**Faculty of Science and Technology**
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**Solution:** BIP210 Well logging
And PET 110 Well Logging

**DATE:** 06.09.14

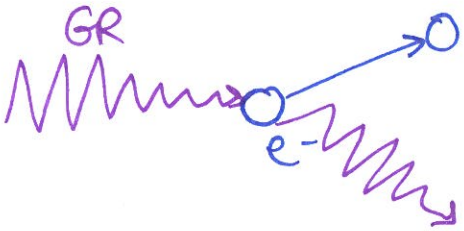
## Exercise 1 – Porosity Logs / Oppgave 1 - Porøsitets logger

Use short answers and sketches. Svar kort med skisser.

*Explain the Compton scattering using sketches.*

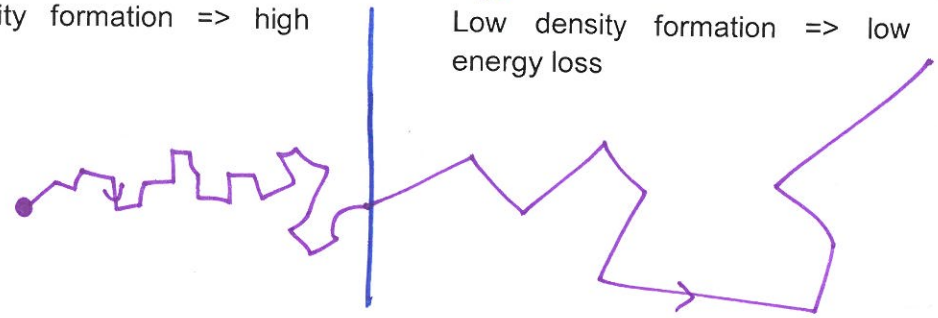
1. *Forklar Compton spredning ved hjelp av skisser.*

This is the loss of energy of the Gamma Ray due to the electrons present in the formation.

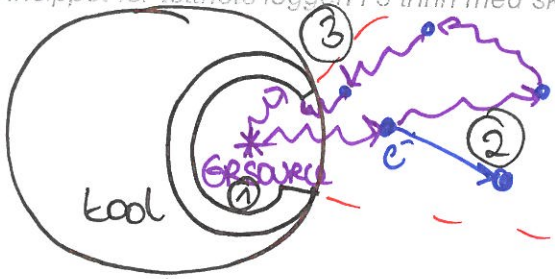



High density formation => high energy loss

Low density formation => low energy loss



1. *Explain the principle of the density log tool in 3 steps using sketches.*
2. *Forklar prinsippet for tetthets loggen i 3 trinn med skisser.*

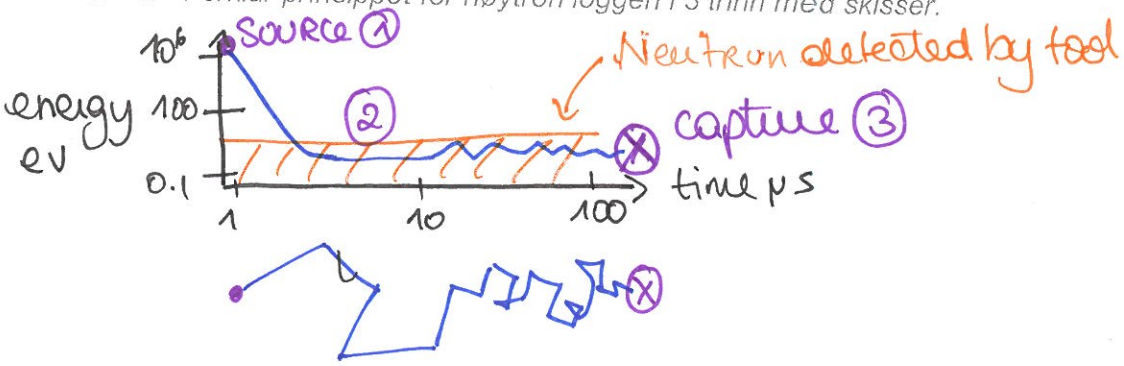



1) Radioactive source emits continuous beam of high energy GR

2) Compton scattering dependent on the density of the formation

3) GR scattered back to the GR detector: count rate of GR (dependent on density) directly converted to density.

2. *Explain the principle of the neutron log tool in 3 steps using sketches.*
3. *3. Forklar prinsippet for nøytron loggen i 3 trinn med skisser.*




1) Neutron emission from source: high energy and fast N

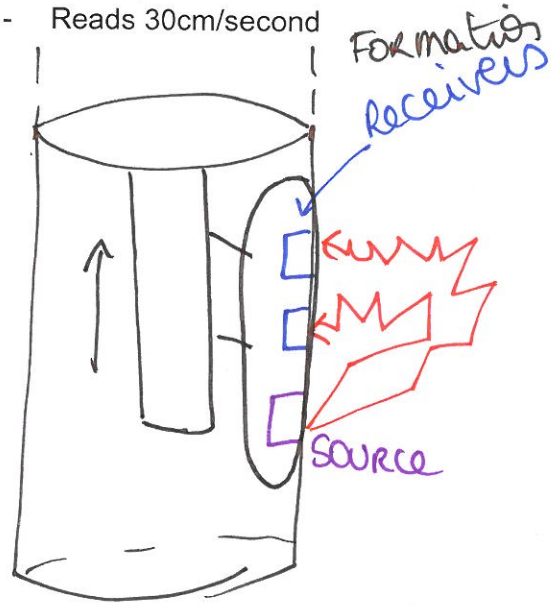
2) Neutron scattering: interaction with other atoms present in the formation. 3 Types of scattering exist and the most efficient is if the other atom has the same mass than the neutron, i.e. Hydrogen atom.

3) Capture of the N by the tool when N at low energy (⇔ when diffusing N)

4. *What are the differences between a wireline tool and logging while drilling tool for both density and neutron logs? Use sketches.*
5. *4. Hva er forskjellen mellom wireline logging og logging under boring for både tetthets loggen og nøytron loggen? Bruk skisser.*

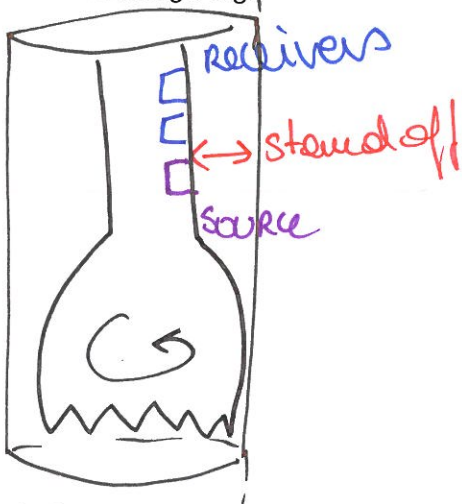
WL tools:

- Tools against the wall: direct reading
- Reads 30cm/second




LWD tools:

- Tools behind steel => less GR and N reach the tool back
- Separated from borehole wall => need to use stabilizers and correction for stand off
- Rotation: image logs




*How is the porosity determined from the three porosity logs?*

5. *Hvordan blir porøsiteten bestemt ut fra de tre porøsitets loggene?*

1) Porosity from density

$$\emptyset_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

2) From neutron: $\emptyset_N = \emptyset_N + 0.04$ for Sandstone

$\emptyset_N$=$\emptyset_N$ for limestone

$\emptyset_N$=$\emptyset_N$-0.07 for dolomite

3) From the P-wave slowness, porosity from the sonic

$$\emptyset_s = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$$

4) Using density and neutron log, by using chart 11 (enclosure 4)

6. *Do we need to correct the sonic porosity for sandstones? If so, explain what this correction is using an example.*

6. *Må vi korrigere sonic porøsiteten for sandstein? Hvis så, forklar denne korreksjonen med a bruke et eksempel.*

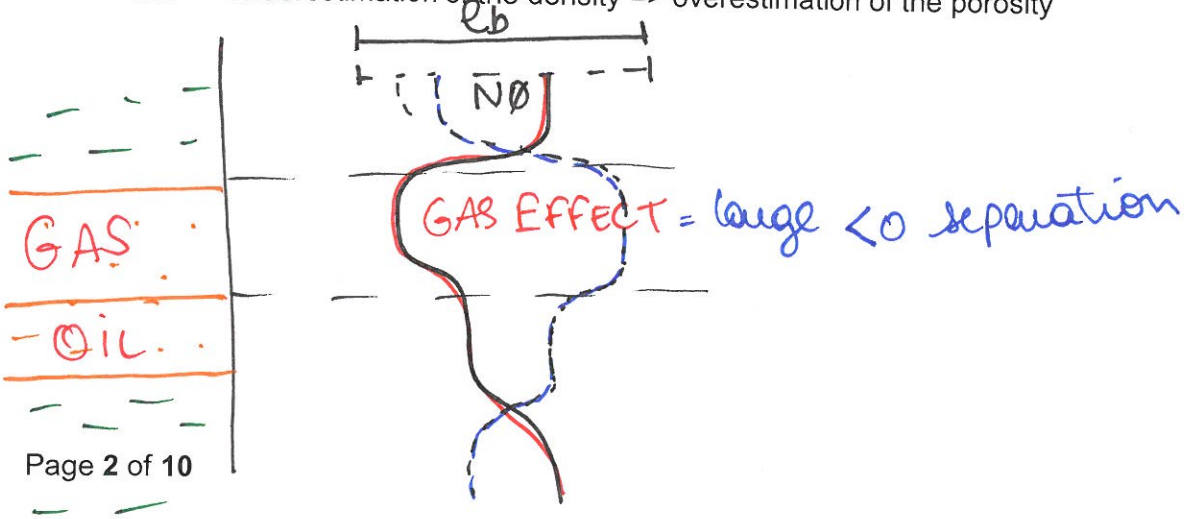
The sandstone might be not consolidated at 100%, we need then to determine the formation strength factor Bcp from the sonic log and the porosity computed for example from the density log. This factor is comprised between 1 and 2 and the correction is applied as follow:

$$\emptyset_s = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \times \frac{1}{B_{cp}}$$

For example, using chart 6 (enclosure 3), if we have a porosity from the density log $\emptyset_D$ = 20% and a sonic of $\Delta t$ = 90 $usec/ft$, we obtain a BCP of 1.30, which means that the formation is not consolidated and we have production problems.

7. *Gas-filled reservoir - Gas reservoar*
   a. *What is the impact of a gas-filled reservoir rock on the density and neutron logs? Explain and illustrate with sketches.*
   b. *a. Hvilken innvirkning har en gassfylt reservoir sone på tetthets loggen og nøytron loggen? Forklar og illustrer med skisser.*

- Gas effect on Neutron: low quantity of H => less scattering of Neutrons => porosity underestimated
- Gas effect on Density: low quantity of electrons => less GR coming back to the tool => underestimation of the density => overestimation of the porosity



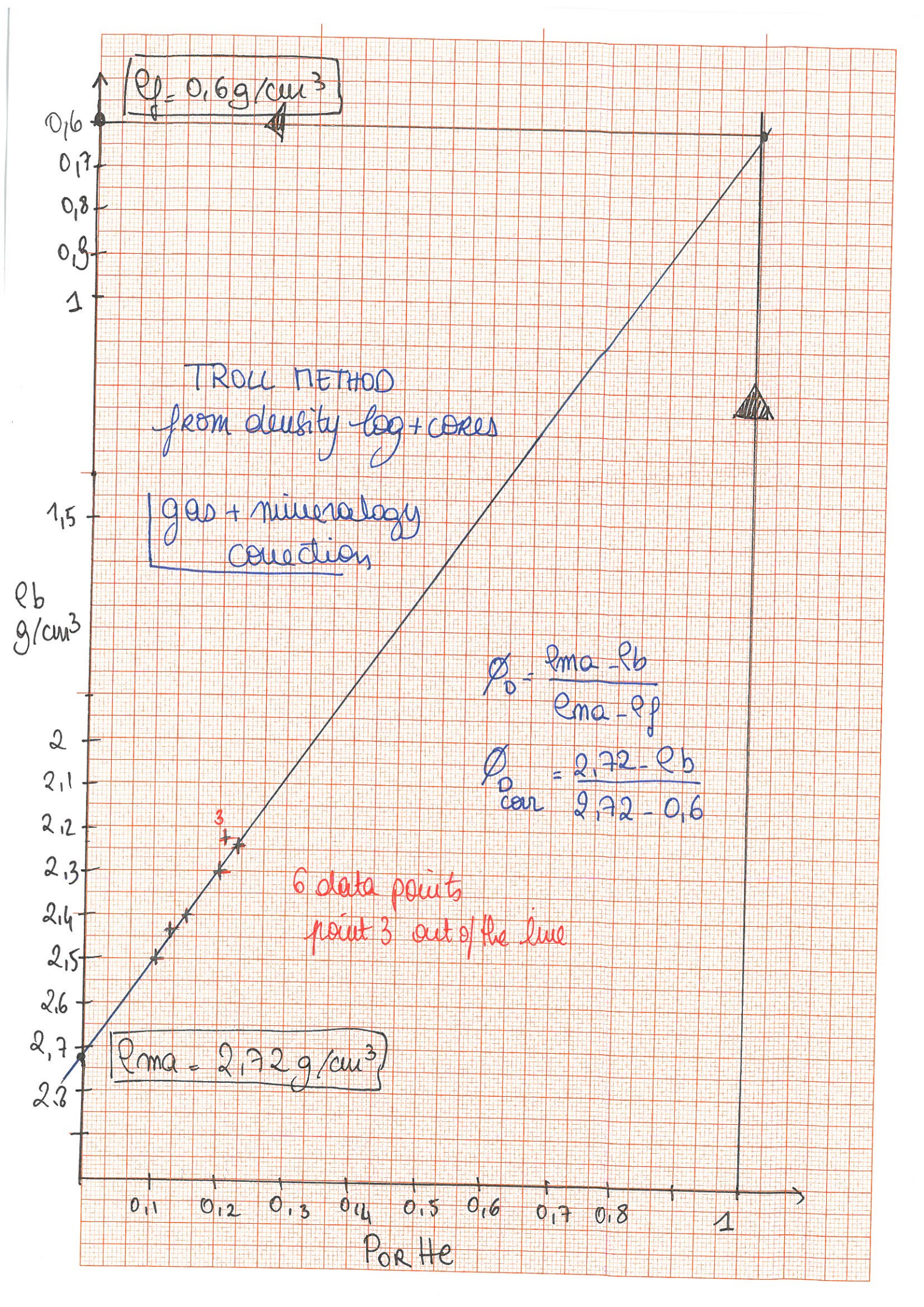
c. *For a sandstone section saturated by gas, we have the following data from the porosity log (ρb) and core porosity (PorHe):*

b. *For en sandstein sone mette med gass har vi følgende data fra porøsitets logg (ρb) og kjerne porøsitet (PorHe):*

| Point/punkt | ρb (g/cm3) | PorHe |
|---|---|---|
| 1 | 2,24 | 0.225 |
| 2 | 2,40 | 0,15 |
| 3 | 2,22 | 0,21 |
| 4 | 2,50 | 0,11 |
| 5 | 2,43 | 0,125 |
| 6 | 2,30 | 0,20 |

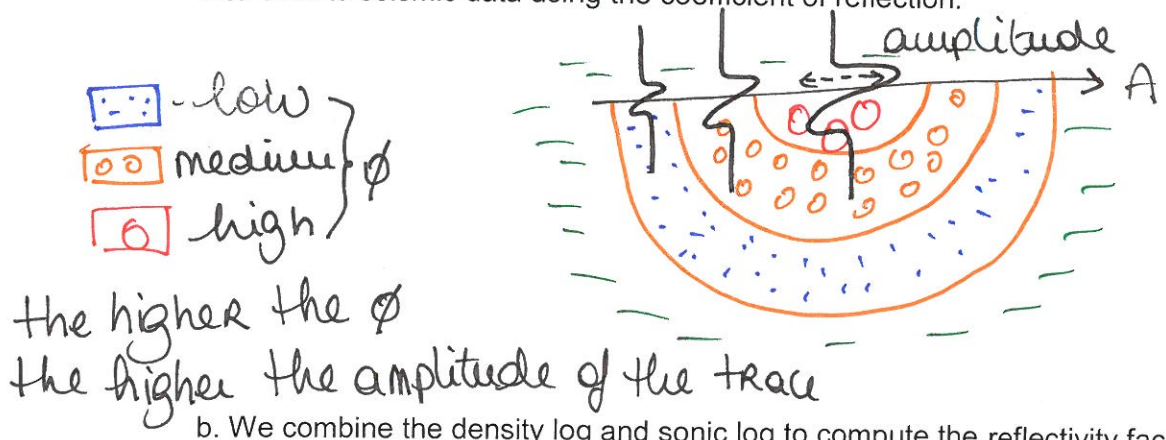
*Use these data to determine the porosity from the density log corrected for the gas effect. This relation is also valid in the formation where there is no core data.*

*Bruk disse data for å bestemme porøsiteten fra tetthets loggen korrigert for gas effekt. Denne relasjonen kan også brukes I formasjoner hvor der ikke er kjerne data.*


$\rho_f = 0,6\ g/cm^3$
0,6
0,7
0,8
0,9
1
TROLL METHOD
from density log + CORES
gas + mineralogy correction
1,5
$\rho_b$ g/cm3
$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$
$\phi_{D\,cor} = \frac{2,72 - \rho_b}{2,72 - 0,6}$
2
2,1
2,2
2,3
2,4
2,5
2,6
2,7
2,8
3
6 data points
point 3 out of the line
$\rho_{ma} = 2,72\ g/cm^3$
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
1
POR HE

8. *Use sketches to illustrate.*
    a. *What do we call seismic lithology?*
    b. *Show how the density log and sonic log can be used in seismic lithology.*
9. . *Bruk skisser til a illustrere*
    a. *Hva kaller vi seismisk lithologi?*
    b. *Vis hvordan tetthets loggen og sonic loggen kan bli brukt i seismisk lithologi.*

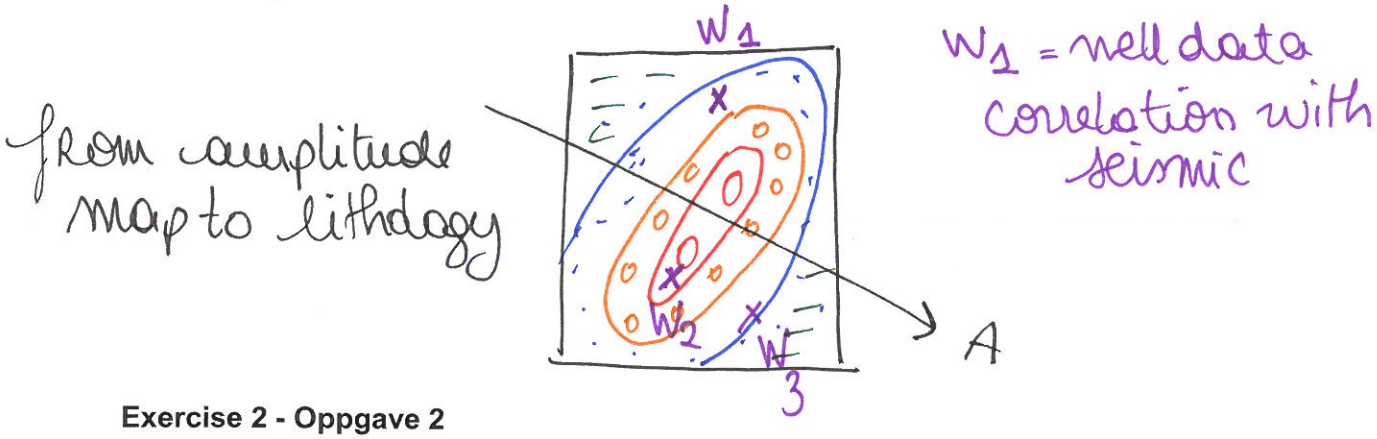
a. We call seismic lithology a technique to determine the lithology by combining the well data to seismic data using the coefficient of reflection.




b. We combine the density log and sonic log to compute the reflectivity factor at a given depth.

$$R = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1}$$

This factor obtained from several wells can be then plotted in seismic map to test our model interpretation.



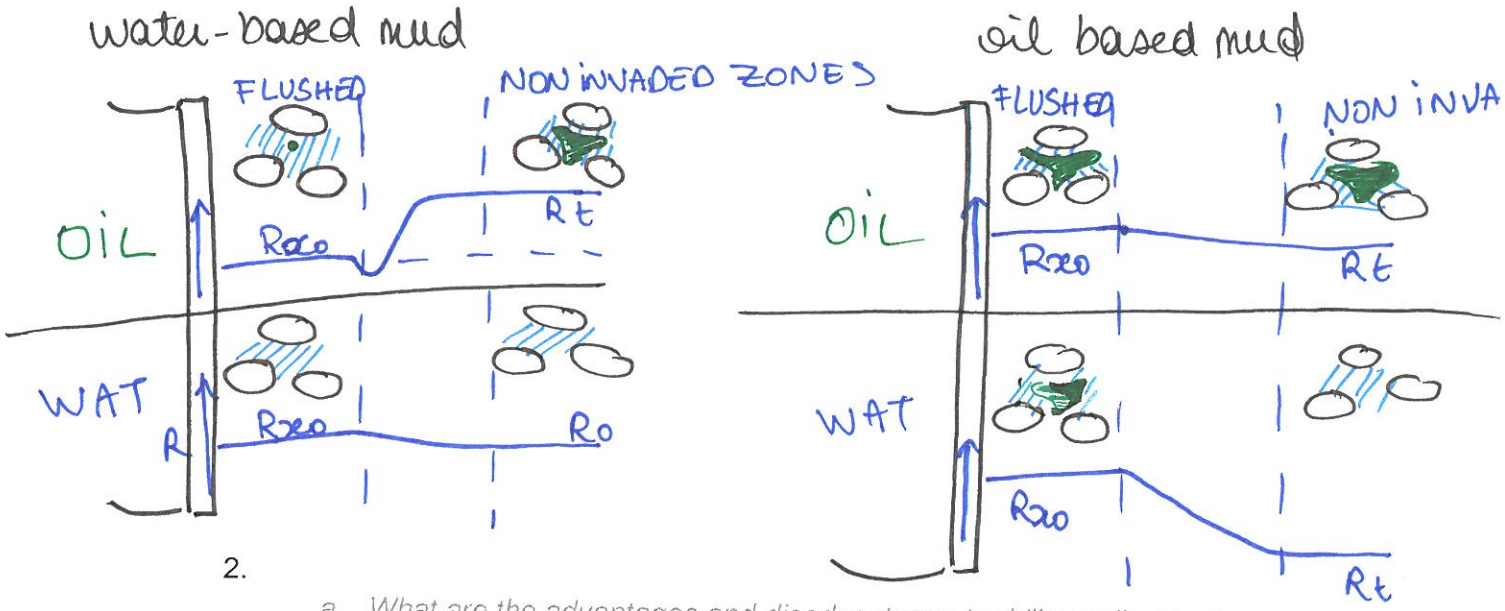

**Exercise 2 - Oppgave 2**

1. *Describe the resistivity profiles for the invaded/flushed zone in around a well both for the oil and water zones in: (Use sketches)*
    a. *Water based mud*
    b. *Oil based mud*

1. *Beskriv motstands profilene for invader/flused sone rundt en brønn både for oljesone og vannsone ved: (Bruk skisser)*

    a. *Vannbasert mud*

    b. *Oljebasert mud*




2.

a. *What are the advantages and disadvantages to drill a well with oil-based mud?*
b. *Which logs cannot be run with oil-based mud?*
c. *Can these logs be replaced with other logs? If yes, which ones?*

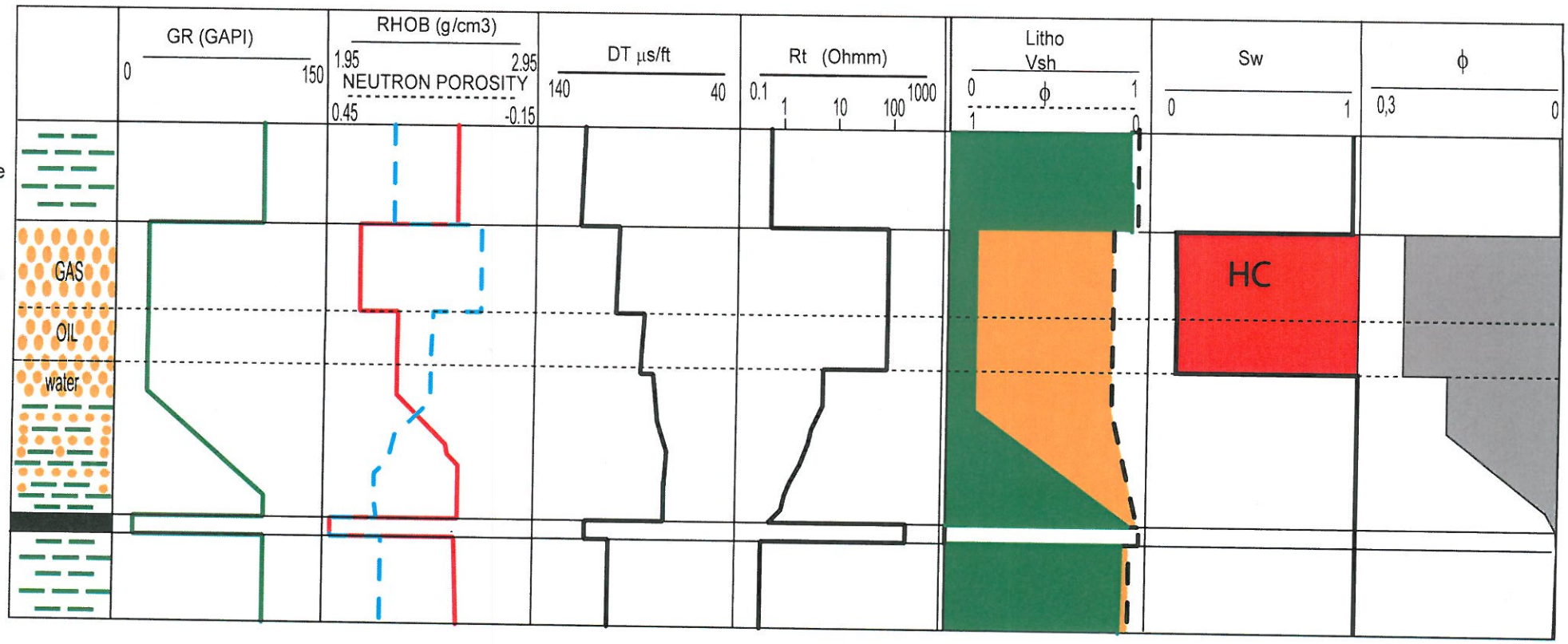
*2.*

d. *Hva er fordelene og ulempene ved å bore en brønn med oljebasert mud?*
e. *Hvilke logger kan ikke bli kjørt med oljebasert mud?*
f. *Kan disse loggene bli erstattet av andre logger? Hvis ja, hvilke logger?*

- advantages: no reaction with oil phase, reduces drilling time, good lubricant
- disadvantages: not conductive: not all the logs can be done and more damaging for the environment
- Logs that cannot be run are laterolog, SP-log and micro-resistivity log (laterolog)
- Laterolog can be replaced by Induction log as well as micro-resisitivity log and SP-log can be replaced by Gamma Ray log.

*3. A CPI plot is a finale interpretation of the raw data and evaluated data (shale/sand composition, net sand, porosity, water saturation and permeability). Draw directly in Figure 2.1 the log responses for the presented lithology section. Create a CPI plot for the sand-shale composition, the finale porosity and water saturation on the track depth in Figure 2.1.*

*3. Et CPI plot er den endelige tolkningen av rådata og evaluerte data. (sand/skifer sammensetning, net sand, porøsitet, vannmetning og permeabilitet). Tegn direkte i figur 2.1 loggresponsene for den gitte lithologi- seksjonen. Lag et CPI plot for sand-skifer sammensetningen, den endelige porøsitet og vannmetning i dybdesporet på figur 2.1*


GR (GAPI)
0
150
RHOB (g/cm3)
1.95
2.95
NEUTRON POROSITY
0.45
-0.15
DT µs/ft
140
40
Rt (Ohmm)
0.1
1
10
100
1000
Litho
Vsh
0
ϕ
1
1
0
Sw
0
1
ϕ
0,3
0
Shale
Sandstone
GAS
OIL
water
Coal
HC

**Exercise 3 – Well evaluation - Øvelse 3 - Brønnevaluering**

*This well is from the Skuld Field in the Haltenbanken area. The following logs are given for an interval from 2400m to 2800m (Figure 3):*

- *Gamma log*
- *Density log*
- *Neutron log*
- *Sonic log*
- *Resistivity log*

*Denne brønnen er fra Skuld feltet i Haltenbanken-området. De følgende logger er gitt for intervallet fra 2400m til 2800m (figur 3):*

- *Gamma logg*
- *Tetthets logg*
- *Neutron logg*
- *Sonic logg*
- *Motstands logg*

1. *Mark the lithology direct in the depth track.*
1. *Marker lithologien direkte i dybdesporet.*

2. *Explain the lithology in point A.*
2. *Forklar lithologien i punkt A.*

*- High density 2.8*

*- Low porosity neutron ~05.0*

*- Low GR (not radioactive)*

*- really high resistivity*

*- low slowness (fast wave propagation)*

*Anhydrite explains this behavior ($\rho_b$ = 2,96, $\phi_N$ = 0.05, so high resistivity and low slowness).*

3. *Mark the fluid contact.*
3. *Marker væske kontakt.*

4. *What type of sedimentology shows each of the zones Intra Melke, Tofte and Åre?*
4. *Hvilke type sedimentologi viser hver av sonene Intra Melke, Tofte og Åre?*

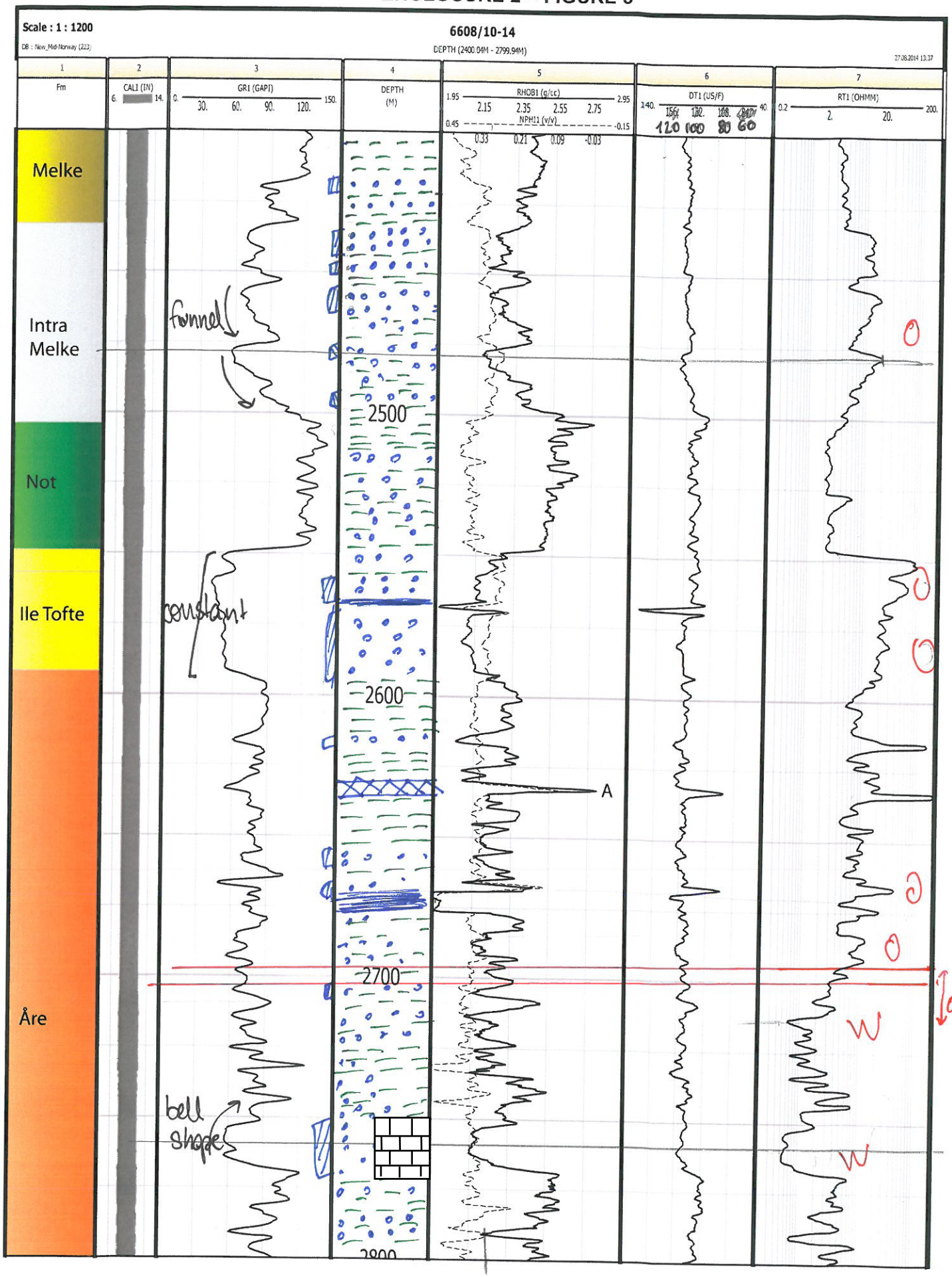
*Intra Melke: funnel shape, coarsening upwards => regression*

*Tofte: uniform deposition => channel, fluvial*

*Åre: bell shape , fining upwards => transgression*

5. *For the deepest Intra Melke sand:*
   a. *Estimate the porosity using the three methods.*
   b. *Which porosity will you use for the next calculations? Justify.*
   c. *Estimate the water saturation.*
5. *For den dypeste Intra Melke sand:*
   d. *Bestem porøsiteten fra de 3 metodene.*
   e. *Hvilken porøsitet vi du bruke for de neste evalueringene? Forklar.*
   f. *Bestem vannmetningen*

## ENCLOSURE 2 – FIGURE 3






Sandstone Shale Limestone- Coal

| | | GR (API) | Density (g/cm3) | Neutron | Sonic (µs/ft) | Resistivity (Ohmm) |
|---|---|---|---|---|---|---|
| Oil zone | 2478m | 58 | 2,18 | 0,24 | 104 | 20 |
| Water zone | 2760m | 58 | 2,16 | 0,32 | 98 | 0,6 |

- OIL ZONE: determination of porosity from 3 methods:
  - Porosity from density

$$\emptyset_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

$$\emptyset_D = \frac{2.65 - 2.18}{2.65 - 1.00}$$

$$\emptyset_D = \mathbf{0.285}$$

  - Porosity from sonic

$$\emptyset_s = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$$

$$\emptyset_s = \frac{104 - 55}{189 - 55}$$

$$\emptyset_s = \mathbf{0.37}$$

This value should be corrected with the Bcp using $\emptyset_D = \mathbf{0.28}$ and enclosure 3: Bcp = 1,28

$$\emptyset_s = \frac{104 - 55}{189 - 55} \times \frac{1}{1,28}$$

$$\emptyset_s = \mathbf{0.287}$$

  - Porosity from density and neutron logs using chart 11 enclosure 4:

$$\emptyset = \mathbf{0.285}$$

The three calculated porosity are really close to each other. We will use $\emptyset = \mathbf{0.285}$ as it was both found by the porosity from density but also by the porosity taking into account two logs density and neutron.

- Formation factor in oil zone

$$F_oil = \frac{0.62}{0.285^{2.15}} = 9.22$$

- WATER ZONE
  - Porosity from density

$$\emptyset_D = \frac{2.65 - 2.16}{2.65 - 1.00} = 0.297$$

  - Formation factor
    - in sandstones

$$F_wat = \frac{0.62}{0.297^{2.15}} = 8.4$$

- in limestone

$$F_wat = \frac{1}{0.297^2} = 11{,}34$$

- Rw
  - In sandstones

$$Rw = \frac{Ro}{F_wat} = \frac{0.6}{8.4} = 0.0714$$

  - In limestones

$$Rw = \frac{Ro}{F_wat} = \frac{0.6}{11{,}34} = 0.0529$$

- Water saturation in oil zone

$$Sw = \sqrt[2]{\frac{F_oil \times Rw}{Rt}} = \boldsymbol{Sw}$$

$$Sw = \sqrt[2]{\frac{9.22 \times 0.0714}{20}} = \mathbf{0.18} = \boldsymbol{Sw}$$

$$Sw = \sqrt[2]{\frac{9.22 \times 0.0529}{20}} = \mathbf{0.156} = \boldsymbol{Sw}$$

6.

a. *What is the Net Sand?*
b. *Mark the net sand zone on the logs*

7.

a. *Hva er Net Sand?*
b. *Marker net sand sonene på loggene.*

Net Sand = producible sand

K>0.05mDa which is equivalent to Ø > 0.1 and Vcl <0.4