residuum of amphibole, pyroxenes and possibly minor calcic plagioclase and garnet. According to the model, the residuum may remain as a basic amphibole-rich lower crust with a Vp of about 7.5 km/sec, overlain by a sialic upper crust consisting of the calc-alkaline rocks extracted from the parental amphibolite. The upper crust has a much lower seismic velocity in the vicinity of 6 km/sec. Alternatively if most of the water is driven from the residual amphibolite while high temperature conditions prevail, then the amphibolite would change to a granulite assemblage. Then, when volcanic activity has ceased and the abnormally high temperature-depth distribution had returned to normal, the granulite may over a long period of time transform to eclogite. The residuum from the partial melting will be comparatively poor in alkalies and similar to a nepheline basanite. The work of D. H. GREEN and RINGWOOD (1967a) demonstrates that such a composition would transform to eclogite at a lower pressure than other basalts. If the transformation to eclogite takes place then the residuum may subsequently sink into the mantle (cf. RINGWOOD and D. H. GREEN, 1966).

A second series of experiments to be described in this paper was designed to investigate this hypothesis. In these experiments the fractional melting and fractional crystallization of a saturated basalt have been studied at 9—10 kb. at conditions of $P_{H_2O} < P_{LOAD}$.

The hypotheses (d) and (e) are essentially complementary to each other since they both involve derivation of the calc-alkaline suite by a two-stage magmatic process, incorporating in the first stage large scale extrusion of saturated basaltic magma in the earth's crust. The subsequent history of this basalt pile, whether it remains dry and transforms to eclogite, or whether water has access while high temperature conditions pertain, determines whether the calc-alkaline suite is produced according to model (d) or (e). Both models might explain the derivation of the suite in areas where no sialic material occurs and also provide a mechanism for continental evolution from an undersaturated upper mantle.

Since minor basalt magma is frequently erupted along with the more abundant calc-alkaline magmas (basaltic andesite — andesite — rhyolite), the two complementary hypotheses (d) and (e) for the origin of the calc-alkaline series, must also explain this close association with basalt magma. In the case of the first hypothesis (d), the calc-alkaline magmas rising from the partial melting of quartz eclogite at 100—150 kms depth may cause instability in the mantle at shallower levels. This may result in renewed fractional melting in the upper mantle giving basalt magmas as discussed in detail by D. H. GREEN and RINGWOOD (1967b) and T. H. GREEN, D. H. GREEN and RINGWOOD (1967). This second generation of basalts may then rise to the surface in association with the liquids obtained by partial melting of the quartz eclogite. Alternatively in the case of the second hypothesis (e), a high temperature gradient is needed in the amphibolite to allow partial melting. Renewed or continued basaltic volcanism from the mantle is the most likely ultimate cause of this high temperature gradient, so that the association of basalt lavas with calc-alkaline lavas at the earth's surface is to be expected.

Thus in both these models the occurrence of basalts with the calc-alkaline series may be explained as a function of the thermal mechanism giving rise to the series, rather than as a direct chemical link between the basalts and the more salic rocks of the calc-alkaline suite.

Linked with these two models there is a third possible way in which the calc-alkaline series may be derived. In this third model a basaltic magma is contaminated with water and undergoes fractional crystallization under hydrous conditions (with $P_{H_2O} < P_{LOAD}$) at 30—40 kms depth. The crystallization will be dominated by amphibole, and to a smaller extent will involve pyroxenes, and possibly calcic plagioclase and garnet. The residual liquids derived from this crystallization will correspond to intermediate or acid members of the calc-alkaline suite, depending on the degree of fractional crystallization. Circumstances where water may have access to a basalt magma at 30—40 kms depth could occur at the margins of the oceans, where, according to the hypothesis of sea-floor spreading (HESS, 1962) downward "convection currents" are present. These "currents" may carry hydrated rocks into contact with basalt magma derived by partial melting of the mantle (cf. D. H. GREEN and RINGWOOD, 1967 b). The sea-floor spreading hypothesis may also be linked to the sinking eclogite model for the origin of calc-alkaline rocks (RINGWOOD and D. H. GREEN, 1966).

Experimental

The experimental procedure followed has been to prepare a series of glasses with compositions approximating to typical members of the calc-alkaline series, high-alumina olivine tholeiite, high-alumina quartz tholeiite, basaltic andesite, andesite, dacite and rhyodacite. After fusion, the oxidation state and iron content have been checked by chemical analysis (E. KISS, A. J. EASTON, A.N.U. analysts), and in some cases the glass composition has been further checked by electron microprobe analysis. The compositions are listed in Table 2. The basalts chosen are high-alumina tholeiitic types similar to basalts found associated with the calc-alkaline series e.g. western North America (ANDERSON, 1941; WILLIAMS, 1935 and THAYER, 1937), Japan (KUNO, 1960) and New Zealand (CLARK, 1960) and similar to basalts dredged from ridges of the Atlantic, Pacific and Indian Oceans (ENGEL, ENGEL and HAVENS, 1965; ENGEL, FISHER and ENGEL, 1965). Apart from the high-alumina content, the quartz tholeiite is approximately similar to the overall composition of many major basalt sequences e.g. continental flood basalts (TURNER and VERHOOGEN, 1960) and basalt piles in oceanic areas (Hawaii: MACDONALD and KATSURA, 1964; Iceland: CARMICHAEL, 1964).

The andesite composition (Table 2) was originally prepared for a different problem (T. H. GREEN, 1967 a, b) and compared with the dacite chosen for this investigation it has a slightly high potash content. Initially, as an approximation to a rhyodacite composition an adamellite (termed rhyodacite I in this paper) previously prepared and described by D. H. GREEN and LAMBERT (1965) was used.

The glasses have been subjected to a wide range of closely controlled temperature-pressure conditions in a piston-cylinder, high pressure and high temperature apparatus similar to that described by BOYD and ENGLAND (1960, 1963). The high pressure experimental techniques involved have been described fully elsewhere (D. H. GREEN and RINGWOOD, 1967 a). A pressure correction of -10% has been applied and the resulting pressures are believed to be accurate to $\pm 3\%$ in the range 15—40 kb (T. H. GREEN, RINGWOOD and MAJOR, 1966).

A detailed study of fractional crystallization and crystal-liquid equilibria in the different compositions listed in Table 2 has been made at a series of pressures up to 36 kb. The nature, proportion and composition of mineral phases present have been determined by optical, x-ray and electron microprobe techniques, and the principal fractionation trends at high pressure have been established. In this way the model for the origin of the calc-alkaline series by fractional melting of quartz eclogite at 100—150 kms has been tested experimentally. In addition to this detailed dry high pressure study, a series of reconnaissance runs have been carried out under wet conditions. The procedure followed has been use to undried pressure cell components without boron nitride sleeves. The sample is packed into a thin walled platinum tube and about 1 mgm of water added. The tube is then crimped, but not sealed. Wet runs have generally been conducted for 1—8 hours. This procedure results in uncontrolled