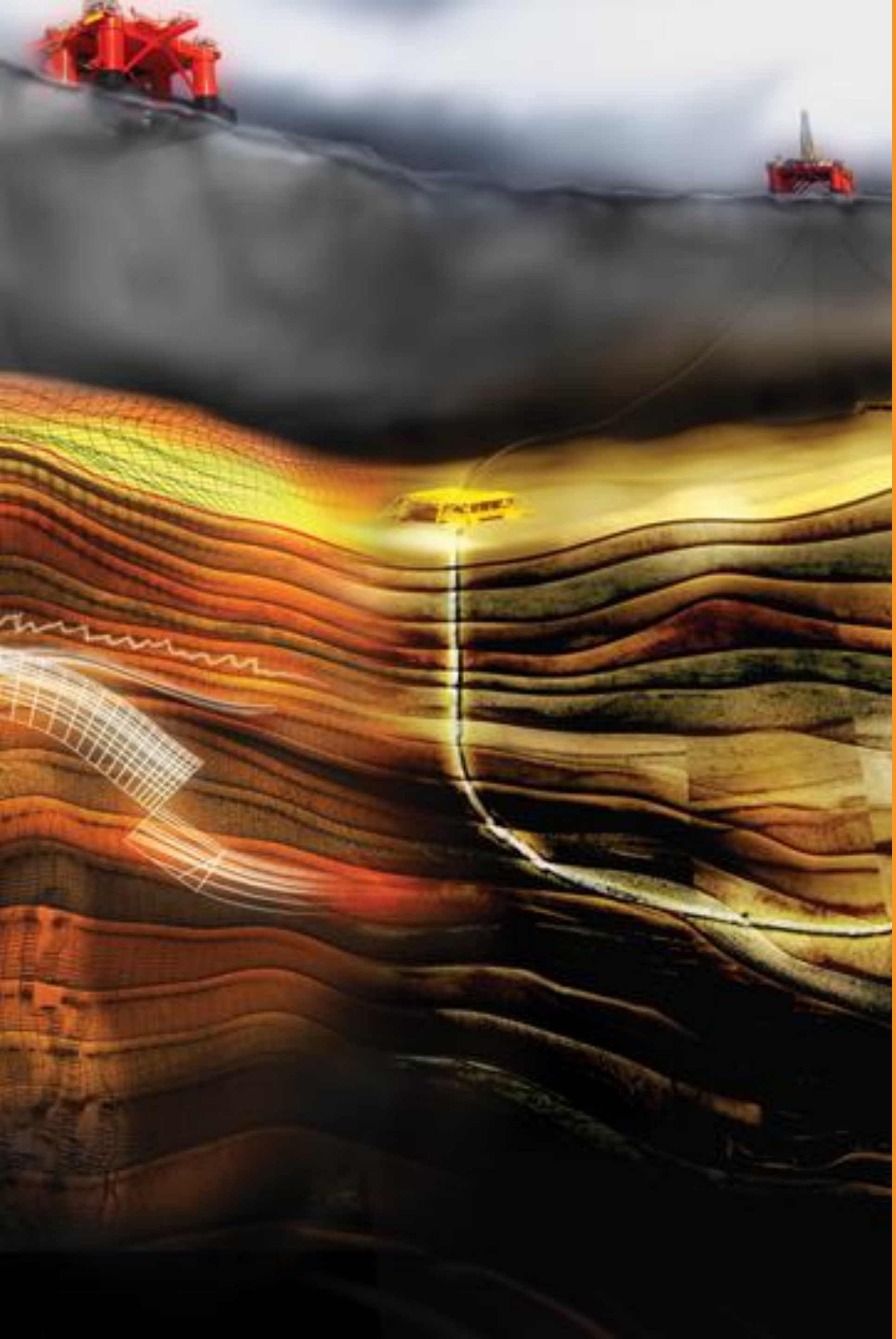


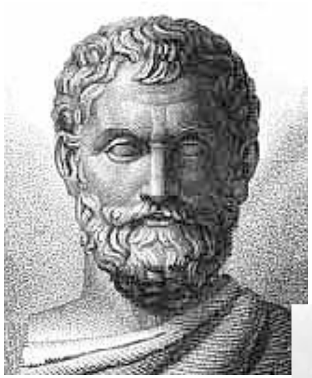
Water Saturation Modelling – A Multi-disciplinary Approach

FORCE Seminar

Tor Barkve
January 24, 2017

www.roxarsoftware.com

EMERSON Process Management



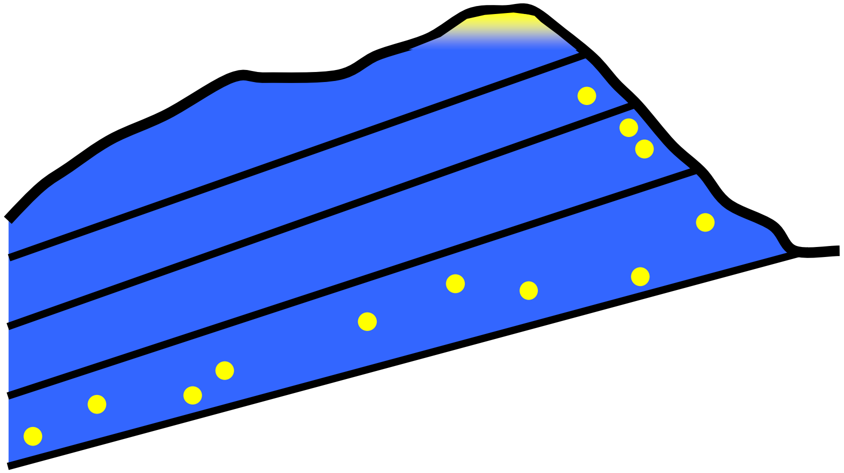
Thales of Miletus (~ 500 B.C)
Everything is water

Gus Archie (~ 1940 A.C)
Not all is water

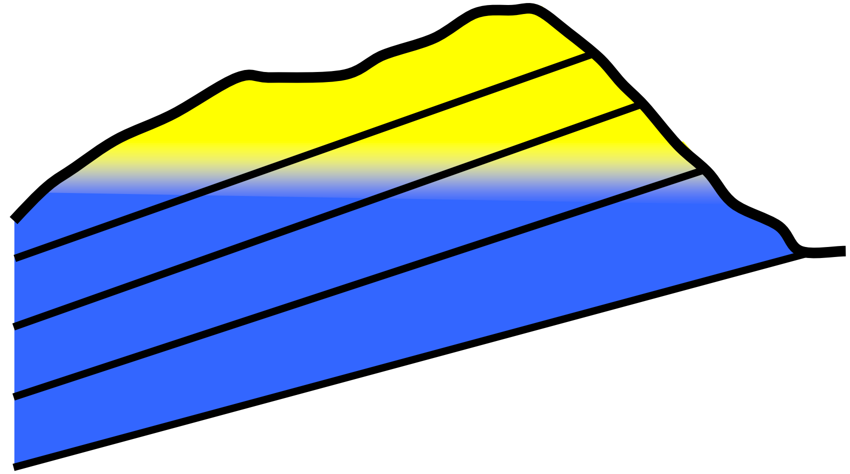
Herman Friele (~ 2000 A.C)
There is much water

Eldar Sæthre (~ 2017 A.C)
Too much is water

In the beginning, there was water…



Migration of oil:
A drainage process

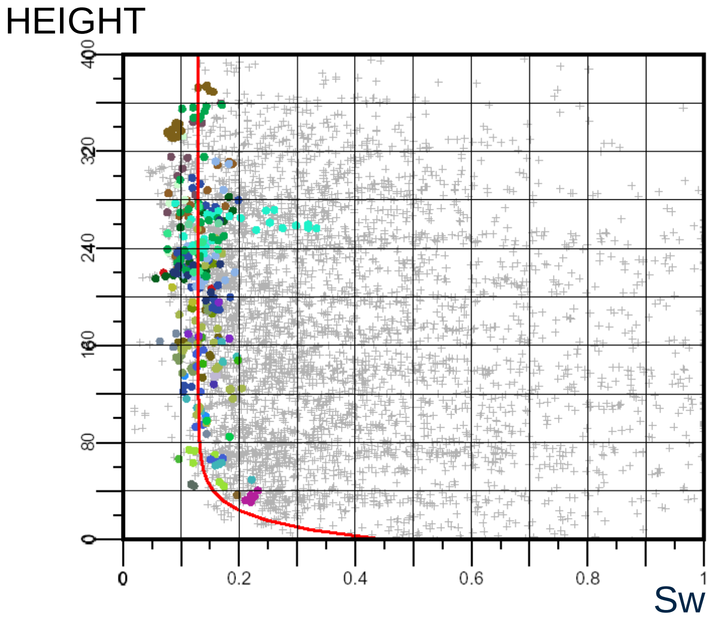


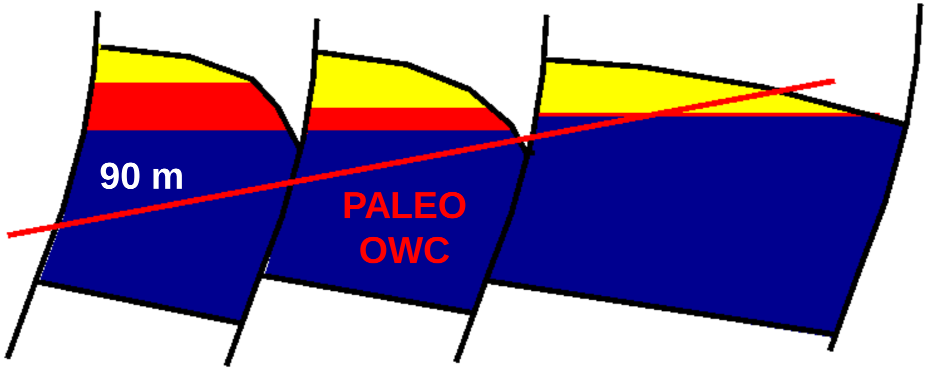
The initial distribution should be described by a primary drainage capillary pressure curve

What do we observe?

The observed initial distribution may deviate from the ideal smooth curve due to

- A complex geological history
- Changes in lithology
- Changes in wettability





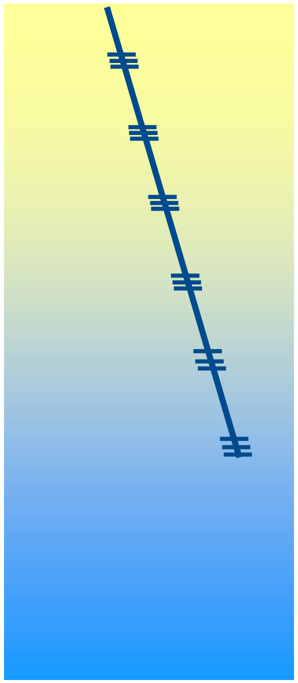
Troll relic oil zone:
Residual oil below OWC

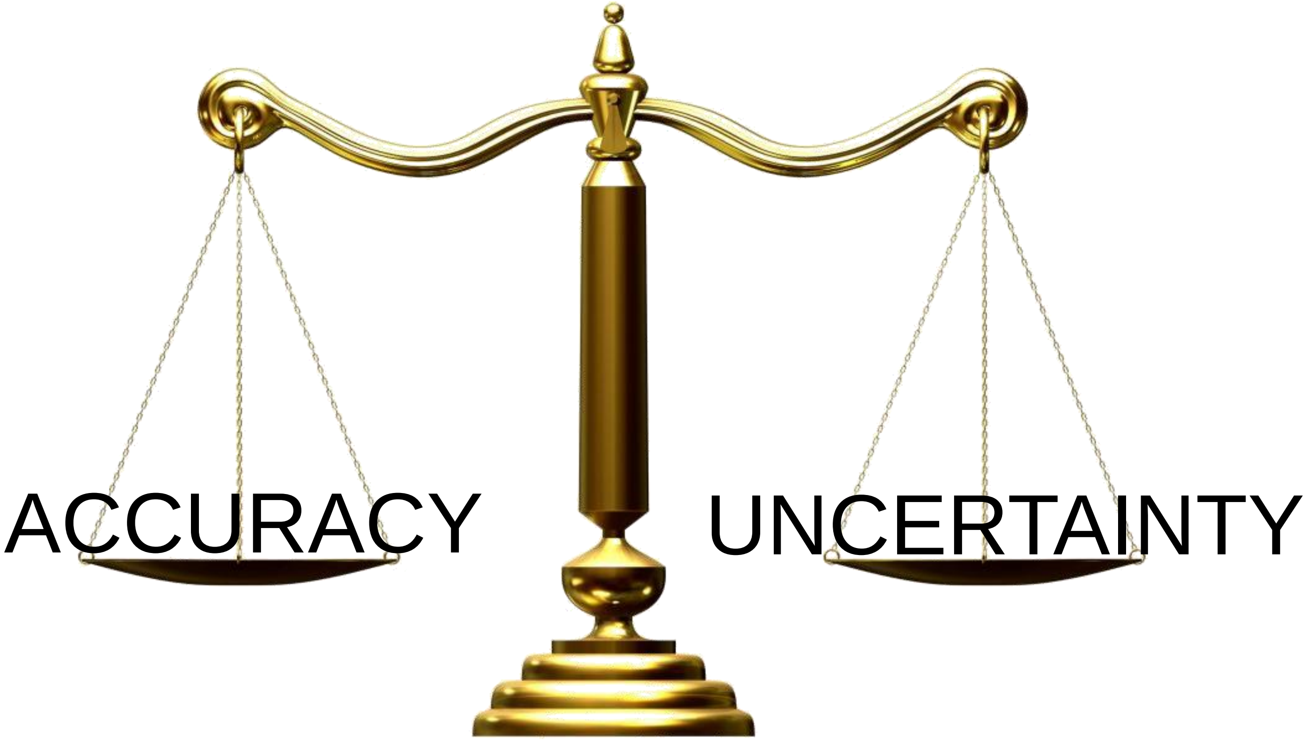
What do we observe?

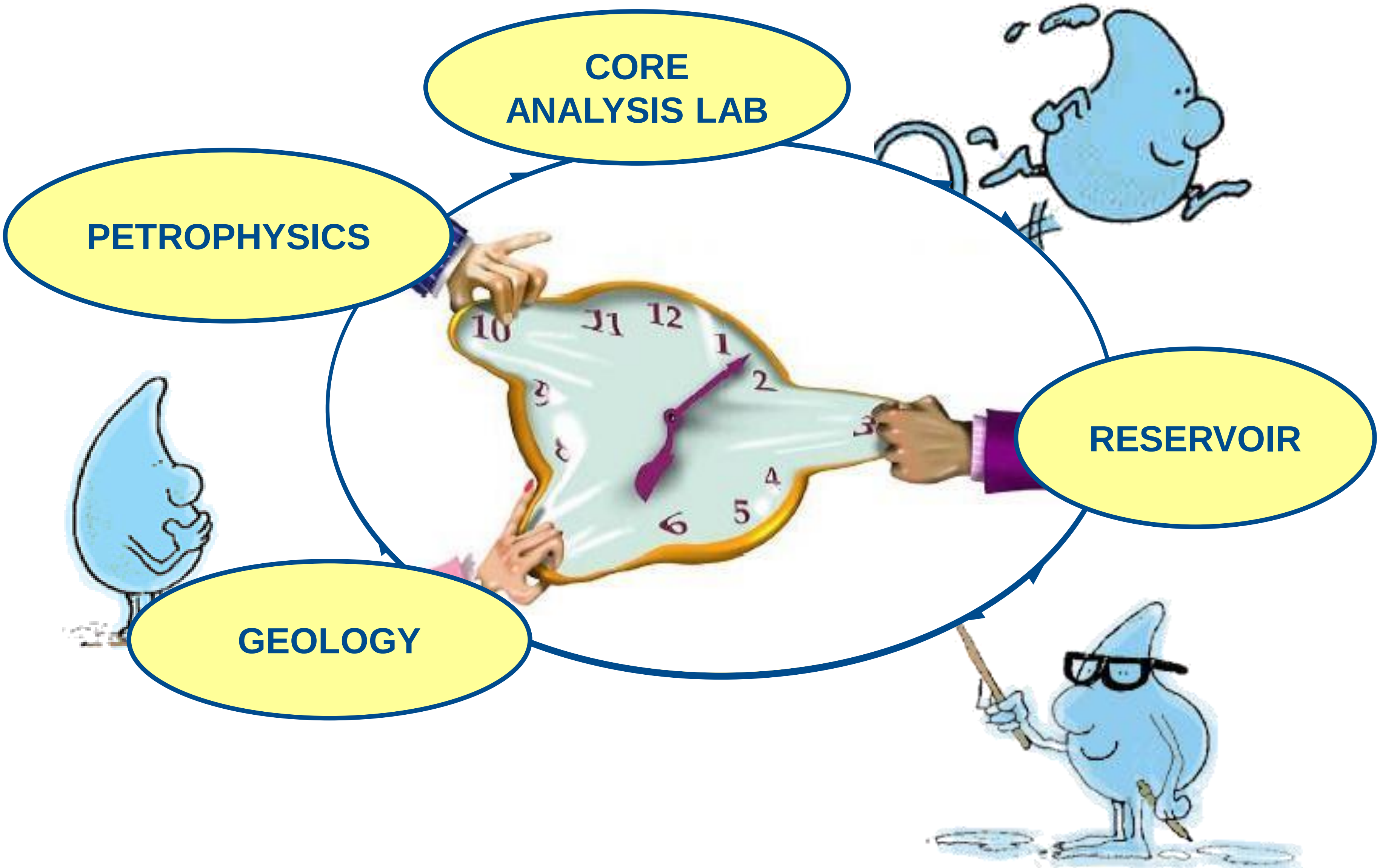
Snorre production tests were performed at different depths in the transition zone.

A very high water saturation was necessary before produced water was observed.

The initial production of water cannot be explained by a simple capillary pressure/ relative permeability model.




ACCURACY
UNCERTAINTY

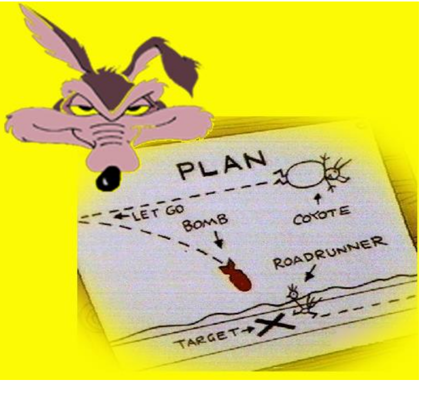

CORE
ANALYSIS LAB
PETROPHYSICS
RESERVOIR
GEOLOGY

We too often fail to plan...

- Unclear overall responsibility
  - Is that correct?
- We don't know how to plan
  - That's correct!
- It's of no use; the plan will not be followed
  - That may be correct!

Planning

- Goals for all disciplines
- Responsibilities
- Terminology
- Which model to use in each domain
- Scale handling
- Product deliveries and documentation



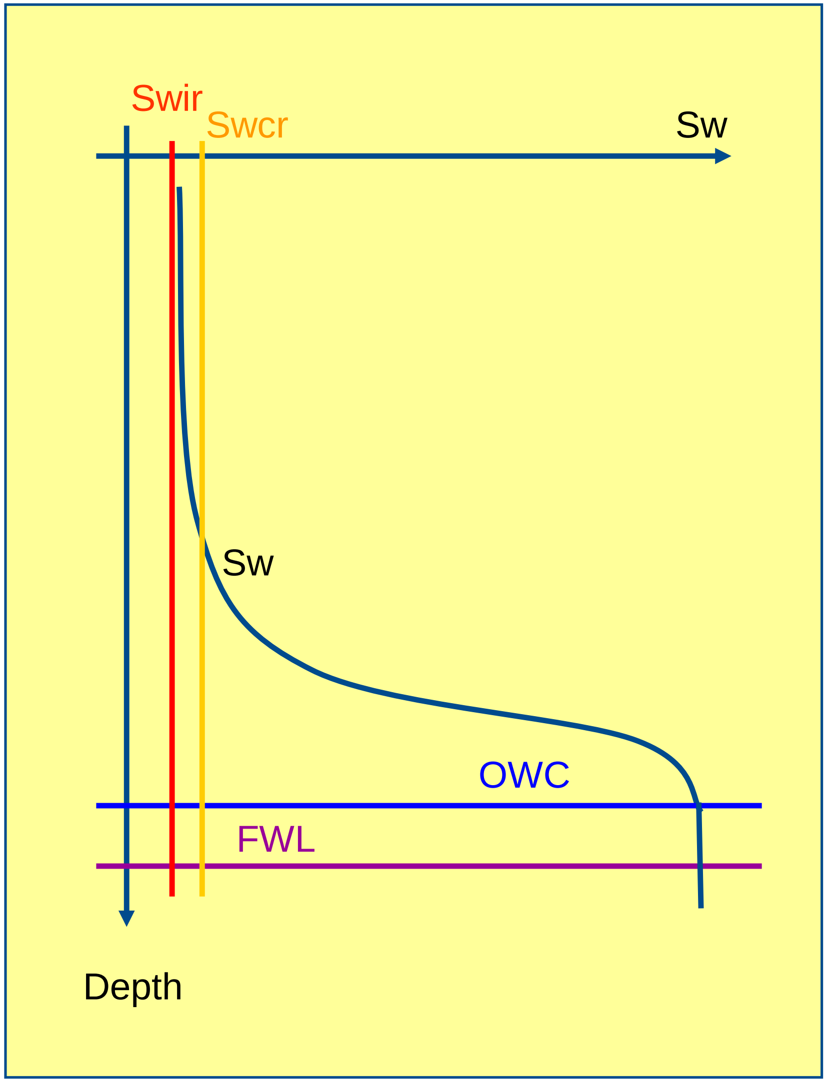
A shared language

Swir – Irreducible Sw:
The minimum water saturation in the capillary pressure curve.

Swcr – Critical Sw:
The maximum water saturation where water is immobile.

FWL – Free water level:
The depth where the water/oil capillary pressure is zero.

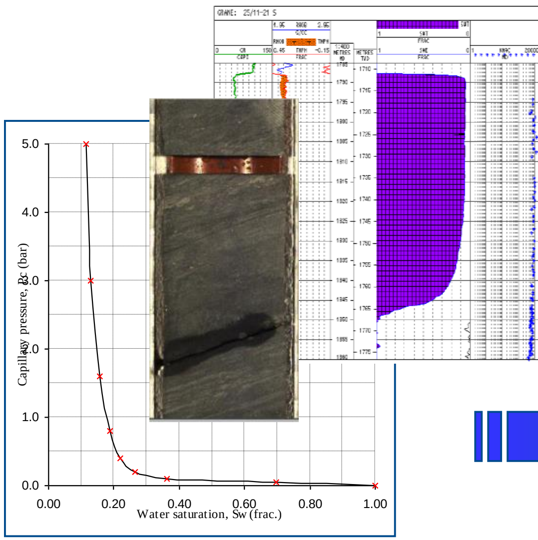
OWC - Oil/water contact:
The minimum depth where the water saturation has it’s maximum value.



Dangerous terms...

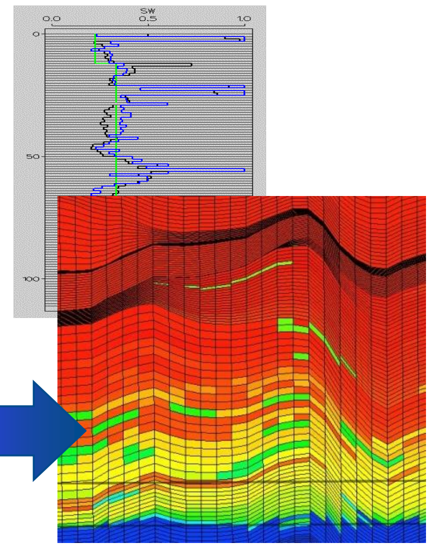
Connate water
Effective porosity
Effective permeability
Fluid contact
Transition zone

Petrophysical modelling



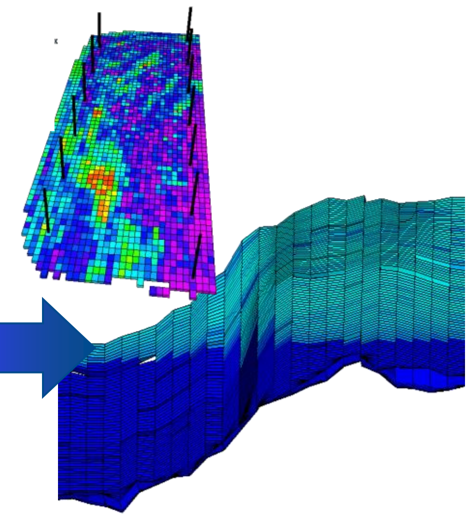
Establish Sw functions honouring both log and core data.
Define fluid levels.

Geological modelling



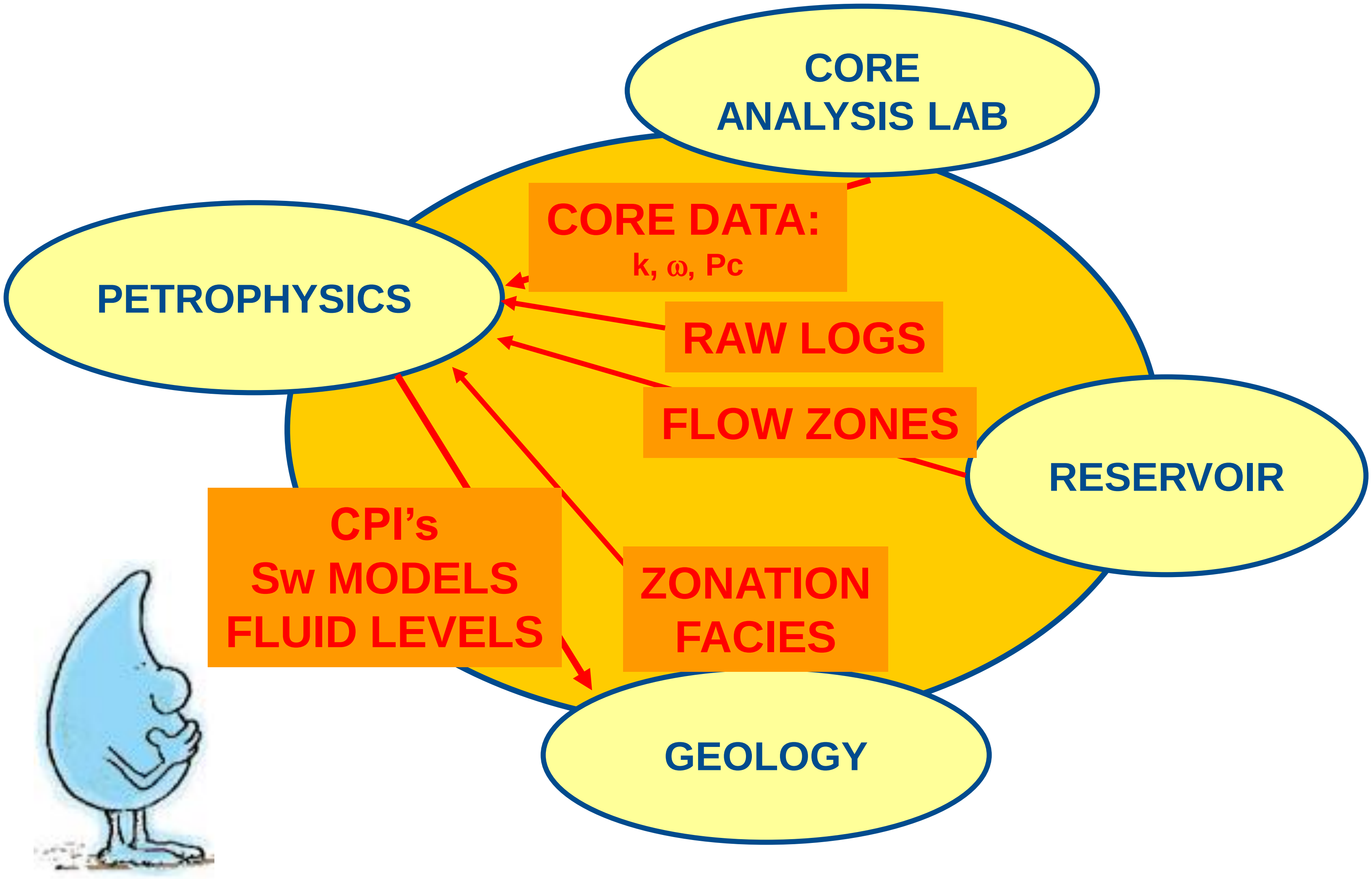
Define fluid segments and populate the geo model with water utilising an established Sw function and mapped rock properties.
Report initial volumes.

Flow modelling



Initialize the flow model honouring upscaled saturations from the geo model and SCAL.
Report produced volumes.

Workflow for petrophysical Sw-model



Petrophysical modelling

Many possible models:

- Leverett's J function
- Modified J function
- Non-Leverett correlation
- Normalised or non-normalised saturation

There is only one single model which can be used by all involved disciplines and at all involved scales:

The Leverett J function

(Non-modified, with or without normalised saturations)

Leverett's J function

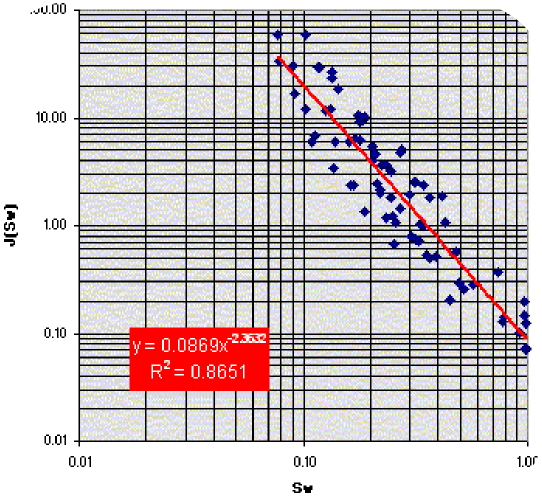
$$p_c(S_w) = \sigma \cos\theta \sqrt{\frac{\varphi}{k}} J(S_w) = (\rho_w - \rho_o) g H$$

$$J(S_w) = \alpha\, S_w^{\beta}$$

$$\log H \sqrt{\frac{k}{\varphi}} = k_1 + k_2 \log S_w$$

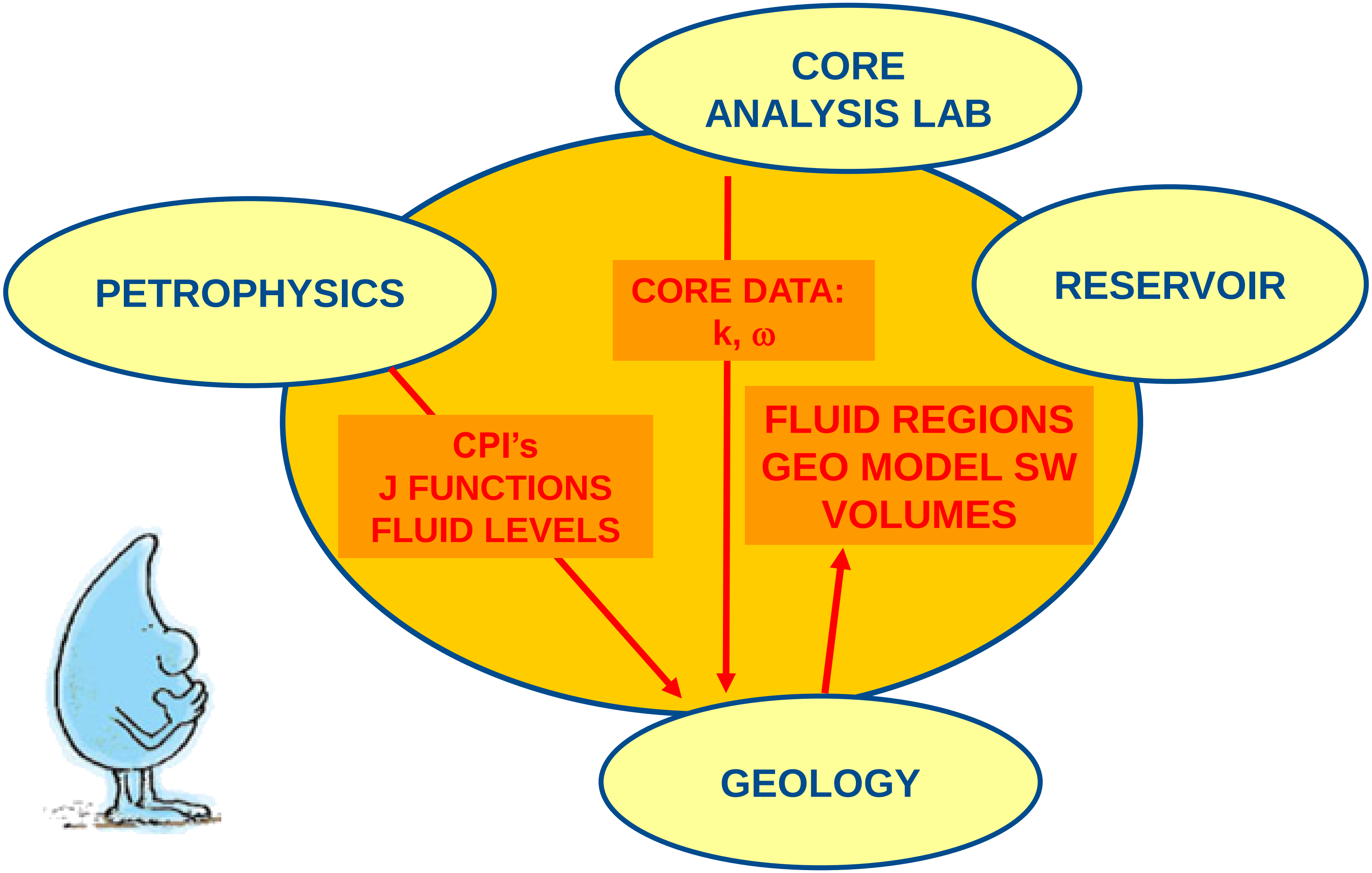
Defining J functions

Core data and/or log data?
Use of petrophysical parameters
Grouping?

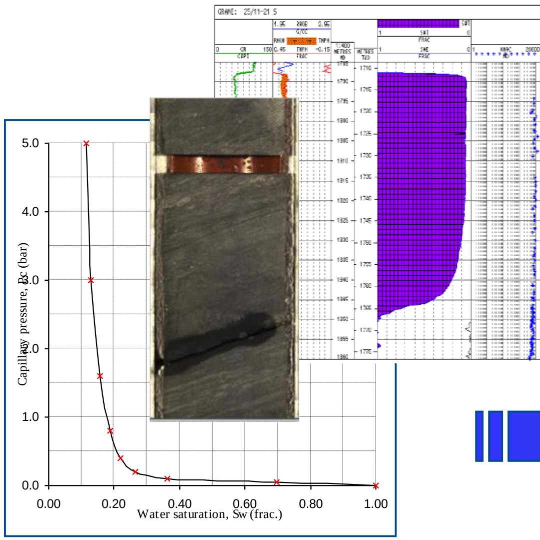


$$S_w = S_w(H, k, \varphi, x)$$

X = Zone, Facies, RQI, FZI, ...

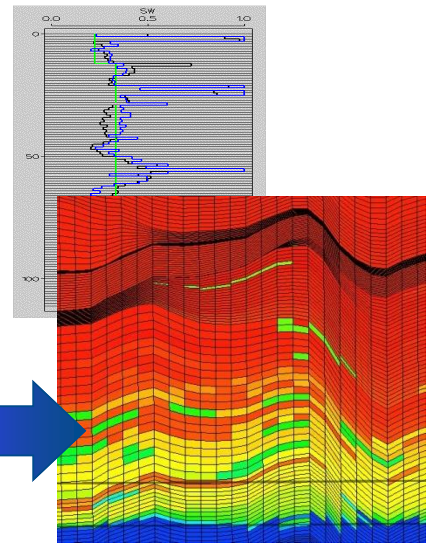

CORE
ANALYSIS LAB
PETROPHYSICS
RESERVOIR
CORE DATA:
k, ω
CPI's
J FUNCTIONS
FLUID LEVELS
FLUID REGIONS
GEO MODEL SW
VOLUMES
GEOLOGY

Petrophysical modelling



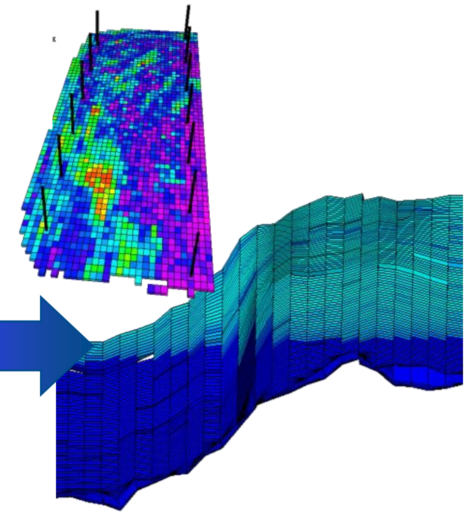
Establish J functions.
Define fluid levels.

Geological modelling



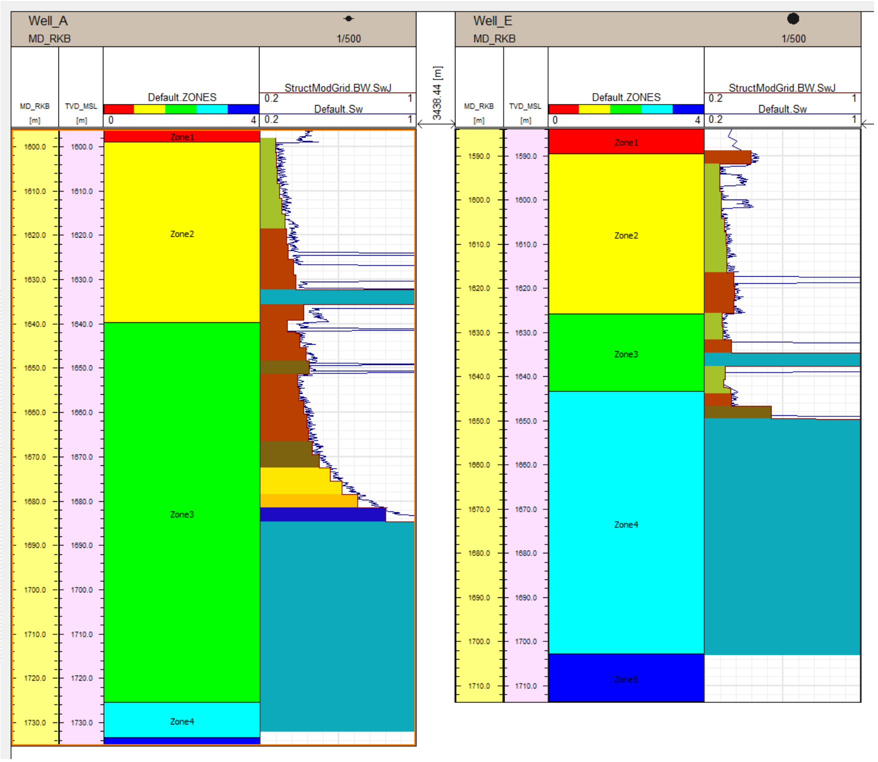
Define fluid segments and populate the geo model with water utilising established J functions and mapped rock properties.

Flow modelling



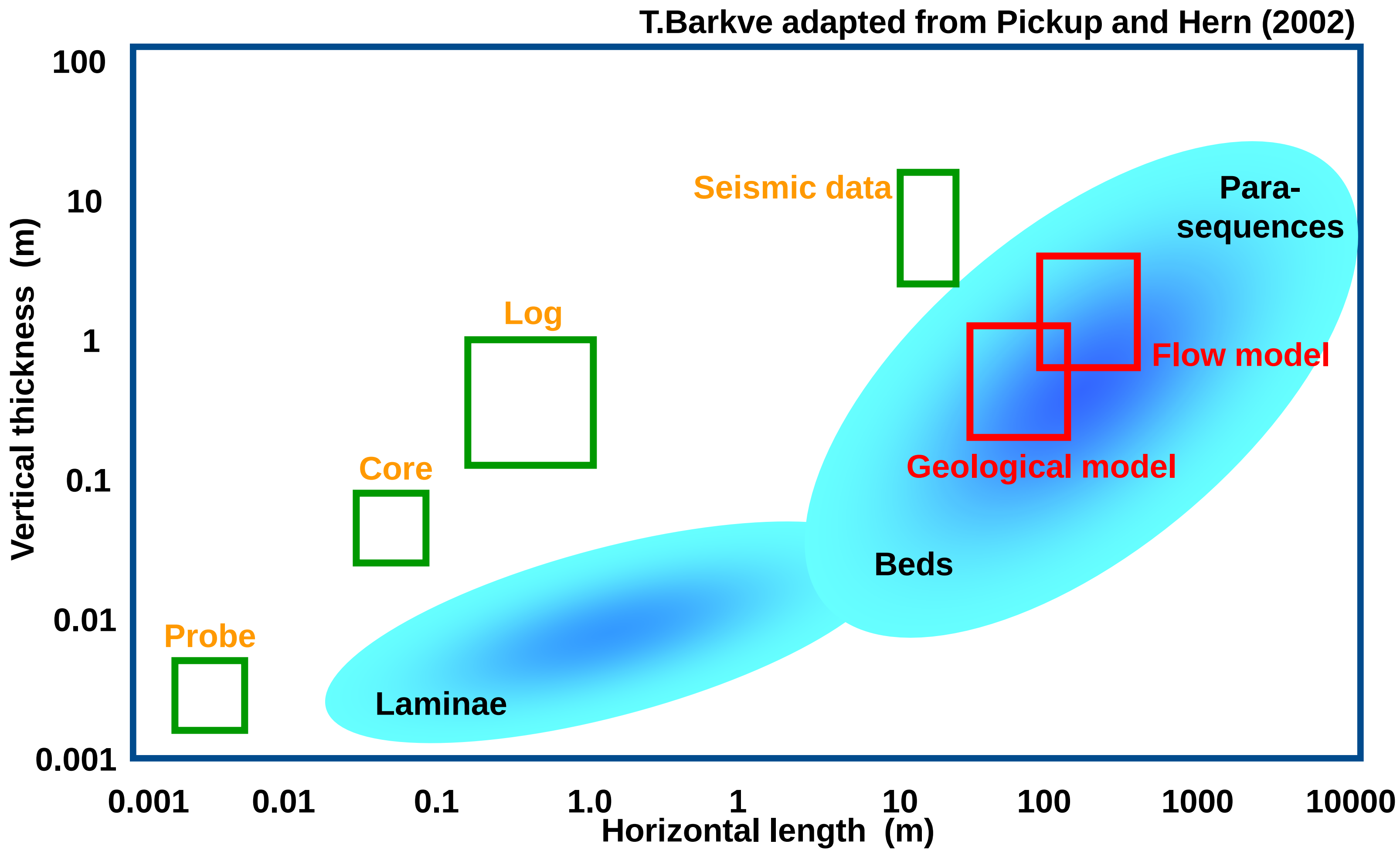
Initialize the flow model using the established J functions.
Report produced volumes

Scale effects



J functions are defined at log/core scale, but applied at cell scale

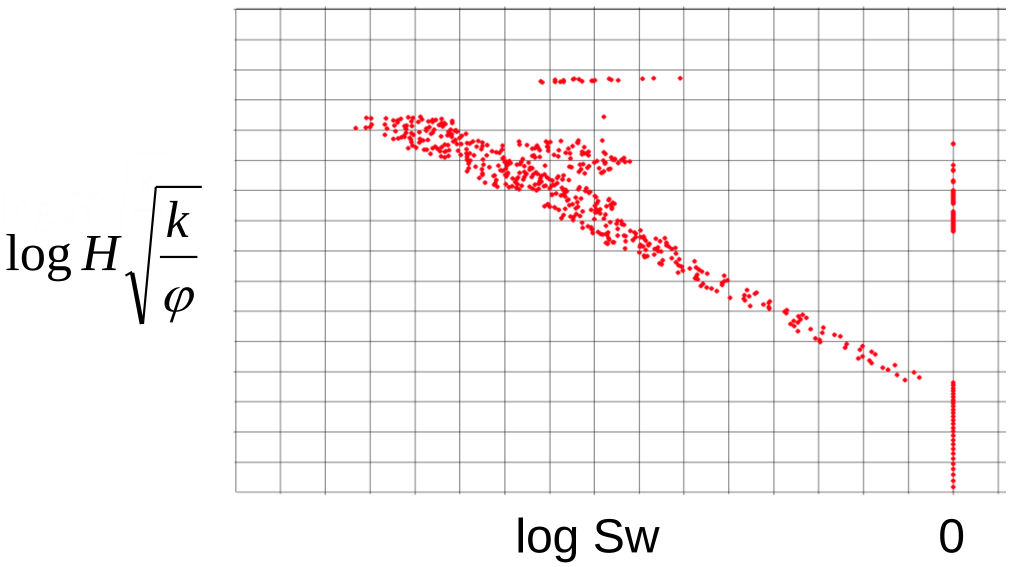
Sedimentological scales



Investigating scale effects – geo model

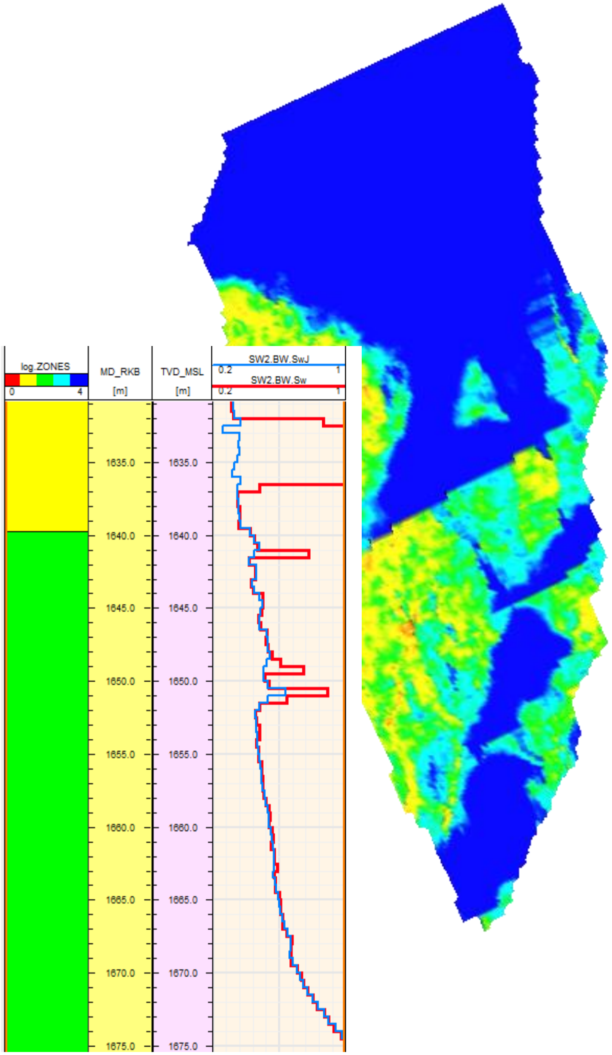
1) Calculate Sw in geo model by blocking log data
2) Calculate Sw in geo model from Leverett's J function

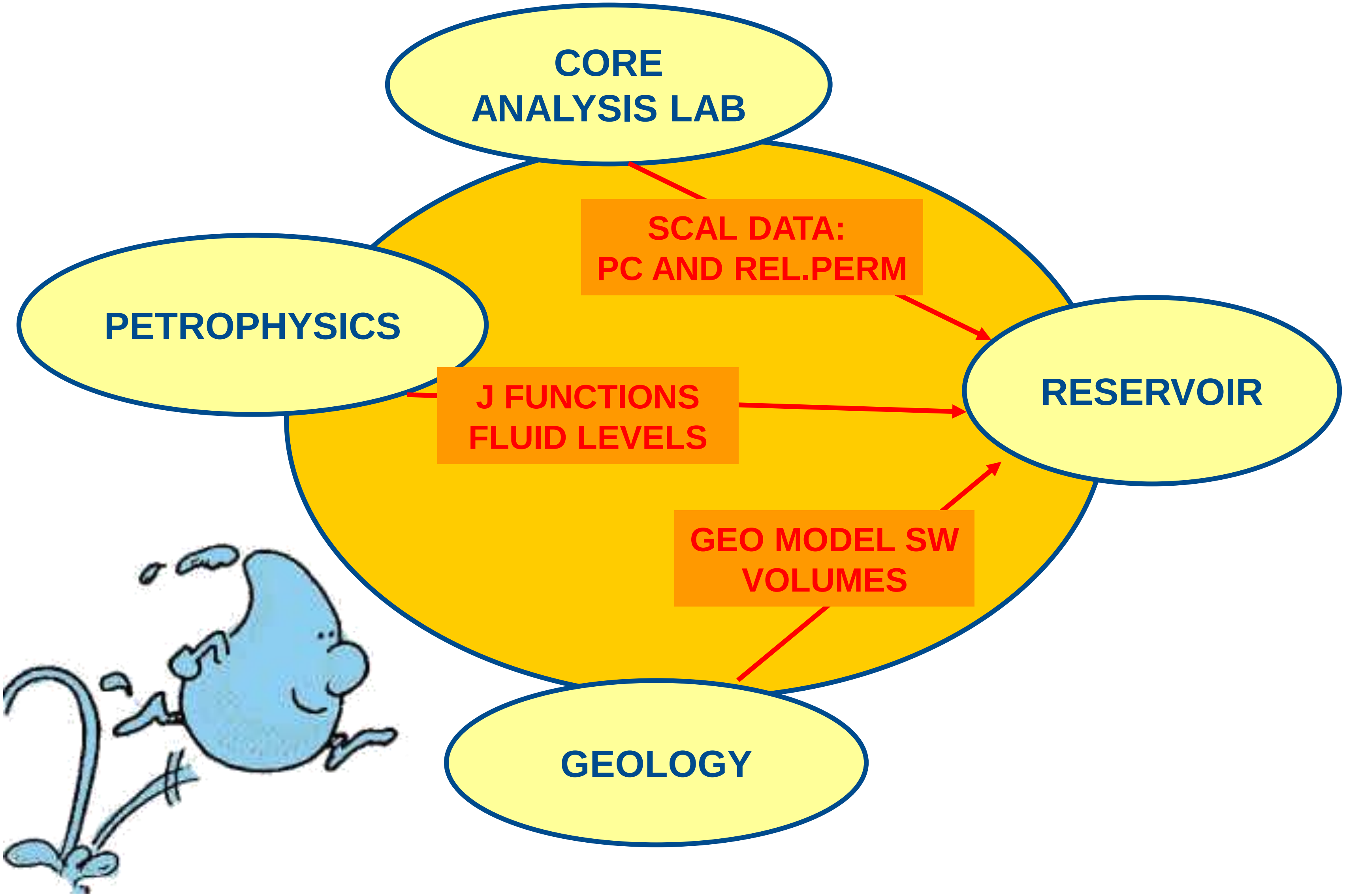
$$\log H\sqrt{\frac{k}{\varphi}} = k_1 + k_2 \log S_w$$



Elements of quality control of geo model

- Variation in volumes
- Compare blocked logs versus J curves
  - Scale effects
- Visual inspection
  - Logs and blocked logs
  - HCPV maps

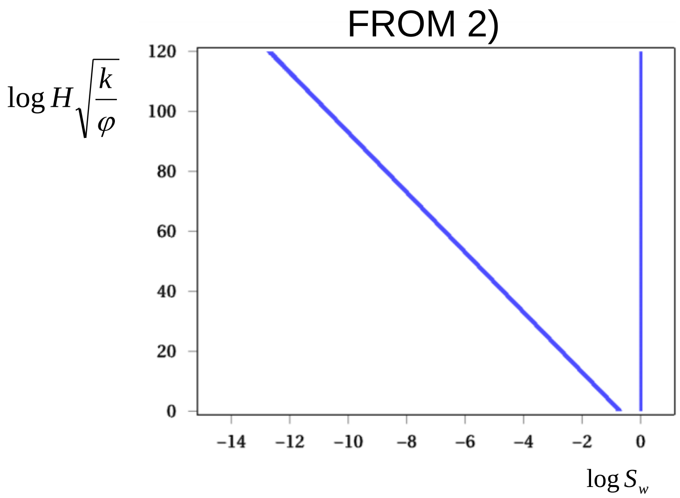


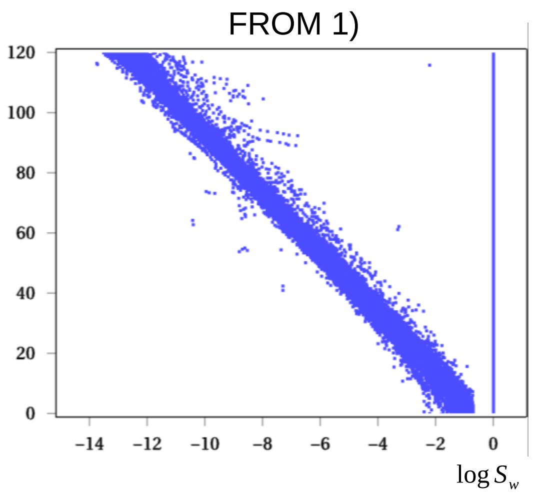

CORE
ANALYSIS LAB
SCAL DATA:
PC AND REL.PERM
PETROPHYSICS
J FUNCTIONS
FLUID LEVELS
RESERVOIR
GEO MODEL SW
VOLUMES
GEOLOGY

Investigating scale effects – flow model

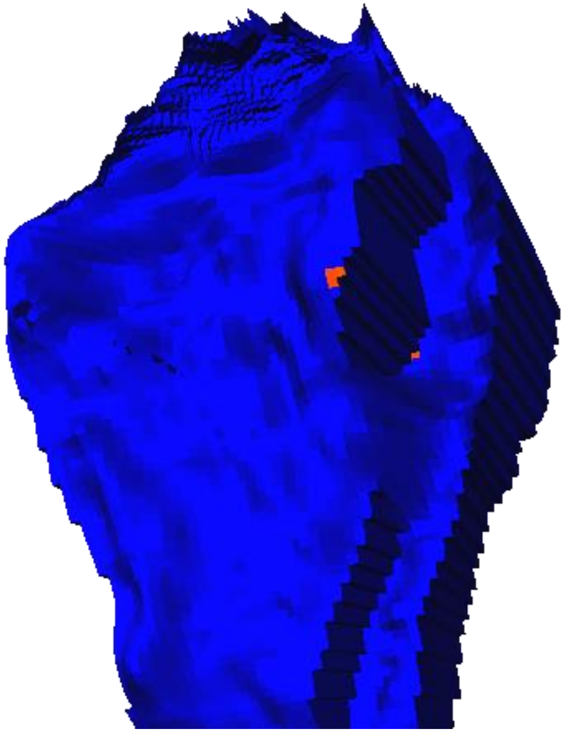
1) Calculate Sw in flow model by upscaling geo model Sw
2) Calculate Sw in flow model from Leverett's J function

$$\log H\sqrt{\frac{k}{\varphi}} = k_1 + k_2 \log S_w$$





Potential dangers in Sw upscaling

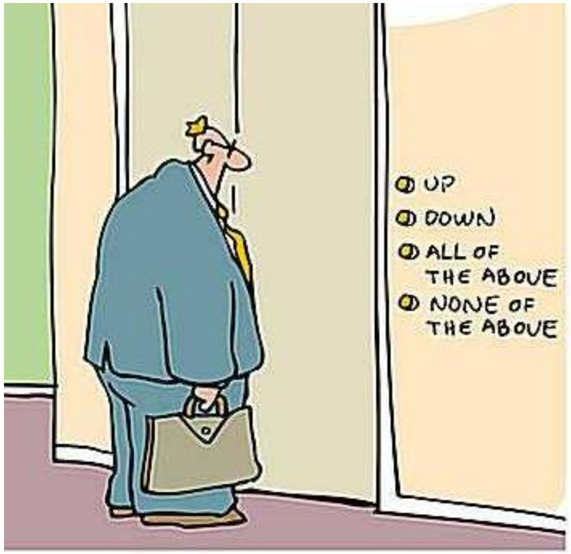


$\phi = 0.2$ K = 0.001 mD Sw = 1	$\phi = 0.2$ K = 100 mD Sw = 0.1
$\phi = 0.2$ K = 100 mD Sw = 0.1	$\phi = 0.2$ K = 100 mD Sw = 0.1

$\phi = 0.2$
K = 75 mD
Sw = 0.325

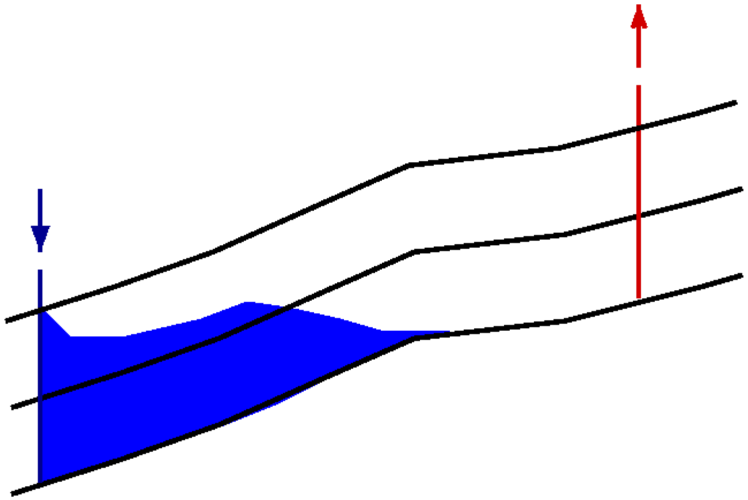
Alternative Sw models in the flow simulator

- Pc = 0.   Swcr = min(Swi, cutoff)
- Pc model with multiple regions
- J function model



Effects of Pc on dynamic modelling

In reservoirs with large-scale contrasts in reservoir properties, selection of Pc data may have a significant impact on the dynamic result.



Water injection → Imbibition data.

Often, dynamic effects of capillary pressure are negligible

Hysteresis in capillary pressure is often overkill, but could be considered in WAG simulations.
Rel.perm hysteresis is usually more important!

Summary

- Sw modelling is difficult and time consuming
- Plan as a team!
- The (non-modified) J function approach is the only formulation which can be used by all disciplines
- If possible, use a shared J function model at all scales
  - Core, log, geo, flow
  - Scale effects can be investigated in log-log plots
- Be clear on distinction between data used for modelling and data used for verification
- Be careful with using upscaled Sw
- Keep the formulation simple, consider uncertainty
- Plan as a team!