Reservoir Characterization and Exploration Assessment of Tight Gas Sands related to Unconventional Concepts. Queen City Formation, Burgos Basin, Mexico*

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Abstract

The middle Eocene, Queen City Formation in the Burgos Basin northeast Mexico, is composed of unconventional reservoirs with low permeability and complex lithology. These tight gas sandstones are related to wave influenced sand bar deposits in a growth faulted system where the main reservoirs are associated to structural-stratigraphic traps controlled by major listric faults. Hydraulic fracturing is required to get commercial gas rates.

The aim of this study is to use well and seismic data to develop an integrated reservoir characterization model and re-explore mature fields based on unconventional concepts (independent of trap), assessing new reserves and resources down dip in the structure close to growth faults where facies, rock quality and thickness improve.

The methodology integrates: (1) the geological model based on wells and regional information, identifying main sand bodies related to growth faults. (2) A multi-mineral petrophysical model and rock types related to Winland cross-plot analysis calibrated with the production performance. (3) The rock physics analysis, geobodies and attributes, generated cross-plotting P Impedance - S Impedance as part of the elastic inversion AVO-AVA, searching for sweet spots related to rock and fluid responses. (4) An AVO analysis with fluid substitution in the position of down dip sweet spots anomalies coming from the simultaneous inversion, reducing uncertainty about high water saturation. (5) Probabilistic evaluation of resources and risk analysis.

The developed analysis has been applied in a real case study related to Queen City Formation sand in two fields where the link between the rock types coming from the Winland analysis and the multivolume attributes coming from the simultaneous inversion, helped to discover and appraise new volumes of reserves independent for the trap.

The contribution of the presented study is to provide a methodology of characterization and re-exploration of tight gas sands reservoirs of complex lithology based on unconventional concepts.

Selected References

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PETROBRAS

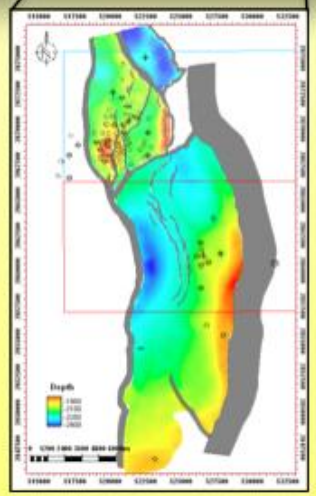
PEMEX

JASON
A CGG Company

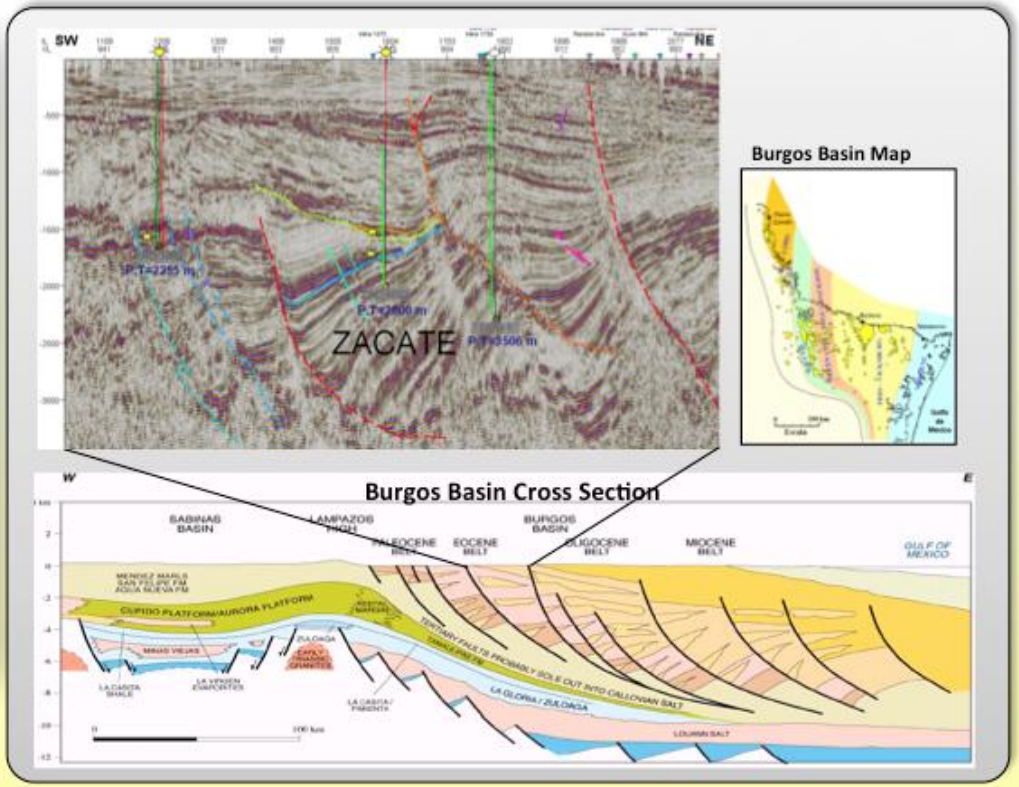
- ✓ LOCATION.
- ✓ BACKGROUND.
- ✓ OBJECTIVE AND OUTCOME.
- ✓ TIGHT GAS SANDS CONCEPTS.
- ✓ GEOLOGICAL MODEL.
- ✓ PRODUCTIVITY / LOW WATER PRODUCTION.
- ✓ PRESSURE BEHAVIOR.
- ✓ RESERVOIR CHARACTERIZATION AND PROSPECT EVALUATION.
- ✓ TESTING UNCONVENTIONAL CONCEPTS.
- ✓ QUEEN CITY A TIGHT GAS SANDS BUT HOW UNCONVENTIONAL?
- ✓ PROSPECT RELATED TO UNCONVENTIONAL RESOURSES.
- ✓ CONCLUSIONS.

LOCATION

Location

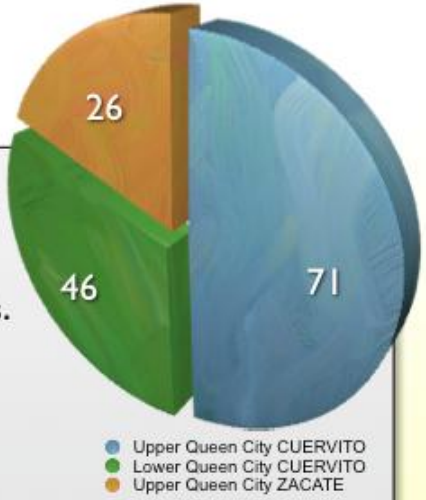


Geological Setting



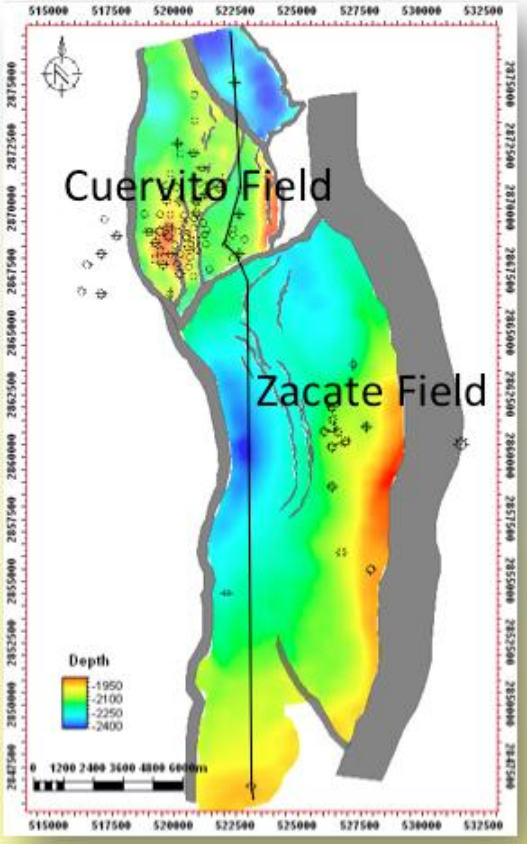
BACKGROUND

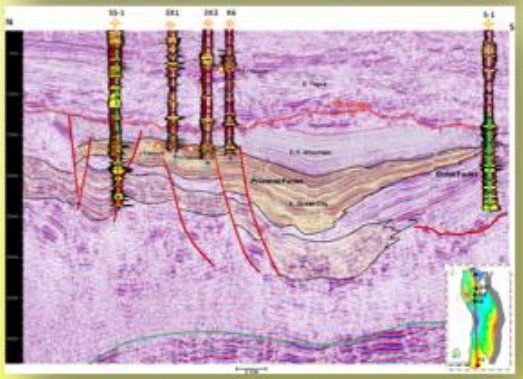
OFFICIAL RESERVES (BCF)
December 31th 2012

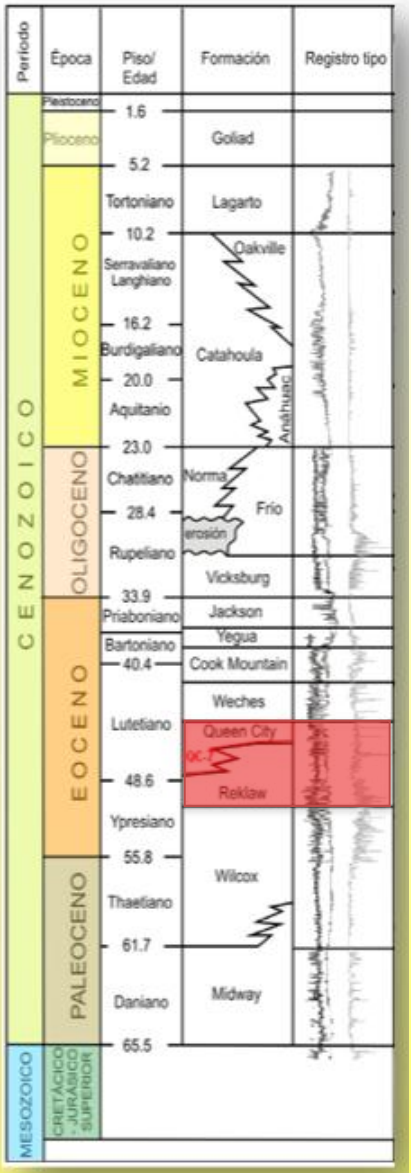


- Fields: Cuervito and Zacate.
- Age: Middle Eocene.
- Reservoir: Queen City sands.
- Wet Gas.
- Area: 200 Km^2.
- Depth: 2300 – 2980 mbsl.
- Discovery: Cuervito (1966); Zacate (1950).
- Dry Hole: 7.
- # Wells: 76.
- Gi: 2 mmscf.
- Tight Gas Sands.
- K: 0.1 – 0.005 mD.
- PHIE: 9 – 13 %.
- SW: 33 – 57 %.
- Overpressure: 0.65 – 0.78 psi/f.
- Geological Setting: Growth Faulted System.
- Facies: Stacking Bars (Waves).
- Completation: Tubingless / Hydraulic Fracturing.

UPPER QUEEN CITY STRUCTURAL







Objective

Cohesively combine the well and seismic data to develop a reservoir characterization model and re-explore mature fields based upon unconventional concepts. The aim is to assess reserves and resources down dip into the structure; close to growth faults where facies, rock quality and thickness improve. The case study is Queen City Formation on the Zacate and Cuervito Field.

Outcome

-Integrate the *Rock Types Analysis* with elastic seismic inversion looking for rock and fluid response -*Sweet Spots*- in high impedance sands.

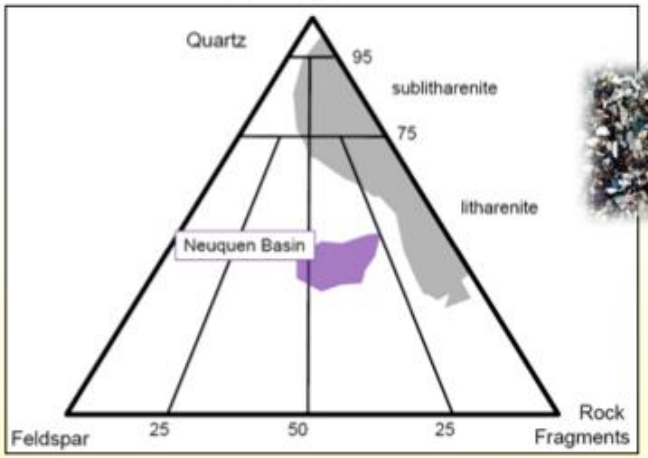
-Incorporate the geological model to provide consistency to the geophysical anomalies and attributes.

-Identify opportunities for new reserves and potential unconventional resources independent of the trap.

- Analysis and comparison of results related to unconventional concepts reported in literature.

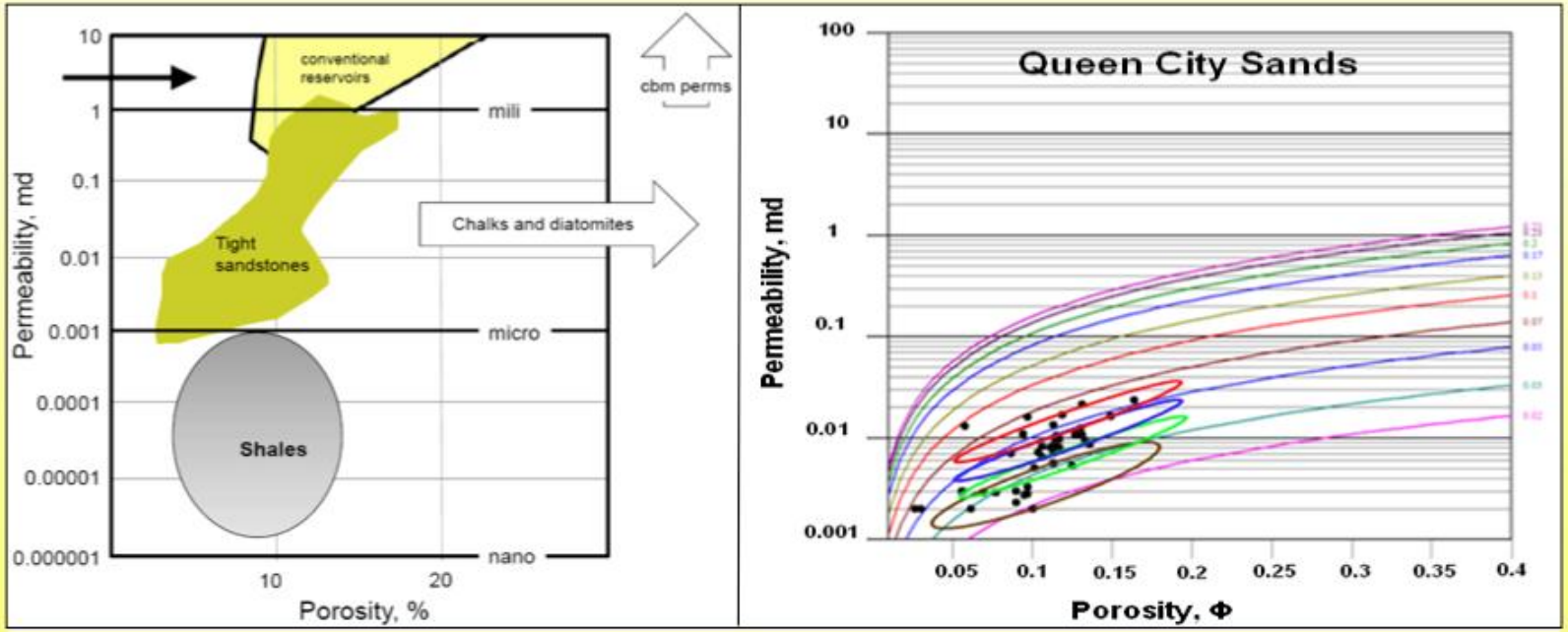
- Low Permeability (Less than 0.1 mD)
- Abnormal Pressures.
- Complex lithology (fine grain / muddy sandstones, diagenesis, authigenic cement).
- Require Technology (Hydraulic Fracturing)
- Little water production.

Compositional Range of Tight Gas Sands Reservoirs



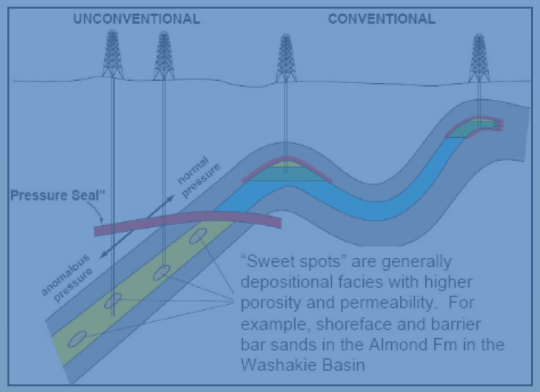
Meckel, 2008

Textural Range of Tight Gas Sands Reservoirs



Basin Centered Gas

- Widespread resource.
- Little to no petroleum system risk (no obvious seal or trap).
- Reservoirs generally close to source rocks
- Risk transferred to resource extraction.
- Large in-place resource, but very low recovery factor.
- Geologic "Sweet Spots" of production.
- No down dip water leg.



Surdam (1997)

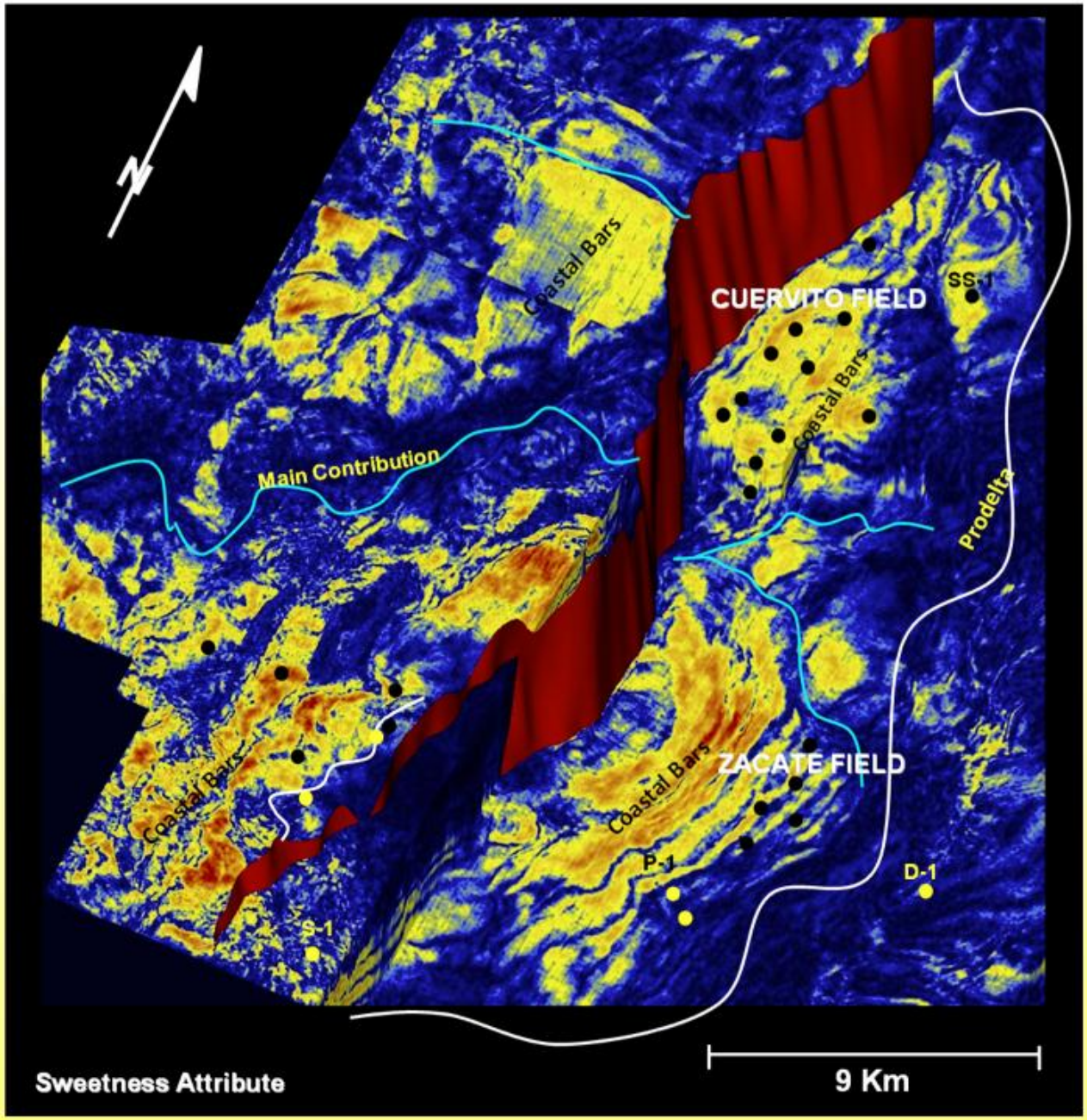
"Although tight gas sands are an important type of basin-centered gas reservoir, not all of them are Basin-centered gas (BCGAs)"

Naik, 2003

Shanley et al., (2003)

- Emphasis on traps.
- All elements of petroleum system risk present.
- Added risks due to fluid-flow in low permeability rocks.
- Conventional traps complicated by low quality reservoir rock.
- Need to be much more discerning

GEOLOGICAL MODEL

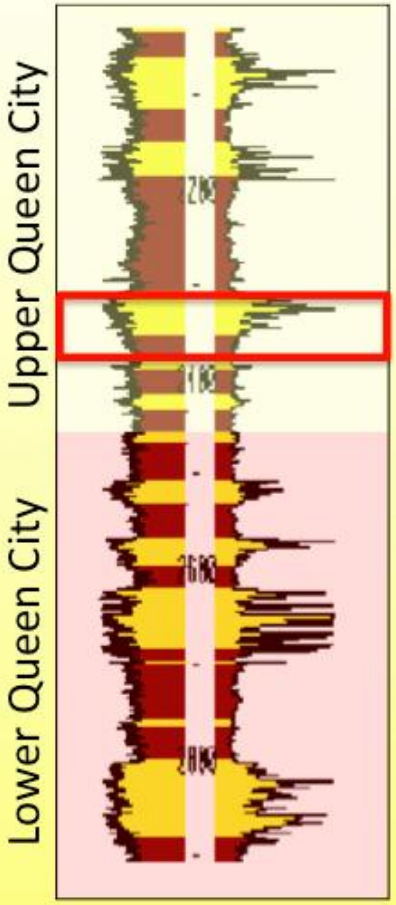


-Wave influenced sand bars.

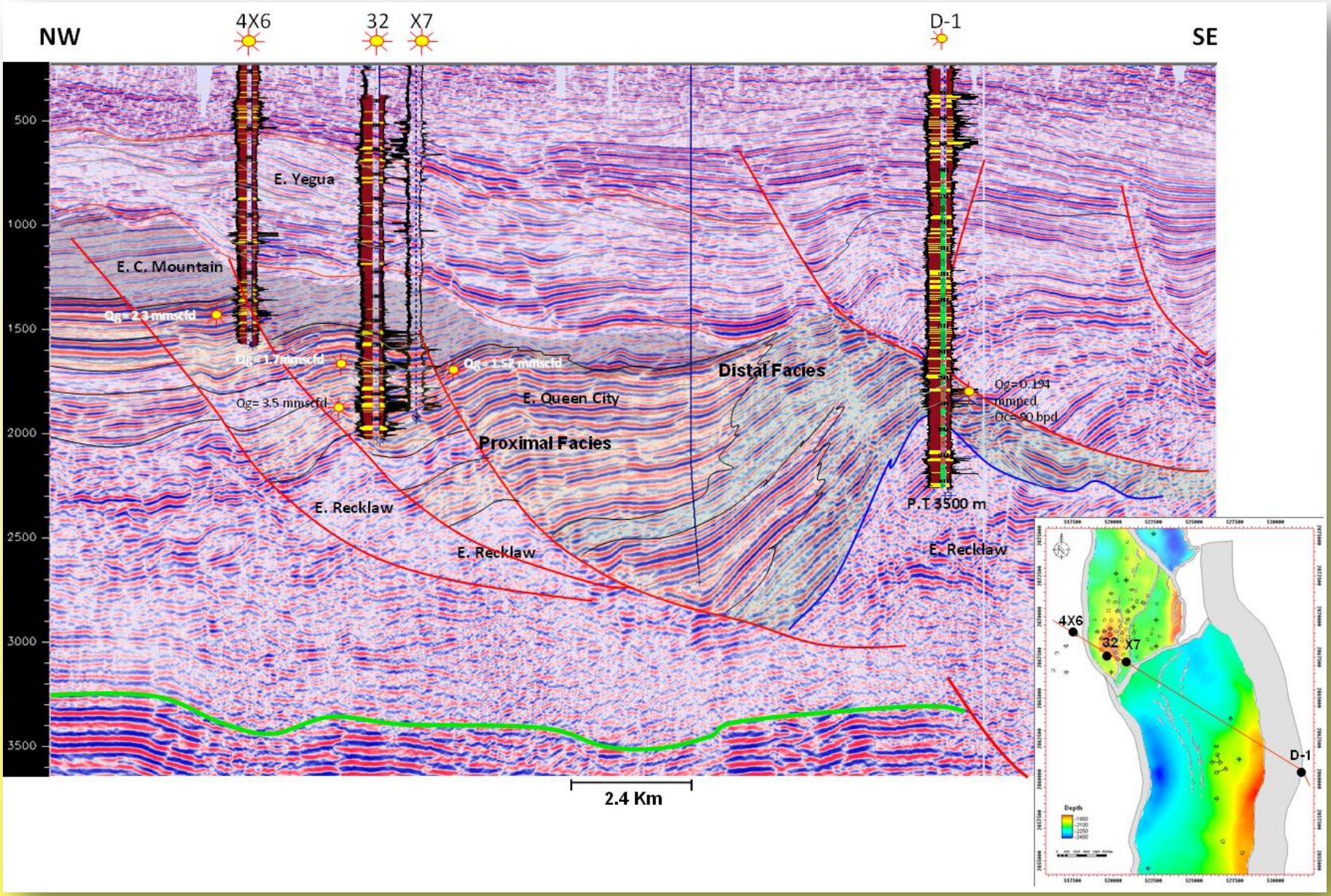
- Bars align North – South.

-Bathymetry: Neritic (Inner / Middle Shelf).

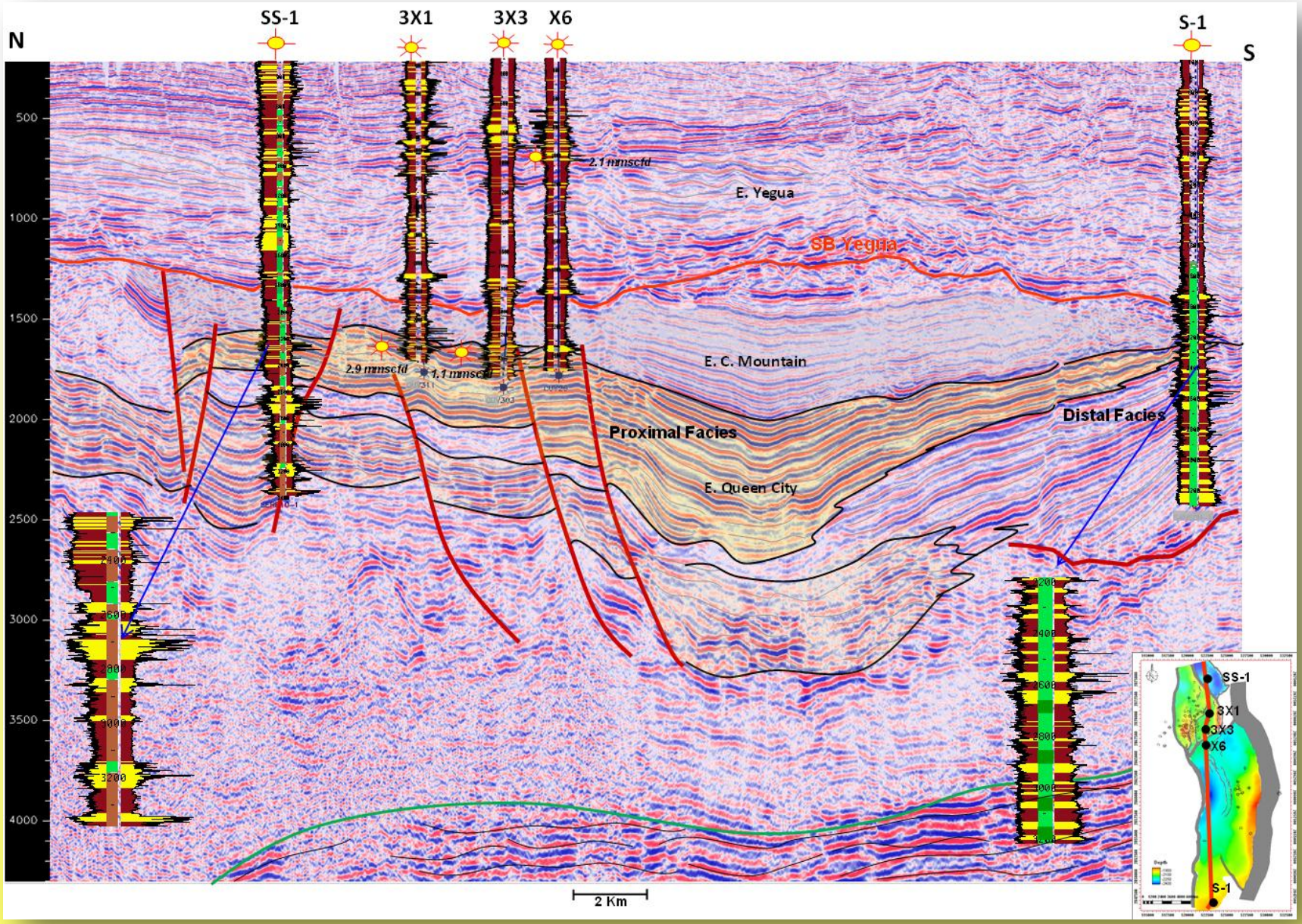
- Fine Grain laminar sandstones.



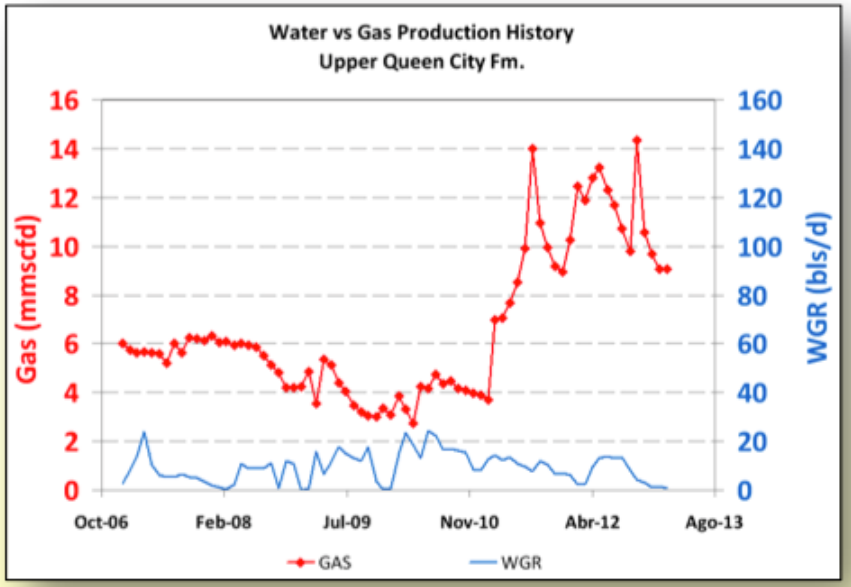
GEOLOGICAL MODEL (Seismic Section)



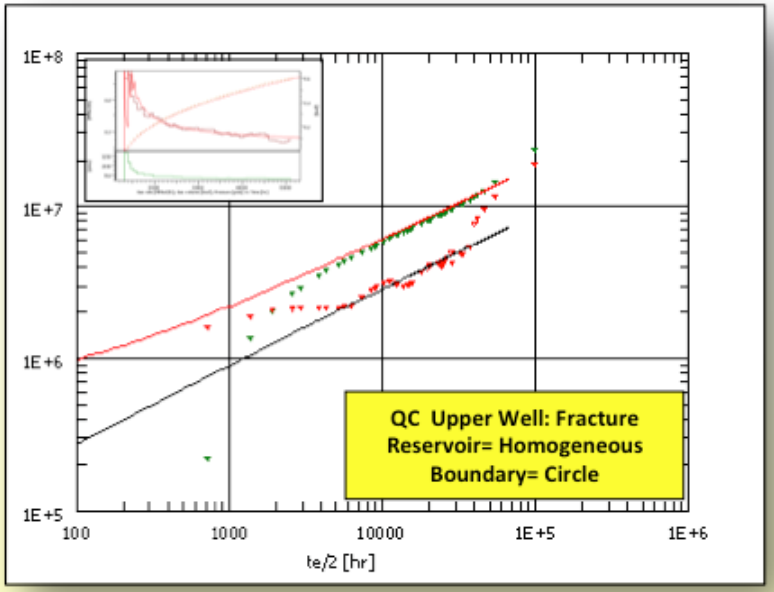
GEOLOGICAL MODEL (Seismic Section)

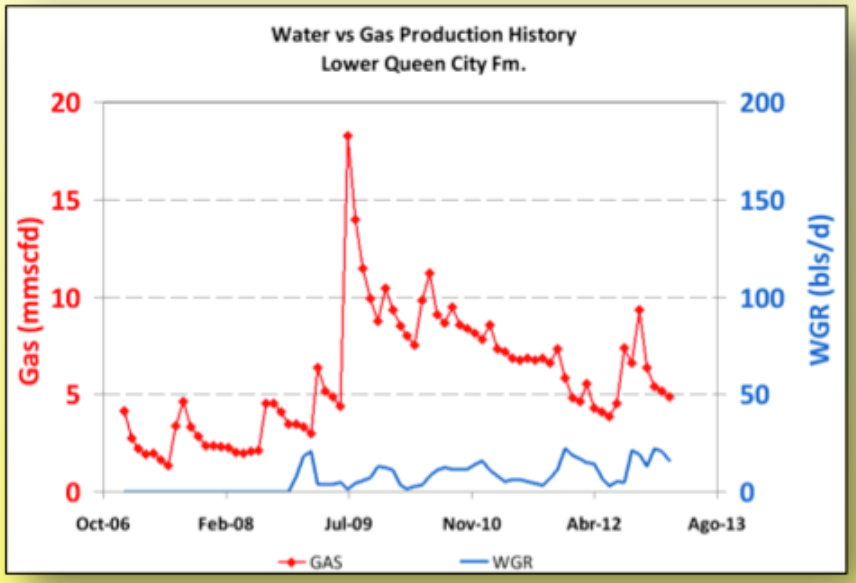


CUERVITO FIELD

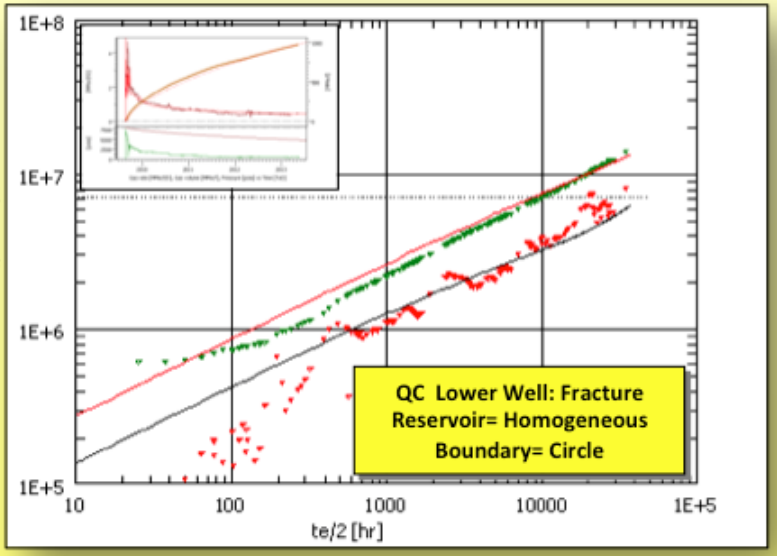


Reservoir Analysis Upper Queen City Fm.



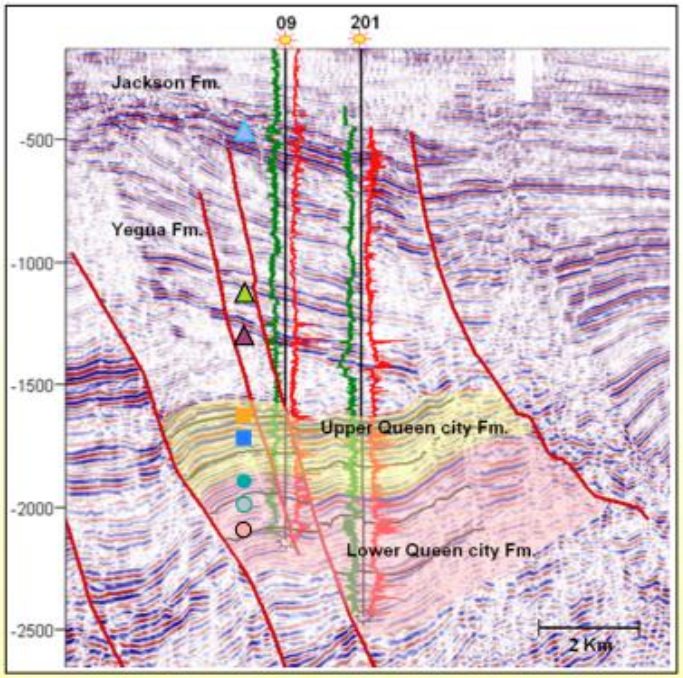


Reservoir Analysis Lower Queen City Fm.

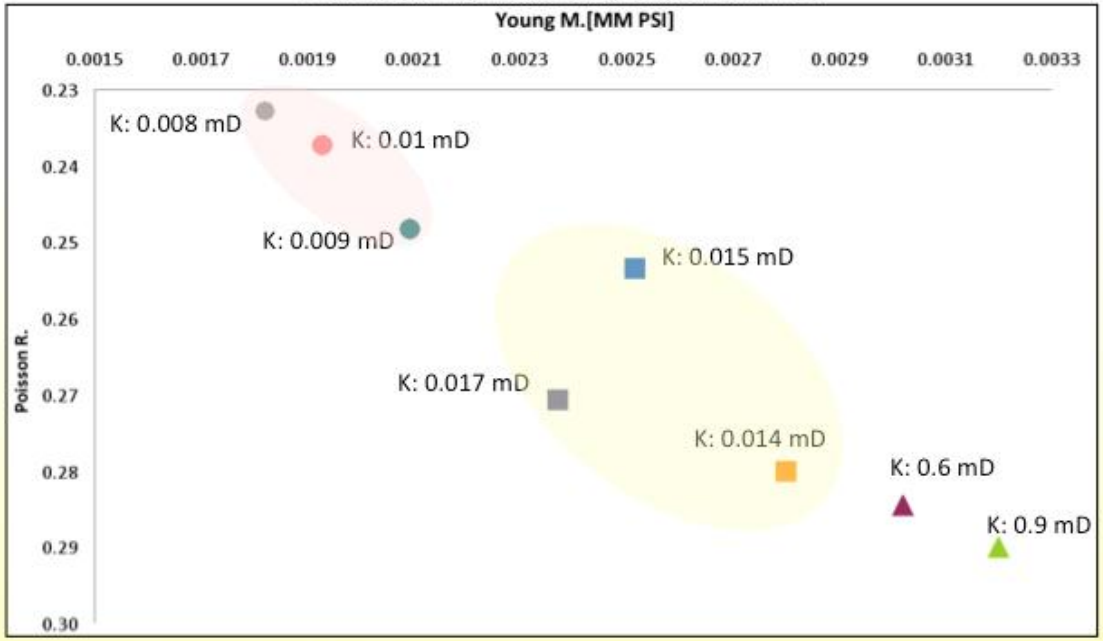


PRESSURE BEHAVIOR

W-E Seismic Section. CUERVITO FIELD



Petro-elastic Parameters Cuervito Field

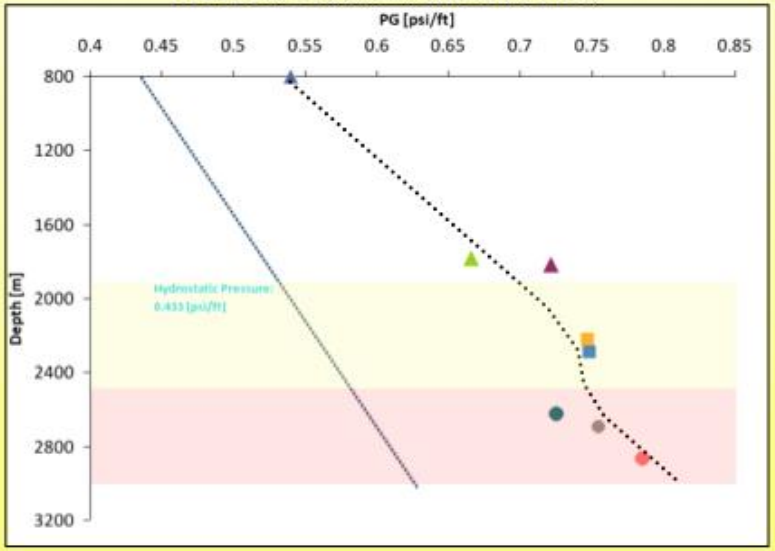


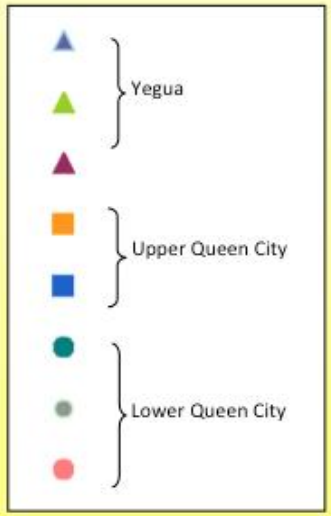
Overpressure:

- Controlled by loading rate, porosity and the permeability evolution of the sediment during burial.
- Happen where the permeability becomes too low to allow complete dewatering.
- Fluid expansion related to clay deshidratation and *smectite – illite* transformation.

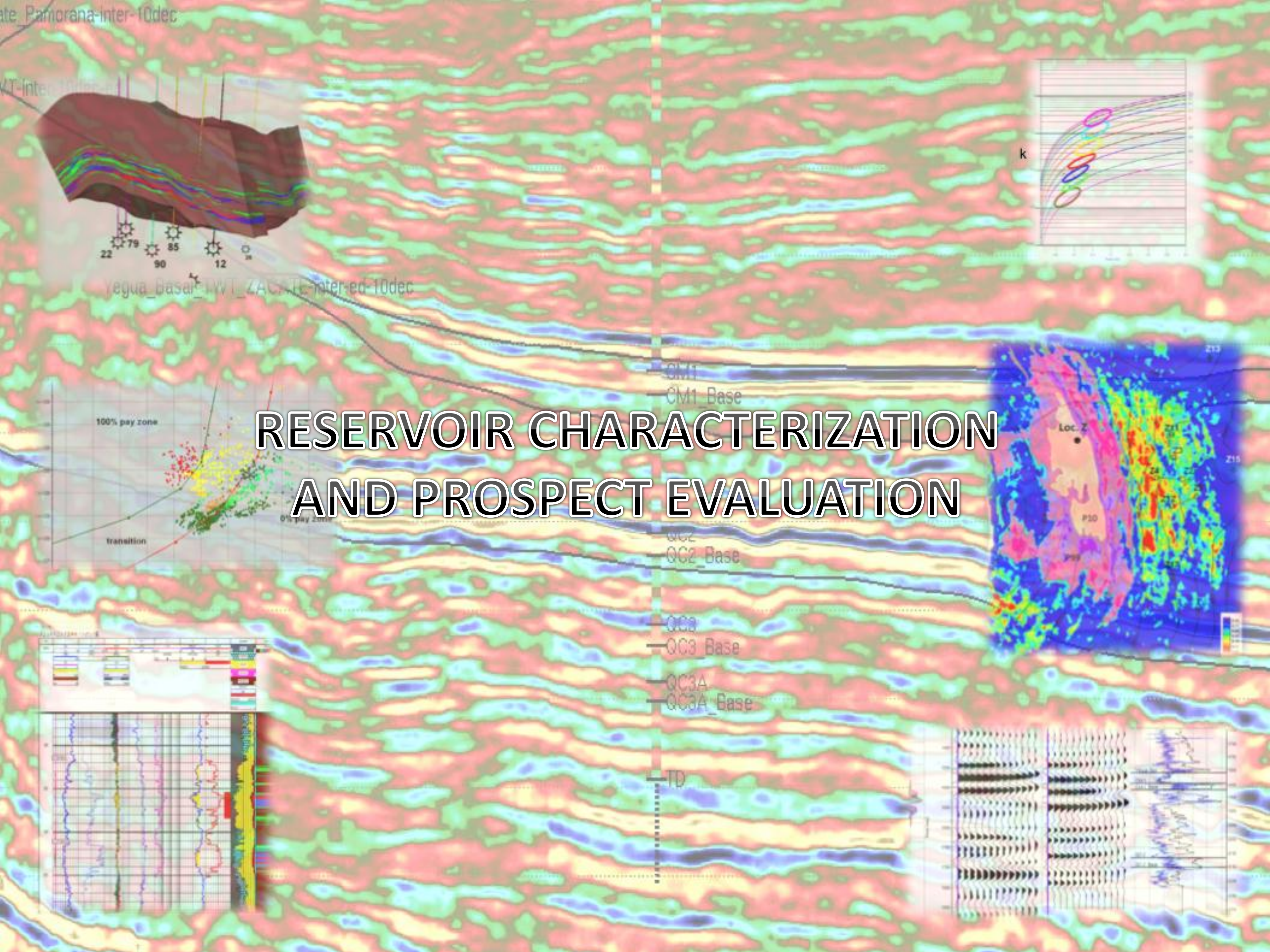
Swarbrick et al. 2002

Pressure Gradient Cuervito Field

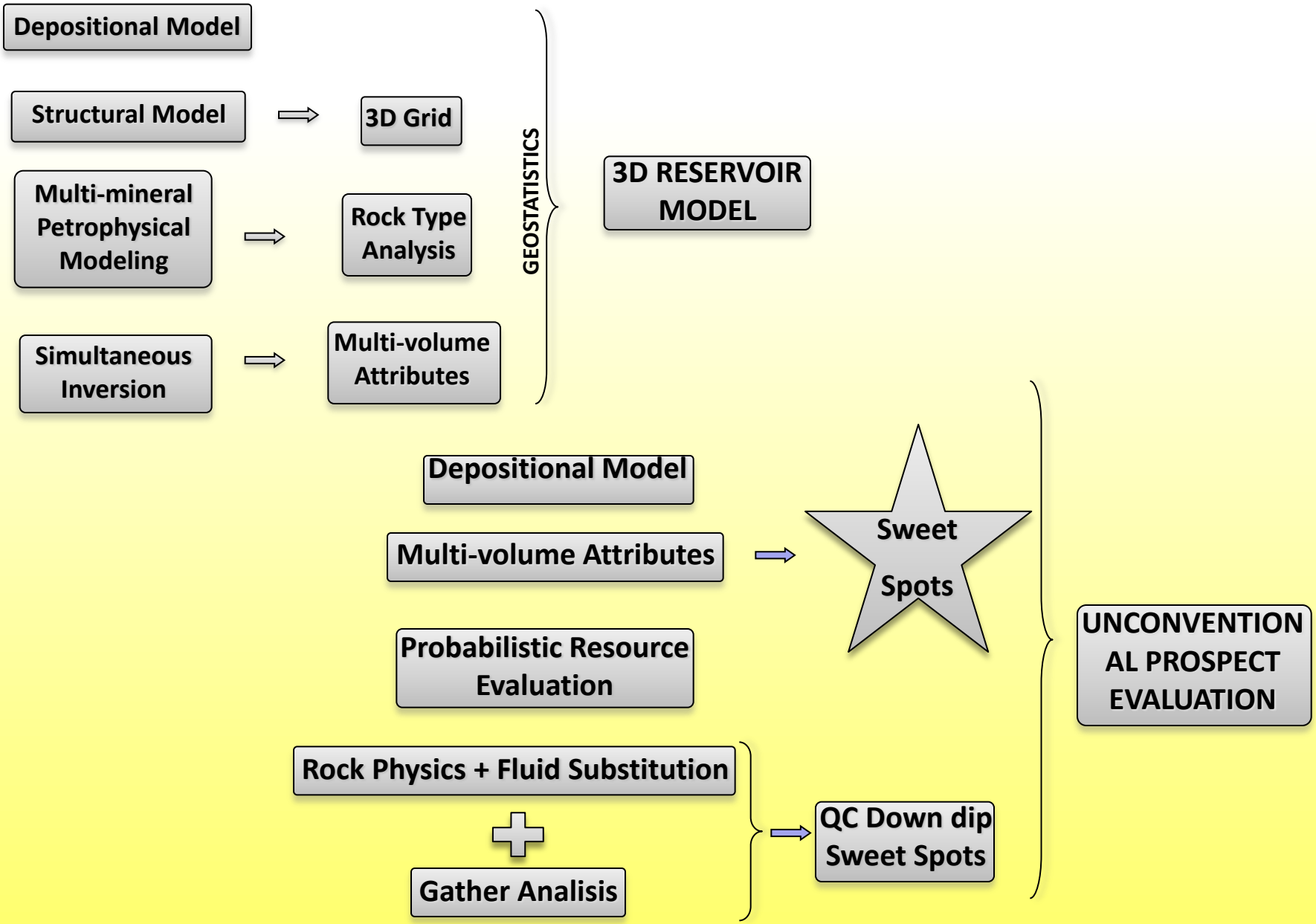




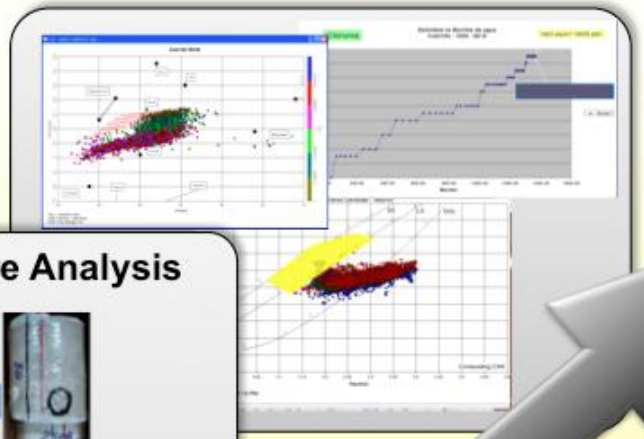
RESERVOIR CHARACTERIZATION AND PROSPECT EVALUATION



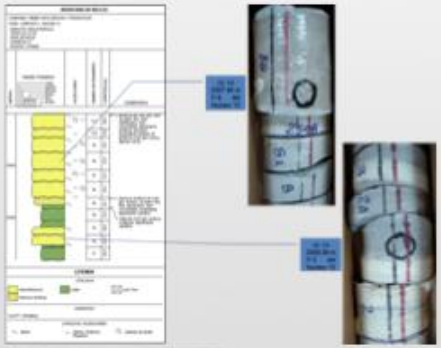
METHODOLOGY

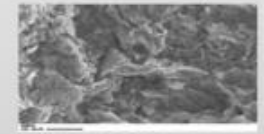


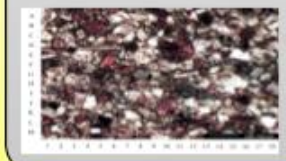
MULTI-MINERAL PETROPHYSICAL MODEL



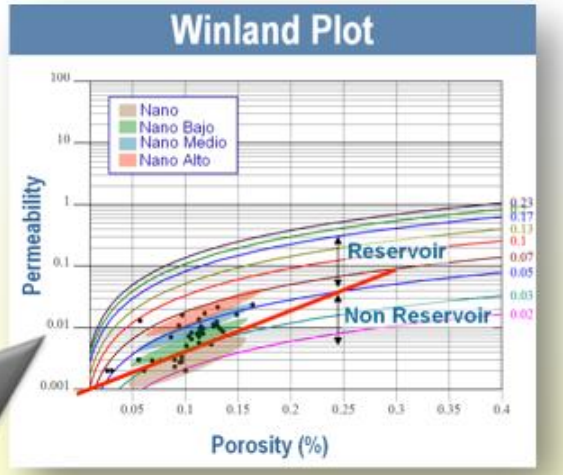
Well 24 Core Analysis







INTEGRATION



Nano High

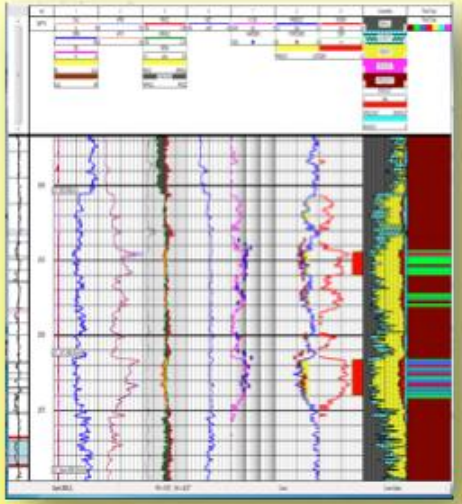
Nano Medium

Nano Low

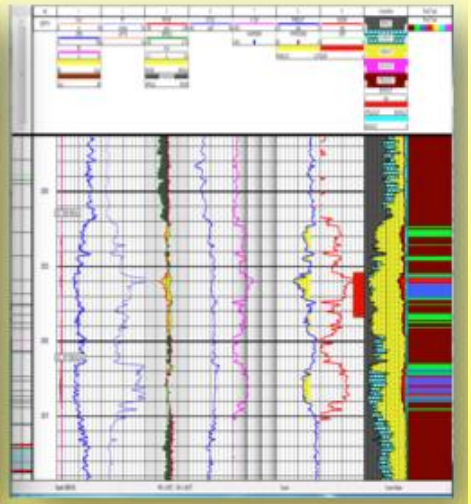
Nano

Rock Type enhance relationship between petrophysics and production. Helping predict well behavior

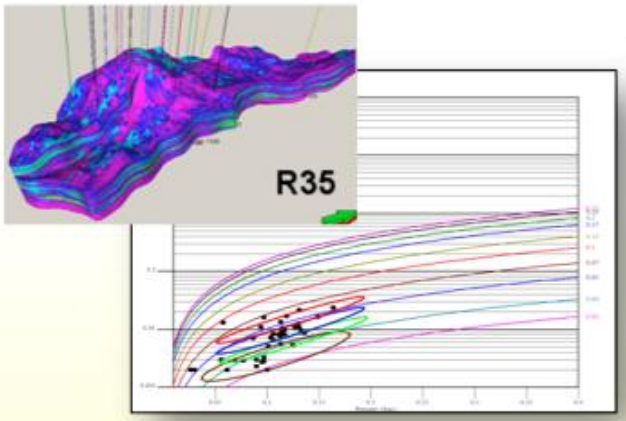
WELL 24



WELL 80



ROCK TYPE MODELING

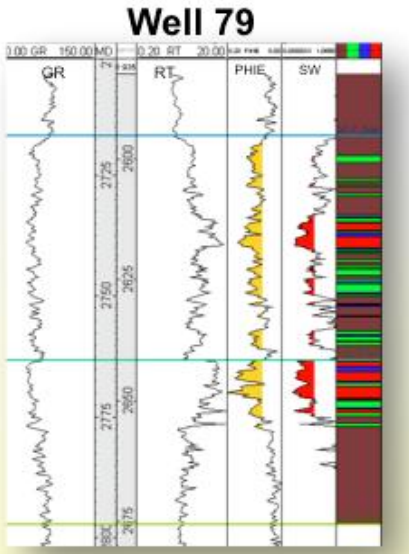


R35 > 0.04 micron = Nano High

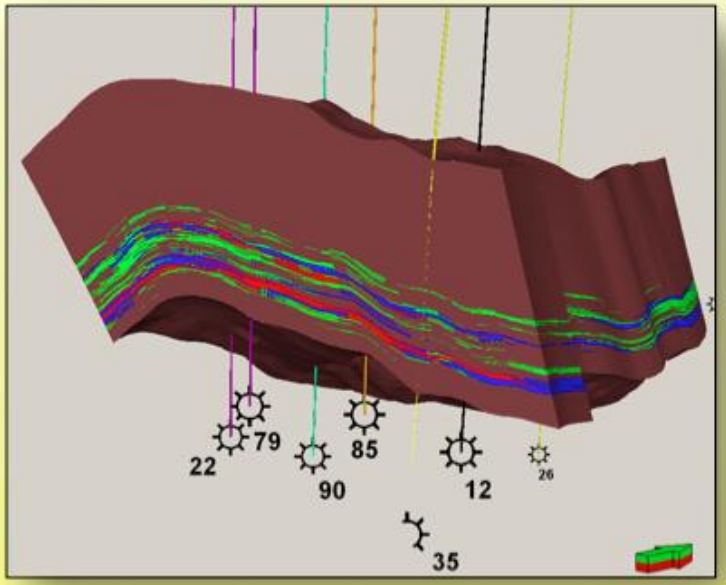
0.04 >= R35 > 0.035 micron = Nano Medium

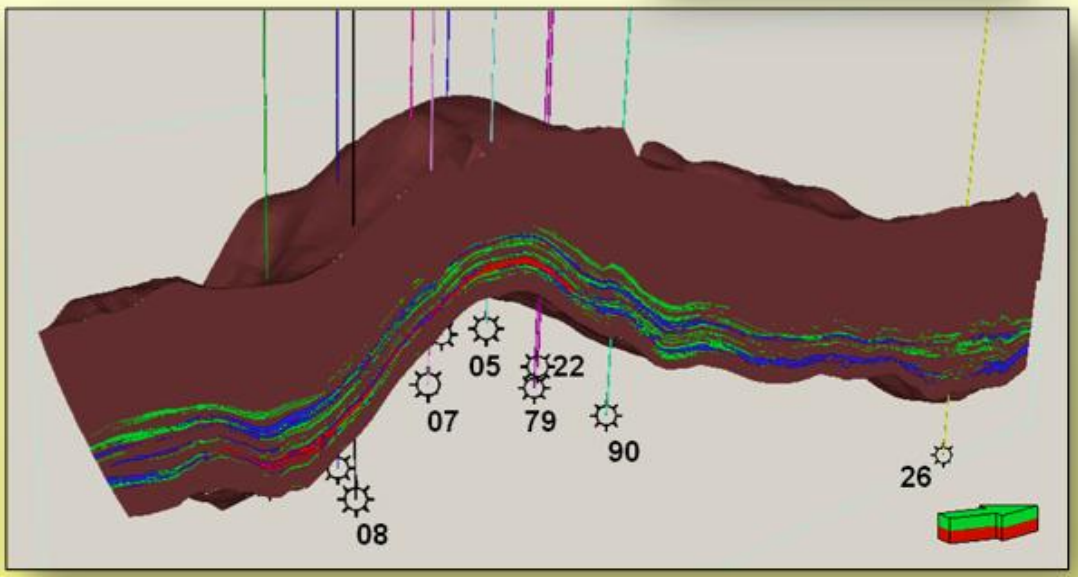
0.035 >= R35 > 0.03 micron = Nano Low

R35 < 0.03 micron = Nano



Log R35 = 0.732 + 0.588 log Kair – 0.864 log Phi core

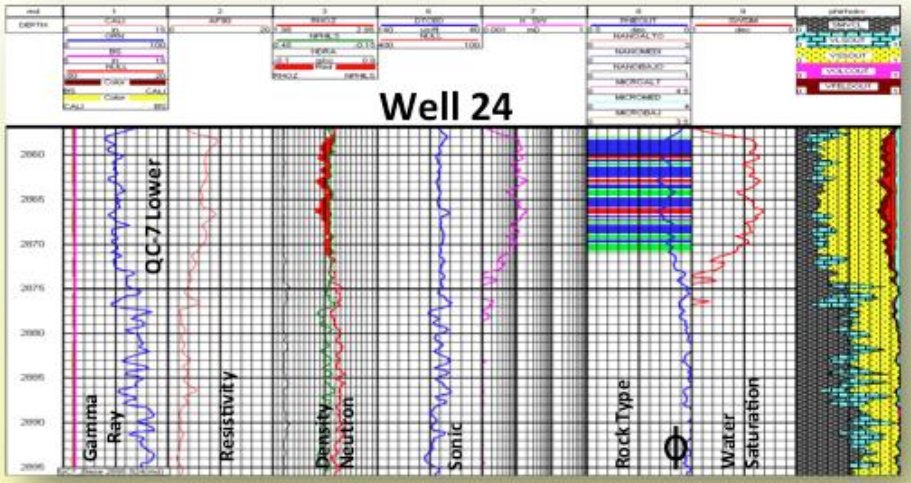


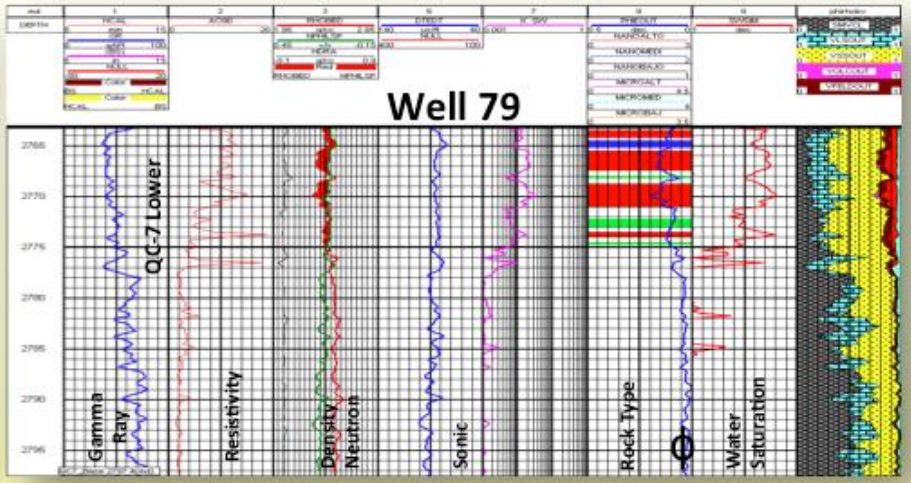


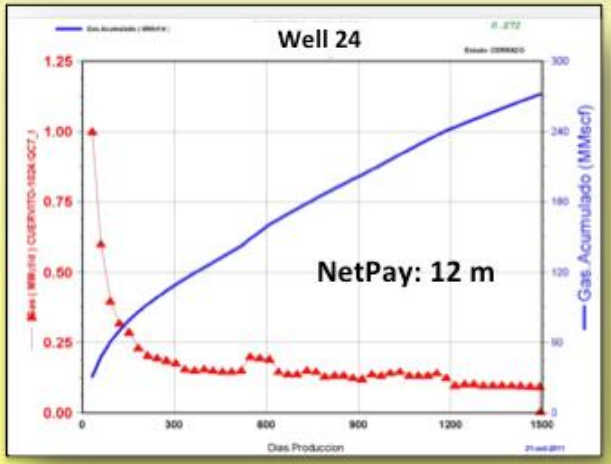
R35= PORE THROAT RATIO

Wells with similar net gas thicknesses but different production performance

Difficult Reservoir Analysis

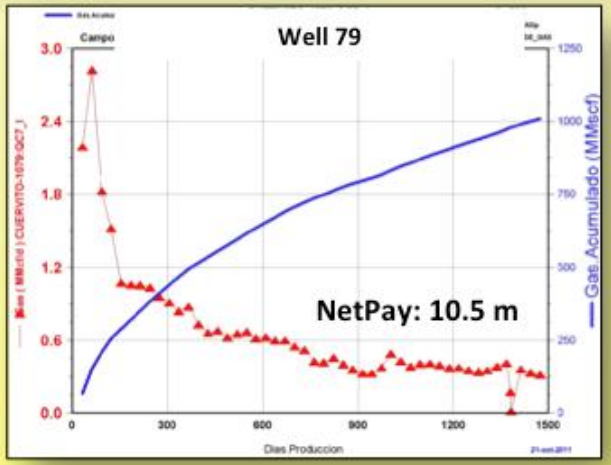




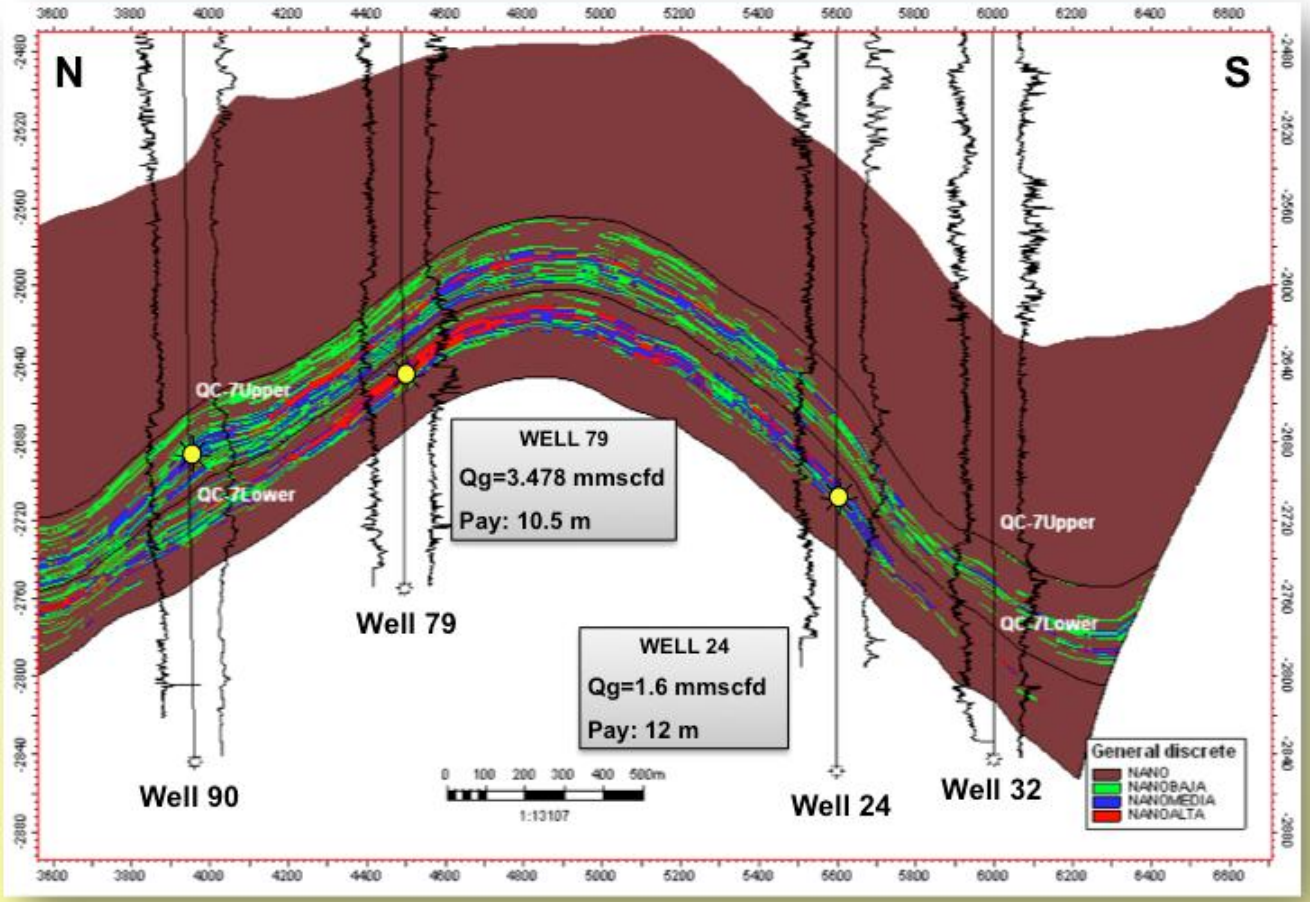


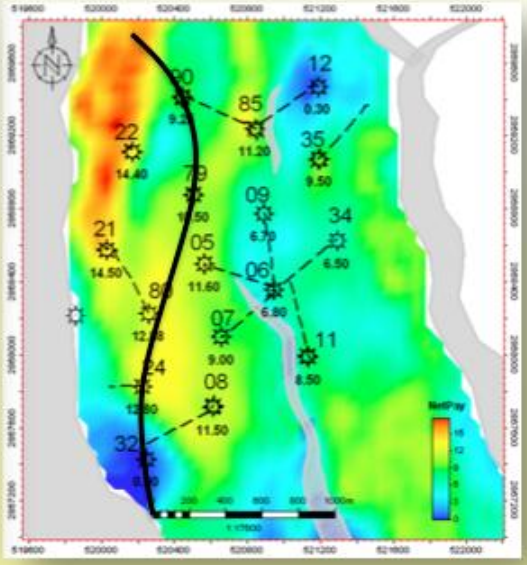
ROCK TYPES

- Nano High
- Nano Medium
- Nano Low
- Nano



ROCK TYPE MODELING / PRODUCTIVITY

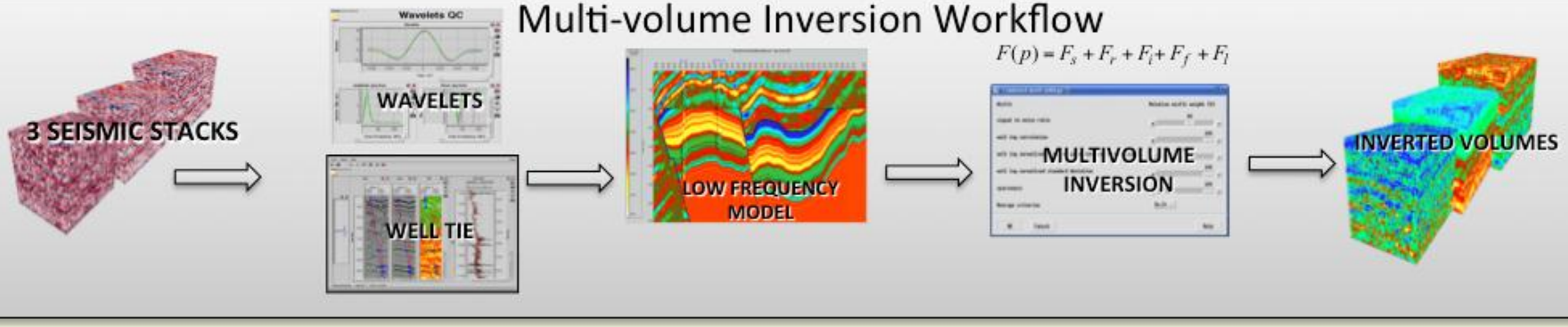




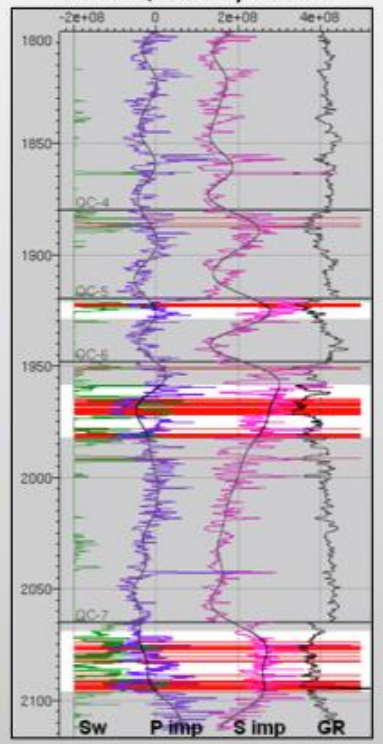
Initial gas rates have better correlation with the *Nano High* Rock Type than the Net Gas Thickness

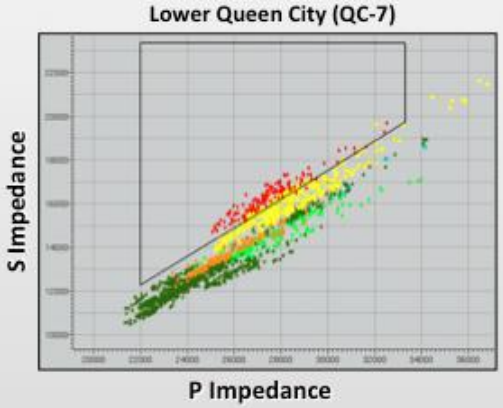
SIMULTANEOUS INVERSION

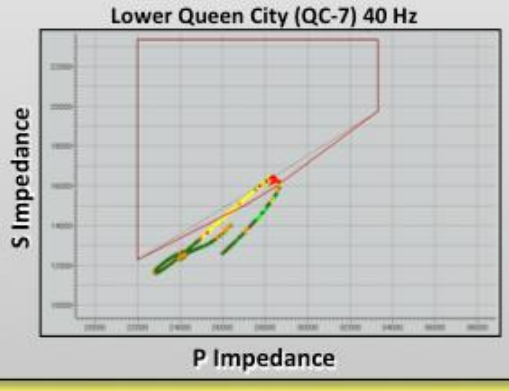
Multi-volume Inversion Workflow

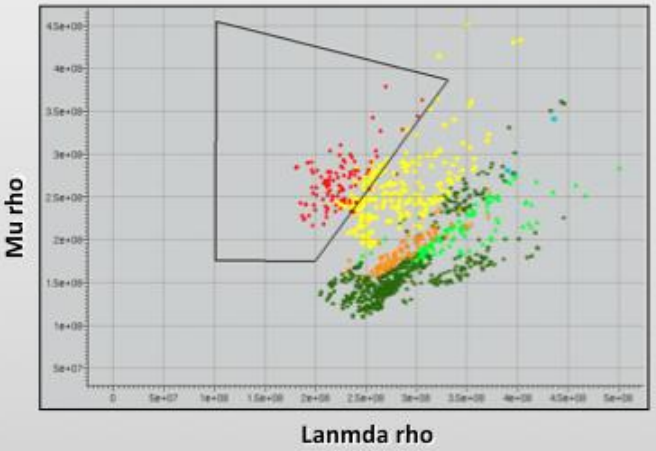


Multi-volume Interpretation





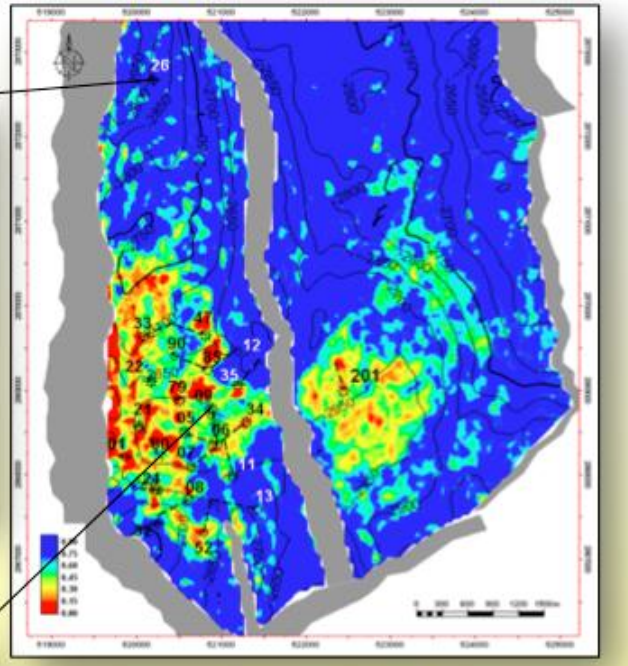




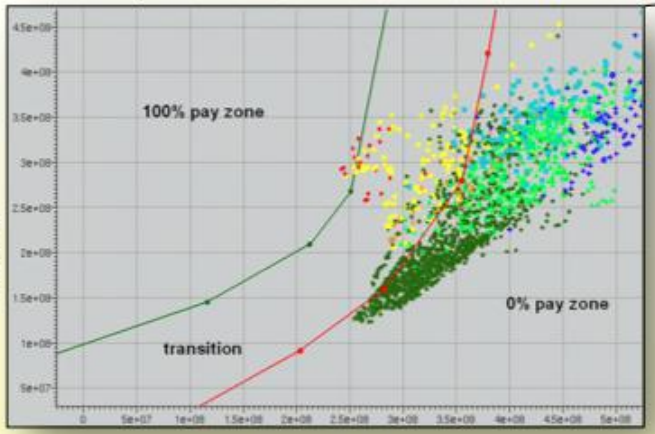
Multi-volume Interpretation

RFI ⇒ **Rock Fluid Index** ⇒ **Probabilistic Index**

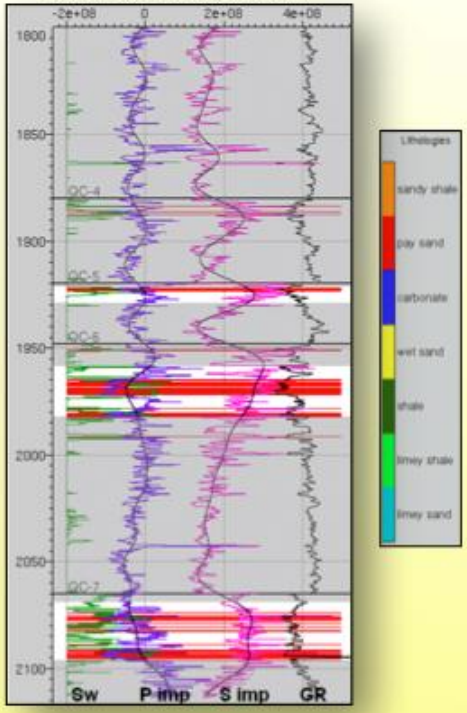
Rock Fluid Index Lower Queen City (QC-7)



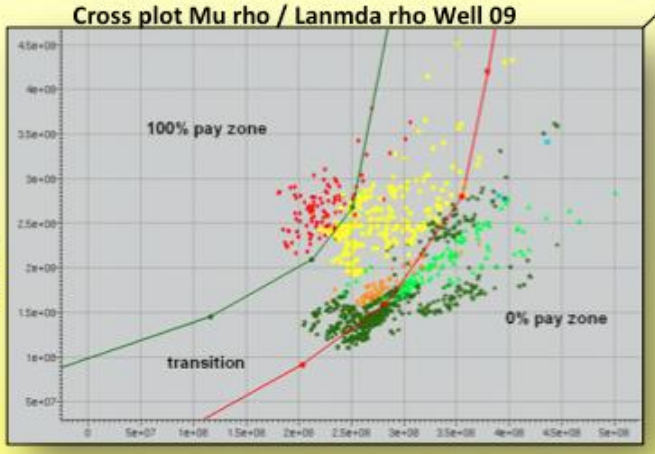
Cross plot Mu rho / Lanmda rho Well 26



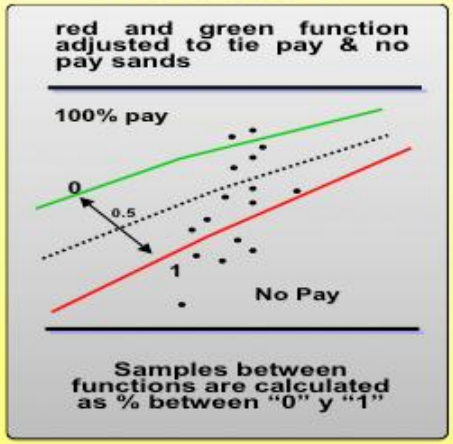
Lower Queen City Well 09



Cross plot Mu rho / Lanmda rho Well 09

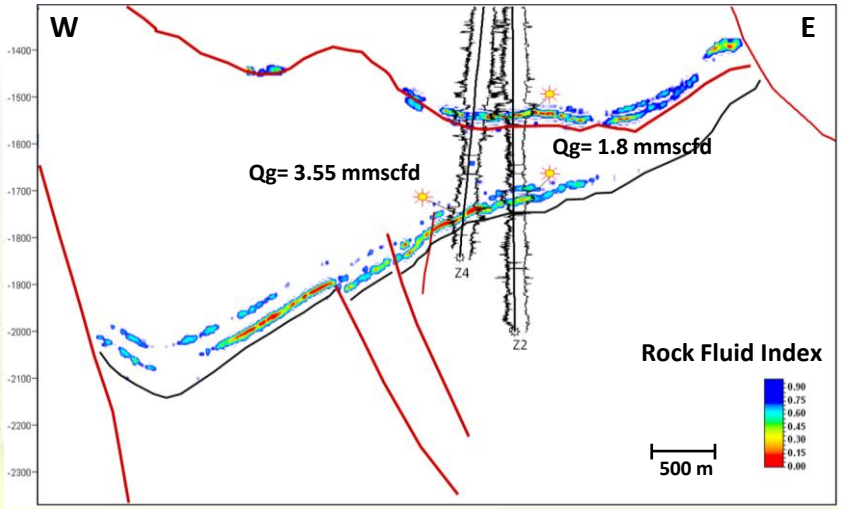


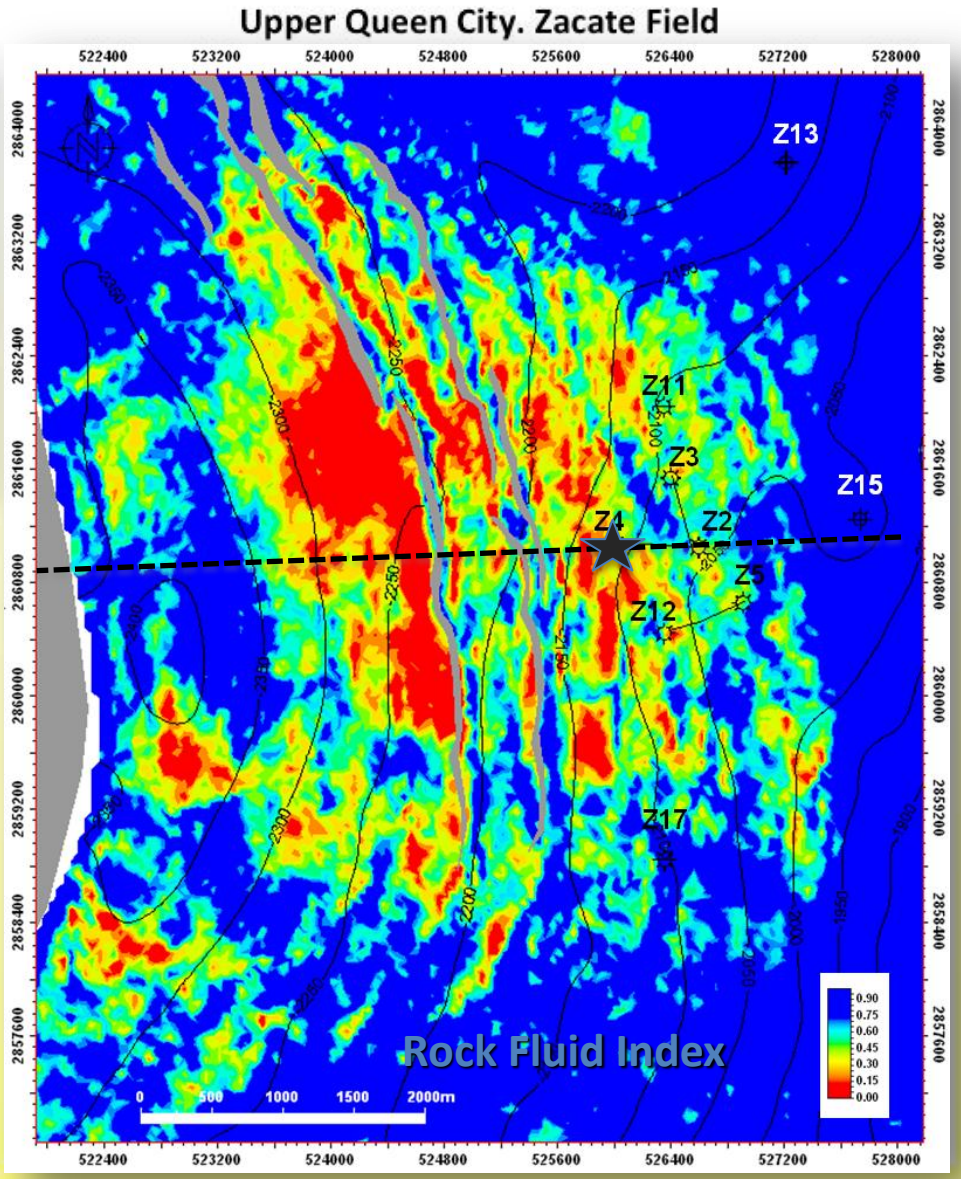
How to create RFI?



TESTING UNCONVENTIONAL CONCEPS (ZACATE FIELD)

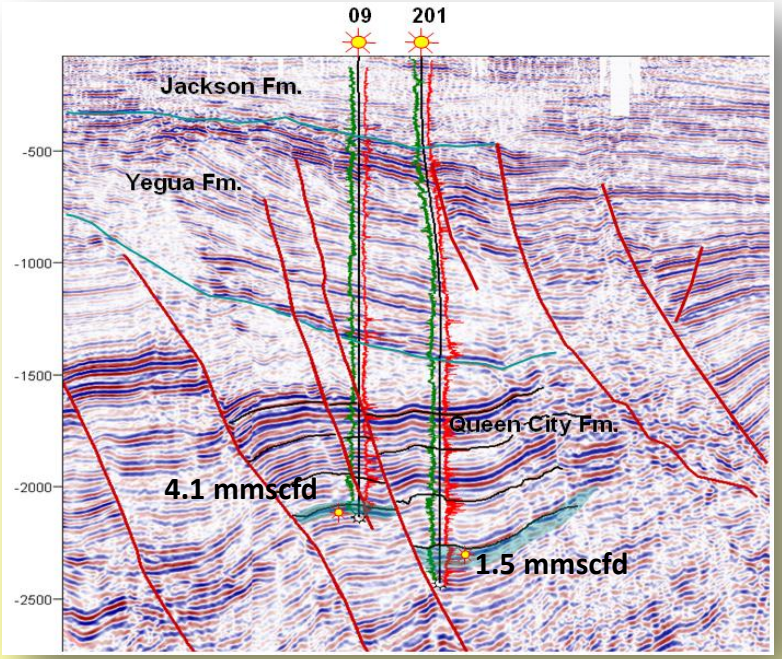
Case 1: Well Z4





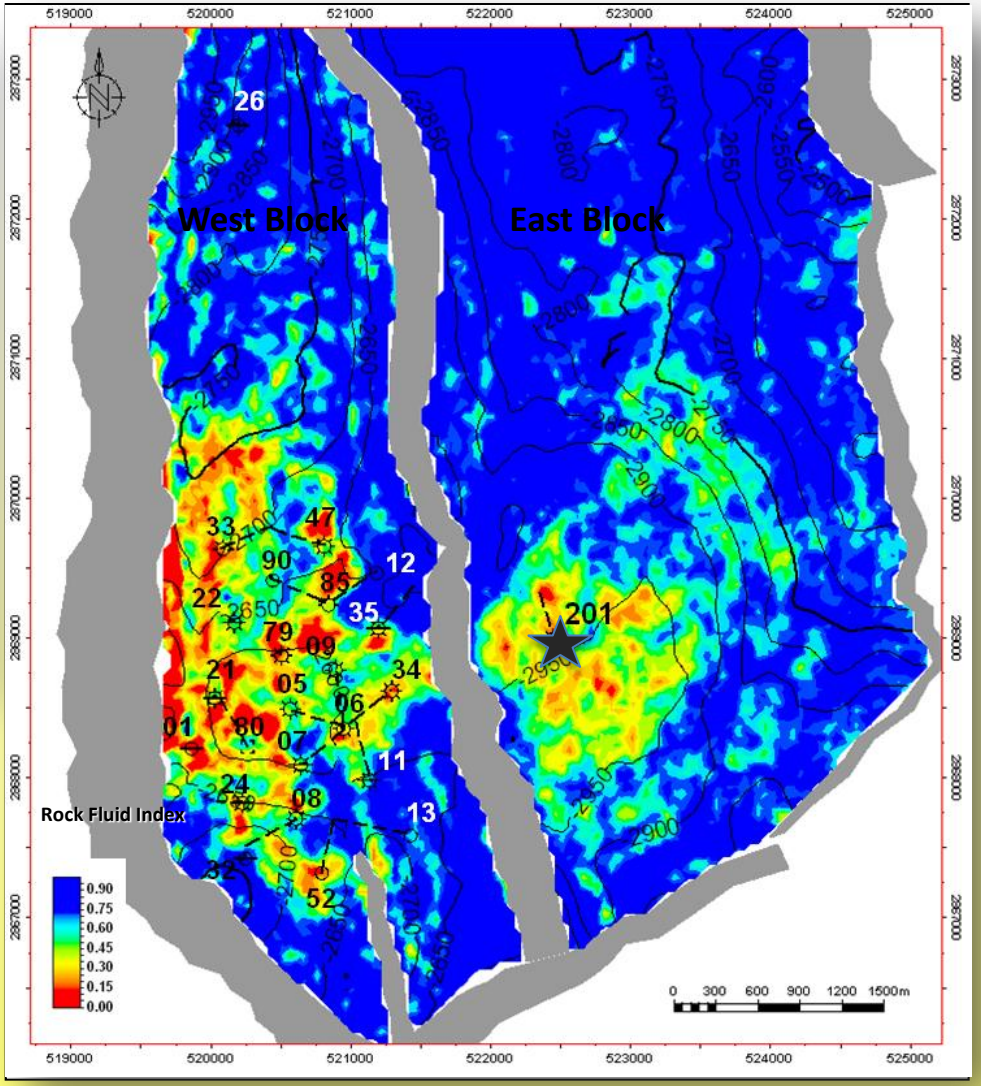
- Well: Z-4.
- Target: Upper Queen City.
- Concept: drill an area down deep to the West, 20 m bellow LKG. (Sweet Spot Seismic Inversion Anomaly)
- Highest net Pay / Highest Initial gas rate.
- Phie: 13 %
- K: 0.011 mD

Case 2: Well 201



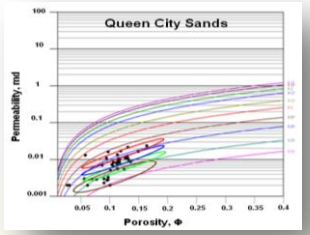
- **Well: 201**
- **Target: Lower Queen City.**
- **Concept: drilled an *Step Out Well* down deep to the East, 270 m bellow LKG West Block (Sweet Spot Seismic Inversion Anomaly)**
- **Gas Shows.**
- **Phie: 9 %.**
- **K: 0.01 mD**

Lower Queen City. Cuervito Field

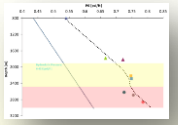


QUEEN CITY FORMATION A TIGHT GAS BUT UNCONVENTIONAL?

- Low Permeability (Between 0.008 and 0.1 mD).



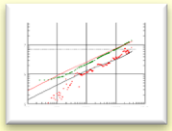
- Rock quality as function of pore throat ratio (R35). Productive sand (0.04> R35 > 0.035 micron).



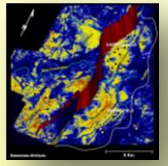
- Overpressure sands. (0.65 psi/f to 0.78 psi/f).

- Complex lithology (fine grain/ muddy sandstones).

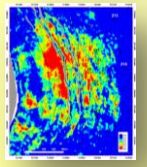
- Not a well define water gas contact.



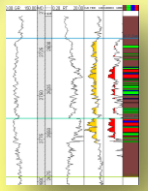
- Sweet spots related to proximal facies (down dip close to listric faults).



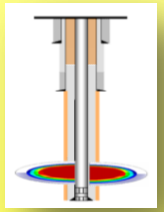
- Sweet spots defined by multivolume attributes (Seismic Inversion).



- Productivity more related to rock types than overall pay thickness.



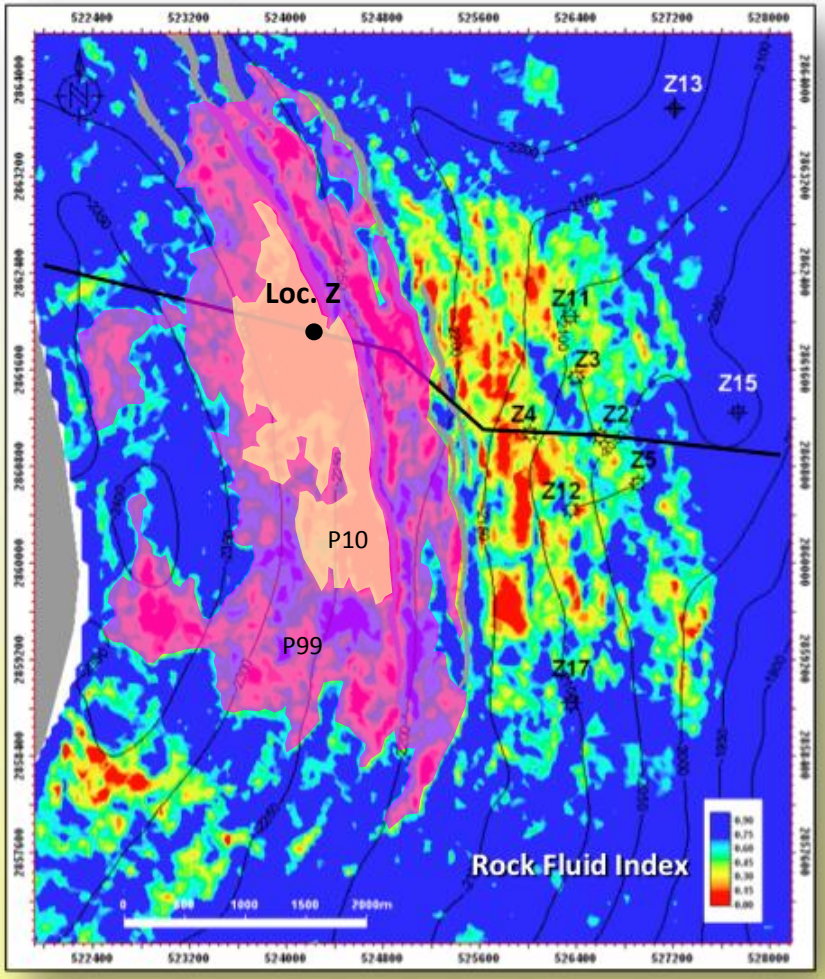
- Require Technology (Hydraulic Fracturing).



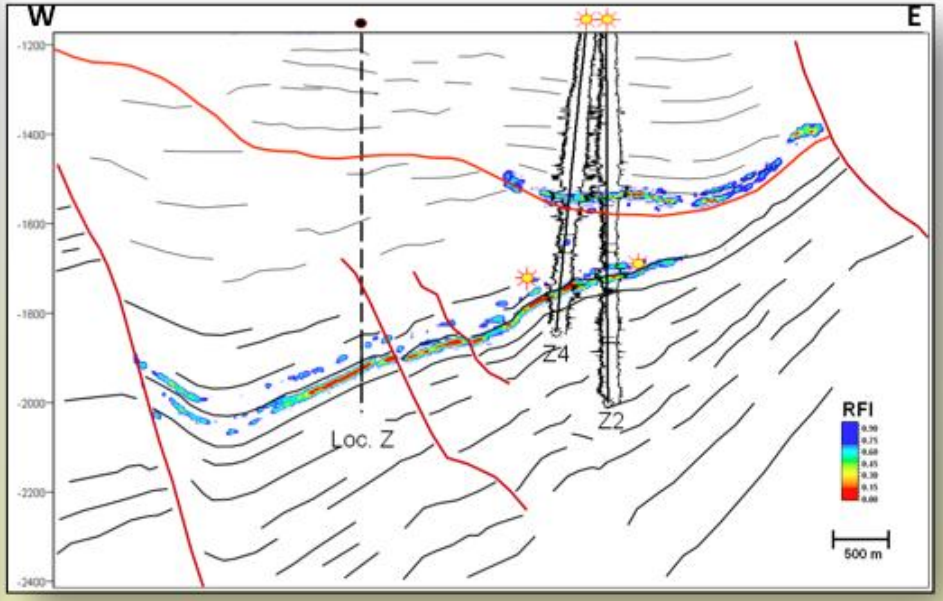
- Little water production.

PROSPECTS RELATED TO UNCONVENTIONAL RESOURCES

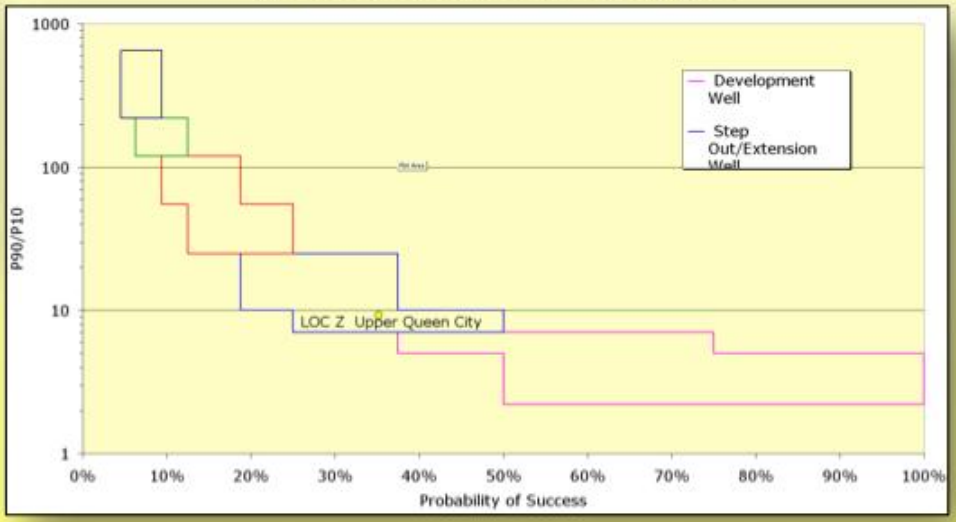
Upper Queen City



Rock Fluid Index Cross Section



Probabilistic Resource Analysis



-Loc. Z

- Field: Zacate.

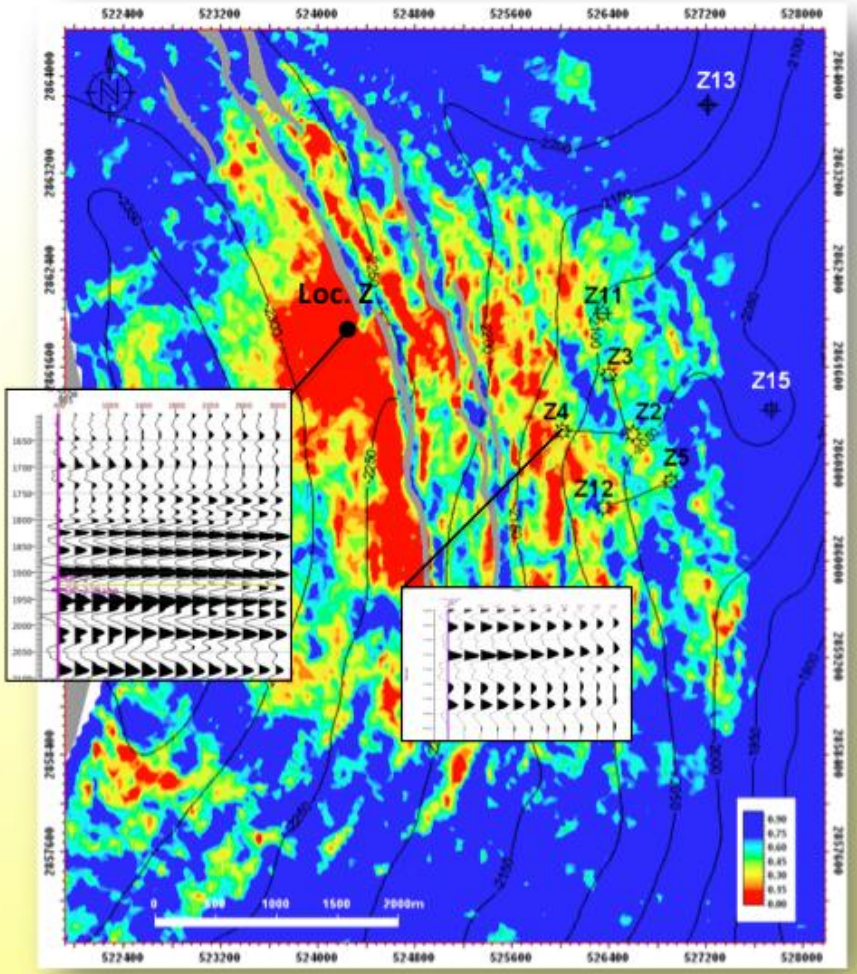
-Step Out Prospect.

-Proximal Facies / High Rock Quality / Down dip Structural Position.

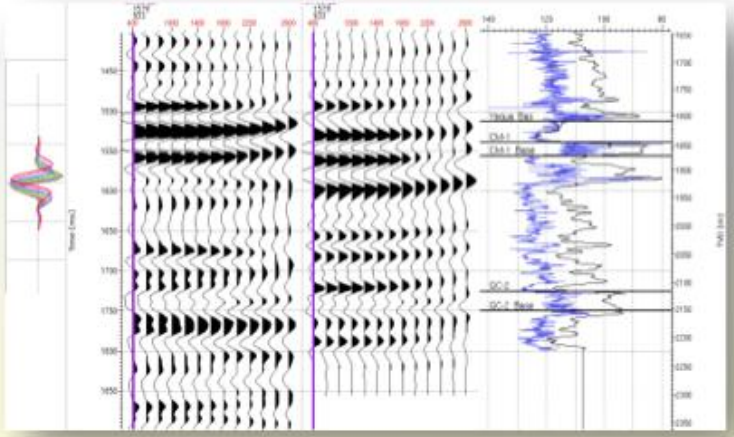
-Potential Area: P99= 18 / P10=2 Km^2.

-P_{MEAN}= 17 BCF

PROSPECT RELATED TO UNCONVENTIONAL RESOURCES



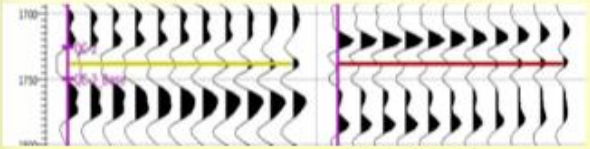
Gathers Z-4 / Offset 400-3000 m



Z-4 Fluid Substitution (Upper Queen City)

Seismic

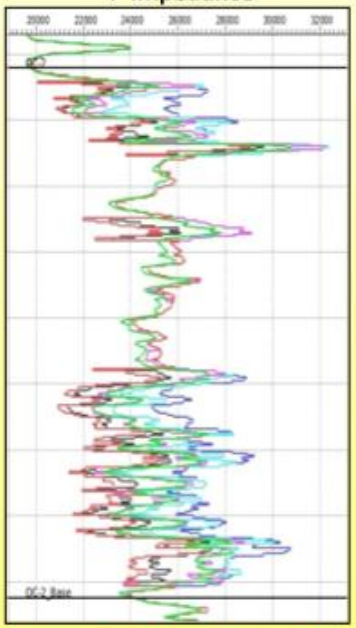
Synthetic



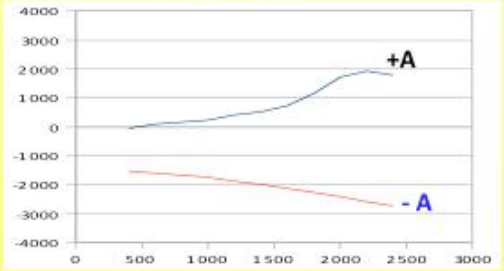
25 – 40% Sw

Corr = 0.8662

P Impedance



Amplitude vs Offset



Green: in-situ Red: 5% Sw Blue: 100% Sw

Purple: 50% Sw Rose: 70% Sw

CONCLUSIONS

- **Although the study areas are considered conventional traps related to a growth faulted system, there is a significant amount of unconventional resources (*Tight Gas Sands*).**

- **Queen City Tight Gas Sands are lithic and sub-lithic arenites fine grain overpressure sand with low permeability where *sweet spots* are related to facies, thickness, permeability and rock types *commonly* independent for the trap.**

- **The multimineral petrophysical model based on the Winland concepts is a critical element in reservoir characterization and important to understand the productivity of tight gas sands of Queen City Formation.**

- **Multi-volume attributes related to simultaneous inversion in high impedance sands of Queen City are critical in identifying Sweet Spots and new development opportunities.**

- **The understanding of unconventional concepts related to Tight Gas Sands and use of proper characterization methodology will allow the search of new volume and reserves in the Burgos Basin, considered in a mature stage of development.**

ACKNOWLEDGEMENTS

PEMEX E&P

Grupo Multidisciplinario de Proyectos de Exploración, Incorporación de Reservas y Estudios de Plays

PETROBRAS MEXICO

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