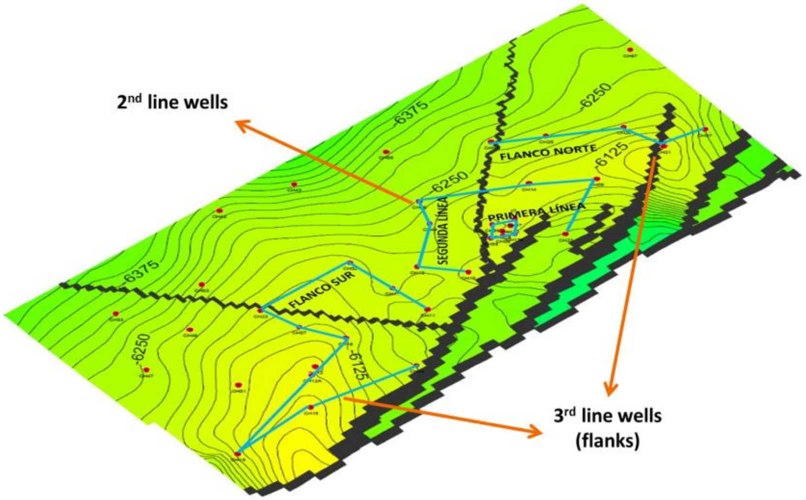
# Posibilidades y Retos para la Combustión in Situ en Colombia

*Universidad Nacional de Colombia*
*Facultad de Minas*
*2017*



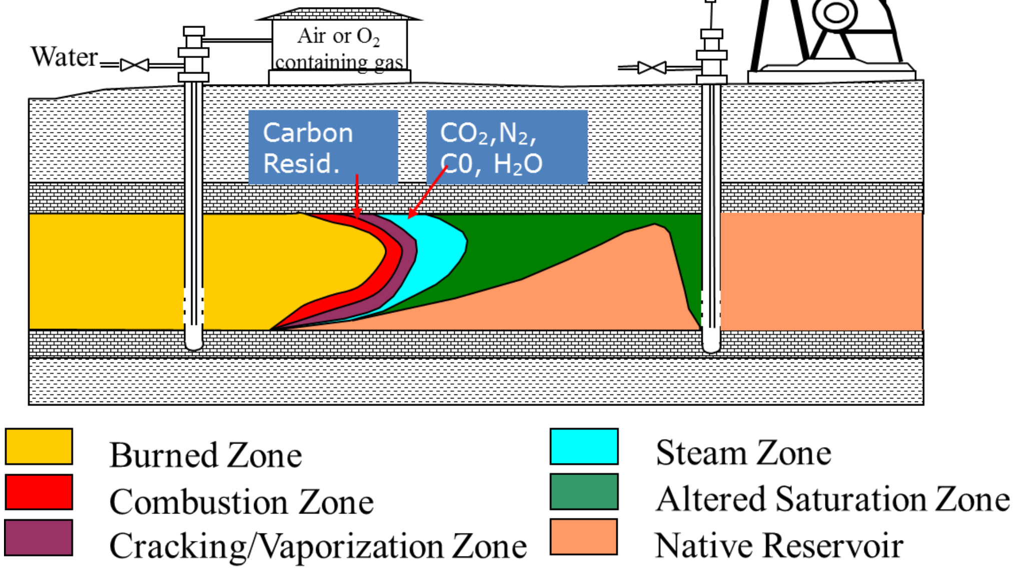


Eider Niz Velásquez
Líder de área de conocimiento EOR, ICP


ecopetrol

# Outline

- In situ Combustion
- The Chichimene ISC Pilot
  - History
  - Current Status
- Laboratory Studies
- Nitrogen Conectivity Test
- Challenges and Future Activities



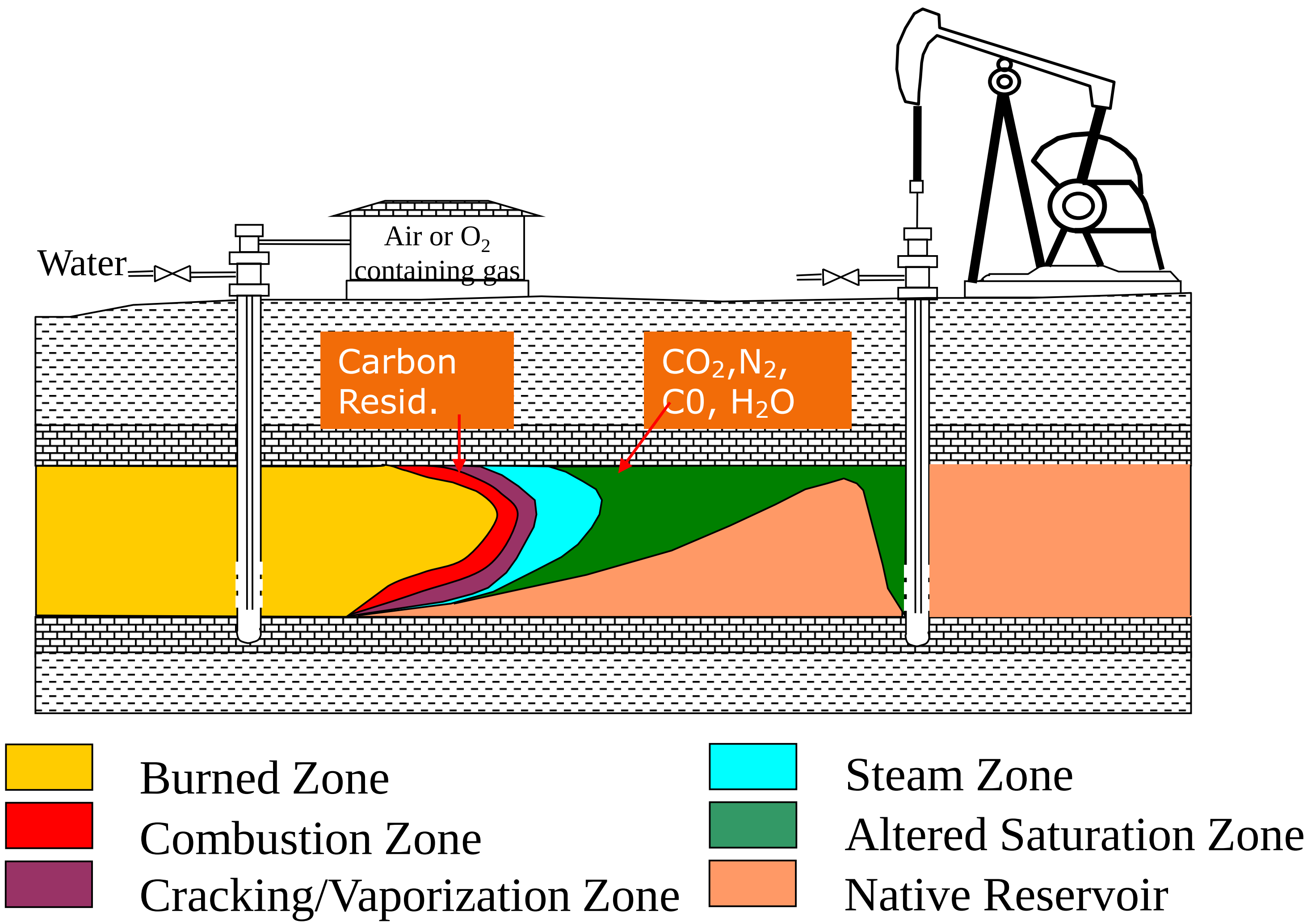

# COMBUSTIÓN IN SITU

# *In-Situ* Combustion

**Inject Air or Oxygen**

- Advantages:
  - Heat generated in-situ
  - No surface/wellbore heat losses
    - Fewer limitations on depth
  - Not dependent on latent heat
    - Fewer pressure constraints
  - Fuel used is residual OIP (usually 5 – 10% of OIIP is consumed)
  - Not dependent on water source
  - Applicable to thin reservoirs
- Disadvantages:
  - Difficult to control
  - Can result in well loss or damage
  - Produces combustion products
    - $N_2$, $NO_x$, if air is injected
    - $CO_2$
    - Various environmentally-unfriendly products
  - HSE risk if $O_2$ breaks through (auto-ignition risk if $O_2$ > 9 mole%)
  - HSE risk – air compression
  - Gas treatment of produced solution gas mixed with flue gases

# "Classical" In Situ Combustion Process Schematic



# Propiedades de Yacimiento – Principales Proyectos

| Campo, País | Formación | Buzamiento | Profundidad (ft) | Temperatura de yacimiento (°F) | Espesor neto (ft) | Porosidad (%) | Saturacion de Agua irreducible (%) | Saturación de aceite al inicio CIS (%) | Permeabilidad (mD) |
|---|---|---|---|---|---|---|---|---|---|
| Suplacu de Barcau, Rumania | S | 5- 8 | 115-720 | 65 | 20- 89 | 32 | 15 | <85 | 5000-7000 |
| Balol, India | S | 4-7 | 3280 | 158 | 9-50 | 28 | 30 | 70 | 3000-8000 |
| Santhal,India | SS | 3-5 | 3280 | 158 | 9-50 | 28 | 30 | 70 | 3000-5000 |
| Bellevue, Lousiana, USA | SS | 0-5 | 400 | 75 | 10-83 | 32 | 27 | 73 | 650 |

| Campo, País | Viscosidad del crudo (cp) | Gravedad (°API) | P inic/ P. inicio CIS (psi) | OOIP (MMbbl) |
|---|---|---|---|---|
| Suplacu de Barcau, Rumania | 2000 | 16 | 140 / 80 | 310 |
| Balol, India | 100-450 | 16 | 1450 /1450 | 128 |
| Santhal,India | 50-200 | 18 | 1450 /1450 | 300 |
| Bellevue, Lousiana, USA | 676 | 19 | / 40 | 4.6 ;10.6 |

Fuente: TURTA A, et al. Current status of comercial in situ combustion projects worldwide. Journal of Canadian petroleum technology.

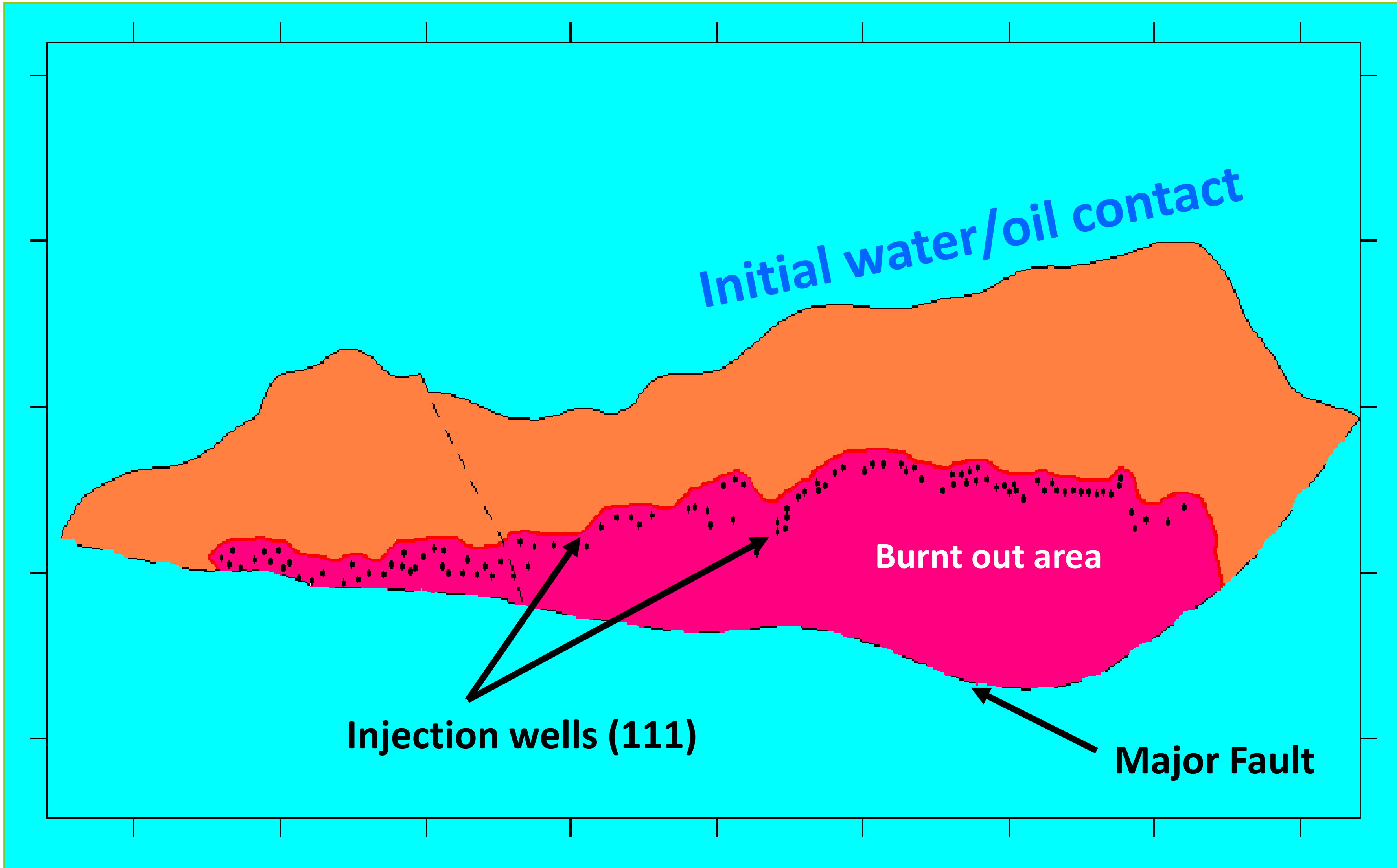
# Resultados de los Principales Proyectos

| Campo, País | Fecha (inicio de operación ) | Presión inyección (psi) | N de pozos inyectores | N de pozos productores | Producción diaria con ISC (Bbl/día) | Corte de agua (%) | Utilización de $O_2$ (%) | Relación aire/crudo (scf/bbl) | Recobro esperado de crudo (%) |
|---|---|---|---|---|---|---|---|---|---|
| **Suplacu de Barcau, Rumania** | 1971 | 150- 200 | 111+ | 736+ | 9000++ | 82 | 95 | 14000 | 52 |
| **Balol, India** | 1997 | 1300- 1600 | 30 | 75 | 4400 | 60 | >95 | 5600 | 38 |
| **Santhal,India** | 1997 | 1200-1500 | 30 | 105 | 4000 | 60 | >95 | 5600 | 36 |
| **Bellevue, Lousiana, USA** | 1970 | 60 | 15 | 90 | 300 | 90 | 80 | 15000 | 60 |

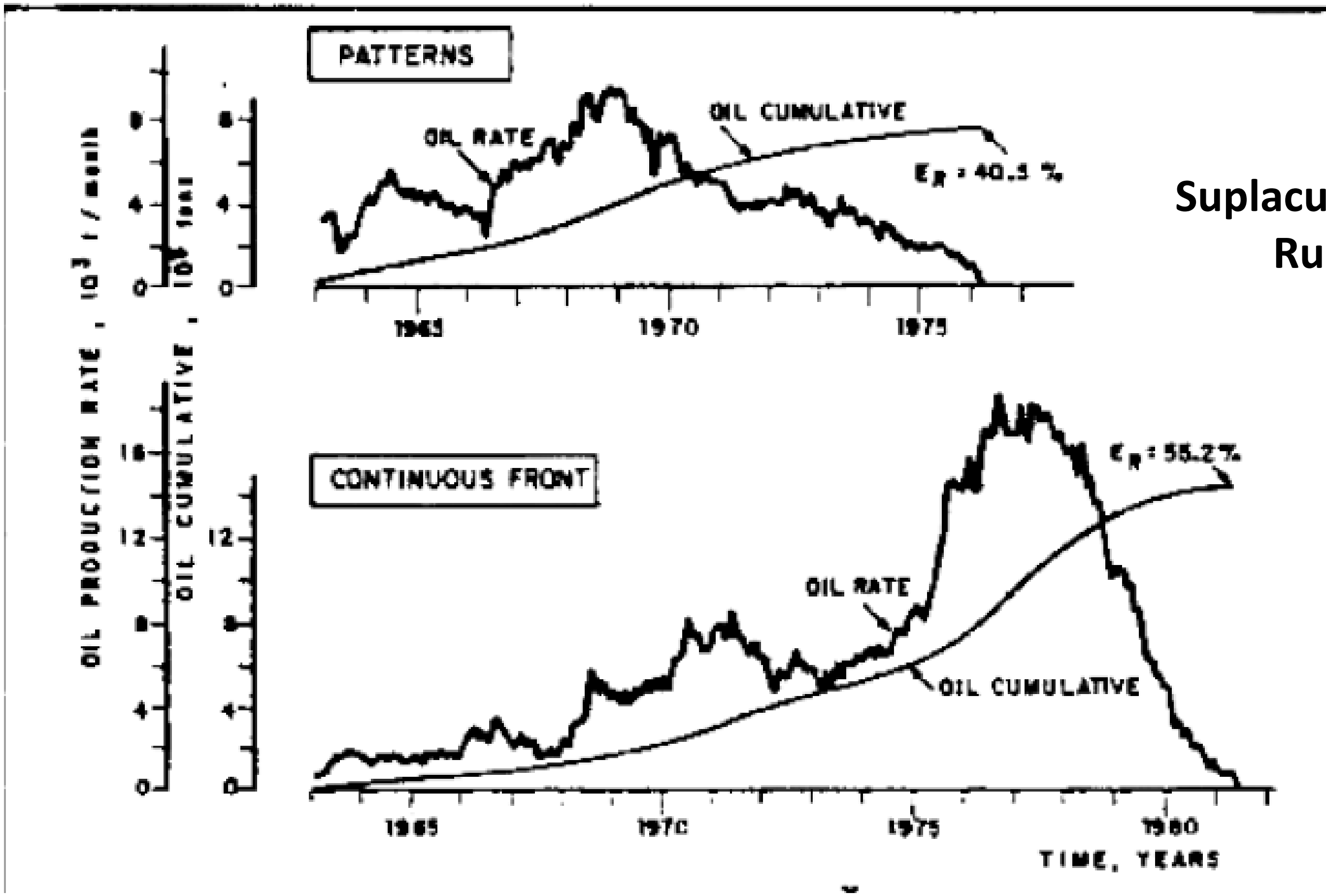
+ 24 de los pozos fueron estimulados bajo inyección cíclica de vapor (CSS)

Fuente: TURTA A, et al. Current status of comercial in situ combustion projects worldwide. Journal of Canadian petroleum technology.

# Suplacu de Barcau. Position of the combustion front as of July 1st, 2004



# Patterns bad line drive good




Suplacu de Barcau, Rumania

# Suplacu: Essential Results/Problems

## Results

- Ultimate oil recovery: >50%
- AOR in the range of 6,000 to 18,000 scf/bbl(1,000 – 3,000 $sm^3/m^3$ ), increasing in time
- At the low inj. presure., even the AOR of 18,000 scf/bbl is economical
- Water cut increased slowly, up to 82%

## Operational Aspects

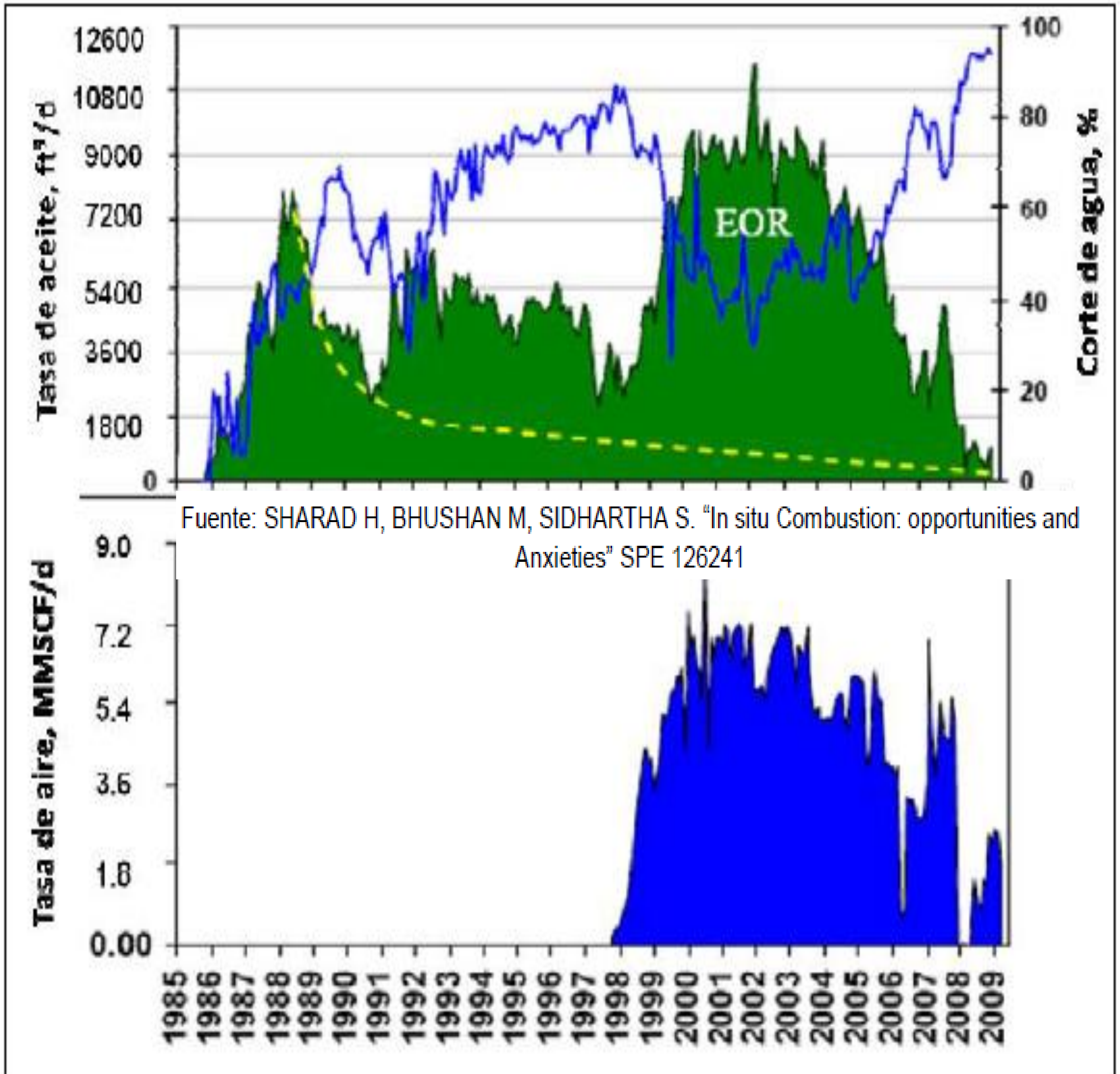
- Burning out of some producers
- Hot well workover challenges; special killing drilling mud needed
- Dehydration/desalting coupled with a stripping unit for processing of crude oil
- Leakage to the surface of some combustion gases/air

# Balol and Santhal - Reservoir Properties

| Field | Depth<br>ft | Gross pay<br>ft | Oil viscosity<br>mPa.s | Permeability<br>mD | Res. Pressure<br>Initial / @ start of ISC<br>(psi) | Observations |
|---|---|---|---|---|---|---|
| Suplacu de Barcau | 115-720 | 27-290 | 2,000 | 5,000-7,000 | 140/80 | |
| **Balol** | **3280** | **10-95** | **100-450** | **3,000-8,000** | **1450/1450** | Very strong edge water drive |
| **Santhal** | **3280** | **16-195** | **50—200** | **3,000-5,000** | **1450/1450** | |
| Bellevue | 400 | 70/30 | 676 | 650 | /40 | |

* Coal and carbonaceous material is present in the formation; sulphur content: 0.14

# Desempeño del Campo Balol



Fuente: SHARAD H, BHUSHAN M, SIDHARTHA S. "In situ Combustion: opportunities and Anxieties" SPE 126241

# Balol & Santhal: Results/Problems

## Results

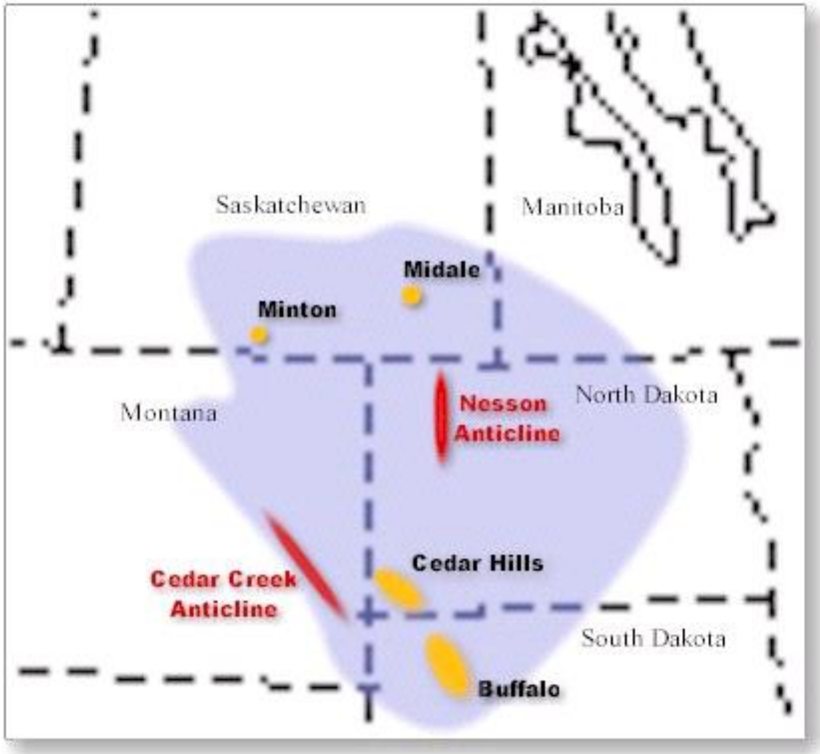
- Ultimate oil recovery: >36%
- AOR 5,600 scf/bbl (1,000 $sm^3/m^3$)
- High inj. presure: 1,500 psi ( 10.3 MPa)
- Average water cut: reduced from 70%-90% to 5-20%, due to ISC application (in some cases)
- Spontaneous ignition used for ISC initiation

## Operational Aspects

- Hot well workover challenges;
- Some $H_2S$ is present in combustion gases, which are flared in tall flare stacks with outside make-up gases
- Challenges of operating separately two layers in the same stack

# HPAI: Reported field applications

***Williston Basin***




*www.northrim.sk.ca*

•**Medicine Pole Hills Unit (MPHU)**
Secondary HPAI
Air injection started in 1987

•**Buffalo Red River Unit (BRRU)**
Secondary HPAI
Operations started in 1979

•**Horse Creek Field**
Secondary Air Injection started in 1996
Some published results

Others:

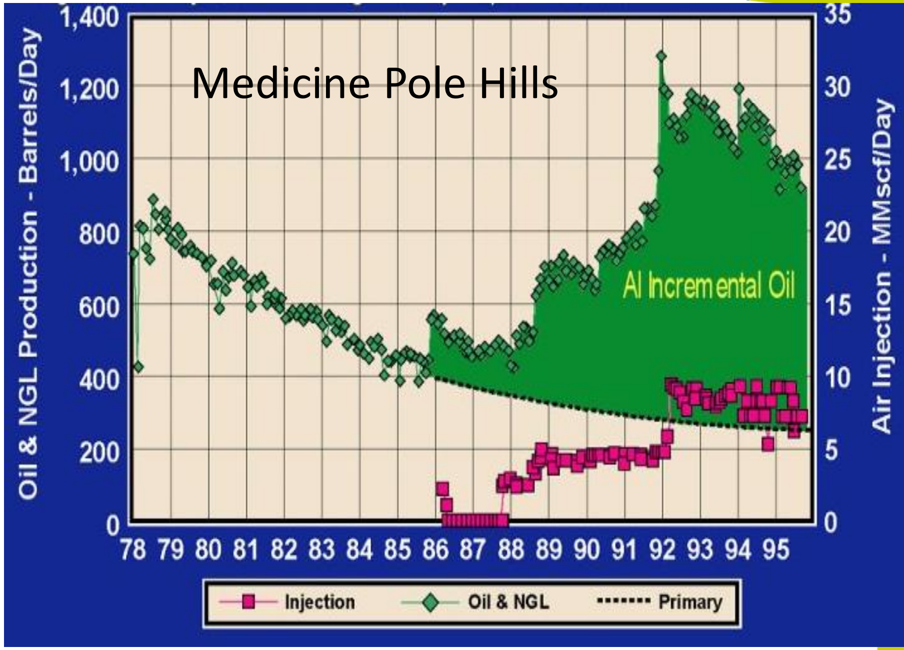
•**West Hackberry Field** - Louisiana
Tertiary Pilot in 1996

•**Handil Field - Indonesia**
Recent HPAI Pilot (2001)

•**Barrancas Field** - Argentina (2005)

# HPAI = High Pressure Air Injection in Williston Basin

- Tight limestone / dolomitic limestone
- Net Pay 10-18 ft
- Porosity 15-20%
- Sw around 50%
- Permeability 10 mD
- Reservoir pressure 3600 psi




Why Air injection?

- Water injectivity low (low perm, low water rel.perm) – needs high well density
- Air is cheap
- HPAI = flue gas drive (thermal contribution to RF is <25%)
- RF 18% on 160-320 Acre spacing

# Cuenca Williston (EE.UU.): Petróleo Liviano

| | Medicine Pole Hills | Buffalo Red River | Horse Creek |
|---|---|---|---|
| Formación | Red river | Red river | Red river |
| Zona productora | B y C | B | D |
| Profundidad | 9500 | 8450 | 9125 |
| Porosidad Promedio | B 19%, C 15% | 20% | 16% |
| Permeabilidad Promedio | B y C 5 md | 10 md | 10 y 20 md |
| Net pay promedio | 18 | 10 | 20 |
| GOR SCF/STB | 525 | 120 | 205 |
| Saturación de agua promedio | B 37%, C48% | 45% | 35% |
| Temperatura de yacimiento °F | 230 | 215 | 220 |
| Presión inicial de yacimiento psi | 4120 | 3600 | 4000 |
| Gravedad API | 39 | 30 | 32 |
| OOIP | 40,000,000 | 37,000,000 | 45,740,260 |
| Factor de recobro primario % | 15 | 5.95 | 9.92 |
| Factor de recobro incremental % | 14.25 | 15.67 | 16.62 |
| Factor de recobro total % | 29.25 | 21.62 | 26.53 |

Fuente: paper spe 38359

# Field Case: HPAI vs Waterflood

| TABLE 10 – INCREMENTAL RECOVERY (1988 – 2005) | | | | | | |
|---|---|---|---|---|---|---|
| | WBRRU | | | WBBRRU | | |
| Year | Prim. (STB) | AI (STB) | Incr. (STB) | Prim. (STB) | WF (STB) | Inc. (STB) |
| 1988 | 60,992 | 102,986 | 41,994 | 61,868 | 50,118 | (11,750) |
| 1989 | 53,796 | 146,187 | 92,391 | 52,785 | 49,441 | (3,344) |
| 1990 | 46,623 | 159,297 | 112,674 | 43,508 | 51,679 | 8,171 |
| 1991 | 37,234 | 170,067 | 132,833 | 37,339 | 54,045 | 16,706 |
| 1992 | 31,906 | 158,013 | 126,107 | 30,525 | 57,660 | 27,135 |
| 1993 | 24,851 | 133,579 | 108,728 | 26,411 | 82,661 | 56,250 |
| 1994 | 21,588 | 124,671 | 103,083 | 22,902 | 112,541 | 89,639 |
| 1995 | 16,849 | 118,380 | 101,531 | 18,671 | 117,723 | 99,052 |
| 1996 | 12,238 | 113,839 | 101,601 | 15,133 | 99,958 | 84,825 |
| 1997 | 10,175 | 126,817 | 116,642 | 12,450 | 99,057 | 86,607 |
| 1998 | 9,269 | 122,165 | 112,896 | 10,914 | 86,225 | 75,311 |
| 1999 | 7,301 | 110,171 | 102,870 | 8,440 | 81,695 | 73,255 |
| 2000 | 4,831 | 98,869 | 94,038 | 6,915 | 79,282 | 72,367 |
| 2001 | 3,264 | 102,025 | 98,761 | 4,461 | 75,966 | 71,505 |
| 2002 | 2,100 | 94,550 | 92,450 | 2,946 | 73,102 | 70,156 |
| 2003 | 1,949 | 87,907 | 85,958 | 2,079 | 68,653 | 66,574 |
| 2004 | 0 | 75,140 | 75,140 | 1,920 | 70,522 | 68,602 |
| 2005 | 0 | 136,409 | 136,409 | 0 | 69,759 | 69,759 |
| **TOTAL** | **344,966** | **2,181,072** | **1,836,106** | **359,267** | **1,380,087** | **1,020,820** |
| **RF (%)** | **1.2** | **7.5** | **6.3** | **1.7** | **6.7** | **5.0** |

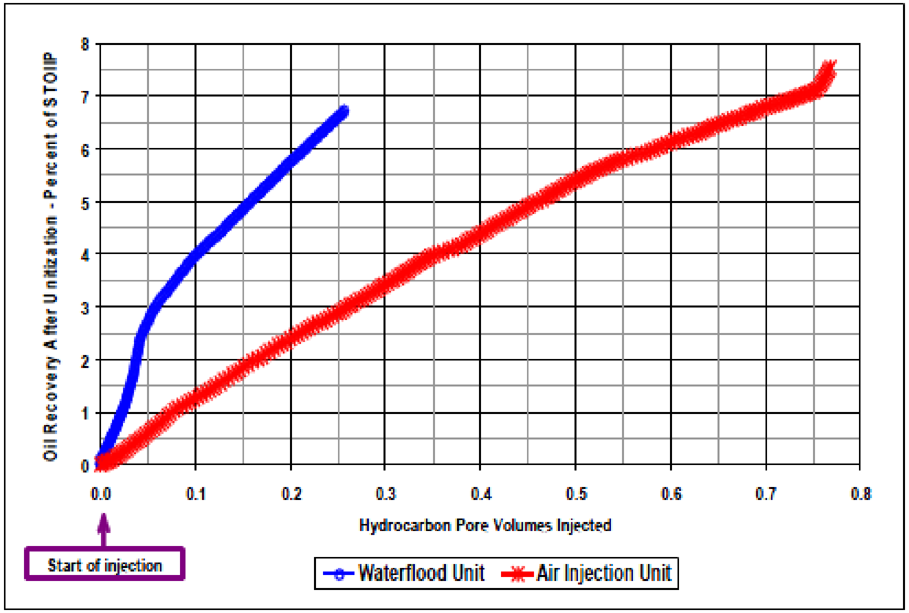


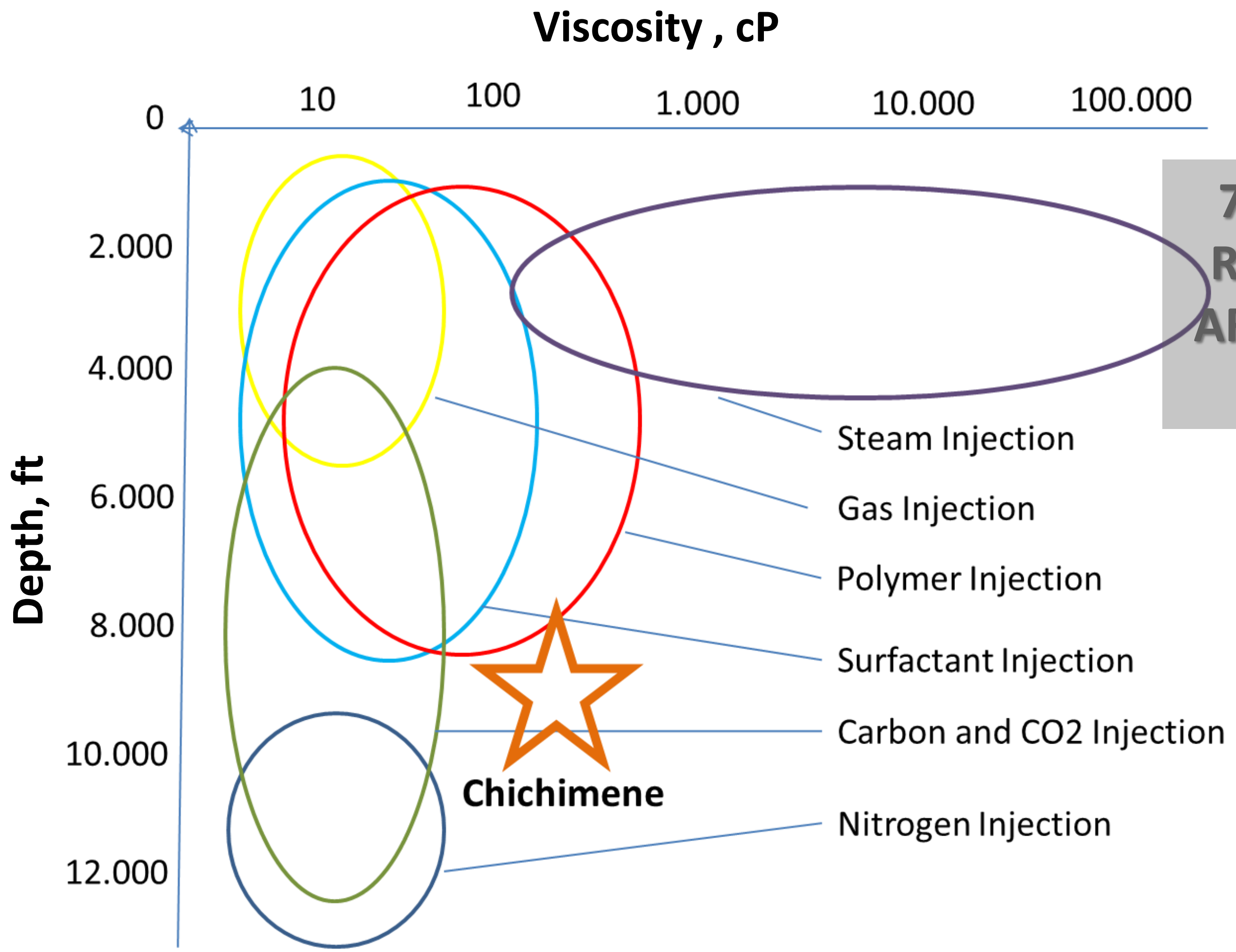

**Fig. 11 Displacing Efficiency**

SPE 99454: Air Injection and Waterflood Peformance Comparison of Two Adjacent Units in Buffalo Field: Technical Analysis

V.K. Kumar, D. Gutiérrez, G. Moore, S. Mehta


# PILOTO DE INYECCIÓN DE AIRE EN CHICHIMENE

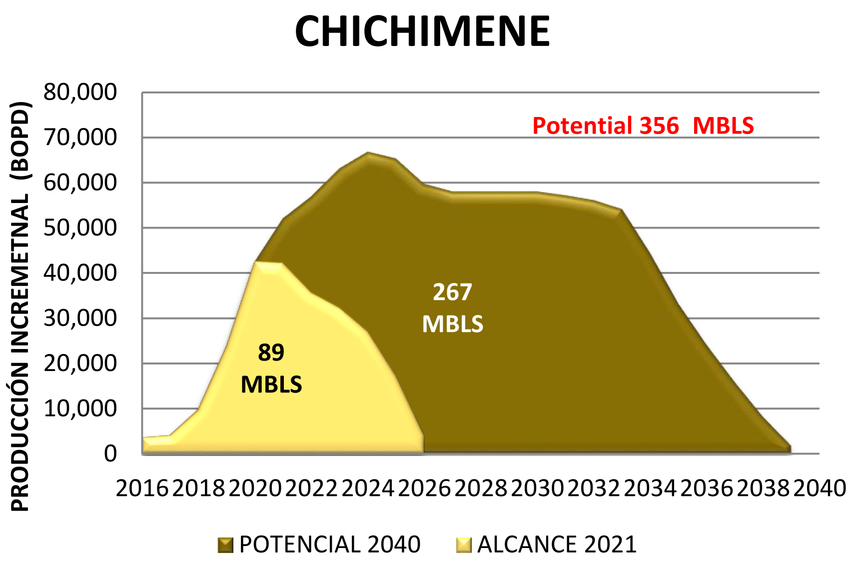
# Why In situ Combustion in Colombia?

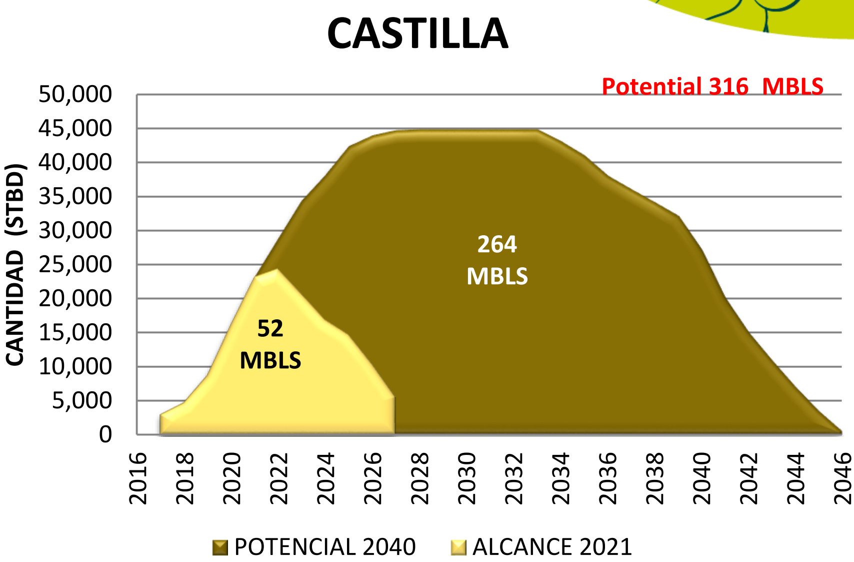


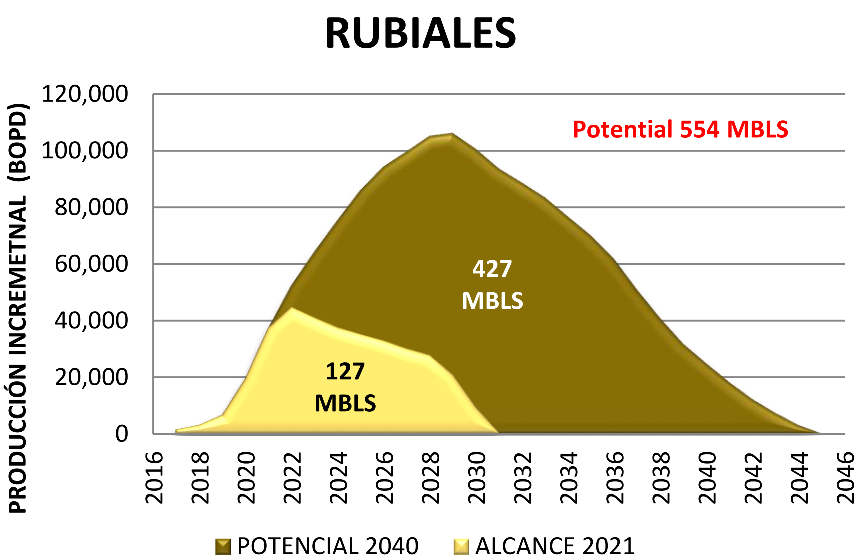

70 % OF THE HEAVY OIL RESERVES IN COLOMBIA ARE LOCATED AT A DEPTH > 6000 FT

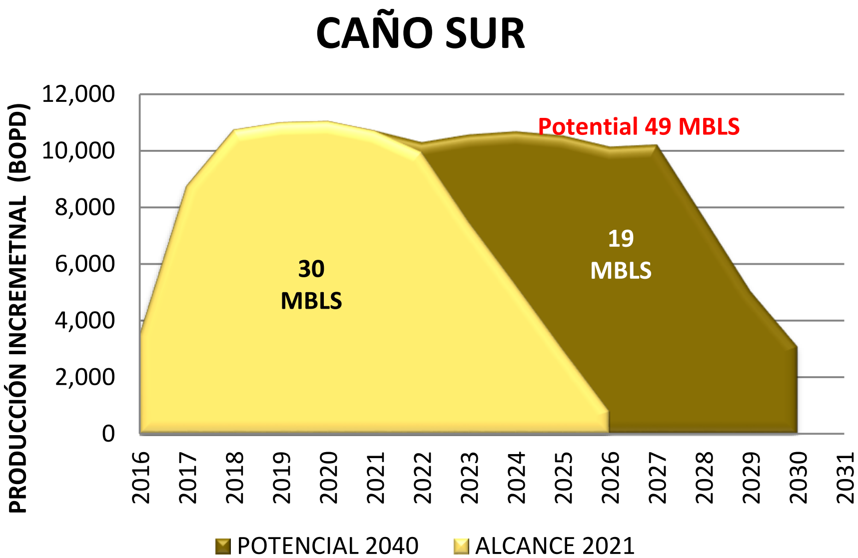
Source: Enhanced Oil Recovery (EOR) Report, Royal Dutch Shell.

# PRODUCTION FORECAST - EXPANSIONS

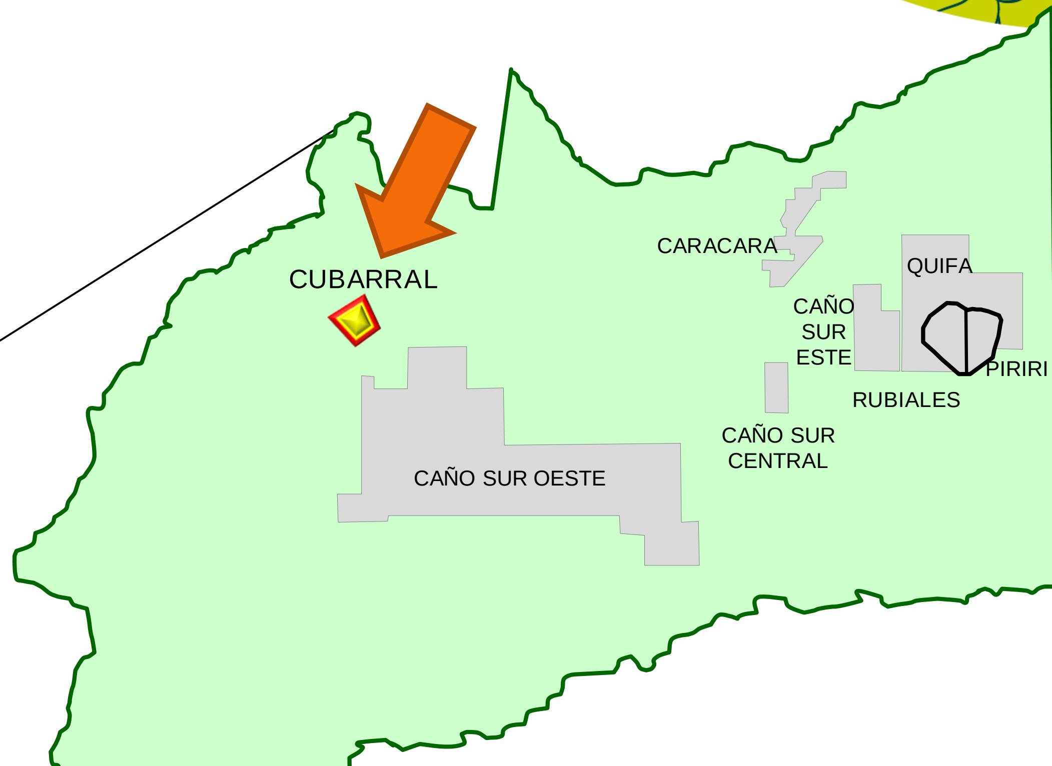


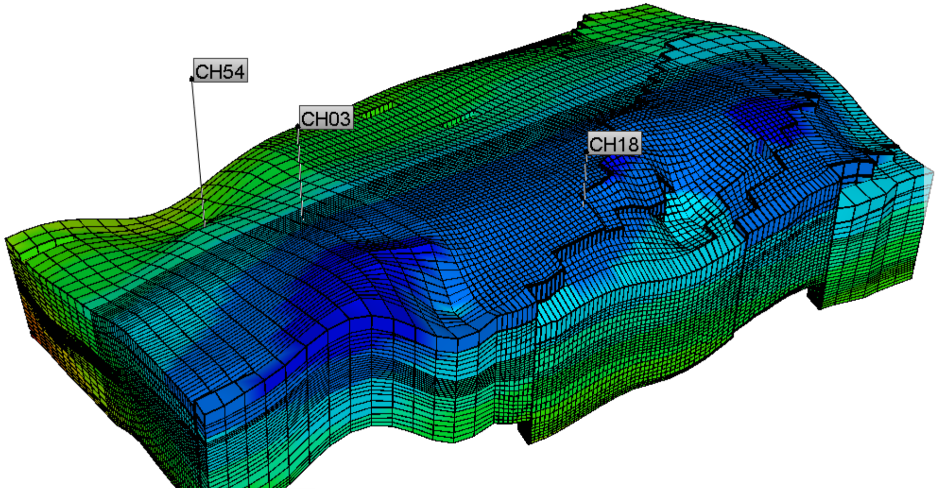



# Chichimene Field


**Discovery:** 1969, Chevron
**Start of Operations:** 1985
**Back to Ecopetrol:** August, 2000
**Current Production:** 80,000 bpd
**Steep Pressure Decline**
**Primary UER≈ 9%**




Allied with world-class strategic partners, Ecopetrol has acquired skills and capacities for ISC physical and numerical modeling for extra-heavy oil reservoirs.

UNIVERSITY OF CALGARY

AT EOR CONSULTING INC
*Alex Turta*

ifp Innovation Energie Environnement

Universidad Industrial de Santander

STANFORD UNIVERSITY

UNIVERSIDAD NACIONAL DE COLOMBIA

BELGRAVE OIL AND GAS CORP.

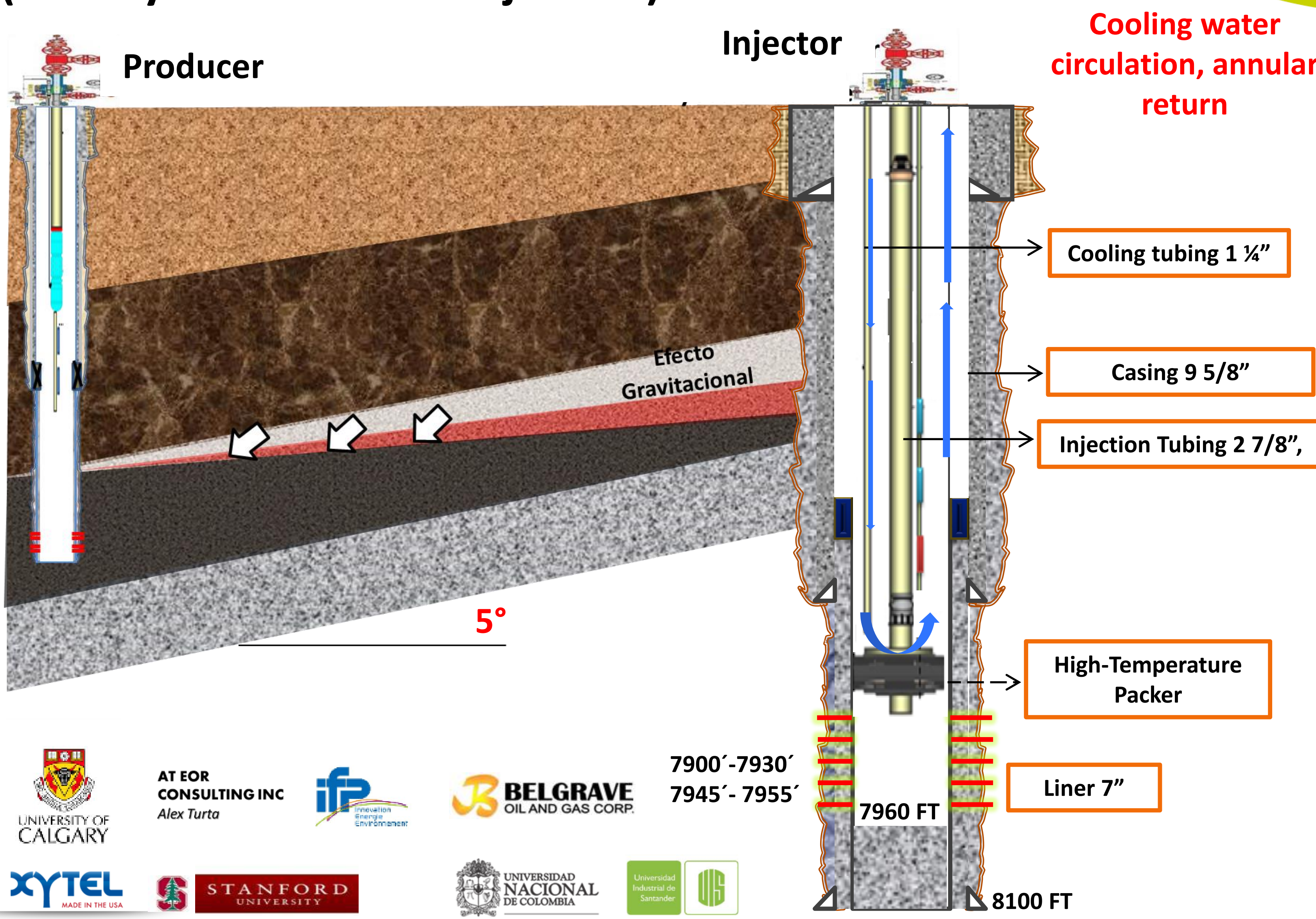
XYTEL MADE IN THE USA

**Combustion Tube Reactor**

**RTO Kinetics Cell**

**Isothermal Cell**

# Eco-GSAI® Pilot Design
## (Gravity-Stabilized Air Injection)

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AT EOR CONSULTING INC
*Alex Turta*

BELGRAVE OIL AND GAS CORP.

XYTEL MADE IN THE USA

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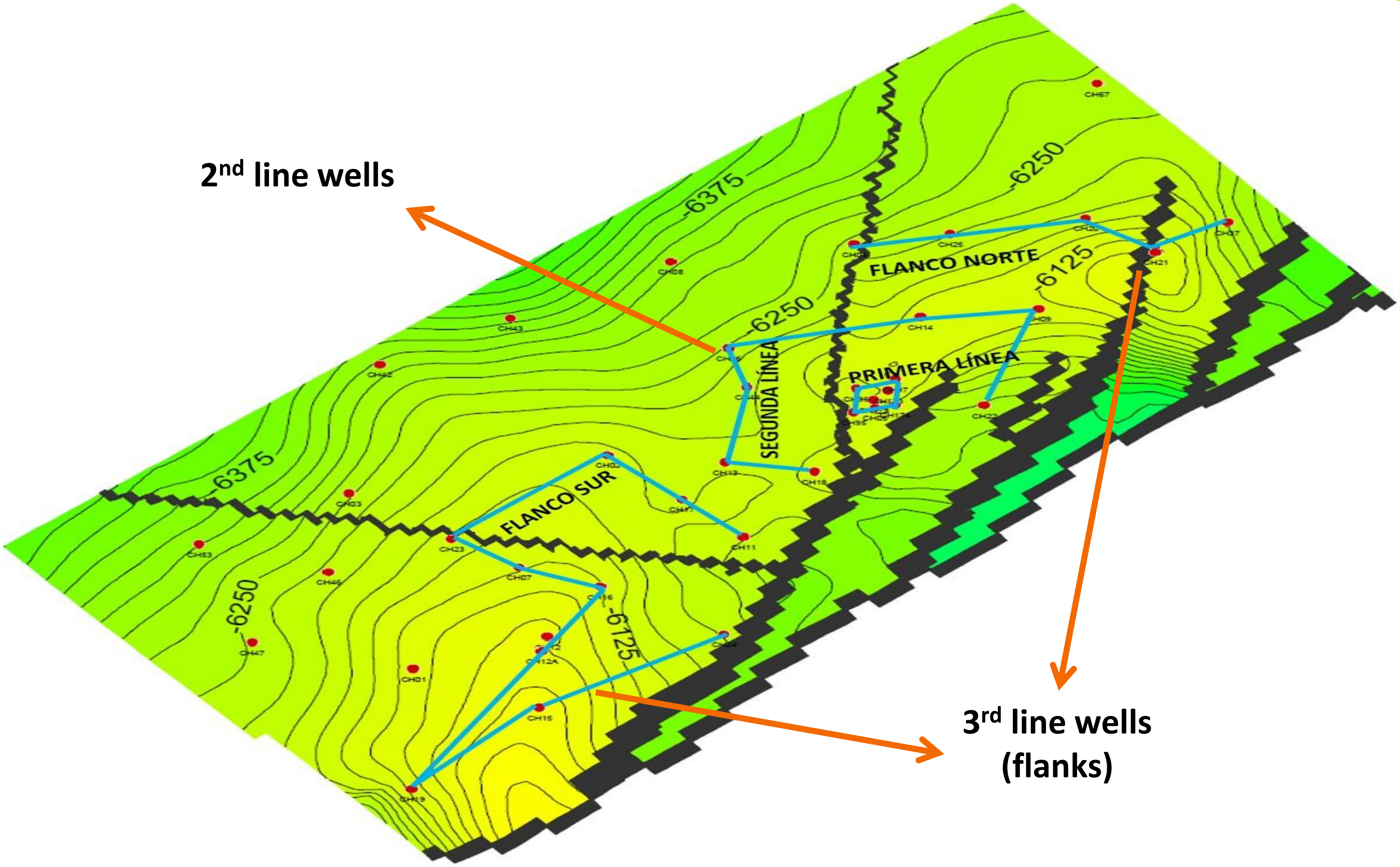
UNIVERSIDAD NACIONAL DE COLOMBIA

Universidad Industrial de Santander

# Pilot Design



# Pilot Premises

- Able to prove the technology concept for deep, extra-heavy oil reservoirs
- Evaluation time of 2 years is sufficient
- Ultimate RF of 35% OIIP is possible

# Project Timeline

2012-2014: Construction of own ISC laboratory and equipment, Pilot detailed design

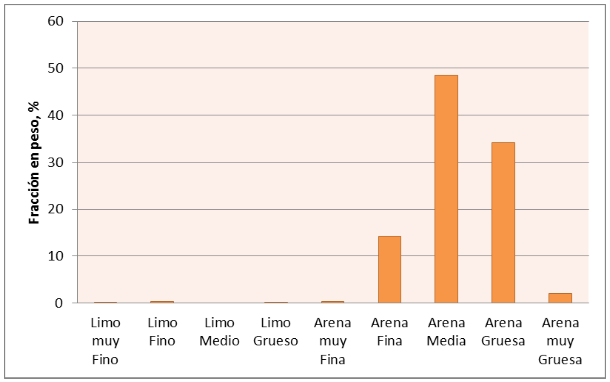
2015-2017: Construction of field facilities, Detailed lab tests, Connectivity test, Ignition

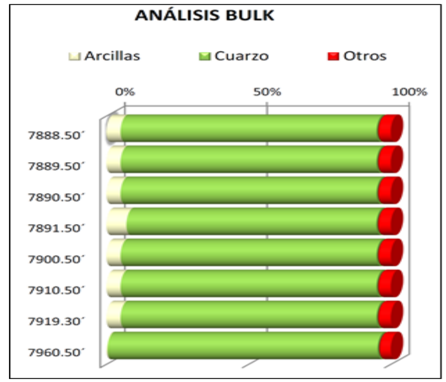
Before 2011: Screening, preliminary lab tests, kinetics model, ISC world survey, People assignment (40+ professionals)

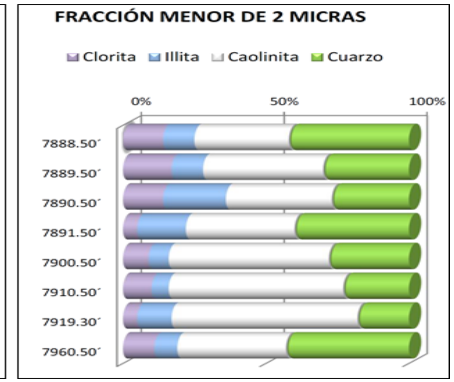
# Reactivity Studies: Core vs. Outcrop

**Particle size distribution** | **Bulk Composition** | **Clay Composition**

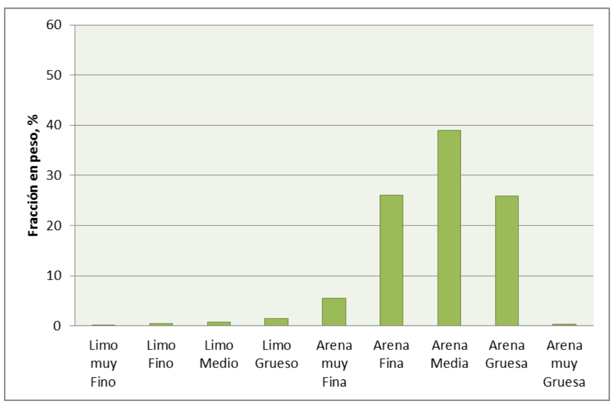
**Core**

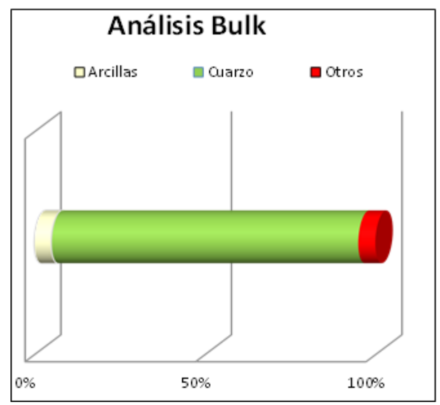


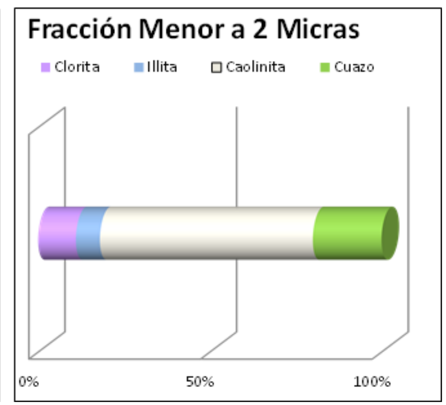




**Outcrop**



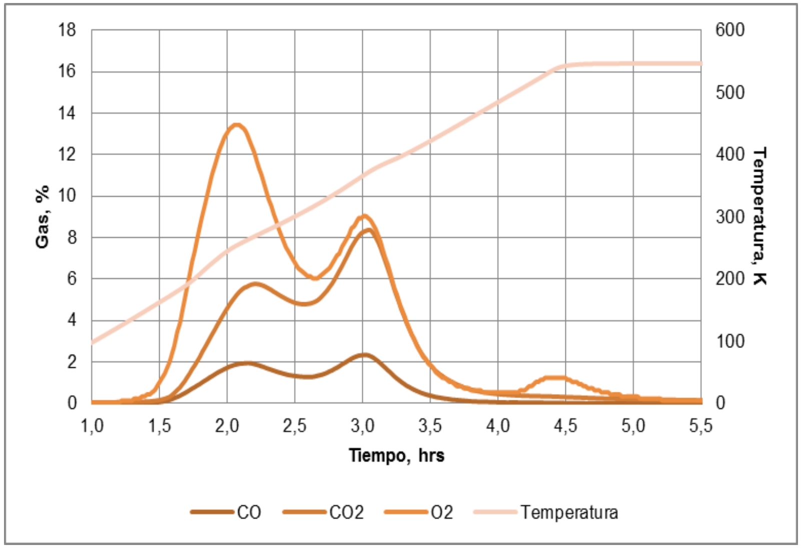



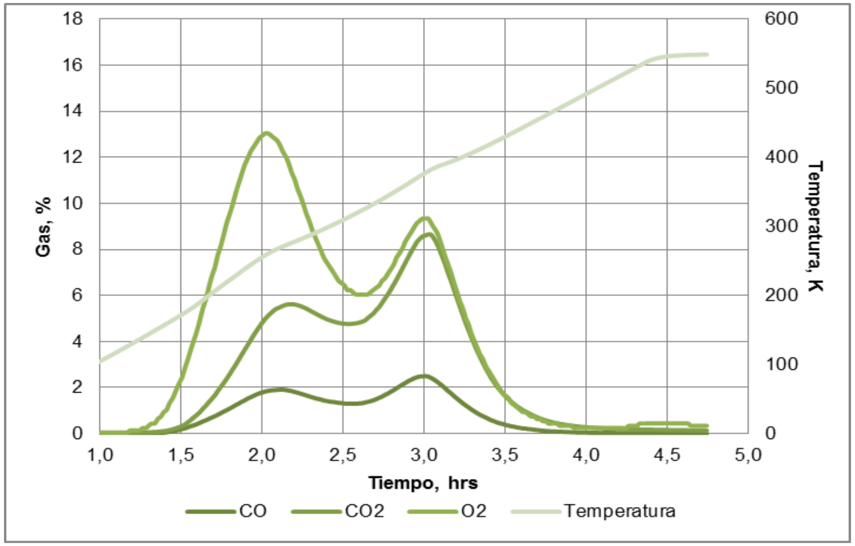

TRUJILLO, M.: EVALUACIÓN DE LA INFLUENCIA DE LA MATRIZ DE LA ROCA EN LA CINÉTICA DE LA COMBUSTIÓN PARA EL PROCESO DE INYECCIÓN DE AIRE EN CRUDOS PESADOS. Master of Science Thesis, Universidad Industrial de Santander, Colombia, 2015.

# Reactivity Studies: Core vs. Outcrop

## Core

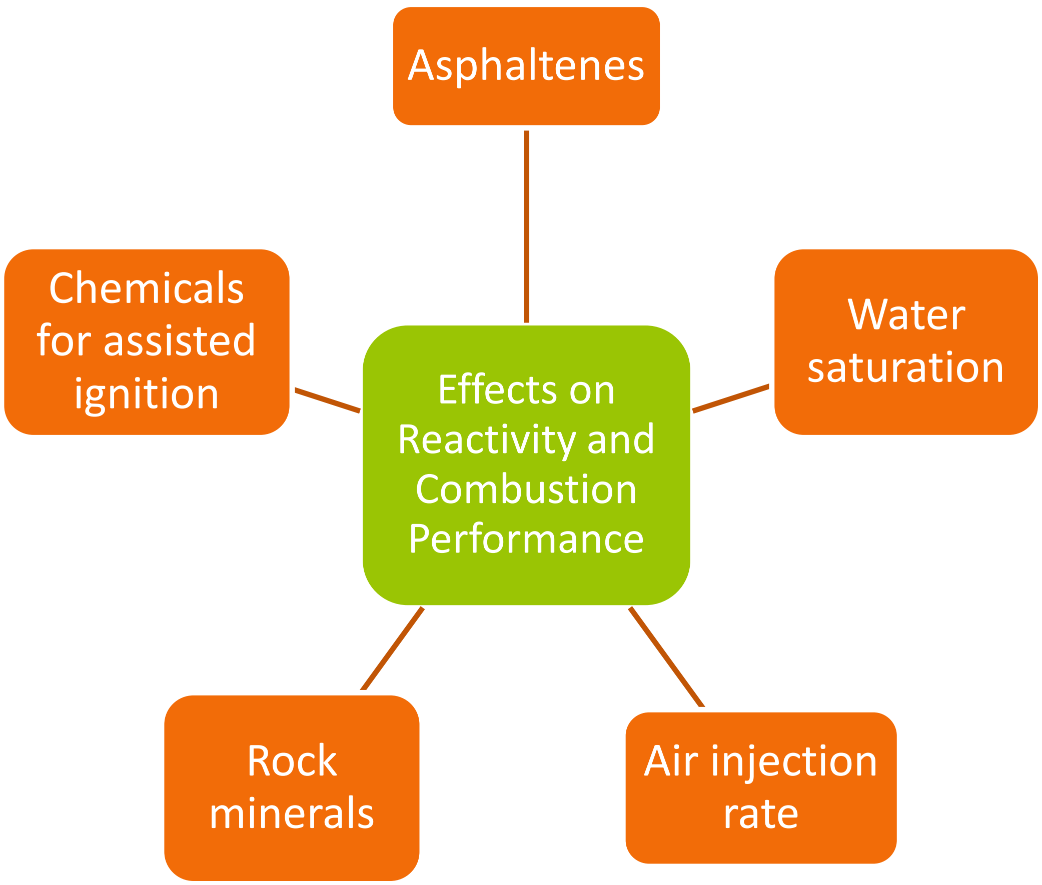



## Outcrop




- The outcrop samples compositionally resemble the reservoir rock
- Their reactivities are also comparable
- This means using the outcrop rock for RTO and combustion test studies is feasible
- It results in significant cost savings
- Enables experimental studies to evaluate the effect of reservoir and operating parameters on reactivity and combustion performance

# Experimental Studies at the ISC lab

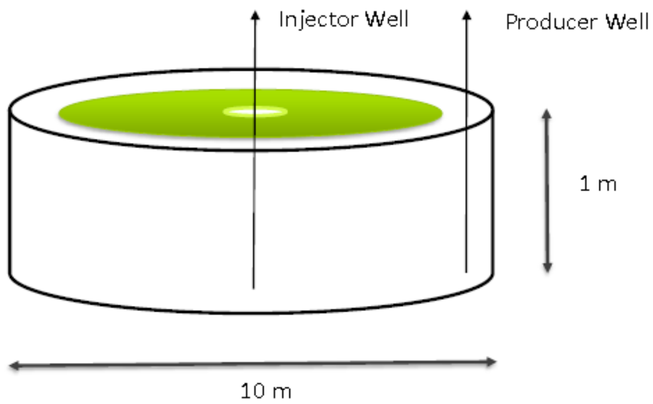



- RTO Reactor
- Isothermal Cell
- Combustion Tube

# Ignition Study

(**Ignition Evaluation of In-Situ Combustion Process of Chichimene Field,** *H. Bottia*, M. Aguillón, H. Lizcano, C. Delgadillo, C. Gadelle, ThEOR 2016, Kazan, Russia)


**Isothermal Cell Experiments**

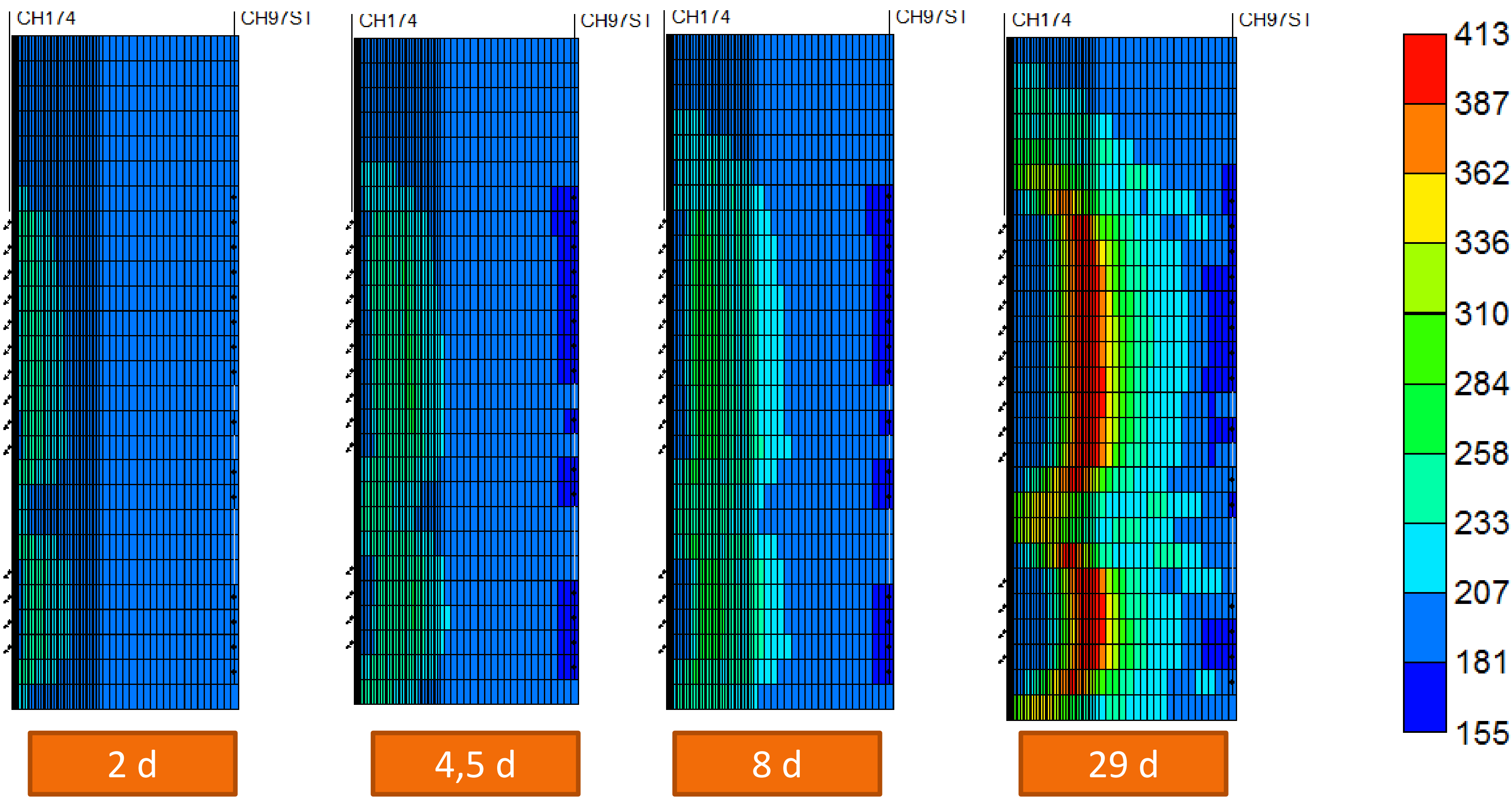



**Analytical & Numerical Modeling**

- **Ignition delay ≈ 2 days**
- **Ignition distance ≈ 2 m**

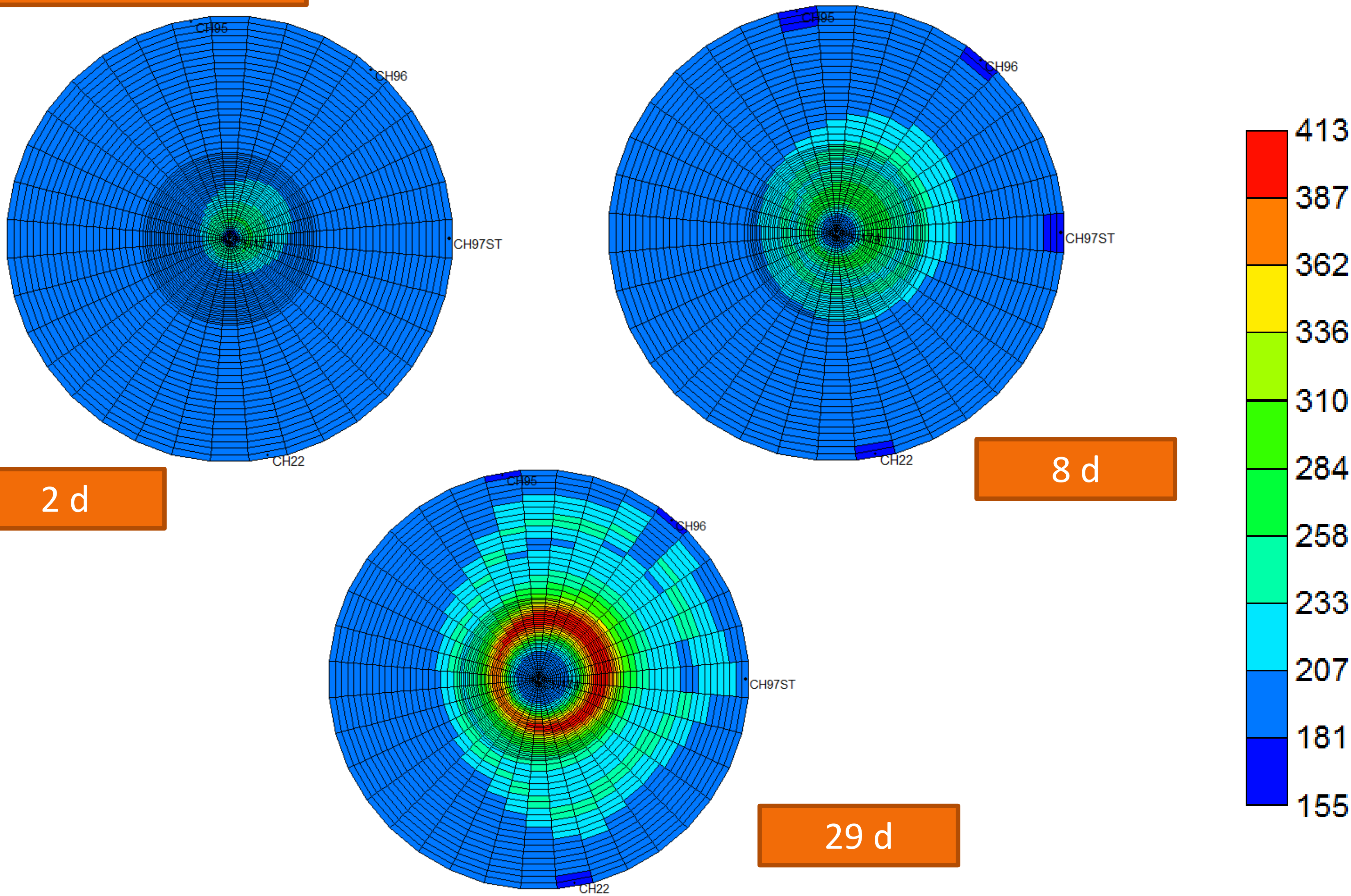
# High Resolution Radial Model (Ignition)

Results:



# High Resolution Radial Model (Ignition)

Results:

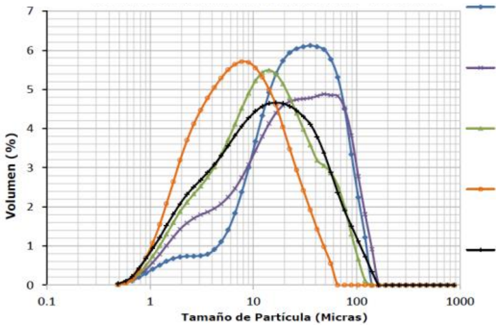


# Experimental Study: Emulsions

Produced oxidized crude oil in a continuous flow reactor (Patent pending)

Create synthetic emulsions.

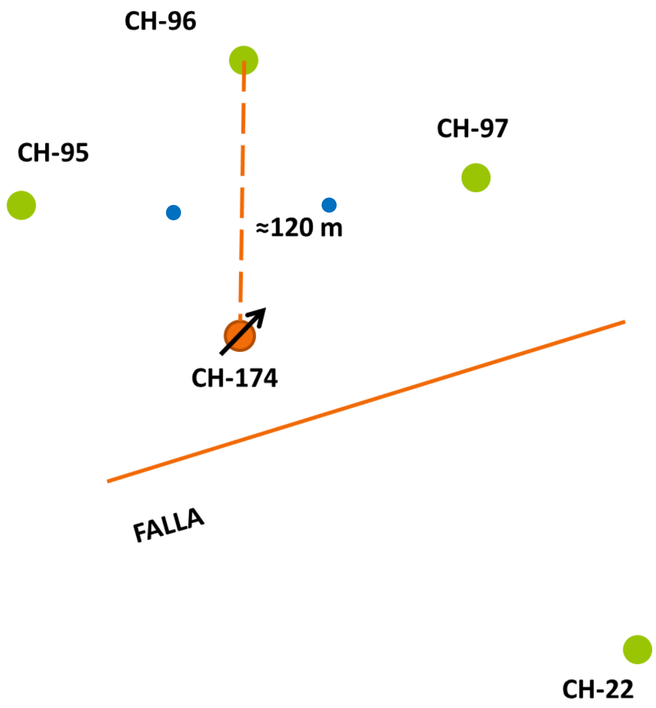
They are comparable with analogue field produced emulsions




Proactively studying alternatives for effective treatment: Chemical, dilution, thermal, combined.

# Nitrogen Connectivity Test

- Objectives:
  - Test if any preferential direction for gas flow exists
  - Dimension the residence time of the combustion gases in the pilot area
  - Test the response of the artificial lift system to increased GOR
  - Update the simulation model



# Connectivity Test Development

ES pumps had a hard time with high GORs. The wells were eventually shut in

$N_2$ broke through between days 8-10 at the 1st line wells

Injection continued for almost 30 days. $N_2$ was measured in almost all of the 2nd line wells and some 3rd line wells.

# How are we for ISC? Challenges:

## Oxygen Production

High reactivity at reservoir T

**Transit time (8 d) longer than ignition delay (2 d)**

## Emulsions

Proactively preparing a response for treatment

## Artificial Lift

Fewer options at 8,000 ft deep, extra-heavy oil, high GOR

Optimizing ESP design for expected rates and GORs.

# Next Steps

- Deploy the artificial lift solution
- Predict the ignition performance based on the updated simulation model
- Make slight adjustments to treatment facilities to allow for flexible emulsion treatment
- Adjust the monitoring plan for ignition and steady air injection
- Continue with the experimental efforts to support the operation before any deviation

# Challenges and Future Activities

- Predictive modeling of ISC at field scale (Stanford)
- Nano-catalysts for promoting ignition
- Finishing “base lines” and measuring deviations
- Operate the pilot with minimal disturbance
- Extrapolate the pilot findings to the field scale
- Deal with hot well operations (expansion)
- Cost reduction (lower-grade metallurgy, fluid treatment, compressor reliability)
- Environmental (Emissions, flue gas use, water quality)

# Acknowledgments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