Stanford | ONLINE

Unconventional Reservoir Geomechanics
Spring 2019

Homework 3: Ductility and Stress Magnitudes

Due April 29, 2019 at 08:00 UTC
Please direct any questions to the Piazza Discussion Forum on the course page

Background

This assignment focuses on the relationship between rock ductility and the stress magnitudes. You will first develop an understanding of the relationship between ductility and composition by studying laboratory measurements of creep on samples from different lithologies. You will then use the relationship between creep and viscoelastic stress relaxation to calculate the accumulated differential stress in each lithology over geologic time.

Utilize a scientific computing and/or plotting program such as MATLAB, Python or Excel to follow the steps below. Then, answer the questions on the page below.

Part 1: Creep and stress relaxation

You may find the following article useful for your understanding and further reading:

Sone, H., & Zoback, M. D. (2013). Mechanical properties of shale-gas reservoir rocks—Part 2: Ductile creep, brittle strength, and their relation to the elastic modulus. Geophysics, 78(5), D393-D402.

The time-dependent deformation (creep) of unconventional reservoir rocks can be described in terms of a viscoelastic power law with the form:

$$\varepsilon_{creep}(t) = B\sigma t^{n} \tag{1}$$

a. How are power law parameters *B* and *n* expected to vary with clay + kerogen content and sample orientation?
b. *Sone & Zoback* (2014) studied creep deformation in a wide range of lithologies. The sample compositions and the experimental results are given below:

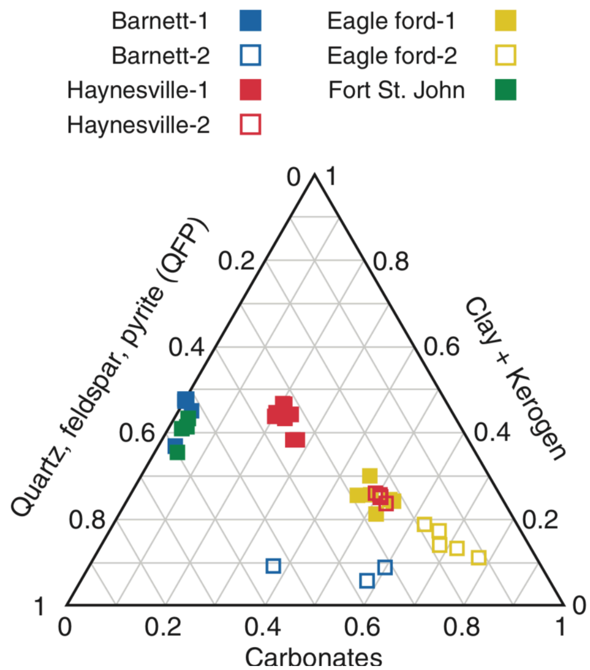

Figure 1

Table 1
Power-law constitutive parameters recovered for each sample group.

Sample group	Vertical samples (bedding perpendicular)		Horizontal samples (bedding parallel)	
	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
Hayneville-1	3.7–8.9	0.023–0.081	1.8–2.7	0.027–0.062
Hayneville-2	1.6–3.1	0.025–0.060	1.5–1.8	0.011–0.049
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
Fort St. John	–	–	2.2–2.9	0.023–0.057

Consider the following samples: **Barnett-2**, **Haynesville-1 and Eagle Ford-1 (only vertical samples)**. Using the **lower limits** of B and n values provided in Table 1, calculate the amount of creep strain, $\varepsilon(t)$, that would occur due to the application of 30 MPa differential stress over timescales of 1 year, 10^5 years and 10^8 years. 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 + kerogen content.

Note: Use the ternary diagram (Fig. 1) to read the clay + kerogen content for each sample. Use units of seconds for time in all calculations.

c. Is there any correlation between the amount of creep strain and the clay + kerogen content?

d. Re-arrange the Eqn. 1 to obtain the expression below for the creep compliance function $J(t)$. Plot log $J(t)$ vs. log t for each sample. Show how the values of B and n are obtained from this plot.

$$\log J(t) = \log B + n \log t \tag{2}$$

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

$$\sigma(t) = \dot{\varepsilon} \frac{1}{B(1-n)} t^{1-n} \tag{3}$$

Part 2: Answer the questions on the page below

Use the plots and calculations from Part 1 to answer the questions on the page below. The answers and solutions will be posted after the due date. Numerical entry types responses have only a limited range of accepted values and are graded electronically, so follow the directions closely and adhere the to the given values of constants to prevent misgrading of your submissions.