Unconventional Reservoir Geomechanics
Spring 2020

Homework 3: Ductility and Stress Magnitudes

Part 1: Creep and stress relaxation

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

B represents the elastic compliance and n represents the relative contribution of the time-dependent deformation to the total strain at a given time. Both B and n increase with increasing clay + TOC *within individual basins* (e.g., Barnett-1 vs. Barnett-2). In general, B increases with increasing clay + TOC (similar to elastic stiffness), but n is not necessarily correlated with clay + TOC. Since B represents the elastic compliance, it is approximately equal to the inverse of elastic stiffness or Young's modulus. In terms of sample orientation, B and n are both greater for vertical samples than for horizontal samples because vertical samples show lower elastic stiffness and greater creep strain.

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.

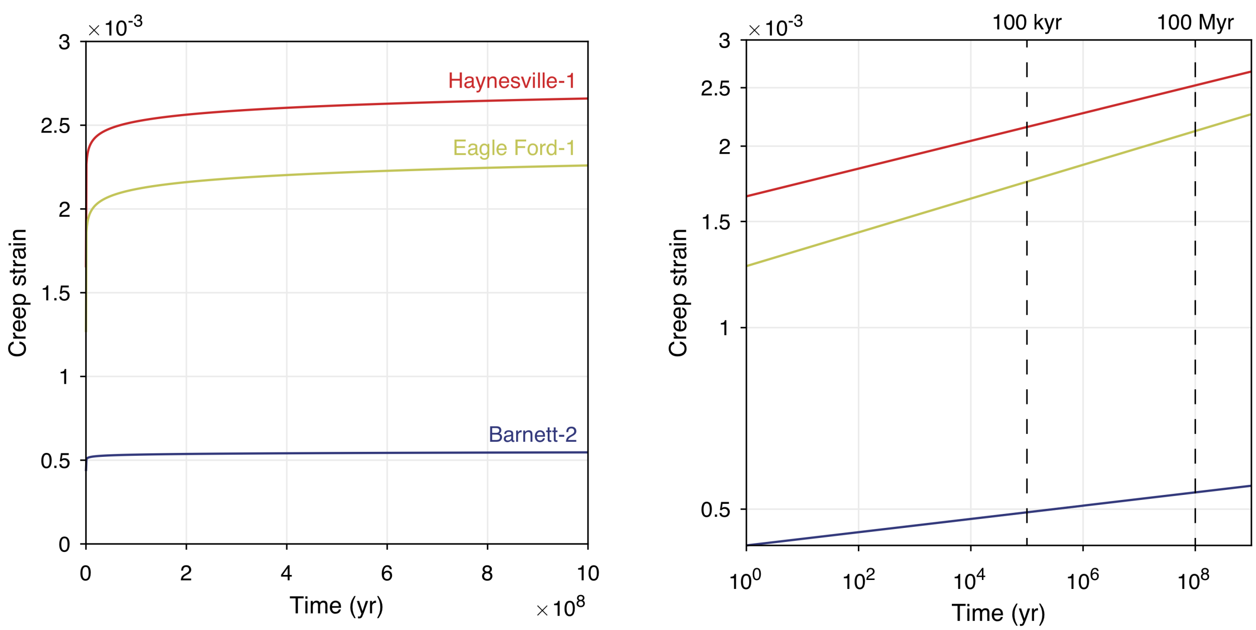

Figure 1: (right) Creep strain as a function of time. (left) Logarithim of creep strain as a function of logarithim of time.

Table 1: Creep strain as a function of time for select shale samples

	1 yr	100 kyr	100 Myr
Barnett-2	4.35e-4	4.94e-4	5.33e-4
Eagle Ford-1	1.30e-3	1.70e-3	2.10e-3
Haynesville-1	1.70e-3	2.20e-3	2.50e-3

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

For these three samples, creep strain increases with increasing clay + TOC.

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

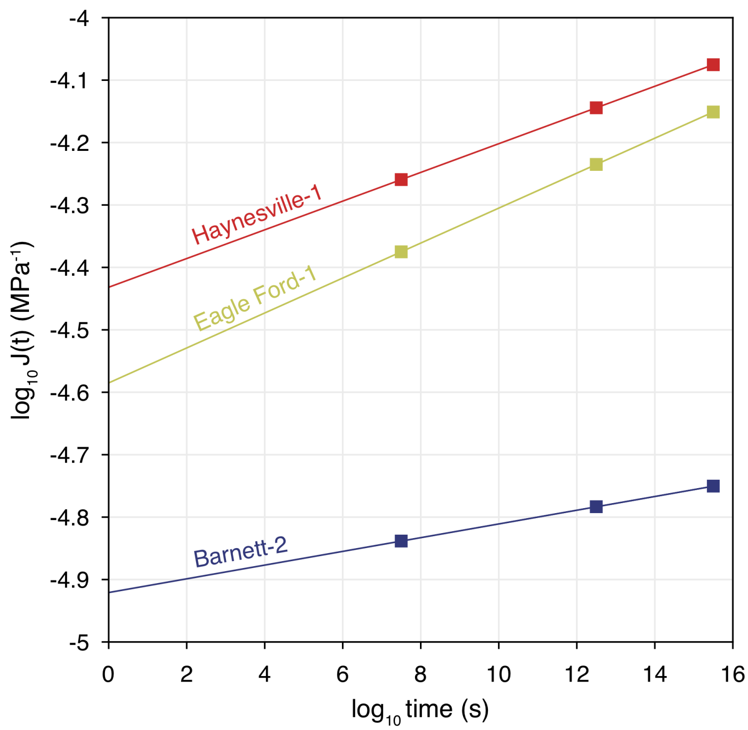

Figure 2: Logarithim of creep compliance $J(t)$ as a function of logarithim of time.

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

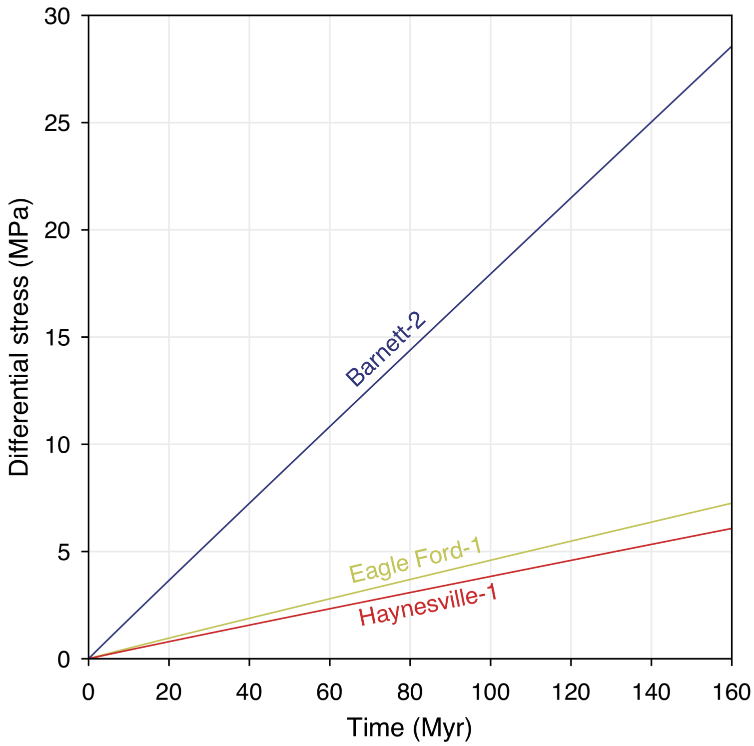

Figure 3: Accumulated differential stress as a function of time.

The accumulated differential stress in Barnett-2, Eagle Ford-1 and Haynesville-1 is 26.80 MPa, 6.81 MPa and 5.71 MPa, respectively.

Part 2: Effects of viscoplastic creep on stress magnitudes

a) For a normal faulting environment, calculate the lower bound on the least principal stress.

The lower bound on the least principal stress (S_{hmin}) is 43.04 MPa.

b) 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.

$$\epsilon_0 = (S_1 - S_3)\frac{(1-n)}{Et^{-n}}$$

The value for n from the linear fit line at $E = 40$ GPa is 0.03. ϵ_0 at 100 Myr is 0.0018.

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.

Using the upper bound value of n, S_{hmin} evolves to S_V ~100 kyr. Using the linear fit value of n, S_{hmin} evolves to 61.7 MPa at 100 Myr. Using the lower bound value of n, S_{hmin} evolves to 48.1 MPa at 100 Myr.

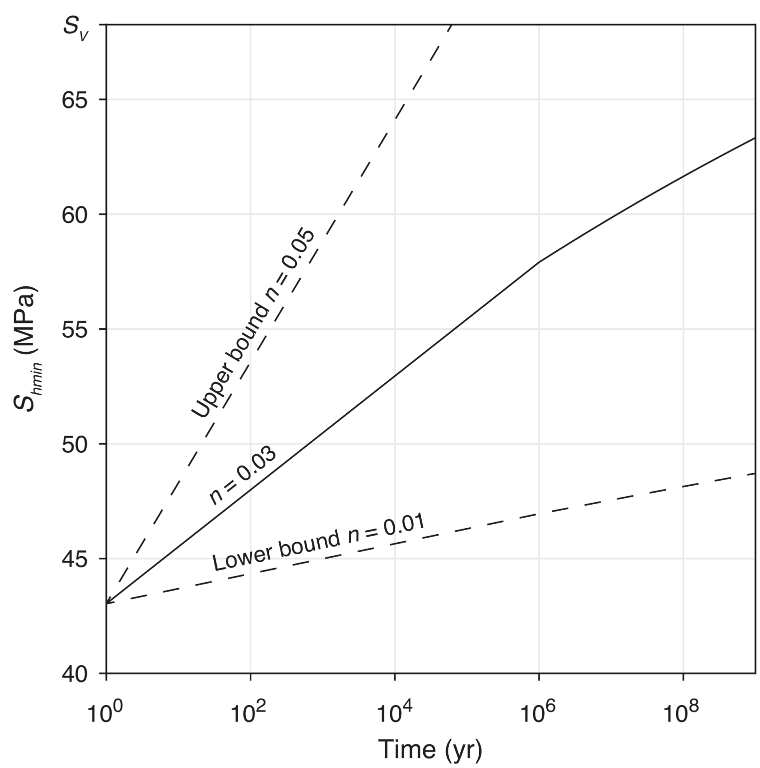

Figure 4: Evolution of S_{hmin} as a function of time for different values of power law parameter n. The maximum value of S_{hmin} is S_V.

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)?

Layer B is the most brittle or least ductile because it supports the most differential stress (the difference between S_1 and S_{hmin}) or in other words, it has experienced the least viscoplastic stress relaxation.

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

Layer D is the thinnest formation, but is overlain by two layers with lower values of S_{hmin} (fracture gradient). This means taht a hydraulic fracture originating in Layer D would tend to propagate upward into Layers B and C.

Layer B is moderately thick and is bound from the top and bottom by layers with higher values of S_{hmin}. Layers A and C will likely act as barriers to vertical propagation, resulting in a relatively wide, vertically limited hydraulic fracture.

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

Hydraulic fractures propagate perpendicular to the least principal stress (S_3). If horizontal hydraulic fractures are observed, the vertical stress S_V is likely the least principal stress. Therefore, $S_{Hmax} > S_{hmin} > S_V$. However, since this a strike slip faulting regime ($S_{Hmax} > S_V > S_{hmin}$), it can also be concluded that S_{hmin} is very close to S_V, or $S_{hmin} \approx S_V$.