

## Genesis of the Calc-Alkaline Igneous Rock Suite

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*Abstract.* A high pressure experimental study of the partial melting fields of synthetic high-alumina olivine tholeiite, high-alumina quartz tholeiite, basaltic andesite, andesite, dacite and rhyodacite under dry and wet ( $P_{H_2O} < P_{LOAD}$ ) conditions has been conducted in order to investigate possible origins of the calc-alkaline series from the upper mantle. Detailed analyses of crystallizing phases using the electron microprobe has enabled calculation of the liquid line of descent in these compositions at various pressures.

At 27—36 kb garnet and clinopyroxene are the liquidus or near-liquidus phases in dry tholeiite, basaltic andesite and andesite, while quartz is the liquidus phase in dry dacite and rhyodacite. Under wet conditions at 27 kb garnet, not quartz, is the liquidus phase in the dacite. Qualitatively these results show that the low melting fraction of a quartz eclogite at 27—36 kb under dry conditions is of andesitic composition whereas under wet conditions it is rhyodacitic or granodioritic. At these pressures under dry conditions the andesite liquidus lies in a marked low temperature trough between the more basic and more acid compositions. Quantitatively, the calculated compositions of liquid fractionates for varying degrees of melting of the quartz eclogite under dry conditions broadly follow the calc-alkaline trend.

At 9—10 kb under wet conditions ( $P_{H_2O} < P_{LOAD}$ ) sub-silicic amphibole and pyroxenes are the near-liquidus phases in tholeiite and basaltic andesite compositions. Calcic plagioclase and garnet occur nearer the solidus. The calculated liquid fractionates follow the calc-alkaline trend and demonstrate that the calc-alkaline series may be derived by the partial melting of amphibolite at lower crustal depths under wet conditions ( $P_{H_2O} < P_{LOAD}$ ), or by the fractional crystallization of a hydrous basalt magma at similar depths.

These experimental results support two complementary hypotheses for the derivation of the calc-alkaline igneous rock suite from the mantle by a two stage igneous process. In the first stage of both hypotheses large piles of basalt are extruded on the earth's surface. Subsequently this pile of basalt may, under dry conditions, transform to quartz eclogite, sink into the mantle and finally undergo partial melting at 100—150 kms depth. This partial melting gives rise to the calc-alkaline magma series leaving a residuum of clinopyroxene and garnet. Alternatively, if wet conditions prevail in the basalt pile and the geotherms remain high, partial melting of the basalt may take place near the base of the pile, at about 10 kb pressure ( $P_{H_2O} < P_{LOAD}$ ). The liquids so formed constitute the calc-alkaline suite and the residuum consists of amphibole, pyroxenes and possibly minor garnet and calcic plagioclase. Both models may be directly linked to the hypothesis of sea-floor spreading.

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## Introduction

The calc-alkaline suite is comprised dominantly of the basalt-andesite-dacite-rhyolite volcanic series together with their plutonic equivalents, gabbro, diorite, granodiorite and granite. Representatives of this suite, particularly intermediate and acidic types, are the most abundant igneous rocks in orogenic belts. The association of this rock suite with past and present tectonically active zones is suggestive of a close relationship between the genesis of calc-alkaline rocks, the fundamental mechanism of orogenesis and the evolution of continental areas (WILSON, 1954; ENGEL, 1963). RUBEY (1951, 1955) has argued strongly that the earth's atmosphere, hydrosphere and crust have been formed gradually, over geological time, by degassing and fractional melting of the upper mantle. Some mechanism for the derivation of the calc-alkaline series from the upper mantle would provide the most effective means for the formation of the sialic crust, in harmony with the observed abundances and location of the common igneous rock types. Accordingly in this paper the problem of the genesis of the calc-alkaline suite is considered with particular reference to its possible ultimate origin in the upper mantle. A brief description of the salient features of the calc-alkaline series will be given, followed by a review of the various hypotheses of origin of these rocks. Two additional complementary hypotheses of origin will then be outlined and finally high pressure experimental work conducted to test these hypotheses will be described.

### *Chemistry of the Calc-Alkaline Suite*

The characteristic features of the chemistry of the calc-alkaline suite are brought out in a triangular plot of total iron (as FeO), magnesia and alkali contents (soda and potash) of the rocks (the FMA diagram of POLDERVAART, 1949). An example of such a diagram is given and described in a later section, but the main feature is that the rocks of the calc-alkaline suite fall in an almost straight band extend-