Current Research (1996) Newfoundland Department of Natural Resources, Geological Survey, Report 96-1, pages 329-342

EVIDENCE AND IMPLICATIONS FOR THE SYNTECTONIC EMPLACEMENT OF THE CAPE FREELS GRANITE: A SILURIAN PLUTON EMPLACED INTO THE GANDER LAKE SUBZONE, NORTHEAST NEWFOUNDLAND

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ABSTRACT

The Late Silurian to Early Devonian Cape Freels Granite of the northeastern Gander Lake Subzone, Newfoundland Appalachians, was emplaced during regional transpression and protracted polyphase deformation of the host Hare Bay Gneiss. Detailed analyses of structural relationships and petrographic features show that the Cape Freels Granite was emplaced syntectonically with respect to local D3 deformation during the retrograde cooling of host gneiss and migmatite from amphibolite- to upper-greenschist facies. D3 deformation produced early subvertical magmatic to high-temperature solid-state foliations in the granite and complex refolding of aureole rocks, overprinted by moderate-temperature protomylonite and mylonite resulting from sinistral shearing. D3 structures in both granite and host rock are locally overprinted by strongly partitioned dextral strike-slip fabrics attributed to greenschist-facies D4 deformation.

INTRODUCTION

Much of the Gander Zone of northeastern Newfoundland (Gander Lake Subzone of Williams *et al.,* 1988) comprises complexly deformed supracrustal rocks, which formed during compressional and transpressional deformation, intruded by a variety of pre-, syn-, and posttectonic granitoid rocks (e.g., Williams, 1968; Jayasinghe and Berger, 1976; Blackwood, 1977; Hanmer, 1981; O'Neill, 1991; Holdsworth *et al.*, 1993; D'Lemos *et al.*, 1995; Figure 1). The study of granite plutons in such a setting is important in unravelling orogenic events, as they can be used to bracket deformation episodes and are readily dated using U - Pb geochronology. Recent investigations have focused on the study of syntectonic plutons that have been used to closely constrain the age of specific deformation episodes, and also to evaluate pluton emplacement models, which require host-rock deformation as a means of creating space (e.g., Hutton, 1982; Guineberteau *et al.*, 1987; D'Lemos *et. al.*, 1992; Morand, 1992; Ingram and Hutton, 1994). Syntectonic plutons may also help constrain ambient country-rock thermal conditions during emplacement. Tribe and D'Lemos (1996) suggested that because plutons cool to regional ambient conditions in considerably shorter time than overall periods of deformation, syntectonic granites will commonly display a down-temperature fabric record that is biased toward the thermal conditions of the host. It is possible to deduce the approximate temperature of formation of the main fabric elements within a granite by investigation of the micro-structures present, and consequently provide a record of regional deformation at the time of emplacement (Tribe and D'Lemos, *op. cit.*).

Although syntectonic granites may provide important data, several authors have recently pointed to difficulties in determining whether a pluton is truly syntectonic— i.e., intruded into rocks that are actively deforming—or simply bracketed by two deformation events (e.g., Paterson and Tobbisch, 1988; Paterson *et al.*, 1989; Gower, 1993). Widely recognized criteria that need to be taken into consideration in recognizing syntectonic plutons are summarized as follows (after Hutton, 1988; Paterson *et al.*, 1989; Ingram and Hutton, 1994; Tribe and D'Lemos, 1996): 1) the parallelism of pluton and regional structures (L and S fabrics), 2) the concordance of pluton shapes with regional structures, 3) the presence of syntectonic porphyroblasts in the contact aureole, 4) the existence of a continuum of magmatic through to high-temperature solid-state deformation within the pluton, 5) difference in foliation strain pattern developed within pluton (grain-scale S – C fabrics) and host rock (heterogeneous foliations), 6) consistency of magmatic shear criteria with regional sense of shear, and 7) the presence of fabrics formed during the same deformation event, but at higher temperatures within the pluton and aureole, than outside of the aureole.

This paper provides initial results of a detailed field and petrographic investigation of the Cape Freels Granite (CFG), a Late Silurian to early Devonian pluton (G. Dunning, personnel communication, 1996), which is viewed to have been emplaced during active sinistrally transpressive deformation of its host rocks in the Gander Lake Subzone. Rigid criteria are here applied in a comprehensive fashion to demonstrate the syntectonic nature of the intrusion and to attempt to constrain ambient regional thermal conditions during emplacement; the latter may, in future, enable the inference of regional PTtd paths. Data are related to regional kinematic interpretations and granite pluton – host-rock relationships provided by Holdsworth *et al.* (1993), Holdsworth (1994) and D'Lemos *et al.* (1995), and ongoing geochronological research (G. Dunning, personal communication, 1996).

GEOLOGICAL BACKGROUND

The Gander Lake Subzone is juxtaposed against the Avalon Zone (Figure 1) to the southeast by a crustal-deep lineament, the surface expression of which is the Dover Fault (Marillier *et al.*, 1989; Stockmal *et al.*, 1990). The Dover Fault is a 1- to 2-km-wide zone of mainly dextral, brittle-ductile deformation (e.g., Blackwood and Kennedy, 1975; Blackwood, 1977; Holdsworth, 1991) that overprints a 20-km-wide zone of dominantly sinistral ductile deformation within the eastern margin of the Gander Lake Subzone (Holdsworth, 1991, 1994).The Gander Lake Subzone includes the low- to moderate-grade metasedimentary Gander Group, and paragneisses that comprise the Square Pond Gneiss and part of the Hare Bay Gneiss (e.g., Blackwood, 1977, 1978; Jayasinghe, 1978; Figure 1). The paragneisses are considered to be derived by high-grade metamorphism of Gander Group protoliths (Blackwood, 1978;

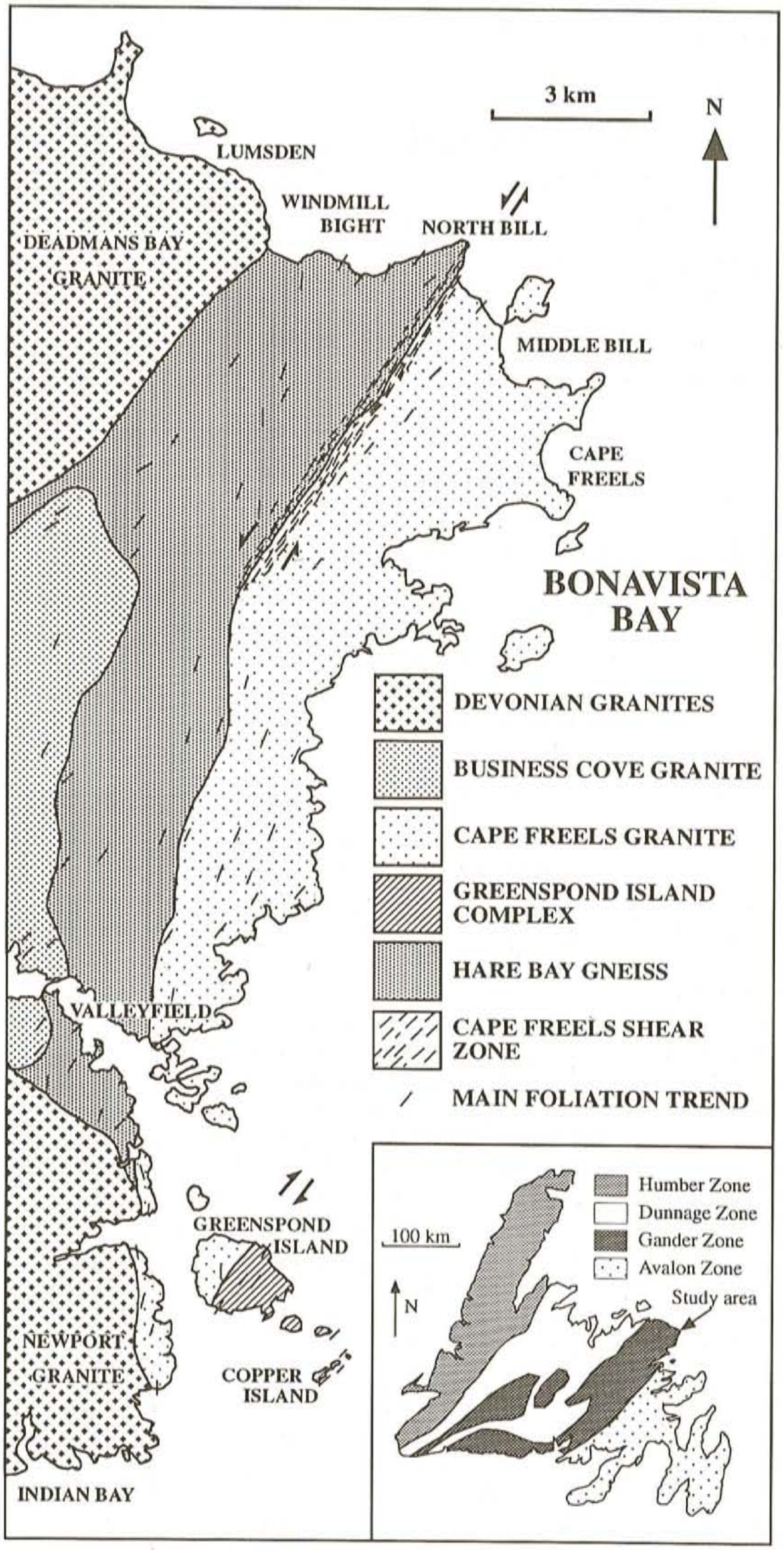

Figure 1. *Simplified geological map of the northwest coast of Bonavista Bay (after Blackwood, 1978), indicating the location of the study region with respect to simplified tectonostratigraphic framework (inset). The trace of regional deformation fabrics is shown in dashed lines.*

D'Lemos and Holdsworth, *in press*). At highest grades, this results in the formation of banded migmatites, containing small degrees of melt, and of inhomogeneous diatexites. In the latter rocks, anatexis has exceeded ca. 30 percent, and this has led to mobility (D'Lemos and Holdsworth, *in press*). The protoliths to the migmatites and paragneisses were intruded by granitoids and basic sheets, preserved as polydeformed granitic orthogneiss and amphibolite (Blackwood, 1977). The main tectonothermal event is believed to have occurred during the Silurian (Dunning *et al.* 1990; G. Dunning, personal communication, 1994), when a spectrum of megacrystic and non-megacrystic granites, which includes the Cape Freels Granite, were emplaced (Figure 1). These plutons are commonly deformed, although they do not display pervasive metamorphism. The variability of deformation, and local existence of crosscutting relations are the result of emplacement of the plutons at different stages during regional transpressive deformation (Holdsworth, 1994). All these components have been intruded by extensive "posttectonic" plutons (Devonian granites of Figure 1) that crosscut regional structures and metamorphic isograds, develop discrete contact aureoles and were emplaced at high structural levels (Jayasinghe, 1978; D'Lemos *et al.*, 1995). These are believed to be Devonian, and may have been emplaced into extensional spaces created during late movements on the Dover Fault (D'Lemos *et al.*, 1995).

Detailed fieldwork in the Gander Lake Subzone supports previous field interpretations that deformation has been strongly partitioned into sinistral and dextral shear zones (Hanmer, 1981; Holdsworth, 1994). Preliminary thermo-barometric data and recent field observations indicate that these formed at different times and under differing thermal regimes. One such high-strain zone is the Cape Freels Shear Zone (CFSZ, Holdsworth *et al.*, 1993), located within the western margin of the CFG and extending west, several kilometres into the country rocks, up to the boundary of the Deadman's Bay Granite (DBG) (Figure 1).

The CFG is a foliated alkali-feldspar granite (Dickson, 1974; Jayasinghe and Berger, 1976; Jayasinghe, 1978), in which both magmatic and solid-state fabrics are well developed. Holdsworth *et al.* (1993) considered the parallelism of these fabrics to support a syntectonic origin for the CFG. Kinematic features recorded on the western margin indicated emplacement during sinistral deformation. Contrasting kinematic features from the gabbro – diorite – granodiorite – granite complex exposed on Greenspond Island and adjacent Copper Island at the eastern margin of the CFG were taken to imply emplacement during local dextral movement. The opposing senses of shear were interpreted as possibly relating to the development of a pair of conjugate strike-slip shear zones. Our recent field studies and application of rigorous criteria support syn-emplacement sinistral movement at the western margin of the CFG. However, our ongoing studies indicate that the Greenspond Island assemblage may be unrelated to the CFG, and was juxtaposed by post-emplacement brittle-dextral movements.

GEOLOGICAL RELATIONSHIPS AT THE WESTERN MARGIN OF THE CAPE FREELS GRANITE

This paper describes the contact region of the Cape Freels Granite and Cape Freels Shear Zone where it is best exposed along the coastline between the settlements of Cape Freels and Lumsden (Figure 1). Two across-strike traverses converging on the CFG contact (Figures 2 and 3) enable description of the main units. The section has been divided into a number of zones on the basis of the dominant rock types and deformation styles present, as summarized in Figures 2 and 3. The relative ages of events (e.g., D1, D2,..) and associated fabric elements are based upon a local history; possible regional correlations are discussed briefly in a later section.

ZONE 1, EAST OF WINDMILL BIGHT

The coastline for 500 m east of the beach at Windmill Bight comprises metasedimentary rocks, granitic orthogneiss and metabasite, intersheeted on a scale of 50 cm to 5 m (Figures 2 and 3). The sheets are strongly transposed, and have a penetrative metamorphic L – S fabric, dipping steeply southeast. Relict fold hinges are preserved within low-strain zones. Metasedimentary rocks exposed at the extreme eastern end of the beach, preserve centimetre-scale psammite - semipelite lithological banding. Bands display a penetrative schistosity defined by alternating millimetre-scale quartzofeldspathic domains and foliation-forming micaceous domains. Metabasite occurs as strongly foliated continuous sheets (ca. 1-m wide), thin bands, smears (ca. 0.5- to 5-cm wide) and lenses enclosed by metasedimentary rocks or orthogneiss. Orthogneiss occurs as continuous sheets (up to ca. 5-m wide) displaying a penetrative, banded, millimetre - centimetre-scale fabric. The latter is defined by quartz - plagioclase - K-feldspar domains and associated relict alkali-feldspar megacrysts and biotite - chlorite domains. Within the intersheeted zone, amphibolite-facies fabrics and assemblages are rarely preserved, having been overprinted by mica-rich, greenschist-facies fabrics. All the above rocks are cut by deformed granite and pegmatite.

ZONE 2, WEST OF NORTH BILL

This region predominantly comprises granitic orthogneiss and minor paragneiss and metabasite. The paragneiss assemblage is principally exposed ca. 2 km east of the CFG

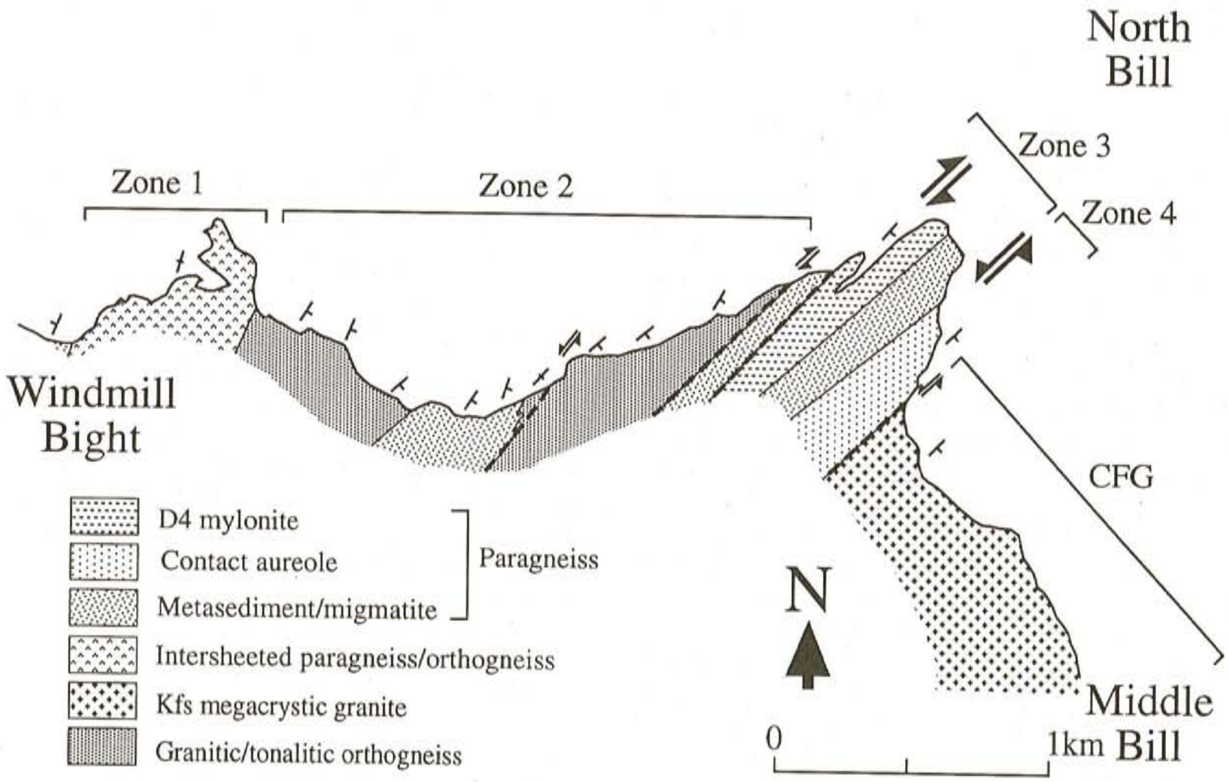

Figure 2. *Geological map of the Cape Freels Granite margin study area, indicating the locality of lithological and structural zones described in the text.*

contact (Figures 2 and 3). At this locality, a 400-m-wide screen of metasedimentary rocks and migmatite is preserved within granitic orthogneiss. The metasedimentary rocks display transposed lithological layering, similar to that in the intersheeted zone, and a penetrative amphibolite-facies schistosity composed of biotite – sillimanite (fibrolite) – muscovite domains and quartz-plagioclase domains. Coarse-grained, sillimanite-bearing schlieric migmatites occur as pods that break up the composite fabric; these are interpreted as invading anatectic melt.

The paragneisses are considered to be the oldest rocks in the region. They display S0 lithological layering with fully transposed schistosity S1; F1 structures were not observed in these rocks. The S0/S1 fabric is deformed into complex fold interference patterns (F2/F3). F3 folds are dominant and these are tight, upright structures, folded about a strongly curvilinear northeast - southwest-plunging axis, parallel to L3 mineral lineation. The F3 structures are associated with a strong, fibrolite-bearing axial-planar fabric (S3). Migmatitic portions, which occur closely associated with the schistose metasediments, contain folds of similar style to F3 but lack earlier structures, suggesting syn-D2 migmatization.

Granitic orthogneiss is typically a banded augen gneiss, ranging in composition from granite to tonalite, and characterized by partly or fully recrystallized alkali-feldspar or plagioclase megacrysts, which coalesce to form a regular L – S gneissosity. Moderate temperature (ca. >550°C) fabrics are evidenced by abundant ductile bending and marginal recrystallization of megacrysts. Lower temperature (ca. 450°C) deformation is indicated by anastomosing, non-penetrative, biotite – muscovite high-strain zones, displaying ductile bending and marginal recrystallization of micas, and associated with sinuous quartz ribbons. Contacts with adjacent paragneiss and migmatite are strongly transposed or sheared and do not preserve original igneous relations. The orthogneisses, nevertheless, contain rafts of deformed metasediment and are interpreted as being intrusive. The main fabric is folded by a single phase of upright structures (Plate 1), which are correlated with F3 structures in the folded contact and adjacent migmatites. The main orthogneiss foliation is, therefore, S2. Absence of early structures suggests post-D1 intrusion. Limbs of F3 structures are commonly attenuated defining a streaky, steeply southeast-dipping S3 fabric. This fabric intensifies to form metre-scale shear zones on the limbs of larger scale structures, and becomes the prevalent mylonitic fabric toward the CFG contact.

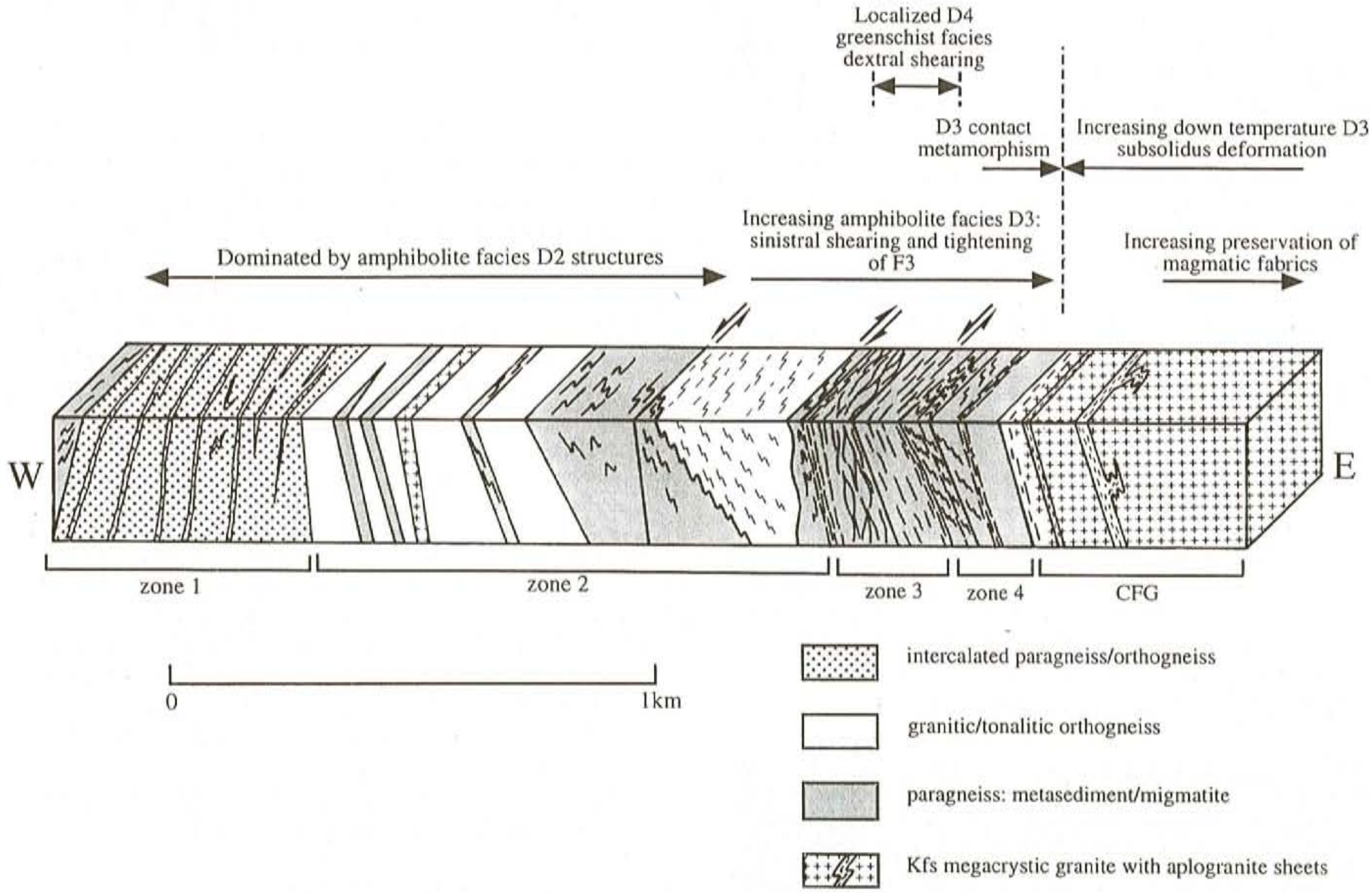

Figure 3. *Schematic cross-section of the Cape Freels margin study area, indicating the locality of lithological and structural zones described in the text.*

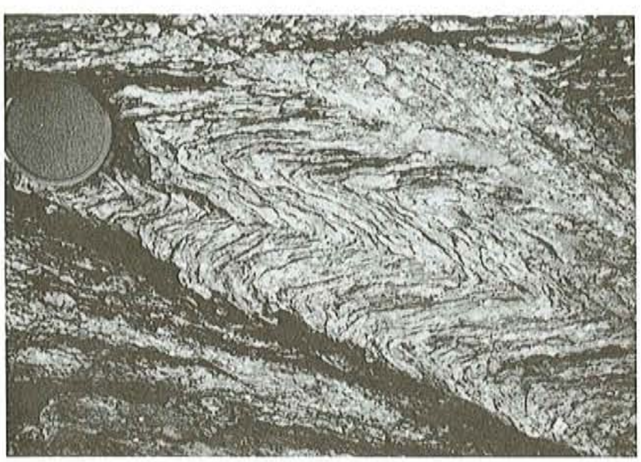

Plate 1. *Photograph showing S2 gneissosity in tonalitic – granitic orthogneiss, deformed into regular F3 structures (Zone 2).*

A 200-m-wide zone of orthogneiss (Figures 2 and 3) exhibits upright F3 structures on a scale of approximately 20 cm to 3 m. On the attenuated fold limbs, asymmetric porphyroblasts, grain-scale S – C fabrics and shear bands, and a strong subhorizontal mineral lineation, indicate both dextral and sinistral sense of movement. The grade of dextral and sinistral shearing appears similar in both cases and sense of shear on a given fold limb tends to be consistent. Complex switches in plunge and vergence of small-scale structures may indicate that this zone of anomalous shearing reflects larger scale sheath folds, propagating along a subhorizontal *X* direction.

Metabasite occurs closely associated with both orthogneiss and paragneiss. These are commonly highly retrogressed and display a penetrative schistosity defined by densely packed biotite laths. Orthogneiss and paragneiss assemblages are crosscut by sheets of sheared coarse-grained, alkali-feldspar megacrystic granite, up to ca. 15 m across. Prismatic megacrysts define a subhorizontal, northeast – southwest-trending L fabric. These are set within a matrix that displays moderate-temperature subsolidus deformation, defined by strongly ribboned quartz, and anastomosing quartz-biotite shear planes and S – C structures. The absence of intrusive amphibolite sheets, the lack of amphibolite-facies metamorphic fabrics, and the lack of widespread megacryst recrystallization, indicate that these granitic rocks postdate the highly deformed orthogneiss. The rocks bear many similarities to megacrystic CFG both in composition and deformation history, and may be coeval with it.

ZONE 3, NORTH BILL

The area between the eastern margin of the orthogneiss and the Cape Freels Granite contact is composed predominantly of migmatite, strongly overprinted by high-strain fabrics that become more prevalent with proximity to the CFG contact (Figure 3).

In low-strain zones, evidence for F1 structures is preserved as a bedding-parallel metamorphic schistosity, which is folded about flat-lying F2 isoclines. F2 fold axes and axial-planar S2 fabrics are folded into open, upright F3 structures (Plate 2). The S2 fabric is crenulated in the hinge zones of outcrop-scale F3 structures, and there is growth of S3 axial-planar fibrolite in the pelitic rocks.

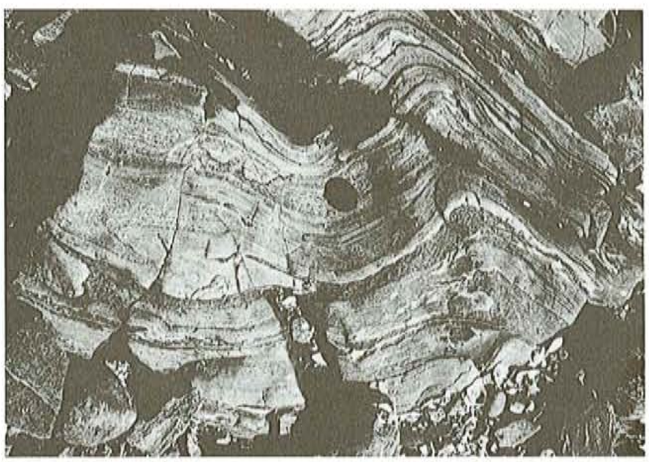

Plate 2. *Photograph showing composite S0-1 foliation in paragneiss, deformed into isoclinal F2 structures, and subsequently refolded into upright F3 structures (Zone 3).*

F3 fold axes, preserved between metre-spaced mylonite belts, are strongly curvilinear and form complex fold patterns. These are attributed to sheath geometries propagating along a subhorizontal *X* direction, associated with a steeply southeast-dipping *XY* surface, reoriented into sinistral drag structures during D3 shearing. Intensification of shearing on F3 fold limbs has produced a platy L – S fabric, which wraps around preserved fold hinges. The enveloping fabric preserves an intense northeast – southwest-trending subhorizontal mineral lineation, and sinistral S – C fabrics (Plate 3). The curvilinear nature of folds, the observed gradation into mylonite, and the similarity of the metamorphic grade with that preserved in the fold hinges, are all consistent with intensifying of D3 deformation.

Immediately to the west of this, amphibolite-facies S3 mylonites are overprinted by a ca. 275-m-wide-zone of intensely deformed, platy L – S tectonites. These platy rocks are characterized by subvertical foliations, northeast – southwest-trending subhorizontal lineations, dextral shear bands and the presence of abundant muscovite; these are interpreted as greenschist-facies S4 tectonites (Figure 3). Platy S4 fabrics pass gradationally eastward into heterogeneously sheared, anastomosing bands that wrap around pre-existing amphibolite-facies S3 mylonites.

The eastern contact between orthogneiss and adjacent migmatite is tectonic and is defined by a northeast-trending zone of brittle-ductile faulting and quartz veining. However, the increase in ductile strain recorded in the orthogneiss, coupled with the tightening of F3 structures, and the sub parallelism of foliations in the migmatites adjacent to the fault zone, indicate that the contact was ductiley sheared prior to the late faulting. S – C fabrics, asymmetric porphyroblasts and a strong subhorizontal mineral lineation demonstrate dextral shearing. Rocks displaying these features pass eastward into a ca. 50-m zone of heterogeneously sheared and tectonically interleaved migmatite and granite.

ZONE 4, EAST OF NORTH BILL

This zone comprises hornfelsed paragneiss and mylonite, which define the inner metamorphic aureole of the CFG (Figures 2 and 3). Veinlets, narrow sheets, and subrounded nodules, comprising fine biotite - muscovite - chlorite cores and quartz - K-feldspar, rims occur at a distance of ca. 300 m from the CFG contact; these crosscut S0-S2 fabrics at a high angle (Plate 4). Decussate textures within the nodules indicate replacement of an earlier assemblage that may have contained cordierite (cf. Knill, 1959; Knill and Knill, 1961). The texture and mineralogy of these rock, combined with their occurrence adjacent to the CFG, indicate that they have arisen through contact (possibly hydrothermal) alteration.

This zone is characterized by highly recrystallized psammitic and semipelitic metasedimentary rocks and S3 mylonite exhibiting subhorizontal lineations and sinistral kinematic indicators. As the CFG is approached, F3 structures are tighter and associated shear fabrics are more intense. About 200 m from the contact, tight, steeply northeast-plunging F3 fold hinges are preserved in low-strain pods between metre-wide bands of mylonite. Within the mylonite, the limbs of the folds are completely transposed. These folds deform the contact-related veinlets and nodules, which become strongly flattened in the limbs, and rodded parallel to

Plate 3. *Photomicrograph (XPL) showing high-strain amphibolite-facies S3 fabric in paragneiss with sinistral kinematic indicators defined by S–C fabrics and assymetrical mica-fish (Zone 3).*

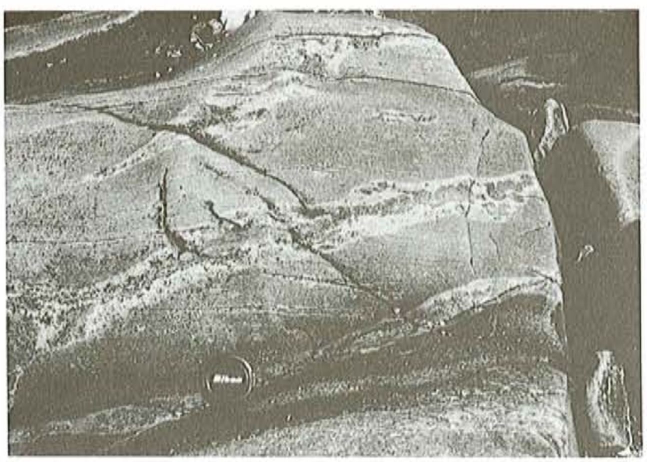

Plate 4. *Photograph showing contact-related nodules crosscutting composite S0-2 layering in paragneiss (Zone 4).*

fold hinges. These features indicate that the veinlets and nodules were formed post-D2, and pre- and/or syn-D3.

The ca.100-m-wide zone adjacent to the CFG contact is characterized by homogeneously deformed, hornfelsed psammitic and semipelitic metasedimentary rocks that exhibit chaotic fold patterns disrupted by intruded granitic veinlets and sheets, which are themselves folded by sinistrally vergent F3 structures (Figures 2 and 3; Plate 5). These rocks record the onset of partial melting and marked rheological softening. Melt pods form thin bands, predominantly defined by quartzofeldspathic domains containing rare pseudo-hexagonal intergrowths of muscovite and chlorite; the latter represent pseudomorphs of idioblastic cordierite. Intervening mesocratic domains are composed of biotite, muscovite and fibrolite, and rare (syn-D3) garnet porphyroblasts. Psammitic schollen blocks are disrupted and enveloped by invading granitic veinlets, which are interpreted as *in situ* melt portions. Melt also occupies veinlets across which there has been demonstrable attenuation of fold-limbs. As the quartzofeldspathic material does not have a solid-state fabric, this shearing is attributed to shearing in a magmatic state. The sense of displacement across these melt-filled shears is variable, but dominantly sinistral. Within 10 m of the contact, the folds and veinlets in the hornfels have been strongly attenuated in the solid state, indicating subsequent lower temperature deformation. The contact between the aureole and CFG at this locality is a minor brittle fault.

MIDDLE BILL TO NORTH BILL

The ca. 1-km-section exposed in the foreshore from Middle Bill, northwest toward the CFG contact, records intensification and steepening of fabrics within the CFG. This is accompanied by a progressive change from heterogeneous granitoid rocks containing mainly magmatic fabrics, through more homogeneous megacrystic granite containing subsolidus fabrics (Figures 2 and 3). The distinction between magmatic and subsolidus deformation is based on the ability to recognize deformation in which strain is taken up by minerals that rotate freely within the surrounding melt pre-RCMP (pre-rheologically critical melt portion; cf. Tribe and D'Lemos, 1996), as opposed to subsolidus fabrics in which deformation is accommodated through recrystallization or internal deformation. Approximate temperature conditions given below are

Plate 5. *Photograph showing sheared and deformed migmatite from the CFG contact aureole (Zone 4).*

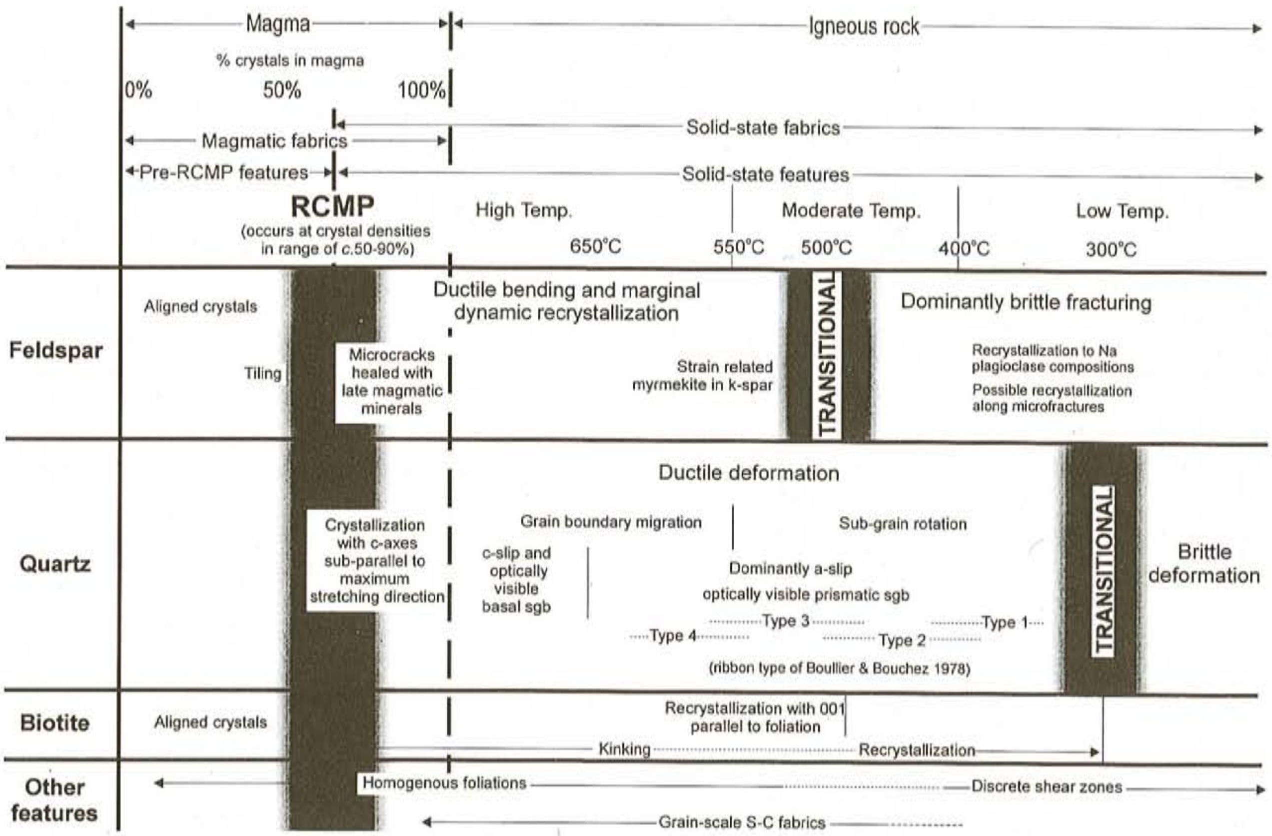

Figure 4. *Compilation of microstructural criteria for the recognition of pre-rheologically critical melt percentage (RCMP) magmatic fabrics, and high-, moderate-, and low-temperature solid-state fabrics (after Tribe and D'Lemos, 1996). Data compiled from Voll (1976); Boullier and Bouchez (1978); Brodie (1981); Brodie and Rutter (1985); Simpson (1985); Gapais and Barbarin (1986); Raase* et al. *(1986); Tullis and Yund (1987); Hutton (1988); Gapais (1989); Paterson* et al. *(1989); O'Hara (1990); Bouchez* et al. *(1992); Fitzgerald and Stunitz (1993).*

based on a synthesis of deformation styles of the constituent mineral phases (see Tribe and D'Lemos, 1996; Figure 4). The conditions are uncalibrated in detail and are dependant on strain partitioning and strain rate; however, broad values of high (ca. >550°C), moderate (ca. 550 to 400°C), and low (ca. <400°C) temperatures are applicable.

At Middle Bill, ca. 1 km east of the CFG contact, outcrop is composed of two interdigitating varieties of megacrystic granite (*sensu stricto*), intruded by several generations of aplogranites and late pegmatite. The predominant megacrystic granite, which comprises ca. 60 percent of the exposure, is distinguished by euhedral, tabular, strongly zoned megacrysts (10 to 70 mm), a strong, moderate to steep southeast-dipping S to L – S fabric, and biotite-rich oblate-shaped mafic enclaves. The second megacrystic granite is typified by densely packed prismatic megacrysts (10 to 40 mm) alligned in a strong northeasterly trending L fabric, and contains biotite-rich, prolate-shaped, mafic enclaves. Pre-RCMP fabrics are predominant in both varieties. The fabrics are typified by 1) aligned and tiled euhedral megacrysts and groundmass plagioclase showing no marginal recrystallization, 2) ovoid quartz pools, and 3) schlieric biotite domains composed of weakly-aligned laths (Plate 6). The varieties of megacrystic granite probably represent either different pulses of magma intruded into separate, predominantly flattening, and predominantly shearing deformational environments or strong partitioning of shear strain during granite emplacement. Low-strain, high- to moderate-temperature subsolidus deformation (ca. 550°C) is indicated by the presence of rare strain-related myrmekite along the long axes of some megacrysts, and ductile bending of biotite and plagioclase (Plate 6). Weak, low-temperature deformation is indicated by recrystallization of quartz to give serrated grain boundaries or core and mantle textures; this has occurred without sufficient strain to impart a ribboned texture. Such a style of deformation is consistent with the observed strain partitioning into a patchy, weakly penetrative, anastomosing fabric defined by fine-grained recrystallized biotite (Plate 6). The megacrystic granite sheets are folded together into tight northeasterly plunging structures. Three generations of crosscutting aplogranites (10 to 200 cm across)

Plate 6. *Photomicrograph (XPL) showing pre-RCMP fabric defined by aligned K-feldspar megacrysts and ovoid quartz pools, subsolidus deformation is evidenced by locally weakly recrystallized quartz and anastomosing biotite foliae.*

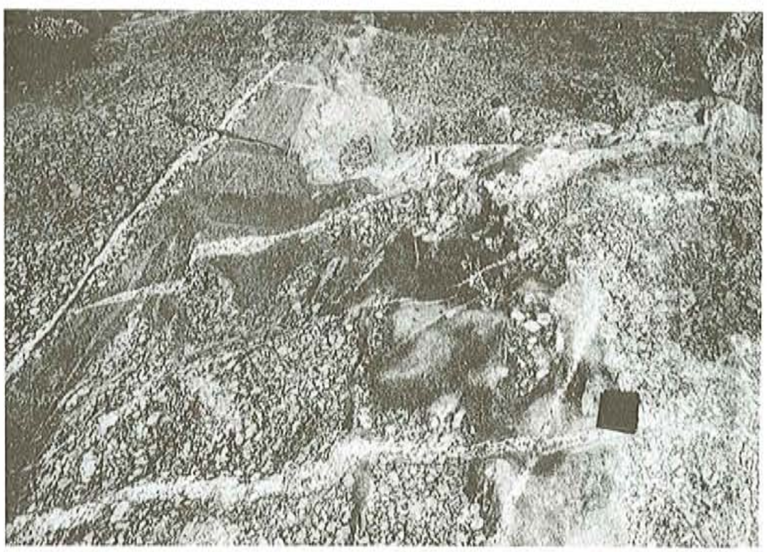

Plate 7. *Photograph showing folds developed in aplogranite sheets, with the main fabric in the megacrystic CFG, axial planar to these structures.*

occur as steeply dipping sheets, transposed subparallel to the main foliation (Plate 7), or as isolated fold hinges. These contain enclaves of foliated megacrystic granite and thus postdate formation of the pre-RCMP fabrics. This package of rocks is crosscut at a high angle by regularly spaced muscovite-bearing pegmatites; these have been locally folded around a similar axis, in which megacrysts have grown subparallel to the main fabric.

About 600 m east of the CFG contact, magmatic fabrics in the CFG are mainly overprinted by subsolidus fabrics (Plate 8). The dominant fabric is a steep, southeast-plunging L – S fabric, defined by alignment of euhedral to subhedral megacrysts, elongate quartz ribbons and anastomosing biotite domains; clear zones of prismatic or tabular megacrysts are no longer distinct. Marginal dynamic recrystallization of alkali-feldspar megacrysts is evident, suggesting high- to moderate-temperature (ca. 650 to 500°C) deformation (Plate 9). Subsequent moderate-strain low-temperature (ca. 400 °C) deformation is indicated by the formation of weakly defined type 1 quartz-ribbon structures (after Boullier and Bouchez, 1978; Plate 9). Prismatic and tabular megacrysts and quartz aggregates are aligned to define a subhorizontal southwesterly plunging mineral lineation. Strongly transposed, steeply dipping aplogranites also contain penetrative subsolidus fabrics.

About 400 m from the contact, anastomosing fine-grained biotite domains and quartz-filled dilatant brittle microcracks in alkali-feldspar megacrysts indicate increased strain and overprinting by strong, and moderate to low-temperature deformation (ca. 500°C). A subhorizontal mineral lineation and consistent alkali-feldspar asymmetries indicate sinistral strike-slip deformation at this locality.

About 200 m from the contact, increased strain in the CFG produces a protomylonite (Plate 10), composed of lensoid or asymmetrical alkali-feldspar porphyroclasts (10 to 30 mm). In many caases, recrystallized porphyroclast margins define core and mantle textures, which coalesce into discontinuous gneissose bands. Porphyroclasts have a fine-grained matrix, in which planar quartz ribbons composed of mainly annealed, strain-free grains are pinned by planar biotite domains. Plagioclase is entirely recrystallized into strained, fine-grained plagioclase – quartz ribbons. Ductiley deformed biotite grains show marginal recrystallization to fine-grained biotite – chlorite mats. Narrow zones of higher strain produce mylonites in both the CFG and interleaved aplogranite sheets. These have a northeasterly trending subhorizontal mineral lineation, defined principally by quartz aggregates. The mylonites have grain-scale sinistral S – C fabrics, asymmetrical alkali-feldspar porphyroclasts and discrete sinistral shear bands. Taken together, these features indicate that sinistral shearing probably initiated at high to moderate temperatures (ca. >500°C) and persisted through to lower temperatures (500 to 400°C).

Plate 8. *Photograph showing well-developed subsolidus foliation in the CFG, defined by marginal recrystallization of individual alkali-feldspar megacrysts, development of sinuous quartz ribbon structures, and a penetrative biotite foliation.*

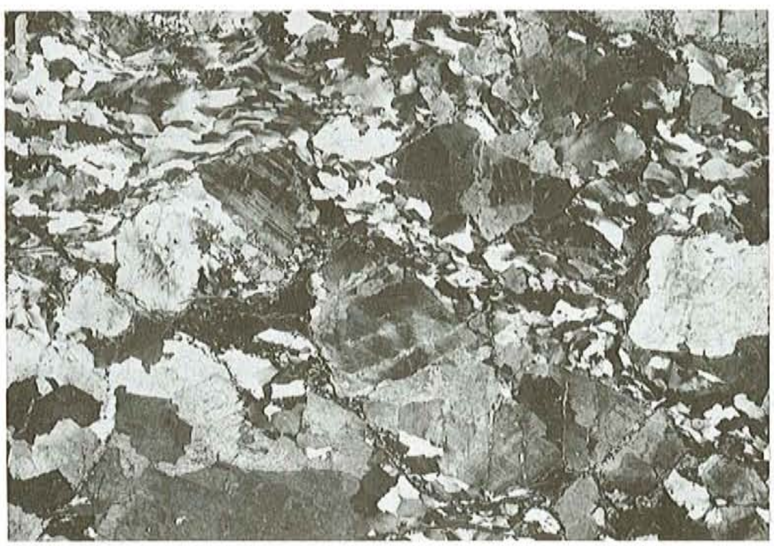

Plate 9. *Photomicrograph (XPL) showing moderate-temperature subsolidus fabric, indicated by well-developed marginal ductile recrystallization of alkali feldspar, formation of quartz ribbons and anastomosing biotite domains.*

Within the 10 m adjacent to the contact zone, high strain is indicated by rounded alkali-feldspar porphyroclasts (5 to 20 mm), which though mainly strain free, have undergone protracted marginal recrystallization, and appear to float in a dark-green, fine-grained matrix. Sinistral deformation is demonstrated by micro-shear bands and porphyroclast asymmetries. Marginal myrmekite developed on some porphyroclasts again suggests initial shearing at moderate temperatures (ca. 550°C); subsequent moderate- to low-temperature deformation (ca. <500°C) is indicated by the presence of fine-grained muscovite – chlorite – biotite domains (Plate 11). Despite high strain at this locality, zoning is still preserved in alkali-feldspar porphyroclasts; this demonstrates that deformation is generally concentrated at grain boundaries. Quartz – plagioclase - K-feldspar domains are strained, and show widespread undulose extinction, and serrated or lobate grain boundaries. Ribbons that are composed entirely of quartz, however, contain coarser, annealed grains.

Localized low-temperature (ca. 400°C) dextral overprint in megacrystic CFG is evident as narrow laterally discontinuous, east – west-trending shear bands. These are associated with more mafic phases of the CFG. Muscovite-rich dextral shear pods are also present, and have apparently been partitioned into aplogranite sheets.

IMPLICATIONS OF OBSERVATIONS

EVIDENCE FOR SYNTECTONIC EMPLACEMENT OF THE CAPE FREELS GRANITE

Internally, the CFG records magmatic fabrics that, toward the plutons, contacts are progressively overprinted by increasingly intense but similarly orientated solid-state protomylonitic fabrics. The fabrics reflect down-temperature deformation. Together, these indicate that the pluton was being actively deformed as it cooled from a magmatic state to the country-rock temperature. Contact-related nodules postdate F2 structures, are folded by F3 folds, and are overprinted by S3; they demonstrate a post-D2, pre- to syn-D3 age for intrusion. The granite fabrics are parallel to S3 and L3 in the aureole rocks, indicating that they formed under the same stress regime; all relate to local D3. S3 axial-planar fibrolite in the aureole could have resulted from heat input from the CFG, as fibrolite was not recorded greater than 3 km from the contact. D3 shearing at distances greater than 500 m from the contact was heterogeneous, and was concentrated into spaced, metre-scale, high-strain zones surrounding low-strain pods, in which F3 structures are preserved. Within a few hundred metres of the contact, the sinistral deformation became progressively

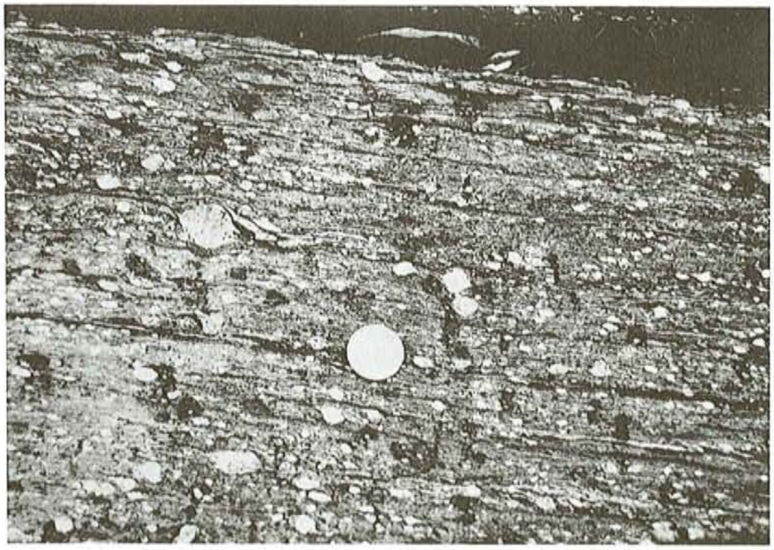

Plate 10. *Photograph showing low-temperature granite mylonite at the margin of the CFG; sinistral shearing is indicated by assymetry of individual, marginally recrystallized K-feldspar megacrysts.*

Plate 11. *Photomicrograph (PPL) of strongly deformed CFG adjacent to the contact with the country rock. Moderate- to low-temperature shearing is indicated by abundant marginal recrystallization of alkali-feldspar megacrysts to form rounded porphyroclasts linked by fine-grained quartzofeldspathic domains, and a fine-grained anastomosing biotite-chlorite foliation.*

more homogeneous, and took place at higher temperatures, forming flow folds and culminating in shearing in melt-filled zones. The higher temperatures of D3 deformation in proximity to the CFG is attributed to localized high-heat flow during contact-aureole formation, again demonstrating that emplacement was syn-D3.

COUNTRY-ROCK AMBIENT CONDITIONS

The dominant fabrics in the CFG margin record down-temperature magmatic to subsolidus fabrics. Microstructures indicate that the dominant deformation took place at about 500°C. If the pluton cooled to the ambient country-rock temperatures relatively rapidly, it would record a bias toward fabrics developed under these conditions (cf. Tribe and D'Lemos, 1996). Assuming rapid cooling, it can be concluded that the country rocks were at these temperatures during intrusion of the CFG and prior to completion of D3. This is supported by the presence, outside of the aureole, of similarly oriented D3 features that formed under upper-greenschist to low-amphibolite conditions.

CONTROLS ON STRAIN PARTITIONING AND DEFORMATION STYLE

Deformation was focused into the granite margin and aureole. Flattening deformation leading to tightening of F3 in the aureole region may have occurred partly in response to ballooning during pluton inflation. Shear component, producing a wide protomylonite zone, was probably focused into the granite margin because this represented the site of maximum anisotropy.

SUMMARY OF REGIONAL IMPLICATIONS

The observations made here suggest that the Hare Bay orthogneiss in this area postdates at least one phase of deformation. Holdsworth (1994) suggested that the Hare Bay orthogneisses around Valleyfield (Figure 1) postdate at least two phases of deformation in host paragneiss. Due to the complex deformation, a similar relationship has yet to be proven unequivocally in the Cape Freels area. However, assuming that the dominant gneissosity is the same as that developed in the lithologically similar orthogneisses at Valleyfield, the main gneissosity (local S2) is then equivalent to regional S3. The relationships infer that regional D1 and D2 predate the emplacement age of the protolith of the orthogneiss. Preliminary geochronology from this area (G. Dunning, personnel communication, 1996) is consistent with this view and confirms the pre-Silurian age of the orthogneisses.

The local D2 (regional D3) represents the peak regional metamorphic conditions in the Gander Lake Subzone. This regional tectonothermal event is related to the sinistrally transpressive Silurian docking of Avalon and Gander zones (cf. Holdsworth, 1994). Local D3 (regional D4) deformation was broadly synchronous with the intrusion of the CFG, which is now confirmed as a Late Silurian - earliest Devonian event (G. Dunning and R.D. Tucker, personnel communication, 1996). The kinematics of this deformation and that of the main metamorphic event (local D2, regional D3) were similar, although deformation was more localized in the later case. Local D3 deformation took place at low-amphibolite to upper-greenschist conditions (ca. 500°C). This suggests that the regional D3 and D4 actually represent a broad continuum of deformation during regional cooling and exhumation, rather than being separate events.

D4 (regional D5) occurred at yet lower temperatures, with a distinct assemblage and deformation style, and may broadly relate to a later period of deformation recorded in the Dover Fault zone, which shares similar dextral kinematics and formed at similar greenschist-facies conditions (Holdsworth *et al.*, 1993; Holdsworth, 1994). D'Lemos *et al.* (1995) suggested that some dextral movements were broadly synchronous with emplacement of Devonian plutons, and thus the deformation might have been synchronous with the emplacement of nearby Deadman's Bay Granite.

CONCLUSIONS

The Cape Freels Granite was emplaced syntectonically with respect to sinistral movement in country rocks. Microtextures and the mineralogy within the granite and host rocks indicate ambient upper-greenschist to low-amphibolite-facies conditions at the time of emplacement. The Cape Freels Granite was probably emplaced during the regional exhumation and cooling of the Hare Bay Gneiss in a continuation of Silurian sinistrally transpressive deformation.

ACKNOWLEDGMENTS

The authors would like to thank Oxford Brookes University for research funding and technical assistance, S.J. O'Brien and S.P. Colman-Sadd for helpful advice and logistical assistance. I.R. Tribe, R.E. Holdsworth and G.R. Dunning are also thanked for useful discussion and geochronological data. An earlier version of the manuscript was read by S.J. O'Brien.

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