Optimizing CO_2 Sweep based on Geochemical, and Reservoir Characterization of the Residual Oil Zone of Hess's Seminole Unit

Project Number: **DE-FE0024375**

Ian Duncan

Research Scientist

Bureau of Economic Geology, University of Texas at Austin

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Presentation Outline

- Benefit to the Program
- Project Overview: Goals and Objectives
- Expected Outcomes

- Technical Status
- Accomplishments
- Summary

Benefit to the Program

- Supports DOE’s Programmatic goal No. 2, to “Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness”.

Project Overview:
Goals and Objectives

Project objective: “To improve the understanding of how much CO_2 can be stored in residual oil zones (ROZ) given current practice and how much this could be increased, by using strategies to increase sweep efficiency”.

These same strategies will increase the efficiency of oil production.

Technical Status

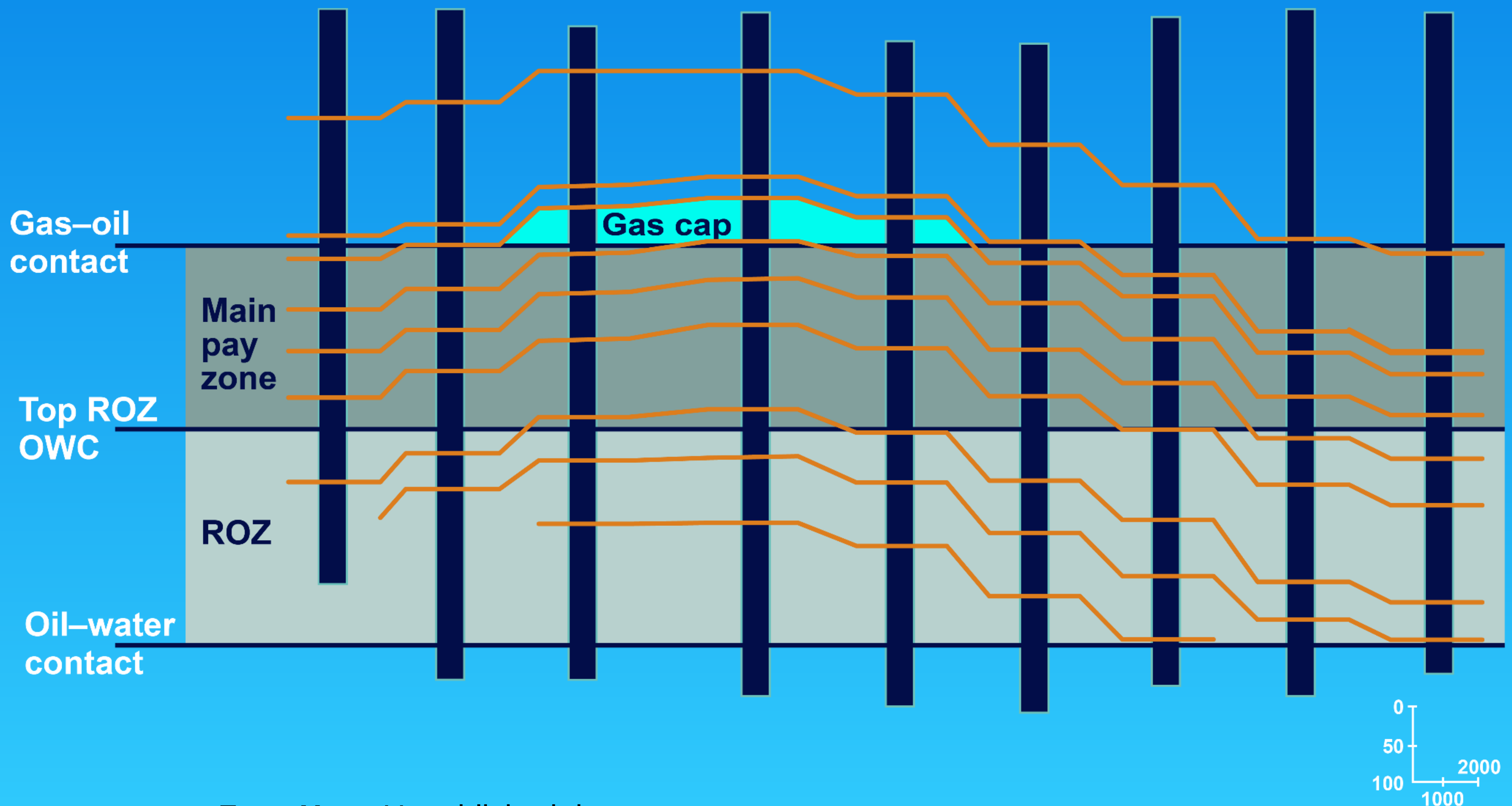
Middle San Andreas Paleogeography with Location of Industry Documented ROZ

QAe3886

GEOLOGY of SEMINOLE UNIT

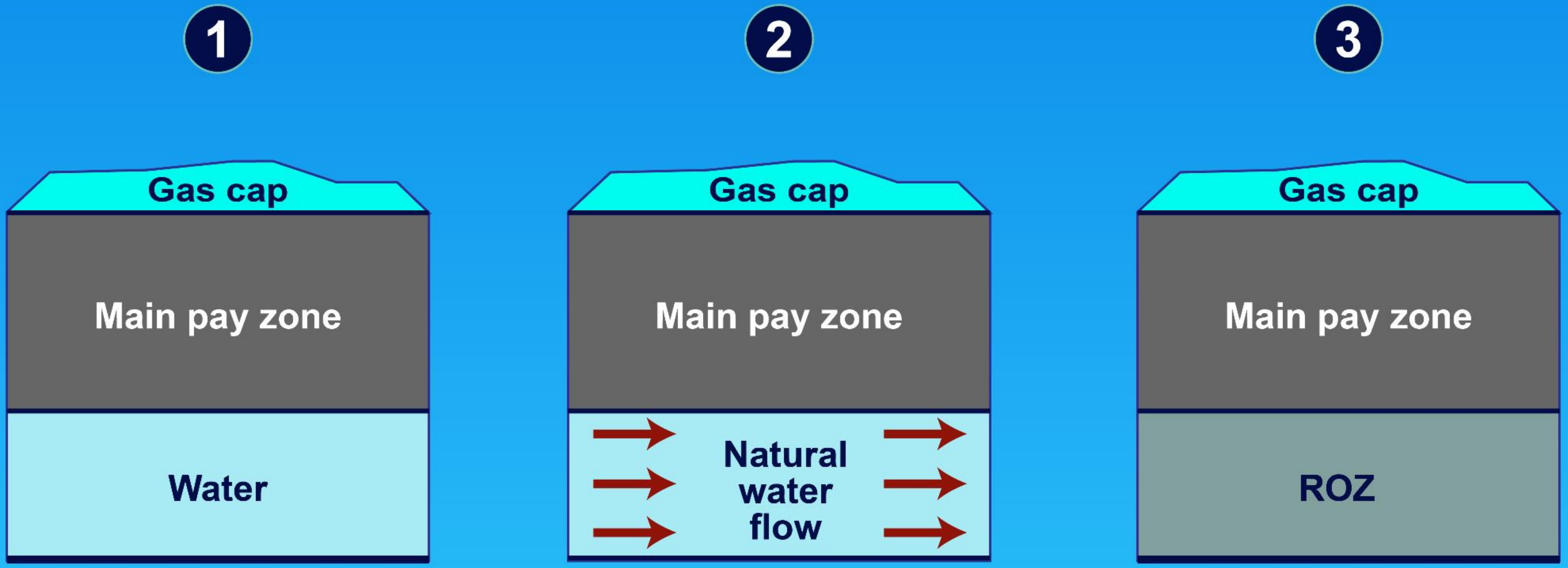
Seismic and geological analysis show that Seminole a **carbonate ramp reservoir**, one of several isolated platforms built during the lower San Andres and became linked with the rest of the platform during progradation of the upper San Andres sequence.

Structural Cross-Section
East to West



From **Hess** Unpublished data

ROZ Genesis


1
2
3
Gas cap
Gas cap
Gas cap
Main pay zone
Main pay zone
Main pay zone
Water
Natural
water
flow
ROZ

A UNIQUE DATA SET

824 wells within Seminole San Andres Unit:

- Cores from 66 wells, 17,556 feet total, complete ROZ core total 3,297 feet.
- Cores through entire MPZ for 24 wells
- Cores through entire ROZ for 12 wells
- Cores with full MPZ & ROZ for 5 wells
- 5 Sponge cores
- 7 cores with SCAL

- **Core Analyses:**

~17,000 core plug analyses for porosity, permeability, grain density, and fluid saturations, as well as 148 MICP analyses;

Wireline Logs:

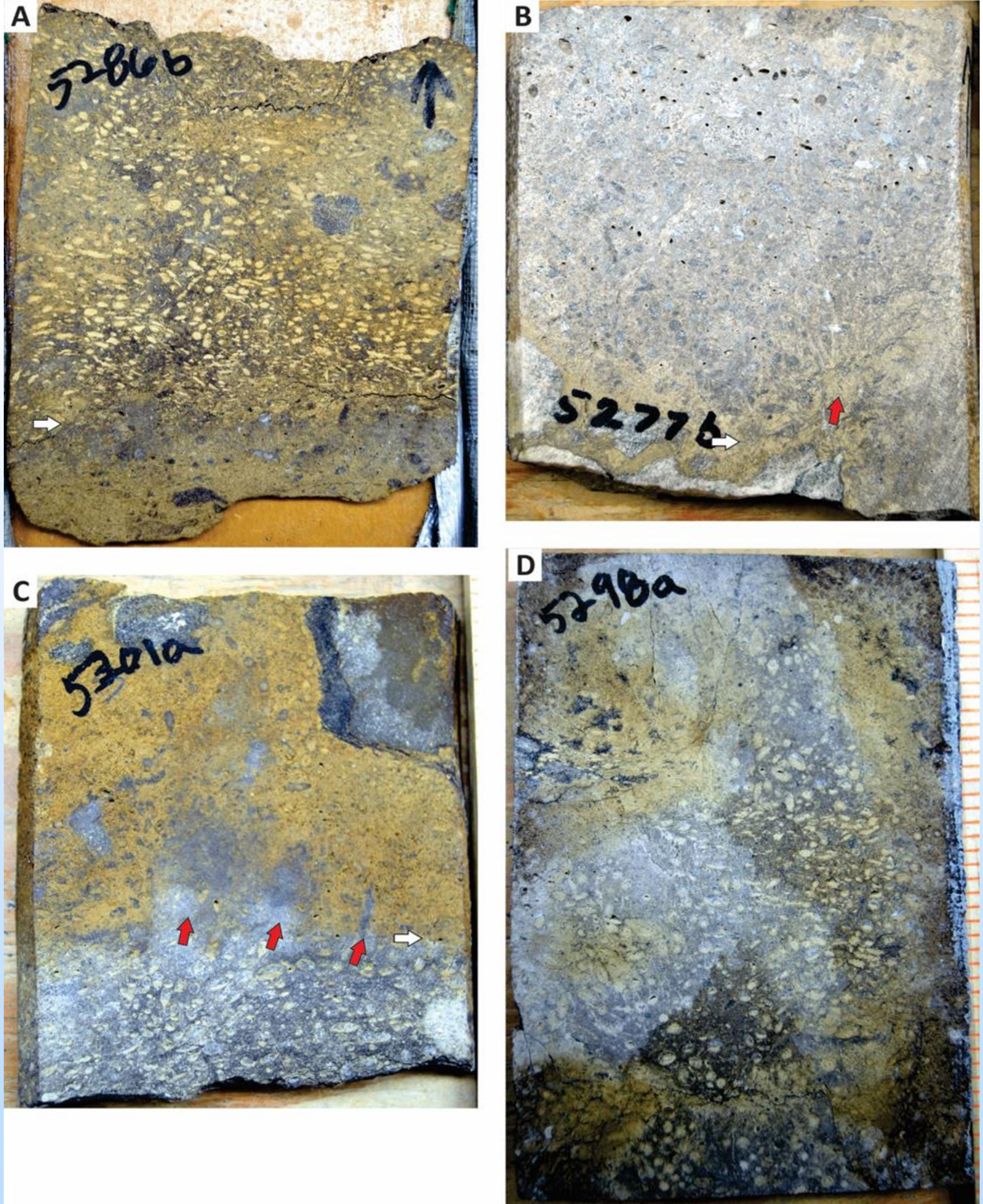
Gamma Ray: 612 wells ; *Density Porosity*: 283 wells; *Neutron Porosity*: 296 wells; *Sonic Porosity*: 294 wells; *Caliper*: 408 wells; *SP*: 33 wells; *Shallow Resistivity*: 235 wells; *Deep Resistivity*: 252 wells; *Photoelectric*: >68 wells

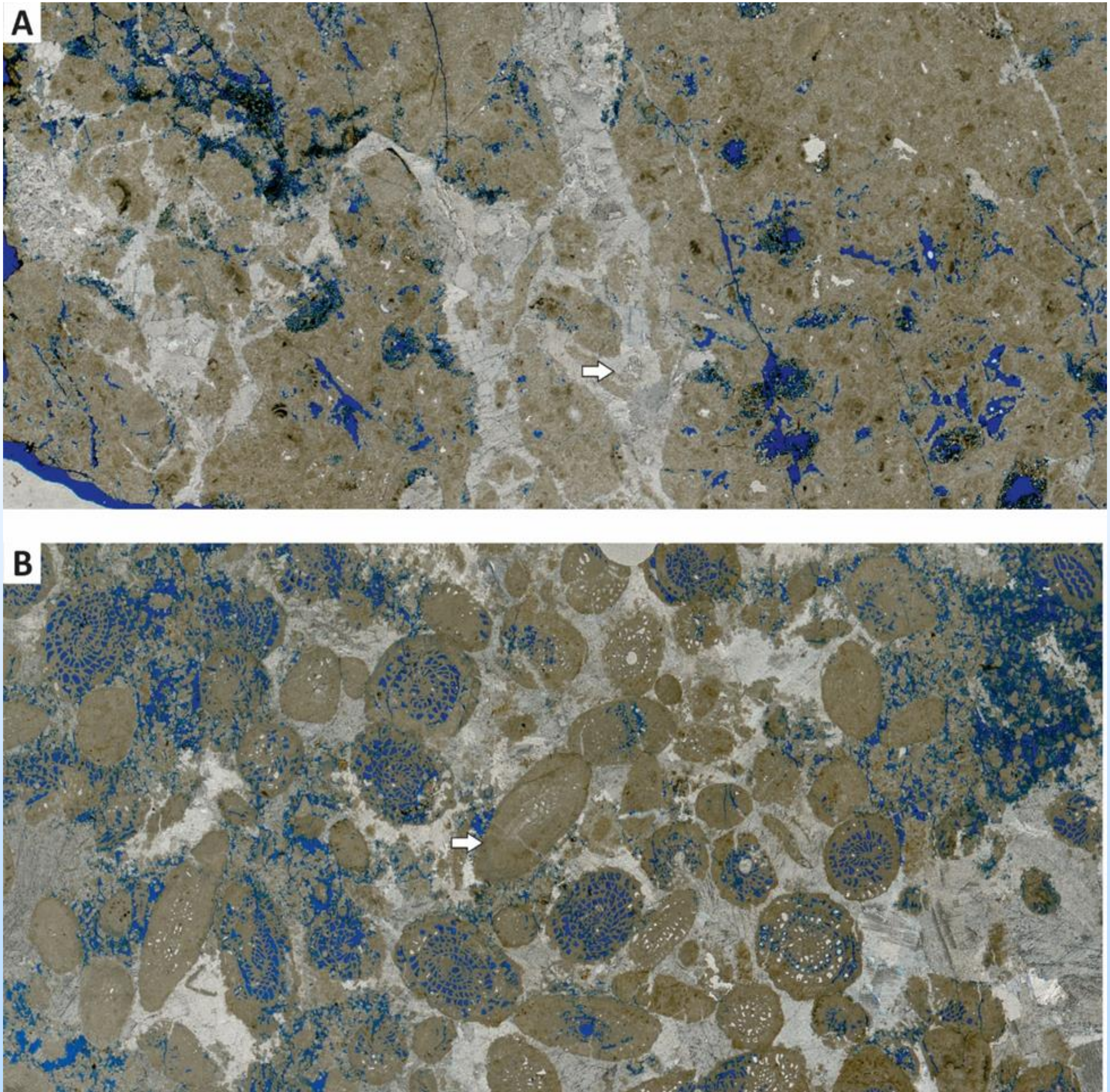
DEVELOPING A STATIC RESERVOIR MODEL

- Geologic logging cores… **new facies interpretations**… new modern analogues
- New approach to **upscaling** porosity and permeability
- New analysis of petrophysical data.
- Extensive **new lab measurements** of permeability, compressive strength, seismic velocities, electric resistivity, and NMR.

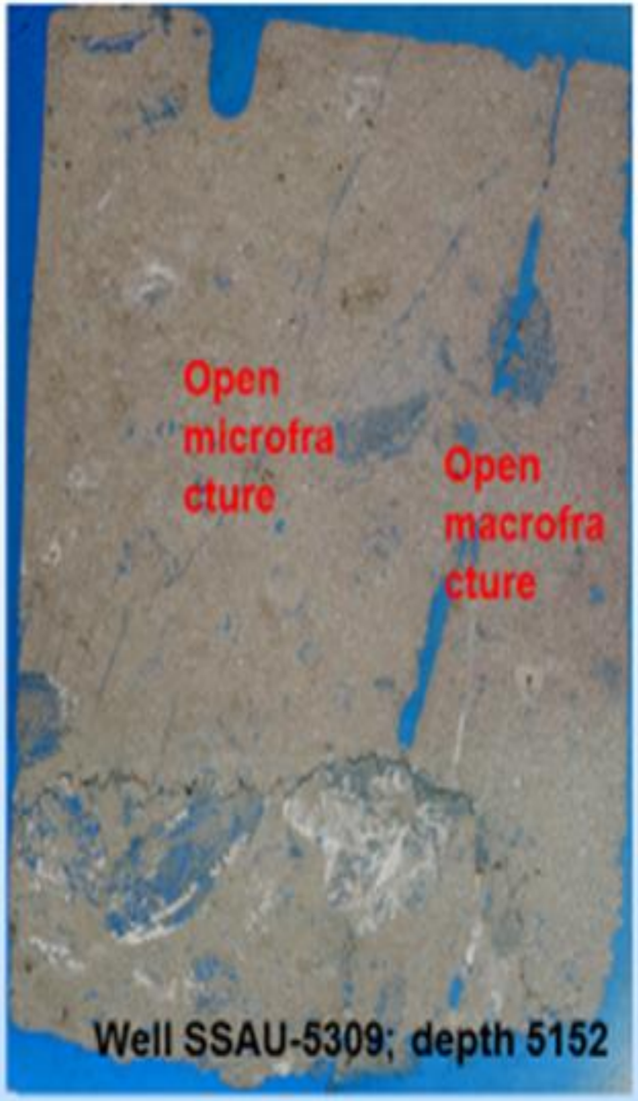
Seminole Unit core being logged

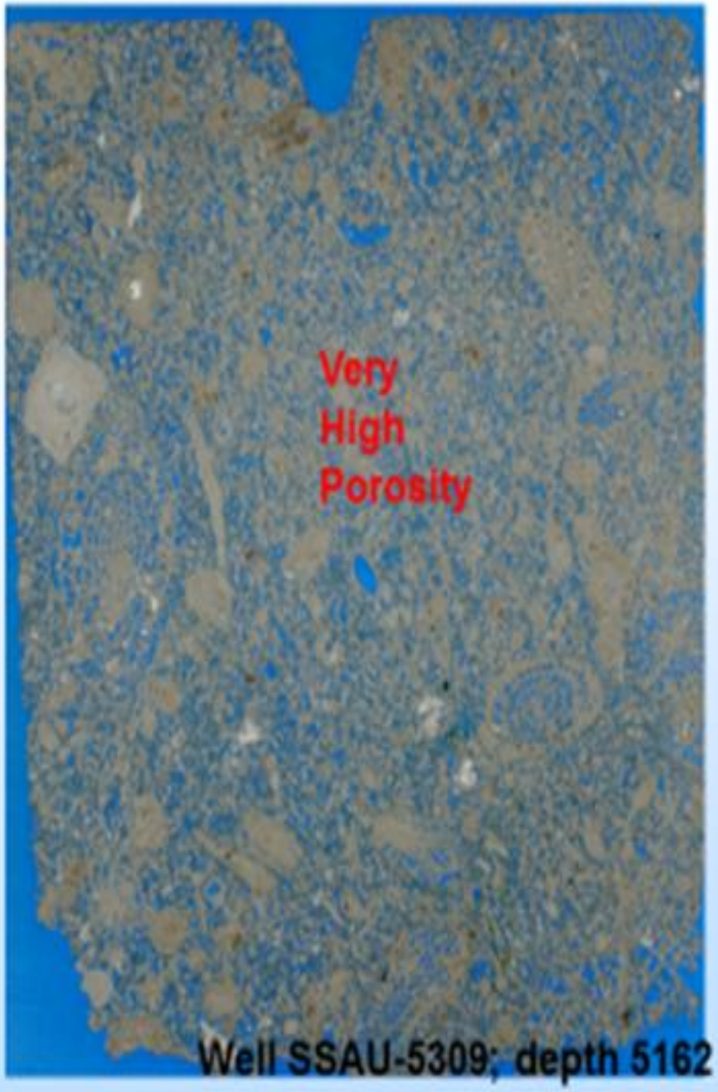
REINTERPRETING GEOLOGIC FACIES


A
5286b
B
5277b
C
5301a
D
5298a

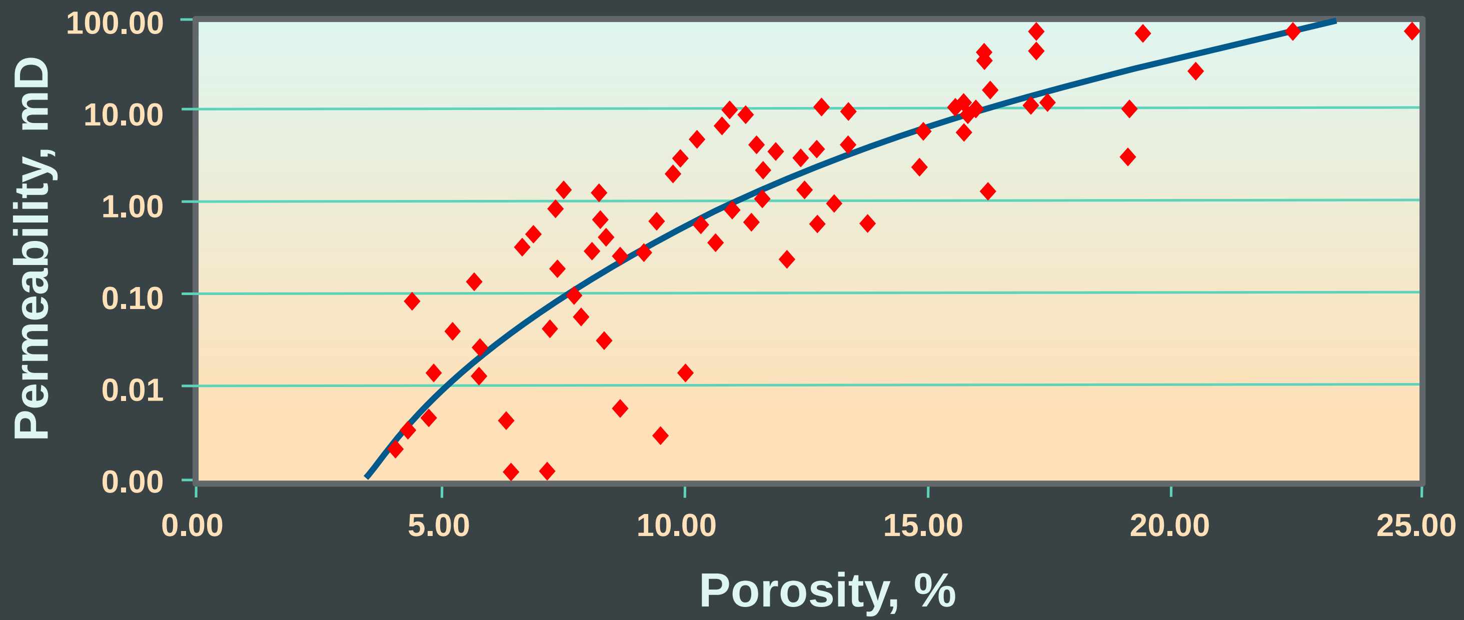

A
B

UNDERSTANDING RESERVOIR PERMEABILITY


Open microfracture
Open macrofracture
Well SSAU-5309; depth 5152


Very High Porosity
Well SSAU-5309; depth 5162

Core Plug Porosity vs. Permeability – SSAU 3123RO²



Source: SPE, 2010, Honarpour, M. M., and others
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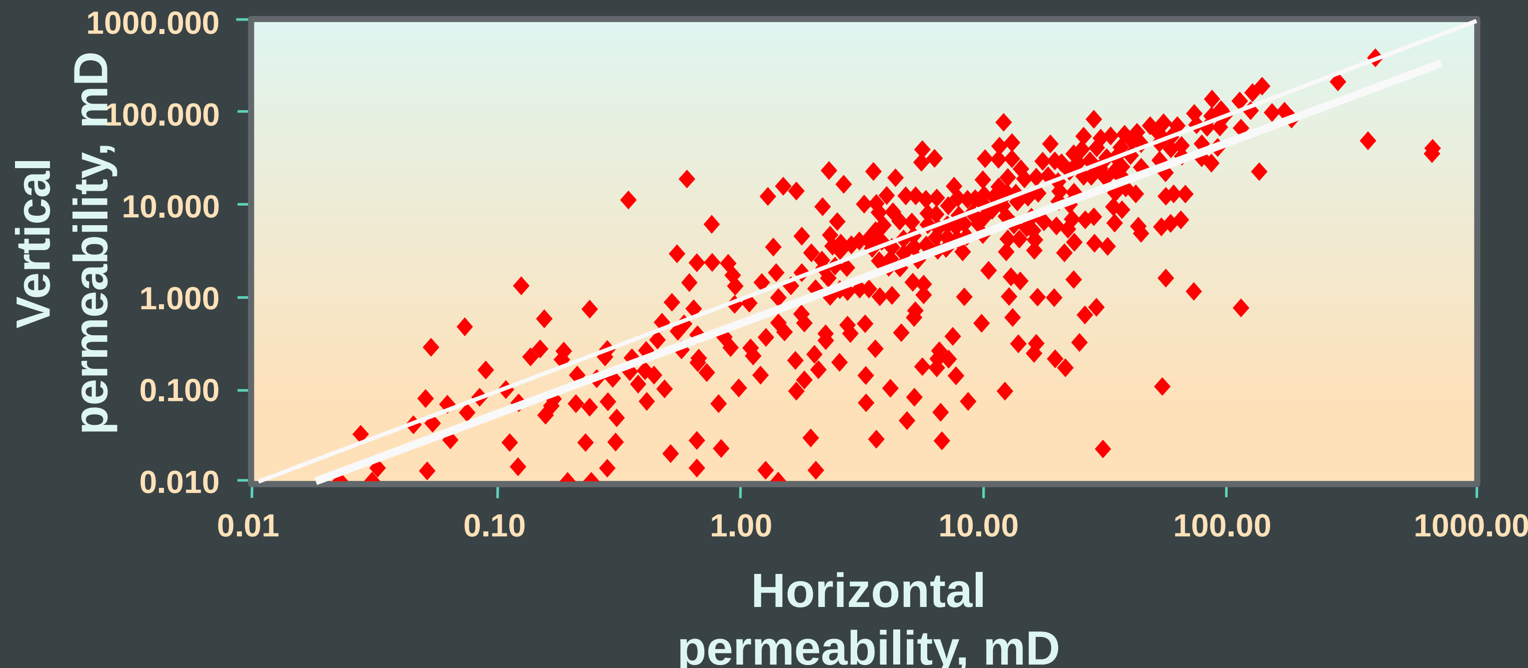
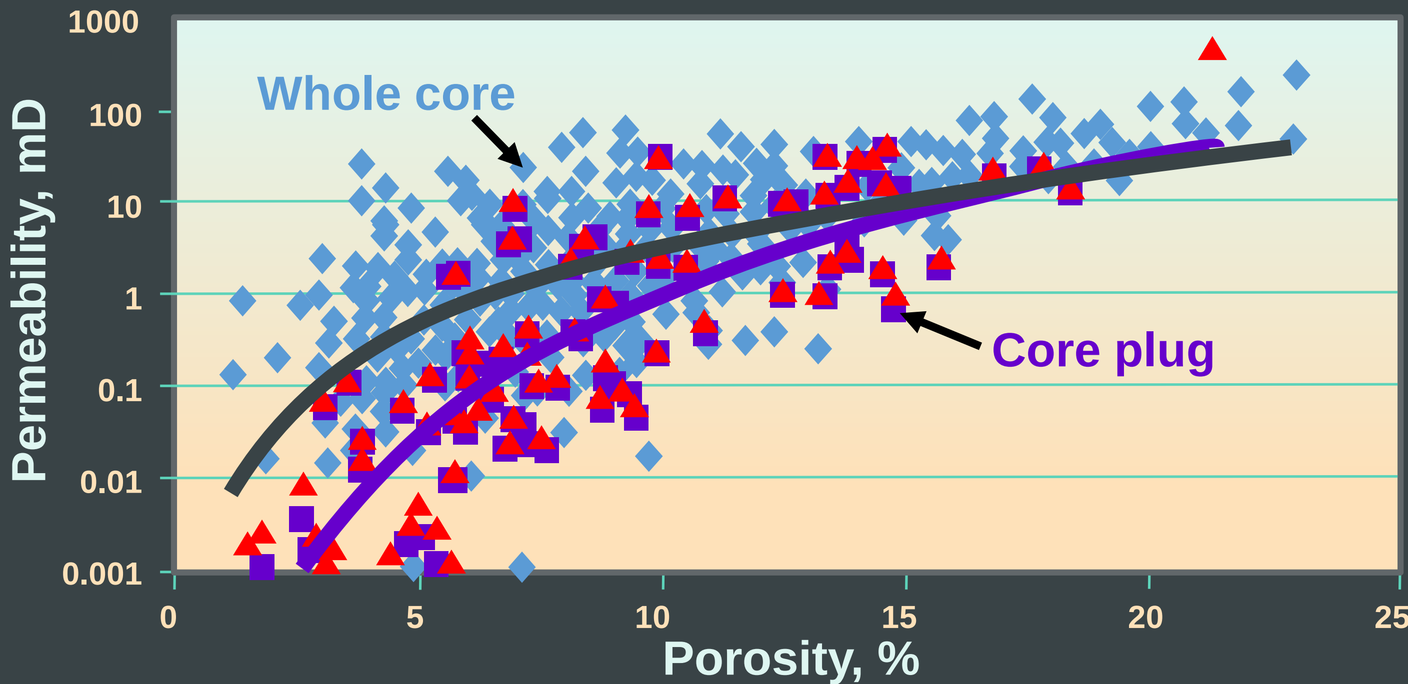
Vertical vs. Horizontal Permeability – Full Core SSAU-3903



Source: SPE, 2010, Honarpour, M. M., and others
QAe4803

Whole Core vs. Plug Porosity-Permeability



Source: SPE, 2010, Honarpour, M. M., and others
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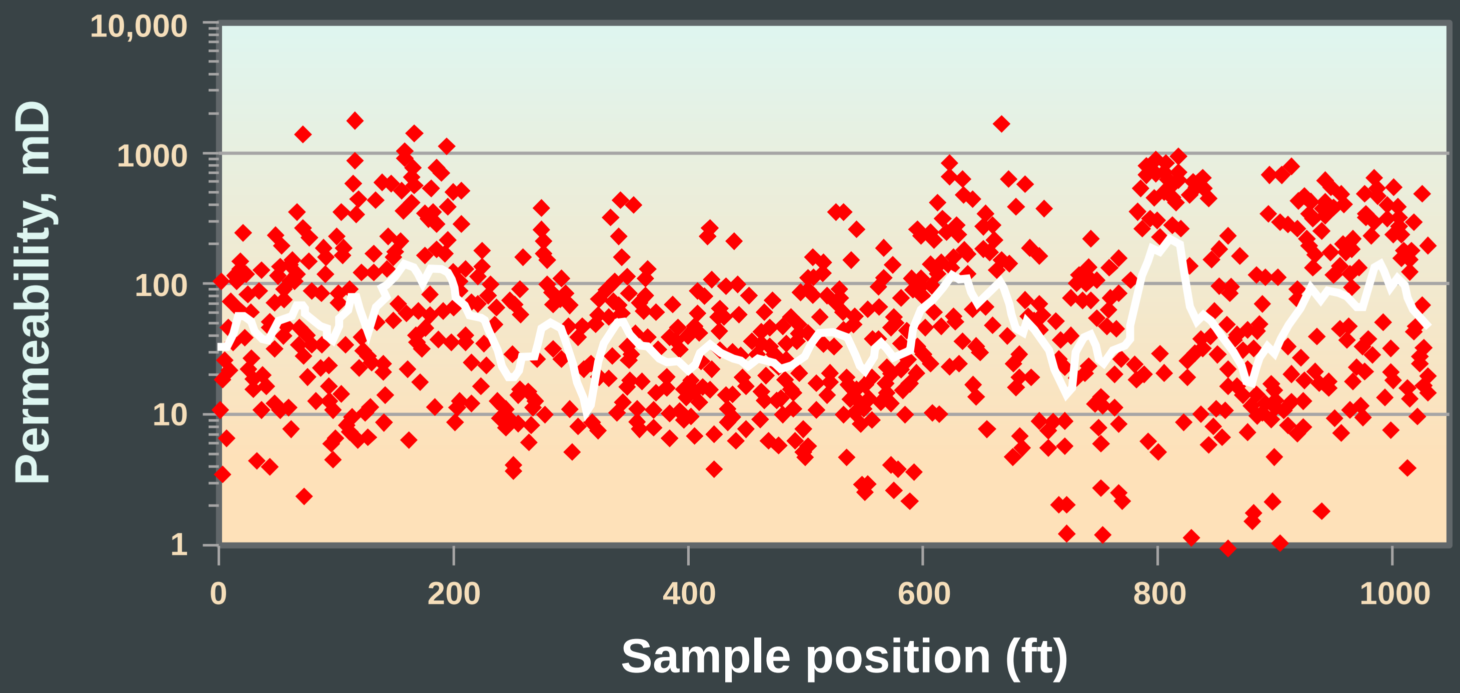
LATERAL PERMEABILITY VARIATION SURFACE OUTCROP



Source: SPE, 2010, Honarpour, M. M., and others
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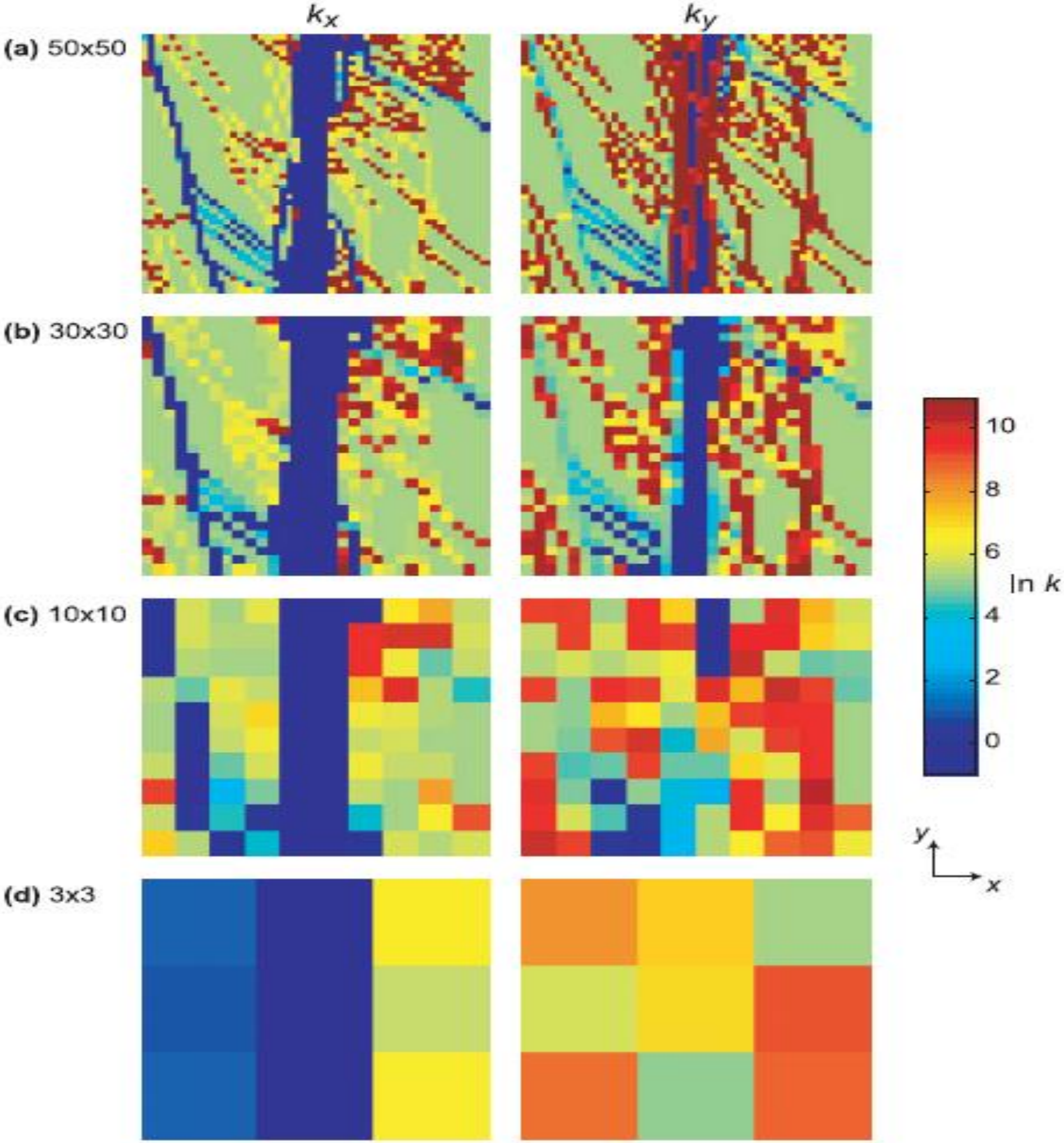
THE UPSCALING PROBLEM

- Typically in building a static reservoir model there are 10 or more times resolution in permeability measurements as the vertical dimensions of model cells

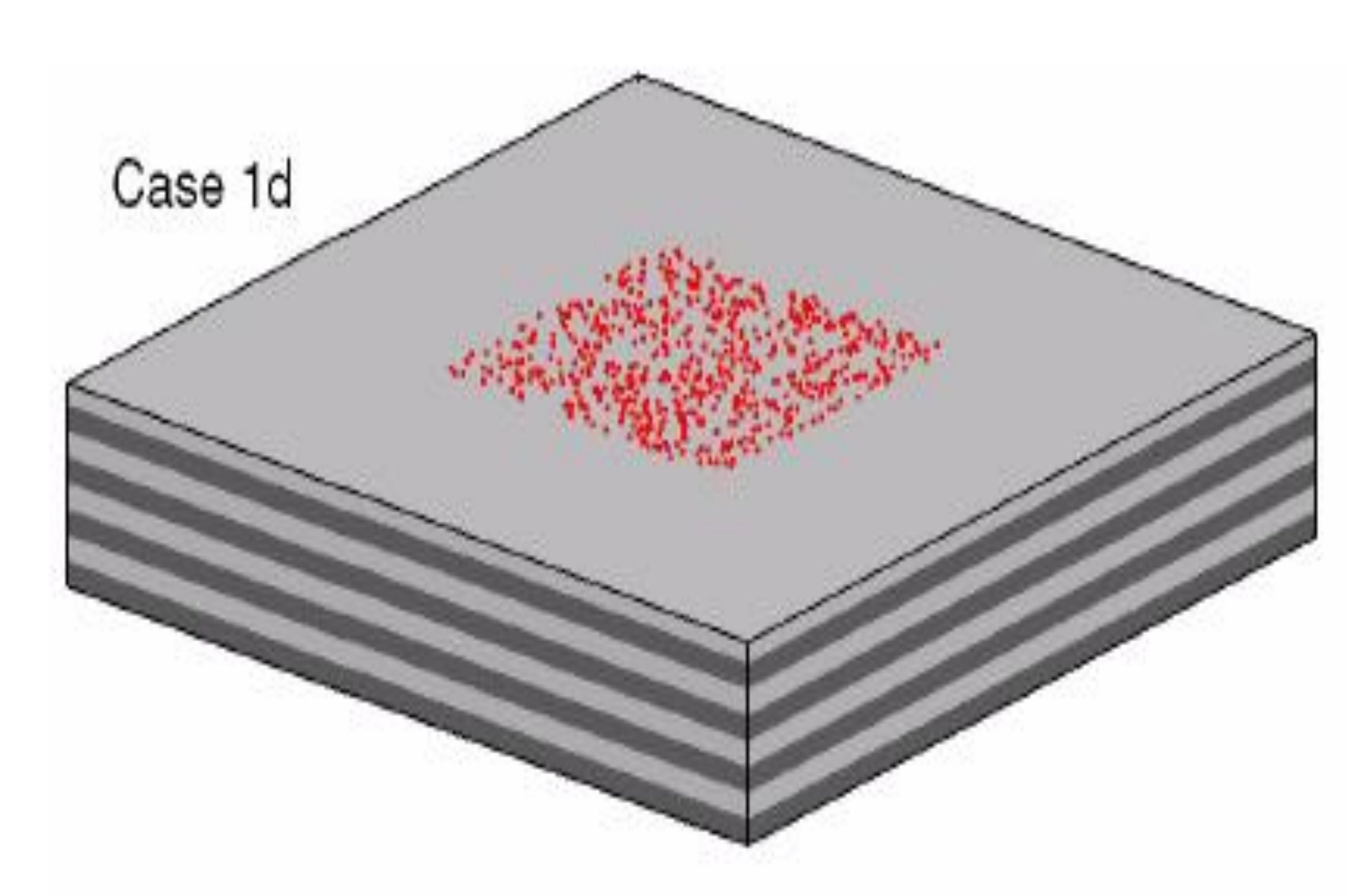
- Upscaling is the key step in all simulation modeling for EOR and CO_2 sequestration



From: Flodin et al, 2004

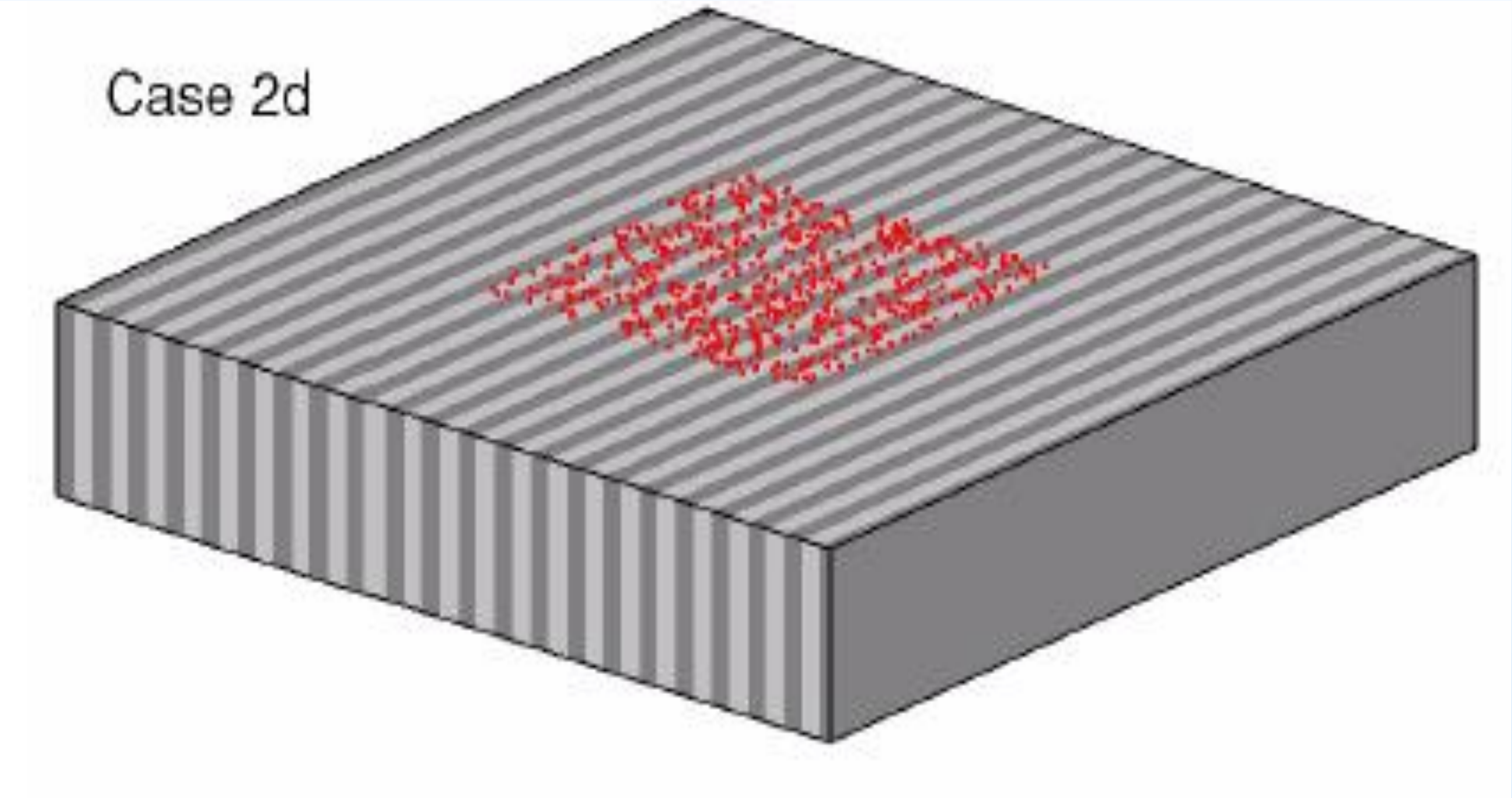
Harmonic Mean

$$k_{eff} = \frac{\Delta z}{\frac{d_1}{k_1} + \frac{d_2}{k_2}}$$

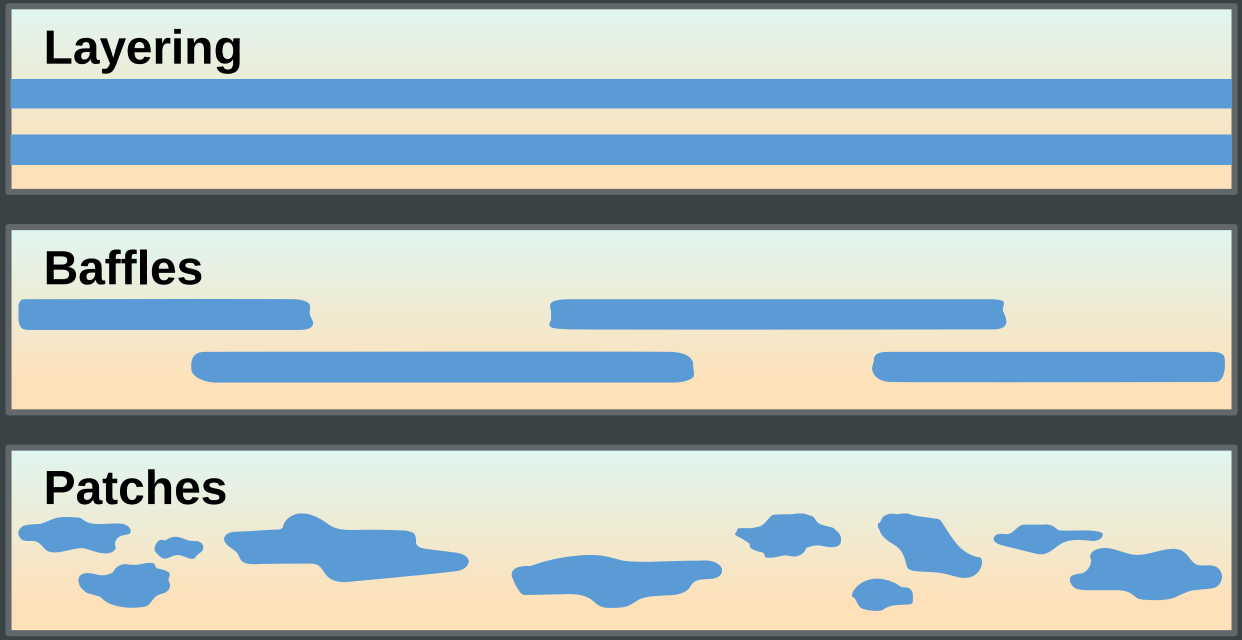


Geometric Mean

$$k_{eff} = \frac{k_1 d_1 + k_2 d_2}{\Delta x \Delta y}$$



SPATIAL VARIATION HIGH PEREABILITY



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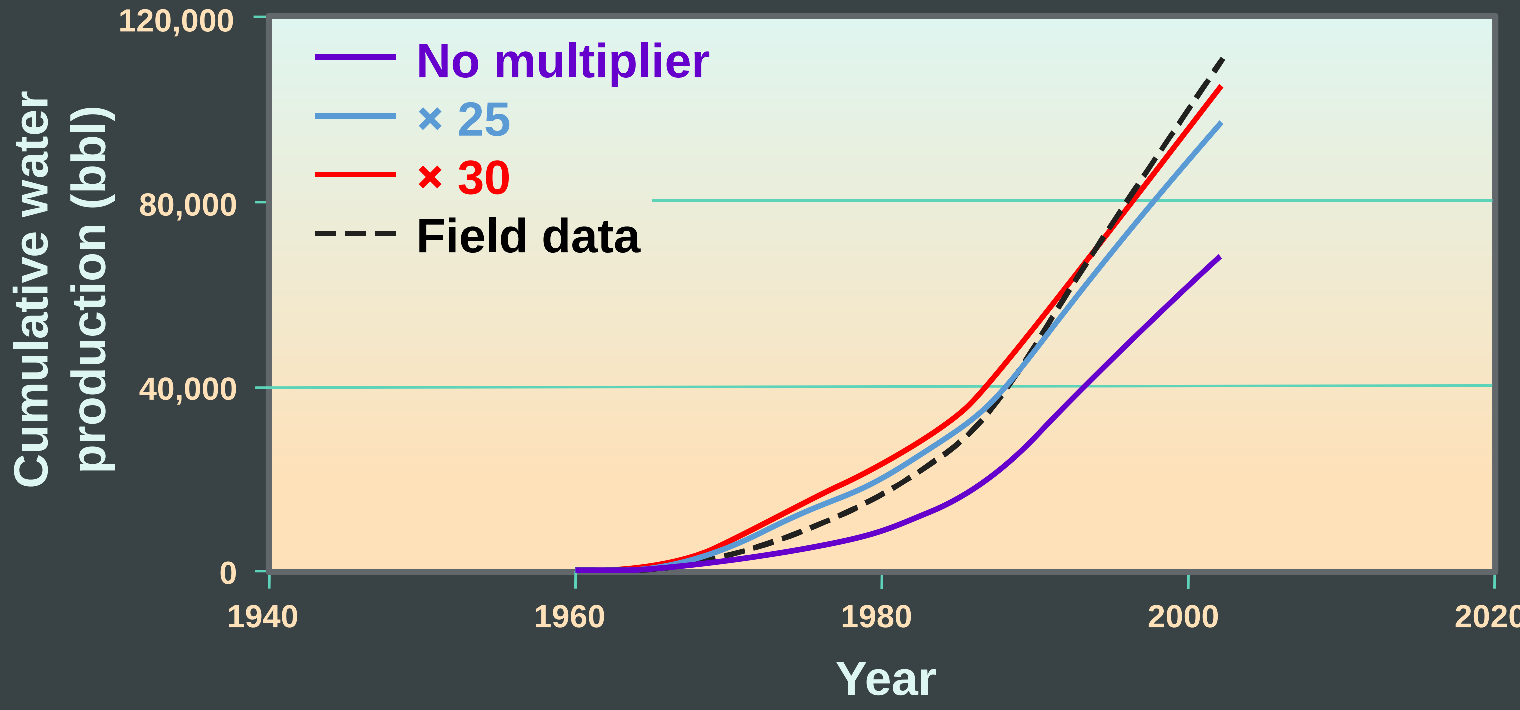
PERMEABILITY DEFICIT DISORDER

- Reservoir simulations of major Permian Basin oil fields cannot match observed data unless much higher permeability magnitudes are used in simulations.

- Typical “Permeability Multipliers” used are between 2 and 10.

CUMULATIVE WATER PRODUCTION VERSUS PERMEABILITY MULTIPLIER, FULLERTON FIELD,



Modified from Wang and Lucia, 2013
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Impact of Fracture Permeability

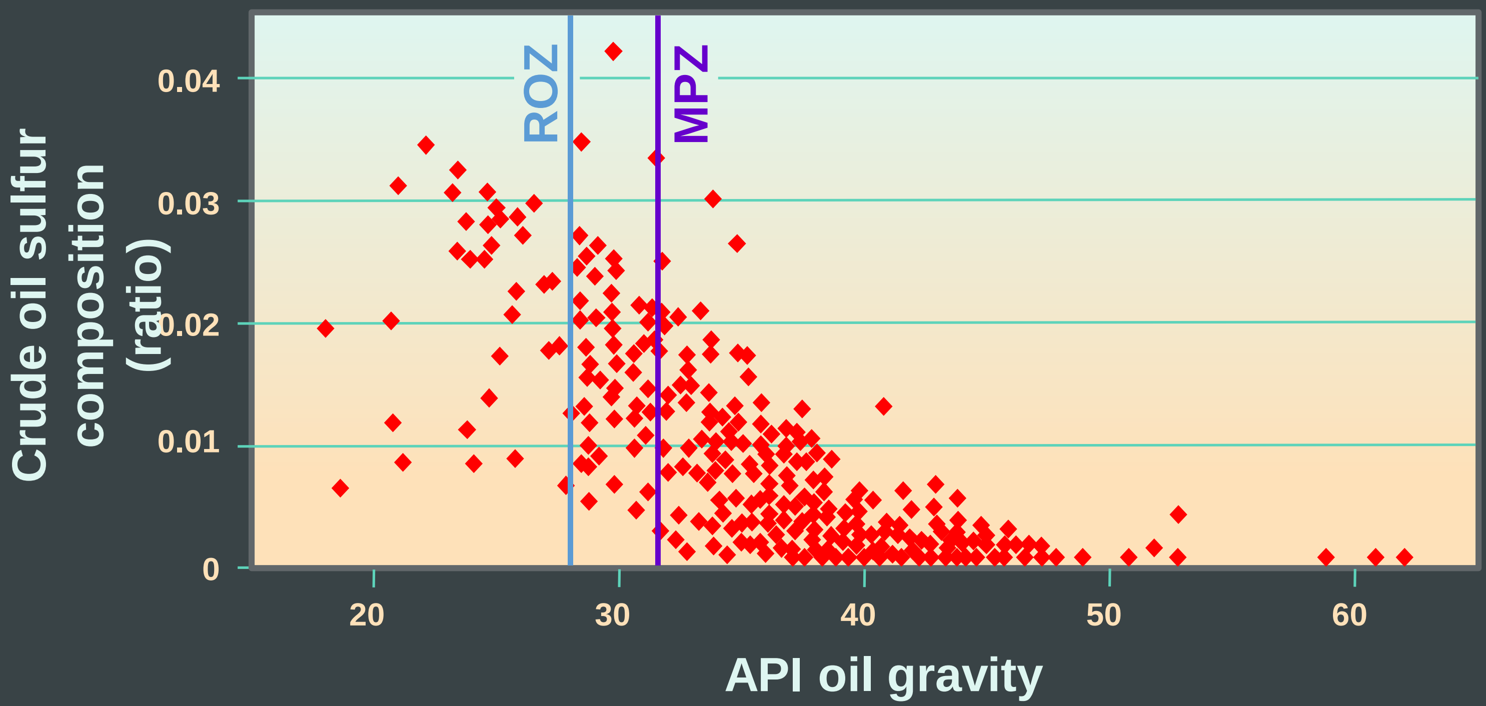
Total permeability ranges between 2 and 10 times larger than the matrix permeability as a result of natural fractures….

From Philip (2005)

CAN SULFUR BE USED TO TRACE HIGH PERMEABILITY PATHWAYS?

- In Permian Basin ROZ oil appears higher in sulfur (native sulfur replaces anhydrite)
- In Seminole pyrite often found along stylolites, reflecting H_2S.
- Currently investigating distribution of sulfur compounds and H2S within reservoir.
- Sulfur isotope study being intiated.

API vs. Oil Sulfur Content



After Logan, 2014
QAe5000

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Accomplishments

- We have assembled a unique collection of data from our partner HESS
- We have complete data base of all geologic data, well logs, and petrophysical measurements in PETRA.
- We have evaluated several upscaling approaches for permeability
- WE have completed preliminary study of diagenesis and have initiated CLT, SEM and isotopic studies

Synergy Opportunities

– Our study will provide the first detailed publically available study of a ROZ….. We are reaching out to other projects as our data becomes cleared for release by Hess.

Summary

– Key Findings

We are modifying published facies classification scheme for the San Andres

Upscaling previously used for these type of reservoirs is defective… new approaches offer significant benefits in more realistic flow simulation

There is extensive evidence of H2S migration apparently between the ROZ and the overlying main pay zone reservoir.

Summary

– **Lessons Learned**

Sulfur isotopes of pyrite, anhydrite, produced water, and oil will likely be needed to resolve origin of pyrite along fluid pathways in MPZ and test connection to large scale anhydrite dissolution in ROZ

Summary

– **Future Plans**

We plan to:

(1) Complete geologic logging and facies analysis

(2) Apply new upscaling to Petrel reservoir model

(3) Complete analysis of MCIP and CT data

(4) Carry out electric resistivity and NMR measurements on selected perm plugs.

(5) Carry of chemistry and isotopic studies of fluids

(6) Initiate simulation modeling

Appendix

Organization Chart

Project Director Ian Duncan	
Task 1 Management	**Task 2 through 6**
Task Leader/Back-up Duncan/Ambrose	**Task Leader/Back-up** Duncan/Ambrose

Gantt Chart

	Yr1 Q1	Yr1 Q2	Yr1 Q3	Yr1 Q4	Yr2 Q1	Yr2 Q2	Yr2 Q3	Yr2 Q4	Yr3 Q1	Yr3 Q2	Yr3 Q3	Yr3 Q4
2	X	X	X	X	X	X	X	X	X	X D7	X	
2.1	x	x	x D3	x	x	x	x	x				
2.2		x	x	x	x	x D11	x	x				
2.3			x	x	x	x	x	x	x			
2.4				x	x	x	x	x D8				
2.5				x	x	x	x	x	x	x D9		
3		X	X	X	x D4							
4		X	X	X	X	X	x D5	X	x D6	X	X	
4.1				x	x	x						
4.2			x	x	x	x	x					
5		X	X	X	X	X	X	X	X	X	X D10	
6						X	X	X D12	X	X	X	X D13

Bibliography