6TO. CONGRESO IAPG
Producción y Desarrollo de Reservas
HACIA UN DESARROLLO DE RECURSOS SUSTENTABLE

IAPG INSTITUTO ARGENTINO DEL PETROLEO Y DEL GAS

24 - 27 Octubre 2016
Llao Llao Hotel&Resort
Bariloche, Argentina

EOR en Escenarios Shale Oil

Propuesta de Incremento del EUR Mediante Uso de Fuerzas Capilares

Preparado Para el VI Congreso de Producción y Desarrollo de Reservas
24 al 27 de Octubre de 2016, Bariloche, Argentina

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Labayen I.(INLAB SA)
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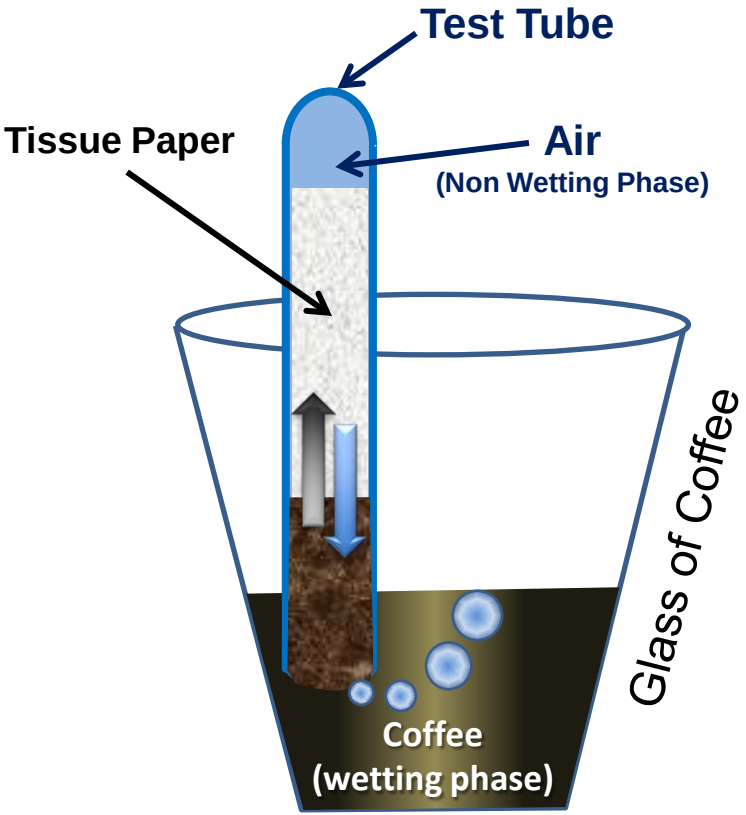
inLab

VYP CONSULTORES S.A.

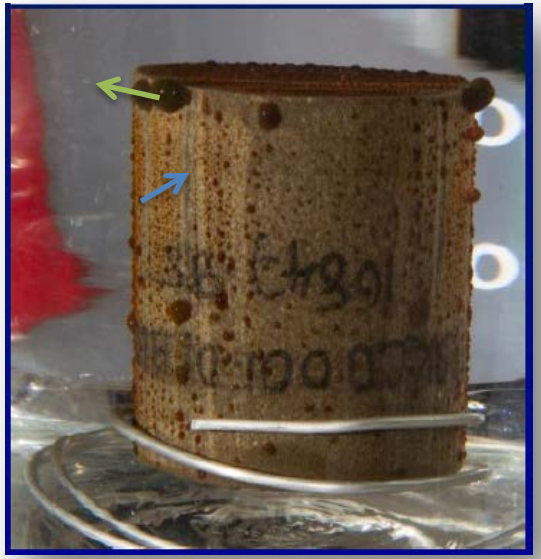
IDEA

To ***Increase EUR*** in unconventional reservoirs (Shale Oil Scenarios) based on ***Counter-Current Imbibition***

Countercurrent Imbibition



Bakken Low Salinity

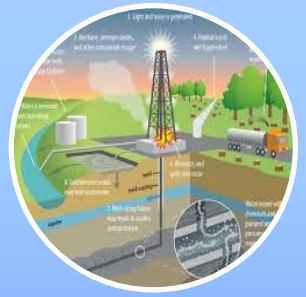


SOURCE: "*Creating a Worldwide Unconventional Revolution Through Technically Justifiable Strategies"* Kurtoglu, B; SPE Distinguished Lecturer Presentation held in Buenos Aires, Sep-2016

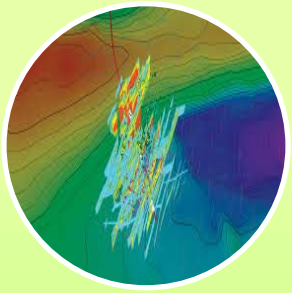
MAIN Uncertainty

Will it work in real wells?

1. ***Could we inject water without damaging the current frac system?***
2. ***Will it produce the effect of spontaneous imbibition?***
3. ***Will it recover enough incremental oil? → How much is enough?***



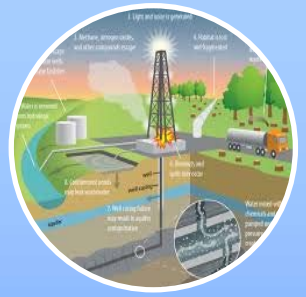
Conceptual



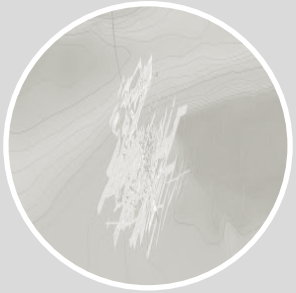
Theoretical

Experimental

PROPOSAL DE-RISKING



Conceptual



Theoretical

Experimental

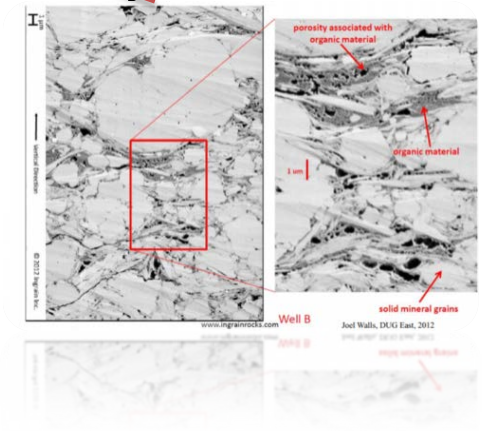
PROPOSAL DE-RISKING

CONCEPTUAL MODEL

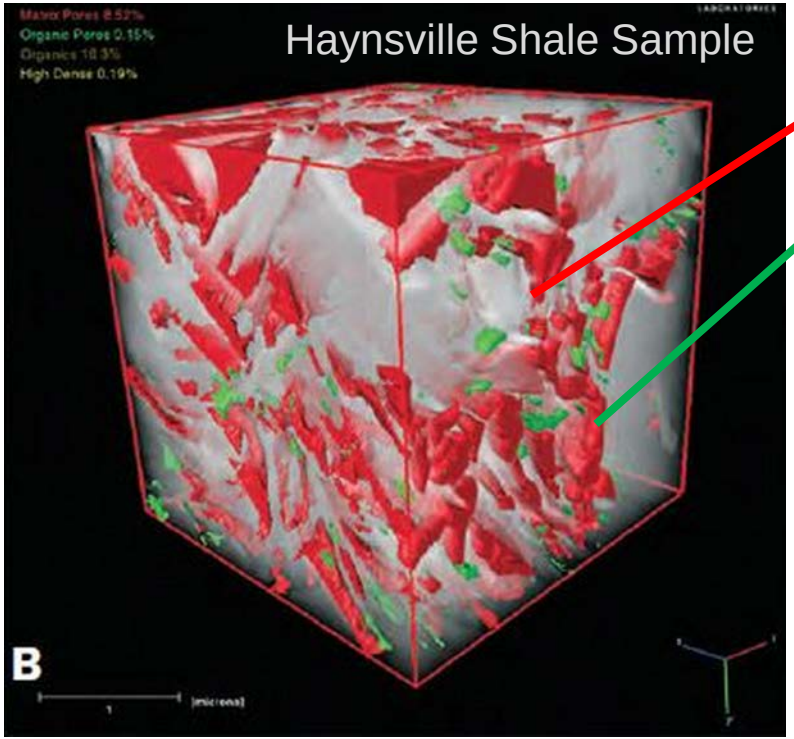
- **Flowback Water Behavior**
  - Rapid Salinization of Flowback Water
    - Rate of Salinization is linked to exposed area/complexity
  - High Flowback water retention (FBWR)
  - Positive Correlation Between Low FBWR and EUR
  - Early Oil Production (as early as hours with FBWR ¿< 5%?)

CONCEPTUAL MODEL

- **Shale Description**
  - Described as ~~dehydrated~~, ~~dissecated~~ or ~~"thirsty"~~ → ***Desaturated***
  - Conceptually, the Shale structure has:
    - **Matrix** (high storage, low perm):
      - **Organic Pores** (oil wet, dissconected)
      - **Inorganic Pores** (mostly Water wet)

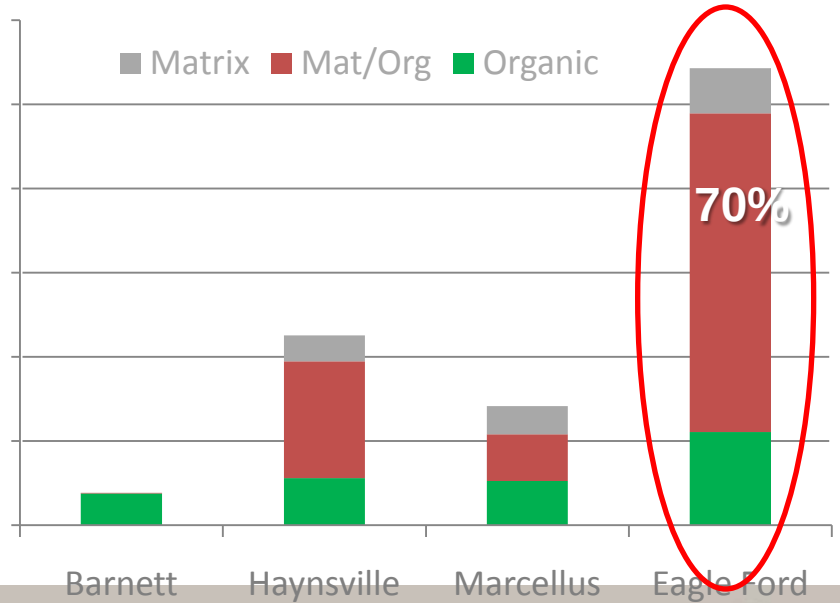


CONCEPTUAL MODEL



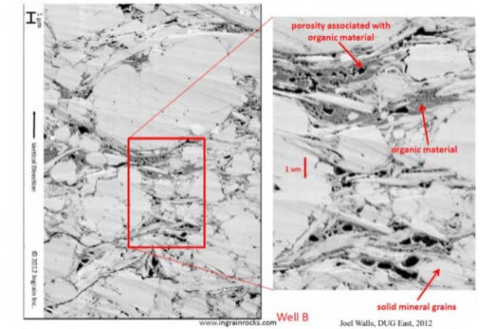
WW Matrix Porosity 4%

OW Organic Porosity 1%



CONCEPTUAL MODEL

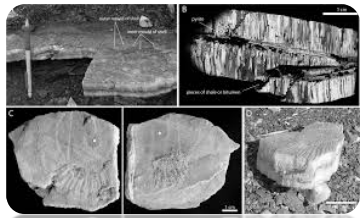
- **Shale Description**
  - Described as dehydrated, dissecated or “thirsty”
  - Conceptually, the Shale structure has :
    - **Matrix** (high storage, low perm):
      - **Organic Pores** (oil wet, dissconected)
      - **Inorganic Pores** (mostly Water wet)
    - **Fractures** (low storage, high perm)
      - **Natural**
      - **Induced** (Propped & Unpropped)



CONCEPTUAL MODEL

- **Overpressures (origin)**
  - Lithostatic (all fluids will be over pressured, no impact on Pc)
  - Due to Hydrocarbon generation (imply large Pc)
    - Volume Increase due to HC molecular bonding breakage
    - Needs a water “escape route” → Beefs are abundant in Vaca Muerta

Over pressures in VM could be a measure of Capillary Pressure developed over geologic times



CONCEPTUAL MODEL

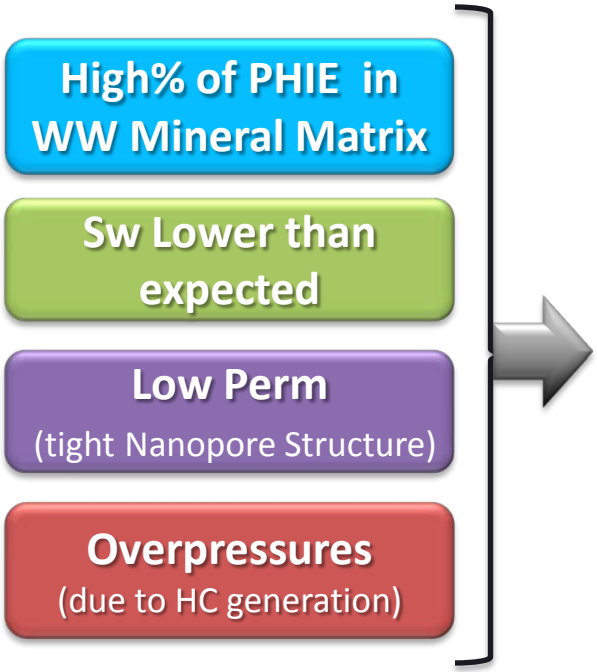
- Overpressures in Vaca Muerta could easily reach ***2,000-3,500 psi***
  - Then If Pc = 3,000 psi and P_{oil} = 8,000 psi → P_w = 5,000 psi

- The main production mechanism is imbibition?
  - This is not new data…**Lawati S., SPE36688 oct-1996**

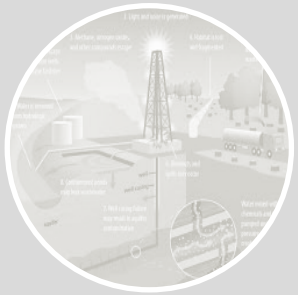
"…Tight highly fractured reservoirs do not respond to conventional waterflooding because **capillary forces** are the major contributors of reservoir drive…"

- It is an "exchange" mechanism, NOT a displacement
  - **1 Vol / 1 Vol (if water is imbibed, oil MUST be produced)**

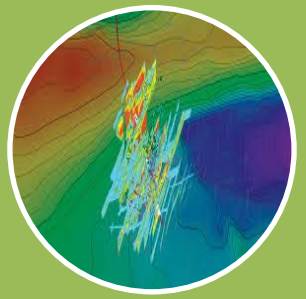
SUMMARY of CONCEPTUAL MODEL



- Imbibition will occur if exposed to high press. water
- Speed will be relate to exposed surface (complexity)
- Imbibition of water will expel the oil increasing EUR



Conceptual



Theoretical

Experimental

PROPOSAL DE-RISKING

THEORETICAL MODEL

- A first **analytical** approach was followed, obtaining promising results with the data available in the technical literature.

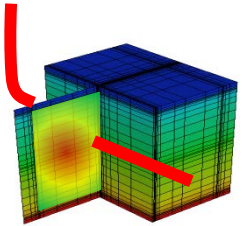
"…with frac surfaces in the order of a million m^2, 80% of the fluid could be imbibed as fast as in 5 day shut in periods…" (1)

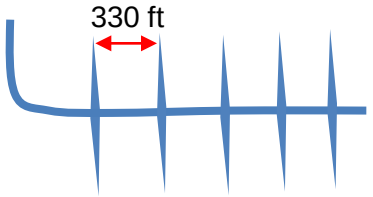
- Then, shifted to try to capture more realistic cases with **numerical** models

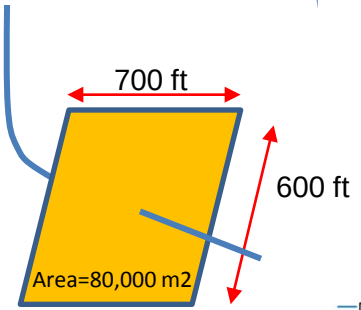
(1) Birdsell, D., Department of Civil, Environmental and Architecture, University of Colorado, Boulder, Colorado, USA.

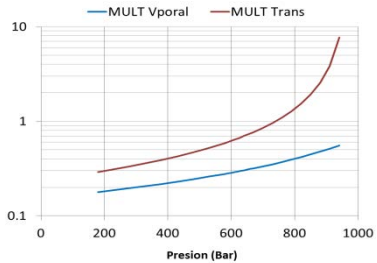
NUMERICAL THEORETICAL MODEL

- **Well and 3D Grid**:
  - Cartesian «Tartan» Log – spaced
  - Single Porosity – Dual K (Matrix and Frac)
  - 500m, 5 stage Horizontal Well
- **Frac Model**:
  - Single, Planar, orthogonal, 5 stages (1 frac/s)
  - Dimensions: Xf =350 ft m, h=600 ft, W=0.1in
  - Stage spacing = 330 ft
  - Perms (x=y=z) = 2 Darcies and PHIE = 25%
  - Variable Compressibility and Transmissibly
- **Matrix Model**:
  - PHIE = 6.5% and Perm (x=y=z) = 400 nD



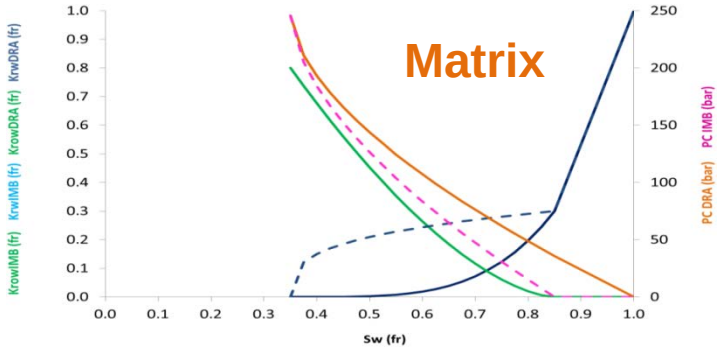


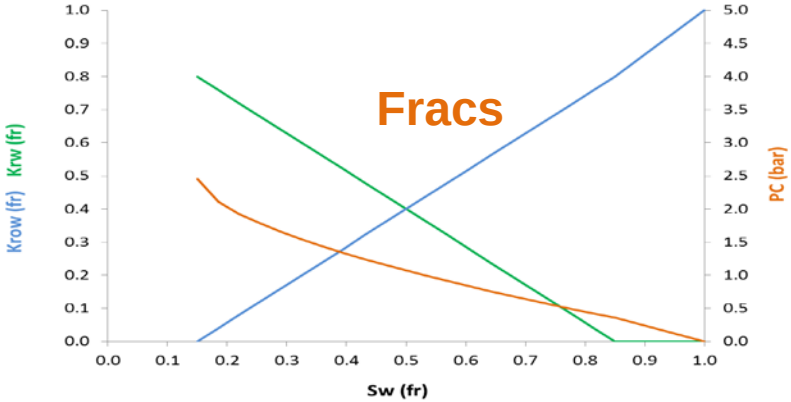




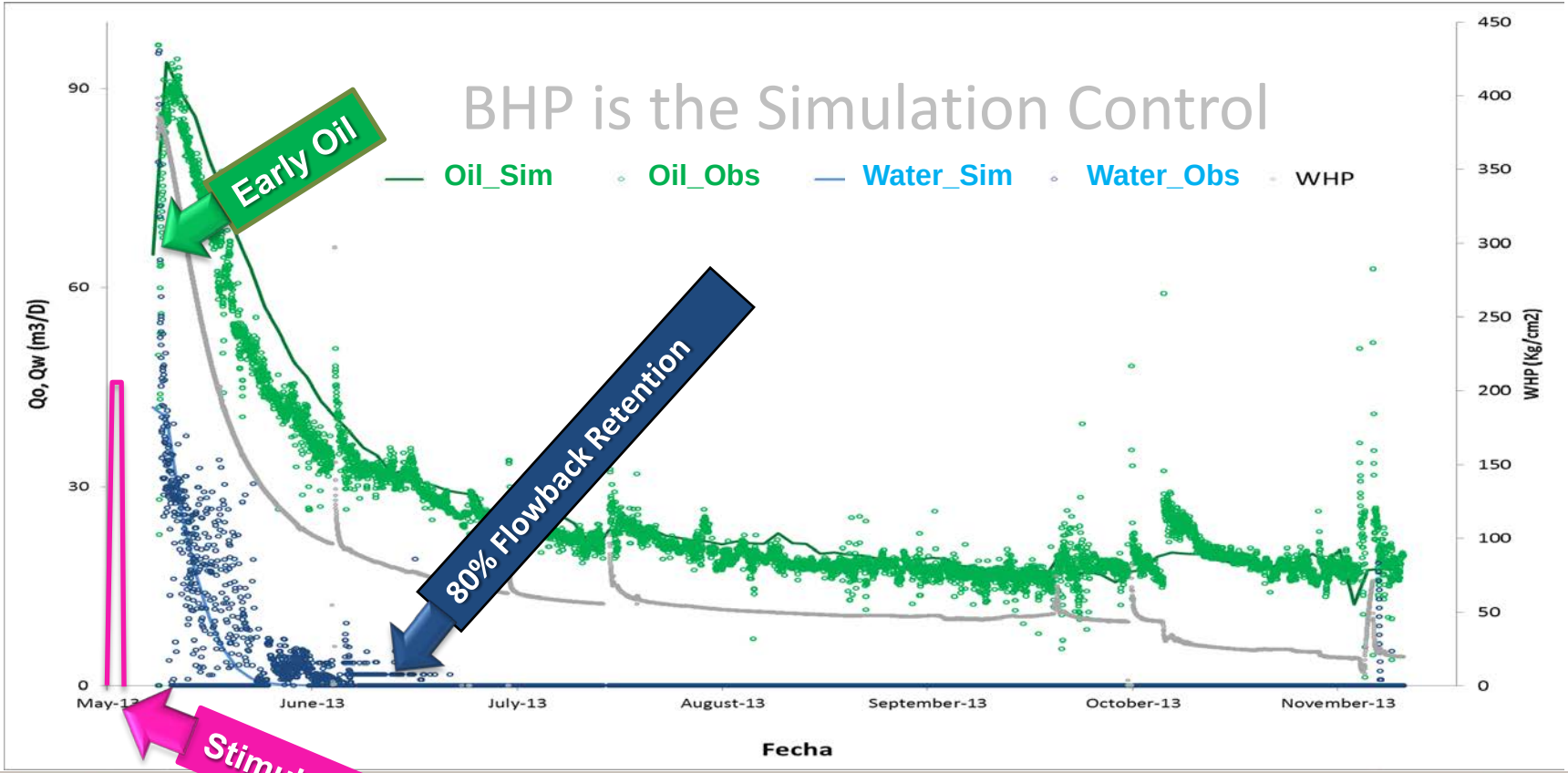
NUMERICAL THEORETICAL MODEL

- **Saturation Functions:**
  - 2 regions (Frac and Matrix)
  - Hysteresis (Drainage and Imbibition)
- **PVT:**
  - Black Oil (Rs: 150 m3/m3 y API: 45)
  - Pi: 8,000 psi, Pb: 3,300 psi, Ti=100 C
  - Boi: 1.45, Bwi : 1
  - Muo: 0.55, Muw: 0.4 cP
- **Stimulation and Flowback:**
  - Total Injected Volume = 2500 m3
  - 6 hs pump time + 5 days of soaking time
  - Flowback Water Retention of 80 %
  - 200 producing days of historical data



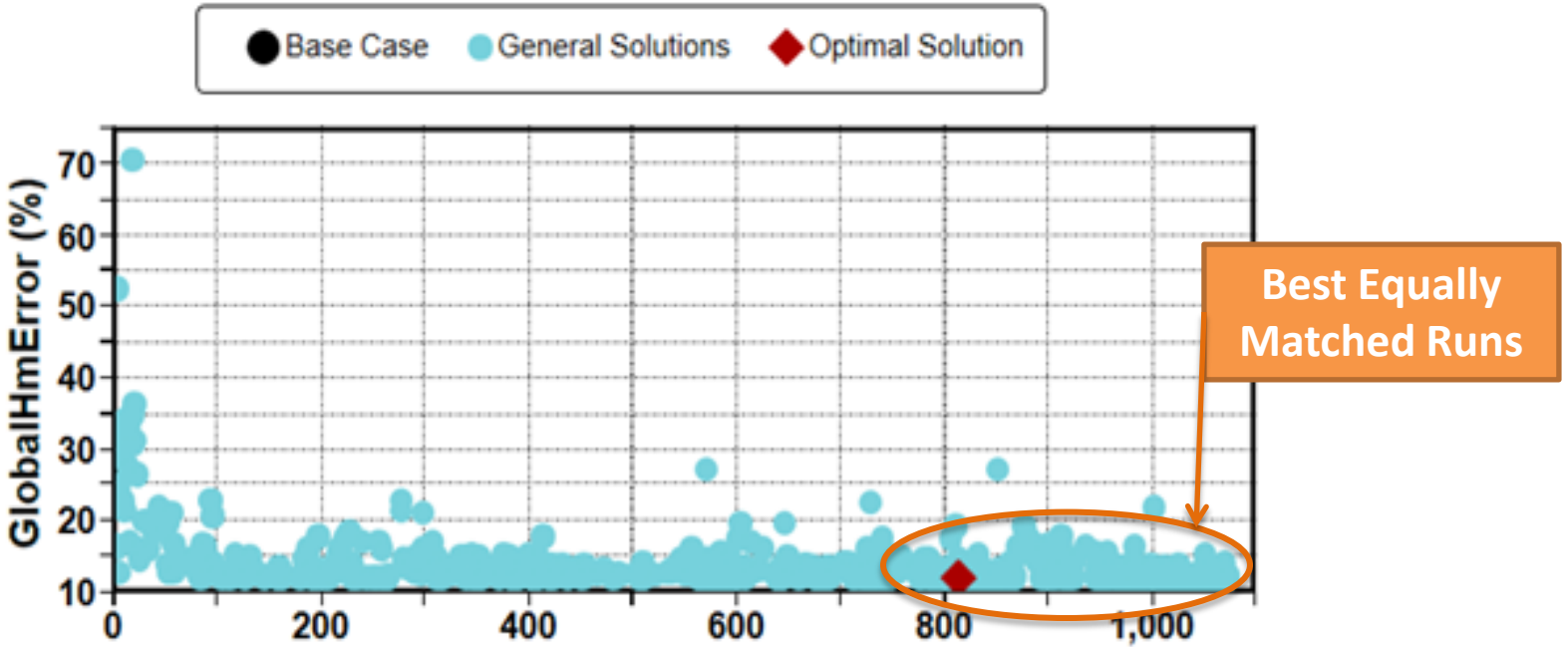


FLOWBACK SINGLE HISTORY MATCH – NUMERICAL MODEL



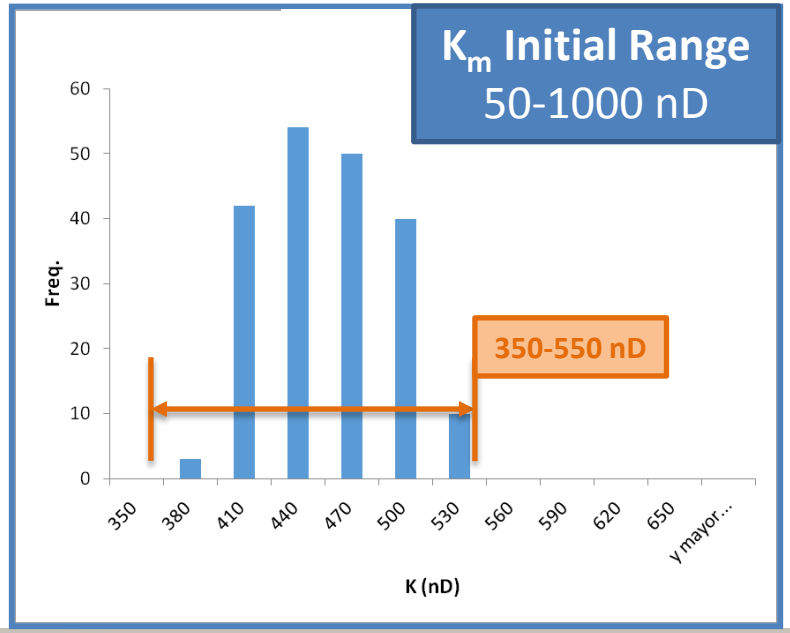
HISTORY MATCH OPTIMIZATION

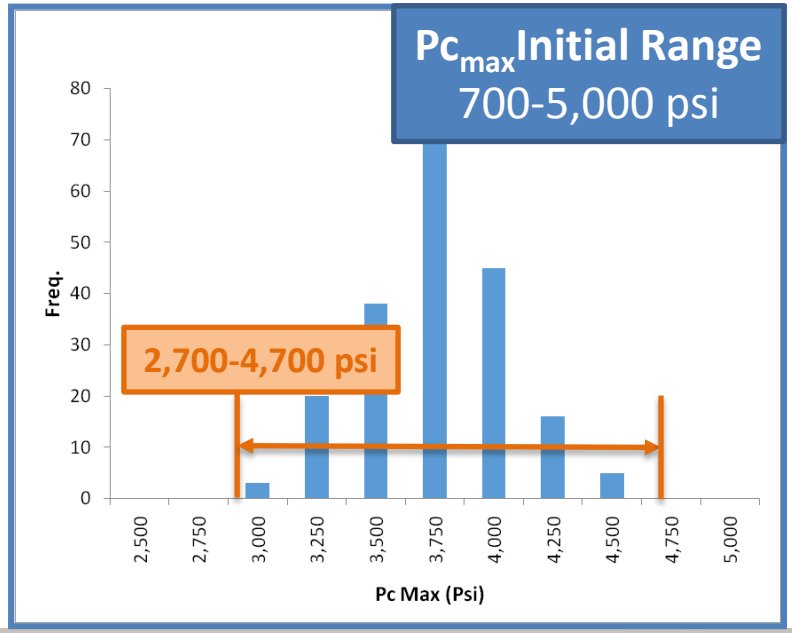
- Selection of 200 best “equally match” runs to explore ranges



HISTORY MATCH OPTIMIZATION

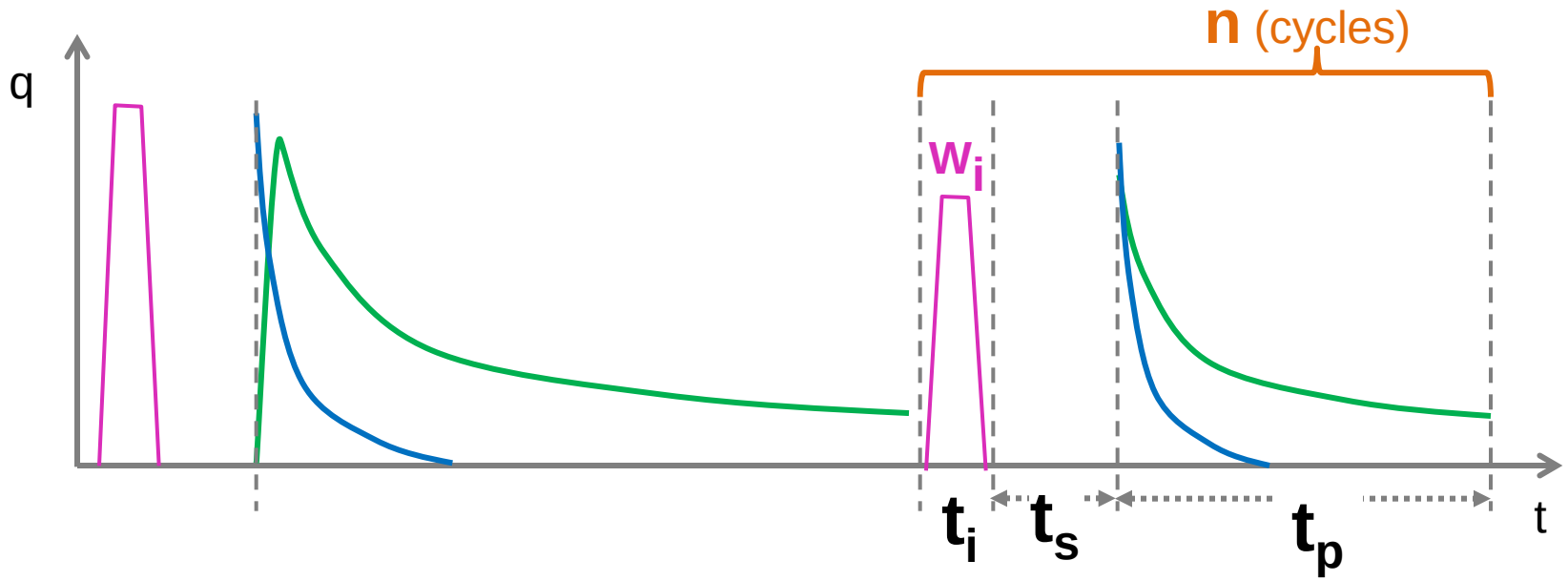
- Parameters adopted by the best 200 matched runs





PROPOSAL – DESIGN AND OPTIMIZATION

- Optimize Treatment Parameters to improve Field Test
- Quantify Expected Incremental Oil (Incremental EUR vs Base Case)



PROPOSAL – DESIGN AND OPTIMIZATION

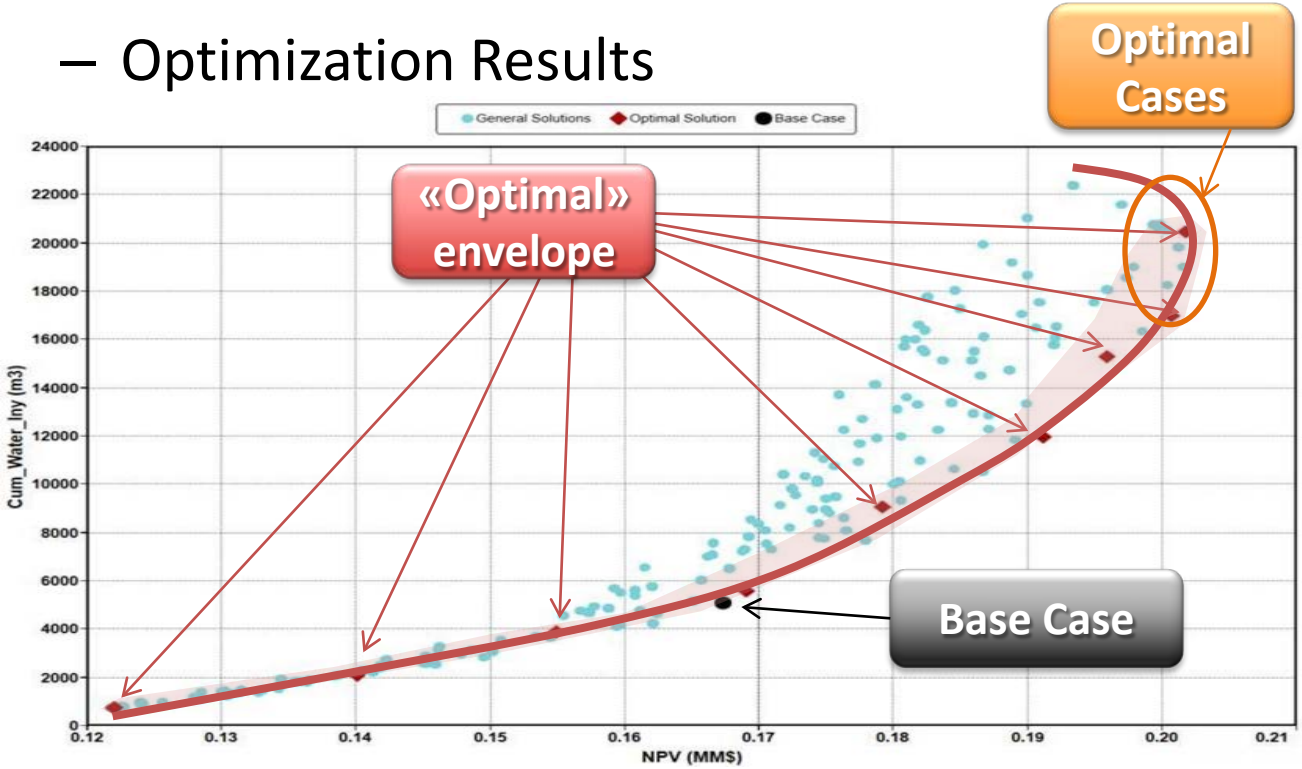
- Variables and Ranges

Parameter	N (cycles)	Qinj (m3/d)	t_{prod} (dias)	$t_{iny+Soak}$ (days)
Max	3	10	200	5
Min	15	100	700	90

- Objective Function To Maximize
  - NPV (Net Present Value) assuming 40 u$s/bbl and 5 us$/bbl cost of water injection, 10% rate and 20 yrs of production
  - 200+ runs
  - Optimization (using Particle Swarm Optimization)

PROPOSAL – DESIGN AND OPTIMIZATION

– Optimization Results



Average Optimal Parameters

N = 15 cycles

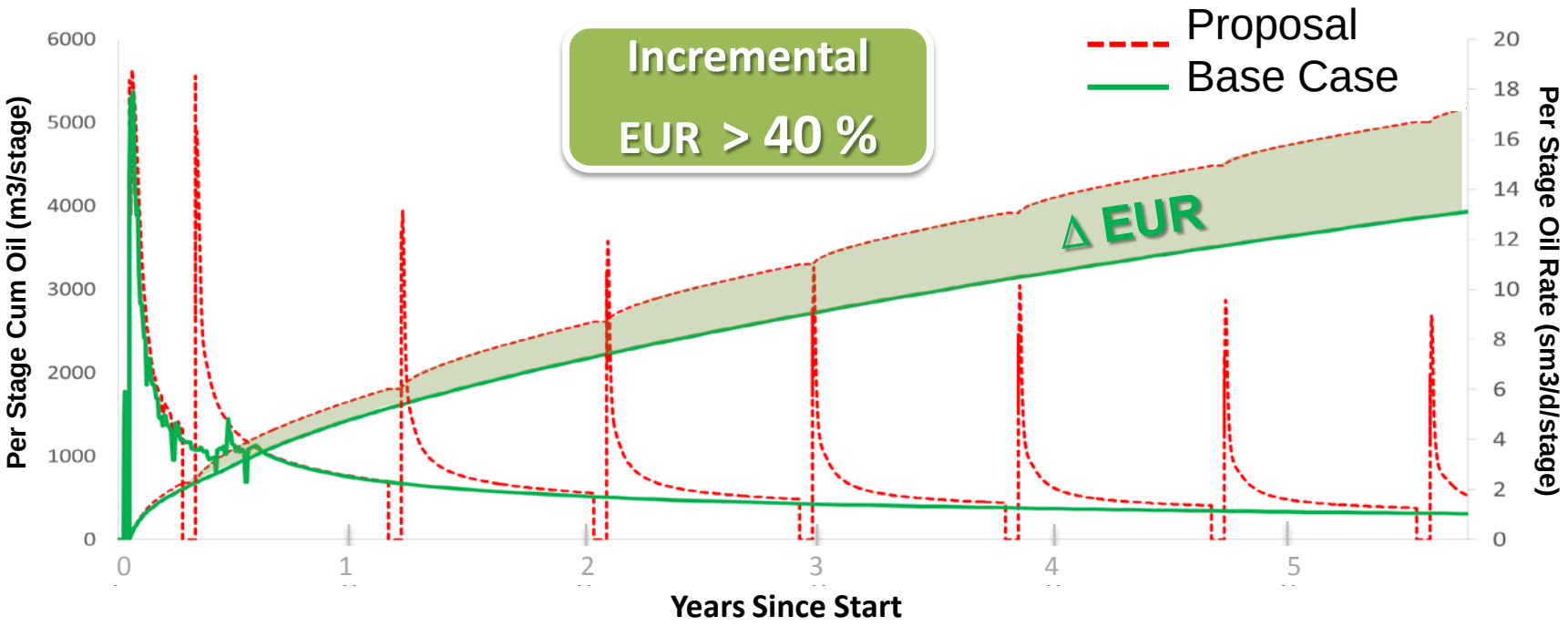
Qiny = 63 m3/d

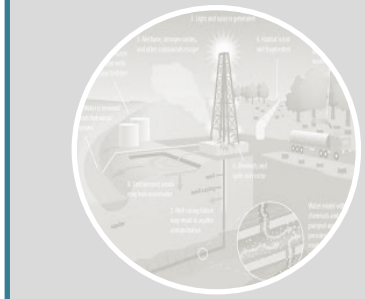
Tp = 210 days

$T_{iny+soak}$ = 33 days

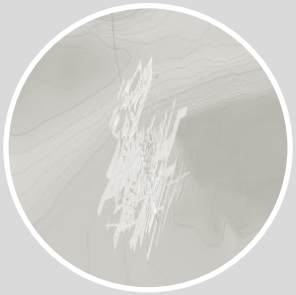
PROPOSAL – RESULTS

– Substantial Incremental Recoveries Expected





Conceptual



Theoretical

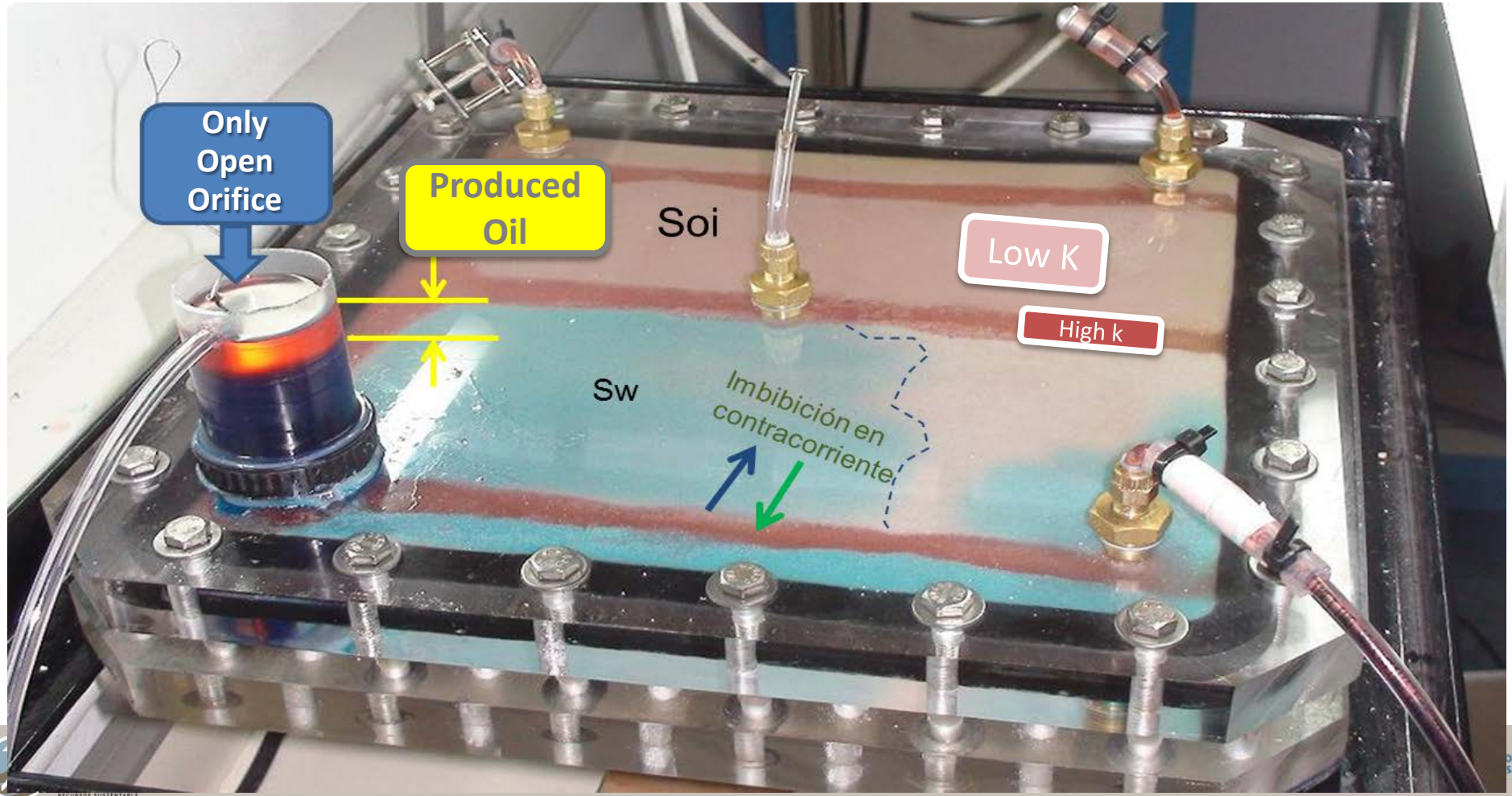
Experimental

EXPERIMENTAL MODEL

- **Lab** (using real Vaca Muerta Rock and Fluids)

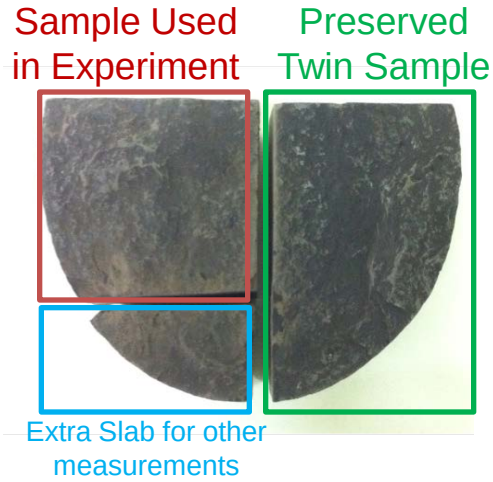
- **Field Tests**

Conceptual Model Tested in Glass Beads Cell



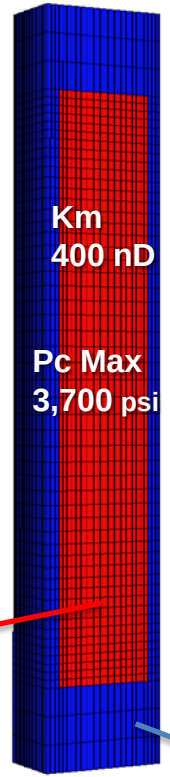
EXPERIMENTAL MODEL (LAB)

- **Core Analysis Procedure**
  - An experimental methodology was designed to test spontaneous imbibition in 3 full diameter Vaca Muerta core samples

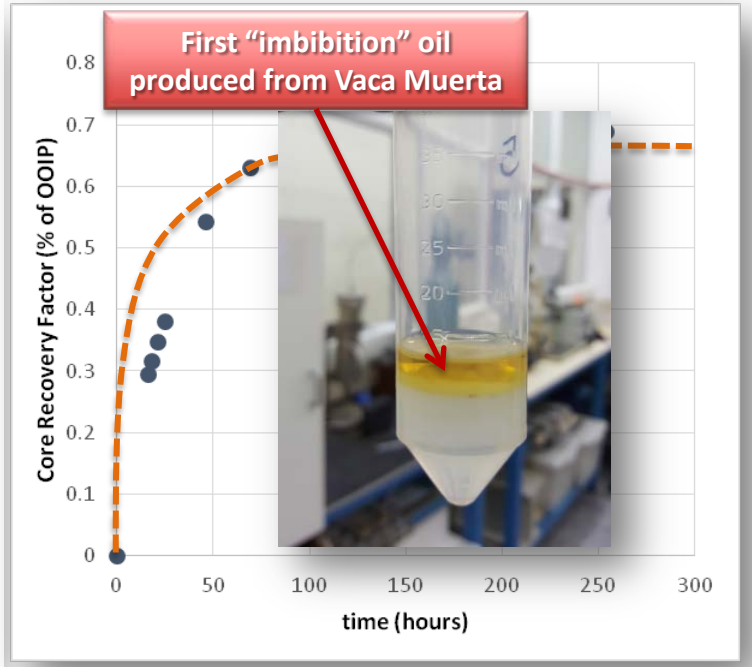


EXPERIMENTAL MODEL (LAB)

- **Core Analysis Results**
  - Recovered **exceeded 60%** of OOIP in less than **120 hours**
  - Same rock-fluid parameters as the well numerical model (Pc, Km and Rel Perms)
  - produced a satisfactory match



Core Model



Core Holder Model

EXPERIMENTAL MODEL

- **Core Analysis Conclusions**
  - Substantial recoveries in all samples ***(EURs > 60% of the OOIP)***
  - Results are extremely promising vs. primary drainage
  - But….Lab conditions may differ from real field experiments

EXPERIMENTAL MODEL

- **Lab** (using real Vaca Muerta Rock and Fluids)

- **Field Tests**

EXPERIMENTAL MODEL

- **Field Tests**
  - Undocumented experiences in Vaca Muerta (one well)
  - Poorly documented EOR experiences in the Bakken, US

"…Too few data exist for the six injection tests performed in the Bakken to perform thorough engineering and geologic analysis, nor are the designs or test objectives fully understood…"

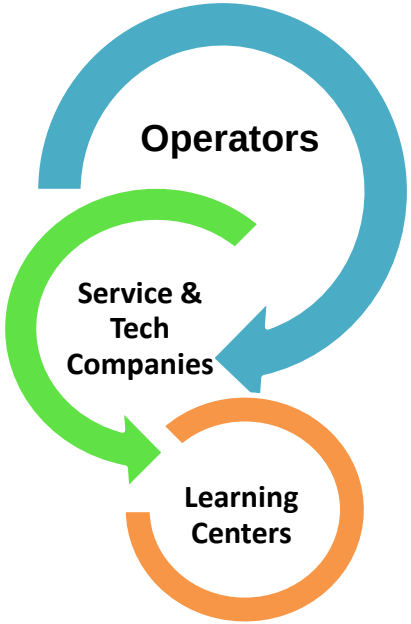
Source: "Enhanced Oil Recovery (EOR) in Tight Oil: Lessons Learned from Pilot Tests in the Bakken", Sorensen J. Energy & Environmental Research Centre, 2015.

EERC Energy & Environmental Research Center

EXPERIMENTAL MODEL

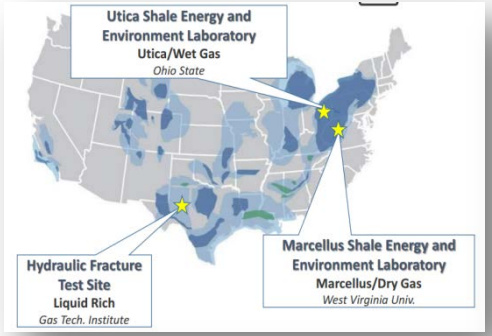
- **Field Tests → NEXT STEPS**
- We are on the verge of producing a properly desigend field test in Vaca Muerta (oil window)
- These results will provide invaluable insight to pursue this potential ***"game changing"*** task…

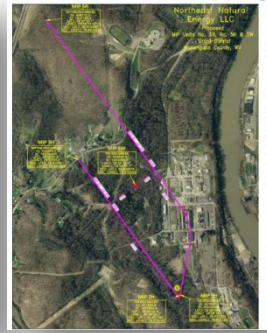
WHO will take the challenge?

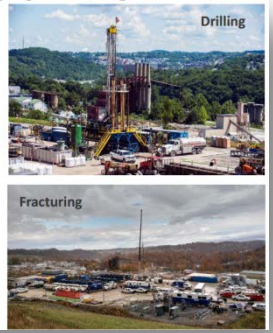


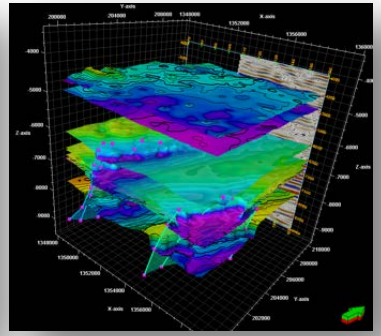
Unconventional Resource Development EOR Workshop, Austin Oct 12-13, 2016

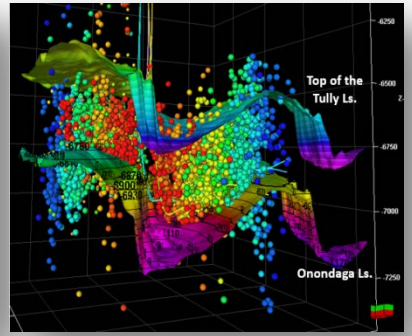
Field Observatories

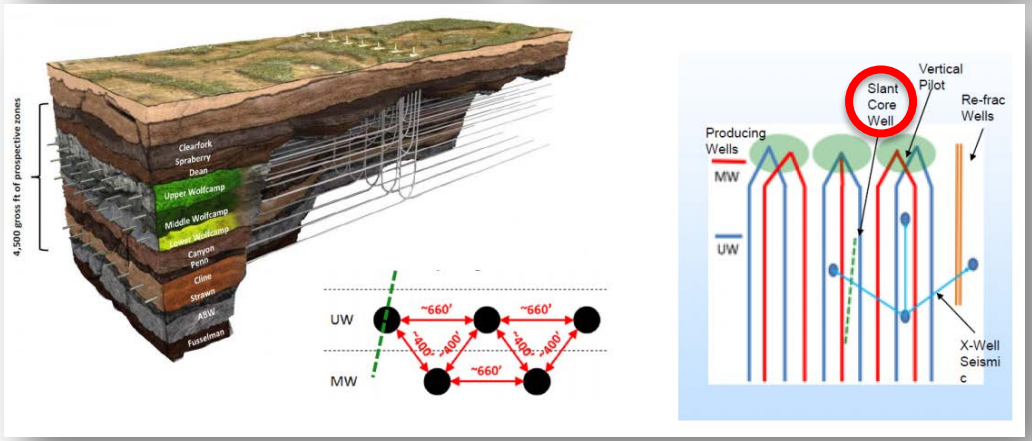












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Juan Di Nucci and Alexis Airala (VYP Consultores SA)

Preguntas?

....demasiadas quizas?

IMPLICATIONS of CONCEPTUAL MODEL

- Additional Benefits:
  - Production above the bubble point (no depletion → decrease spacing?)
  - Having access to the full extent of these “2D reservoirs” opens a huge potential for additional chemical stimulation (acids?)
  - Cyclic injection could use paraffin deposition reducers (additives?)
  - Reduction in costs and footprint due to re-usage of flowback water.

IMPLICATIONS of CONCEPTUAL MODEL

- We believe we are Pessimistic in our estimates as we did not consider:
  - Water adsorption in clay minerals
  - Effect of microfractures generates greater surface to imbibe onto
  - Osmotic potential may increase → depending on salinities of fluids
  - Direction of imbibition paralel to bedding planes
  - Surfactants