

**Assignment: Phase Diagrams, Thermodynamic Modeling and Crystallization Paths**

1. Answer the following questions with respect to the **Fo-SiO<sub>2</sub>** binary phase diagram.

- *Describe the equilibrium changes that occur on cooling composition Y from the temperature indicated.*
- *Describe the equilibrium process that occur on heating composition X from the indicated temperature.*
- *What kind of points are those labeled 1 and 2?*

Describe the importance/significance of the Fo-Ab join to igneous petrology as shown on the **Fo-Ne-SiO<sub>2</sub>** liquidus diagram.

Describe the crystallization path and sequence of minerals that form on cooling point X on the **Enlarged Fo-Ne-SiO<sub>2</sub>** diagram.

2. Thermodynamic Modeling Problem

The following tables contain analyses of minerals, glasses and rocks from the 1968 eruptions of Kilauea Volcano, Hawaii. The problem is to model the crystallization paths of these lava flows. To solve this problem, you will need to calculate the saturation curves for olivine, plagioclase and clinopyroxene, the isobaric fractionation paths at several pressures, and isenthalpic fractionation paths. Before making a lot of thermodynamic calculations, you should figure out whether the rocks can all be from one magma batch, which rock represents the most primitive magma, what minerals crystallized or accumulated on the fractionation path from one magma to the next, etc.

At the end of the exercise you should be able to say whether the magmas rose adiabatically, what was the liquidus phase, at what depth or within what depth range a second phase joined the liquidus phase, whether the chemical variations in the suite are consistent with a fractionation model, whether mineral accumulations occurred, and at what stages in the crystallization histories of the magma batches did events take place that left evidence for their occurrence in the mineralogy and petrology.

Look at the descriptions by Ryan, *et al.* (1981) and Klein, *et al.*, (1987) of the plumbing system beneath Kilauea. Are your interpretations of the crystallization histories consistent with these descriptions? Explain and illustrate.

Other references to this suite of rocks are given by Nicholls and Stout (1988).

**Table 7. Electron Microprobe Analyses of Olivine. Maximum Zoning Ranges in Mg and Fe.**

	East-rift Picrites					
	Hi2 Ph C	Hi2 Ph R	Hi2 Mph C	Hi2 Mph R	Hi2 Gm	Hi2 Gm
SiO <sub>2</sub>	39.47	39.70	39.62	39.93	39.39	39.28
Cr <sub>2</sub> O <sub>3</sub>	0.11	0.10	0.19	0.07	<0.05	0.05
FeO	12.74	16.23	13.58	14.46	14.79	18.14
MnO	0.15	0.19	0.18	0.18	0.20	0.20
NiO	0.43	0.39	0.35	0.26	0.24	0.17
MgO	46.21	43.25	45.26	44.62	43.87	41.47
CaO	0.25	0.31	0.26	0.28	0.33	0.37
Total	99.36	100.17	99.44	99.80	98.82	99.68

	Number of ions on the basis of 8 positive charges					
Si	0.991	1.003	0.997	1.003	1.002	1.005
Cr	0.002	0.002	0.004	0.001		0.001
Fe	0.267	0.343	0.286	0.304	0.315	0.388
Mn	0.003	0.004	0.004	0.004	0.004	0.004
Ni	0.009	0.008	0.007	0.005	0.005	0.003
Mg	1.729	1.628	1.697	1.671	1.663	1.582
Ca	0.007	0.008	0.007	0.008	0.009	0.010

Ph = phenocryst, Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

**Table 7, cont.: Olivine Analyses**

	East-rift Picrites					
	Hi3 Ph C	Hi3 Ph R	Hi3 Mph C	Hi3 Mph R	Hi3 Gm	Hi3 Gm
SiO <sub>2</sub>	40.15	39.21	40.55	39.80	38.89	39.31
Cr <sub>2</sub> O <sub>3</sub>	0.10	0.07	0.08	0.10	<0.05	0.05
FeO	11.88	16.79	11.33	16.03	14.70	19.55
MnO	0.16	0.21	0.17	0.19	0.13	0.25
NiO	0.40	0.21	0.35	0.29	0.30	0.23
MgO	46.44	42.19	46.83	42.73	45.97	41.47
CaO	0.24	0.30	0.24	0.31	0.28	0.35
Total	99.37	98.98	99.55	99.45	100.27	101.21

	Number of ions on the basis of 8 positive charges					
Si	1.002	1.005	1.006	1.011	0.977	0.998
Cr	0.002	0.001	0.002	0.002		0.001
Fe	0.248	0.360	0.235	0.340	0.309	0.415
Mn	0.003	0.005	0.004	0.004	0.003	0.005
Ni	0.008	0.004	0.007	0.006	0.006	0.005
Mg	1.727	1.611	1.733	1.617	1.721	1.569
Ca	0.006	0.008	0.006	0.008	0.008	0.010

Ph = phenocryst, Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

**Table 7, cont.: Olivine Analyses**

	East-rift Picrites					
	Hi12 Ph C	Hi12 Ph R	Hi12 Mph C	Hi12 Mph R	Hi12 Gm	Hi12 Gm
SiO <sub>2</sub>	39.69	39.04	40.16	39.60	38.90	38.30
Cr <sub>2</sub> O <sub>3</sub>	0.09	0.06	0.18	<0.05	0.07	0.11
FeO	11.65	17.24	13.44	17.80	15.61	17.14
MnO	0.11	0.26	0.20	0.24	0.27	0.19
NiO	0.37	0.33	0.26	0.20	0.23	0.18
MgO	46.83	42.12	45.27	41.80	43.21	42.23
CaO	0.25	0.32	0.26	0.31	0.29	0.31
Total	98.99	99.37	99.77	99.95	98.58	98.46

	Number of ions on the basis of 8 positive charges					
Si	0.994	1.000	1.005	1.008	0.997	0.991
Cr	0.002	0.001	0.004		0.001	0.002
Fe	0.244	0.369	0.281	0.379	0.335	0.371
Mn	0.002	0.006	0.004	0.005	0.006	0.004
Ni	0.007	0.007	0.005	0.004	0.005	0.004
Mg	1.748	1.608	1.688	1.586	1.651	1.628
Ca	0.007	0.009	0.007	0.008	0.008	0.009

Ph = phenocryst, Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

Table 7, cont.: Olivine Analyses

	East-rift Picrites					
	Hi14 Ph C	Hi14 Ph R	Hi14 Mph C	Hi14 Mph R	Hi14 Gm	Hi14 Gm
SiO <sub>2</sub>	40.66	39.59	39.53	38.32	38.94	38.41
Cr <sub>2</sub> O <sub>3</sub>	0.11	0.05	0.07	<0.05	0.08	<0.05
FeO	11.56	19.65	15.39	19.78	19.24	21.01
MnO	0.17	0.15	0.19	0.23	0.25	0.29
NiO	0.33	0.17	0.30	0.19	0.20	0.17
MgO	47.60	41.00	44.19	40.41	41.25	40.27
CaO	0.25	0.31	0.27	0.31	0.33	0.34
Total	100.68	100.92	99.94	99.24	100.29	100.49

	Number of ions on the basis of 8 positive charges					
Si	0.999	1.006	0.997	0.995	0.997	0.990
Cr	0.002	0.001	0.001		0.002	
Fe	0.238	0.418	0.325	0.429	0.412	0.453
Mn	0.004	0.003	0.004	0.005	0.005	0.006
Ni	0.007	0.003	0.006	0.004	0.004	0.004
Mg	1.744	1.553	1.661	1.564	1.574	1.547
Ca	0.007	0.008	0.007	0.009	0.009	0.009

Ph = phenocryst, Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

**Table 7, cont.: Olivine Analyses**

	Halemaumau Basalts					
	HM2 Mph C	HM2 Mph R	HM2 Gm	HM2 Gm	HM4 Mph C	HM4 Mph R
SiO <sub>2</sub>	38.47	38.30	37.92	38.26	39.96	38.98
Cr <sub>2</sub> O <sub>3</sub>	<0.05	<0.05	<0.05	0.05	<0.05	
FeO	18.31	21.56	21.46	22.13	16.87	21.44
MnO	0.23	0.26	0.24	0.25	0.21	0.24
NiO	0.25	0.11	0.11	0.21	0.21	0.17
MgO	42.60	38.96	38.85	38.94	42.25	39.24
CaO	0.26	0.34	0.33	0.32	0.28	0.33
Total	100.12	99.53	98.91	100.16	99.78	100.40

	Number of ions on the basis of 8 positive charges					
Si	0.984	0.999	0.996	0.995	1.014	1.005
Cr				0.001		
Fe	0.392	0.470	0.471	0.481	0.358	0.463
Mn	0.005	0.006	0.005	0.006	0.005	0.005
Ni	0.005	0.002	0.002	0.004	0.004	0.004
Mg	1.624	1.514	1.520	1.509	1.598	1.509
Ca	0.007	0.010	0.009	0.009	0.008	0.009

Ph = phenocryst, Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

Table 7, cont.: Olivine Analyses

	Halemaumau Basalts					
	HM4 Gm	HM4 Gm	HM12 Mph C	HM12 Mph R	HM12 Gm	HM12 Gm
SiO <sub>2</sub>	38.53	38.69	39.14	38.85	37.86	37.78
Cr <sub>2</sub> O <sub>3</sub>	<0.05	<0.05	<0.05	0.07	<0.05	<0.05
FeO	23.05	24.04	16.87	19.84	23.89	24.87
MnO	0.29	0.32	0.16	0.25	0.30	0.31
NiO	0.17	0.12	0.17	0.17	0.13	0.13
MgO	37.47	37.12	43.30	40.54	37.11	36.40
CaO	0.31	0.30	0.28	0.30	0.34	0.33
Total	99.77	100.57	99.92	100.02	99.63	99.82

Number of ions on the basis of 8 positive charges

Si	1.008	1.008	0.994	1.000	0.998	0.999
Cr				0.001		
Fe	0.504	0.524	0.358	0.427	0.527	0.550
Mn	0.006	0.002	0.003	0.005	0.007	0.007
Ni	0.003	0.002	0.003	0.004	0.003	0.003
Mg	1.461	1.442	1.639	1.555	1.458	1.434
Ca	0.009	0.008	0.008	0.010	0.009	

Ph = phenocryst, Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

**Table 7, cont.: Olivine Analyses**

Halemaumau Basalts				
	HM15	HM15	HM15	HM15
	Mph C	Mph R	Gm	Gm
SiO <sub>2</sub>	38.97	37.60	38.73	38.13
Cr <sub>2</sub> O <sub>3</sub>	<0.05	0.05	<0.05	<0.05
FeO	20.07	24.51	22.03	22.36
MnO	0.19	0.28	0.23	0.18
NiO	0.19	0.16	0.13	0.11
MgO	40.98	36.86	39.25	38.86
CaO	0.25	0.30	0.32	0.32
Total	100.07	99.71	100.69	99.96

Number of ions on the basis of 8 positive charges				
Si	0.996	0.994	0.999	0.994
Cr	0.001	0	0	0
Fe	0.429	0.542	0.475	0.487
Mn	0.004	0.006	0.005	0.004
Ni	0.004	0.003	0.003	0.002
Mg	1.562	1.452	1.509	1.510
Ca	0.007	0.008	0.009	0.009

Ph = phenocryst, Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

**Table 8: Electron Microprobe Analyses of Plagioclase. Maximum Zoning Ranges in Ca and Na.**

	East-rift Picrites Halemaumau Basalts							
	Hi14	Hi14	Hi14	Hi14	HM2	HM2	HM2	HM2
	Mph C	Mph R	Gm	Gm	Mph C	Mph R	Gm	Gm
SiO <sub>2</sub>	51.66	52.53	51.11	52.59	51.33	52.60	51.59	53.85
Al <sub>2</sub> O <sub>3</sub>	30.54	29.56	30.43	28.80	29.26	28.33	29.63	28.40
Fe <sub>2</sub> O <sub>3</sub>	0.77	0.83	0.89	0.96	0.75	0.75	0.81	0.69
MgO	0.24	0.33	0.25	0.25	0.22	0.26	0.24	0.22
CaO	14.19	13.77	14.19	13.32	14.14	13.23	14.07	12.38
Na <sub>2</sub> O	3.36	3.66	3.50	3.92	3.47	3.90	3.48	4.42
K <sub>2</sub> O	0.11	0.12	0.10	0.14	0.12	0.15	0.12	0.18
Total	100.87	100.80	100.47	99.98	99.29	99.22	99.94	100.14
	Number of ions on the basis of 16 positive charges							
Si	2.334	2.373	2.322	2.394	2.358	2.411	2.354	2.438
Al	1.626	1.574	1.630	1.545	1.584	1.530	1.593	1.516
Fe <sup>3</sup>	0.026	0.028	0.030	0.033	0.026	0.026	0.028	0.024
Mg	0.016	0.022	0.017	0.017	0.015	0.018	0.016	0.015
Ca	0.687	0.666	0.691	0.650	0.696	0.650	0.688	0.601
Na	0.294	0.321	0.308	0.346	0.309	0.347	0.308	0.388
K	0.006	0.007	0.006	0.008	0.007	0.009	0.007	0.010

Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as Fe<sub>2</sub>O<sub>3</sub>

**Table 8, cont. Plagioclase Analyses.**

	Halemaumau Basalts							
	HM4 Mph C	HM4 Mph R	HM4 Gm	HM4 Gm	HM12 Mph C	Hm12 Mph R	HM12 Gm	HM12 Gm
SiO <sub>2</sub>	51.74	54.47	51.06	54.06	52.30	52.72	52.41	53.85
Al <sub>2</sub> O <sub>3</sub>	30.15	27.92	30.17	27.58	29.66	28.05	29.47	28.78
Fe <sub>2</sub> O <sub>3</sub>	0.68	0.94	0.84	1.04	0.80	1.02	0.88	1.07
MgO	0.22	0.22	0.20	0.21	0.25	0.28	0.28	0.23
CaO	14.17	11.90	14.02	11.66	13.95	12.71	13.77	12.59
Na <sub>2</sub> O	3.40	4.73	3.50	4.90	3.61	4.28	3.68	4.26
K <sub>2</sub> O	0.12	0.20	0.12	0.22	0.13	0.18	0.12	0.18
Total	100.48	100.38	99.91	99.67	100.70	99.24	100.61	100.96

Number of ions on the basis of 16 positive charges

Si	2.346	2.460	2.332	2.461	2.366	2.417	2.372	2.422
Al	1.611	1.486	1.624	1.480	1.581	1.516	1.572	1.526
Fe <sup>3</sup>	0.023	0.032	0.029	0.036	0.027	0.035	0.030	0.036
Mg	0.015	0.015	0.014	0.014	0.017	0.019	0.019	0.015
Ca	0.688	0.576	0.686	0.569	0.676	0.624	0.668	0.607
Na	0.299	0.414	0.310	0.432	0.317	0.380	0.323	0.372
K	0.007	0.012	0.007	0.013	0.008	0.011	0.007	0.010

Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as Fe<sub>2</sub>O<sub>3</sub>

**Table 8, cont.: Plagioclase Analyses.**

	Halemaumau Basalts			
	HM15 Mph C	HM15 Mph R	HM15 Gm	HM15 Gm
SiO <sub>2</sub>	51.99	52.90	51.68	53.55
Al <sub>2</sub> O <sub>3</sub>	29.30	29.29	29.69	29.11
Fe <sub>2</sub> O <sub>3</sub>	0.90	0.92	0.95	0.98
MgO	0.23	0.23	0.21	0.24
CaO	14.09	13.19	14.14	12.67
Na <sub>2</sub> O	3.43	3.88	3.52	4.21
K <sub>2</sub> O	0.11	0.14	0.11	0.16
Total	100.05	100.55	100.30	100.92

	Number of ions on the basis of 16 positive charges			
Si	2.368	2.392	2.351	2.410
Al	1.573	1.561	1.592	1.544
Fe <sup>3</sup>	0.031	0.031	0.033	0.033
Mg	0.016	0.015	0.014	0.016
Ca	0.688	0.639	0.689	0.611
Na	0.303	0.340	0.310	0.367
K	0.006	0.008	0.006	0.009

Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as Fe<sub>2</sub>O<sub>3</sub>

**Table 9: Electron Microprobe Analyses of Pyroxene. Maximum Zoning Ranges in Ca, Mg and Fe.**

	East-rift Picrites				
	Hi14 Mph C	Hi14 Mph R	Hi14 Gm	Hi14 Gm	Hi14 Gm
SiO <sub>2</sub>	50.81	53.31	50.84	53.33	51.85
TiO <sub>2</sub>	1.53	0.78	1.27	0.76	1.29
Al <sub>2</sub> O <sub>3</sub>	4.54	1.98	3.38	1.83	2.87
Cr <sub>2</sub> O <sub>3</sub>	0.40	0.44	0.72	0.62	0.40
FeO	6.86	8.19	7.24	9.26	9.92
MnO	0.12	0.20	0.16	0.18	0.26
NiO	0.08	0.06	0.07	0.07	0.05
MgO	15.80	18.76	16.40	20.24	18.41
CaO	20.09	17.25	20.29	14.92	15.76
Na <sub>2</sub> O	0.26	0.14	0.26	0.14	0.17
Total	100.49	101.11	100.63	101.35	100.98
	Number of ions on the basis of 12 positive charges				
Si	1.863	1.933	1.870	1.927	1.894
Al <sup>iv</sup>	0.137	0.067	0.130	0.073	0.106
	2.000	2.000	2.000	2.000	2.000
Ti	0.042	0.021	0.035	0.021	0.035
Al	0.059	0.018	0.017	0.005	0.018
Cr	0.012	0.013	0.021	0.018	0.012
Fe <sup>2</sup>	0.210	0.248	0.223	0.280	0.303
Mn	0.004	0.006	0.005	0.006	0.008
Ni	0.002	0.002	0.002	0.002	0.001
Mg	0.863	1.014	0.899	1.090	1.002
Ca	0.789	0.670	0.800	0.578	0.617
Na	0.018	0.010	0.019	0.010	0.012
Total	1.999	2.002	2.021	2.010	2.008

Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

**Table 9, cont.: Pyroxene Analyses.**

	Halemaumau Basalts					
	HM2 Mph C	HM2 Mph C	HM2 MPh C	HM2 Gm	HM2 Gm	HM2 Gm
SiO <sub>2</sub>	51.55	52.04	51.63	50.69	52.54	51.44
TiO <sub>2</sub>	1.07	0.80	1.24	1.04	0.83	1.40
Al <sub>2</sub> O <sub>3</sub>	2.58	2.24	2.29	3.13	1.71	2.55
Cr <sub>2</sub> O <sub>3</sub>	0.37	0.28	0.30	0.36	0.25	0.15
FeO	8.00	8.65	9.27	8.67	8.68	9.67
MnO	0.19	0.25	0.13	0.24	0.17	0.23
NiO	0.06	<0.04	0.06	0.06	0.07	0.05
MgO	16.40	17.60	16.81	16.45	17.78	16.65
CaO	19.47	18.20	18.30	19.59	18.14	18.02
Na <sub>2</sub> O	0.23	0.25	0.23	0.12	0.19	0.20
Total	99.92	100.31	100.26	100.35	100.36	100.36
	Number of ions on the basis of 12 positive charges					
Si	1.908	1.916	1.908	1.877	1.931	1.902
Al <sup>iv</sup>	0.092	0.084	0.092	0.123	0.069	0.098
	2.000	2.000	2.000	2.000	2.000	2.000
Ti	0.030	0.022	0.034	0.029	0.023	0.039
Al	0.020	0.013	0.008	0.014	0.005	0.013
Cr	0.011	0.008	0.009	0.011	0.007	0.004
Fe <sup>2</sup>	0.248	0.266	0.287	0.268	0.267	0.299
Mn	0.006	0.008	0.004	0.008	0.005	0.007
Ni	0.002		0.002	0.002	0.002	0.001
Mg	0.905	0.966	0.926	0.908	0.974	0.917
Ca	0.772	0.718	0.725	0.777	0.714	0.714
Na	0.017	0.018	0.016	0.009	0.014	0.014
Total	2.011	2.019	2.011	2.026	2.011	2.008

Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

**Table 9, cont.: Pyroxene Analyses**

	Halemaumau Basalts					
	HM4 Mph C	HM4 Mph R	HM4 Mph C	HM4 Gm	HM4 Gm	HM4 Gm
SiO <sub>2</sub>	52.06	51.60	49.39	51.94	53.32	49.92
TiO <sub>2</sub>	1.09	1.01	2.38	1.03	0.80	2.06
Al <sub>2</sub> O <sub>3</sub>	2.28	1.85	4.35	2.27	1.56	4.45
Cr <sub>2</sub> O <sub>3</sub>	0.42	0.27	0.28	0.47	0.47	0.16
FeO	8.15	10.72	11.67	7.87	9.40	10.62
MnO	0.23	0.23	0.21	0.17	0.23	0.25
NiO	0.06	0.06	0.04	<0.04	<0.04	0.06
MgO	16.55	17.62	15.22	16.81	18.15	15.34
CaO	19.42	16.26	16.67	19.64	17.37	17.75
Na <sub>2</sub> O	0.20	0.13	0.27	0.22	0.17	0.25
Total	100.46	99.75	100.48	100.42	101.47	100.86
	Number of ions on the basis of 12 positive charges					
Si	1.916	1.919	1.839	1.911	1.938	1.846
Al <sup>iv</sup>	0.084	0.081	0.161	0.089	0.062	0.154
	2.000	2.000	2.000	2.000	2.000	2.000
Ti	0.030	0.028	0.067	0.029	0.022	0.057
Al	0.015	0.000	0.030	0.010	0.005	0.040
Cr	0.012	0.008	0.008	0.014	0.014	0.005
Fe <sup>2</sup>	0.251	0.333	0.363	0.242	0.286	0.328
Mn	0.007	0.007	0.007	0.005	0.007	0.008
Ni	0.002	0.002	0.001			0.002
Mg	0.908	0.977	0.845	0.922	0.983	0.845
Ca	0.766	0.648	0.665	0.774	0.677	0.703
Na	0.014	0.009	0.019	0.016	0.012	0.018
Total	2.005	2.012	2.005	2.012	2.006	2.006

Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

**Table 9, cont.: Pyroxene Analyses.**

Halemaumau Basalts

	HM12 Mph C	HM12 Mph R	HM12 Gm	HM12 Gm	HM12 Gm
SiO <sub>2</sub>	51.33	50.93	50.73	52.22	50.69
TiO <sub>2</sub>	1.31	1.50	1.49	0.98	1.39
Al <sub>2</sub> O <sub>3</sub>	2.82	3.77	3.63	2.21	3.12
Cr <sub>2</sub> O <sub>3</sub>	0.49	0.19	0.36	0.35	0.40
FeO	9.10	9.92	8.46	9.32	10.19
MnO	0.25	0.23	0.19	0.20	0.27
NiO	0.08	0.05	0.08	0.06	0.05
MgO	16.87	16.38	16.21	18.48	16.72
CaO	17.99	17.47	18.80	16.43	16.91
Na <sub>2</sub> O	0.23	0.28	0.25	0.19	0.22
Total	100.47	100.72	100.20	100.44	99.96

Number of ions on the basis of 12 positive charges

Si	1.893	1.875	1.874	1.915	1.883
Al <sup>iv</sup>	0.107	0.125	0.126	0.085	0.117
	2.000	2.000	2.000	2.000	2.000
Ti	0.036	0.042	0.041	0.027	0.039
Al	0.015	0.039	0.032	0.011	0.020
Cr	0.014	0.006	0.011	0.010	0.012
Fe <sup>2</sup>	0.281	0.305	0.261	0.286	0.317
Mn	0.008	0.007	0.006	0.006	0.008
Ni	0.002	0.001	0.002	0.002	0.001
Mg	0.927	0.899	0.893	1.010	0.926
Ca	0.711	0.689	0.744	0.646	0.673
Na	0.016	0.020	0.018	0.014	0.016
Total	2.010	2.008	2.008	2.012	2.012

Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

**Table 9, cont.: Pyroxene Analyses.**

Halemaumau Basalts

	HM15 Mph R	HM15 Mph R	HM15 Mph R	HM15 Gm	HM15 Gm	HM15 Gm
SiO <sub>2</sub>	51.92	52.28	50.77	51.67	52.39	50.86
TiO <sub>2</sub>	1.08	0.99	1.80	1.02	0.90	1.64
Al <sub>2</sub> O <sub>3</sub>	2.63	2.26	3.89	2.35	2.00	3.42
Cr <sub>2</sub> O <sub>3</sub>	0.41	0.34	0.30	0.48	0.38	0.26
FeO	7.82	8.19	9.93	8.42	8.17	10.09
MnO	0.12	0.14	0.14	0.19	0.18	0.18
NiO	0.06	0.05	0.07	0.05	<0.04	0.05
MgO	16.44	17.05	16.23	16.94	17.44	16.20
CaO	20.01	19.10	17.91	19.50	18.82	17.70
Na <sub>2</sub> O	0.25	0.25	0.23	0.23	0.20	0.25
Total	100.74	100.65	101.27	100.85	100.48	100.65

Number of ions on the basis of 12 positive charges

Si	1.906	1.918	1.862	1.900	1.923	1.878
Al <sup>iv</sup>	0.094	0.082	0.138	0.100	0.077	0.122
	2.000	2.000	2.000	2.000	2.000	2.000
Ti	0.030	0.027	0.050	0.028	0.025	0.046
Al	0.019	0.015	0.031	0.001	0.010	0.026
Cr	0.012	0.010	0.009	0.014	0.011	0.008
Fe <sup>2</sup>	0.240	0.251	0.305	0.259	0.251	0.312
Mn	0.004	0.004	0.004	0.006	0.006	0.006
Ni	0.002	0.001	0.002	0.001		0.001
Mg	0.899	0.932	0.887	0.928	0.954	0.891
Ca	0.787	0.751	0.704	0.768	0.740	0.700
Na	0.018	0.018	0.016	0.016	0.014	0.018
Total	2.011	2.009	2.008	2.021	2.011	2.008

Mph = microphenocryst, Gm = groundmass, C = core, R = rim. All Fe reported as FeO

**Table 10: Lava Flow and Averaged Electron Microprobe Glass Analyses.**

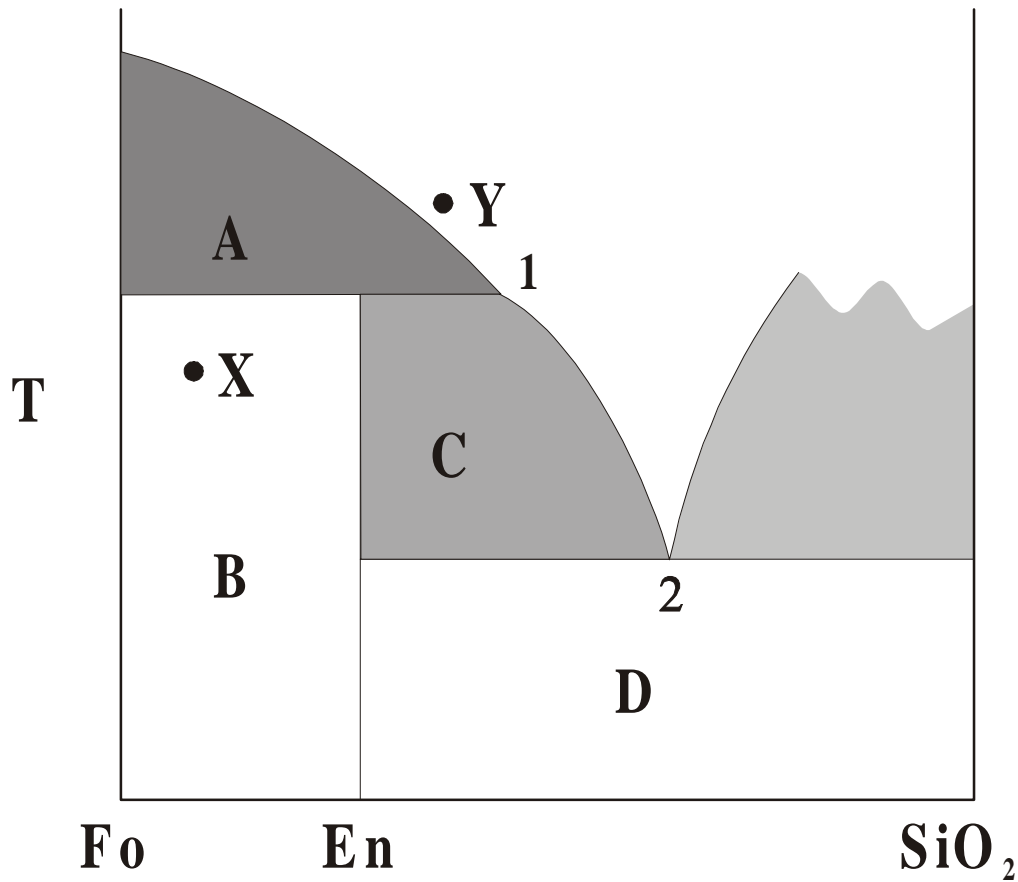
	Hi68 12	Hi68 14	Hi68 3	Hi68 2	Hi68 2G	Hi68 2I
SiO <sub>2</sub>	49.31	48.90	48.06	47.84	50.13	50.16
TiO <sub>2</sub>	2.37	2.29	2.05	2.01	2.84	2.16
Al <sub>2</sub> O <sub>3</sub>	12.49	12.06	11.32	11.00	13.24	13.55
Fe <sub>2</sub> O <sub>3</sub>	1.08	1.73	1.06	1.02		
FeO	10.48	9.99	10.92	10.98	11.52	10.72
MnO	0.17	0.17	0.18	0.18		
MgO	11.04	12.27	15.09	15.44	7.03	7.07
CaO	10.21	9.86	9.08	8.97	11.25	11.40
Na <sub>2</sub> O	2.12	1.99	1.81	1.81	2.49	2.42
K <sub>2</sub> O	0.47	0.45	0.41	0.41	0.52	0.49
P <sub>2</sub> O <sub>5</sub>	0.24	0.23	0.20	0.32 <sup>1</sup>	0.26	0.26
Total	99.98	99.94	100.18	99.89	99.28	98.23
	Hi68 3G	Hi68 3I	Hi68 12G	Hi68 12I	Hi68 14G	
SiO <sub>2</sub>	50.31	50.89	50.21	50.89	50.97	
TiO <sub>2</sub>	3.17	2.39	2.81	2.57	3.39	
Al <sub>2</sub> O <sub>3</sub>	12.92	13.97	13.29	13.70	13.31	
Fe <sub>2</sub> O <sub>3</sub>						
FeO	11.62	9.97	10.75	10.53	12.37	
MnO						
MgO	6.05	6.23	7.27	5.98	5.80	
CaO	10.80	11.89	11.13	11.40	10.56	
Na <sub>2</sub> O	2.54	2.45	2.39	2.52	2.70	
K <sub>2</sub> O	0.61	0.50	0.52	0.51	0.60	
P <sub>2</sub> O <sub>5</sub>	0.30	0.27	0.26	0.30	0.32	
Total	98.32	98.56	98.63	98.40	100.02	

G = glass, I = glass inclusions in olivine phenocrysts. Mn not analysed in glasses. All Fe reported as FeO in glasses. Rock analyses from Wright, 1971 and Wright, *et al.*, 1975. 1. This value for P<sub>2</sub>O<sub>5</sub> is inconsistent with the microprobe analyses of the glasses and minerals because it is larger than the concentration measured in any of the phases in the rock.

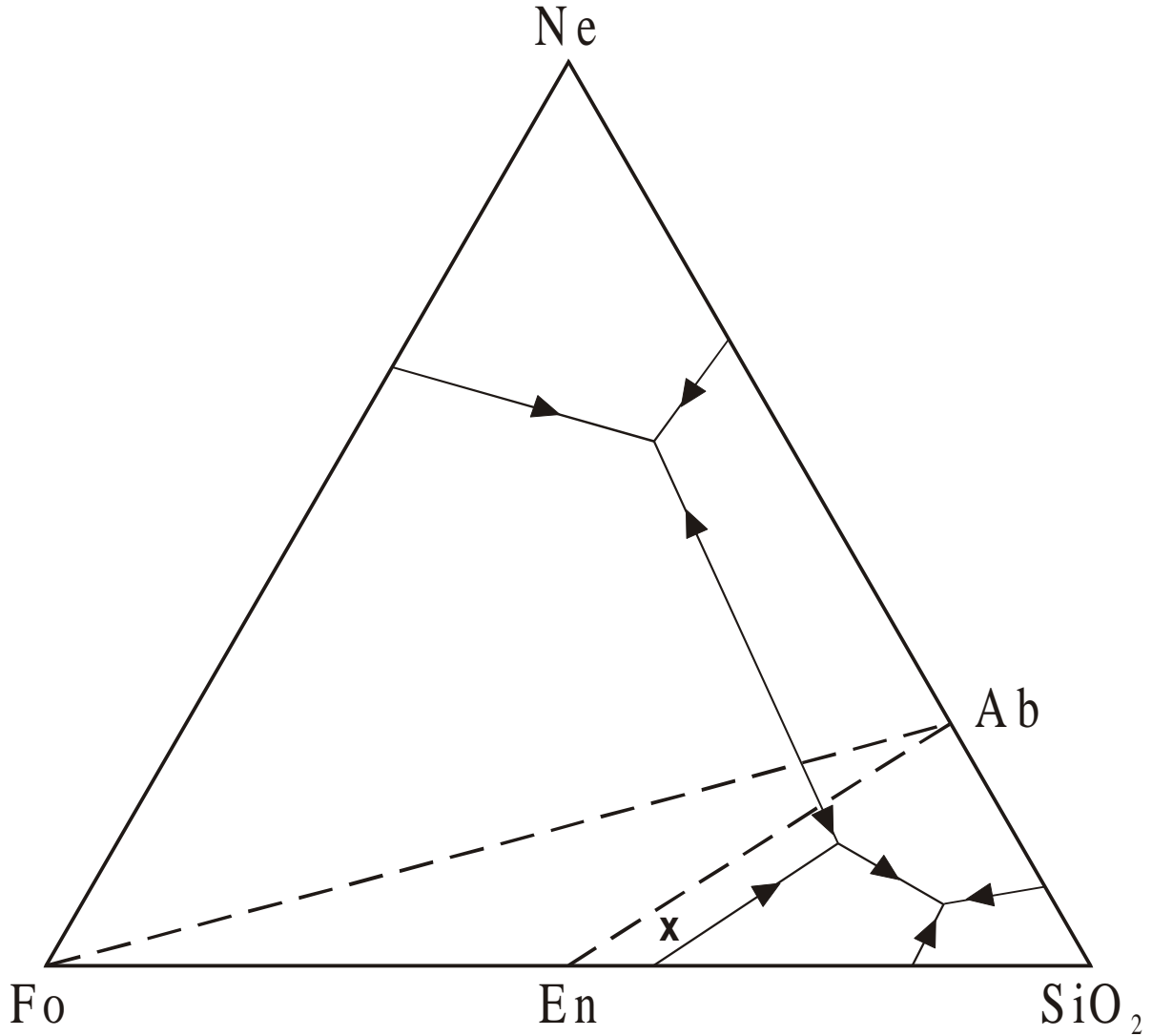
**Table 10, cont.: Lava Flow and Glass Analyses**

	HM68 1967	HM68 2	HM68 4	HM68 12	HM68 15	HM68 15G
SiO <sub>2</sub>	50.24	50.18	50.48	50.24	50.25	50.35
TiO <sub>2</sub>	2.65	2.57	2.69	2.62	2.62	3.72
Al <sub>2</sub> O <sub>3</sub>	13.56	13.63	13.52	13.70	13.61	12.56
Fe <sub>2</sub> O <sub>3</sub>	1.36	1.66	1.49	1.61	1.49	
FeO	9.95	9.72	9.95	9.77	9.86	13.28
MnO	0.17	0.17	0.17	0.17	0.17	
MgO	7.59	7.63	7.41	7.58	7.63	5.63
CaO	11.06	11.02	11.08	11.17	11.14	9.92
Na <sub>2</sub> O	2.31	2.25	2.31	2.29	2.32	2.65
K <sub>2</sub> O	0.54	0.54	0.52	0.53	0.55	0.70
P <sub>2</sub> O <sub>5</sub>	0.26	0.25	0.28	0.25	0.26	0.36
Total	99.69	99.62	99.90	99.93	99.90	99.17

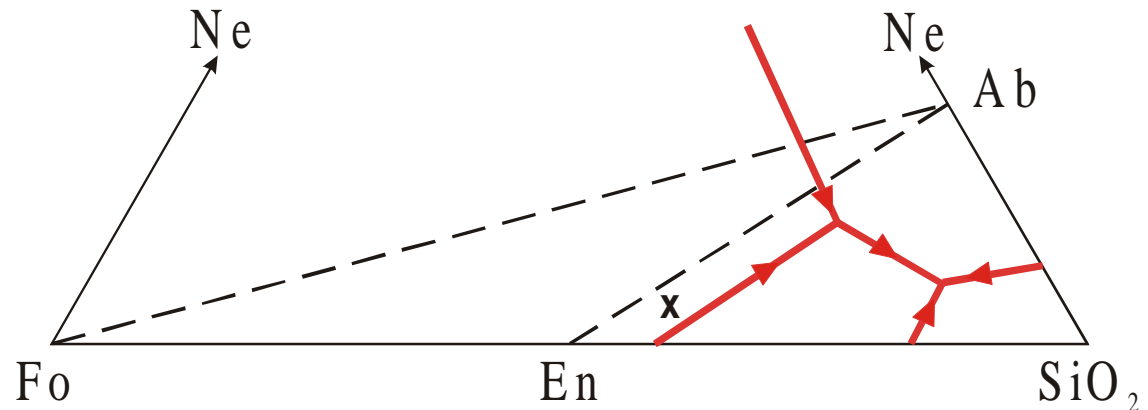
G = glass. Mn not analysed in glasses. All Fe reported as FeO in glasses.  
 Rock analyses from Wright, 1971 and Wright, *et al.*, 1975.



Fo-SiO<sub>2</sub> Diagram: Question 1.



Fo-Ne-SiO<sub>2</sub> Diagram: Question 1.



Enlarged Fo-Ne-SiO<sub>2</sub> diagram