THE MINERALOGY, PETROLOGY AND GEOCHRONOLOGY OF GRANITOIDS AND ASSOCIATED INTRUSIVES FROM THE SOUTHERN PORTION OF THE NEW ENGLAND BATHOLITH

by

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I certify that the substance of this thesis has not already been submitted for any degree and is not being currently submitted for any other degree.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

Hans-Dieter Hensel

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ABSTRACT

The Permo-Carboniferous New England Batholith, which is composed of a large number of individual plutons, stocks, dykes and complexes, exemplifies the type of complex intrusive activity manifest in Pacific-type orogenic belts. Granitoids and related rocks predominate, and together their study constitutes the major part of this thesis. The mafic intrusives of this batholith are volumetrically minor, but because they display a close spatial and temporal relationship to these granitoids, and have not been documented previously, they have also been studied in detail.

The Carboniferous Hillgrove Suite comprises a comagmatic series of stressed, corundum-normative granitoids which typically contain graphite, coexisting reddish-brown and green biotite, two generations of plagioclase feldspar, highly ordered microcline, ilmenite as the sole iron-titanium oxide, coexisting blue and colourless quartz, Fe-Mg and calciferous amphiboles, almandine-rich garnet, pyrrhotite, and, more rarely, ferrohypersthene. These data, combined with comparative experimental phase relations, collectively provide compelling evidence for an origin by partial melting, of predominantly volcanogenic greywackes. This hypothesis is supported by Sr isotope data which indicate that the country rock greywackes possessed essentially the same $^{87}Sr/^{86}Sr$ ratios at ~ 320 m.y. as the initial $^{87}Sr/^{86}Sr$ ratio of the granitoids. However, REE data provide an important constraint on this proposal, suggesting that a derivation of these granitoids from the greywackes presently exposed is unlikely, but that a sedimentary sequence containing some greywackes with less fractionated and lower REE abundances, such as those from the Tamworth Trough, would provide ideal source characteristics. Flood and Shaw (1975) and Chappell (1978) divided granitoids from this batholith into S- and I-type suites according to the type of inferred source material. However, on the basis of detailed mineralogical, chemical and isotopic studies it is concluded that this distinction is artificial and that the source rocks for the S-type suites, particularly the Hillgrove Suite, and for the so-called I-type New England Suite were essentially the same.

Spatially associated with the Hillgrove Suite and originally included as part of it, are a number of complexes comprising mainly mafic rocks of either tholeiitic or calc-alkaline affinity. Dominating the tholeiitic complexes are cumulate olivine gabbros containing coexisting Ca-poor and

Ca-rich pyroxenes (including inverted pigeonite in some of the low-*MG*[†]gabbros), moderately calcic plagioclase (An_{65-75}), olivines (Fo_{62-77}) with reaction coronas, ubiquitous ilmenite and a complex assemblage of coexisting primary and secondary amphiboles and micas. The compositions of the coexisting primary ferromagnesian phases and the order of their crystallization (olivine → clinopyroxene → orthopyroxene) are not consistent with the host rock compositions (*MG* ~ 75). A model is offered where precipitation of magnetite ± ilmenite in a rising magma column results in the enrichment of the remaining intercumulus liquid in Mg. Subsequent post-cumulate re-equilibration with small (< 5%) amounts of intercumulus liquid further modified original mineral compositions.

The olivine gabbros are characterized by low TiO_2, FeO, MnO, Na_2O, P_2O_5, K_2O and related incompatible elements, Nb and Li, high Al_2O_3, CaO, MgO, Cr and Ni and very high *MG* numbers. In addition to low REE abundances (~ 2-4x chondrite), the olivine gabbros display slight to moderate LREE depletion (La_N/Sm_N = 0.25 - 0.50), small but pronounced positive Eu anomalies (Eu/Eu* = 1.3 - 2.2), near-chondritic ratios for Al_2O_3/TiO_2 and CaO/TiO_2, and the lowest $^{87}Sr/^{86}Sr$ ratios (0.7025 - 0.7028) so far recognized from the fold belts of eastern Australia. Collectively, these data strongly suggest that the New England tholeiitic gabbros are derived by crystal accumulation from a basaltic parental melt very similar in composition to young mid-ocean ridge tholeiites. Despite their emplacement through presumably thick continental crust, the 'primitive' characteristics of the gabbros have been preserved, facilitated by (a) deeply-tapping faults generated by uprise of the Hillgrove Suite plutons, and (b) a protective 'outer shell' of cumulate diorite which generally prevented reaction between the gabbros and the country rocks.

Low pressure fractionation of tholeiitic magma which has been slightly contaminated by crustal material, or which has reacted with deep-seated wall-rock fluids, produced a range of derivatives displaying a trend of absolute iron-enrichment, in addition to other compositional changes. These changes are reflected predominantly by the systematic variation in the compositions of the amphiboles and biotites, phases which are typically absent from tholeiitic rocks. Compared to experimentally determined phase equilibria the compositions of these hydrous phases suggest crystallization at low and decreasing fO_2. Other felsic derivatives of tholeiitic gabbros exhibit extreme Mg- and Na-enrichment and have crystallized clinopyroxene which is highly calcic (26% CaO) and magnesian (*mg*[†]88).

[†] *MG* throughout this thesis is 100 $Mg/Mg+Fe^{2+}$; distinguishing it from *mg* which is 100 $Mg/Mg+\Sigma Fe$ expressed as FeO.

Gabbros which appear truly tholeiitic but which are intimately associated in the field with apparently cogenetic calc-alkaline rocks provide a sound basis for the interpretation that the calc-alkaline complexes associated with the Hillgrove Suite have resulted from contamination of primitive tholeiitic magma by crustal material. Rb/Sr ages on these complexes, combined with textural data and field relationships, indicate that their emplacement was almost synchronous with, or only slightly later than, the emplacement of the Hillgrove Suite.

During the early-to mid-Permian a zone of crustal weakness again developed in New England, extending north-south for several hundred kilometers, and heat was once more channelled from the upper mantle into the thick sequences of downbuckled volcanogenic sediments. A complex sequence of progressive fractional melting events followed and produced the compositionally diverse New England Suite. The majority of plutons are mixtures of minimum or relatively low-temperature non-minimum melt and refractory crystalline residue (restite); however, the formation of microtonalites involved the breakdown of biotite in the source rocks. The high concentration of volatiles in the 'granitic' melt fraction resulted in their rapid intrusion to sub-volcanic levels. Geothermometry on coexisting pyroxenes in the monzonites suggest that the maximum temperatures attained during this melting sequence exceeded 900° C. Hence, the formation of these intermediate rocks may have involved the breakdown of amphibole, in addition to biotite. Very high concentrations of incompatible elements in the monzonites strongly imply that the degree of melting at this stage was very small. The collective data on these plutons suggest that they were derived from mainly Devonian volcanogenic sedimentary material of essentially the same composition as that which generated the Hillgrove Suite. The possibility that New England is underlain by Precambrian crust is dismissed on the basis of Sr isotopes.

Evidence for plate subduction as a mechanism for magma generation in the development of the New England Batholith is limited to a group of isolated granitoids associated with the Peel Fault. Low contents of K_2O (~ 2%) and related incompatible elements, very low initial $^{87}Sr/^{86}Sr$ ratios (0.7035 - 0.7045), and textures which indicate direct and rapid crystallization from a total melt, are characteristic of these granitoids. Their derivation by partial melting of amphibolitized ocean-floor basalts is consistent with the presence of high-pressure metamorphic assemblages along the present and possibly original line of the Peel Fault.