Three Dimensional Geological Modeling using Seismic Inversion in a Reservoir Integrated Study for a Giant Heavy Oil Field: Rubiales Field, Eastern Llanos Basin, Colombia, South America*

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Search and Discovery Article #20218 (2013)**
Posted November 11, 2013

*Adapted from oral presentation given at AAPG International Conference and Exhibition, Cartagena, Colombia, September 8-11, 2013

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Abstract

The Rubiales Field is located in the southeast of the eastern Llanos Basin, the area with the largest heavy oil reserves in Colombia (12 degree API). The reservoir is Tertiary sandstones of the lower Carbonera Formation, deposited in a predominantly fluvial environment, informally known in the area as “Arenas Basales”. As of January 2013, more than 700 wells have been drilled and completed in this reservoir with cumulative oil production of 205,600 million barrels of oil.

The available information for this study was 349 kilometers of 2D seismic, 325 km² of 3D seismic, hydrocarbon indicator volumes, shale volume and porosity volume (from Elastic Seismic Inversion) and laboratory data from 14 cores. The integration of different disciplines and the use of 3D seismic elastic inversion, with a detailed study of the sedimentary framework, has helped to improve the field development strategies.

The goal of this study was to quantify original oil in place, reserves, and to improve strategies for the field development plan. Specifically, non-drained areas were identified with analytical and numerical simulation models. A particular challenge of this study was to identify the economic development strategies under the very tight time constraint for the development of the field.

Previous stochastic models were generated using a Gaussian simulation process for facies population. However, the prediction of the geometry of the sand bodies was not satisfactory due to reservoir complexity. This new model, based on seismic elastic inversion, gave a better understanding of the continuity of the sand bodies and provided better prediction of reservoir properties. It became the static model input to numerical simulation of the reservoir.

The main product of this study was a model that captured the complex stratigraphic variations of the reservoir unit. This in turn has allowed for optimizing locations of both vertical and horizontal wells.

Selected Reference

Bosch, M.E., G. Bertorelli, G. Alvarez, A. Moreno, R. Colmenares, and E. Garcia, 2012, Deterministic and stochastic seismic inversion methods for gas discrimination at La creciente field, Colombia: EAGE, Colombian Association of Petroleum Geologists and Geophysicists, Extended Abstract 56611.

Three dimensional geological modeling using seismic inversion in a Reservoir Integrated Study for a Giant Heavy Oil.

Rubiales Field. Eastern Llanos Basin, Colombia. South America

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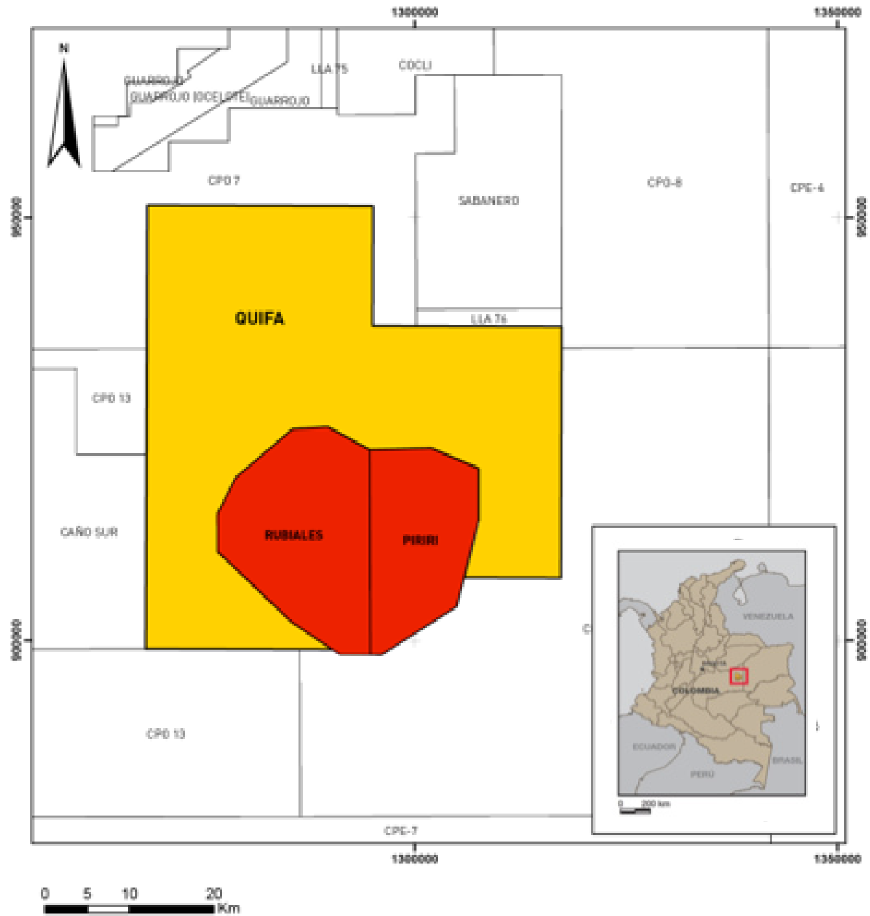
Theme 3- Challenges in Heavy Oil: Reservoir Characterization

Agenda

1. **Geographical Location**
2. **General Geological Aspects**
3. **Reservoir Study**
   - ❑ Workflow of Integrated Reservoir Study
   - ❑ Seismic interpretation
   - ❑ Elastic Seismic Inversion
   - ❑ Reservoir Characterization
   - ❑ Geological modeling
   - ❑ Numerical Model
4. **Challenges**
5. **What is in progress?**
6. **Conclusions**

1. Geographical Location



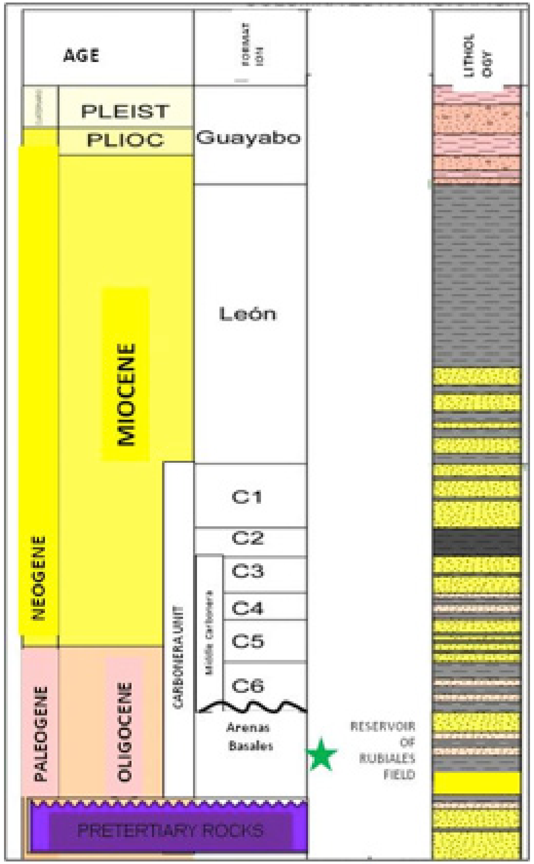
Pacific Rubiales Energy

2. General Geological Aspects

Basin Location: Eastern Llanos Basin
Basin Type: Foreland
General Field Description: Monocline. One of the largest Heavy oil field in the Basin.
Reservoir Rocks: Sandstones
Reservoir Age: Oligocene
Petroleum Type: Heavy Oil (12º API)
Depositional environment: Fluvial System
Trap Type: Mix (stratigraphic, structural & hydrodynamic)
General Data*: STOOIP near to 4440 Millions Stock Tank Barrels (MM STBBLS)

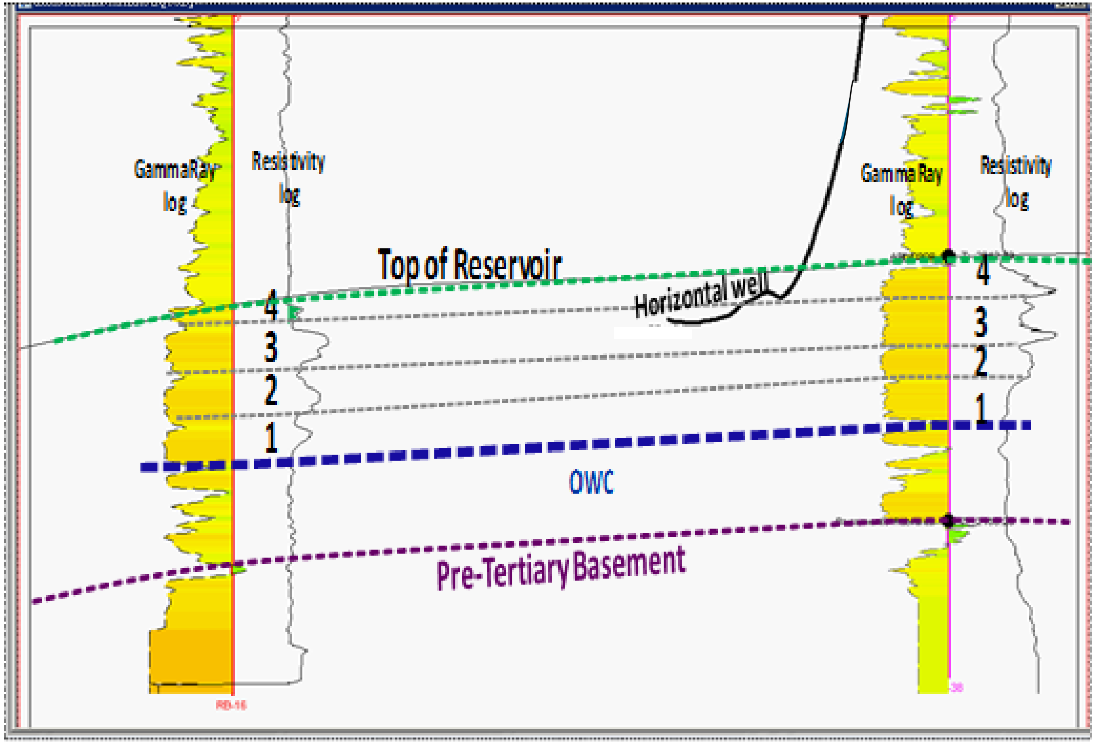
(*Source: Pacific Rubiales Energy, Investment Report,2013*)

Local stratigraphic column at Rubiales field



Pacific Rubiales Energy

2. General Geological Aspects



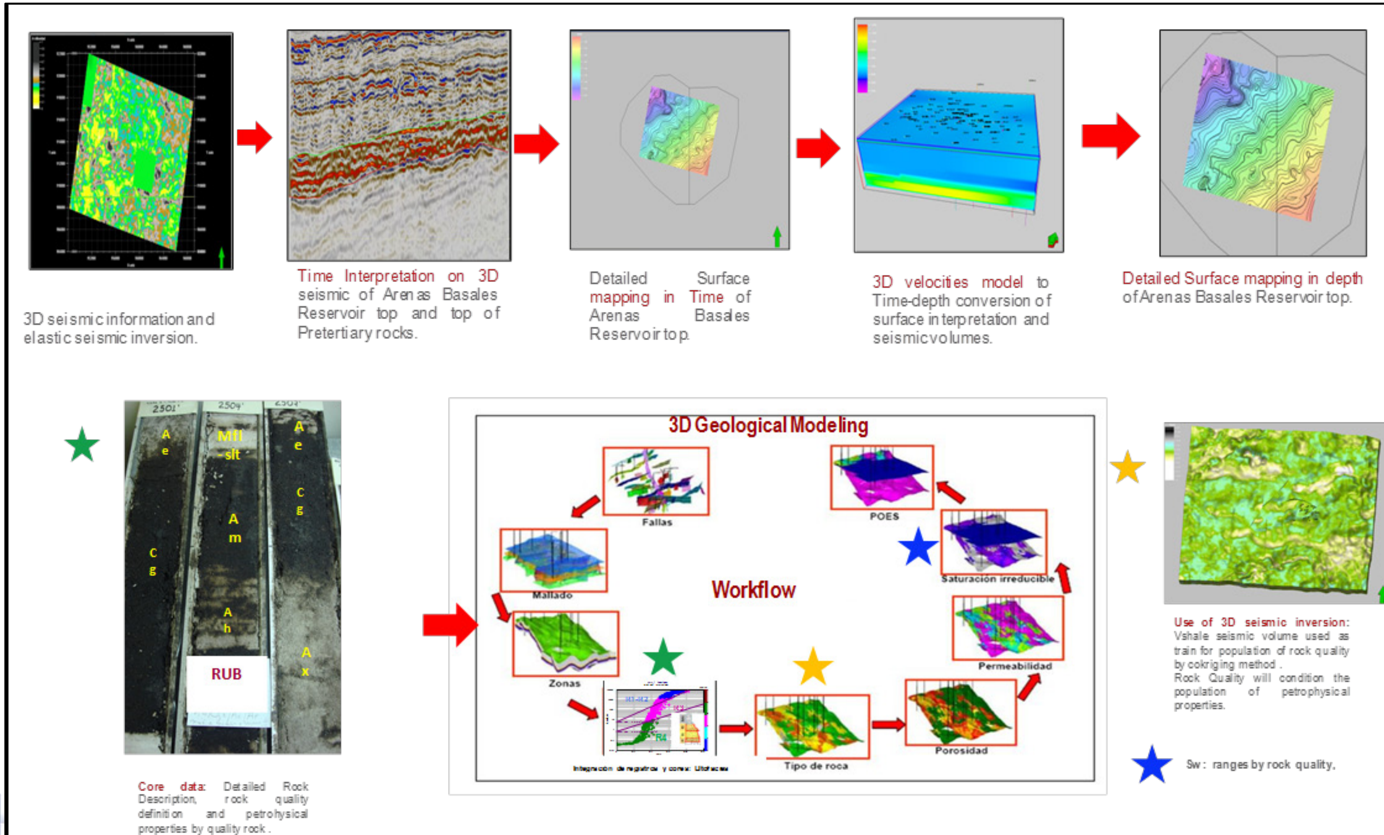
Squematic Cross section at Rubiales Field

The development strategy at Rubiales Field is mainly with horizontal wells. These are drilled in the upper part of reservoir, as far as possible from the oil -water contact (distance measured in vertical depth)

Vertical wells are drilled to identify quality sand bodies and to define the oil-water contact with this information the path of horizontal wells are defined. The configuration of horizontal wells is called a“cluster”

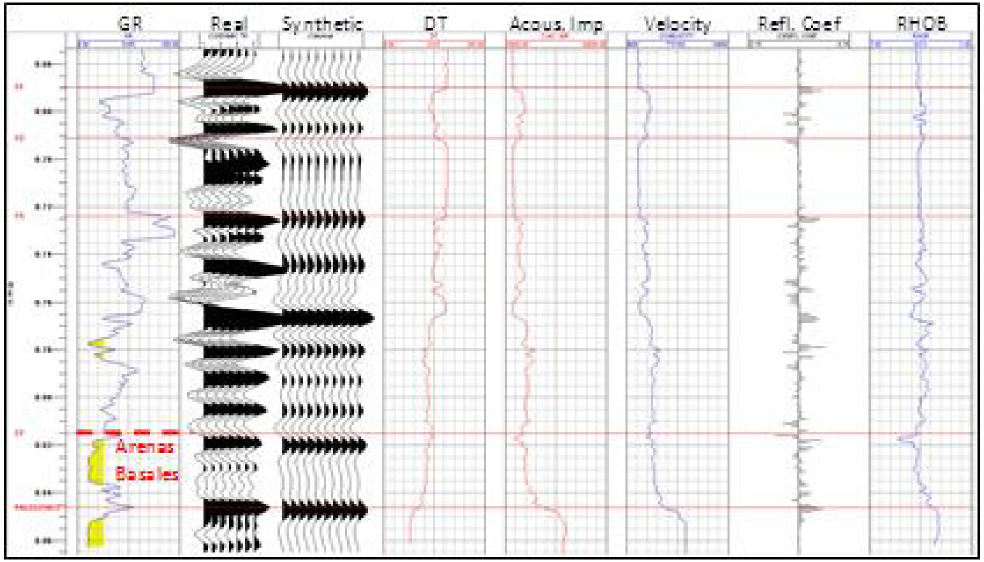
3. Reservoir Study

- Workflow of Integrated Reservoir Study

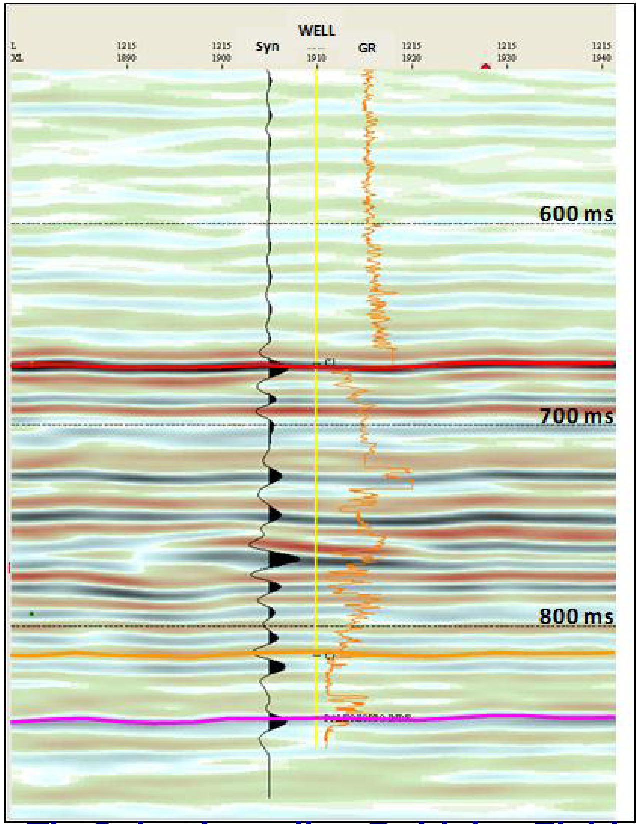


3. Reservoir Study

- ❑ Seismic Interpretation



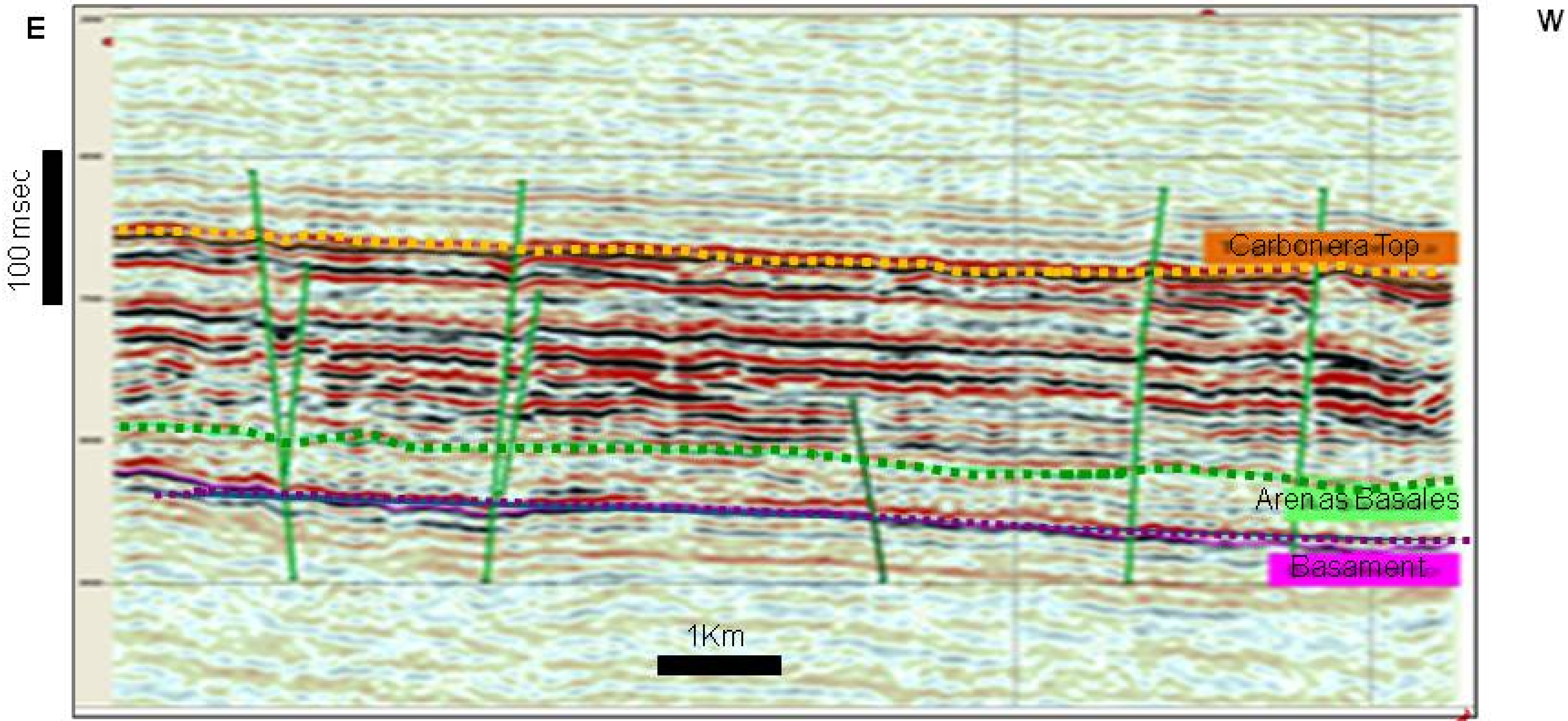
Synthetic Seismogram at Rubiales Field



Tie Seismic-well at Rubiales Field

3. Reservoir Study

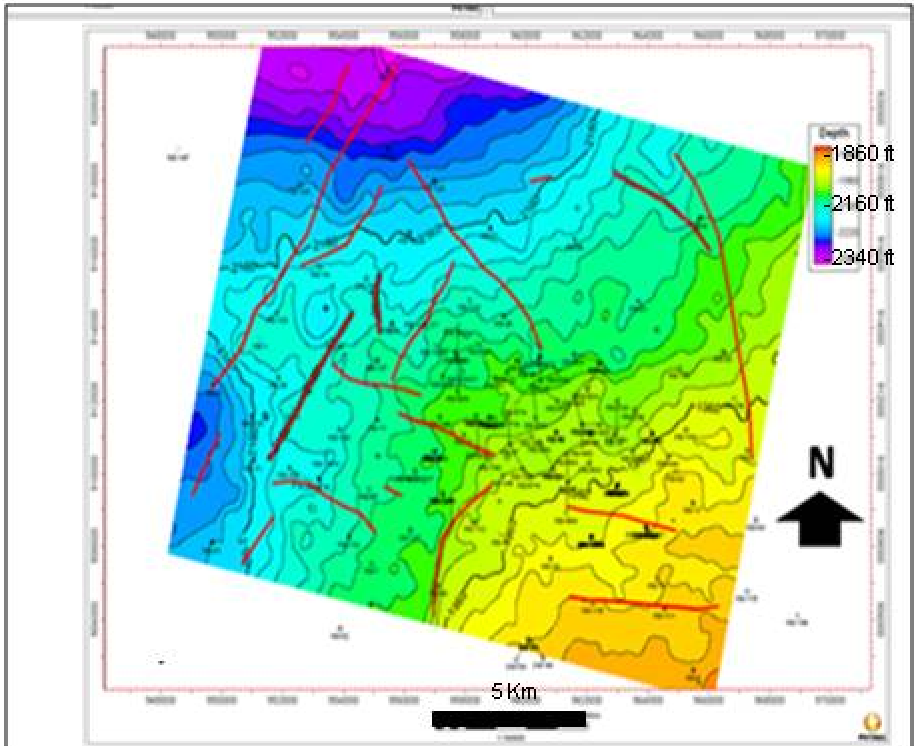
- Seismic Interpretation



The structural style of Rubiales field can be described as a monocline affected by normal fault.

3. Reservoir Study

- Seismic Interpretation



The structural style of Rubiales field can be described as a monocline with a dip from 0.2 to 2° and strike North-East. The monocline is affected by three families of normal fault.

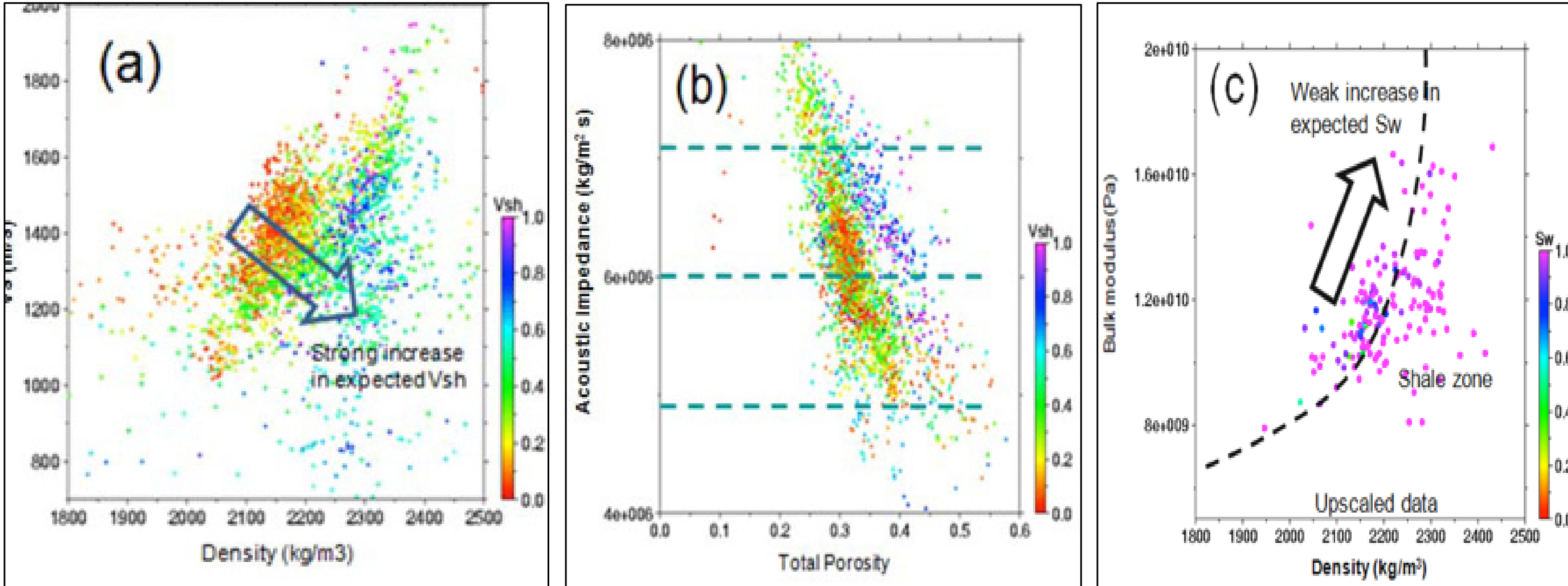
The main trend of faulting in the area strikes at N 40°E.

The structural closure of the field has not yet been established because the limit of the reservoir is beyond of the contract area.

Map in depth at reservoir top

3. Reservoir Study

- Elastic Seismic Inversion

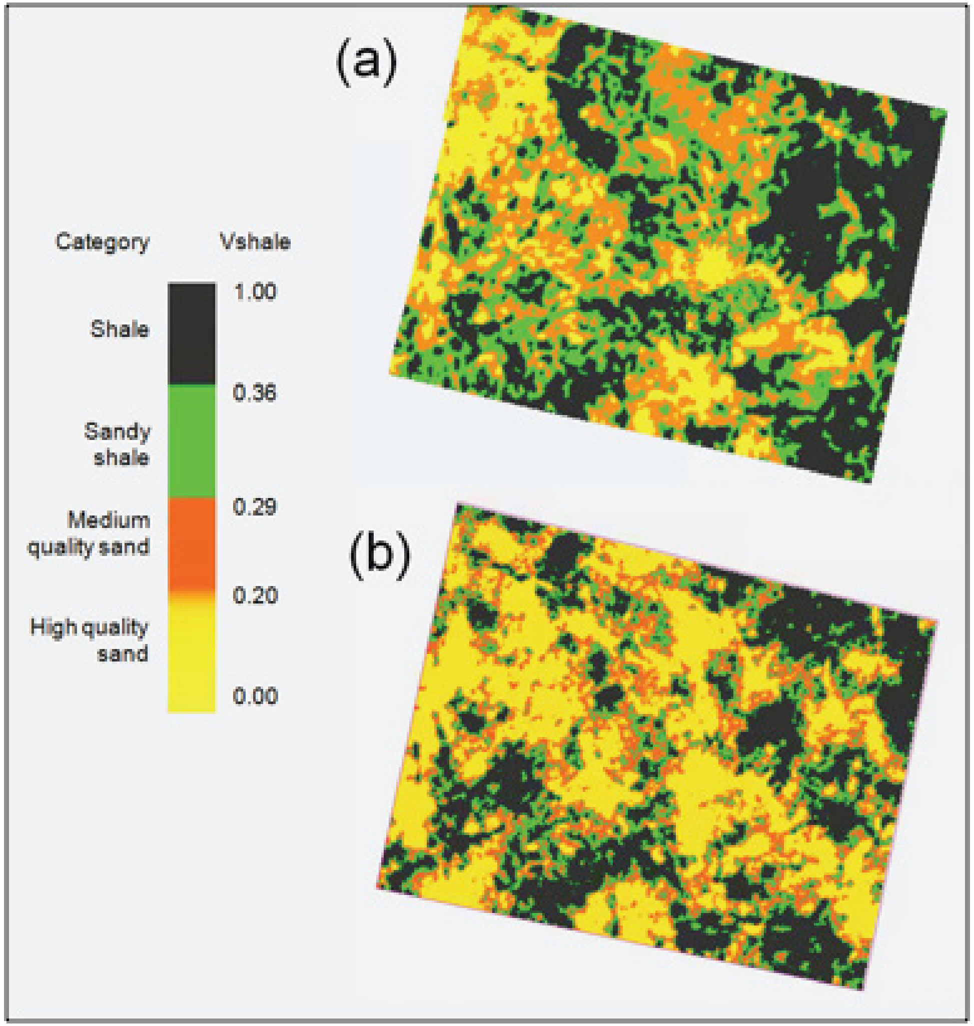


Crossplots of elastic and reservoir properties calculated from well-logs of “Arenas Basales". Figure from **Bosch, et al, 2012**. Figure (a) Shear velocity versus density. The arrow indicates the direction of increasing Vshale. Figure (b) Acoustic impedance versus total porosity. Colour scales correspond to Vshale (a and b). Figure (c) Bulk modulus versus density. Colour scales correspond to water saturation.

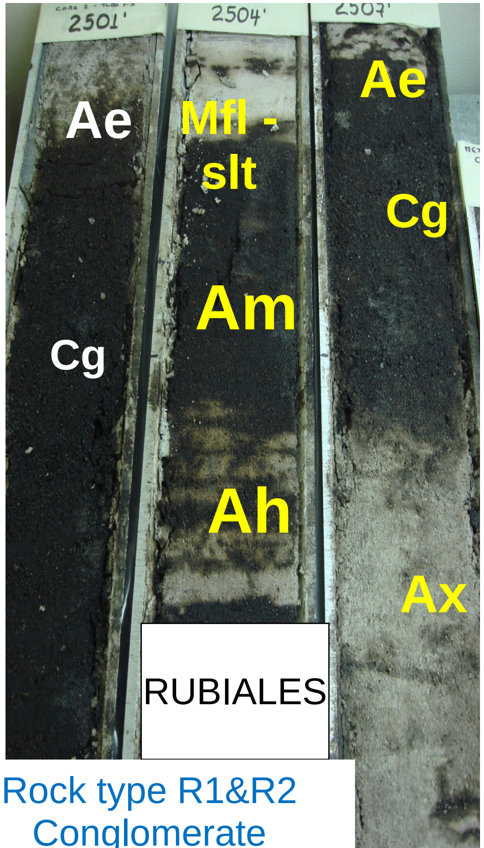
3. Reservoir Study

❑ Elastic Seismic Inversion

Horizon depth slices showing the estimated shale volume obtained from (a) the seismic information via inversion methods and (b) the geostatistical combination of the seismic Vshale and well-log data. Figure from **Bosch, et al, 2012**.

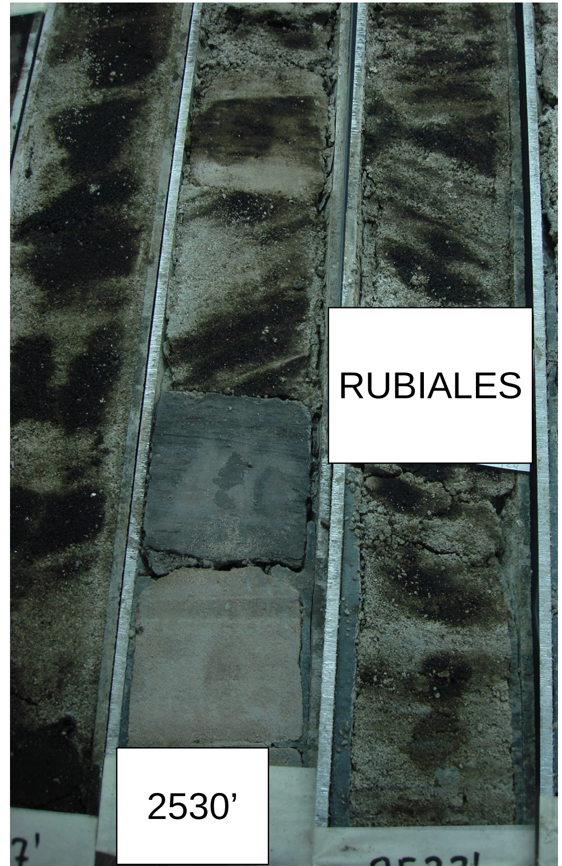


3. Reservoir Study

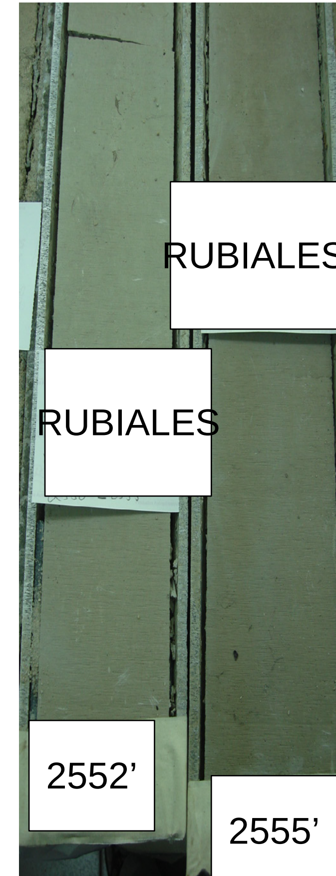


Rock type R1&R2 Conglomerate

Rock type R3 grain fine sands with ripples



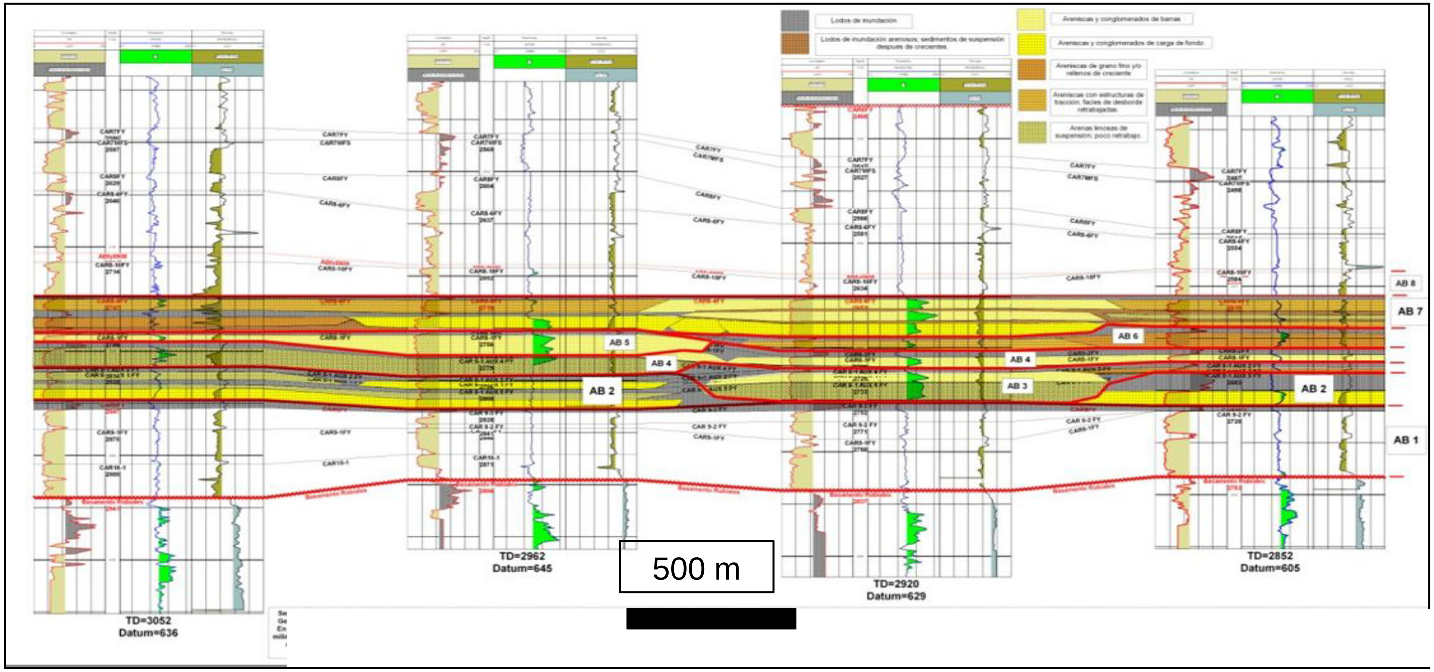
Rock type R4 grain fine sands with ripples



3. Reservoir Study

- Reservoir Characterization

Stratigraphic framework

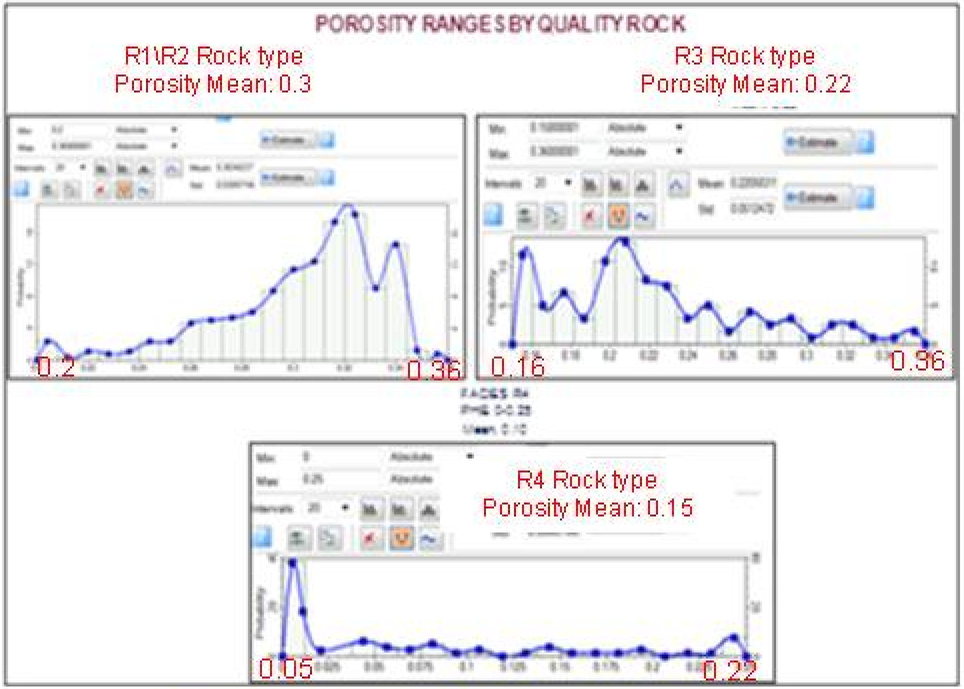


Stratigraphic correlation showing the sand body units in Rubiales Field. Picture from Yoris, F and Lugo, J. 2011

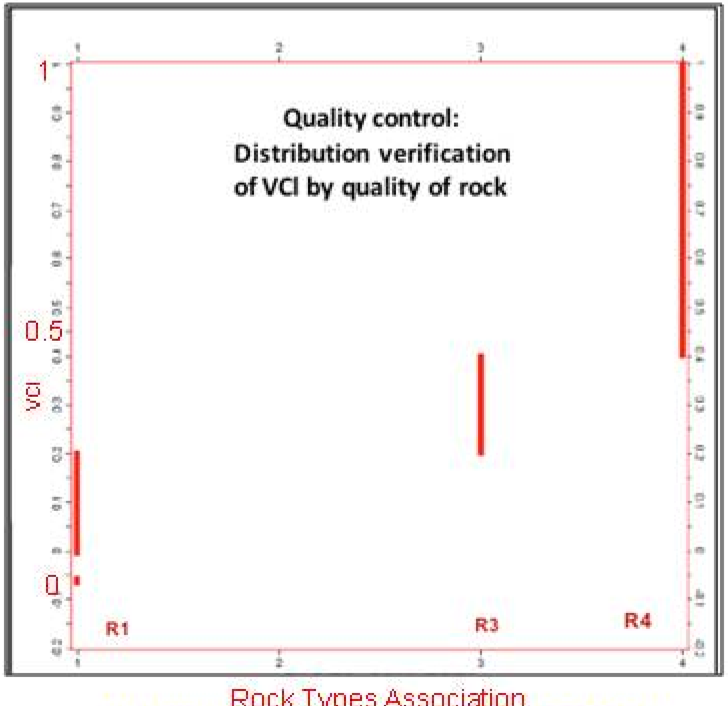
3. Reservoir Study

❑ Reservoir Characterization

Petrohysical Evaluation- Data Analysis



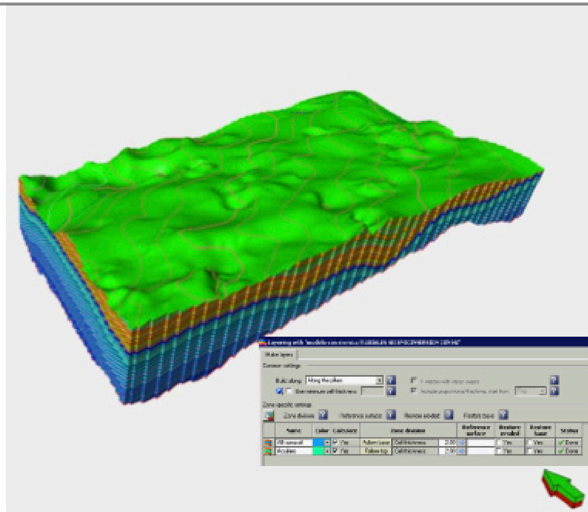
Porosity ranges of facies association.



Vcl ranges of Rock types association

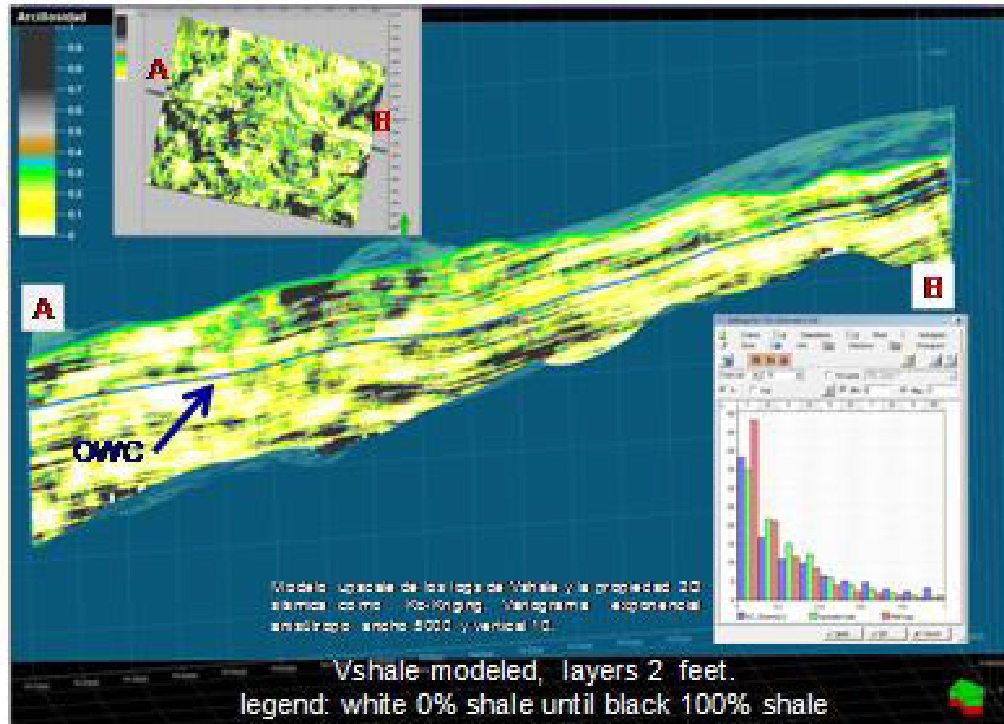
3. Reservoir Study

- 3D geological modeling



grid

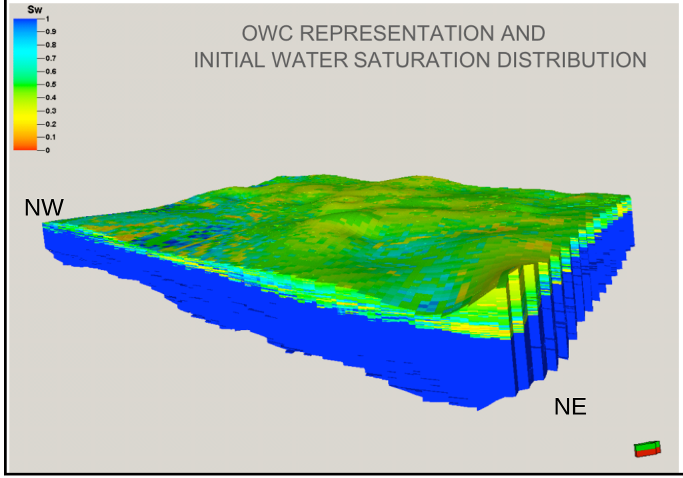
X*Y:	50 m*50 m
Z (layer thickness):	2 ft
Layers :	183 layers
Zones:	2 Zones
	zone1: top reservoti until OWC
	zone 2: OWC until Pretercіary rocks
cells3D :	27' 274.320



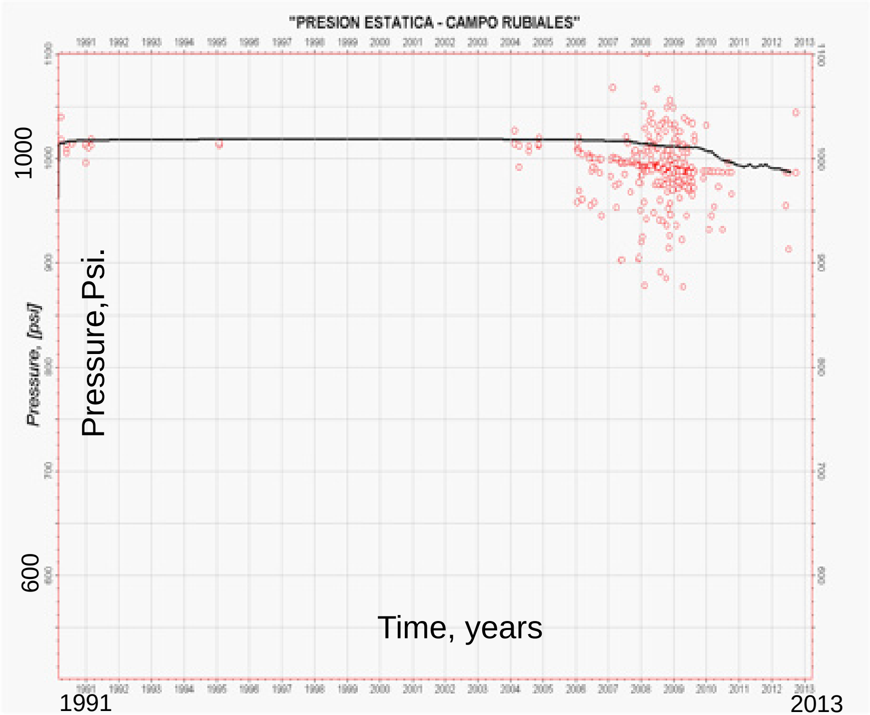
3. Reservoir Study

❑ Numerical Simulation

- Type : Bottom up and Lateral aquifer Support with charge from west and southeast
- Thickness: 250 ft
- Porosity: 31%
- Permeability: 3000 mD
- Model: Carter Tracy (Infinite Extent)



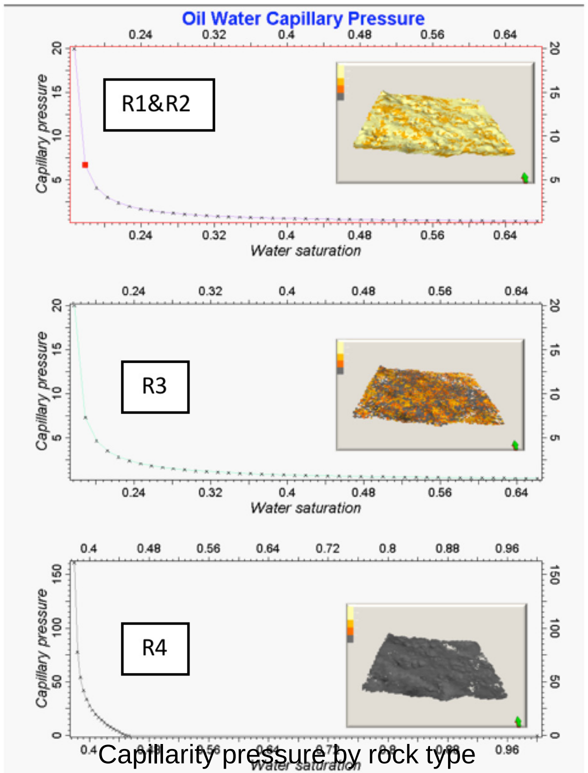
Aquifer Definition



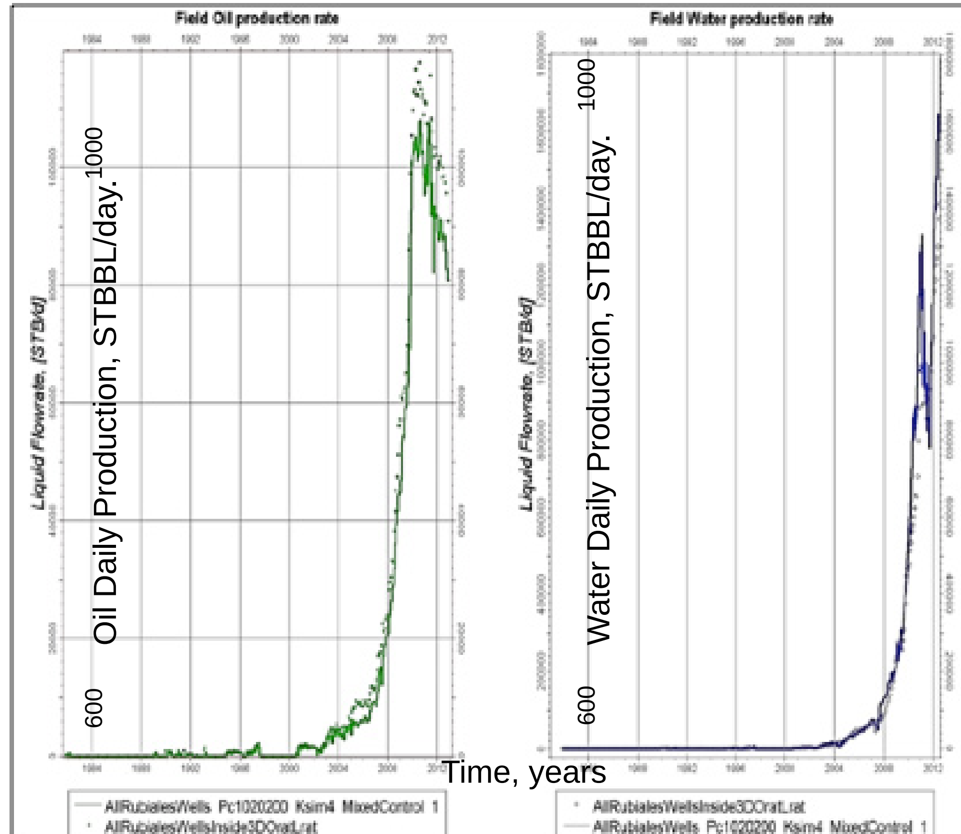
Pressure History Match

3. Reservoir Study

❑ Numerical Simulation



Capillarity pressure by rock type



4. Challenges

- Geophysical: It was possible to find a methodology using elastic seismic inversion where the acoustic impedance has poorly correlated with lithology and acoustic seismic models are not useful for lithology estimation. Elastic seismic inversion obtained the relationship between the elastic parameters and petrophysical reservoir properties such as, shale volume fraction and porosity.

- Geological: One of most important issues at Rubiales Field is the understanding of the continuity of the sand bodies providing a prediction of reservoir properties. The Vshale seismic volume was used to populate the quality rocks through cokriging simulation (geostatistical method). The result was a volume of Vshale seismic combined with well logs scaled to the grid.

- Numerical simulation: The representation of the difference in structural depth of the Oil Water contact was done by using many equilibrium regions, avoiding strong changes in depth from region to region. This representation leads to a reasonable history matching honoring the geological model.

5. What is in progress?

- Local correlation of sand bodies and refined local geological gridding in non-dreinaged area.
- Local detailed simulation to identify different options of thermal recovery

6. Conclusions

- The structural style of Rubiales field is a monocline with a dip from 0.2 to 2°and strike is North-East. The monocline is affected mainly by a trend of faulting striking N 40°E.

- The structural closure of the field has not yet established because the limit of the reservoir is beyond the 3D seismic coverage.

- The oil trap at Rubiales field is a combination of the stratigraphic complexity of interconnected sand bodies and structure. The stratigraphic complexity allow different oil-water contacts.

- “Arenas Basales” sands are interpreted to be a succession of diverse regimes of fluvial deposits: Braided and meandering regimen.

- In the field, the mapping of the good quality sand bodies is important, due to the stratigraphic complexity and the oil-water contact, particularly for positioning horizontal well's paths.

- In general, the best reservoir facies coincide with low-regime, traction sedimentation (cross-stratified, pebble gravel/ coarse sand bars). In second place, also a good facies is the “bottom channel”, massive, pebble gravel/ coarse sands.

- Elastic inversion of the seismic data provided estimation of Vp, Vs, mass density, elastic modulus and ratios, which were used to infer reservoir properties and lithotypes.

- The aquifer of Rubiales field is a strong a bottom and lateral drive. The aquifer could be constantly recharged from surface to maintain constant the reservoir pressure during more than 20 years of field exploitation.

- The use of saturation functions and PVT regions were a key factor for representing some of the complexity issues of the field in the Simulation Model.

- Multidisciplinary work is the best way to improve the knowledge of a field then it is the key to improve Reservoir Management strategies.

ACKNOWLEDGMENTS

The authors are grateful to the Vice Presidency of Geosciences and the Vice-Presidency of Reservoir Engineering of Pacific Rubiales Energy. The authors give special thanks to Ecopetrol for allowing the publication of this study.