# The Difference between Net Pay and Net Reservoir, how to pick them and their Application to Reservoir Modelling

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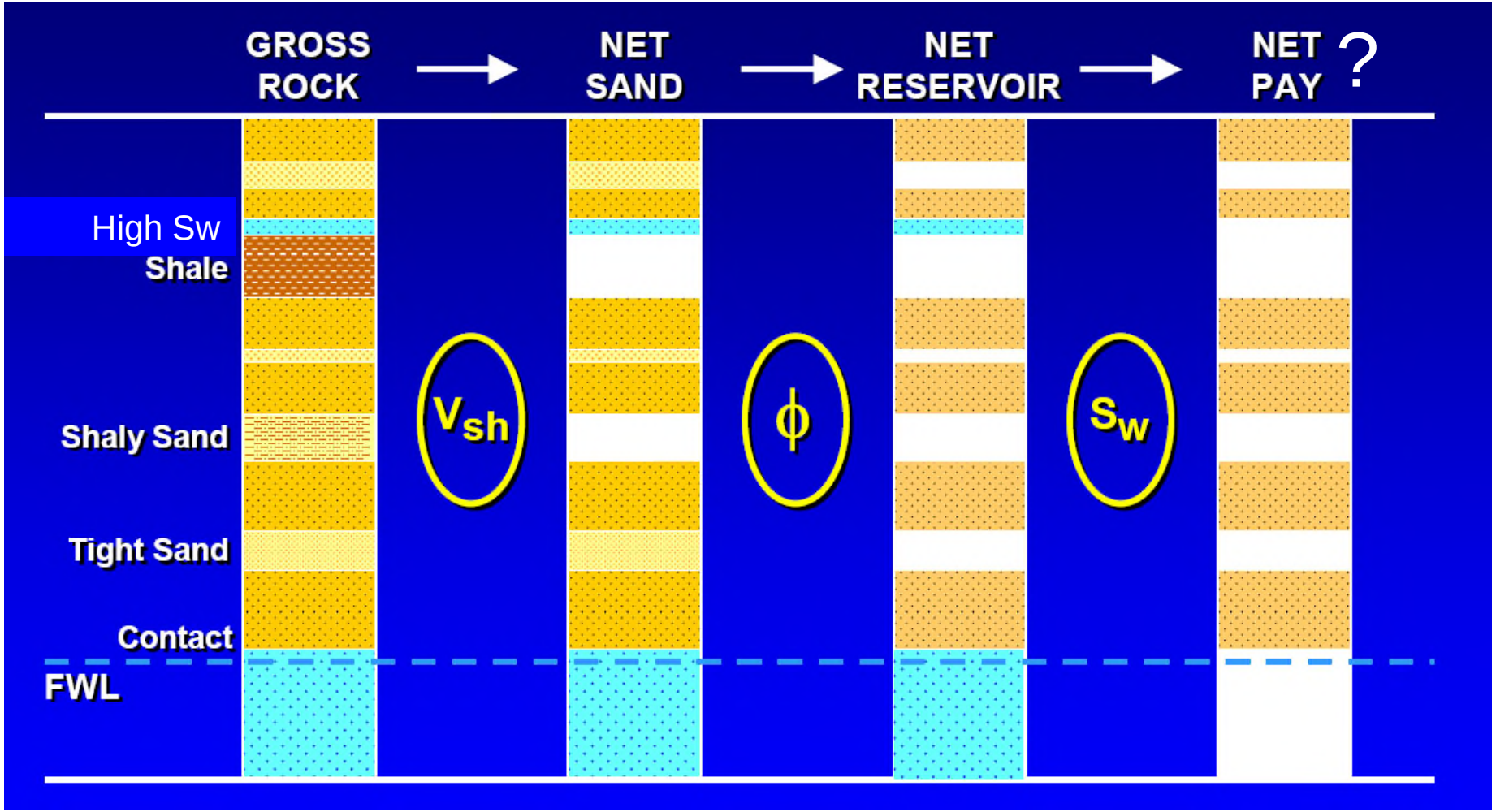
27th September 2017

# Outline

- Definitions of Net Pay and Net Reservoir
- How to determine Net Pay and Net Reservoir from Core and Electrical Logs
- How to correctly upscale Net reservoir properties for the 3D reservoir model

# Common ideas about Net Cut-offs



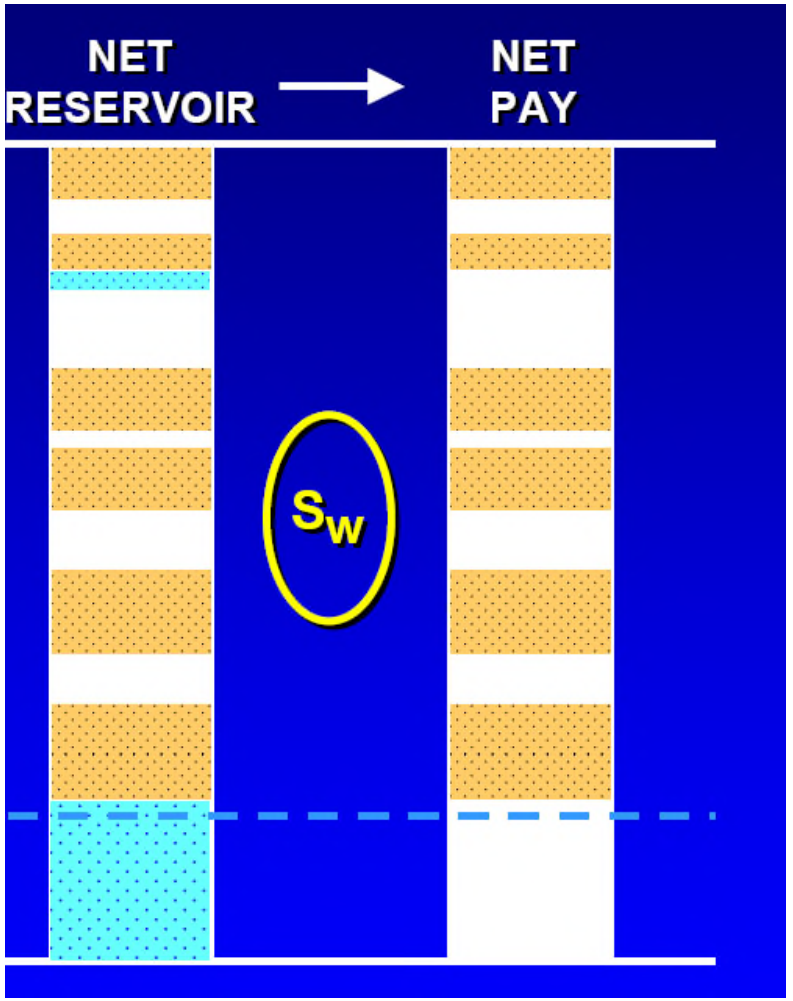
# What is Net?

- Net Reservoir
  - The portion of reservoir rock which is capable of storing hydrocarbon
  - Required for upscaling and reservoir modelling
  - Relatively easy to pick

- Net Pay
  - “The portion of reservoir rock which will produce commercial quantities of hydrocarbon” - SPWLA
  - The portion of reservoir rock which will produce or help support production of hydrocarbon over field development timescales
  - Required to select intervals to be perforated?
  - More difficult to pick

# How can Net Pay be Determined?

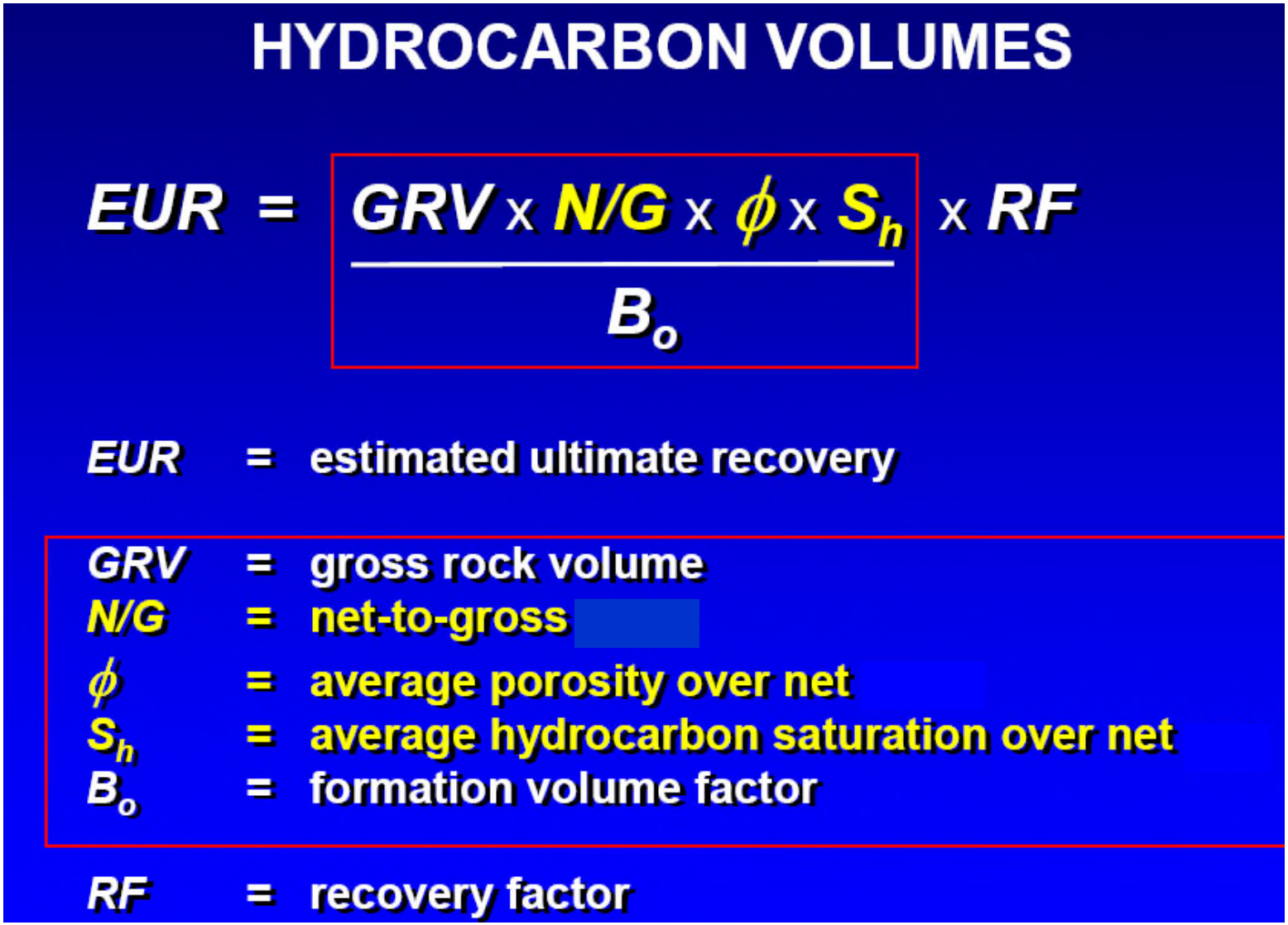
- Microlog => mudcake
- Sxo > Sw  => moveable HC
- Mud losses – esp. for fractures
- Formation pressure
- NMR
- Borehole gas chromatography
- Production logs
- DST



# Net Pay

- Usually defined using a permeability and/or Sw cut-off
- But what about?
  - Kh/Kv
  - Shape of the transition zone
  - Standoff distance from the FWL
  - Water cut
  - Fractures
  - Gas and water drive
  - Draw down
- All the hydrocarbon above the FWL is potentially producible
- Is Net Pay therefore a function of the oil price?
- Net Pay is difficult to define

# Why we need a Net Reservoir cutoff



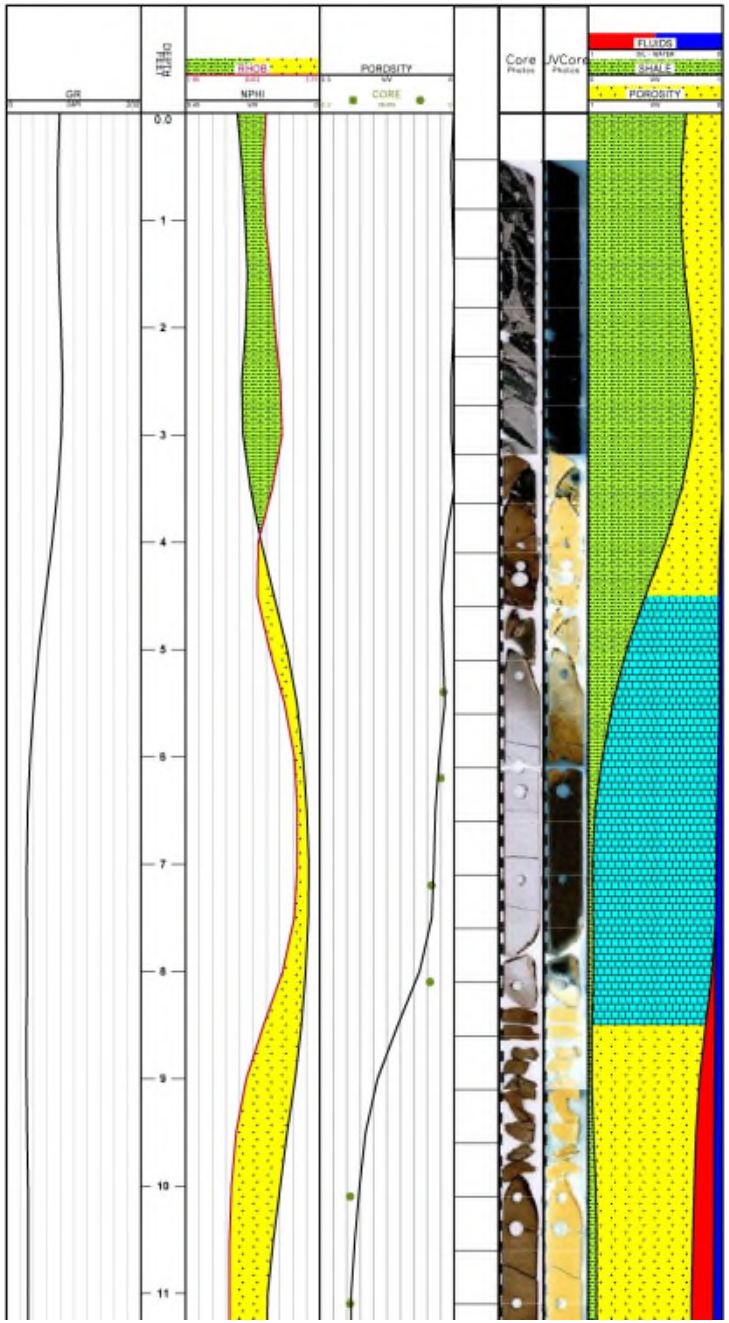
# Net Reservoir

- Net Reservoir is much easier to define
  - The portion of reservoir rock which is capable of storing hydrocarbon

- Knowledge of Net Reservoir is essential
  - For upscaling
  - For reservoir averaging, 3D geomodelling
  - Reservoir modelling – transmissibilities

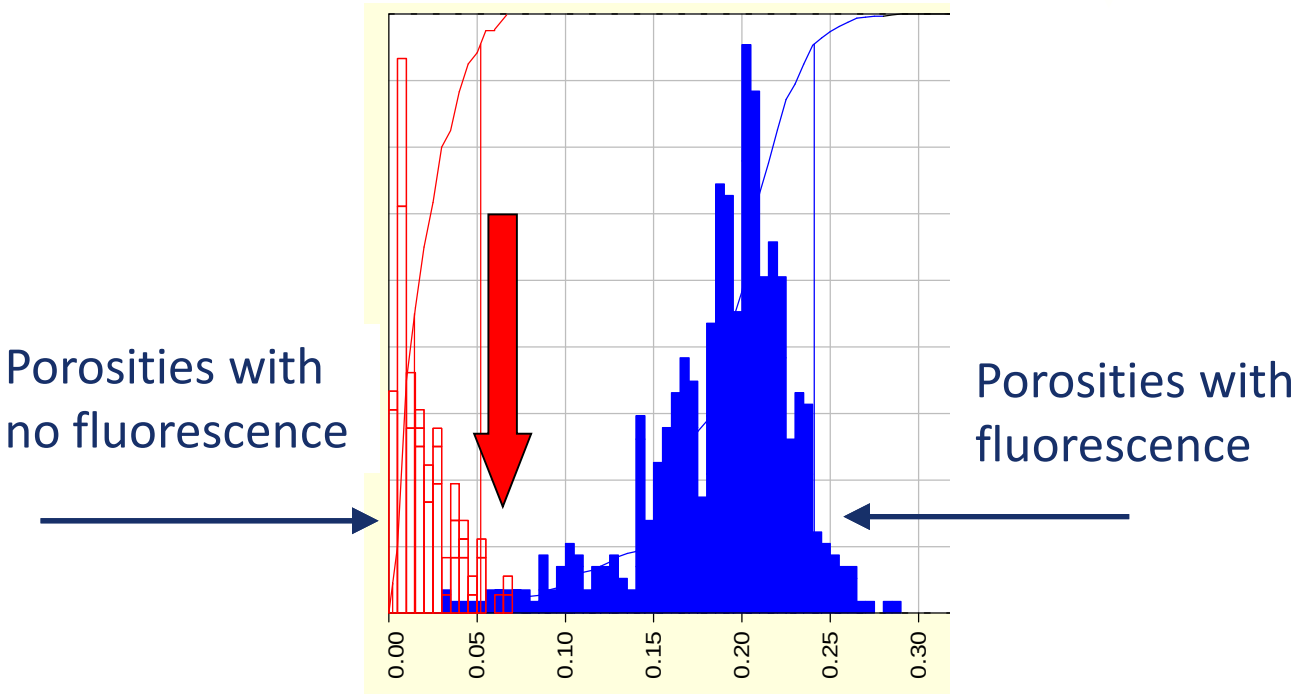
# Net Reservoir from Core

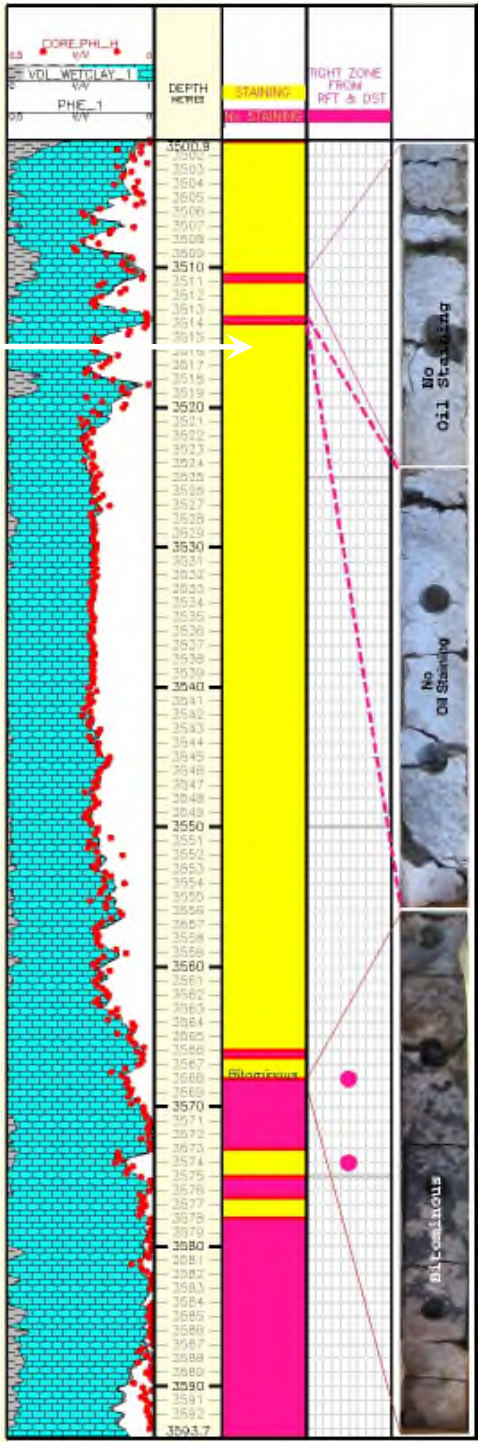
- Better vertical resolution compared to electrical logs
- Net from core analysis
  - Lithology analysis
  - Useful if there are sharp boundaries
- Net from U/V fluorescence
  - Only useful for oil
  - Only gives the upper limit



# Net Reservoir from Core

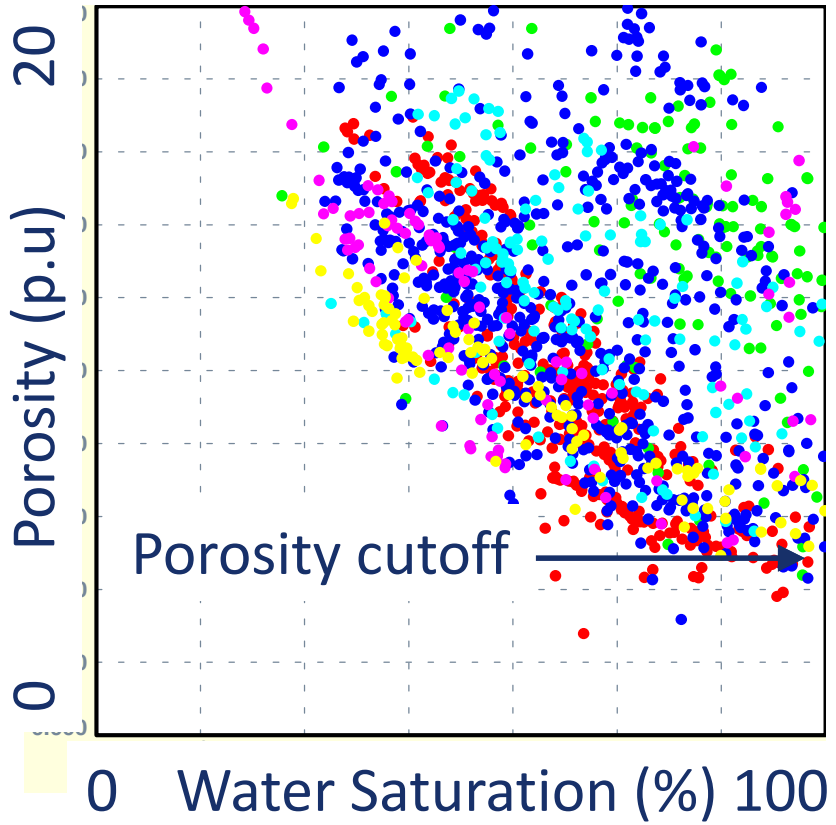
- Define net and not-net reservoir from U/V photos
- Porosity histogram is used to define porosity cut-off



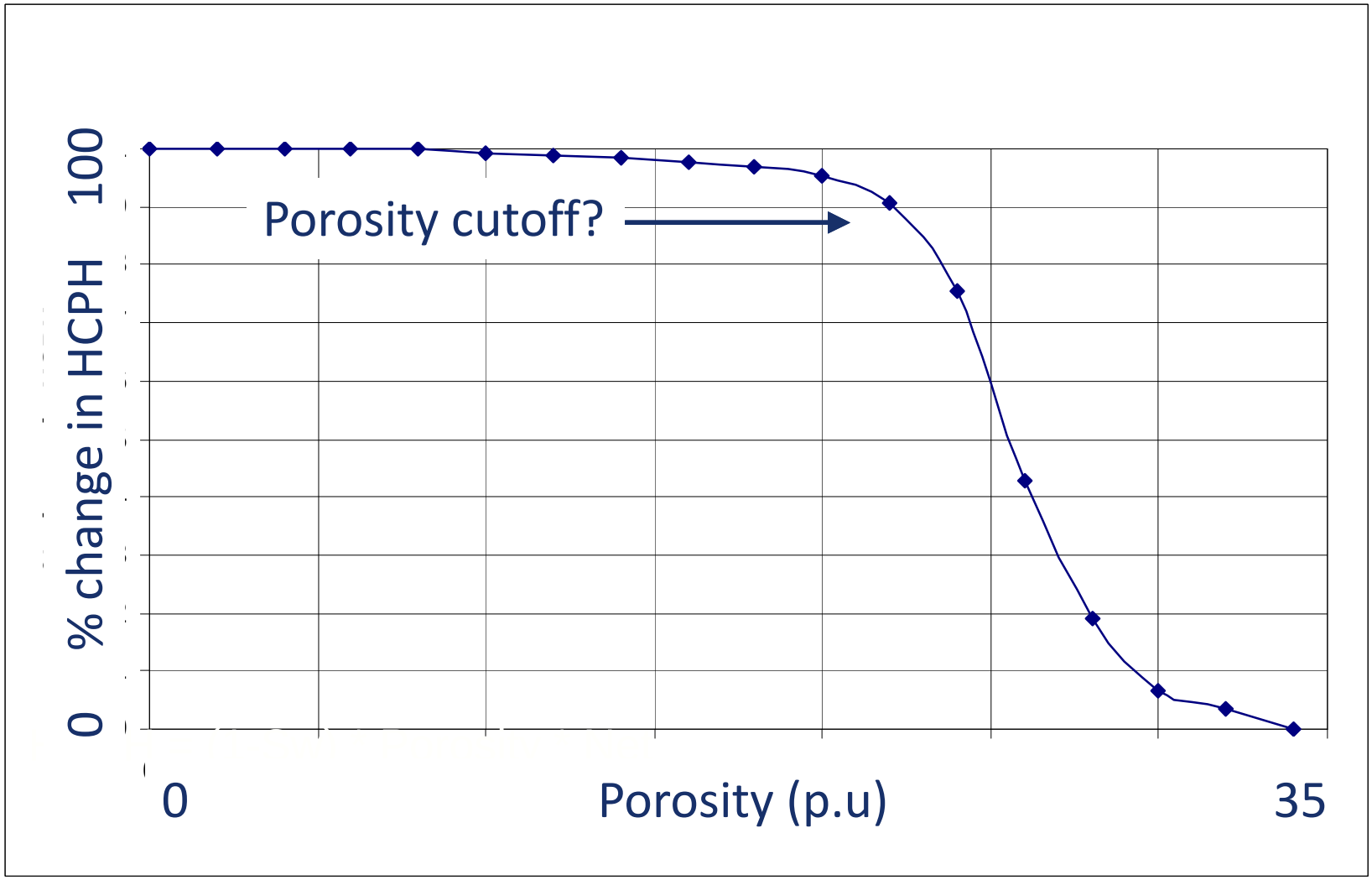
# Net Reservoir from Logs

- Fast Xplot technique
- Sw vs. Porosity above the FWL
- Shows “the portion of reservoir rock which is storing hydrocarbon”
- Assumes net reservoir above and below the FWL are similar



# Net Reservoir Sensitivity

Shows hydrocarbon pore height as a function of net cutoff

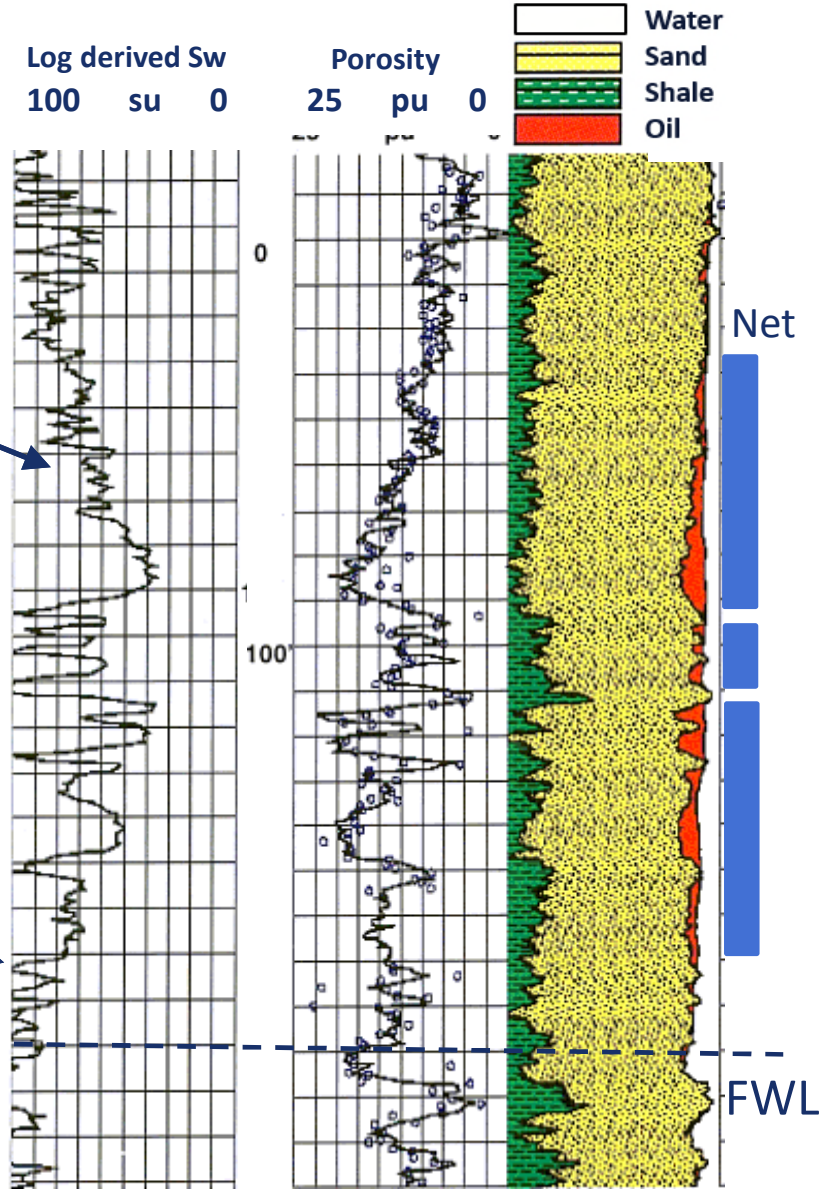


# Net Reservoir from Water Saturation

Reservoir high above the FWL has low saturations of capillary bound water and hydrocarbon enters the smaller pores

Reservoir just above the FWL, with higher porosities, contains high saturations of capillary bound water and there is a no room available for hydrocarbons

Consequently, the Net Reservoir cut-off varies as a function of the height above the FWL

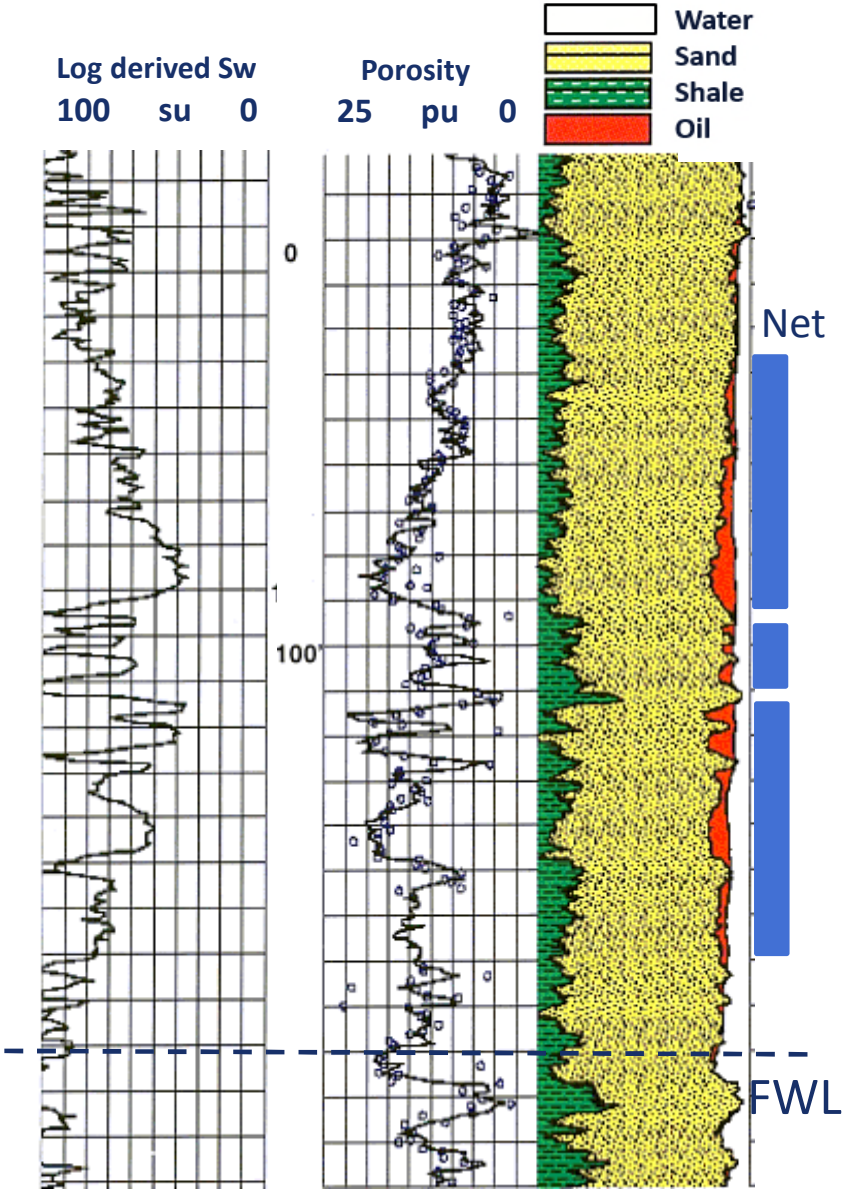


# Net Reservoir from Bulk Volume of Water

The Net Reservoir cut-off varies as a function of the height above the FWL

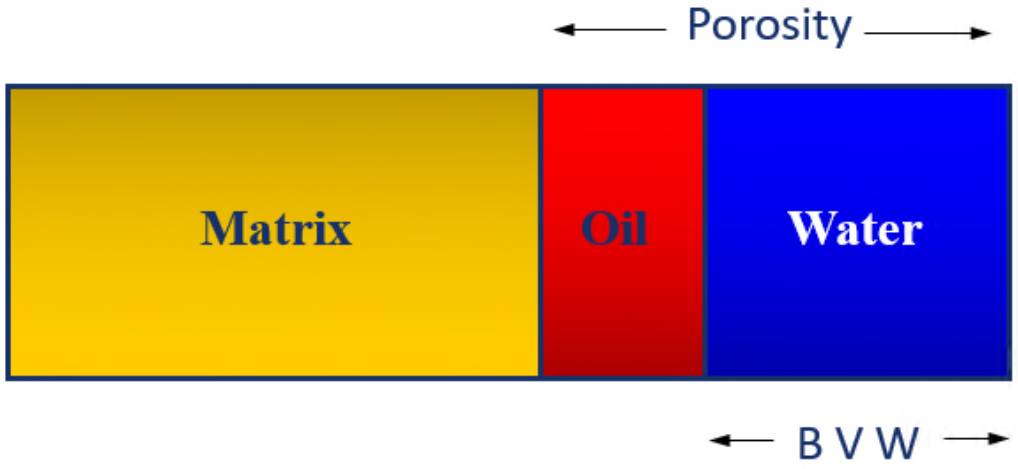
Sw varies as a function of porosity

BVW varies only as a function of height above the FWL



# Bulk Volume of Water

Bulk Volume of Water = Porosity x Water Saturation




B V W = % volume of water in a unit volume of reservoir

This is what is measured by electrical logs by core analysis

# Net from the Saturation Height Function

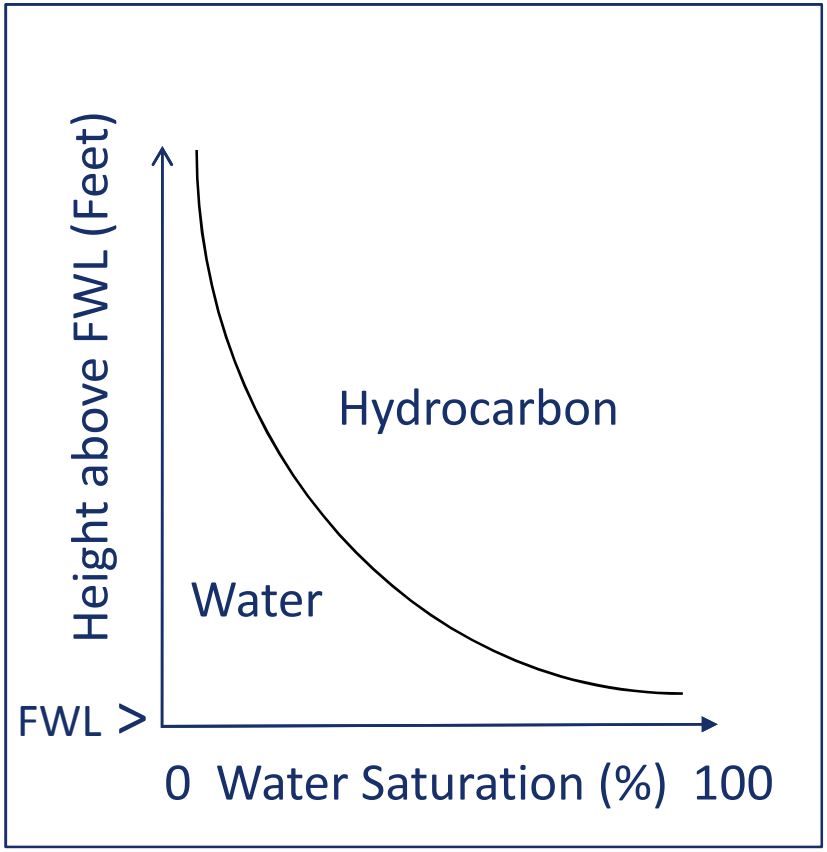
Tells us how water saturation varies as a function of the height above the Free Water Level (FWL)

Tells us how the formation porosity is split between hydrocarbon and water

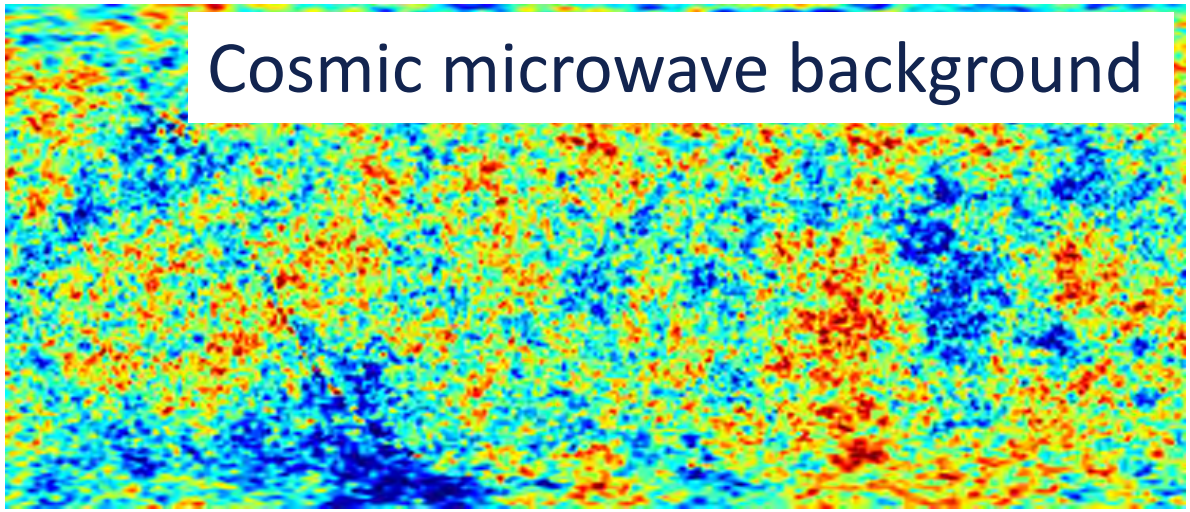
Tells us the shape of the transition zone

Used to initialize the 3D reservoir model

Tells us how net varies as a function of height



# Fractals throughout Nature



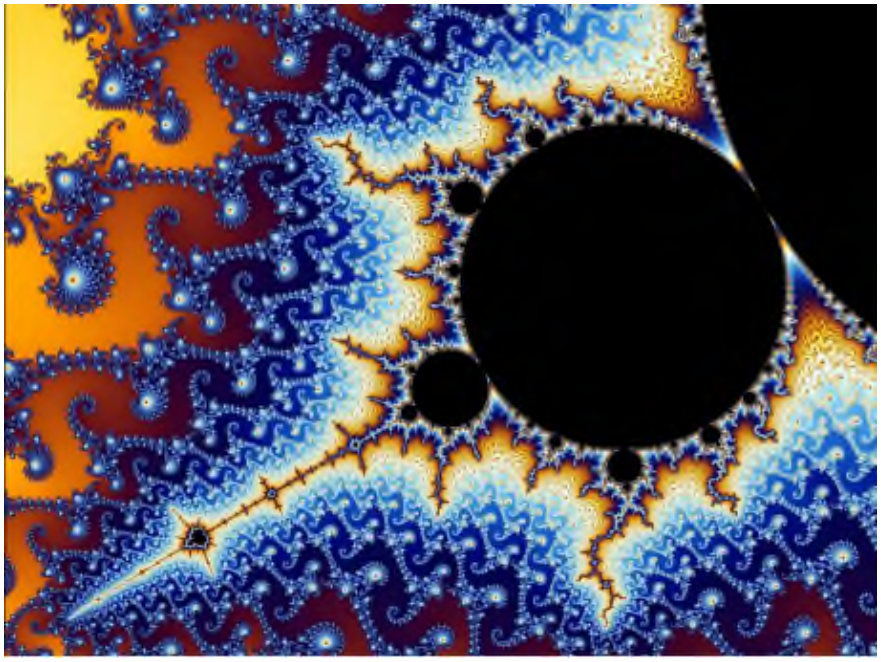
# What are Fractals?

A fractal is a never-ending pattern

Fractals are infinitely complex patterns that look the same at every scale

They are created by simple repeating process

Benoit B. Mandelbrot set ->



Other names for fractals are

- Self-similarity
- Scale invariance

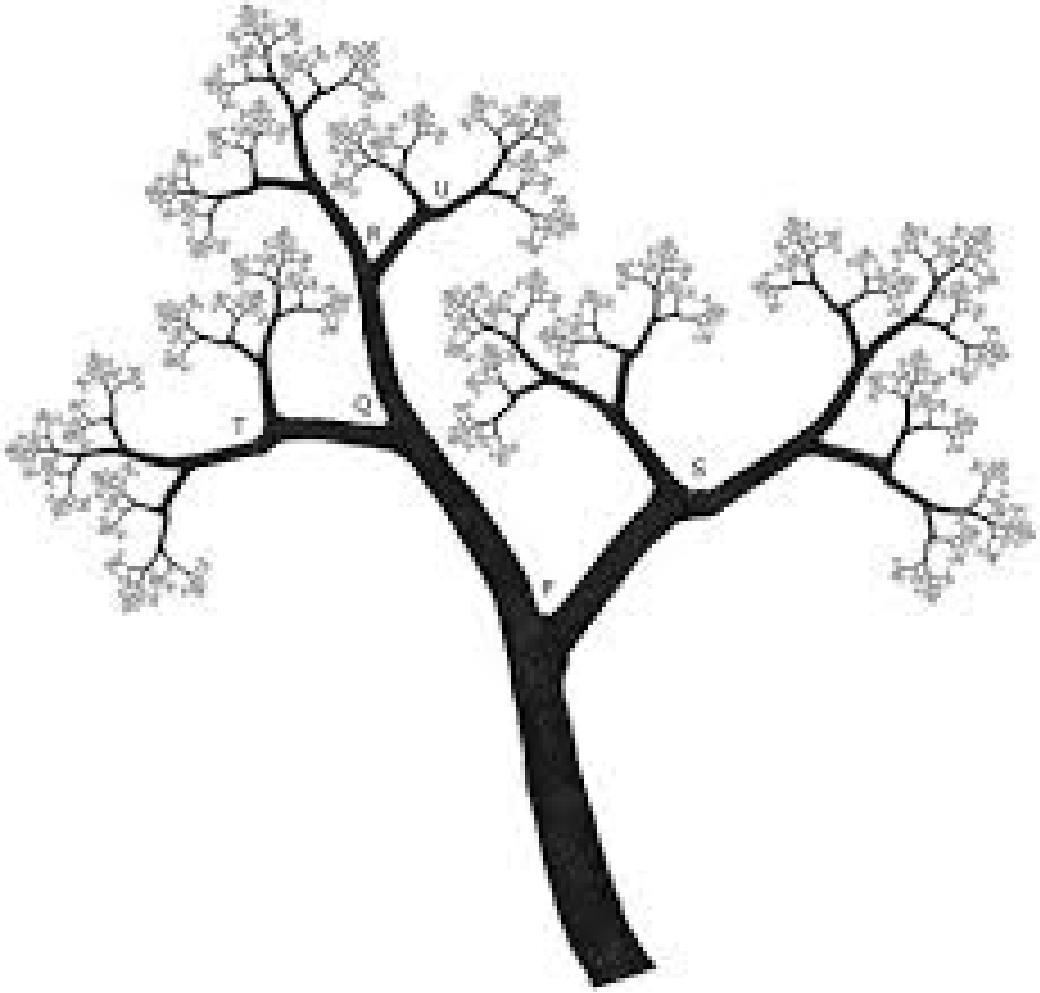
# Why fractals are useful

Fractals are objects where their parts are similar to the whole except for scale

A simple repeating process can create a complex object

Many complex objects can be described by fractals

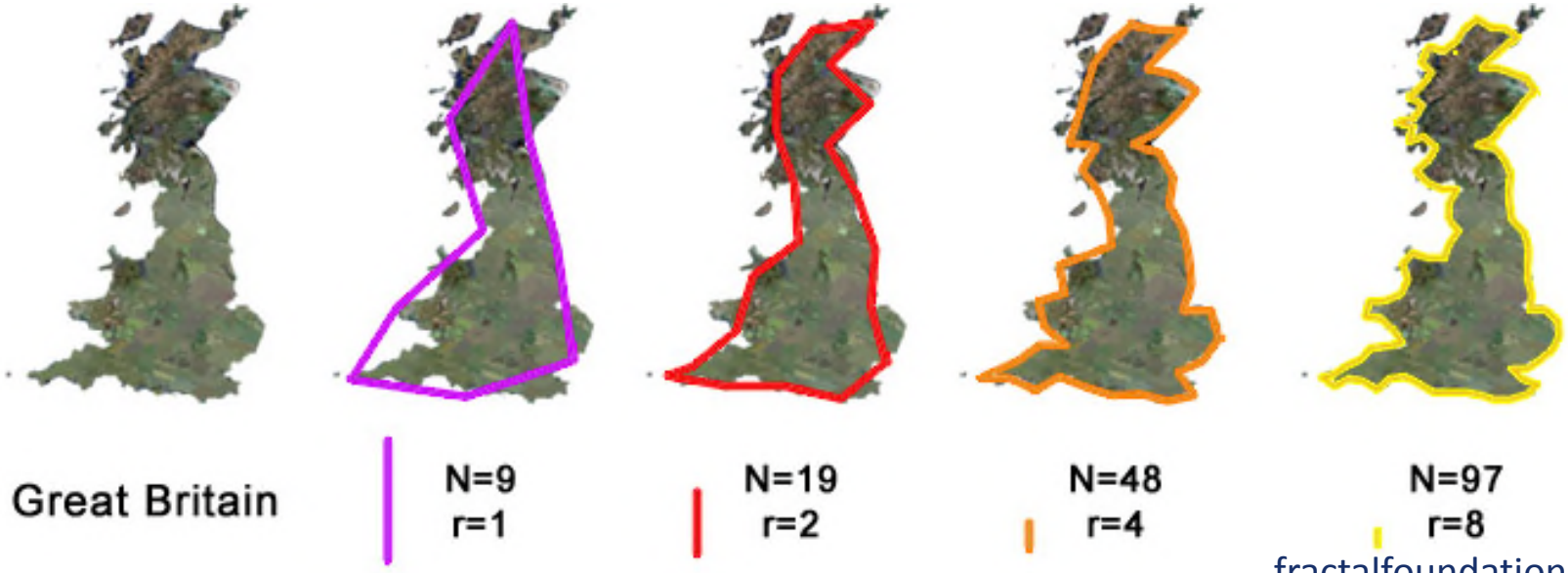
Mathematically simple



# Coastline Fractals

Coastlines show move detail the closer you zoom in

The length Great Britain's coastline (N) depends on the length of your ruler (r)

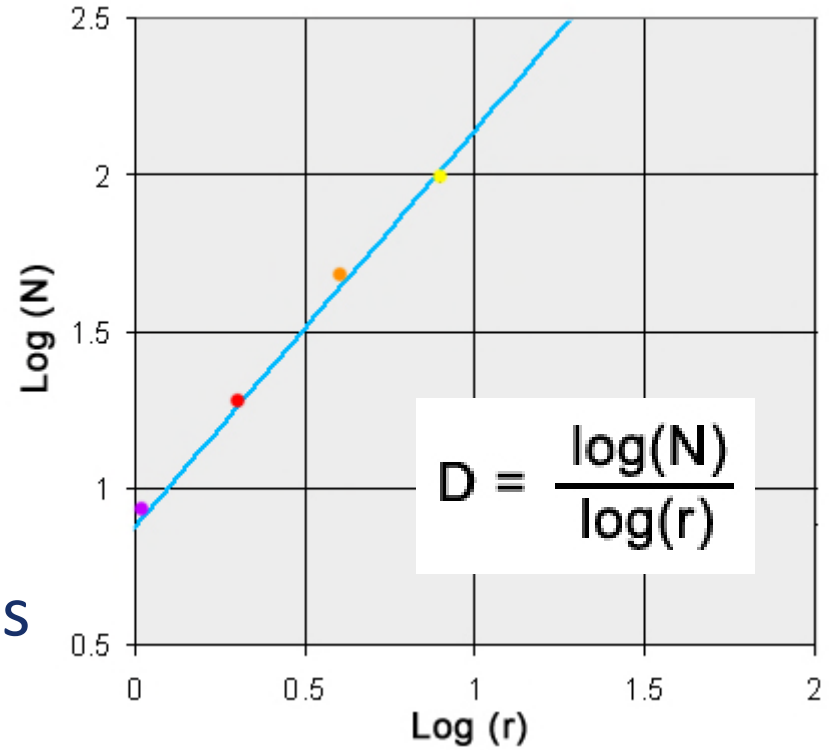


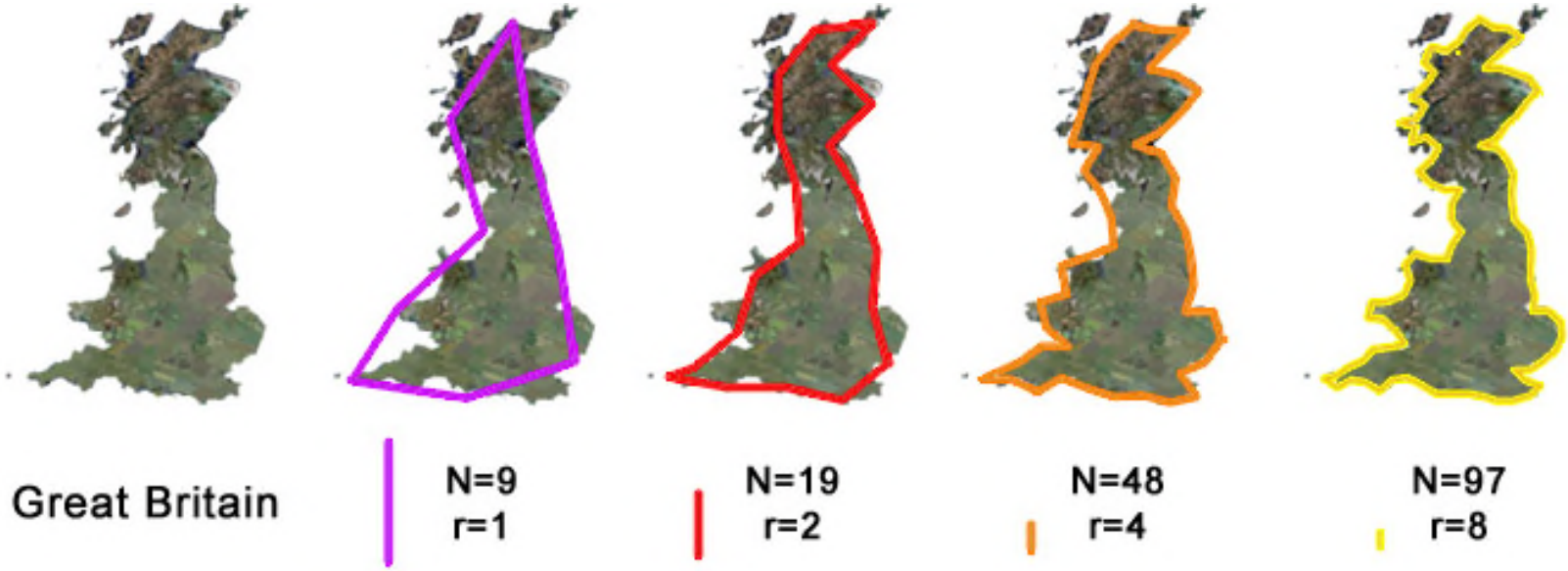
# Coastline Fractals

As the ruler shrinks the measured coastline increases.

If the coastline is fractal the relationship between r and N is linear when plotted using log scales

D = fractal dimension

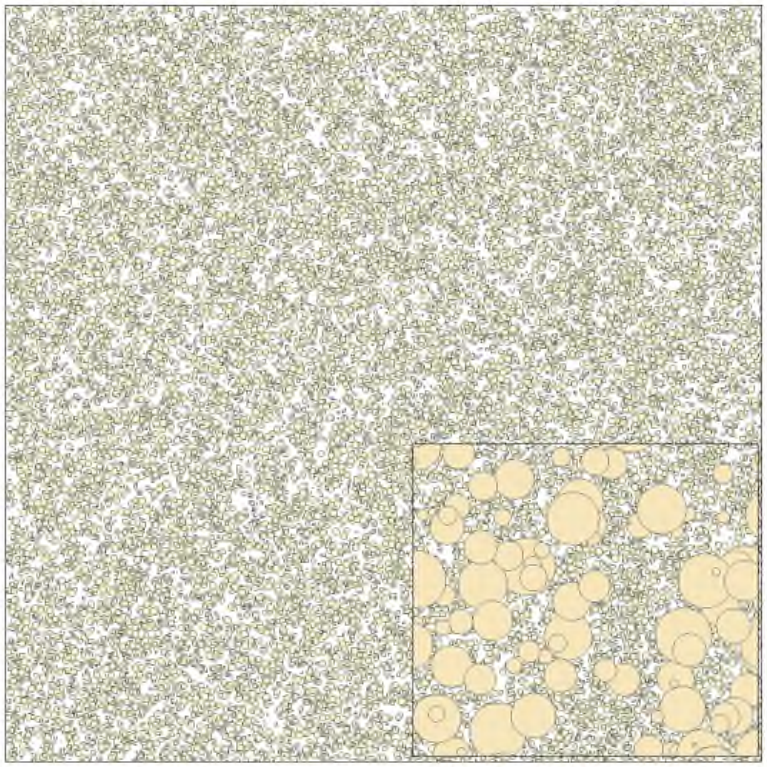


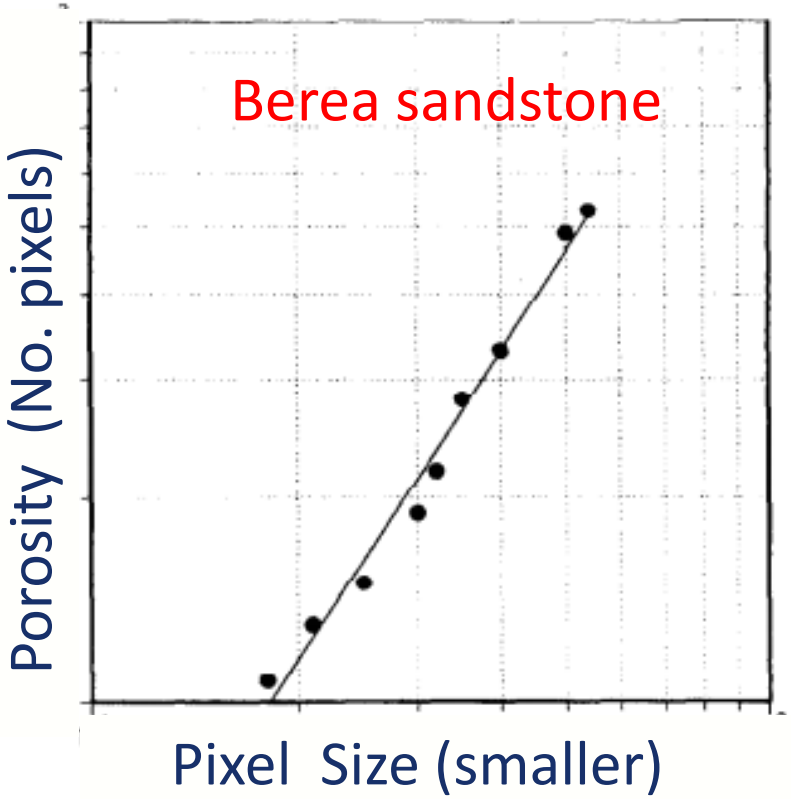



# Fractals in reservoir rocks

Thin sections of reservoir rocks are imaged with a scanning electron microscope (SEM )

For different magnifications the number of pixel units representing porosity are counted





# Fractals describe the rock pore network

The rock pore space can be described by the fractal formula

$$V = r^{(3-Df)}$$

Where:

| | |
|---|---|
| *V* | Pore space in rock volume |
| *r* | Radius of the rock capillaries |
| *Df* | Fractal dimension (non-integer constant) |

This reduces to

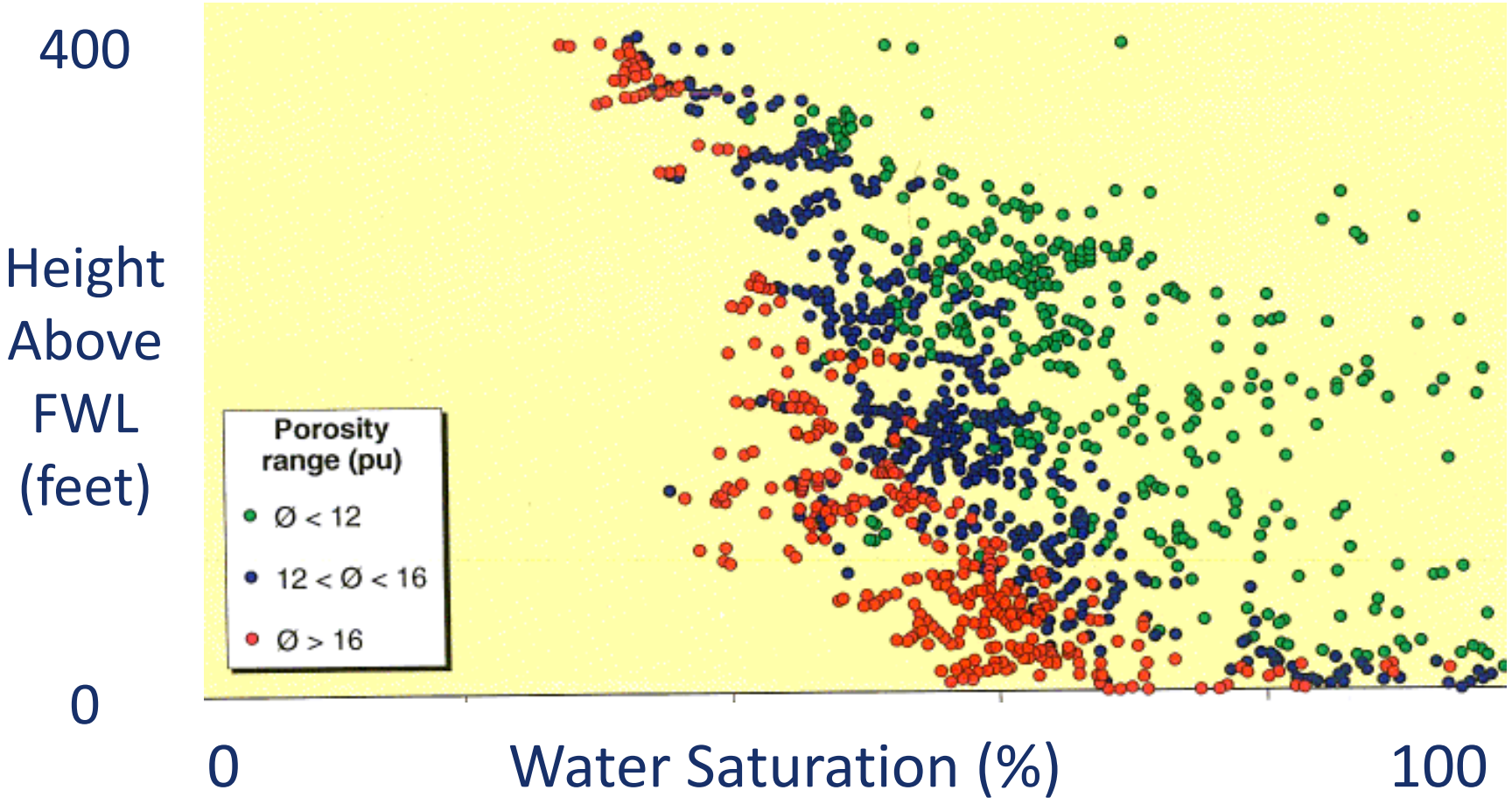
$$BVW = aH^b$$

Where:

| | |
|---|---|
| *BVW* | Volume of capillary bound water in the rock |
| $H$ | Height above the free water level |
| $a$ & $b$ | constants |

# Water Saturation vs. Height Data

What do we see in the well data?

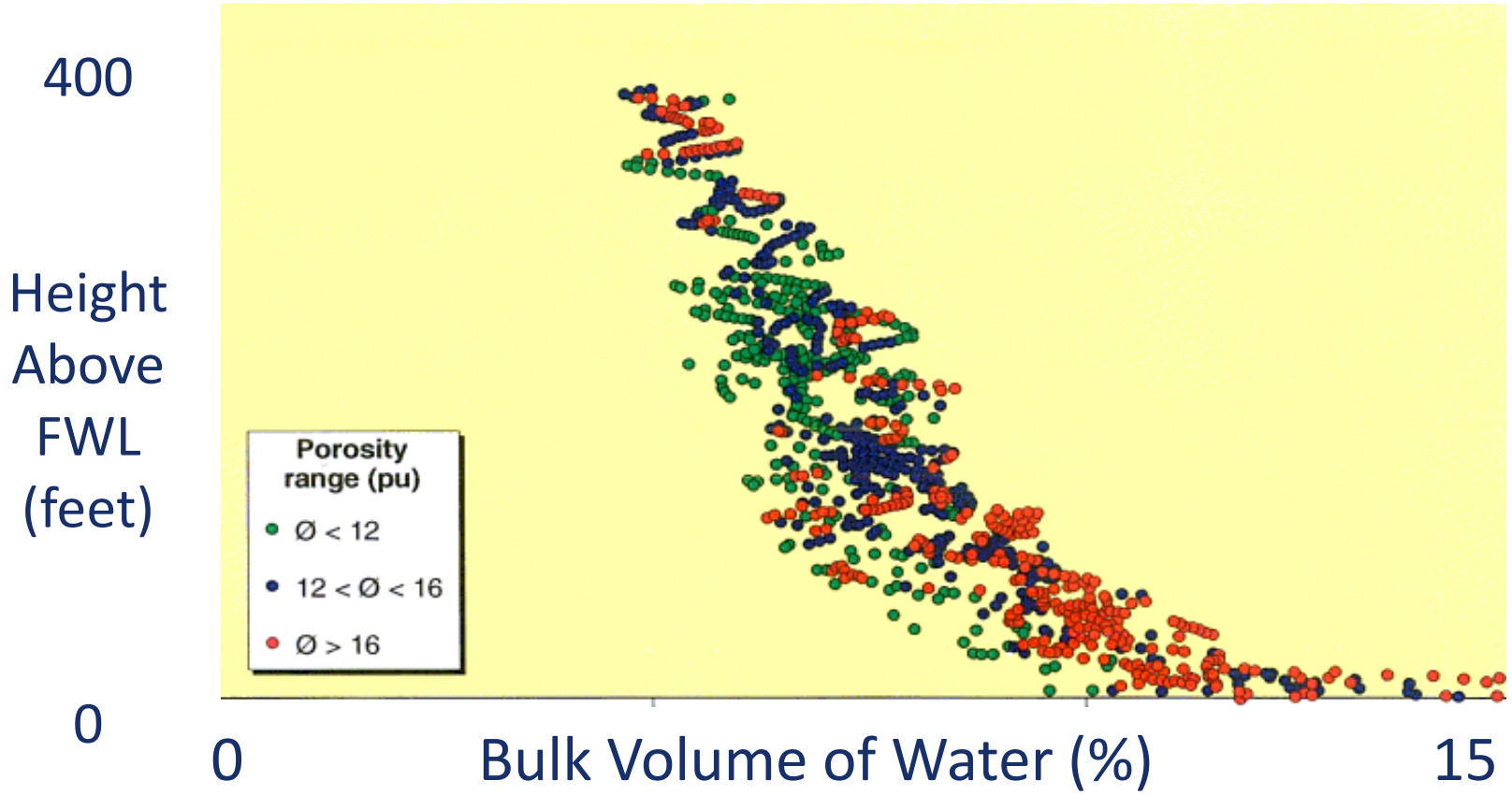



Source – Southern North Sea Gas field

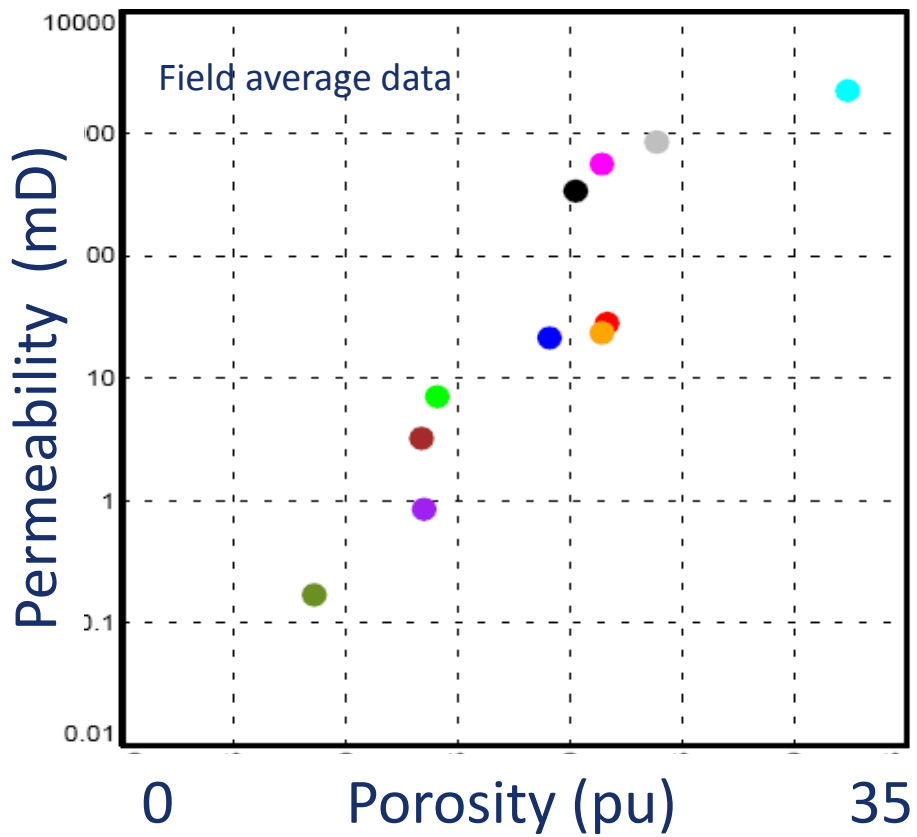
# BVW is Independent of Rock Properties

The bulk volume of water is independent of rock properties

Can be verified by simply plotting facies-type, porosity or permeability on the z-axis on the cross-plot



# Log and core data from 11 North Sea fields



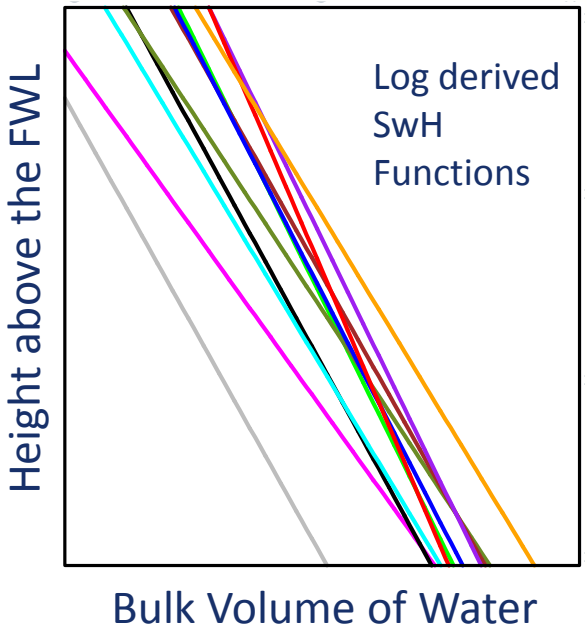

| Field | Fluid | Type | Porosity (pu) | Perm (mD) |
|---|---|---|---|---|
| | Gas | Permian Fluvial | 9 | 0.2 |
| | Oil | M. Jurassic Deltaic | 13 | 3 |
| | Oil | Devonian Lacustrine | 14 | 7 |
| | Gas | Permian Aeolian | 14 | 0.9 |
| | Oil | Palaeocene Turbidite | 20 | 21 |
| | Gas | Permian Aeolian | 20 | 341 |
| | Gas Condensate | L. Cretaceous Turbidite | 24 | 847 |
| | Oil | U. Jurassic Turbidite | 21 | 570 |
| | Oil | Palaeocene Turbidite | 21 | 24 |
| | Oil | Palaeocene Turbidite | 22 | 27 |
| | Gas | Palaeocene Turbidite | 32 | 2207 |

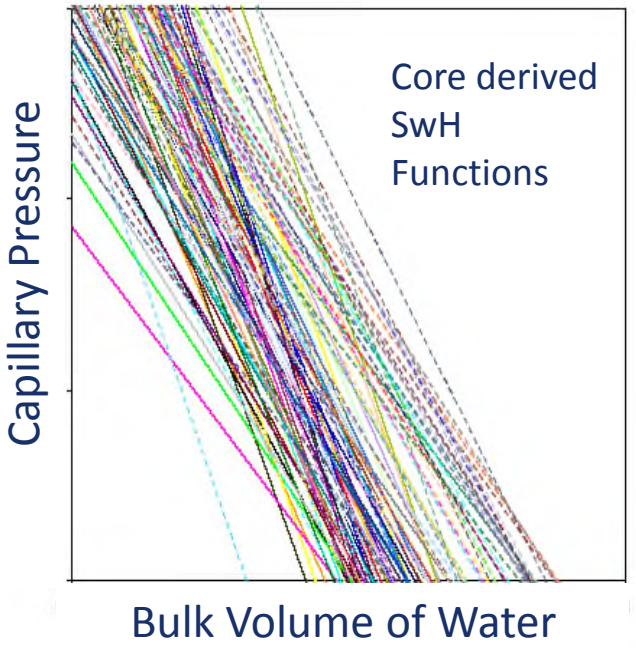
# Comparison between Log & Core SWHF

The Fractal Function is linear on log-log scales

Log and core functions are the same irrespective to whether they were determined from logs or core data

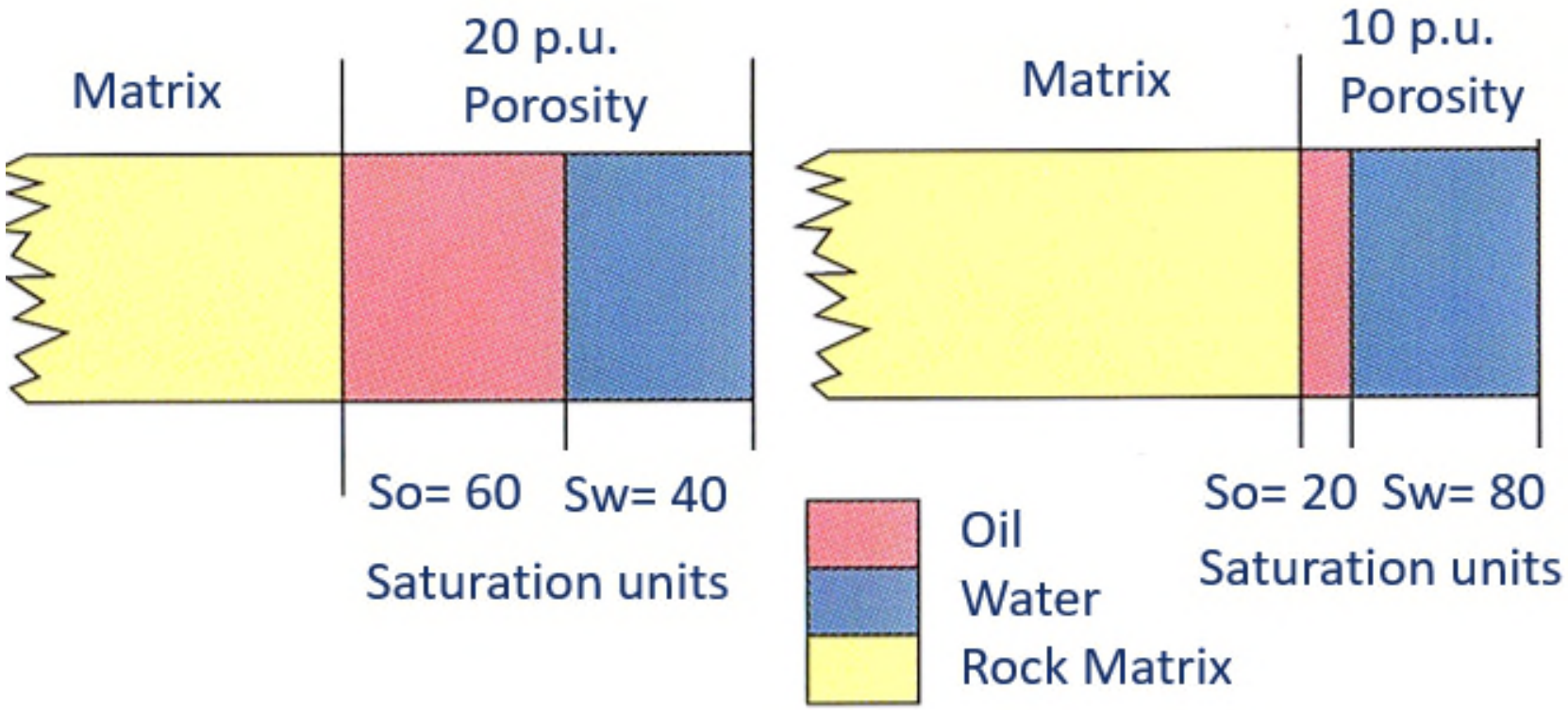
This confirms the fractal distribution of reservoir capillaries



# What BVW tells us

Bulk Volume of Water = Function (Height above the FWL)




- The BVW Swh function gives the net reservoir cutoff
- In this example: porosity > 9 porosity units

# BVW vs. Height Fractal Swh Function

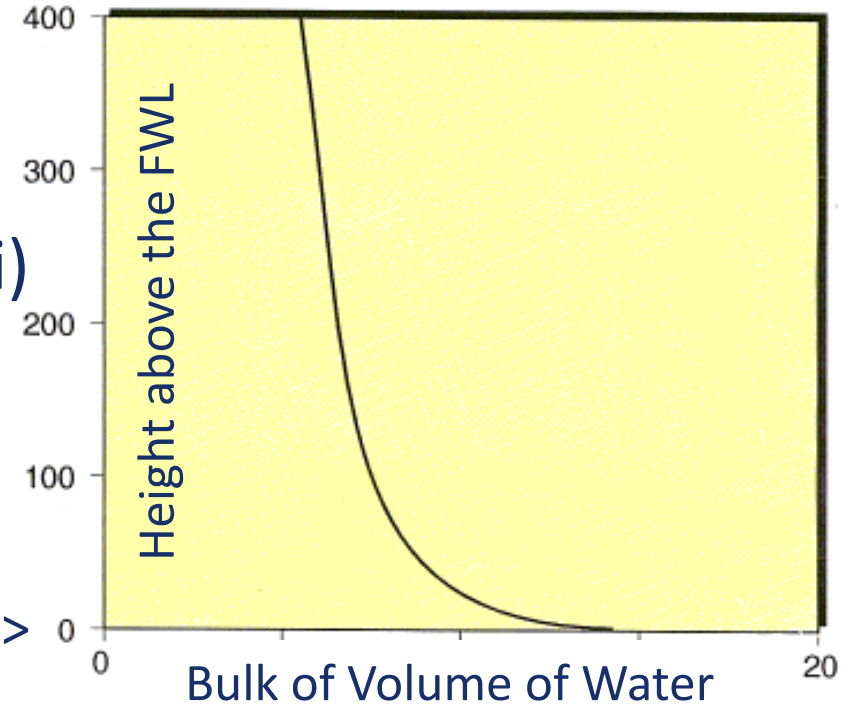
$$BVW = aH^b$$

Where:

$BVW$ = Bulk Volume Water (Sw*Phi)

$H$ = Height above FWL

$a, b$ = Constants



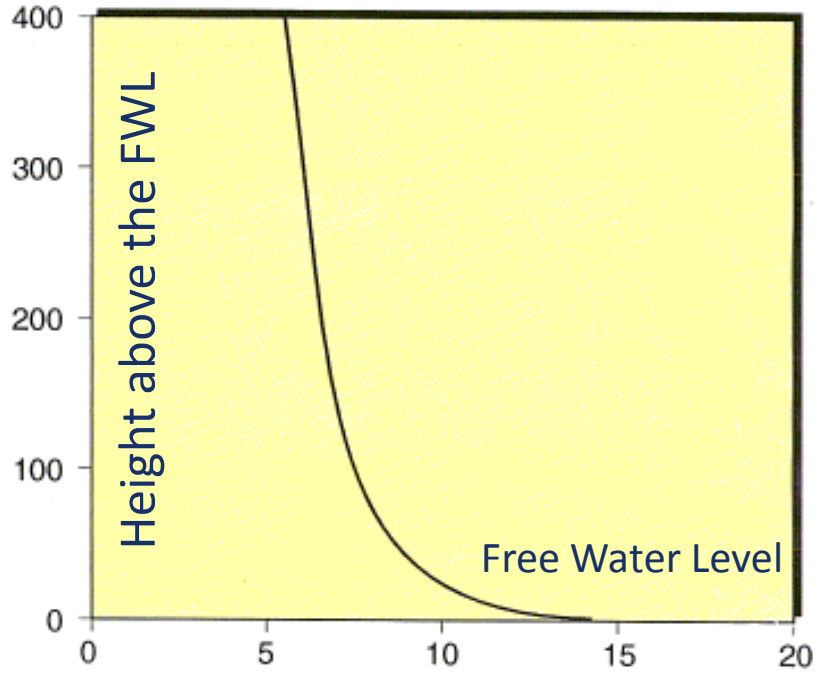

- Derived from the fractal nature of reservoir rocks
- Based on the bulk volume of water
- Independent of facies type, porosity and permeability
- Two parameters completely describe the reservoir
- The function is linear in log-log space

# Net Reservoir Cut-off

The net reservoir cut-off varies as a function of height above the FWL

This is given by the fractal Swh function

The net cut-off is required for averaging porosity, water saturation and permeability in the reservoir model




Net reservoir porosity cut-off

# Upscaling

From ½ foot to the cell size of the reservoir model

Net flag required

Sw-Height functions (SWHF) are used to initialize the reservoir model. It is essential that the SWHF predicted water saturations upscale accurately

This is done by integrating the Sw-Height function

Unlike other parameters, such as porosity, water saturation must be pore volume averaged

# Upscaling Water Saturations

$$\overline{Sw} = \frac{\left(\overline{\Phi_1 Sw_1} + \overline{\Phi_2 Sw_2}\right)}{\left(\overline{\Phi}_1 + \overline{\Phi}_2\right)}$$

$\overline{Sw}$ = average water saturation

$\overline{\Phi}$ = average porosity

$\overline{\Phi Sw}$ = average bulk volume of water

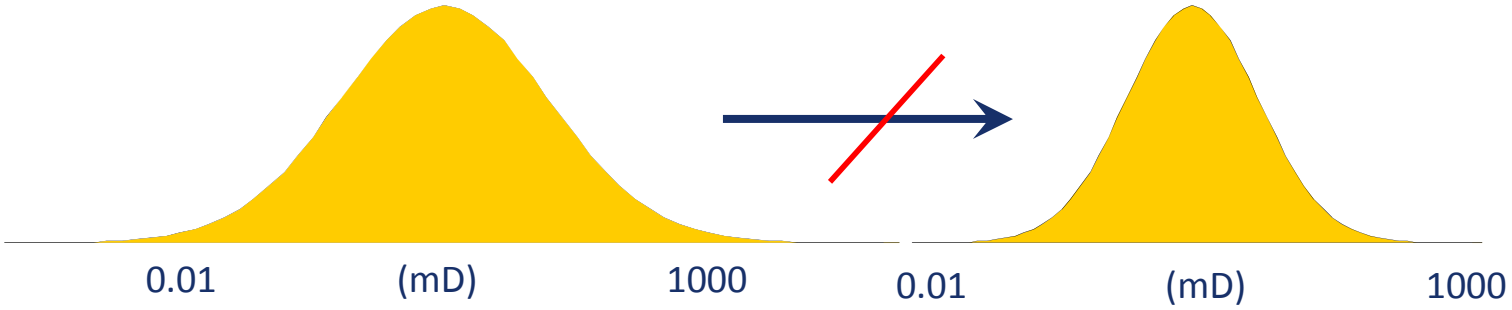
"A function that predicts *BVW* from height is especially appropriate to this application" Paul Worthington

# Upscaling Permeability

Log and core permeabilities represent typically 2 feet

To be used in a reservoir model the predicted permeabilities must upscale correctly

They must have the same dynamic range as the core data




Least squares regresses towards the mean

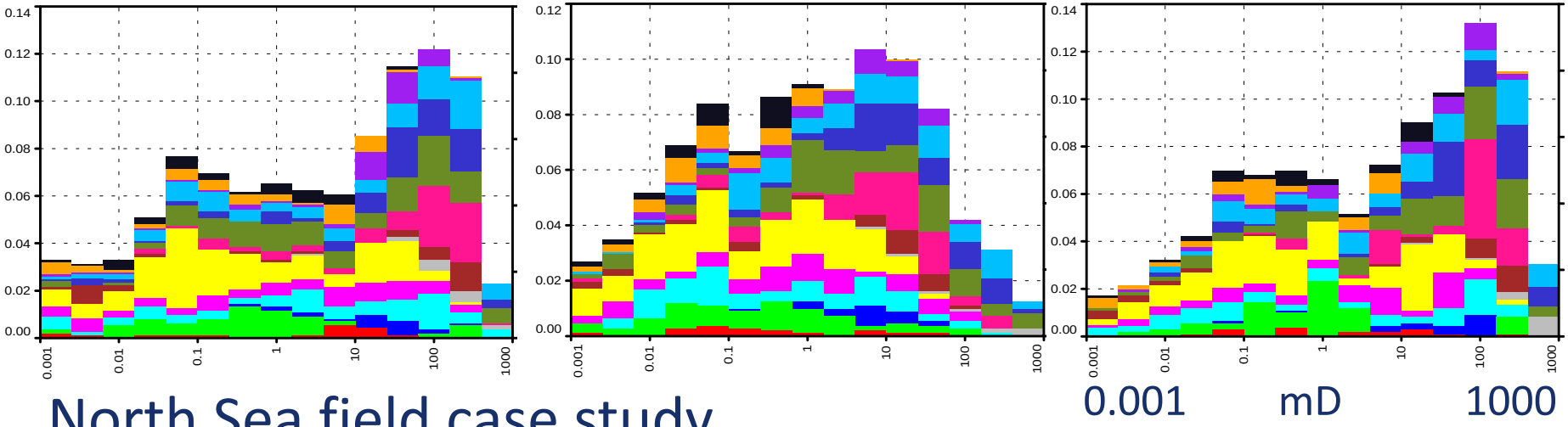
Fuzzy logic predictions preserves the dynamic range

# Core permeability upscaling

Core distribution

Linear Regression

Fuzzy logic




North Sea field case study

Permeability frequency plots

- Colour represents data from 15 cored wells

Regression permeability techniques are poor at the extremes and therefore will be incorrect when upscaled

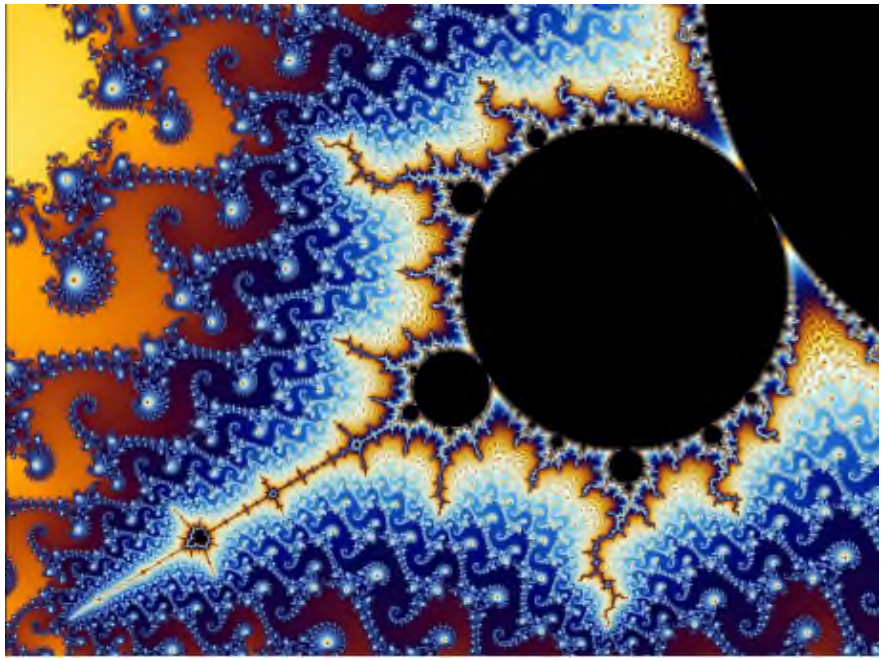
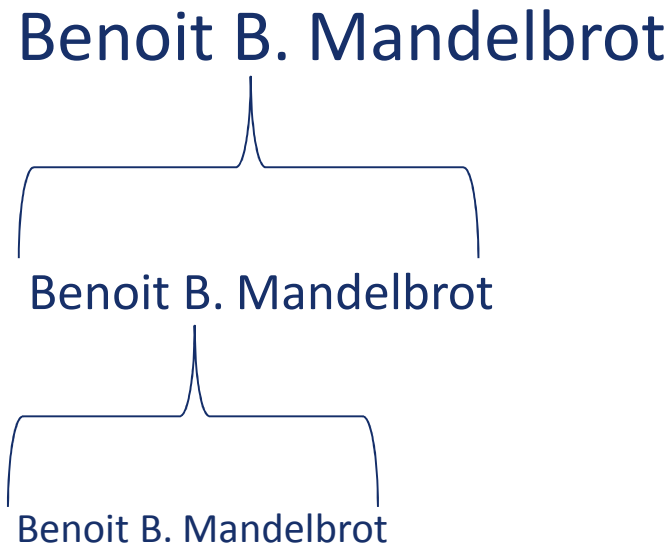
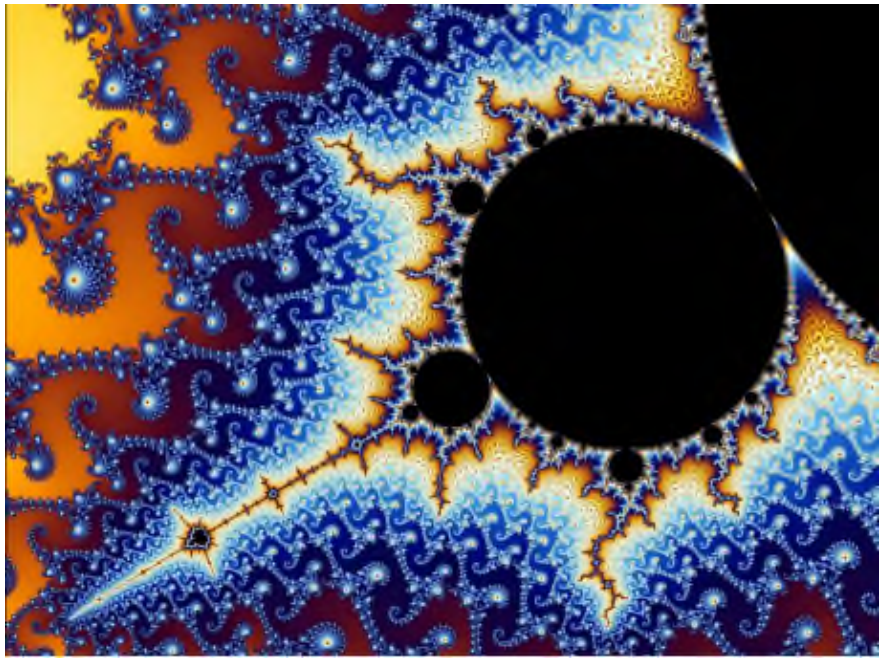
Fuzzy logic predicted permeability matches the core distribution

# Conclusions

- Net Pay
  - Is difficult, if not impossible, to define
  - Depends on the oil price
- Net Reservoir is rock capable of holding hydrocarbon
- Net Reservoir can be determined using
  - Using core, logs and Sw-height functions
  - Net reservoir depends on the height above the FWL
- Upscaling requires:
  - Net reservoir cut-off for porosity, Sw and permeability
  - Correct upscaling for the 3D reservoir model is essential

# What’s Benoit B. Mandelbrot middle name?

Benoit B. Mandelbrot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