AFES Aberdeen Formation Evaluation Society

SOCIETY OF PETROPHYSICISTS AND WELL LOG ANALYSTS

Should Petrophysics calculate Total or Effective Porosity?

Steve Cuddy

Outline

- The difference between shale and clays
- Total and effective porosity defined
- Calculating porosity from core analysis
- Calculating porosity from electrical logs
- The difference between net pay and net reservoir

What is Porosity?

Porosity - The void space that can contain fluids (SPWLA)

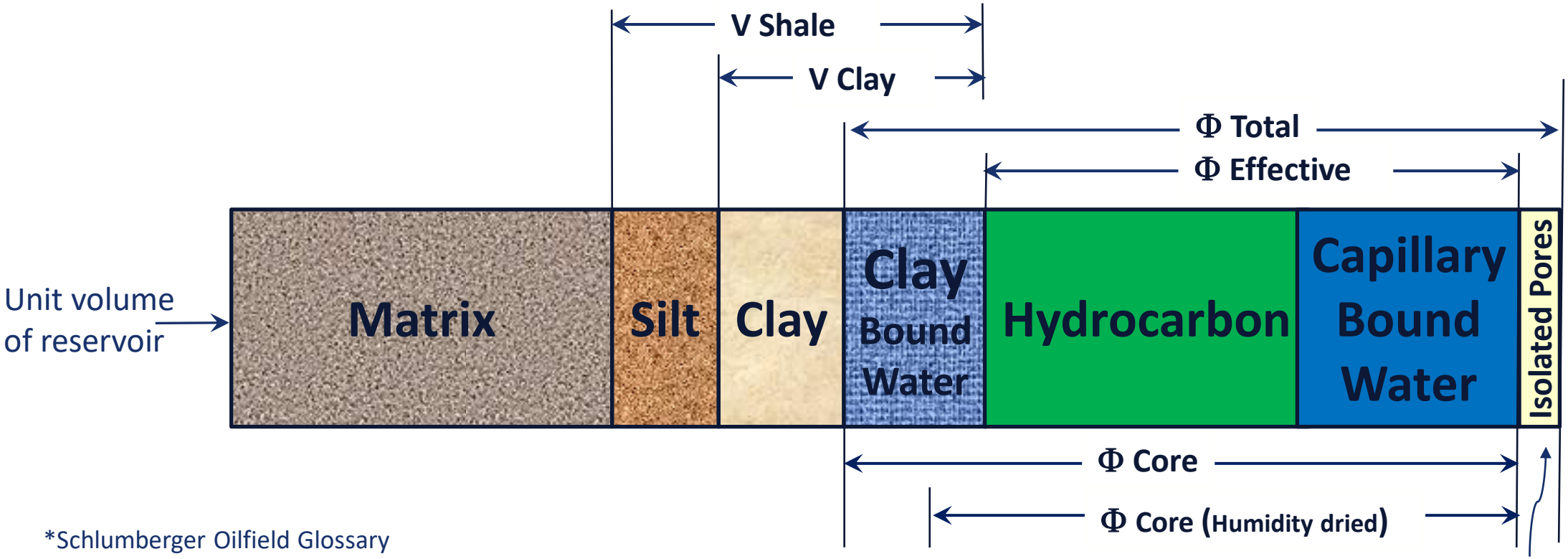
The Fog of Confusion - Clays and Shale*

- Clays and Shales mean different things to geologists, reservoir engineers and petrophysicists
- Some petrophysicists use the terms clay and shale interchangeably
  - clearly this is wrong
- Shale is composed of clay and silt
- When computing porosity we need to account for the clay minerals, because their density is often different from the matrix density
- The clays adsorb water on their surfaces
  - If the mineral chemically holds water on its surface it is a clay
- When computing water saturation we need to account for the excess conductivity due to the clay minerals in the shales
- Petrophysicists define clay in such a way to compute the most accurate porosity and water saturation

*** from Spooner**

Porosity - Petrophysicist's definition

- PHIT - The total porosity includes isolated pores and the space occupied by clay-bound water*
- PHIE - Effective porosity excludes isolated pores and pore volume occupied by water adsorbed on clay minerals*
- PHIT = PHIE + Clay Bound Water

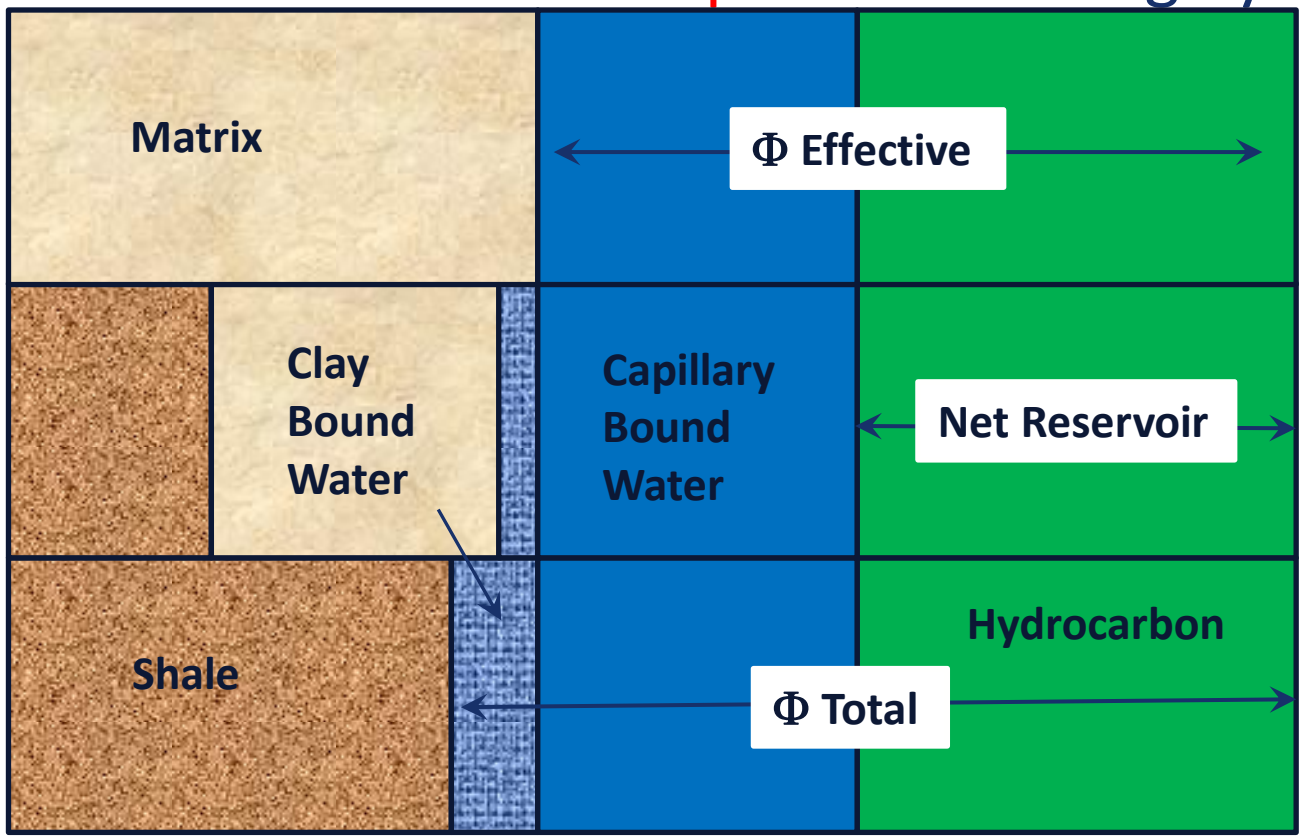


*Schlumberger Oilfield Glossary

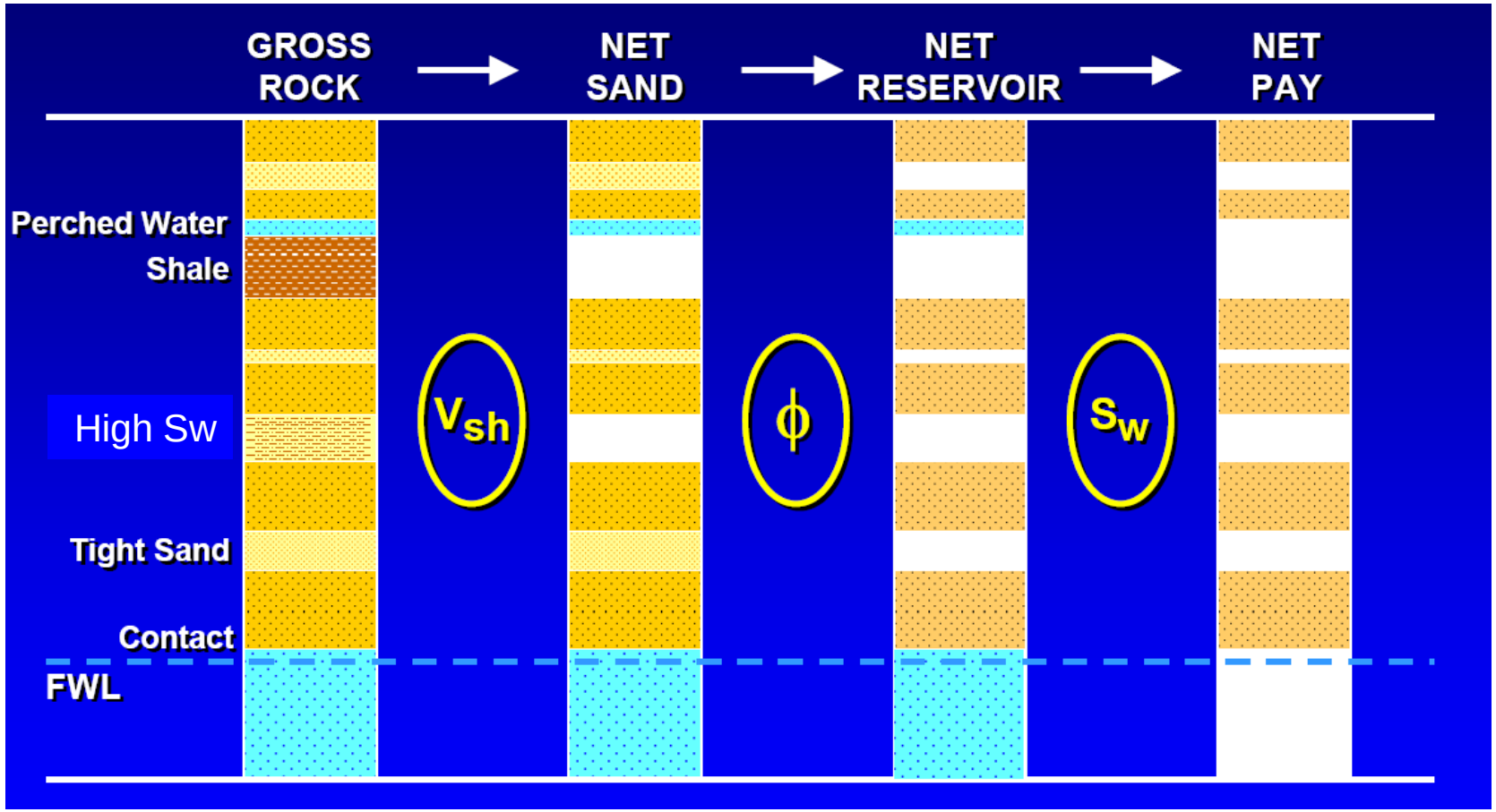
Isolated pores can be neglected in most clastic formations

Total and Effective Porosities

- PHIT is the total reservoir rock containing all fluids
  - Hydrocarbon, Capillary Bound Water, Clay Bound Water
- PHIE - reservoir rock containing Hydrocarbon, Capillary Bound Water
  - Capillary Bound Water = Bulk Volume of Water (BVW)
- Net Reservoir is the reservoir rock capable of storing hydrocarbon



Net Pay and Net Reservoir



- Net Sand removes the shaly intervals
- Net Reservoir removes the low porosity intervals
- Net Pay removes the intervals of high water saturation

The Difference between Net Reservoir and Net Pay

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

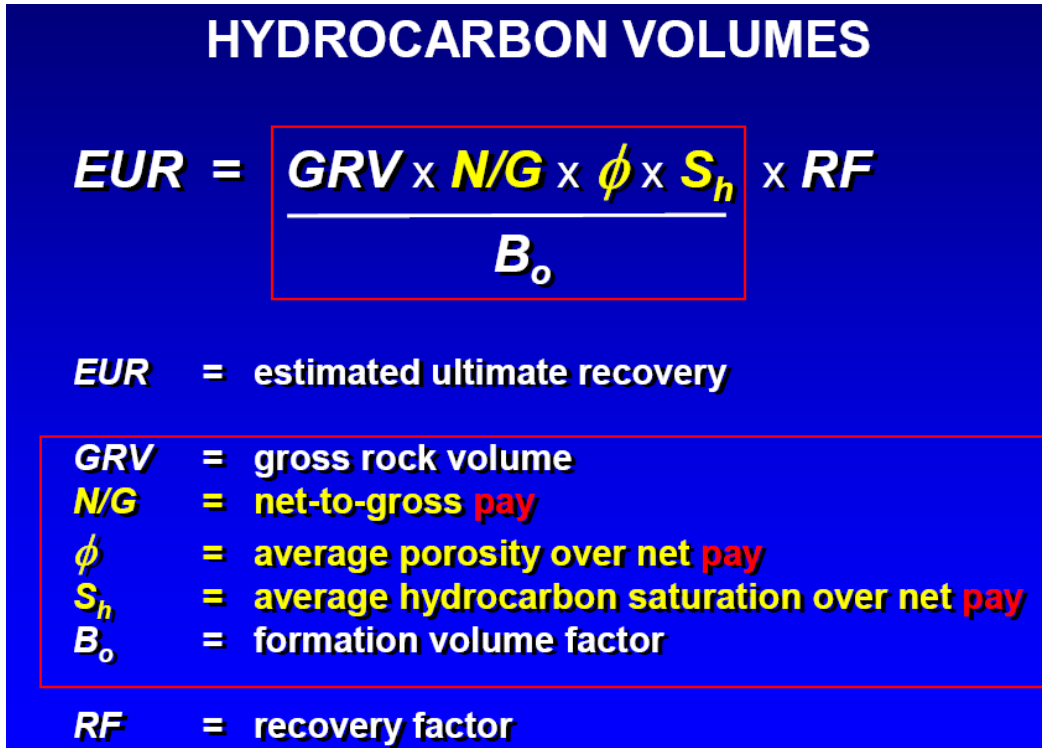
- Net Pay
  - "The portion of reservoir rock which will produce commercial quantities of hydrocarbon"- SPWLA
  - *or* The portion of reservoir rock which will produce or help support production of hydrocarbon over field development timescales
  - Useful to help select perforation intervals
  - More difficult to pick

Net Pay

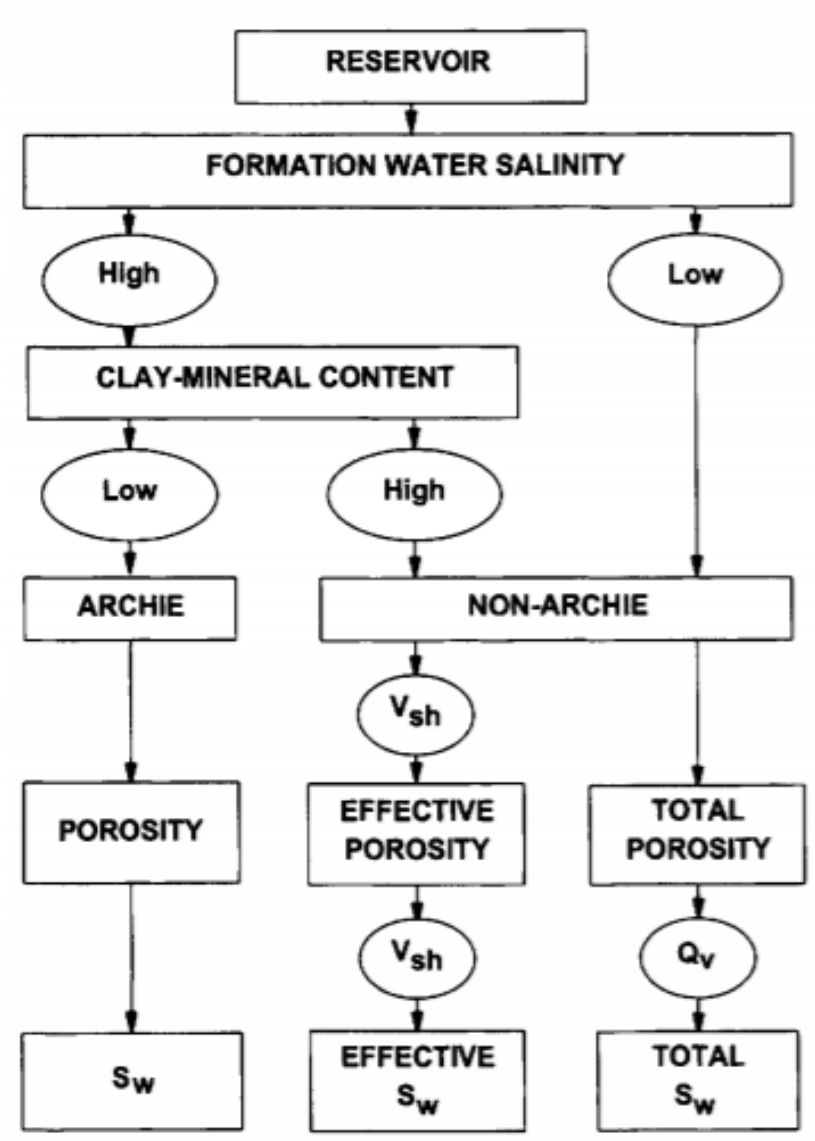
- Usually defined using a Sw and/or permeability cutoff
- But it doesn't include:
  - The ratio of horizontal to vertical permeability (Kh/Kv)
  - Standoff distance from the FWL
  - Shape of the transition zone
  - Gas and water drive
  - Draw down
  - Water cut
  - Fractures
- Most of hydrocarbon above the FWL is potentially producible
- The amount of hydrocarbon produced depends on how hard we try
- Is Net Pay therefore a function of the oil price?
- Net Pay is difficult to define

Net Reservoir

- Net Reservoir is much easier to define than Net Pay
  - As it is defined as the portion of reservoir rock which is capable of storing hydrocarbon
- Knowledge of Net Reservoir is essential for:
  - Upscaling for reservoir averages
  - Reservoir modelling
- Net Reservoir is used to calculate Net/Gross



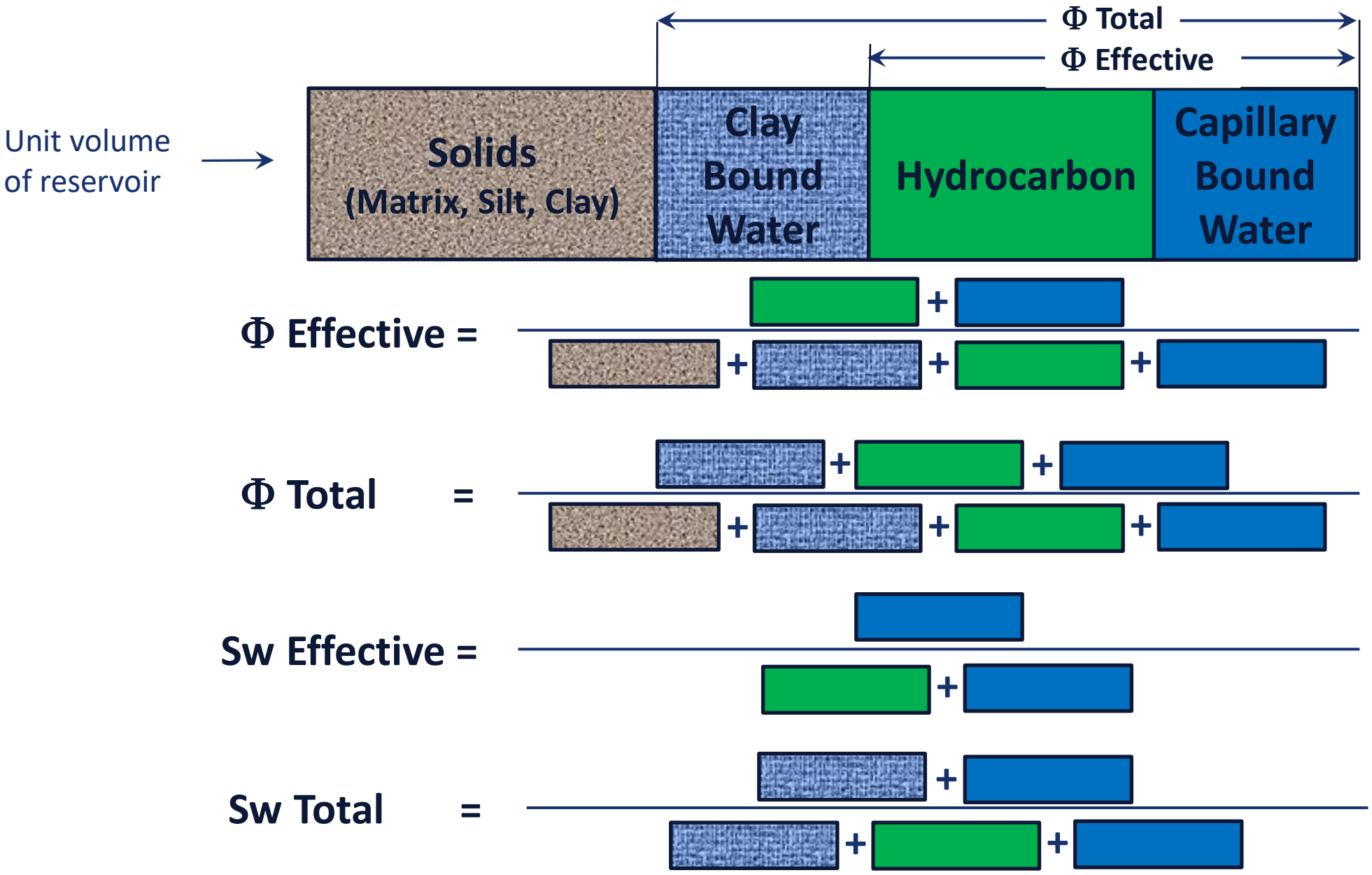
Archie vs. Non-Archie Reservoirs



*from Worthington

- Reservoirs with a high formation water salinity and a low clay mineral content are Archie reservoirs, where the effective and total porosities are essentially the same, because there are negligible clay bound water effects
- Otherwise, they are non-Archie reservoirs, because there can be a significant clay bound water saturation
- Non-Archie reservoirs can be evaluated in terms of either effective or total porosity

Total and Effective Water Saturation



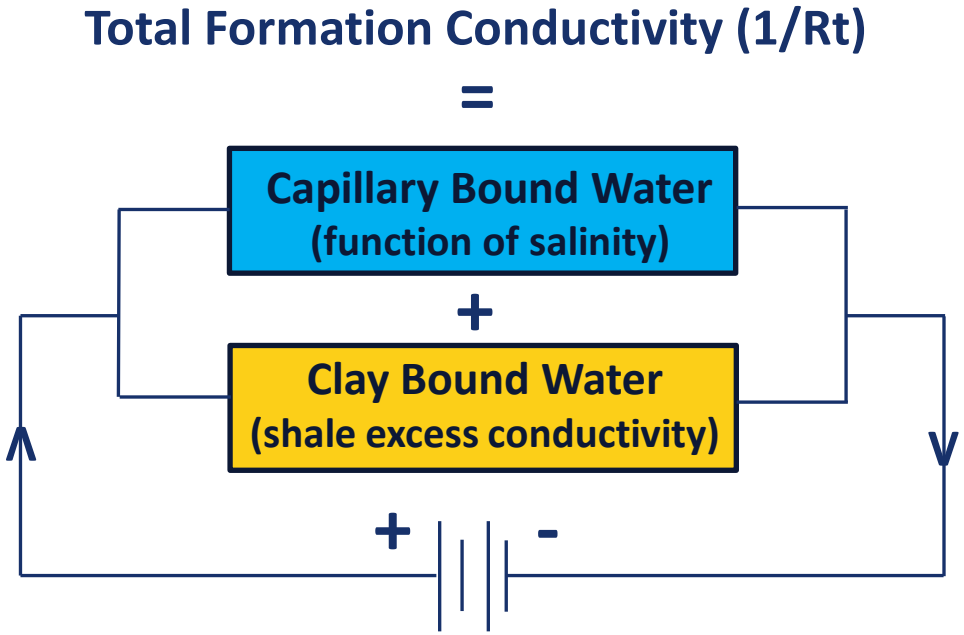
SWE is the % of capillary bound water in the effective porosity

SWT is the % of capillary and clay water in the total porosity

Where Total Porosity and Effective Porosity are used

- Different water saturation equations use different porosities:
  - Archie equation assumes clean formation PHIT = PHIE
  - Waxman-Smits, Juhasz and Dual Water use PHIT
  - Simandoux and Indonesia use PHIE

- Shaly sand water saturation equations correct for the shales' excess conductivity



Should petrophysicists use Total or Effective Porosity?

- Using PHIT or PHIE should give you the same hydrocarbon in place (HCIP)
- The question is which is most useful and gives the most accurate determination of HCIP

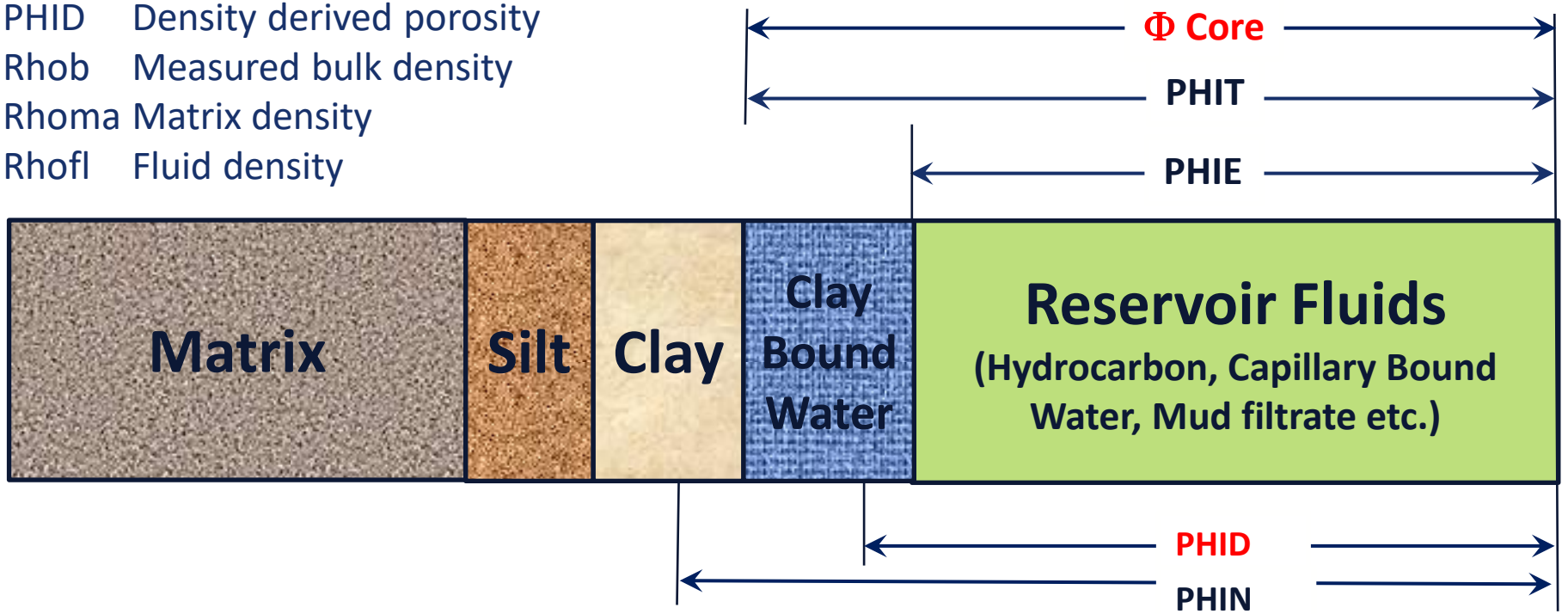
Porosity from core

- Density Porosity PHID is not PHIT
  - PHID is somewhere between PHIT and PHIE
  - Rhoma and Rhofl are for clean formation and may be different in the shales
  - It is necessary to calibrate PHID to the Core Porosity

- $PHID = \frac{Rhoma - Rhob}{Rhoma - Rhofl}$

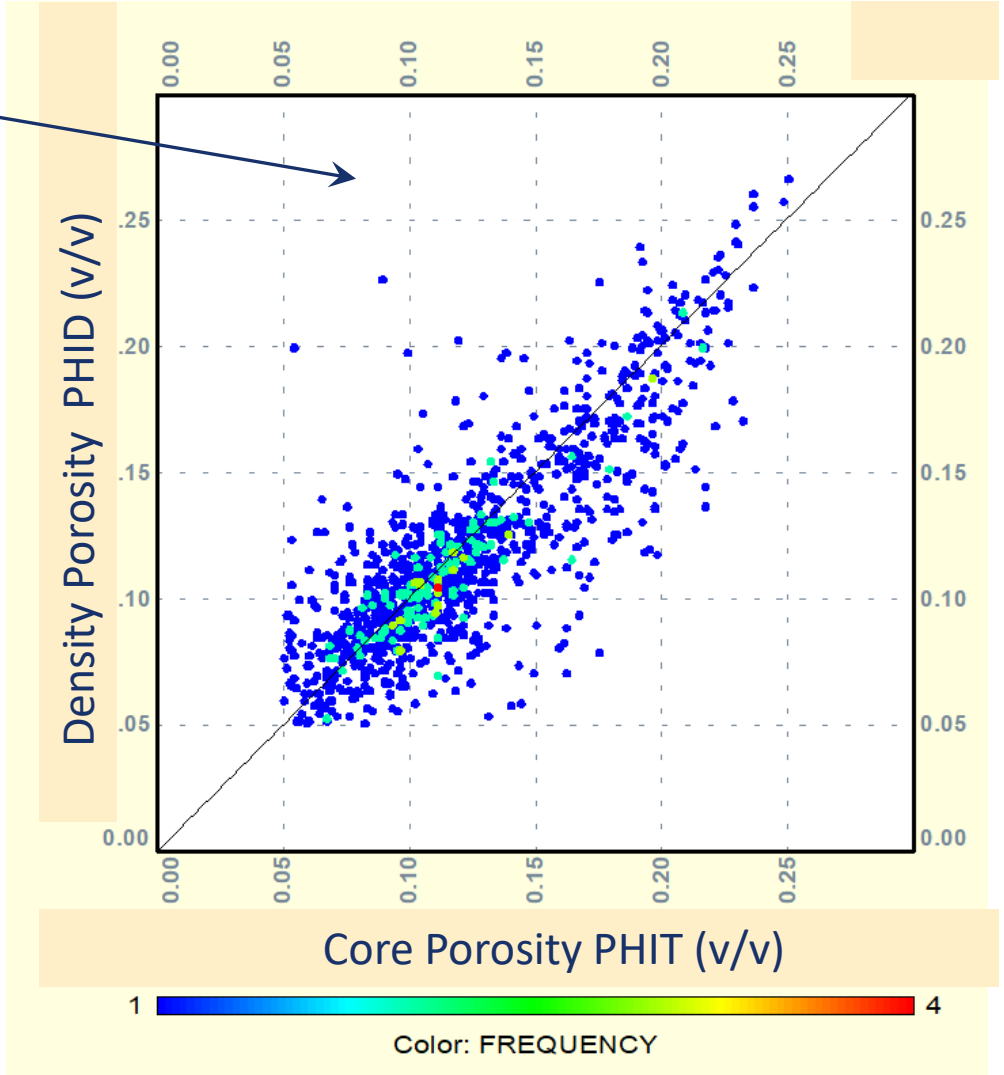
Where:

PHID	Density derived porosity
Rhob	Measured bulk density
Rhoma	Matrix density
Rhofl	Fluid density



Porosity from density log vs. core regression

- Density Porosity PHID is not PHIT
  - PHID is somewhere between PHIT and PHIE
  - It is therefore necessary to calibrate PHID to the Core Porosity



- PHIT = PHID * Constant

- $PHIE = PHIT\left(1-\frac{0.6425}{\sqrt{S}}+0.22\right)Qv$

where:
S = salinity in g/l NaCl
Qv = CEC/PV (meq/ml)
(from Hill, Shirley & Klein)

or

- PHIE = PHIT – VSH*PHISH

where:
PHISH = Shale porosity
(See later slide)

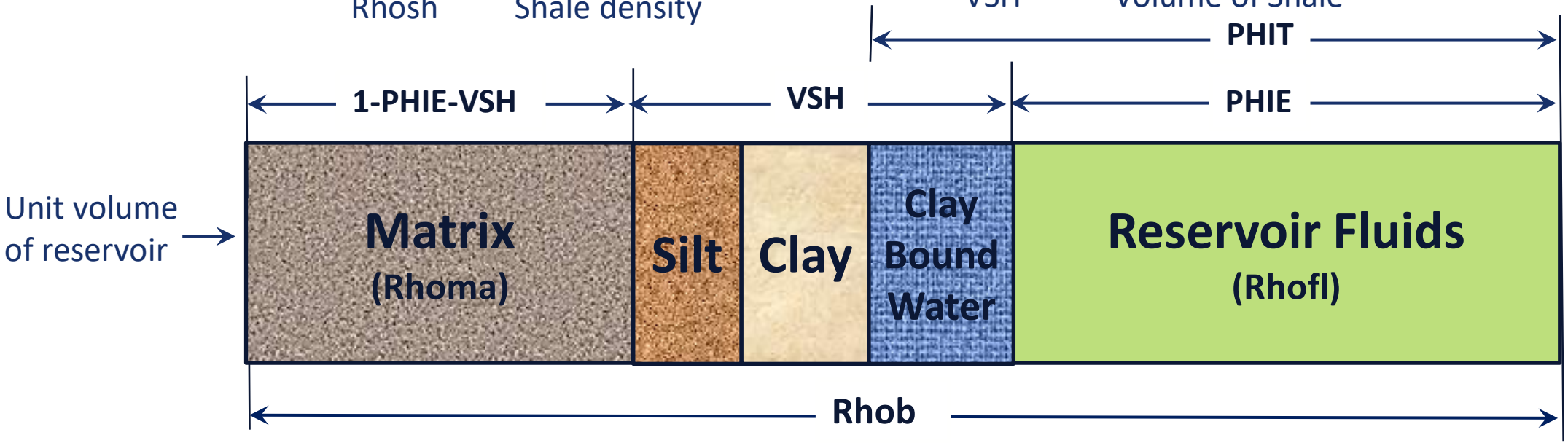
Porosity from electrical logs

- Density Porosity is not PHIT
  - Somewhere between PHIT and PHIE
  - Without core it is necessary to calculate PHIE before PHIT
- The density response equation:
- Rhob = (1 - PHIE - VSH) * Rhoma + VSH * Rhosh + PHIE * Rhofl)

Can be modified for Sxo

Where:

Rhob	Measured bulk density
Rhoma	Matrix density
Rhosh	Shale density
Rhofl	Fluid density
PHIE	Effective porosity
VSH	Volume of Shale



Porosity from electrical logs

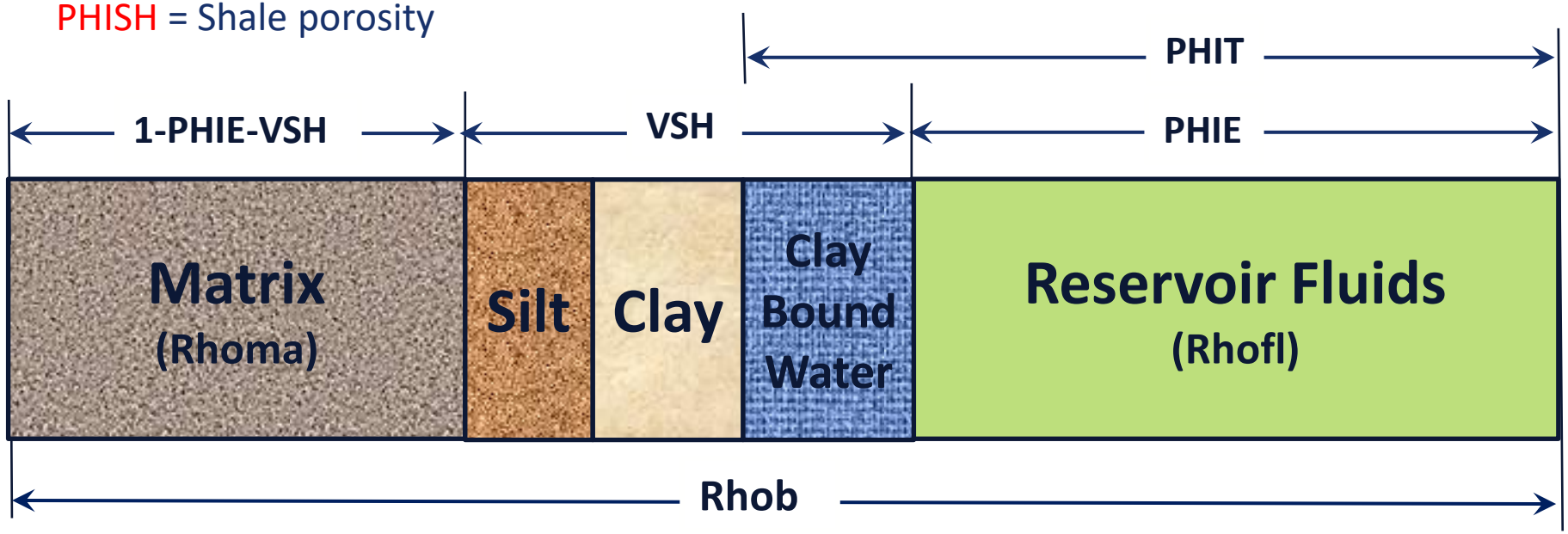
Solving for PHIE:

$$PHIE = \frac{Rhoma - Rhob}{Rhoma - Rhofl} - VSH * \frac{Rhoma - Rhosh}{Rhoma - Rhofl}$$

PHIT is then calculated from PHIE

$$PHIT = PHIE + VSH * PHISH$$

Where:
PHISH = Shale porosity



Calculation of shale porosity PHISH

PHISH = Shale porosity due to the Clay Bound Water

- PHISH is often assumed to be 10% if the shale contains an equal mixture of illite, chlorite and kaolinite clay minerals
  - but only for non-smectite formations

- PHISH can be calculated from:

$$PHISH = \frac{Rhodsh - Rhosh}{Rhodsh - Rhow}$$

Where:

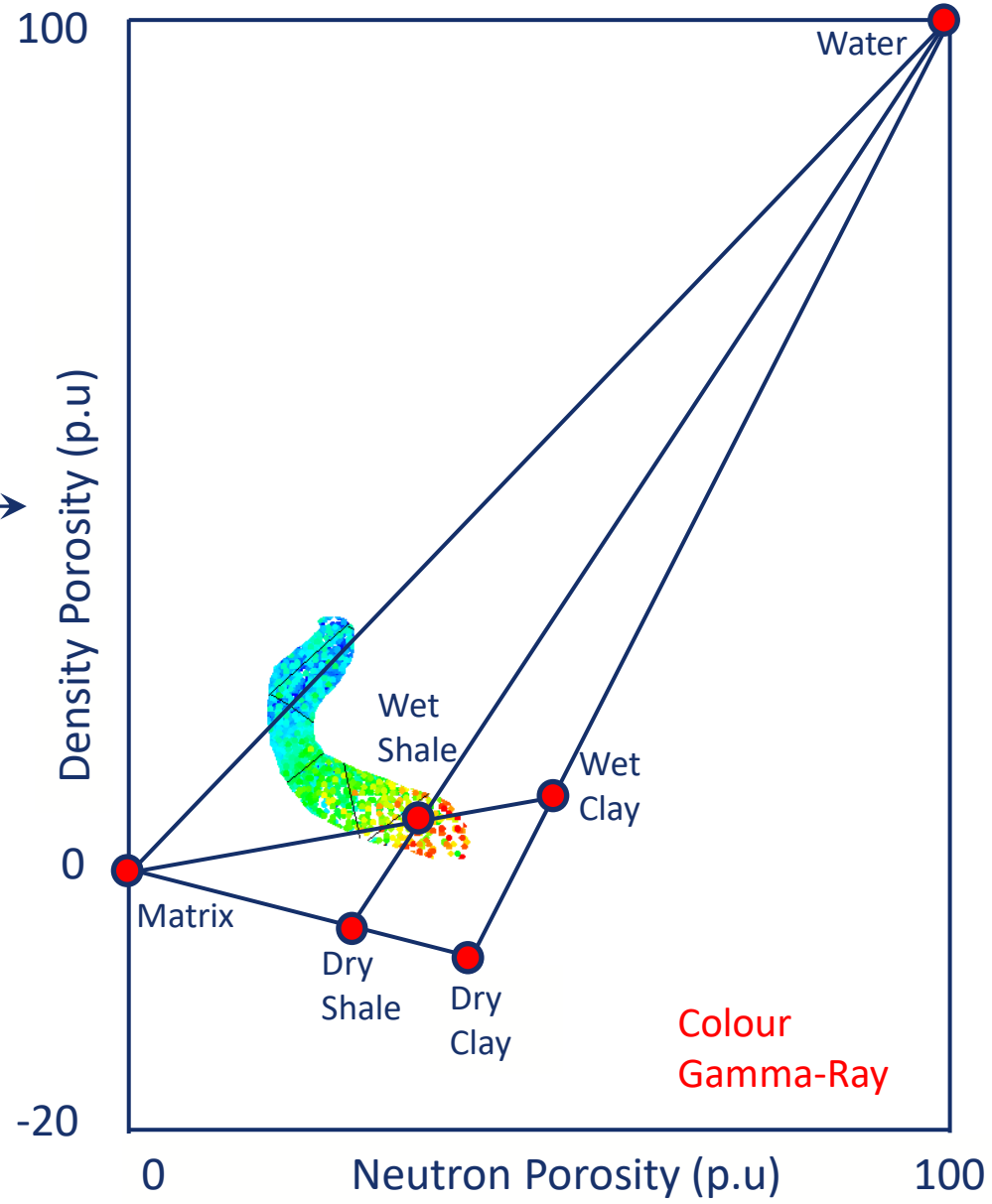
Rhodsh	Dry shale density
Rhosh	Shale density
Rhow	Shale water density

- The dry shale point, Rhodsh does not exist on the logs, as they are always wet insitu
- Rhodsh can be determined from the density vs. neutron porosity crossplot

Calculation of shale porosity PHISH

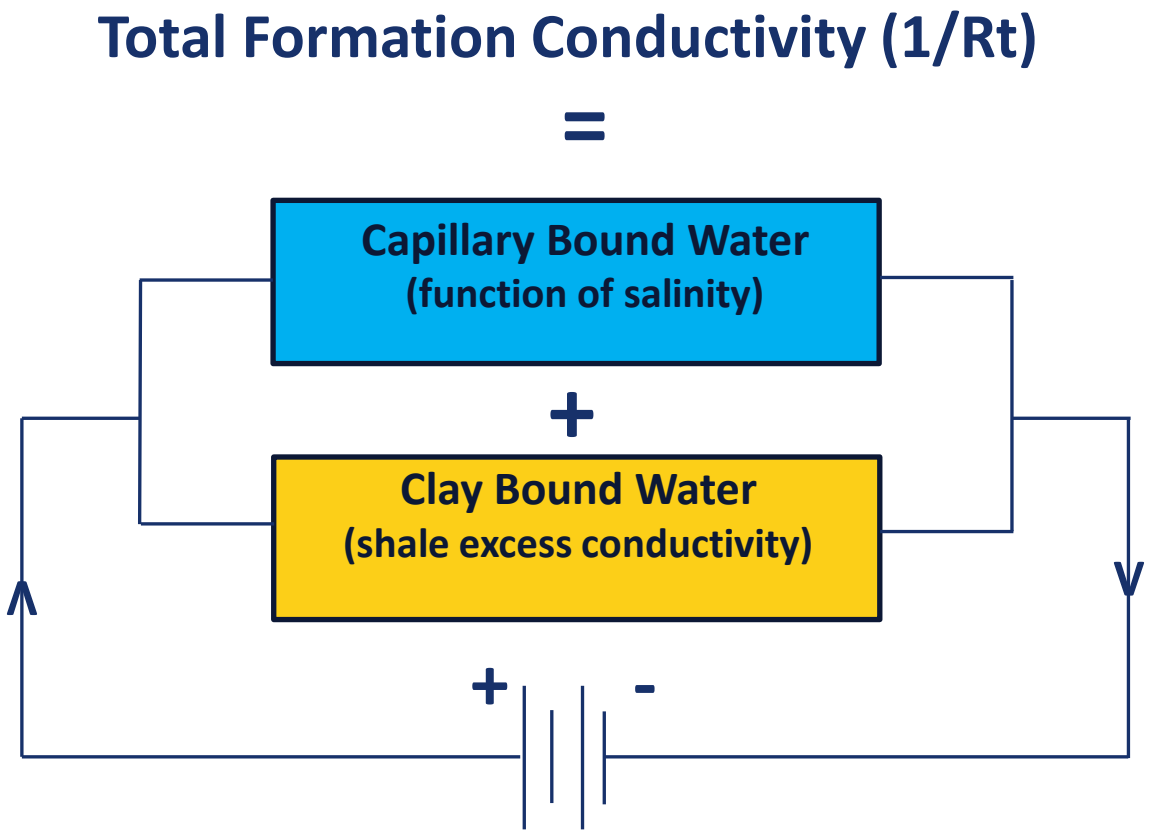
$$PHISH = \frac{Rhodsh - Rhosh}{Rhodsh - Rhow}$$

- The dry shale point, Rhodsh does not exist on the logs, as they are always wet insitu
- The dry shale density can be determined from density vs. neutron porosity crossplot
- Dry clay density can be inferred from knowledge of the clay mineralogy
- The wet shale point is at the end of the data boomerang
- The dry shale is the extrapolation of the shale line to the dry line



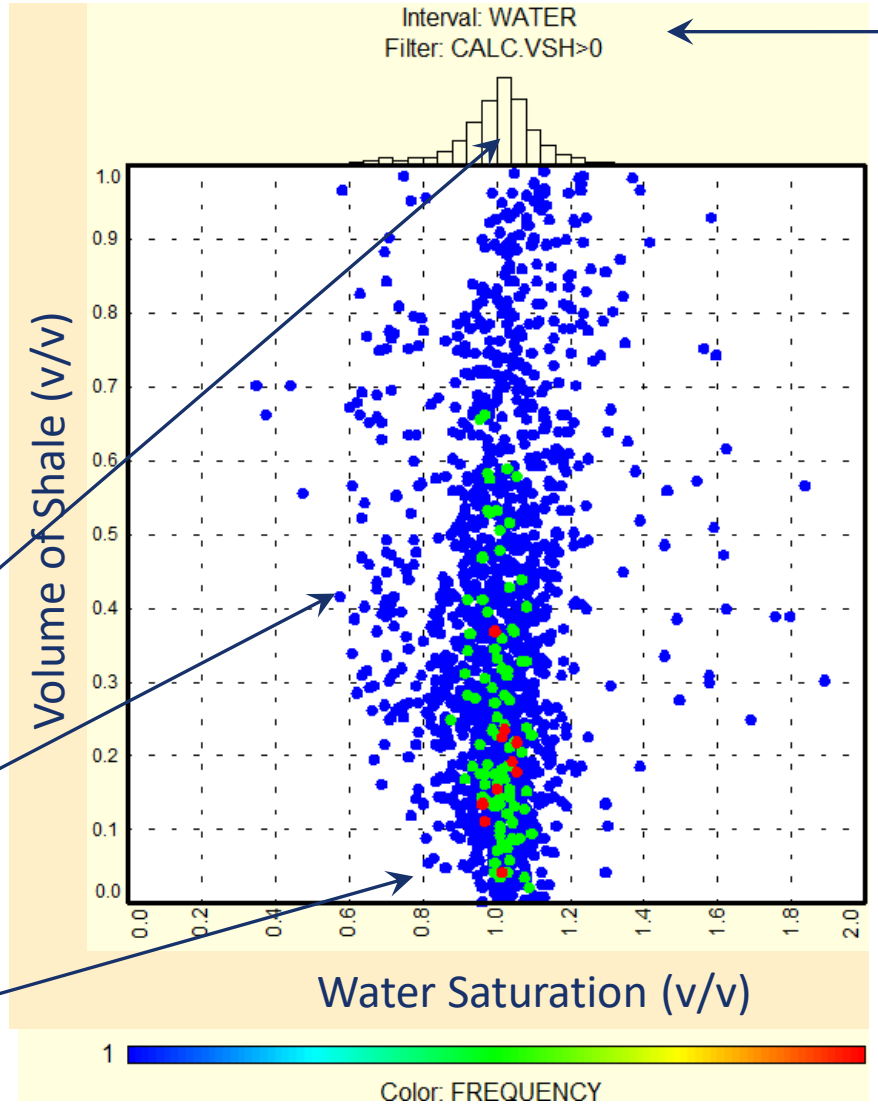
Shaly Sand Water Saturation Equations

- These must correct for the shales' excess conductivity



Confirmation of the Shaly Sand Water Saturation Equation

- The shaly sand water saturation equation must correct for the excess conductivity of the shale
- Plot unlimited Sw vs. Vsh in the water leg
  - Essential crossplot
- Sw should average 1 as shaliness increases
  - Trend should be vertical
- Rw confirmation in clean intervals



NB:
Only Water Leg data

Conclusions

- Petrophysics should calculate both PHIT and PHIE
- Density Porosity PHID is not PHIT
  - The density derived porosity is between PHIT and PHIE
- If core data is available calculate PHIT, then PHIE
- If no core data is available calculate PHIE, then PHIT

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Questions?

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