by partial or complete melting of older granitic rocks. Thus these conclusions support the hypotheses for the origin of the calc-alkaline igneous rock series presented in this paper.

Summary

The experimental work supports three possible models for the origin of the calc-alkaline suite. These models have been outlined in the introductory sections of this paper. In two of the models the calc-alkaline series forms as a result of a two-stage magmatic process. In the first stage, fractional melting of the pyrolite mantle produces undersaturated basaltic magma which rises to higher levels and following fractionation of this magma at depths of less than 15 kms, large piles of basalt with an overall quartz-normative composition will be formed. Likely crustal areas where such piles may develop include continental margins, oceanic rift systems, island arcs and some oceanic rises (RINGWOOD and D. H. GREEN, 1966). If the geotherms in the area where the basalt pile has developed drop after the basaltic volcanism has ceased, and the basalt pile remains dry, then it may eventually transform to eclogite (RINGWOOD and D. H. GREEN, 1966) and sink back into the mantle. The mineralogy of the sinking eclogite will consist of chiefly garnet-clinopyroxene-quartz. In the second stage of the two stage process at depths of approximately 100—150 kms where the temperatures are sufficiently high, partial melting of the eclogite will take place, giving rise to members of the calc-alkaline suite. If the melting takes place under dry conditions basaltic andesite or andesite (plutonic diorite or quartz diorite) will be obtained, or if wet melting takes place, dacite or rhyodacite (plutonic granodiorite or adamellite) will be produced. The initial overall composition of the basaltic pile and the temperature and depth at which partial melting of the eclogite occurs, will be important factors in governing the composition of the calc-alkaline magmas obtained. However, additional processes such as varying degrees of crystallization of the magma during its upwards progress will also operate, causing variation in composition of the final lava flow or pluton. For instance some dacite and rhyolite magmas may be derived from andesite by fractional crystallization at pressures corresponding to those deep within the crust, leaving a residuum of plagioclase and subordinate pyroxene (gabbroic anorthosite — T. H. GREEN, 1967 b); the low melting liquid resulting will vary from dacite to rhyolite depending on the degree of fractionation. This mechanism is probably significant in provinces where the K_2O/Na_2O ratio is greater than unity in the more acid members of the calc-alkaline suite and is similar to the plagioclase effect proposed by BOWEN (1928).

Alternatively in the second model proposed, access of water to the basalt pile developed in continental margin or island arc areas results in formation of amphibolite in the lower parts of the pile. The water content of such an amphibolite may be of the order of 1%. Subsequent heating of this amphibolite, due to renewed or continued volcanic activity from the mantle, may result in partial melting taking place. The pressures at which partial melting takes place may be as high as 10 kb, corresponding to the base of the crust, but water vapour pressure is likely to be less than load pressure and the magmas produced will not be saturated in water, since insufficient water occurred in the parent amphibolite. The residual phases from such melting will consist mainly of amphibole and clinopyroxene and subordinate orthopyroxene, calcic plagioclase and possibly garnet,

depending on the degree of partial melting. As in the first model, the initial overall composition of the basalt pile and the temperature and depth at which wet partial melting of the basalt occurs, will be important factors determining the composition of the derived calc-alkaline magmas. Similarly the rate of progress of the magma to the surface and the degree of crystallization during this movement will cause variation in composition of the final lava flow or pluton. The fact that the melting has taken place under conditions of $P_{H_2O} < P_{LOAD}$ means that decrease in pressure due to upward movement of the magma will not result in sudden crystallization due to the raising of the liquidus consistent with the lower P_{H_2O}. This would be the case if $P_{H_2O} = P_{LOAD}$ in the magma unless the magma was in a superheated condition.

The residuum left after partial melting of the amphibolite may remain as a lower crust of amphibolite or alternatively it may subsequently transform to eclogite, if most of the water has been driven off and if the temperature decreases. The eclogite will then sink into the mantle (cf. Ringwood and D. H. Green, 1966). This will solve any room problem regarding the presence of a large crystalline residuum remaining after the partial melting process.

A third model for the origin of the calc-alkaline series involves the fractional crystallization of a hydrous basalt magma at 30—40 kms depth. The basalt magma is derived by partial melting of the mantle (cf. D. H. Green and Ringwood, 1967b). Access of water to the magma may have resulted from contamination with hydrated rocks introduced into the mantle by a sinking limb of a convection cell, as in the hypothesis of "sea-floor spreading" (Hess, 1962). This, in turn, might also explain the association of calc-alkaline rocks with a particular tectonic environment.

These models provide a mechanism for adding sialic material to the crust from the mantle as a result of a two stage process. Features of the calc-alkaline series which may be explained by these models include:

(i) The characteristic Fe/Mg fractionation trend, which shows only slight iron enrichment relative to magnesium with increasing acidity. This is attributed to the presence of relatively iron-rich mafic phases (garnet or amphibole — see Tables 11, 24) in the residuum left after fractional melting or crystallization.

(ii) The sequence and relative volumes of the different rock types. This is governed by the composition of the initial basalt pile, the depth and degree of partial melting or fractional crystallization and whether it is dry or wet melting and finally the progress of the liquid to its final site of crystallization.

(iii) Low initial Sr^{87}/Sr^{86} ratios of members of both the extrusive and plutonic calc-alkaline series, due to their derivation from basaltic material with a low initial Sr^{87}/Sr^{86} ratio.

(iv) Presence of almandine-rich garnets of magmatic origin in the more acid members of the calc-alkaline series. These may have formed at lower crustal or upper mantle pressures.

(v) Presence of resorbed quartz phenocrysts in dacites and rhyodacites. These may have crystallized at depth and later became out of equilibrium when carried in the magma to a low pressure environment.

In addition, the models described provide a highly efficient way of deriving acidic compositions from a basic parent, by separation of silica-poor garnet and aluminous pyroxene phases (model I) or silica-poor amphibole and aluminous