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EMPLACEMENT AND CONSTRUCTION OF DEVONIAN 'POSTTECTONIC' GRANITES, NORTHEAST NEWFOUNDLAND APPALACHIANS

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ABSTRACT

The Deadman's Bay and Newport granites, two of several, large Devonian plutons outcropping within the northeastern Gander Zone exhibit a number of features that indicate their emplacement occurred at high structural levels and after (i.e., 'posttectonic' to) regional Silurian ductile deformation and amphibolite-facies metamorphism. The plutons crosscut wall-rock deformation fabrics and metamorphic isograds; contacts are typically sharp and stoped blocks of country rock are locally common near the margins; discrete contact metamorphic aureoles are developed; there is no development of penetrative foliations within the plutons and only local, mainly magmatic flow fabrics occur. The absence of ductile thinning of adjacent wall rocks and the lack of extreme flattening fabrics within marginal facies of the plutons, indicate that emplacement was mainly passive and not forceful. Space for the plutons is envisaged as occurring due to dextral deformation of wall rocks related to brittle–semi-ductile movements along a major, northeast–southwest-trending, crustal-deep transcurrent structure, the Dover Fault. Tear faults and splays within the fault system provided an opening mechanism for smaller plutons (e.g., Newport Granite), whereas large-scale deviations in the trend of the fault could have acted as releasing bends, which, in part, created space for larger plutons (e.g., Deadman's Bay Granite). Assuming fault movement rates of between 1 and 10 cm per year, hundreds of thousands to millions of years are required to create voids the size of the plutons over this period. Consistent with this, the plutons exhibit subtly different facies with cryptic contacts indicative of construction by batch filling. As differences between magma batches were small, it is not at first obvious that the plutons are composite. Evidence for mingling and mixing includes numerous grain-scale disequilibria textures, cryptic or gradational contacts, and outcrop heterogeneity and variation across each pluton. Hence, magma was emplaced prior to complete crystallization of previously emplaced magma so that a complex of multiple dykes (sheeted architecture) did not form. Whereas the plutons may be viewed as posttectonic, with respect to Silurian ductile deformation in the region, they are syntectonic with respect to brittle Devonian shearing and faulting within the upper crust.

INTRODUCTION

Recent years have seen much discussion of the possible mechanisms by which vast granite plutons may be emplaced into the crust (e.g., Hutton, 1988; Paterson and Fowler, 1993a,b). Much has been made of the notion of mid-crustal 'syntectonic plutons' (e.g., Miller and Paterson, 1994; Tommasi *et al.*, 1994), where emplacement is often viewed as occurring in extensional voids within shear-zone systems during regional tectonic movements (e.g., Hutton, 1982; Guinberteau *et al.*, 1987). However, such arguments are often difficult to reconcile with plutons emplaced at high crustal levels (e.g., Paterson and Fowler, 1993b) as they often have extremely large volumes (100's to 1000's of cubic kilometres) and apparently postdate regional ductile deformations ('posttectonic plutons'). If space for such plutons involves regional tectonic movements, where and in what ways are these recorded? How can vast plutons be accommodated in the upper crust and how do they fill with magma? This study forms part of a multidisciplinary investigation into the generation, ascent and emplacement of Silurian through Devonian plutons in the northeast Gander Zone. In this paper, some summary conclusions of observations from a number of Devonian plutons are presented. These have traditionally been described as 'posttectonic' plutons (e.g., Colman-Sadd *et al.*, 1990; Kerr *et al.*, 1993) because they crosscut regional fabrics and metamorphic isograds and were emplaced after the main ductile (Silurian) deformation events in the region. The approach used here to understanding the controls on pluton siting and processes of construction combines detailed (thin-section to outcrop-scale) observation with regional-scale kinematic analysis. Whereas such an approach likely ignores many of the detailed processes operating, it is nevertheless valid. Future work will test the hypotheses proposed here in more detail and will likely refine many of our ideas.

Field and petrographic evidence is presented from two plutons, the Deadman's Bay Granite and Newport Granite. Kinematic and temporal analysis of contacts and regional structures shows that emplacement was largely passive and closely linked to regional-scale brittle to semi-ductile fault movements. Subtle internal heterogeneities are present at all scales within the plutons. These include different facies that have cryptic contacts, fabrics that formed in the magmatic state and small-scale disequilibria textures. These features are consistent with assembly by batch filling during tectonic opening of the pluton with partial or thorough mixing occurring between magma pulses, thus locally obscuring the plutons composite nature. Whereas the plutons are posttectonic with respect to Silurian mid-crustal ductile deformation, they are syntectonic with respect to Devonian upper-crustal brittle deformation.

GEOLOGICAL SETTING OF THE PLUTONS

The Devonian plutons (ca. 400 to 350 Ma) of the northeast Gander Zone, Newfoundland (Figure 1) are characterized by coarse-grained megacrystic granite bodies, which vary in size from ca. 100 to 1000 km² (Jayasinge and Berger, 1976; Kerr *et al.*, 1993). They intrude a sequence of metasedimentary rocks (Gander Group) and their migmatitic equivalents (Hare Bay gneisses) which record deformation, metamorphism and syntectonic plutonism under greenschist- to upper-amphibolite-facies conditions during the Late Silurian to Early Devonian (ca. 430 to 400 Ma) (Blackwood, 1978; Hanmer, 1981; O'Neill, 1991; Holdsworth, 1994; Dunning *et al., in press*). The present boundary between the Gander Zone and the adjacent Avalon Zone is marked in the northeast by the Dover Fault (Figure 1), a major crustal-deep structure, which coincides with the western extent of widespread Silurian deformation and magmatism within the Gander Zone (Younce, 1970; Blackwood and Kennedy, 1975; Marillier *et al.*, 1989; Holdsworth, 1991; Holdsworth and O'Brien, 1993). Metamorphic assemblages and kinematic indicators together with the geochronologic data and crosscutting relationships demonstrate that the Gander–Avalon zone boundary, including the Dover Fault and the wider zone of deformation within which it is located, represents a zone of long-lived, possibly episodic, dominantly transpressional deformation (cf. Holdsworth, 1994). Sinistral amphibolite-facies ductile deformation of Silurian age (Dunning *et al., in press*) is overprinted by Devonian brittle-ductile dextral greenschist-facies deformation of likely Devonian age (Hanmer, 1981; Holdsworth and O'Brien, 1993; Holdsworth, 1994).

OBSERVATIONS FROM THE DEADMAN'S BAY AND NEWPORT GRANITES

CONTACT RELATIONSHIPS

Observations presented here were made from the best-exposed contact zones around the plutons. Features are typical of pluton emplacement at high crustal levels, and include the development of discrete contact-metamorphic aureoles, stoping, and crosscutting relationships with earlier ductile deformation fabrics.

Deadman's Bay Granite

At Musgrave Harbour (Figure 1), the western margin of the Deadman's Bay Granite is mainly defined by a brittle fault; there the granite is closely jointed and has undergone low-grade alteration. Metasedimentary rocks adjacent to the contact consist of folded psammites and pelites. Locally, patches of biotite-rich, granitic melt occur and these contain centimetre-sized blocks of psammite. Large crystals of muscovite mica are common within about 30 m of the contact. These features are interpreted as the result of contact metamorphism of Gander Group metasedimentary rocks. Similar contact metamorphic effects have been reported by O'Neill (1991) within surrounding metasedimentary rocks to the south of the pluton (i.e., growth of andalusite and cordierite). On the west side of Windmill Bight (Figure 1), the eastern contact is less well defined. The boundary there is represented by a 50-m-wide zone, in which foliated Deadman's Bay Granite is interbanded with metasediments and orthogneisses belonging to the Hare Bay Gneiss. Foliations are similarly oriented within both the granite and metasediments and dip steeply eastward parallel to sheet contacts. Xenoliths of folded metasediment are locally common within the granite. The granite is interpreted to have intruded the metasediments and undergone some deformation shortly after emplacement (see below).

Newport Granite

The contact between the Newport Granite and Hare Bay Gneiss is exposed on the north side of Loo Cove (Figure 1). Within 50 m of the contact, the Newport Granite contains numerous metre-sized, angular xenoliths of foliated Cape Freels Granite (Plate 1). Numerous centimetre- to metre-wide veins of fine-grained granite intrude the neighbouring Hare Bay gneisses and Cape Freels granite at the contact. This has locally caused rotation and apparent disruption of the foliation within the gneisses. No features of country rock melting have been observed. However, the granoblastic texture of the host rocks is consistent with contact metamorphism.

INTERNAL CHARACTERISTICS

A detailed field and petrographic study of the internal features of the Deadman's Bay and the Newport granites forms part of an ongoing Ph.D. thesis by JP. Here, some of the salient features of the plutons are briefly summarized. Key localities were mapped in detail in order to illustrate the variation in, and relationships between, the rocks within the plutons.

Internal Contacts and Facies around Deadman's Point

Detailed examination of the Deadman's Bay Granite exposed along a 2-km coastal section at Deadman's Point (Figure 1) has revealed the existence of numerous, subtle internal contacts and features consistent with mixing and interaction between coexisting granite magmas (see Figure 2). Contacts are typically diffuse, lobate (although macroscopically sharp in places), and randomly orientated and separate texturally and compositionally variable granites (Figure 2A to F). The contacts invariably separate granites of differing megacryst content (Figure 2B and D) and areas of equigranular granite and microgranite from the enclosing megacrystic granite (Figure 2A, B, C, E and F). The occurrence of isolated megacrysts within areas of equigranular

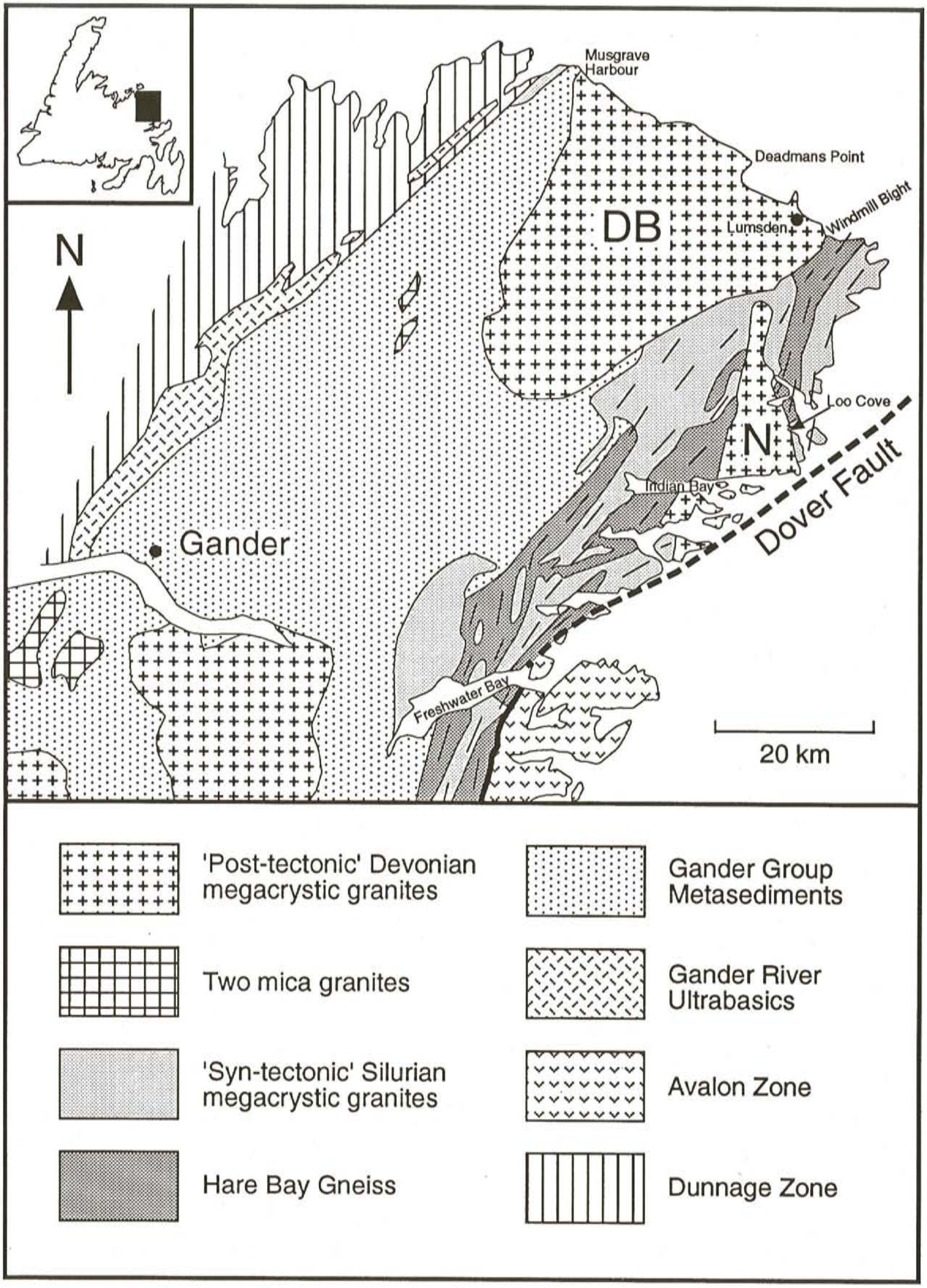


Figure 1. *Simplified geological map of the northeast Gander Zone. DB = Deadman's Bay Granite, N = Newport Granite.*

Plate 1. *Angular xenoliths of foliated Cape Freels Granite within Newport Granite, Loo Cove. Whereas brittle stoping occurs at the pluton margin, it is a local phenomenon and not the mechanism by which space was made for the granite as a whole.*

granite, especially in close proximity to their contact with surrounding megacrystic granite, is suggestive of interaction between these two facies. Macroscopically sharp contacts are gradational on a centimetre scale and are characterized by megacrysts transecting the contact and a subtle gradational decrease in the mafic rocks across it; these features are indicative of intrusion late in the crystallization process (Hibbard and Watters, 1985). Synplutonic microgranite sheets in various stages of disaggregation (Figure 2B, C and E) and equigranular granite patches are both widespread, and both contain rounded enclaves of the host, megacrystic facies (Figure 2A and F). These enclaves have boundaries that are typically gradational with the surrounding granite. Mafic enclaves are scarce, although partially disaggregated, synplutonic mafic sheets occur at a few localities (Figure 2D). Large pods of pegmatitic quartz (up to 2 m in length) occur in close association with late, synplutonic microgranite sheets (Figure 2E). Heterogeneous distribution of megacrysts is most striking, with megacryst clusters and zones composed almost entirely of K-feldspar megacrysts adjacent to or completely enclosed within non-megacrystic, equigranular granite (Figure 2B and D). Megacrysts and groundmass exhibit a number of small-scale features that have been widely reported from a variety of magma mixed rocks (e.g., Hibbard, 1991). Megacrysts commonly exhibit rapakivi texture, zoning, cellular cores and concentric biotite inclusion zones, often all within one crystal. Textural heterogeneity is widespread with megacrysts displaying a variety of morphologies occurring alongside those that do not contain any of the features mentioned above. The entire outcrop is crosscut by fine-grained, mafic and felsic sheets (Figure 2B, D and E).

Internal Contacts and Granite Facies East of Lumsden

The Deadman's Bay Granite east of Lumsden (see Table 1 and Figure 3) consists of seven granite facies, which generally form sheets striking northwest–southeast. Megacrysts and deformed enclaves within the granites are aligned broadly parallel to this trend. The dominant facies (1, 2 and 3; Figure 3) are megacrystic granites having variable enclave contents. These are intruded by facies 4, 5, 6 and 7, which are typically non-megacrystic and markedly finer grained. Facies 6 exhibits alternating sheets of megacrystic and coarse inequigranular granite, which trend broadly parallel to the main fabric in facies 3, although the contact with facies 3 is discordant (see Figure 3).

Contacts between facies 1, 2 and 3 are gradational over 10 to 100 cm and display decreases in enclave content and changes in megacrysts morphology (Plate 2). Contacts between facies 4, 5, 6 and 7 are mostly sharp although diffuse and mingled locally (see Table 1 and Plate 3). The contacts between the former and latter group of facies are also sharp overall.

Internal Contacts within the Newport Granite

The Newport Granite (Strong *et al.*, 1974), which is situated in the southeastern part of the Wesleyville area, has a north–south-elongated, 17-km-long outcrop area (170 km²), narrow in the north but widening to 12 km in the south at Indian Bay (Figure 1). The pluton mainly consists of coarse-grained, K-feldspar porphyritic biotite granite with rare enclaves (Jayasinghe, 1978; Kerr *et al.*, 1993). Examination at two well-exposed localities along the Greenspond Road and around Loo Cove reveal a number of subtle variations.

Generally, there is little overall variation across the granite, other than subtle changes in grain size and megacryst morphology. Megacrysts are mainly rectangular (rectangular:equant = 40:1) and vary in shape from euhedral to subhedral and in many cases display inclusion zones of plagioclase and quartz that parallel the sides so that in those megacrysts whose corners are rounded off, oval inclusion zones occur, whereas megacrysts having sharp, angled corners have squared zones. The variation in morphology of the megacrysts suggests some have undergone resorption whereas others have not. Megacrysts are distributed heterogeneously throughout the pluton and tend to become smaller and more rounded toward the centre of the pluton. Megacryst-rich areas occur adjacent to megacryst-poor areas. Such areas measure 10 to 100 cm in diameter and vary in shape from circular

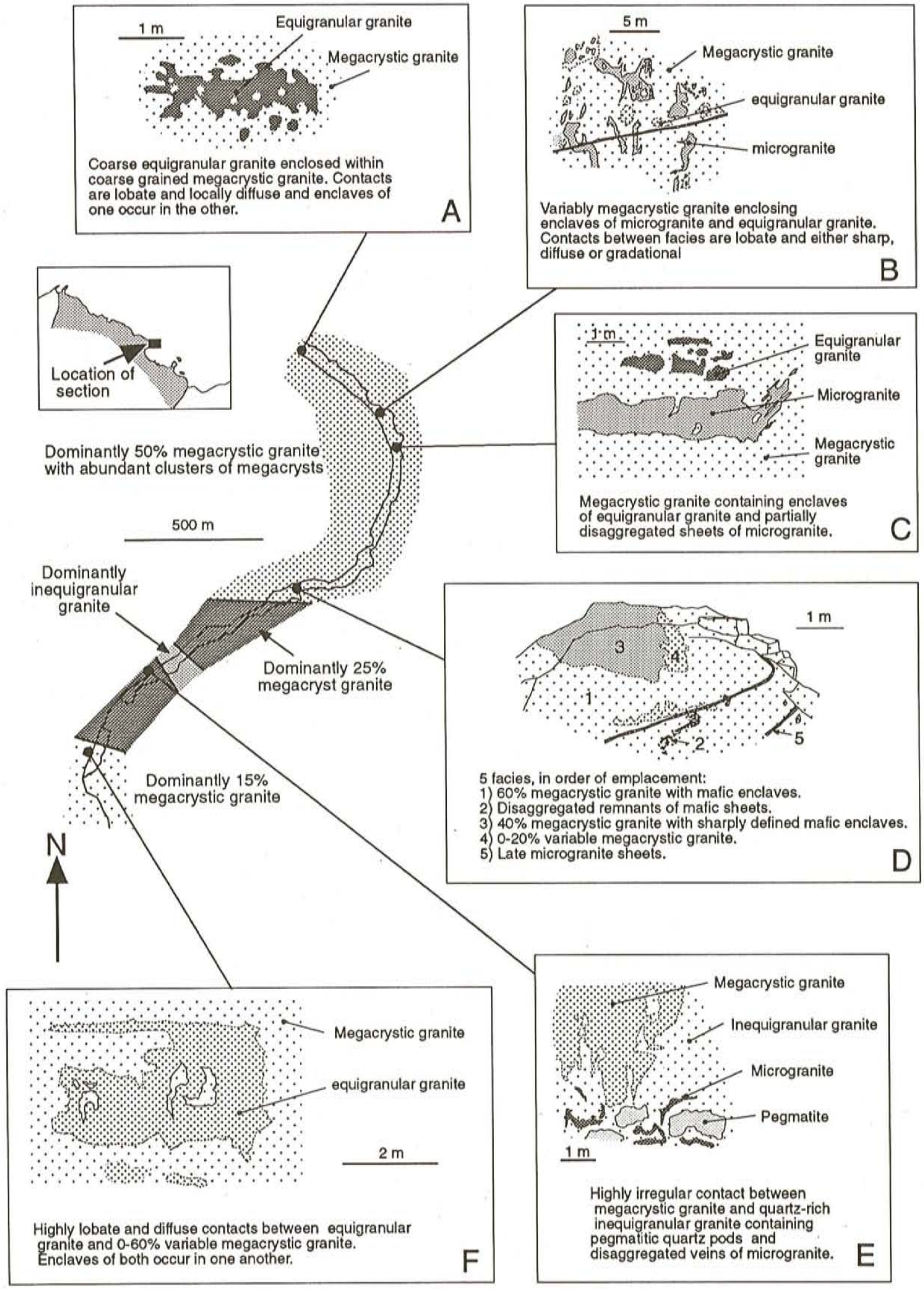


Figure 2. *Contact relationships between different facies of Deadman's Bay Granite around Deadman's Point.*

Table 1. *Characteristics of granite facies within the Deadman's Bay Granite east of Lumsden (see also Figure 3)*

FACIES	DESCRIPTION	CONTACT RELATIONSHIPS
Facies 1	Enclave rich, megacrystic granite with enclave and megacryst accumulation zones. Fabric swings into these zones. Mafic, felsic and countryrock enclaves occur.	Gradational contact with facies 2 over 10 cm. Discontinuous mafic rich zone at contact. Facies 1 is intrusive into facies 2.
Facies 2	Enclave poor, megacrystic granite. Numerous internal mafic contacts surrounding megacryst clusters and synplutonic inequigranular patches and sheets.	Decrease in mafics and increase in euhedral shape of megacrysts away from contact with facies 1.
Facies 3	Enclave rich, megacrystic granite with mafic, felsic and countryrock enclaves evenly distributed. Similar to facies 2, NW/SE magmatic fabric defined by megacrysts and elongate enclaves.	Contact with 2 is gradational over 1 m and is defined by an increase in enclave content in facies 3. Contact is parallel to foliation (NW/SE). Complex contact with facies 4, sharp overall, locally gradational where interaction between 3 and 4 has occured.
Facies 4	Variable, coarse, pink-weathered, mafic poor, equigranular granite with 3 subfacies. Grey, quartz rich, granite with minor K-feldspar, pink K-feldspar rich granite with minor quartz and a granite with quartz and K-feldspar in roughly equal proportion.	3 subfacies separated by diffuse and highly lobate contacts. Enclaves of facies megacrystic granite occur. Local abundance of biotite due to contamination. Facies 3 flows into 4 at SE corner of outcrop. Megacrysts, and mafic enclaves deformed parallel to minor contacts.
Facies 5	Dark grey, coarse equigranular granite with a high mafic content. Enclaves of 5 occur in 4. Equigranular, leucogranite rims these enclaves perhaps as a result of interaction between 4 and 5.	Contact between 4 and 5 mostly sharp except at southern eastern corner of facies 4 outcrop where mixing has caused an increase in K-feldspar content of 5. This facies appears to cross-cut the regional, NW/SE foliation in facies 3 and is in sharp contact with it. However, megacryst in facies 3 flow around the contact and are generally parallel to it suggesting that its intrusion was post-tectonic but prior to full crystallisation of facies 3.
Facies 6	Sheeted enclave poor, leucogranite with alternating sheets of inequigranular and megacrystic granite roughly 1-2 m wide. Often separated by mafic contacts. Mafic bands also exhibit complex cross-cutting boundaries (pseudo-crossbedding).	Sharp contact with 3 ie. 6 has a lower mafic content and enclaves are virtually absent. 6 cross-cuts regional foliation therefore intrusive into 3. Both sharp and gradational contacts exist between 5 and 6.
Facies 7	Coarse, pink, equigranular, garnetiferous granite. Zoned garnets upto 15 mm in diameter. Garnets decrease in size and abundance towards contacts.	Contact with 6 is sharp, defined by a mafic rich, magmatic shear zone within 6 giving a dextral sense of movement. Partially disaggregated sheet of 3 intrudes 7 for 15 m. Sharp contact with facies 1 to the east.

to elongate; contacts between these areas are lobate and diffuse. Mafic microgranitoid enclaves occur, although they are rare, having a frequency of around 1 per m^2; these measure from 3 to 10 cm in length. Regular and gradational zones exist within the pluton across which a transitional variation in mafic and megacryst content occurs. Each zone begins with a narrow mafic rich band (~ 3 cm wide), adjacent to which the granite is devoid of megacrysts (i.e., coarse equigranular). These mafic-rich bands are sharp and straight on one side, where it is adjacent to the previous zone, and display flame-like structures that interfinger with the granite on the other side. There is a gradational decrease in biotite content and a corresponding increase in megacrysts over a distance of 1 to 2 m, until a point is reached where megacrysts account for around 90 percent of the rock. These megacryst-rich veinlets measure between 8 and 50 cm across. There then follows another biotite-rich, medium to coarse, equigranular band and the pattern is repeated. Sixteen such zones were identified on a single, 25-m-wide continuously exposed quarry wall beside the Greenspond Road. In some vertical sections, these megacryst-rich veins widen upwards and disaggregate to form megacryst clusters.

In Loo Cove, megacryst-rich granite is in gradational contact with megacryst-poor granite and mafic grains are dispersed over a 50-cm-wide zone. The mafic bands vary in width from 3 to 15 cm. Enclave concentrations are common and these involve both felsic and mafic microgranitoid

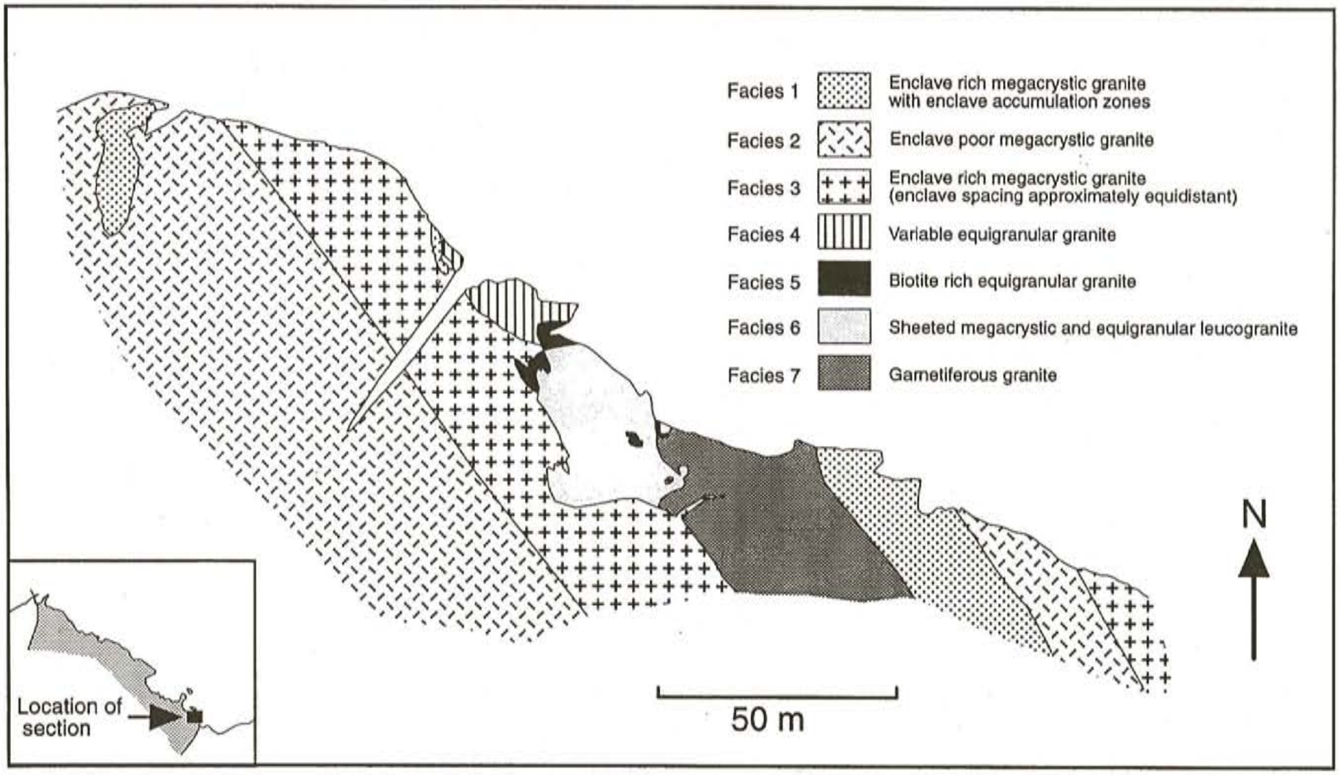


Figure 3. *Map of the coastline east of Lumsden showing different granite facies present (see also Table 1).*

enclaves with associated megacryst enrichment zones. These are separated from equigranular areas by mafic contacts. The mafic contacts range from coarse to fine grained and vary between narrow, sharp contacts and wide, diffuse varieties. Locally, megacryst and/or pegmatite veins occur parallel to mafic and felsic rich bands.

Interpretation

Previous studies of the Newport and Deadman's Bay granites have viewed them as being essentially homogenous bodies. In contrast, our observations indicate that while this is certainly true on a gross scale, in detail, subtle features show them to be heterogeneous. Differing magma compositions, grain sizes, heterogeneities in mineral phase distributions, enclaves, diffuse and sharp internal contacts and rhythmic sheets are present, all features record processes occurring within an evolving magma chamber. Contact relationships between differing granite types are typical of those commonly found between coexisting magmas, where mixing and mingling have taken place. The subtle nature of these features results from the close similarity in compositions of magmas being emplaced.

PLUTON FABRICS

Fabric Types

The most common fabric within both plutons is defined by an alignment of euhedral megacrysts (Plate 4). Fabric analysis was accomplished using acetate sheet traces of megacrysts and quartz aggregates in two orthogonal planes (Figure 4). This enables an assessment of the orientation and strength of any fabric from the 3D form of megacrysts and quartz aggregates. Megacrysts are everywhere tabular and do not impinge significantly on one another; quartz and mafic aggregates form spheroidal pools (Plate 4 and Figure 4). The megacryst fabric is S-type (planar) in the nomenclature of Hutton (1988) as there is no obvious linear alignment developed. The interstitial, coupled with the absence of either quartz recrystallization or bending and fracturing of megacrysts, demonstrates that quartz crystallized after feldspar alignment took place. Thus, the alignment cannot be the result of solid-state deformation. Instead, the megacrysts were able to rotate freely within a melt, without significantly interacting with neighbouring crystals. This implies that the fabric developed in the magmatic state (crystals + melt), rather than in the solid state, and at low, rather than high, crystal densities (see Paterson *et al.*, 1989). At high crystal densities, crystals come into contact resulting in solid-state deformation. Experimental studies on partially molten samples (e.g., Arzi, 1978; Van der Molen and Paterson, 1979) indicate that this change to solid-state deformation of a magma occurs over a rapid transition at crystal densities of above 50 to 80 percent, termed the Rheologically Critical Melt Percentage (RCMP). Thus, the fabrics described above are interpreted as forming in the magmatic state at melt contents greater than the RCMP and are termed pre-RCMP magmatic fabrics (I. Tribe and R. D'Lemos, unpublished data; cf. Paterson *et al.*, 1989). Fabrics developed post-RCMP and in the solid state are only recorded

Plate 2. *Contact between facies 1 and 2 picked out by change in enclave concentration and megacryst morpholgy and by narrow mafic-rich zone, Lumsden. The contact runs approximately from the bottom to top of the field of view. Several such contacts, often only identified by narrow mafic zones, occur along a wide tract of 100-percent exposed rock platform at Lumsden and can be traced continuously for distances of up to several hundreds of metres.*

Plate 3. *"Pseudo-cross bedding" features picked out by concentrations in amphibole and biotite, marking contacts between small magma batches, Lumsden. These features likely result from the mechanical movement of magmas against one another during emplacement and magmatic flow.*

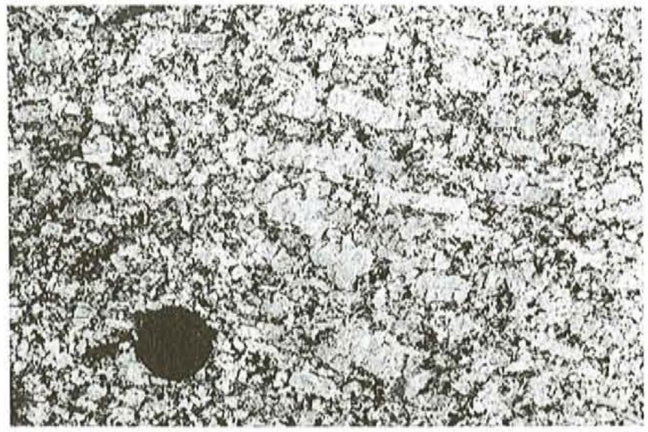


Plate 4. *Pre-RCMP (Rheologically Critical Melt Percentage) magmatic state fabric from Deadman's Bay Granite. The megacrysts were aligned prior to crystallization of interstitial quartz (see text for discussion).*

very locally, and mainly in a narrow zone at the margins of the Deadman's Bay Granite (e.g., at Windmill Bight and Musgrave Harbour; Figure 5). The pre-RCMP magmatic state fabric intensifies into a fabric characterized by solid-state mineral deformation, such as flattening and elongation of mica and quartz–feldspar aggregates and rounding and marginal recrystallization of megacrysts (Plate 5). Feldspar recrystallization indicates temperatures of solid-state deformation in excess of 500°C (e.g., Simpson, 1985; Gapais, 1989). As the pluton was emplaced after regional high-temperature deformation into relatively cool brittle crust (i.e., below 500°C), the elevated temperature of solid-state fabric development can not be due to post-emplacement deformation and metamorphism. Thus, the fabric must have formed during or shortly following emplacement, while there was sufficient magmatic heat to enable ductile solid-state flow of minerals.

Fabric Interpretation

Pre-RCMP magmatic fabrics occur throughout both plutons but are most common in the Deadman's Bay Granite. Close to the margins of the pluton, these fabrics dip steeply (inward), strike sub-parallel to the contact and in many cases are overprinted by high-temperature, solid-state fabrics (Figure 5). These margin-parallel pluton fabrics could reflect one or more of the following: 1) flow parallel to, and controlled by, the edge of the magma chamber, 2) deformation imposed on the pluton concentrated along pluton contacts, and 3) outward ballooning during emplacement of magma at the centre of the developing pluton. Evidence for either 2) and/or 3) around the Deadmans Bay pluton are supported by the development of marginal high-temperature solid-state fabrics demonstrating some syn-emplacement deformation.

Away from contacts, only magmatic fabrics occur, and there the orientation is more varied (e.g., Figure 5). At outcrop scale in both plutons, the fabrics become parallel against mafic contacts. The fabrics lack of a consistent orientation and its local swirling are most consistent with

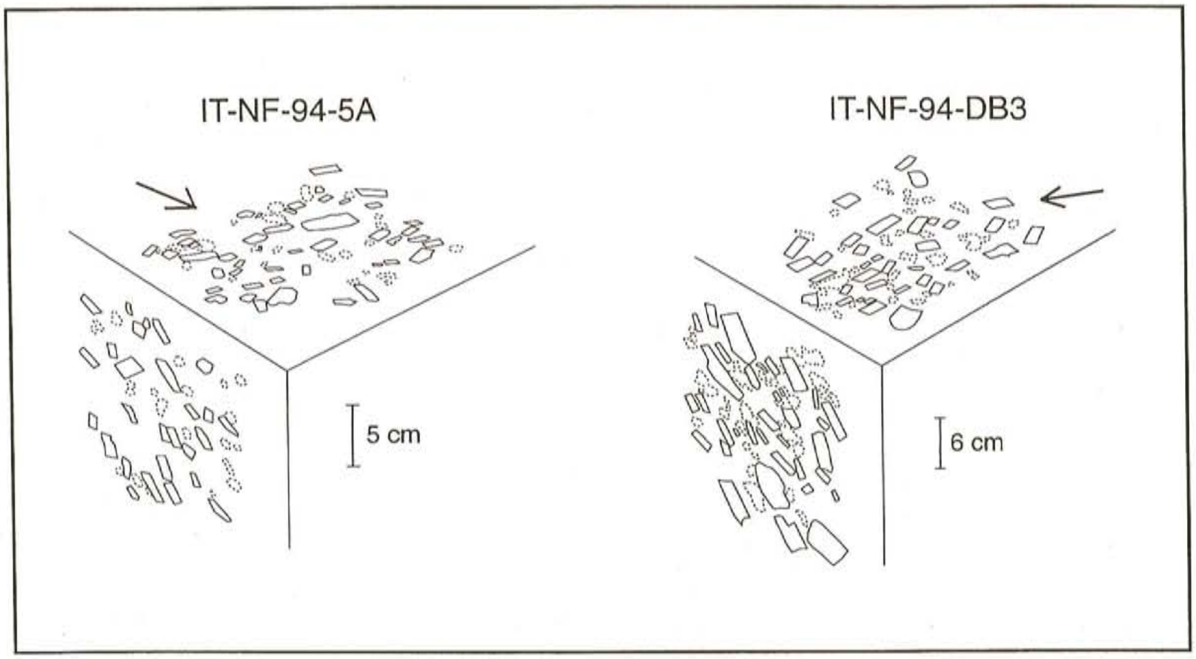


Figure 4. *Tracings of phenocrysts (solid lines) and quartz pools (dashed) from vertical and horizontal polished rock surfaces (localities of DB3 and 5A given in Figure 5; direction of N shown by arrow). Original acetate sheets onto which the phenocrysts and quartz pools had been traced in the field have been scanned into a Macintosh drawing package (Aldus Freehand), digitized and distorted so as to illustrate the fabrics in 3D. Note how quartz pools have similar equant shapes on both surfaces indicating that they are approximately spherical in 3D. Also note the strong alignment of tabular feldspar phenocrysts interpreted to be a pre-RCMP magmatic fabric.*

development by magmatic flow, with movement controlled by internal contacts, rather than by the contacts of the pluton as a whole.

MODEL FOR PLUTON EMPLACEMENT AND ASSEMBLY

PLUTON EMPLACEMENT

As there is no evidence for thinning of adjacent wall rocks or for the development of extensive and intense solid-state fabrics at the margin of the plutons, emplacement must have been largely passive rather than forceful. There is little evidence for stoping, thus space for emplacement of plutons must have been created by the effective displacement of surrounding host rocks.

Newport Granite

The present outcrop geometry of the Newport Granite is roughly wedge-shaped, trending north–south (Figure 6). The regional trend of Silurian country-rock fabrics northeast of the pluton is 035 to 045°, whereas adjacent to the east side of the pluton between Valleyfield and Fox Bay, regional fabrics are apparently rotated ca. 30° anti-clockwise to between 000 to 010° (Figure 6). This is interpreted as reflecting lateral movement of eastern wall rocks toward the northeast during the progressive opening and emplacement of the pluton. This was accomplished by dextral deformation along the southern part of the pluton related to semi-brittle to brittle movements along the northeast–southwest-trending Dover Fault. The northern tip and west side of the pluton remained pinned and the eastern margin moved outwards so as a void opened in a 'scissor' fashion. The angle subtended by the margins at the northern extremity of the pluton is equivalent to the angle of rotation of eastern wall-rock fabrics (30°; Figure 6), supporting the model. The pluton is itself displaced by, and cataclased within the Dover Fault system (e.g., Frying Pan Island; Holdsworth, 1994) indicating that fault movements continued after emplacement. $^{40}Ar/^{39}Ar$ mica cooling ages of ca. 390 to 360 Ma obtained from fault-zone fabrics associated with the Dover Fault (Dallmeyer *et al.*, 1981) overlap with a U–Pb crystallization age for the Newport Granite (G. Dunning, unpublished data; Dunning *et al.*, *in press*) demonstrating broad contemporaneity of pluton emplacement and Dover Fault movement.

Deadman's Bay Granite

In contrast to the Newport Granite, a model for the emplacement of the Deadman's Bay Granite is more difficult to constrain, given the large size of the pluton and relative paucity of data. However, the following points may be pertinent. Marginal deformation fabrics related to ballooning could only account for a fraction of the space needed to emplace the pluton and hence a mainly passive mode of emplacement is required. Recent isotopic dating (G. Dunning, unpublished data; Dunning *et al.*, *in press*) shows the emplacement of the Deadman's Bay Granite is broadly coeval

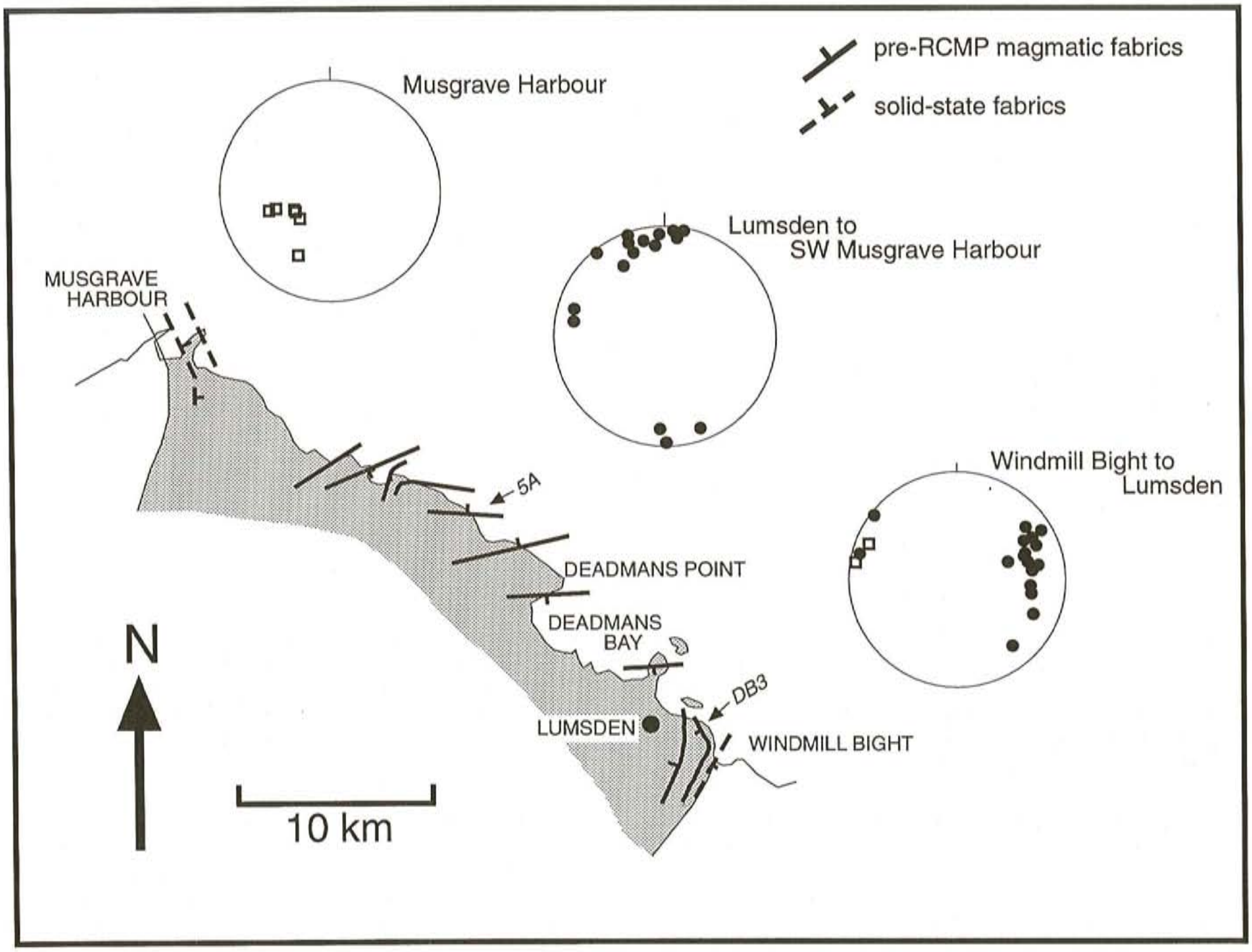
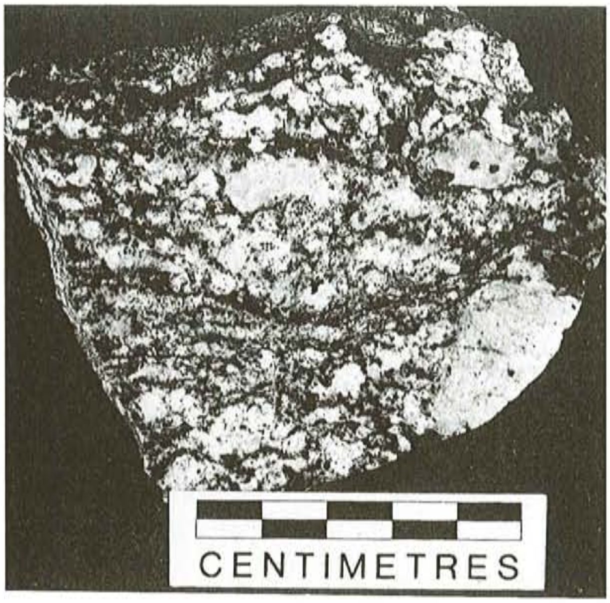


Figure 5. *Fabric orientations within the Deadman's Bay Granite. Within stereonets, closed circles = poles to pre-RCMP magmatic state fabrics; open squares = poles to solid-state fabrics. Fabrics are parallel to the margins near to contacts but have a less consistent orientation away from contacts. Locations of fabrics in Figure 4 are shown (DB3, 5A).*

with Newport Granite and from the previous discussion, is therefore likely to also be broadly contemporaneous with movement on the Dover Fault. Syntectonic pluton emplacement is consistent with local evidence of a continuum of down-temperature magmatic to high-temperature solid-state deformation. Therefore, tectonic means are also likely to account for emplacement of the Deadman's Bay Granite.

Between the northern contact of the Ackley Granite to Freshwater Bay, a distance of ca. 85 km, the regional trend of the Dover Fault is ca. 025°; north of Freshwater Bay the overall trend is deflected to ca. 060° (Holdsworth and O'Brien, 1993). This might reflect significant outward movement of a crustal block on the eastern side of the Deadman's Bay Granite during opening. However, in such a model, simple outward movement is unlikely to have been the sole mechanism of space creation since closing the pluton to a pre-pluton reconstruction would result in an unfeasibly narrow width to the northernmost exposure to the Gander Zone. This model would hence require a large part of crustal material to move either upward or downward as well as outward allowing the pluton to take a laccolithic form. Alternatively, the change in orientation of the trace of the Dover Fault may reflect significant deviations in the overall geometry of a major fault system. Large-scale deviations in the trend of major Silurian shear zones bounding tectonostratigraphic zones have been recognized within adjacent parts of the Appalachian Orogen across New Brunswick, Nova Scotia, Cape Breton Island and southwest Newfoundland (see Williams, 1979; Lin *et al.*, 1994). Thus, despite having been reactivated, it is possible that the present day S-shaped trace of the Dover–Hermitage Bay Fault (Figure 7) is a continuation of this configuration and reflects its overall geometry during the Silurian. Dextral strike-slip reactivation of the Dover Fault during the Devonian (e.g., see Holdsworth and O'Brien, 1993; Holdsworth, 1994) could explain the siting of several of the plutons within the Gander Zone. In this respect, the Deadmans Bay pluton (and Ackley Granite) may have been emplaced adjacent to extensional releasing bends in the Dover Fault zone system (Figure 7).



PLUTON ASSEMBLY

Assuming rates of faulting of between 1 and 10 cm per year (e.g., Paterson and Tobisch, 1992), ca. hundreds of thousands to millions of years would be required to open voids the size of the plutons. It follows that magma must have been supplied to the plutons commensurate with their development over an equivalent period (Figure 8). Consistent with this, our observations of pluton-wide facies heterogeneity and magma-mingling and mixing demonstrate quasi-continuous addition of magma batches during wall-rock opening. Mixing

Plate 5. *Post-RCMP solid-state fabric from Deadman's Bay Granite at Windmill Bight. Note elongate, recrystallized biotite and quartz–feldspar aggregates and oval-shaped feldspar phenocrysts. The large alkali feldspar porphyroclast (partially visible) is recrystallized to fine new grains that are drawn out into the foliation. These features are consistent with high-temperature, ductile solid-state deformation.*

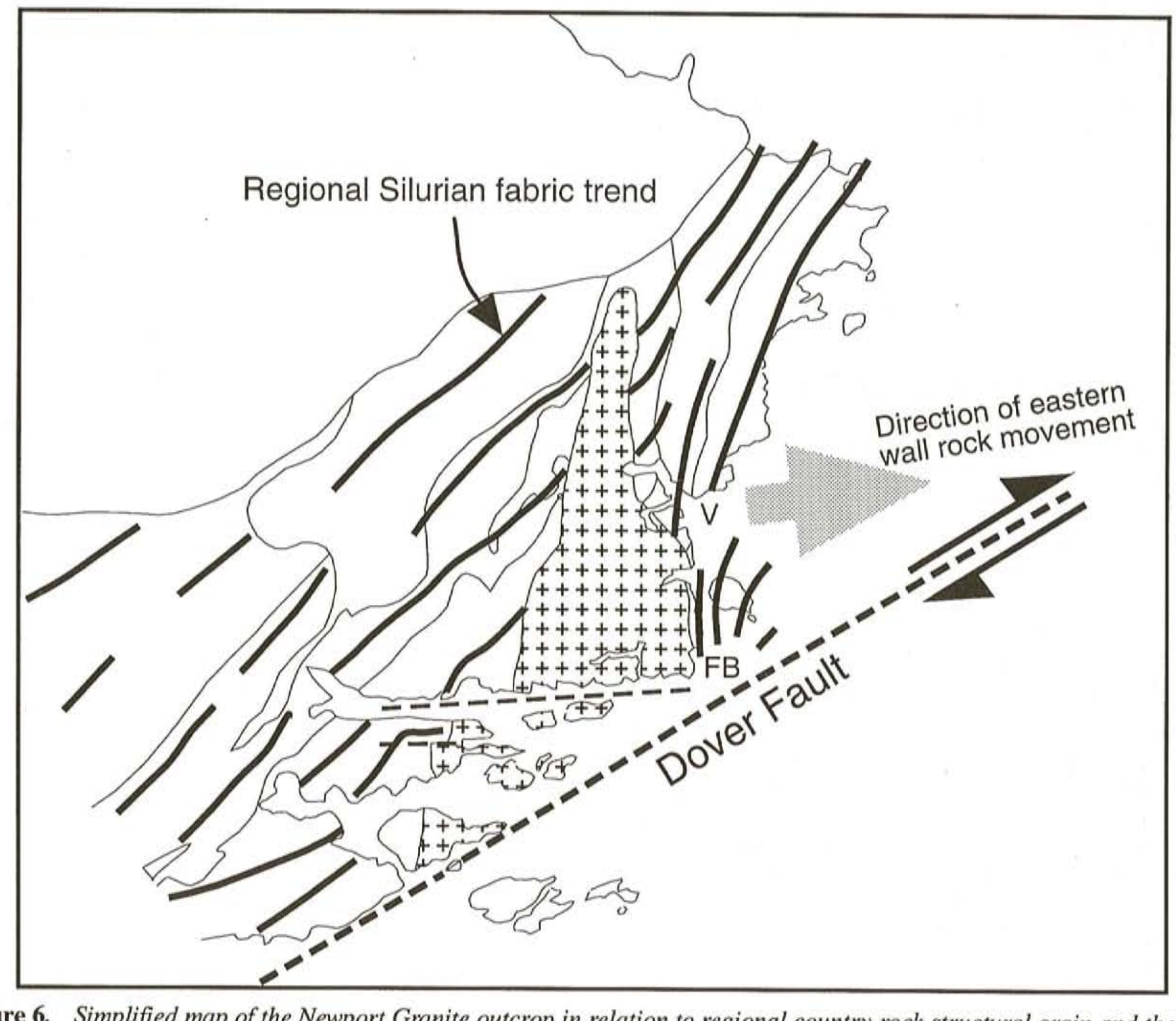


Figure 6. *Simplified map of the Newport Granite outcrop in relation to regional country-rock structural grain and the Dover Fault. FB = Fox Bay; V = Valleyfield; + = Newport Granite.*

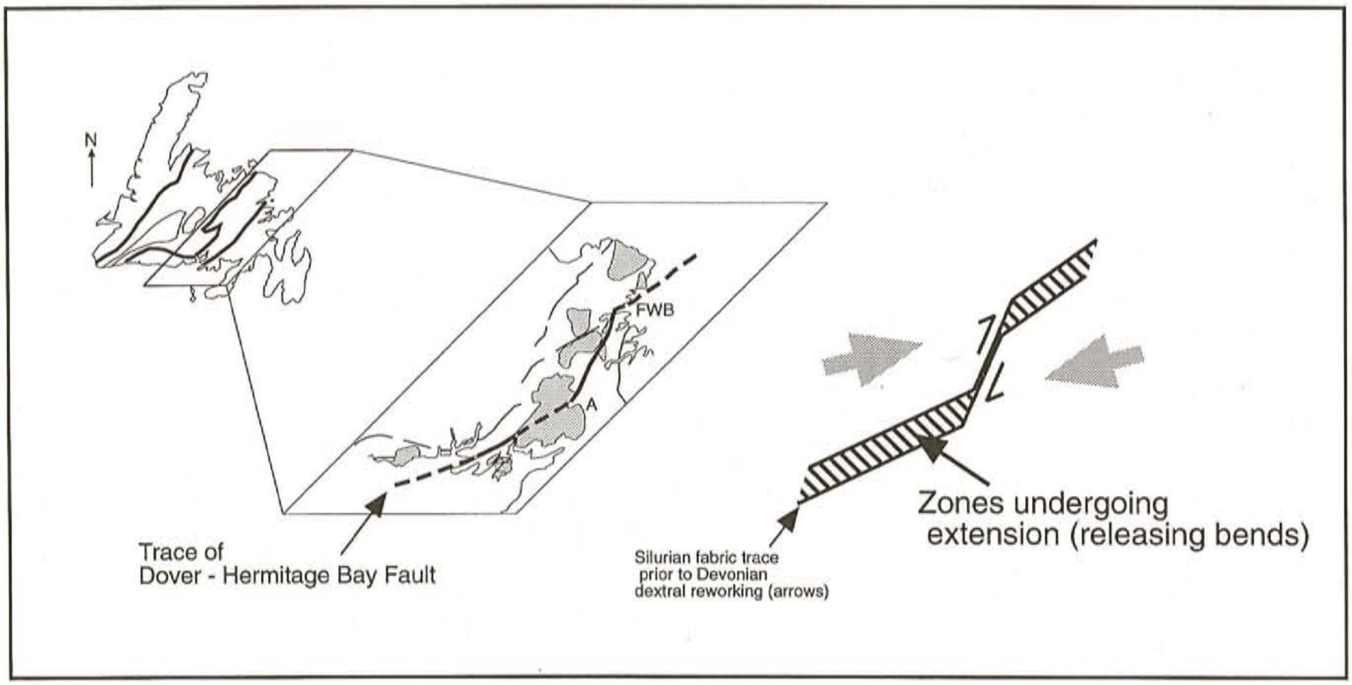


Figure 7. *Spatial relationship between Devonian granite plutons (shaded) and 'S-shaped' trace of the Dover–Hermitage Bay Fault showing regions adjacent to the fault undergoing extension during Devonian dextral reactivation. These zones broadly correspond with the position of the Ackley and Deadman's Bay granites, possibly explaining their sitting (see text for further discussion). A = Ackley Granite; FWB = Freshwater Bay.*

and mingling between batches demonstrate emplacement of individual pulses occurred prior to complete crystallization of resident magma.

DISCUSSION

Our interpretation shows that the Deadmans Bay and Newport plutons are syn-kinematic with respect to brittle to semi-ductile Devonian faulting in the upper crust. This raises questions as to whether the plutons should truly be regarded as 'posttectonic' and highlights the shortfalls of using such terminology. Although the plutons are posttectonic with respect to ductile Silurian deformation, they are syntectonic with respect to brittle Devonian deformation. The differences in style of deformation simply reflect ambient conditions, most importantly crustal level. Presumably, while brittle deformation was occurring in the upper crust during the Devonian, ductile deformation was occurring synchronously in the mid-crust and hence one might expect to find typical syntectonic granites of Devonian age, if such structural levels were exposed (cf. D'Lemos *et al.*, 1992). In essence, the syn- or posttectonic nature of plutons largely reflect their emplacement level and their relationship to orogenic exhumation histories. This will be most apparent in regions, such as the Gander Zone, where the period of emplacement of any single pluton is far shorter than the overall tectonic activity recorded in the wall rocks.

The presence of several large plutons of Devonian age is indicative of major regions of overall extension within this portion of the Appalachian Orogen. Analysis of the plutons with regards to broadly contemporaneous large-scale fault patterns may provide insights into both emplacement mechanisms of plutons and to pluton siting. In the region of the Gander–Avalon boundary, we suggest that dextral Devonian movements between the two zones strongly controlled both the siting of plutons and ultimately provided the mechanism for their ascent through the crust and final emplacement. Tear faults and splays within the fault system provided an opening mechanism for smaller plutons (e.g., Newport), whereas large-scale deviations in the trend of the fault may have acted as releasing bends, which allowed ingress of magmas to form larger, possibly laccolithic, plutons (e.g., Deadman's Bay Granite and Ackley Granite).

Consideration of rates of deformation and magma supply and crystallization indicate that plutons should be constructed by increments of magma being added to the fault jog as it progressively opens (Paterson and Fowler, 1993b). Field evidence presented here is consistent with batch filling of Devonian plutons of the Gander Zone. Paterson and Fowler (1993b) have suggested that plutons formed in this way should consist of sheeted dyke complexes (e.g., Hutton, 1982, 1992); this is not the case for the majority of plutons, which have a large elliptical geometry and lack obvious sheeting. Because resident magma had not fully crystallized prior to emplacement of later batches, brittle fracturing did not occur, and thus sheets were less likely to develop or be preserved. Subsequent mixing between magma batches, often of broadly similar compositions, has meant that evidence for

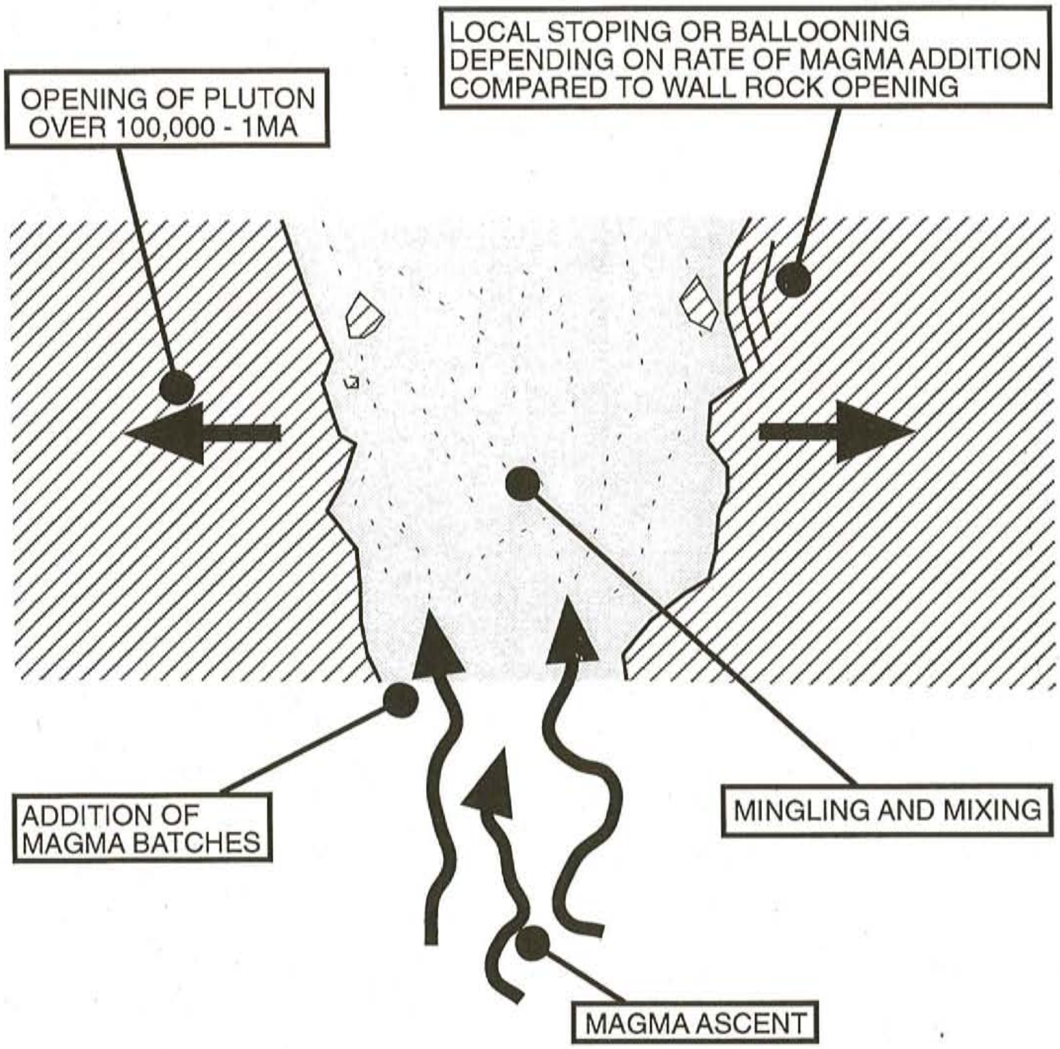


Figure 8. *Relationships between magma supply and wall-rock deformation during pluton emplacement and construction.*

construction of the plutons is cryptic. A certain extent of heterogeneity is likely to be characteristic of almost all plutons and we suggest that this is consistent with magma-mixing and mingling between several magma batches added during pluton construction. A focus of ongoing work is the development of criteria that may be used in the identification of mixing in such circumstances.

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