Unconventional Reservoir Geomechanics
Spring 2020

Homework 3: Ductility and Stress Magnitudes

Due May 4, 2020 00:00 PST

Instructions

This assignment focuses the relationship between the viscoplastic properties (ductility) of reservoir rocks and the state of stress in different lithofacies.

Part 1: Creep and stress relaxation

Sone & Zoback (2013b) describe the time-dependent deformation (creep) in terms of a viscoelastic power law with the form (Unit 7, slide 10):

$$\epsilon_{creep}(t) = \sigma B t^n$$

a) What do the power law parameters B and n represent? How do they vary with clay + TOC? sample orientation? elastic stiffness?

b) Consider the following samples: Barnett-2, Haynesville-1 and Eagle Ford-1 (vertical samples). Using the lower limits of B and n values provided in Table 1, calculate the amount of creep strain, $\epsilon_{creep}(t)$, that would occur due to the application of 30 MPa differential stress over times of 1 yr, 100 kyr, and 100 Myr. Construct a table of the results and/or a scatter plot of the creep strain as a function of time with the points colored based on the clay + TOC.

c) What is the relationship between the amount of creep strain and clay + TOC?

d) The creep compliance function $J(t)$ of the viscoelastic power law model is given by:

$$J(t) = Bt^n$$

Plot log $J(t)$ versus log t for each sample and show how the values of B and n are obtained.

e) For each sample, calculate the accumulated differential stress, $\sigma(t)$, for a constant strain rate of $\dot{\epsilon} = 10^{-19}\ s^{-1}$ over 150 My using the following expression:

$$\sigma(t) = \dot{\epsilon} \frac{1}{B(1-n)} t^{1-n}$$

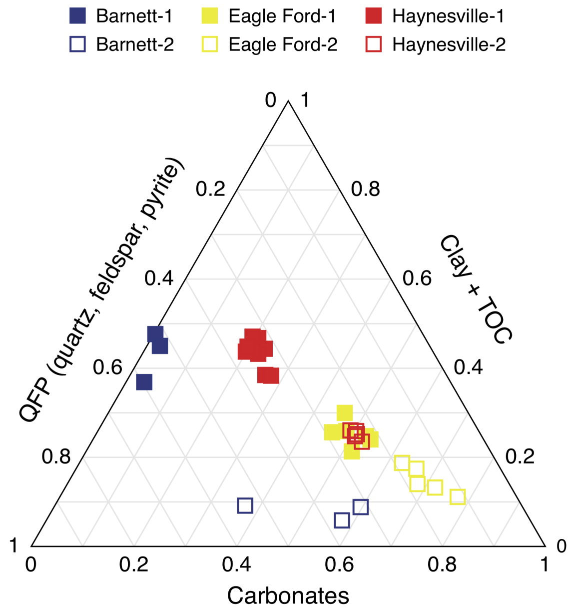

Figure 1: Ternary composition of relatively high (-1) and low (-2) clay + TOC sample groups from different shale basins. From Sone & Zoback (2013a).

Table 1: Power law constitutive parameters for each sample group (Sone & Zoback, 2013b).

	Vertical samples		Horizontal samples	
	B (10^{-5} MPa^{-1})	n	B (10^{-5} MPa^{-1})	n
Barnett-1	3.5-4.2	0.015-0.024	2.0-2.6	0.012-0.021
Barnett-2	1.2-1.8	0.011-0.027	1.6-1.6	0.009-0.010
Eagle Ford-1	2.6-8.5	0.028-0.095	1.7-2.3	0.024-0.053
Eagle Ford-2	2.2-7.1	0.019-0.085	1.7-1.8	0.023-0.049
Haynesville-1	3.7-8.9	0.023-0.081	1.8-2.7	0.027-0.062
Haynesville-2	1.6-3.1	0.025-0.060	1.5-1.8	0.011-0.049

Part 2: Effects of viscoplastic creep on stress magnitudes

a) For a normal faulting environment, calculate the lower bound on the least principal stress using the following parameters:

Depth, $d = 9000$ ft
Coefficient of friction, $\mu = 0.6$
Pore pressure gradient $= 0.5$ psi/ft
Vertical stress, $S_v = 1.1$ psi/ft

b) Viscoplastic stress relaxation. The variation in differential stress with time is given by the expression below (Unit 7, slide 17):

$$S_1 - S_3 = \epsilon_0 t^{-n} \frac{E}{1-n}$$

where ϵ_0, the total strain, is a fitting parameter. What is ϵ_0 at $t = 100$ Myr for $E = 40$ GPa? Use the plot below to find the value of n from the linear fit line.

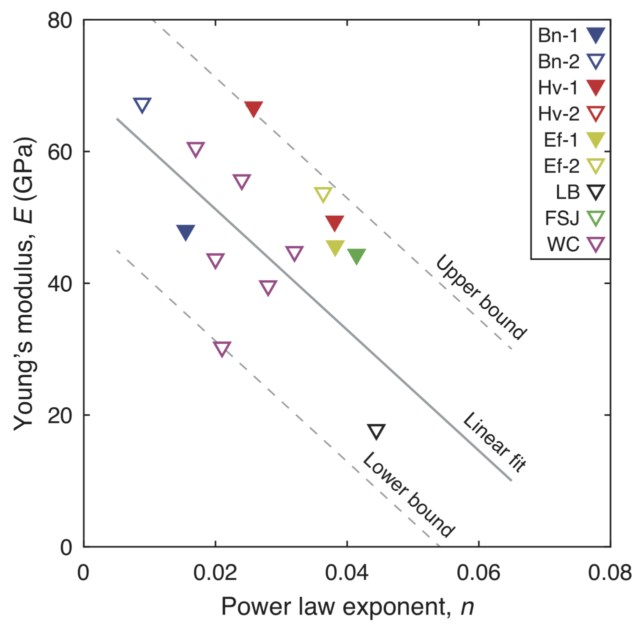

Figure 2: Correlation between Young's modulus and power law parameter n for several shale reservoir samples. From Ma & Zoback (2018).

c) How much would you expect the value of S_{hmin} to evolve due to viscoplastic stress relaxation? Use $t = 100$ Myr and the upper/lower bound values of n to determine the range of S_{hmin} values.

Part 3: Vertical growth of hydraulic fractures in layered media

a) Figure 3 shows S_{hmin} magnitudes as a function of depth for a layered sequence. Based on this stress profile, which formation is the least ductile (most brittle)?

b) Assuming a strike-slip faulting regime, which layer would you stimulate to achieve a wide, confined fracture with limited vertical extent?

c) Suppose that stimulating layer E results in horizontal hydraulic fractures. What does this tell you about the relative stress magnitudes in layer E?

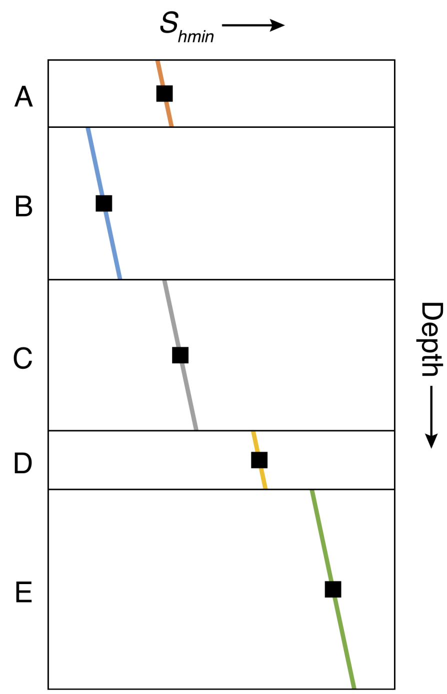

Figure 3: Variation of the minimum horizontal stress with depth in a layered sequence.