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The program will begin soon.

You will not hear audio until we begin.

Webinars

Reservoir Rock & Rock-Fluid Heterogeneities - Impact on Recovery Processes

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February 6, 2023

SPE International

Honarpour Technology Company, HTC, LLC

100 Years of Prosperity for Mankind

Achievements and Shortcomings Beyond API RP-40 (continued)

Achievements

- Set standard for Basic Routine Core Analysis, RCA: porosity, permeability, fluid saturation, grain density measurement for homogeneous rocks
- Improved precision and accuracy because of new instrumentation, techniques, automation and workflow - NMR, petrographic, imaging and flow tests
- Lead to higher quality data, faster measurements and analysis

After SPE, 2022, RAC on Core Analysis

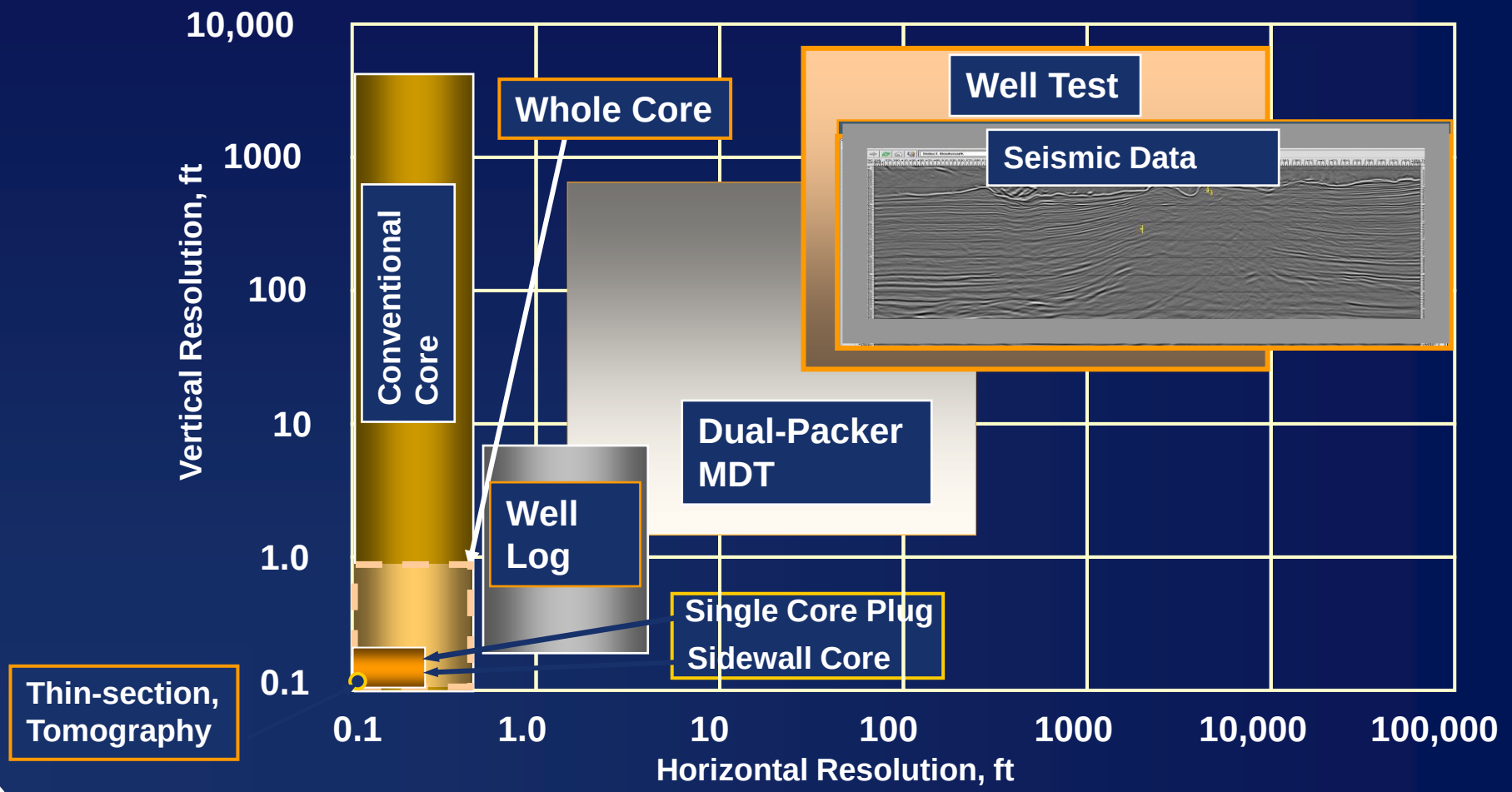
Achievements and Shortcomings Beyond API RP-40

Shortcomings

- Advanced technologies for effective Low Invasion Coring
- Identification and characterization of the critical heterogeneities at downhole conditions for design of well location, data collection and optimization of recovery in heterogenous rocks
- Integration of geological/ petrographic data, with wireline logs, downhole flow tests, geochem and associated uncertainties
- Standards for RCA of Unconventional reservoirs, Special Core Analysis, Geomechanical properties and Scale-up
- Training of new generation of engineers and geoscientist with strong data analysis skills to compensate for recent loss of experienced experimentalists and core analysists

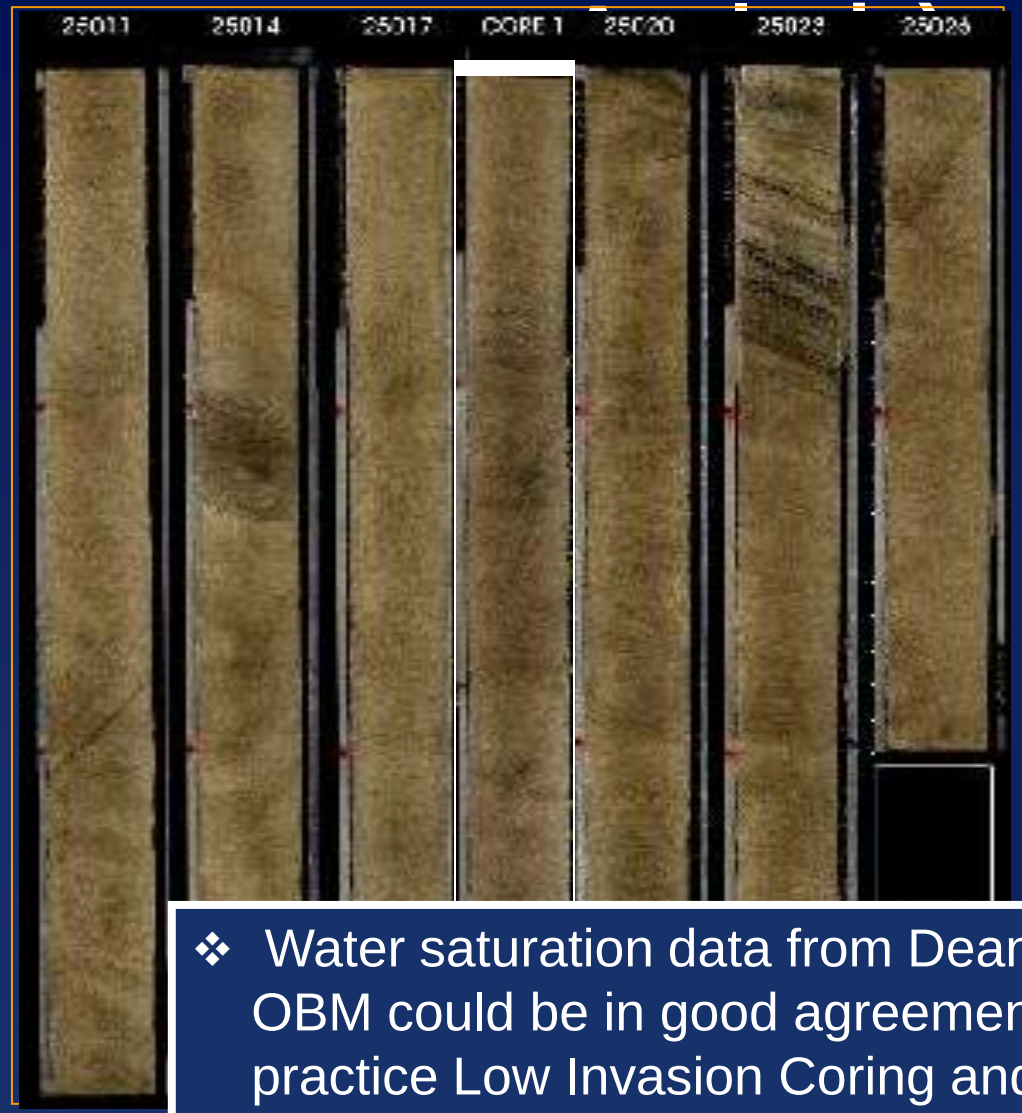
After SPE, 2022 RAC on Core Analysis

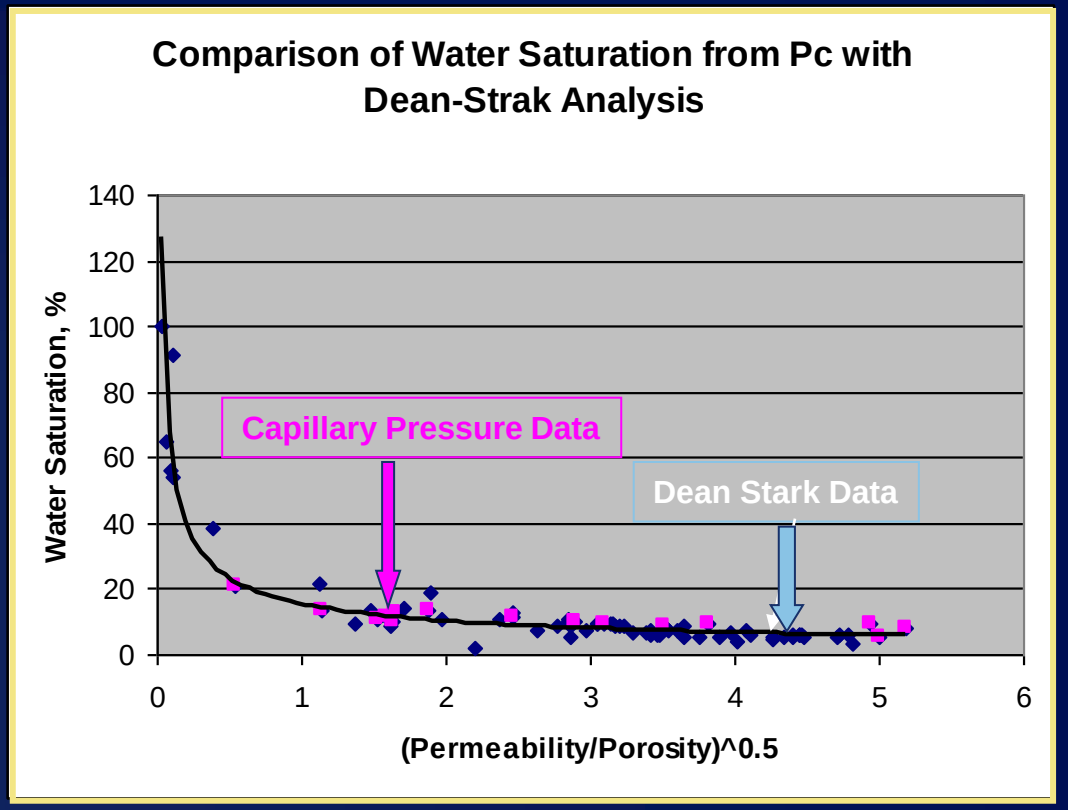
Integration of core & other data



Modified from Vinson and Bissell (1992)

Water Saturation in Un-invaded Core – Data from Capillary Pressure and RCA (D/S)

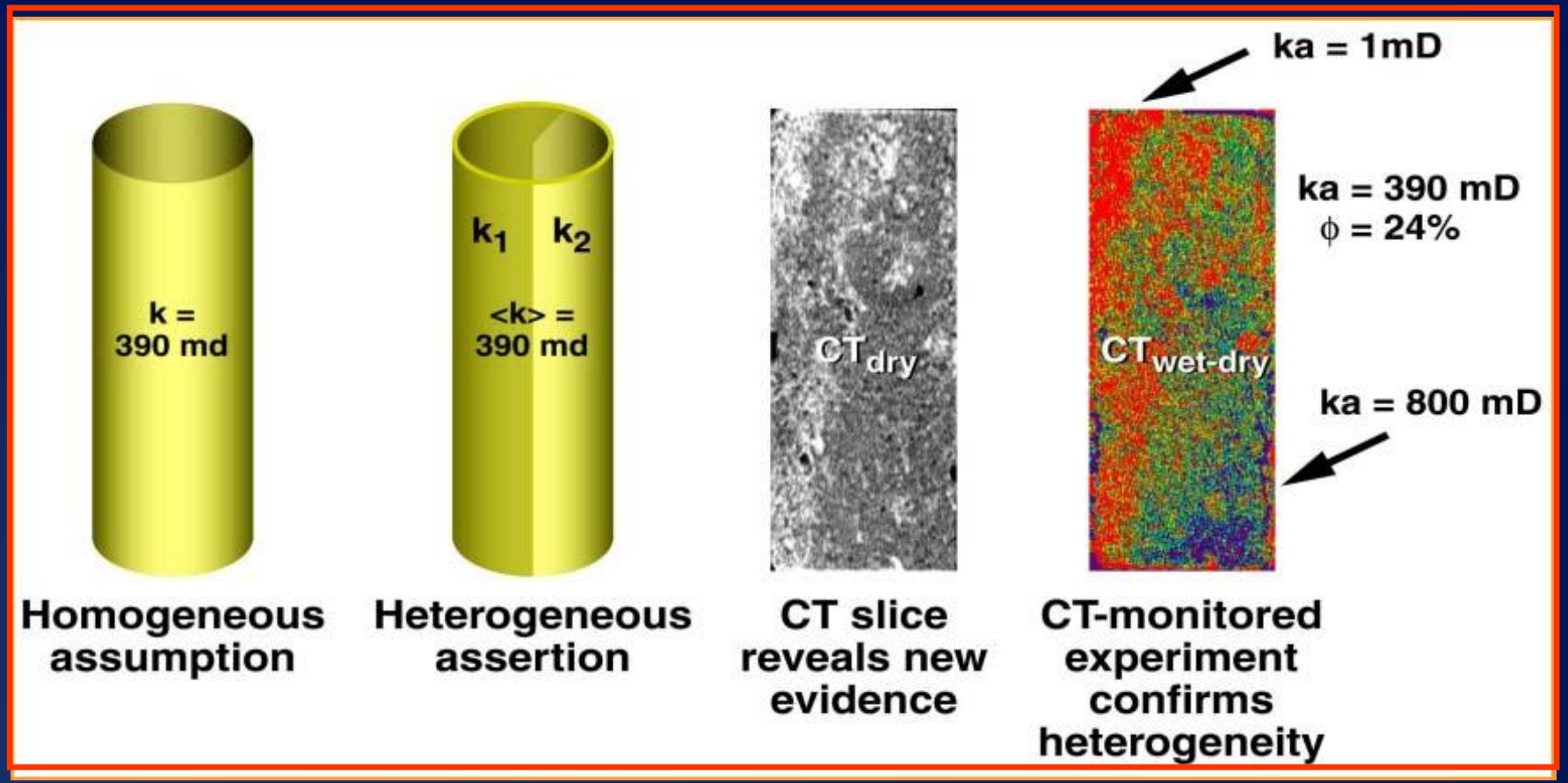




- Water saturation data from Dean - Stark analysis of cores taken with OBM could be in good agreement with capillary pressure data when best practice Low Invasion Coring and testing are implemented.

M. M. Honarpour, N. F. Djabbarah, K. Sampath: Drilling Mud Invasion and **Alteration** of Initial Water Saturation, ATCE 2012

Scale of Heterogeneity Similar to Core Plug Size
Middle East Carbonate RCA Core Plug



Heterogeneity in core plug shown by CT density and permeability

M. M. Honarpour, N. F. Djabbarah, K. Sampath, SPE 81575-PA

Full Diameter Core Analysis Data form Heterogeneous Core Experience and Challenges

M. M. Honarpour, N. F. Djabarah, K. Sampath, SPE 81575-PA, SPE 12418

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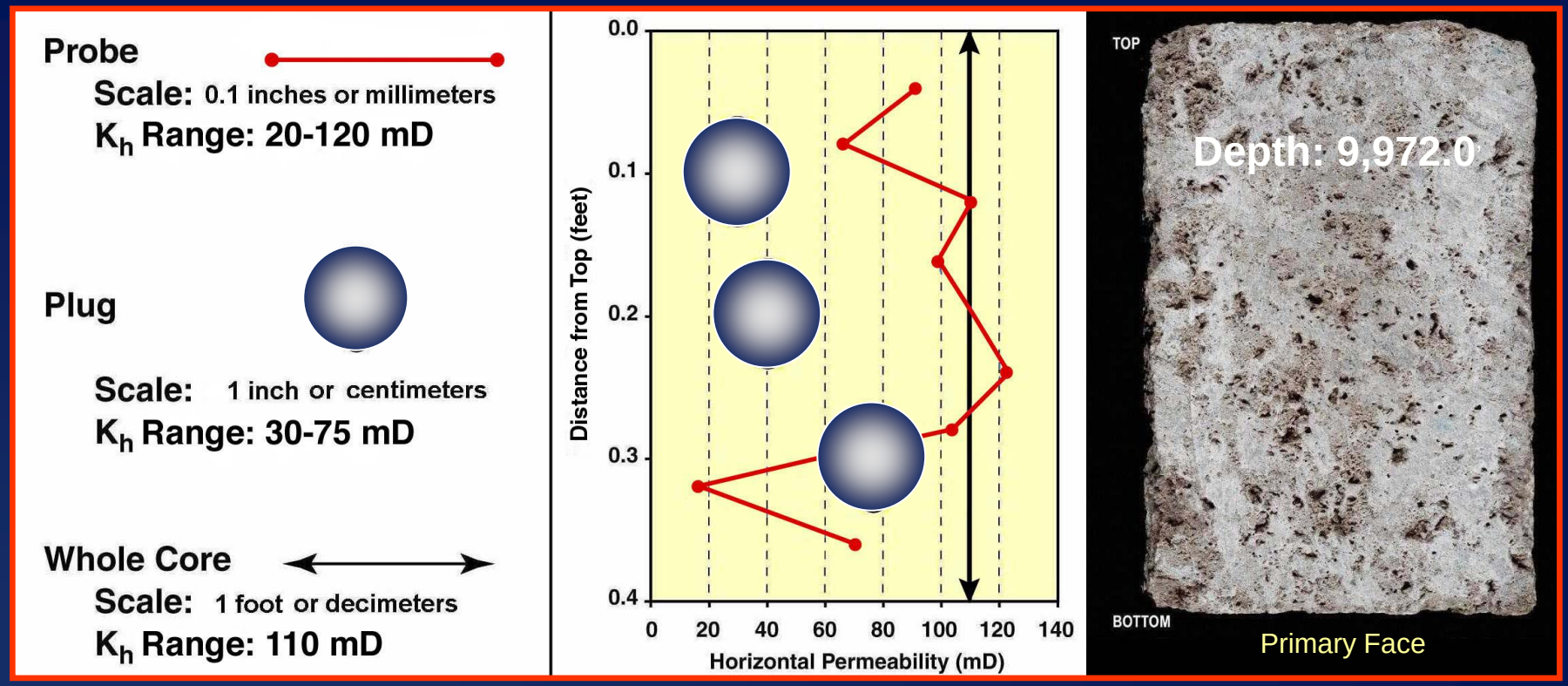


Averaged plug permeability may not agree with data from full diameter

carbonate core from Arun Field, Indonesia

Critical condensate saturation was a function of porosity, vug volume

M. M. Honarpour, N. F. Djabarah, K. Sampath, SPE 81575-PA, SPE 12418

What Distinguishes Carbonates from Sandstone?

- Kinetically & thermally unstable (unstable mineralogy)
- More susceptible to mechanical & chemical alteration
- High organic content from deposition (byproduct of organism)
- Interbedded with organically rich facies

Heterogeneity

- Permeability variability and presence of Stylolites
- Dual porosity/ permeability - Fractures and/ or vugs
- Bi-modal pore size distribution - e.g. Moldic
- Three - Dimensional flow path

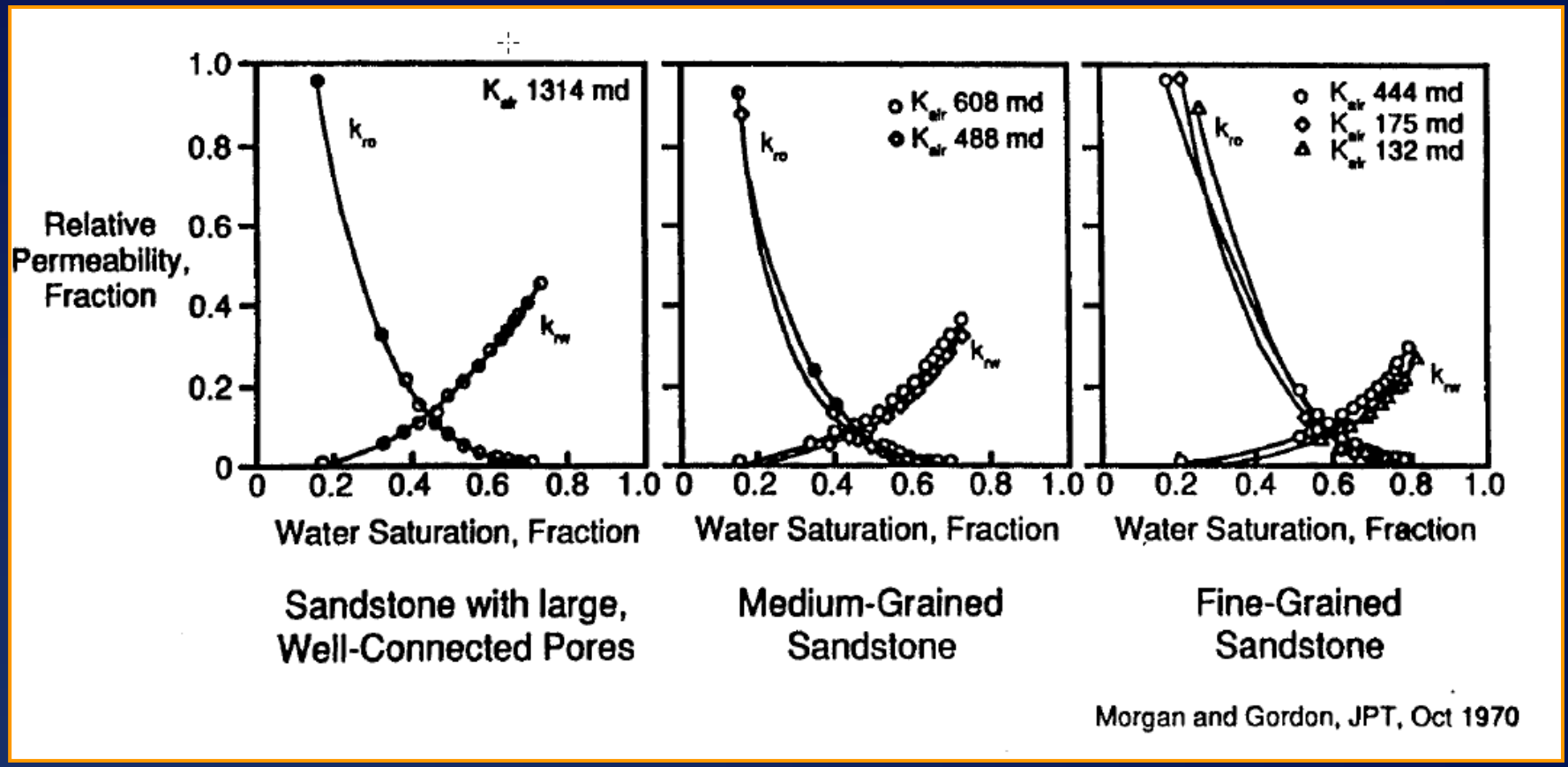
Surface Properties - Implication on Wettability

- Difficulties with cleaning and wettability restoration
- Presence of bitumen/ pyrobitumen, gypsum/ anhydrite, sulfur
- General tendency toward more oil-wet (intermediate)

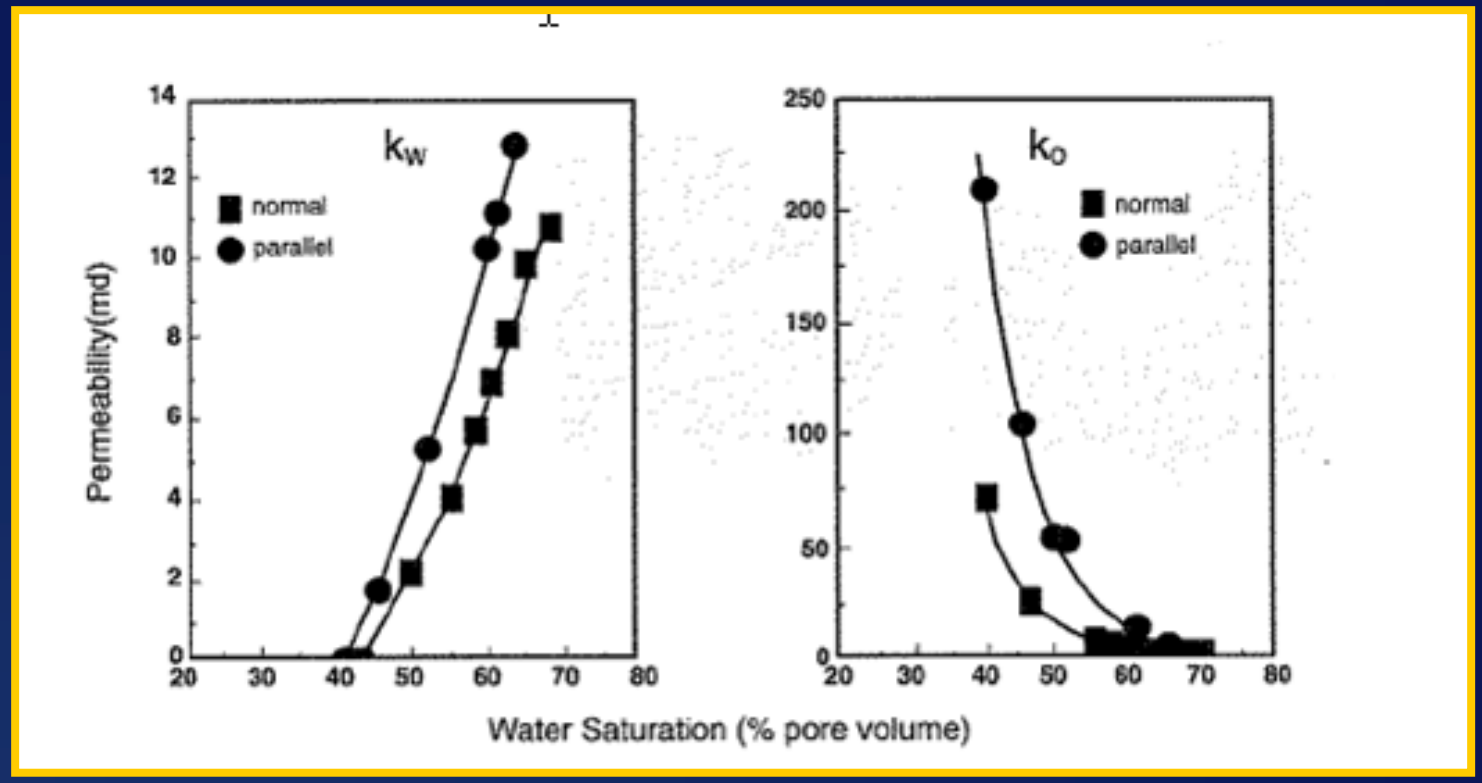
Thick Transition zone in many Giant Fields

- Microporosity
- Lack of well- defined WOC/ GWC due to heterogeneity
- Possibility of remaining oil saturation below contacts
- Impact of aquifer contribution to performance

Influence of Pore Geometry, Grain Size and Texture on W/O Relative Permeability, Sorw and Performance



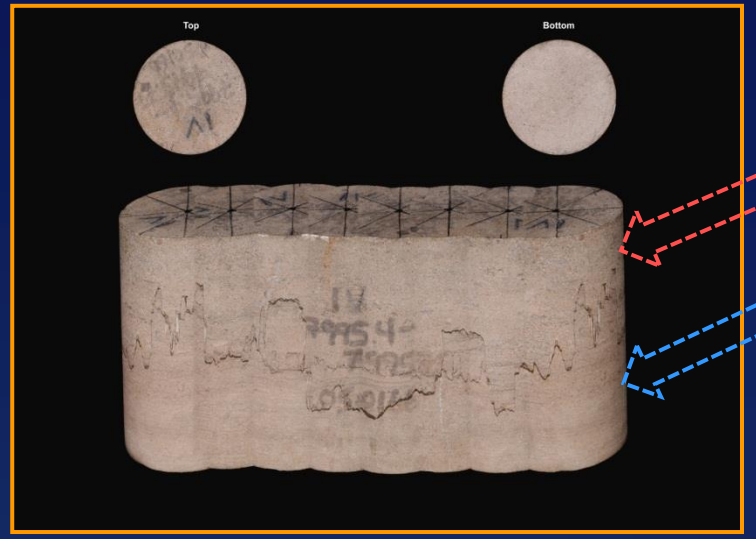
Water and Oil Effective Permeabilities – Parallel and Perpendicular to Bedding

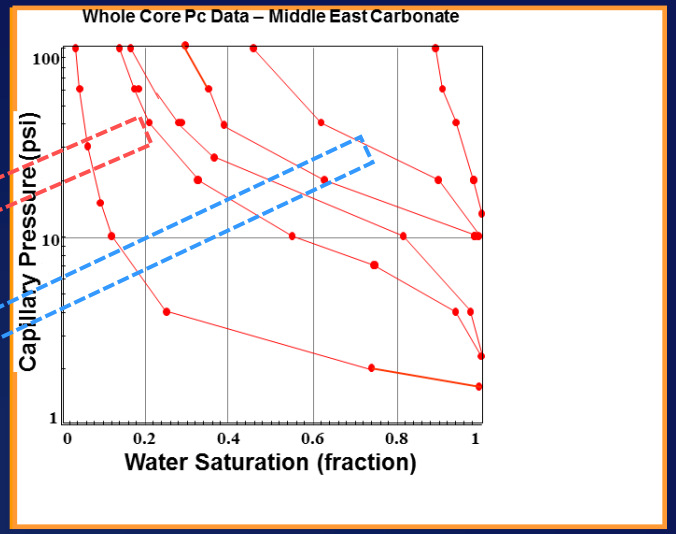


- Relative Permeability is more depressed when flow is perpendicular to bedding plane
- It becomes more depressed as flow become more segregated as kv/kh decreases with increasing stress

M. M. Honarpour, U. Tulsa, 100 Year Anniversary, Effect of Lamination on Kr, August, 1994

Stylolite and Deformation Bands - Their Impact on kv/kh and Swi Distribution



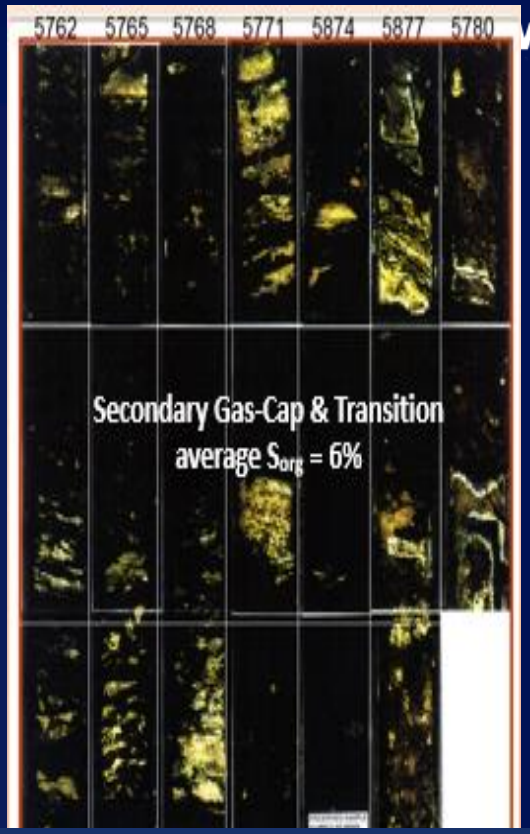


- High permeability contrast between top and bottom - Impact on sweep
- Significant Variation in Entry Pressure, Transition & “Irreducible Saturation
- Can averaging and scale-up help with composite properties?

A. Bu Ali, M. M. Honarpour, Presented ADCO Field, Abu Dhabi

Heterogeneity Patterns - Impact on ROS/ Sorg Should be Evaluted on Representative Cores

- **Identification** of **rock heterogeneities, fluid variabilities**: mineralogy, texture, permeability patterns from pore to stratigraphic scale, dip, deformation bands, bedding, continuity anisotropy and asphaltene content that could impact RF
- **Utilization of** Dual Energy CT, laboratory flow test, probe permeameter, rock compressibility, logs, downhole tests, mud gas data **and use of Data Science/ Eng. Analytics**
- **Quantification** of controlling flow parameters, barriers/ baffles, slumps and their **alteration – compressibility, permeability and relative permeability** responsible for **bypassed oil** in performance prediction
- **Validation** of heterogeneities and uncertainties at bed **scale, IPTT, PTA/ RTA, VSP, DAS, mini frac & 4D Seismic**
- **Integration** of quantified heterogeneities in relation for any to decision on well placement and implementation of appropriate recovery process



Effect of Heterogeneties on S_{org} pattern after 25 years of Gravity dominated Gasflood

❖ **Heterogeneities must be identified, quantified, scaled-up in simulation model for decision making on well placement & RF**

S_{org} in Primary and Secondary Gas Cap Preserved Slabbed Core under UV Light Ubit Field, Western Flank

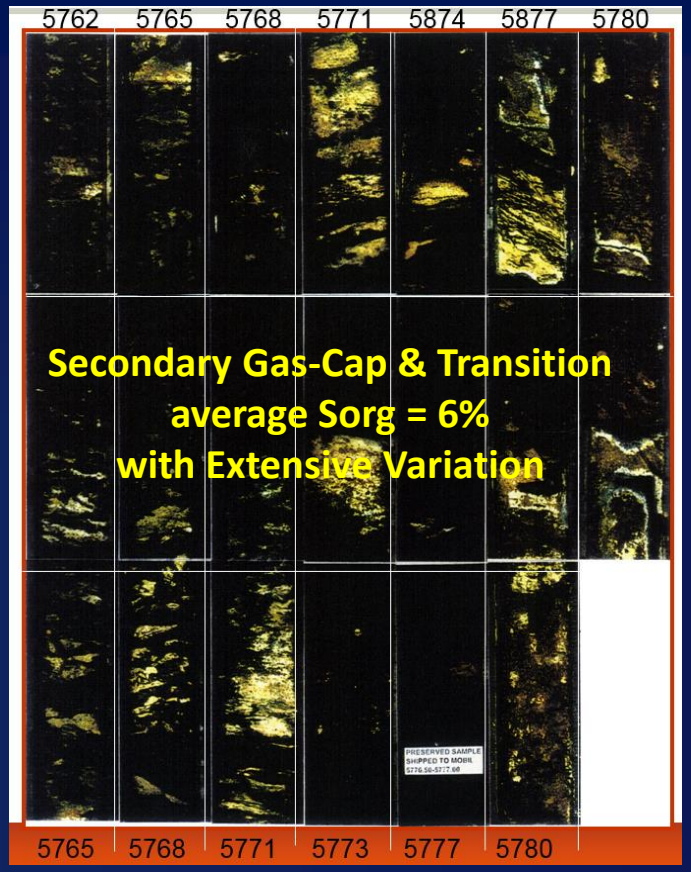
- Ubit, a Giant SS
- Black Oil Reservoir,
- Offshore Nigeria.

Western Flank:

- Prograding Shallow Marine System

Eastern Flank:

- Disturbed Extensive Slumps & Block sliding



Honarpour, Edwards
SPE 49316 & 49165
ATCE 2010

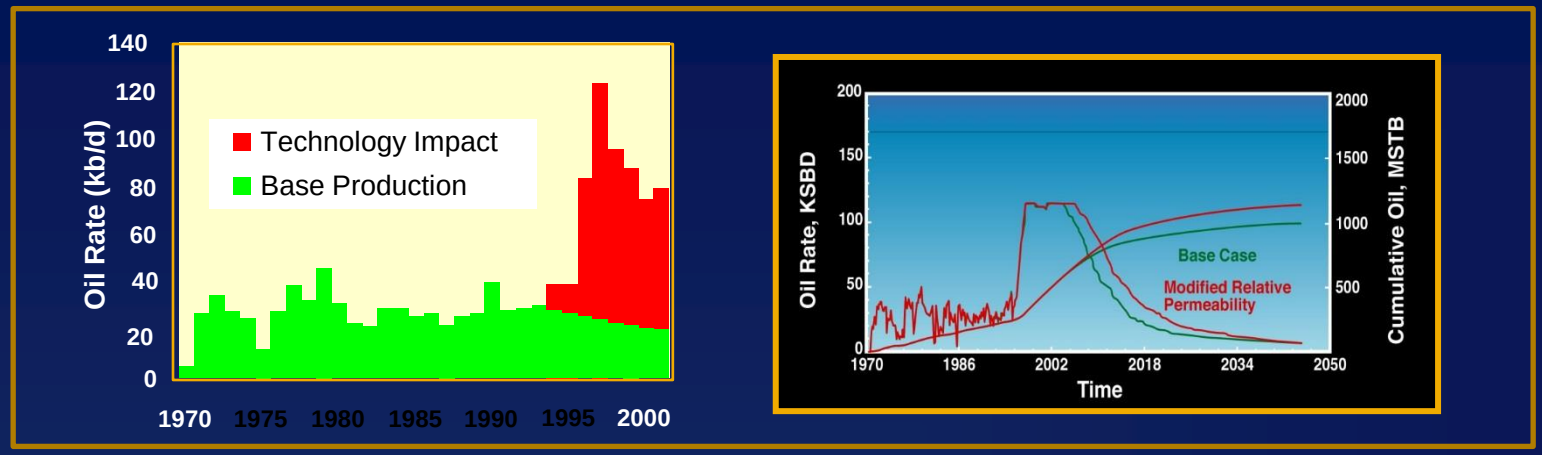
- Heterogeneities control distribution of initial & remaining oil saturation bypassed oil - gravity drainage gasflood process
- Net to Growth pattern need to be distributed for representative performance
- Patterns of heterogeneities causing fluid flow in more tortuous path with impact on rate and recovery

De-pressurized Remaining Oil Saturation Preserved Slabbed Core under UV Light

- Gravity Drainage is an efficient gas displacement process but certain criteria need to be present to happen
- $K_V < k_h$, absence of conductive fractures of slumps perpendicular to well orientation
- Reservoir simulation grid size in Z-direction should be fine to capture this variation for performance prediction
- Oil relative permeability needs scaling to capture drainage near Sorg

Honarpour, Edwards
SPE 49316 & 49165
ATCE 2010

Impact of Gravity Drainage Gas Displacement when Gas BT due to channeling is minimum

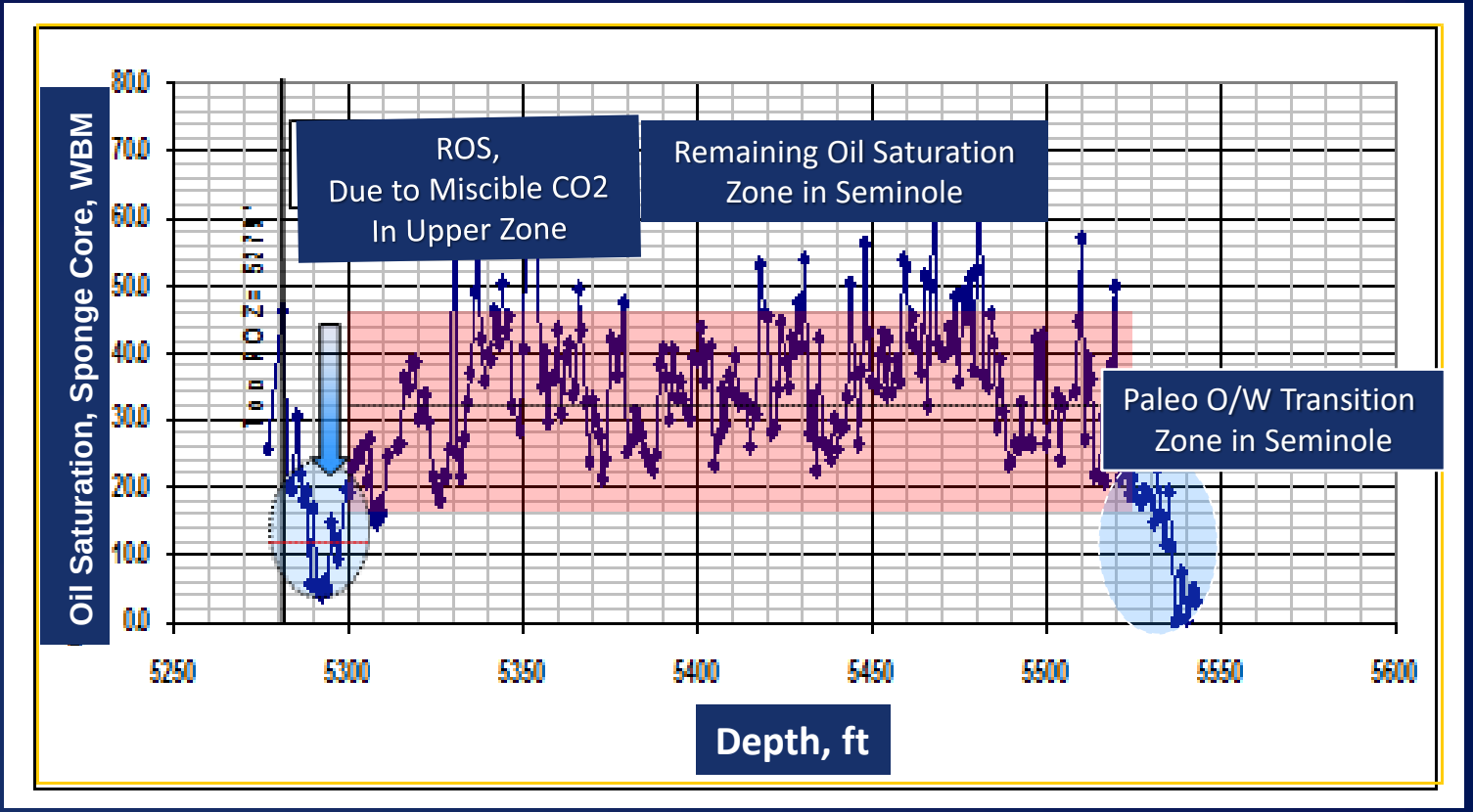


- Effectiveness of GD process – 0.5 billion bbl.
- Stable GD in absence of gas breakthrough in Ubit reservoir, western flank (W. flank)
- How can we avoid gas or water BT/ coning - Horizontal/ lateral Well, Recompletion, natural baffle or barrier
- What is the potential for formation damage as a result of asphaltene dropout?
- Does low Lab Sorg lead to efficient displacement process – Effect of heterogeneities
- HC gas injection was initiated after this pilot, contributing to 0.5 billion bbl. W. Flank
- HC gas injection failed in E. flank due to extensive.

Honarpour, T. Edwards

SPE 49316 & 49165, ATCE 2020

Remaining Oil Saturation in ~300' Heterogenous Carbonates, Seminole Formation, West TX after Structurally Induced WF – Impact of Heterogeneities

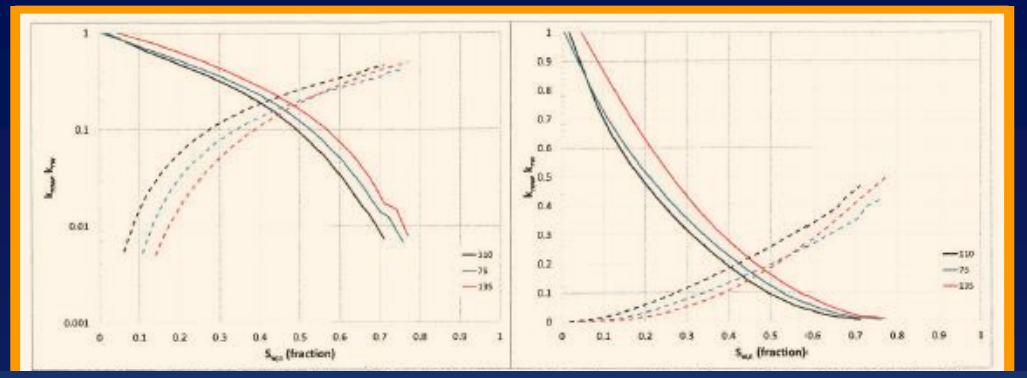


- Porosity & Permeability are not the Only Controlling Parameters,

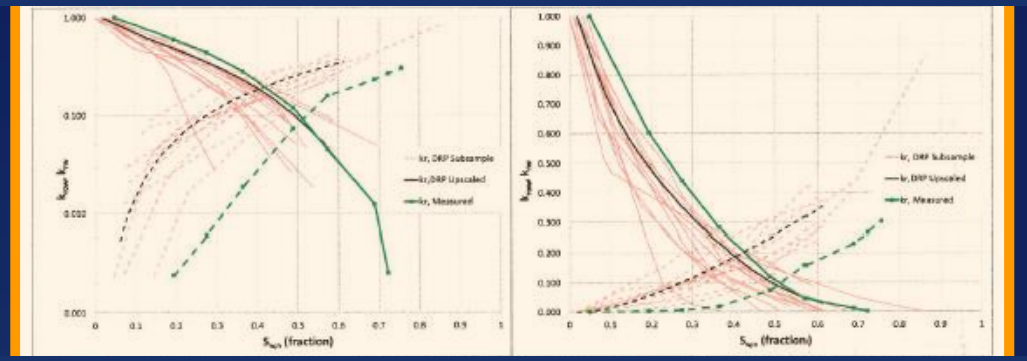
Mineralogy, Geochemistry, Pore Geometry and Wettability May be too

Honarpour, et.al. SPE Paper 133089, 2010 ATCE

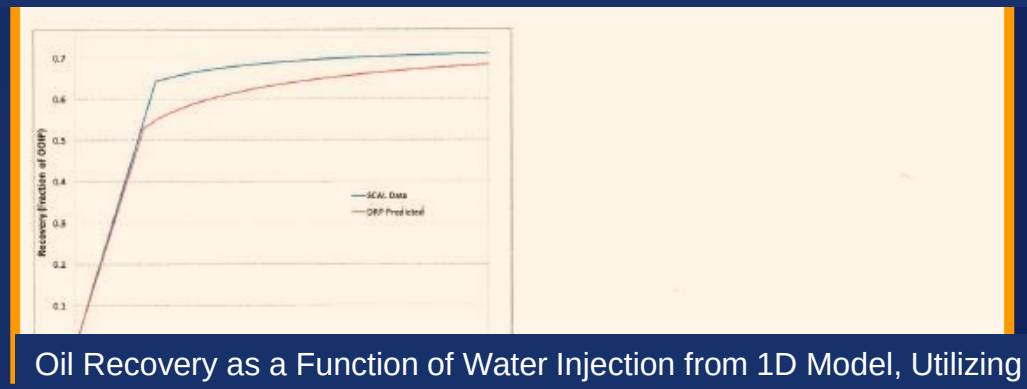
Advancement in Data & Models Scale up are needed



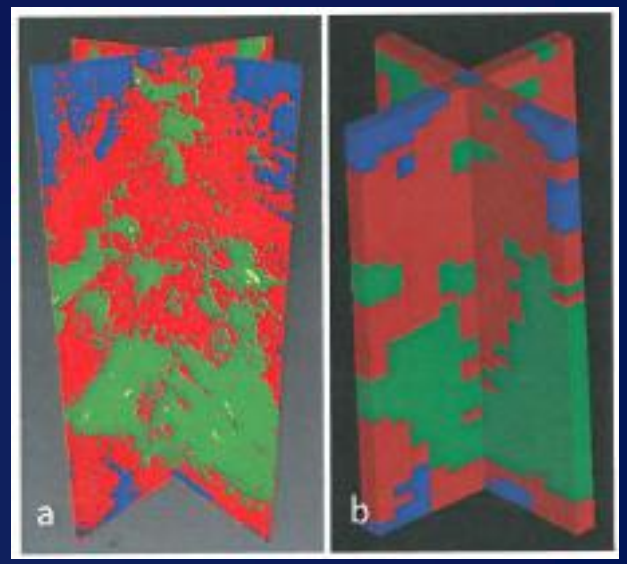
Upscaled W/O Imbibition kr at 3 Wettability Conditions – Upscaled DRM



W/O imbibition kr; lab measured (Green) DRP (red) and upscale (black)



Oil Recovery as a Function of Water Injection from 1D Model, Utilizing Measured SCAL Data - Blue (Based on Measured Data), Red (DRP)



Orthogonal Slices from (a) Segmented CT Model and (b) Upscaled Simulation Model

J. G. Kralik et.al., 2008, ExxonMobil, URC

M. M. Honarpour, S. Culik, JPT, Nov. 1995

Summary

- Potential geological, petrophysical, geochemical, mechanical and rock-fluid heterogeneities should be characterized in both reservoir and aquifer at multi-scales
- Longer term data collection using automation are needed as part of the workflow (Fluid Flow, NMR, petrographic, imaging) to capture more reliable effect of heterogeneities over longer time when significant
- Multiscale data collection such as geochem, geomechanics, multiphase flow and imagining at downhole conditions are key for integration
- Close Collaboration among disciplines and service companies are essential for using suitable scanning technologies and selection of representative samples for Integration

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