About You

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Your Activity or Assignment

Activity/Assignment Title: **Using candy bar deformation experiments as an analogue for understanding rock rheology**

Type of Activity (*e.g.*, problem set, case study, experiment, long-term project, etc.):

This is an in-class experiment-based exercise that allows students to gain an intuitive understanding of how temperature, pressure and strain rate affect the way in which material responds to an applied stress field.

Context

To help your colleagues understand when or how they might successfully use your activity with their own students, please provide the following information on context:

Briefly describe the type and level of course in which you use this activity or assignment:

This exercise was designed for an introductory 200-level structural geology class for geology majors.

Briefly describe or list the skills and concepts that students must have mastered before beginning the activity:

The students should have a good understanding of the concepts of stress and strain, and should have recently been exposed to the idea of creep, elastic, plastic and viscous behavior, and linear and non-linear rheologic behavior.

Briefly describe how the activity is situated in your course (*e.g.*, as a culminating project, as a stand-alone exercise, as part of a sequence of exercises):

This is a stand-alone exercise that is performed during the first lecture on rheology, which I teach after stress and strain during the first month of class.

Goals of the Activity or Assignment

To help your colleagues understand the role of this activity or assignment in your course, please provide a statement of the goals that you have for students in the following three areas:

- Content or concepts (*e.g.,* pure vs. simple shear, deformation mechanisms, kinematic analysis; accurate description of samples)

- **Concept of rheology, the complex relationship between stress and strain and the influences of external variables like temperature, pressure and strain rate on rock deformation.**

- Higher order thinking skills (*e.g.*, analysis of data, formulation of hypotheses, synthesis of ideas, critical evaluation of competing models, development of computer or analog models)
  - **Concept of analogue models and their advantages and disadvantages**
  - **Understanding experimental assumptions.**
  - **Extrapolation of observation and understanding to real world conditions.**
- Other skills (*e.g.,* writing, operating analytical equipment, searching the WWW, oral presentation, working in groups).
  - **The students work in small groups and discuss their observations amongst themselves.**
  - **The students present their observations to the rest of the class during a post exercise (or following lecture) group discussion**

Description

Please provide a short description of your activity or assignment and its outcomes. Please be sure to include essential key words or index terms to help users find resources using our search/browse functions. You will find a sample description below:

Description

Very little student preparation is needed for this classroom experiment. The student should have done their background reading on rheology prior to the lecture. Moreover, the students should have been exposed to the ideas of stress, strain, and should have recently been exposed to the idea of creep, and elastic, plastic and viscous behavior, and linear and non-linear rheologic behavior. In class, students receive a short handout that introduces the exercise. The handout contains some blank graphs for the students to plot up their empirical observations and space to write up their observations. I organize the students into small groups and pass out all of the necessary equipment, which includes several candy bars, gloves and mat for the mess, and a confining pressure apparatus designed especially for this experiment. After everyone is briefly introduced to the exercise, I set the students up for their experiments and let them run with it. I walk around the class as the students progress in order to assure that they are doing the experiments as I envision so that they get the most out of their observations. Their task is to answer several questions about their observations and construct an empirical plot of the relationship between stress and strain as a function of 1) temperature, 2) strain rate, and 3) confining pressure. The activity gives students exposure to analogue experiments and observation interpretation. The students must ultimately explain her observations to the class in a post experiment class discussion.

Evaluation

Describe briefly how you determine whether students have met the goals of this assignment or activity:

I usually go through each variable (e.g., temperature and strain rate) and have the different groups present to the class their intuitive understanding of how their assigned variable changes the way in which the candy bar responds to applied stresses. Then I have them try to extrapolate those ideas to the Earth's crust. After the group reaches a consensus, we then look at some real experimental results and discuss the similarities and differences to our own experiments. Finally we finish with a review of what we have learned.

Structural Geology - Geology 204

In Class Exercise - Rock rheology and the Candy Bar

Name____________

Objectives:

- Introduce the concept of rheology
- Gain an intuitive understanding of the complex relationship between stress and strain
- Gain an intuitive understanding of the role temperature, strain rate and confining stresses have on the rheologic response of a rock to forces and stresses

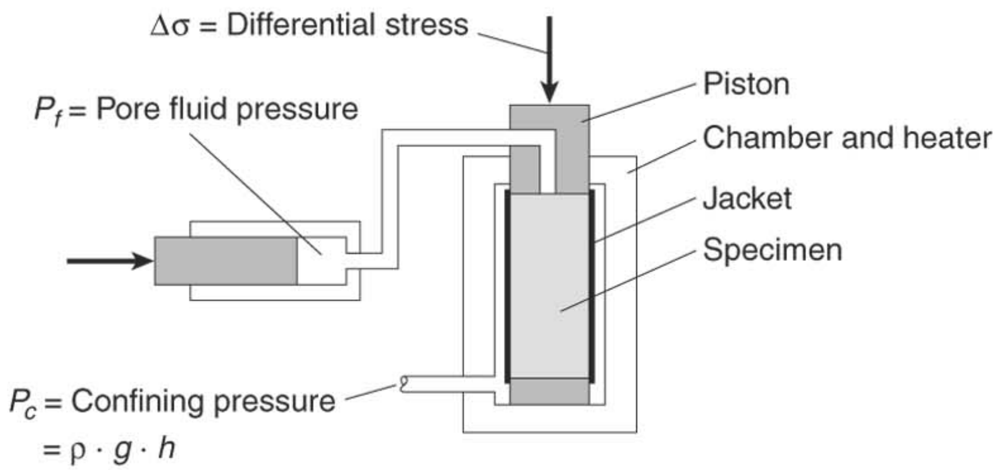
Rheology, in its simplest form, is the study of the response of rocks to stress. We have already defined strain as the change in shape that a body undergoes while exposed to a stress field. Consequently, we already have a since that stress and strain are related in some way - a sort of chicken and egg scenario; however, the relationship between stress and strain is not always easy to physically define. Moreover, the relationship between stress and strain is complicated by several parameters that vary from place to place (mainly with depth) throughout the Earth's crust, including temperature, pressure, strain rate and pore fluid pressure.

Ideally structural geologists would be able to predict, given conditions of pressure, temperature, strain rate and pore fluid pressure, the strain a given section of the crust would sustain under a given stress condition. Likewise, it would be ideal if structural geologists could observe a strained rock and be able to reconstruct the conditions that let to the rocks present deformed state. Geologists, and engineers have approached these issues using experimental and theoretical techniques. This classroom exercise is an experimental approach to understanding rheology, and is a take off of classic rock mechanics experiments in which rocks are subjected to forces and stresses under different controlled conditions. The observations you make during this exercise will hopefully provide you with an intuitive understanding of how rock strain varies under different condition in the Earth's crust.

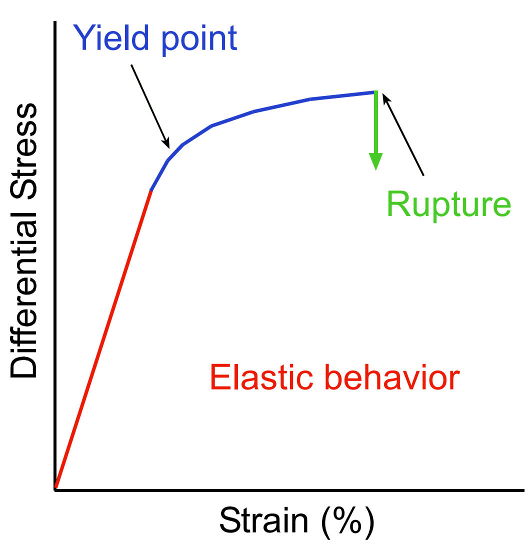
The analogue we will be using for rock is the classic, and oh so tasty, CHARLESTON CHEW candy bar (chocolate, vanilla or strawberry all work equally as well).

It should be understood that the Earth's crust is not made of artificially flavored chewy nougat, and thus the scaling of this analogue is not ideal, but for the purposes of providing insight I believe the nougat does a good job.

In classic deformation experiments, a rock core is subjected to controlled stress, temperature, confining pressure, pore fluid and strain rate conditions in a triaxial stress experiment (named because all three principal stresses are nonzero). During the experiment, a number of the variables are held fixed, while σ_1 is progressively increased until the rock fails, or some critical experimental threshold is reached. A schematic triaxial stress apparatus is shown below in which temperature, pressure, and pore fluid can be varied.



Classroom Experiments: You will be performing three basic sets of experiments, 1) varying temperature, 2) varying strain rate, and 3) varying confining pressure. For each experiment set you will, 1) record your observations of how the candy bar responds to your applied stress conditions as the given variable is increased or decreased, 2) plot your observations on an schematic graph of differential stress versus strain graph.



This graph shows a typical experimental plot for a triaxial experiment. First (red curve), the sample experiences elastic behavior (notice the linear stress strain relationship) that results in reversible instantaneous strain. Meaning once the stress is removed, the sample will return to its initial shape, experiencing no permanent strain. Second (blue curve), the sample reaches its elastic limit, or yield strength, and begins to flow. Finally (green curve), the sample ruptures by faulting.

Questions: Knowing that Charleston Chew candy bars are made of chewy nougat, and not rock, is it likely that they can behave elastically? Why or why not?

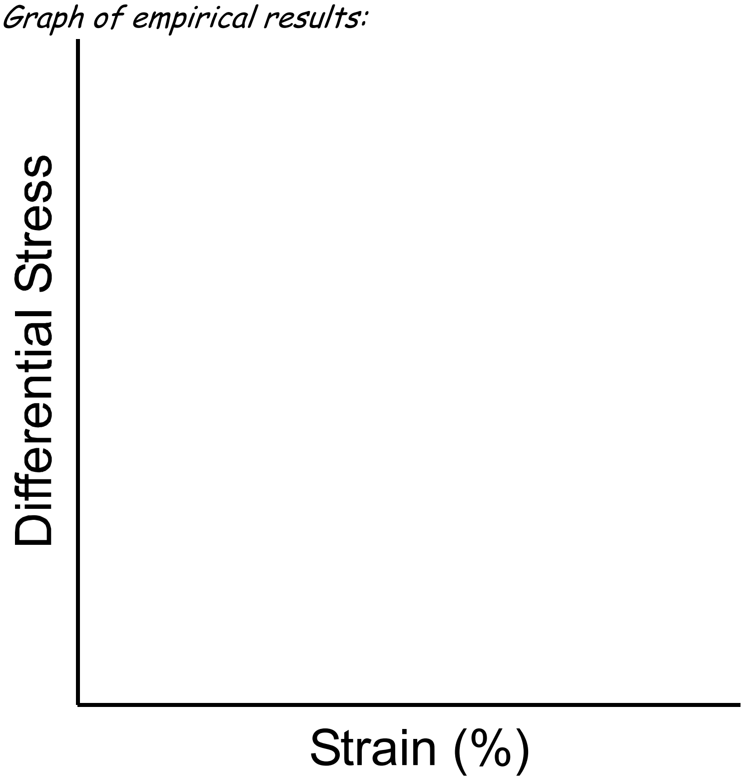
How does this limit our experimental set up? (we will have a short discussion to come to a consensus on this)

Temperature

You will be given two candy bar halves, one frozen and one warm. Apply a stress to each of the candy bars and record your observations on how the two different temperature states affect the way that the candy bar deforms. Is there any difference in the way the outer chocolate layer responds to your stress compare to the inner nougat?

Observations:

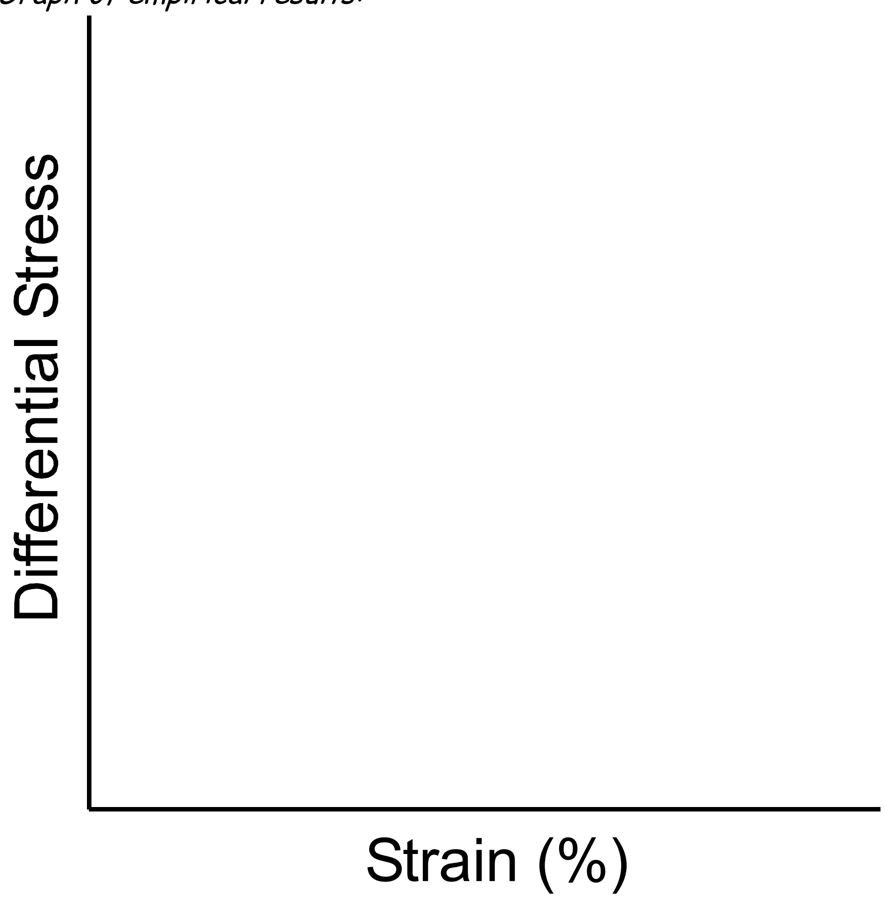
Graph of empirical results:



Strain Rate
You will be given two candy bar halves. With this experiment you will simulate a dramatic change in strain rate, and like the previous experiment set you will record your observations on how the two different strain rate states affect the way that the candy bar deforms. Again, pay attention to any difference in the way the outer chocolate layer responds to your strain rate conditions compared to the inner nougat?

Observations:

Graph of empirical results:

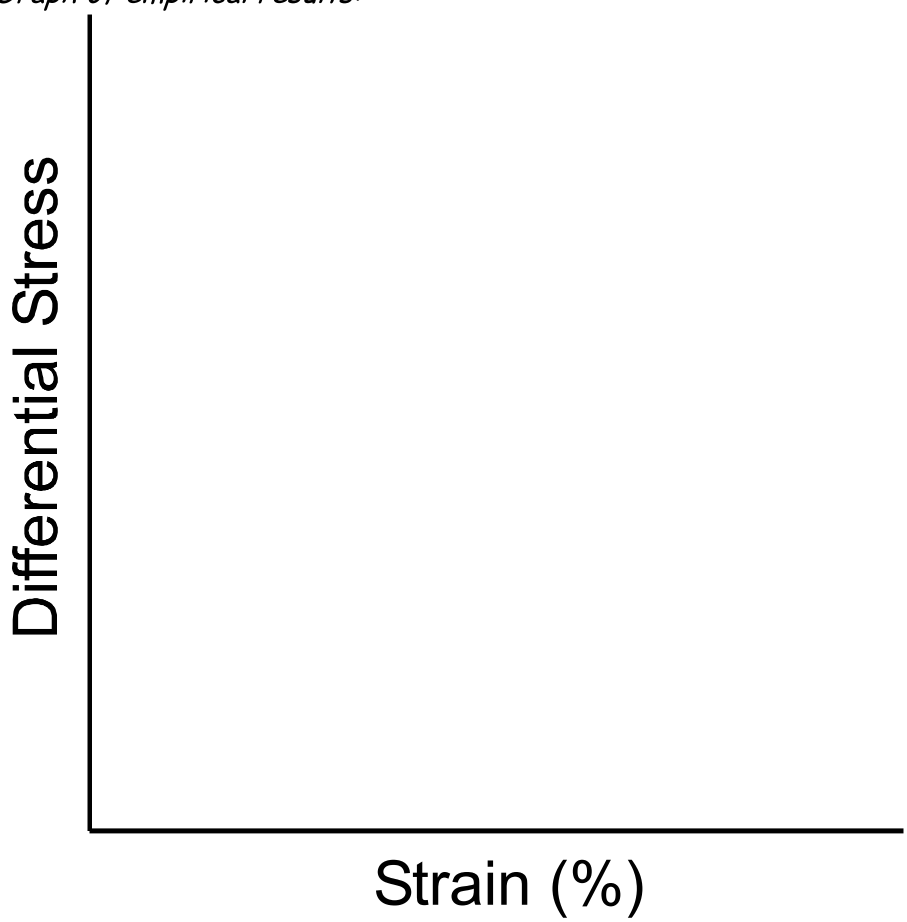


Confining Pressure

You will be given two candy bar halves. With this experiment you will simulate a change in confining pressure, and like the previous experiment sets record your observations on how the two different confining pressure states affect the way that the candy bar deforms. Pay close attention to the forces you need to apply in the two experiments (confined and unconfined) in order to strain the bar.

Observations:

Graph of empirical results:

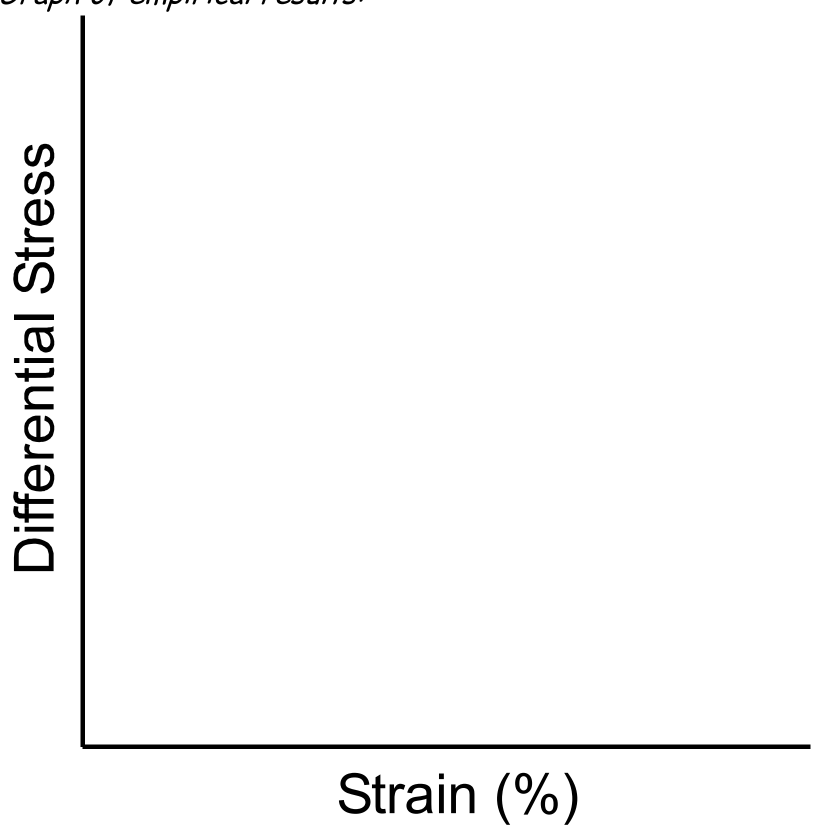


Ad-lib:
Use the attached observation/graph sheet to devise an experiment using the variables you have controlled during your previous tests to set up a fourth experiment. Before you perform the experiment write down how you think your candy bars will behave.
Experimental set-up

Predications:

Observations:

Graph of empirical results:



Food for thought:

Discuss several of the limitations of our simplified experiments.

Recall that pore fluid pressure results in an outward directed force that is equal in all directions. How does an increase in pore fluid pressure affect a rocks strength and ductility? How does pore fluid pressure affect confining pressure, and consequently how does pore fluid pressure affect the response of a rock to an applied stress field (thinking about your confining pressure experiment set)?