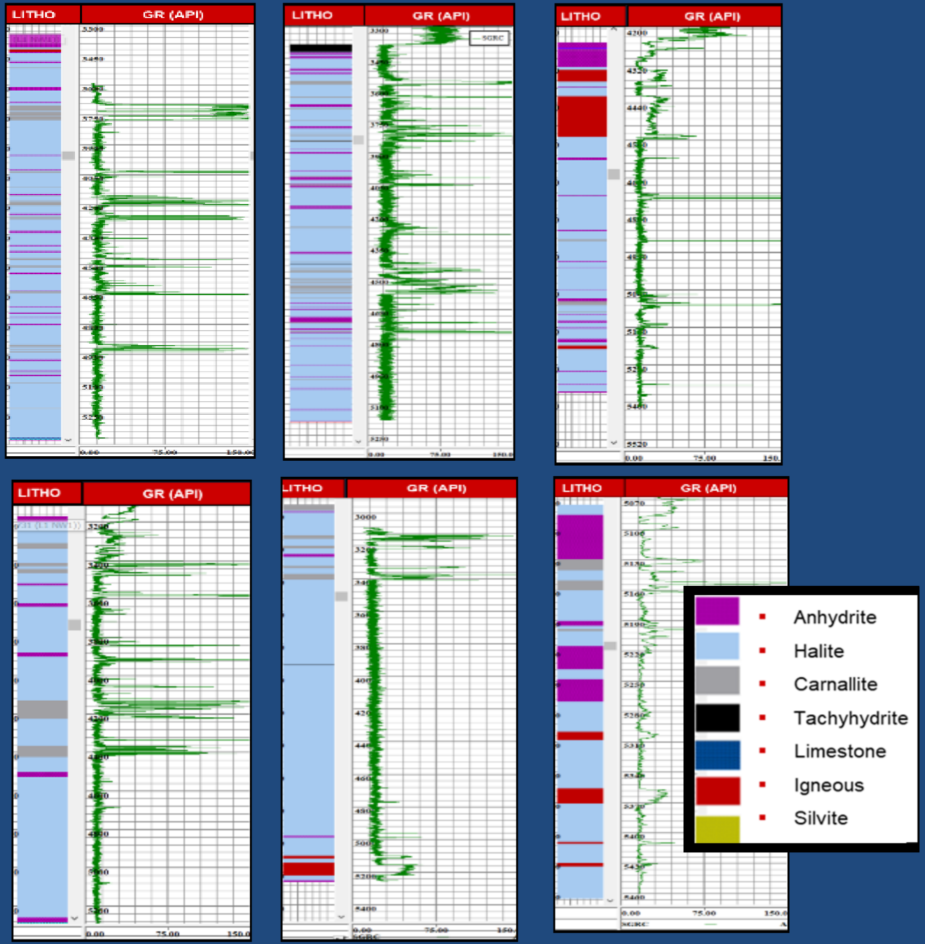
- Anhydrite
- Halite
- Carnallite
- Tachyhydrite
- Limestone
- Igneous
- Silvite

Cross Plot

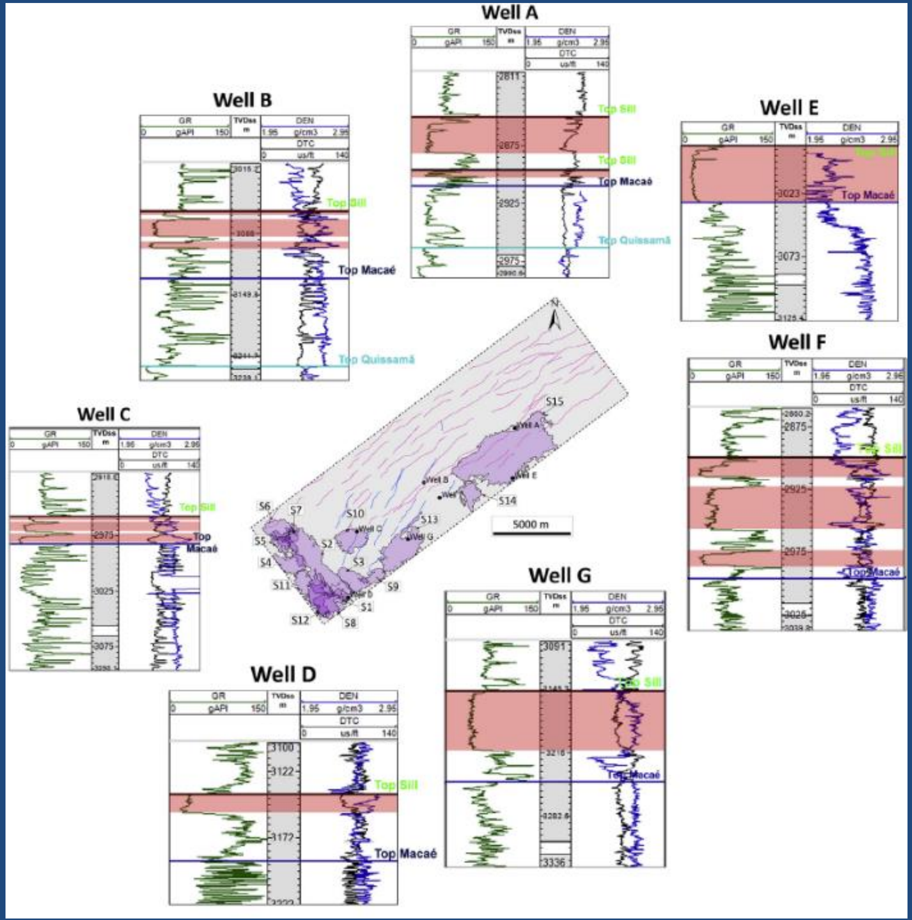
- DTC (sonic)
- Gamma ray



Challenges Salt: Different Models



Challenges Post-Salt: Igneous Rocks



Costa Correia, *et al., 2019*

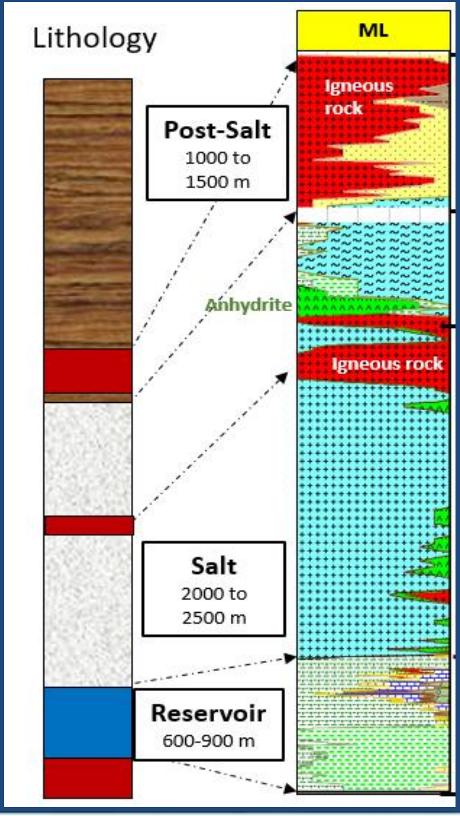
Challenges: Post Salt- Salt Pre Salt Carbonates

Post Salt & Salt Challenges

- Borehole instability
- High torque and vibration during drilling.
- Difficulty to maintain the trajectory through the salt due to hard rock intercalations (igneous rock)
- Salt creep, and the risk of stuck pipe.

Pre Salt Reservoir Challenges

- Low rate of penetration and hard and abrasive carbonate
- Silica and vuggy porosities and Igneous rocks intercalations
- Severe loss of fluids
- Natural and Tensile Fractures; Break-out and Washout Cavern and caves (Karst)
- High CO2 and H2S
- Complicated cementation stage
- Complicated OH and CH FE



Summary technologies)
(Excellent Solutions)

Salt Section

- SDL (Lithofact) (Cutting samples)
  - X-Ray Difraction/X-Ray Fluorescence/Gas Fact / GR
- LWD (Real Time)
  - GR – Resistivity - Sonic – NMR-
  - (Mechanical Specific Energy)
    Geostoping/Lithology ID
  - (DES) Creep Control (Excellent Solutions)

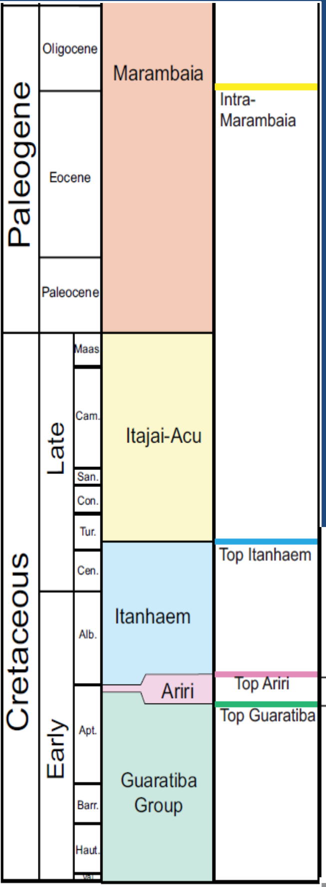
Reservoir Section

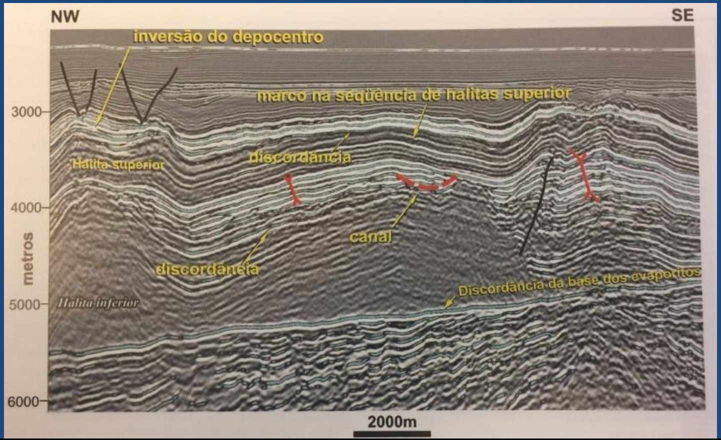
Wireline Logs

- Run #1: GR – Neu – Den – NMR - RT- GR SPEC – GEM
- Run #2: RDT (Sampling and Pre-Test) ICE
- Run #3: Rotary Side-Wall Core
- Run #4: Sonic–Resistivity and Acoustic Image and Cement evaluation CAST- I BSAT (CBL-VDL)
- Integrated Digital Petrophysics Analysis (Ingrain –HAL)

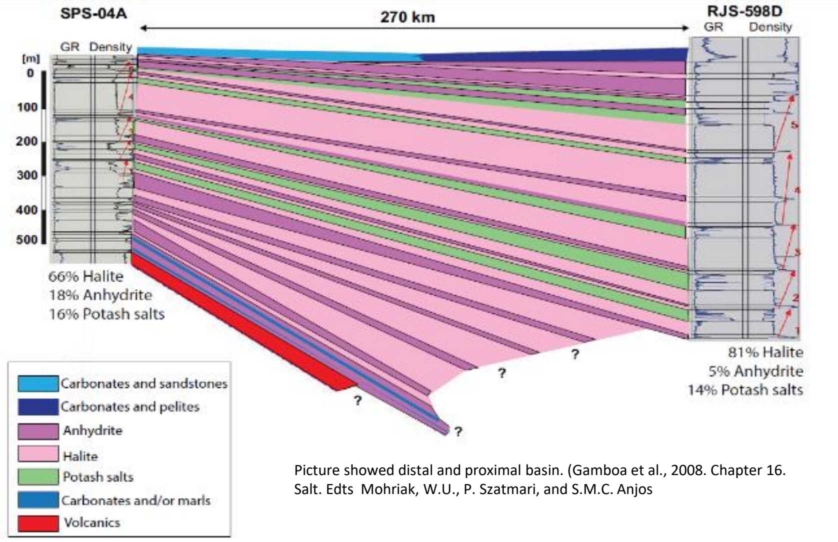
Reductions of well construction time and cost

Challenges: Post Salt, Salt and Pre Salt Carbonate

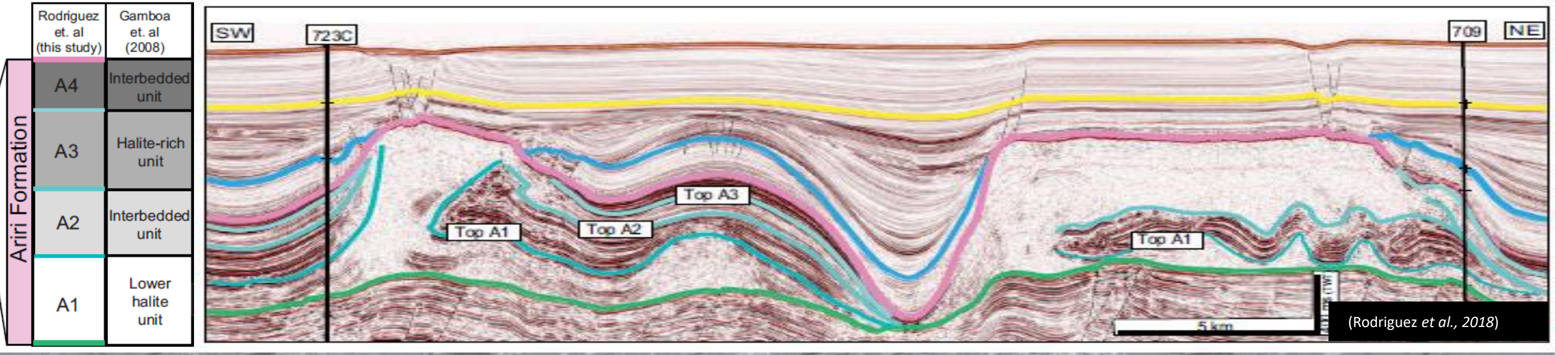




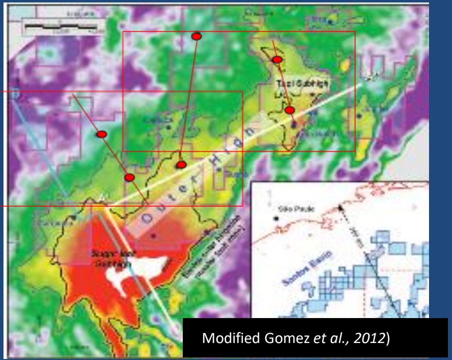
(Gamboa et al., 2008. Chapter 16. Salt. Edts Mohriak, W.U., P. Szatmari, and S.M.C. Anjos)



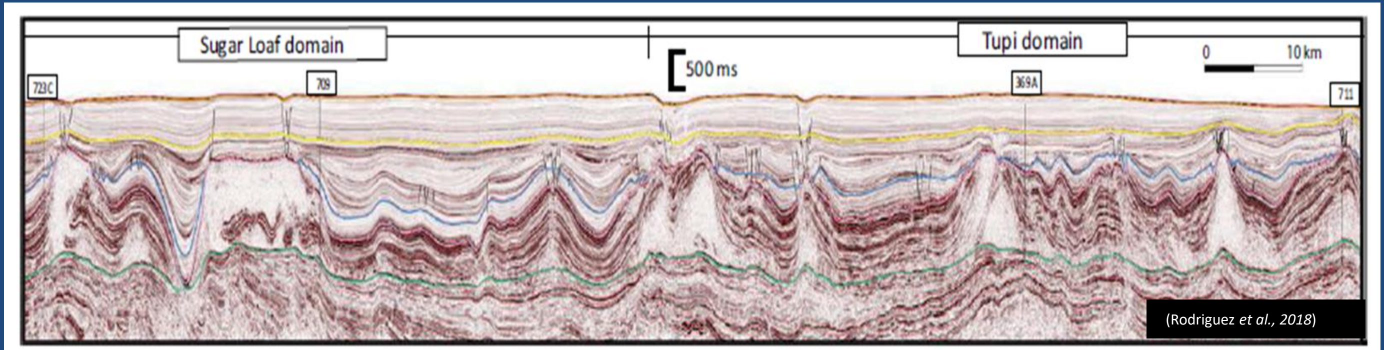
Picture showed distal and proximal basin. (Gamboa et al., 2008. Chapter 16. Salt. Edts Mohriak, W.U., P. Szatmari, and S.M.C. Anjos



(Rodriguez *et al., 2018*)



Modified Gomez *et al., 2012*)



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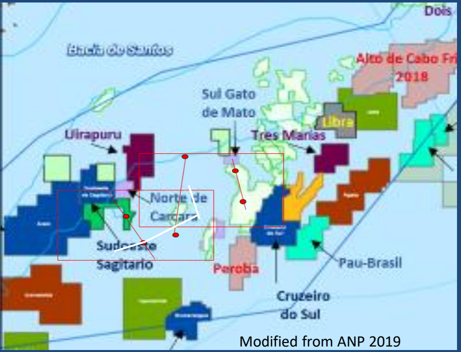
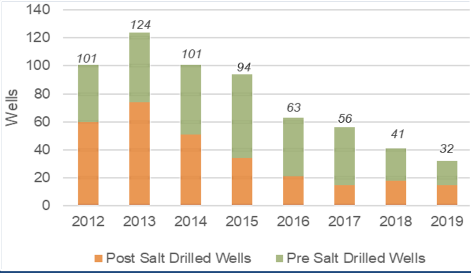
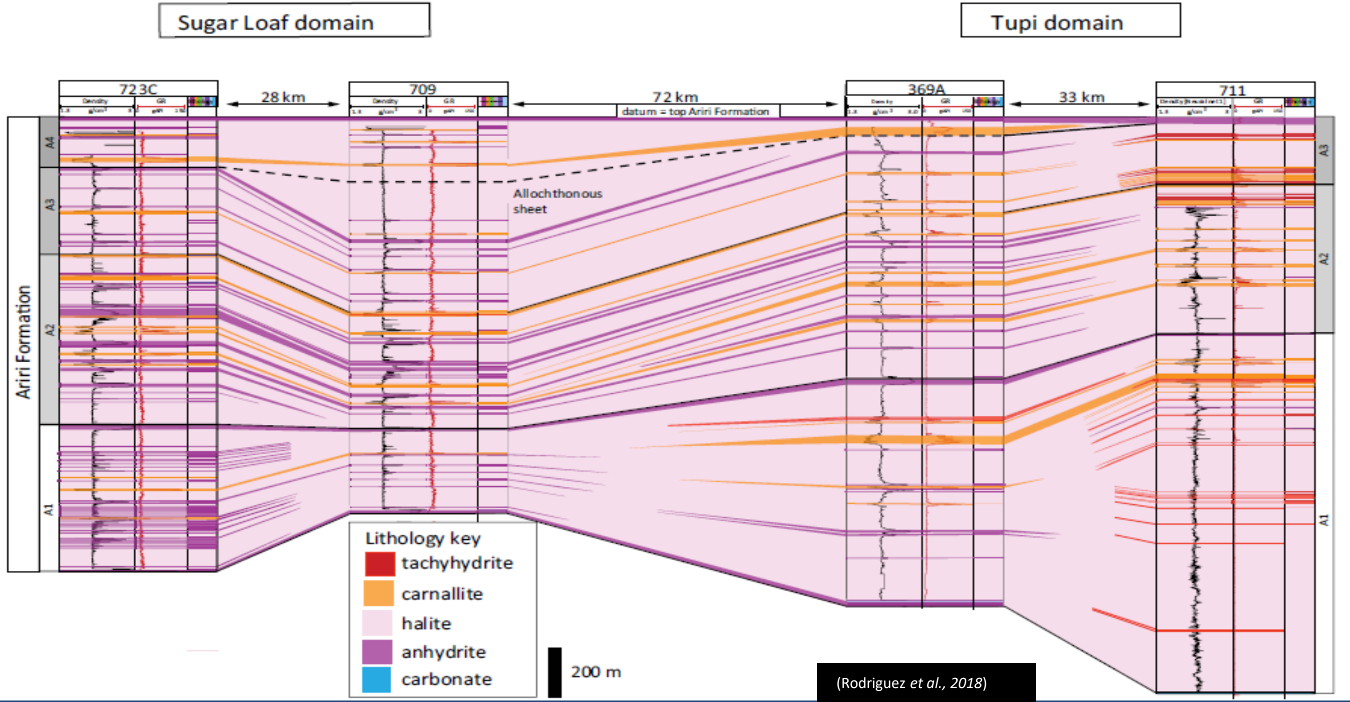


Modified from ANP 2019

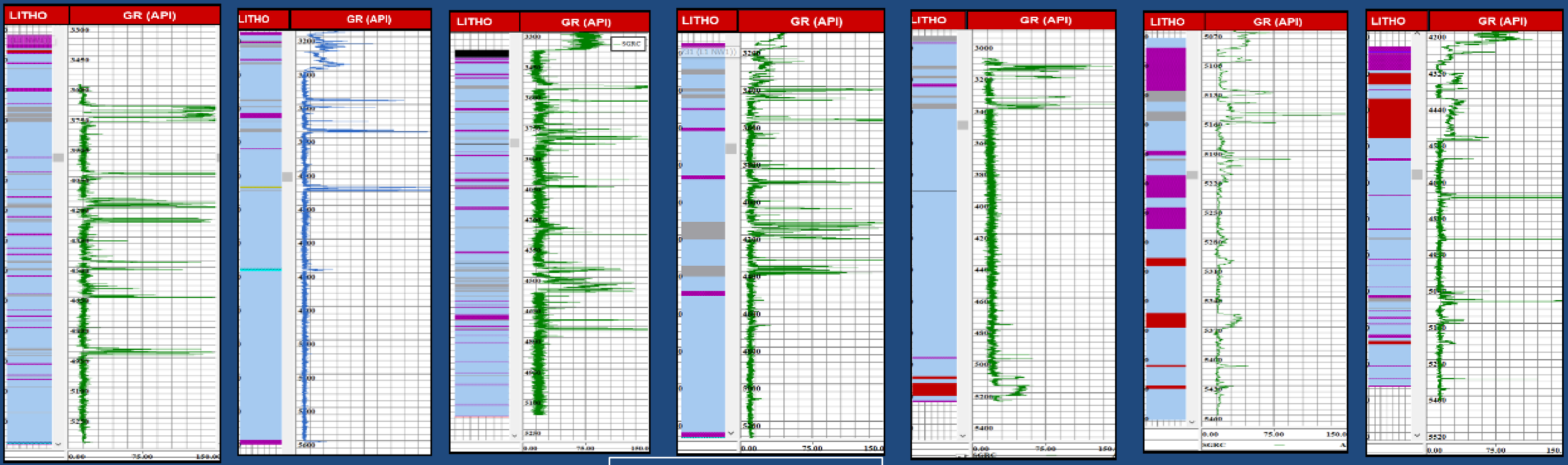
Number of Wells Drilled Pre-Salt (more >200)





(Rodriguez *et al., 2018*)

Different Models of Salt



Vibrations, Salt Fluency and Stuck Pipe. Creep Control

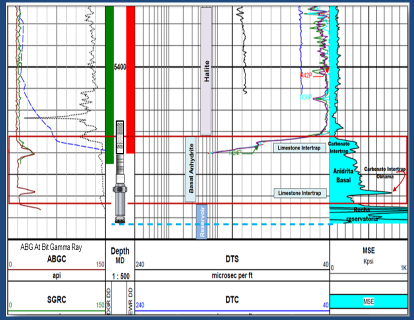
ECD/ OBG Percentage Ratio X Well Signals

Levels	ECD X OBG Ratio (%)	Well Occurrences	Alert colors
I	90 a 85%	Drilling without Vibrations	Green
II	85 a 84%	Small oscillations in surface parameters	Yellow
III	84 a 82%	Rising Vibrations Stick Slips	Red
IV	82 a 80%	Stuckpipes Threats and Occurrence	Purple

Salt Performance

Wells	ROP m/h	Salt length	Fluid type
1	24.1	2015	SBM
2	25.4	2210	WBM
3	15.9	1644	SBM
4	32.6	1960	WBM
5	30.7	2150	SBM
6	4.5	385	SBM
7	16.5	1087	SBM

Salt Solutions – MSE (Mechanical Specific Energy)

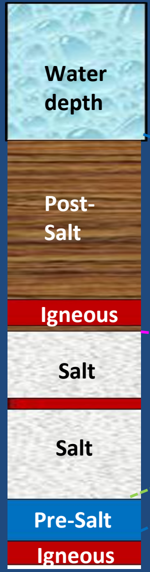


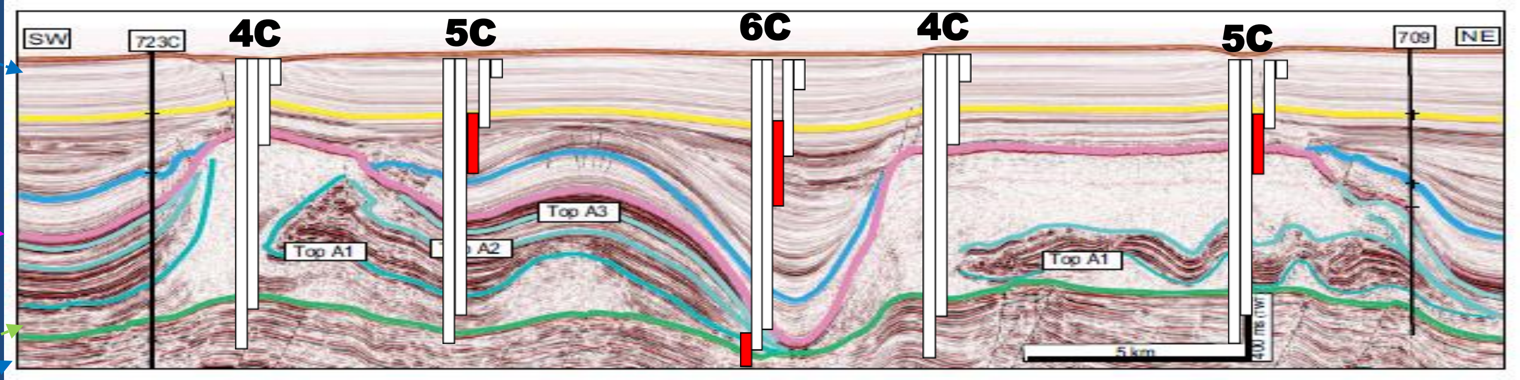
Challenges: Number of Casing for Drilling (4C, 5C, 6C)

Post Salt & Salt Challenges

- Borehole instability and High torque and vibration during drilling.
- Difficulty to maintain the trajectory through the salt due to hard rock intercalations (igneous rock)
- Salt creep, and the risk of stuck pipe.

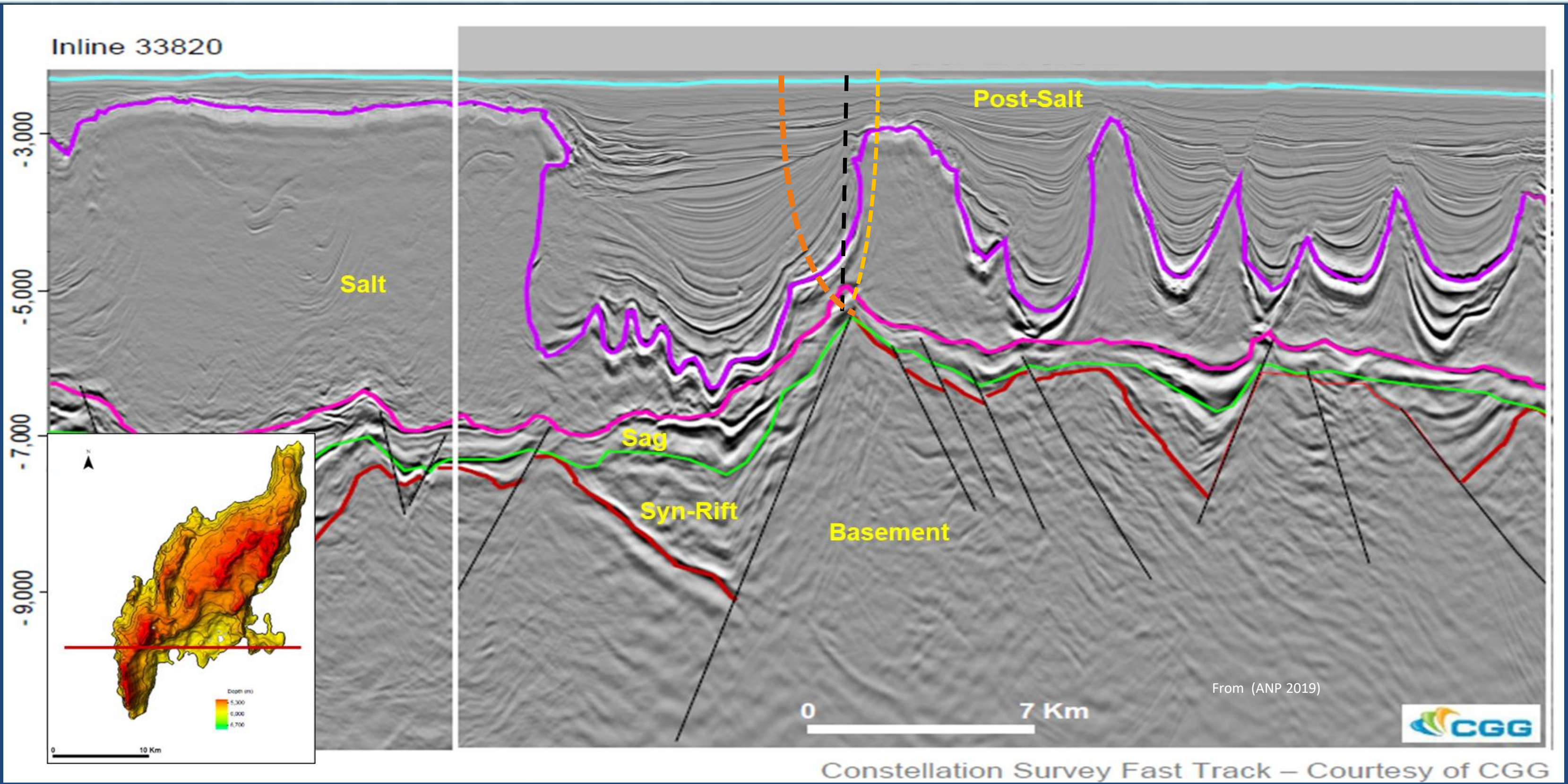
Lithology





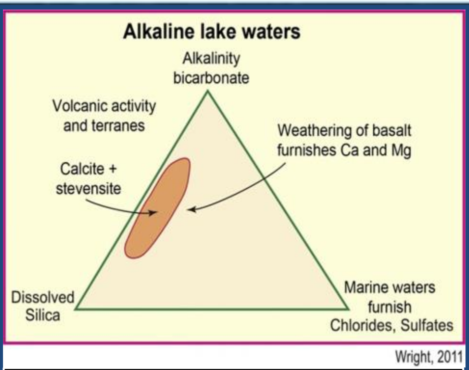
(Edited of Rodriguez *et al.*, 2017)

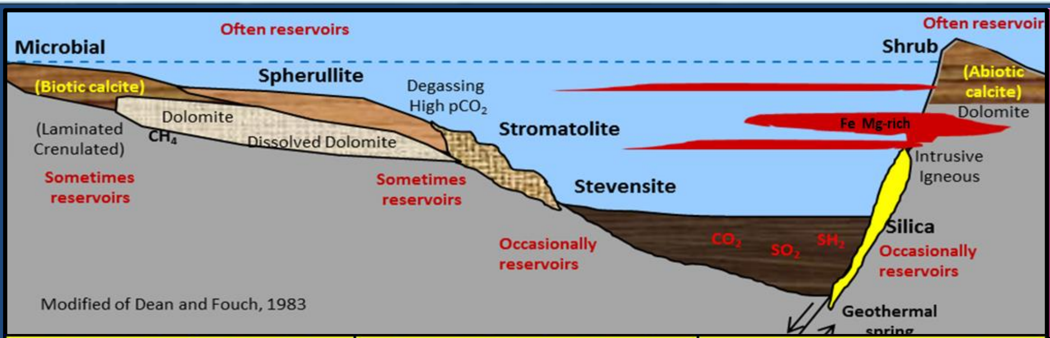
Challenges: Number of Casing for Drilling (4C, 5C, 6C)

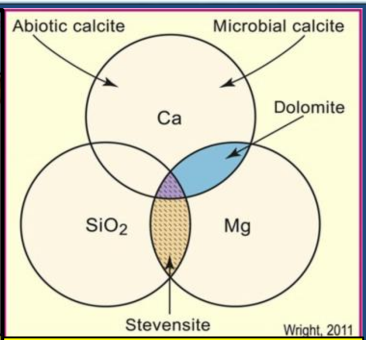


Post Salt, Salt and Pre-Salt Challenges in Exploratory Well

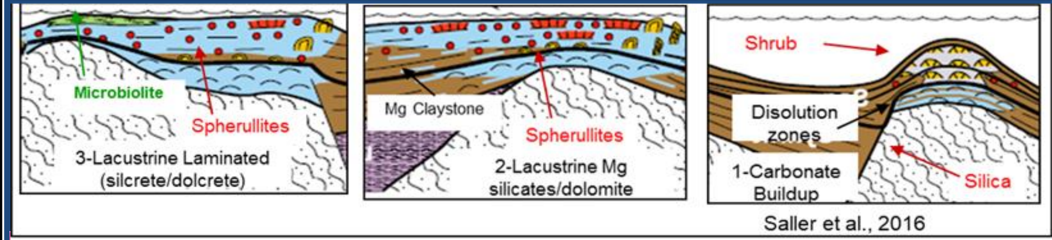
Diagenetic Process

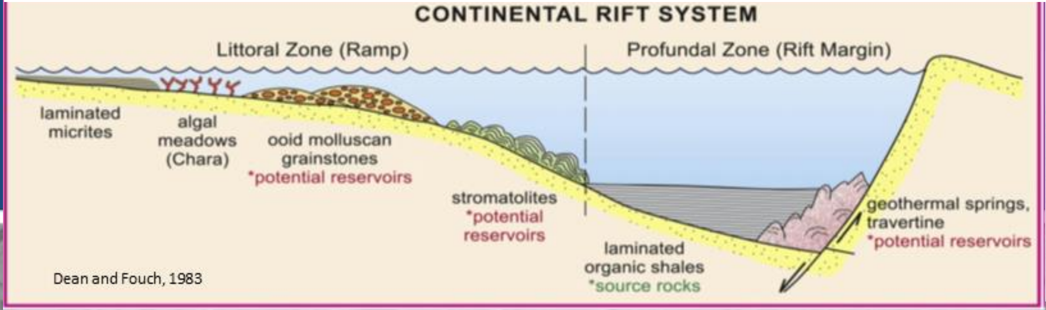


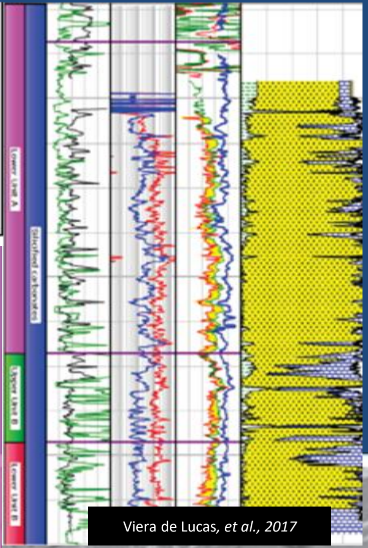




Microbial (Vugs) + Spherullite | ***Spherullite Mg-rich + Dolomite*** | ***Shrub (Vugs + fracture)*** | ***Carbonate & Silica Mixed***



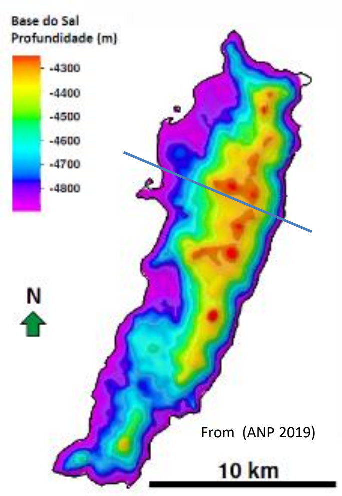


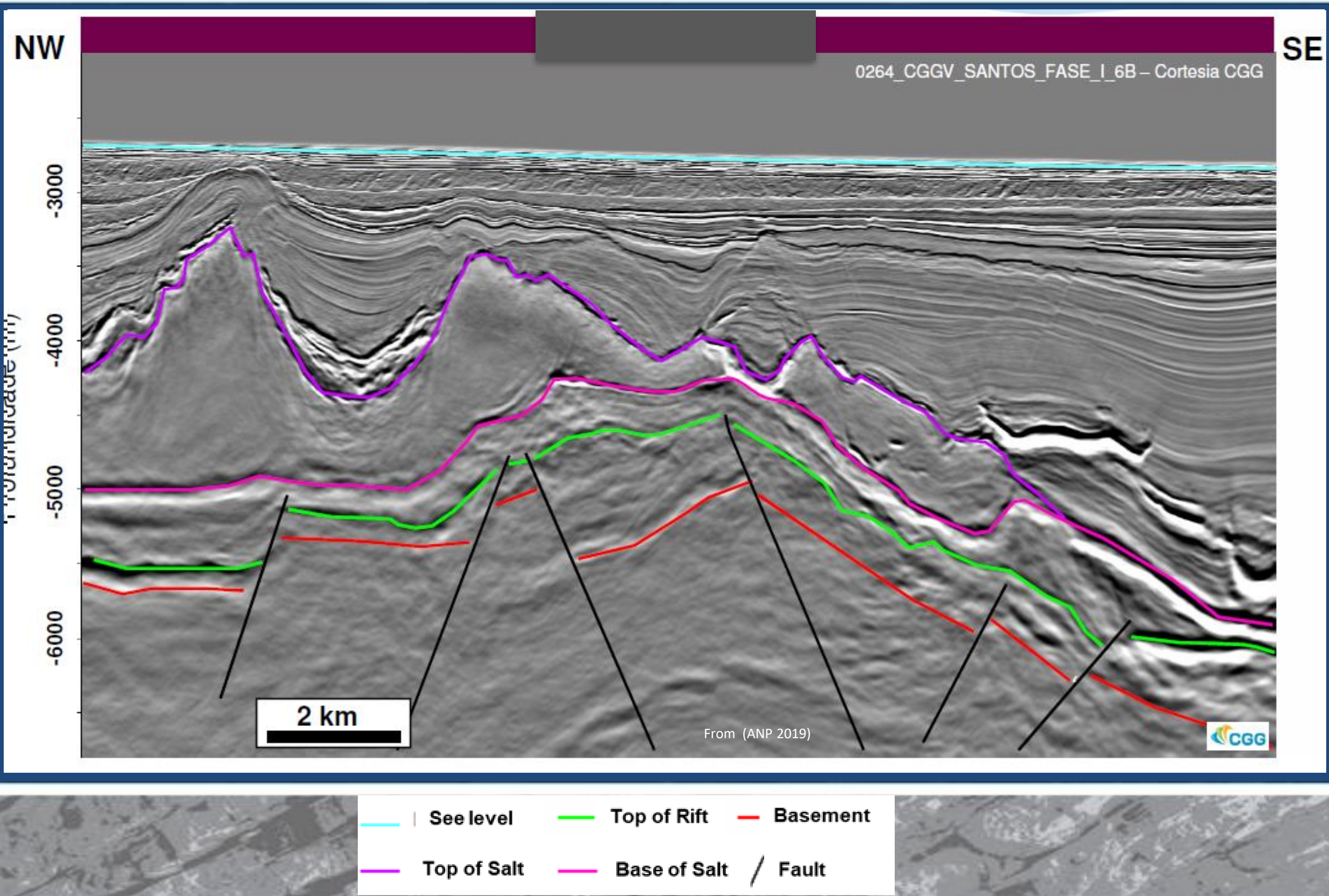


Pre Salt Reservoir Challenges

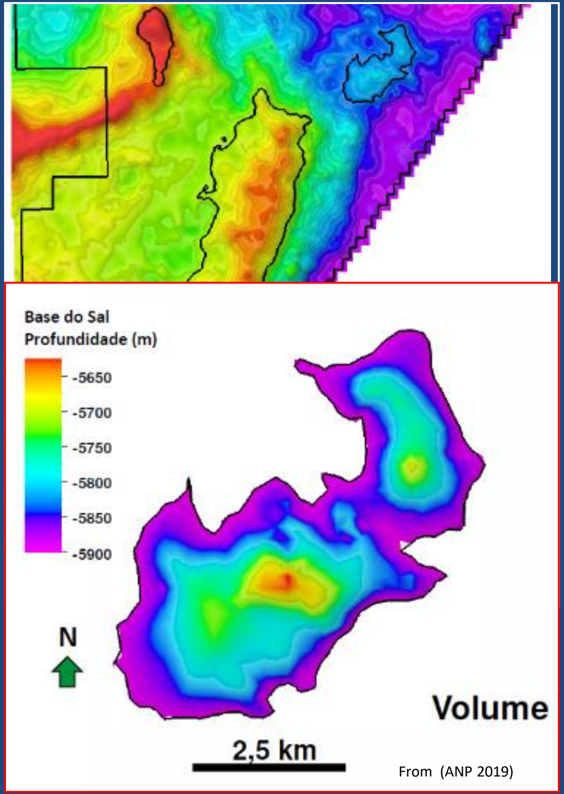
- Low rate of penetration and hard and abrasive carbonate
- Silica and vuggy porosities and Igneous rocks intercalations
- Severe loss of fluids
- Natural and Tensile Fractures; Break-out and Washout Cavern and caves (Karst)
- High CO2 and H2S
- Complicated cementation
- Complicated OH and CH FE

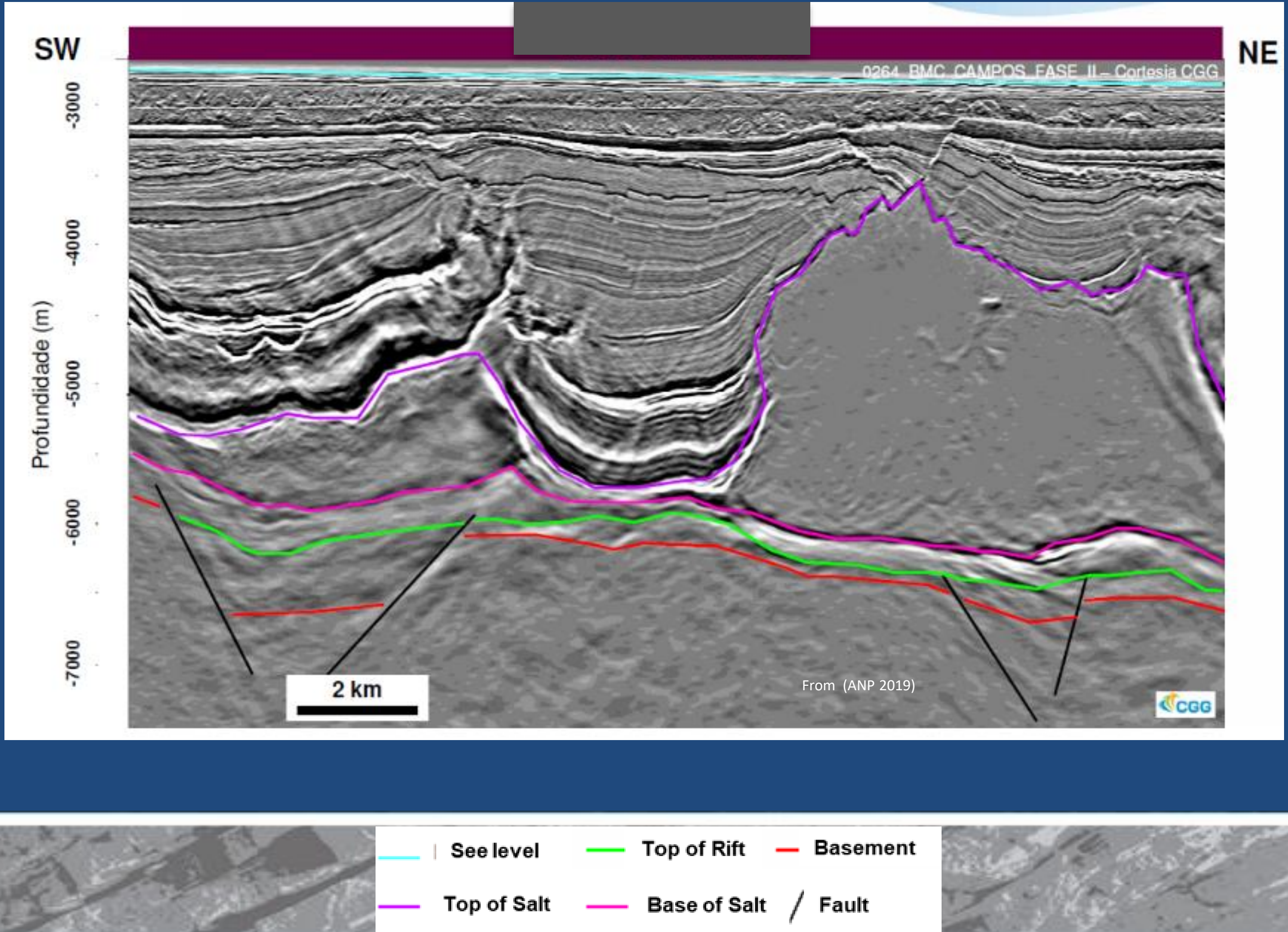
Post Salt, Salt and Pre-Salt Challenges in Exploratory Well





Post Salt, Salt and Pre-Salt Challenges in Exploratory Well

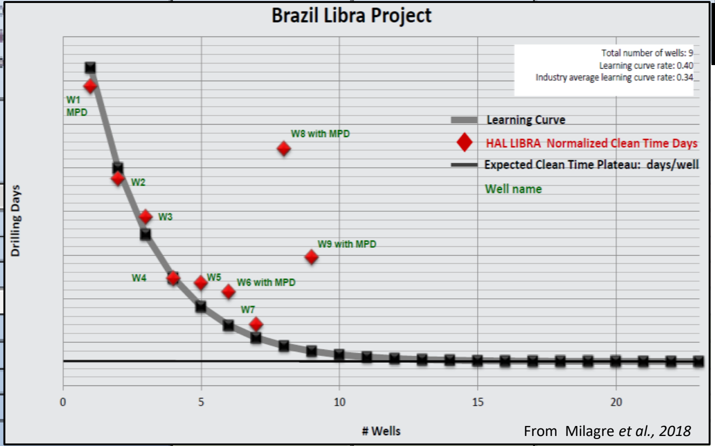


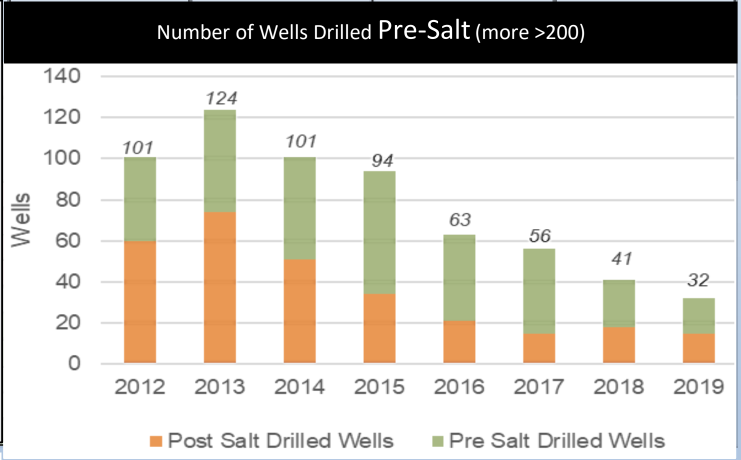


Post Salt, Salt and Pre-Salt Challenges in Exploratory Well

	Santos Basin				Campos Basin		
Fields	Uirapuru	Peroba	Três Marias	AdCF Central	AdCF Central	2 Irmãos (Pedra Branca)	2 Irmãos (Arpoador / Pedra Bonita)
Consortium	Petrobras: 30% Petrogal: 14% Equinor: 28% Exxonmobil: 28%	Petrobras: 40% BP: 40% CNOOC: 20%	Petrobras: 30% SHELL: 40% Chevron: 30%	Petrobras: 50% BP: 50%	Petrobras: 50% BP: 50%	Petrobras: 45% BP: 30% Equinor: 25%	Petrobras: 45% BP: 30% Equinor: 25%
ANP Tender Round	Fourth	Third	Fourth	Third	Third	Fourth	Fourth
Depositional Model (In base to experienc Complex Carbonate (Libra Field) and Regi Studies from PBR and diverses author fro plus ANP data releases)							
Best Offset Wells							
Risk							
Phase Post Salt							
Phase Salt							
Phase Pre-Salt (Reservoir)							
Wells Probability							
# wells							
% Wells							
Well Design 4 Phases							
Well Design 5 Phases							
Sea Bed (m)							

# wells All Project	
Well Design 4 Phases	
Well Design 5 Phases	





LC=C1*e$^{(1-N)*C2}$+C3. SPE 15362

C1: how much longer the initial well takes to drill than the idealized final well)

C2: speed which the drilling organization reaches the minimum drilling time (C3)

C3: idealized minimum drilling time

N: consecutive well number

Muito Obrigado!