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Distinguished Lecturer Program

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Development of Mature Oil Fields: Enhanced Oil Recovery Option

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Society of Petroleum Engineers
Distinguished Lecturer Program
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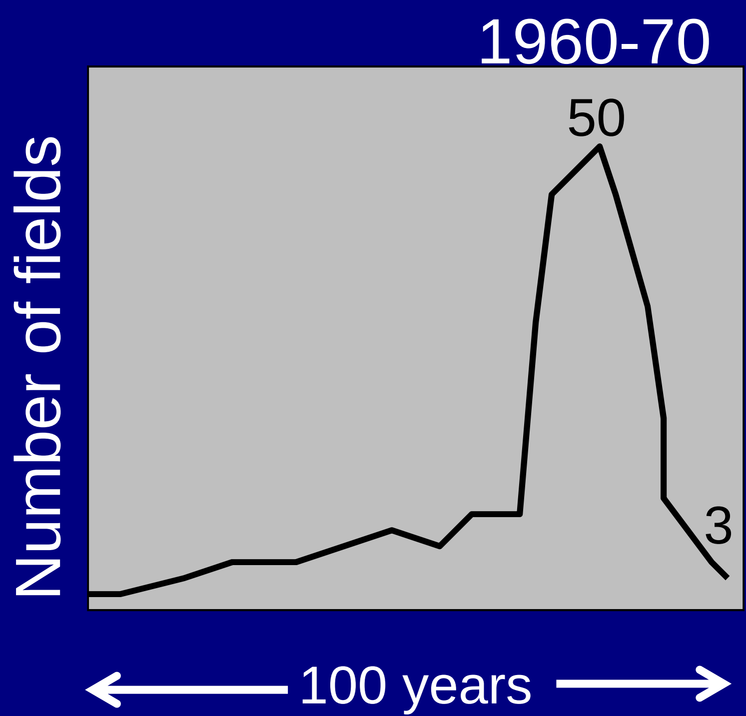
OUTLINE

- **What is a mature/marginal field**
- **How much oil is left and where it is**
- **Recovery of remaining oil: Tertiary recovery**
  - Laboratory scale
  - Field scale
- **Reservoir management practices**
- **Key points and suggestions**

What is a Mature Field?

- Rate: Producing but declining
- Recovery Factor: 50% - 60 years (99% water cut)
- Recovery Factor: 10% - 60 years   (0% water cut)

Giant Field Discoveries



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OIL FIELDS IN THE WORLD: 30,000

TOTAL RESERVES: 150 $MMMm^3$

33 Fields:	51%
239 Fields:	26%
29,700 Fields:	23%

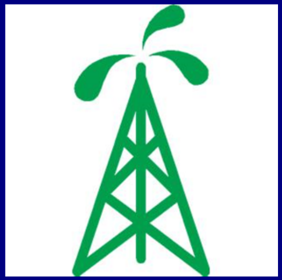
Additional reserves are from new discoveries or existing fields?

50-70% left behind!!!

Stages In Mature Field Development

BROAD SUBJECT

Well



WELL ENHANCEMENT
- o Optimization of lift
- o Well stimulation
- o Re-visiting wells

DRILLING
- o Verticals / Horizontals
- o Multilaterals / Side-tracking
- o Infills

Reservoir

SECONDARY RECOVERY
- o Pressure maintenance
- o Waterflooding
- o Gas (immiscible) injection

TERTIARY RECOVERY
- o Gas (CO_2, hydrocarbon-rich)
- o Chemical (surfactant, micellar)
- o Thermal (air)

Development of Mature Fields

Advantages

Data and experience gained

History

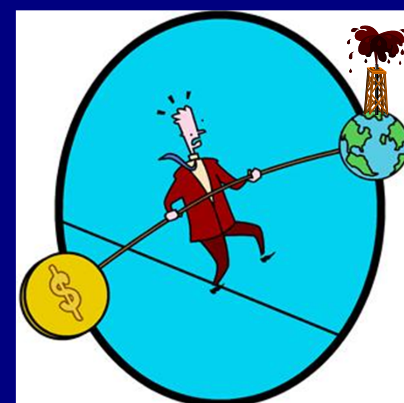
Modern technologies

Disadvantages

Cost

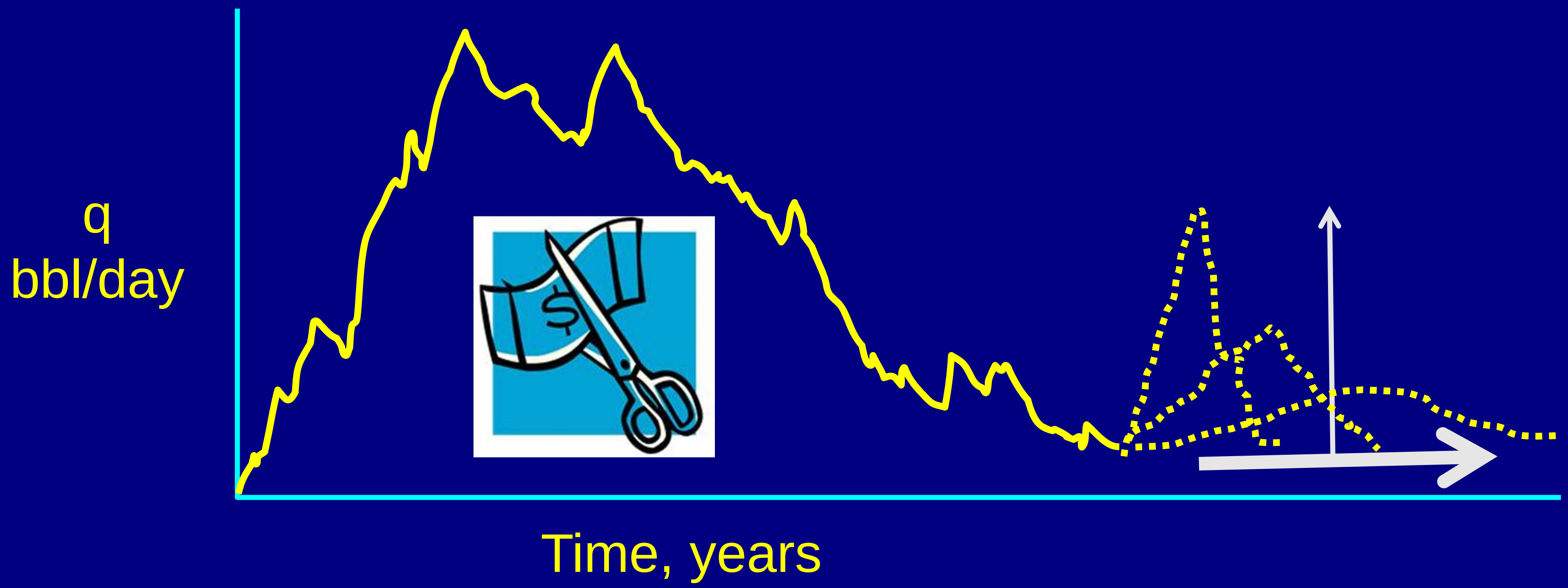
Efficiency

Time to start the project



- Incremental OIL (How much)
- Recovery TIME (How fast)
- COST (How expensive)
- Company Size
- Long/Short Term

What is Mature Field?



TERTIARY vs. SECONDARY

Recovery is lower - Investment is higher

Company's cut-off limit for cost: $10, $30, $50/bbl?
Your target is residual oil reduction rather than rate?

Elements of Mature Field Development
(Reservoir Engineering)

How much oil is left and where it is

Tertiary recovery

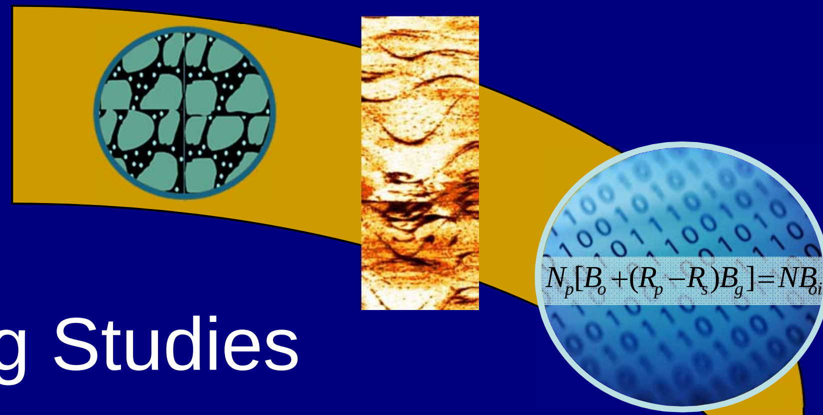
Laboratory

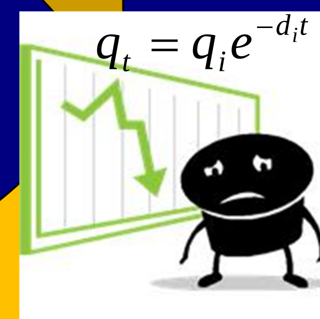
Field

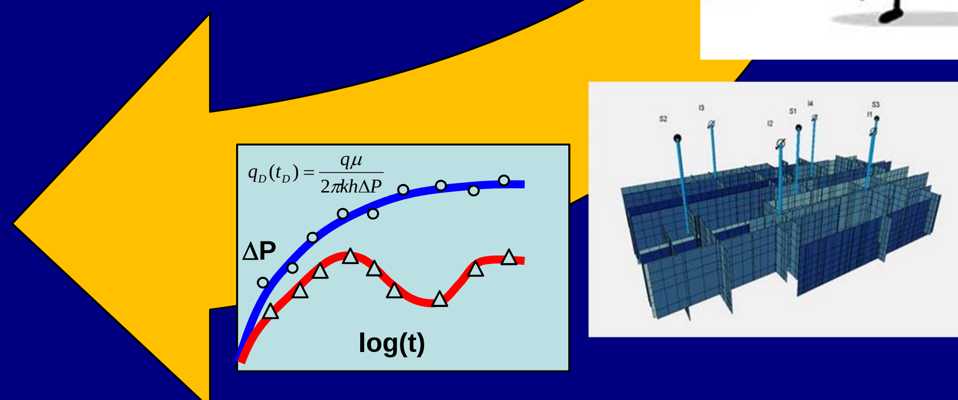
Reservoir management practices

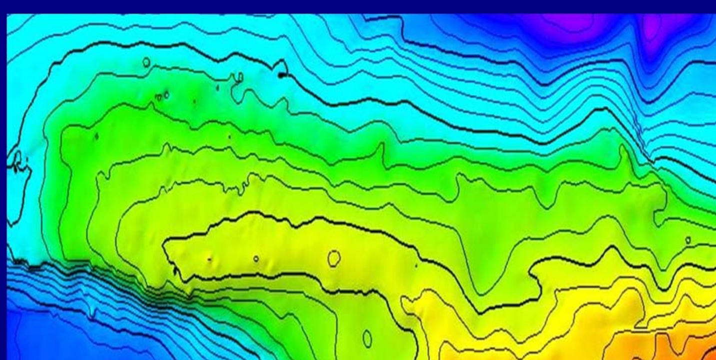
Determination of Residual Oil Saturation

- •Core Analysis
- •Logs
- •Reservoir Engineering Studies
- •Production Data
- •Chemical Tracers
- •Well Testing (with core analysis)



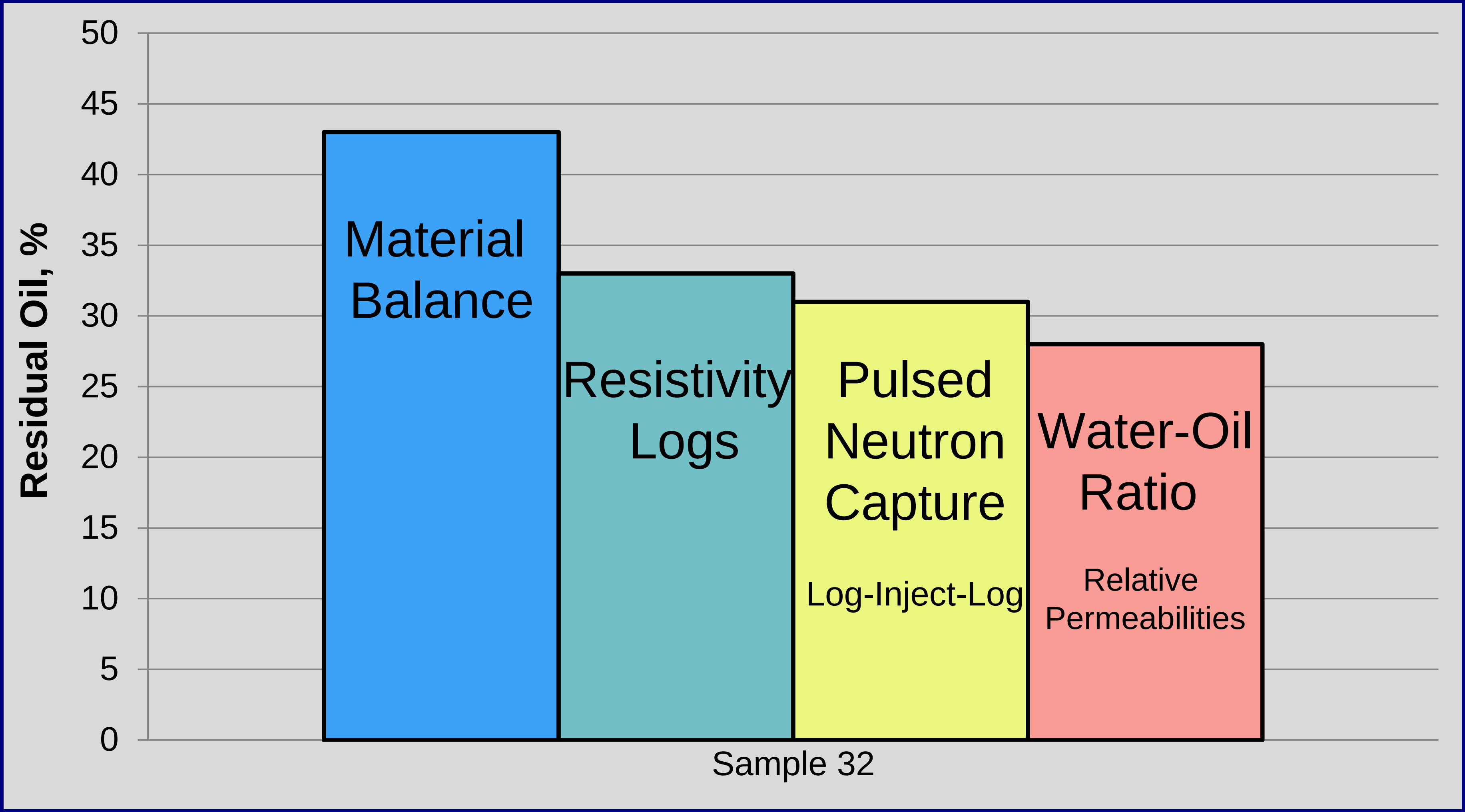






Residual Oil Saturations – Different Methods

(33 sandstone fields)



Determination of Residual Oil Saturation, Bond, Hocott, Poettmann (Eds.), Interstate Oil Compact Comm., 1978

Advantages - Disadvantages

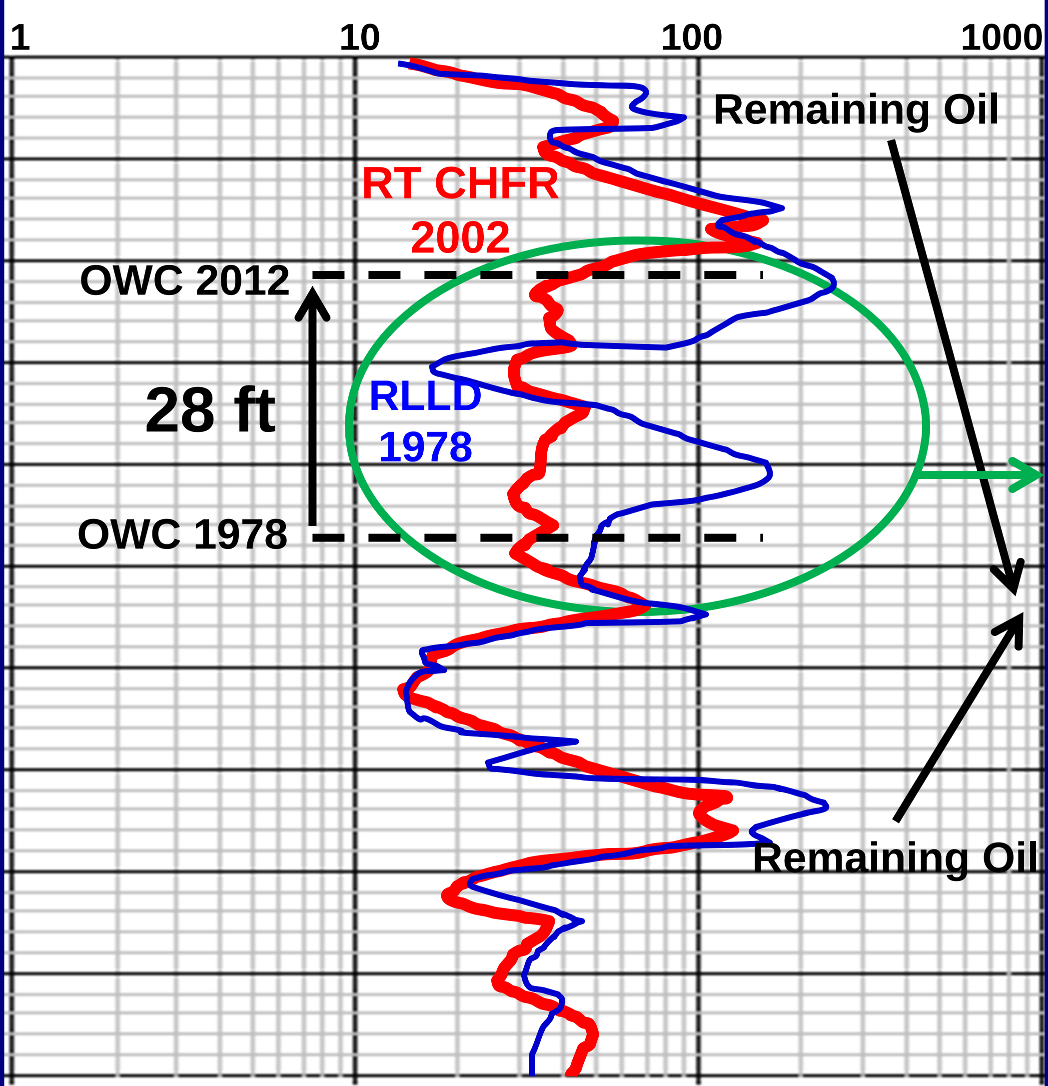
Field	RESIDUAL OIL		SOLUTION
	Material Balance (% PV)	Tracer Test (%PV)	
1	16	12	No tertiary oil recovery More wells between producers
2	40	29	Tertiary oil recovery
3	44	12	Oil in isolated pockets Infill

-Remaining Oil
-No Distribution

-Remaining Oil
-Distribution

Determination of Residual Oil Saturation, Bond, Hocott, Poettmann (Eds.), Interstate Oil Compact Comm., 1978

Cased Hole Formation Resistivity Logs



(Petrophysics, 2004 no.4)

-Nuclear logs (Neutron, C/O) : Not reliable

-New tool for resistivity through metal casing

Cement squeeze

Re-perforate

Oil: From 34 to 253 bbl/d

Water: Completely stopped

Remaining Oil Saturation: Yates Field

- Discovered in 1927
- 1.3 billion barrel produced
- Strongly heterogeneous mixed wet carbonate
- 1100 producers - 57 injectors (1992)

PROBLEMS

$$S_w = \left(\frac{aR_w}{\varphi^m}\right)^{\frac{1}{n}}$$

n and m between 1 and 5 (in space - time)

Borehole filled with gas, no electromagnetic propagation

SOLUTION : NMR

Alternative to resistivity saturation.

Insensitive to gas

Oil/water by diffusion coefficient

SPE 63216

Comparison: Residual Oil Saturation (SOR)

SOR (Core, log, tracer) $<$ SOR (Material balance)

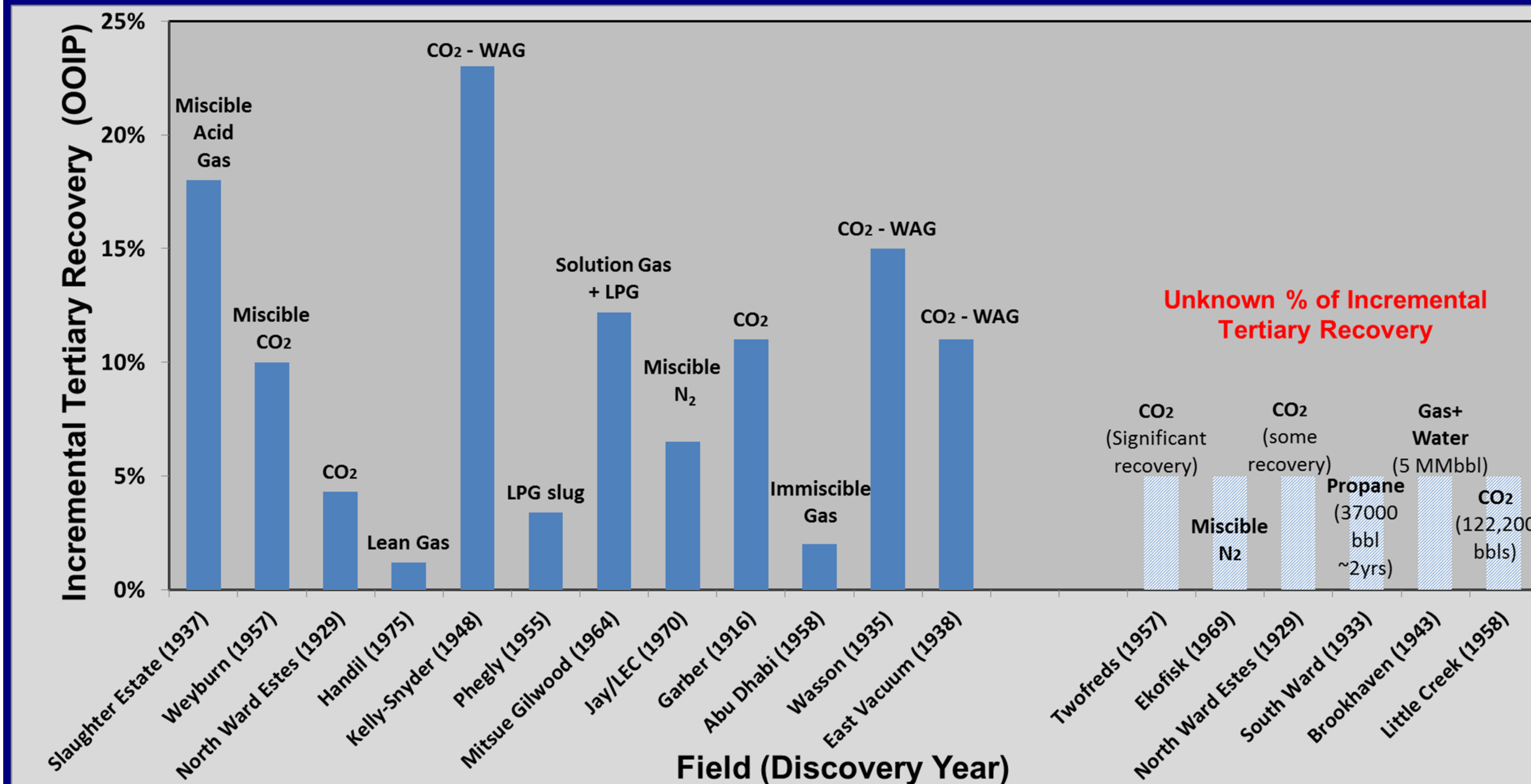
SOR (Pulsed Neutron Capture) $=$ SOR (Resistivity)

SOR (Single well tracer) $<$ SOR (Logs)

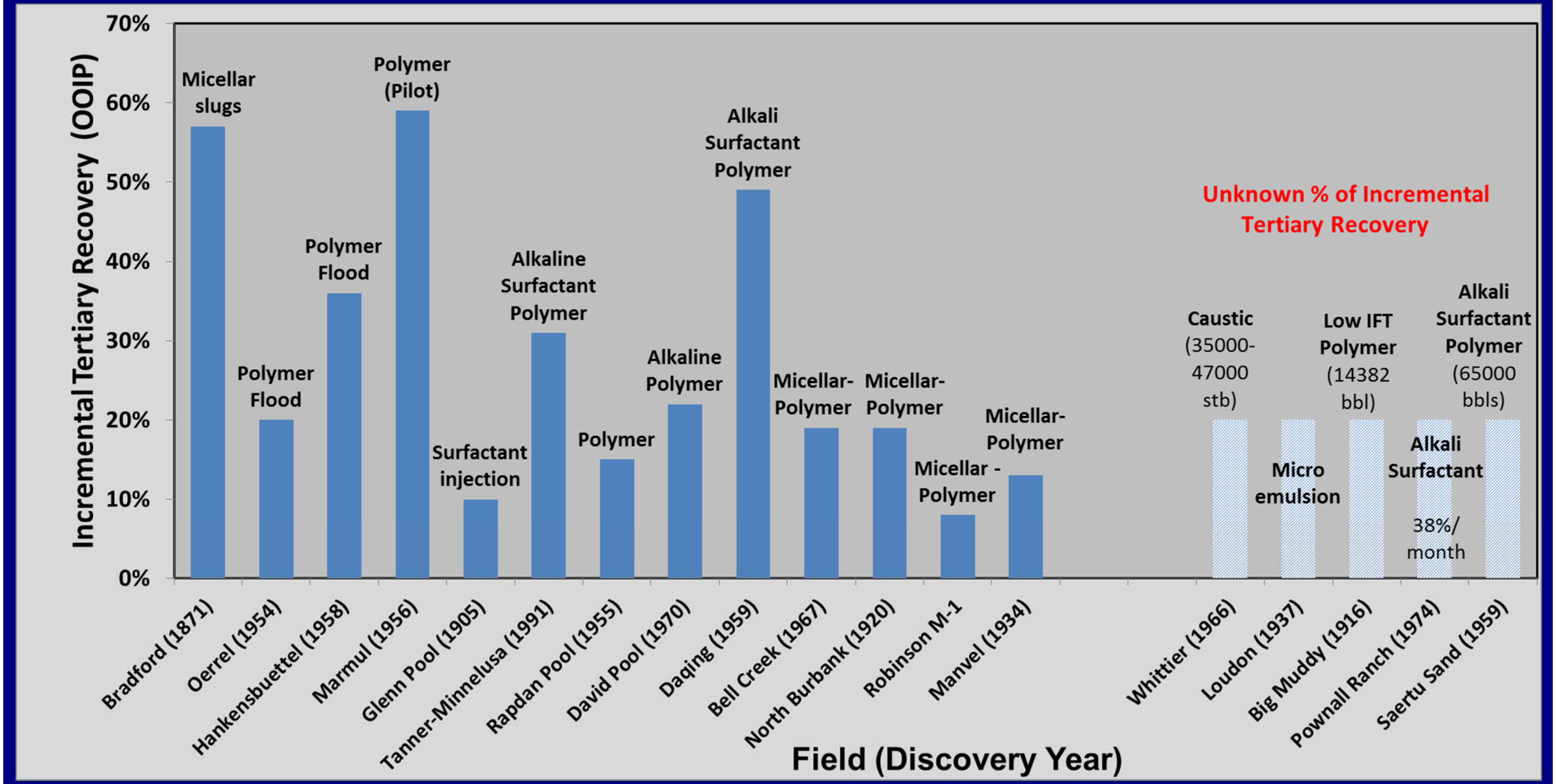
Tertiary Recovery – Lab Studies

- **Immiscible gas injection**
  - -Double displacement
  - -Inert gas
- **Miscible gas injection**
  - -HC gases
  - -CO_2
- **Chemical (surfactant) injection**
- **Air injection**

Tertiary Gas Injection Applications



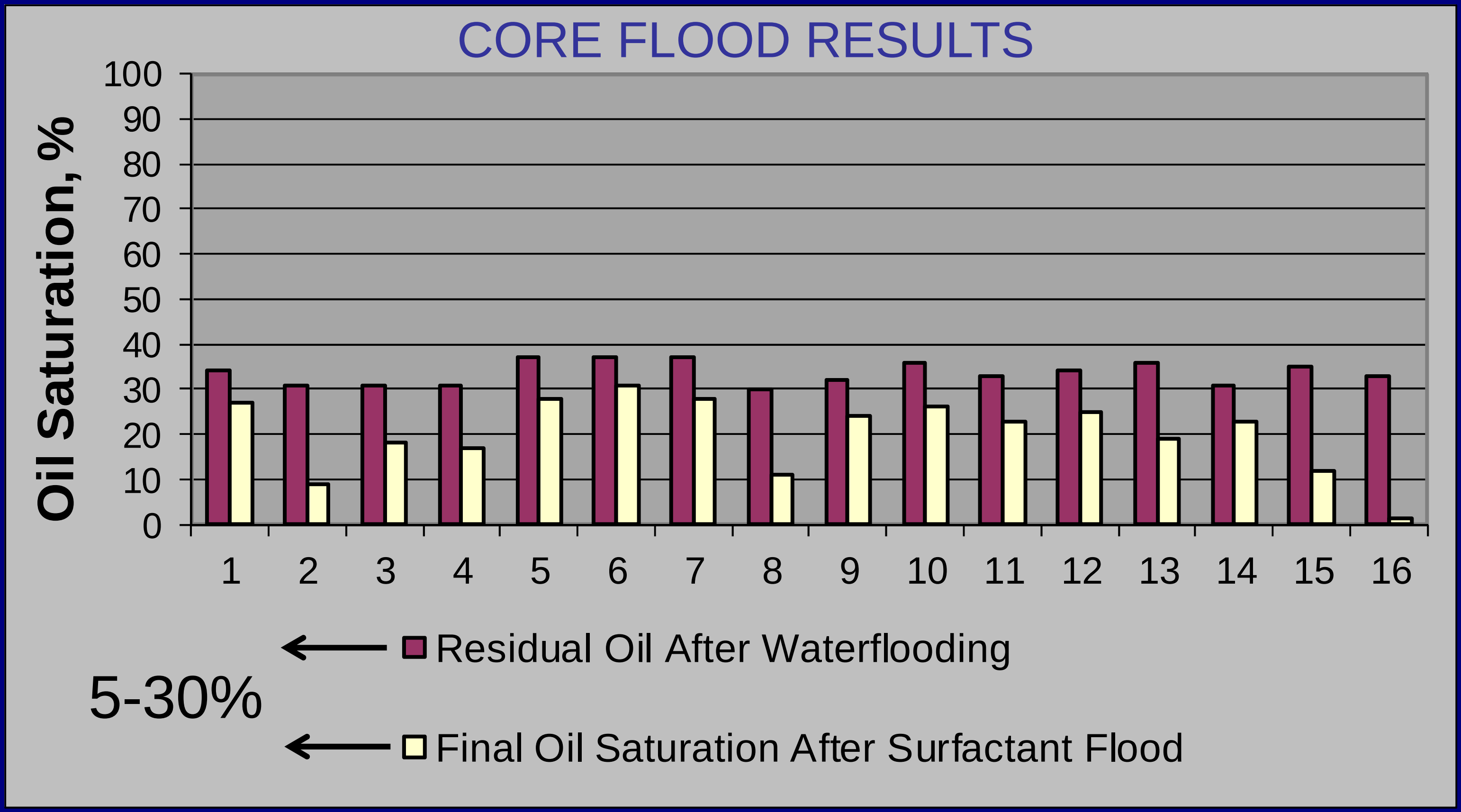
Tertiary Chemical Injection Applications



Surfactant Flood: Incremental Recovery

Loudon Field: 13 years primary, 38 years waterflooding.

Remaining oil: 50 % OOIP



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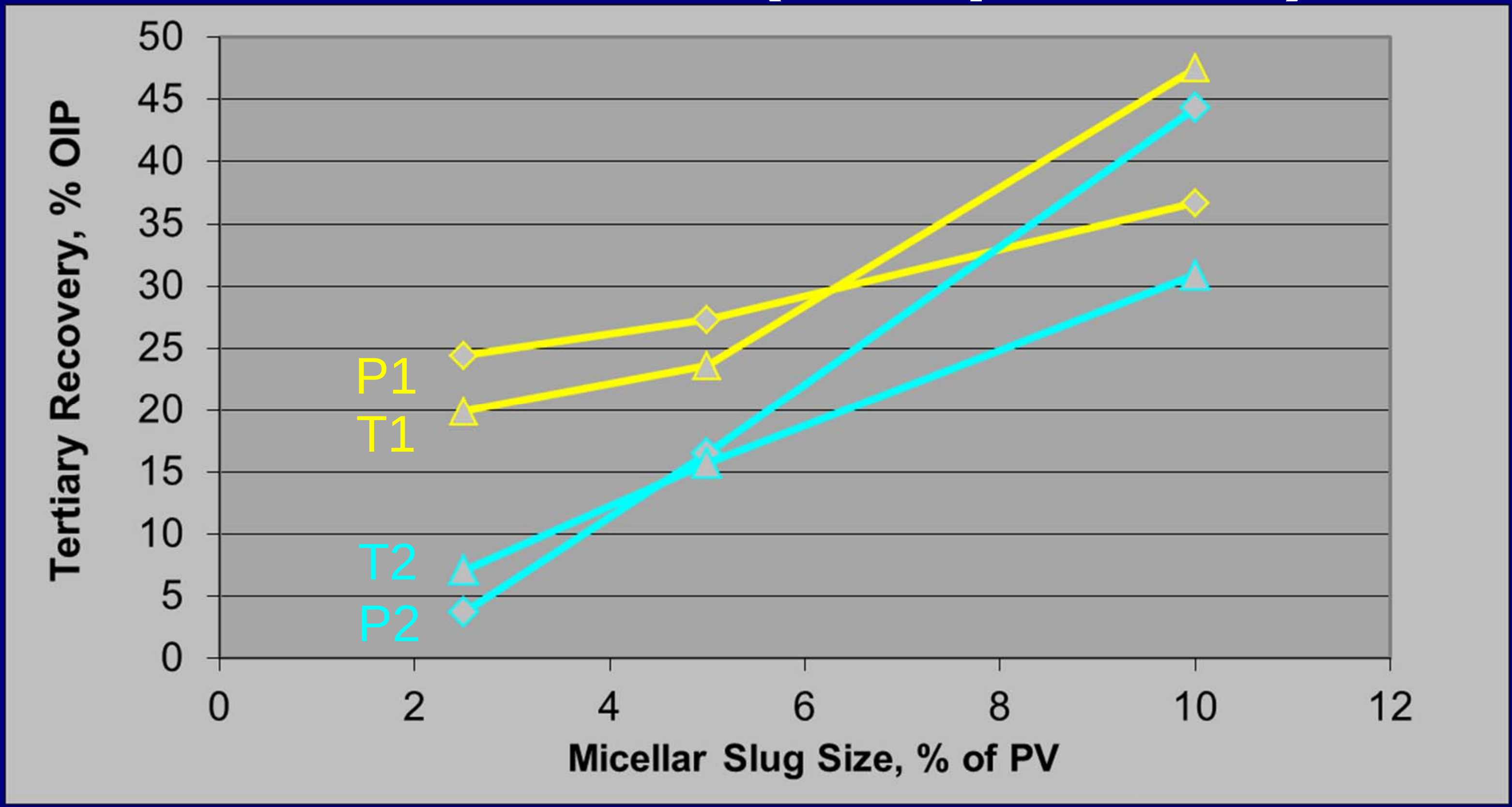
Micellar Flood (Composition)

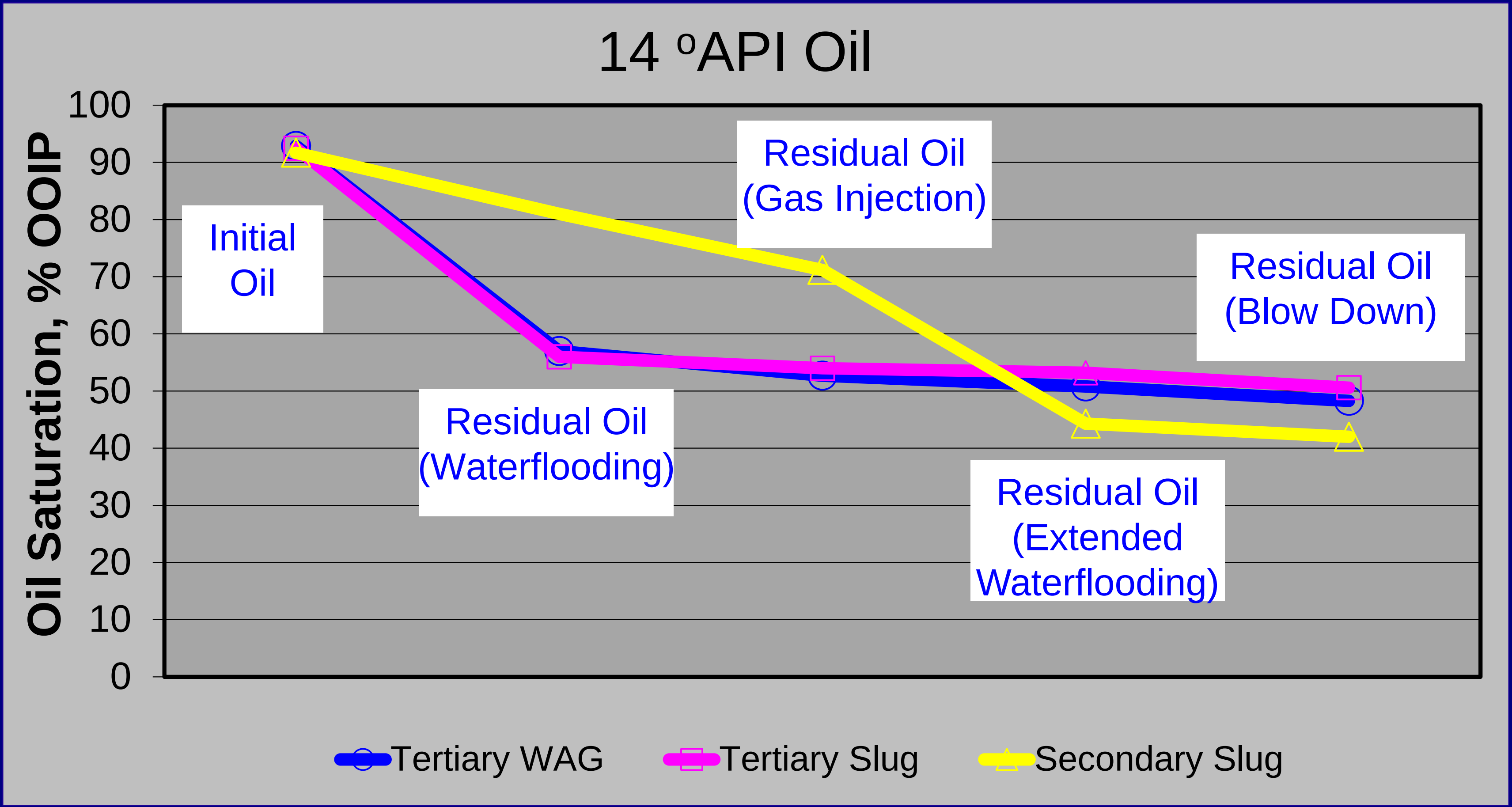


Type	Oil (%)	Brine (%)	Surfactant (%)	Co-Surfactant (%)
P1	64	20	12	4 (Isopropyl Alcohol)
T1	85	5	8.5	1.5 (Isopropyl Alcohol)
P2	6	84	7.5	3 (Cyclohexanol)
T2	2	93	4	1.5 (Cyclohexanol)

JCPT
Jan-Feb
1990

Sequence of Methods

Flue gas injection as slug or water-alternating-gas (WAG)

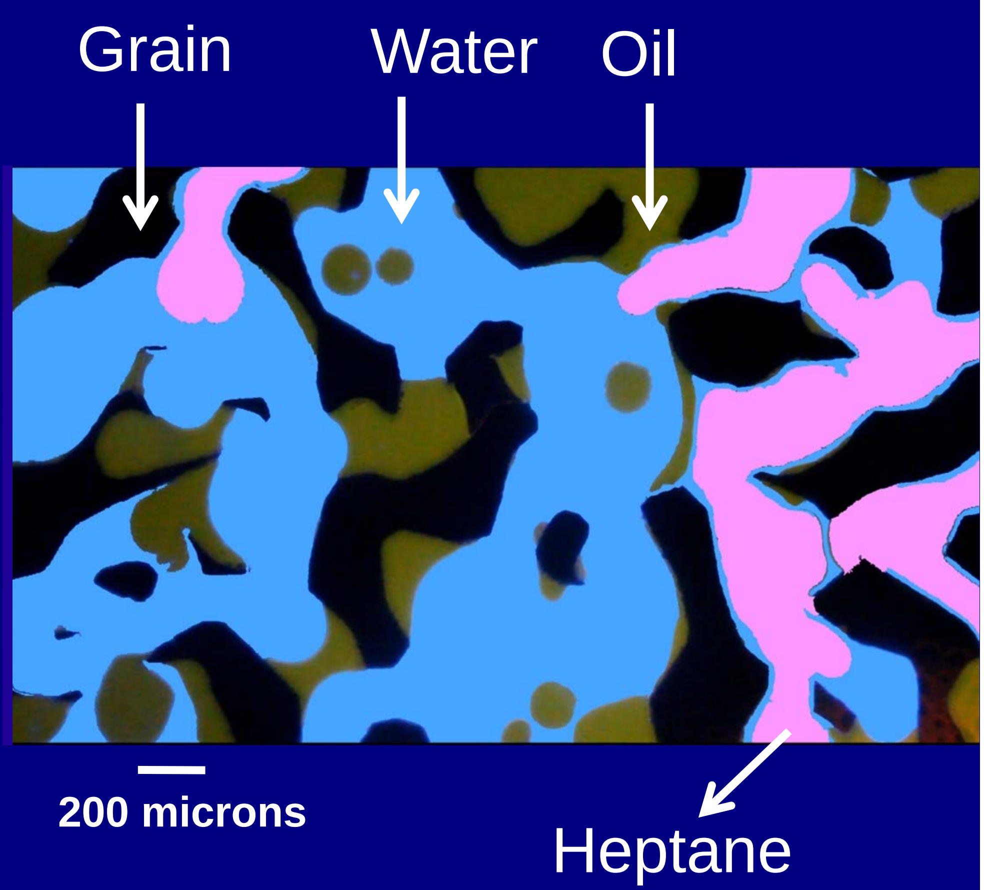


46th Annual Tech. Meet. of the Petroleum Society, Banff, Canada, 1995, Paper 65-95

Tertiary Recovery by Hydrocarbon Solvent

Miscibility after waterflood

- Solvent invade only water filled pores.
- Solvent entrance into water filled (small pores) takes time.
- Oil may not be displaced from the smaller pores.
- Water film between solvent and oil/grain

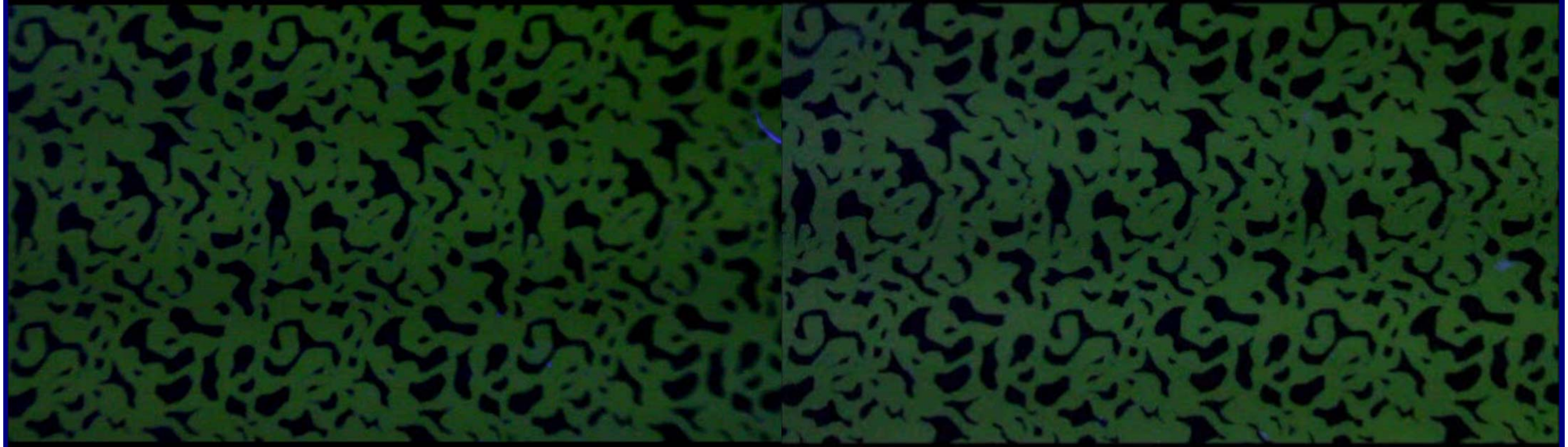


Tertiary Recovery by Solvent

Kerosene (2 cp)

Solvent → Water

Water→ Solvent → Water



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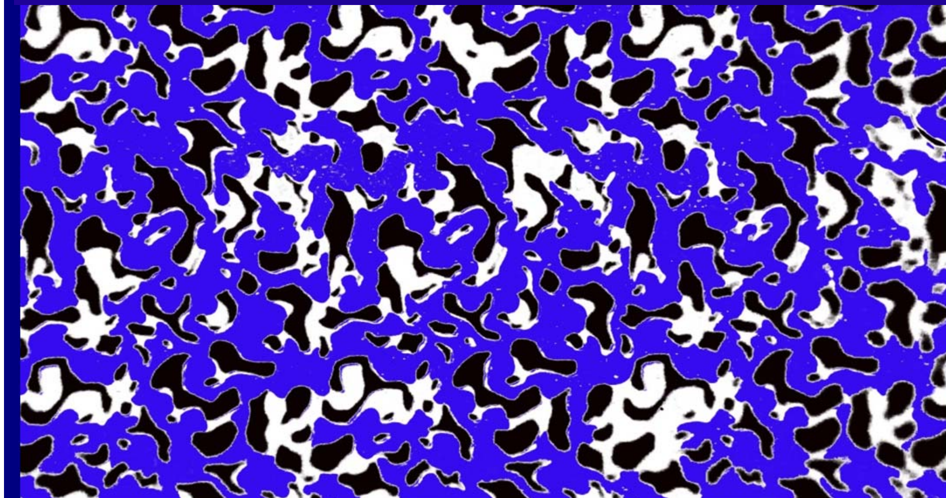
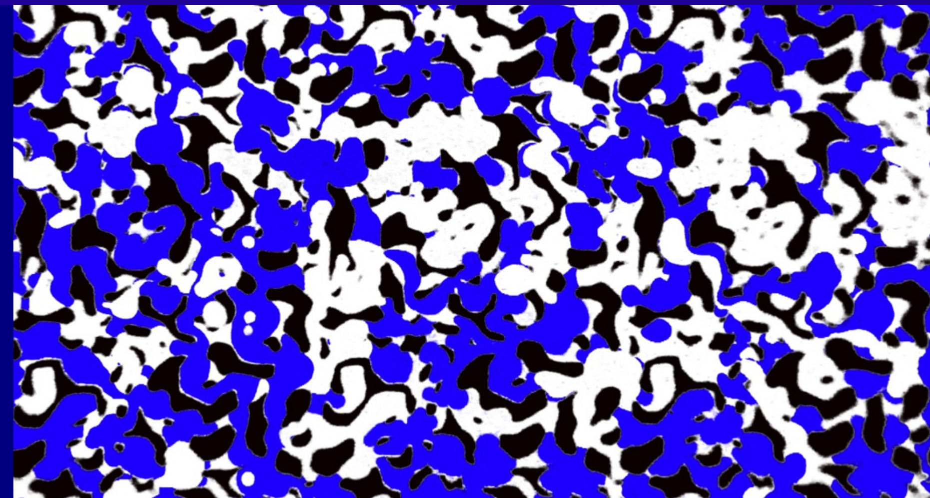
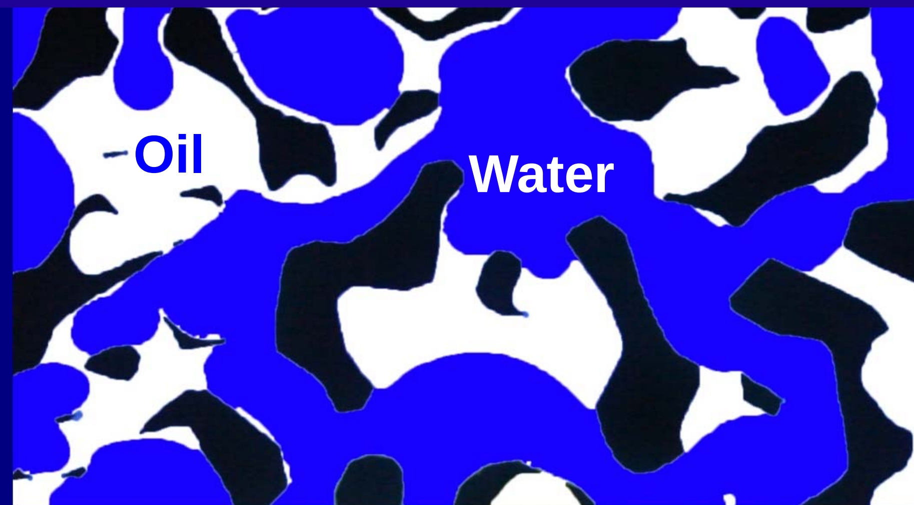




RF=69%

RF=47%

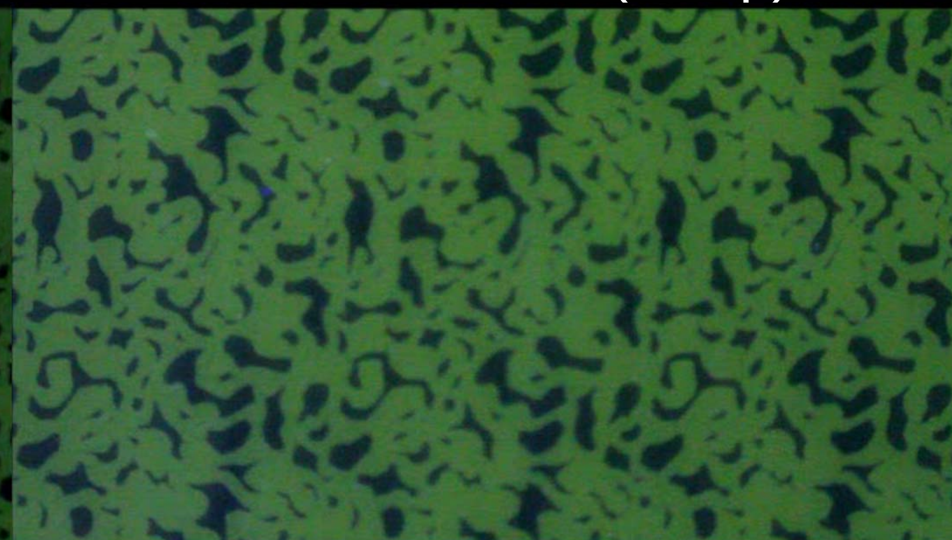


Tertiary Recovery by Solvent

Water→ Solvent → Water

Kerosene (2 cp)

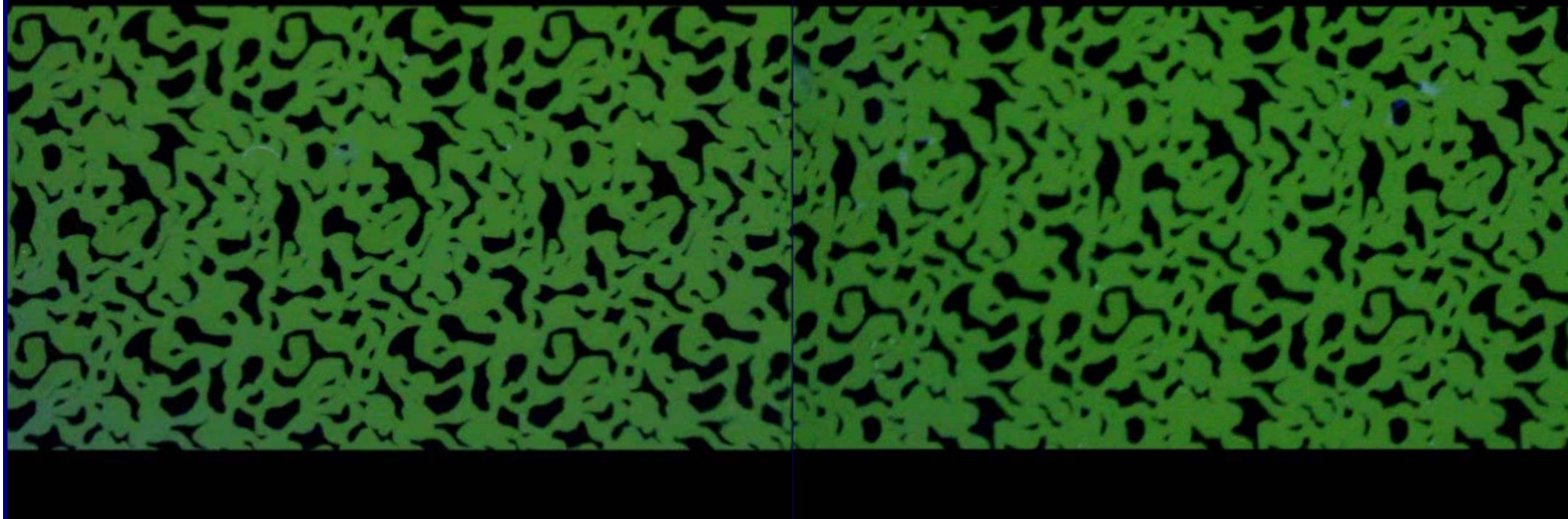
Mineral Oil (40 cp)



Tertiary Recovery by Solvent

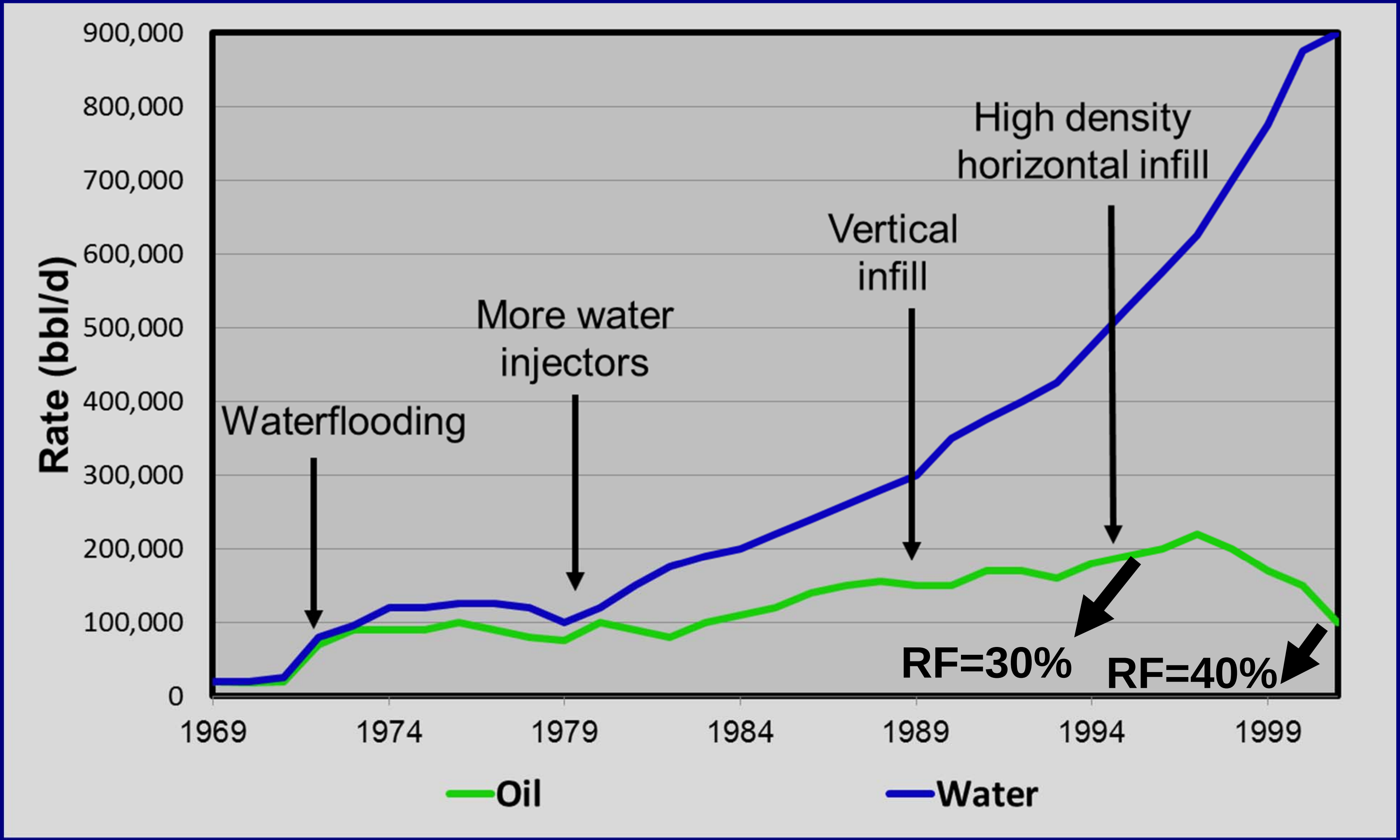
Kerosene (2 cp) - Mixed Wet

Solvent → Water		Water → Solvent → Water		



RF=85%	Mixed wet	RF_{water} =73%	S_w=20%	RF_{final} =64%
RF=69%	Water wet	RF_{water} =66%	S_w=39%	RF_{final} =47%

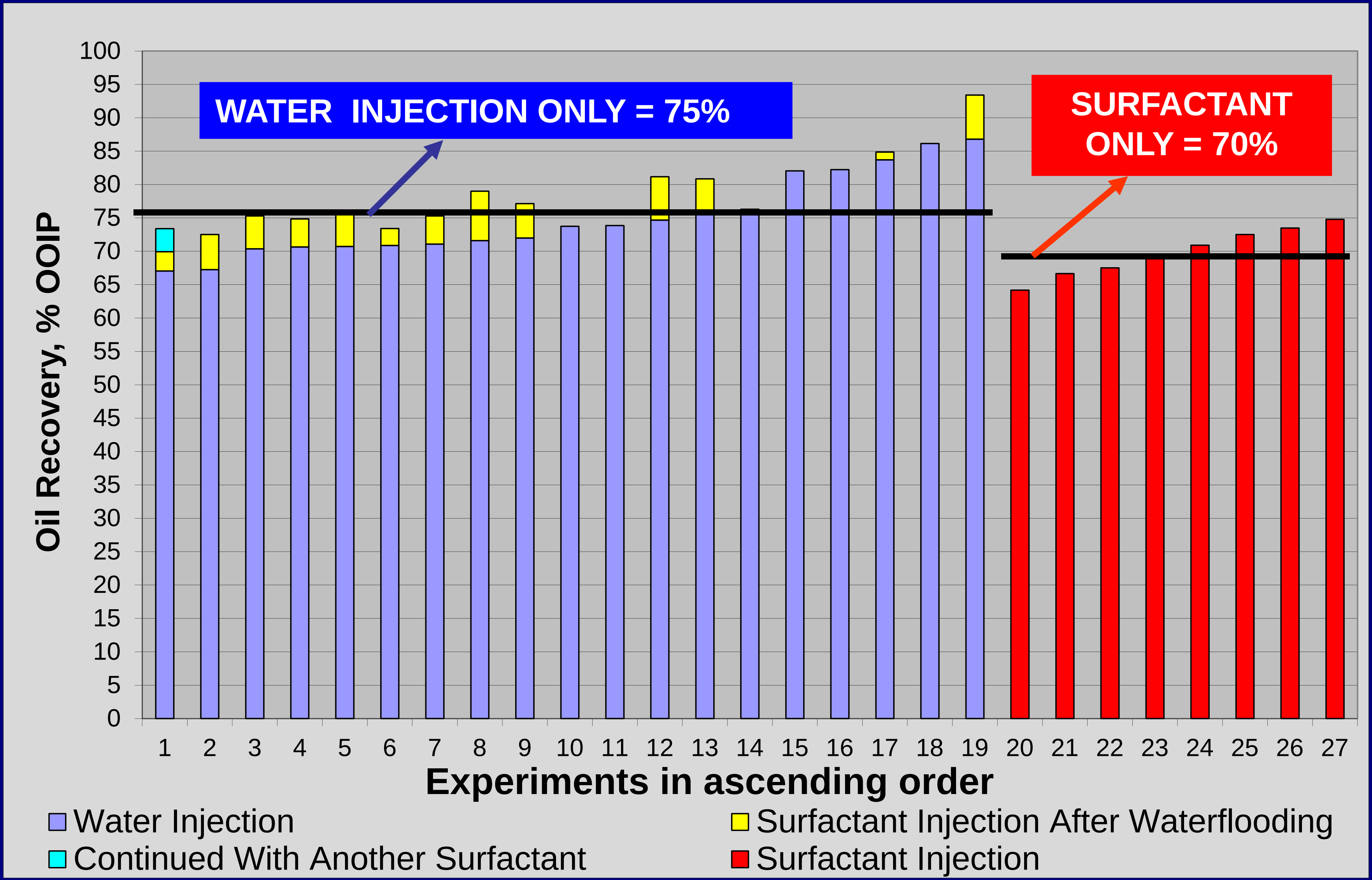
YIBAL FIELD



- Big field: 450 wells
- Long term targets
- High investment
- Chalky carbonate
- Light oil (1cP)
- Natural water influx

SPE 77641

Yibal Field (Chalk) Dilute Surfactant Performance



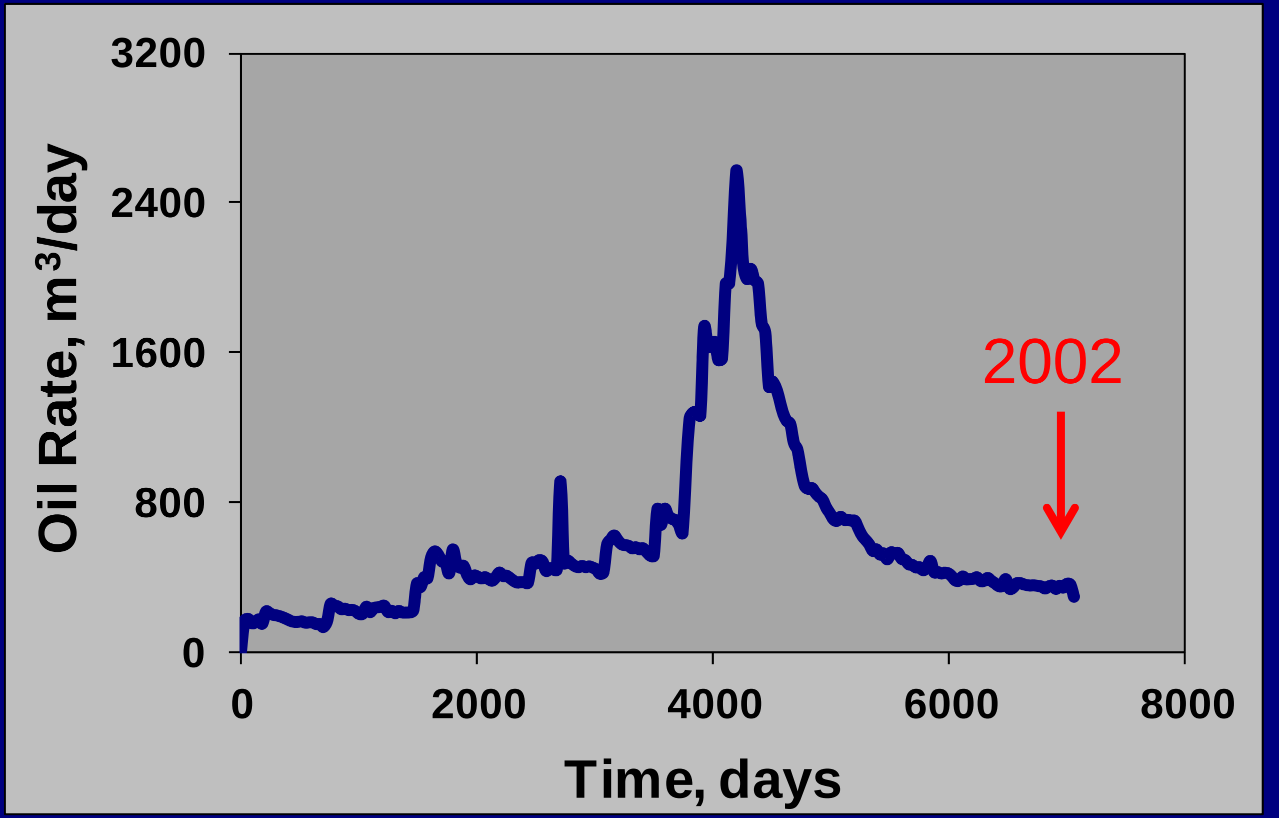
SAHMAH FIELD

-Small field: 20 wells

-Small company

-Short term targets

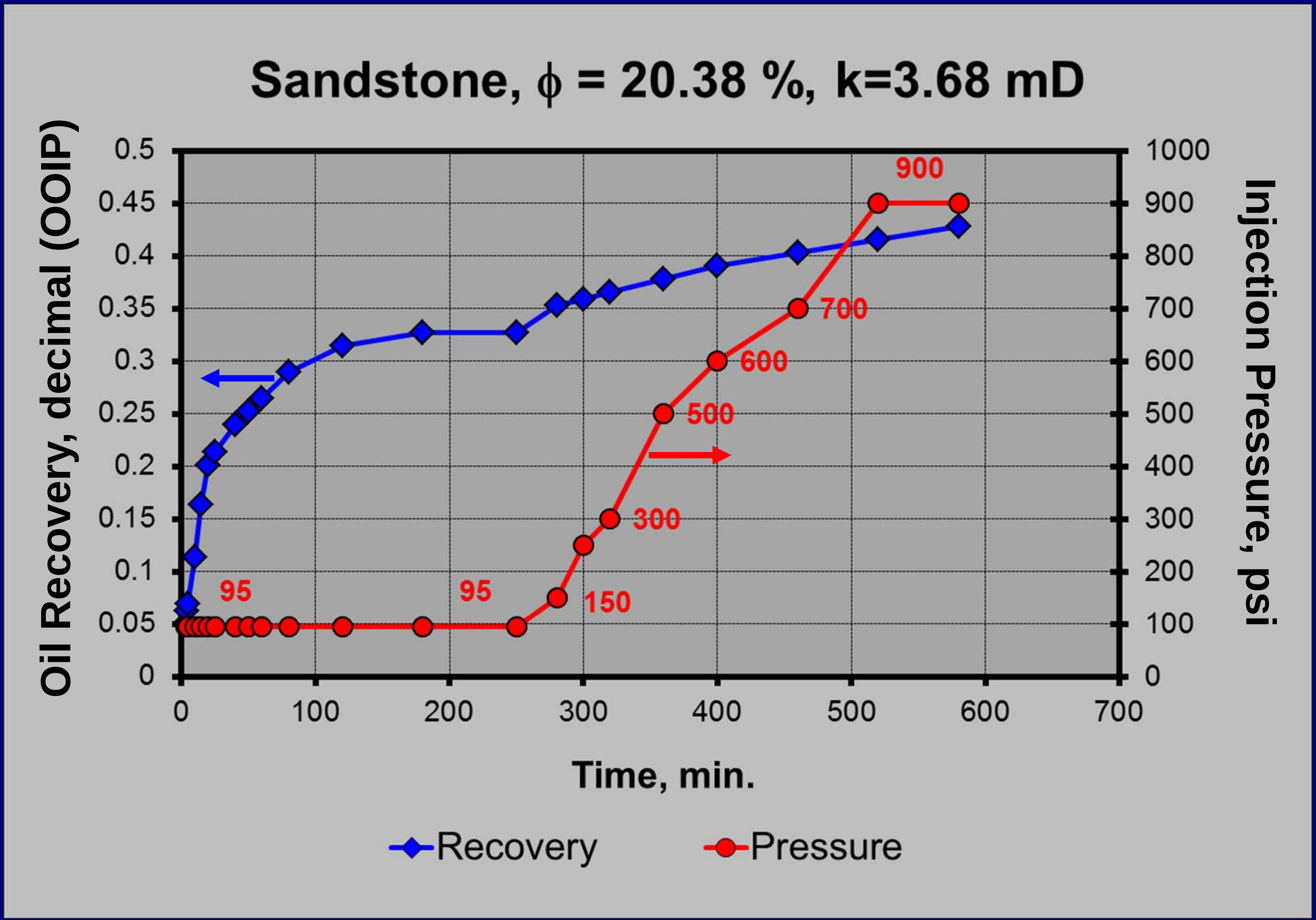
-Low investment



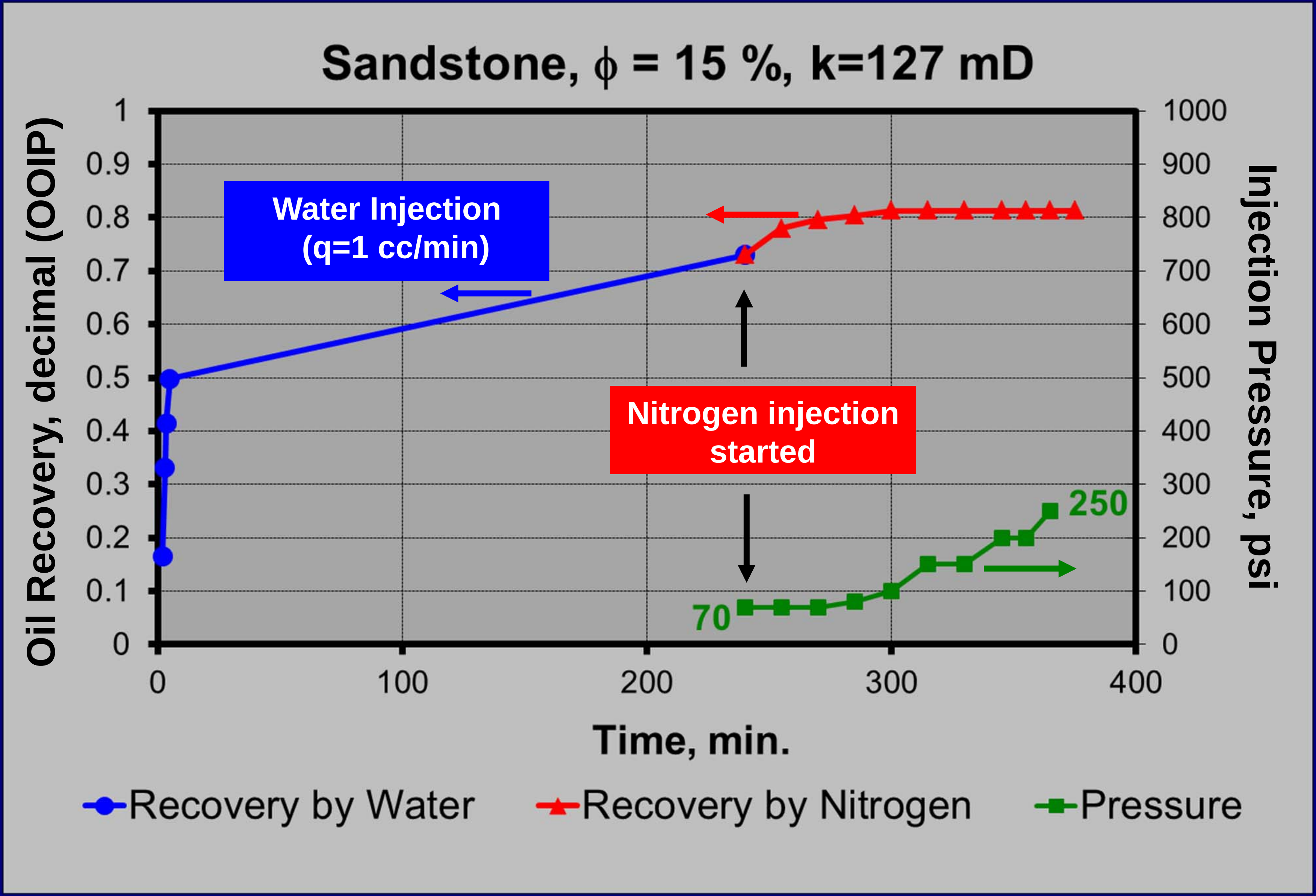
- Sandstone
- Oil: 45 ºAPI, 1 cP
- Natural water influx

- Two sandstone layers:
  - Low permeability (1 mD), RF=10%
  - High permeability (150 mD), RF=70%

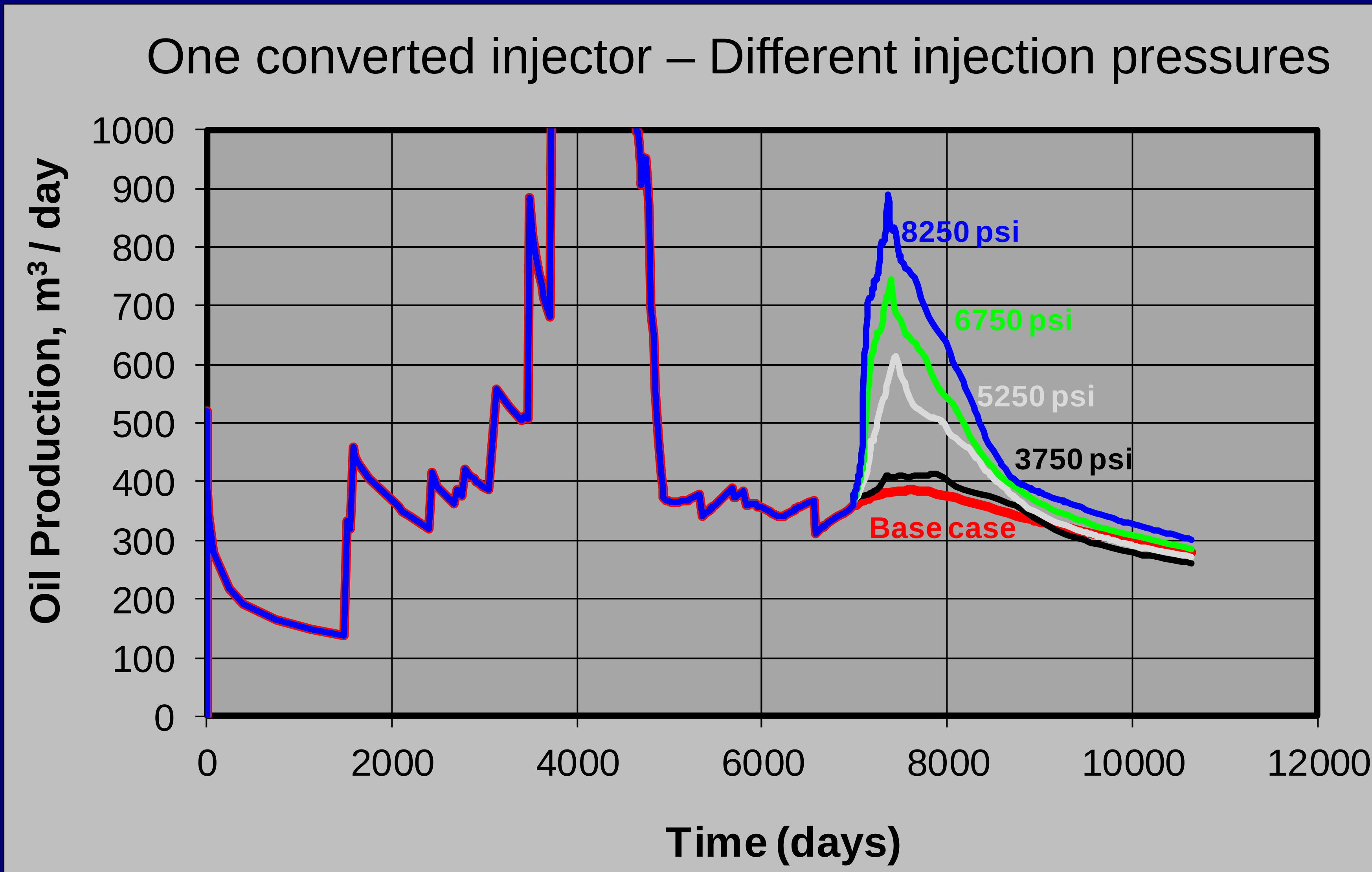
Nitrogen injection into tight zone



Nitrogen injection into waterflooded zone



Field scale simulation



Reservoir Management Practices

- Infills (horizontal/vertical)
    - Is infill drilling a way to reduce residual oil saturation?
    - Are horizontal wells a way to reduce residual oil saturation?
- Existing (production) data for reservoir characterization
- Re-alignment of patterns, injector-producer conversion
- Water management (gels or re-designing wells)

Concluding Remarks

- Locate the remaining oil
- Proper tertiary recovery method
    - Small companies → faster recovery (short term)
    - Big companies → higher ultimate recovery (long term)
- Laboratory experiments
    - When to start tertiary recovery
    - Role of water (or gas) saturation history
    - Interaction with injectant to reduce residual oil saturation
    - Injection design (sequence, WAG ratios, slug sizes)

Further Suggestions

- Be proactive: Forecast the impacts a few decades ahead
- Reservoir characterization for optimal design
- Human factor: Experience and expertise

Bottom Line

No luxury of leaving ~50% of oil trapped in mature and marginal fields.

The careful selection and design of technically and economically viable technique.

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