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# SPE Distinguished Lecturer Series

# *Viscous Oil EOR by Viscosity Reducing Immiscible (VRI) WAG Process*

*Bharat S Jhaveri*

*BP Exploration (Alaska) Inc.*

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† SPE 93914
Viscosity Reduction WAG: An Effective EOR Process for North Slope Viscous Oils
P. L. McGuire, BP Exploration (Alaska) Inc., R. S. Redman, ConocoPhillips Alaska Inc., B. S. Jhaveri, K. E. Yancey, S. X. Ning, BP Exploration (Alaska) Inc.

# Outline

- Motivation
- Miscible WAG* EOR
- Viscosity Reducing Immiscible WAG
- North Slope Situation
- Closing Remarks

* Water-Alternating Gas

# Motivation For Gas EOR in Viscous Oil

- Conventional technology* not applicable
  - Too deep
  - Offshore
  - Arctic
- Big projects with many high rate wells
- Available gas resource

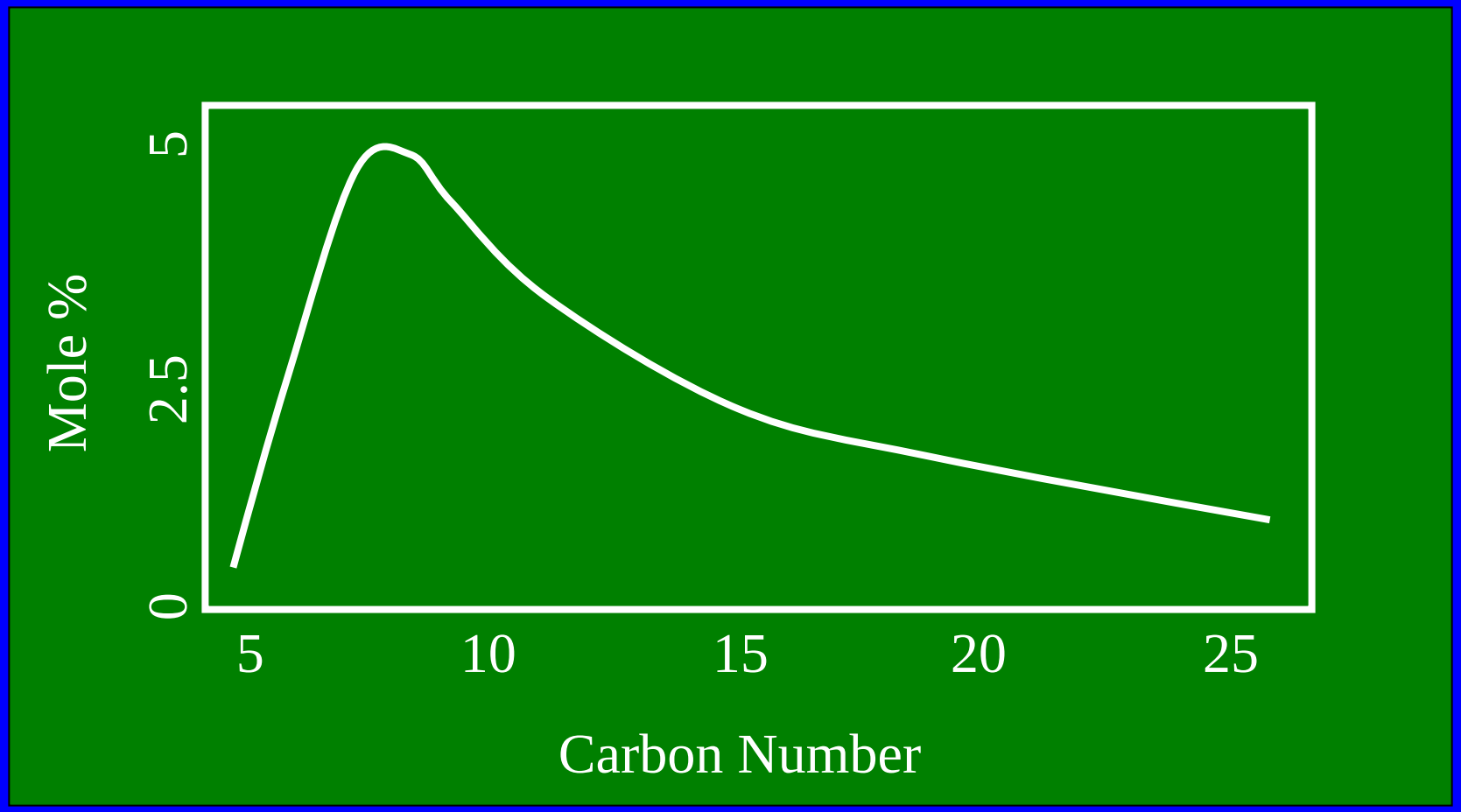
* e.g. Steam, Hot water flooding

# Outline

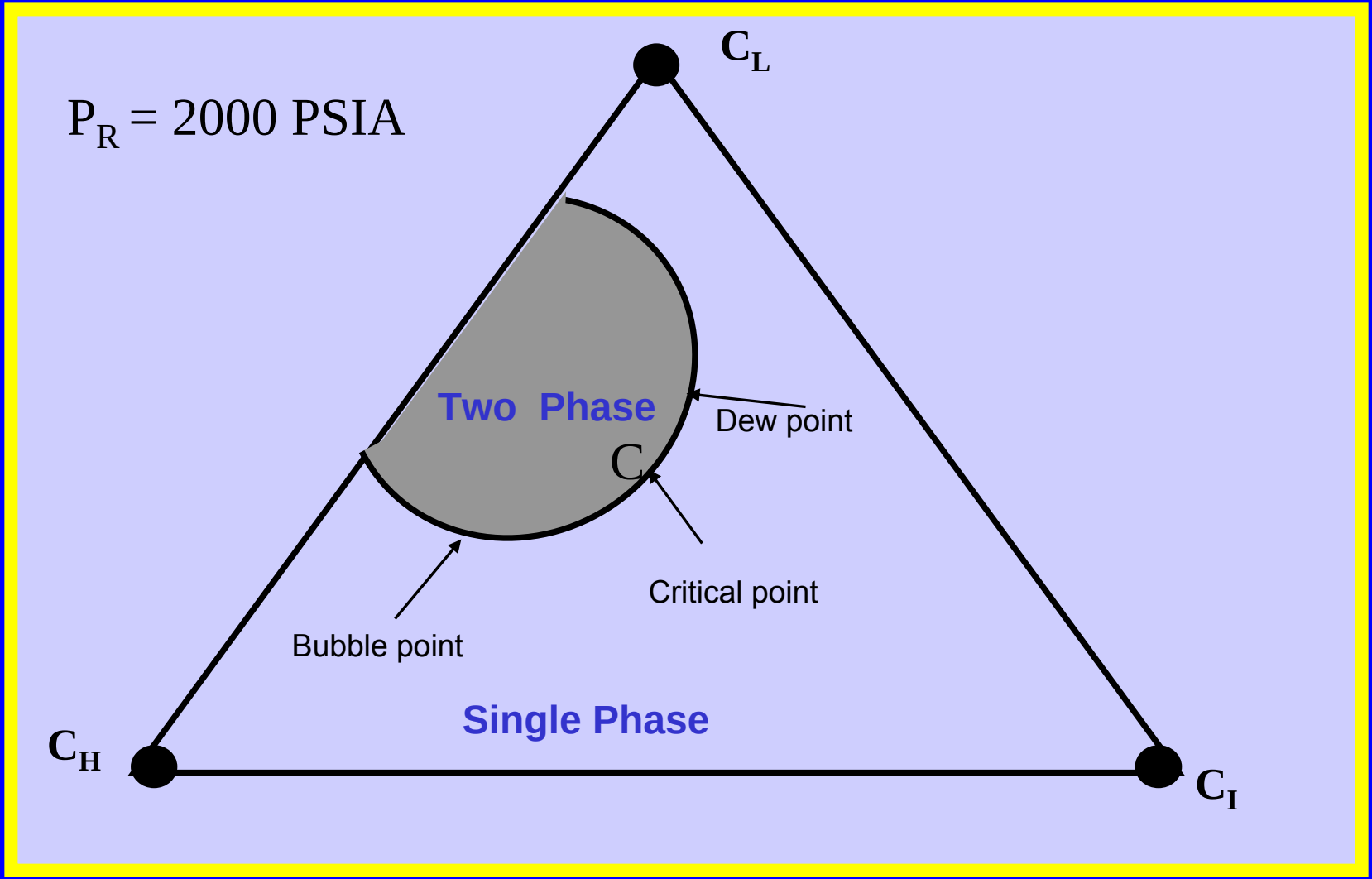
- Motivation
- Miscible WAG EOR
  - Enriched Gas Drive
  - Vaporizing Gas Drive
- Viscosity Reducing Immiscible WAG
- North Slope Situation
- Closing Remarks

# Miscibility Mechanism

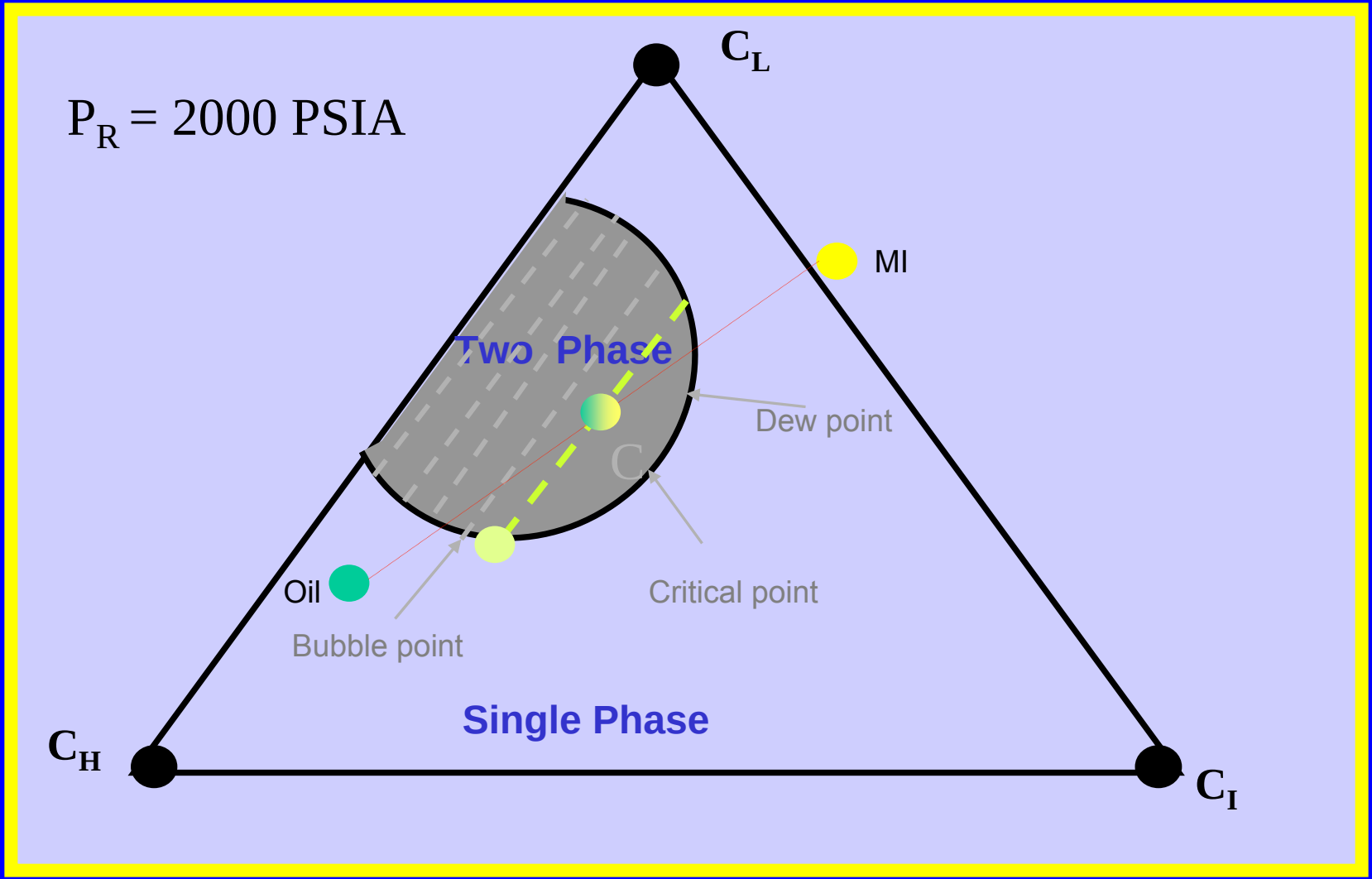
# Low Viscosity Oil – 10 cp



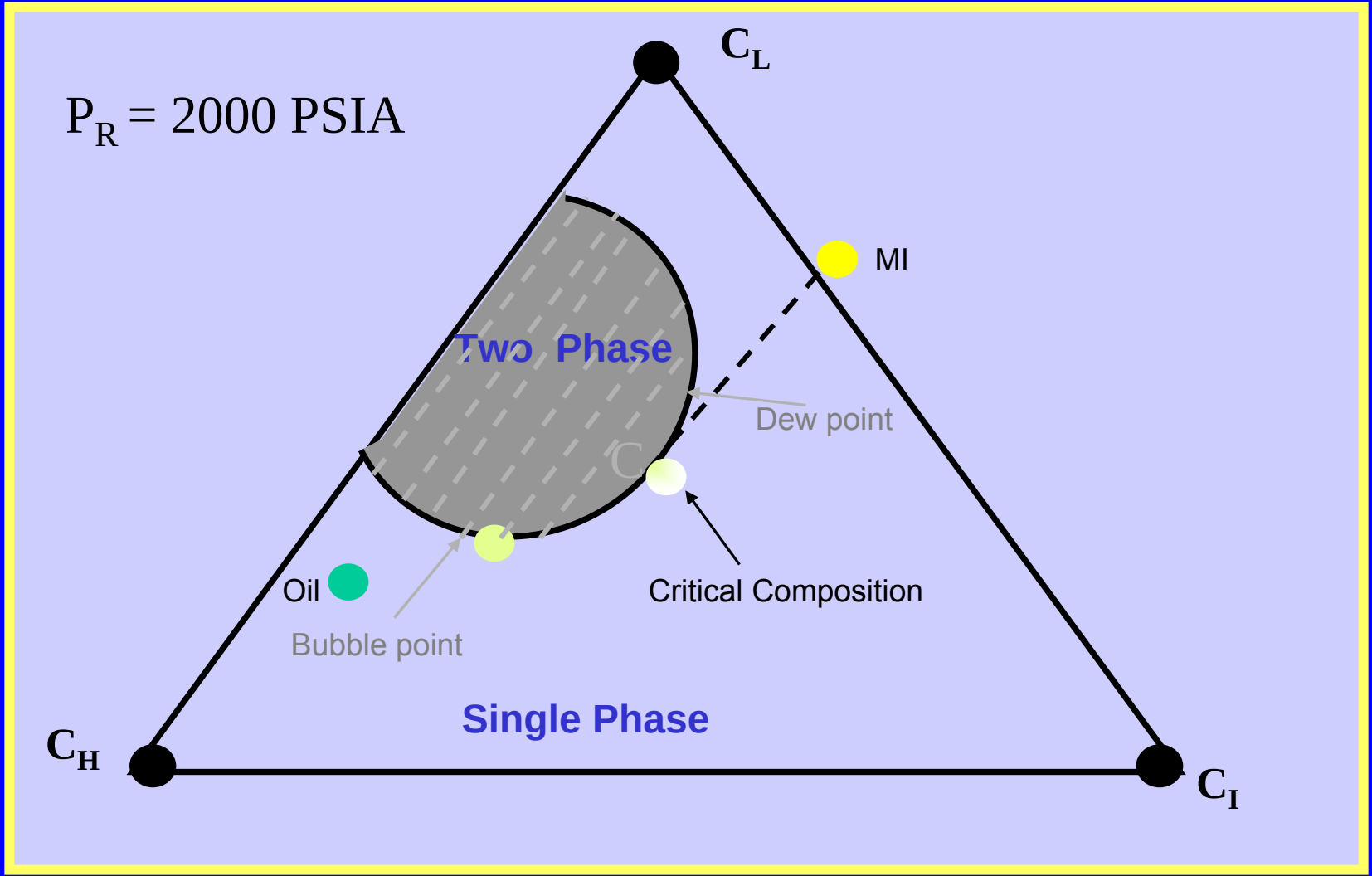
# Pseudo-Ternary Diagram



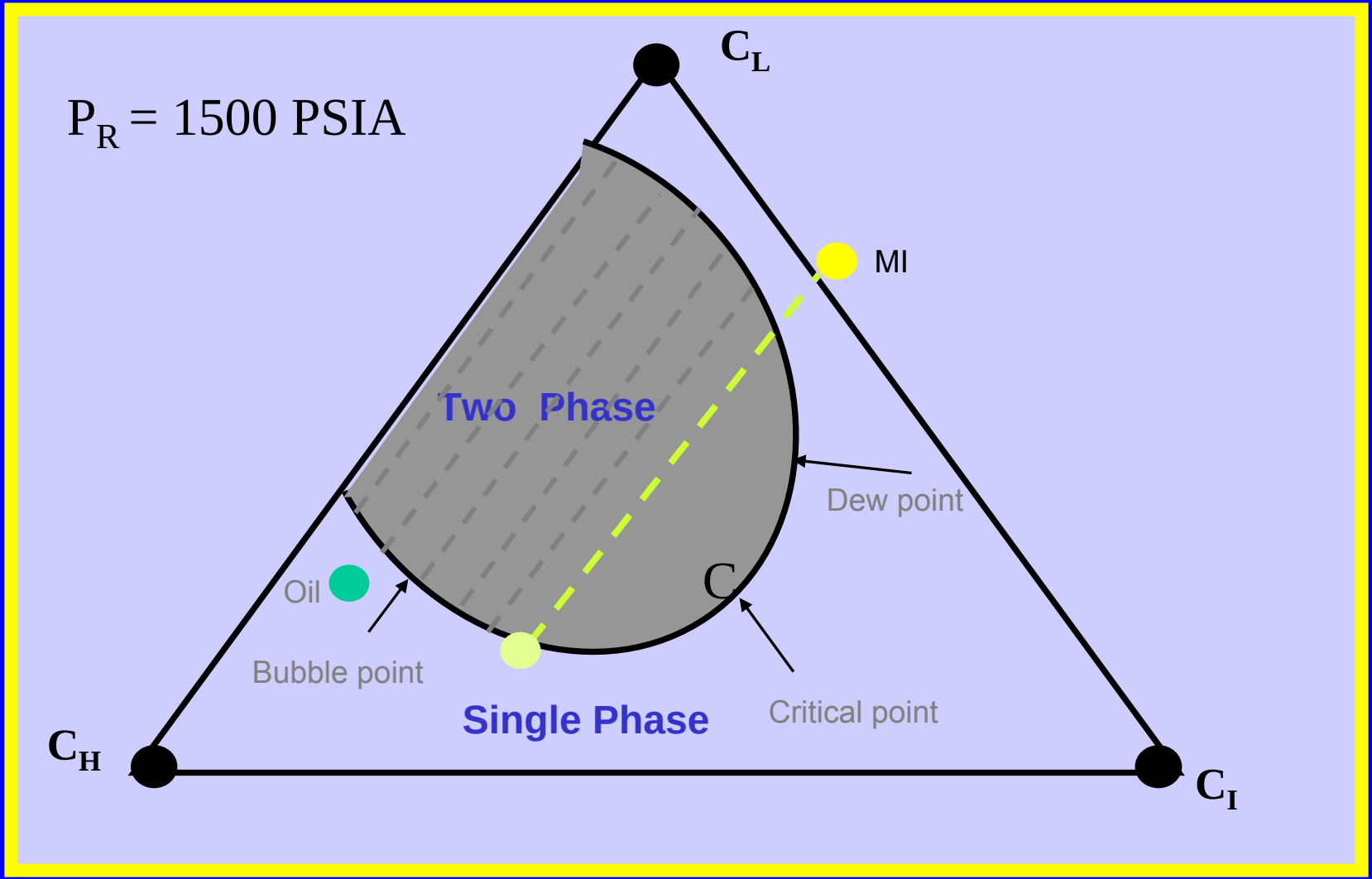
# Enrichment Process



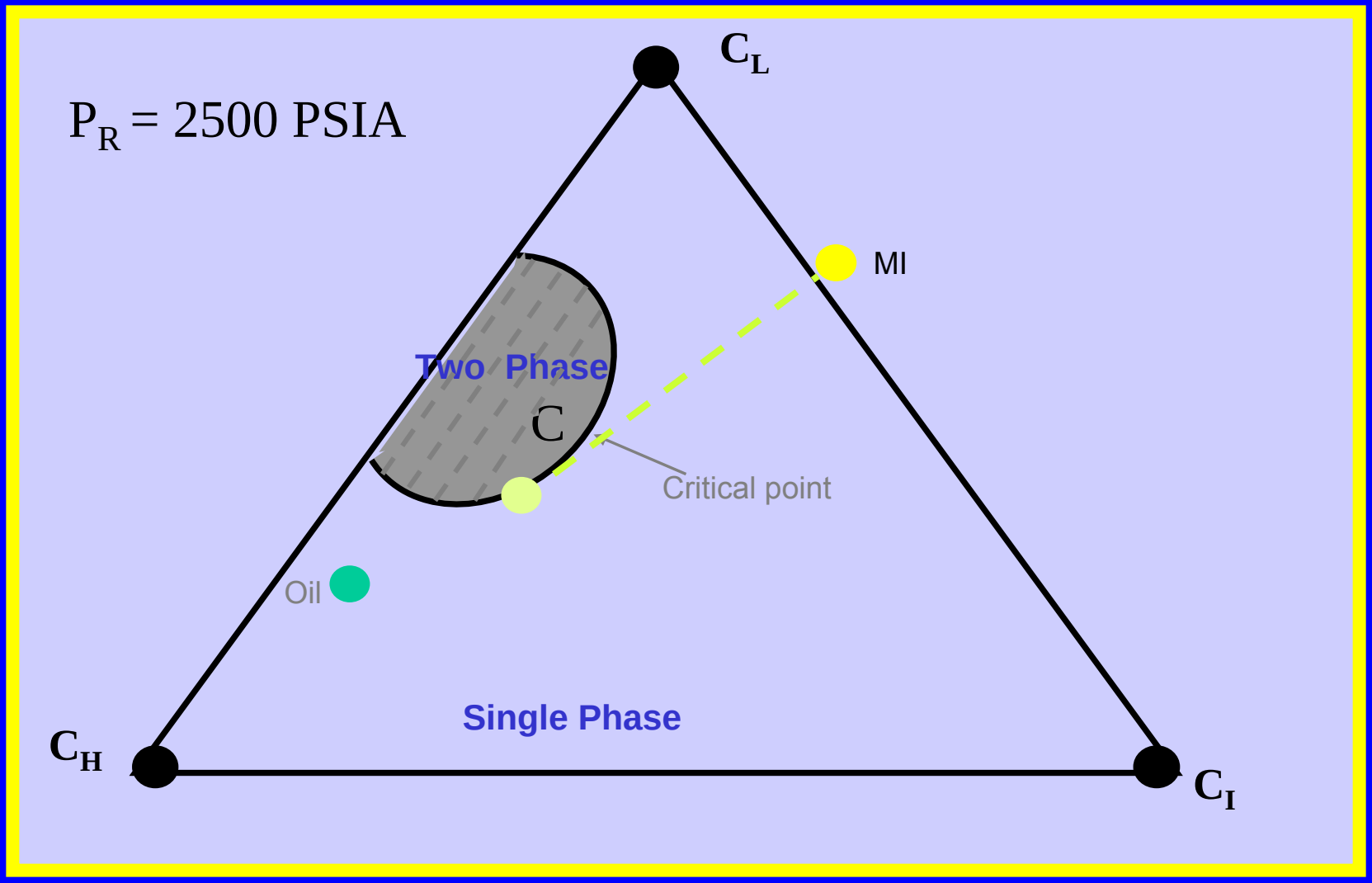
# MI - Oil Miscibility



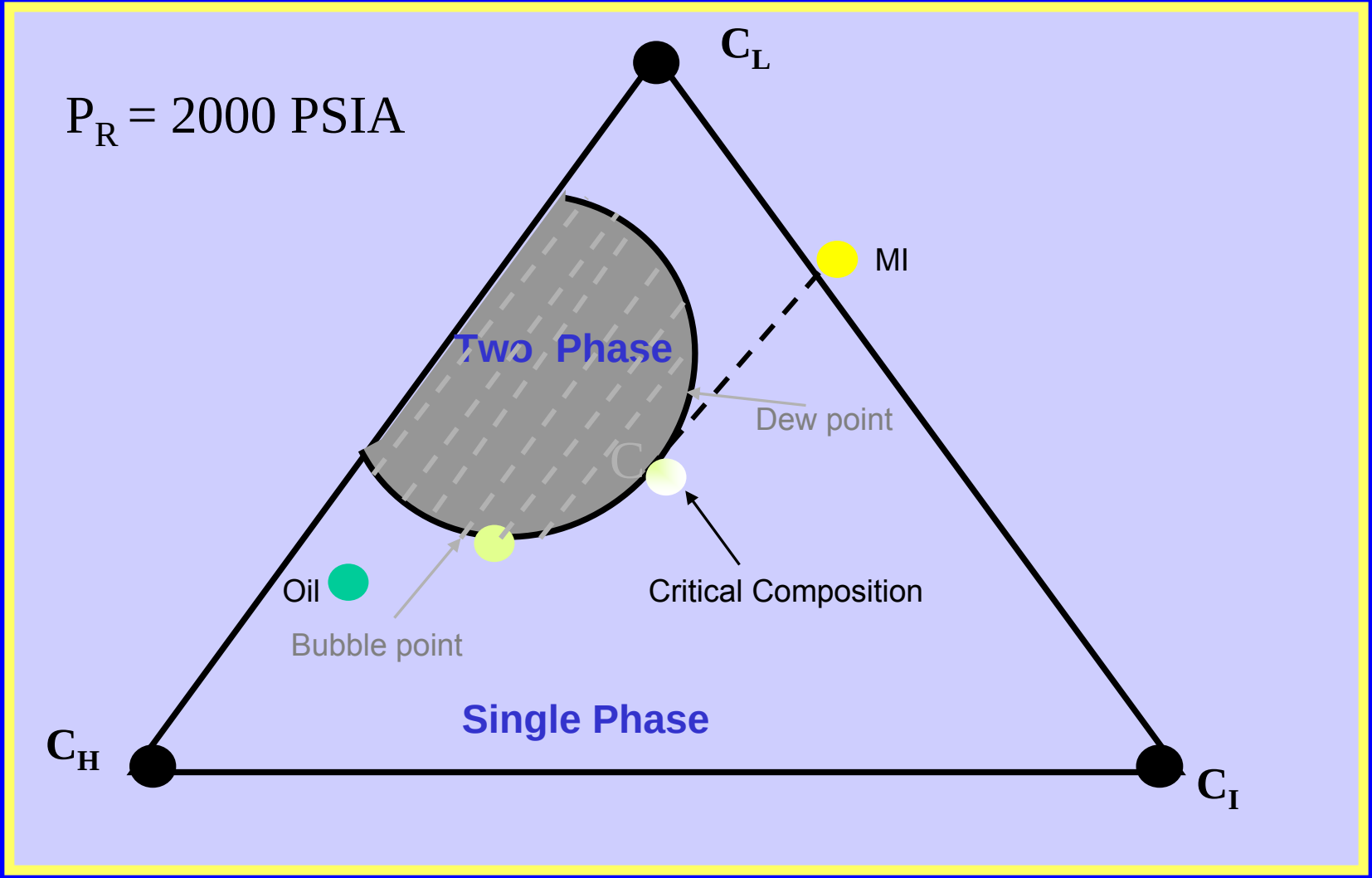
# Pressure Dependence ↓



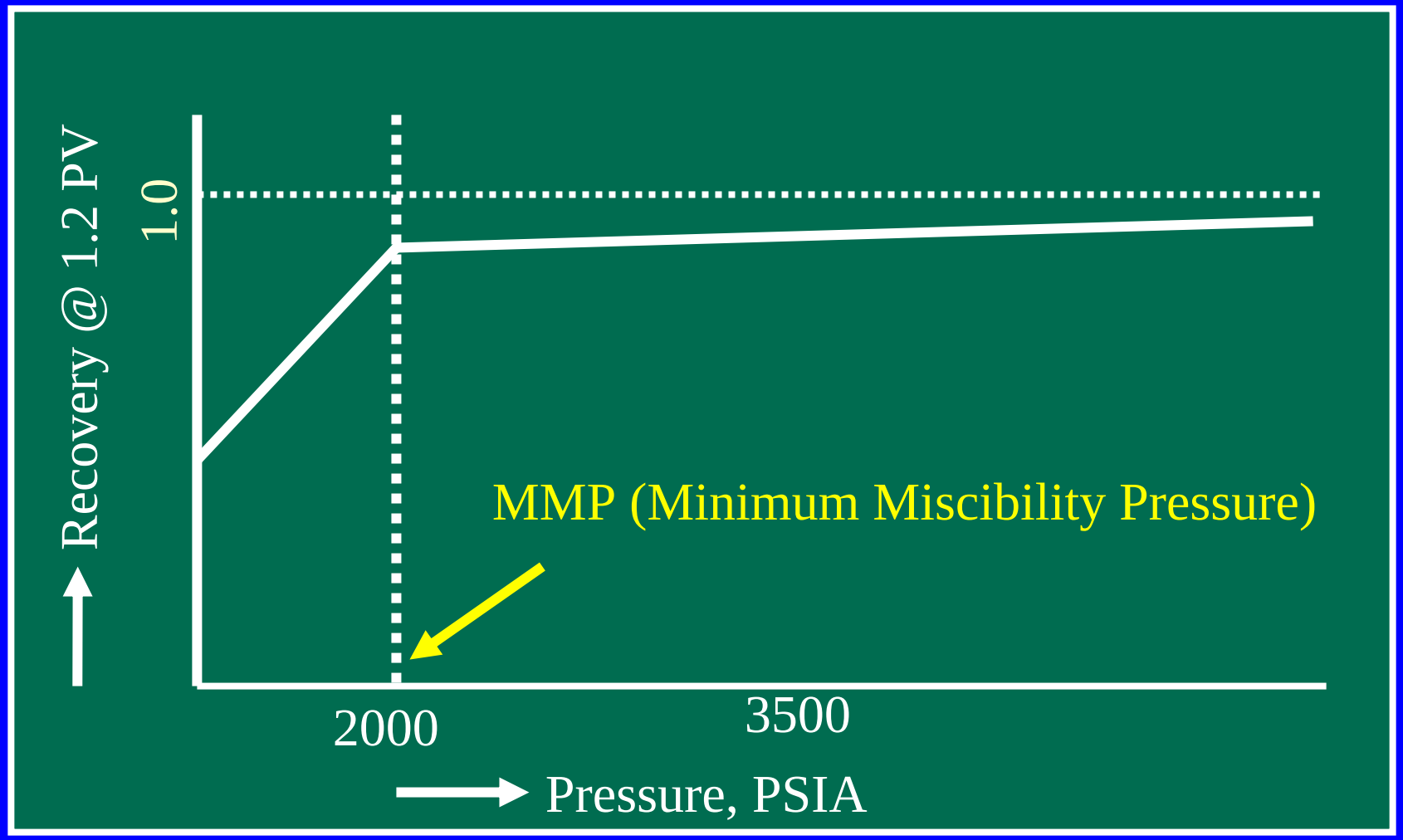
# Pressure Dependence ↑



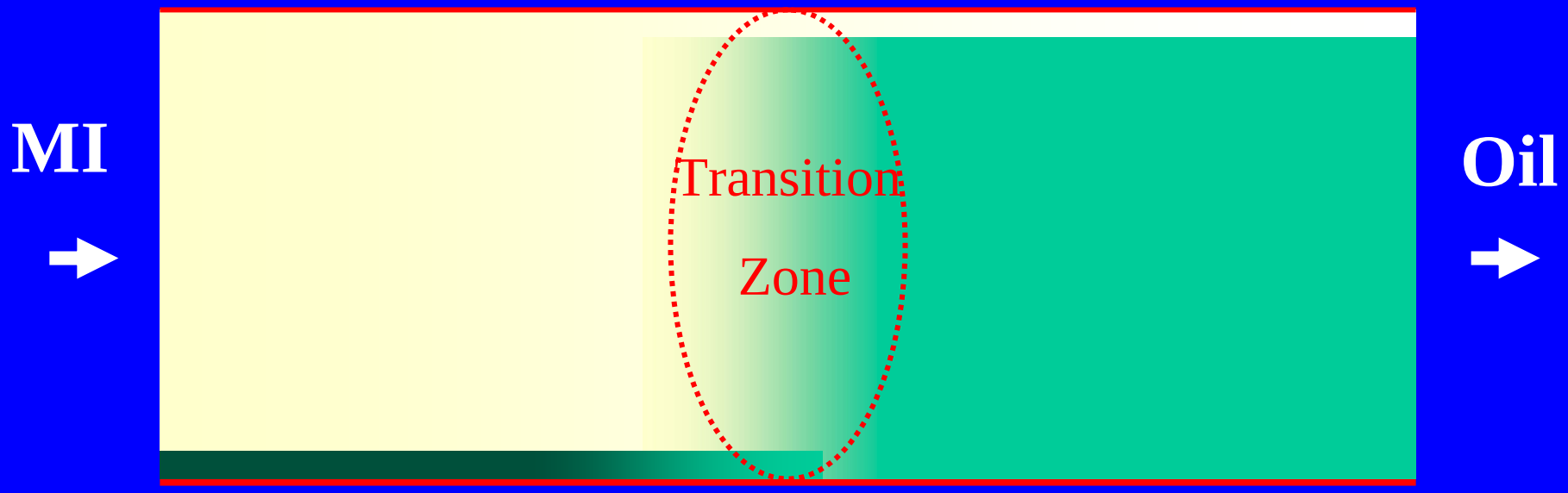
# Minimum Miscibility Pressure (MMP)



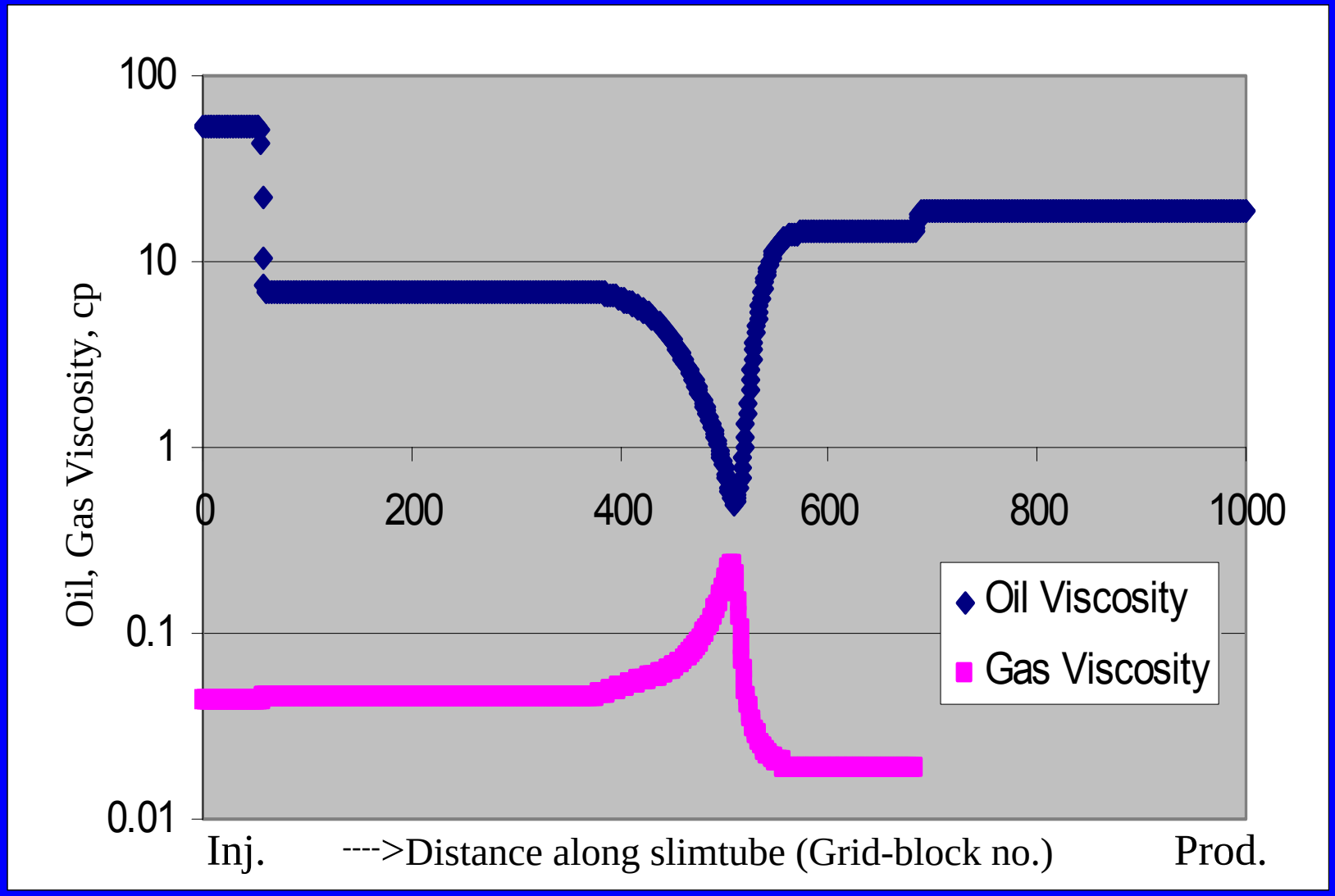
# Slimtube Recovery: Miscible



# Miscible Displacement Process



# Phase Viscosities in Slimtube



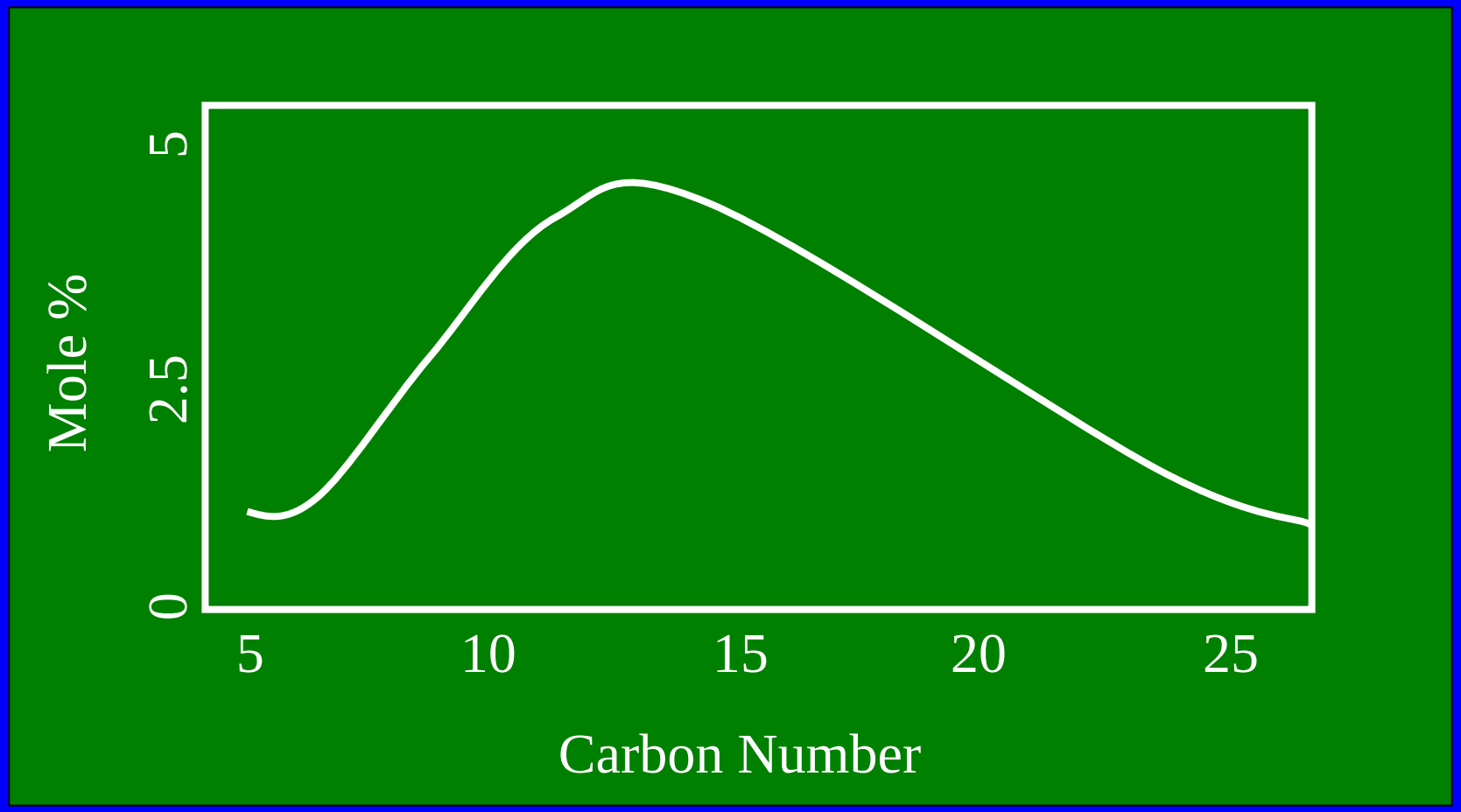
# Miscible WAG EOR Summary

- Injection gas rich in ($C_2$-$C_4$) hydrocarbons
- Fluid properties change by mass transfer
- MI composition a key design parameter
- WAG process to optimize gas sweep

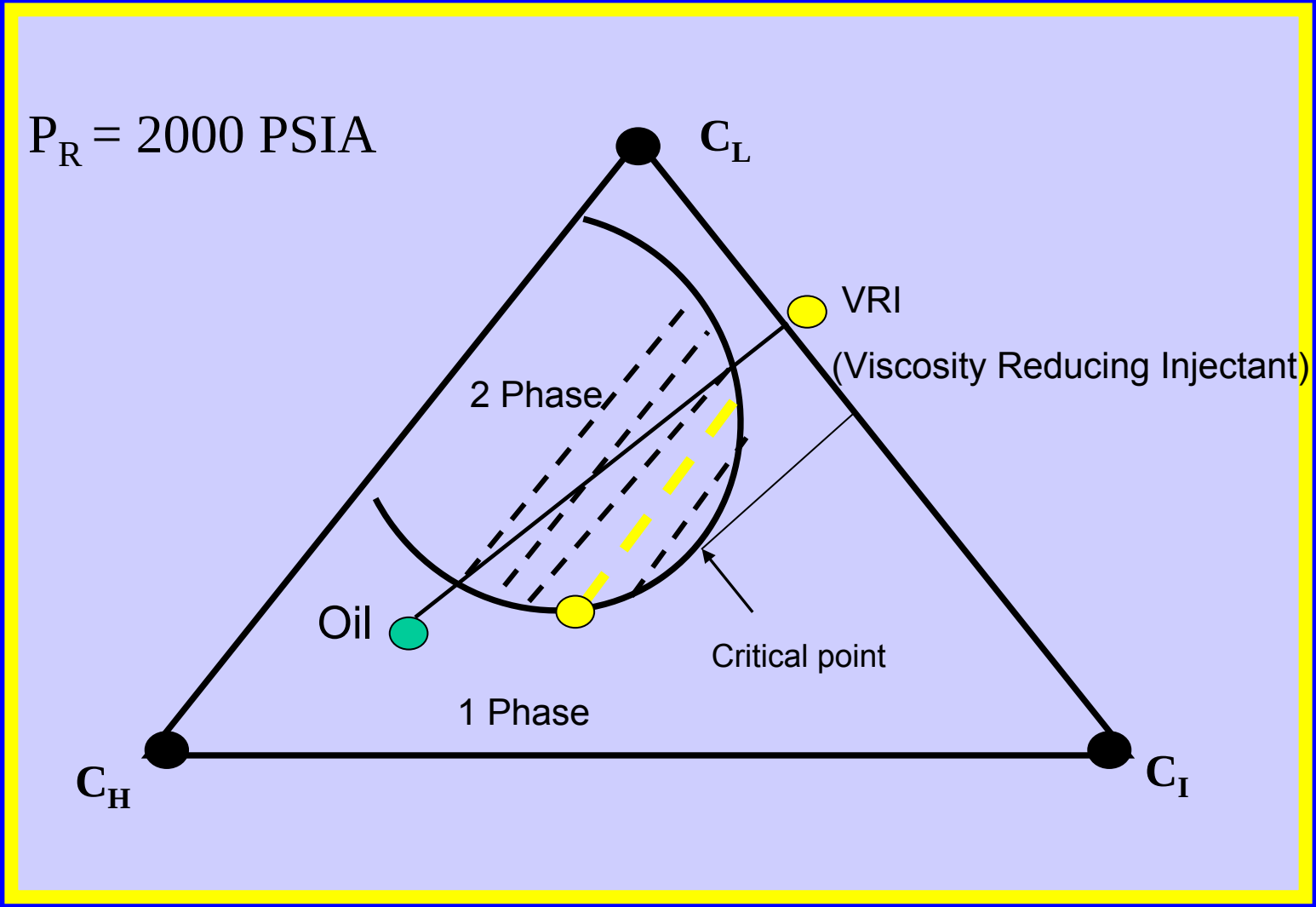
# Outline

- Motivation
- Miscible WAG EOR
- **Viscosity Reducing Immiscible WAG**
- North Slope Situation
- Closing Remarks

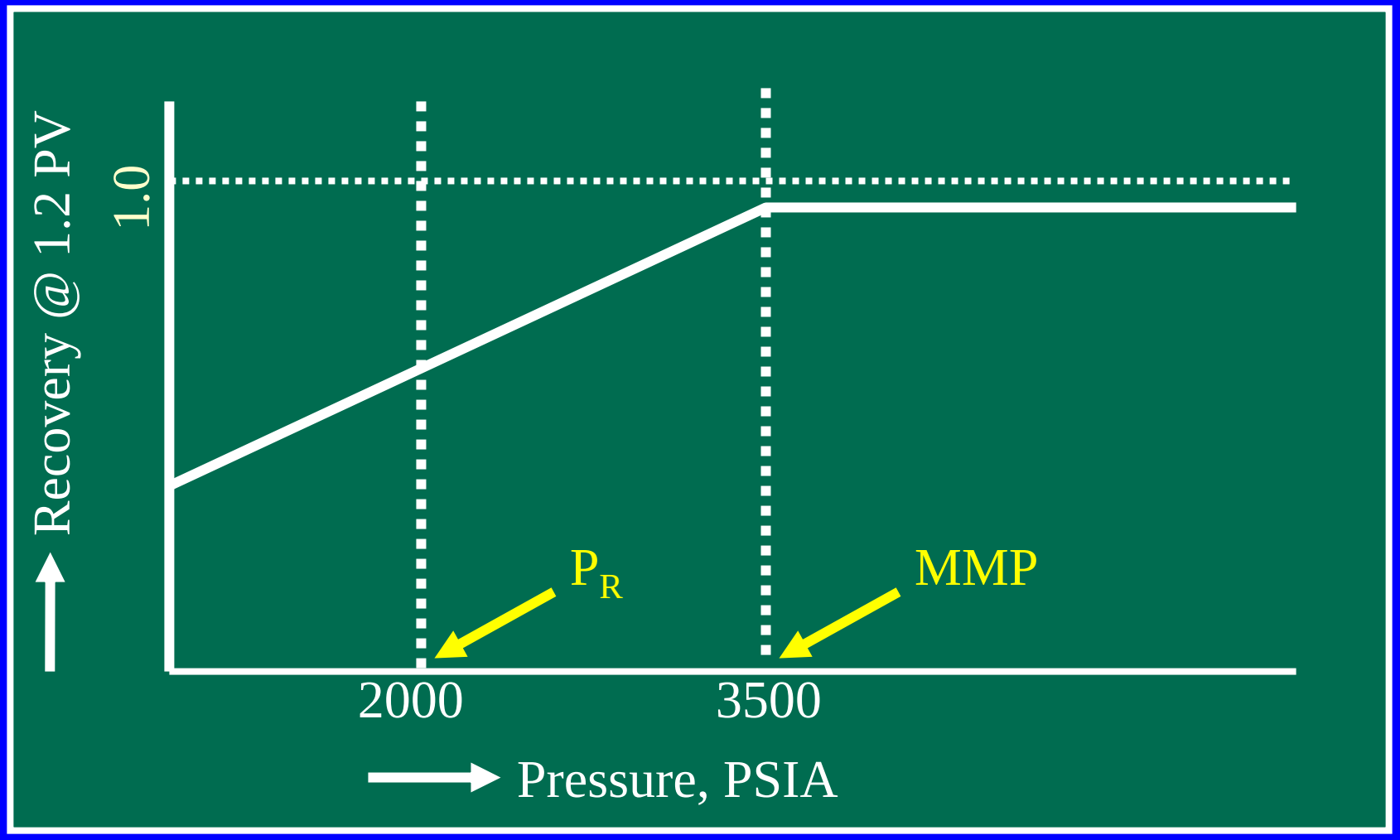
# Moderate Viscosity Oil – 57 cp



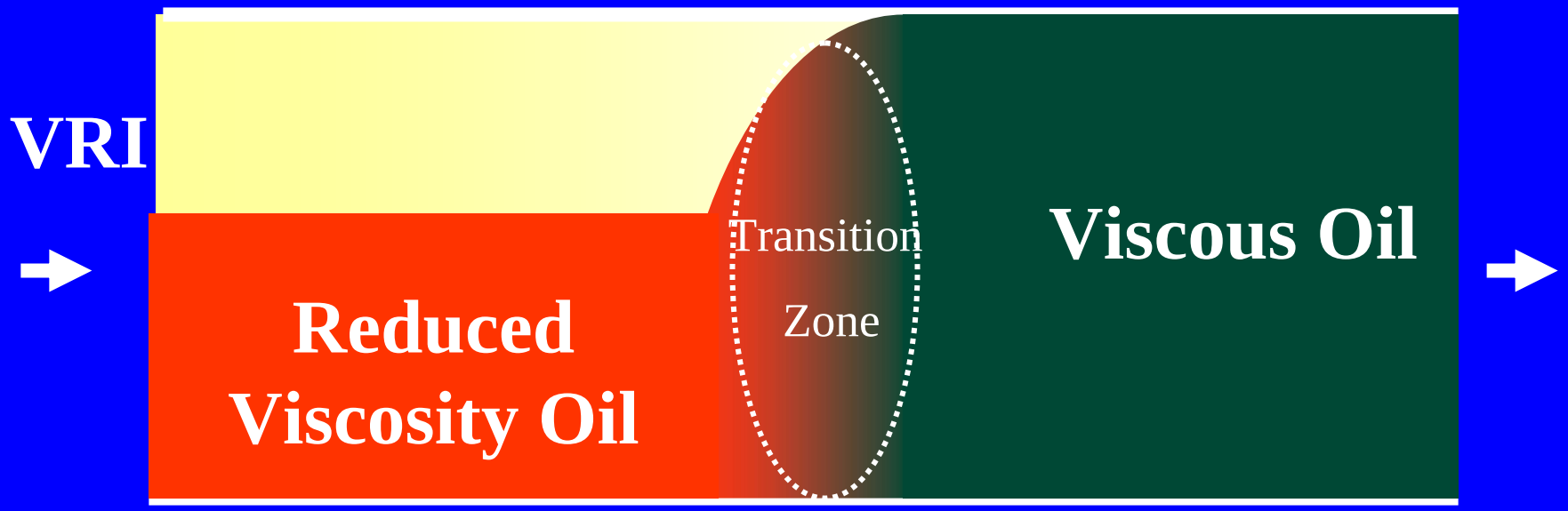
# VRI Mechanism



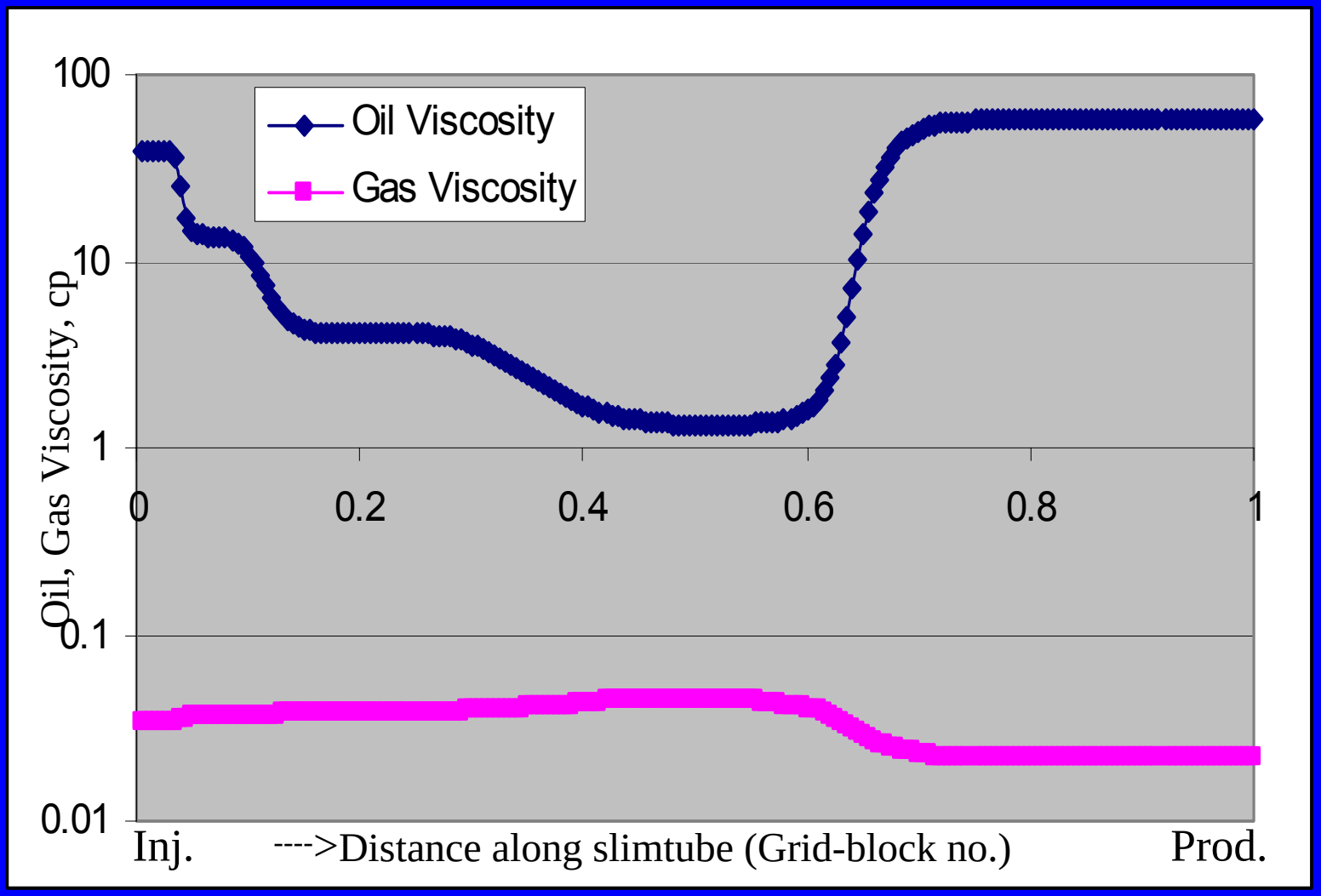
# Slimtube Recovery: Immiscible



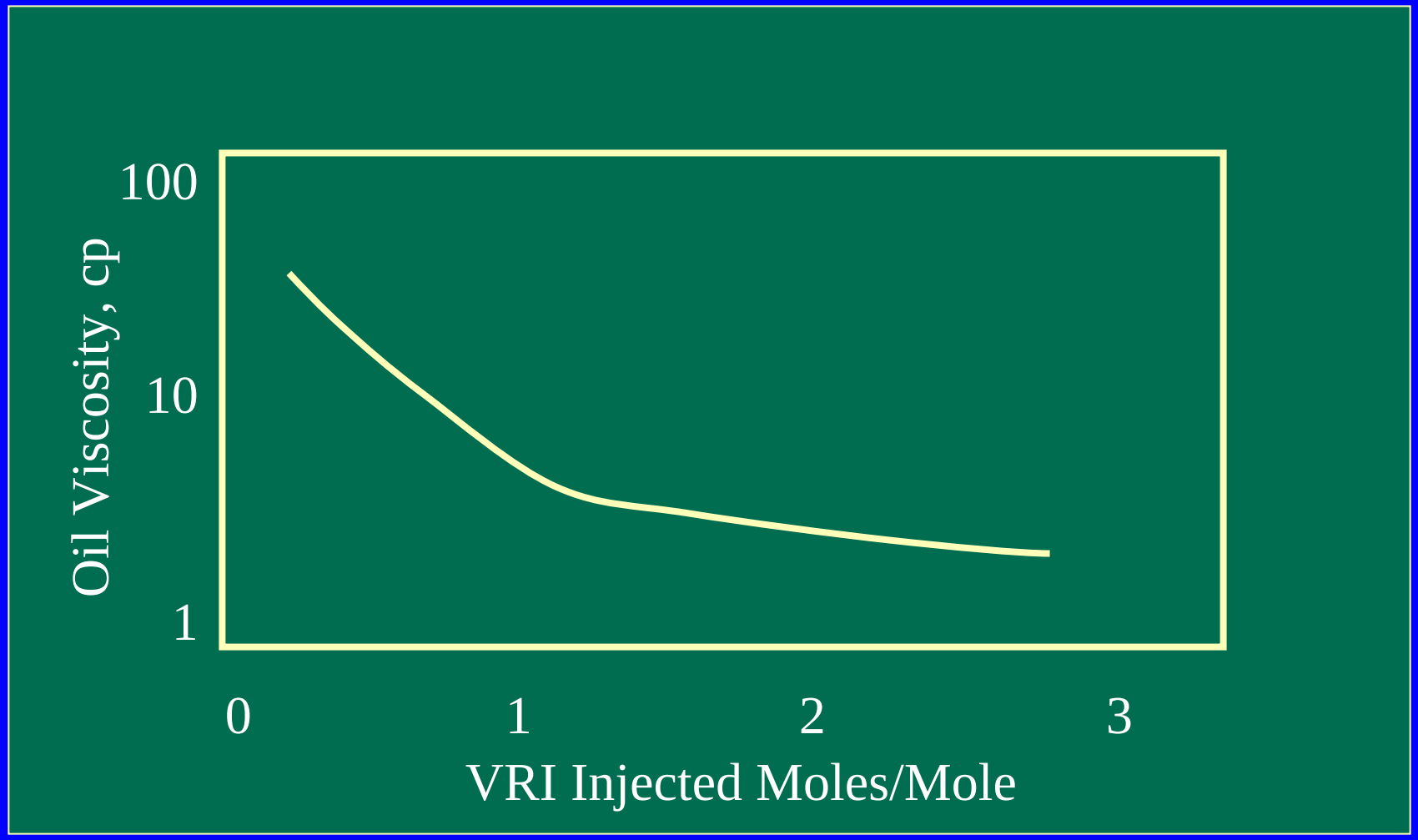
# VRI Displacement Process



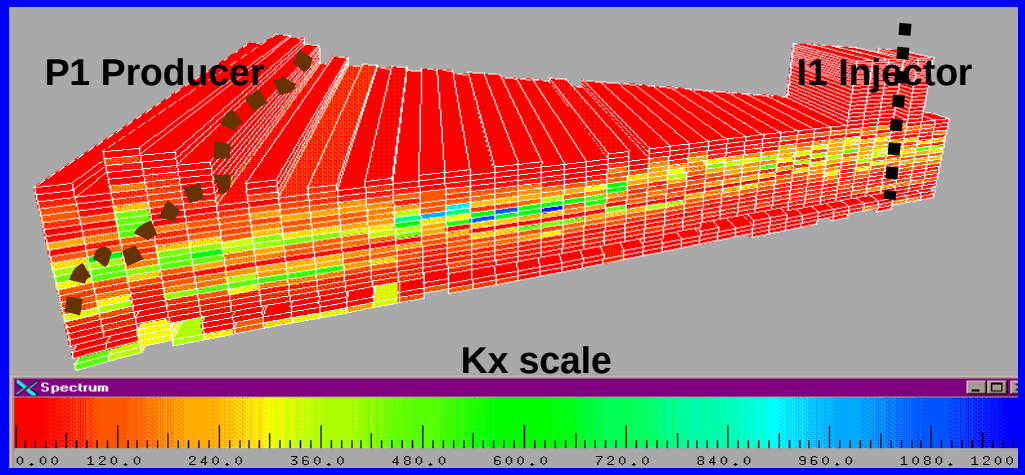
# Viscosity Reduction in Slimtube



# Viscosity Reduction in PVT Cell



# VRI Reservoir Process (2D)

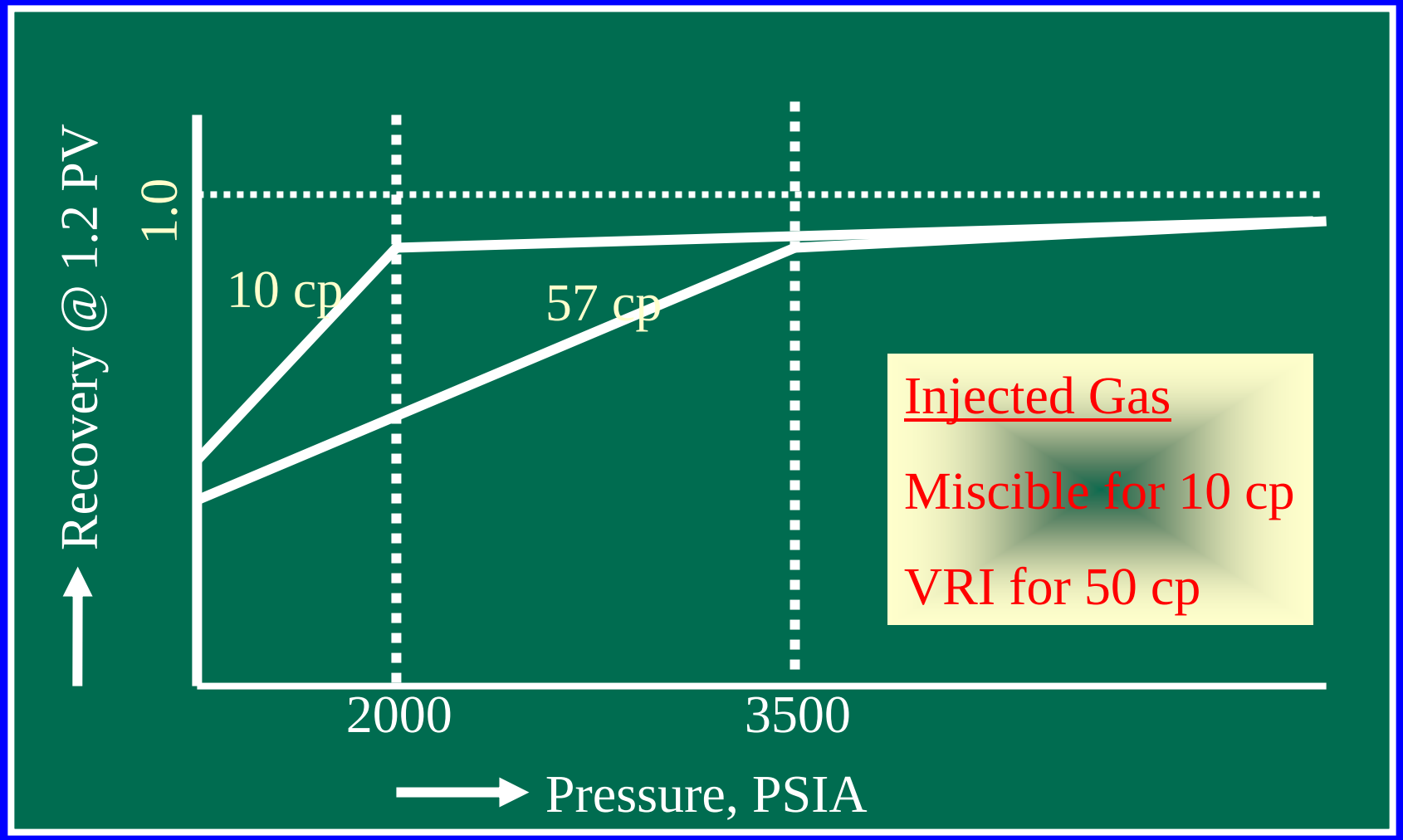



- Vertical injector, horizontal producer
- Waterflood, WAG simulations
- Low and Moderate Viscosity Oils
- 1:1 WAG ratio, 30% HCPV  Gas Injection

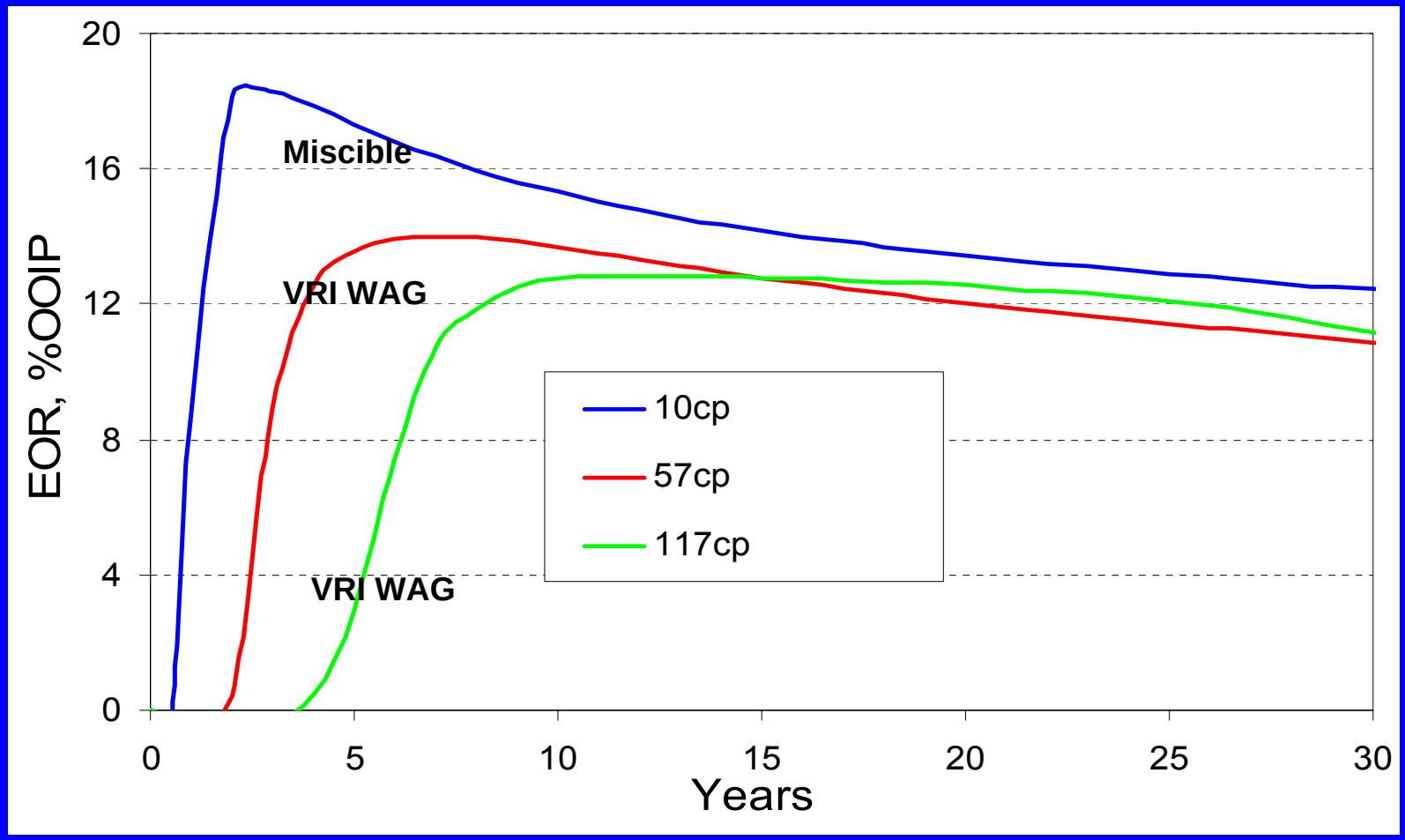
# Injectant Description

- Low viscosity (10 cp) oil miscible with injected gas (MI)
- The same MI immiscible with moderate viscosity (57 & 117 cp) oils
- Injectant referred to as VRI for moderate viscosity oils

# Slimtube Recoveries for 2 Oils

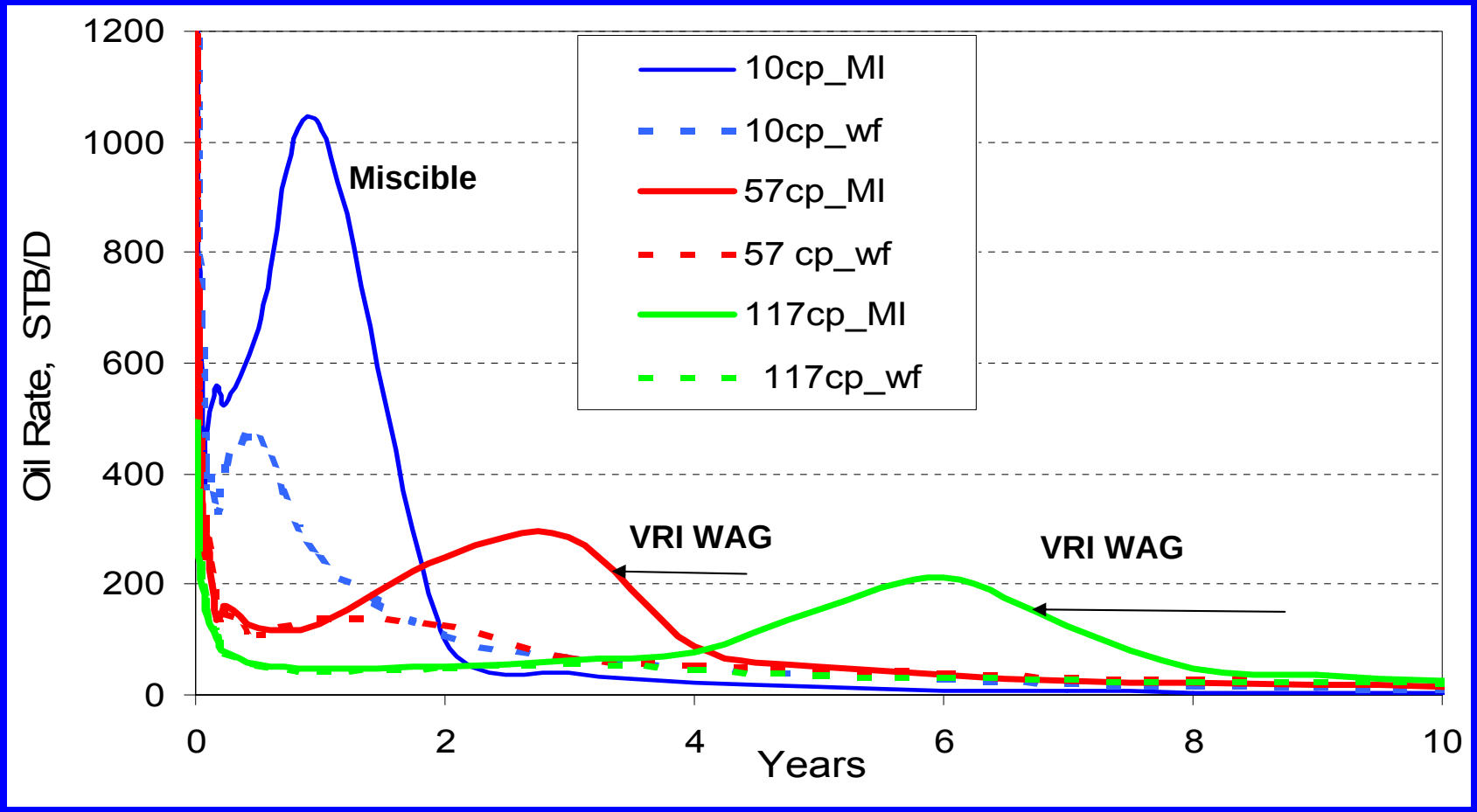


# EOR Recoveries for MI & VRI (2D)



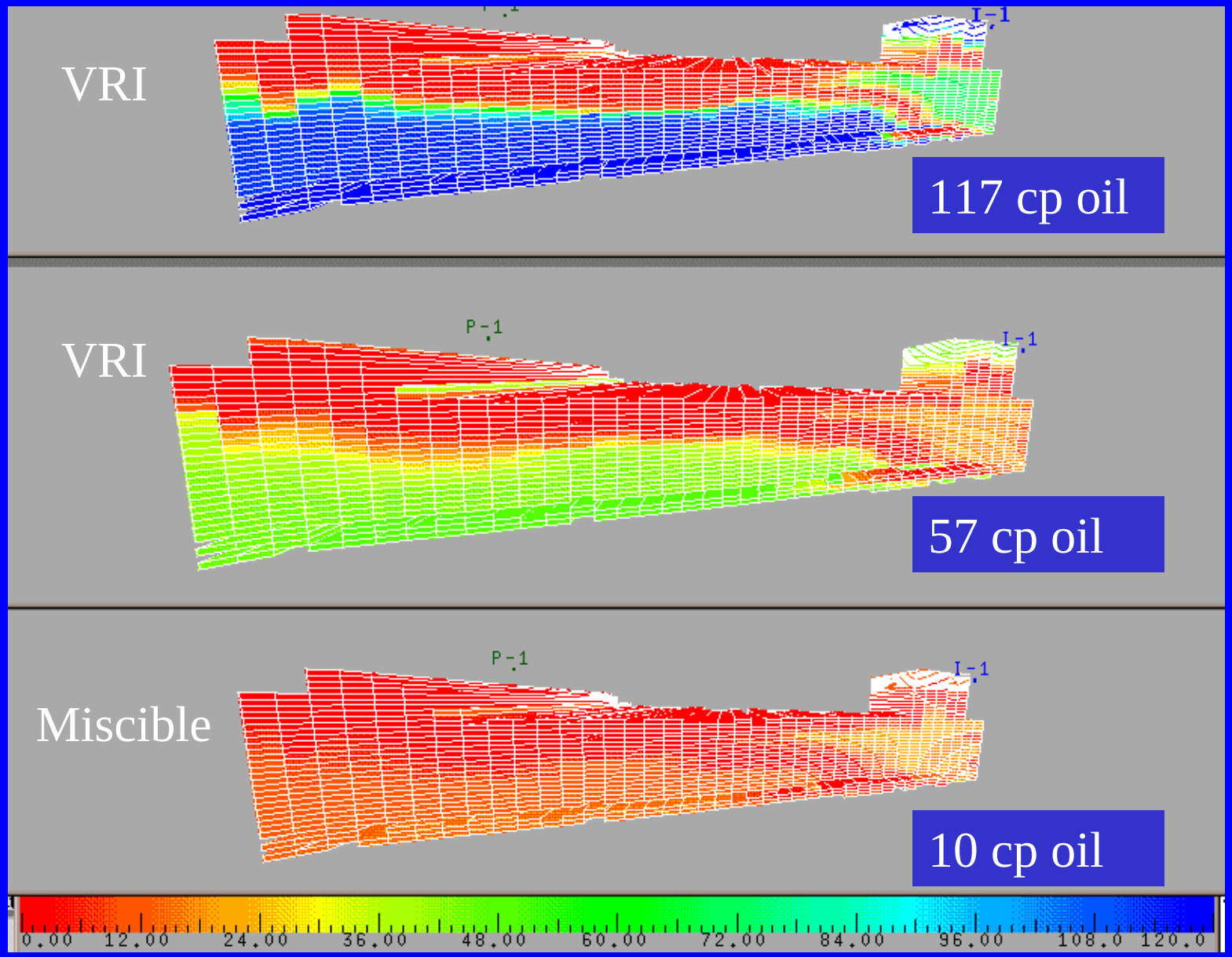

**EOR recovery similar for MI & VRI**

# Oil Rate for MI & VRI (2D)




**Earlier EOR response for lower viscosity oils**

# Oil Viscosity Map (after 30 years)



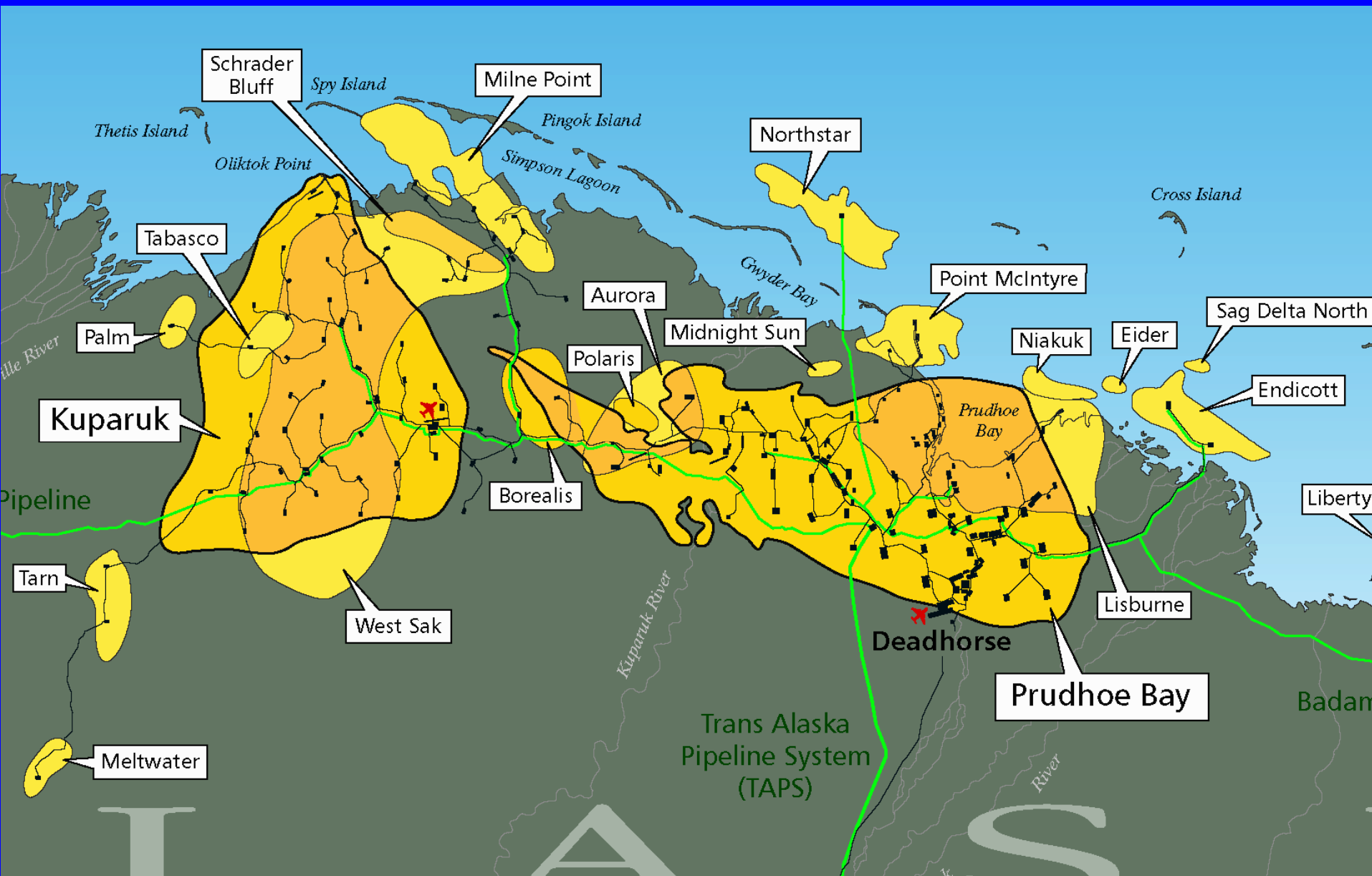
# VRI WAG Process

- Injectant not rich enough in ($C_2$-$C_4$) hydrocarbons
- Oil viscosity reduction and swelling by mass transfer
- Improved displacement by subsequent water injection
- WAG process to optimize gas sweep

# Outline

- Motivation
- Miscible WAG EOR
- Viscosity Reducing Immiscible WAG
- **North Slope Situation**
- Closing Remarks

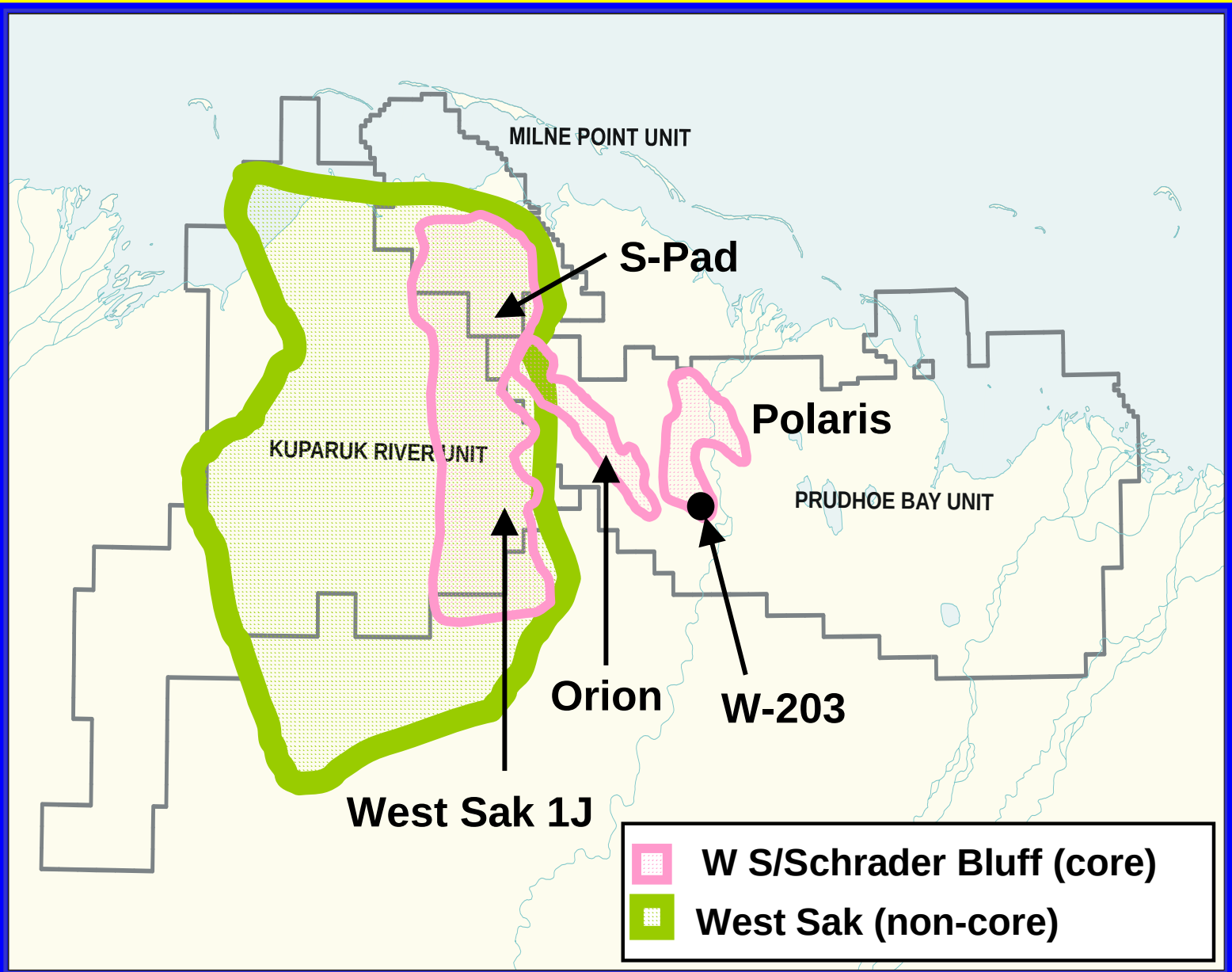
# Map of Alaska North Slope



# Prudhoe Bay Central Gas Facility

- ~500 mmscf/d MI

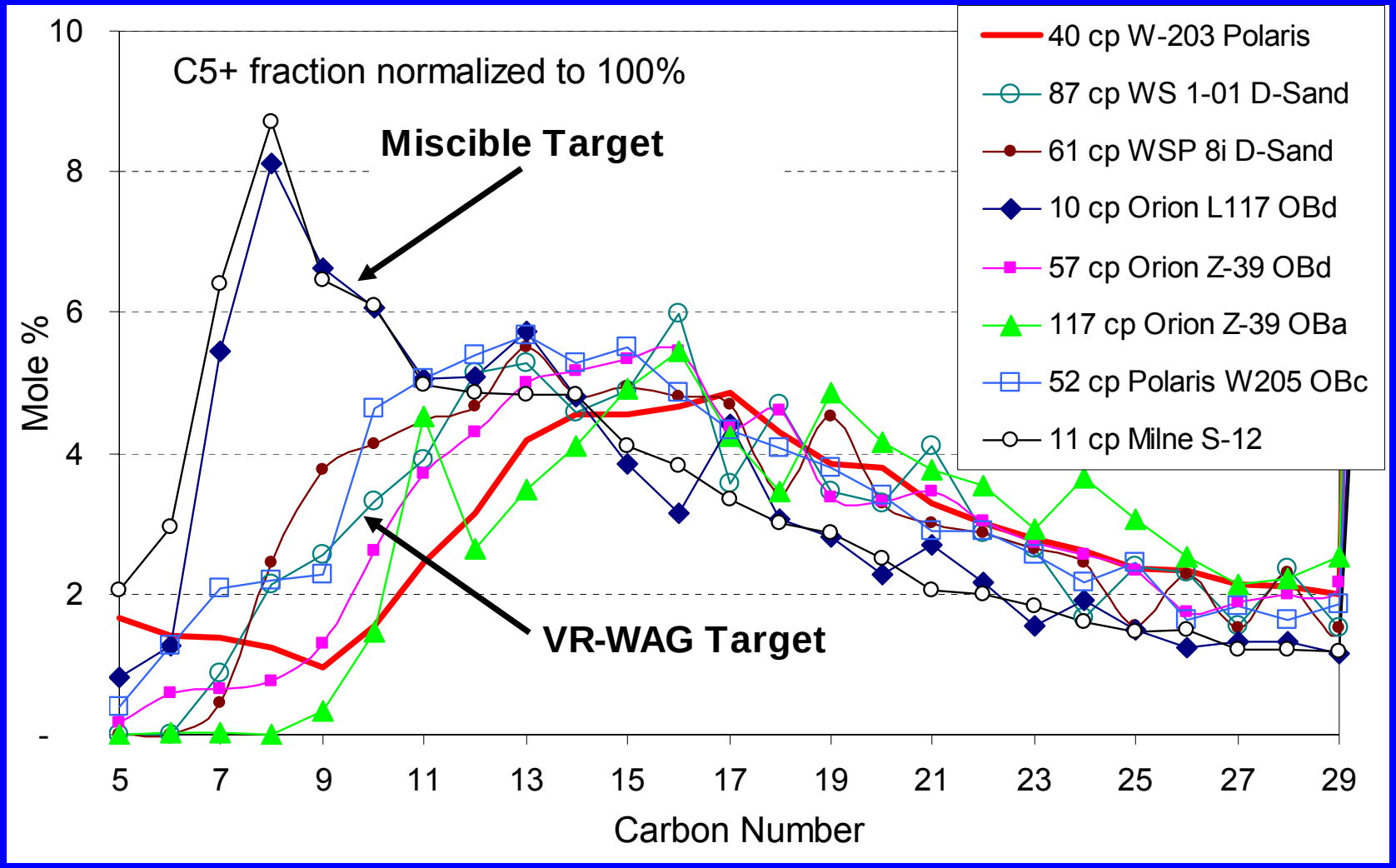
# North Slope Viscous Oil Resource



# NS Viscous Oil Opportunity

- Huge Resource (Tens of BSTB)
- Current development targets ~5 BSTB in W. Sak/Schrader Bluff Formation
- Low primary & waterflood recovery
- Available Gas Resource
- Prudhoe MI not miscible with moderate to high viscous oil (>15 cp)

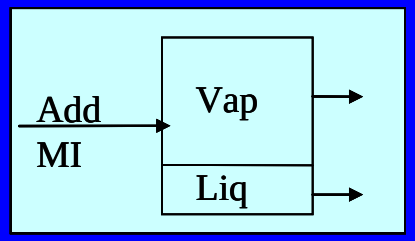
# Schrader Bluff Oil Quality Variation



# EOR Prediction Methodology

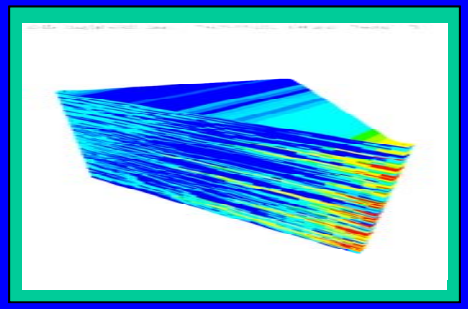
**Phase Behavior Model**

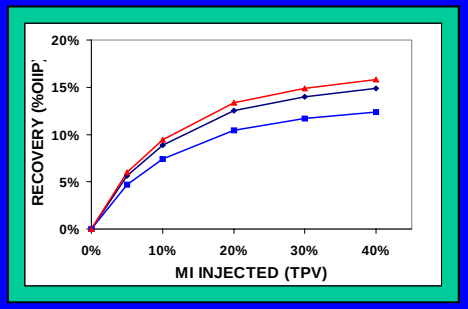
- PVT, Slimtube Data
- EOS




**Reservoir Simulation**

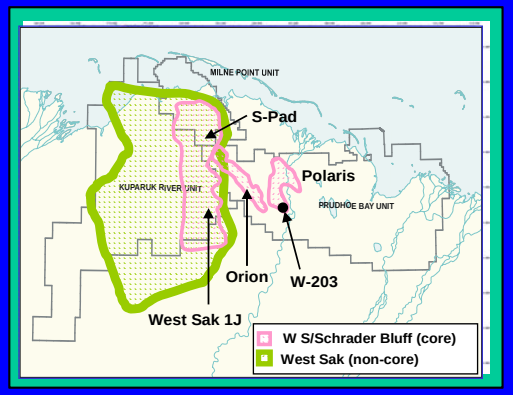
- Type patterns (based on reservoir description)
- EOR Type Curves (Oil, MI, RMI)






**Field Scaleup**

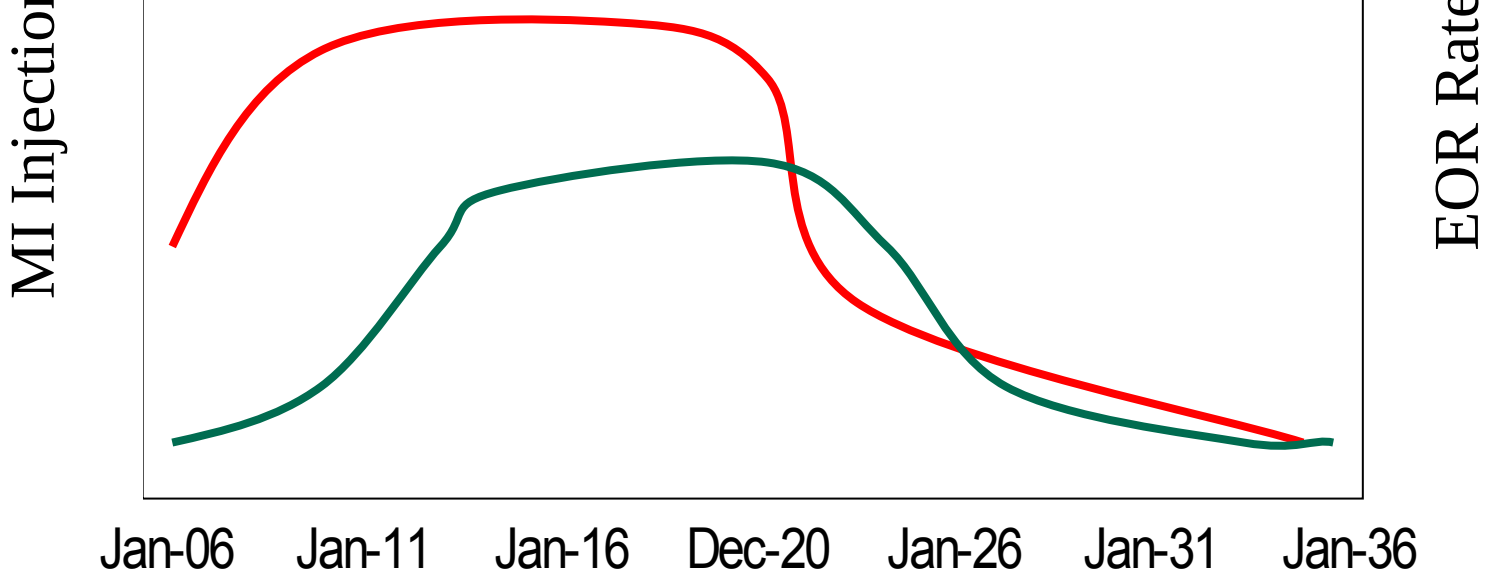
- Project area segments (segment PV, well allocations)
- Tank model scaleup




SPE 99569, "A New Scaleup Approach for Nonpattern Field Development Under Water or WAG Injection", B. S. Jhaveri, BP Exploration (Alaska) Inc

# NS Field Scaleup Example

- Huge Development Target
- 50 mmscf/d of VRI injection
- 12 MBD EOR rate, 6% (OOIP) EOR
- MI efficiency close to classical miscible



# North Slope VRI Status

- VRI project designed for Polaris & Orion fields
- IRS ruled VRI process as a qualified recovery method for EOR tax credit
- Alaska State approval to commence VRI injection in Polaris reservoir.
  - Injecting 2 mmscf/d MI in W-215
  - 6% EOR recovery from 350 MSTB OOIP
- Application for Orion VRI injection approved
  - 1,000 MSTB OOIP target with similar EOR recovery expected

# Key Project Design Components

- (Lean Gas, NGls, MI Capture)
- Surveillance (Gas Analysis, Well Intervention)
- Injectivity (Water/MI, Gas Trapping)
- Conformance (Zonal, Volumetric)
- Flood Management MI Resource (Voidage Replacement, Pressure Maintenance, WAG Ratio, MI Slug ,MI Allocation)
- Asphaltenes Dropout (Reservoir & Facility)

# Closing Remarks

- When conventional technology not applicable
- VRI technology can dramatically increase primary and waterflood recovery in viscous oil reservoirs
- Recovery enhancement by viscosity reduction and swelling
- Developed approach for the design, engineering, and evaluation of viscous oil gas EOR projects

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