Universitetet
i Stavanger

FINAL EXAM IN: PET670 FORMATION EVALUATION AND WELL TESTING

DURATION: 4 HOURS

DATO: 10TH DECEMBER 2018

"TOOLS" ALLOWED: Simple calculator

EXAM STRUCTURE: This exam consists of two Parts, A and B, on 7 pages, including this one; and Supplements on 3 pages (10 pages total)

Part A: Formation Evaluation

Please provide short and precise answers. You will get zero points for vague, too long, or unreadable answers even if they do contain correct information.

The Supplements with your marks are to be handed in together with the rest of your answers.

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1. Explain the difference between GOIP and STGOIP. *(3 p.)*
   Compare GOIP and STGOIP for a gas reservoir: which one is greater? Explain why. *(2 p.)*
2. Name four methods to measure the porosity of a rock sample in the lab. *(4 p.)*
   One of these methods is also used to measure the capillary pressure curve. Which one? *(1 p.)*
3. Define the concepts FWL and OWC. *(2 p.)*
   How are these two located with respect to each other if the reservoir rocks are water-wet? Explain why. What if the reservoir rocks were oil-wet? *(3 p.)*
4. What does it mean if we say a reservoir fluid is overpressurized? *(1 p.)*
   Explain the following concepts: invasion; mud cake; mud filtrate. *(3 p.)*
   Explain why invasion has limited depth. *(1 p.)*
5. What is caliper logging and how does this log respond to porous and permeable formations? *(2 p.)*
   Name at least three uses of caliper logging. *(3 p.)*
6. What are the typical footprints of the following lithologies on the combined density/neutron log: pure limestone with fresh water in pores; clean sandstone with oil in pores; clean sandstone with gas in pores; shale; and coal? *(5 p.)*
7. Explain how sonic logging in combination with another tool (which one?) can be used to identify fractures. *(3 p.)*
   In terms of sonic logging, what is the compaction trend and how does it help to identify overpressurized zones? *(2 p.)*

8. Explain the difference between resistance and resistivity. *(1 p.)*
   How does resistivity of a brine depend on the salt concentration in the brine and on the temperature of the brine? *(2 p.)*
   What is the difference between laterologs and induction logs? *(2 p.)*

9. Explain what these notations mean: R_{xo}, R_{mf}, R_t, R_m, S_w. Place these notations onto the corresponding empty spaces on Supplement A. Hand in the Supplement together with the rest of your answers. *(5 p.)*

To answer Questions 10 and 11, use the RFT data from Supplement B.
Make necessary marks directly on the Supplement sheet
and hand in this sheet together with the rest of your answers.

Two porous and permeable zones of interest are marked A and B. From other logs it is known that there is one fluid present in Zone A, and two different fluids are found in Zone B. The zones are separated by a shale bed. Pressure measurements were made at a range of depths; the results are shown on Supplement B. In addition, it is known from the lab that the reservoir rocks have an initial displacement pressure of 0.2 bar.
You may need to know that $1\,\text{bar} = 10^5\,\text{Pa}$ and $g \approx 9.8\,\text{m/s}^2$.

10. Estimate the pressure gradients and hence the fluid densities. *(4 p.)*
    Identify the fluids. *(1 p.)*

11. At which depth is the FWL located? *(1 p.)*
    Specify the depth where the OWC is. *(2 p.)*
    Are Zones A and B connected? Explain your answer. *(2 p.)*

To answer Questions 12-15, read the well logs from Supplement C.
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 $\rho_{ma} = 2.65\,\text{g/cm}^3$. Assume that the cementation and saturation exponents are $m = n = 2$. Non-saline drilling mud was used.

12. Use the logs to perform a lithological analysis. Draw the lithologies in the depth track. Provide a brief explanation. *(5 p.)*

13. Use the logs to identify oil and water zones and explain briefly which criteria you use. Mark these zones on the logs. *(5 p.)*

14. Evaluate the shale volume at depth marked red using two different methods. Make the necessary marks directly on the logs. *(2 p.)*
    Calculate the sandstone porosity in the water zone. *(3 p.)*

15. Calculate the formation factor in the water zone. *(1 p.)*
    Find the resistivity of the formation water. Specify which law(s) you are using. If you are using log data, show where the data is taken from and why. *(2 p.)*
    Estimate oil and water saturation in the zone marked green. Explain which logs the data is taken from. Which assumptions do you make? *(2 p.)*

Part B: Well Testing

Well Testing Problem 1 ***(26 p.)***
With data from a 24 hours drawdown in a newly fractured well producing at 300 STB/D, use parameters from Table 1, pressure drawdown data from Table 2 and Fig. 1 to answer the questions and carry out the analysis below.

(a) Fig. 1 shows a log-log plot of the drawdown data. Identify flow regimes in the data and indicate the range of each (start and end). *(4 p.)*

(b) With Fig. 1 as reference, carry out a standard semi-log analysis of the drawdown data based on representative data points from Table 2 to compute m, k, $p_{1\text{hr}}$, S and Δp_s. *(10 p.)*

(c) With Fig. 1 as reference, use representative data points from Table 2 to compute the slope, m', and using the permeability value from the previous point, estimate fracture half-length, x_f. Compared to the computed skin value, what is likely fracture type? *(6 p.)*

(d) Derive an estimate of the pressure drawdown after 1 week of production; and if the well will produce at double rate, 600 STB/D, for the same period of time (1 week). *(4 p.)*

(e) Compute pressure after 24 hours of build-up, if the well will be shut-in after 24 hours of production at 300 STB/D. *(2 p.)*

Well Testing Problem 2 ***(24 p.)***
With data from a 24 hours build-up in a newly vertical well following just 1 hour production at 500 STB/D, use parameters from Table 1, pressure build-up data from Table 3 and Fig. 2 to answer the questions and carry out the analysis below.

(a) Fig. 2 shows a log-log plot of the build-up data. Identify radial flow regime in the data and indicate the range (start and end). *(2 p.)*

(b) With Fig. 2 as reference, carry out a standard semi-log analysis of the build-up data based on representative data points from Table 3 to compute m, k, $\Delta p_{1\text{hr}}$, S and Δp_s *(10 p.)*

(c) Based on the build-up data, estimate the minimal area consistent with the pressure response. *(2 p.)*

(d) Use semi-log analysis to estimate the formation pressure as extrapolated pressure, p^*. Also, derive an estimate of the pressure drawdown after 24 hours, if the well continued to produce at the initial rate without being shut-in. *(4 p.)*

(e) How will the estimated skin, S, change, if total compressibility, c_t, will be increased by a factor of 2? How will the estimated permeability, k, change, if it will be found that the formation thickness, h, is given in SI units (m), instead of field units (ft)? *(6 p.)*

Good luck!

Table 1 – Input parameters for Problems 1 and 2

Formation thickness, h	=	300	ft
Porosity, ϕ	=	0.3	
Viscosity, μ	=	0.65	cp
Total compressibility, c_t	=	$7.5\text{x}10^{-6}$	psi^{-1}
Formation volume factor, B	=	1.03	RB/STB
Wellbore radius, r_w	=	0.3	ft
	=		

Table 2 – Pressure drawdown data

Elapsed Time (hr)	Pressure (psia)	Elapsed Time (hr)	Pressure (psia)	Elapsed Time (hr)	Pressure (psia)
0.0000	5000.000	0.1265	4986.650	10.5047	4941.224
0.0001	4999.623	0.1592	4985.075	11.0047	4940.677
0.0002	4999.468	0.2005	4983.356	11.5047	4940.154
0.0003	4999.348	0.2524	4981.497	12.0047	4939.653
0.0004	4999.247	0.3177	4979.508	12.5047	4939.172
0.0005	4999.155	0.4000	4977.401	13.0047	4938.710
0.0006	4999.052	0.5036	4975.189	13.5047	4938.265
0.0008	4998.936	0.6340	4972.884	14.0047	4937.836
0.0010	4998.806	0.7981	4970.501	14.5047	4937.423
0.0013	4998.661	1.0048	4968.056	15.0047	4937.023
0.0016	4998.497	1.2649	4965.551	15.5047	4936.636
0.0020	4998.314	1.5924	4963.004	16.0047	4936.261
0.0025	4998.108	2.0047	4960.420	16.5047	4935.898
0.0032	4997.878	2.5047	4957.892	17.0047	4935.545
0.0040	4997.619	3.0047	4955.809	17.5047	4935.203
0.0050	4997.328	3.5047	4954.037	18.0047	4934.870
0.0063	4997.002	4.0047	4952.495	18.5047	4934.547
0.0080	4996.636	4.5047	4951.131	19.0047	4934.232
0.0100	4996.226	5.0047	4949.907	19.5047	4933.925
0.0126	4995.765	5.5047	4948.798	20.0047	4933.626
0.0159	4995.248	6.0047	4947.783	20.5047	4933.334
0.0200	4994.669	6.5047	4946.848	21.0047	4933.049
0.0252	4994.018	7.0047	4945.982	21.5047	4932.771
0.0318	4993.289	7.5047	4945.174	22.0047	4932.499
0.0400	4992.470	8.0047	4944.418	22.5047	4932.233
0.0504	4991.551	8.5047	4943.707	23.0047	4931.973
0.0634	4990.521	9.0047	4943.036	23.5047	4931.719
0.0798	4989.367	9.5047	4942.401	23.7524	4931.595
0.1005	4988.079	10.0047	4941.798	24.0000	4931.472

Table 3 – Pressure build-up data

Elapsed Time (hr)	Pressure (psia)	Elapsed Time (hr)	Pressure (psia)	Elapsed Time (hr)	Pressure (psia)
0.000	4539.083	2.505	4747.124	13.505	4751.260
0.010	4558.709	3.005	4747.919	14.005	4751.296
0.020	4575.756	3.505	4748.501	14.505	4751.330
0.030	4590.741	4.005	4748.947	15.005	4751.362
0.040	4603.994	4.505	4749.298	15.505	4751.392
0.050	4616.157	5.005	4749.583	16.005	4751.420
0.063	4629.539	5.505	4749.819	16.505	4751.446
0.080	4643.831	6.005	4750.017	17.005	4751.471
0.100	4658.565	6.505	4750.185	17.505	4751.494
0.126	4673.146	7.005	4750.331	18.005	4751.516
0.159	4686.928	7.505	4750.457	18.505	4751.537
0.200	4699.334	8.005	4750.569	19.005	4751.557
0.252	4709.964	8.505	4750.667	19.505	4751.576
0.318	4718.670	9.005	4750.755	20.005	4751.593
0.400	4725.548	9.505	4750.834	20.505	4751.610
0.504	4730.869	10.005	4750.906	21.005	4751.627
0.634	4734.972	10.505	4750.970	21.505	4751.642
0.798	4738.178	11.005	4751.029	22.005	4751.657
1.005	4740.737	11.505	4751.083	22.505	4751.671
1.265	4742.822	12.005	4751.133	23.005	4751.684
1.592	4744.544	12.505	4751.179	23.505	4751.697
2.005	4745.974	13.005	4751.221	24.000	4751.710

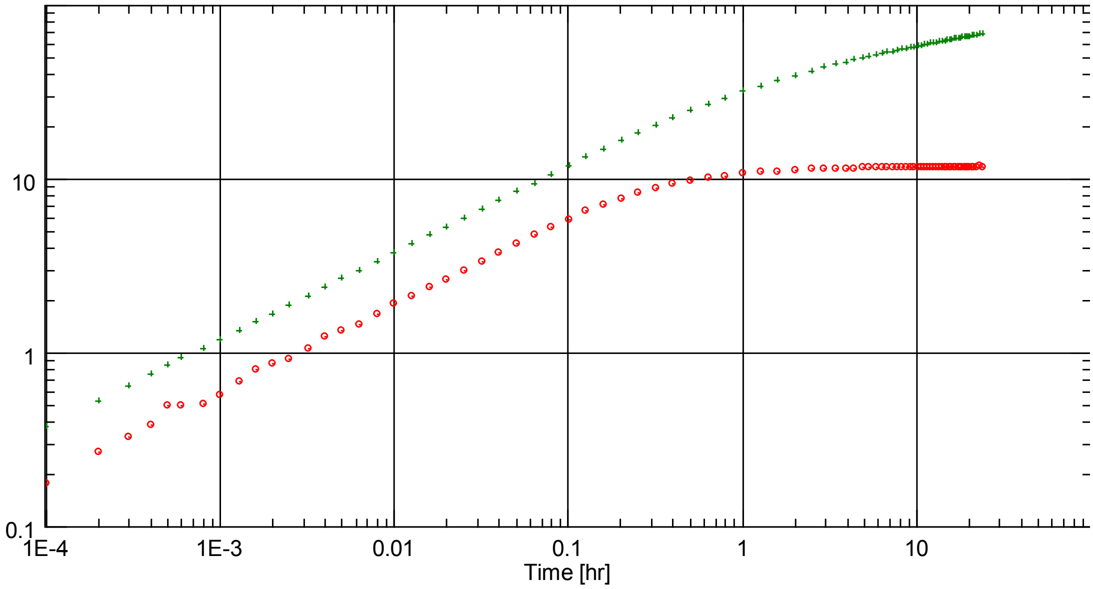

Figure 1. Pressure drawdown for fractured well.

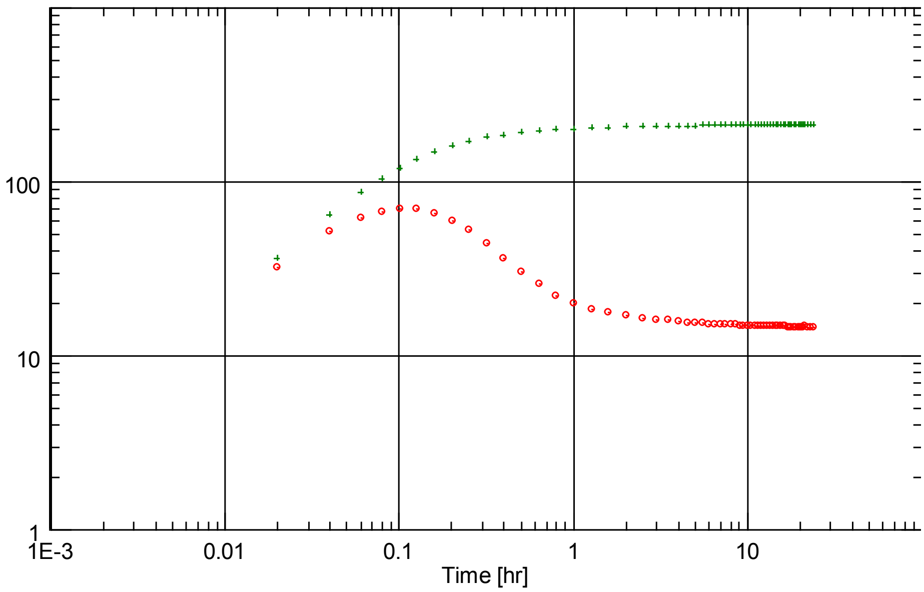

Figure 2. Pressure build-up for vertical well.

STANDARD EQUATIONS WELL TESTING

$$p_D = \frac{kh}{18.66qB\mu}\Delta p$$ (SI units, oil; field units: 18.66 → 141.2)

$$t_D = \frac{0.000355k}{\phi\mu c_t r_w^2}t$$ (SI units, oil and gas; field units: 0.000355 → 0.000264)

$$m = \frac{21.49qB\mu}{kh}$$ (SI units; field units: 21.49 → 162.6)

$$p_{wf}(t) = p_i - m\left(\log t + \log\frac{k}{\phi\mu c_t r_w^2} - 3.098 + \frac{S}{1.151}\right)$$ (SI units, DD data; field units: 3.098 → 3.228)

$$S = 1.151\left(\frac{p_i - p_{1hr}}{m} - \log\frac{k}{\phi\mu c_t r_w^2} + 3.098\right)$$ (SI units, DD data; field units: 3.098 → 3.228)

$$p_{ws}(\Delta t) = p_{wf,s} + m\left(\log\frac{\Delta t}{t+\Delta t} + \log t + \log\frac{k}{\phi\mu c_t r_w^2} - 3.098 + \frac{S}{1.151}\right)$$ (SI units, BU data; field units: 3.098 → 3.228)

$$S = 1.151\left(\frac{p_{1hr} - p_{wf,s}}{m} - \log\frac{t}{t+1} - \log\frac{k}{\phi\mu c_t r_w^2} + 3.098\right)$$ (SI units, BU data; field units: 3.098 → 3.228)

$$\Delta p_S = \frac{m}{1.151}S$$

$$r_{inv} = 0.0286\sqrt{\frac{kt}{\phi\mu c_t}}$$ (SI units; field units: 0.0286 → 0.0246)

$$d = 0.0141\sqrt{\frac{kt}{\phi\mu c_t}}$$ (SI units; field units: 0.0141 → 0.0122)

Fractured wells:

$$m' = \frac{0.624qB}{hx_f}\sqrt{\frac{\mu}{k\phi c_t}}$$ (SI units; field units: 0.624 → 4.064)

$$S = \ln\frac{2r_w}{x_f}$$ (fracture with infinite conductivity)

$$S = \ln\frac{er_w}{x_f} = \ln\frac{2.718r_w}{x_f}$$ (fracture with uniform flux)

Gas tests:

$$q_{sc} = C\left(\bar{p}^2 - p_{wf}^2\right)^n$$ (simplified deliverability, p^2 formulation)

$$\bar{p}^2 - p_{wf}^2 = aq_{sc} + bq_{sc}^2$$ (LIT based deliverability, p^2 formulation)

$$AOF = \frac{1}{2b}\left(-a + \sqrt{a^2 + 4b\bar{p}^2}\right)$$ (LIT based AOF, p^2 formulation)

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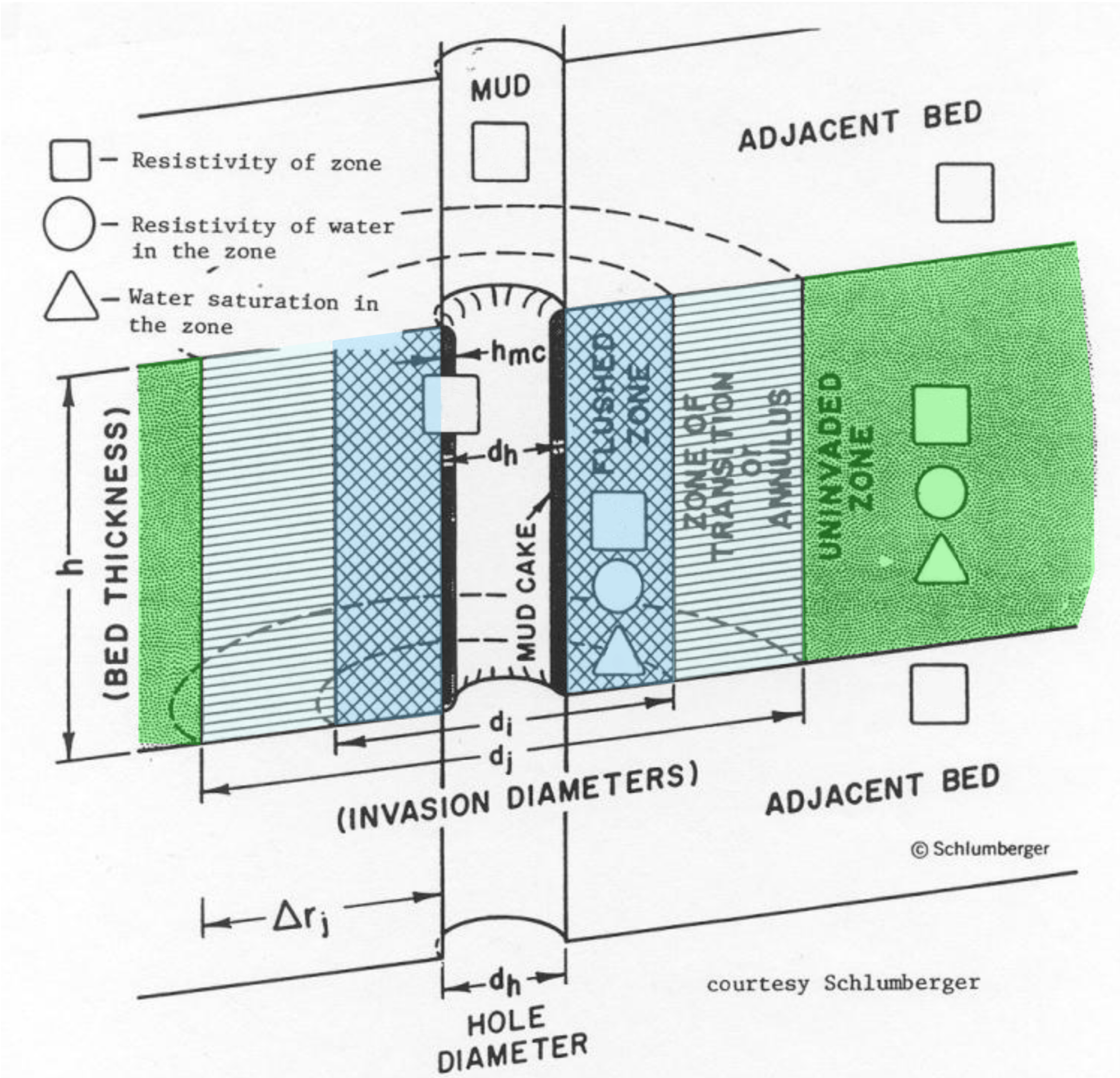
Please write your candidate number in the corresponding field.

Candidate number: ______________________



Supplement A: Borehole environment

This sheet is to be handed in together with your answers.

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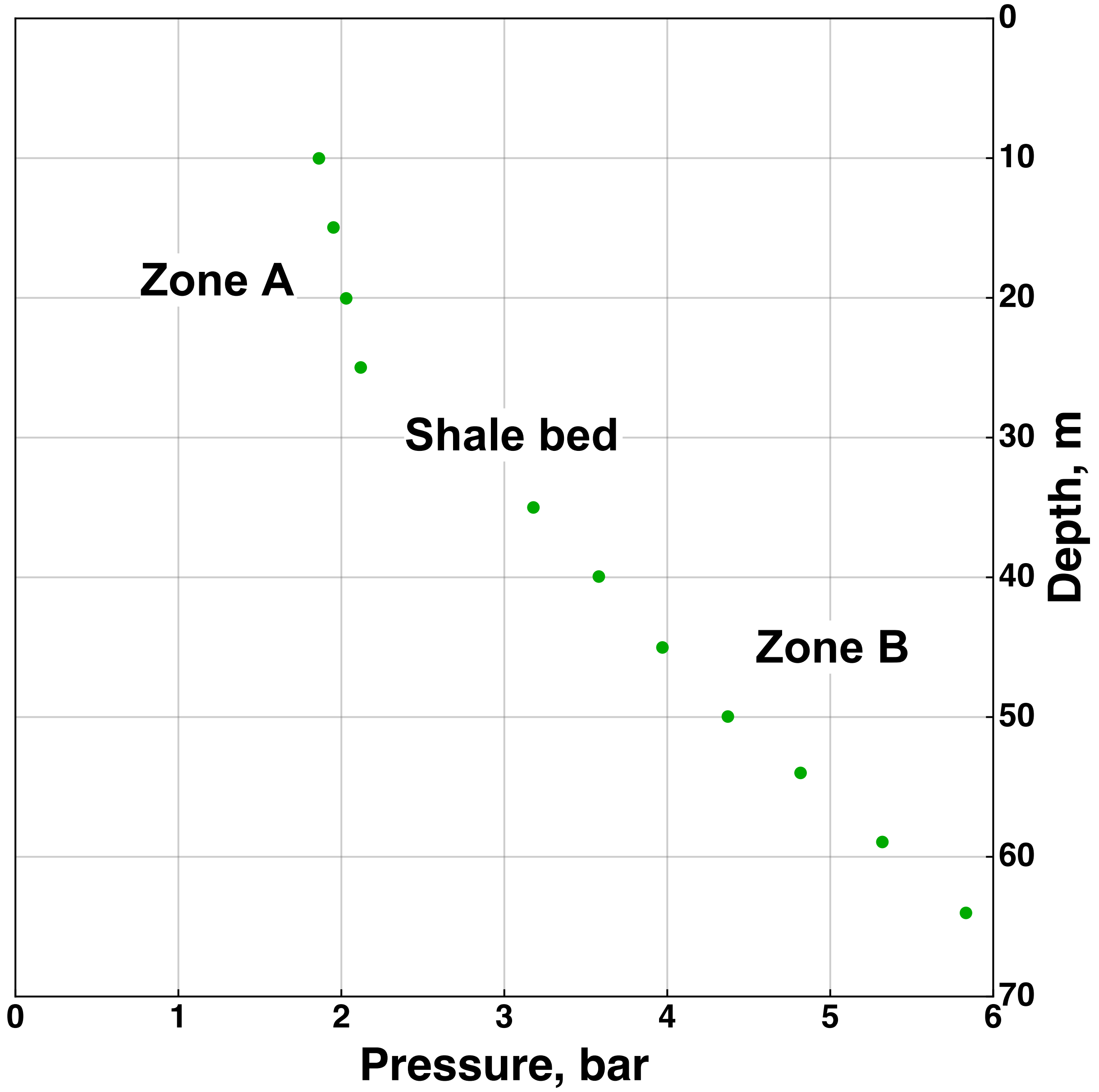

Supplement B: RFT Pressure Data

This sheet is to be handed in together with your answers.

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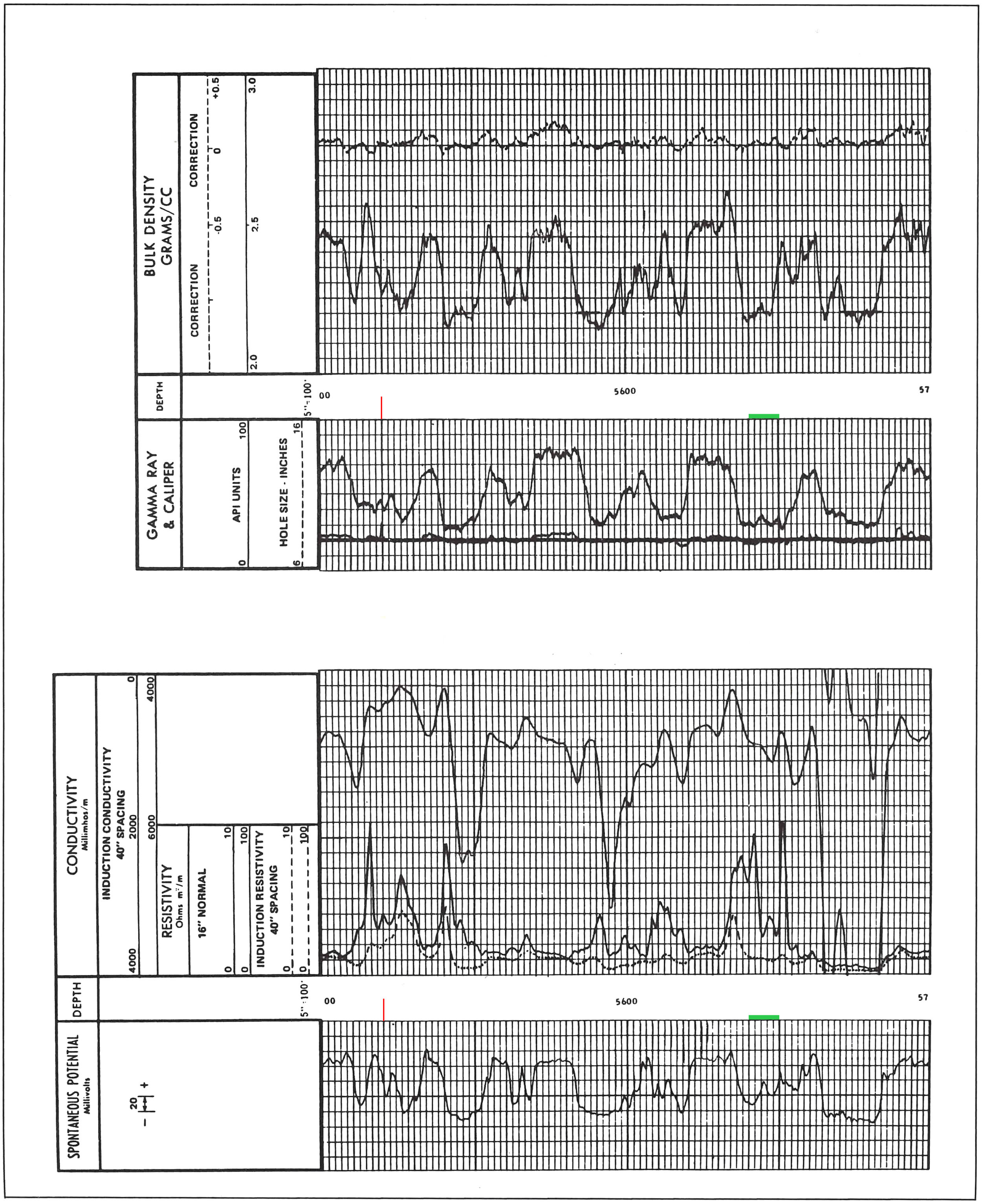

Supplement C: Log reading exercise