ESS103A Igneous Petrology Name________________________
Homework 6: Paricutin Volcano
Due: May 31, 2006

Paricutin is often referred to as "the volcano born in the Mexican cornfield". (http://en.wikipedia.org/wiki/Paricut%C3%ADn, http://volcano.und.nodak.edu/vwdocs/volc_images/img_paricutin.html) In all, 1.3 km^3 of lava erupted between 1943 and 1952. The eruption produced a cinder cone and associated mafic to silicic andesitic lava flows. The lavas showed a progressive increase in SiO_2 as the eruption proceeded, ranging from <55 wt.% SiO_2 to over 60 wt%, with most of the SiO_2 variation exhibited in the last 25 volume% of the eruption.

The following compositional data have been obtained for the first 75 volume % of the eruptive sequence:

Major and trace element compositions of Paricutin lavas

	51-W-18	W-47-27	W-47-23	W-46-27
Year erupted:	1943	1944	1945	1946
Cumulative volume:	1%	51%	64%	75%
SiO_2	54.59	55.71	55.79	56.13
TiO_2	0.99	1.01	0.9	1.02
Al_2O_3	17.83	17.24	17.48	17.34
Fe_2O_3	2.01	2.06	1.83	1.74
FeO	5.43	5.48	5.3	5.42
MnO	0.12	0.13	0.12	0.12
MgO	5.44	5.61	5.75	5.58
CaO	7.25	6.98	6.81	6.99
Na_2O	3.95	3.99	3.81	3.79
K_2O	0.91	1.18	1.19	1.30
P_2O_5	0.27	0.33	0.3	0.36
Ba	315	388	440	413
Sr	607	596	537	588
Co	35	32	27	30

1) Use the change in K_2O from sample 51-W-18 to W-46-27 to estimate how much fractional crystallization would be required to explain the variation in K_2O observed in the lavas, assuming that K is perfectly incompatible (i.e., that there is no K_2O in the crystallizing solids so D=0). Use the equation for Rayleigh fractionation $C_{liq}/C_o = F^{(D-1)}$.

2) Harker variation diagrams for the Paricutin lavas are shown on an attached page, along with estimated compositions of the various mineral phases. The arrows indicate the effect of olivine subtraction (fractionation) on the composition of residual (fractionated) liquids. The following questions pertain to the "early" lavas with SiO_2

≤ 56 wt.%. You don't need to answer question 2: but it will be informative to read the answers and look at the attached Harker diagram.

a. Which phase do you expect to produce the variation in Al_2O_3 in the early lavas? plagioclase

b. Which phase accounts for the fact that MgO doesn't increase with increasing differentiation? olivine

c. Why doesn't the MgO decrease as rapidly as you would expect from fractionation of that phase?

d. Why doesn't SiO_2 change much despite the amount of differentiation you calculated in question #1? Plagioclase is also being crystallized: so this keeps the MgO in the melt relatively high and removes Si from the melt so that it remains fairly constant.

3) The following partition coefficients apply to the trace elements Ba (barium), Sr (strontium), and Co (cobalt) in mafic lavas:

	Olivine	plagioclase
D(Ba)	0.01	0.16
D(Sr)	0.014	1.8
D(Co)	6.6	0.01

a. Which of these elements is most likely to behave incompatibly during differentiation of the mafic Paricutin lavas?

b. Match each phase (olivine, plagioclase, liquid) to the element that is most sensitive to its behavior.

c. Plot the Paricutin data on two diagrams, one showing concentrations of Sr (y-axis) versus Ba (x-axis) and the other showing concentrations of Co (y-axis) versus Ba (x-axis).

d. Determine how well the Ba, Sr, and Co concentrations of sample W-46-27 match those predicted for fractionation crystallization of sample 51-W-18 by making use of the equation for Rayleigh fractionation ($C_{liq}/C_o = F^{(D-1)}$). Calculate the % difference between the expected value and actual value. Apply the following conditions:

  i. C_o: Use the concentrations of Ba, Sr, and Co in sample 51-W-18.

  ii. D: Use a relative abundance of olivine:plagioclase of 30:70 to obtain the bulk distribution coefficient for each element.

  iii. F: Use the value of F you obtained in Q#1.

e. Realizing that there is a certain amount of "geologic" scatter in any data set, evaluate whether you think that the change in Ba, Sr, and Co compositions that occurs in the first 75% of the eruption can be explained by fractionation of the phases you observed in the lavas.

4) The most differentiated Paricutin lava has 60 wt.% SiO_2. It also has a $^{87}Sr/^{86}Sr$ value of 0.704150, compared to a value of 0.703934 for the least differentiated lava. Uncertainties in these values are <0.000015.

   a. Based on the isotopic data, do you think the most differentiated Paricutin lava could have evolved by closed-system fractional crystallization of mafic magma like that represented by sample 51-W-18? Why or why not? (Hint: think about what could and could not cause fractionation of Sr isotopes).

   b. Granites in the area near Paricutin have isotopic compositions of $^{87}Sr/^{86}Sr$ = 0.7045 to 0.7085. Explain how these rocks could affect the isotopic characteristics of the Paricutin lavas.

   c. Crustal xenoliths contained in the Paricutin samples have [Sr] of about 227 ppm. Determine the amount (in wt%) of crustal material that must be assimilated into the least differentiated Paricutin lava (51-W-18) to account for the [Sr] observed in the most differentiated Paricutin lava (W-46-27).

5) The equation for trace element equilibrium between a liquid and solid:

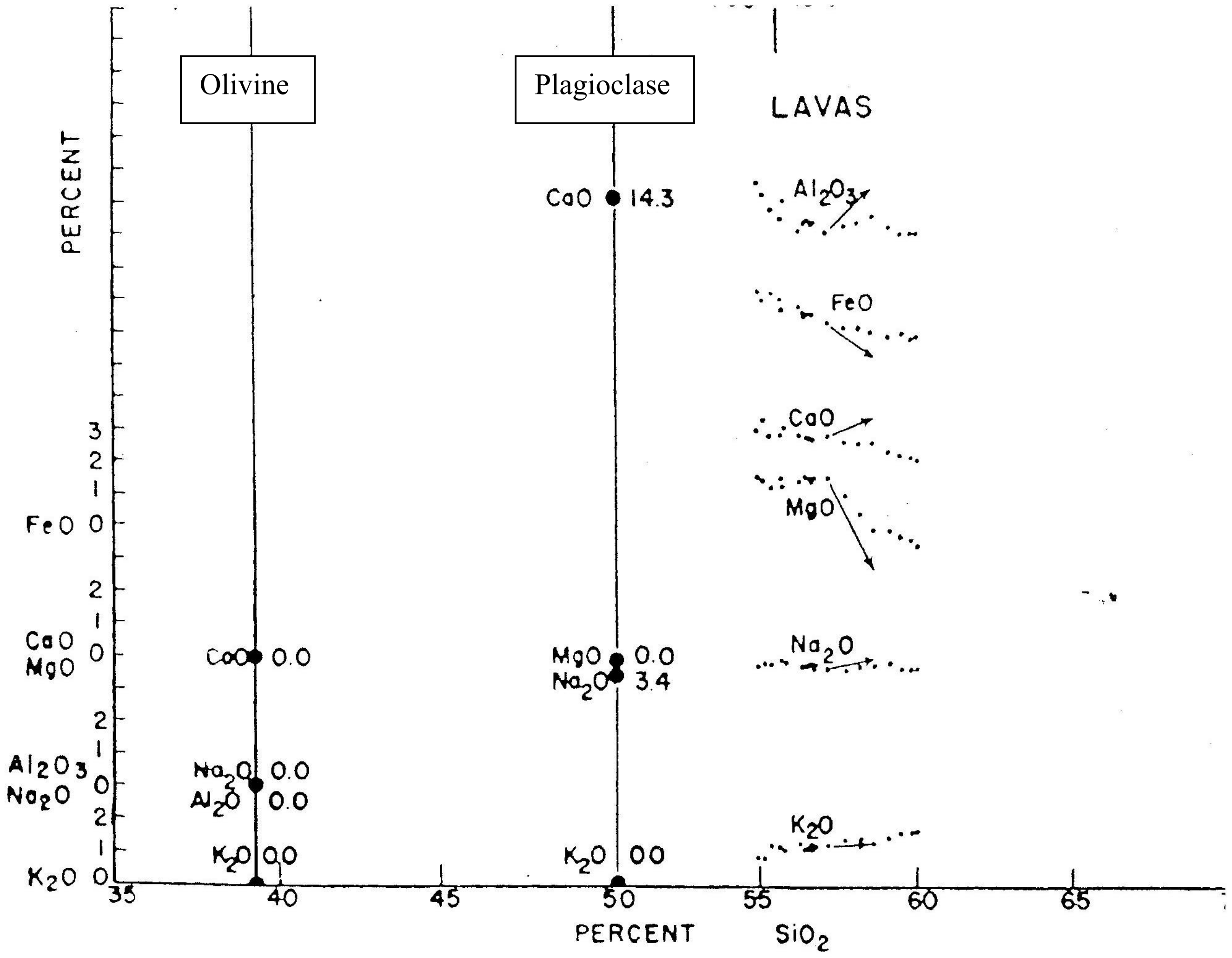
$$C_o = C_{liq}F + DC_{liq}\,(1-F)$$

Can be rewritten as:

$$F = (C_o - DC_{liq})/(C_{liq} - DC_{liq})$$

   a. Assume that the most mafic Paricutin lava (51-W-18) was derived by melting of the mantle with no subsequent crystal fractionation. If the mantle contains 0.1 wt% K_2O and no K_2O is retained in the mantle during melting (i.e., D=0), what degree of partial melting of the mantle would sample 51-W-18 represent?

   b. If sample 51-W-18 HAS differentiated since melting occurred, would your estimate for the degree of partial melting be a maximum or a minimum?


Olivine
Plagioclase
LAVAS
PERCENT
FeO
CaO
MgO
Al2O3
Na2O
K2O
3
2
1
0
CaO 0.0
Na2O 0.0
Al2O 0.0
K2O 0.0
CaO 14.3
MgO 0.0
Na2O 3.4
K2O 00
Al2O3
FeO
CaO
MgO
Na2O
K2O
35
40
45
50
55
60
65
PERCENT
SiO2