

# Lifting the Fog of Confusion Surrounding Total and Effective Porosity in Petrophysics

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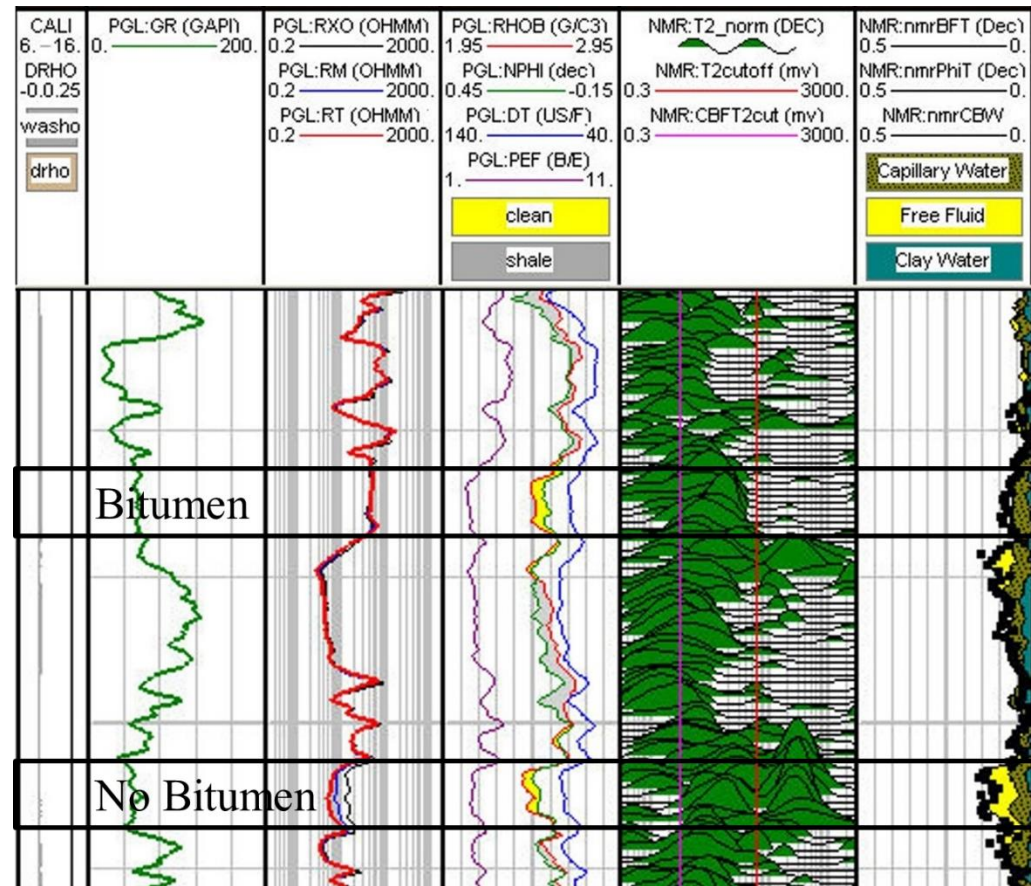
## Paper RRR

- The AFES 2016 AGM was followed by a 'Porosity Debate' which recognised many definitions of effective porosity in the industry, e.g. six in Wikipedia.
- The debate became a discussion about methodology, do you compute total porosity first and then effective porosity or vice-versa?
- This paper reviews several deterministic porosity methodologies common in the industry and demonstrates the inconsistencies inherent in many of them.
- It should not be a case of which to solve first, but rather ensuring 'consistency'
- A 'consistent' methodology yields both total and effective porosity with the same results whichever is solved first, and of course, matches core data.



# Total Porosity

- From Wikipedia:  
*The volume of the reservoir rock which is fluid (oil, water, gas) filled, expressed as a percentage or a fraction of the gross (bulk) rock volume.*
- Bitumen is “a general name for various solid and semi-solid hydrocarbons that are fusible and are soluble in carbon bisulfide” (Bates R, Jackson J, 1984)
- So is Bitumen part of the pore space or part of the matrix?



Example of density, neutron and NMR logs in sandstone with bitumen, and sandstone without bitumen



# Effective Porosity - Wikipedia has 6 definitions

- $\Phi_{e1}$  is oven dried core porosity

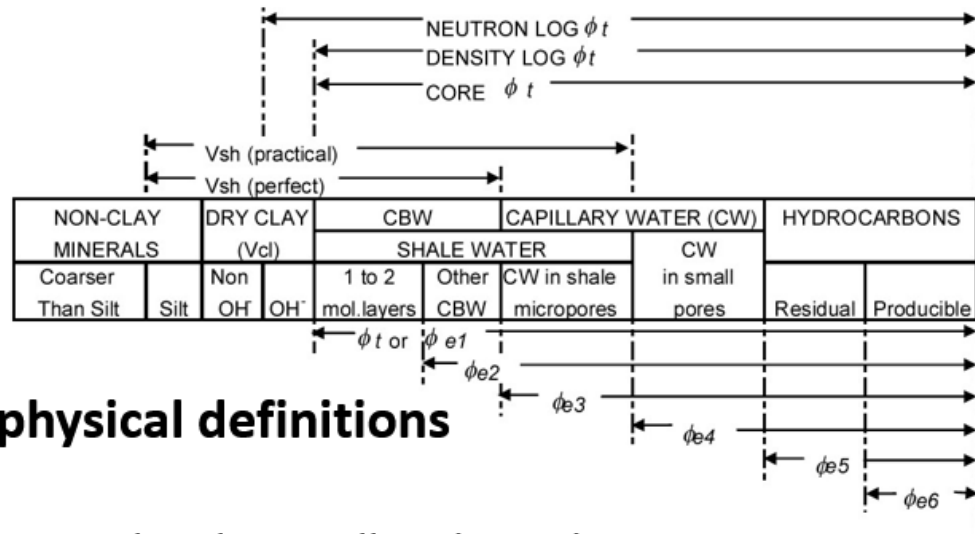
- $\Phi_{e2}$  is humidity core porosity

- $\Phi_{e3}$  and  $\Phi_{e4}$  are the 'normal' petrophysical definitions

- $\Phi_{e3}$  is  $\Phi_t$  minus 'clay water'
- $\Phi_{e4}$  is  $\Phi_t$  minus 'shale water', i.e. clay water plus the capillary bound water associated with the silt in the shale but excluding the capillary bound water associated with the silt in the sand..... but how do we discriminate that from logs?

- $\Phi_{e5}$  and  $\Phi_{e6}$  only consider pore space available to store hydrocarbons

- i.e. they exclude all the bound water



From Wikipedia - based on the Eslinger & Pevear concept (Eslinger, Pevear, 1988)



# Effective Porosity in Petrophysics

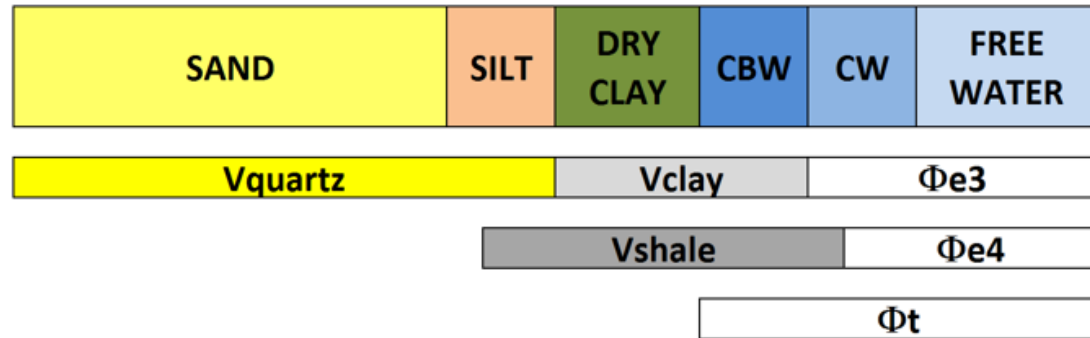
- **Most definitions refer to Connected Porosity**
  - Which tools do we have to measure this?
  - Sonic vs Density?
  - Not really....
- **Its confusing to use 2 different definitions of Effective Porosity in Petrophysics**
  - $\Phi_t$  minus 'clay water' ( $\Phi_{e3}$ ) is based on a mineral model
    - This is the definition used by all commercial non-deterministic solvers
    - This is also the definition used by some commercial deterministic models
  - $\Phi_t$  minus 'shale water' ( $\Phi_{e4}$ ) is based on a rock model
    - This is the definition used by some other commercial deterministic models



# Several 'Methods' are used to determine $\Phi_{e3}$ & $\Phi_{e4}$

## • For a given rock:

Vol sand = 0.5	$V_{\text{quartz}} = 0.62$
Vol silt = 0.12	$V_{\text{clay}} = 0.19$
Vol dry clay = 0.15	$V_{\text{shale}} = 0.30$
Vol clay bound water = 0.04	$\Phi_t = 0.23$
Vol capillary bound water = 0.04	$\Phi_{e3} = 0.19$
Vol free water = 0.15	$\Phi_{e4} = 0.18$



**we can compare different methods of calculating  $\Phi_e$  from the density log:**

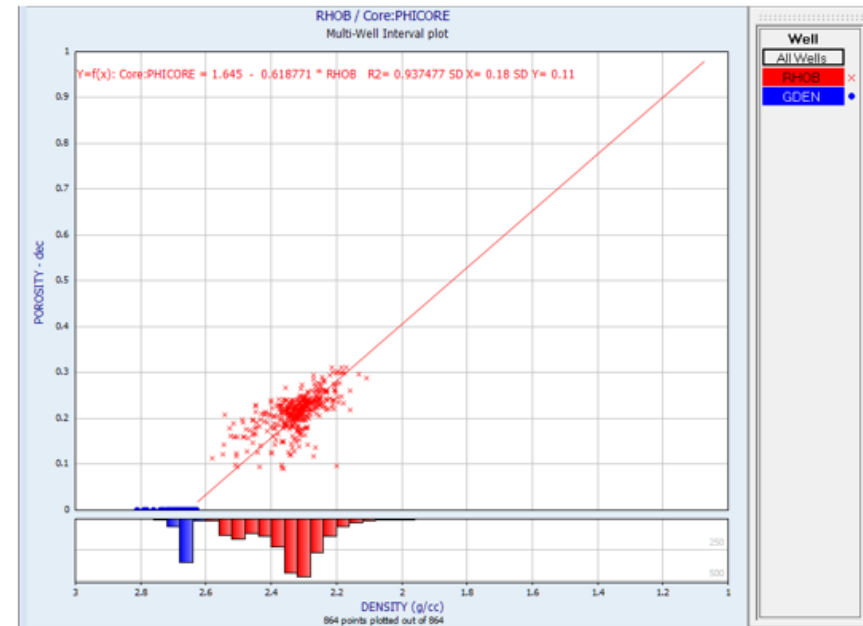
- **$\Phi_t$  first** – intuitively feels correct as we 'correct'  $\Phi_t$  to get  $\Phi_e$ 
  - Method 1 – calibrate directly to core
  - Method 2 –  $\Phi_t = (\rho_{ma} - \rho_b) / (\rho_{ma} - \rho_{fl})$  and  $\Phi_{e4} = \Phi_t - V_{sh} * \Phi_{tsh}$  where  $\Phi_{tsh} = (\rho_{ma} - \rho_{sh}) / (\rho_{ma} - \rho_{fl})$
  - Method 3 –  $\Phi_t$  same as Method 2 and  $\Phi_{e3} = \Phi_t - V_{cl} * \Phi_{tcl}$  where  $\Phi_{tcl} = (\rho_{ma} - \rho_{cl}) / (\rho_{ma} - \rho_{fl})$
  - Method 4 – replace  $\rho_{ma}$  in Methods 2 or 3 with a shale or clay corrected Grain Density
- **$\Phi_e$  first**
  - Method 5 – solve the tool response equations directly for  $\Phi_e$





# Method 1

- **Crossplot Regression of density log against core porosity**
- **This assumes a fixed  $\rho_{ma}$  and  $\rho_{fl}$** 
  - May be robust in homogeneous formations
  - Less robust in heterogeneous formations
    - Changing mineralogy
    - Changing clay content
    - Changing Net-To-Gross
    - Changing fluid types
    - Changing fluid saturations
    - Non cored intervals
  - Does not address differences in resolution
    - Problematic in thinly bedded shaley-sands
    - Logs 'see' a different volumetric average
    - Core may be preferentially plugged in clean sands



# Methods 2 and 3

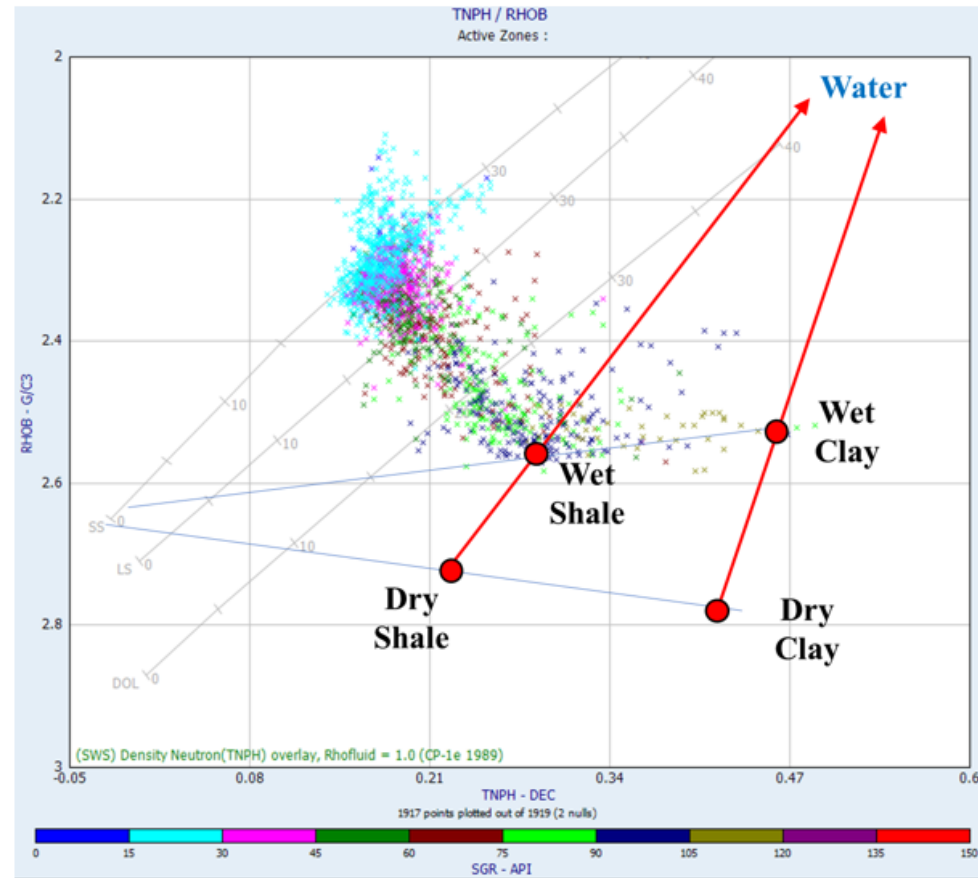
- **Both give the wrong  $\Phi_t$** 
  - $(\rho_{ma}-\rho_b)/(\rho_{ma}-\rho_{fl})$  gives the wrong  $\Phi_t$  as it ignores the clay minerals
- **Both give the wrong water volume**
  - $(\rho_{ma}-\rho_{sh})/(\rho_{ma}-\rho_{fl})$  gives the wrong shale water vol as it uses the wrong matrix point
  - $(\rho_{ma}-\rho_{cl})/(\rho_{ma}-\rho_{fl})$  produces wrong clay water vol as it uses the wrong matrix point
- **But both Methods do actually give the right  $\Phi_e$  ....**
  - Remarkably, 2 wrongs make a right!
- **However, this can lead to several problems**
  - Comparing the wrong  $\Phi_t$  to core  $\Phi_t$  can cause parameters to be wrongly picked, e.g.  $V_{cl}$
  - Using the wrong  $\Phi_t$  in SwT equations will give the wrong SwT
  - If  $\rho_{fl}$  is solved as a function of  $S_{xo}$  then that might be wrong as well
  - The correct  $\Phi_t$  still has to be calculated from  $\Phi_e$  using the correct water volumes
  - So, even when done correctly, its still  $\Phi_e$  first anyway!





# Correct Shale Water and Clay Water volumes

- **Calculated using the Dry and Wet points, not  $\rho_{ma}$** 
  - $\Phi_{tsh} = (\rho_{dsh} - \rho_{sh}) / (\rho_{dsh} - \rho_{fl})$
  - $\Phi_{tcl} = (\rho_{dcl} - \rho_{sh}) / (\rho_{dcl} - \rho_{fl})$
  - Dry clay density can be inferred from knowledge of the clay mineralogy
  - Dry shale density?
- **$\Phi_t$  re-calculated after  $\Phi_e$** 
  - $\Phi_t = \Phi_e + V_{sh} * \Phi_{tsh}$
  - $\Phi_t = \Phi_e + V_{cl} * \Phi_{tcl}$
- **This last step is often ignored**



## Method 4

- **Various forms of shale or clay correction to  $\rho_{ma}$  are in common use, e.g.**
  - $G_d = (1 - V_{sh}) \cdot \rho_{sd} + V_{sh} \cdot \rho_{sh}$
  - $G_d = (1 - V_{cl}) \cdot \rho_{sd} + V_{cl} \cdot \rho_{cl}$
  - $G_d = (1 - (V_{sh} \cdot CLY_{sh})) \cdot \rho_{sd} + (V_{sh} \cdot CLY_{sh} \cdot \rho_{dcl})$  where  $CLY_{sh}$  is Vol of dry clay in wet shale
- **All of these give the wrong Grain Density**
  - Many of these mix up dry and wet terms so they are inconsistent
  - Grain Density is given by  $(V_1 \cdot \rho_1 + V_2 \cdot \rho_2 + \dots + V_n \cdot \rho_n) / (V_1 + V_2 + \dots + V_n)$ 
    - i.e. it is the dry rock density normalized by  $(1 - \Phi_t)$
  - So using any volumetric sum ignoring the porosity gives the wrong Grain Density
- **So they give the wrong  $\Phi_t$**



# Method 5

- **The definition of bulk density is**
  - $\rho_b = V_1 \cdot \rho_1 + V_2 \cdot \rho_2 + \dots + V_n \cdot \rho_n$
- **For 2 minerals, matrix and clay, and 2 fluids, water and hydrocarbon**
  - $\Phi_e = (\rho_{ma} - \rho_b - V_{cl} \cdot (\rho_{ma} - \rho_{cl})) / (\rho_{ma} - \rho_w \cdot S_{xo} - (1 - S_{xo}) \cdot \rho_{hc})$  and  $\Phi_t = \Phi_e + V_{cl} \cdot \Phi_{tcl}$
  - This produces a fully consistent result with all the porosities and volumes correct
  - I.e. the tool response equation yields  $\Phi_e$  not  $\Phi_t$
- **Treating shale as a 'mineral', i.e. matrix, shale, water and hydrocarbon**
  - $\Phi_e = (\rho_{ma} - \rho_b - V_{sh} \cdot (\rho_{ma} - \rho_{sh})) / (\rho_{ma} - \rho_w \cdot S_{xo} - (1 - S_{xo}) \cdot \rho_{hc})$  and  $\Phi_t = \Phi_e + V_{sh} \cdot \Phi_{tsh}$
  - This also produces a fully consistent result with all the correct porosities and volumes
- **Note that there are no terms for structural, dispersed or laminated!**
  - The bulk density log response is not influenced by the distribution of the clays or shales
- **We can solve  $S_{xo}$  iteratively as it is a function of porosity**
  - It is more robust to incorporate R<sub>xo</sub> data than rely entirely on porosity logs (ND)



# Neutron Density Porosity

- **2 corrected porosities ( $\Phi_{DC}$  and  $\Phi_{NC}$ ) are often averaged**
  - $\Phi_e = (\Phi_{DC} + \Phi_{NC})/2$  (without gas)       $\Phi_e = ((\Phi_{DC}^2 + \Phi_{NC}^2))^{1/2}/2$  (with gas)
  - $\Phi_t = \Phi_e + V_{sh} * \Phi_{tsh}$  where  $\Phi_{tsh} = \delta * \Phi_{Dsh} + (1 - \delta) * \Phi_{Nsh}$  where  $\delta$  is 0.5 to 1
  - These are empirical averages that do not properly solve the problem
- **Neutron Porosity**
  - Often simply corrected in a similar manner to Methods 2 & 3 but this is wrong
  - The full tool response equation also includes Matrix, Excavation and Salinity corrections
  - The matrix correction should include the silt from both the sand and the shale volumes
  - Therefore, for Method 5, we should use the  $V_{cl}$  option, not  $V_{sh}$
- **2 equations solved together**
  - Second variable can be one of the common parameters, e.g.  $\rho_{ma}$ ,  $S_{xo}$ ,  $\rho_{hc}$ ,  $V_{cl}$
  - $\rho_{ma}$  makes an excellent variable to QC the interpretation

$$\phi_{e3} = \frac{\rho_{ma} - \rho_b - V_{cl} * (\rho_{ma} - \rho_{cl})}{\rho_{ma} - \rho_w * S_{xo} - (1 - S_{xo}) * \rho_{hc}}$$

$$\phi_{e3} = \frac{\phi_N - V_{cl} * N_{cl} + N_{ma} + \text{Exfact} + N_{sal}}{S_{xo} + (1 - S_{xo}) * N_{hc}}$$



**Thank you, Any Questions?**

