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DEFORMATION OF THE CAPE FREELS GRANITE RELATED TO DEXTRAL DISPLACEMENTS ALONG THE DOVER FAULT, NORTHEAST NEWFOUNDLAND

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ABSTRACT

Intrusion of the K-feldspar megacrystic Cape Freels Granite postdates early sinistral shear associated with regional migmatization of the adjacent country rocks, the Hare Bay Gneiss.

The western margin of the pluton coincides with a persistent, north-trending belt of sinistral shear, here named the Cape Freels Sinistral Shear Zone (CFSSZ). Near its western contact, the granite is emplaced as a series of north-trending dykes that contain tectonic fabrics that are indicative of deformation in the magmatic state. These preserve evidence of syn-intrusion sinistral shear. The early magmatic fabrics are variably overprinted by sinistral, solid-state deformation, which at lower temperatures, has formed a greenschist-facies mylonite belt along the pluton's western contact.

The southeastern part of the Cape Freels Granite, in the area of Greenspond Island, is a northeast-trending dyke complex, comprising a diverse range of broadly coeval magmas that range from gabbro through to megacrystic biotite granite. All these rocks contain magmatic deformation fabrics, but the associated sense of shear is uncertain. The Greenspond dyke complex is overprinted by a steep, northeast-trending, solid-state fabric that intensifies southeastward, eventually becoming mylonitic. Mineral lineations plunge shallowly to the southwest and associated shear-sense criteria are consistently dextral. It is proposed that this zone of shearing is caused by the northeastern extension of the ductile Dover Fault, the present day Gander—Avalon Zone boundary in northeastern Newfoundland. There is some evidence that dextral, solid-state displacements overprint sinistral fabrics, but the possibility that these shearing events are coeval on a regional scale cannot be discounted. These findings emphasize that shear sense alone should not be used as a chronological marker when correlating local with regional structural histories.

INTRODUCTION

The Cape Freels Granite (Figure 1) is one of several coarse-grained, K-feldspar megacrystic biotite granites that are intruded into amphibolite-facies gneisses of the Gander Zone in northeast Newfoundland (Strong *et al.*, 1974; Jayasinghe and Berger, 1976; Jayasinghe, 1978). Most of these granites have been deformed to varying degrees in both the magmatic and solid state and many appear to have been intruded synchronously with regional deformation that is related to displacements along the Gander—Avalon Zone boundary (Hamner, 1981; Holdsworth, 1991). Here we outline new structural observations that suggest, for the first time, that part of the Cape Freels Granite is deformed in the solid state by early dextral displacements, probably along the northeastern offshore extension of the ductile Dover Fault.

THE CAPE FREELS GRANITE

The petrography of the Cape Freels Granite is described by Dickson (1974), Jayasinghe and Berger (1976) and Jayasinghe (1978). Most of the pluton is composed of granite, in which K-feldspar megacrysts, up to 8 cm long, are set in a coarse-grained matrix of quartz, oligoclase, biotite and K-feldspar. In many areas, networks of finer grained, two-mica granites, aplites and pegmatite are intruded into the granite. In many cases, these are intimately interfingered with the host, possibly indicating syn-plutonic emplacement. In the region of Greenspond Island and adjacent islands, extending northeast to Cabot Island (Figure 1), a diverse assemblage of granites, granodiorites, gabbro and country rocks are preserved (Jayasinghe and Berger, 1976). These intrusions are more variably megacrystic and appear to form a slightly earlier marginal phase, which compositionally grades westward, over several hundred metres, into the main granite.

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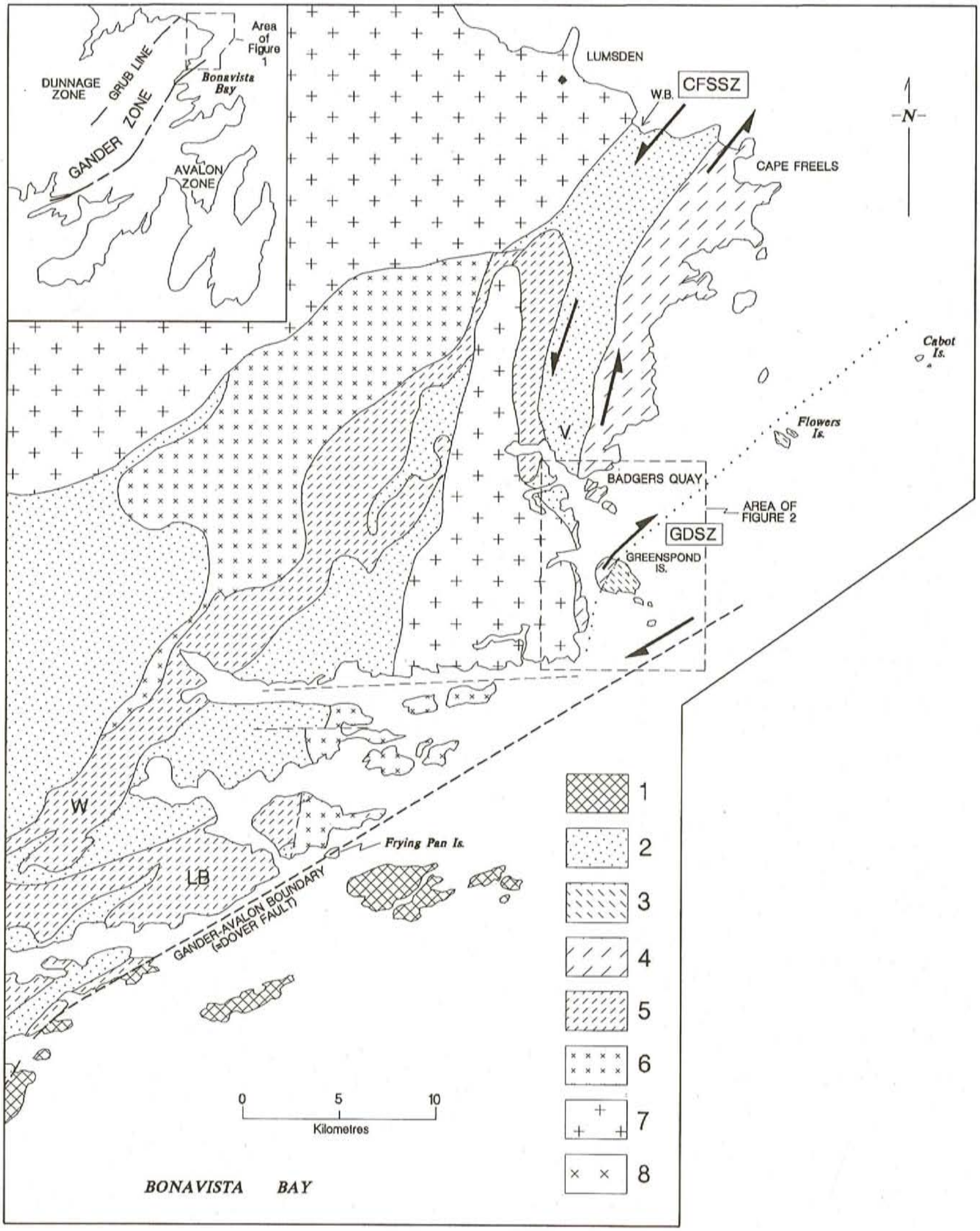
Area of Figure 1
DUNNAGE ZONE
GRUB LINE
GANDER ZONE
Bonavista Bay
AVALON ZONE
LUMSDEN
W.B.
CFSSZ
CAPE FREELS
N
Cabot Is.
Flowers Is.
V
BADGERS QUAY
AREA OF FIGURE 2
GDSZ
GREENSPOND IS.
W
LB
Frying Pan Is.
GANDER-AVALON BOUNDARY (=DOVER FAULT)
0
5
10
Kilometres
BONAVISTA BAY
1
2
3
4
5
6
7
8

RELATIONSHIPS WITH OTHER GEOLOGICAL UNITS

Intrusive Relationships

The main, megacrystic Cape Freels Granite crosscuts rocks assigned to the Hare Bay Gneiss by Jayasinghe (1978) (Figure 1). In the region immediately west of the granite, there are two distinct parts to the gneiss complex that were interfolded prior to emplacement of the Cape Freels Granite; these are amphibolite-facies psammites, pelites and amphibolites, and crosscutting bodies of deformed, early granite. On the western side of Windmill Bight (Figure 1), sheets of megacrystic granite, of identical appearance to the main Cape Freels body, are intruded into metasedimentary rocks. These sheets are deformed in the solid state with the country rocks and both are crosscut by the K-feldspar megacrystic Deadmans Bay Granite (Jayasinge, 1978) (Figure 1), which contains a weakly developed, magmatic state deformation fabric. The Cape Freels Granite is also truncated to the southwest by the posttectonic, K-feldspar megacrystic Newport Granite (Figure 2), one of the latest major igneous intrusions in this area (Jayasinghe and Berger, 1976; Jayasinghe, 1978).

Structural Relationships

The deformed nature of a large part of the Cape Freels Granite has been recognized since the pluton was first defined by Dickson (1974) who, together with Jayasinghe and Berger (1976), recognized that the western margin is marked by a spectacular zone of greenschist-facies mylonites. This zone, which is up to 200 m thick, is here termed the Cape Freels Sinistral Shear Zone (CFSSZ). Solid-state deformation related to this shear zone affects a broad region of gneisses and granite, either side of the granite contact. A sub-vertical, northeast-trending, solid-state foliation is developed in most exposures of the granite, and in the field, this is most obviously manifested by ribboning of quartz. As the strain rises toward the CFSSZ, the fabric intensifies and rotates anticlockwise into a more north–south orientation within the mylonites (e.g., Figures 1 and 2; Jayasinghe, 1978). Hamner (1981) recognized that this asymmetric pattern, together with the subhorizontal stretching lineations in the mylonites and abundant shear-sense indicators, suggested that the shear-zone displacements were sinistral and parallel to the granite contact. Increasing amounts of retrogression are associated with the increase of strain and this may indicate that the later, lower temperature stages of deformation could have become increasingly focussed along the western contact of the granite.

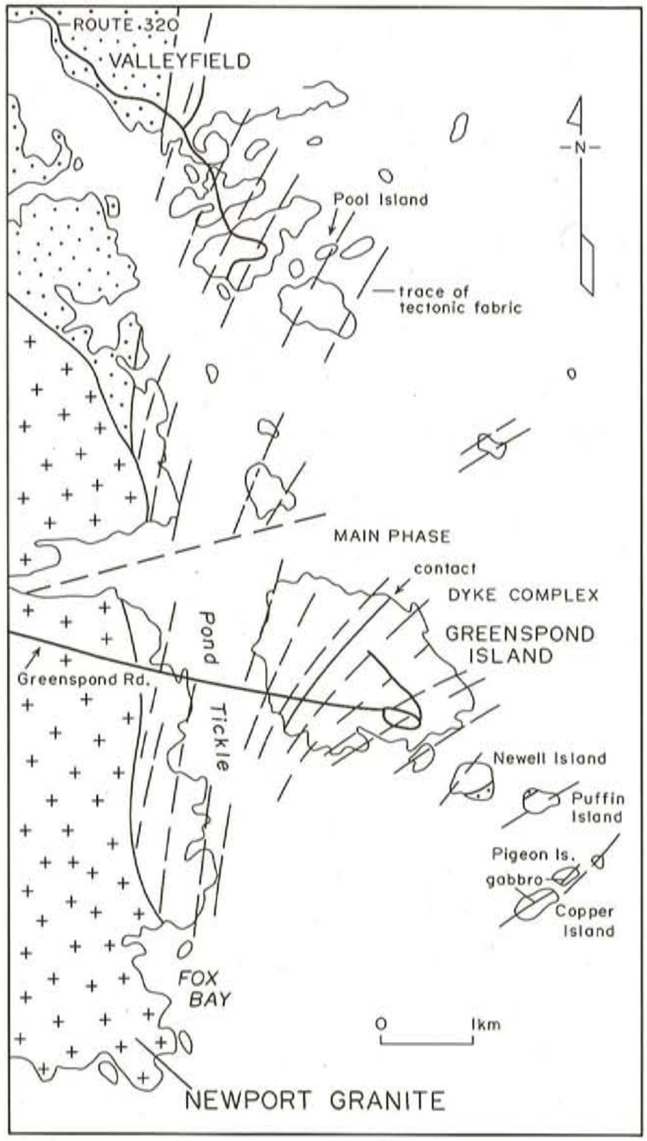

Figure 2. *Geological sketch map of the Valleyfield–Greenspond area showing the southwestern part of the Cape Freels Granite (unpatterned areas) and adjacent units (after Jayasinghe, 1978, with modification). The trace of the solid-state deformation fabric in the granite is also shown by dashed and solid lines. Symbols are the same as in Figure 1.*

The most recent study of this area (Holdsworth, 1991) suggests that sinistral shear was operative synchronous with granite intrusion. In the western parts of the pluton, the granite has the form of a north–south-oriented, sheeted-dyke

Figure 1. *Simplified geological map of the northwest coast of Bonavista Bay (after Blackwood, 1984) showing probable offshore trace of the Gander Zone–Avalon Zone boundary, the Dover Fault. Key to map units: 1 = undifferentiated Avalon Zone; 2 = Hare Bay Gneiss; 3 = Greenspond dyke complex, Cape Freels Granite; 4 = Main Cape Freels Granite; 5 = foliated megacrystic granite; LB = Lockers Bay Granite; W = Wareham Granite; 6 = muscovite–biotite granite; 7 = Deadmans Bay Granite; 8 = unseparated Newport Granite and Big Round Pond Granite. Note that a brittle fault zone in the Newport Granite on Frying Pan Island is thought to correspond approximately to the Gander Zone–Avalon Zone boundary. Solid-state shear sense along western and southeastern granite margins are shown. WB = Windmill Bight; V = Valleyfield; CFSSZ = Cape Freels sinistral shear zone; GDSZ = Greenspond dextral shear zone.*

complex, in which all of the sheets or dykes carry an earlier magmatic state deformation fabric defined by alignments of the K-feldspar megacrysts and biotite. Offsets across dykes and asymmetric boudinage of mafic enclaves (Plate 1) demonstrate consistently sinistral displacements. This suggests that the CFSSZ lies along an older zone of sinistral shear that was active during granite emplacement.

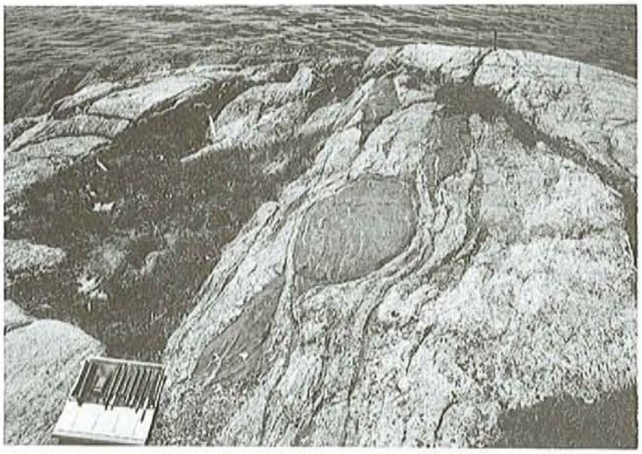

Plate 1. *Asymmetric boudinage of mafic enclaves in sheeted Cape Freels Granite suggesting sinistral shear synchronous with intrusion. Note the extreme attenuation of the enclave tails, a feature consistent with syn-magmatic age of the deformation. View looking south–southeast, Badger's Quay.*

In the coastal exposures at Valleyfield (Figure 2), the solid-state CFSSZ fabrics strongly overprint early folds and fabrics recognized in the adjacent gneisses (Hamner, 1981). These 'Early Ductile' phase structures (Holdsworth, 1991) are coincident with the major period of migmatization and related sinistral shear associated with the development of the Hare Bay Gneiss in a 20-km-wide zone of deformation and melting that formed along the eastern margin of the Gander Zone. Hence, the formation of the gneisses and the intrusion of the Cape Freels Granite are synchronous with sinistral shear prior to formation of the greenschist-facies CFSSZ mylonites. This led Holdsworth (1991) to suggest that intrusion could have occurred synchronous with the Early Ductile deformation in the country rocks. This conclusion has significant regional implications because the Early Ductile shear zone is postulated to have formed during the initial juxtaposition of the Gander and Avalon zones, probably during the Silurian (e.g., O'Brien *et al.*, 1991; Soper *et al.*, 1992). The original boundary is obscured by the later dextral displacements that formed the present Gander Zone–Avalon Zone contact, namely, the ductile Dover Fault. Thus, the age of intrusion of the Cape Freels Granite could place a lower limit on the age of sinistral docking between the Gander and Avalon zones *prior* to the formation of the Dover Fault. Our new observations confirm that the southeastern part of the granite is overprinted by solid-state deformation structures related to the Dover Fault. However, they also reveal significant uncertainties concerning the timing and kinematics of granite intrusion relative to earlier deformations, meaning that isotopic dating cannot be interpreted unambiguously at this stage.

NEW OBSERVATIONS IN THE GREENSPOND AREA

Rock Types

Greenspond Island and adjacent islands to the southeast (Figure 2) display a diverse assemblage of intrusive units from granites through to gabbros, together with large areas of country rock, notably on Newell and Puffin islands (Jayasinghe and Berger, 1976; Jayasinghe, 1978). Williams (1968) assigned the metasedimentary rock there to the Love Cove Group of the Avalon Zone, but the migmatized psammites, semipelites and pelites (together with subordinate amphibolites) are identical to Hare Bay Gneiss of the Gander Zone. A diverse assemblage of dioritic, granodioritic and granitic dykes are aligned subparallel to the steep northeast–southwest banding in the gneisses. Individual dykes range in thickness from a few centimetres to several tens of metres (Plate 2). There is widespread evidence for magma mingling, with complex dioritic enclaves being especially abundant in many granitic units. Similarly, on Copper and Pigeon islands in the extreme southeast, a large sheet of fine- to medium-grained gabbro (Plate 3), also displays intermingling textures with associated granite sheets.

Plate 2. *Northeast-trending dykes of pale granite and dark granodiorite with an overprinting solid-state foliation and later dextrally verging Z-folds. Plan view, northeast to right, Newell Island.*

Structure

The earliest structures recognized in the granites of Greenspond Island are tectonic deformation fabrics that formed in the magmatic state. They are defined by alignments of K-feldspar megacrysts and mafic minerals and lie subparallel to the northeast–southwest sheeted dykes in which they occur. A reliable sense of syn-magmatic shear could not be deduced.

All of the rocks carry a steeply dipping, generally northeast-trending, solid-state deformation fabric, which swings sharply anticlockwise into a north–south orientation across Pond Tickle, the channel that separates the island from

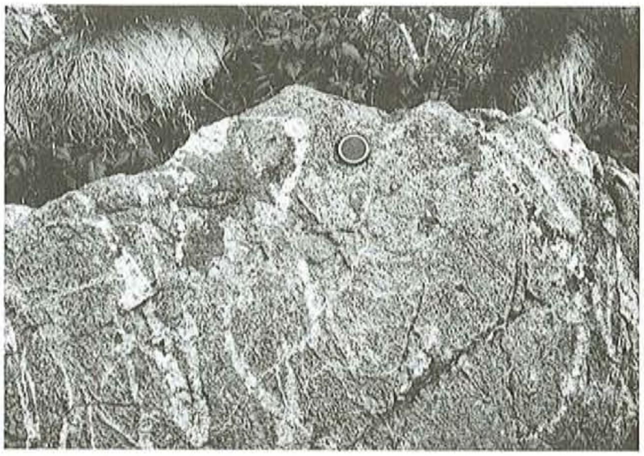

Plate 3. *Undeformed gabbro with granitic veins in a low strain pod, Copper Island.*

the mainland to the west (Figure 2). Solid-state strains are least intense in the northwest, on Greenspond Island, where growth of albite rims around sparse K- feldspars megacrysts indicates that temperatures were initially high (> 500°C; Simpson, 1985) at the onset of solid-state deformation. These fabrics are locally overprinted by lower temperature, narrow (<1.5 m) mylonite–ultramylonite zones, which trend east–northeast.

Farther southeast, the solid-state fabric intensifies and becomes increasingly mylonitic, so that in the gabbro and granite on the southeast side of Copper and Pigeon islands, most igneous textures are totally obliterated by ductile deformation (Plates 4 and 5). On Copper Island, the mylonitic foliation dips steeply to the northwest and carries a pervasive shallowly southwest- plunging mineral lineation (Figure 3). Dextral shear criteria are recognized across the entire area and these include σ-porphyroblasts, shear bands, open- to close, steeply plunging Z-folds and asymmetric fabrics typical of simple shear zones (e.g., Plates 2, 4 and 5).

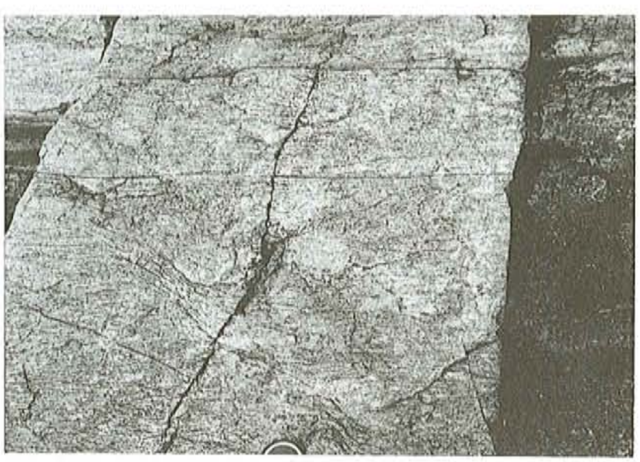

Plate 4. *Mylonitized gabbro with dextral shear bands, Copper Island. Plan view, northeast to right.*

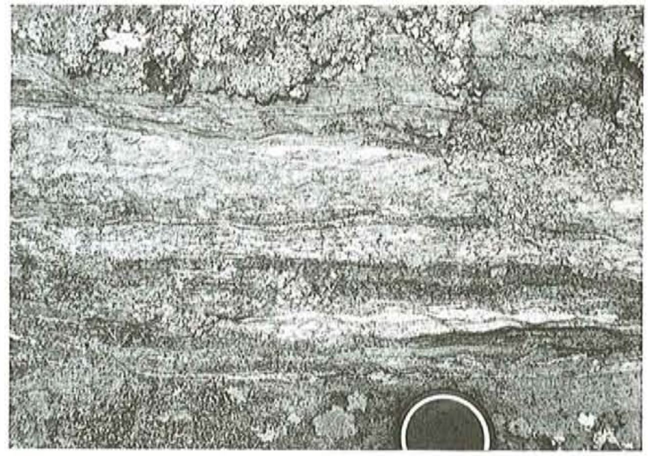

Plate 5. *Mylonitized granite with oblique dextral shear zone, Copper Island. Plan view, northeast to right.*

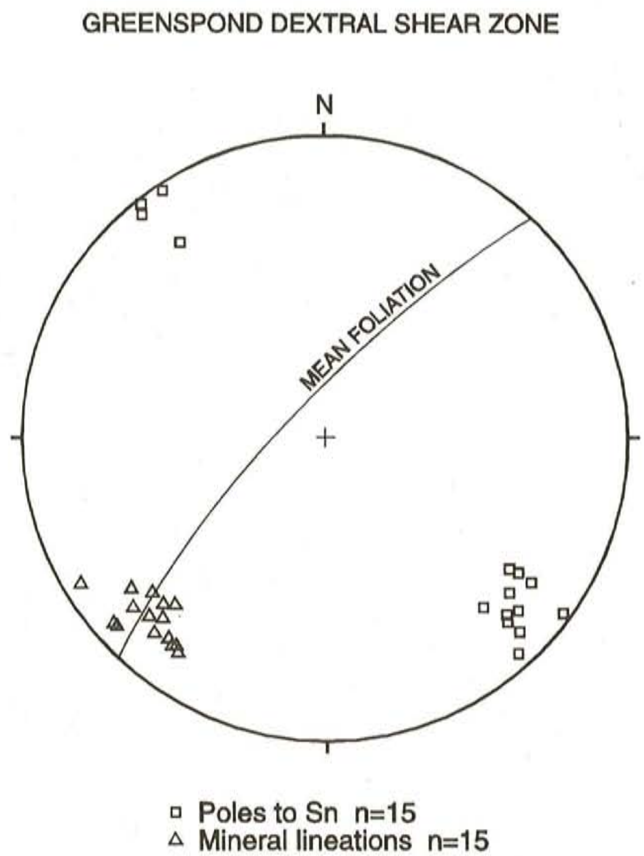

Figure 3. *Stereonet showing solid-state foliation and lineation data collected from the mylonites on Copper Island.*

The relative age of the dextral and sinistral solid-state deformations along the southeastern and western margins of the Cape Freels Granite is difficult to deduce because much of the region where the two shear zones converge is underwater (Figures 1 and 2). However, at Fox Bay (Figure 2), the main sinistral solid-state foliation in the granite trends north–south and is overprinted by two sets of narrow shear zones (Plate 6). The earlier set are steeply dipping north–

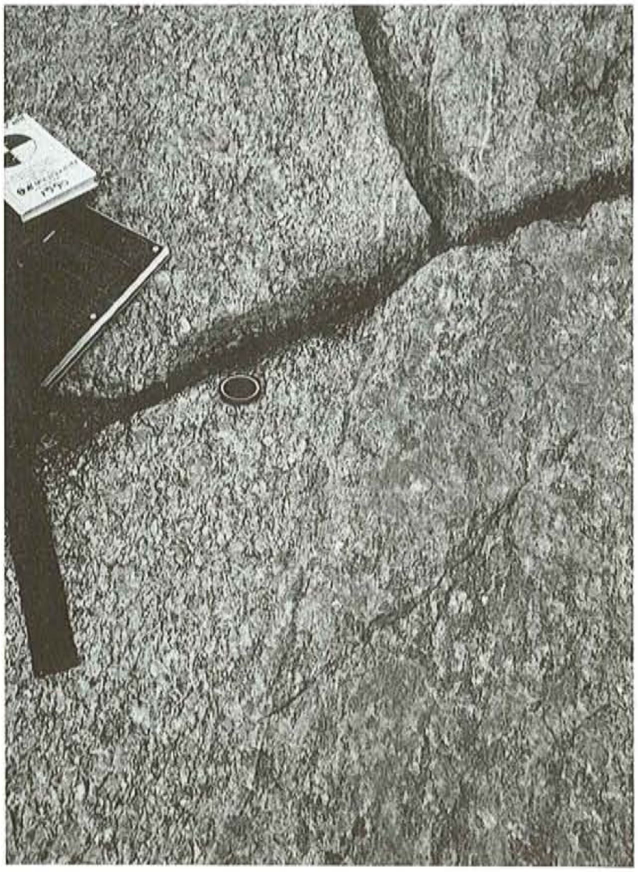

Plate 6. *Foliated Cape Freels megacrystic granite (on the left) cut across clockwise by northeast-trending mylonite zone (on the right) with dextral shear-sense indicators. Both are then offset by the northwest-dipping dextral reverse shear zone seen in the top of the picture. Oblique view looking north, Fox Bay.*

northeast-trending mylonite zones (up to 1 m wide), that cut clockwise across the main fabric at low angles. They carry large dextral σ-porphyroblasts of K-feldspar. These structures are postdated by numerous centimetre-scale, dextral, reverse shear zones that dip variably to the northwest (Plates 6 and 7); these are associated with gently northeast-plunging, minor Z-folds. Small dextral brittle faults, along which thin seams of pale-green cataclasite are developed, offset all other structures. These observations suggest that dextral displacements locally postdate sinistral events. However, they cannot be unequivocally correlated with the structures seen on Greenspond and adjacent islands because of their immediate proximity to the Newport Granite.

The contact of the Cape Freels and Newport granites is exposed at Fox Bay and close to the Greenspond road (Figure 2). The easternmost exposures of Newport Granite contain only a weakly defined, margin-parallel magmatic fabric, defined by alignments of K-feldspars and mafic enclaves. Inclusions of foliated Cape Freels Granite are common close to the contact. In the Cape Freels Granite nearest to the contact, dextral-reverse (or top-to-the-east) shear zones

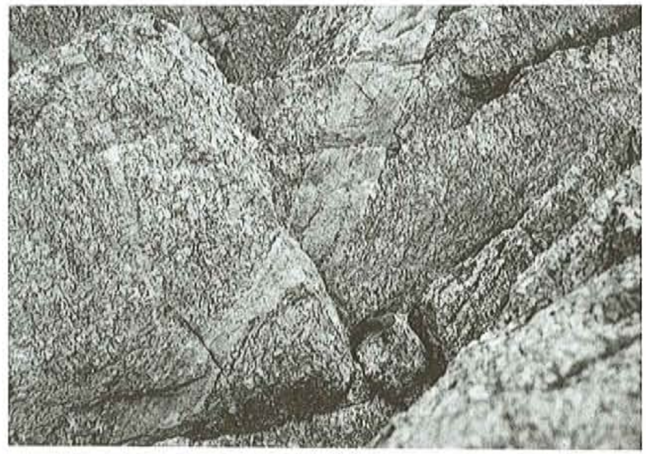

Plate 7. *Discordant pink granite vein (possibly related to an early phase of the Newport Granite) that cuts solid-state fabric in Cape Freels Granite and is offset by small dextral reverse shear zone. Viewed in cross-section, looking north, Fox Bay.*

and folds are common. These die out over a short distance to the east. In the same region, abundant, weakly foliated dykes and sheets of pale-pink granite crosscut the solid-state fabric in the Cape Freels Granite. These sheets are offset by the dextral reverse shear zones (Plate 7), so it is possible that they were intruded and subsequently deformed during the early stages of emplacement of the Newport Granite, i.e., they may not have regional significance. However, the relationship between the later granite sheets and the earlier set of dextral mylonites seen at Fox Bay is unknown.

DISCUSSION

The features described above strongly suggest that the granites and associated rocks forming the southeastern part of the Cape Freels Granite are deformed by a major northeast–southwest-trending structure located on the northwest side of Bonavista Bay. This structure is here termed the Greenspond Dextral Shear Zone (GDSZ). We propose that this zone is a previously unrecognized, northeastern continuation of the dextral Dover Fault, the offshore projection of which, according to most published maps, must lie close to this location (Figure 1). It is also likely that the Dover Fault defines the southeastern tectonic boundary to the Cape Freels Granite, juxtaposing the pluton against rocks of the Avalon Zone.

The relative timing of dextral and sinistral, solid-state deformations along the margins of the Cape Freels Granite is uncertain, although there is localized evidence (e.g., at Fox Bay) of dextral displacements overprinting sinistral displacements.

The relative timing of the syn-intrusion deformations that affected the two marginal dyke zones of the Cape Freels Granite is also uncertain. Sinistral shear accompanied intrusion along the western margin, but the sense of shear along the northeast-trending precursor to the GDSZ is unknown. The parallelism between granite dykes, magmatic fabrics and solid-state deformation suggests that the southeastern margin of the pluton follows a persistently active tectonic boundary (cf. the western margin). This structure could be the precursor to the Dover Fault. Until the syn-magmatic shear sense has been determined it is not possible to use the granite to further constrain the age of displacements along the Gander–Avalon boundary. Note, however, that if the southeastern margin displacements were dextral during emplacement, this could be related to the onset of right-lateral displacements along the Dover Fault. It would also imply that emplacement of the Cape Freels Granite had occurred by space-creating displacements along a pair of conjugate, strike-slip shear zones.

Finally, we would caution against any direct correlation of the three phases (Early Ductile, syn-granitic and post-granitic) of sinistral shear seen developed within the CFSSZ along the western margin of the Cape Freels Granite. There is little to distinguish the solid-state dextral and sinistral deformation along the granite margins in terms of the observed textures or syn-shearing metamorphic grade. They are also significantly lower temperature episodes compared to the sinistral Early Ductile event (e.g., see Holdsworth, 1991), which they clearly overprint (e.g., in the Valleyfield exposures). This raises the possibility that there are early high-temperature and later lower temperature sinistral displacements in the eastern Gander Zone, a proposal apparently supported by observations made in other areas of the Hare Bay Gneiss (O'Brien and Holdsworth, 1992; Holdsworth and O'Brien, *this volume;* Holdsworth, unpublished data). The absolute time span that separates these sinistral events from each other and from dextral displacements along the Dover Fault is uncertain. Furthermore, the temperatures of deformation recorded in a group of exposures may relate to local controls that do not reflect regional conditions, i.e., within or adjacent to a recently emplaced granite body. These factors present potential problems for regional isotopic-dating studies because in an area displaying sinistral shear criteria, for example, it may be difficult to distinguish 'early' and 'late' sinistral deformations. In these circumstances, field observations of the relative timing of igneous intrusion and deformation may be ambiguous in relation to regional events. Therefore, we would emphasize that sense of shear *alone* should not be applied to regional problems in a chronological sense, i.e., in the Newfoundland Appalachians, sinistral deformations are *not necessarily* early.

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