DATE: 4th of March 2020

FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: PET-500 PVT of Reservoirs and Fluids

TIME: 4 hours

AID: No printed or written means allowed. Definite basic calculator allowed.

THE EXAM CONSISTS OF 2 PARTS ON 11 PAGES.

Part 1 is given equal weight as Part 2.

REMARKS: All answers in English. Answers on carbon paper.

Part 1, *(50% of exam):*
PVT of Fluids, 8 Questions

A bottom hole sample (BHS) is taken from a reservoir and brought to a PVT-lab.

Given reservoir data:

- Temperature: T_{res} = 130 °C
- Pressure: P_i = 450 bara
- P_b = 332.5 bara
- Porosity: ϕ = 0.25
- Initial water: S_{wi} = 0.25
- Bulk res. volume: 10^6 m^3

The BHS undergoes a single flash to standard conditions, and the following data are given:

- GOR = 382 Sm^3/Sm^3
- $(B_o)_b$ = 2.29 m^3/Sm^3
- M_{STO} = 187
- ρ_{STO} = 839.4 kg/m^3
- γ_g = 0.837
- $(M_o)_{res}$ = 59.5
- Comp. of STO as molefractions: x_i (i = C_1 – C_{10+})
- Comp.of gas as molefractions: y_i (i = C_1 – C_{10+})

a.

Characterize the reservoir fluid by means of a PT-diagram.

b.

M_{STO} is determined experimentally. Describe shortly the principles of the analysis.

Use formula.

c.

Derive a formula to calculate M_{C10+} for STO; $M_{C10+} = f((w\%)_i, (wt\%)_{C10+}, M_i)$ where $i=C_1$- C_9 for x_i and $i=C_1$- C_9 for M_i.

d.

Calculate the composition as mole fraction of reservoir fluid; $z_i = f(x_i, y_i)$.

A Constant Mass Expansion (CME) has been performed, and the data from the analysis are presented below.

Constant Mass Expansion at 130 °C

Pressure Bara	Rel Vol **V/V_b**	**Compress 1/bara**	**Y Factor**	**Density g/cm³**
500.00	0.9261	3.563E-04		0.5808
450.00	0.9439	4.073E-04		-
425.00	0.9539	4.379E-04		0.5638
400.00	0.9648	4.728E-04		0.5575
375.00	0.9768	5.130E-04		0.5506
350.00	0.9899	5.598E-04		0.5433
332.51	1.0000	5.973E-04		-
325.00	1.0091		2.53	
300.00	1.0443		2.45	
250.00	1.1455		2.27	
200.00	1.3174		2.09	
150.00	1.6378		1.91	

e.

Verify that P_b is correctly determined.

f.

Calculate the density of reservoir fluid at P_b and P_i at T_{res}.

Below the saturation point, a differential gas liberation analysis has been performed, and the data are shown below.

Differential Gas Depletion at 130 °C

Pressure Bara	Oil FVF B_{od}	R_{sd} Sm^3/Sm^3	Gas FVF B_{gd}	Oil Density g/cm^3	Z Factor Gas
332.51	3.081	566.7		0.5378	
300.00	2.634	436.1	4.470E-03	0.5662	0.939
250.00	2.249	317.7	5.151E-03	0.6025	0.903
200.00	1.997	237.5	6.318E-03	0.6354	0.887
150.00	1.809	176.8	8.413E-03	0.6668	0.886
100.00	1.655	127.7	1.279E-02	0.6978	0.898
50.00	1.516	84.9	2.632E-02	0.7301	0.923
1.01	1.069	0.0	1.437E+00	0.8102	0.986
1.01	1.000			0.8663	

g.

4. Describe by formula how the Z-factor of the equilibrium gas is calculated based on the "Corresponding State Theorem".

The reservoir fluid has been produced through a 3-step separator system, and flash calculations gave the following results:

1. step: V_1=0.5216 L_1=0.4784

2. step: V_2=0.3254 L_2=0.6746

3. step (sc): V_3=0.2517 L_3=0.7483

$(\gamma_g)_{average}$ = 0.7977

M_{STO} = 173.8

ρ_{STO} = 828.7 kg/Sm^3

h.

1. Calculate the total GOR, (Sm^3/Sm^3)
2. Calculate the GOR for separator 2 (2. step) (Sm^3/Sm^3)

Addition 1.

Important conversion factors, formula/correlations.

Temperature:

°K = 273.15 + °C

°F = 1.8 x °C + 32

°R =°F + 459.69

Pressure:

1atm = 1013.250 mBar = 1.013250 bar = 101.3250 kPa = 0.1013250 MPa = 14.69595 psia

psia = 14.69595 + psig

1 atm = 760.002 mmHg at 0 °C

Density:

1 g/cm^3 = 62.43 lb/ft^3 = 350.54 lb/bbl

1 lb/ft^3 = 16.0185 kg/m^3

ρ_w = 0.999015 g/cm^3 (60 °F, 1 atm)

ρ_w = 0.9991 g/cm^3 (15 °C, 1 atm)

Specific density:

For liquids: Determined relative to water at sc.

For gases: Determined relative to air at sc.

$$\gamma_o = \frac{\rho_o}{\rho_w} = \frac{141.5}{131.5 + °API}$$

$$°API = \frac{141.5}{\gamma_o} - 131.5$$

$$\gamma_g = \frac{M_g}{M_{air}} = \frac{M_g}{28.96}$$

Cragoe`s formula (empirical formula giving molecular weight of hydrocarbons):

$$M_o = \frac{6084}{^o API - 5.9}$$

Volume:

1 bbl = 5.615 ft^3 = 0.15898 m^3

1 ft^3 = 0.0283 m^3

1 US Gallon = 3.785 litre

1 Imp. Gallon = 4.546 litre

Molar volume of gas at standard conditions:

V_m = 379.51 SCF/lb mole (60 °F and 14.69595 psia)

V_m = 23644.7 cm^3/g mole = 23.6447 m^3/kg mole (15 °C and 101.3250 kPa)

Air:

Z_{air} = 0.9959 (60 °F, 14.69595 psia)

M_{air} = 28.96

Gas constant:

R = 10.732 (psia, ft^3, °R, lb mole)

R = 0.082054 (atm, litre, °K, g mole)

R = 8.3145 (kPa, m^3, °K, kg mole)

Part 2, (50*% of exam):*
Reservoir Geology (10 Questions + Bonus)

1. Reservoir rocks often are related to continental margins. **Mention two types of continental margins, sketch them** (e. g., as cross sections) **and give the name of one typical sedimentary basin for each of the margins.** The basins should be part of your sketches (or they can be sketched separately).

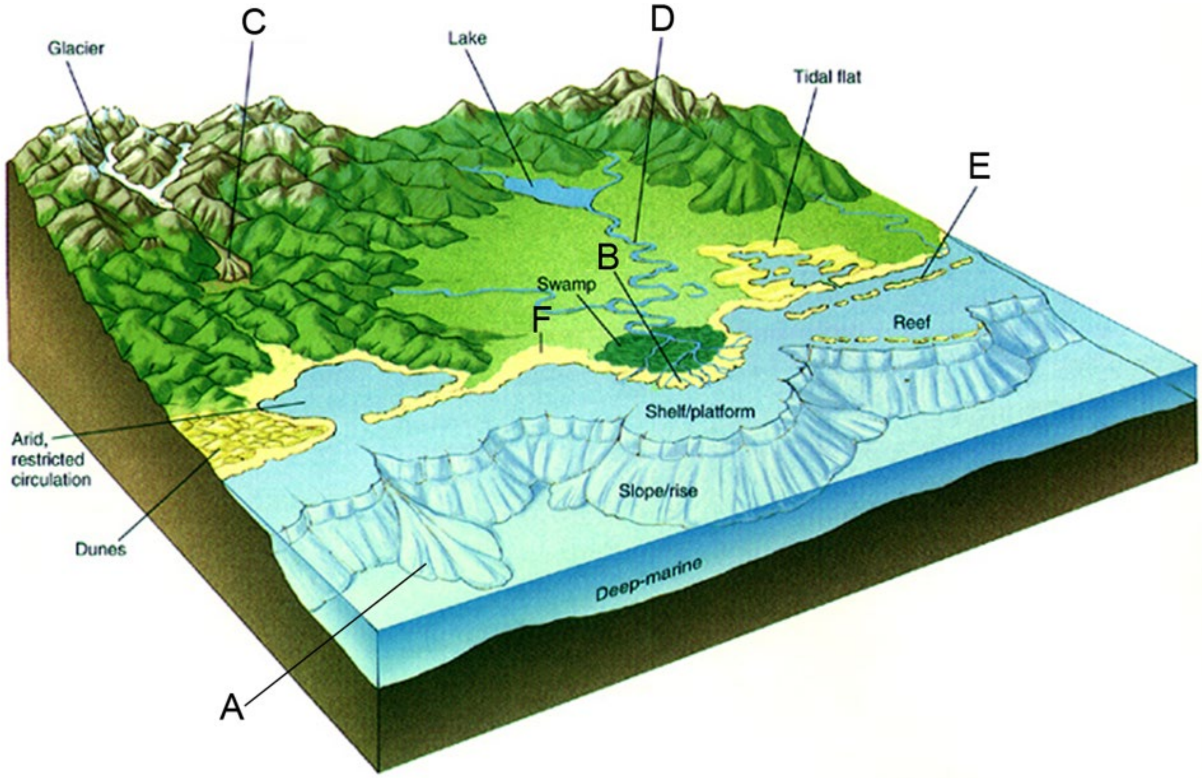
2. **Mention two common reservoir-rock types and give definitions of them** (i. e., differentiate between the two). Include your relative assumptions for porosity and permeability (e. g., low, high) for the two rock types.

3. **Mention two common cap-rock types and explain why they can work as cap rocks.**

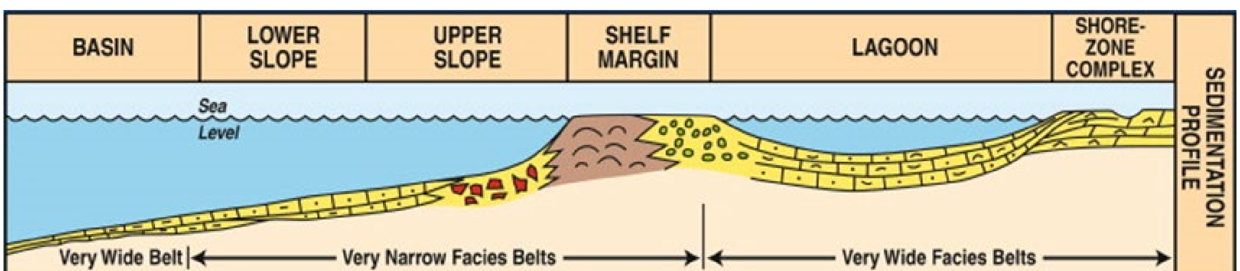
4. **Explain the difference between mechanical and chemical compaction. What effect does compaction have on porosity and permeability? Mention and explain a process that can revert or avoid the porosity-permeability effect of compaction.**

5. Depositional systems

5a. **Name the six depositional systems A-F** in the Figure below.

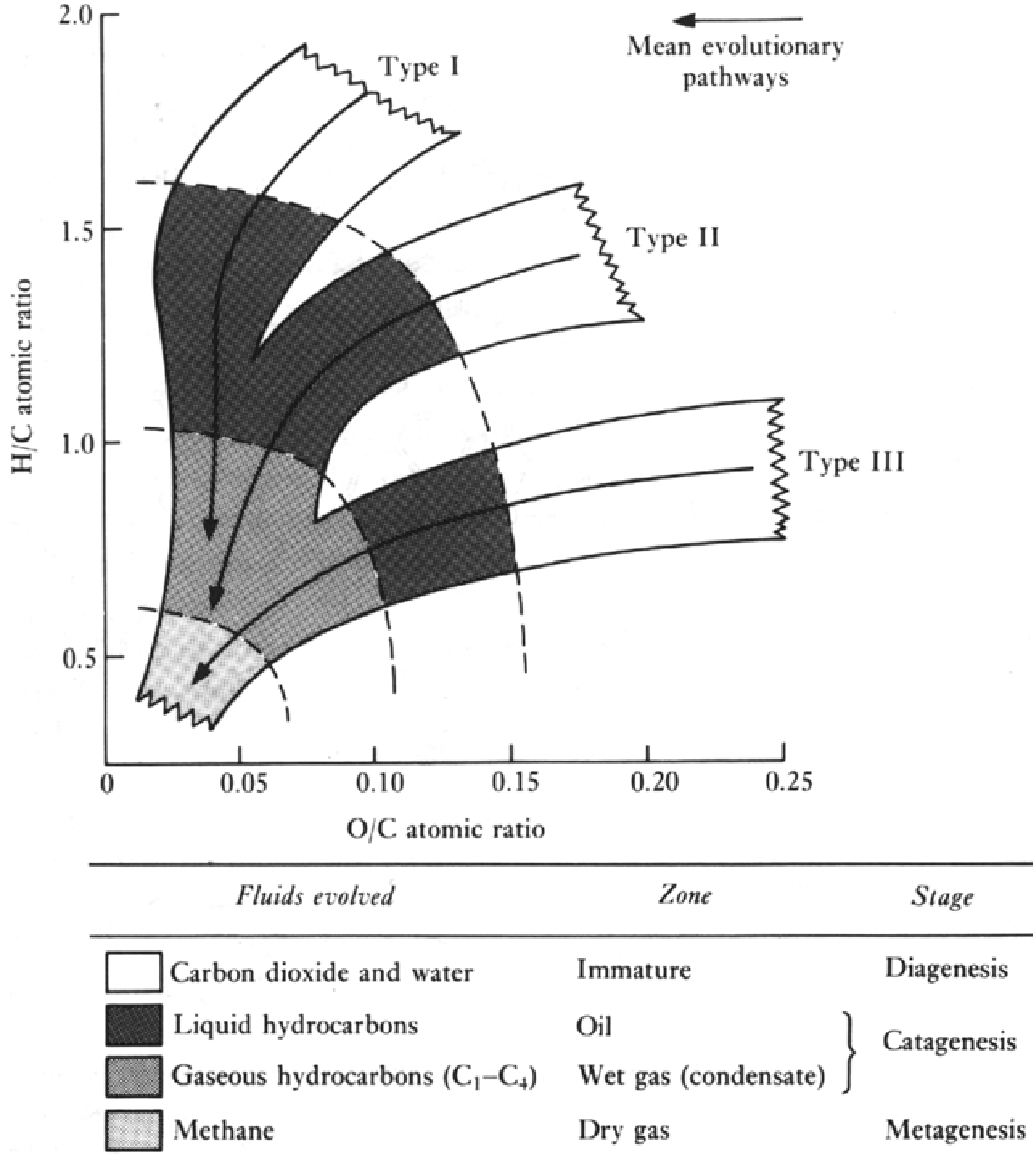


5b. **Where in the marine carbonate cross section below would you consider to find the best reservoir rock** (assuming post-depositional burial and a suitable trap)? **Why**?

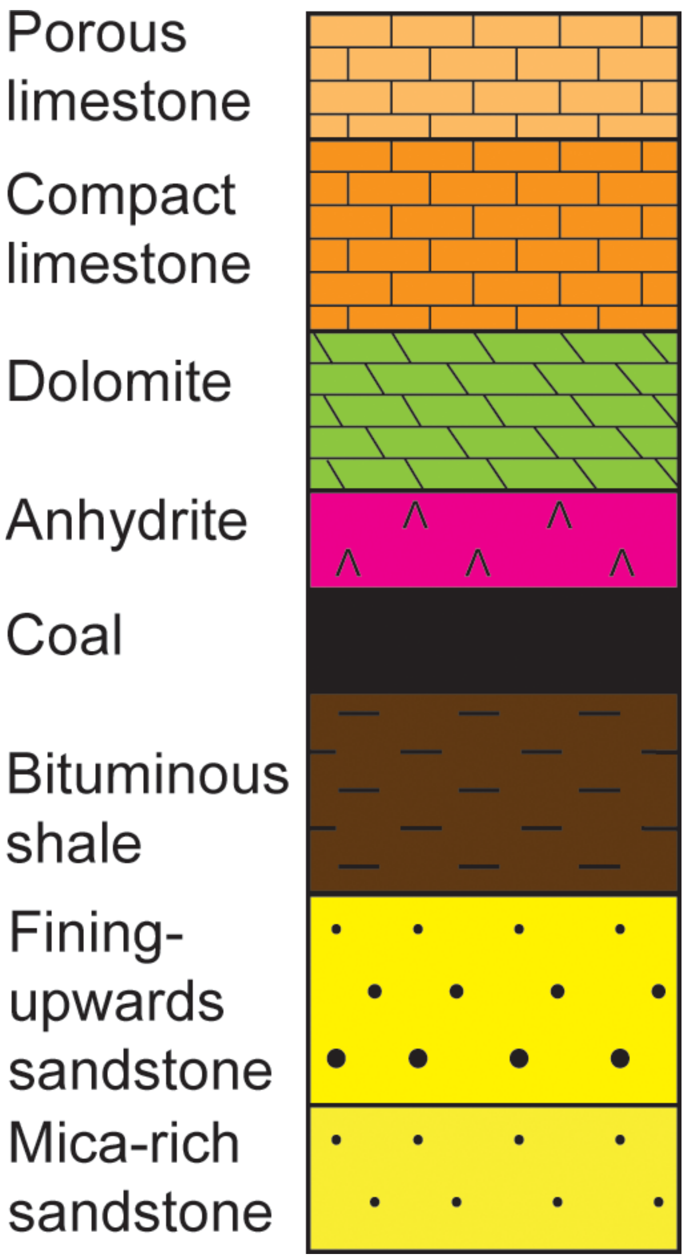


BASIN	LOWER SLOPE	UPPER SLOPE	SHELF MARGIN	LAGOON	SHORE-ZONE COMPLEX	
Very fine-grained carbonate, siliciclastic turbidites associated with basin floor fans Shaley, chert bearing thin bedded limestones Cemented mounds with exotic methanogenetic faunas associated with gas seeps Chalks and bedded cherts	Coarse-fine grained carbonate and siliciclastic turbidites Uniform tine bedded mudstone units Large-scale low relief channel cut-outs	Mega-breccia debris flows Algal mounds Thin bedded wackestones to mudstones Coarse-grained carbonate and siliciclastic turbidites Coarse-grained packstone submarine channel fills	Framework reefs including patch, fringing and barrier Submarine mobile sand flats Grainstone islands Biohermal mounds on the interior margin	Tidal flats associated with islands and on lagoon margins Patch reefs Grainstone wash-over fans along outer lagoon margin Thick lagoon-wide subaqueous evaporites Widespread restricted, burrowed fossiliferous pellet packstone to wackestones units Collumnar stromatolites on the lagoon margins	Low energy tidal flats, sabkhas w/ siliciclastics, evaporites, dolomites Tee Pee structures Low relief stromatolites and tidal channels Beaches spit-channel com-plexes along the margin	FACIES COMPONENTS

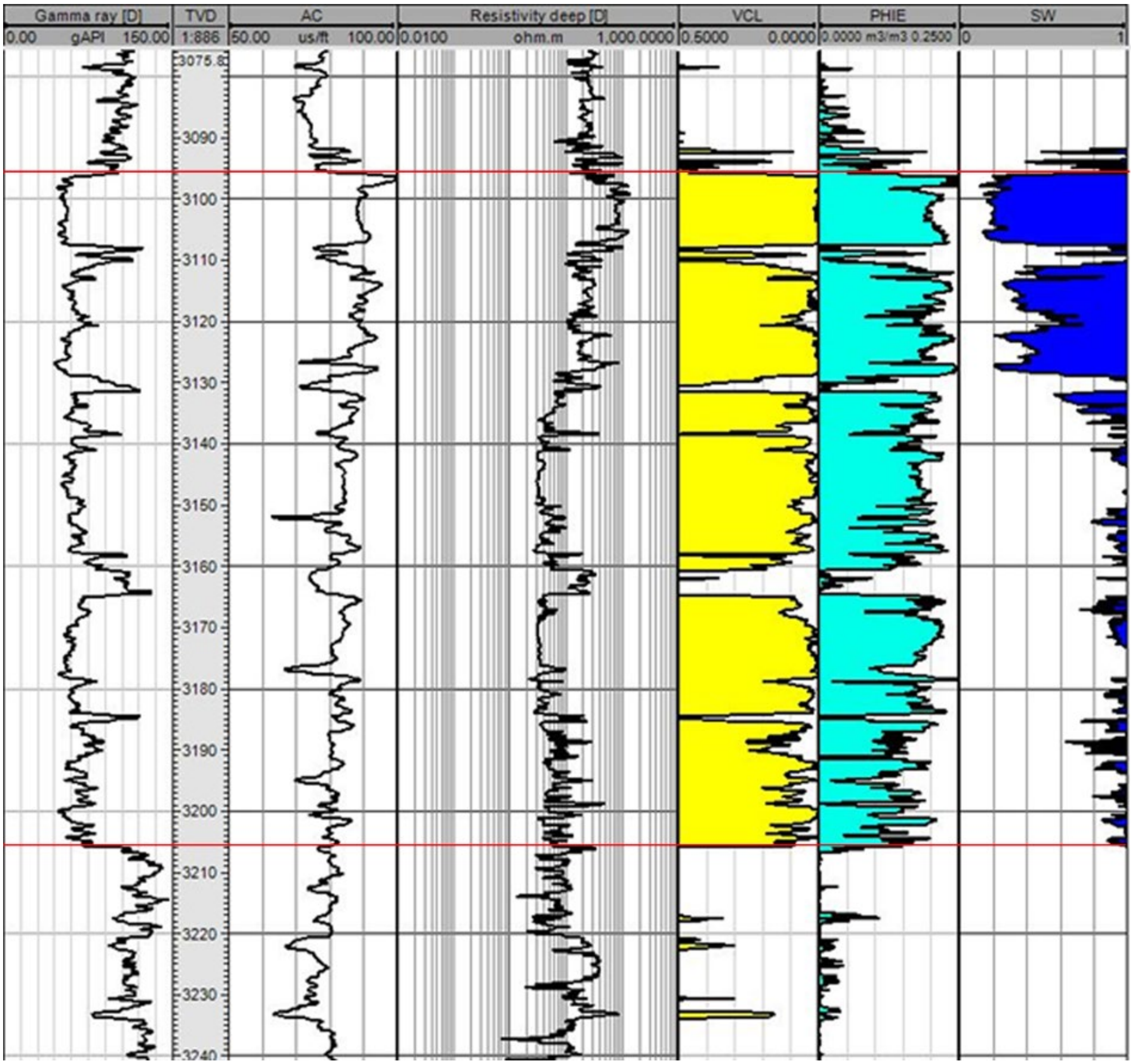
6. **What is the dominating starting organic material for each of the 3 kerogen types** (I, II, III) in the Van Krevelen diagram below? Which **kerogen type produces most gas and which one produces most oil if maturity is reached?**



7. **What are the principles behind gamma-ray, sonic and Capiler logs? Draw tentative gamma-ray, sonic and Caliper logs next to the lithological log below** (remember to hand in this page!).



The figure below shows log curves for the Upper Jurassic of a well in the northern North Sea. The base and top of the Sognefjord Formation, the reservoir unit, are marked with red lines. The unit is composed of five thick sandstone layers. See the next page the questions related to this image.



Composite logs of well 35/11-13, northern North Sea. TVD = Total vertical depth; AC = Acoustic (=sonic) log; VCL = Clay volume; PHIE = Effective porosity; Sw = Water saturation.

8. The porosity of reservoirs can be estimated from sonic logging as

$$\varphi_s = \frac{\Delta t_{log} - \Delta t_{Matrix}}{\Delta t_f - \Delta t_{Matrix}}$$

Calculate the sonic derived porosity ($\boldsymbol{\varphi_s}$) for the Sognefjord Formation. For this, you should assume that the interval transit time of the matrix (Δt_{Matrix}) is $54\ \mu s/ft$, and the interval transit time of the pore fluid (Δt_f) is $187\ \mu s/ft$. Estimate the average transit time for the Sognefjord Formation (Δt_{log}) from the sonic log.

9. Acoustic impedance is the product of velocity (v) and density (ρ). **Estimate the acoustic impedance for the sandstone in the Sognefjord Formation.** To calculate the sandstone density, use the calculated porosity from Question 8 (use a logical porosity value for sandstone reservoirs if you did not solve Question 8). Assume a grain density of 2.65 g/cm^3 (corresponding to quartz) and a fluid density of 0.76 g/cm^3 (crude oil). The velocity in the Sognefjord Formation is 5500 m/s.

10. Vertical resolution of seismic data represents the distance between two interfaces as separate reflectors. In general, layers can be distinguished when their thickness is more than 1/4 of the dominant wavelength. Based on the sandstone-layer thicknesses, **calculate the minimum frequency requirement that allows all sandstone layers to be discerned**. Use information given in previous question(s) to gain all necessary parameters.

BONUS QUESTION (correct answer will credit an incorrect answer in questions 1-10)

The Gross rock volume (GRV) is the volume of rock between the top and base of the reservoir that contains hydrocarbon. It can be calculated with the area (A) multiplied by the gross pay thickness (h). Using a simplified cylinder model, **calculate the gross rock volume (GRV), net rock volume (NRV), net pore volume (NPV), hydrocarbon pore volume ($HCPV$), and hydrocarbon initial in place ($HCIIP$) of the sandstone reservoir of the Sognefjord Formation**.

(1) Assume that the area (A) $is\ 420\ km^2$.

(2) For the net pay thickness (h) and net-to-gross ratio (NGR):

Use relevant well logs in the figure and the cut-off values below to calculate the thickness of gross sandstone, net sandstone, gross pay, and net pay. Calculate the net-to-gross ratio of the pay zone that contains hydrocarbon from those values.

Cut offs:

Clay content $V_{sh} = 10\%$

Porosity $\varphi = 10\%$

Water saturation $S_w = 80\%$

Bulk volume water $BVW = Sw * \varphi_s = 0.175$

(3) You may use the sonic-derived porosity from Question 8.

(4) You need to find out average hydrocarbon saturation from the well log.

(5) Assume that the oil formation volume factor (FVF) is 1.25.

factor (FVF) is 1.25.