

CRYSTALLIZATION OF BASALT AND ANDESITE
UNDER HIGH PRESSURE HYDROUS CONDITIONS

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Experimental crystallization of synthetic high-alumina quartz tholeiite and basaltic andesite glasses at 9–10 kb under conditions of $P_{H_2O} < P_{load}$ demonstrates that sub-silicic clinopyroxene, orthopyroxene and amphibole are the near-liquidus phases above 1000°C. Amphibole is the dominant phase at temperatures of about 960°C and less. Calcic plagioclase occurs nearer the solidus. In an andesite composition plagioclase and clinopyroxene are the near-liquidus phases at 940°C, joined by orthopyroxene, amphibole and garnet at lower temperatures. Electron microprobe analysis of phases crystallizing from the basalt allows calculation of the composition of liquid fractionates obtained under these conditions. The calculated liquid fractionate compositions follow the calc-alkaline trend and demonstrate that the calc-alkaline igneous rock suite may be derived by the fractional crystallization of basalt under hydrous conditions at 30–40 km depth ($P_{H_2O} < P_{load}$) or alternatively by the partial melting of amphibolite under similar conditions. In both cases the crystalline residuum will consist dominantly of amphibole, with subordinate clinopyroxene and orthopyroxene, and possibly minor calcic plagioclase and garnet, depending on the degree of fractionation.

1. INTRODUCTION

In the course of an experimental investigation of the origin of the calc-alkaline series, an exploratory study of fractional crystallization of basalt, basaltic andesite and andesite under hydrous conditions at pressures of 9–10 kb ($P_{H_2O} < P_{load}$) has been carried out. The preliminary results and implications of this study are reported in this communication. Preliminary results of an experimental investigation of an alternative hypothesis of origin of the calc-alkaline series viz. partial melting of quartz eclogite at depths of 100–150 km have already been reported [1]. The detailed experimental results and conclusions from both investigations will be given in a subsequent longer paper.

The hypothesis that the calc-alkaline series may be derived by hydrous fractional crystallization or par-

tial melting of mafic material near the base of the crust or in the upper mantle (e.g. at 30–40 km depth) has frequently been referred to in the literature [2–6], but so far there have been no experimental data directly applicable to the testing of this hypothesis. Yoder and Tilley [7] conducted pioneering work on the crystallization of a number of natural basalt compositions under controlled water vapour pressure conditions from 0–10 kb ($P_{H_2O} = P_{load}$) using a gas apparatus. They demonstrated lowering of the liquidus of the compositions with increasing P_{H_2O} , together with a marked increase in the size of the field of crystallization of amphibole, but the composition of the amphibole was not known. The presence of such a large field of crystallization of amphibole from basalt under these conditions suggests that the composition of the amphibole may be a key factor in testing the hypothesis for the derivation of calc-alkaline rocks from a basic parent under hydrous conditions. Accordingly, in the present investigation the sequence of crystallization and the composition of the

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Table 1
Compositions of synthetic rock mixes used in the experimental work.

	1. High-alumina quartz tholeiite	2. Basaltic andesite	3. Andesite
SiO ₂	52.9	56.4	62.2 **
TiO ₂	1.5	1.4	1.1 **
Al ₂ O ₃	16.9	16.6	17.3 **
Fe ₂ O ₃	0.3 *	3.0 *	0.3 *
FeO	7.9 *	5.7 *	5.9 *
MnO	0.2	0.1	0.1
MgO	7.0	4.3	2.4 **
CaO	10.0	8.5	5.2 **
Na ₂ O	2.7	3.0	3.3 **
K ₂ O	0.6	1.0	2.3 **
	100.0	100.0	100.1
Mol. $\frac{100 \text{ MgO}}{\text{Prop. MgO} + (\text{FeO} + 0.9\text{Fe}_2\text{O}_3)}$	60.4	47.7	41.0

* Denotes chemically determined content (E. Kiss, A.N.U., analyst).

** Denotes content determined by electron microprobe analysis.

crystallizing phases (obtained using the electron microprobe) in quartz tholeiite, basaltic andesite and andesite compositions have been determined for conditions of $P_{\text{H}_2\text{O}} < P_{\text{load}}$ (such conditions are considered geologically more probable than $P_{\text{H}_2\text{O}} = P_{\text{load}}$ at depths of 30–40 km in the lower crust or upper mantle). These results have then been used to determine quantitatively the composition of liquid fractions obtained from a parent basic composition.

2. EXPERIMENTAL

The experimental work has involved use of the same series of synthetic glass compositions described previously [1]. The compositions are given in table 1. Oxidation states and iron contents have been checked by chemical analysis (E. Kiss, A.N.U., analyst). The glasses have been subjected to pressures of 9–10 kb at temperatures of 800–1000°C in a piston-cylinder high pressure apparatus similar in design to the one described by Boyd and England [8, 9]. The high pressure experimental techniques involved have been described fully elsewhere [10], with the exception that in these hydrous runs undried pressure cell components without boron nitride sleeves have been used,

and the sample is packed into a thin walled platinum tube (0.004 in. wall thickness) with about 1 mgm of water. The tube is then crimped but not sealed. The runs have been conducted for 1–8 hr. At the conclusion of a run the sample has been examined by optical, X-ray and, in selected cases, electron microprobe techniques. The procedure results in uncontrolled hydrous conditions during the experiment, with $P_{\text{H}_2\text{O}}$ undoubtedly less than P_{load} . The water present caused a lowering of the liquidus by about 200°C and the probable $P_{\text{H}_2\text{O}}$ causing this effect would be from 2–5 kb. The exact value is not known. A pressure correction of -10% has been applied to the nominal load pressure, to allow for friction and imperfect pressure transmission in the furnace assemblies [11]. The experimental method is not ideal because of some iron-loss to the platinum sample capsules during the long experiments, and also because of the uncertainty of $P_{\text{H}_2\text{O}}$ on the sample, but it is adequate for this exploratory investigation. An empirical correction for the iron-loss effects based upon a comparison of measured $\text{Fe}/(\text{Fe}+\text{Mg})$ crystal-liquid partition coefficients in an additional series of runs carried out in graphite capsules, in which no iron was lost, has been applied. It can be demonstrated that this correction adequately compensates for the iron loss.