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HIGH PRESSURE EXPERIMENTAL STUDIES ON THE MINERALOGICAL CONSTITUTION OF THE LOWER CRUST

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Diorite and gabbroic anorthosite have been proposed as two possible overall compositions constituting the lower crust. The mineral assemblages stable in these compositions under anhydrous conditions at temperatures of 900–1200 °C and pressures of up to 36 kb have been determined. The low pressure mineralogy is dominated by plagioclase, with subordinate pyroxene and minor quartz. With increasing pressure garnet appears, and garnet, quartz and clinopyroxene form at the expense of plagioclase. Finally at pressures greater than 20 kb at 900–1200 °C plagioclase disappears and the high pressure assemblage consists of clinopyroxene + quartz (coesite) + garnet + K-feldspar ± kyanite(?). Extrapolating the experimental results to *P–T* conditions predicted for a stable, anhydrous lower crust and calculation of compressional wave velocities for these compositions supports the models of a lower crust composed of diorite or gabbroic anorthosite, where the mineralogy of these compositions consists of clinopyroxene, sodic plagioclase and subordinate quartz, garnet.

1. Introduction

Previous experimental investigations on natural rock systems have established the mineral assemblages formed in basaltic and granitic (adamellite) rocks at high pressures and temperatures under anhydrous conditions (GREEN and RINGWOOD, 1967; GREEN and LAMBERT, 1965). These results, complemented by data of other workers on relevant simple systems (BIRCH and LECOMTE, 1960; KUSHIRO and YODER, 1966), have been used to interpret the mineralogy expected in natural rocks under the pressure–temperature conditions predicted for the lower crust. The present investigation provides data on high pressure mineral assemblages in diorite and gabbroic anorthosite compositions, which fall between the extremes of basaltic and granitic rocks previously studied.

Recently proposed crustal models indicate that the earth's continental crust has an overall composition approximating to diorite or andesite (TAYLOR and WHITE, 1965). In crustal areas where there has been a long history of metamorphism and igneous activity (e.g. Precambrian shield) the crust may be differentiated into an upper granodioritic fraction underlain by a more basic fraction (TAYLOR, 1968; HARRIS, 1967). This basic fraction would approximate to gabbroic anorthosite if the initial overall composition was dioritic or andesitic (GREEN, 1968). Thus rocks of diorite or gabbroic anorthosite composition may well be major constituents of the lower crust, and determination of their mineralogies under lower crustal pressure–temperature conditions is important in enabling comparison of the properties of these compositions with the geophysically determined data for the lower crust. Accordingly this paper describes an experimental investigation of the mineral assemblages found in diorite and gabbroic anorthosite with increasing pressure, followed by estimates of the geophysical properties of these assemblages and finally a comparison with the available geophysical data for the lower crust in order to qualitatively evaluate the merits of these models.

It should be emphasized that from a detailed petrological point of view it is unlikely that the lower crust consists of a homogeneous layer of diorite or gabbroic anorthosite. Rather it is more likely to be composed of a mixture of rock types (cf. DEN TEX, 1965) among which diorite and gabbroic anorthosite may dominate. Alternatively, when viewed on a gross scale (e.g. by geophysical methods) the varied rock types combine to give characteristics expected of a rock of uniform intermediate composition (RINGWOOD and GREEN, 1966).

2. Experimental

The high pressure experimental work has been conducted using a solid medium piston-cylinder high pressure apparatus of the type described by BOYD and ENGLAND (1960a, 1963). The detailed experimental procedure has followed that of BOYD and ENGLAND (1960b, 1963) and GREEN and RINGWOOD (1967). Loss of pressure transmitted to the sample due to friction effects and non-uniform distribution of pressure in the solid medium pressure cell is allowed for by applying a -10% correction to the nominal pressure values for a single stage, instroke run (i.e. approaching the desired *P–T* values with the piston moving in), and the resulting pressures are believed to be accurate to $\pm 3\%$ for the range 15–40 kb (GREEN *et al.*, 1966). For pressures lower than 15 kb the results are probably accurate to $\pm 5\%$. In two-stage runs where the piston has been retracted a -4.5% pressure correction has been applied, based on the results of GREEN *et al.* (1966) for similar two-stage runs, and the probable accuracy is $\pm 5\%$. Temperature is measured with a Pt/Pt 10% Rh thermocouple and is believed accurate to ± 15 °C. No corrections for any pressure effect on the e.m.f. of the thermocouple have been made.

The compositions were carefully prepared by thoroughly mixing highest purity Fisher chemical compounds in the requisite proportions (table 1). The gabbroic anorthosite composition is based on the average of 7 analyses of gabbroic anorthosite from the Adirondack anorthosite complex (BUDDINGTON, 1939). A crushed glass of this composition was held in a sealed, evacuated silica tube with an iron pellet at 900 °C for 24 hours, then chemically analyzed for FeO and Fe_2O_3 to check the oxidation state. This procedure resulted in devitrification of the glass to a finely crystalline mix of feldspar and pyroxene which was used for the experimental work. The diorite composition is based on the average andesite composition proposed by TAYLOR (1968). It was prepared as a reacted mix, held in an evacuated silica tube with an iron pellet at 900 °C for 24 hours. Subsequent chemical analysis of the diorite indicated that the iron was present as FeO, with negligible Fe_2O_3.

In this project it was necessary to carry out runs at as low temperature as possible while still allowing equilibrium to be obtained in a reasonable time, in order to simulate as closely as possible the *P–T* conditions of the lower crust. Experience showed that reaction rates were extremely slow under anhydrous conditions at temperatures less than 1000 °C. The presence of water provides a catalytic effect for silicate reactions, but only a low water content as a catalyst could be tolerated in the present work otherwise hydrous phases crystallized, and it is unlikely that in general the activity of water in the lower crust is sufficient to produce such phases (RINGWOOD and GREEN, 1966). Thus the experiments were carried out under conditions of low water activity in the subsolidus fields of the two compositions for the temperature range 900–1200 °C at pressures up to 36 kb. Even at these temperatures, times of up to 72 hours were needed to enhance attainment of equilibrium. The results of the runs were then extrapolated to *P–T* conditions of the lower crust.

At 900–1000 °C unsealed gold capsules were generally used, though in a few cases silver–palladium capsules

TABLE 1

Composition and CIPW norms of synthetic diorite and gabbroic anorthosite used in the experimental work.

	Diorite	Gabbroic anorthosite
SiO_2	59.9	53.5*
TiO_2	0.7	1.0*
Al_2O_3	17.3	22.5*
Fe_2O_3	—	0.9†
FeO	6.3†	4.7†
MnO	—	0.1
MgO	3.4	2.1*
CaO	7.1	9.9*
Na_2O	3.7	3.7*
K_2O	1.6	1.1*

* denotes content determined by electron microprobe analysis of a glass fragment.
† denotes content chemically determined.

CIPW norms	Diorite	Gabbroic anorthosite
Qz	9.2	2.1
Or	9.4	6.5
Ab	31.3	31.3
An	25.8	41.5
Diop	7.8	6.3
Hyp	15.0	8.5
Mt	—	1.3
Ilm	1.3	1.9
Density (g/cm³)	2.84	2.84
V_P (km/s) approx.	6.6	7.0