Part I. Write your answer in the space provided. Use equations and sketches in addition to words (as needed).

1. a. Give a qualitative definition of porosity.

The fraction of a rock that is occupied by voids or pores -- an intensive property of a rock that is a measure of its fluid storage capacity

b. Give a quantitative definition of porosity (ϕ). Define all terms.

$$\phi = \frac{V_p}{V_b} = 1 - \frac{V_m}{V_b}$$ where

V_p is pore volume
V_m is matrix volume
V_b is bulk volume

c. Give three examples of geologic processes in the development of induced porosity.

- grain dissolution in sandstones or carbonates
- vugs and solution channels in carbonates
- fracture development in some sandstones, carbonates and shales

2. a. Give a qualitative definition of permeability.

an intensive property of a rock-fluid system that is a measure of its fluid conductivity or its capacity to transmit fluid

b. Give a quantitative definition of permeability (k). Define all terms.

$$k = \frac{q \mu L}{A \Delta p}$$ where

q is volumetric flowrate (cm^3/s)
μ is viscosity (cp)
L is length of flow path (cm)
A is cross-section area of flow path (cm^2)
Δp is pressure difference along flow path (atm)

$$\left(d = \frac{cp \cdot cm^2}{atm \cdot s}\right)$$

c. Give three sources for permeability determination.

- core analysis
- well test analysis
- production data
- log data

3. a. Give a qualitative definition of isothermal compressibility.

The fractional change in volume caused by a change in pressure at constant temperature -- an intensive property -- always positive.

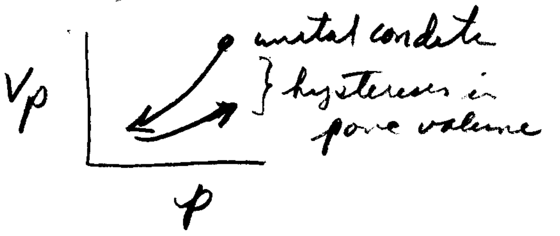
b. Give a quantitative definition of isothermal compressibility (c). Define all terms.

$$c = -\frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_T$$

where V is volume
p is pressure
T is temperature

c. Explain the term, "hysteresis".

- The lagging of an effect behind its cause
- used to describe effects of path dependence & irreversibility in res prop



4. a. Give a qualitative definition of non-Darcy flow.

any flow which is not laminar and hence cannot be modeled by the Darcy eqn.

b. Give two examples of non-Darcy flow.

- gas slippage
- inertial effects and turbulence

c. Show that the dimension of the non-Darcy flow coefficient is $[L]^{-1}$.

Forchheimer eq: $-\frac{dp}{ds}\left[\frac{P}{L}\right] \Rightarrow \left[\beta \rho_g \left(\frac{q_g}{A}\right)^2\right] = \left[\frac{P}{L}\right]$

ie, $[\beta]\left[\frac{M}{L^3}\right]\left[\frac{L}{T}\right]^2 = \left[\frac{P}{L}\right] = \left[\frac{F}{L^3}\right]$

but, $[\beta]\left[\frac{M}{L^3}\right]\left[\frac{L}{T}\right]^2 = [\beta]\left[\frac{F}{L^2}\right] \Rightarrow [\beta] = \left[\frac{1}{L}\right]$ □.

Part II. Work out the answer in the space provided. Show details of your work and clearly identify your answer. Grading will be on the basis of approach and answers.

5. The equation shown below is the Darcy equation for radial, horizontal flow of a real gas for pressures where the μz product is constant, in Darcy Units.

$$q_r = \left(\frac{T_{sc}}{p_{sc}}\right)\left(\frac{2\pi kh}{\mu z T \ln\left(r_e/r_w\right)}\right)\left(\frac{p_e^2 - p_w^2}{2}\right)$$

Determine the constant, C and its units, to convert the terms to the following units: q in standard ft^3/day , k in md, h in ft, p in psi, μ in cp, and T in °R. Assume standard conditions are 60 °F and 14.73 psia.

C has units $\dfrac{(\text{std ft}^3/\text{day})(\text{cp})(°\text{R})}{(\text{md})(\text{ft})(\text{psi}^2)} = \dfrac{\text{cp}\cdot\text{ft}^2\cdot°\text{R}}{\text{md}\cdot\text{day}\cdot\text{psi}^2}$

$$C = \pi \left|\frac{1.1271\times10^{-3}\ \text{cp}\cdot\text{bbl}}{\text{md}\cdot\text{ft}\cdot\text{day}\cdot\text{psi}}\right|\frac{5.61458\ \text{ft}^3}{\text{bbl}}\left|\frac{(60+459.67)\,°\text{R}}{14.73\ \text{psi}}\right.$$

$$= 0.70138\ \frac{\text{cp}\cdot\text{ft}^2\cdot°\text{R}}{\text{md}\cdot\text{day}\cdot\text{psi}^2}$$

6. A reservoir has a thickness of 100.0 feet, a porosity of 0.15, and a formation compressibility of 5.0 x 10^{-6} psi^{-1}. Assume the formation subsides when the fluid pressure decreases and the bulk volume compressibility is equal to the product of the porosity and the formation compressibility. Determine the subsidence of the top of the formation when the reservoir pressure decreases 2000.0 psi.

$$V_b = \phi c_f = \frac{1}{V_b}\frac{dV_b}{dp} = \frac{1}{h}\frac{dh}{dp} \quad (\text{since } V_b = Ah)$$

Separating variables and integrating

$$\int_{h(p)}^{h(p-2000)} \frac{dh}{h} = \phi c_f \int_{p}^{p-2000} dp \quad (\text{assume } \phi c_f \text{ is constant})$$

$$h(p-2000) = h(p)e^{-2000\phi c_f} \Rightarrow$$

$$h(p) - h(p-200) = \Delta h = h(p)(1-e^{-2000\phi c_f})$$

$$= (100)(1-0.995) = \underline{\underline{0.15 \text{ ft}}}$$

$$\text{Or, } \phi c_f = \frac{1}{h}\frac{dh}{dp} \approx \frac{1}{h}\frac{\Delta h}{\Delta p} \Rightarrow$$

$$\Delta h = h\phi c_f \Delta p \quad (\text{NOTE } \phi c_f \Delta p \text{ is 1st order approximation of } 1-e^{-\phi c_f \Delta p})$$

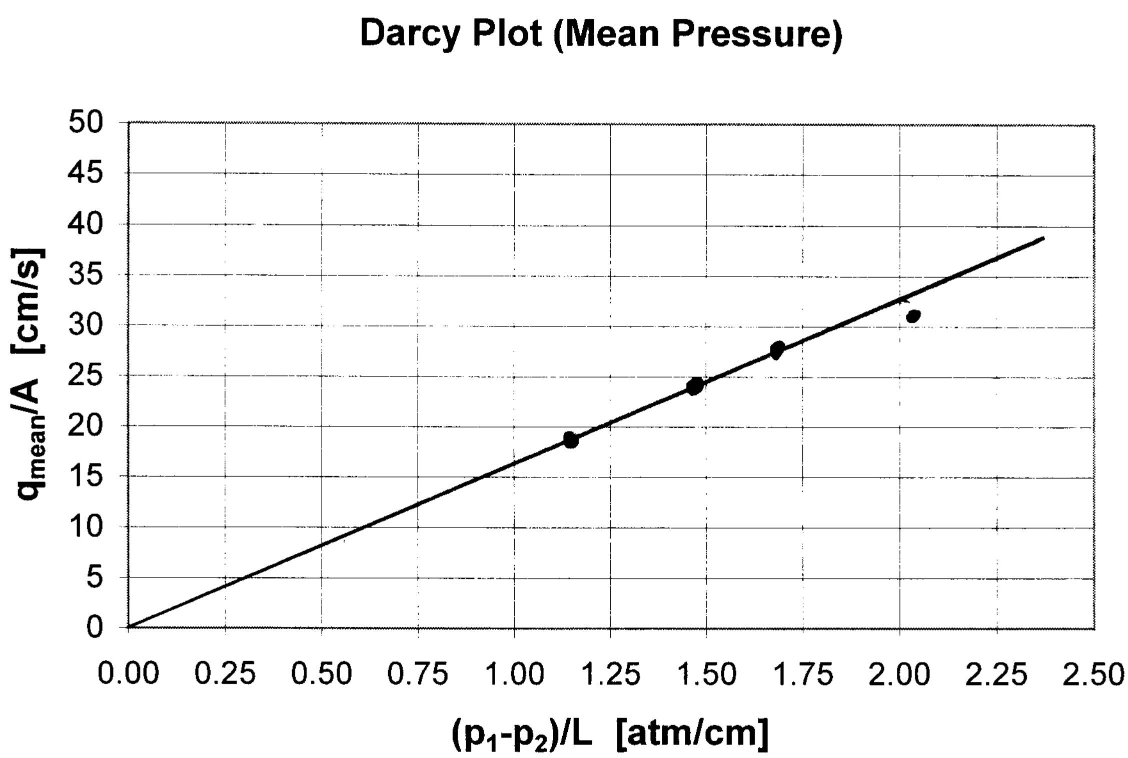
$$= (100)(0.15)(5\times10^{-6})(2000) = \underline{\underline{0.15 \text{ ft}}}$$

7. Using the gas flow data below on a small cylindrical sample, determine the absolute permeability by plotting the appropriate terms of the mean pressure form of Darcy's Law. A blank graph format is provided for the plot. The downstream pressure is atmospheric.

$$\bar{q} = \frac{kA}{\bar{\mu}_g L}(p_1 - p_2)$$

Atmospheric Pressure, atm	Sample Length, in	Sample Diameter, in	Gas Viscosity (at mean pressure), cp
1.000	1.005	0.995	0.0176

Absolute Upstream pressure, atm	Mean Flow Rate (at mean pressure), cm^3/s	$\bar{q}/A$ cm/s	$\frac{p_1-p_2}{L}$ atm/cm	
6.23	152	30.3	2.05	
5.34	141	28.1	1.70	
4.75	122	24.3	1.47	
3.90	94.2	18.8	1.14	



Slope $= 16.5 \frac{cm^2}{atm \cdot s} = \frac{k}{\bar{\mu}_g} \Rightarrow k = 0.290 \frac{cp\,cm^2}{atm \cdot s}$

$= \underline{\underline{0.29\ d}}$

8. To determine the matrix volume of a limestone core, a whole core 3.01 inches in diameter and 6.05 inches in length is placed in Cell 2 of a Boyles Law device. Each of the cells has a volume of 1000.0 cm³. Cell 1 is pressured to 50.0 psig and Cell 2 is evacuated. The cells are connected and the resulting pressure is 28.1 psig. Assume the atmospheric pressure is 14.5 psia. Determine the porosity of the core.

$$V_b = \frac{\pi d^2 L}{4} = 705.47\ cm^3$$

$$p_1 V_1 = p_2 V_2$$

$$V_2 = \frac{p_1}{p_2} V_1 = \frac{(50.0 + 14.5)\ psia\ (1000)\ cm^3}{(28.1 + 14.5)\ psia}$$

$$= 1514.08\ cm^3$$

$$V_{ma} = 2000 - V_2 = 485.92\ cm^3$$

$$\phi = \frac{V_b - V_{ma}}{V_b} = 1 - \frac{V_{ma}}{V_b} = 1 - \frac{485.92\ cm^3}{705.47\ cm^3}$$

$$\underline{\underline{= 0.311}}$$

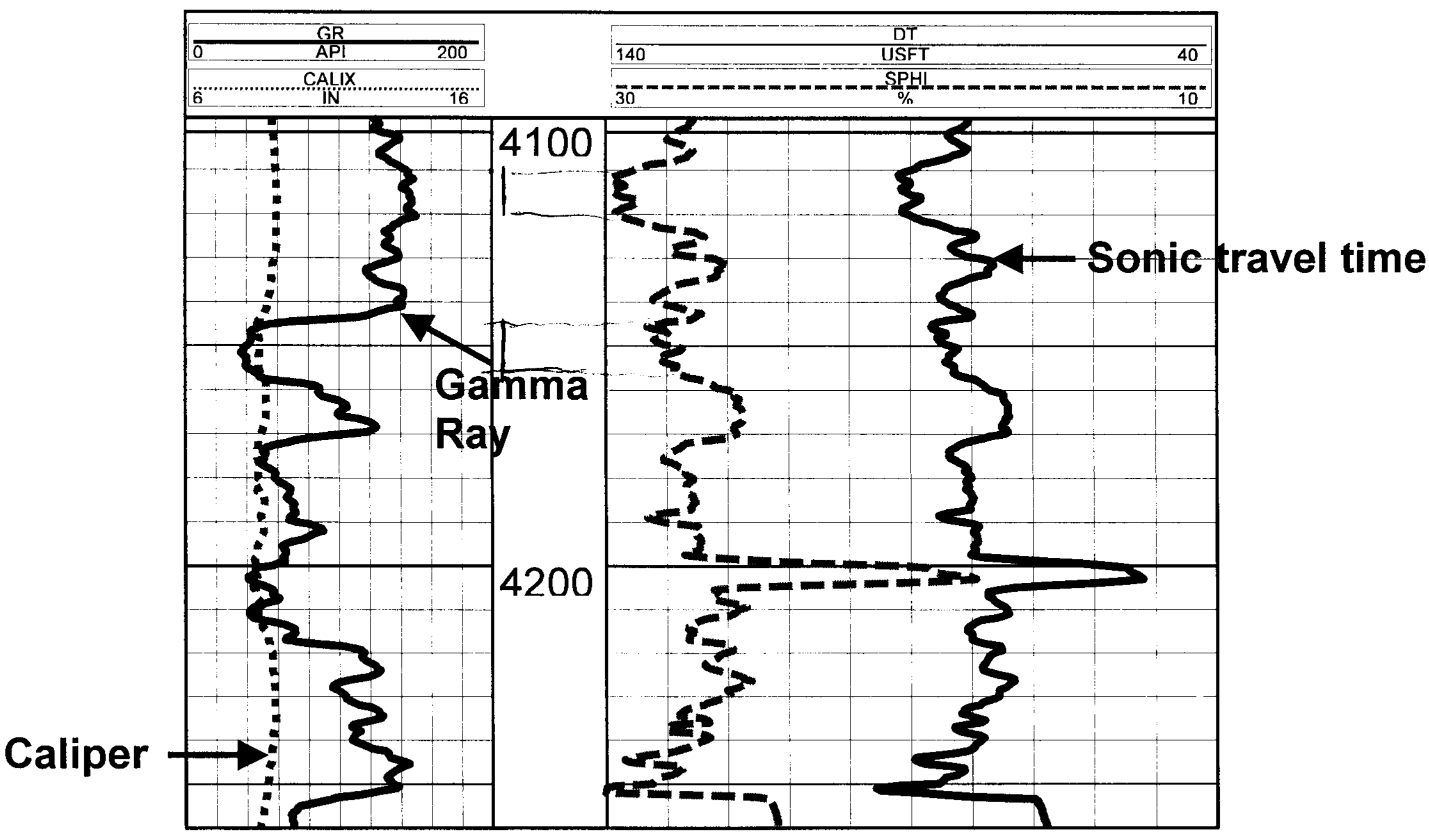
9. a. Determine the readings of the Caliper (CALIX), Gamma Ray (GR), and Sonic Travel Time (DT) Logs at the following intervals:

Interval (feet)	Caliper (inches)	Gamma Ray (API Units)	Sonic Travel Time (μsec/ft)
4110-20	8 in	144 API	90 μsec/ft
4145-55	7.4 in	40 API	84 μsec/ft

b. Use these readings to determine the porosity at 4245-55 ft, assuming matrix is limestone and the fluid in the pores is water ($\Delta t_{ma} = 47.5$ μsec/ft, $\Delta t_f = 189$ μsec/ft).

$$\Delta t_{log} \approx \phi \Delta t_f + (1-\phi)\Delta t_{ma} \Rightarrow$$

$$\phi = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} = \frac{84 - 47.5}{189 - 47.5} = \underline{0.258}$$



10. Consider the following whole core analysis data.

Sample Number	Depth (ft)	Horizontal Permeability (md)	Vertical Permeability (md)	Porosity (fraction)
96	9131.5- 32.0	35.9	119.	0.166
97	9132.0- 33.0	46.7	304.	0.179
98	9133.0- 34.0	27.8	22.1	0.154
99	9134.0- 35.0	15.1	12.9	0.132
100	9135.0- 36.0	4.61	2.94	0.118
101	9136.0- 37.0	25.5	92.5	0.169

Determine the average horizontal permeability, the average vertical permeability, and the average porosity of these data.

$\underline{k_h}$

$$\bar{k} = \frac{\Sigma kh}{h} = \frac{137.86 \text{ md ft}}{5.5 \text{ ft}} = \underline{\underline{25.0 \text{ md}}} \qquad (26.0)$$

$\underline{k_v}$

$$\bar{k} = \frac{L}{\Sigma \frac{L}{K}} = \frac{5.5 \text{ ft}}{0.4812 \frac{\text{ft}}{\text{md}}} = \underline{\underline{11.4 \text{ md}}} \qquad (11.3)$$

ϕ

$$\phi = \frac{\Sigma \phi h}{h} = \frac{0.835 \text{ ft}}{5.5 \text{ ft}} = \underline{\underline{0.152}} \qquad (0.153)$$