Announcements

Be on time for Field Trip: 9:45 AM on Friday
Rayleigh Fractionation

\[
\frac{C_L}{C_o} = F^{(D-1)}
\]

- **\(C_L\)** = concentration in melt
- **\(C_o\)** = concentration in total original assemblage
- **\(F\)** = fraction of melt remaining
- **\(D\)** = bulk distribution coefficient = \(X_1K_1 + X_2K_2 + \ldots\)

Relevant to... perfect fractional crystallization!!!!!!
Rayleigh fractionation in petrology I

• Application: fractional crystallization of a melt
• Trace elements will partition preferentially into a melt or a mineral during this process (chemical fractionation)

Example: Eu
Initial concentration: 2 ppm
$K_{Dplag} = 4$
When have 20 wt% fractional crystallization
What is concentration of Eu in melt?

$C_L = 1$ ppm
Stable Isotopes

- Stable: last ~ forever
- Chemical fractionation is (impossible)
- Mass fractionation is the only type possible
Oxygen isotopes

- Terrestrial abundances: $^{16}\text{O}=99.76/^{17}\text{O}=0.04/^{18}\text{O}=0.20$
- $\delta^{18}\text{O} = 1000 \left( \frac{^{18}\text{O}/^{16}\text{O}_{\text{sample}}}{^{18}\text{O}/^{16}\text{O}_{\text{std}}} - 1 \right)$

Std = Standard Mean Ocean Water (SMOW)

Mass-dependent fractionation
Rayleigh fractionation in petrology

- Oxygen isotopes are fractionated during evaporation and rain cycles

Fraction of water vapor remaining
Figure 9-9. Relationship between $d(^{18}O/^ {16}O)$ and mean annual temperature for meteoric precipitation, after Dansgaard (1964). *Tellus*, 16, 436-468.

• Why is this relevant to igneous petrology?
Cooling of an intrusive body

- Magma convection
- Fractional crystallization results in solidification from bottom up (and top down)
Cooling of an intrusion

Groundwater or meteoric water: from precipitation
Hydrothermal exchange of minerals

“…every part of the crystal must have had to ‘swim’ across the ‘river’ in solution in order to reach the other side.” – O’Neil and Taylor, 1967

Solution and redeposition in fluid film at interface between exchanged and unexchanged feldspar.
Temperature dependence of $\delta^{18}O$ in feldspar

Larger fractionation between two minerals at a LOWER temperature

HOT hydrothermal activity >450 °C will tend to draw down mineral $\delta^{18}O$ to lower values
What is effect of large scale circulation and exchange of water with crystallized but hot intrusion?

Groundwater: -5 to -25 ‰ in temperate areas

Whole rock granite \( \delta^{18}O \sim +6 \) to +13 ‰

\( > 450^\circ C; \delta^{18}O_{\text{min-water}} \) is negative
Cooling of an intrusion: model

Figure 6-34. The Skaergaard intrusion set up a large hydrothermal system in which meteoric water heated by the cooling gabbro moved through the permeable basaltic rocks of the roof and upper walls. (After H. P. Taylor and R. W. Forester, 1979. Jour. Petr. 20:355-419).
Cooling and hydrothermal exchange

In map view? Would fractional xtalization produce this picture?
Famous example: Comstock
Hydrothermal systems and trace elements
Fumaroles

• Glass exchanges oxygen with water faster than the feldspar phenocrysts

• In small hydrothermal system = low total water

• Glass oxygen isotopes change while the feldspar $\delta^{18}O$ stays pretty much the same.