**ESCI 458/658 – Homework 1 (100 points)**

**Assigned: Sept. 13th at class**

**Due: Sep. 27th at class**

**Show work in all sections. I suggest you utilize MATLAB/Octave for developing functions and plotting (although other languages [Python, R] are allowed). Please include axes labels, units, and titles on all plots. Plot logs vertically (y axis is depth). Please place all results in a single word/pdf file for review. Essay answers should be complete. Please include all functions and scripts in the write-up. You are allowed to discuss the homework assignment with others but every student must turn in their own report and independently develop scripts/codes.**

**Part I: Understanding Bounding Models.** (50 points) You are given a small data set consisting of velocity measurements on 54 different clastic samples at pressures 5, 10, 20, 30, and 40 MPa. The file is **Data.mat** located on the Canvas site. It contains a matrix of the data (Data) and structure that lists what is in each column of the matrix (Column_Names).

1) *Calculating Bounds* (50 Points). Use the Data.mat file from the Canvas site. Select the *water-saturated* Vp (Column 6), Vs (Column 7), density, porosity, and clay content data for 30 and 40 MPa (Column 5). Discard the rest of the data. After you have the data for 30 and 40 MPa, divide them into two parts: 1 for clean sandstone (Clay < 20%) and shaley sandstone (Clay >= 20%).

2a) Plot the clean sand data, specifically, bulk modulus as a function of porosity. On the same axes, plot Voigt-Reuss bounds of bulk modulus as a function of porosity for a mixture of quartz and water. Label the curves.

2b) On the same axes as 2a), plot upper and lower Hashin-Shtrikman bounds of bulk modulus as a function of porosity. Label the curves

2c) On a 2nd set of axes, repeat 2a) except for shear modulus.

2d) Repeat 2b) except for shear modulus.

***Note***: Make a function for calculating the HS bounds. You will use them in the next part and in the future.

3a) On a 3rd set of axes, plot the clean sand data, this time Vp as a function of porosity. On the same axes, plot the Voigt-Reuss bounds of Vp as a function of porosity. Label the curves.

3b). On the same axes as 3a) plot upper and lower Hashin-Shtrikman bounds of Vp as a function of porosity. Label the curves.

3c) On a 4th set of axes, repeat 3a) except for Vs.

3d) Repeat 2b) except for Vs.

4) Repeat problems 2 and 3 using the shaley sands. For the shaley sandstones, the amount of clay content in the solid mixture is a free parameter, so you must choose how much clay content to use in the bounds. You will still mix a fluid and a solid. The solid, however, is a combination of two minerals (quartz and clay). Mix mineral moduli using the Voigt-Reuss-Hill approach. When you have the mixture of the solids, that is the new 0 porosity end member value for the bounds. Use Table 1 as necessary.

| | Bulk Modulus (GPa) | Shear Modulus (GPa) | Density (g/cc) |
|---|---|---|---|
| Brine | 2.4 | N/A | 1.05 |
| Quartz | 36.6 | 45 | 2.65 |
| Clay | 25 | 8 | 2.55 |

**Table 1. Values for Problem 1.**

**<u>Questions to answer for Part 1:</u>**

a) What are the geometric interpretations of the Voigt-Reuss and Hashin-Shtrikman bounds?

b) Which of the bounds is iso-stress and which is iso-strain?

c) What type of mixture of materials does an iso-stress bound explain? Why?

d) What would happen to the effective mineral moduli if a mixture of 50% quartz and 50% feldspar was used instead of clay and quartz? Look up what the moduli for feldspar are (more than one set exists), and state which one you use to answer this question.

e) For the geometric interpretations of the H-S bounds, what possible depositional and/or diagenetic situations might approximate these two interpretations?

**Part II. Fluid substitution** (50 Points). This problem will provide you with an opportunity to experiment with Gassmann fluid substitution applied to a geologic $CO_2$ dataset from a past sequestration experiment in East Texas. On the Canvas site, you will find a text file called **integratedLogSetV1.dat.** This file contains the following important columns harvested from a sequence of logging runs.

| | |
|---|---|
| Wireline depth in meters (1) | |
| Wireline depth in feet (2) | |
| Density (3) | [kg/m$^3$] |
| Porosity (10) | [fraction, from corrected neutron log] |
| $V_p$ (13) | [m/s, from dipole sonic] |
| $V_s$ (14) | [m/s, from dipole sonic] |

The reservoir interval of concern is from depths of 5055 – 5072 ft, wireline depth.

Use these data for this problem. Use the 'load' function to read in the data. There are 7 columns in the file, and each column and its units are labeled in the top row of the text file. The well data contain two zones that produce gas. The task is to use fluid substitution for several different scenarios.

**<u>Part 1:</u>** Use Gassmann's model and determine the dry frame modulus ($K_{dry}$) from the sonic logs for the reservoir interval (depths above). Assume full brine saturation and quartz as the grain mineral. Remember to keep consistent units in calculations (MKS).

**<u>Part 2:</u>** Derive the equation for grain density assuming fluid properties, porosity, and bulk density are known. Calculate the grain density for the reservoir interval from the given logs assuming 100% brine saturation. Is the assumption that the mineral is only quartz grains reasonable? If not, what is the composition?

**<u>Part 3:</u>** Use Gassmann's model and determine the formation $V_p$ and $V_s$ after 100% $scCO_2$ saturation. Plot the original logs and the property variations after full $CO_2$ saturation in the interval. See the table below for fluid property estimates.

| | Bulk Modulus (GPa) | Shear Modulus (GPa) | Density (g/cc) |
|---|---|---|---|
| Brine | 2.25 | N/A | 1.030 |
| $scCO_2$ | 0.09 | N/A | 0.7 |
| Quartz | 36.6 | 45 | 2.65 |
| Clay | 21 | 7 | 2.58 |

**Table 2. Values for Problem 2.**

**<u>Part 4:</u>** Block the $V_p$, $V_s$, and density values for the $CO_2$ saturated unit and the unit directly above. What is the change in normal P-wave reflectivity generated by $CO_2$ injection?

Suggestions: Make 2 functions: the first calculates the dry rock bulk modulus, and the second computes the saturated-rock bulk modulus. Allow the functions to operate on vectors that are the length of the input curves. Fluid density, matrix density, and fluid bulk modulus should all be vectors.

Make sure that your codes work. You will use this fluid substitution code again in later assignments (and quite possibly in your own work).