E&PS 303 - Igneous Homework #3   Answers

Part I. The rate of sinking of crystals or xenoliths in a magma can be estimated from Stoke's Law:

$$V = \frac{2gr^2(\rho_s - \rho_\ell)}{9\eta}$$

where **V** is the terminal velocity of a solid with radius **r** falling through a melt of viscosity η under gravitational acceleration **g** (9.8 m s^{-2}); ρ_s and ρ_l are the densities of the solid and liquid, respectively. (Note that Stoke's Law assumes that the magma is completely liquid, i.e. that there are no crystals already present in it. If any preexisting crystals are present, they will impede the settling of the crystal or xenolith of interest and Stoke's Law calculations will yield only a <u>maximum</u> settling velocity). *Pay careful attention to <u>units</u> in the calculations that follow!!*

(a) Consider a mafic magma of density 2.58 g cm^{-3} and viscosity 3000 poise (1 poise = 1 g cm^{-1} s^{-1}). How large would a <u>plagioclase grain</u> (ρ = 2.68 g cm^{-3}) have to be in order to settle to the bottom of a magma chamber at the *same rate* as an <u>olivine grain</u> (ρ = 3.70 g cm^{-3}) that has a radius of 1 mm?

$(r_{plag})^2$ x (2.68-2.58 g cm^{-3}) = (0.1 cm)^2 x (3.70-2.58 g cm^{-3})

$(r_{plag})^2$ x (0.10) = 0.01(1.12)

r^2 = 0.112, thus r_{plag} = 0.33 cm = 3 mm

A plag grain must be about **3 times larger** than an olivine grain in order to sink at the same rate

(b) In lab, you saw several examples of cumulate rocks in which the cumulate plagioclase grains were significantly <u>larger</u> than the cumulate olivine grains. How might you explain this observation?

This observation fits with the results of (a): if plag and olivine crystallized at the same horizon in the magma chamber and settled together to the bottom, the plag would have to be larger than the olivine in order to end up together in the same cumulate rock.

(c) Consider the case of a dunite xenolith with a radius of 20 cm that is erupted in an alkali basalt on Hawaii (ρ_{xeno} = 3.45 g cm^{-3}; ρ_l = 2.80 g cm^{-3}; η = 2000 poise). What was the <u>minimum</u> ascent rate of the alkali basalt, in **km/hr**? What is the <u>maximum</u> amount of time that it would have taken for the xenolith take to rise from 100 km depth to the surface, in **days**?

V = 2 x (9.8 m s^{-2}) x (20 cm)^2 x (3.45-2.80 g cm^{-3}) / (9 x 2000 g cm^{-1} s^{-1})

= 2 x (9.8 m s^{-2}) x (100 cm m^{-1}) x (400 cm^2) x (0.65 g cm^{-3}) / (18,000 g cm^{-1} s^{-1})

= 28.3 cm/s

= 28.3 cm/s x (1 m/100 cm) x (1 km/1000 m) x (60 s/min) x (60 min/hr) = **1.02 km/hour**

100 km x (1 hr/1.02 km) x (1 day/24 hrs) = **4 days**

The velocity calculated here is really the velocity needed in order to keep the xenolith at a constant position in the magma column; in order to bring the xenolith to the surface, the velocity must have been faster than that calculated here. Thus, it must have taken **less than 4 days** for the xenolith to reach the surface. (We talk in class about problems with using Stokes Law here – in particular, that it assumes that no crystals are present in the melt during its ascent…).

(d) When Krakatoa erupted in 1883, it sent pumice fragments flying out over the ocean. If the pumice pieces had an average radius of 4 cm and a density of 0.95 g cm^{-3}, <u>how long</u> would it have taken for them

to sink 5000 m to the ocean floor ($\rho_{seawater}$ = 1 g cm^{-3}). Speculate on what the ultimate fate of the pumice might have been. There is a reason that I have not given you the viscosity of seawater. (Remind me to tell you what *actually* happened to the pumice erupted from Krakatoa).

Because the density of the pumice is less than that of the seawater, **it will float, not sink!** (The absence of viscosity data for seawater is designed to make people think about the problem rather than try to solve it directly). Pumice erupted from Krakatoa formed enormous floating rafts, some of which washed up on the east coast of Africa months after the eruption, carrying the bones of some of the victims of the tsunami generated by the eruption.

Part II.

(a) Settling of crystals from a tholeiitic melt can produce substantial changes in the chemistry of the residual melt. Using the chemical analyses in the accompanying table, calculate the <u>composition of the magma residue</u> left behind after *simultaneous fractional crystallization* (removal) of 10% olivine (~Fo$_{82}$), 20% plagioclase (~An$_{75}$), and 10% augite (~Wo$_{40}$En$_{50}$Fs$_{10}$) from the basaltic parental melt. **Be sure to normalize your answer so that the weight percent oxides sum to 100.0%.**

See worksheet.

(b) We will be talking in lecture about magma differentiation along "tholeiitic" vs. "calcalkaline" trends; the former is characterized by a dramatic increase in FeO content with increasing SiO$_2$ during differentiation, whereas the latter shows no such iron enrichment. Does the fractional crystallization history you determined in (a) take the remaining melt on a tholeiitic or a calcalkaline trend? Hint: look at the FeO/MgO ratio for the parental melt in comparison to the residual melt.

FeO/MgO = 1.43 in the parent melt.

FeO/MgO = 43 in the residual melt.

The associated SiO$_2$ content increases from 51% to 53%.

There is thus a dramatic increase in FeO with a small increase in SiO$_2$, and the residual melt follows a **tholeiitic trend**.

Name_____

Compositional data and worksheet for **part II**:

	parental basalt	Olivine	Ol x 0.1	Plag	Plag x 0.2	Augite	Cpx x 0.1	(Basalt – Crystals)	Residual melt
SiO_2	**51.24**	40.0	4.0	50.0	10.0	52.0	5.2	32.04	53.4
TiO_2	**0.83**	0.0	0	0.0	0	0.0	0	0.83	1.38
Al_2O_3	**17.08**	0.0	0	32.0	6.4	0.0	0	10.68	17.80
FeO	**9.64**	17.0	1.7	0.0	0	7.0	1.7	7.24	12.06
MgO	**6.27**	43.0	4.3	0.0	0	18.0	1.8	0.17	0.28
MnO	**0.18**	0.0	0	0.0	0	0.0	0	0.18	0.29
CaO	**11.50**	0.0	0	16.0	3.2	23.0	2.3	6.00	10.00
Na_2O	**2.57**	0.0	0	2.0	0.4	0.0	0	2.17	3.62
K_2O	**0.55**	0.0	0	0.0	0	0.0	0	0.55	0.92
P_2O_5	**0.14**	0.0	0	0.0	0	0.0	0	0.14	0.23
total	**100.0**	100.0	10.0	100.0	20.0	100.0	10.0	60.0	**100.0**

Note: Each cell in "Basalt – Crystals" column = "parental basalt" – (Ol x 0.1) – (Plag x 0.2) – (Cpx x 0.1).

Each cell in "Residual melt" = cell in "Basalt – Crystals" column x (100/sum of "basalt – crystals")