TABLE 1. COMPOSITIONS OF PHASES AND BULK ROCK

Analysis phase P(bars) T(°C) wt % H_2O in melt	1 bulk rock	2 opx	3 plag	4 opx 1,000 980 4.3	5 opx 5,620 1,070 2.5	6 opx 5,430 1,010 4.6	7 opx 10,000 1,000 4.6
		(phenocrysts in natural rock)					
SiO_2	59.1	54.7	54.4	51.4	52.3	52.4	51.0
TiO_2	0.94	0.31	0.05	0.50	0.34	0.33	0.41
Al_2O_3	17.8	1.45	28.8	0.79	1.60	1.99	1.09
FeO*	6.43	18.2	0.22	22.5	21.0	19.4	22.3
MgO	3.05	24.7	0.00	22.5	22.6	24.2	21.5
CaO	6.85	1.35	11.9	1.75	1.42	1.51	1.67
Na_2O	4.27	0.07	4.8	n.d.	0.09	n.d.	0.05
K_2O	1.08	0.01	0.18	n.d.	0.09	n.d.	0.01
Total	99.52	100.79	100.35	99.44	99.44	99.83	98.03

*Total Fe as FeO. Opx = Orthopyroxene, plag = Plagioclase.

than magnetite. In the f_{O_2}–T range we consider reasonable for natural conditions, between the dotted lines on Figure 3, magnetite and ilmenite crystallize 20° to 45°C below the orthopyroxene liquidus and well below the plagioclase liquidus.

Phase relations at H_2O–saturated conditions at the QFM buffer appear in P–T projection in Figure 1 and at H_2O–undersaturated conditions in Figure 2. Figure 2 also shows the relation between weight percent H_2O in the liquid and $X^{fl}_{H_2O}$, as discussed by Eggler (1972a). Water-undersaturated liquidi for anhydrous phases are drawn for H_2O contents in melts of 2.0 and 4.7 percent H_2O. Melting curves for orthopyroxene and plagioclase do not have the same slope because of differences in the ΔV_r and ΔS_r of the melting reactions. The curves are nearly linear at low H_2O contents and become steeper, relative to the dry liquidi, with increasing H_2O content.

Phase relations are clarified by calculation of a T–X section from Figures 1 and 2. Figure 4 clearly shows the melting relations as a function of H_2O content and $X^{fl}_{H_2O}$ at 5 kb total pressure. In the calculation we assume melting temperatures with pure CO_2 are those of the dry liquidi. The diagram also contrasts melting of Mount Hood andesite with a Paricutin andesite (Eggler, 1972a). Liquidi slopes are similar for the two rocks, but their relative positions are different. For example, plagioclase is the liquidus phase in the Mount

Hood andesite for all H_2O contents, while orthopyroxene assumes the liquidus in the Paricutin andesite at about 2 percent H_2O.

Oxides are also stable to higher temperature in the Mount Hood andesite. As at 1 atm, ilmenite appears first, but the relation between ilmenite and magnetite is not entirely clear, inasmuch as in 1 kb H_2O–saturated runs, magnetite appears with ilmenite, but at 2 kb, magnetite crystallizes at least 60°C below ilmenite. H_2O–undersaturated runs indicate that at the QFM buffer, ilmenite appears at least 35°C below the silicate liquidus and magnetite becomes unstable relative to ilmenite with increasing pressure.

The upper temperature limit of amphibole stability is 950°C at 12 kb and H_2O–saturated conditions (Allen and Boettcher, 1971; Fig. 1). Recent investigations (Hill and Boettcher, 1970; Holloway and Burnham, 1972; Holloway, 1973; Eggler, 1972b) have shown that under H_2O–undersaturated conditions the upper temperature limit of amphibole stability may either increase or decrease relative to the H_2O–saturated stability curve. In the pressure range to 10 kb, however, the amphibole-out curve will lie within 20°C of the H_2O–saturated curve unless the melt contains less than about 3.5 wt percent H_2O. Runs on Mount Hood andesite at 5.5 kb containing 4.0 to 4.7 percent H_2O show that amphibole is as stable, within experimental limits, as when the melt is H_2O saturated (10 percent H_2O). However, under

TABLE 2.   RESULTS OF EXPERIMENTAL RUNS AT H_2O-SATURATED CONDITIONS

Conditions of run						Phases present*
P(Kb)	T,°C	P_{H_2} (b)	Time (hrs)	$-\log f_{O_2}$ (b)	Initial ($\%H_2O$)	
0.50	1,090	8.6	5.5	9.69	3.4	gl, pl
0.50	1,060	8.6	17.5	10.13	5.0	gl, pl
1.00	1,050	18.1	23	10.35	10.5	gl, pl
1.00	1,030	18.1	23	10.66	6.6	gl, pl, opx(tr.)
1.02	1,000	7.0	28	10.28	6.0	gl, pl, opx, il, mt(sa)
1.00	980	7.4	36	10.68	6.7	gl, pl, opx, il, mt
2.12	1,000	30.0	27	10.92	8.7	gl
2.12	975	30.0	27	11.34	7.8	gl, pl(sa), opx(tr.)
2.04	955	28.6	21	11.68	7.5	gl, pl, opx, il
2.04	935	28.6	21	12.04	8.3	gl, pl, opx, il
2.07	925	28.6	24	12.21	10.8	gl, opx, pl, hb, il
2.07	905	28.6	24	12.59	10.4	gl, opx, cpx(sa), pl, hb, il
5.52	925	78.0	12	12.06	15.7	gl, hb, opx(sa), pl
5.52	900	78.0	12	12.54	13.7	gl, hb, opx, pl
6.27	965	98.7	2.25	11.37	14.5	gl
6.27	950	66.2	20	11.29	13.2	gl, opx(sa), pl(tr.)

*gl = glass, pl = plagioclase, opx = orthopyroxene, cpx = clinopyroxene, il = ilmenite-hematite solid solution, mt = magnetite-ulvospinel solid solution, tr. = trace, sa = small amount.

H_2O–undersaturated conditions, amphibole is never stable at temperatures near the plagioclase liquidus.

Phase Compositions

Orthopyroxenes encountered in run products are moderately aluminous (Table 4); in some cases, certain grains inverted upon quenching to a clinopyroxene which had a small extinction angle. No plagioclase, amphibole, or clinopyroxene could be analyzed from run products. Amphiboles should be similar to tschermakitic hornblendes from Paricutin andesite runs (Eggler, 1972b) and clinopyroxenes should be similar to those in Paricutin runs, which contained 42 mole percent wollastonite and a maximum of 4.4 percent Al_2O_3 at 10 kb.

OXIDE FRACTIONATION IN THE CALC-ALKALINE SUITE

Various geochemical arguments regarding the fractional crystallization hypothesis of andesite origin have been reviewed by Green and Ringwood (1968). Phase equilibria questions revolve about the problem of iron oxide stability. Model system studies (Osborn, 1959; Roeder and Osborn, 1966; Eggler and Osborn, 1969) and mass-balance calculations
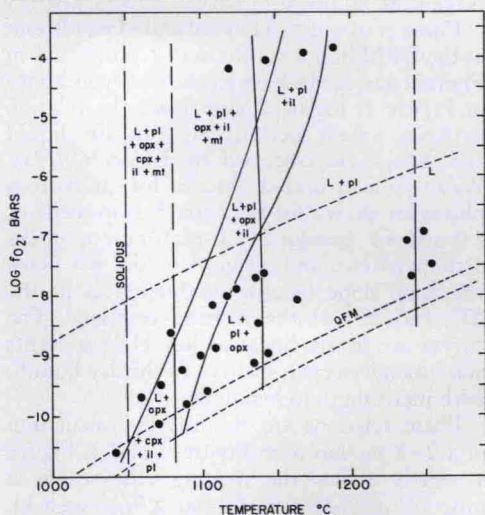

Figure 3. Phase relations for Mt. Hood andesite as a function of F_{O_2} at 1 atm total pressure. Stability limits are long dashed where approximately located. Short dashes contain region of f_{O_2} values expected in natural magmas.

show that magnetite must be subtracted from a basalt melt, along with silicates, to yield an andesite melt derivative. An iron-rich oxide phase must therefore be stable in a parent basalt melt, each succeeding melt, and the