they cannot have formed from pre-existing old crustal material enriched in radiogenic strontium. Similarly the observed trace element and rare earth element abundances in andesite preclude large scale contributions from sialic material e.g. low content of K, Rb, U, Th, rare earths, Sn and Li in andesites (TAYLOR and WHITE, 1966). It is significant that recent work has shown that the calc-alkaline series of oceanic island arc regions is chemically distinct from the calc-alkaline series of continental areas e.g. the series in island arc regions is lower in K than the series in continental areas (DICKINSON, 1967). This type of difference may be linked with different origins of the calc-alkaline rocks of these regions. The hybridization and mixing of magma theories, though demonstrated in some particular cases, fail to explain the evidence for a liquid line of descent in the calc-alkaline series in other areas. Liquids of composition ranging at least from basaltic andesite to rhyolite occur (see p. 107).

c) Contamination of Basaltic Magma with Sialic Crust

DALY (1933) suggested that sialic material incorporated into basaltic magma gave rise to most andesites. Similarly TILLEY (1950) proposed that the calc-alkaline series was derived from fractional crystallization of basaltic magma modified by sialic contamination. This hypothesis has also been followed by KUNO (1950), WATERS (1955) and WILCOX (1954). However this hypothesis, although possibly applicable in some localities, fails as a general explanation for the origin of the calc-alkaline series; in particular it cannot explain the development of the calc-alkaline series in island arcs which have formed across oceanic crust, where no sial occurs.

d) Partial Melting of Quartz Eclogite at 100—150 kms Depth

O'HARA (1963) demonstrated that under dry conditions at a pressure of 30 kb the garnet-pyroxene tie line forms a thermal barrier between undersaturated olivine- and oversaturated quartz-bearing assemblages. Thus oversaturated magmas may only be derived at great depth in the mantle if parent oversaturated compositions (e.g. quartz eclogite) are present in the mantle, and undergo partial melting. However several lines of evidence indicate that the mantle has an undersaturated composition, probably approximating to 3 parts peridotite and 1 part basalt (termed pyrolite; RINGWOOD, 1966). Hence the derivation of the oversaturated calc-alkaline series is not possible by the simple partial melting of the pyrolite mantle at depth.

Recently RINGWOOD and D. H. GREEN (1966), after a study of the gabbro-eclogite transformation, proposed a new model for orogenic processes which provides a mechanism for obtaining oversaturated quartz eclogite compositions in the upper mantle. According to this model, it is envisaged that in present or possible future active orogenic regions of the earth's crust such as island arcs, some oceanic rises, oceanic rift systems and continental margins, large piles of basalt have developed as the first stage in the cycle of orogenic activity and continental growth. As long as active basaltic volcanic activity persists, the geotherms in the particular region remain high. However, with cessation of volcanic activity the geotherms fall and the deeper regions of the basaltic pile begin to transform to eclogite[1]. The quartz eclogite ($\varrho \sim 3.45$ gm/cm^3) is denser than the ultramafic upper mantle ($\varrho \sim 3.3$ gm/cm^3) so that it begins to sink into the mantle. In the early stages, sinking is relatively slow, and results in formation of a geosyncline. At a later stage, sinking becomes catastrophic, leading to severe crustal deformation and folding of the geosyncline. Eventually, the sinking eclogite bodies reach a level in the mantle (probably at depths of 100—150 km) where the temperature is sufficiently high to cause partial melting of the eclogite. Magmas thus produced rise upwards and intrude the folded geosyncline. The possibility is suggested that these magmas may represent the calc-alkaline suite. This hypothesis formed the basis of one of the series of experiments described in this paper. These experiments have aimed at determining whether rocks of typical saturated or near-saturated basaltic composition, when subjected to fractional melting and fractional crystallization at pressures of 30 to 40 kb, are capable of yielding large proportions of typical calc-alkaline magmas, e.g. andesites and granodiorites. Preliminary results, favourable to this hypothesis, have been outlined in a previous paper (T. H. GREEN and RINGWOOD, 1966).

e) Partial Melting of Basalt at 30—40 kms Depth under Wet Conditions ($P_{H_2O} < P_{LOAD}$)

DALY (1933), HAMILTON (1964), COATS (1962), LIDIAK (1965), BRANCH (1967) and others have suggested that the calc-alkaline series may be generated by "wet" partial melting or crystallization of mafic material near the base of the crust or in the upper mantle. Although this hypothesis has been the subject of a considerable amount of speculative discussion, direct supporting evidence, particularly of an experimental nature, is practically non-existent. In the present paper, we propose to develop this hypothesis further, and to subject it to a quantitative experimental investigation.

As in the previous model (d), it is envisaged that in the first stage large piles of basalts develop in the earth's crust in such areas as island arcs, some oceanic rises, oceanic rift systems and continental margins. In this case limited access of water to the basalt pile takes place, due possibly to the repeated extrusion of comparatively thin submarine lava flows. As the pile grows the basalt in the deeper regions where the temperature may be of the order of 400° C will alter to amphibolite.

Subsequently a higher temperature distribution may be obtained in the amphibolite, either as it is buried still further due to continuing volcanic activity, or at a later stage after a period of quiescence followed by a renewed phase of volcanic activity. Under these high temperature conditions partial melting of the amphibolite may take place. In the present study we shall investigate the possibility that this melting may produce magmas of the calc-alkaline suite, leaving a

[1] There is an extensive range of olivine-normative basaltic compositions which, together with quartz-normative basalts, will transform to quartz-bearing eclogites under appropriate conditions (e.g. high-alumina olivine tholeiite with 9.3% normative olivine has 8.5% normative quartz when calculated in terms of an eclogite norm — RINGWOOD and D. H. GREEN, 1966). Most basalts occurring in large scale basaltic volcanic provinces, e.g. Hawaii (MACDONALD and KATSURA, 1964) and Iceland (CARMICHAEL, 1964) are olivine or quartz-normative tholeiites and fall into the category producing quartz-bearing eclogites, if they transform to an eclogite assemblage.