Example exam for 3 hours.   Name:……………………………………Study no. ………...

ANSWERS

Part 1: Case story (figure 1, 2)

In Ruhlermoor (Germany) a fragmented clean sandstone reservoir is recognised at a depth of 2.2 km. The tight sandstone bodies (m = 2, n = 2) are divided by impermeable clay-shale zones and tight faults. Two exploration drillings provided the laboratory with core samples. The regional geothermal gradient is about 4°C/100 m and the yearly average surface temperature is 10 °C.

Core samples are used in the laboratory to measure the porosity, permeability and conductivity. The test samples had a length of 5 cm, a circular diameter of 2 cm and an average dry weight of 27.1 gram. The matrix density is 2.65 $g/cm^{3.}$ Permeability tests showed a pressure drop of 15 bar at a flow rate of 3.6 cm^3/s. In the formation water samples a salinity of 20.000 ppm was measured at a lab temperature of 20°C. The viscosity of the brine is $1,01*10^{-3}$ Pa.s.

A: Give the formula for the geothermal gradient and estimate the bottom hole temperature.

Formula: °C/km = **(Tdepth-Tsurface)/Depth**

Bottom hole temperature: **10 + 22 * 4 = 98 °C**

B: Give the density of the formation fluid and calculate the bottom hole fluid pressure.

Fluid density: **1020** kg/m^3. (20.000 ppm ~ 20 g/kg)

Bottom hole pressure: **224,4 bar or 22.44 Mpa (In bar or MPa). Depth 2.2 km; 2200 * 0.102 = 224.4 bar**

C: Give the Darcy-equation, name the parameters and calculate the porosity and permeability.

$$Q = \frac{k \cdot A \cdot \Delta P}{\eta \cdot L} \Rightarrow k = \frac{Q \cdot \eta \cdot L}{A \cdot \Delta P}$$

Parameter	Definition	Units	Values
k	**Permeability**	**m^2**	**?**
dP	**Pressure drop over the flow path**	**1 bar = 10^5 Pa = 10^5 N/m^2**	**1.5 Mpa or $1.5*10^6$ N/m^2**
L	**Shortest length of the flow path**	**m**	**$5*10^{-2}$**
A	**Cross area of the flow path**	**m^2**	**$3.14*10^{-4}$**
η	**Viscosity pof the fluid or gas**	**Pa.s or kg/m.s**	**$1.01*10^{-3}$**
Q	**Flow rate**	**m^3/s**	**$3.6*10^{-6}$**

Porosity: **0.35 or 35 %: diameter; 2 cm, length; 5 cm, Area; 3.14 cm^2, V; 15.71 cc, ρ_{matrix} ; 2.65 g/cc, $Weight_{bulk}$ 27.1 g, so: (27.1/15.71) gives ρ_{bulk}. $\rho_{bulk}/\rho_{matrix}$ gives the fraction matrix volume: 0.65, so pore volume is 1-0.65 = 0.35**

Permeability: **See values and units in previous table: 0.4 D or $3.86*10^{-13}$ m^2**

D: Give the first Archie relations, name the parameters and calculate Ro at bottom hole conditions.

$$F = \varphi^{-m} = \frac{R_o}{R_w}$$

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Parameter	Definition	Units
φ	**Porosity (0.35)**	**ratio**
R_o	**Resistivity of porous sandstone rock with S_w =1 (?)**	**Ohm.m**
R_w	**Resistivity of water (0.22 ohm.m at 98 °C)**	**Ohm.m**
m	**Cementation factor (2)**	**number**
F	**Formation factor**	**number**

Ro = $R_w * \varphi^{-m}$ ➔ $0.11 * 0.35^{-2}$ =0.9 Ohm.m

The second sand lens appears to contain water and methane gas. The in-situ P,T, matrix and pore properties of this sandstone are the same as for the water-saturated sandstone.
F: Give the second Archie relations, name the parameters and calculate Sw at bottom hole conditions.

$I = S_w^{-n} = R_t/R_o$

Parameter	Definition	Units
I	**Saturation Index (?)**	**number**
S_w	**Water saturation (?)**	**ratio**
n	**Saturation exponent (2)**	**number**
R_t	**True resistivity in a porous sand(stone) (1.7)**	**Ohm.m**
R_o	**Resistivity of porous sandstone rock with S_w =1 (0.9)**	**Ohm.m**

The Laterolog provided information about the virgin zone: Rt = 1.7 ohm.m. What is the hydrocarbon saturation?

HC = ? ➔ $S_w = \sqrt[n]{\frac{R_o}{R_t}}$ **or $(0.9/1.7)^{1/2}$ =0.72 so Hc = 1-S_w thus 1 - 0.72 = 0.28**

G: Now knowing that at 2.2 km depth a mixture of gas and water is present, one likes to know the water column, rising above the free water level. By using and completing the equations below, one can calculate the capillary rise.

Complete: $$\Delta P = P_1 - P_2 = P_C = \frac{2 \cdot \gamma \cdot \cos\theta}{r} = \left(\rho_{water} - \rho_{air}\right) \cdot g \cdot h$$

Parameter	Definition	Units
ΔP	**Pressure difference**	**N/m^2**
P_1	**Pressure at the free water level**	**N/m^2**
P_2	**Pressure at the top water column**	**N/m^2**
P_c	**The capillary pressure**	**N/m^2**
γ	**Surface tension**	**83 dyne/cm (or 83*0.001 N/m)**
θ	**Interface angle**	**COSθ=1**
r	**Radius tube**	**10^{-5} m**
ρ_w	**Density water**	**1020 kg/m^3**
ρ_g	**Gravity**	**In situ: 385 kg/m^3**
g	**Specific gravity**	**9.8 m/s^2**
h	**Column hight**	**? m**

The pore necks of the sandstone can be seen as a tube diameter of 10 micron (10^{-5} m)

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Capillary rise h: **5.22 m** ➔

$$h = \frac{2 \cdot \gamma \cdot \cos\theta}{r \cdot g \cdot \Delta\rho_{water-air}}$$ **or $(2*83*10^{-3}*1)/(5*10^{-5}*635) = 5.22$ m**

Part 2: General questions

A: What is the difference between oil wet and water wet pores.

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- What is the relation between the rock porosity and the interval transit time

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B: What is an empirical relation.

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- Give an example.

SEE LECTURE NOTES

C: Describe the relation between grain sorting and porosity.

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D: Describe the principal physics of the Laterolog ***or*** the induction log.

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- In which types of borehole fluids are these tools to be used?

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E: Which kinds of elements are creating the radioactivity needed for natural gamma ray measurements?

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- Quality of GR-borehole measurements is often depending on logging speed. How?

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G: Name two methods to define the shale volume of a clastic water, oil or gas reservoir.

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- Give one relation: V_{sh} = ---------------------------

Part 3: Log analysis (figure 3, 4)

A: Name the layers from log readings (figure 3) and motivate your choice of sediment type and pore content.

Layer number	Depth range	Sediment type + pore content
1	1500-1507	Shale / claystone
2	1507-1510	Sandstone + pores + gas
3	1510-1517	Shale / claystone
4	1517-1522	Sandstone + pores + oil
5	1522-1527	Shaly sandstone
6	1527-1531	Sandstone + pores + water
7	1531-1536	Shaly sandstone
8	1536-1542	Sandstone + pores + water
9	1542-1545	Shaly sandstone
10	1545-1550	Shale / claystone

B: Use the "Neutron porosity - density" plot to define the shale point, the shale content, the total porosity and effective porosity.

Layer number	Depth range	Shale volume Ratio	Total porosity-%	Effective porosity-%		GR Shale Volume Ratio
1	1500-1507	1	12	0		1
2	1507-1510	0	22	22		0
3	1510-1517	1	12	0		1
4	1517-1522	0.32	12.5	8		0
5	1522-1527	0.8	21	20		0.1
6	1527-1531	0	9	9		1
7	1531-1536	0.30	15	12		1.25
8	1536-1542	0	6	6		0
9	1542-1545	0.55	9	2		0.4
10	1545-1550	1	12	0		1

C: Give the shale volume by using the natural gamma-ray readings in the table above.
The small changes between the outcomes of the neutron/density method and the gamma-ray method can be explained. Name one of the possibilities.

FIGURE 1

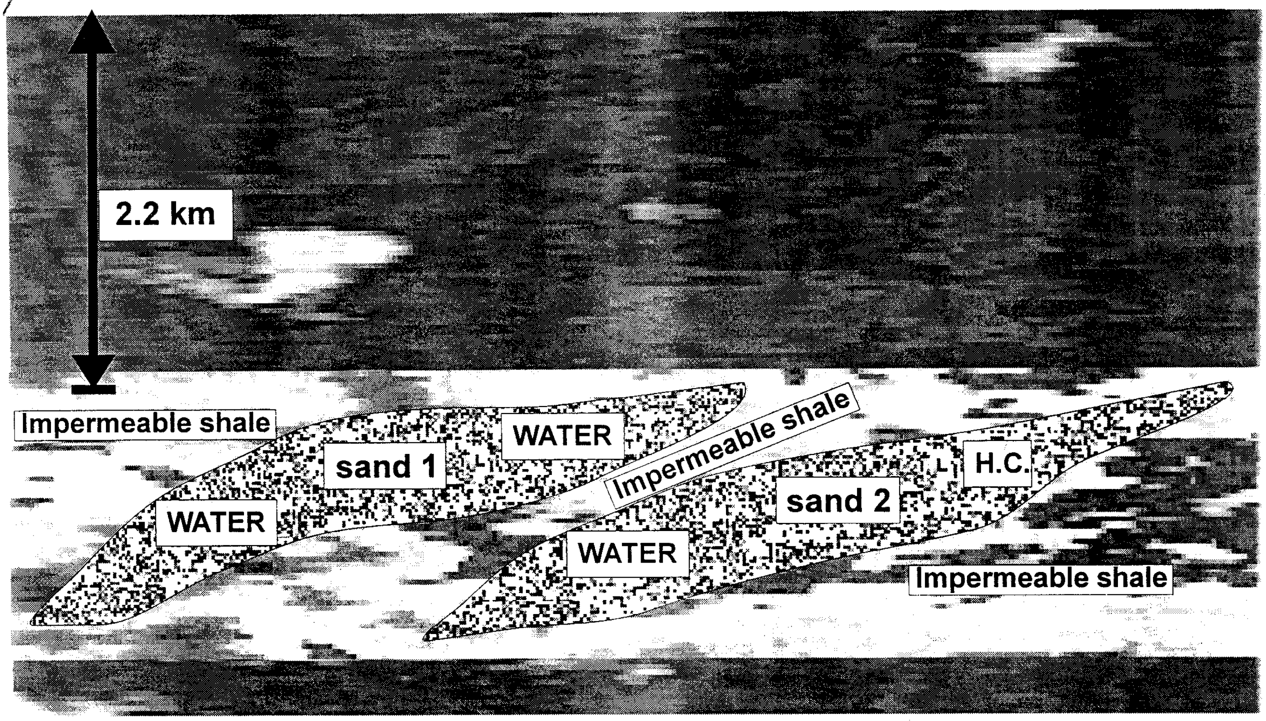
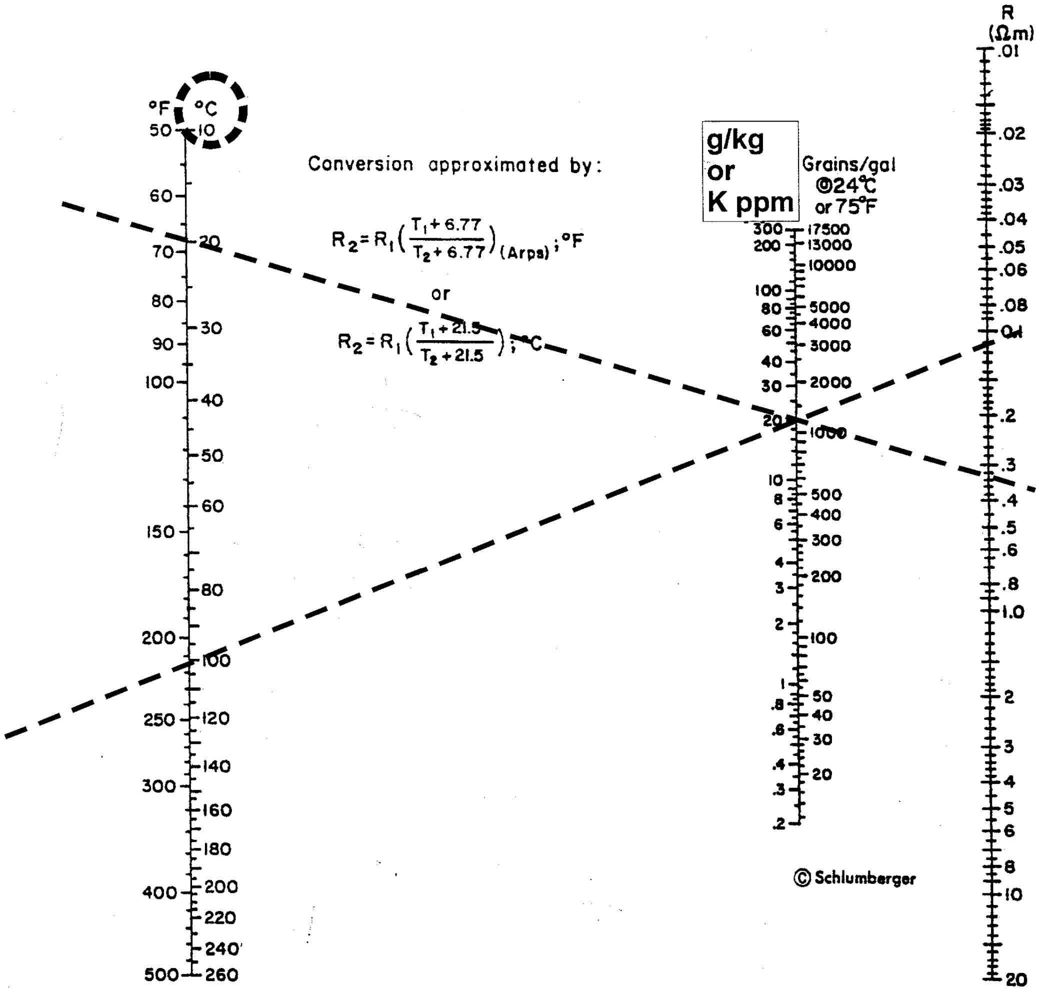


FIGURE 2



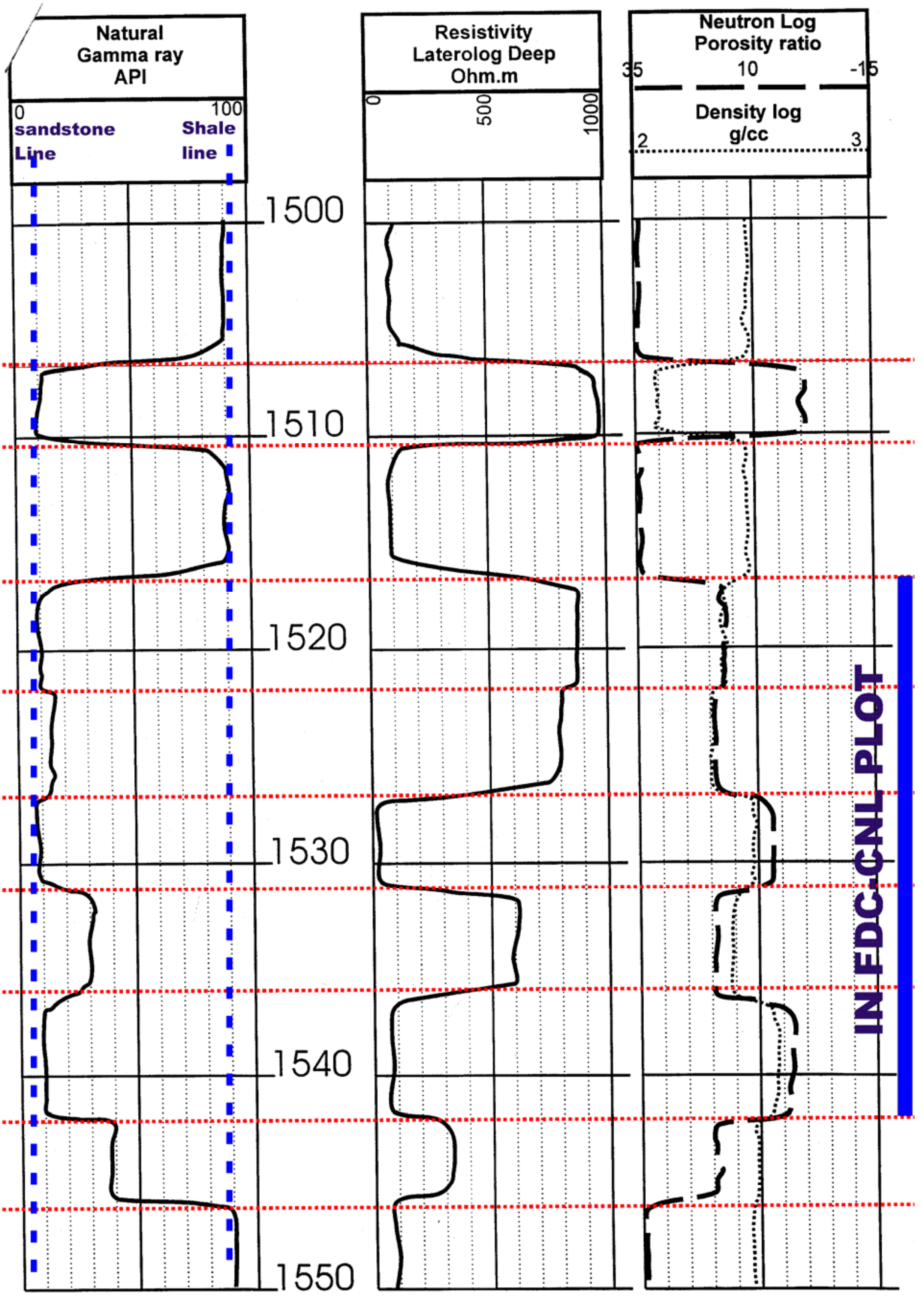

Natural
Gamma ray
API
0
100
sandstone
Line
Shale
line
Resistivity
Laterolog Deep
Ohm.m
0
500
1000
Neutron Log
Porosity ratio
35
10
-15
Density log
g/cc
2
3
1500
1510
1520
1530
1540
1550
IN FDC-CNL PLOT

FIGURE 3

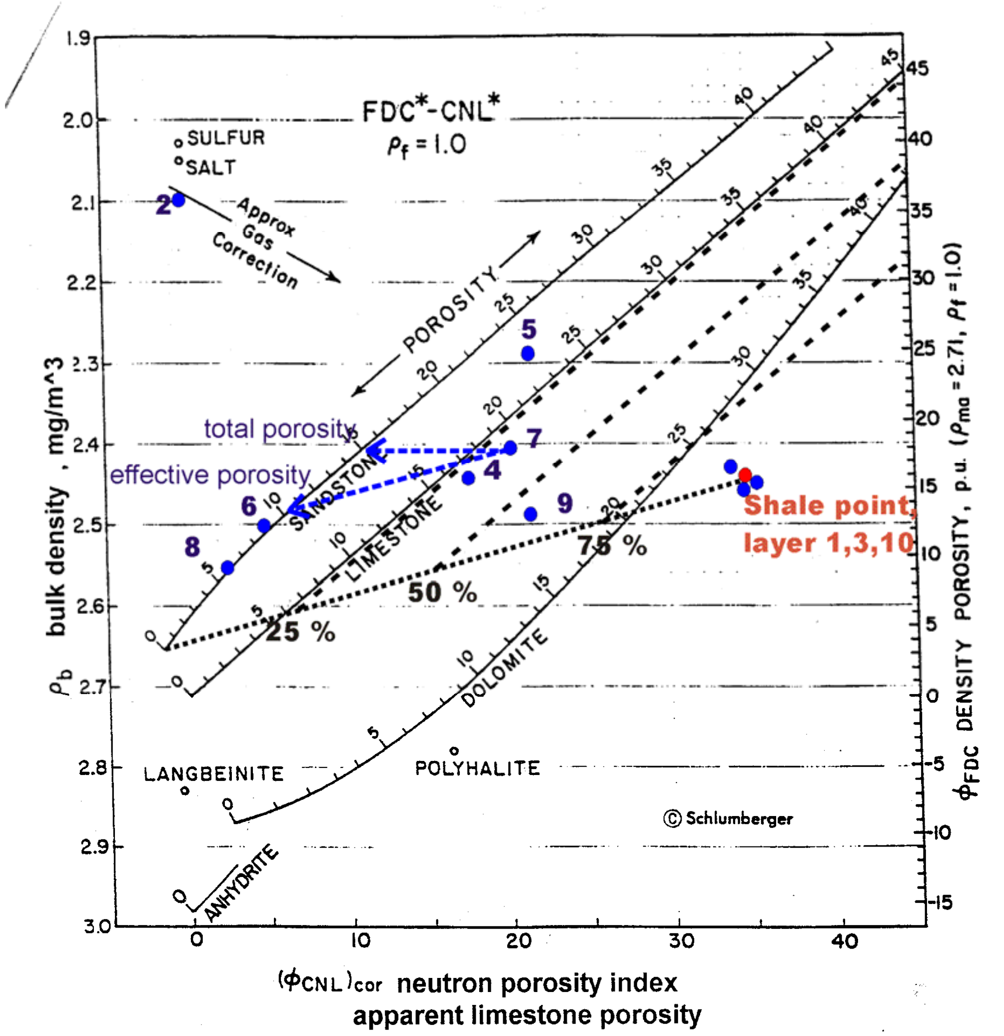


FIGURE 4

Most relevant minerals, composition, density and main occurrence (from Carmichael, 1985 and Schlumberger 1989)

Name	Composition	Density kg/m³ x 10³	Occurrence *
Silicates			
Olivine	$(Mg,Fe)_2 SiO_4$	3.2 - 4.14	i, v
Garnet	$(Fe,Mg,Ca)_3.(Fe,Al)_2.(SiO)_3$	3.75 - 4.25	i, m
Pyroxenes	$(Ca,Mg,Fe,Al).[(Al,Si)O_3]_2$	3.2 - 3.5	i, m
Amphiboles	$Ca_{0-2}(Mg,Fe,Al)_{5-6}[(Al,Si)_4O_{11}]_2.(OH)_2$	3 - 3.2	i, m
Quartz	SiO_2	2.65	i, (v), m, s-cl/ch, d
Feldspar	$(Na,K,Ca).Al.(Al,Si)_3.O_8$	257 - 2.76	i, m, v, d, s-cl
Micas	$K_{0-1}.(Mg,Fe,Al)_3.(Al,Si)_3.O_{10}.(OH)_2$	2.7 - 3.2	i, m, (d)
Clay minerals	$(K,Na,Ca,Mg)_{0-2}.[(Al,Si)_8.O_{20}].(OH)_{2-4}.n(H_2O)$	2.5 - 2.65	s-cl/ch, m, d
Carbonates			
Calcite	$Ca.CO_3$	2.72	s-ch/cl, d (i)
Dolomite	$(Ca.Mg).CO_3$	2.85	s-ch/cl, d (i)
Siderite	$Fe.CO_3$	3.96	s-ch/cl, d
Sulphides & sulphates			
Pyrite	FeS	5.02	i, m, d, s-cl
Galena	PbS	7.6	i, m, d, s-cl
Sphalerite	ZnS	4.1	i, m, d, s-cl
Gypsum	$CaSO_4.n(H_2O)$	2.31	d
Anhydrite	$CaSO_4$	2.96	s-ch, d
Oxides			
Haematite	Fe_2O_3	5.28	i, m, (v), d, s-ch/cl
Magnetite	Fe_3O_4	5.20	i, m, (v), d, s-cl
(Hydro)-Carbons			
Coal	C:H:O - Antracite: 93:3:4, Bituminous; 82:5:13	1.8 - 1.2	s-cl/ch, d
Oil	$n(CH)_2$	0.85	d
Natural Gas	$C_{1.1}H_{4.2}$	$0.83 * 10^{-3}$	d
Fresh water		~1	
Sea water or brine		> 1	

i - igneous; v - volcanic; m - metamorphic; d - diagenetic; s - sedimentary; cl - clastic; ch - chemical