AV Integrated Reservoir Characterisation for EOR: A Case Study from a Giant Carbonate Reservoir in the Middle East*

By
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Abstract

A giant carbonate reservoir in Northern Oman has recently been re-described in preparation for a major EOR project. For the selected concept, uncertainty analysis showed that single-phase permeability, capillary pressure, and relative permeability had the strongest impact on recovery factor. On this basis, a pore characterisation project was undertaken to define rock types with distinct geological and petrophysical properties. The rock type groupings were then iterated with special core analysis data to ensure that each geological body could be assigned appropriate multiphase flow properties.

The heterogeneity of the pore network in this reservoir posed significant challenges. It is characterisation of this heterogeneity, however, that is critical to the prediction of sweep efficiency, since the results show that single-phase rock properties are often not good indicators of sweep efficiency. It is through quantification of the geometry of the pore network that capillary and relative permeability behaviour can be understood.

Since retention of geological descriptors is key to this process, then it is possible to distribute single and multiphase flow properties in the interwell area using geological rules. Such an integrated approach to reservoir characterisation and modelling has increased confidence in production forecasts under EOR, not least because a closer link has now been drawn between geological characterisation and reservoir performance.

Integrated reservoir characterisation for EOR; a case study from a giant carbonate reservoir in the Middle East

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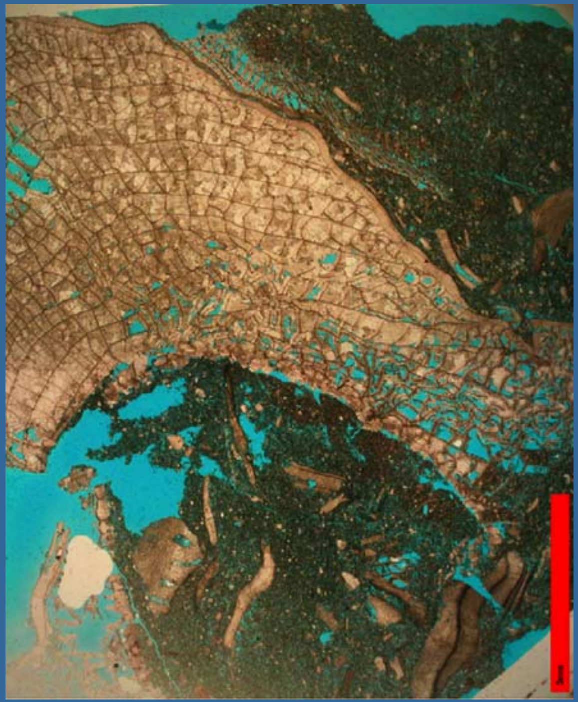
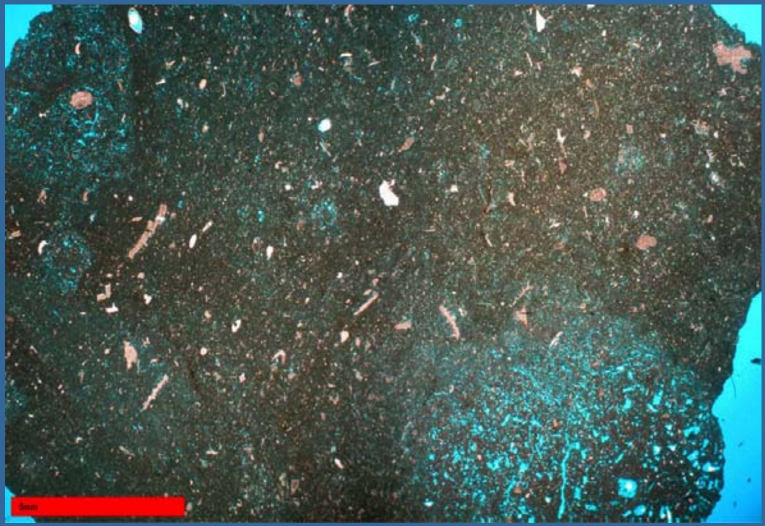
Background and methods

- Mature, giant, fractured carbonate reservoir in the Middle East
- Core program initiated for field development planning for EOR: 1800m new core and a robust routine and special core analysis program
- This study aimed to better relate pore (rock) types with SCAL data for reservoir modelling and field development planning
- Rock types defined on the basis of their pore geometry and evolution using core, petrography, image analysis, MICP and routine core analysis data

Context

- The combined effects of depositional process and diagenesis result in complex pore networks in most carbonate reservoirs
- Reservoir models often rely upon petrophysical delineation of rock types
- However, this approach is not always geologically predictive
- New data suggest that this approach does not always mean the correct multiphase flow properties are applied to geological units in the simulator





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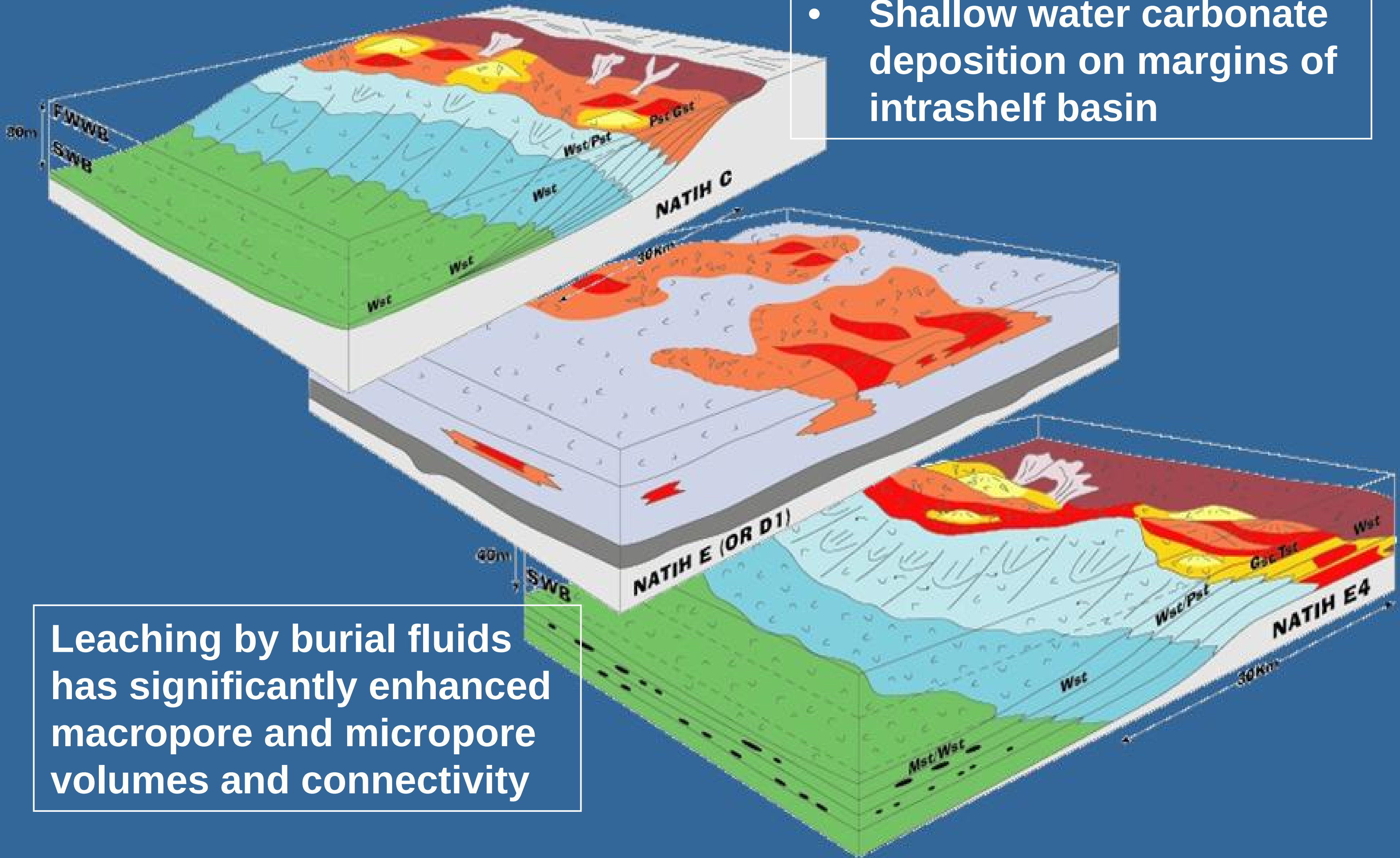
Geological framework

- Middle Cretaceous Natih Formation
- Shallow water carbonate deposition on margins of intrashelf basin



Leaching by burial fluids has significantly enhanced macropore and micropore volumes and connectivity

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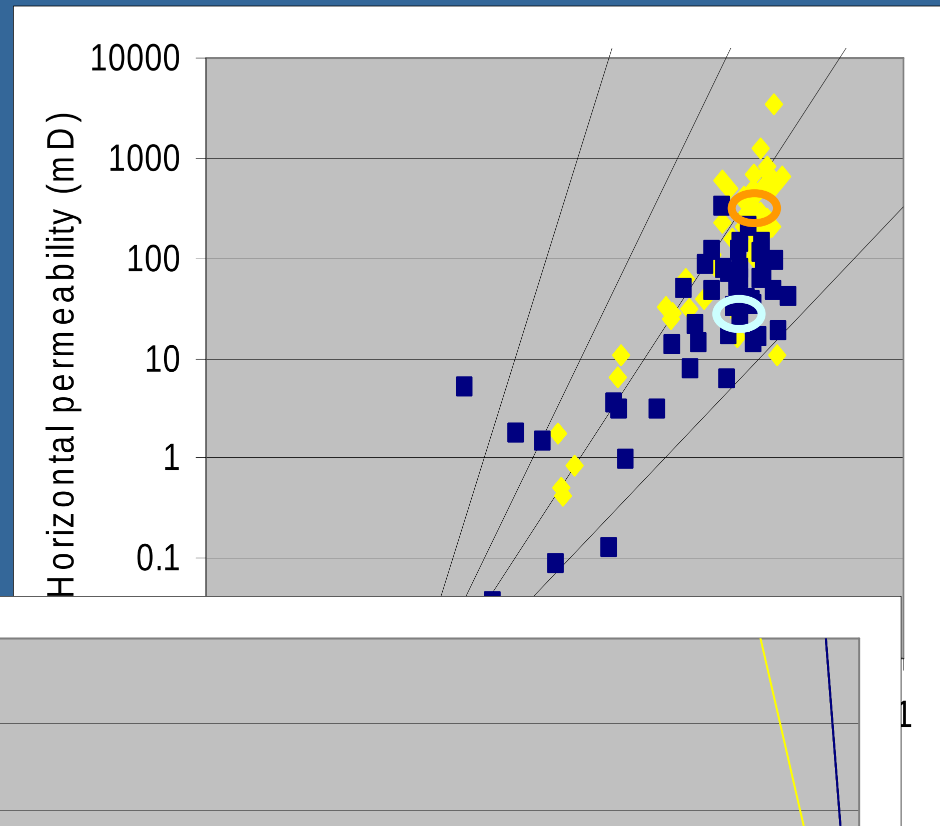
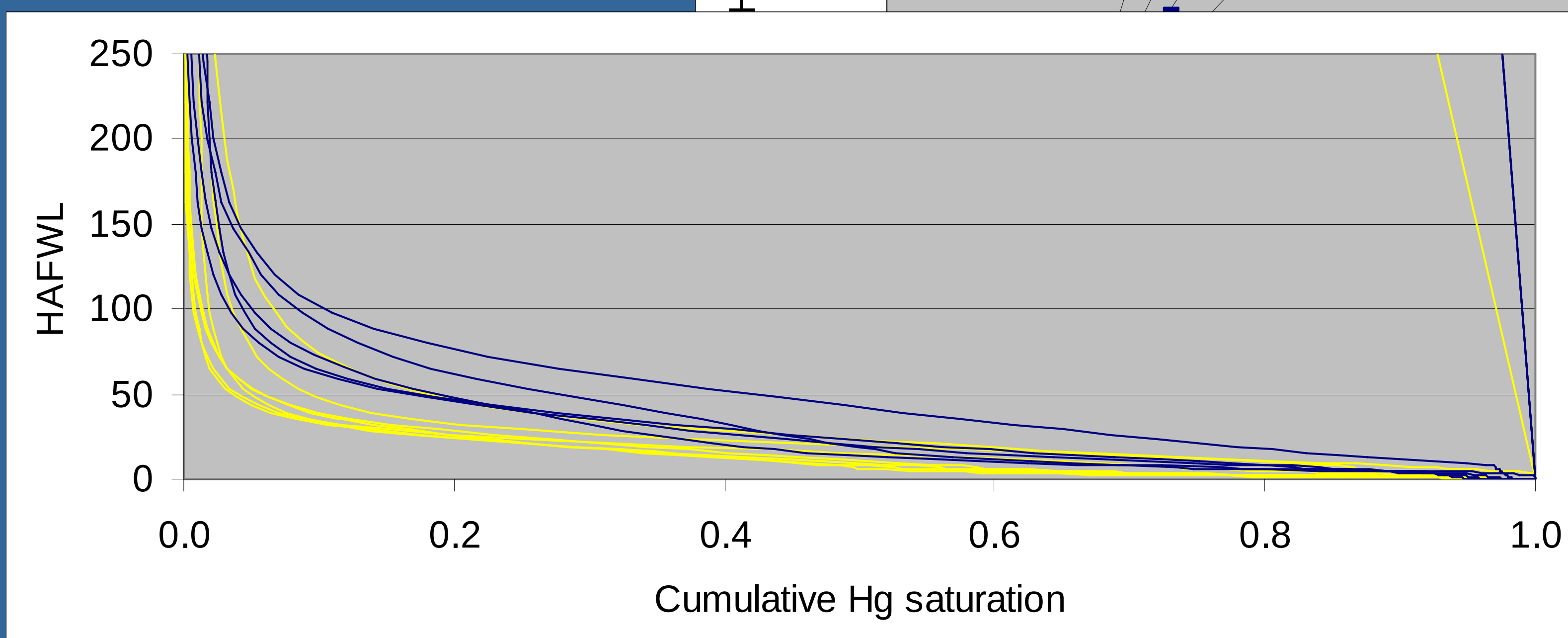
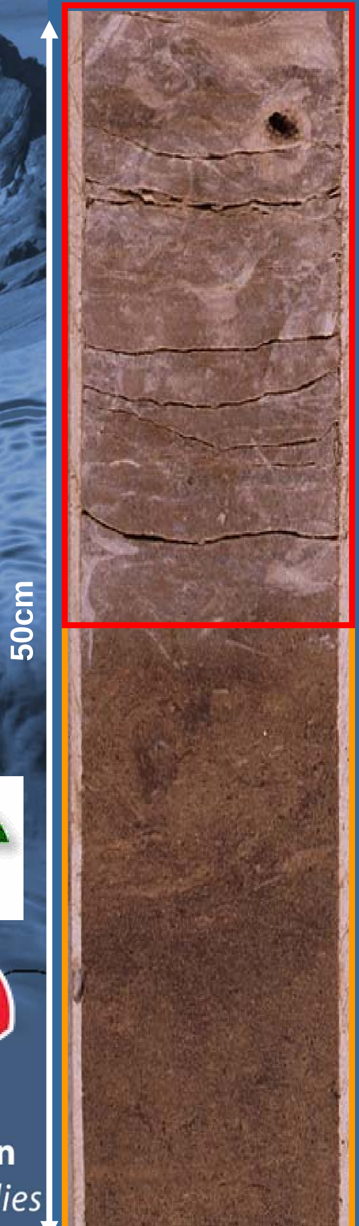
Leached shoal margin facies- Natih A & C

MacroΦ = 7% ,

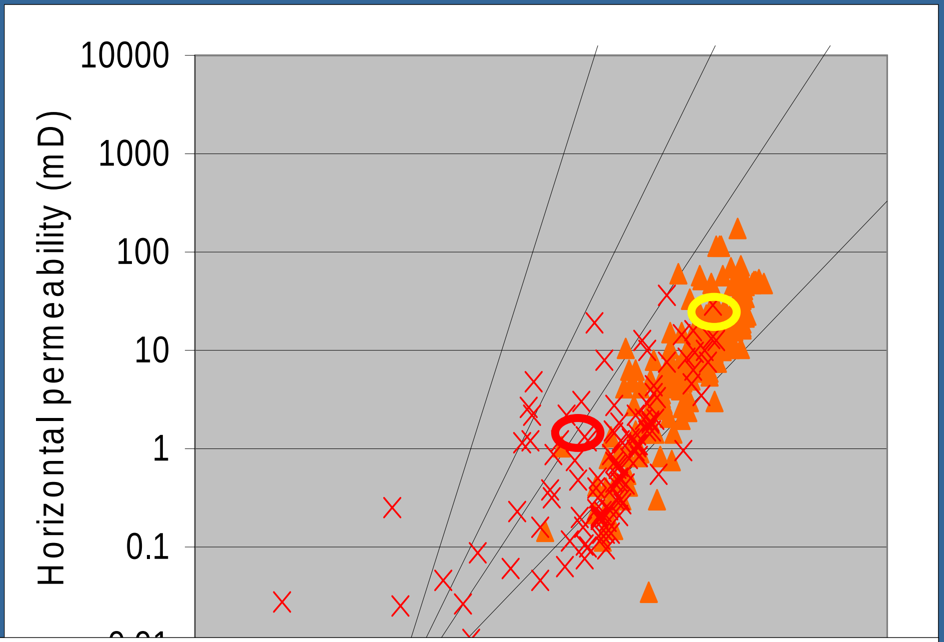


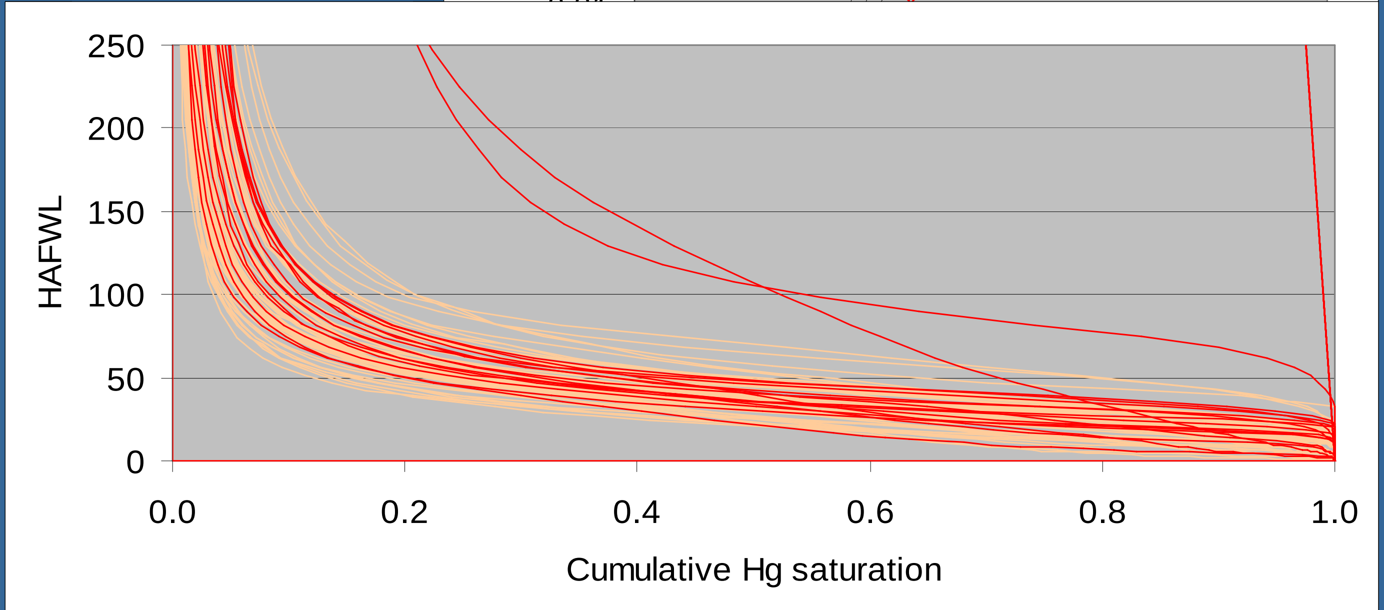


Shoal margin facies- Natih E



MacroΦ = 1%

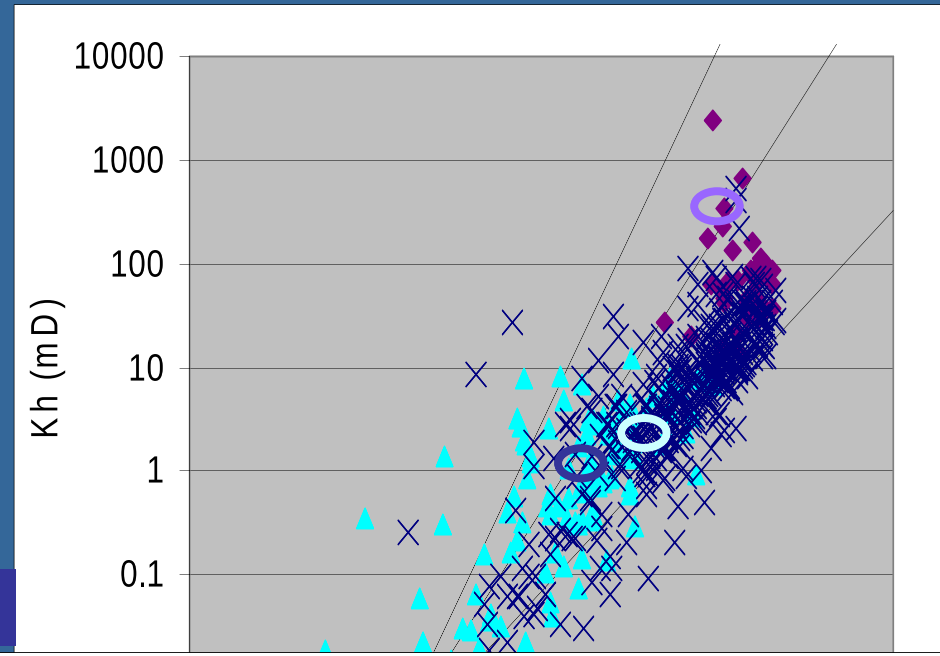


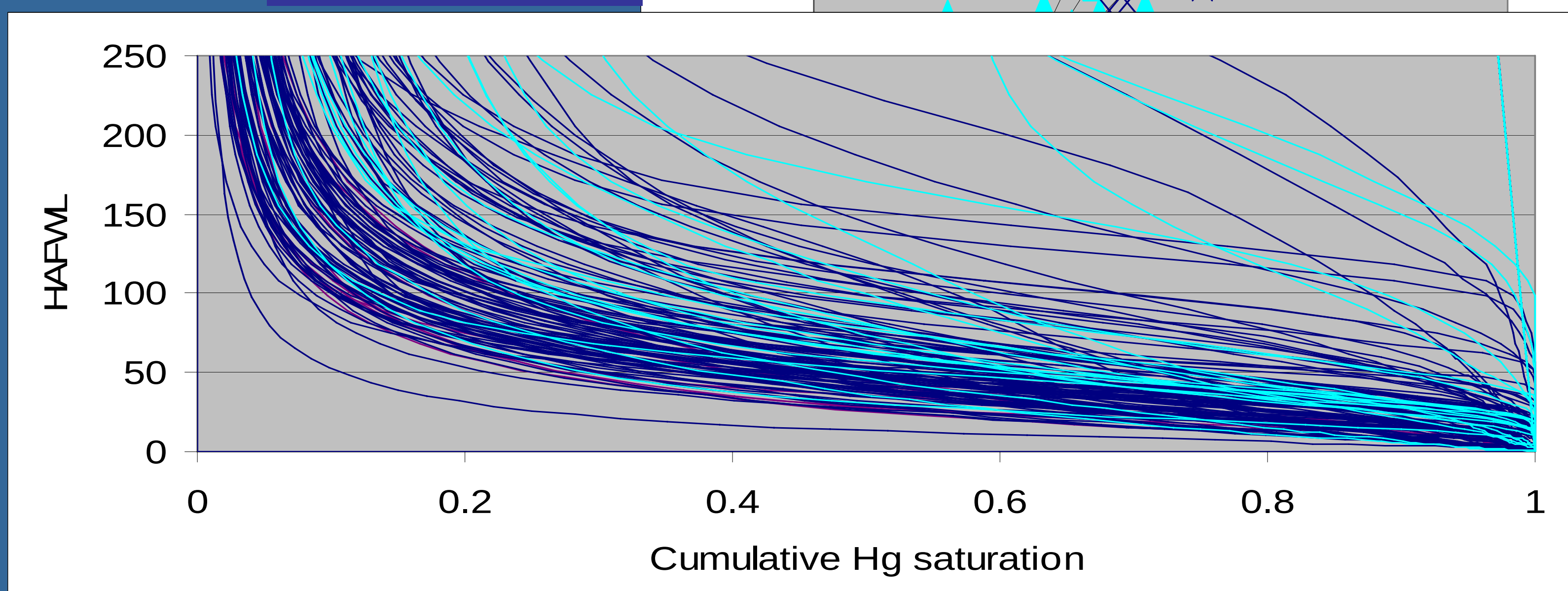


Inner ramp bioturbated facies (Natih C, D & E)

(cemented and leached)

MacroΦ = 1%

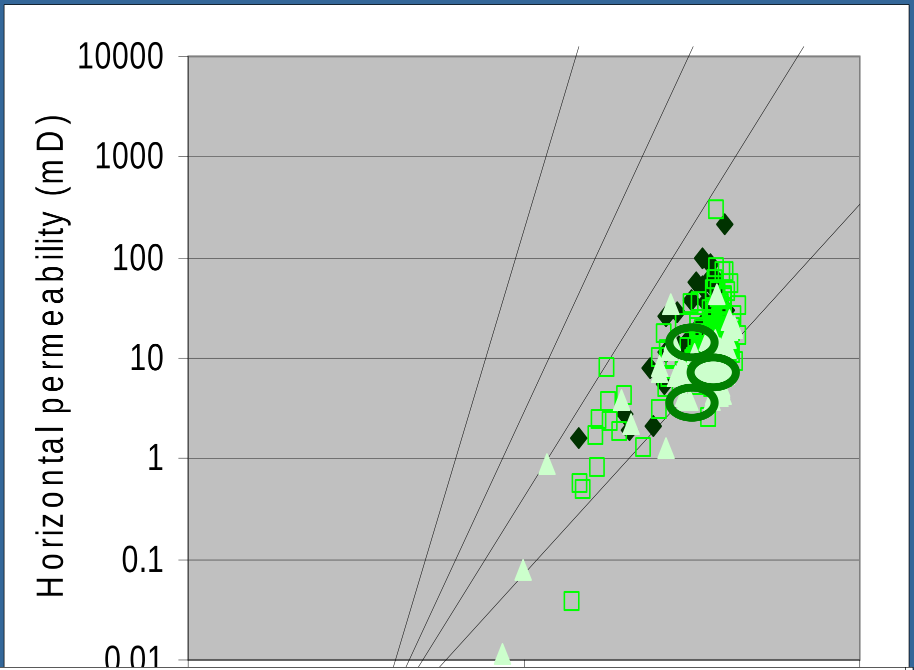


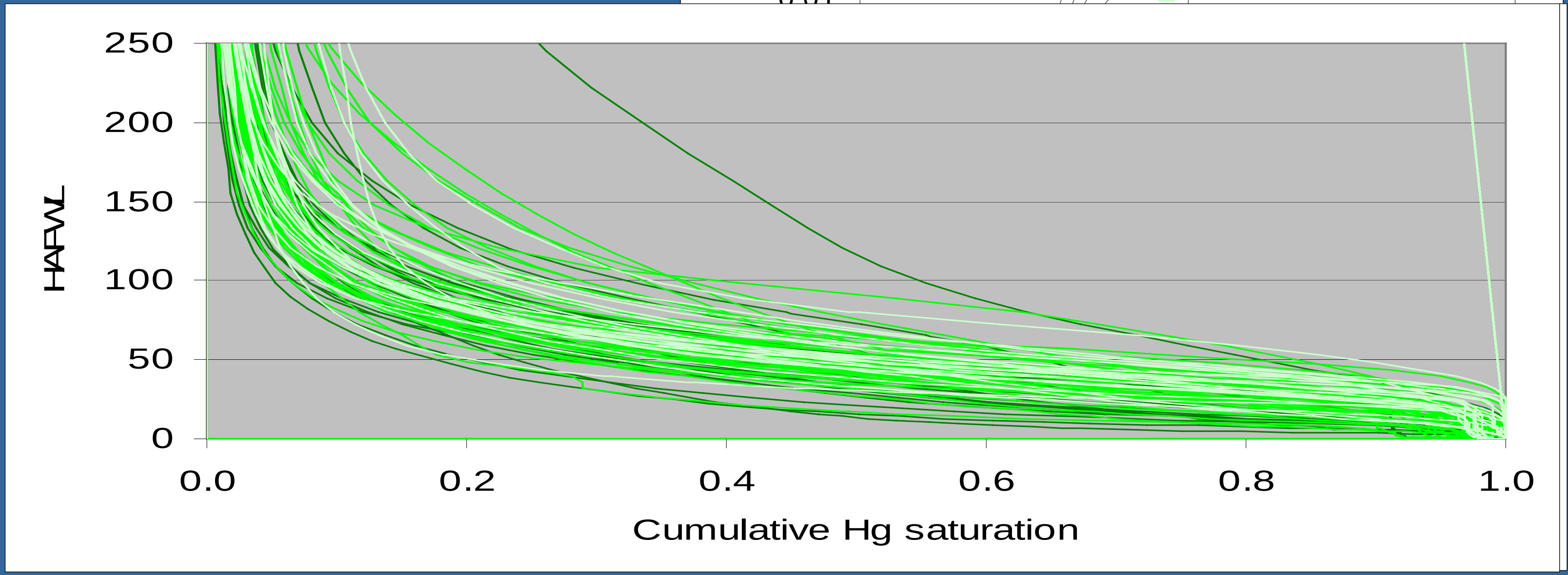


Mid ramp bioturbated facies (Natih A)

(cemented and leached)

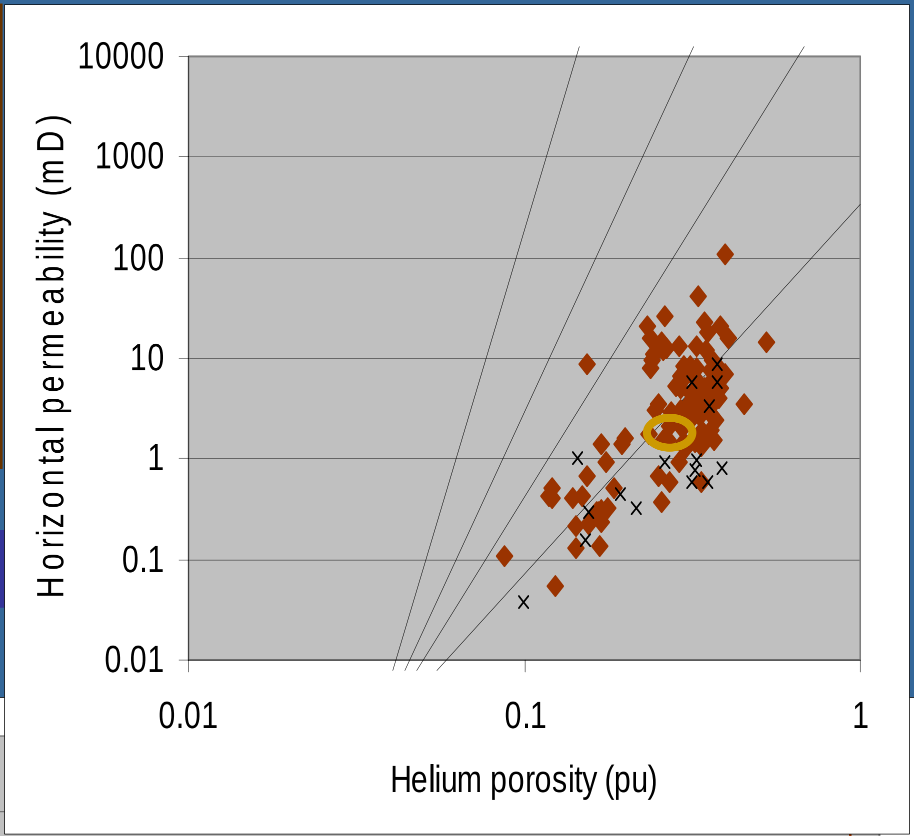
MacroΦ = 3%

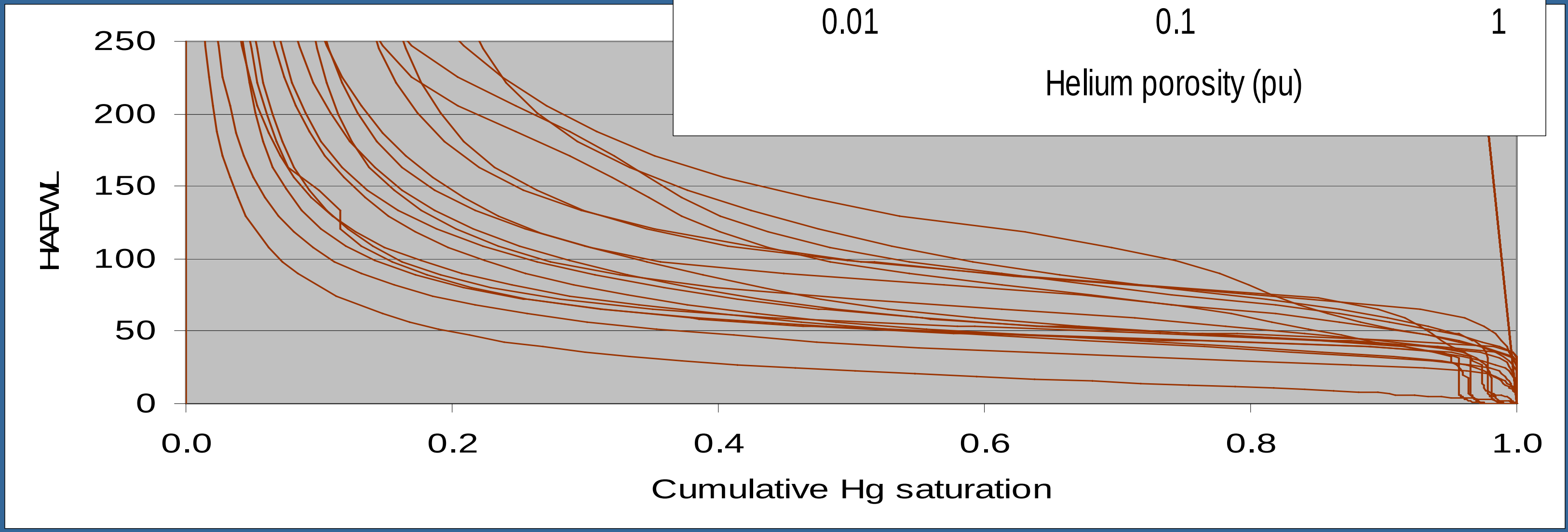




Outer ramp (Natih E and A)

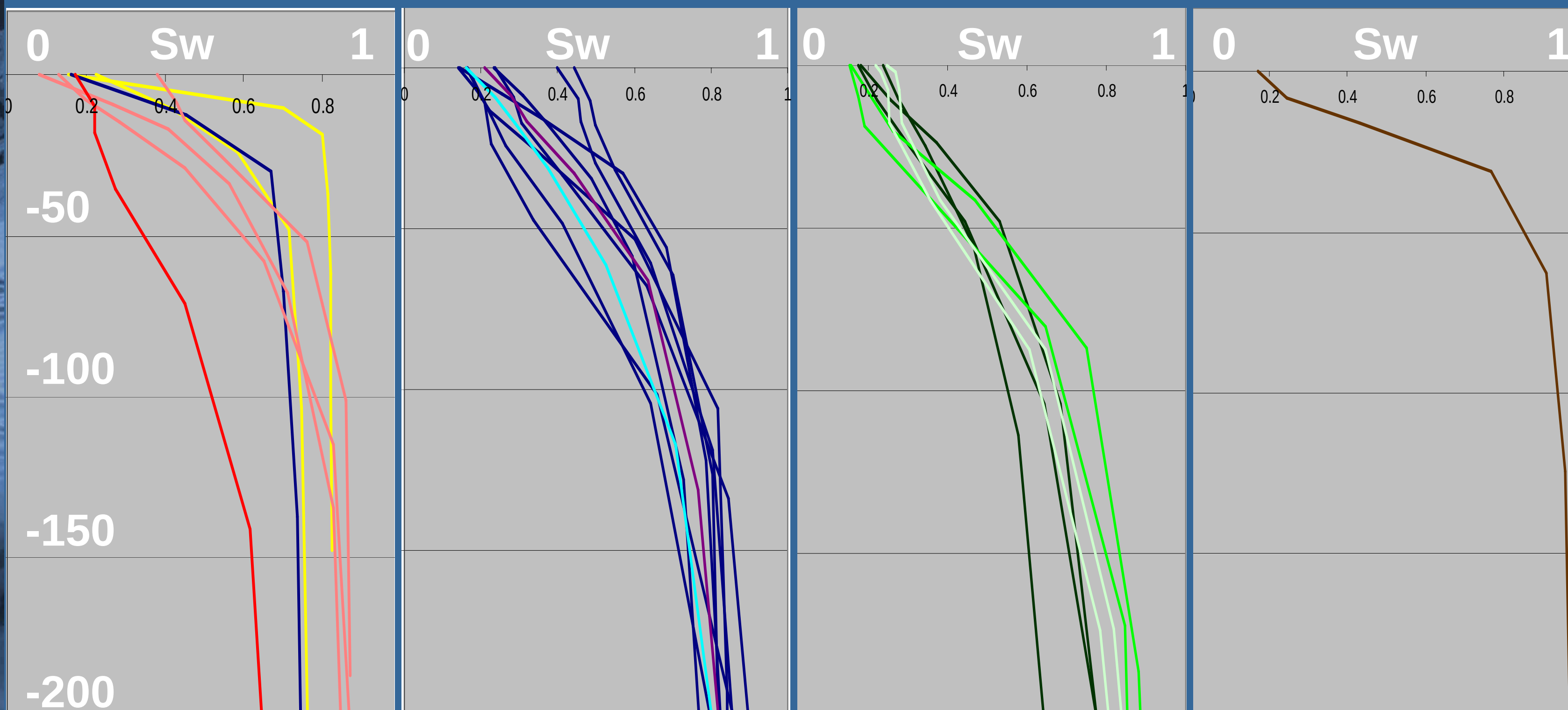
MacroΦ = 1.5%





Imbibition curves

High energy shoal	Inner ramp (bioturbated)	Mid ramp (bioturbated)	Outer ramp



- **Well swept at low pressure but Sor ≥20%,**
- **Leached, high K**
- **MicroΦ matrix**

- **More inefficient sweep with broad range Sor**
- **Heterogeneous, cemented and leached, moderate K**

- **Homogeneous, efficient sweep**
- **Homogeneous**
- **Low K**

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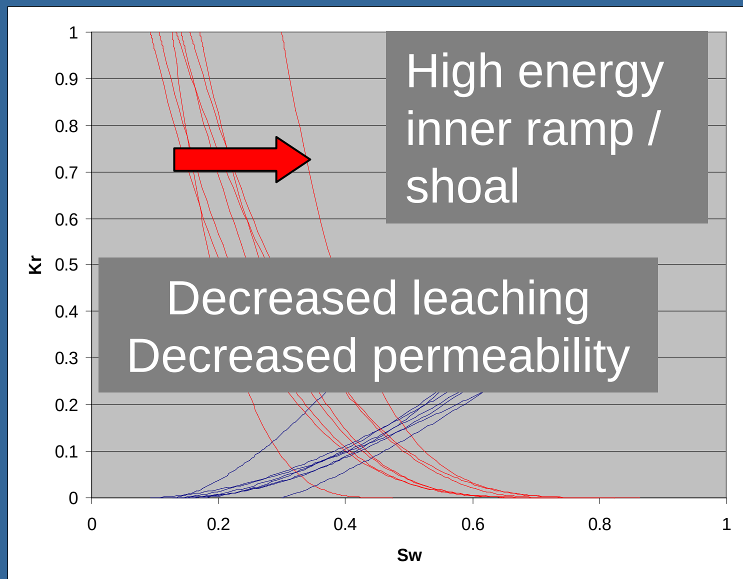
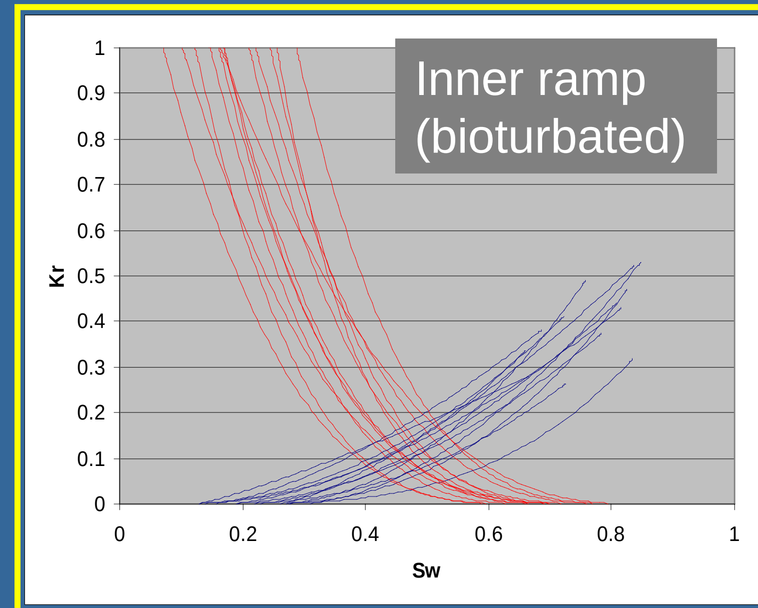
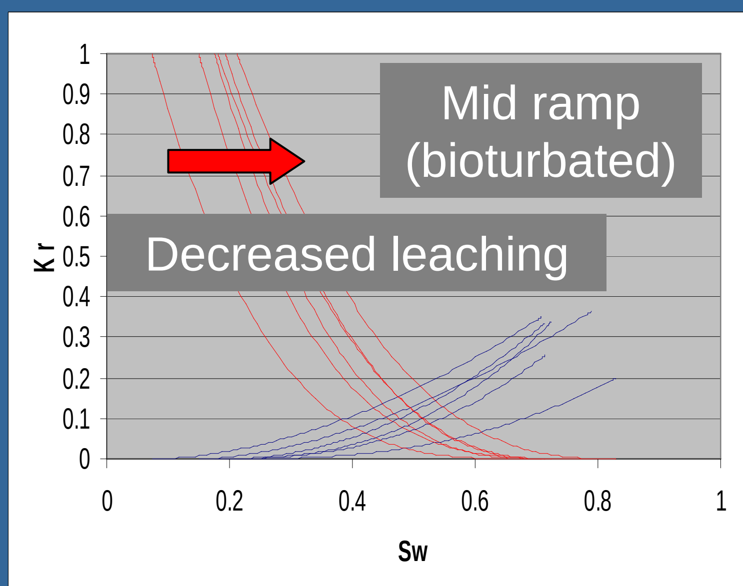
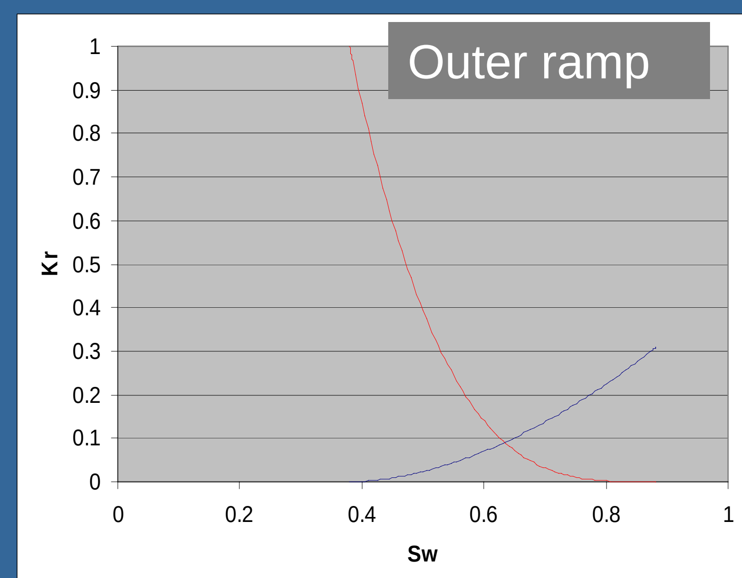
Relative permeability









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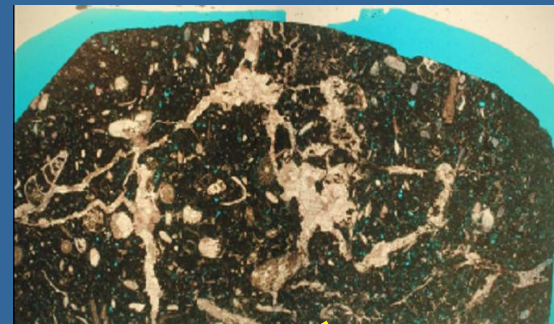
Inner ramp, Natih D

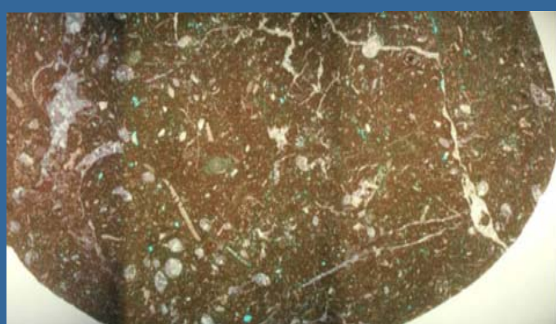
Micro-Φ=91.6%



Micro-Φ=93.5%

Micro-Φ=100%

Micro-Φ=98.6%

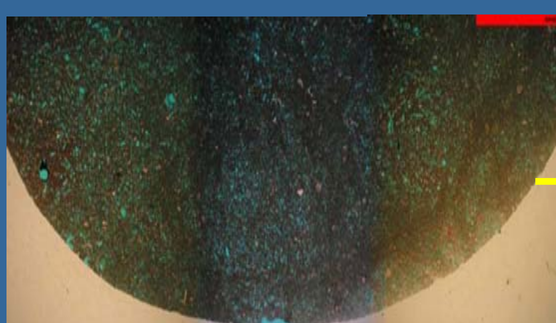


26.2%
2.07mD

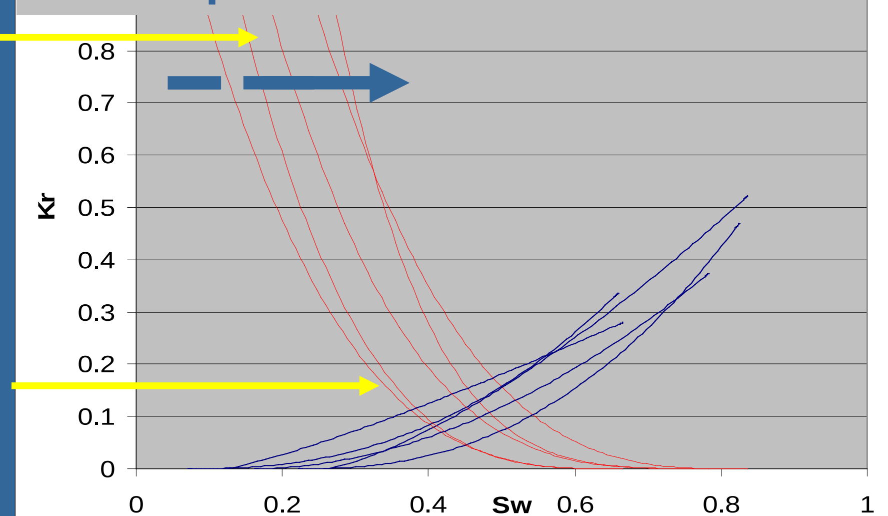
- Decreasing total porosity
- Decreasing Kh
- Broad increase in total micropore volume

32.1%
9.79mD

Micro-Φ=92.5%



42.7%
16.4mD

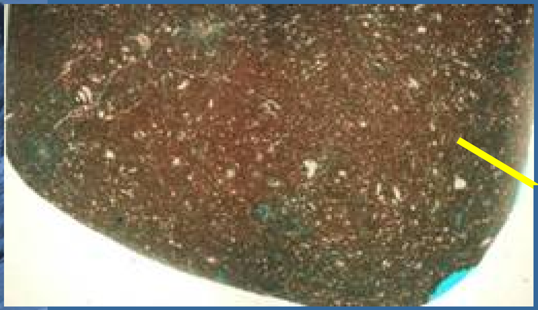


Inner ramp, Natih E

Micro-Φ=99%

- Broad decrease total porosity
- Broad decrease in Kh
- Increase in total micropore volume

Micro-Φ=98.8%



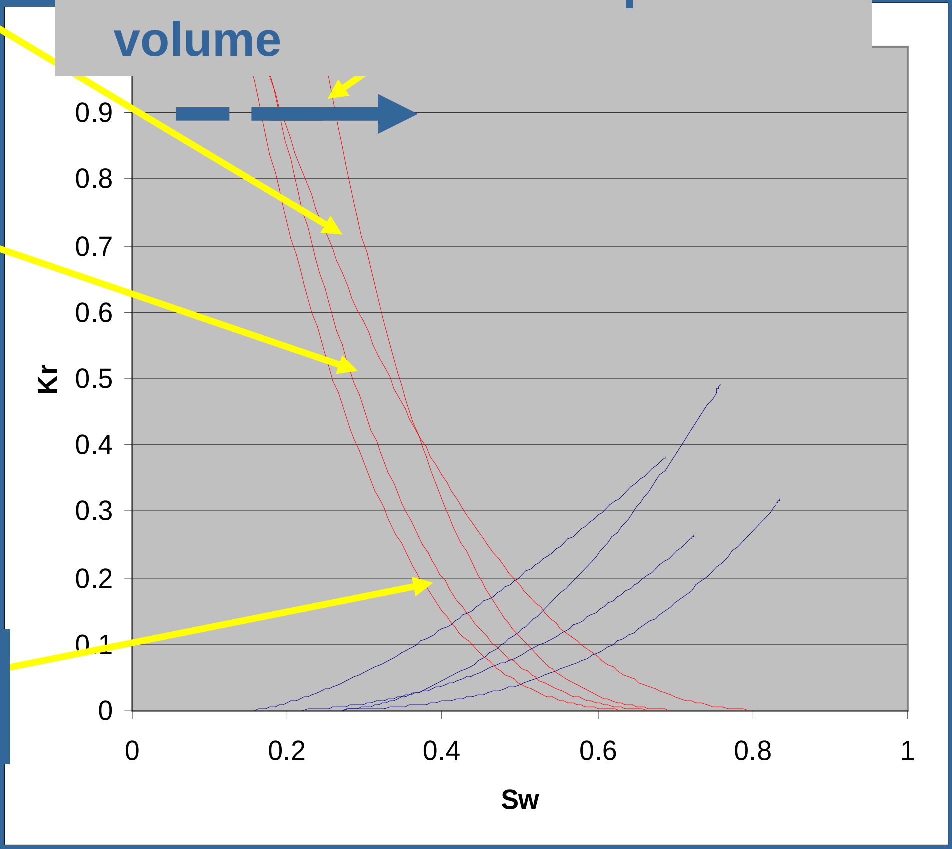
29.1%
5.02mD

Micro-Φ=96.8%

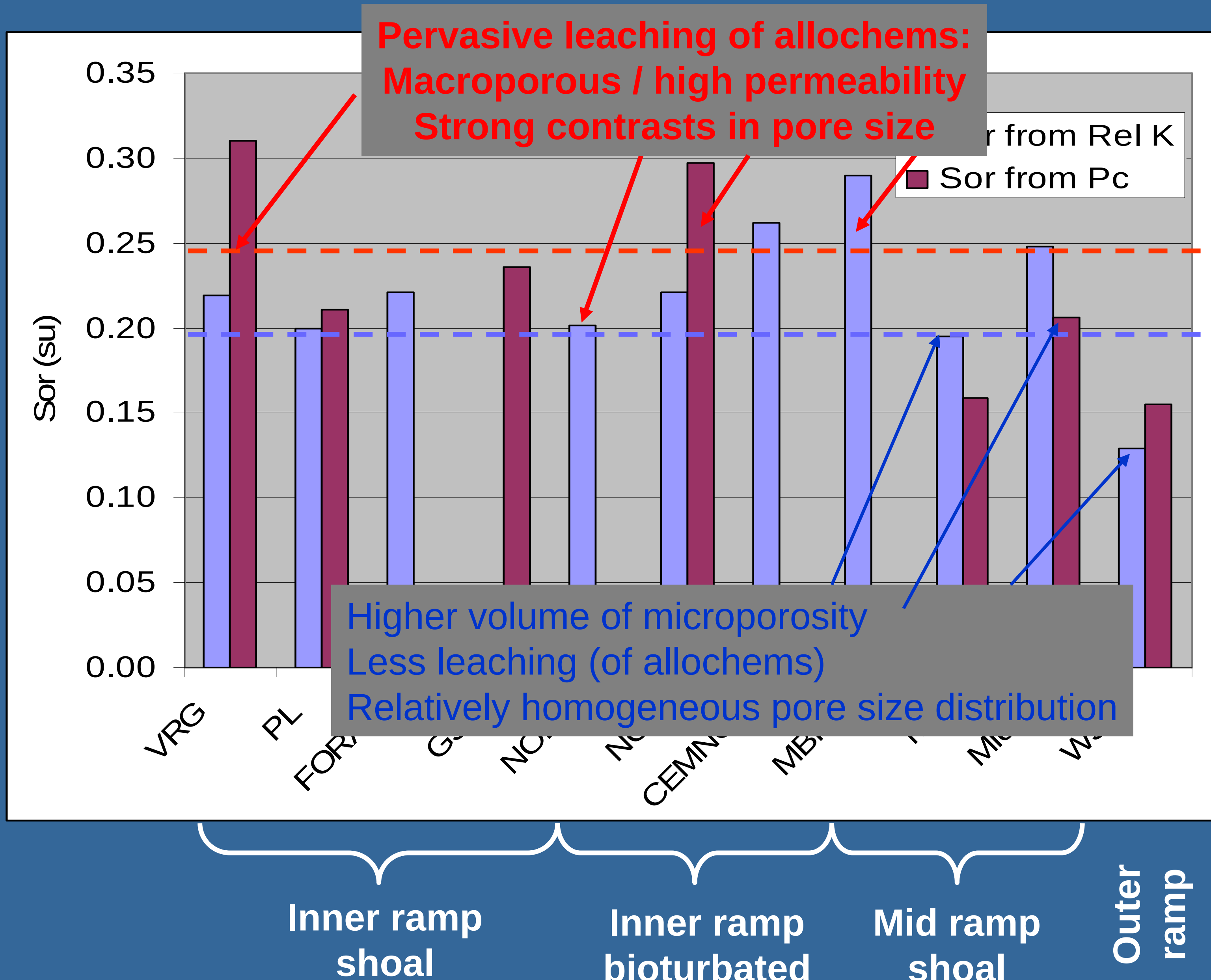
35.9%
1.85mD

Micro-Φ=68.6%

25.1%
6.80mD



Sor


Pervasive leaching of allochems:
Macroporous / high permeability
Strong contrasts in pore size
r from Rel K
Sor from Pc
Sor (su)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
VRG
PL
Higher volume of microporosity
Less leaching (of allochems)
Relatively homogeneous pore size distribution
Inner ramp shoal
Inner ramp bioturbated
Mid ramp shoal
Outer ramp

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Conclusions

- The reservoir is highly microporous. All samples have >60% microporosity and often >>80%, therefore variability in Pc and relative permeability is not strong.
- In many cases, an increase in the volume of microporosity is coupled with an improvement in sweep efficiency
- An increase in permeability does not necessarily lead to a more efficient sweep or lower Sor: often the reverse is true
- Rock type groupings on the basis of permeability and/or primary drainage alone may be misleading
- A closer relationship between rock types and multiphase flow properties is achieved through consideration of pore evolution and pore geometry. This should lead to more confident application of multiphase flow properties in the simulator

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Acknowledgements

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For permission to publish

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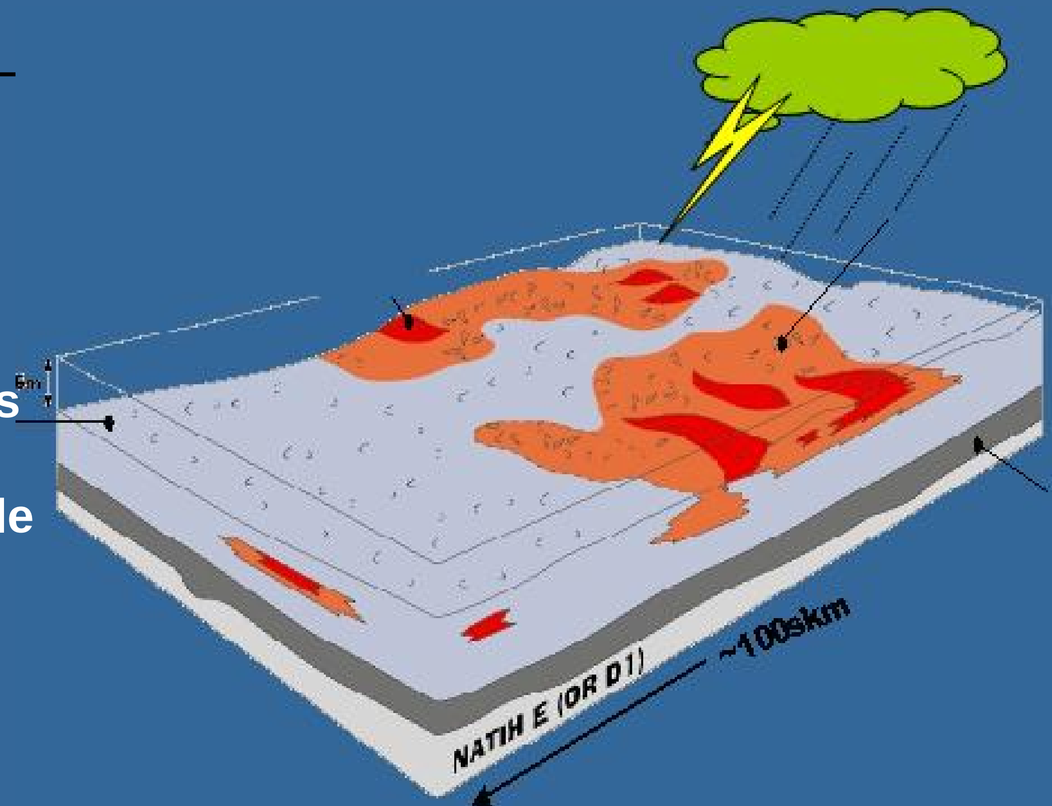
University of Miami and Badley Ashton and Associates for assistance with data collection and manipulation

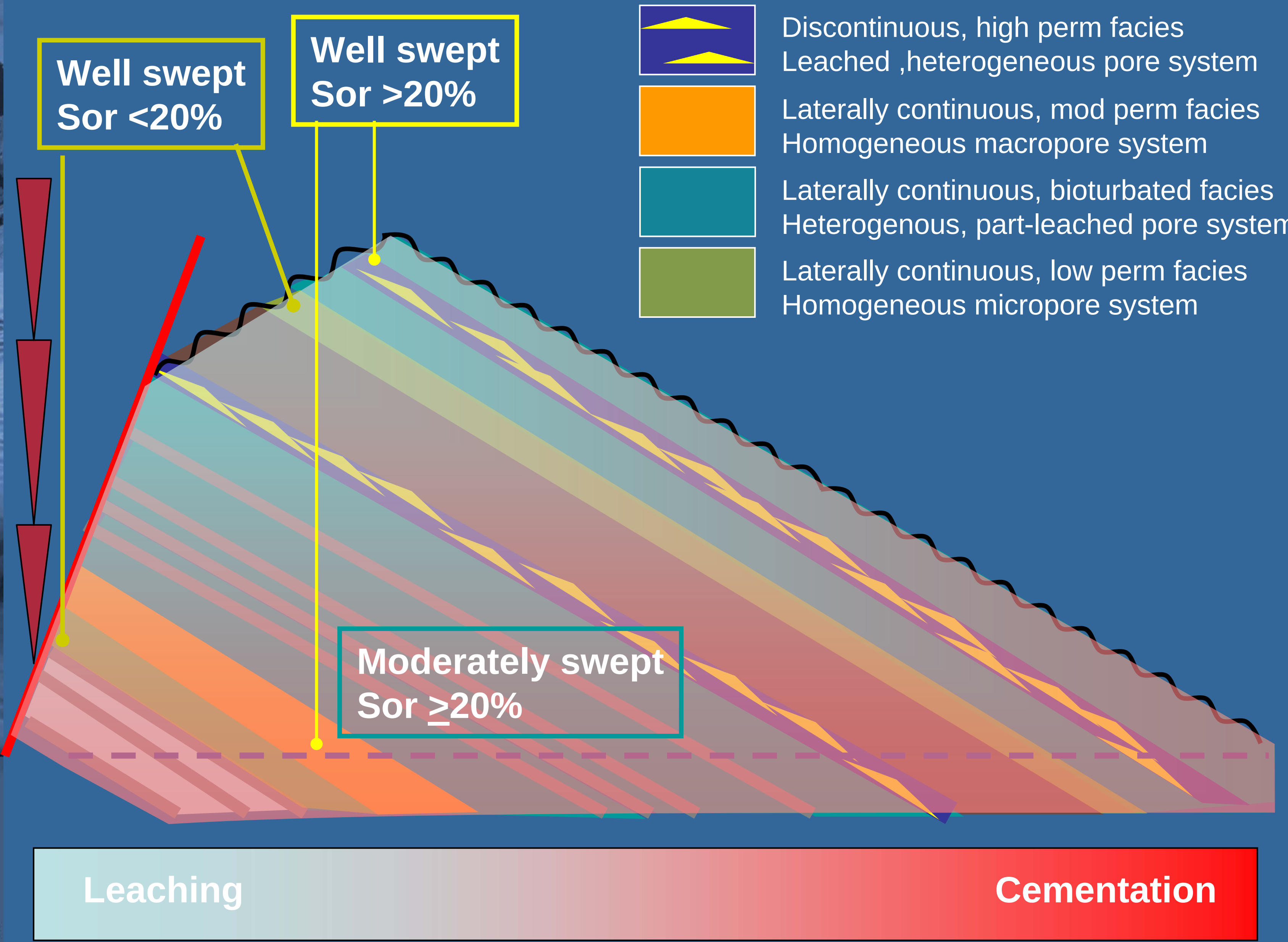
Diagenesis

Previous model: dissolution and cementation from meteoric porewaters beneath sequence boundaries (possible karstification)



Revised model: dominated by leaching (and cementation) from burial fluids. Associated with structuration and hydrocarbon emplacement

Summary



Well swept
Sor <20%
Well swept
Sor >20%
Moderately swept
Sor ≥20%
Discontinuous, high perm facies
Leached ,heterogeneous pore system
Laterally continuous, mod perm facies
Homogeneous macropore system
Laterally continuous, bioturbated facies
Heterogenous, part-leached pore system
Laterally continuous, low perm facies
Homogeneous micropore system
Leaching
Cementation