Advanced Petrophysics
PGE 381L, Fall 2020
Unique Number: 18970

Instructor: Zoya Heidari, Ph.D.

Midterm Exam No. 1

October 15, 2020
3:30 PM to 5:30 PM

Name: Solution

UT EID: _____

Instructions:

1. This examination is OPEN BOOK, OPEN NOTES. The only books you are allowed to use include volumes 1 and 2 of your "Advanced Petrophysics" textbook. The only other resources you are allowed to use are pencil/pen, eraser, calculator, and straightedge.
2. Use of cell phones or electronic communication devices is not permitted.
3. Answers should be provided in an organized manner, with a clear and readable handwriting. There will be no credit for the vague or unreadable answers.
4. Start each problem on a new page. **Show all your work.**
5. You can type your answers or write them on paper. If you choose to write your answers on paper, please scan all the answers and convert them to PDF format. You can also take a picture of your work and convert everything into one PDF file.
6. When you complete the examination, sign the statement below and submit your answers in PDF format.

Total Number of Questions: 10

"I have neither given nor received unauthorized aid on this academic work."

Acknowledged via Your Signature: _____

Question 1: (0 points)

Can you claim that the following statement is true about you? Choose one answer.

"I have neither given nor received unauthorized aid on this academic work."

☐ No

☐ Yes

Acknowledged via Your Signature: _____

25

Question 2: (25 points)

The permeability tensor for a 2D reservoir in the *x-y* Cartesian coordinate system is given by

$$\bar{\bar{k}}(x,y)=\begin{bmatrix}70 & 20\\ 20 & 50\end{bmatrix} md$$

Viscosity of the reservoir fluid can be assumed to be 1 cp. The potential gradient is given by

$$\nabla\vec{\Phi}=0.3i+0.2\,j\,(atm/cm)$$

Answer the following questions:

a) Estimate the maximum directional permeability that can be observed in this reservoir and its direction with respect to *x* coordinate. (10 points)

b) The magnitude and direction of Darcy velocity with respect to *x* coordinate. (10 points)

c) Calculate the angle between Darcy velocity and potential gradient. (5 points)

(a) (6P+4A)

$$\begin{vmatrix}70-\lambda & 20\\ 20 & 50-\lambda\end{vmatrix}=0 \rightarrow \lambda^2+3500-120\lambda-400=0$$

$$\rightarrow \lambda^2-120\lambda+3100=0$$

2 → $\lambda_1=82.36$, $\lambda_2=37.64$ md

$$\begin{bmatrix}70-82.36 & 20\\ 20 & 50-82.36\end{bmatrix}\begin{bmatrix}x\\ y\end{bmatrix}=\begin{bmatrix}0\\ 0\end{bmatrix}$$

$$-12.36x+20y=0 \rightarrow \vec{u}=\begin{bmatrix}20/12.36\\ 1\end{bmatrix}$$

$$\tan 2\theta=\frac{2(20)}{70-50}=2 \rightarrow 2\theta=63.4^\circ$$

$$\rightarrow \theta=31.7 \leftarrow 2$$

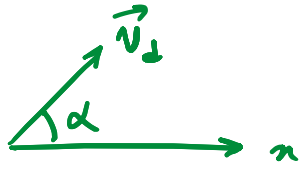
(6P+4A)

(b) $\vec{v}_d = -\frac{\bar{\bar{k}}}{\mu}\vec{\nabla\phi} = \frac{-1}{1}\begin{bmatrix} 0.07 & 0.02 \\ 0.02 & 0.05 \end{bmatrix}\begin{bmatrix} 0.3 \\ 0.2 \end{bmatrix}$

$$\Rightarrow \vec{v}_d = \begin{bmatrix} -0.025 \\ -0.016 \end{bmatrix} (cm/s)$$

$$|\vec{v}_d| = \sqrt{0.025^2 + 0.016^2} = 0.0297 \ cm/s \quad \leftarrow 2$$

$$\cos\alpha = \frac{\vec{v}_d \cdot \vec{u}}{|\vec{v}_d|} = \frac{-0.025}{0.0297}$$



$$\Rightarrow \boxed{\alpha = 212.7^\circ} \leftarrow 2 \quad \text{OR} \quad 147.3^\circ$$

(c) (3P+2A)

$$\cos\beta = \frac{\vec{\nabla\phi} \cdot \vec{v}_d}{|\vec{\nabla\phi}||\vec{v}_d|} = \frac{(-0.025)(0.3) + (-0.016)(0.2)}{(0.0297)\sqrt{0.3^2 + 0.2^2}}$$

$$\Rightarrow \boxed{\beta \simeq 179^\circ} \leftarrow 2$$

20

Question 3: (20 points)

Assume that we have a laminated shaly-sand formation. Volumetric concentration of shale is equal to 45%. Porosity of clean sand and shale layers are 15% and 7%, respectively. Horizonal and vertical resistivities of pure shale are equal to 1 ohm-m. Water saturation in sand and shale layers are equal to 40% and 100%, respectively. Irreducible water saturation and residual oil saturation are equal to 9% and 12%, respectively. Resistivity of formation water is equal to 0.03 ohm-m at reservoir condition. This zone is exposed to mud-filtrate invasion. Drilling mud is OBM. You can assume a, m, and n are equal to 1, 2, and 2, respectively.

Answer the following questions:

a) Estimate the horizontal and vertical effective deep resistivity of this laminated shaly sand. (8 points)

b) Estimate the horizontal and vertical effective shallow resistivity of this laminated shaly sand. You can assume that shallow resistivity is affected by mud-filtrate invasion. Please write your other assumptions, if any. (8 points)

c) Estimate total porosity of this laminated shaly sand. (4 points)

(a)

(8) (4P+4A)

$$R_S = R_W \frac{a}{\phi^m S_W^n} = 0.03 \frac{1}{0.15^2\ 0.4^2} = 8.33\ \Omega.m$$

$$\frac{1}{R_H} = \frac{0.45}{1} + \frac{(1-0.45)}{8.33} \rightsquigarrow R_H = 1.94\ \Omega.m \leftarrow 2$$

$$R_V = 0.45(1) + (1-0.45)(8.33) \rightsquigarrow R_V = 5.03\ \Omega.m \uparrow 2$$

(8) (b) (4P+4A)

$$R_S = 0.03 \frac{1}{0.15^2\ 0.09^2} = 164.6\ \Omega.m$$

$$\frac{1}{R_H} = \frac{0.45}{1} + \frac{(1-0.45)}{164.6} \rightsquigarrow R_H = 2.2\ \Omega.m \swarrow 2$$

$$R_V = 0.45(1) + (1-0.45)(164.6) \rightsquigarrow R_V = 90.98\ \Omega.m \uparrow 2$$

④ Ⓒ

(2P+2A)

$$\phi_t = C_{sh}\,\phi_{sh} + (1 - C_{sh})\,\phi_s$$

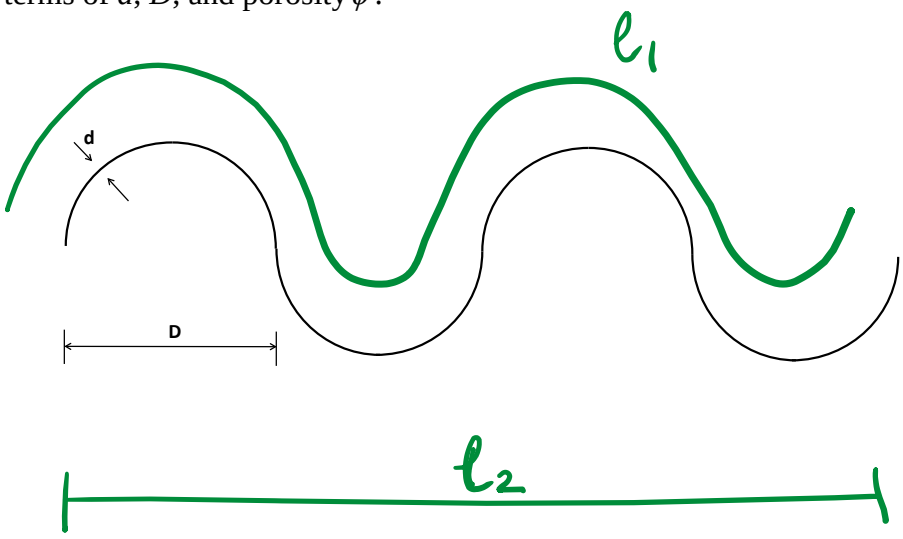
$$= 0.45(0.07) + (1 - 0.45)(0.15)$$

$$\Rightarrow \phi_t = 0.114$$

15

Question 4: (15 points)

(10P+5A) A porous medium is composed of *n* parallel connected tubes with the following shape. Assume the tubes are circular in cross section. Derive an expression for the permeability of this porous medium in terms of *d*, *D*, and porosity ϕ.



Circular cross section $\longrightarrow$ $K_o \simeq 2$

$$\left.\begin{aligned} \ell_1 &= 2\pi D \\ \ell_2 &= 4D \end{aligned}\right\} \Rightarrow \tau = \left(\frac{\ell_1}{\ell_2}\right)^2 = \left(\frac{\pi}{2}\right)^2$$

$$\frac{V}{S} = \frac{\pi r^2}{2\pi r} = \frac{r}{2} = \frac{d}{4} \quad \text{OR} \quad S_p = \frac{2\pi n r \ell_e}{\pi r^2 n \ell_e} = \frac{2}{r} = \frac{4}{d}$$

$$k = \frac{\phi}{2\tau S_p^2} = \frac{\phi}{2\left(\frac{\pi}{2}\right)^2}\left(\frac{d}{4}\right)^2 = \frac{\phi d^2}{8\pi^2}$$

$$\Rightarrow \boxed{k = n\phi d^2/8\pi^2}$$

Question 5: (15 points)

Answer the following questions for the well logs provided in Figure 2. Formation water resistivity at reservoir condition is equal to 0.042 ohm-m. Archie's parameters, a, m, and n are equal to 1, 2, and 2, respectively.

(3) **a)** Compare the salt concentration of formation water and mud filtrate. (3 points)

Salt concentration of connate water ☒ Salt concentration of WBM

(4) (2P+2A) **b)** Estimate total porosity at 2,695 ft? Dominant lithology at this zone is dolomite. Neutron porosity in water-filled dolomite units in this zone is 0.115. (4 points)

$\phi_{N,DI} = 0.115$

$\phi_{D,DI} = \frac{2.45 - 2.87}{1 - 2.87} = 0.22$

$\rightarrow \phi = \sqrt{\frac{0.115^2 + 0.22^2}{2}} = 0.175$

(4) (2P+2A) **c)** Estimate hydrocarbon saturation at 2,695 ft? (4 points)

$R_t = R_w \frac{a}{\phi^m S_w^n} \rightarrow 10 = 0.042 \frac{1}{0.175^2 S_w^2}$

$\Rightarrow S_w = 0.37 \rightsquigarrow S_{HC} = 1 - 0.37 = 0.63$

(4) (2P+2A) **d)** Estimate hydrocarbon density at 2,695 ft? (4 points)

$\rho_b = \phi \rho_f + (1-\phi)\rho_m$

$\rightsquigarrow 2.45 = 0.175 \rho_f + (1 - 0.175)(2.87)$

$\Rightarrow \rho_f = 0.47 \ g/cm^3$

$\rho_f = S_w \rho_w + S_{HC} \rho_{HC} \rightsquigarrow 0.47 = (1)(0.37) + \rho_{HC}(0.63)$

$\Rightarrow \rho_{HC} = 0.16 \ g/cm^3$

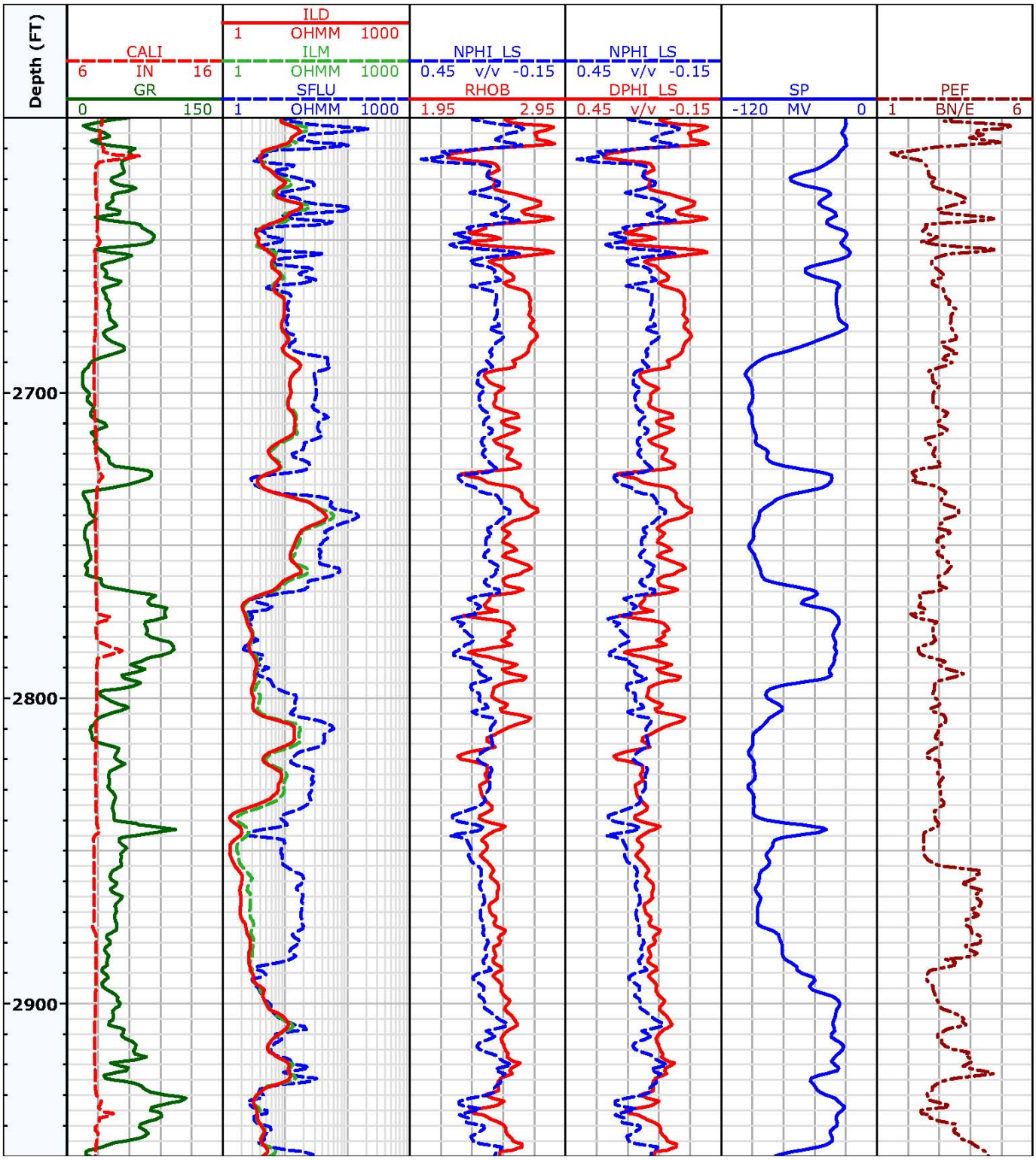


Figure 2: Well logs required for Question 5

Provide short answers to the following questions:

5

Question 6: Why should we be careful about the temperature used for drying of clay-rich rocks? (5 points)

Capillary tension developed by liquid-gas menisci
→ Damage to clay minerals

5

Question 7: (5 points)

How do the pressures applied in the laboratory for permeability assessment can affect mean free path of the gas molecules? How would that affect estimates of permeability to gas in the laboratory? Would you expect to overestimate or underestimate permeability to gas?

Lab → low P → Mean free path of gas molecules is about the same size as the pores

→ slippage at pore walls → k↑ compared to actual

⇒ Overestimate

5

Question 8: (5 points)

(2P+3A)

We estimated permeability of an organic-rich mudrock sample using an experimental setup. This sample contains micro-fractures. We know that the overburden pressure in-situ condition decreases the width of the micro-fractures to almost a quarter of what we experience in our experimental setup. Estimate the maximum relative error (due to the presence of fractures) that you would expect to have for laboratory-based permeability estimates compared to in-situ permeability?

$$k_f = \frac{w^2}{12} \qquad k_f' = \frac{(w/4)^2}{12} = \frac{1}{16}\left(\frac{w^2}{12}\right)$$

$$\frac{k_f - k_f'}{k_f'} = \frac{1 - 1/16}{1/16} = 1500\ \%$$ (OK if w respect to k_f)

Assumption: matrix k is significantly less than frac. k

(5)

Question 9: (5 points)

(2P+3A)

Assume that we have two rocks, A and B, with identical pore structure, porosity, water saturation, and mineralogy? Rock A is water-wet and rock B is oil-wet. A petrophysicist has calibrated his resistivity model for water saturation assessment using rock A. He plans to use the same model parameters for water saturation assessment in rock B. would you expect an overestimation or underestimation of water saturation? Explain your answer.

$$(R_t)_A < (R_t)_B$$

$$R_t = R_w \frac{a}{\phi^m S_w^n}$$

$$R_t \uparrow \xrightarrow[\text{const.}]{a,m,n} S_w \downarrow$$

$$\Rightarrow \underline{\text{Underestimation}}$$

(5)

Question 10: (5 points)

(2P+3A)

Porosity to permeability ratio in formation A is four times that in formation B. Assuming other properties remain the same, quantitatively compare the radius of investigation of a welltest in formations A and B.

$$\left(\frac{\phi}{k}\right)_A = 4\left(\frac{\phi}{k}\right)_B$$

$$r_{inv} = 0.03248\sqrt{\frac{kt}{\phi\mu c_t}} = \alpha\sqrt{\frac{k}{\phi}}$$

$$\left.\begin{aligned}(r_{inv})_A &= \alpha\left(\sqrt{\frac{k}{\phi}}\right)_A \\ (r_{inv})_B &= \alpha\left(\sqrt{\frac{k}{\phi}}\right)_B = \alpha(2)\left(\sqrt{\frac{k}{\phi}}\right)_A\end{aligned}\right\} \Rightarrow$$

$$\Rightarrow \boxed{(r_{inv})_A = 1/2\,(r_{inv})_B}$$