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Distinguished Lecturer Program

Development of Mature Oil Fields: Enhanced Oil Recovery Option

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University of Alberta

Society of Petroleum Engineers
Distinguished Lecturer Program
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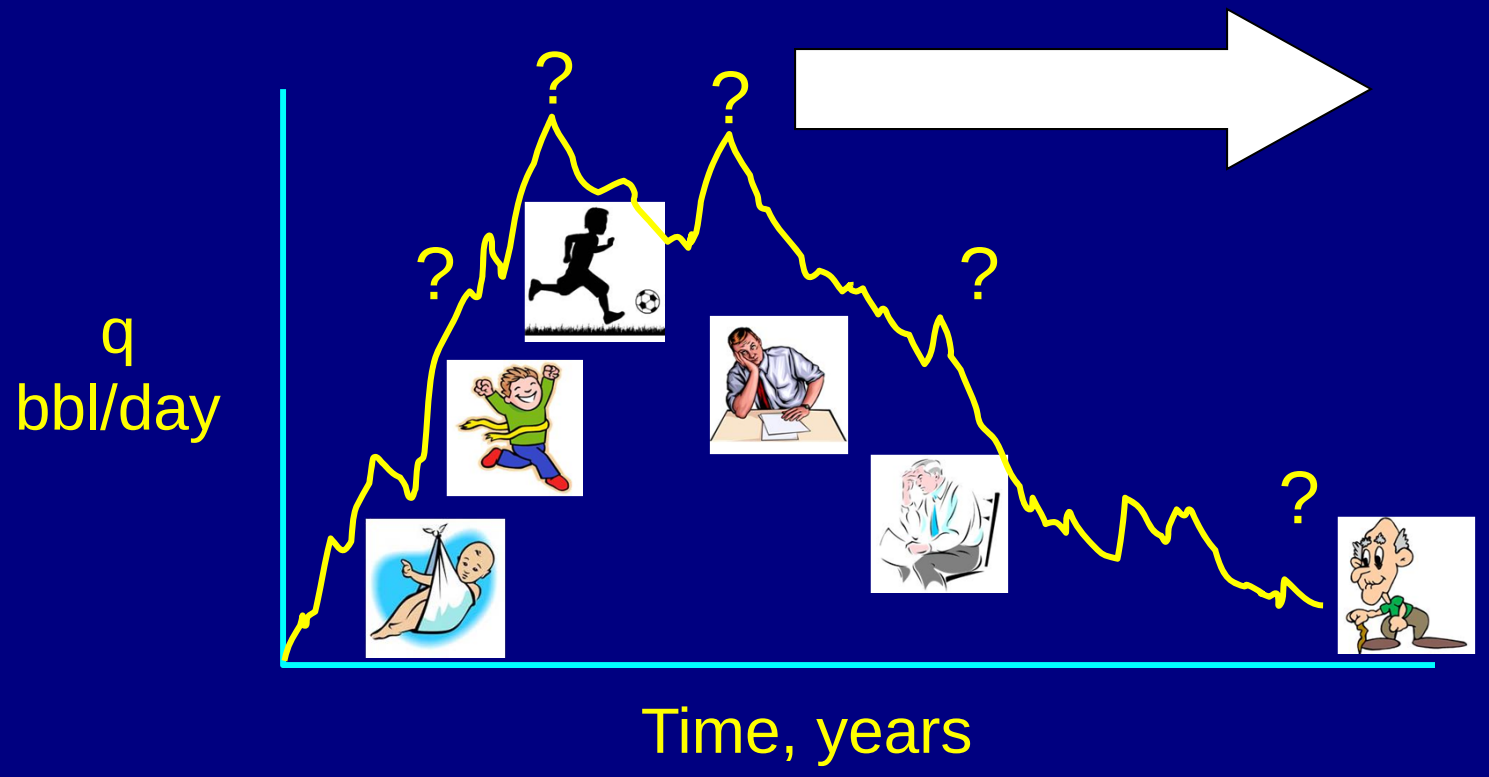
OUTLINE

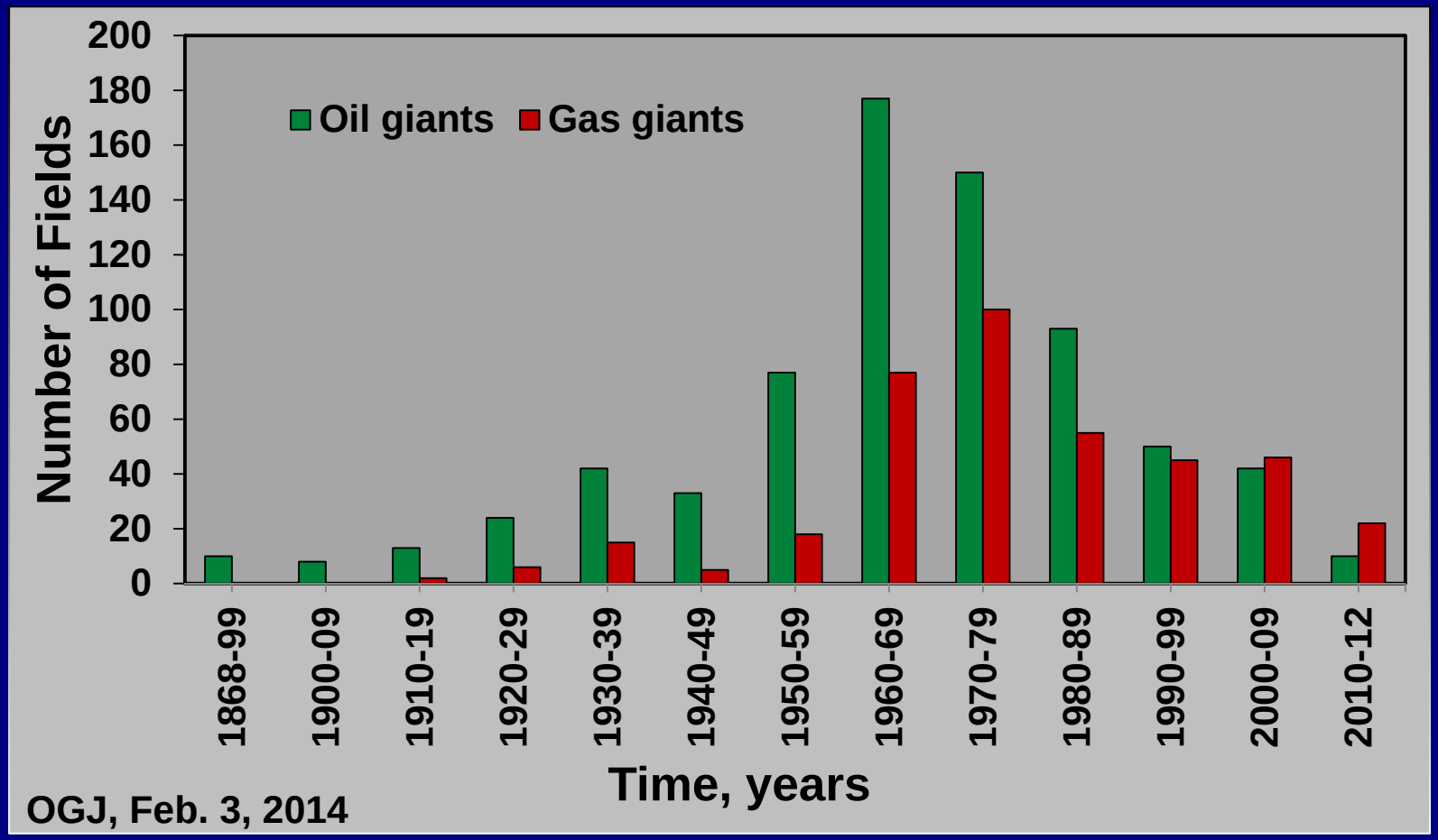
- **What is a mature field?**
- **How much oil is left and where it is**
- **Recovery of remaining oil: Tertiary recovery**
  - Laboratory scale
  - Field scale
- **Key points and suggestions**

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

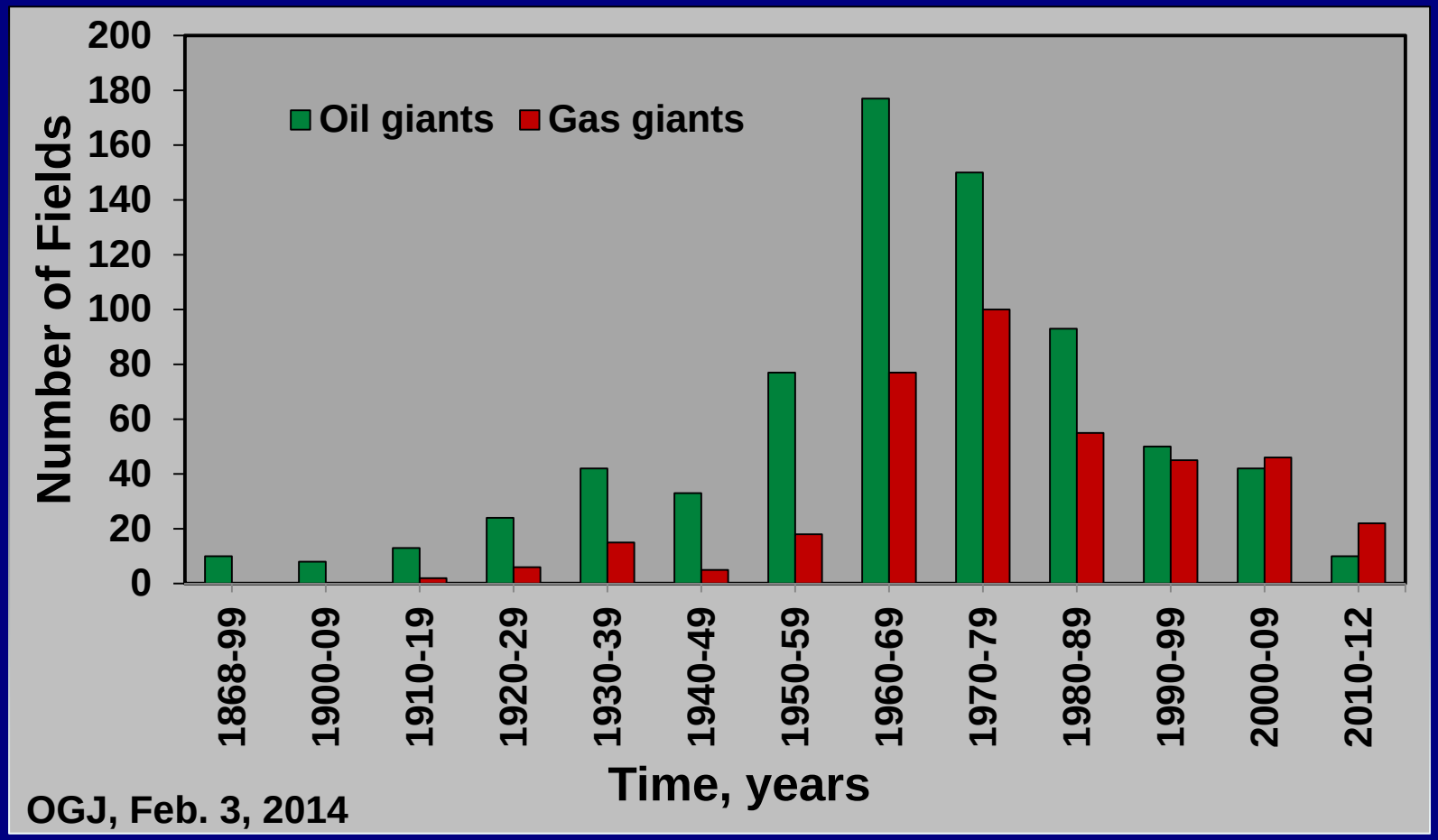


OIL FIELDS IN THE WORLD: 30,000

TOTAL RESERVES: 150 MMMm^3

} 33 Fields: 50%

Giant Field Discoveries



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

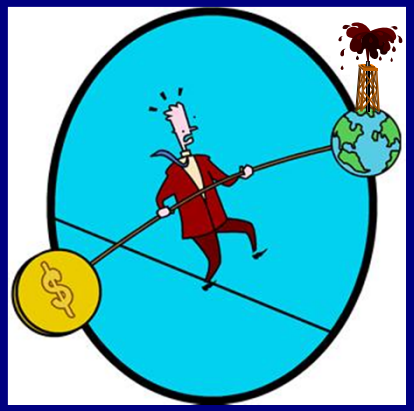
Modern technologies

Disadvantages

Cost

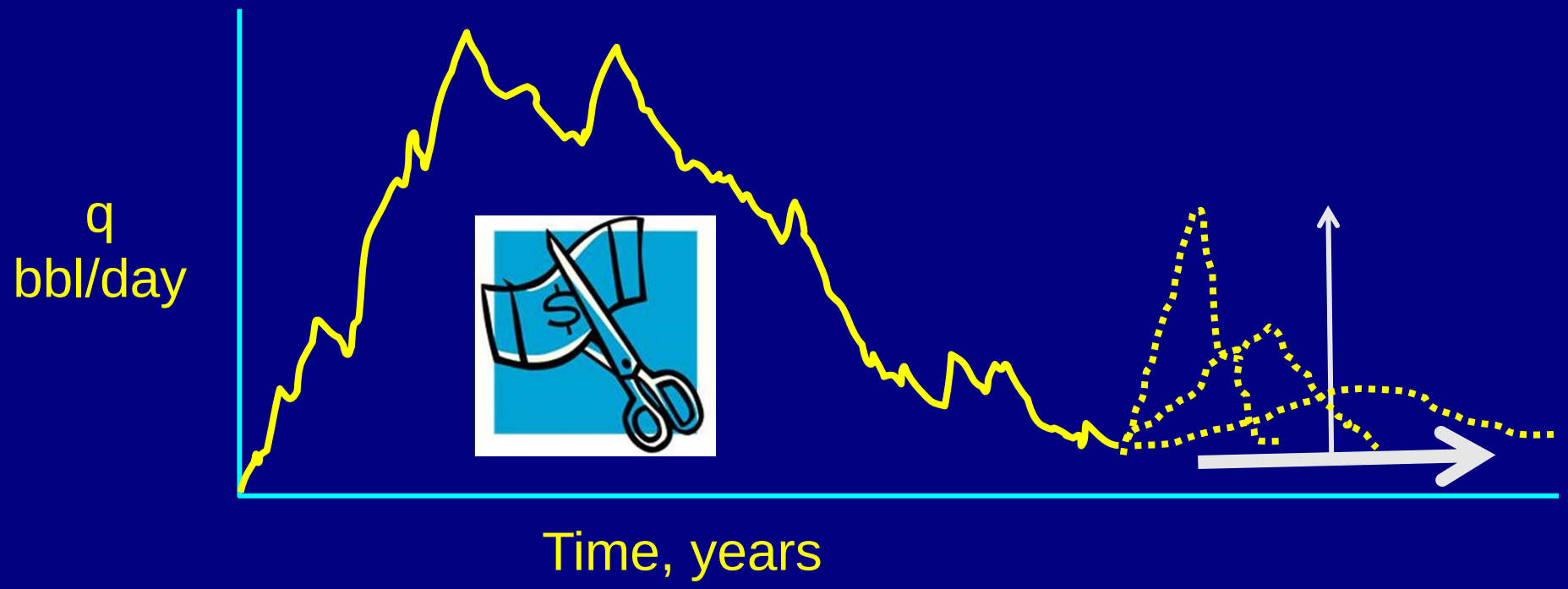
Efficiency

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
(Tertiary Recovery)

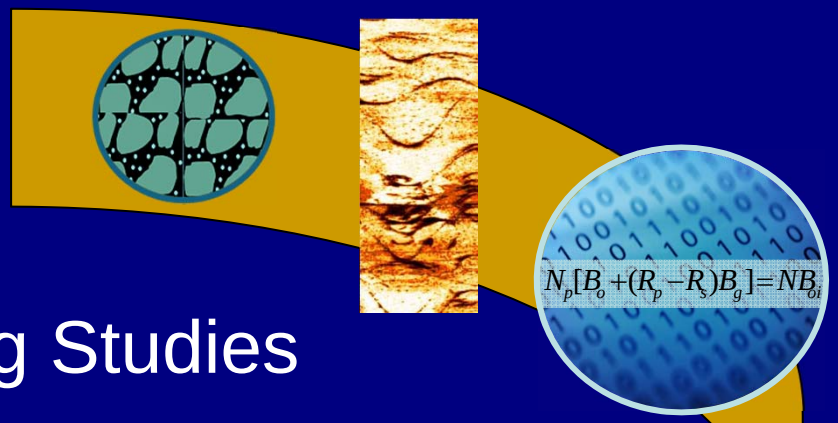
How much oil is left and where it is

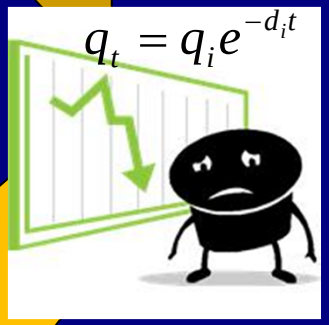
Tertiary recovery

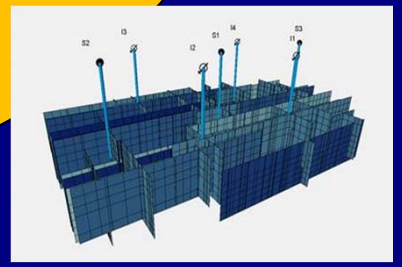
- **Laboratory**
- **Field**

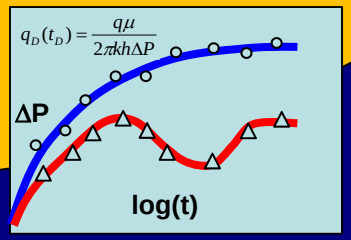
Determination of Remaining Oil Saturation

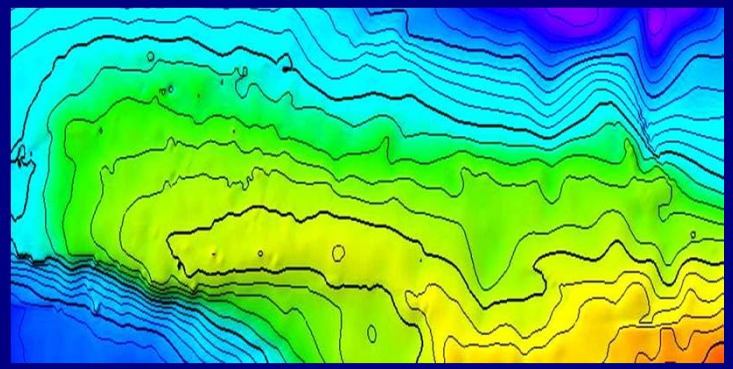
- Core Analysis
- Logs
- Reservoir Engineering Studies
- Production Data
- Chemical Tracers
- Well Testing (with core analysis)





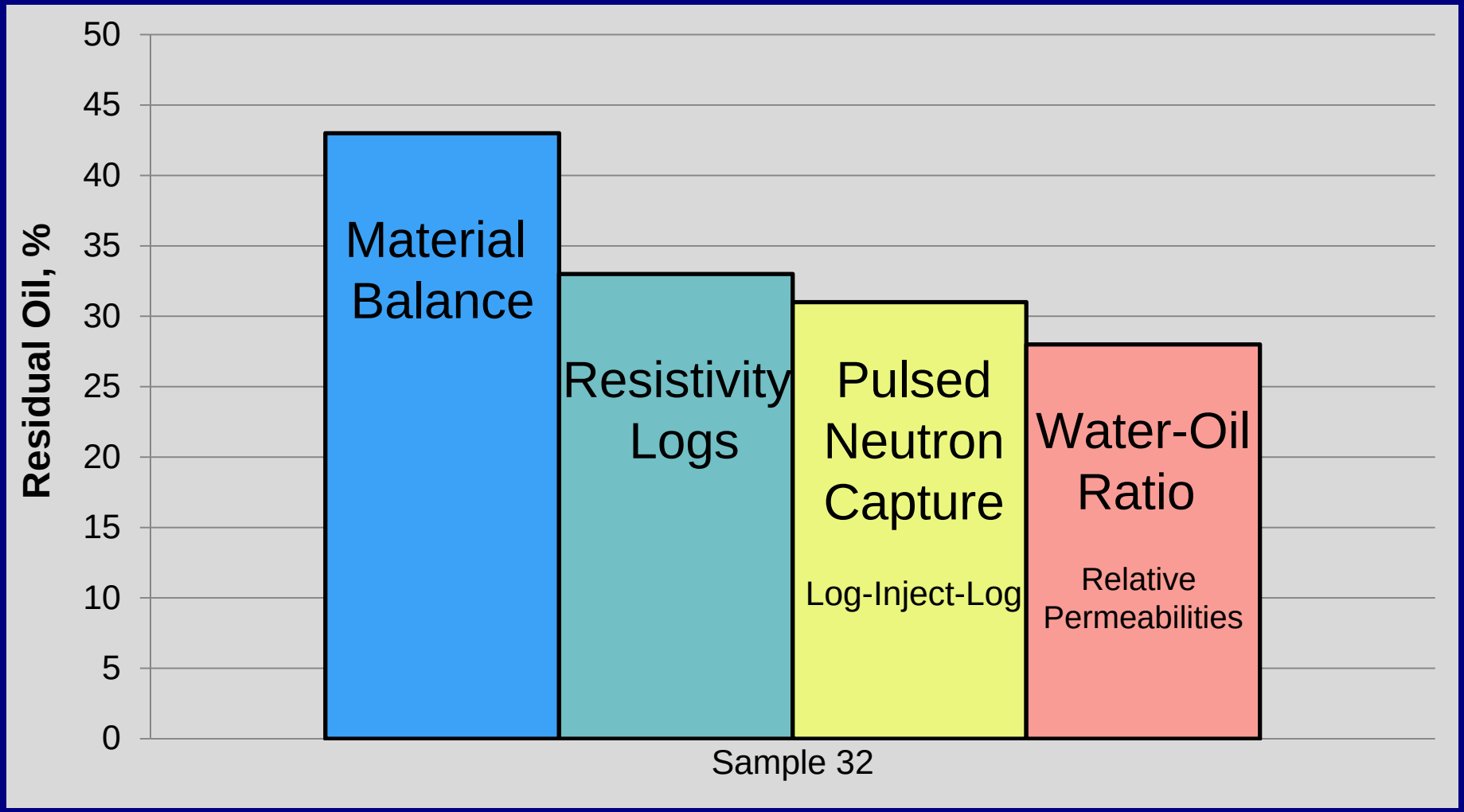






Remaining Oil Saturations – Different Methods

(33 sandstone fields)



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

Remaining Oil Saturations – Different Methods

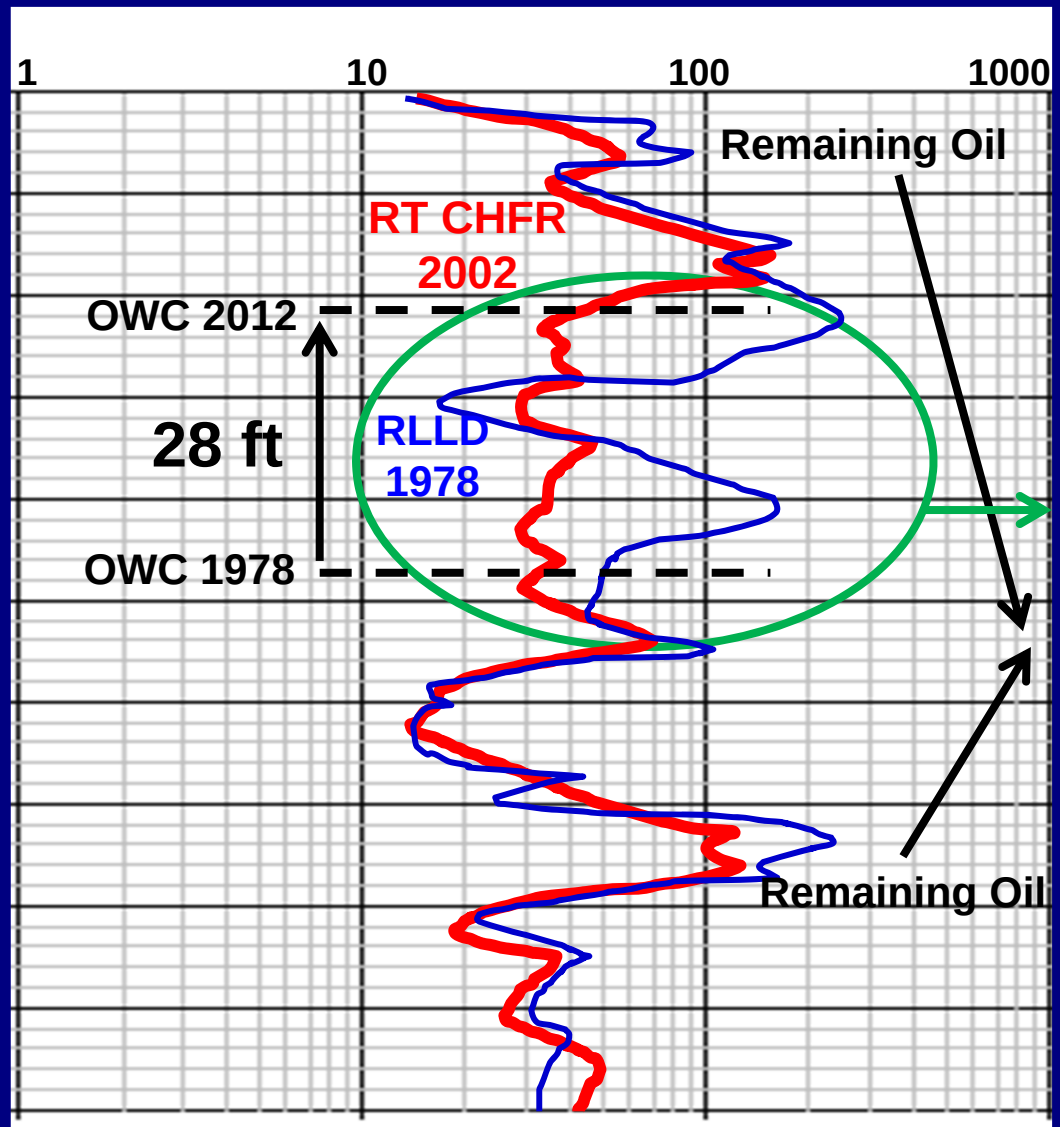
Field	RESIDUAL OIL		SOLUTION
	Material Balance (% PV)	Tracer Test (%PV)	
1	16	12	No tertiary oil recovery More wells between producers
2	40	29	Tertiary oil recovery
3	44	12	Oil in isolated pockets Infill

-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: Remaining Oil Saturation (ROS)

ROS (Core, log, tracer) < ROS (Material balance)

ROS (Pulsed Neutron Capture) = ROS (Resistivity)

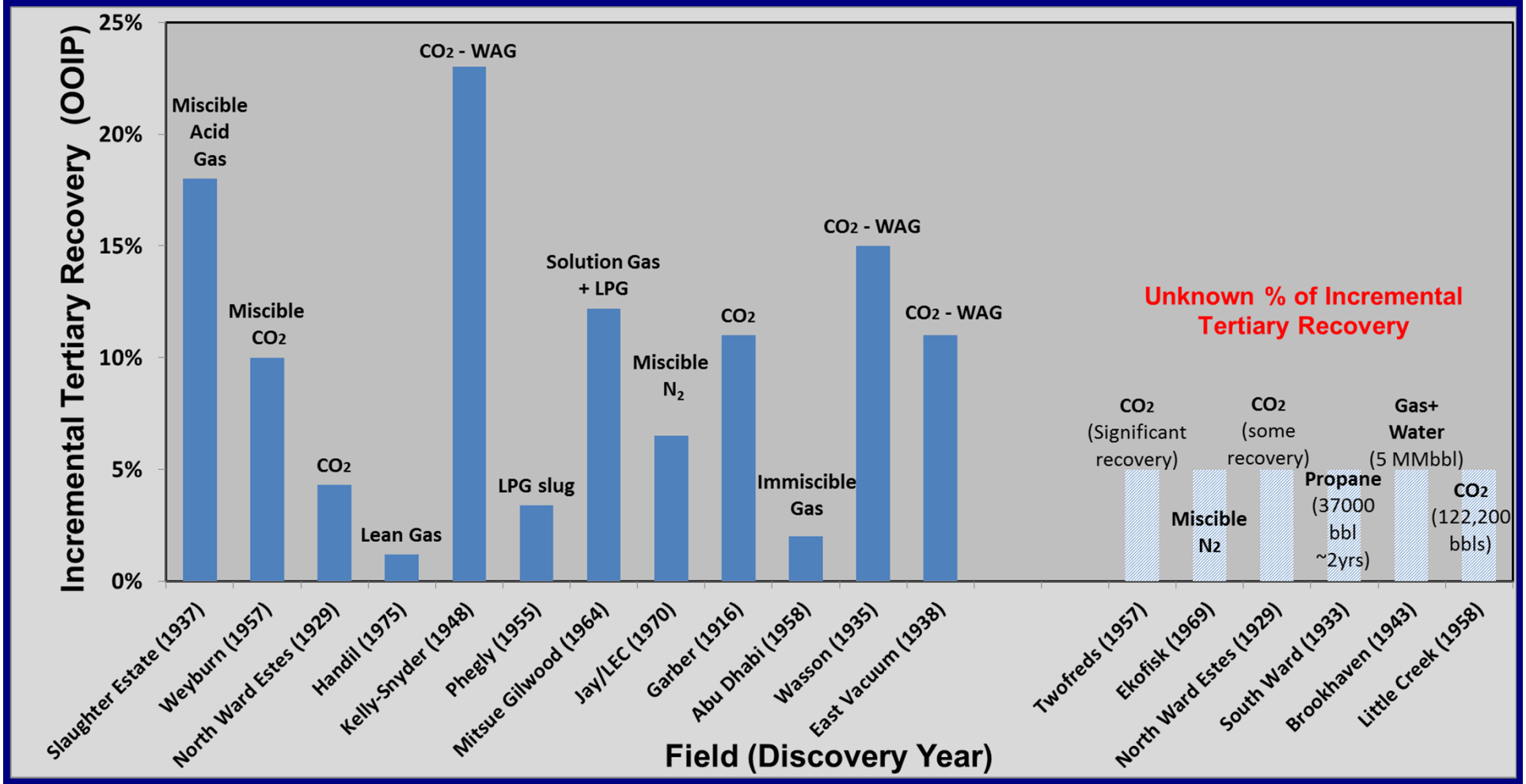
ROS (Single well tracer) < ROS (Logs)

Tertiary Recovery – Field Applications

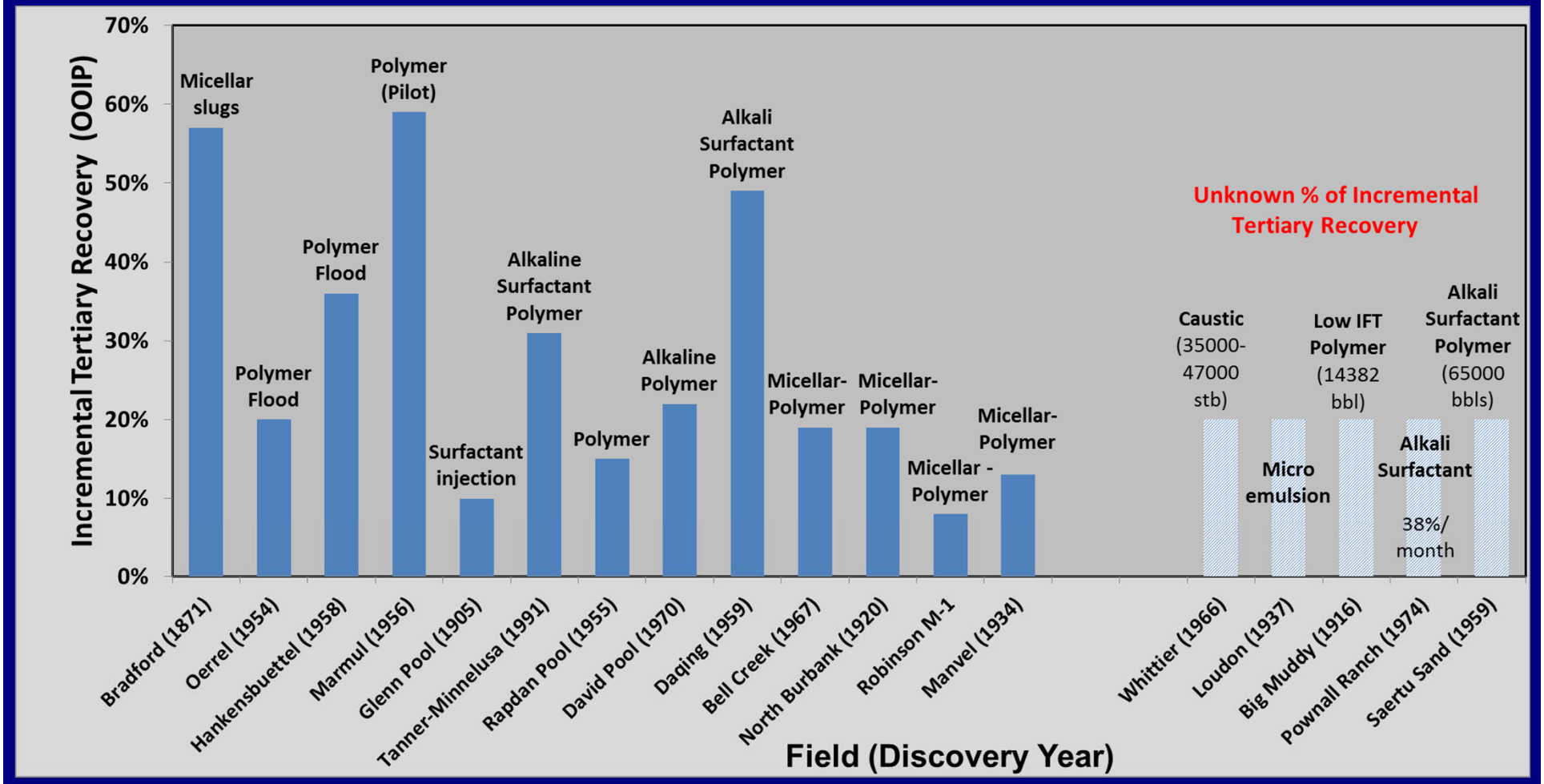
- **Immiscible gas injection**
  - -Double displacement
  - -Inert gas
- **Miscible gas injection**
  - -HC gases
  - -CO_2

- **Chemical (surfactant) injection**

Tertiary Gas Injection Applications



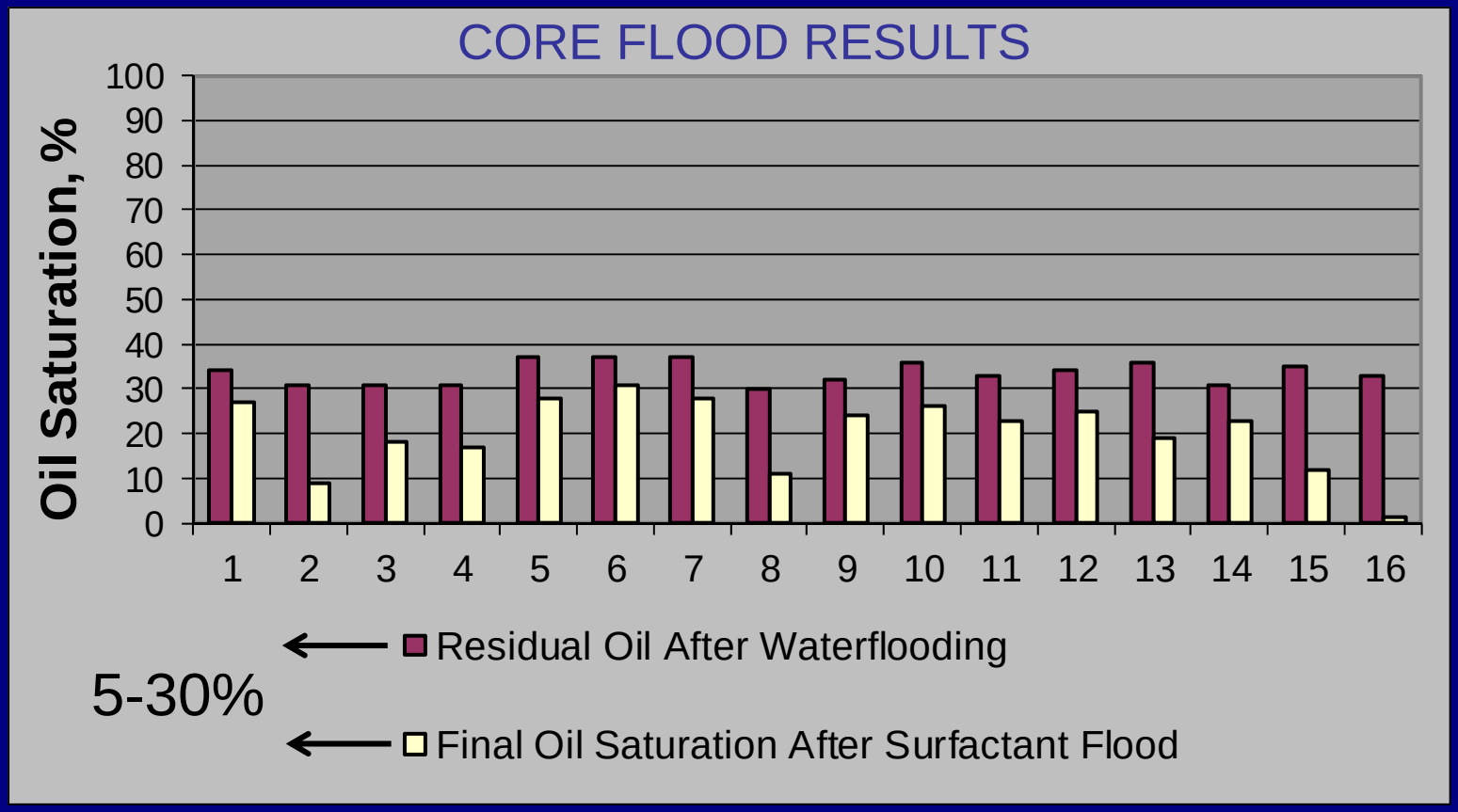
Tertiary Chemical Injection Applications



Surfactant Flood: Incremental Recovery

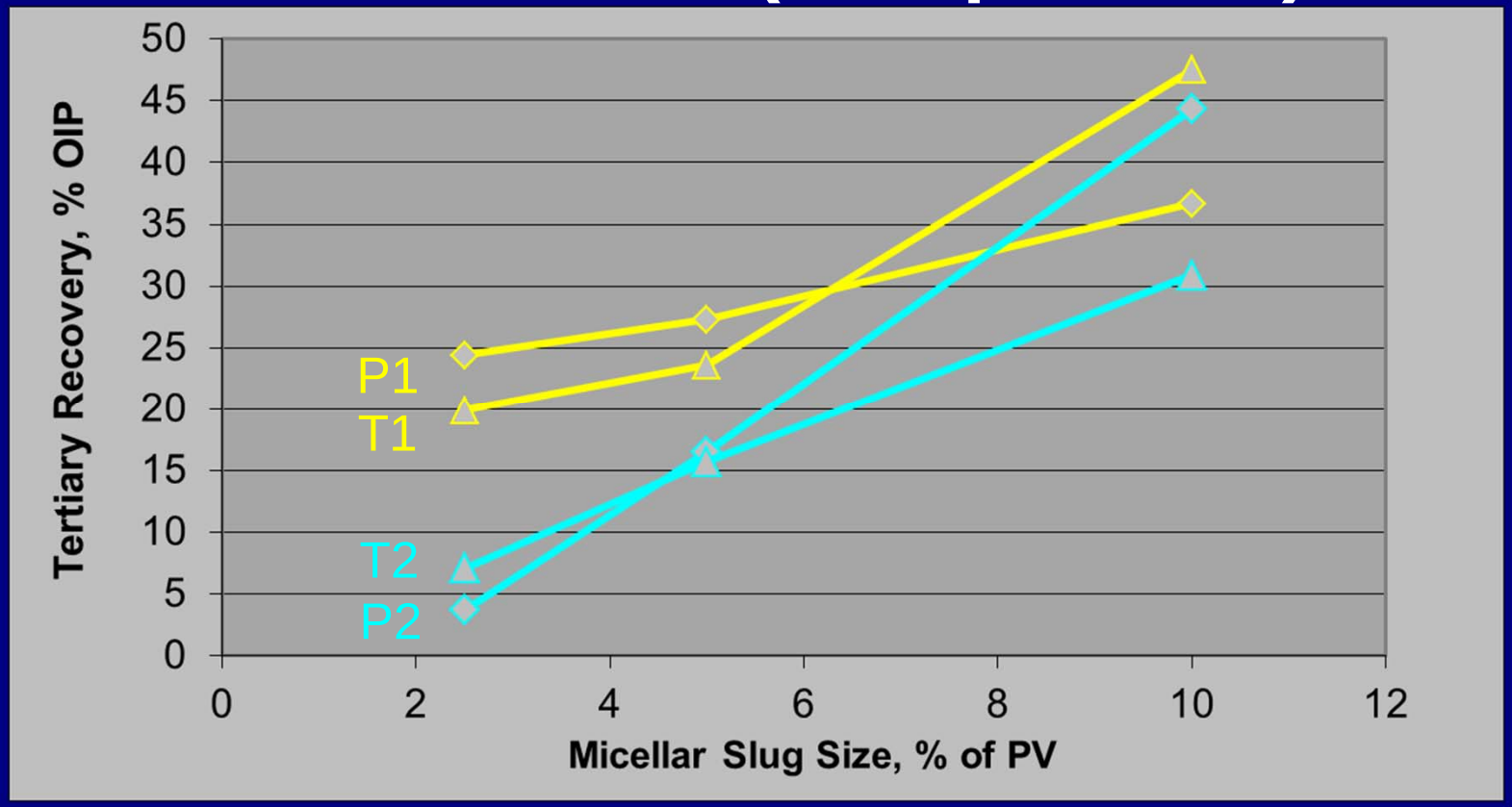
Loudon Field: 13 years primary, 38 years waterflooding.

Remaining oil: 50 % OOIP



SPE 20218

Micellar Flood (Composition)

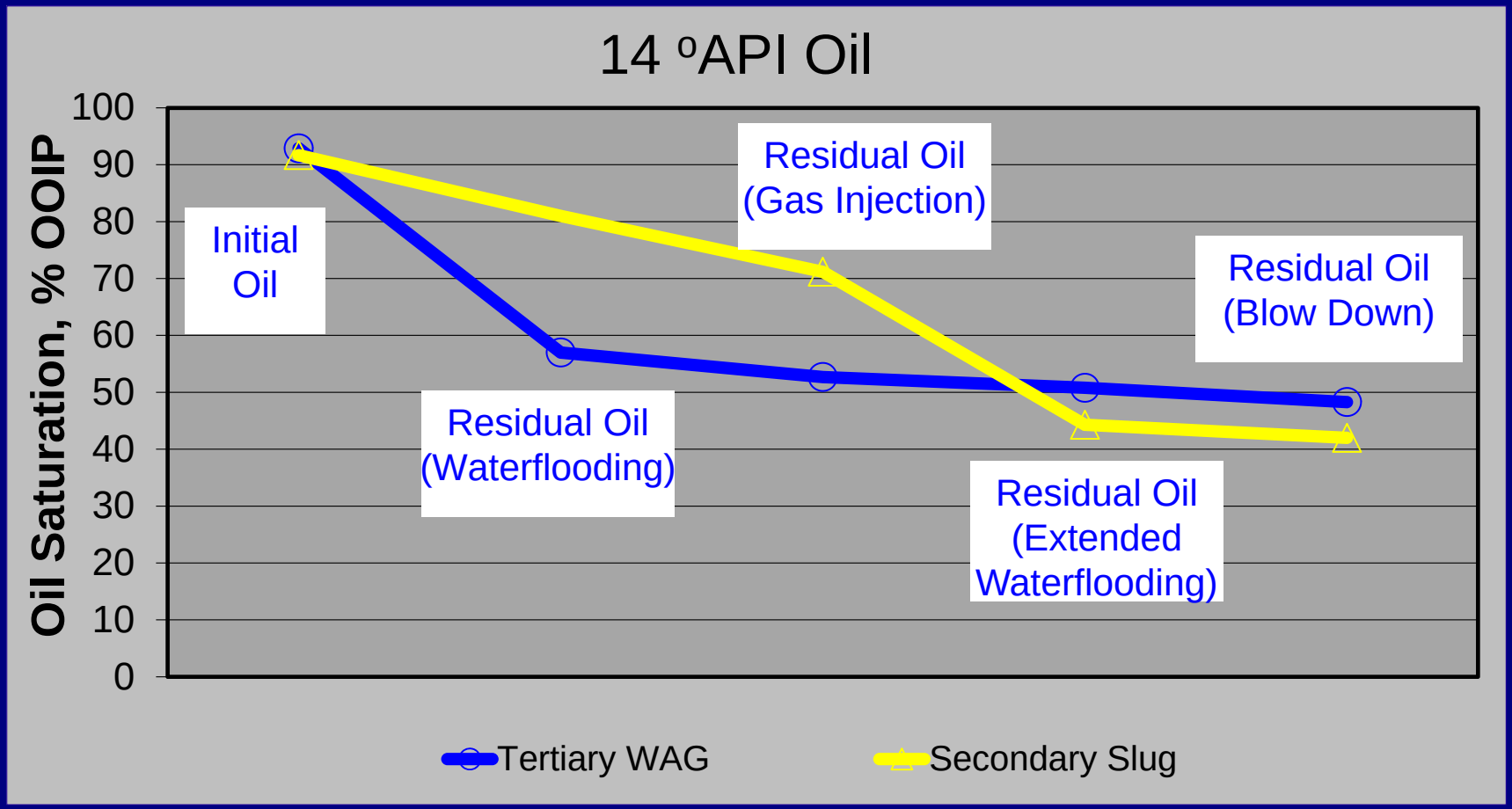


Type	Oil (%)	Brine (%)	Surfactant (%)	Co-Surfactant (%)
P1	64	20	12	4 (Isopropyl Alcohol)
T1	85	5	8.5	1.5 (Isopropyl Alcohol)
P2	6	84	7.5	3 (Cyclohexanol)
T2	2	93	4	1.5 (Cyclohexanol)

JCPT
Jan-Feb
1990

Sequence of Methods

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

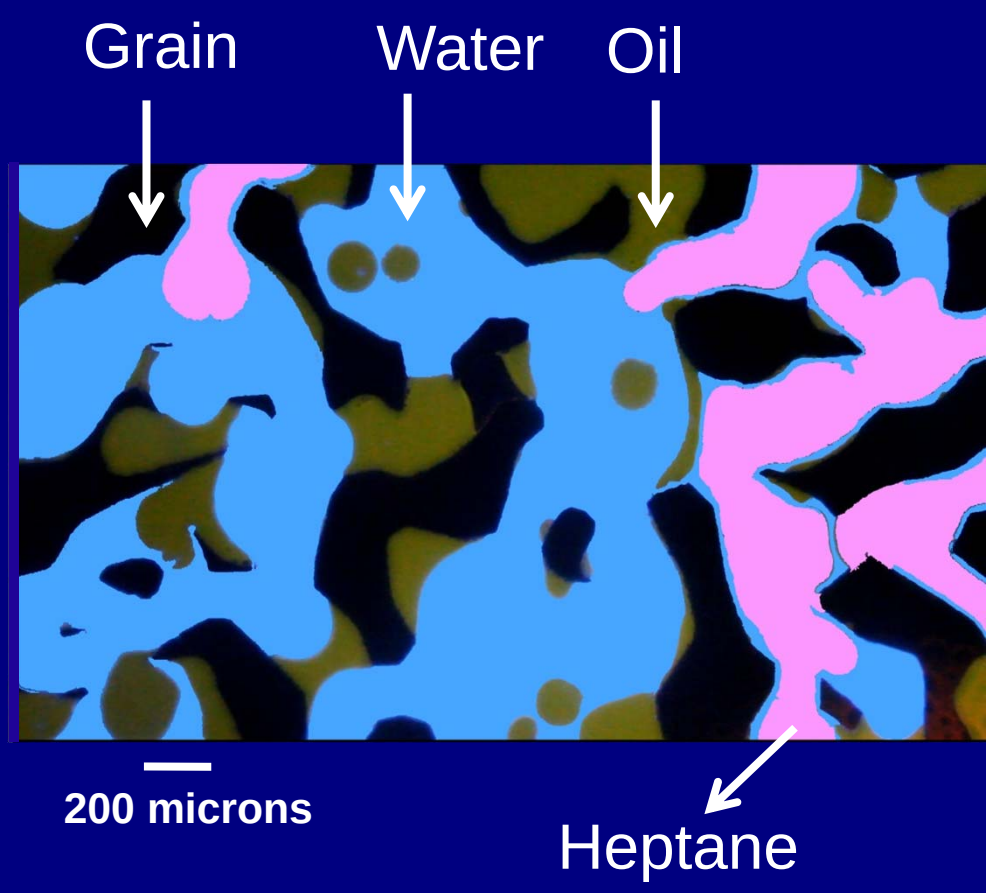


46th Annual Tech. Meet. of the Petroleum Society, Banff, Canada, 1995, Paper 65-95

Tertiary Recovery by Hydrocarbon Solvent

Miscibility after waterflood

- Solvent invade only water filled pores.
- Oil may not be displaced from the smaller pores.
- Water film between solvent and oil/grain



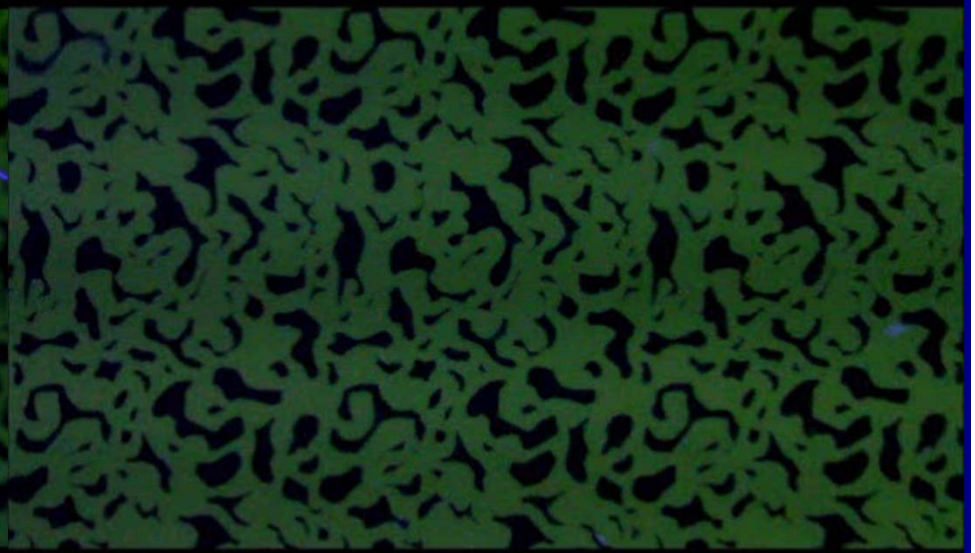
Tertiary Recovery by Solvent

Kerosene (2 cp)

Solvent → Water

RF=69%

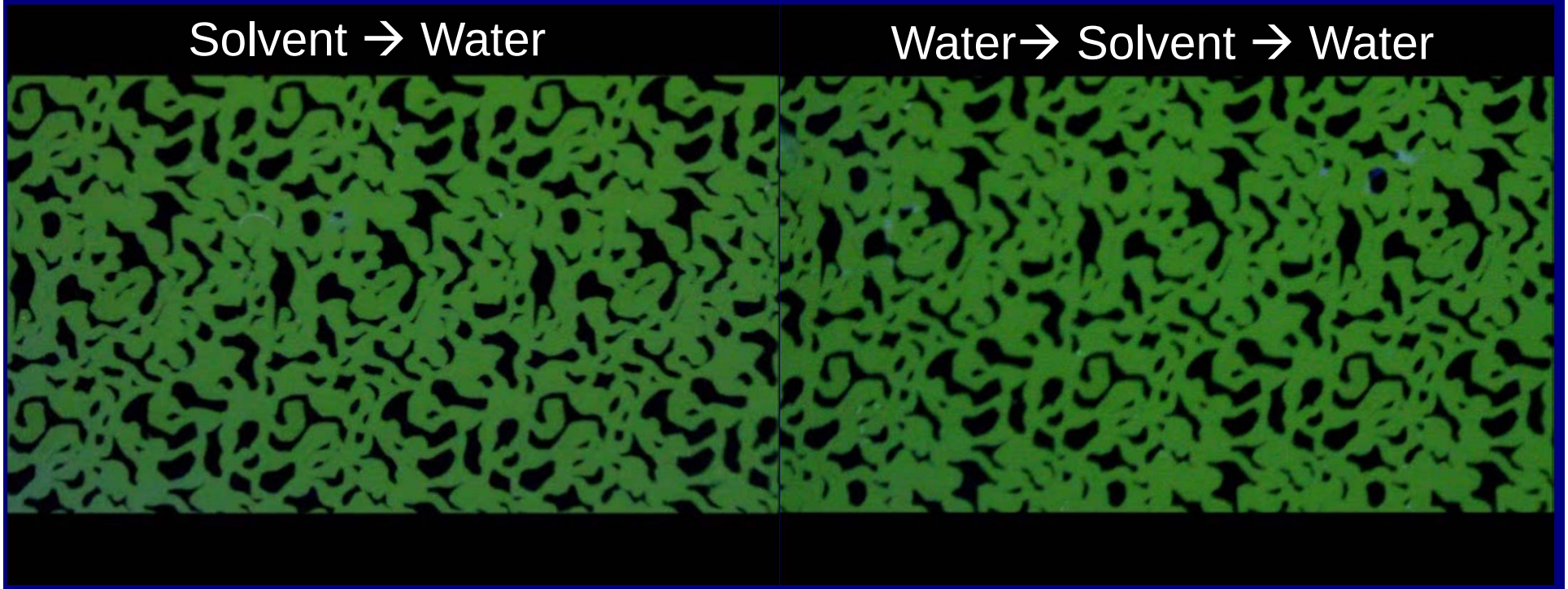
Water→ Solvent → Water



RF=47%

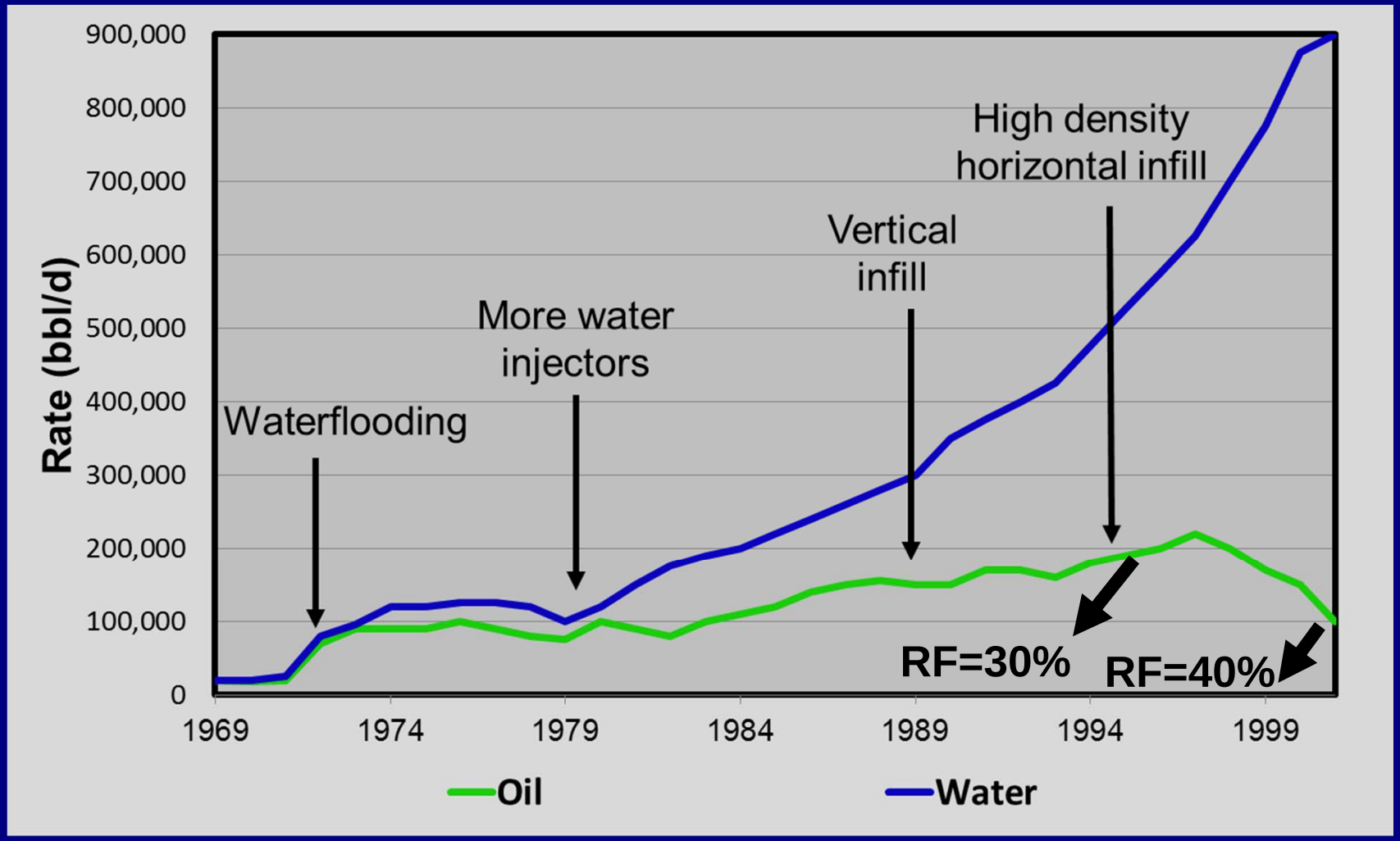
Tertiary Recovery by Solvent

Kerosene (2 cp) - Mixed Wet



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

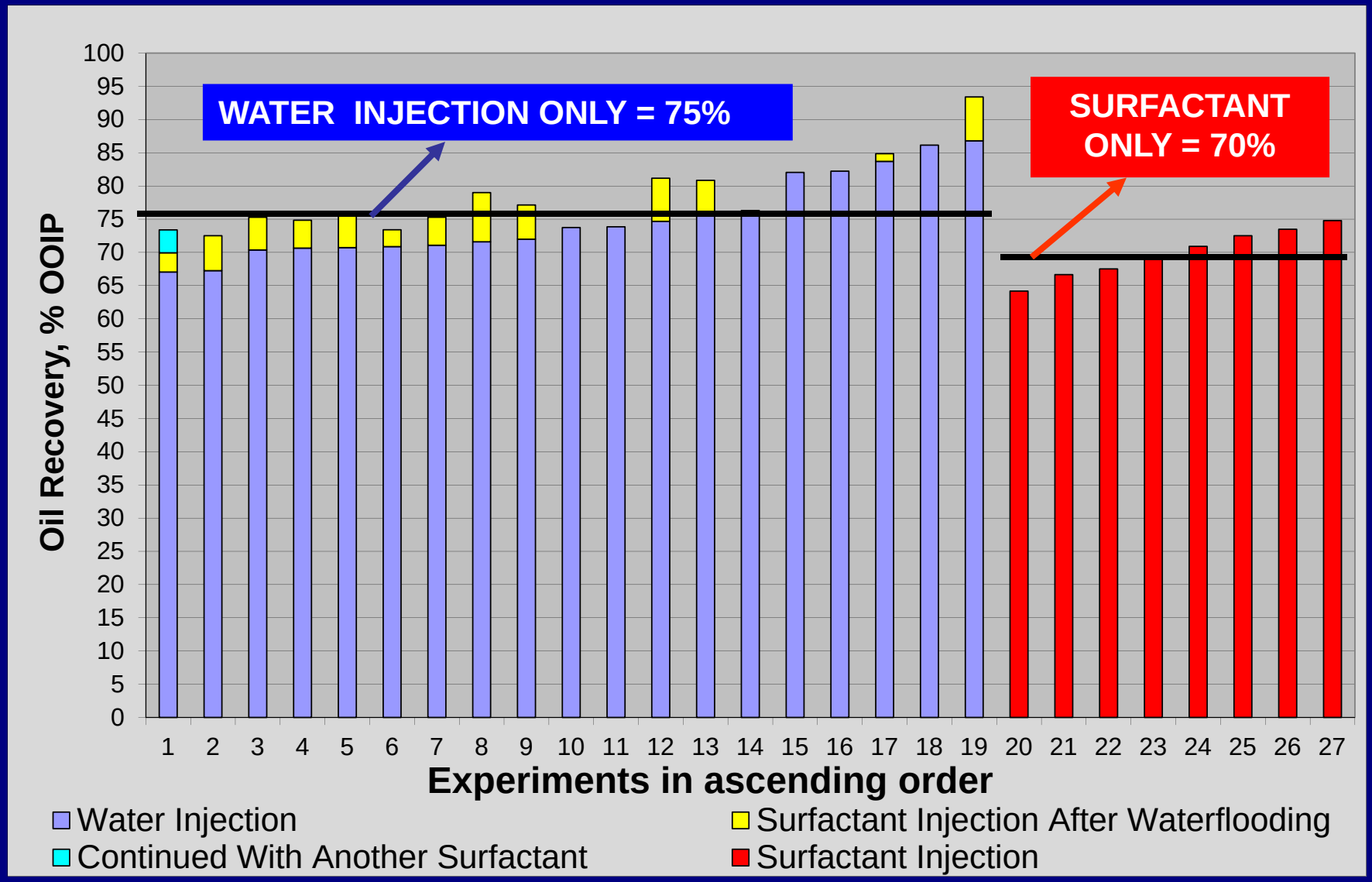
YIBAL FIELD



- 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



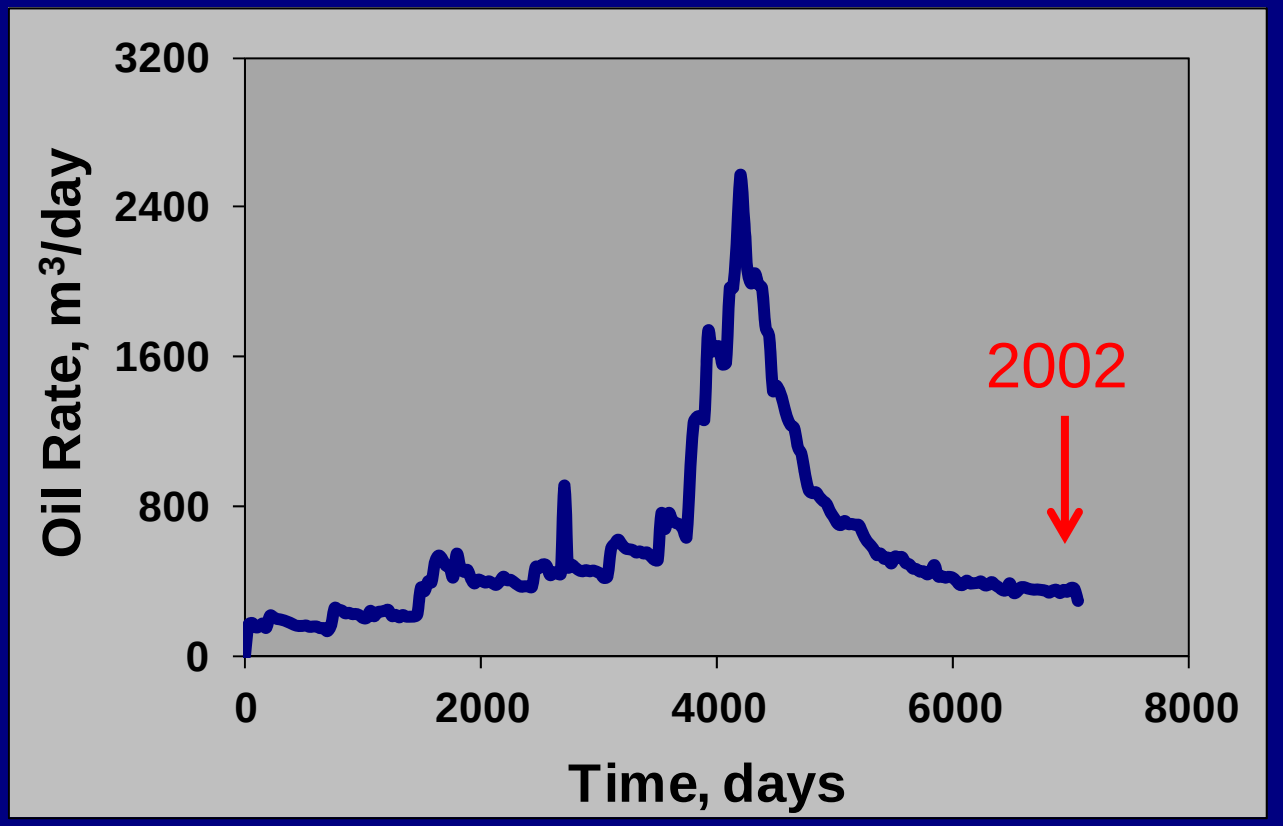
SAHMAH FIELD

-Small field: 20 wells

-Small company

-Short term targets

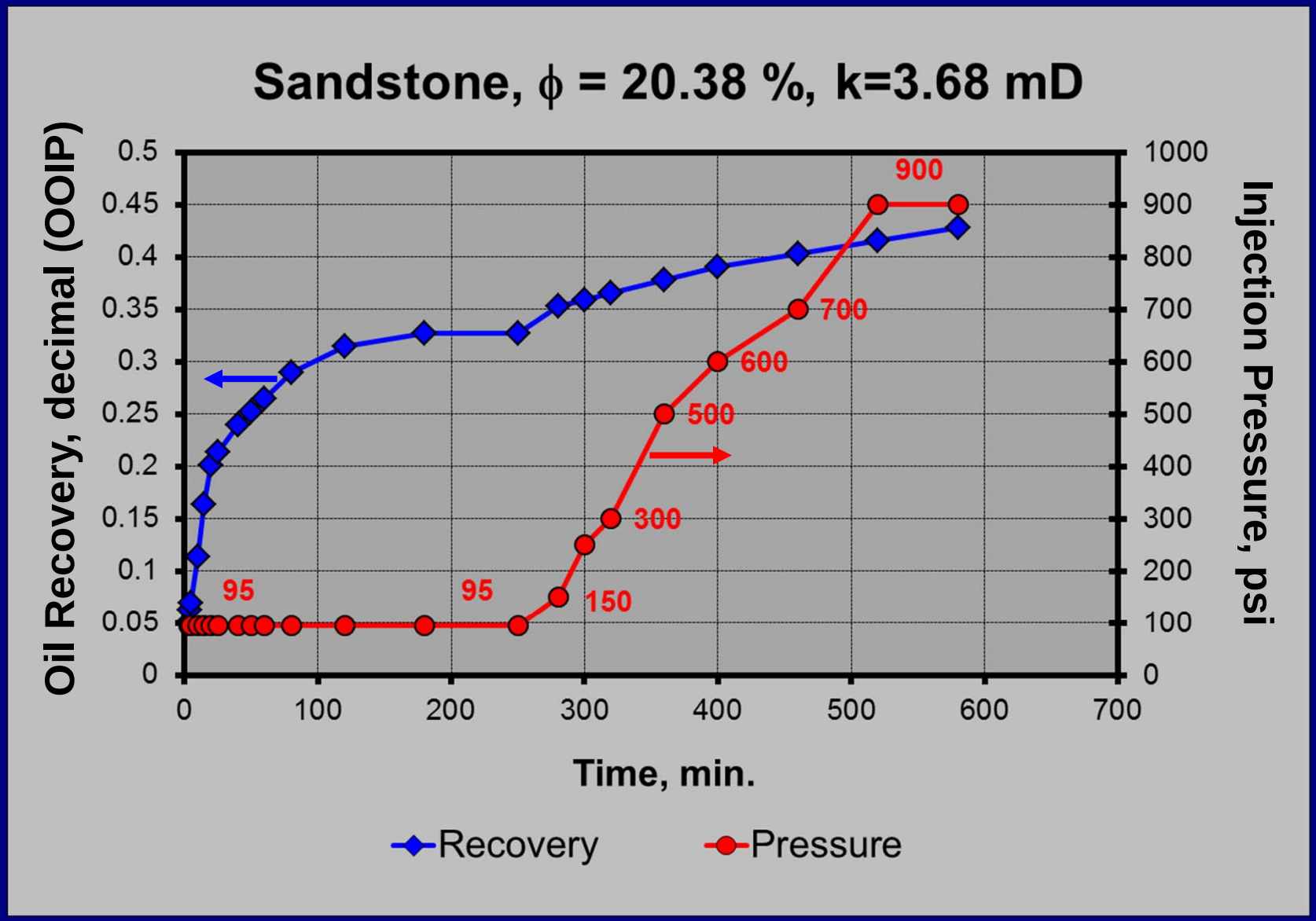
-Low investment



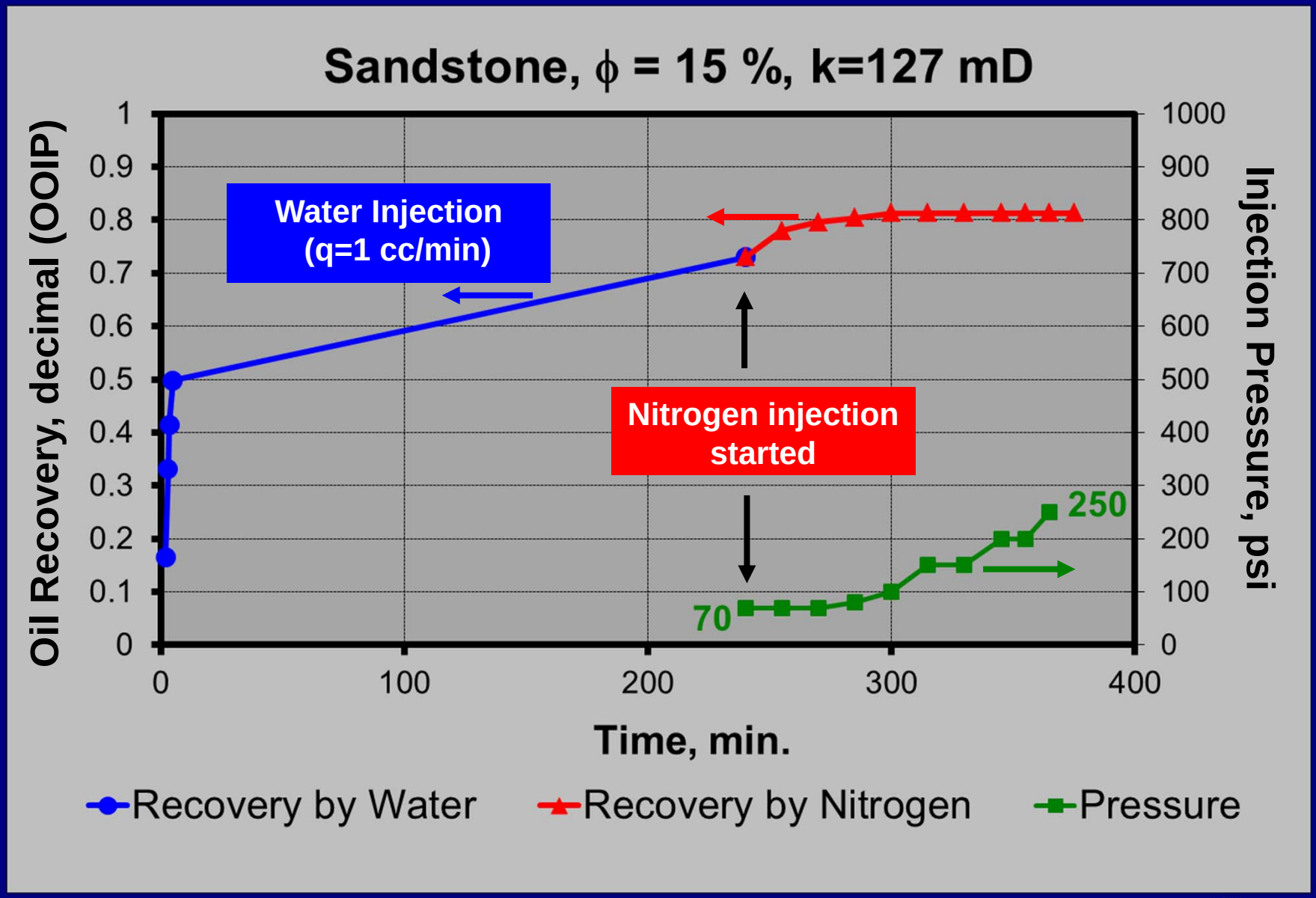
- Sandstone
- Oil: 45 ^{o}API, 1 cP
- Natural water influx
- Deep: 3,250m

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

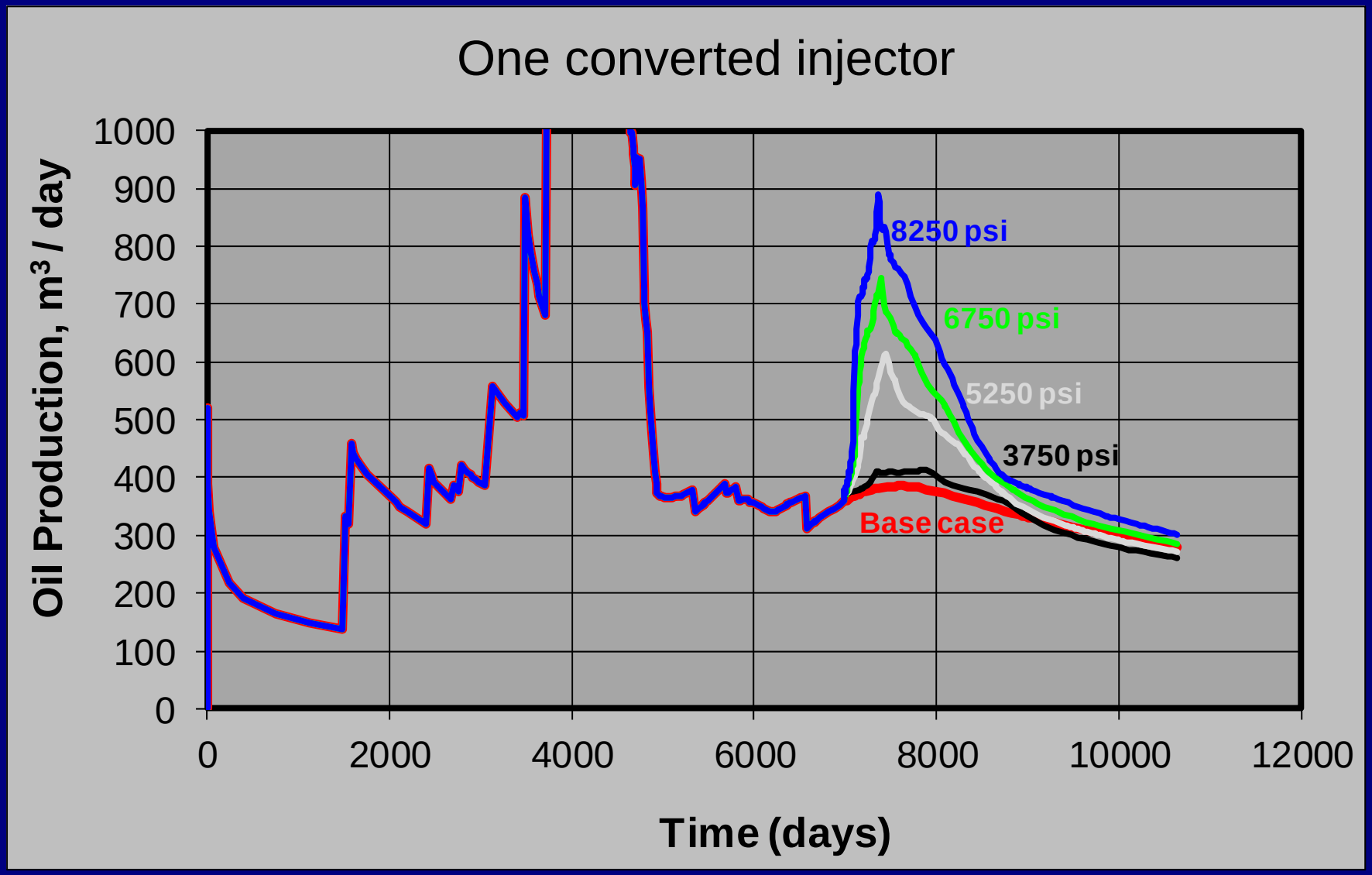
Nitrogen injection into tight zone



Nitrogen injection into waterflooded zone



Field scale simulation



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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