Problem 1 (40 points)

1. The following table contains the estimated bulk mass densities as a function of depth for an offshore location in Brazil. Water depth is 500m. Measurements indicate that porosity of shale layers estimated through resistivity measurements.

Depth (m)	Bulk mass density (kg/m^3)	Shale porosity
0	1025	
100	1026	
200	1026	
300	1030	
400	1030	
500	1031	
600	1900	
700	2190	
800	2200	
900	2230	
1000	2235	
1100	2240	
1200	2275	0.305
1300	2305	0.297
1400	2310	0.286
1500	2308	0.281
1600	2310	0.285
1700	2305	0.293
1800	2310	0.307
1900	2324	0.305
2000	2319	0.298

a. Plot S_v as a function of depth (in SI units)

b. Plot hydrostatic water pressure as a function of depth. Assume the density of brine water is 1031 kg/m^3 in the rock pore space (in SI units).

c. Additional compaction lab measurements on shale cores indicate a good fit of the porosity-effective vertical stress relation through the equation $\phi = \phi_0 \exp(-\beta(S_v - P_p))$, with parameters $\phi_0 = 0.38$ and $\beta = 3 \cdot 10^{-2}$ MPa^{-1}. Estimate the pore pressure in the shale. Is there overpressure? At what depth does it start?

d. Plot vertical effective strees, σ_v^{eff} as a function of depth (in SI units).

Problem 2 (20 points)

Compare the characteristic hydraulic time of escape in a sandstone formation with porosity 0.25 and the one with the same matrix grains, but more compacted, with porosity 0.12.

- You can assume that permeability can be estimated using equation $k = Cd^2\phi^3$ where C is a given constant, d is sandstone grain diameter and ϕ is porosity. When using the formula, assume that constant C and grain diameter d do not change during compaction. Compressibility β of a material is inverse of its bulk modulus K. Bulk modulus for brine water and quartz grains are given as $K_f = 2.2$ GPa and $K_r = 41$ GPa.

Problem 3 (30 points)

Assume stresses are given as $S_{hmin} = 40$ MPa, S_{Hmax}=60 MPa, S_v=45 MPa and S_{hmin} acts in the East-West direction. For each of the faults below, calculate the normal and shear stress and then determine what kind of fault would it be, **if** it were to slip.

a. Fault with strike north-south, dip 65° to the east.

b. Fault with strike north-south, dip 50° to the west

c. Fault with strike east-west, dip 25° to the north.

Problem 4 (20 points)

A major fault in your reservoir has strike N35°W and dip 60° from horizontal. S_{hmin} in this area acts along 020°, and in situ stresses are $S_{hmin} = 70$ MPa, $S_{Hmax} = 80$ MPa, $S_v = 65$ MPa. Assume the pore pressure $P_p = 30$ MPa. Is the fault likely to slip if the respective frictional coefficient is $\mu = 0.7$?

Problem 5 (40 points)

Assuming the same reservior conditions as Problem 4, write a computer code that can compute the resolved shear stress magnitude and normal effective stress on a fault characterized by the strike direction and dip angle. Now randomly generate 10000 faults (use a statistical distribution to choose random pairs of strike and dip) and plot the resolved shear stress on the fault as a function of resolved normal effective stress. Where do near vertical strike-slip faults appear on this diagram? Where do the oblique-slip faults fall?

Problem 6 (10 points)

Repeat Problem 5 but make $S_{hmin} = S_{Hmax} = 45$ MPa (i.e. stress isotropic in the horizontal plane. How has the plot changed? Is this still a 3D problem?