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Distinguished Lecturer Program

From 3D pore scale imaging to Reservoir inputs: Next generation reservoir characterization & description

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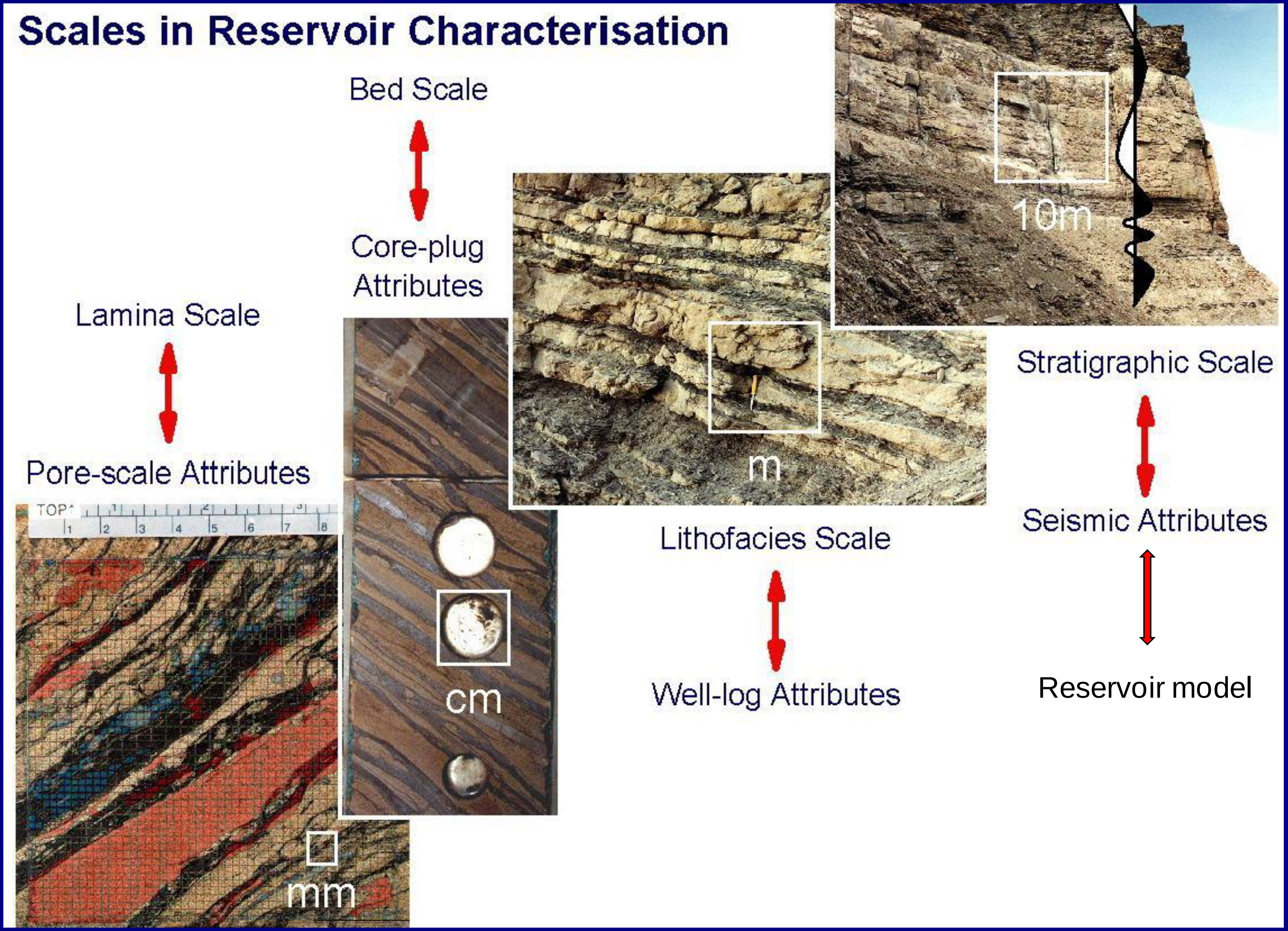
Overview

- Problem Statement
  - The challenge of integrating scale
- Digital rock technology
  - Introduction: Pore to plug
  - Fast turnaround & Sensitivity Studies
  - Enhanced Understanding
- Multiscale Reservoir Characterization
  - Upscaling and Uncertainties
  - Upscaling in a SYSTEMATIC manner (calibrated at each scale)

Problem Statement

Size matters in reservoir characterization



The Multi-scale Reservoir Characterisation Problem

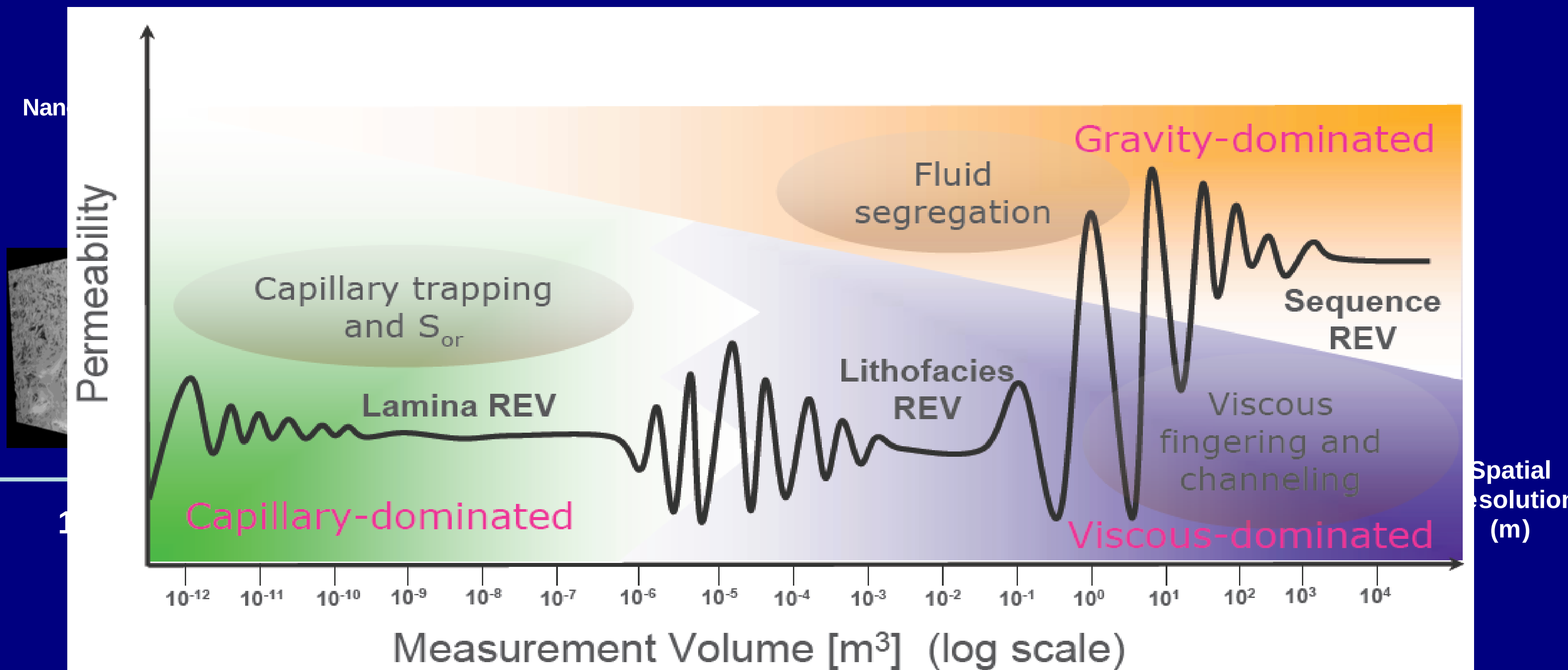
Question:

- How do we accurately and effectively model fine-scale heterogeneities & predict petrophysical response & fluid flow at larger scales (log/geo/reservoir-scale)

?

Properties are measured at a range of scales

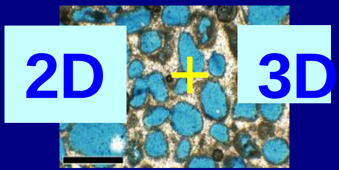
Goal: Assign properties measured at fine scale to the commercial scales.

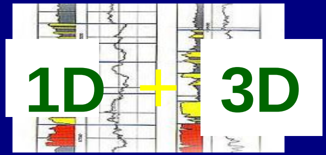


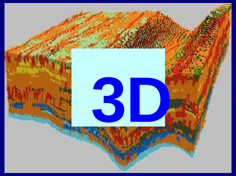
Physics & data changes

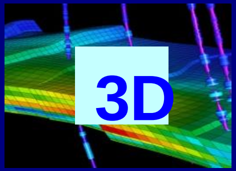
6

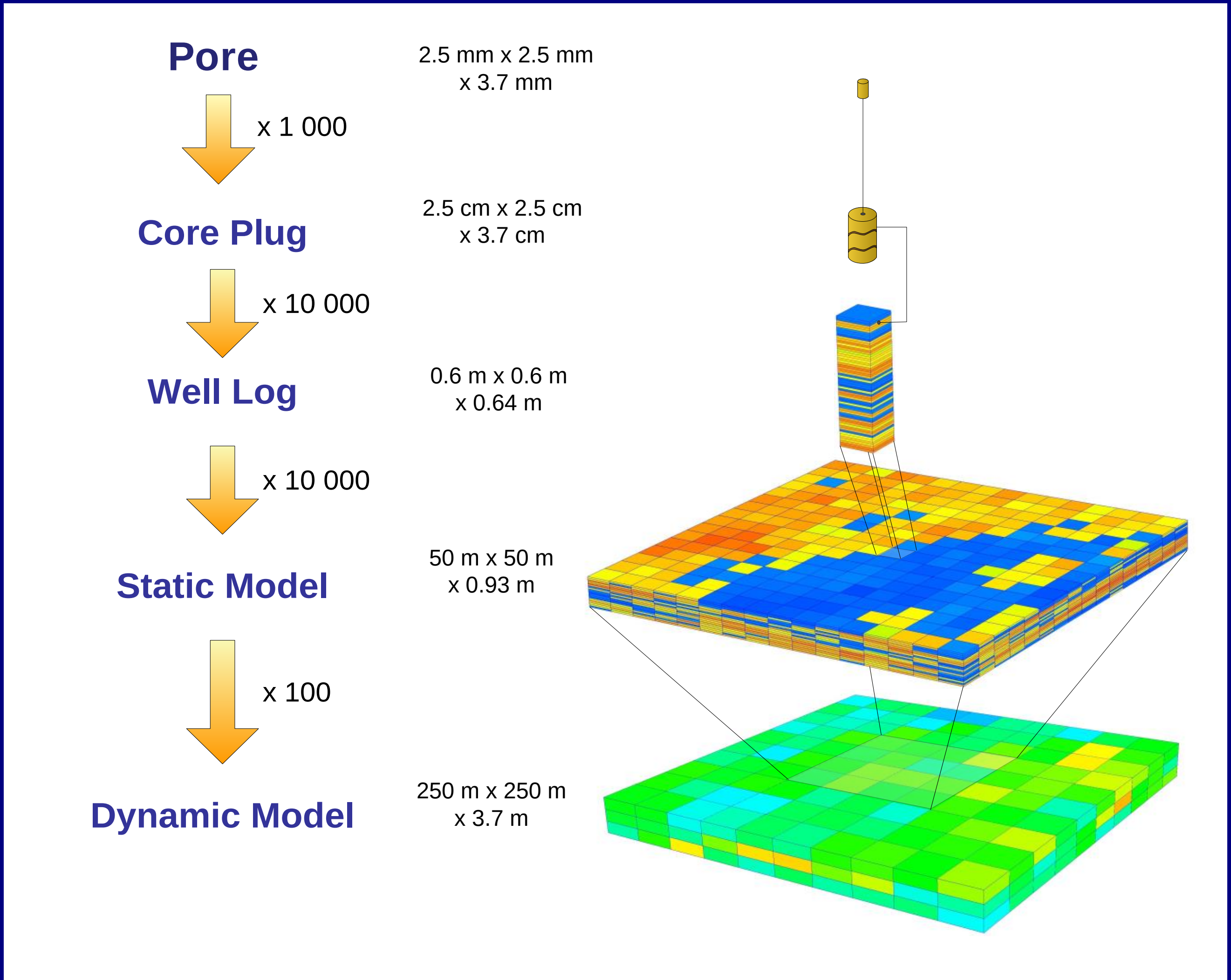
Multi-scale Reservoir Characterisation







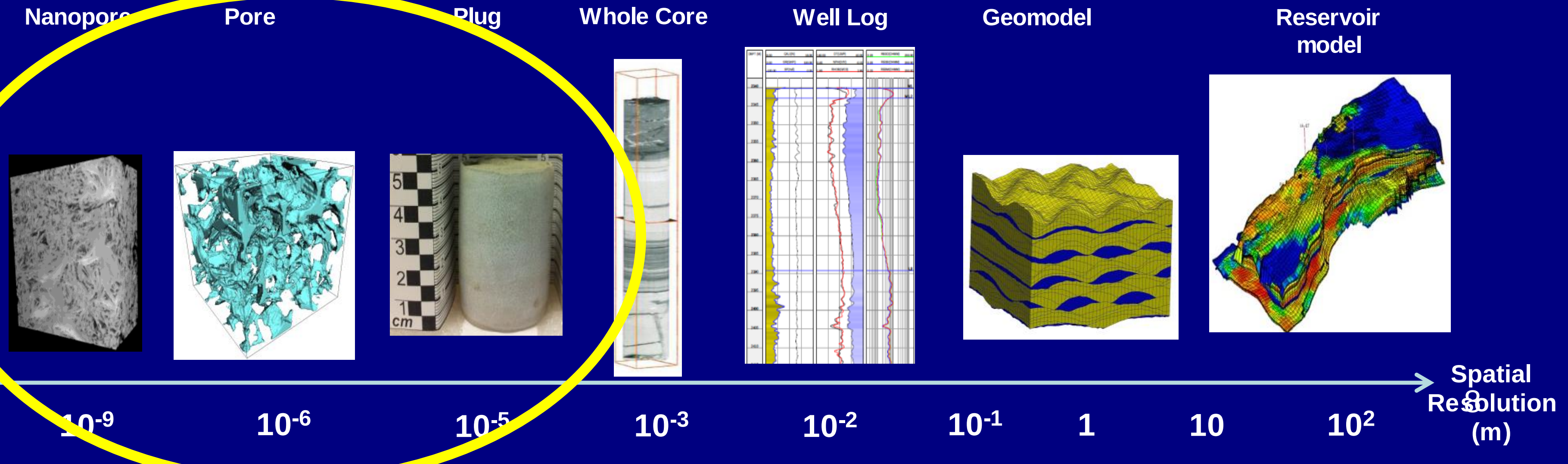




Challenge: We need to assign properties measured at fine scale to the commercial scales

Overview

- Problem Statement
  - The challenge of integrating scale
- Digital rock technology: Pore to Plug
  - Technology Development and alternate SCAL data
  - Enhanced Understanding

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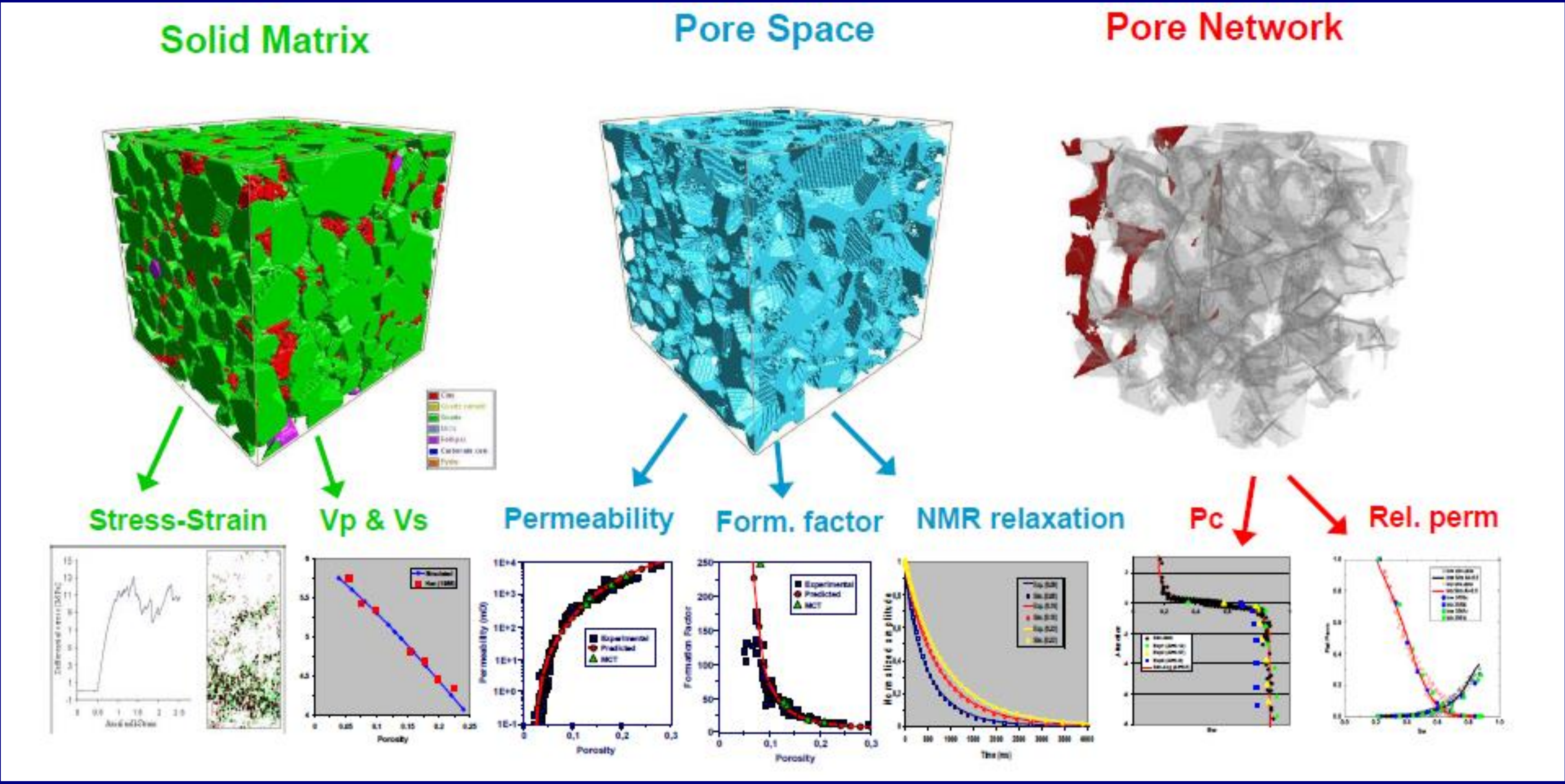
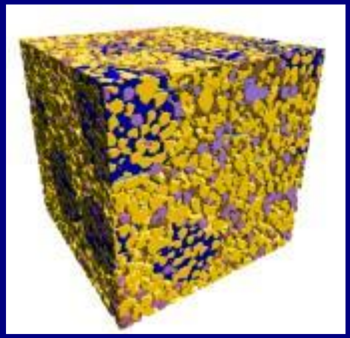
www.videomach.com

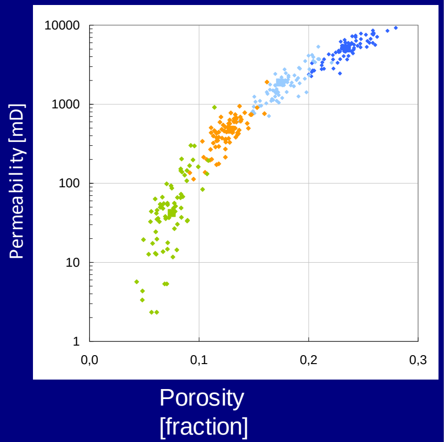
Digital Rock Technology

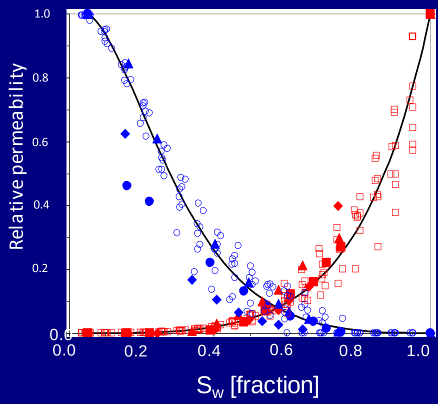


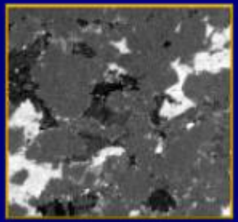
Digital Workflow

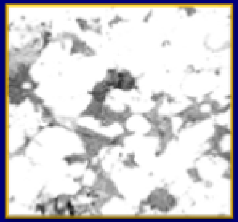
3D DIGITAL ROCK	DIGITAL ROCK PROPERTIES		QUALITATIVE
	PETROPHYSICAL	FLUID FLOW	4D IMAGING





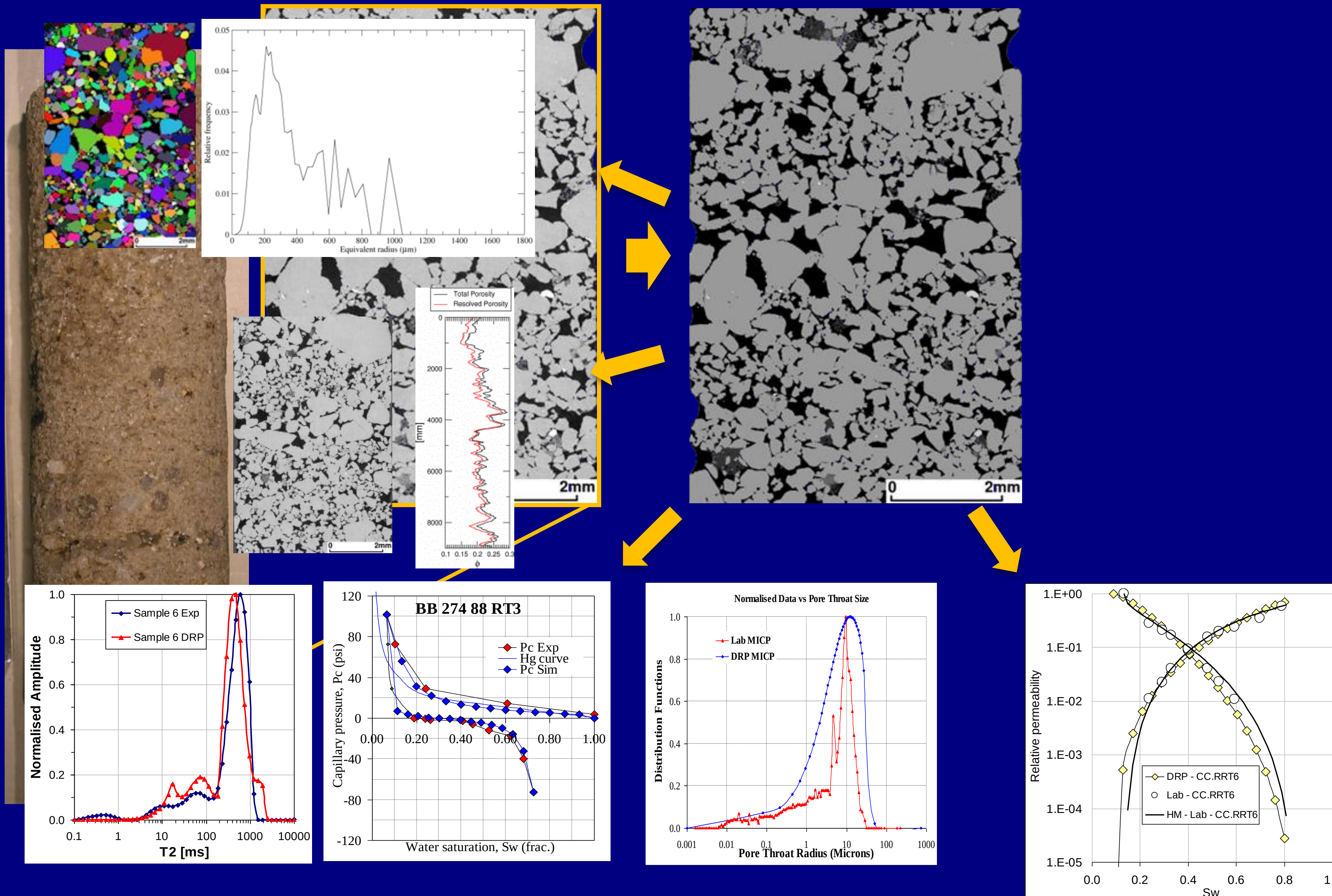






PETROPHYSICAL	FLUID FLOW	4D IMAGING
Porosity	Capillary pressure	Oil in Place
Absolute permeability	Relative permeability	EOR/IOR
FRF	Resistivity index	Formation damage
Cementation exponent	Saturation exponent	Fluid sensitivity
Elastic moduli	Wettability analysis	Unconventional Play
Acoustic velocities	Sw sensitivity	Geochem. Reactivity
NMR relaxation times	IFT sensitivity	Wettability mapping
Mercury injection	Rate sensitivity	

Workflow – Conventional



Main Application Areas for Digital Rock Technology

1) SCAL: Fast turnaround, Difficult cases

Derive (primarily) kr and Pc data for reservoir modelling with fast turnaround. Undertake otherwise impossible SCAL: Cuttings, Sidewall, damaged core.

2) Enhanced Understanding

Fluid distributions, EOR/IOR recovery mechanisms, wettability, heterogeneity, uncertainties

3) Upscaling and Uncertainties

Upscaling in a SYSTEMATIC manner (calibrating at each scale). Analyse heterogeneous/complex rocks (e.g, thin beds, carbonates)

Main Application Areas for Digital Rock Analysis

1) SCAL: Fast turnaround, Difficult cases

Derive (primarily) kr and Pc data for reservoir modelling with fast turnaround

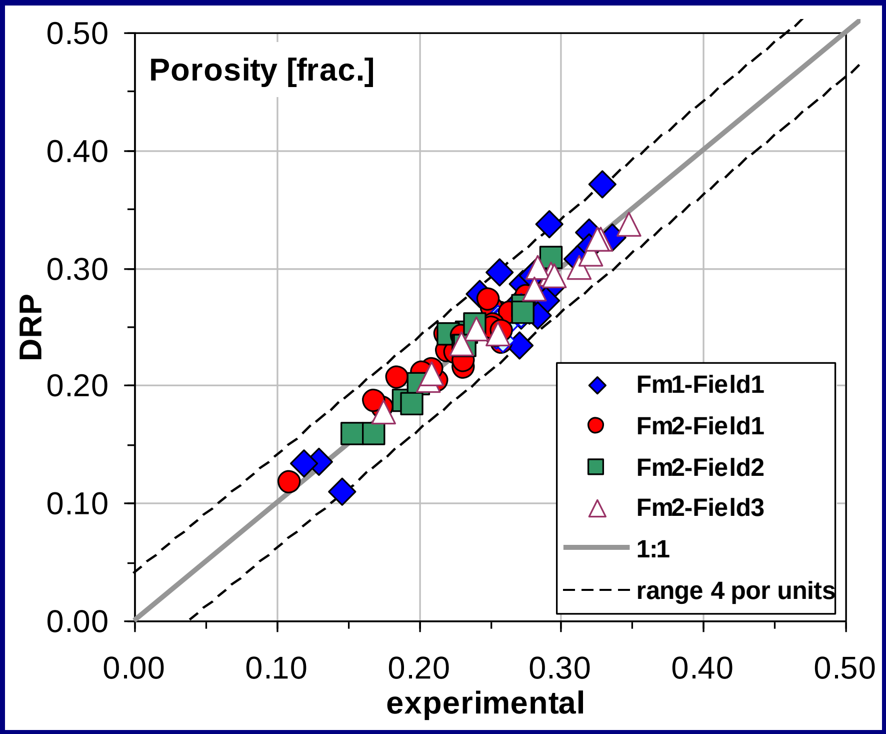
- 2-3 month turnaround
- Multiple sensitivity studies: Incorporate ranges of behaviour– perform 100’s of experiments on same core plug to understand options and uncertainties
- Next generation reservoir description: Orders of magnitude more data (SPE Forum 2011)
- Applicable on sidewall and cuttings. Restoration of data for old core material

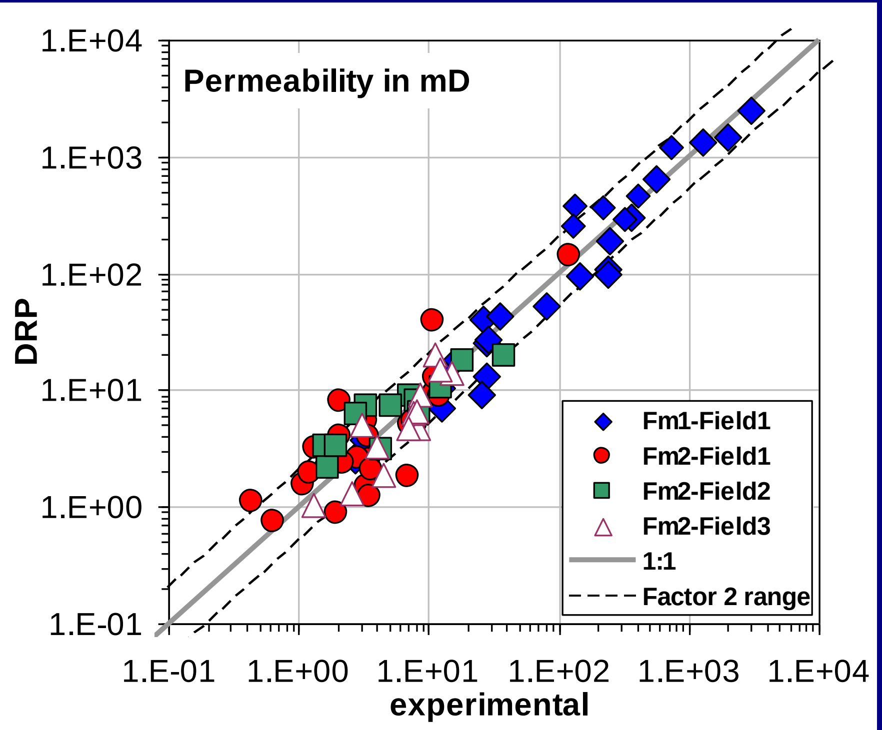
Project Example: ADCO Carbonate Reservoir Study

- Within <1 year, 95 core plugs were analysed:
  - A data set of porosity, permeability, *FRF, m, n*
  - Samples represent 16 rock types spanning 4 orders of magnitude in permeability and 20 porosity units
  - P_c curves for primary drainage and water flooding
  - k_r curves for primary drainage, water flooding and gas/oil @ S_{wi}
  - Resistivity index curves for primary drainage and water flooding

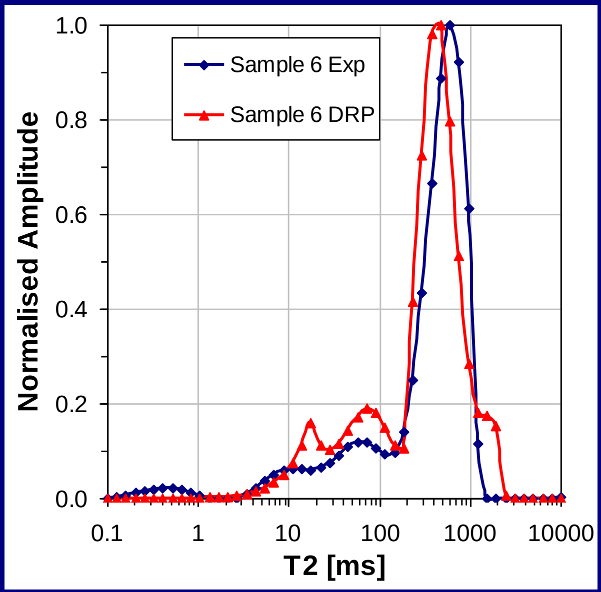
  - Two Papers at 2012 Society of Core Analysts: SCA2012-03 & 13

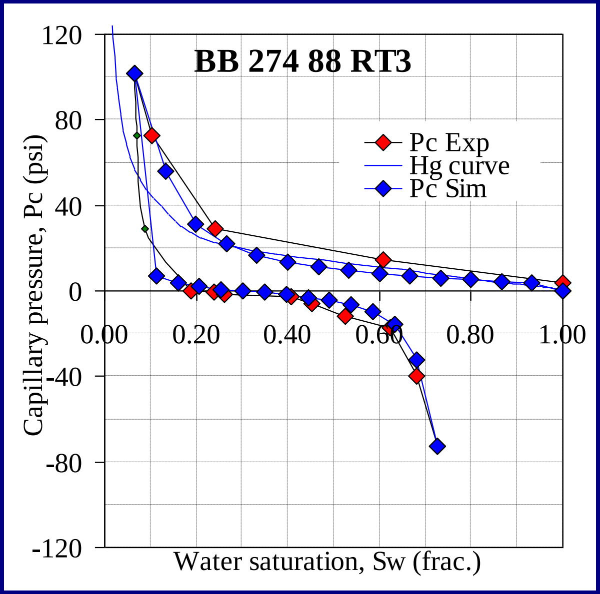
Predicted vs. Experimental

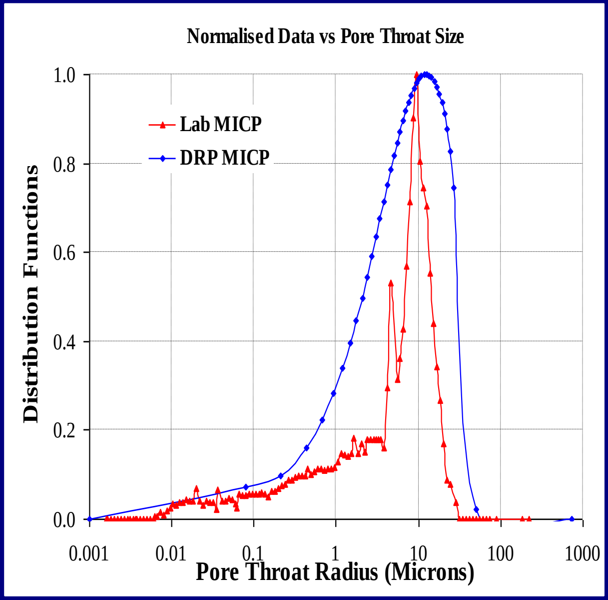


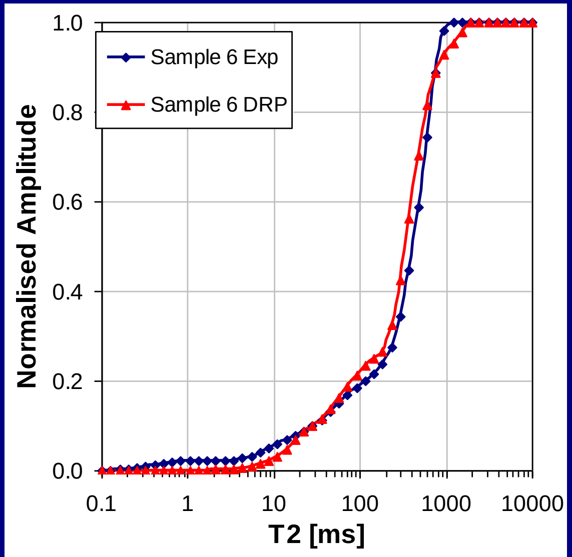


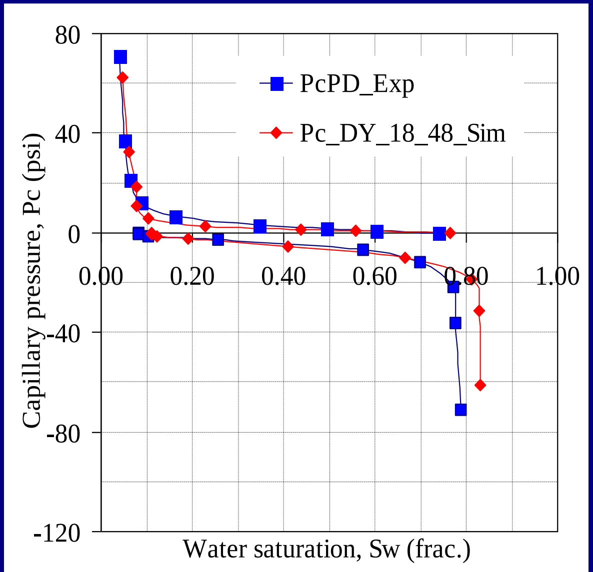
Example: NMR - Pc - MICP

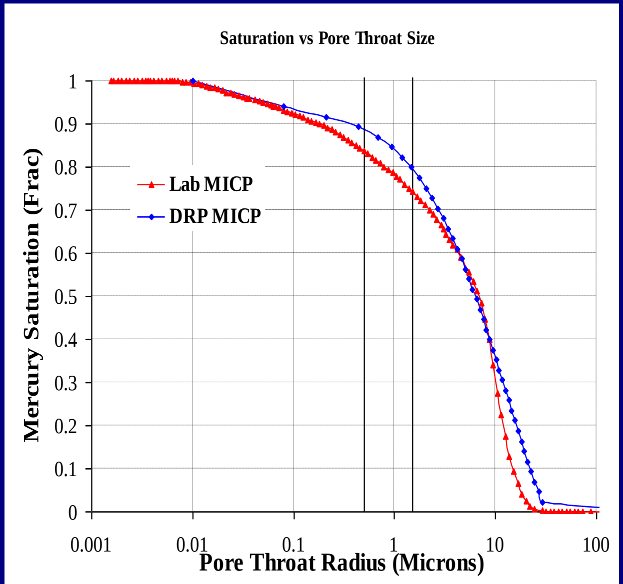






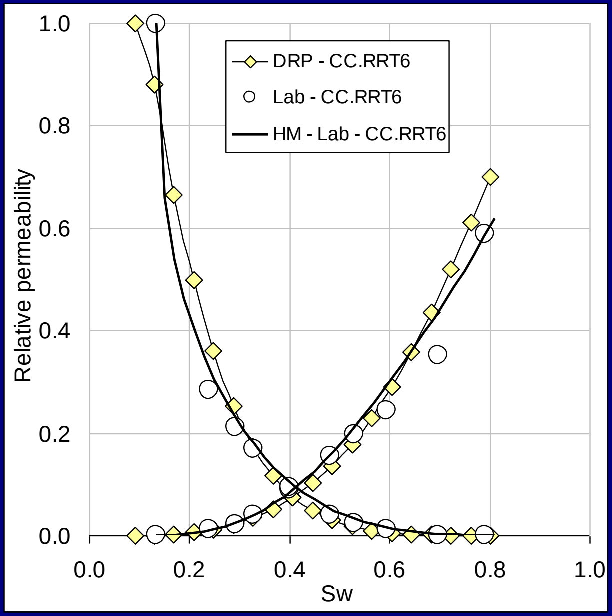


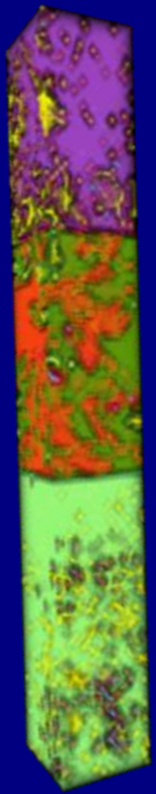


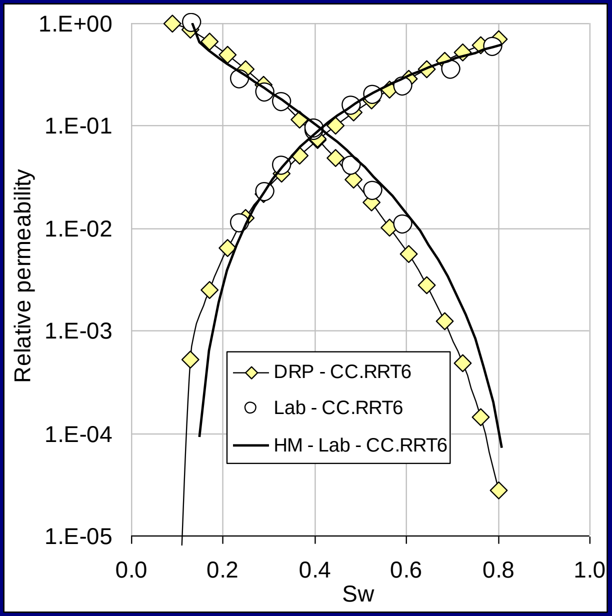


Predicted vs. Experimental – SS Relative Permeability

R
R
T
6







Samlple ID	RRT6	BU_570_36	BU_570_37	BU_570_106	DRP - CC.RRT6
k(mD)	17.5	13.3	25.8	9.31	23.1
Porosity (frac.)	0.275	0.26	0.301	0.264	0.269
Swi	0.134	0.1	0.06	0.11	0.09
Sorw	0.19	0.13	0.09	0.13	0.20
krw(Sorw)	0.62	0.88	0.86	0.82	0.70

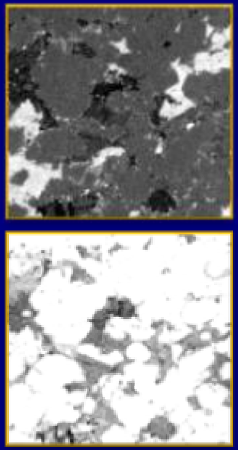
Pore to Plug Bonus: Understanding of processes

– **Enhanced Understanding**

Fluid distributions, EOR/IOR recovery mechanisms, wettability, heterogeneity, uncertainties

QUALITATIVE

4D IMAGING



Oil in Place

Enhanced Oil Recovery

Formation damage

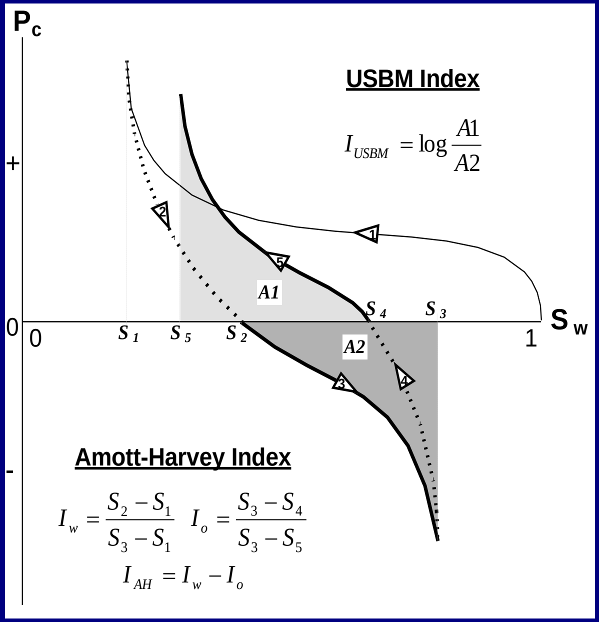
Fluid sensitivity

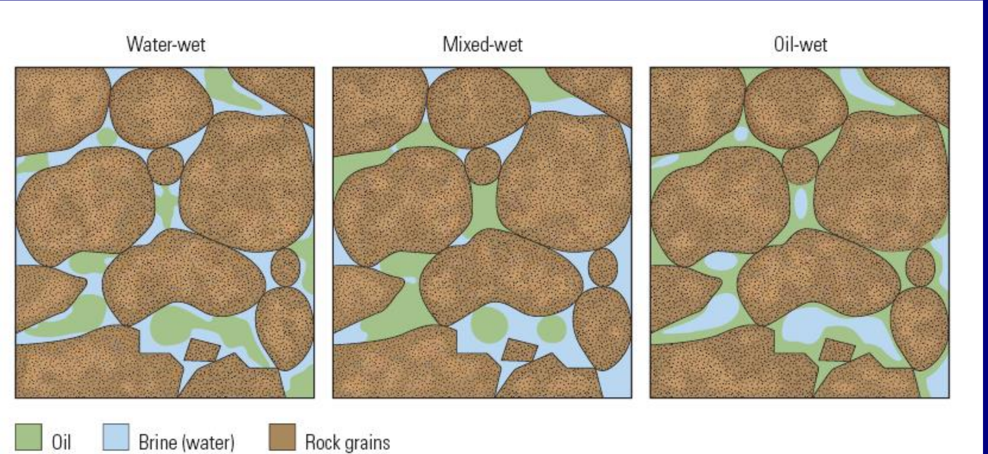
Unconventional reservoirs

Geochemical reactivity

Wettability

Pore scale wettability mapping



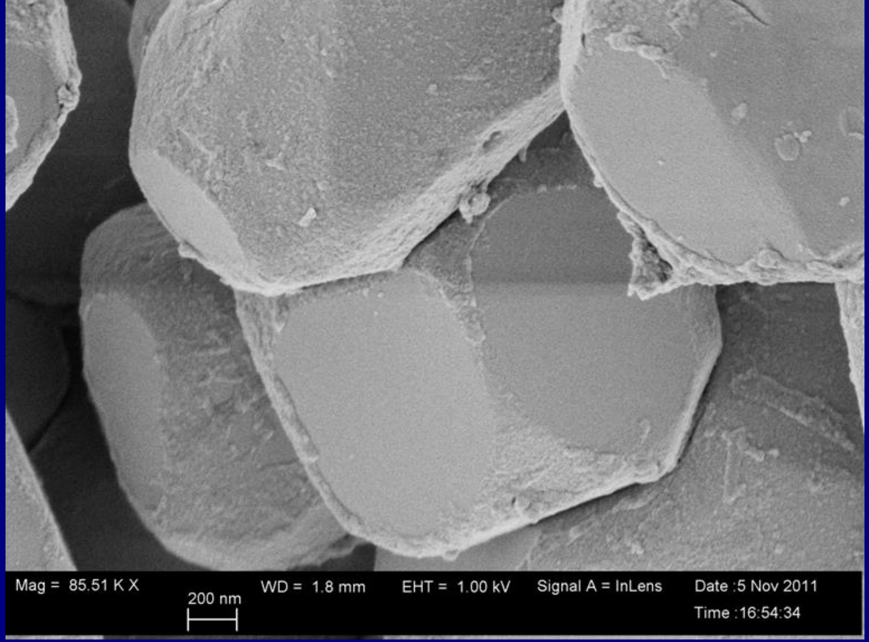


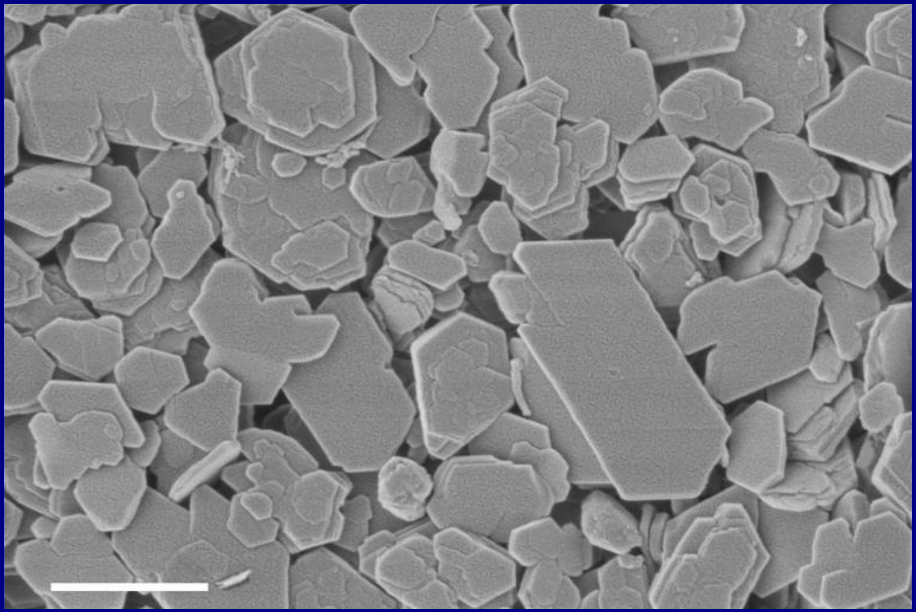
^ Wetting in pores. In a water-wet case (*left*), oil remains in the center of the pores. The reverse condition holds if all surfaces are oil-wet (*right*). In the mixed-wet case, oil has displaced water from some of the surfaces, but is still in the centers of water-wet pores (*middle*). The three conditions shown have similar saturations of water and oil.

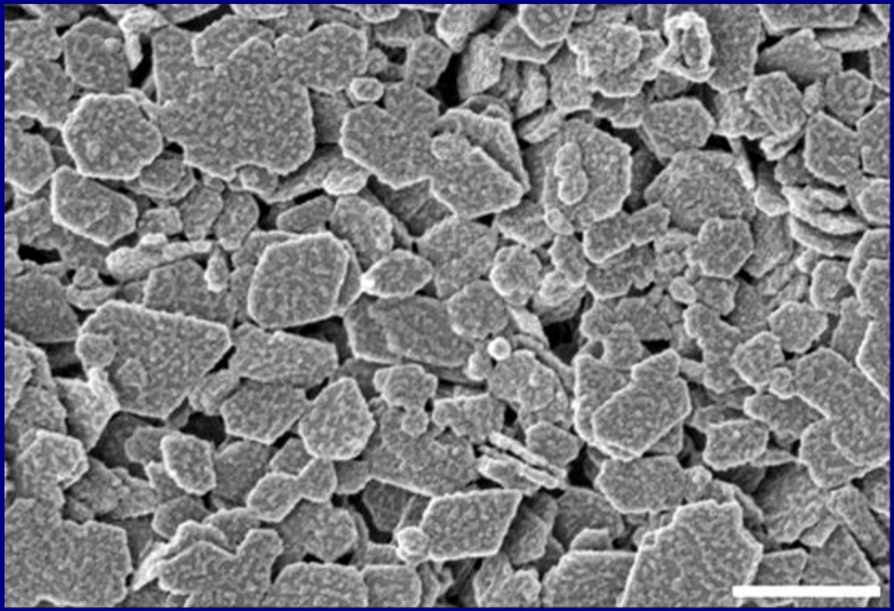
Montaron, SPE 105041

Wettability Analysis

- Wettability characterization at molecular and pore scales
- Couple with direct imaging of fluid distributions







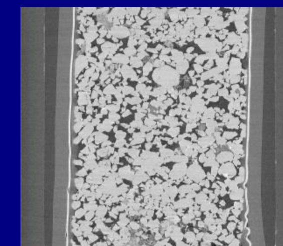
Fogden, SCA 2011

ENABLES FLUID MAPPING IN 3D

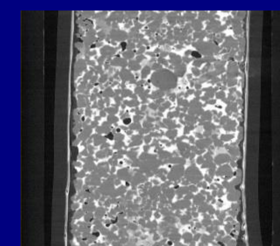
Dodd et al., IPTC 17696, 2014

Multistage Experimental Flooding Workflow

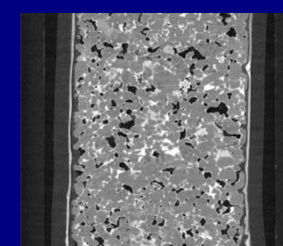
- Sample preparation:



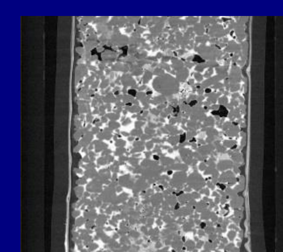
- **Dry image:** Axial pressure: 1600psi, confining pressure: ~1500psi, temperature: ~50



- **Brine saturation:** ~150 pore volume of brine passes through the core (1.5mol KCl+1mol NaI), @0.01cc/min pore pressure:~1300psi



- **CO_2 injection**: ~50 pore volume of scCO_2 @0.01cc/min is flushed through the sample & pressure:~1300psi



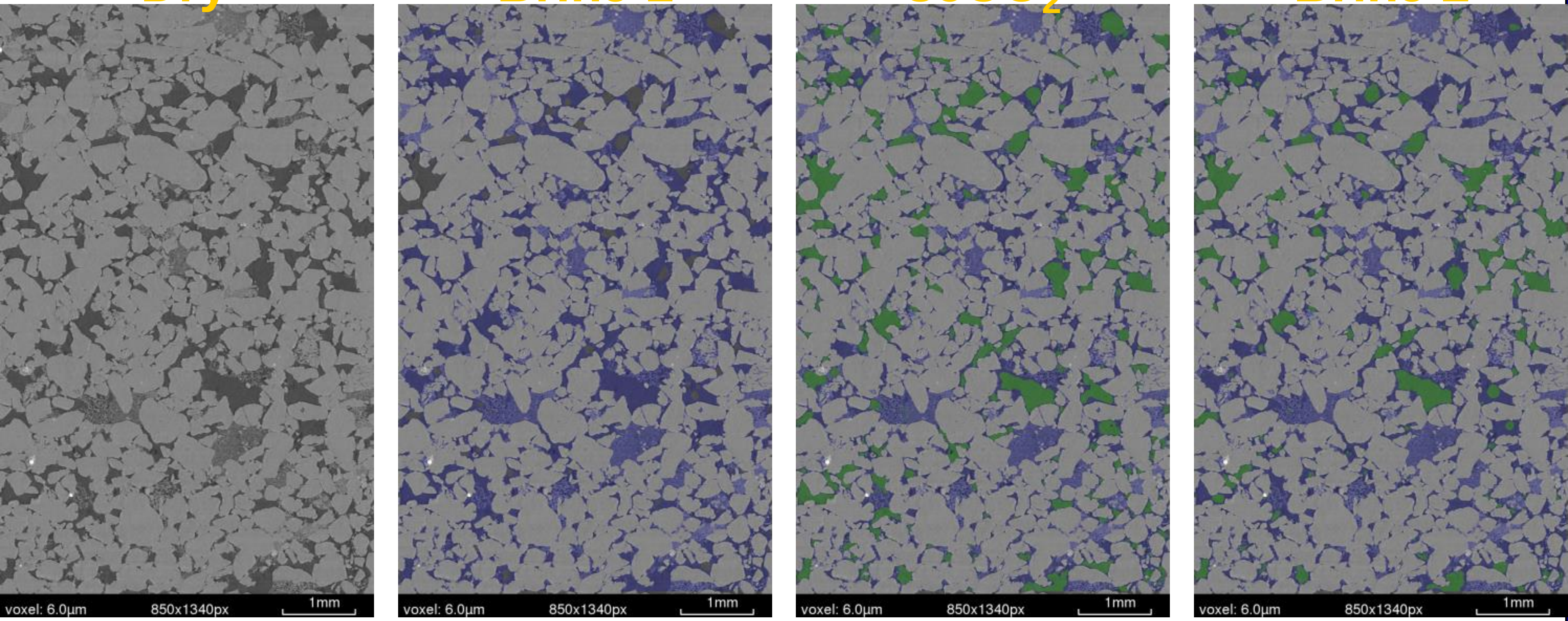
- **Brine injection**: ~150 pore volume of brine @0.01cc/min is flushe through the sample, pressure: ~1300psi

Imaging of flooding at Reservoir T & P

X-Slices

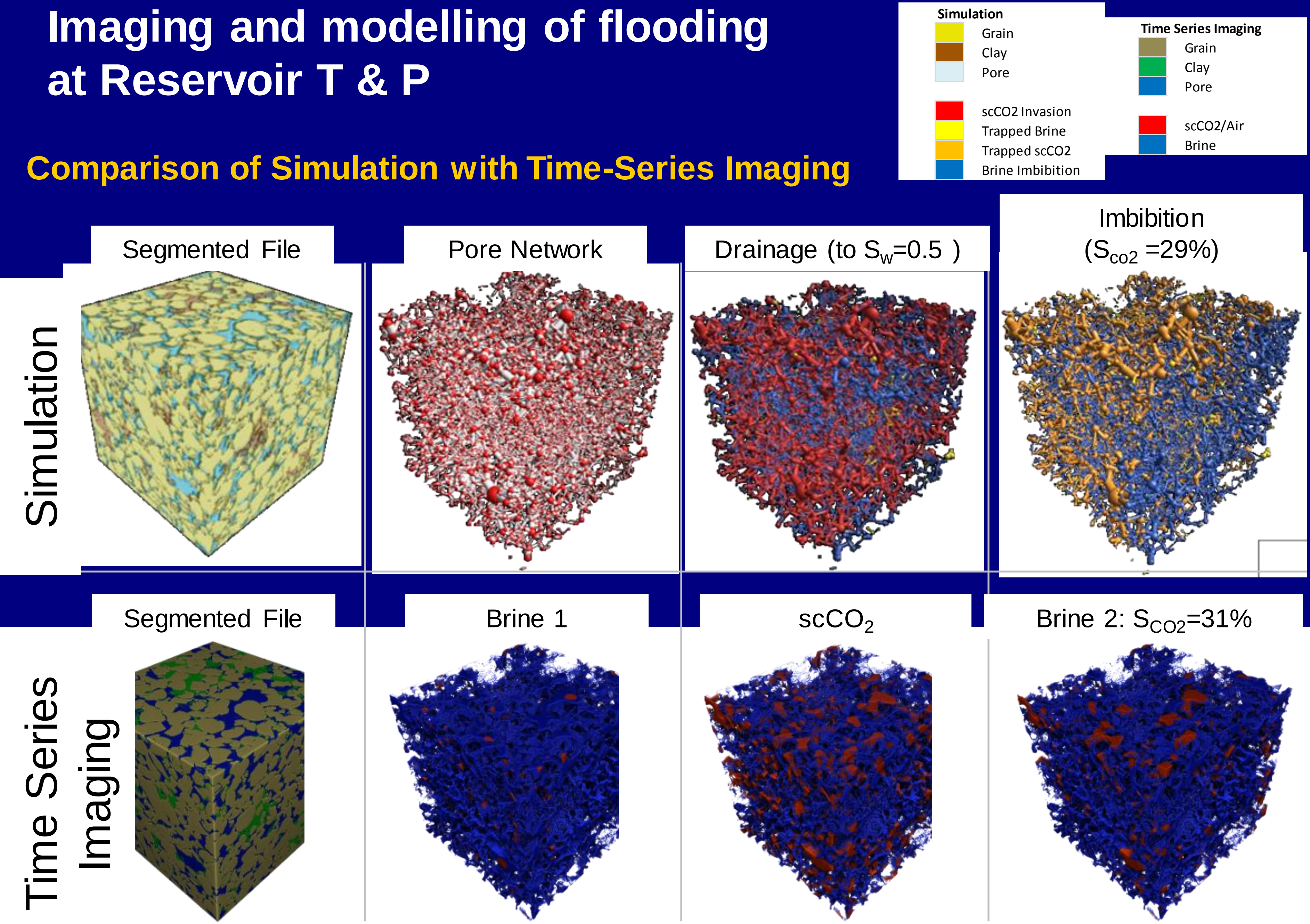
Legend
( ) $scCO_2$
( ) Brine

Dry → **Brine 1** → **$scCO_2$** → **Brine 2**

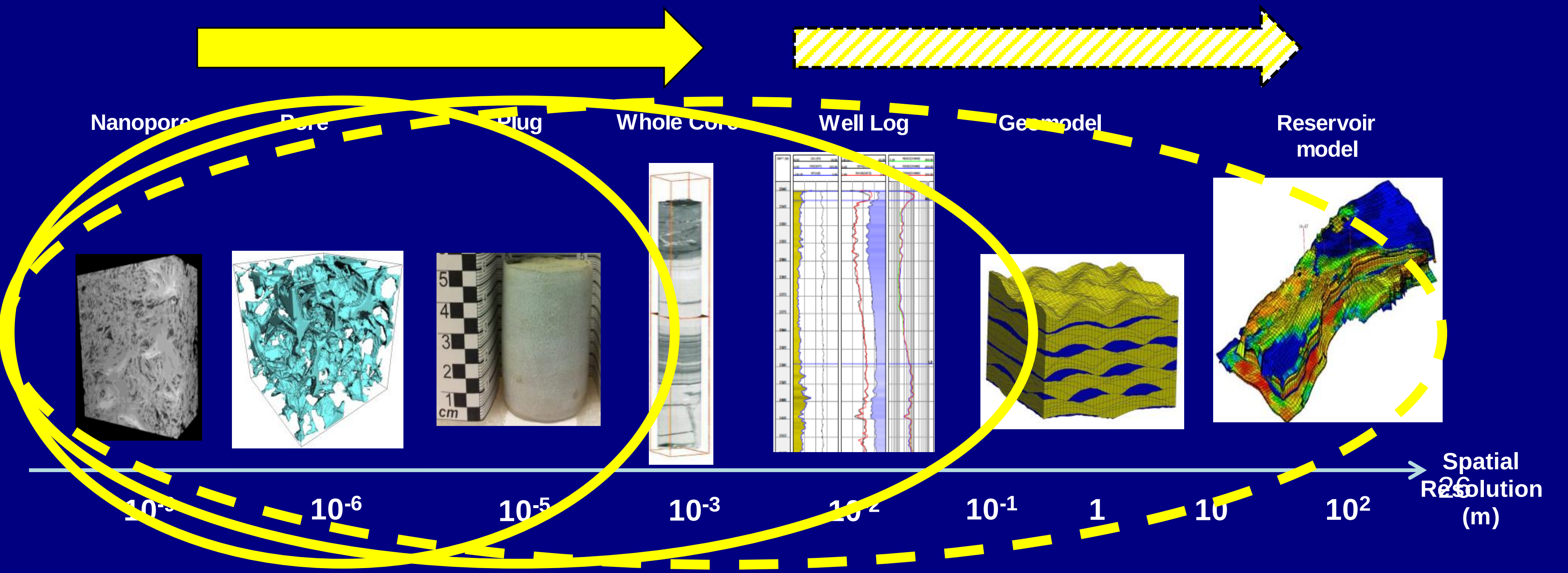


Imaging and modelling of flooding at Reservoir T & P

Comparison of Simulation with Time-Series Imaging

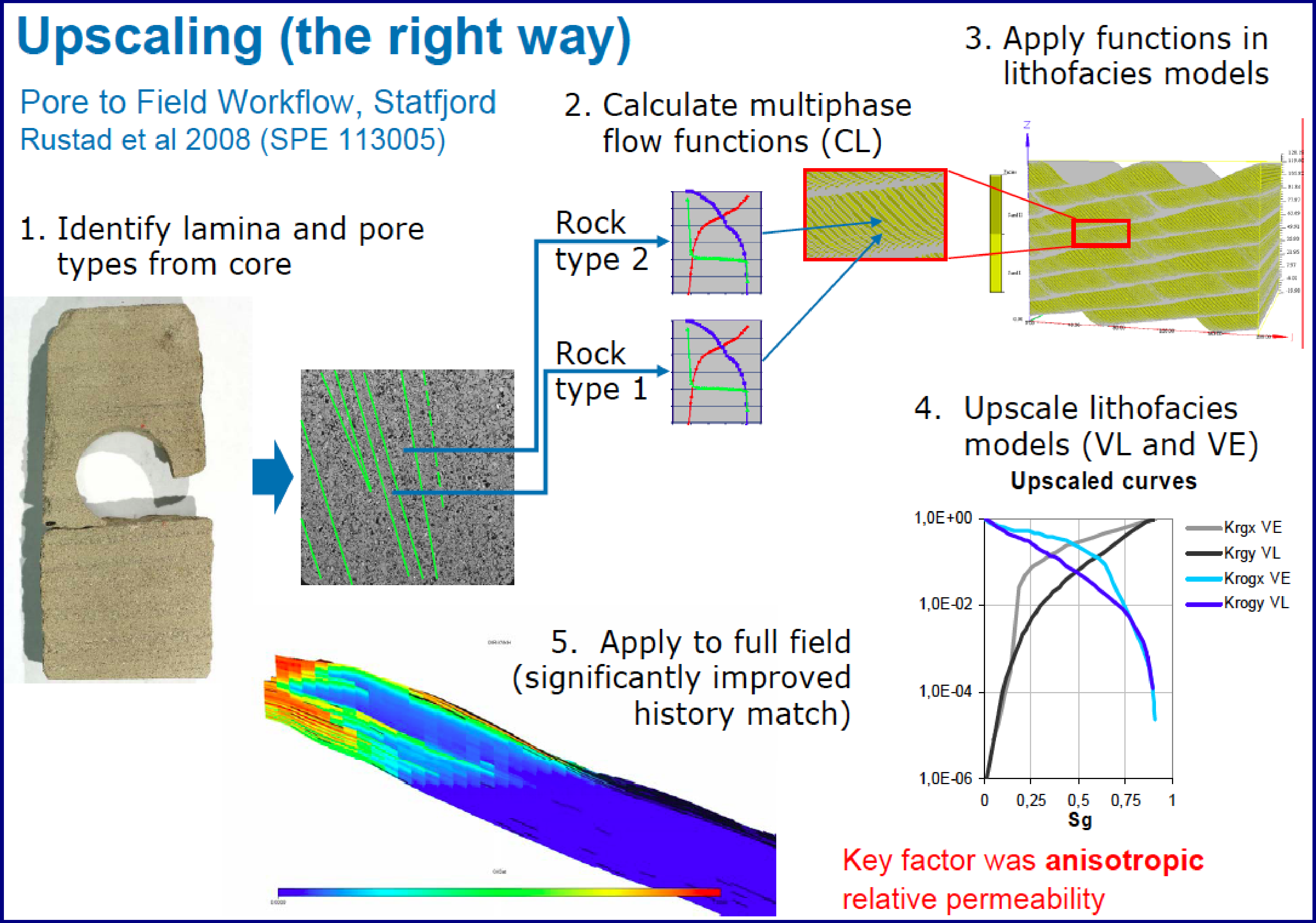


Moving beyond plug scale… new territory



- Upscaling & Uncertainties
  - Upscaling in a SYSTEMATIC manner (calibrated at each scale)

Basic Methodology

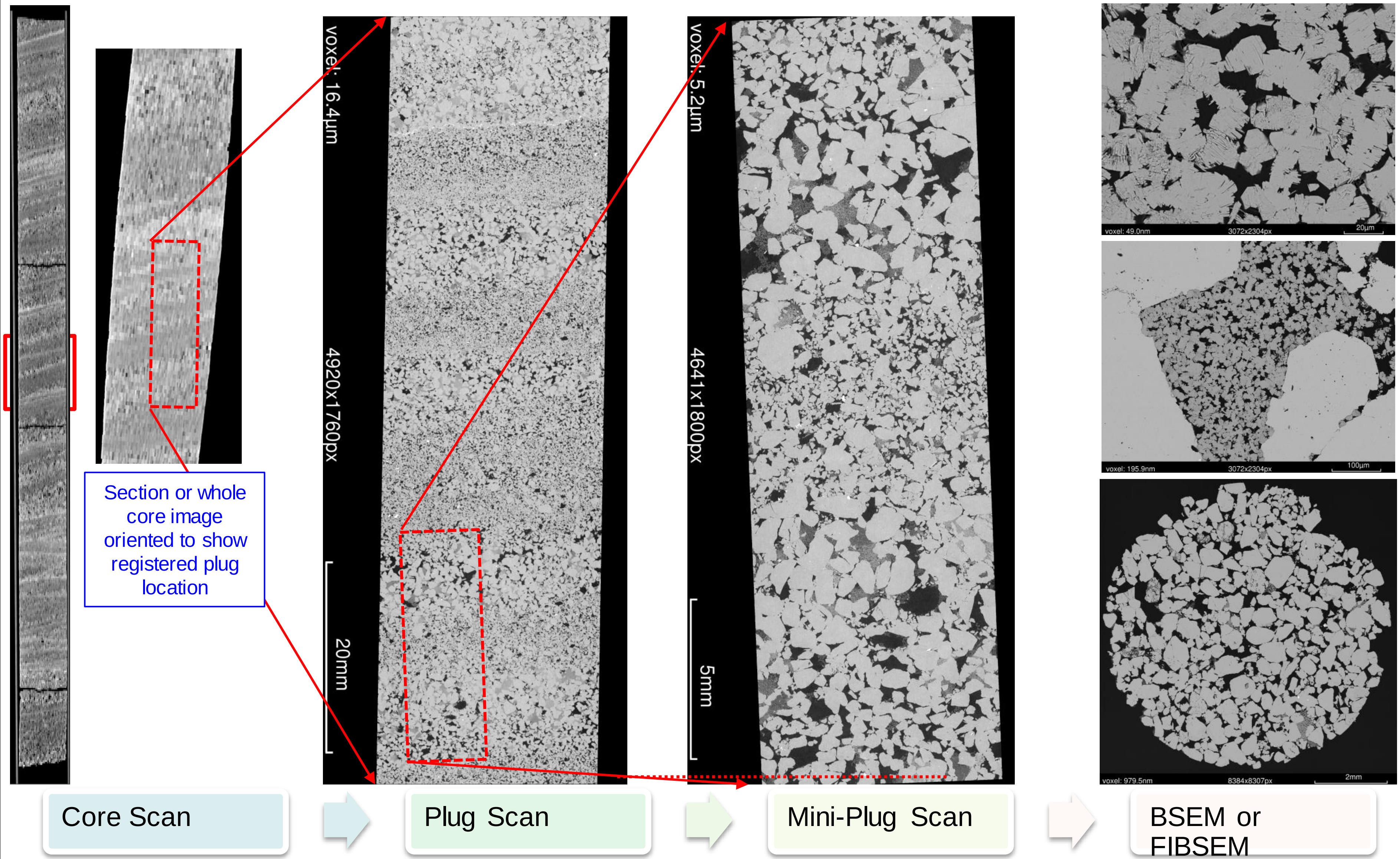


Ringrose, Svalbard Workshop: Modelling and risk assessment of geological storage of CO2, 2009

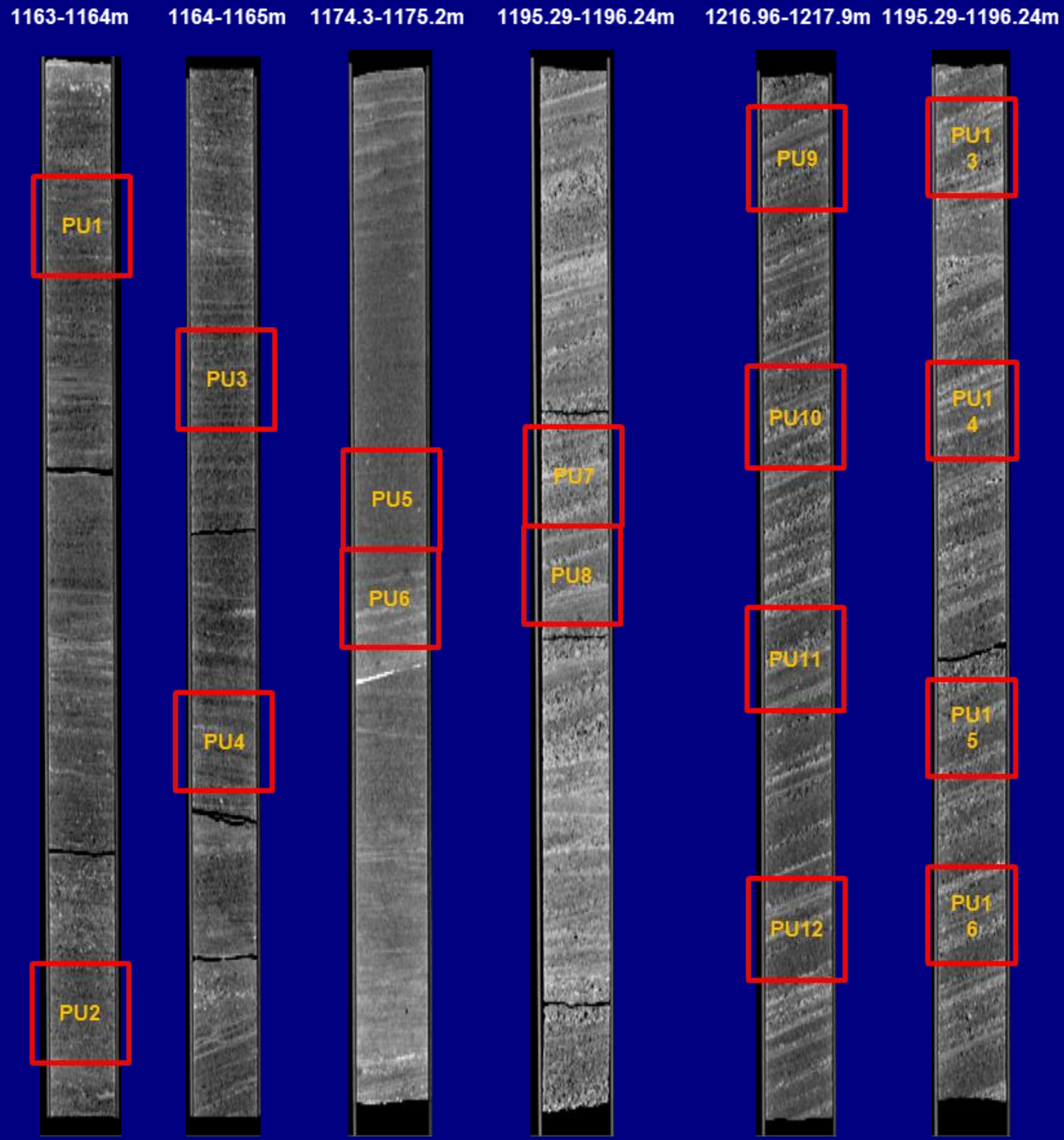
Pore to Whole core (Log scale) upscaling via digital rock technology

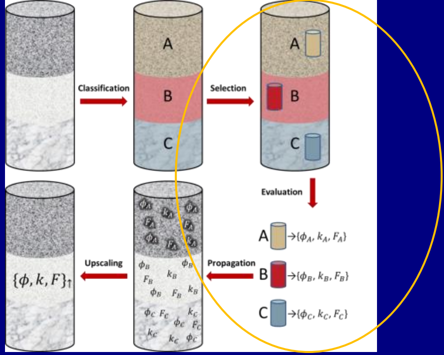
- Imaging and registration at whole core down to pore scale enables one to to classify (cluster) the rock at each scale into rock types
- Rock types can be treated as distinct units in the upscaling process
- Enables pore to plug, plug to core and core to log workflows that integrate and upscale data in a consistent manner for improved reservoir characterisation
- Aim to deliver dynamic data anchored to log responses

Images acquired and integrated at various scales

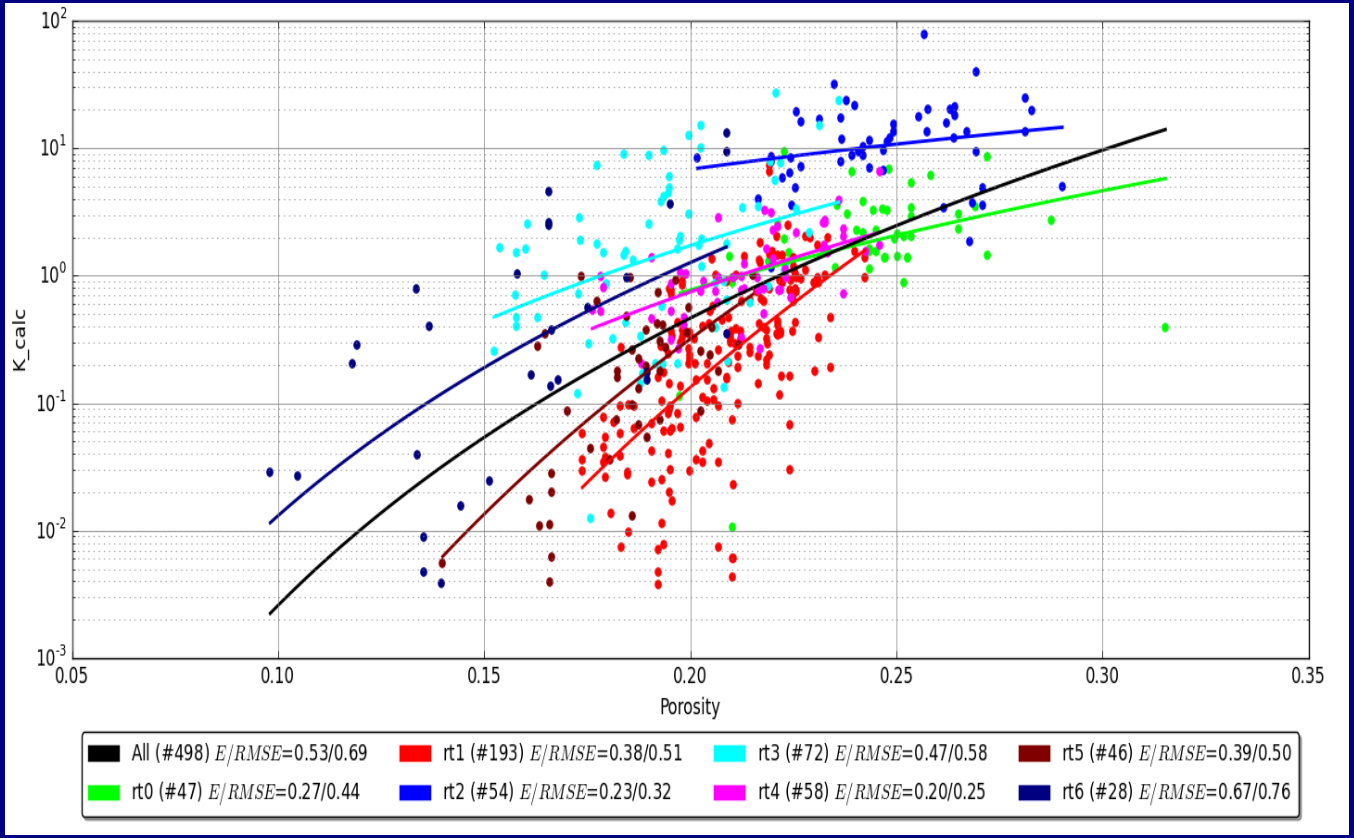


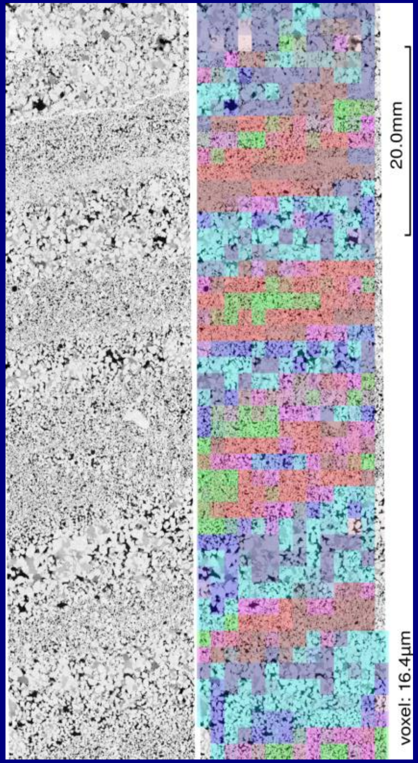
Whole Core CT Original Image resolution = 200x200x2000 μm





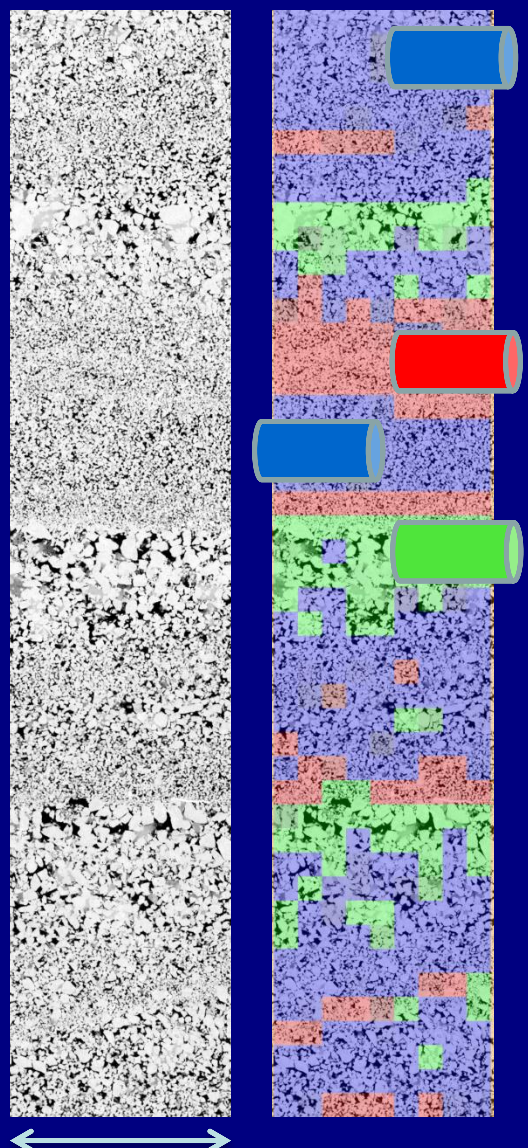
Porosity permeability trends by rock type

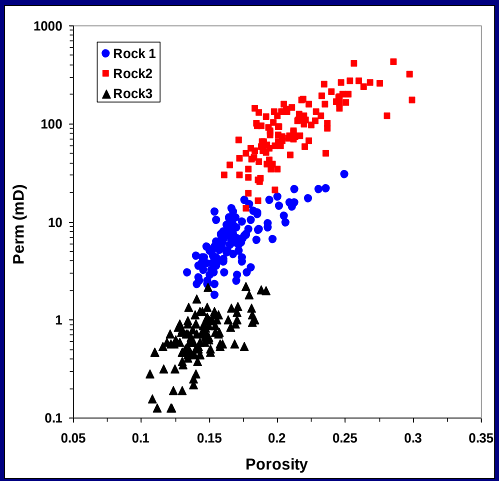


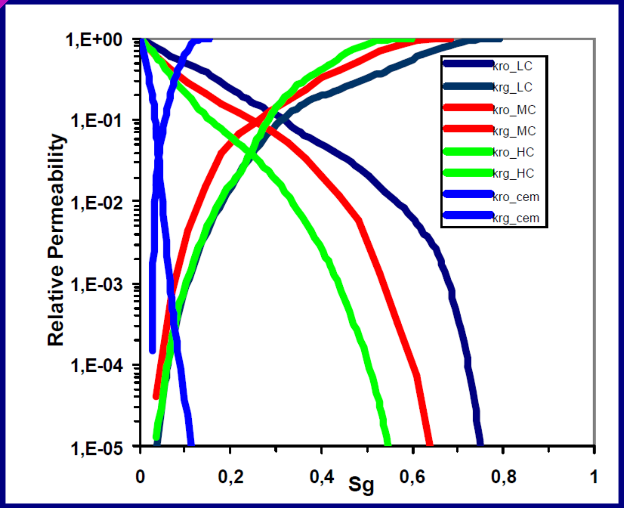


From plug images derive….

…properties derived on individual "cm-inch" scales (on individual rock types)



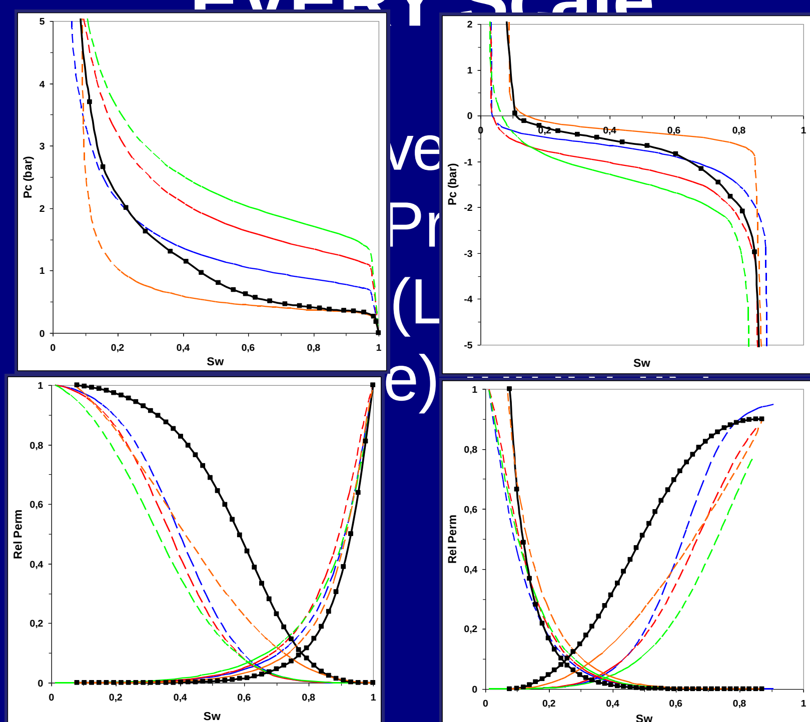


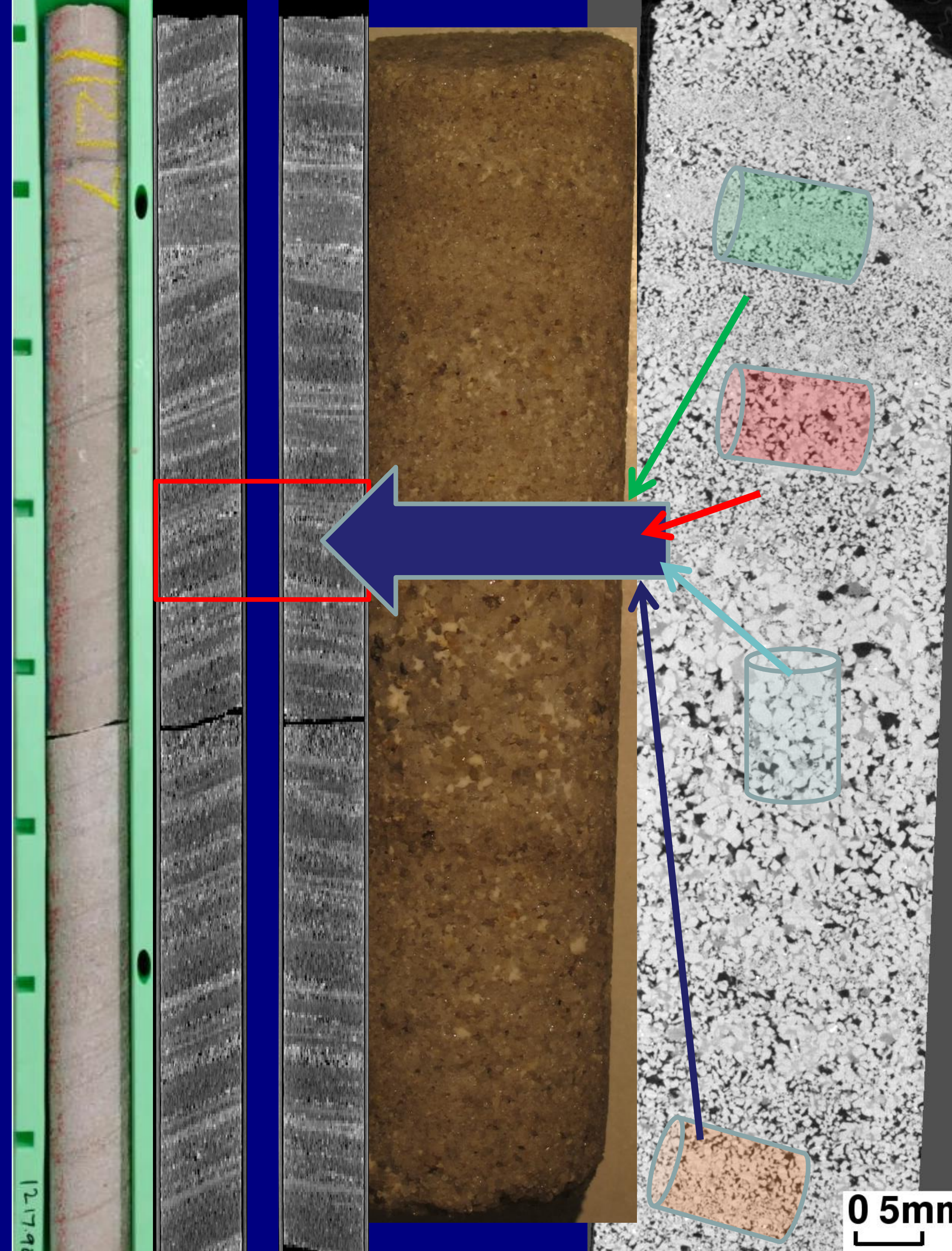


Methodology that honours Properties and Uncertainties at EVERY Scale

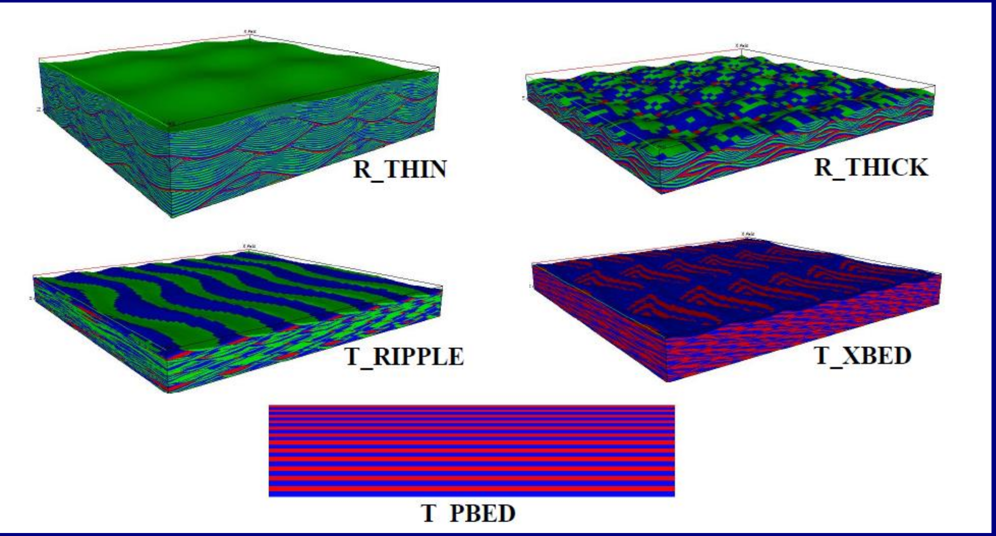
Drainage

Waterflood





Static Properties to lithofacies scale



<u>Have identified rock types at pore scale</u>

Rock type	Porosity mean	std.dev.	Permeability [mD] mean	mean ln(k)	std.dev. ln(k)	Variogram range [cm]
R_THIN_S1	0.25	0.02	113	4.6	0.5	20
R_THIN_S2	0.2	0.02	11.3	2.3	0.5	20
R_THIN_MUD	0.17	0.04	5.0	1.1	1	20
R_THICK_S1	0.28	0.02	298	6.2	0.5	20
R_THICK_S2	0.25	0.02	113	4.6	0.5	20
T_RIPPLE_S1	0.28	0.02	298	6.2	0.5	5
T_RIPPLE_S2	0.25	0.02	113	4.6	0.5	5
T_RIPPLE_MUD	0.15	0	0.1	-2.3	0	0
T_PBED_S1c	0.32	0.02	4560	8.3	0.5	20
T_PBED_S1f	0.26	0.02	89.6	5	0.5	20
T_PBED_S2c	0.31	0.02	3380	8	0.5	20
T_PBED_S2f	0.25	0.02	113	4.6	0.5	20
T_XBED_S1	0.29	0.02	599	6.9	0.5	10
T_XBED_S2	0.25	0.02	113	4.6	0.5	10

Vary geometry & properties (e.g., rock type distribution, lamina thickness, permeability, porosity

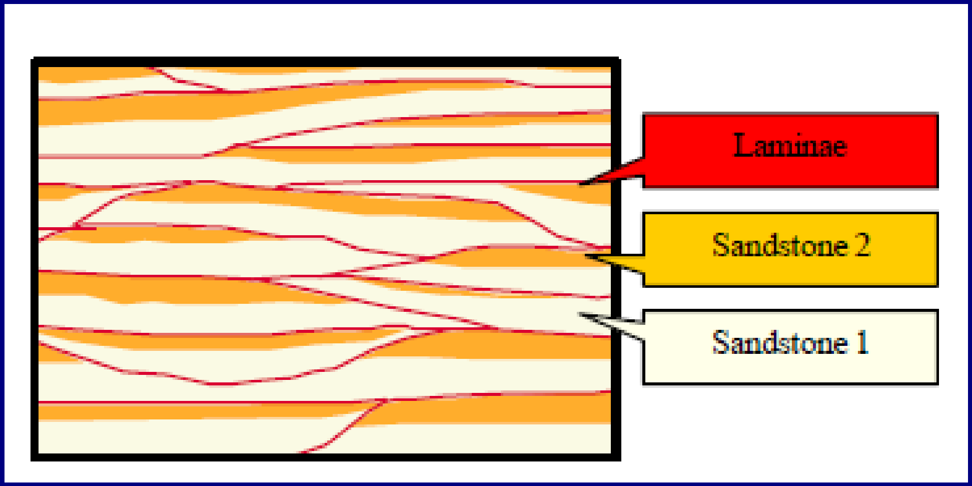
Model	Dimension	Rock types	Poro	Kh [mD]	Kv [mD]	Kv:Kh
T_RIPPLE	0.5x0.5x0.05m	S1, S2, MUD	0.231	171	34.0	0.20
T_PBED	2.5x2.5x0.5m	S1, S2	0.280	1700	438	0.29
T_XBED	0.5x0.5x0.05m	S1, S2	0.172	740	138	0.19
R_THIN	2.5x2.5x0.5m	S1, S2, MUD	0.173	87.5	12.6	0.15
R_THICK	5x5x0.5m	S1, S2	0.258	448	179	0.41

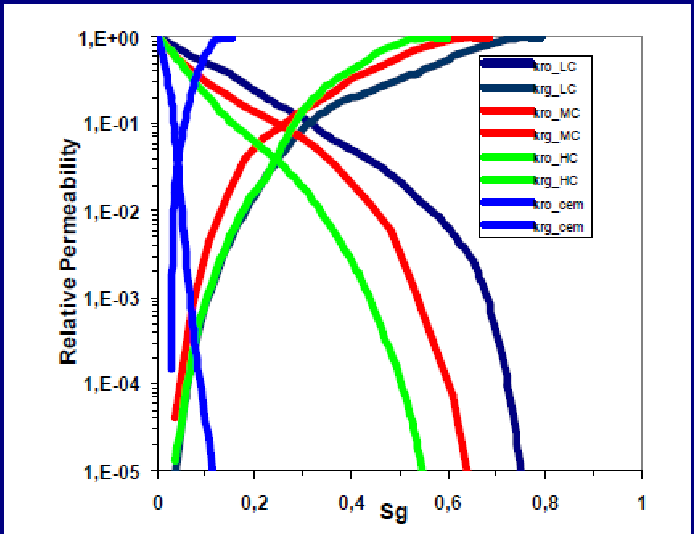
Propagate the variability identified at the pore scale <u>directly</u> to lithofacies curves

Enumerate the most probable flow properties at the lithofacies scale including variability

Rustad, SPE11305, 2008

Dynamic Properties to lithofacies scale

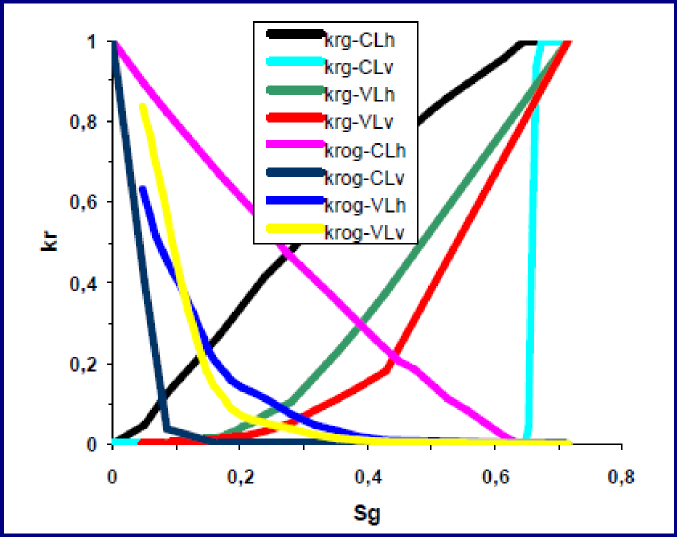




Enumerate the most probable MP flow properties at the lithofacies scale including variability

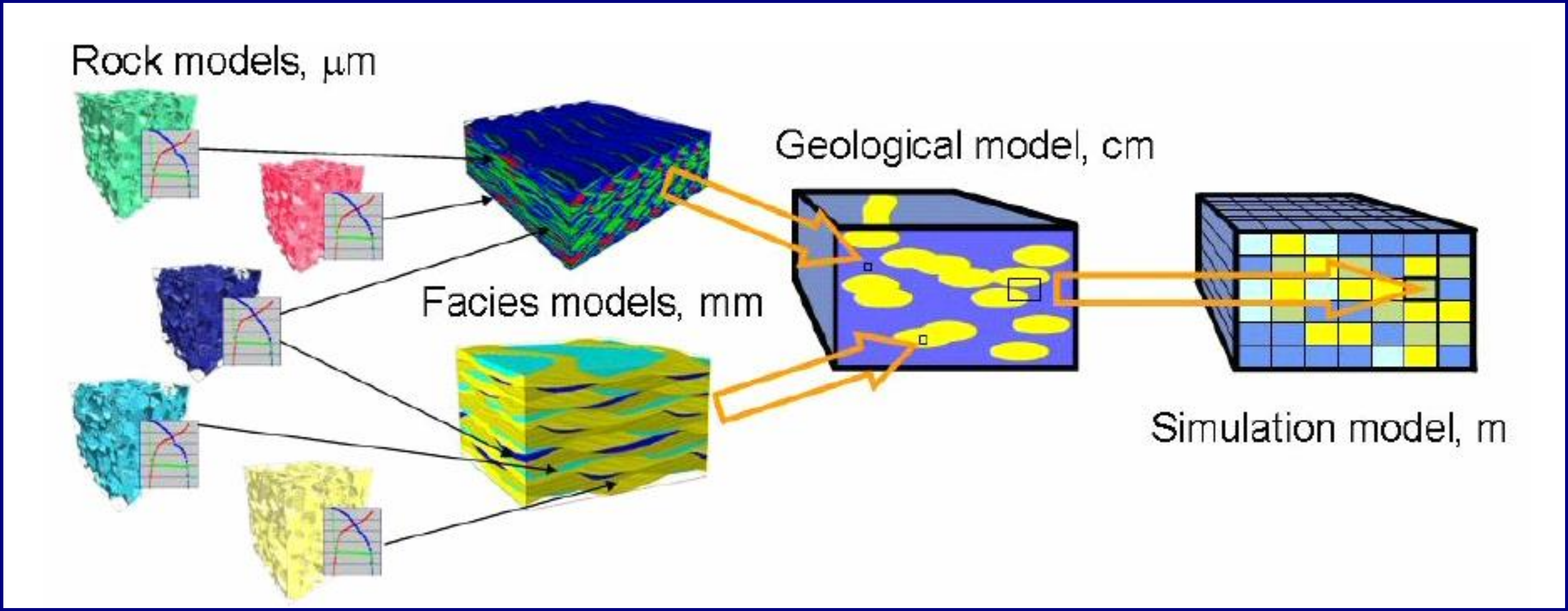
Account for the direction of flow and the balance of gravitational, viscous and capillary forces at various scale: Need CL, VL & VE, tensorial based

Applied to full field gave significantly improved history match



Klov, SPE84549, 2005

Future: Multistage Process

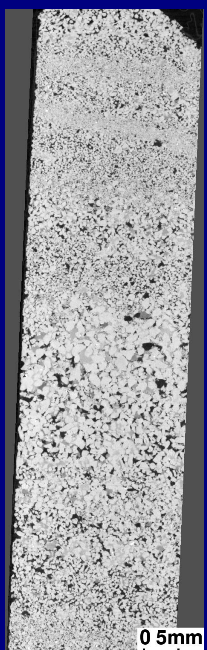


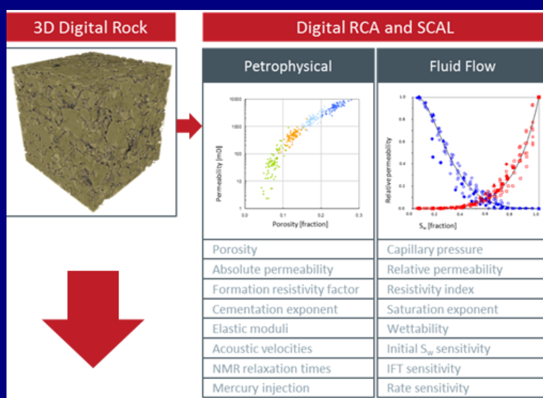
Pore to core to log/facies to….

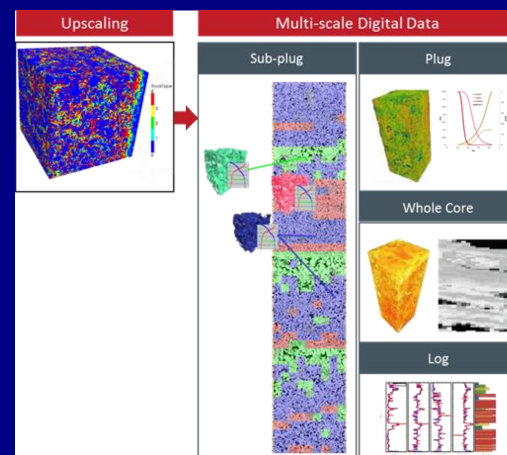
Conclusion: The Multi-scale Reservoir Characterisation Problem

Question:

How do we accurately and effectively model fine-scale heterogeneities that will impact on petrophysical response & fluid flow in a reservoir-scale model?







Option: Follow a detailed, sequential, multi-scale, **pore-to-plug-to-log- (**to-reservoir) characterisation workflow which incorporates 3D multiscale imaging, robust classification and upscaling procedures

Distinguished Lecturer Program

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