# CIDER Rheology Tutorial

*espm.wustl.edu/PRADA*

Experimental rock mechanics seeks to determine empirically the deformational properties of planetary materials. In this tutorial, we will be performing creep tests on paraffin wax (a rock analog) at room temperature and pressure. Creep tests are experiments that are conducted by loading a sample with a constant stress and recording progressive strain. We will be working in small groups with the Portable Rock-Analog Deformation Apparatus (PRADA), an atmospheric pressure dead-weight creep rig built specifically for this purpose. The objectives of this exercise are to 1) to calculate the viscosity of paraffin wax at these conditions, 2) compare the results to published data on paraffin, and 3) understand some of the methods and assumptions that underlie experimental rock mechanics.

*Materials: PRADA; water bucket for applying load; paraffin wax cylinders; calipers; laptop with Excel logging program installed;*

**Part 1 – Creating and characterizing your starting material**

1) Samples are already cast! See PRADA user manual for details. Thanks to Helene Couvy for all the prep work!
2) To quantify strain we must accurately measure and record the initial dimensions of the rod (diameter and length) using the digital calipers. Enter these values in the tables below before and after each experiment.

**Part 2 – Preparing an experiment**

1) Position a test specimen under the loading shaft.
2) PRADA measures displacement using a Mitutoyo digital indicator. This indicator has a range of 13 mm and a precision of 0.001 mm (one micron). You want to be near the lower limit of the indicator's range so that you have enough room to record the shortening of the sample. If necessary, you may prop up the sample on one or more of the acrylic spacers that are included with your apparatus. Gently push down the loading shaft until it makes contact with the paraffin. Zero the digital indicator.
3) These indicators can communicate with a laptop using the included USB input device. The input device treats the digital indicator like a keyboard. When you plug it into a USB slot for the first time it should load the necessary drivers automatically. Once it is configured, pressing the blue "data" button will write the value on the face of the digital indicator. I have

provided an Excel file that will allow you to input displacements, and adds a time stamp so you can calculate strain-rates. Place the cursor in cell C3, F3, or I3, at the start of the experiment.

4) Paraffin wax rheology is highly temperature sensitive. If possible, position a thermometer near the sample to determine the ambient temperature during the experiment(s).

**Part 3 – Experiment One**

1) For the first experiment you will use a load (loads have units of force, such as pounds or Newtons) of ~8-12 lbs. We will generate load using graduated buckets with water. We have pre-calibrated the buckets as follows:

| Liters | Mass (kg) | Force (lbs) |
|---|---|---|
| 0 | 1.2 | 2.6 |
| 2 | 3.05 | 6.7 |
| 4 | 4.92 | 10.8 |
| 6 | 6.72 | 14.8 |
| 8 | 8.59 | 18.9 |
| 10 | 10.47 | 23.1 |
| 12 | 12.34 | 27.2 |
| 14 | 14.23 | 31.4 |

2) Record the load and the initial dimensions of test specimen one in the table below. Following the experiment you can measure the final dimensions and calculate the stresses, strain-rate, effective viscosity (see Part 5):

| Experiment 1 | Load: | |
|---|---|---|
| | $\sigma 1$: | |
| | $\sigma 3$: | |
| | $\sigma_d$ $(=\sigma 1 - \sigma 3)$: | |
| | Steady state strain-rate $\dot{\varepsilon}$: | |
| | Effective viscosity: | |
| | Diameter | Length |
| *Initial Dimensions* | | |
| *Final Dimensions* | | |

3) Place the sealed water bucket on the circular plate to begin deformation.
4) Every ~5 seconds, record the position by pressing the blue button on the data input device. The time increments do not have to be constant, but should be frequent enough that you are able to capture the curvature of the stress-strain diagram (Figure 1). At the very beginning of the experiment and at larger loads (when strain-rates are high) you may want to record position more frequently.
5) Continue monitoring the change in length until you think the strain-rate is constant.

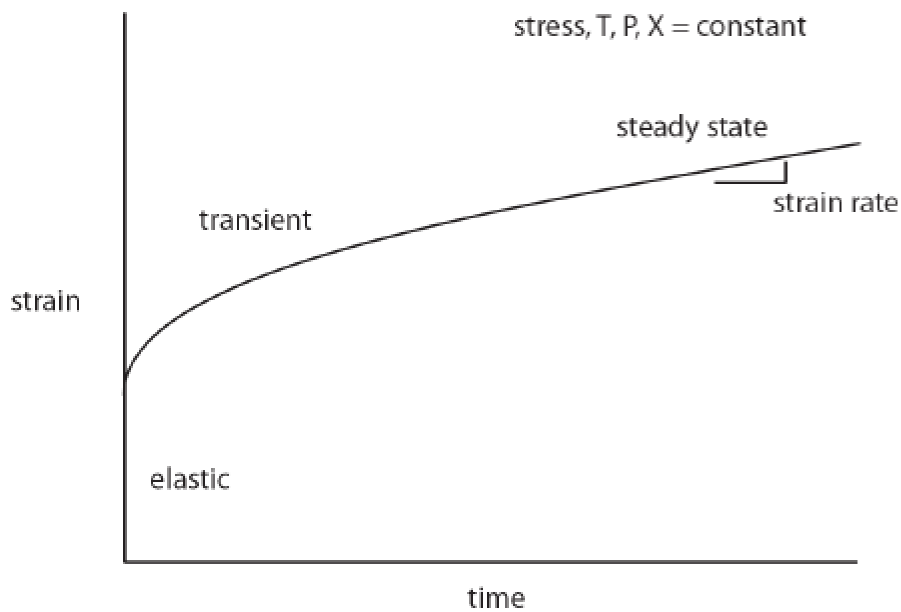


**Figure 1:** Schematic creep curve for a test at a constant temperature (T), hydrostatic pressure (P), chemical composition (X), and load. The initial strain is entirely elastic, followed by an interval of transient creep in which strain-rate decreases monotonically, followed by a period of steady-state creep where strain accumulates linearly.

**Part 4 – Experiments two and three**

1) Repeat Part 3 using new samples and for increasingly large loads.

| Experiment 2 | Load: | |
|---|---|---|
| | $\sigma 1$: | |
| | $\sigma 3$: | |
| | $\sigma_d$ $(=\sigma 1 - \sigma 3)$: | |
| | Steady state strain-rate $\dot{\varepsilon}$: | |
| | Effective viscosity: | |
| | Diameter | Length |
| *Initial Dimensions* | | |
| *Final Dimensions* | | |

| Experiment 3 | Load: | |
|---|---|---|
| | $\sigma 1$: | |
| | $\sigma 3$: | |
| | $\sigma_d$ $(=\sigma 1 - \sigma 3)$: | |
| | Steady state strain-rate $\dot{\varepsilon}$: | |
| | Effective viscosity: | |
| | Diameter | Length |
| *Initial Dimensions* | | |
| *Final Dimensions* | | |

**Part 5 – Analysis and interpretation**

1) For all three experiments make a plot of strain versus time (as in Figure 1). Recall that strain is defined as the change in length normalized by the initial length, and is dimensionless. Using the section of the curve that you believe to be steady state, calculate the strain-rate. Mathematically, this is the slope of the line over the range where the curve is completely linear. The units of strain-rate are [1/s]. Differential stress is the difference between the maximum compressive stress ($\sigma_1$) and minimum compressive stress ($\sigma_3$) and has units of [Pa]. Effective viscosity is the differential stress divided by strain-rate and has units of [Pa*s].

2) Recall that for materials deforming plastically:
$$\dot{\varepsilon} = A{\sigma_d}^n$$
where $\dot{\varepsilon}$ is strain-rate, $A$ is a constant that contains the pre-exponential and temperature-dependent Arrhenius terms, $\sigma_d$ is the differential stress and $n$ is the stress exponent that can distinguish between Newtonian and power-law creep. A plot of log ($\dot{\varepsilon}$) versus log ($\sigma_d$) has a slope of $n$. For each of the experiments take the log of the stress and plot it against the log of the steady state strain-rate. Fit a line through these three data and calculate n.

3) Add your stress and strain-rate data to the group plot: https://goo.gl/sgH35o

**Part 6 – Extra Credit**

1) If time allows: download and read the following paper (available online and on the CIDER wiki):

   Rossetti, F., Ranalli, G., Faccenna, C. (1999) Rheological properties of paraffin as an analogue material for viscous crustal deformation, *Journal of Structural Geology* **21**:413-417

2) Using the data from their 29.1°C experiment (Figure 1a) calculate the log ($\dot{\varepsilon}$) versus log ($\sigma$) pairs for each of the nine strain-rate steps. Each strain-rate step is denoted by a roman numeral, which corresponds to a particular strain rate. Add these data to the plot of log ($\dot{\varepsilon}$) versus log ($\sigma$) that contains your own data. Are your data consistent with the results from Rossetti et al (1999)? Explain why or why not.

3) What are the sources of error in your experiment? What are the sources of error in Rossetti et al. (1999)? How might you improve your own experiments to mitigate these sources of error?