Universitetet
i Stavanger

FINAL EXAM IN: PET670 FORMATION EVALUATION AND WELL TESTING

DURATION: 4 HOURS

DATO: 15TH FEBRUARY 2019

"TOOLS" ALLOWED: Simple calculator

The Grading System

General rules
In order to pass the exam, you need to score at least 40% in each of the Parts A and B. Both parts count equally (50%) for the total grade.

Grading
First, your completion percent (CP) in each of the Parts, A and B, is calculated. If both CPs are equal to or higher than 40, you pass. Then, your overall CP is calculated as a half-sum of CPs in Parts A and B. The final grade is then set according to the following scheme:
CP 40-49: E
CP 50-59: D
CP 60-79: C
CP 80-89: B
CP 90-100: A

Part A: Formation Evaluation

General information

You are expected to give short and precise answers to theoretical questions.
You do not get Points for too lengthy answers, even if the answer to the question is present in the text.
Unreadable answers are not graded as well.

Question 1

Q: What is logging? `[1 p.]`
A: Measuring properties of penetrated geological formations as functions of depth.

Q: What do abbreviations WL and LWD mean? `[2 p.]`
A: WL – wireline logging; LWD – logging while drilling.

Q: What is formation volume factor? `[2 p.]`
A: Formation volume factor, B, of a hydrocarbon, is the ratio of specific volume (volume

of a unit mass) of the hydrocarbon at reservoir conditions to that at surface (stock tank) conditions.

Question 2

Q: Describe any one method of determining porosity of a rock sample in the lab. [5 p.]
A: See the lecture notes for details. You could describe any of the following: saturation method, buoyancy method, helium porosimetry, and mercury porosimetry.

Question 3

Q: What is capillary pressure? [1 p.]
A: The pressure difference across a fluid-fluid interface.

Q: If a fluid-fluid interface is in equilibrium, how can one quickly find out which phase is under higher pressure – and what is the direction of the capillary force? [4 p.]
A: The phase containing the center of curvature is under higher pressure. The capillary force is directed from the wetting phase towards the non-wetting phase.

Question 4

Q: How can the location of FWL be found from the pressure vs. depth data? [1 p.]
A: It is at the depth at which oil and water pressure lines intersect.

Q: What is the capillary pressure curve? Name three methods of obtaining it in the lab. [4 p.]
A: The displacement pressure plotted against water saturation in the rock. The three methods are: porous plate, centrifuge, and mercury porosimetry.

Question 5

Q: What is the difference between total GR and SGR logs? [1 p.]
A: SGR measures the individual contribution of different sources of gamma-radiation, while total GR measures only the sum of these contributions.

Q: Name three main sources of natural radiation. [3 p.]
A: The radioactive potassium isotope $^{40}_{19}\mathrm{K}$, uranium-radium (U-Ra) series, thorium (Th) series.

Q: What is the main application of SGR log? [1 p.]
A: Subtle lithological analysis.

Question 6

Q: What is the principle of formation density logging? [4 p.]
A: The tool emits γ-radiation into the formations and measures their flux after they pass the formation. Higher density of the formation $\rightarrow$ more electrons per unit volume in the formation $\rightarrow$ more photons undergo Compton scattering and photoelectric absorption $\rightarrow$ more significant attenuation of the γ-ray flux.

Q: How is density-derived porosity value affected by gas in the formation? [1 p.]
A: It is overestimated.

Question 7

Q: Name the two key processes affecting the fate of neutrons emitted into the formation by the neutron logging tool. [2 p.]
A: Neutron scattering and neutron absorption.

Q: Does a fast neutron lose much of its original energy if it collides with a lead atom in the formation? With a hydrogen atom? Why? [3 p.]
A: With a lead atom – very little energy is lost, with a hydrogen atom – much energy is lost by by the neutron. This comes from classical physics (elastic collisions, energy and momentum conservation) and from the facts that the mass of a lead atom is much higher than that of a neutron, and the mass of a hydrogen atom is almost identical to that of the neutron.

Question 8

Q: In the context of neutron-density crossplot, what is called positive and negative separation? [2 p.]
A: Positive separation: high density and high neutron porosity (ρ-plot is to the right of ϕ_N-plot). Negative separation: low density, low apparent porosity (ρ-plot is to the right of ϕ_N-plot).

Q: What can the following neutron-density crossplot readings indicate: large positive separation; zero separation; small negative separation? [3 p.] **A:** Shale; pure limestone with fresh water; and clean sandstone with oil or water, respectively.

Question 9

Q: What is V_{sh}, and what can this number be used for? [2 p.]
A: Shale volume: the "degree of shaliness" of a shaly sand/sandy shale zone. Distinguishing between reservoir and non-reservoir rocks by setting a threshold value for V_{sh}.

Q: Name at least three logs which can be used to estimate V_{sh}. [3 p.]
A: GR log, SP log, bulk density/neutron porosity combination.

Question 10

Q: What are resistivity and conductivity – and which units are used for these quantities? [3 p.]
A: Resistivity, r [Ohm $\cdot$ m], is a property of material which shows how strongly the material opposes the electric current. Conductivity, C [S/m], is the inverse physical quantity: $C = 1/R$.

Q: What is the use of microlog, and what does it mean when ML and MIV readings separate? [2 p.]
A: Detecting porous and permeable formations. Separation of ML and MIV indicates mud cake.

Question 11

Q: What are the Hingle plot and the Pickett plott, and what is their main use? [5 p.]
A: Both plots are made for a reservoir zone with constant m, n, and ϕ and are cross-plots of R_t and ϕ data.
Hingle plot: horisontal axis – ϕ, linear scale; vertical axis – $R_t^{-1/m}$, ticks placed so that R_t is read off directly. Use: determination of S_w from ϕ and R_t values.
Pickett plott: horisontal axis – ϕ, log scale; vertical axis – R_t, log scale. Use: determination of I (or S_w) from ϕ and R_t values.

Question 12

Q: Explain what these notations mean: S_{xo}, S_w, R_{xo}, R_{mf}, R_{mc}. Place these notations onto the corresponding empty spaces on Supplement A. Hand in the Supplement together with the rest of your answers. [5 p.]
A: S_{xo}: water saturation in the flushed zone; S_w: water saturation in the uninvaded zone; R_{xo}: resistivity of the flushed zone; R_{mf}: resistivity of mud filtrate; R_{mc}: resistivity of mud cake. See Supplement A.

Question 13

Q: Explain how one can estimate the movable hydrocarbon saturation, $S_o - S_{or}$, from deep and shallow resistivity logs. Explain all the notations, make clear which laws you rely upon and which logs/zones must the measurements be taken from. [5 p.]
A: Before invasion: water and oil, $S_w + S_o = 1$.
After invasion: mud filtrate (water-based) and residual oil, $S_{xo} + S_{or} = 1$.
Movable oil saturation $S_o - S_{or} = S_{xo} - S_w$.
S_w is calculated from deep resistivity log reading R_t in the oil-bearing zone using Archie's combined law (assumed ϕ, m, n and formation water resistivity R_w known):

$$R_t = R_w \phi^{-m} S_w^{-n}.$$

S_{xo} is calculated from shallow resistivity log readings R_{xoor} in the oil-bearing zone using combined Archie's law (assumed ϕ, m, n are the same as above and mud filtrate resistivity R_{mf} known):

$$R_{xoor} = R_{mf} \phi^{-m} S_{xo}^{-n}.$$

Questions 14-15

To answer Questions 14-15, read the well logs from Supplement B. Make necessary marks directly on the Supplement sheet and hand in this sheet together with the rest of your answers.

Clean sandstone has matrix density $\rho_{ma} = 2.65\,\mathrm{g/cm^3}$.

Question 14

Q: Use the logs to perform a lithological analysis. Draw the lithologies in the depth track. Provide a brief explanation. [5 p.]
A: Porous and permeable formations (assuming sandstone): indicated by low GR. Shales: high GR. Sandy shales and shaly sands in the transition areas. Drawing sand/shale lines in the GR log is useful (see Supplement B).

Question 15

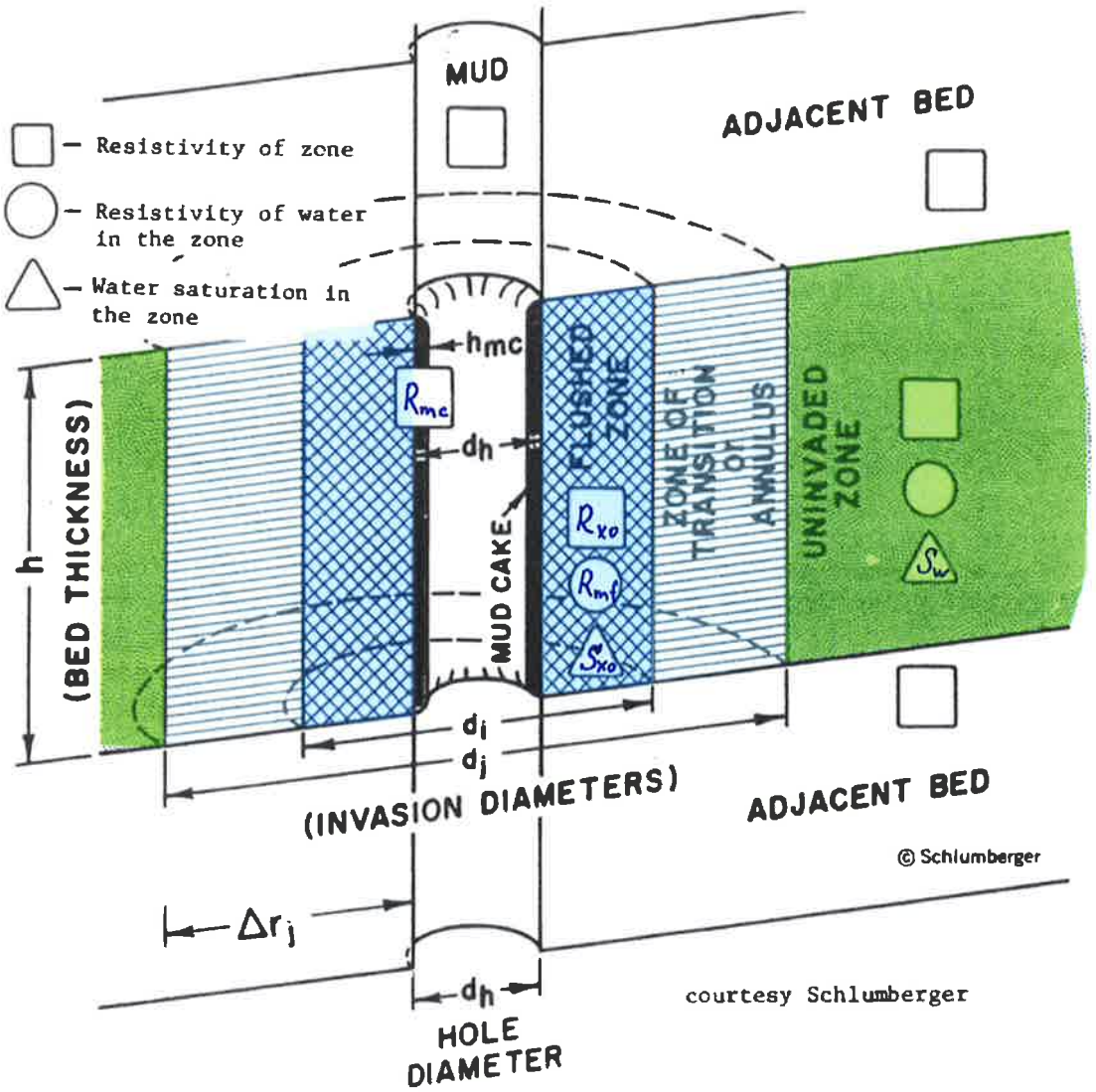
Q: Resistivity log (not shown in the Supplement) indicates the presence of hydrocarbons in the sand zone. Is it possible to find out – based on the density log readings only – if the sand zone contains gas, oil or both? Explain your answer and support it by calculations. [5 p.]
A: Gas is more likely present than oil, but one cannot say for sure without looking at resistivity logs.
Estimation of porosity value in the upper clean sand zone yields:

$$\phi = \frac{\rho_{\mathrm{matrix}} - \rho_{\mathrm{log}}}{\rho_{\mathrm{matrix}} - \rho_{\mathrm{water}}} = \frac{2.65 - 2.05}{2.65 - 1.00} \approx 0.36\ (36\%);$$

The corresponding value in the lower sand zone is around 30%. Both values are really high. If they really are the true values of porosity (which is not very likely, but still possible), the hydrocarbon is oil. If the real porosity is lower, the hydrocarbon is gas.

This sheet is to be handed in together with your answers.
Please write your candidate number in the corresponding field.

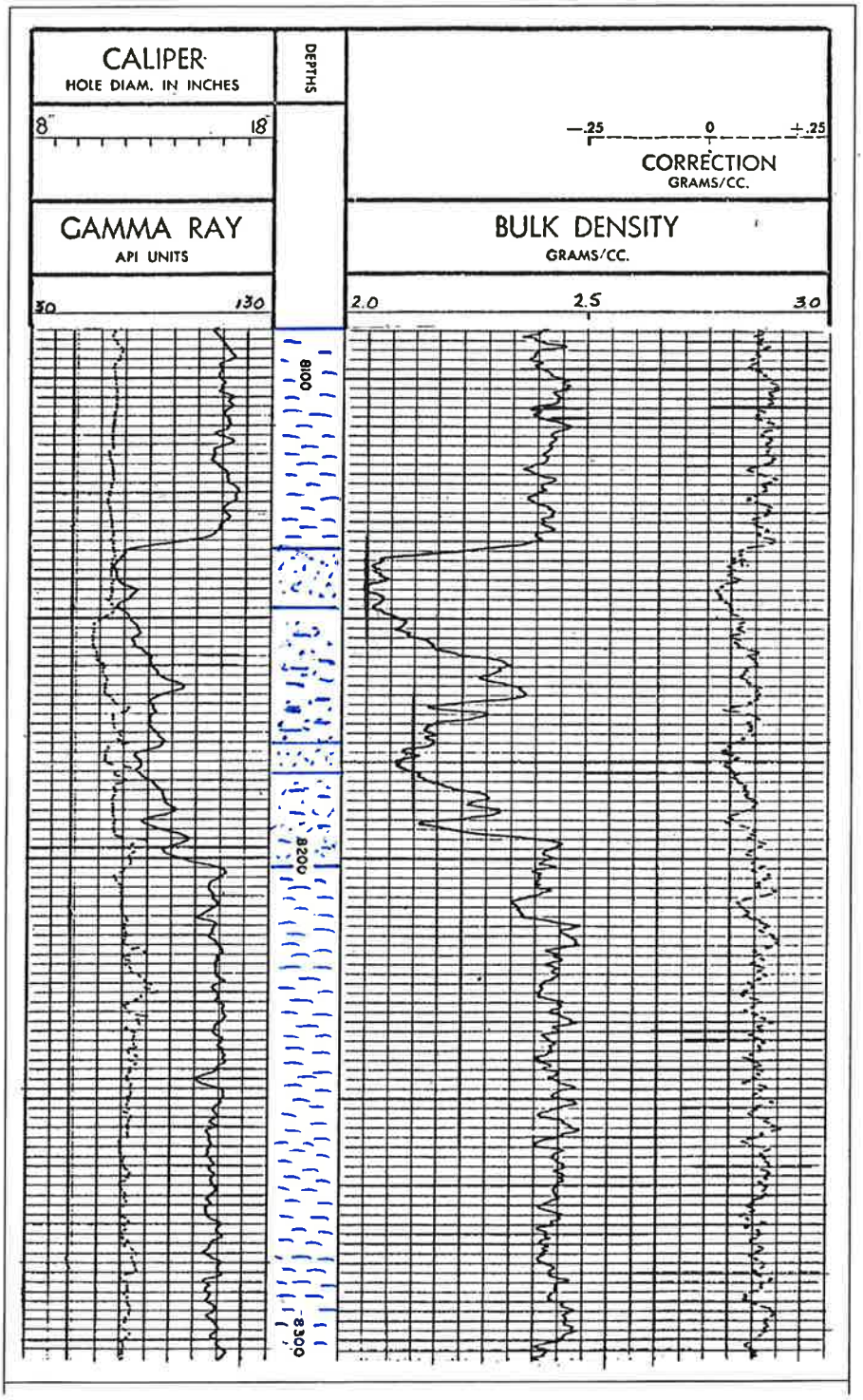
Candidate number: Løsningsforslaget



Supplement A: Borehole environment

This sheet is to be handed in together with your answers.
Please write your candidate number in the corresponding field.

Candidate number: Løsningsforslaget



Supplement B: Log reading exercise