HW-9.1: TRAP INTEGRITY

INTRODUCTION:

In this homework, you will explore capillary sealing and stress sealing of buoyant fluids (oil, gas, C02) as discussed in Chapter 9 of (Flemings, 2021). In a previous homework, you calculated the hydrocarbon phase and water phase pressures in the J2 sand of the Bullwinkle oil field. You found the following results:

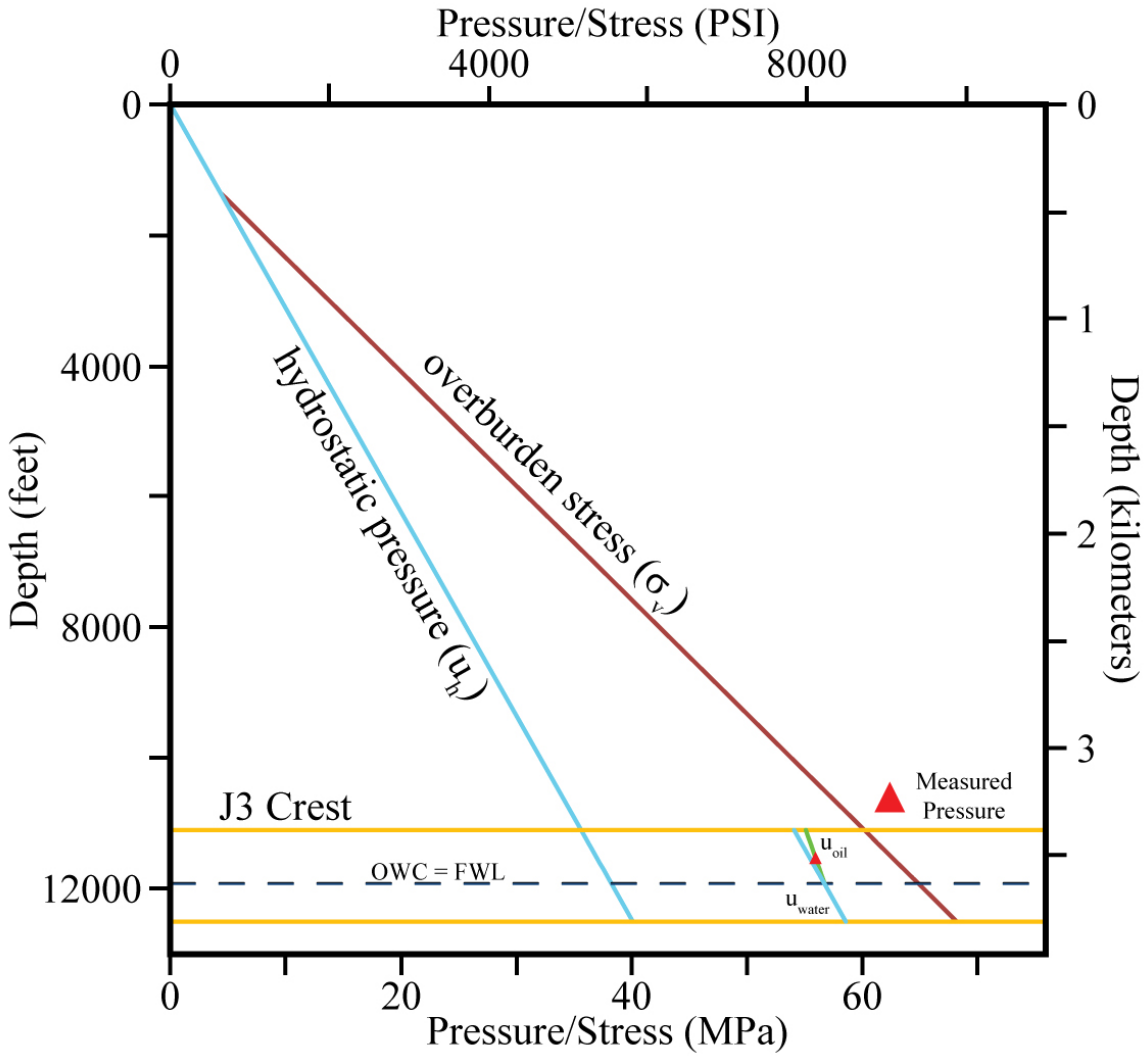


Figure A1: Pressure profiles at Bullwinkle from sea level through the J3 sand.

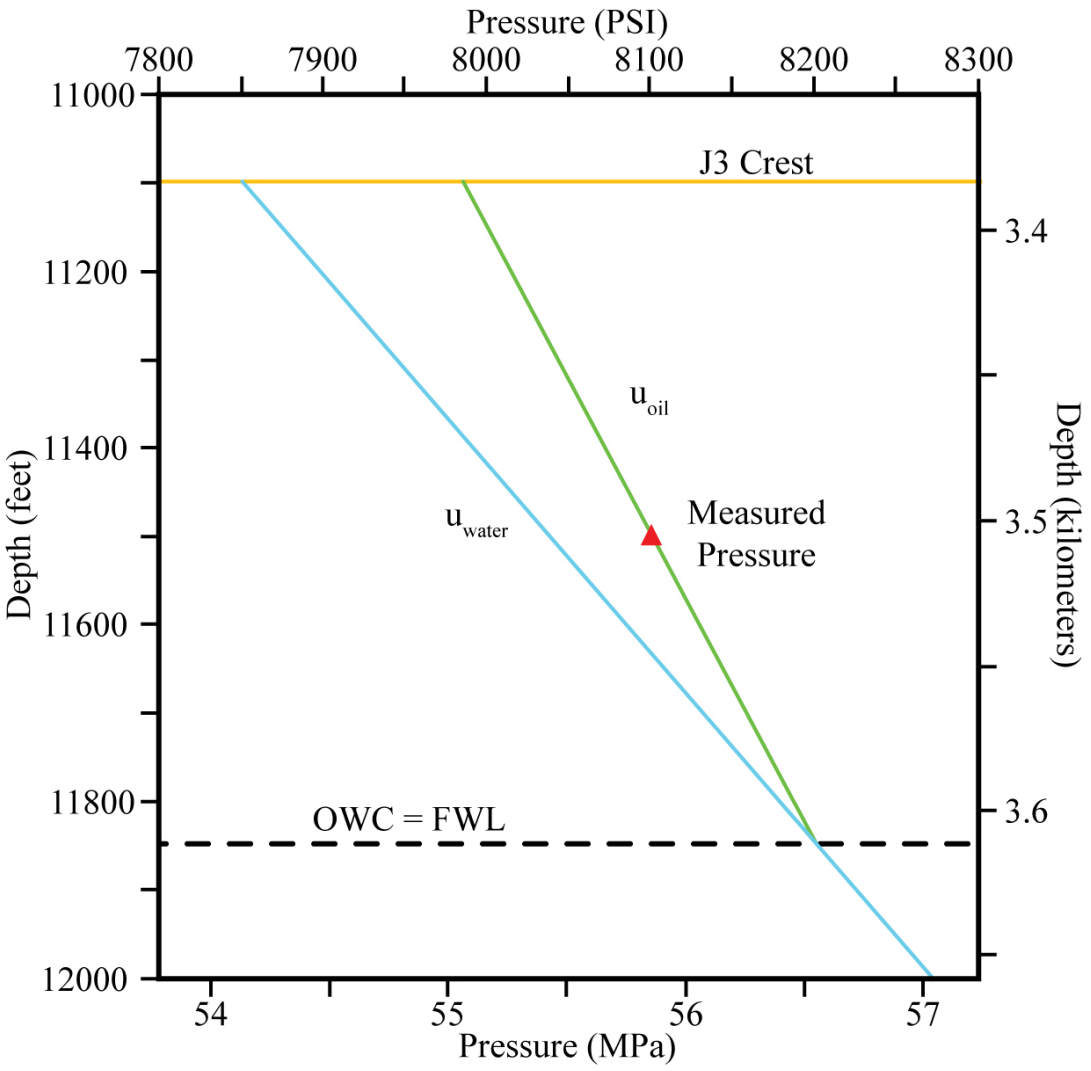


Figure A2: OWC is at 11850 ft, and the FWL is at 11850 ft. At the OWC, u_{cmig} = 0 within the reservoir, which means that the depth of the OWC and the FWL are the same.

Table 1

At the top of the J3 Sand		
Pressures	PSI	MPa
Oil (u_o)	7986	55.06
Water (u_w)	7851	54.13
Capillary (u_o - $u_{aquifer}$)	134	0.92
Aquifer Overpressure ($u_{aquifer}$ - u_h)	2689	18.55
Overburden Stress (σ_v)	8720	60.12

Table 2

Zero Displacement Pressure Scenario			
Capillary Pressure @ OWC (psi)	PSI	MPa	
	0	0	
Depth @ FWL (psi)	feet	meters	
	11850	3612	
Note: Pressure @ OWC = Pressure at FWL			
		PSI	MPa
Pressures @ top of the J3 Sand	Oil	7986	55.06
	Water	7851	54.13
	Capillary (u_{cow})	134	0.92

CAPILLARY SEALING:

TASK:

The mercury-air capillary behavior of the caprock is shown in Figure 3. u_{de} is the extrapolated displacement pressure and this is interpreted to be the migration pressure (u_{cmig}) (See Chapter 2, text).

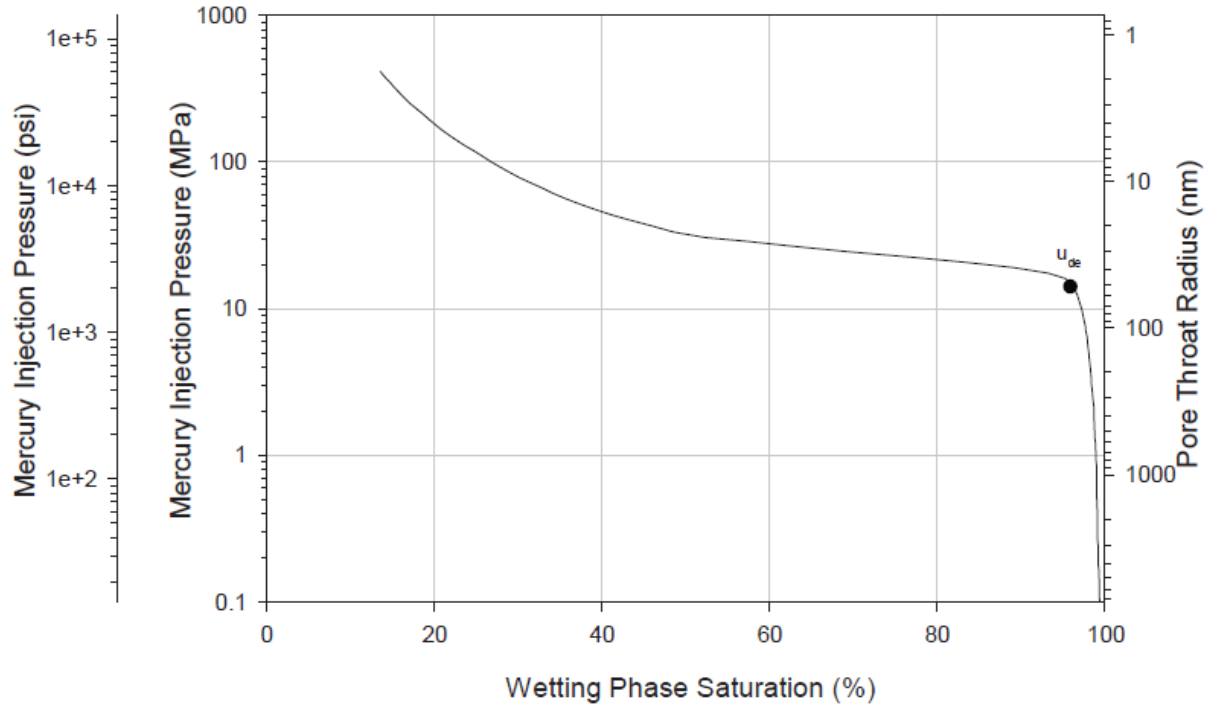


Figure 3: See (Flemings, 2021) Figure 9.4.

To convert mercury-air injection pressure to oil water, use Eq. 2.22.

$$u_{cow} = u_{cHg-air}\left(\frac{\gamma_{ow}\cos\theta_{ow}}{\gamma_{Hg-air}\cos\theta_{Hg-air}}\right). \qquad \text{Eq. 2.22}$$

Parameters for Eq. 2.22 are shown in Table 3:

Table 3 (see Table 2.4 in text).

System	Contact Angle (θ)	Interfacial Tension (γ)($\frac{dyn}{cm}$)
Laboratory		
Air-water	0	72
Oil-water	30	48
Air-Mercury	140	480
Air-oil	0	24
Reservoir		
Water-oil	30	30
Water-gas	0	50*
Oil-gas	0	24
*pressure/temp dep.		

The height above the free water level is:

$$h_{FWL} = \frac{u_{cmig}}{\Delta\rho g}. \qquad \text{Eq. 9.1}$$

Assume that water gradient is 0.46 psi/ft (1.06 g/cc) and that the oil gradient is 0.29 psi/ft (0.67 g/cc). **Use contact angle (θ) = 0° for oil/water reservoir conditions.**

Calculate the maximum column of oil that can be trapped (Eq. 9.1).

$$u_{cow} = u_{cHgair}\left(\frac{\gamma_{ow}\cos\theta_{ow}}{\gamma_{Hgair}\cos\theta_{Hgair}}\right)$$

$u_{cow} = 3000\ \text{psi}\ \left(\frac{30*\cos(0)}{480*\cos(140)}\right) = 245\ \text{PSI (1.69 MPa)},$
where 3000 psi is interpreted to be the migration pressure, which is found at a wetting phase saturation of about 95%.

$$u_{cow} = 3000\ \text{psi}\ \left(\frac{30 * 1}{480 * (-0.765)}\right) = 245\ \text{PSI (1.69 MPa)}$$

$$h = \frac{u_{cow}}{\Delta\rho g h} = \frac{245\ \text{PSI}}{0.46\frac{\text{psi}}{\text{ft}} - 0.29\frac{\text{psi}}{\text{ft}}} = 1440\ \text{feet of oil (439 meters)}$$

See Figure 9.5 and associated discussion for further insight.

MECHANICAL SEAL: HYDRAULIC FRACTURE CONTROL:

Leak off measurements at Bullwinkle constrain the value of the least principal stress in the seal (σ_3^{seal}) to be 8546 PSI.

$u_{crit}^{res} = \sigma_3^{seal}$, Eq. 9.3

$h_{FWL} = \frac{u_{crit}^{res} - u_w^{res}}{\Delta\rho g}$. Eq. 9.4

Assume that the caprock pore pressure is equal to the water phase pressure at the top of the sand. What is the height of the trapped column (eq. 9.3)?

$$h_{FWL} = \frac{\sigma_3^{seal} - u_w^{res}}{\Delta\rho g} = \frac{8546\text{psi} - 7851\text{psi}}{0.46\frac{\text{psi}}{\text{ft}} - 0.29\frac{\text{psi}}{\text{ft}}} = 4088\ \text{feet of oil (1246 meters)}$$

See Figure 9.14 and associated discussion for further insight.

MECHANICAL SEAL: CRITICALLY STRESSED FAULT:

Calculate the hydrocarbon column height if there is leakage along critically stressed faults (Eq. 9.5).

Calculate u_{crit}^{res}:

$$u_{crit}^{res} = \frac{\sigma_h^{seal} - \left(\frac{1-sin\phi'}{1+sin\phi'}\right)\sigma_v}{\left[1-\left(\frac{1-sin\phi'}{1+sin\phi'}\right)\right]}. \qquad \text{Eq. 9.5}$$

Assume the friction angle (ϕ') is equal to 30 degrees and that the caprock pore pressure is equal to the water phase pressure at the top of the sand. What is the height of the trapped column (Eqs. 9.3 & 9.5)?

$$u_{crit}^{res} = \frac{\sigma_h^{seal} - \left(\frac{1-\sin\phi}{1+\sin\phi}\right)\sigma_v}{\left[1-\left(\frac{1-\sin\phi}{1+\sin\phi}\right)\right]}$$

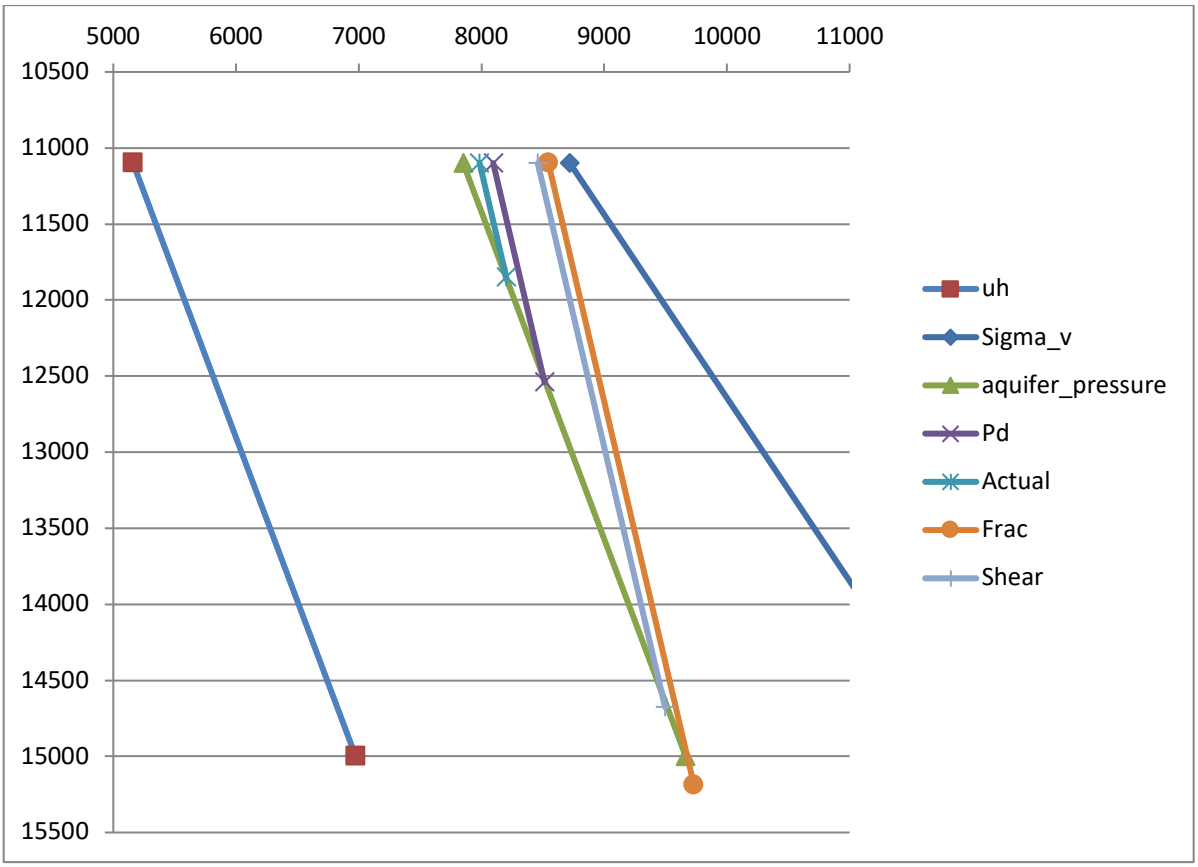
$$u_{crit} = \frac{8546 - \left(\frac{1-\sin 30}{1+\sin 30}\right)8720}{\left[1-\left(\frac{1-\sin 30}{1+\sin 30}\right)\right]} = 8459 \text{ PSI } (58.32 \text{ MPa})$$

$$u_{crit} = \frac{8546 - \left(\frac{1-0.5}{1+0.5}\right)8720}{\left[1-\left(\frac{1-0.5}{1+0.5}\right)\right]} = 8459 \text{ PSI } (58.32 \text{ MPa})$$

$$u_{crit} = \frac{8546 - \left(\frac{1}{3}\right)8720}{\left[1-\left(\frac{1}{3}\right)\right]} = 8459 \text{ PSI } (58.32 \text{ MPa})$$

$$h = \frac{u_{crit} - u_w}{\Delta\rho g} = \frac{8459\text{psi} - 7851\text{psi}}{0.46\frac{\text{psi}}{\text{ft}} - 0.29\frac{\text{psi}}{\text{ft}}} = 3576 \text{ feet of oil } (1090 \text{ meters})$$

See Figure 9.14 and associated discussion for further insight



Flemings, P., 2021, A Concise Guide to Geopressure: Origin, Prediction, and Applications, Cambridge Press.