Dynamics of the mantle and lithosphere
Practical: Rheology of the Earth

651-4008-00 G

Q1 Yield strength envelopes of the continental lithosphere

We will consider the strength profile within the present day continental lithosphere. The flow law we will use is given by:

$$\dot{\epsilon} = A\, d^m\, \sigma^n \exp\left[\frac{-(Q_a + V_a p)}{RT}\right], \tag{1}$$

where d is the grain-size, σ is the differential stress, Q_a is the activate energy, V_a is the activation volume, p is the pressure, R is the universal gas constant and T is the temperature.

We will assume the present day temperature profile (K) can be approximated by

$$T(z) = 273 + z'\left(\frac{\Delta T}{\Delta z'}\right),$$

where z' is the depth (measured in km), and $\Delta T/\Delta z' = 15$ K/km. The gas constant is given by $R = 8.314472$ J/K/mol and we will assume that $V_a = 15 \times 10^{-6}$ m^3/mol is valid for all rock/minerals we consider.

Assume the following lithology with depth: upper crust is 25 km thick; lower crust is 10 km thick and the Moho is defined at a depth of 35 km. Assume that the upper crust is composed of quartzite (dry), the lower crust is diabase (dry) and the mantle is composed of olivine (dry). You can assume that the grain-size exponent m, is equal to zero.

Rock/mineral	A [MPa^{-n} s^{-1}]	n	Q_a [kJ mol^{-1}]
Dry Quartzite	6.3×10^{-6}	2.4	156
Dry diabase	2.0×10^{-4}	3.4	260
Dry Olivine	10^4	3	520
Wet Quartzite	1.1×10^{-4}	4.0	223
Granite (wet)	2×10^{-4}	1.9	140
Wet Olivine	4.876×10^6	3.5	515

Table 1: Flow law parameters for use with Eqn (1). Data taken from “Rheology and strength of the lithosphere”, E. Burov, Marine and Petroleum Geology, 28 (2011), 1402–1443.

(a) Using Eqn. (1), derive an expression for the stress and the effective viscosity from the Arrhenius flow law. Leave the grain-size parameter d in your derivation (even though for the remainder of the calculations we will assume $m = 0$).

(b) Plot the yield strength envelope of the continental lithosphere. You should: (i) use both the ductile flow law and a suitable definition of the yield stress for each material type; (ii) use a strain-rate of 10^{-15} 1/s; (iii) plot the solution in z-σ coordinates; (iv) consider a depth range of 160 km. In your answer, please state any assumptions made.

(c) How does the strength envelope change when the strain-rate is varied? Consider using the following strain-rate values; 10^{-12} 1/s, 10^{-18} 1/s and 10^{-20} 1/s. Plot the different yield strength envelopes on the same figure.

(d) Consider a wet lithology for both the lower crust (wet granite) and mantle (wet olivine). Plot the strength profiles obtained when using the following strain-rates; 10^{-12} 1/s, 10^{-15} 1/s, 10^{-18} 1/s and 10^{-20} 1/s. How do the strength envelopes differ from those obtained using dry rheologies? What are the geodynamic implications of these differences?

(e) For one of you strength envelopes (e.g. wet or dry and some selected strain-rate value), plot the effective viscosity as a function of depth.

(f) What do these strength envelopes imply about seismicity at depth?

(g) Assuming that the same continental lithological structure existed 500 Ma years ago (e.g. the depth of the layers didn't change), what would the strength envelope look like?