USC University of Southern California

RMC

# $CO_2$-EOR Reservoir Workflow

## 2nd Biennial $CO_2$ for EOR as CCUS Conference

Metin Karakas

Houston, TX
October 5, 2015

# RMC Objectives

- Identify current key technology gaps
- Focus on interfaces between different disciplines
- Integrate data, information, expertise and workflows
- Maintain a balance between the short term high impact research and long term needs
- Develop dynamic reservoir monitoring (DRM) workflows
- Focus areas:
  - Shale,
  - Carbonate,
  - Deep water

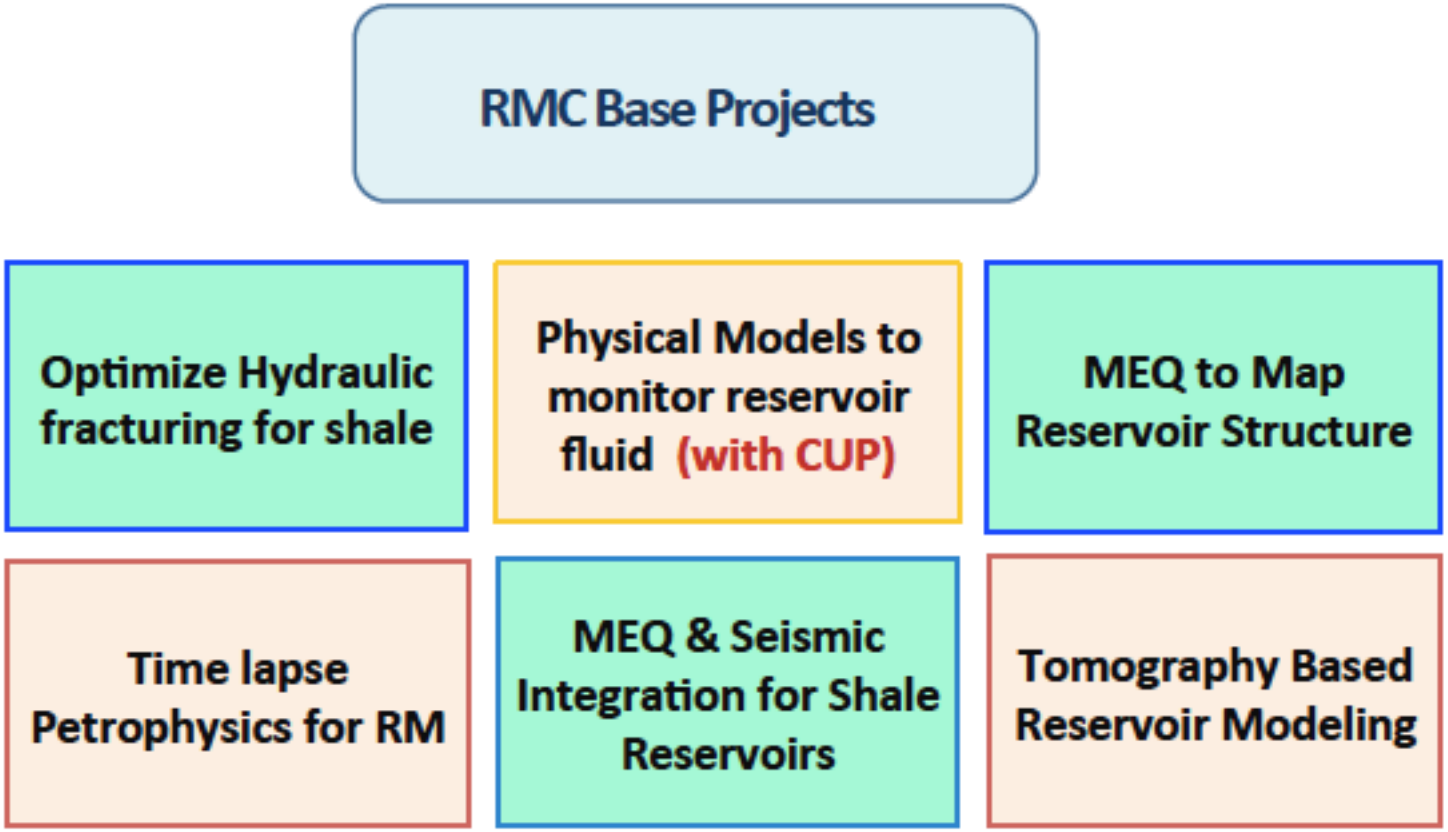
RMC

# Faculty & PhD Students

- Prof. Aminzadeh (Principal Director)
- Prof. Ershaghi
- Prof. Jessen
- Prof. Jafarpour
- Dr. Yesser Haj Nasser (Post Doc)
  - Magdalene Ante (NETL)
  - Ahmed Bubshait (Saudi Aramco)
  - Mehran Hosseini
  - Nima Jabbari
  - Metin Karakas (Chevron Fellowship)
  - Debotyam Maity (now with Gas Technology Institute)
  - Noha Najem (Kuwait Oil Company)
  - Arman Nejad
  - Mahshad Samnejad
  - Tayeb Tafti (now with Aera Energy)
  - Robert Walker (Chevron Fellowship)

RMC

# USC Reservoir Monitoring Consortium



RMC

# $CO_2$-EOR Research Objectives

- To conduct a through research to understand how we could mitigate the undesirable effects during $CO_2$-EOR implementations
- To understand the $CO_2$ fluid flow behavior under adverse reservoir conditions (layering, gravity segregation)
- To assess the relative merits of various measurements (well testing, Seismic & EM surveys) to map the fluid fronts
- To come up with a practical workflow to reduce the uncertainty by combining these measurements

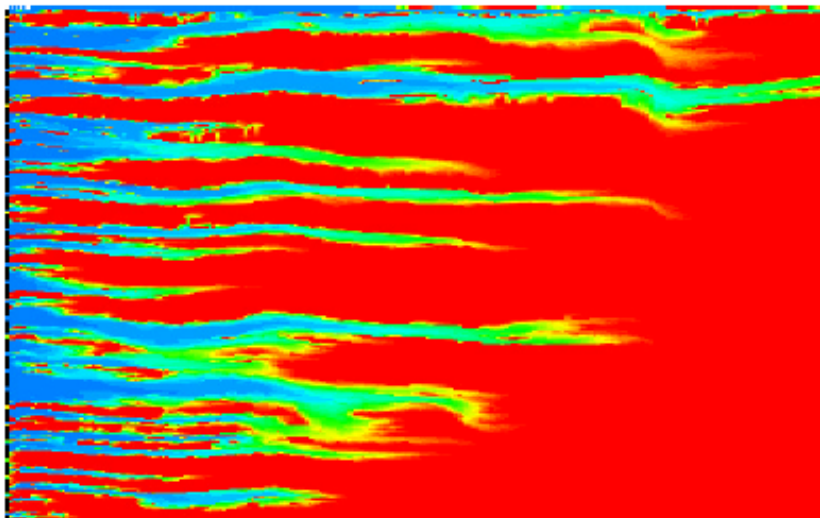
# Successful $CO_2$ - EOR Projects

- Reservoir, Fluid & Rock Characterization
- Reservoir Monitoring
- Data Integration
- Conformance Control

# Reservoir Conformance

RMC

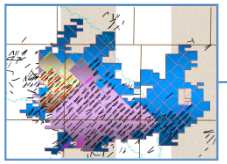
- Low reservoir sweep efficiency under conditions of high (unfavorable) mobility ratios
- Gravity override by the less dense CO2
- Viscous fingering of the CO2
- Channeling of the CO2 in highly heterogeneous reservoirs



# Reservoir Workflow

RMC

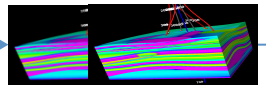
Target Areas for CO2 Pilot



*Saturation & Pressure Distributions*
*Fractures, Risks & Opportunities*

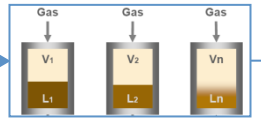
Screening Studies

Reservoir Uncertainties



*Differential Fluid Movement,*
*Facies, Vertical Barriers,*
*High-Perm Streaks, Fracture Corridors*

CO2 Fluid Characterization

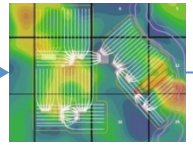



*Representative Fluid Sample*
*Multi-Contact Miscibility,*
*Asphaltine Deposition during production*

CO2 Core Tests

*CO2 SCAL, Residual Oil Saturation*

Sensitivity Studies



*Well and Completion Types, Injection Schemes, Mobility Control Agents*

Site Selection

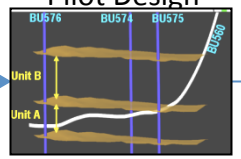
*Key Success Factors*
*Conformance, Residual Oil Saturation, Risks & Opportunities*

Tests under reservoir conditions

*Residual Oil , Miscibility*
*CO2 SCAL, Asphaltine, Foam*
*Fluid & Rock Interactions*

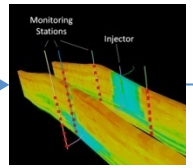
*Technical Success?*

Pilot Design




*Observation Wells*
*Completion Types & Control,*
*Reservoir and Well Monitoring,*
*Mitigation Plans*

Pilot Execution



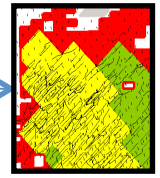

*Reservoir & Well Monitoring*
*Injection & Production Control*
*Mobility Reduction*
*Real-time Model Update*

Pilot Evaluation

*Lessons Learned*
*Data Integration &*
*Production Forecasting*

*Key Success Factors Met?*

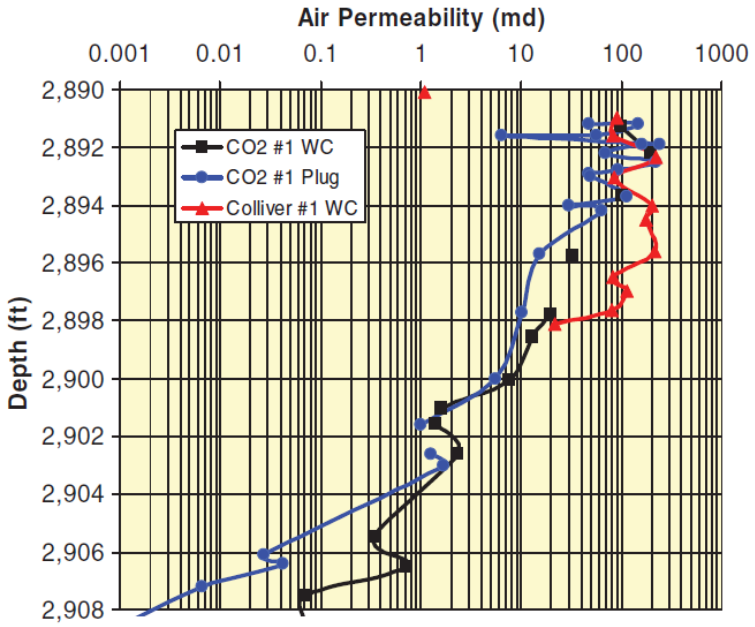
Sector / Field Development

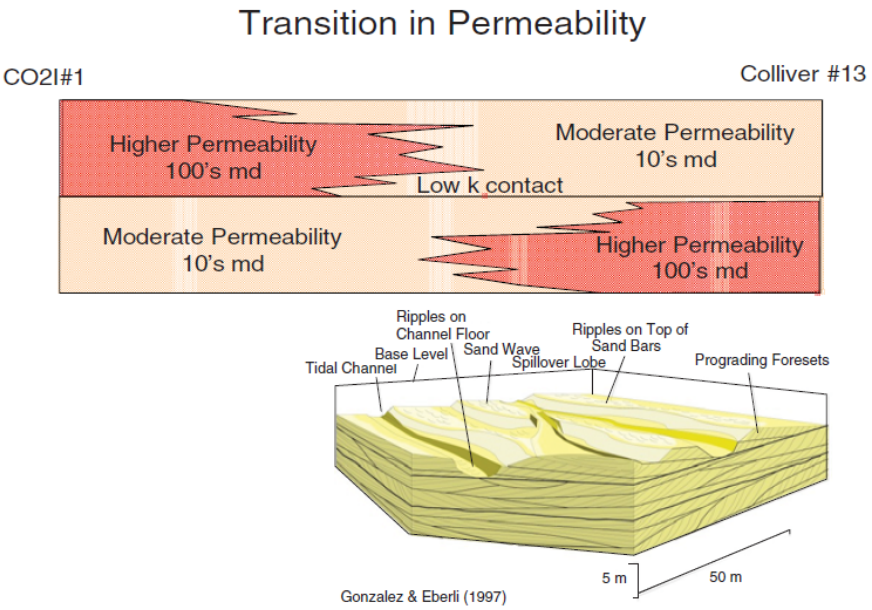


*Sector Model*
*Remaining Uncertainties*
*Risk Mitigation,*
*Opportunities*

# Reservoir Uncertainty

RMC



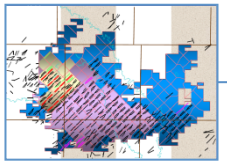




Ref: "A Pilot Carbon Dioxide Test, Hall-Gurrey Field, Kansas" by G.P. Willhite et. al. (2012)

# Reservoir Workflow

RMC

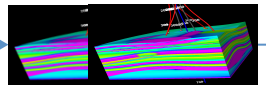
Target Areas for CO2 Pilot



*Saturation & Pressure Distributions*
*Fractures, Risks & Opportunities*

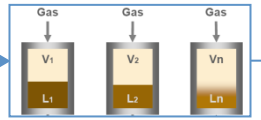
Screening Studies

Reservoir Uncertainties



*Differential Fluid Movement,*
*Facies, Vertical Barriers,*
*High-Perm Streaks, Fracture Corridors*

CO2 Fluid Characterization

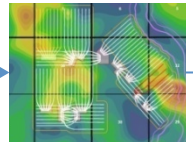



*Representative Fluid Sample*
*Multi-Contact Miscibility,*
*Asphaltine Deposition during production*

CO2 Core Tests

*CO2 SCAL, Residual Oil Saturation*

Sensitivity Studies



*Well and Completion Types, Injection Schemes, Mobility Control Agents*

Site Selection

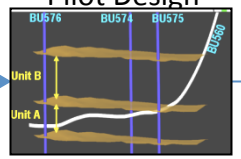
*Key Success Factors*
*Conformance, Residual Oil Saturation, Risks & Opportunities*

Tests under reservoir conditions

*Residual Oil , Miscibility*
*CO2 SCAL, Asphaltine, Foam*
*Fluid & Rock Interactions*

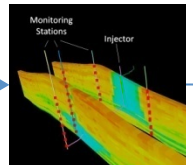
*Technical Success?*

Pilot Design




*Observation Wells*
*Completion Types & Control,*
*Reservoir and Well Monitoring,*
*Mitigation Plans*

Pilot Execution



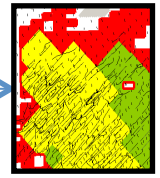

*Reservoir & Well Monitoring*
*Injection & Production Control*
*Mobility Reduction*
*Real-time Model Update*

Pilot Evaluation

*Lessons Learned*
*Data Integration &*
*Production Forecasting*

*Key Success Factors Met?*

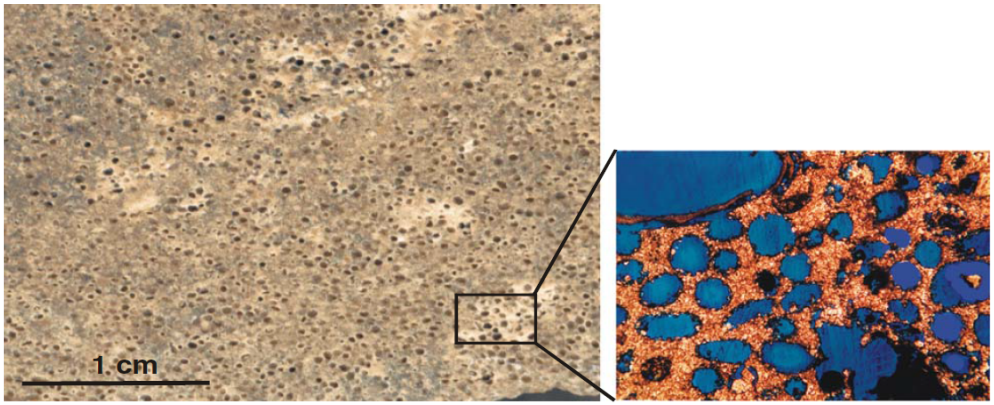
Sector / Field Development

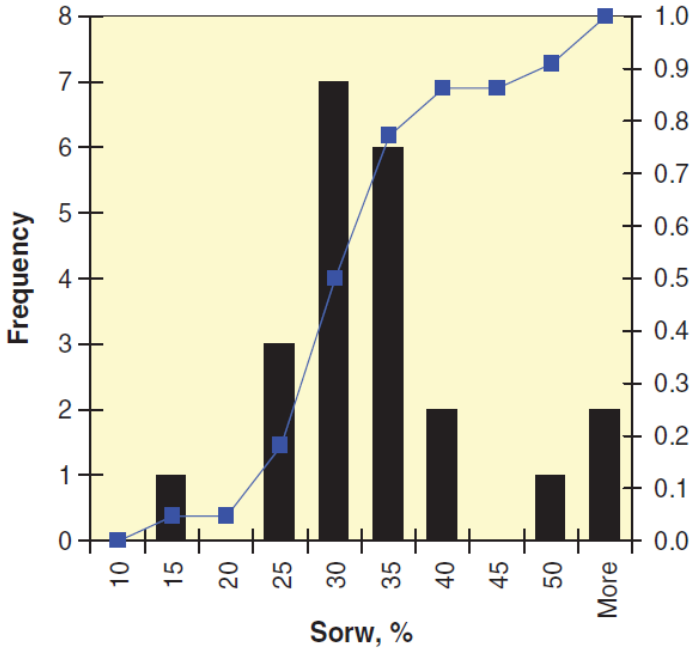


*Sector Model*
*Remaining Uncertainties*
*Risk Mitigation,*
*Opportunities*

# Residual Oil Saturation

RMC



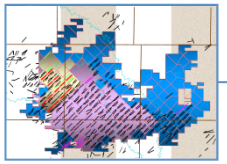




Ref: “A Pilot Carbon Dioxide Test, Hall-Gurrey Field, Kansas” by G.P. Willhite et. al. (2012)

# Reservoir Workflow

RMC

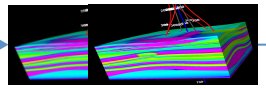
Target Areas for CO2 Pilot



*Saturation & Pressure Distributions*
*Fractures, Risks & Opportunities*

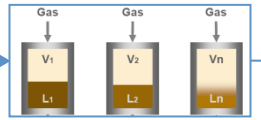
Screening Studies

Reservoir Uncertainties



*Differential Fluid Movement,*
*Facies, Vertical Barriers,*
*High-Perm Streaks, Fracture Corridors*

CO2 Fluid Characterization

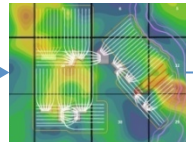



*Representative Fluid Sample*
*Multi-Contact Miscibility,*
*Asphaltine Deposition during production*

CO2 Core Tests

*CO2 SCAL, Residual Oil Saturation*

Sensitivity Studies



*Well and Completion Types, Injection Schemes, Mobility Control Agents*

Site Selection

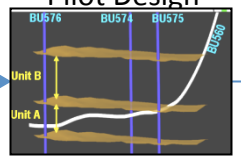
*Key Success Factors*
*Conformance, Residual Oil Saturation, Risks & Opportunities*

Tests under reservoir conditions

*Residual Oil , Miscibility*
*CO2 SCAL, Asphaltine, Foam*
*Fluid & Rock Interactions*

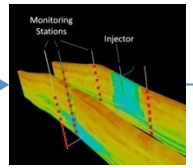
*Technical Success?*

Pilot Design




*Observation Wells*
*Completion Types & Control,*
*Reservoir and Well Monitoring,*
*Mitigation Plans*

Pilot Execution



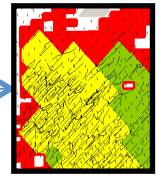

*Reservoir & Well Monitoring*
*Injection & Production Control*
*Mobility Reduction*
*Real-time Model Update*

Pilot Evaluation

*Lessons Learned*
*Data Integration &*
*Production Forecasting*

*Key Success Factors Met?*

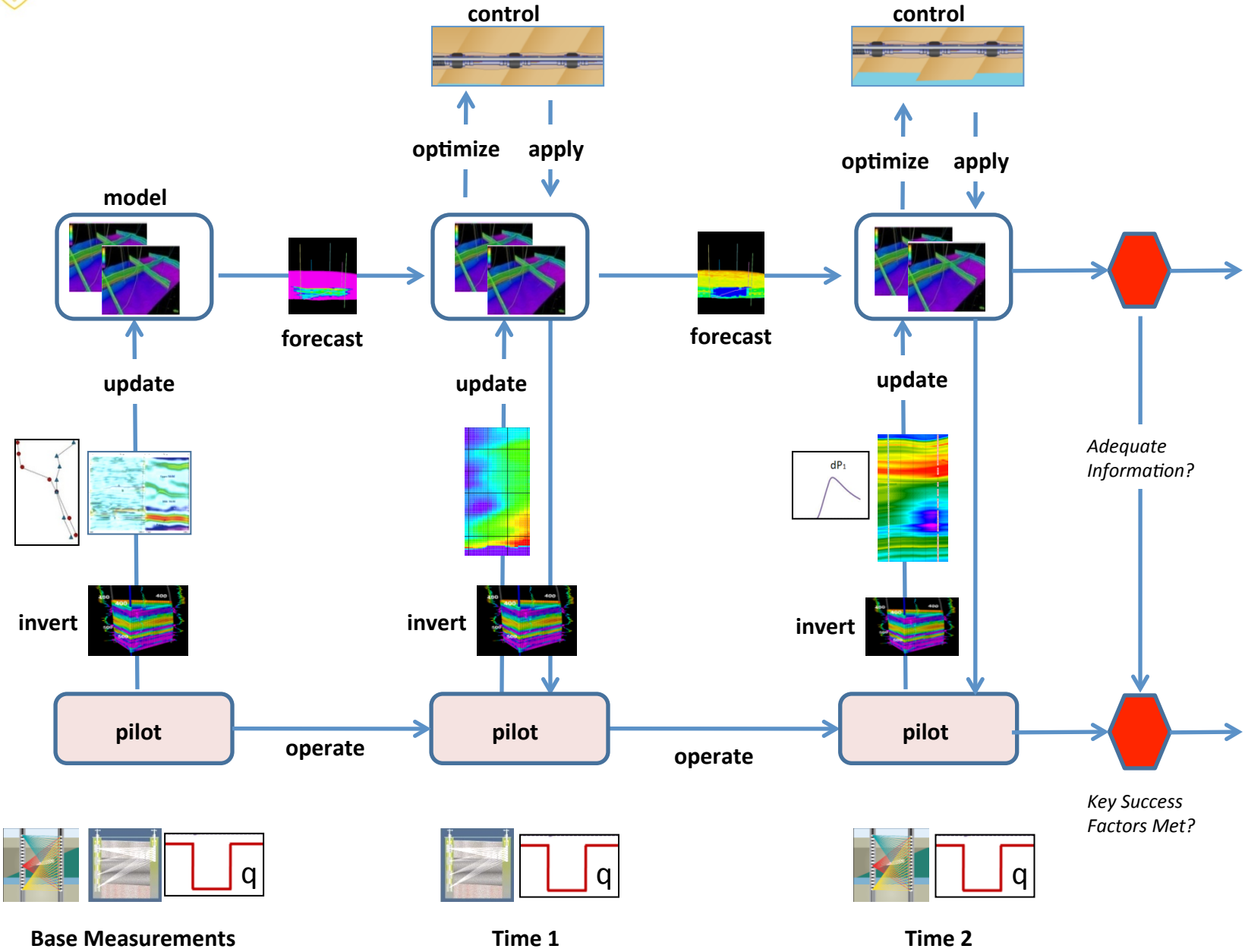
Sector / Field Development



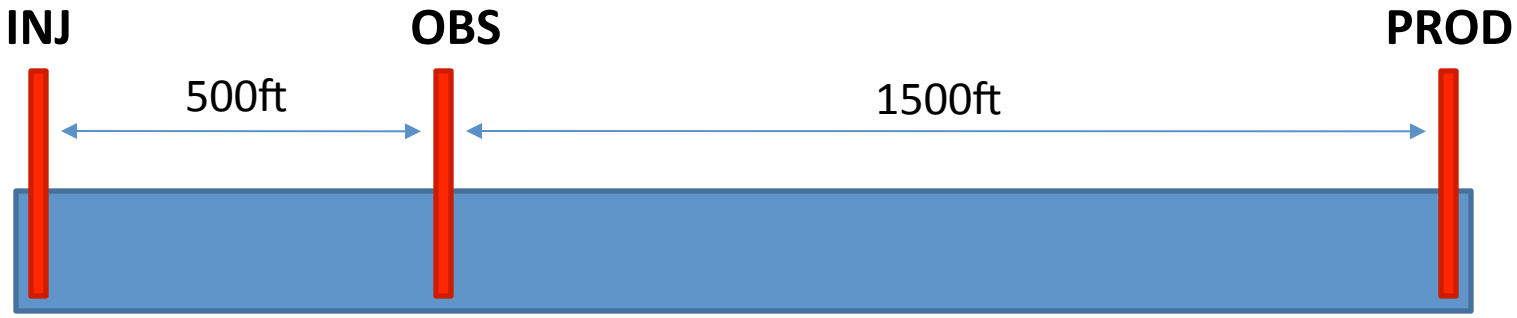
*Sector Model*
*Remaining Uncertainties*
*Risk Mitigation,*
*Opportunities*

# Pilot Execution

RMC

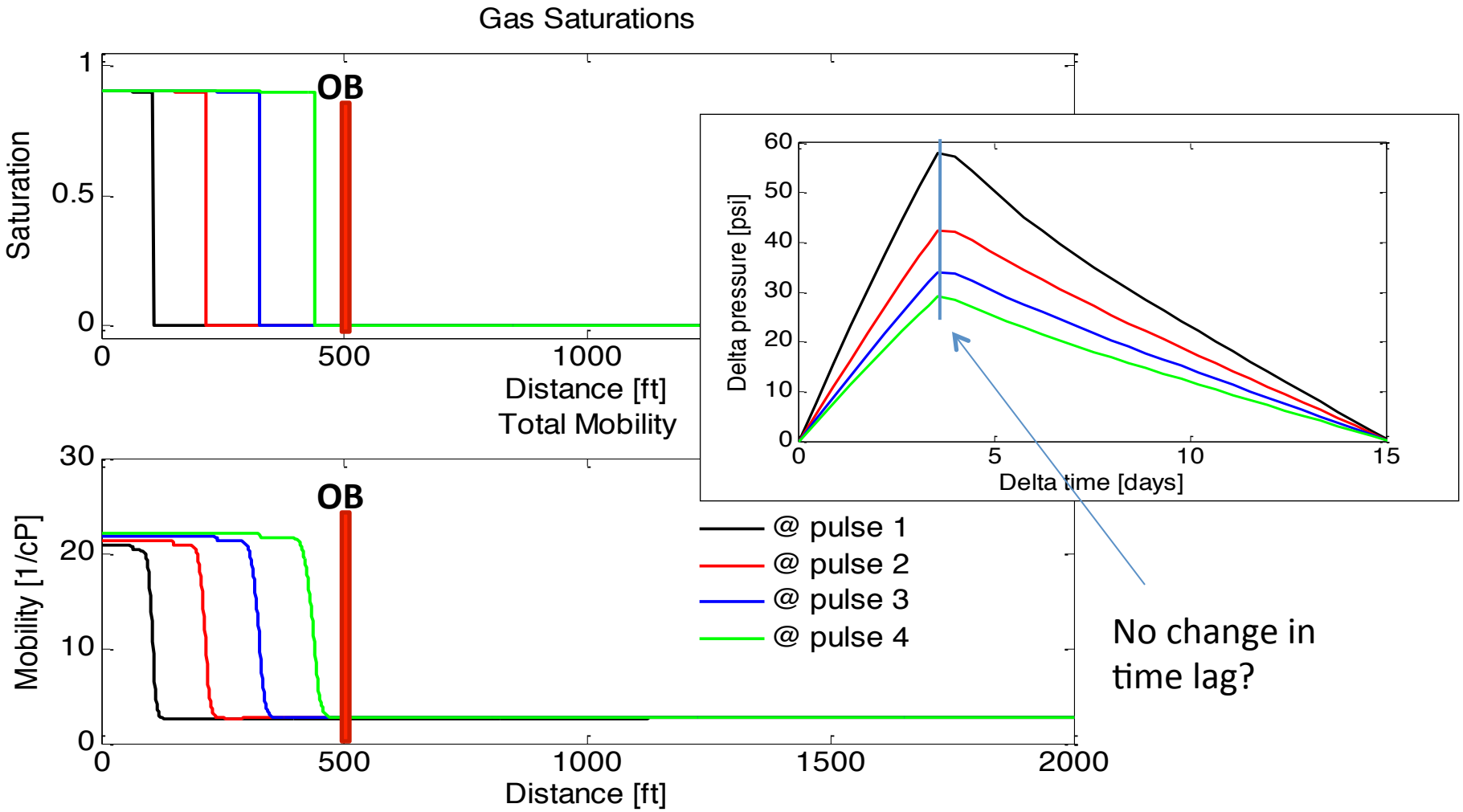


# Cross-Well Testing
# Ref: Karakas & Kristensen
# (Slb, unpublished work - 2011)




- Pulses generated by step changes in injection rate
- Pressure monitored in observer
- Travel time and amplitude of pressure response recorded
- 3 scenarios:
    - Water injection
    - CO2 injection
    - CO2 WAG injection
- Compositional, 1D & 2D models, 2000-5500 blocks
- Initial reservoir pressure varied above/below MMP for CO2

# $CO_2$: Miscible Case: P > MMP



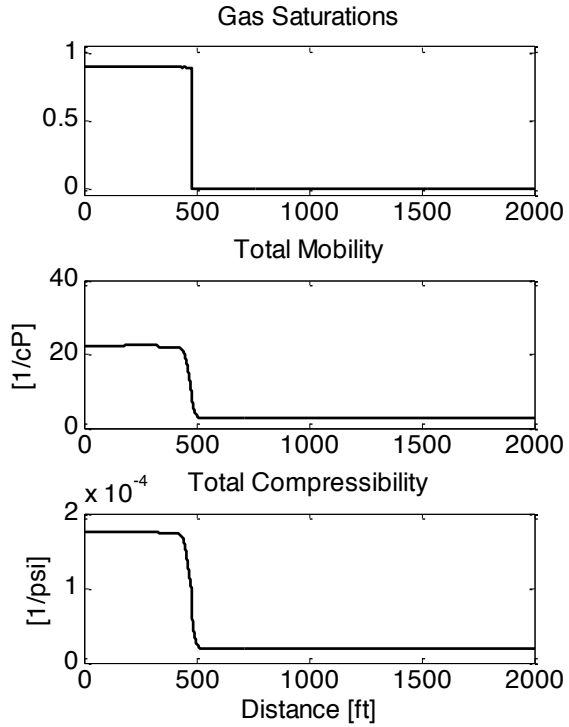
# $CO_2$: Miscible Case: P > MMP

$$t_D \propto \frac{S}{T}$$

$$S = \phi c_t h = \text{storativity}$$

$$T = \frac{kh}{\mu} = \text{transmissivity}$$

$$\text{Time lag} \sim \frac{\text{Compressibility}}{\text{Mobility}}$$




- Change in mobility is offset by change in compressibility
- Therefore no observable change in time lag

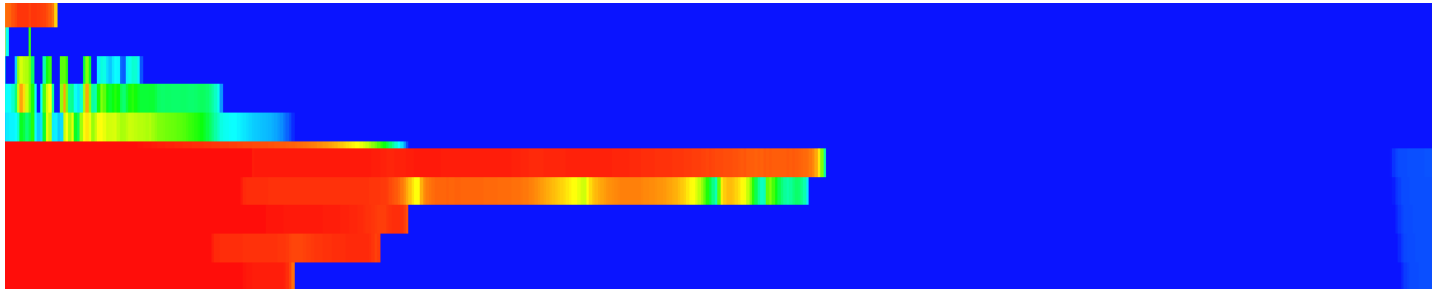
RMC

# Miscible $CO_2$ Injection

Kv = 0.1mD

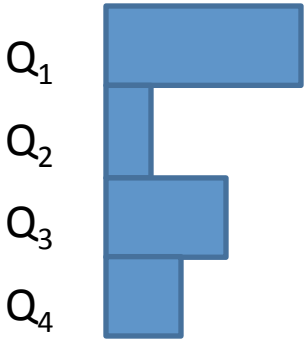
Kv = 0.01mD

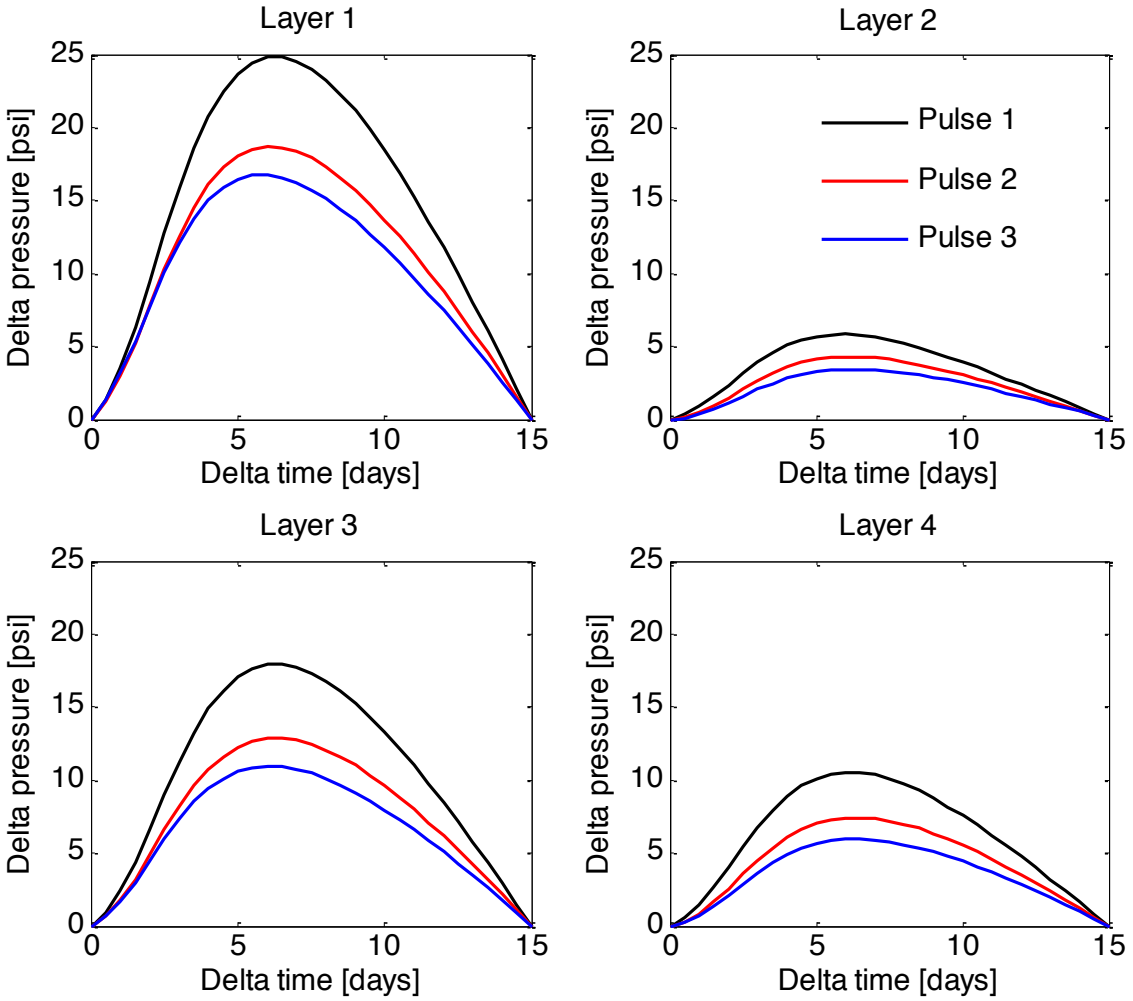
Kv = 0.001mD



# Miscible $CO_2$ Injection

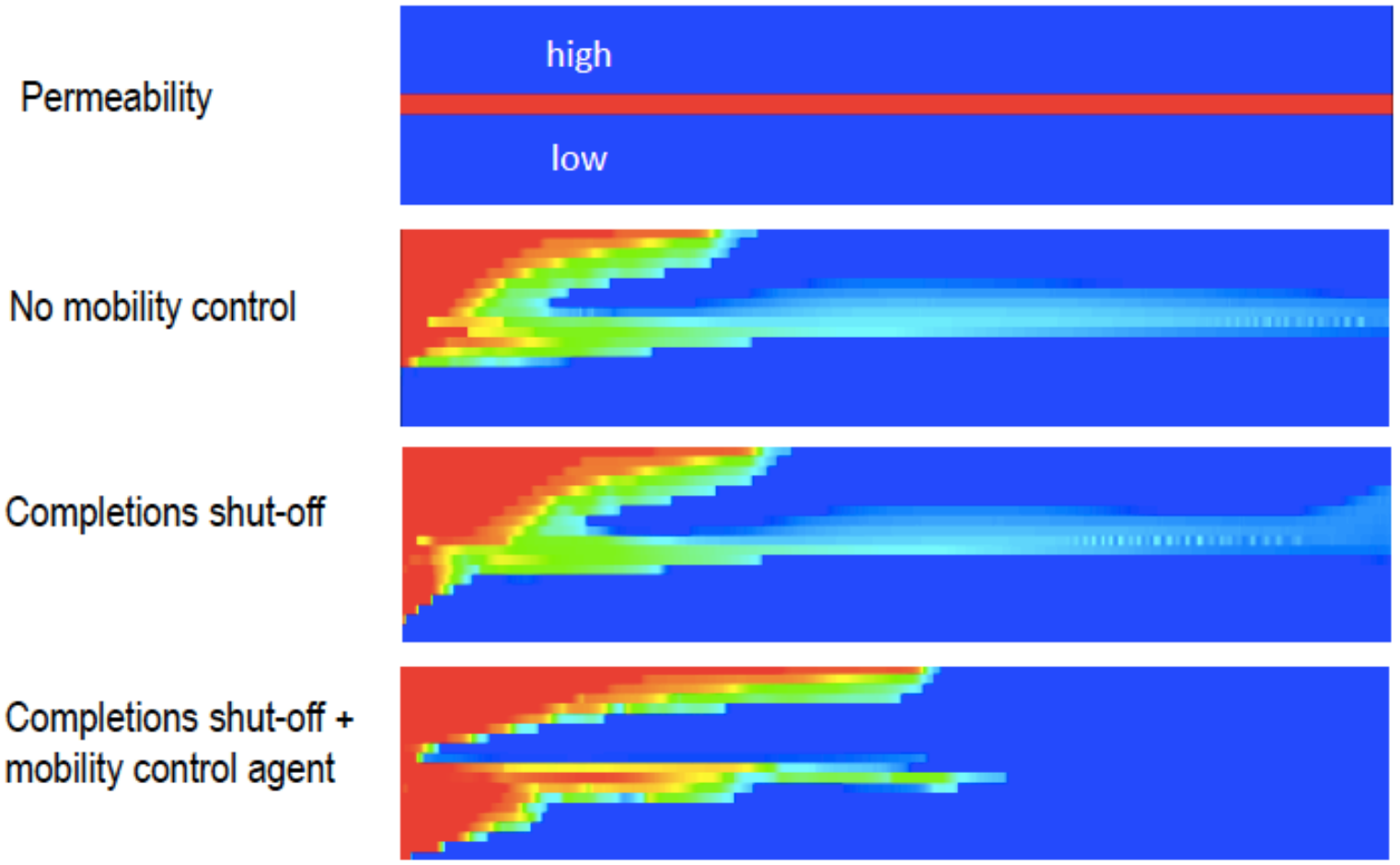
Layer Injection profile:



RMC

# Mobility Control



# Seismic Response during Oil Injection

RMC

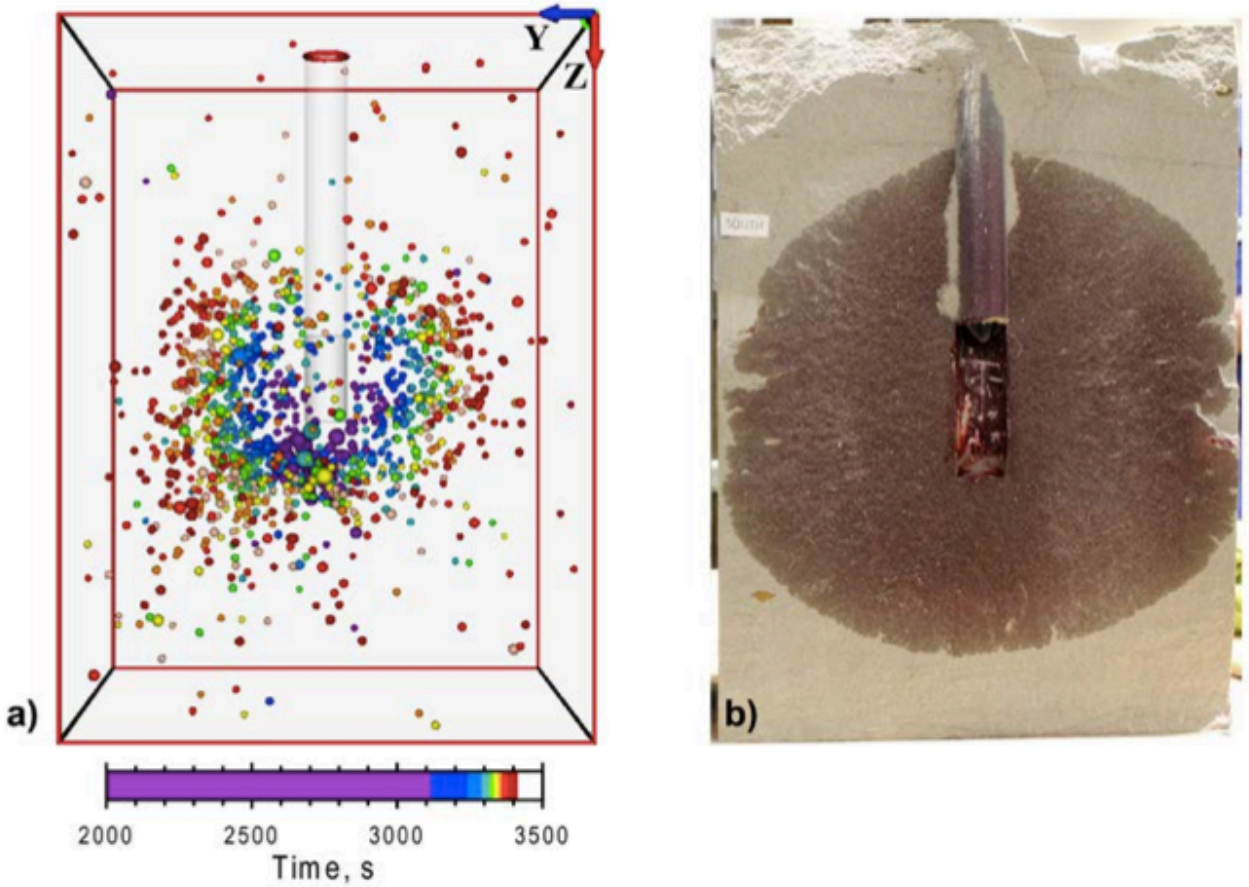



Fig. 9. *(a) YZ distribution of AE hypocenters localized during fluid injection in Test #1. The color of the balls indicates time sequence of AE events appearance according to color bar at the bottom of Figure 9a. The diameter of the balls is proportional to the logarithm of AE amplitude; (b) the photo fracture surface reviled after completion of Test #1, dark red color of oil indicates position of fluid front.*

*** Acoustic Emission and Ultrasonic Transmission Monitoring of Hydraulic Fracture Initiation and Growth in Rock Samples**

Sergey STANCHITS, Aniket SURDI, Eric EDELMAN, Roberto SUAREZ-RIVERA

RMC

# Conclusions

- $CO_2$-EOR is the realistic way forward for $CO_2$ storage
- We need technologies and methodologies that can make difference (cost and containment)
- Petroleum Engineers can make a difference!

Thank you