ANATECTIC PERALUMINOUS GRANITES FROM THE CARMANVILLE AREA, NORTHEASTERN NEWFOUNDLAND

K.L. CURRIE
Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

G.E. PAJARI, JR.
Department of Geology, University of New Brunswick, Fredericton, New Brunswick E3B 5A3

ABSTRACT

In the Carmanville region granitic plutons emplaced within mafic hornblendic rocks are relatively mafic and contain hornblende. Those emplaced within pelitic rocks are peraluminous and contain muscovite, locally with garnet and andalusite. Those emplaced in quartzofeldspathic gneisses are meta-aluminous and contain biotite with little or no muscovite. Pelitic rocks around the peraluminous plutons exhibit a sequence of metamorphic and metasomatic changes leading to the development of peraluminous granitoid rocks. Relations between deformation and metamorphism, together with distribution of the assemblage quartz-muscovite-andalusite-K-feldspar, show that the peak temperatures in the pelitic rocks reached minimum melting conditions for quartzofeldspathic compositions. Major-element geochemistry shows that the plutons could be derived by advanced partial melting of the country rocks. There is no evidence for derivation from a more mafic parent. The composition of the granitoid segregations in the country rocks not only is consistent with the local metamorphic grade, but approaches that of the plutons, although the segregations are more peraluminous. The plutons were probably generated by radiogenic heat in a tectonically thickened sedimentary pile. The melt compositions, originally slightly peraluminous owing to their derivation from peraluminous sediments, were modified by the addition and subsequent escape of strongly peraluminous aqueous solutions derived from the country rocks. The plutons represent not only products of anatectic melting and subsequent differentiation, but also the interaction of melt, host rock and aqueous solution.

Keywords: peraluminous granites, crustal melting, anatexis, northeastern Newfoundland, Davidsville Group.

INTRODUCTION

Granitoid plutons in the Carmanville region of northeastern Newfoundland exhibit striking similarities to their host rocks. Plutons emplaced within mafic hornblendic rocks are relatively
motic and contain hornblende; those emplaced in pelitic rocks are peraluminous and contain muscovite, with local garnet and andalusite; those emplaced within quartzofeldspathic gneisses are metaluminous and contain biotite with little or no muscovite. Metamorphosed pelitic rocks around the peraluminous plutons exhibit a sequence of metamorphic and metasomatic changes leading to the development of peraluminous granitoid rocks. This paper considers the relations between the peraluminous plutons and their surrounding country rocks, and the origin and evolution of their peraluminous character.

**GEOLOGICAL SETTING**

During Cambro-Ordovician time, the Carmanville region formed part of the southeastern margin of the Lower Paleozoic Iapetus Ocean, which underwent a complex series of sedimentational and deformational processes leading to the collapse of the continental rise prism, obduction of oceanic crust and eventual cratonization (Currie et al. 1980). For the present purpose, the host rocks of the granites may be divided into an older psammitic to semipelitic unit (Gander Group), deposited as part of the continental rise prism, and a younger flyschoid semipelitic to pelitic unit (Davidsville Group), formed in an extensive submarine fan environment by turbidity currents, olistostromes and other mechanisms (Pajari et al. 1979). Allochthonous relics of oceanic crust (Gander River ultramafic belt) commonly separate the two units and occur as retransported rafts within the Davidsville Group. Assembly of this package was essentially complete by Caradocian time; stratigraphic evidence demonstrates that deformation and intrusion of the assembled complex commenced in pre-Llandovery (probably Ashgillian) time (Currie et al. 1980).

**FIELD RELATIONS**

The plutons discussed in this report form part of a roughly east-west chain of plutons extending some 50 km across the generally northeast-trending tectonic "grain" of the surrounding sedimentary and volcanic rocks (Fig. 1). The Frederickton and Rocky Bay plutons, emplaced in mafic volcanic rocks, consist largely of hornblende tonalite with minor granodiorite. [Terminology for the granitoid rocks follows the recommendations of Streckeisen (1976).] The Ragged Harbour and Deadmans Bay plutons

![Map of Hamilton Sound and surrounding areas with geological features indicated](image-url)
consist mainly of biotite granite with porphyritic to megacrystic K-feldspar. The eastern part of the Deadmans Bay pluton, one of the largest in Newfoundland, was studied by Jayasinghe & Berger (1976). The present report concerns the White Point, Aspen Cove and Island Pond plutons, as well as minor granitoid rocks within the surrounding Davidsville Group.

Davidsville Group

Over most of its outcrop area the Davidsville Group, although complexly deformed, is metamorphosed only to chlorite + muscovite grade. East of Carmanville the metamorphic grade rises rapidly, as indicated by the sequence of isograds shown in Figure 1b. The isograds curve strongly around the migmatitic White Point pluton. Porphyroblasts within the Davidsville Group exhibit intricate relations with successive periods of deformation (Pickerill et al. 1978), but the isograds appear unaffected by later deformation.

Irregular veins and segregations of quartz occur throughout the Davidsville Group. With increasing grade of metamorphism, these segregations become lenticular in shape and tend to lie at a fixed, usually low, angle to the foliation. Between the andalusite and sillimanite isograds, quartz is joined by pink andalusite crystals, typically surrounded by a thin selvedge of muscovite, and by minor K-feldspar. We did not observe the quartz–albite assemblages so characteristic of rocks of similar metamorphic grade elsewhere (Currie 1968). The appearance of pink andalusite is sufficiently striking and regular that we mapped it as a “splendid andalusite” isograd (Fig. 1). With increasing metamorphic grade, over a distance of about 2 km, andalusite and muscovite increase in relative abundance within the quartz-rich segregations, locally composing as much as 25% of the volume. Potassium feldspar is a minor but ubiquitous component of the segregations.

Near the sillimanite isograd, traces of plagioclase, biotite and tourmaline appear in the segregations, which here form 2–5% of the rock. These lenticular masses lie at a high angle, but not perpendicular, to the prominent foliation (Fig. 2) and are associated with marked “necking” of the surrounding rocks. Despite boudin-like features, the host rock exhibits no obvious competency contrasts, and the segregations are reasonably evenly distributed along and across the foliation (Figs. 2, 3).

With increasing metamorphic grade, the composition of the segregations changes rather abruptly over an interval of about 100 m. Plagioclase and biotite increase in abundance at the expense of quartz and muscovite, although
quartz-rich cores persist for a further 200–300 m. With increasing plagioclase and biotite contents, the relative volume of the segregations increases, reaching 12–20% of the volume, sufficient that the segregations define a new planar structure in the rock (Fig. 4). Along the margins of the White Point complex, the quartzofeldspathic (granitoid) layers are up to 10 cm thick, and the intervening biotite gneiss screens are intensely and tightly folded (Fig. 5). Successive granitoid layers differ substantially from one another in composition, ranging from fine grained muscovite–biotite granite through coarse grained leucocratic muscovite granite occasionally containing traces of andalusite, to aplitic muscovite–garnet granite. Cross-cutting relations, although uncommon, suggest that the varieties have no consistent age relations; that is, each cuts the others. With the exception of the cores of some pods, all the granitoid rocks exhibit a pronounced foliation parallel to the northeast-trending tectonic grain.

On the northern edge of the White Point...
pluton, a screen of muscovite–biotite granite some 200 m in width curves westerly toward the Aspen Cove pluton. The intersection of this screen with the Aspen Cove pluton was not observed owing to lack of outcrop, but it probably connects the two plutons.

**Aspen Cove pluton**

The Aspen Cove pluton forms a kidney-shaped body that transects its host rocks in the southwestern quadrant, but that is generally conformable elsewhere. A poorly exposed contact-aureole occurs southwest of the pluton, but on its eastern side the pluton passes gradationally into a thin zone of granitic screens. On its northern margin the pluton is intensely sheared. Both granite and host exhibit thin schistose foliation, and granitic dykes are isoclinally folded.

The Aspen Cove pluton exhibits a concentric zonation from near-massive medium grained pink to buff biotite granodiorite in the core, through biotite–muscovite granite to muscovite–garnet leucogranite on the margins. The associated dyke suite consists mainly of muscovite–garnet leucogranite. Compositional changes are gradual and progressive. The core contains no primary muscovite, but over a distance of about 1 km the rock grades to biotite–muscovite granite. A marginal zone 50–200 m wide contains no biotite, but rather muscovite + garnet. Nowhere did we observe stable biotite + muscovite + garnet. Xenoliths are extremely rare in the Aspen Cove pluton, although a few occur in dykes associated with the pluton.

**Island Pond pluton**

The Island Pond pluton forms an equant body some 5 km across emplaced in muscovite-chlorite-grade pelitic rocks of the Davidsville Group. A cordierite–andalusite-grade hornfels aureole, extending some 500 m from the contact, is anomalously and intensely small-folded,
suggesting that emplacement of the pluton produced structural disturbance in its surroundings. The marginal parts of the pluton consist of reddened alkali feldspar porphyries (grain size 1–2 mm). Lithologically similar porphyry dykes occur sparingly in the contact aureole. Most of the pluton consists of monotonous coarse grained, leucocratic biotite–muscovite granite. Although most of the pluton is massive, a septum of foliated material crosses the central part. Small dykes of aplite muscovite–garnet granite, similar to parts of the White Point and Aspen Cove plutons, cut the Island Pond pluton.

**Timing and Conditions of Emplacement of the Granitoid Rocks**

Field and petrographic examinations show that, with increasing metamorphic grade, segregations within the pelitic Davidsville Group gradually approach the mineralogy and texture of granitoid rocks cutting the Group. Conversely, granitic rocks in this region are peraluminous only where they are enclosed by pelitic rocks. These observations suggest that the origin of the segregations and the peraluminous character of the granitoid rocks may be connected. Additional evidence of such a connection can be deduced from the timing and conditions of emplacement of the granitoid rocks.

The main fabric of the Davidsville Group resulted from two nearly coplanar deformations (D1 and D2) separated by a period of porphyroblastesis, as can be seen in many thin sections where schistosity or slaty cleavage sweeps around porphyroblasts containing straight inclusion trails inclined to the external fabric (Pickerill et al. 1978). A third period of deformation (D3) kinks or crenulates (or both) the main foliation. A D3 foliation or crenulation overprints parts of all plutons except the Deadmans Bay pluton.

On the west side of Gander Bay, fossiliferous strata of Llandoveryan age contain D1, D2 and D3 (Currie et al. 1980). Porphyroblastesis therefore began in post-Llandovery time. Some pluton emplacement postdated D2 but preceded D3. The Frederickton and Rocky Bay plutons yield K/Ar ages of 405 ±15 Ma (Wanless et al. 1965, unpubl. data). Since the central core of these plutons is massive, their emplacement probably overlapped D3, the minimum age of which is thus fixed at about 405 Ma. According to van Eysinga (1975), the upper limit of Llandovery time lies at 423 Ma. Hence the maximum period available for metamorphism and intrusion is about 20 Ma. Granitoid segregations in the Davidsville Group, whose aluminosilicate mineralogy is congruent with that in the surrounding metamorphic rocks, show little internal foliation, but themselves define a new D3 foliation (Fig. 4). Formation of these segregations, emplacement of the plutons, the peak of metamorphism in the country rocks, and D3 deformation must have been almost contemporaneous. Rare granitic dykes cutting the segregations suggest that granite emplacement may have outlasted the other phenomena.

The evidence suggests that metamorphism commenced in Middle to Late Silurian time, with the peak of metamorphism and emplacement of plutons occurring near the end of the Silurian. Middle Devonian (360 ±14 Ma) K/Ar ages obtained from the White Point pluton suggest that the rocks remained hot for a long period. The post-tectonic Deadmans Bay pluton gives K/Ar ages of 345 ±15 Ma (Wanless et al. 1965, 1972).

Pressure–temperature conditions under which the various granitoid rocks were emplaced can be deduced from mineral assemblages. Color alteration of conodonts (Epstein et al. 1977) indicates that temperatures in the little-metamorphosed Davidsville Group south of Carmanville reached 300°C or more. Just below the andalusite isograd, staurolite occurs with quartz. Richardson (1968) deduced a minimum pressure of about 1.5 kbar for this assemblage with pure iron staurolite. The addition of magnesium would raise this pressure, since the alternative assemblage cordierite + andalusite + quartz is stabilized by the addition of magnesium. Above the “splendid andalusite” isograd, the segregations contain the assemblage andalusite–K-feldspar–muscovite–quartz. For pure phases, this assemblage is stable only along a univariant curve in P–T space in the presence of excess water. Quartz-rich segregations indicate the presence of a hydrous phase (Fyfe et al. 1978, Vidale 1974), and thus the assumption of excess water appears reasonable. For pure phases, and with the pressure of 1.5 kbar previously noted, the temperature of these initial segregations would be roughly 600°C, according to the data of Kerrick (1972).

However, this approximately univariant assemblage appears, not in one place only, but over a belt about 2 km wide in which the grade of the surrounding rocks rises, as indicated by the appearance of sillimanite. If the segregations were in equilibrium with their host, P–T conditions must have changed approximately along the univariant muscovite-breakdown curve. This curve is not strictly univariant, because of possi-
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...of the quartz-andalusite-K-feldspar-muscovite assemblage indicates that originally hotter and deeper rocks are exposed toward the White Point pluton. The disappearance of this assemblage in favor of granitoid material suggests the intervention of melting, probably with conditions near 650°C, 3 kbar.

All the granite plutons contain muscovite with accessory amounts of andalusite. This assemblage (muscovite–albite–K-feldspar–andalusite–quartz), which petrographic evidence suggests as stable and primary, can coexist with melt only along a vapor-absent univariant curve extending from the invariant point I of Figure 6 (cf., Thompson & Algor 1977). The position of this invariant point, together with data on the stability of andalusite, require that the tempera-

Fig. 6. Pressure–temperature conditions of metamorphism and granite emplacement. Point C gives probable temperature reached in the little-metamorphosed Davidsville Group; S indicates minimum conditions for staurolite–quartz stability; A gives the conditions deduced for the appearance of quartz–muscovite–K-feldspar–andalusite. Higher-grade occurrences of this assemblage fall on curve A–I, whose width indicates schematically the P–T variation possibly due to solid solution in K-feldspar and muscovite. At I melt appears. Andalusite granites crystallize on curve A–I in the andalusite stability field. Three estimates of andalusite–sillimanite equilibria are shown: H (Holdaway 1971), R (Richardson et al. 1969) and G (Greenwood 1976).
TABLE 1. CHEMICAL COMPOSITION OF GRANITIC SEGREGATIONS AND ADJACENT COUNTRY ROCKS

<table>
<thead>
<tr>
<th>Site 36C</th>
<th>Site 36 E</th>
<th>MP 76</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granitic segregations</td>
<td>Country rock</td>
<td>Granitic segregations</td>
</tr>
<tr>
<td>SiO₂</td>
<td>76.26</td>
<td>76.30</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.01</td>
<td>0.07</td>
</tr>
<tr>
<td>FeO</td>
<td>0.50</td>
<td>0.49</td>
</tr>
<tr>
<td>MnO</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>MgO</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>CaO</td>
<td>0.32</td>
<td>0.47</td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.13</td>
<td>2.05</td>
</tr>
<tr>
<td>K₂O</td>
<td>6.63</td>
<td>5.74</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.14</td>
<td>0.21</td>
</tr>
<tr>
<td>H₂O</td>
<td>0.86</td>
<td>0.93</td>
</tr>
<tr>
<td>Total</td>
<td>100.30</td>
<td>100.06</td>
</tr>
</tbody>
</table>

CO gives the amount of normative corundum in the analysis in weight percent. - no data

Mineral assemblage data suggest regional temperatures of about 300°C. The succession of isograds indicates temperature increases to about 500°C, > 1.5 kbar, near the andalusite isograd. Hotter, deeper rocks near the White Point pluton crystallized near 650°C, 3 kbar, as did parts of the granite plutons.

**Major Element Geochemistry of the Granitoid Rocks**

Field observations indicate a continuous transition from relatively large masses of granitic rocks (plutons, dykes, screens) through small masses of granitic rocks (seggregations, leucosome of migmatite) to segregations rich in quartz with accessory amounts of feldspar, muscovite and andalusite. We have chemically analyzed the granitic rocks and estimated the composition of the quartz-rich segregations. Below the “splendid andalusite” isograd, the segregations contain more than 95 vol. % quartz. Just below the sillimanite isograd, the segregations contain about 70% quartz, 15% andalusite, 10% muscovite and 5% K-feldspar, equivalent to roughly 83 wt. % SiO₂, 14% Al₂O₃ and 3% (K₂O+Na₂O). This composition is equivalent to about 12 wt. % normative corundum.

We analyzed granitic segregations from three localities shown in Figure 1 and projected the results onto the plane quartz-albite-orthoclase (Fig. 7), an appropriate representation since normative quartz+albite+orthoclase exceeds 90% for all analyses. Segregations from site 36C, lying in pelitic rocks, plot remote from both the minimum-melt composition at 3 kbar and the solute in equilibrium with quartz+albite+K-feldspar at 650°C, 3 kbar. The solubility of quartz-muscovite mixtures is unknown, but the data of Burnham (1967) on solubility of quartz-albite-K-feldspar-muscovite suggest that the K/Na ratio of the solutions would be slightly higher than that of the starting materials. The solubility of muscovite near its stability limit increases sharply relative to K-feldspar+andalusite (cf., Pyfe et al. 1978). The compo-

...
The composition of segregations at site 36E, lying 90 m upgrade from the sillimanite isograd in mixed pelitic and semipelitic rocks, lies very close to the composition of an aqueous solution in equilibrium with quartz–albite–K-feldspar–muscovite mixtures at 650°C, 3 kbar (Burnham 1967, p. 50), i.e., with the compositions of the surrounding quartzofeldspathic gneiss.

The composition of a segregation at site NP76 plots, in Figure 7, on a line joining the minimum-melt composition at 3 kbar to the aqueous solute composition at 650°C, 3 kbar for quartz–albite–K-feldspar–muscovite mixtures. This composition could therefore be the result of the mixing of minimum melt with an aqueous solution derived from the surrounding rocks, both in equilibrium with the surrounding rocks.

Small-scale quartz-rich segregations with mineral assemblages compatible with metamorphic assemblages in the surrounding rocks can be ascribed to the action of a hydrous phase (Fyfe et al. 1978, Vidale 1974), whether the phase serves as a medium for bulk transport or diffusion. The composition of the segregations in the Carmanville region can be explained by this model. The composition at site 36E seems indicative of a high-temperature aqueous solution process, whereas that at 36C could be the result of such a process, but the experimental data to demonstrate that this composition is in equilibrium with surrounding albite-free pelitic rocks are lacking. If so, the range of equilibration must be relatively short, since albite-bearing strata occur within a few tens of metres. Site NP76 suggests that aqueous solutes make a contribution to the composition of the segregations even after the onset of melting, although with increasing degrees of partial melting this contribution presumably declines.

The major element geochemistry of the larger plutons is summarized in Table 2 and shown graphically in Figures 8 and 9. Normative quartz + albite + orthoclase total to more than...
TABLE 2. CHEMICAL COMPOSITION OF THE WHITE POINT, ASPEN COVE AND ISLAND POND PLUTONS

<table>
<thead>
<tr>
<th>Type</th>
<th>White Pond Pluton</th>
<th>Aspen Cove Pluton</th>
<th>Island Pond</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NP 205</td>
<td>NP 206</td>
<td>NP 208</td>
</tr>
<tr>
<td>SiO₂</td>
<td>70.27</td>
<td>73.76</td>
<td>75.42</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.47</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>15.32</td>
<td>14.80</td>
<td>15.13</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.37</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>FeO</td>
<td>1.39</td>
<td>1.09</td>
<td>0.77</td>
</tr>
<tr>
<td>MnO</td>
<td>0.04</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>CaO</td>
<td>1.96</td>
<td>0.86</td>
<td>0.80</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.14</td>
<td>4.17</td>
<td>4.88</td>
</tr>
<tr>
<td>K₂O</td>
<td>3.13</td>
<td>4.94</td>
<td>3.77</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.18</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>H₂O</td>
<td>1.16</td>
<td>0.81</td>
<td>0.85</td>
</tr>
<tr>
<td>CO</td>
<td>1.7</td>
<td>2.7</td>
<td>2.0</td>
</tr>
</tbody>
</table>

CO gives the amount of normative corundum in the analysis in weight percent. Analysis KC 9 is of a composite sample of the Island Pond pluton believed to represent an average. The rock types are 1 biotite granodiorite, 2 biotite-muscovite granite, 3 muscovite or muscovite-garnet leucogranite, pegmatite and aplite.

90% for all the analyses, so that the plane quartz-albite-orthoclase (Fig. 8) is an appropriate representation. Figure 9, a projection onto the plane Al₂O₃-(K₂O+Na₂O)-(FeO+MgO+MnO) through anorthite, is a convenient method of displaying both the mafic mineralogy and the peraluminous character of the rock. The composition of the Island Pond pluton and the leucocratic parts of the Aspen Cove and White Point plutons lie very close to and trend toward the composition of NP76, that is, the highest-grade segregations in the country rocks. The White Point and Aspen Cove plutons display well-defined trends that tend toward this point or to the minimum-melt composition. In a general way, the mafic ends of the trend tend towards the composition of the Davidsville Group. This trend is particularly clear in Figure 9, where the Aspen Cove pluton tends directly towards the projection of the pelitic part of the Davidsville Group, whereas the mafic part of the White Point pluton overlaps the composition of the semipelitic part of the Davidsville Group.

The geometrical analysis of partial fusion (Presnall 1969) suggests that the Aspen Cove and White Point plutons could have arisen by advanced partial fusion of the pelitic and semipelitic parts of the Davidsville Group, respectively. In the projection of Figure 8, the initial melt would lie near the minimum-melt composition at the appropriate pressure (not necessarily the pressure of the host rocks in this instance). After exhaustion of one of the solid phases (presumably albite in this instance), the developing partial melt would migrate up the quartz-orthoclase cotectic line toward the bulk composition of the solid, eventually leaving the cotectic line and reaching the original solid composition upon total melting. An advanced partial melt derived from the Davidsville Group would therefore be expected to project near the quartz-orthoclase cotectic in Figure 8, and with differentiation compositions should travel down the cotectic line toward the minimum-melt composition. If the melt is generated at higher pressure than is appropriate for the level of emplacement, this differentiation trend will appear to migrate from the orthoclase field toward the "ternary" minimum, since the orthoclase-quartz cotectic migrates toward higher quartz content with decreasing pressure, as shown in Figure 10. The polybaric-polythermal evolutionary curve of Figure 10, derived from the data of Tuttle & Bowen (1958), is virtually identical to that ex-
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Fig. 8. Projection of analyses of granitic rocks from the Aspen Cove and White Point plutons into Q–Ab–Or. Cotectic lines for melting in the system Q–Ab–Or at 3 and 5 kbar (after Tuttle & Bowen 1958). Symbols same as Figure 7, except as noted.

The composition of the Aspen Cove pluton can be explained by assuming extensive partial melting of the Davidsville Group at pressures of about 5 kbar, followed by crystallization at pressures decreasing to 3 kbar. The composition
of the White Point pluton can be explained by extensive partial melting of semipelitic parts of the Davidsville Group at pressures of 3-4 kbar. The Island Pond pluton as a whole and the composition of leucocratic parts of the White Point and Aspen Cove plutons tend towards the compositions of the highest-grade segregations within the Davidsville Group. We will now comment on the convergence in composition between the segregations and the granitoid plutons and on the role of the segregations in the generation of anatectic melts.

According to Dimitriadis (1978), partial melts generated from pelitic rocks do not contain more than 2% normative corundum, and commonly less than 1.5%. Comparison with Tables 1 and 2 shows that virtually all the granitoid rocks in the Carmanville region have higher contents of normative corundum and up to 12% in some lower-grade material. We conclude that this composition is due to equilibration between the pelitic wall-rocks and aqueous solutions. Hence, incorporation of aqueous solutions from the country rocks will increase the normative-corundum content of a developing magma. Only magmas undersaturated in water tend to rise and be intruded (Presnall & Bateman 1973, Burnham 1967). Such magmas will tend to absorb water from their surroundings, setting up chemical potential gradients leading to inward diffusion of water. Further, since such magmas have a certain amount of “superheat”, they can assimilate material from the surroundings, including peraluminous segregations originally developed at lower grade. The increase in peraluminous character is enhanced if water later escapes from the magma, since the data of Burnham (1967) show that solutions in equilibrium with granitic magma contain normative sodium silicate. Assuming the solutions taken in resemble 36E in composition, the composition of the magma will also be displaced from minimum-melt composition toward the quartz corner in the projection of Figure 8. Again the effect is enhanced by
Fig. 10. Polybaric-polythermal composition variation of a melt in the system Q-Ab-Or. The melt is assumed to start on the Q-Or coticet at 730°C, 5 kbar (point a), a composition appropriate to advanced partial melting of pelitic compositions such as those shown in Figure 8. The melt remains at 5 kbar until the temperature falls to 710°C (point b), at which point the temperature and pressure simultaneously decrease to reach 665°C, 3 kbar (point c). This curve should be compared with the trend of the Aspen Cove pluton in Figure 8.

subsequent escape of water, since Burnham's data show that in an isothermal system solutions in equilibrium with granite at low pressures contain more albite+orthoclase relative to quartz than those at high pressures. These considerations explain why the leucocratic parts of the plutons converge towards the composition of the segregations. Both represent minimum melts in a system open to aqueous solutions; the incoming solutions equilibrated with pelitic material, and the outgoing solutions, with granitic magma. The leucocratic parts of the plutons contain roughly 3% normative corundum. We assume that the incoming solute contains 6% normative corundum, and that the solute constitutes 3% by weight (Burnham 1967, p. 50). Assuming that the initial melt contains 1.5% normative corundum (Dimitriadis 1978), then if all normative corundum in the aqueous solution remains in the melt, as suggested by the sodium-silicate-normative character of aqueous solutions in equilibrium with granitic magma, a weight of aqueous solution about 8.5 times the weight of magma would have to pass through the developing magma in order to raise its normative corundum content to 3 wt. %. At first sight this value seems preposterously high, raising questions about the significance of material exchange by aqueous solution transport. However, the data of Taylor (1977) indicate that a very large-scale exchange of water between magma and wall rocks is possible.

If the local anatexis model, which we here propose, is incorrect, then the material in the plutons must have originated at greater depth in the crust, or in the mantle. Several qualitative considerations militate against deep-seated sources. Gravity traverses (H. Miller, pers. comm. 1978) indicate no sign of a dense "root" to the plutons, and the geochemistry does not suggest the presence of a more mafic precursor. Indeed, the geochemistry suggests that a signifi-
cant part of the plutons must be of local derivation, regardless of the presence or absence of a deep-seated component. The pattern of K/Ar ages of the plutons, decreasing from west to east from Late Silurian to Carboniferous, can be explained only by ad hoc assumptions if they result from invasion of deep-seated material. This pattern receives a natural explanation if the plutons result from self-heating of a K-rich Davidsville Group (cf. Table 1) thickened in Late Ordovician time into a west-dipping slab, as suggested by regional structural considerations (Pickerill et al. 1978, Currie et al. 1980). Assuming that the overlying rocks lack heat sources, high temperatures are reached first in the deep, western part of the slab, which could lead to early intrusion of magma rising buoyantly into relatively cold country rocks (Frederickton and Rocky Bay plutons). High temperatures are reached later and last longer in shallower and more eastern parts of the slab (Aspen Cove and White Point plutons). Indeed, high temperatures persist for an extended period even after melting temperatures are reached, which possibly explains the young K/Ar ages recorded from the Deadmans Bay pluton. Preliminary computer simulation of the temperature regime (Pajari, Cherry & Currie, in prep.) suggests that the observed pattern of ages could result from self-heating beginning in the Late Ordovician.

**Summary and Conclusions**

The mineralogy of granitoid rocks in the Carmanville region varies with the character of the host rocks. Peraluminous granites appear only in peraluminous host rocks, and the character of segregations in the host rocks progressively approaches that of the plutons as the metamorphic grade rises. Structural considerations show that granite emplacement, the peak of metamorphism and formation of the segregations essentially coincided. The bulk-rock geochemistry of the plutons could have resulted from partial melting of the surrounding rocks at temperatures and pressures close to those indicated by metamorphic mineral assemblages in the surrounding rocks. The anomalously quartz- and normative-corundum-rich character of the plutons could result from large-scale circulation through the magma of aqueous solutions derived from the surrounding country rocks.

We conclude that the peraluminous plutons originated by self-heating of K-rich pelitic rocks tectonically thickened into a west-dipping slab. The three plutons observed represent, respectively, material that has remained essentially at its site of generation (White Point pluton), material that has risen and partially differentiated (Aspen Cove pluton), and strongly differentiated leucocratic material that has risen to a relatively high level (Island Pond pluton).

**References**


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