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THE GEOLOGY AND STRUCTURE OF THE GANDER–AVALON BOUNDARY ZONE IN NORTHEASTERN NEWFOUNDLAND

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ABSTRACT

In the western Bonavista Bay region, the steeply dipping Dover Fault separates a highly deformed sequence of volcanic rocks (Avalon Zone) from adjacent gneisses and granites (Gander Zone).

The metasedimentary rocks of the northeast Gander Zone show a progressive increase in structural complexity and volume of intruded granites toward the Dover Fault. A regional belt of sillimanite-grade gneisses (Hare Bay Gneiss) occurs adjacent to the fault. Within these gneisses, it is apparent that deformation, mobilization and granite emplacement processes are closely associated in both space and time. A regional phase of sinistral transpression occurred at medium to high metamorphic grades and was then overprinted by ductile deformation that occurred at a low metamorphic grade, producing the dextral Dover Fault and sinistral Cape Freels shear zone. Both these structures form broad zones of retrograde mylonites and phyllonites at least 1 km wide. Later brittle dextral faulting is concentrated within these shear zones and has caused extensive disruption of the earlier structures.

The volcanic rocks of the Avalon Zone adjacent to the Dover Fault, previously assigned to the Love Cove Group, are herein viewed to structurally and stratigraphically overlie late Precambrian–Early Cambrian clastic redbeds that are included here in the Musgravetown Group. This relationship would preclude correlation of this volcanic succession with older volcanic rocks of the Love Cove Group, the type area of which lies in a separate belt farther to the southeast. Within the study area, deformation of Avalon Zone rocks occurred at greenschist facies and increases in intensity and complexity toward the Dover Fault. A regional phase of sinistral transpression is overprinted by later ductile and brittle dextral movements in a zone up to 600 m wide adjacent to the Dover Fault.

It is suggested that the early sinistral transpressive events recognized in both the Gander and Avalon zones may be correlated and that they result from the initial juxtaposition of the two terranes during large-scale left lateral movements, which may have occurred during the Silurian. It appears that the Avalon Zone rocks within the study area have not undergone widespread Precambrian (Avalonian) orogenesis. Dextral brittle faulting in the western Bonavista Bay region could be an Acadian (Devonian) event, but, based on existing evidence from the study area, an Alleghenian age of movement cannot be discounted.

INTRODUCTION AND AIMS

Most recent tectonic models for Newfoundland suggest that the Gander–Avalon boundary represents a major tectonic discontinuity, along which large lateral displacements may have occurred, especially during Paleozoic orogenesis (e.g., Blackwood and Kennedy, 1975; Williams, 1979, 1984; Hanmer, 1981; Currie and Piasecki, 1989). Thus, it is generally regarded as an important example of an ancient terrane boundary within the Appalachian orogen.

This report summarizes the findings made in the first field season of a larger multidisciplinary project, which aims to study four problems relevant to the terrane boundary model:

1) the age and kinematic history of the Dover–Hermitage Bay fault system;
2) the age, geometric and kinematic history of orogenesis in the Gander Zone;
3) the nature and controls of magmatic emplacement mechanisms within the Gander Zone; and
4) the distribution and nature of late Precambrian (Avalonian) orogenesis in western Avalon Zone and its possible control on the formation of later Paleozoic structures.

Field studies in 1990 involved detailed mapping of several well-exposed coastal sections located mostly along the northwest shore of Bonavista Bay, northeast Newfoundland (Figure 1). Samples of igneous intrusions and country rocks were collected for isotopic dating in an attempt to erect a chronological framework for structural, metamorphic and igneous sequences that will be established during the project.

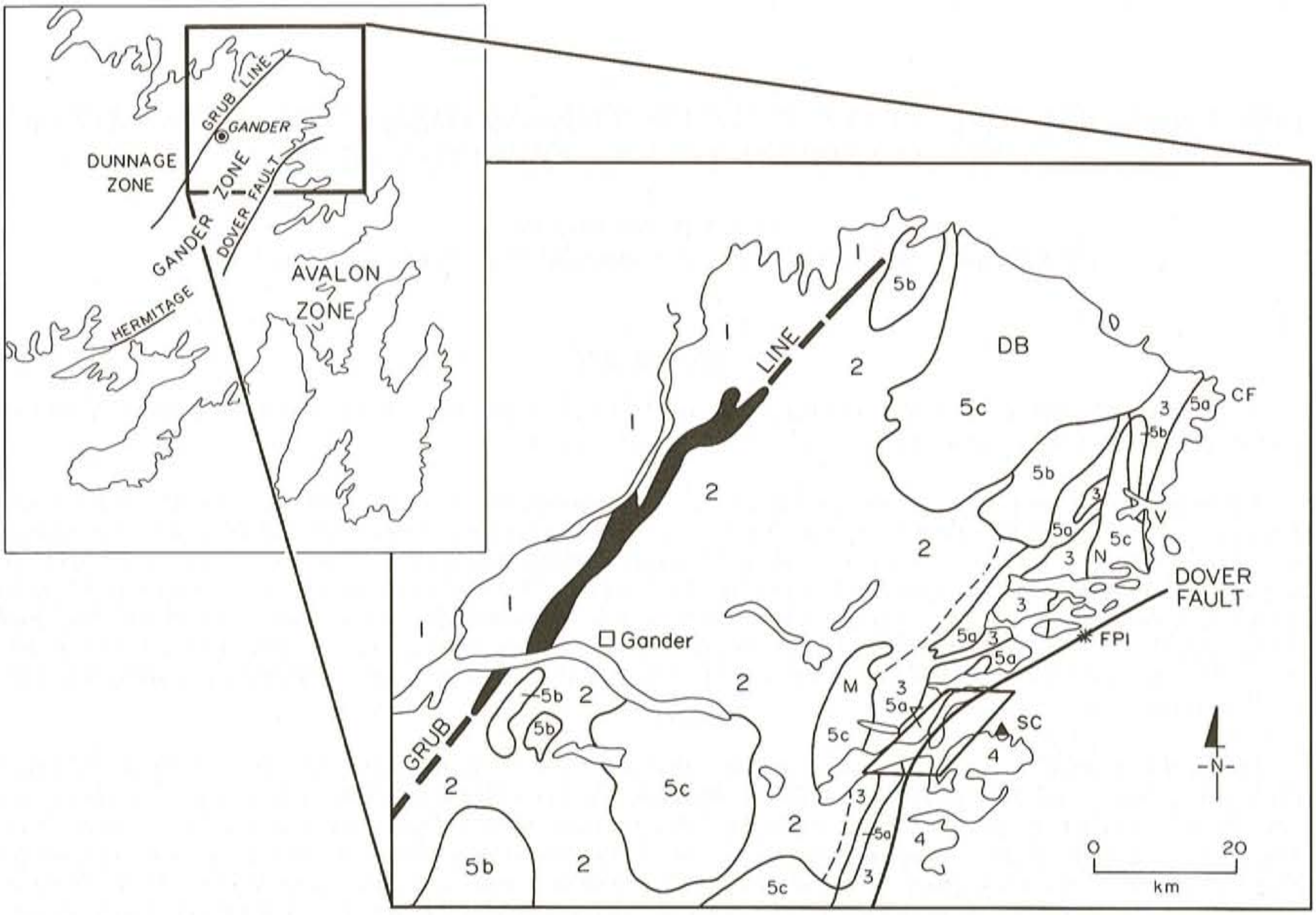

Figure 1. *Inset is map of eastern Newfoundland, showing Avalon, Gander and Dunnage zones and location of larger figure, which is a simplified geological map of northeast Newfoundland.* [*Box along bend in Dover Fault shows location of Figure 2.*] *Dunnage Zone (1), Gander Group (2), Hare Bay Gneiss (3), Avalon Zone (4), foliated megacrystic granites (5a), foliated two-mica granites (5b), unfoliated megacrystic granites (5c). CF=Cape Freels, V=Valleyfield, M=Middle Brook Granite, N=Newport Granite, DB=Deadmans Bay Granite, SC=Shatter Cove, FPI=Frying Pan Island.*

REGIONAL SETTING

The Avalon and Gander zones form the eastern elements of the Appalachian orogenic belt in Newfoundland (Williams *et al.*, 1974; Williams, 1979). In the Bonavista Bay region, they are separated by a prominent zone of faulting known as the Dover Fault (Figure 1; Younce, 1970; Blackwood and Kennedy, 1975).

The rocks of the Gander Zone lying to the northwest of the Dover Fault belong to the Gander Lake Subzone (Williams *et al.*, 1988), which comprises a thick sequence of strongly deformed metasedimentary rocks (Gander Group) and gneisses (Hare Bay Gneiss) intruded by granites (e.g., Jenness, 1963; Williams, 1968; Kennedy and McGonigal, 1972; Jayasinghe, 1978). Some studies (e.g., Blackwood and Kennedy, 1975; Blackwood, 1976, 1977) led to the belief that the gneisses were the basement to the Gander Group, but others led to the conclusion that the rocks are part of a continuous, conformable succession that has undergone increasing intensities of metamorphism eastward (Jenness, 1963; Blackwood, 1978; Hanmer, 1981). With the exception of part of the Indian Bay Big Pond formation (O'Neill and Blackwood, 1989), which contains Arenig–Llanvirn fauna of mixed North American/Balto-Scandian aspect (Wonderley and Neumann, 1984), the Gander Group is unfossiliferous. This formation is thought to be intercalated with the upper parts of the Gander Group, but no fossils are found *in situ* and contact relationships are mostly inferred (e.g., see O'Neill and Knight, 1988). Thus, the evidence for a lower Palaeozoic age for the Gander Group remains open to question. Deformation within the Gander Lake Subzone involves complex folding and fabric formation, with several authors erecting polyphase structural sequences, which usually suggest increasing complexity eastward, associated with a higher metamorphic grade (e.g., Jenness, 1963; Blackwood, 1976, 1977, 1978). Granitic intrusions are abundant in the Gander Lake Subzone, particularly within the higher grade regions to the east (Figure 1). It has long been suggested that there are distinct intrusive sequences and that many of the earlier granites are deformed and contain fabrics also recognized within the country rocks (Jayasinghe and Berger, 1976; Blackwood, 1976, 1978; Jayasinghe, 1978). Some authors, notably Hanmer (1981), have favoured a tectonic model, in which granite emplacement and progressive deformation of the country rocks occur synchronously, and in which much of the Gander Lake Subzone is a major, crustal-scale shear zone. Deformation and plutonism are usually assigned to the loosely defined Siluro-Devonian Acadian Orogeny, as Rb–Sr whole-rock data from the granites give ages in the range ca. 440 to 300 Ma (Blenkinsop *et al.*, 1976; Bell *et al.*, 1977, 1979). However, similarities between this region and the Hermitage Flexure area of southern Newfoundland, where widespread Silurian orogenesis within the region adjacent to the northwest margin of the Avalon Zone has been documented (e.g., Dunning *et al.*, 1990; O'Brien *et al.*, 1991), suggest that events recorded in both areas may be in part coeval.

The rocks of the Avalon Zone, which lie to the southeast of the Dover Fault are a sequence of low-grade, weakly to moderately deformed sedimentary and volcanic rocks of late Precambrian age, overlain by shallow-marine Cambro-Ordovician strata (see O'Brien *et al.*, 1990, for review). The oldest known rocks in the Avalon Zone belong to the Burin Group, a sequence of mafic volcanic and volcaniclastic rocks intruded by gabbro dated at 763 $\pm$ 2 Ma; all are thought to be of oceanic affinity (Strong *et al.*, 1978; Krogh *et al.*, 1988). The Burin Group is fault-bounded and there is no obvious link between these rocks and subsequent Precambrian events within the Avalon Zone. Between about 635 and 560 Ma, a complex history of bimodal volcanism, comagmatic plutonism and sedimentation within fault-bounded basins characterizes the entire Avalon Zone in Newfoundland (O'Brien *et al.*, 1983; Krogh *et al.*, 1988; O'Brien *et al.*, 1990). In general, marine flyschoid sedimentary rocks give way to predominantly deltaic and fluviatile deposits (King, 1980) and in many regions, a widespread angular unconformity is recognized separating older marine clastic rocks from overlying redbeds (Hayes, 1948; Anderson *et al.*, 1975). A second major unconformity separates the Cambro-Ordovician platformal sedimentary rocks from underlying late Precambrian strata (e.g., McCartney, 1967). It is generally agreed that the Precambrian rocks were affected by significant deformation and low-grade metamorphism prior to the Cambrian; this event is known as the Avalonian Orogeny (Lilly, 1966; Hughes, 1970). The precise timing and distribution of events remains uncertain, although recent work (e.g., O'Brien, 1987) suggests that deformation may be localized along certain prominent fault systems. The unconformable Lower Cambrian to Arenig platformal sedimentary rocks are unaffected by Avalonian events; they contain a characteristic Acado-Baltic trilobite fauna (Hutchinson, 1962). No post-Arenig to pre-Devonian rocks are exposed onshore, but offshore seismic reflection profiles (Durling *et al.*, 1987) reveal a thick, folded sequence of Ordovician and Silurian shales unconformably overlain by Devonian redbeds; the folding is thought to be the product of Acadian orogenesis. Onshore, the Acadian event produced widespread low-grade metamorphism, folding, fabrics and faulting, especially in the western Avalon Zone (Williams *et al.*, 1974; Dallmeyer *et al.*, 1981). Existing time constraints are poor, with $^{40}Ar-^{39}Ar$ plateau ages between 400 and 353 Ma for whole-rock phyllites, and between 356 and 352 Ma hornblende ages for posttectonic granites, suggesting a Devonian age for orogenesis (Dallmeyer *et al.*, 1981, 1983). There is little geological evidence for significant post-Acadian orogenic activity within the Avalon Zone.

The Dover Fault separates the upper amphibolite-facies gneisses of the Gander Zone from the greenschist-facies volcanic rocks of the Avalon Zone (Figure 1). It is this contrast in metamorphic grade, together with a lack of obviously correlatable events between the two zones, which makes the Dover Fault the most prominent geological boundary within the Newfoundland Appalachians. It is steeply dipping and is usually described as a mylonite zone between 300 to 500 m across (Blackwood and Kennedy, 1975; Blackwood, 1977, 1978). Deep-seismic data (Keen *et al.*, 1986) suggest that the fault cuts much, if not all, of the crust and that it separates deep crustal blocks of markedly different character. Recent structural studies (Hanmer, 1981; Caron and Williams, 1988a, b) suggest that the Dover Fault has accommodated several phases of substantial strike-slip displacement which, together with the other geological evidence described above, implies that the fault represents an Appalachian terrane boundary. Displacements are usually attributed to Acadian deformation, based on $^{40}Ar-^{39}Ar$ dating of fault-zone phyllites (400 to 353 Ma; Dallmeyer *et al.*, 1981) and the ca. 356 Ma age of the posttectonic Ackley Granite, which crosscuts the Dover Fault to the south (Dallmeyer *et al.*, 1983; Tuach, 1987). Mylonitic fabrics associated with the Dover Fault are thought to be continuous with later stage Acadian fabrics in both the Avalon and Gander zones (e.g., Blackwood, 1977, 1978).

NORTHEAST GANDER ZONE

INTRODUCTION

The present study has concentrated principally on the easternmost, highest grade metamorphic unit of the Gander Lake Subzone, the Hare Bay Gneiss (Figure 1). However, reconnaissance studies were also carried out on the adjacent Gander Group, including rocks previously assigned to the Square Pond Gneiss of Blackwood (1977). The work reported here supports the hypothesis that the sub-divisions belong to a single continuous sedimentary sequence, which according to Blackwood (1977, 1978), were subjected to increasingly high metamorphic grade eastward. The Hare Bay Gneiss is intimately associated with a number of granitic intrusions on a cm to km scale. Many of these granites are deformed together with the country rocks to differing degrees, and it would appear that this has led to an important oversight by many previous workers. In most areas, significant amounts ($<$50 percent) of the country rocks are orthogneisses, which appear to represent slightly earlier, petrographically identical equivalents of the granitic bodies mapped previously. They are 'gneisses' simply because they exhibit strong, solid-state deformation fabrics, often with very well-developed S-C fabrics, and, in some cases, folds. This reinforces the observation that there is a marked eastward increase in the volume of intruded granite, in addition to the rise in metamorphic grade and structural complexity.

Coastal sections were studied in Freshwater Bay, Hare Bay, Shoal Bay, Lockers Bay, Indian Bay, Valleyfield and Cape Freels–Windmill Bight (Figure 1).

HARE BAY GNEISS

This diverse assemblage was first defined by Blackwood (1976, 1977) as a zone of high-grade migmatites, tonalitic orthogneisses and rafts of paragneiss. The present study suggests that the complex can be broadly sub-divided into three components in order of relative age: metasedimentary rocks and amphibolites, mobilized gneisses, and orthogneisses. It is often impossible to map out individual components, first, because they are so intimately intermingled and second, because boundaries are often gradational over distances of up to several tens of metres. Furthermore, the orthogneisses essentially grade into deformed granites, forming early sheeted vein complexes (see below).

Metasedimentary Rocks and Amphibolites

These occur as enclaves and rafts on mm to km scale, and are especially common around Hare Bay, Shoal Bay, western Lockers Bay, central Indian Bay, Valleyfield and Windmill Bight. The metasedimentary rocks are migmatized semipelite, psammite and pelite interbanded on a scale of millimetres to centimetres. Sedimentary way-up criteria were not observed in these rocks. Rare bands of marble and skarn rocks form subordinate units normally less than 1 m thick. Uniform dark greenish-black amphibolites form units up to several hundreds of metres thick, but are only abundant in the area between Lockers Bay Granite and the Dover Fault (Hanmer, 1981). Contacts of amphibolite with metasedimentary rocks are in most places sharp and concordant, but the preservation of a massive igneous texture in regions of low tectonic strain (e.g., Shoal Bay) suggests that the amphibolites may represent mafic intrusive sheets. They carry all the deformational fabrics recognized within the metasedimentary rocks, which suggests that they were intruded at a very early stage in the tectonic history. Lithologically, the metasedimentary rocks and amphibolites are identical to the rocks of the Gander Group (including the Square Pond Gneiss of Blackwood, 1978); the boundary between Blackwood's Hare Bay and Square Pond gneisses was placed where migmatization becomes an ubiquitous feature (Blackwood, 1977, 1978).

Mobilized Gneisses

These are clearly derived from a greater degree of melting of the same metasedimentary country rocks, which occur as numerous small enclaves 'floating' within the granitic to tonalitic leucosome. They range from a relatively coherent, soaked migmatite (Freshwater Bay, Shoal Bay, Lockers Bay East; Plate 1), through to a thoroughly mobilized xenolithic granite (*sensu lato*, Indian Bay; Plate 2).

Orthogneisses

These comprise a series of tonalitic to granitic units, which do not usually include large numbers of country-rock enclaves, and which are not obviously derived from melting or mobilization of the immediately surrounding metasedimentary rocks. The earliest bodies are discrete granitic gneiss sheets found in the Indian Bay and Windmill Bight regions. They are deformed by the main phase of folding observed in the country rocks and only rarely preserve good igneous textures in zones of low strain. Later orthogneisses carry a strong solid-state tectonic fabric, which may include S-C textures, but early folds are mostly absent. They increasingly preserve good igneous textures and pass gradationally into the granitic intrusive suite described below. However, the possibility that at least some of the orthogneisses represent a much earlier phase of igneous intrusion cannot be ruled out based on preserved field relationships.

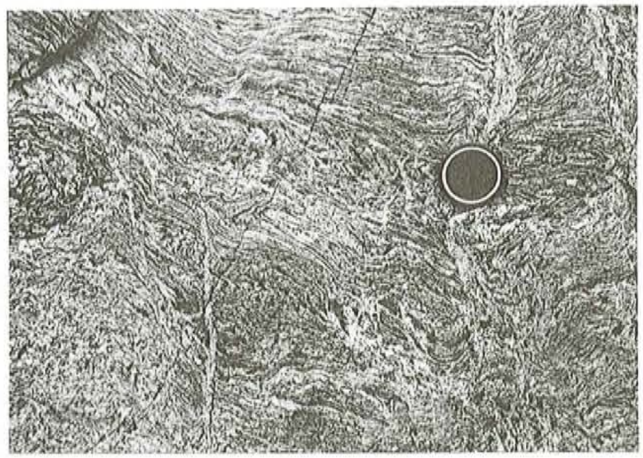

Plate 1. *Semi-pelitic migmatites of the Hare Bay Gneiss, western Hare Bay. Open to close upright Early Ductile folds refold earlier flat-lying isoclines; note that the segregation fabric is deformed by both sets of folds.*

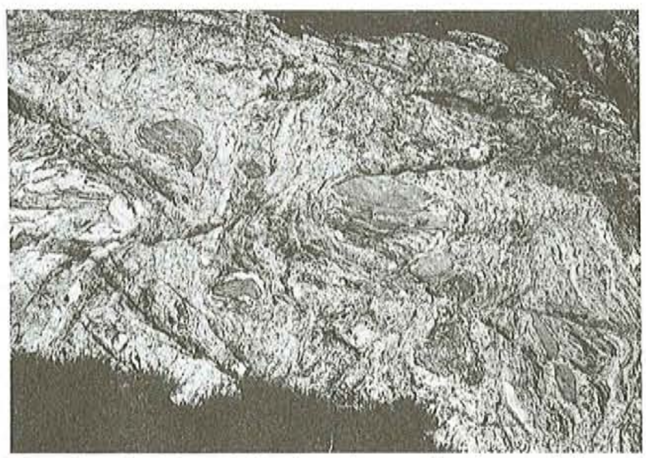

Plate 2. *Highly mobilized gneiss grading into a deformed xenolithic granite, Hare Bay Gneiss, Indian Bay. Note the contorted and irregular form of the cm-scale Early Ductile folds, which implies a lack of mechanical coherence.*

INTRUSIVE ROCKS

Igneous intrusions form a major component of the northeast Gander Zone and are increasingly abundant toward

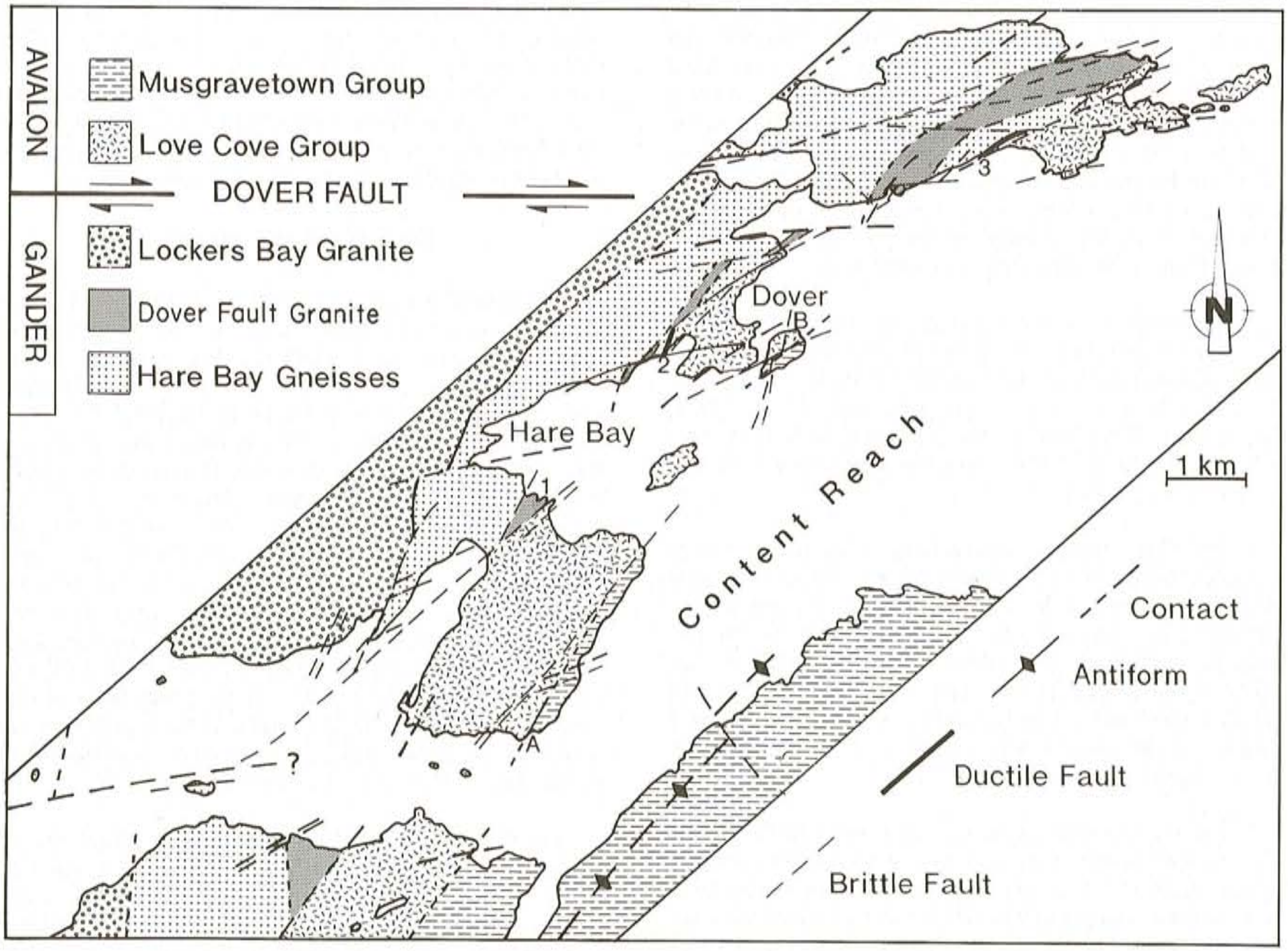

Figure 2. *Geological map of the Hare Bay–Dover region, Bonavista Bay. A and B are locations of exposed conformable contacts between the Musgravetown Group and younger volcanic rocks; other contacts are faulted. 1, 2 and 3 refer to location sites. See text for details.*

the Dover Fault (Figure 1). The majority are broadly granitic in composition, and can be sub-divided into five main groups: aplogranite veins, early sheeted complexes, foliated megacrystic biotite granites, two-mica garnetiferous granites, and unfoliated megacrystic biotite granites (Figure 1; Blackwood, 1978).

The aplogranites are a minor intrusive phase. They are fine-grained, pinkish-grey granites, which in many areas form irregular and anastomosing networks within parts of the Hare Bay Gneiss. They commonly contain biotite and are crosscut by all other intrusive phases.

The sheeted complexes are entirely restricted to the Hare Bay Gneiss and are in many areas spatially associated with, and crosscut by, the foliated megacrystic granites, notably the Dover Fault and Lockers Bay granites (Figure 2) and the Cape Freels granite. They comprise a diverse series of foliated dioritic to granitic sheets intruded into the Hare Bay Gneiss sub-parallel to the regional foliation. In general, the earliest sheets are the most mafic, whereas the latest are granites of very similar composition to the nearby megacrystic intrusions. The intrusions are all strongly foliated (±S-C fabrics) and, where they contain numerous enclaves of metasedimentary rocks (e.g., East Lockers Bay), both are deformed by folds and fabrics identical to the structures associated with the main phase of early deformation seen elsewhere in the Hare Bay Gneiss. As this is apparently the same phase that is associated with high-grade metamorphism and mobilization in the gneisses, it suggests that intrusion of the sheeted complexes occurred at the same time or soon after these events. This proposal is consistent with the apparent gradation between early granite sheets and 'later' orthogneisses.

The foliated megacrystic biotite granites are mostly coarse-grained, linear bodies, largely restricted to the extreme southeast parts of the Hare Bay Gneiss. One discontinuous sheeted unit, the Dover Fault Granite, lies close to and sub-parallel with the Dover Fault (Figure 2; Blackwood, 1977). All these granites carry weak to strong, steeply dipping, northeast-striking foliations, of which a significant component is a 'pre-full crystallization' (PFC) fabric (*sensu* Hutton, 1988). The PFC fabrics comprise a strong alignment of K-feldspar phenocrysts, together with highly flattened and 'smeared out' dioritic enclaves, which are locally abundant within most of the granites. Narrow sheets of deformed biotite–muscovite–garnet–tourmaline-bearing leucogranite and pegmatite (mostly less than 2 m thick) are found within many of the megacrystic granites, notably the Cape Freels and Lockers Bay bodies. These sheets lie at low angles or sub-parallel to the foliation in the granite host, and are uncommon in the surrounding country rocks.

The medium- to coarse-grained, two-mica garnetiferous granites range from early foliated plutons that are elongate in the regional foliation, to irregular fine-grained bodies that lack any foliation (e.g., Jayasinghe and Berger, 1976; Blackwood, 1978). They occur throughout the Gander Zone (Figure 1; Blackwood, 1978) and consistently crosscut foliated megacrystic granites.

The final group, the unfoliated megacrystic biotite granites, form some of the largest and latest intrusive plutons found within the Gander Zone. Certain bodies have locally foliated and deformed marginal phases (Middle Brook, Deadmans Bay), whereas others crosscut all structures and other intrusions. Because of its crosscutting relationships with adjacent rocks and its largely undeformed nature, the Newport Granite has historically been viewed as the youngest pluton in the region (cf. Jayasinghe, 1978).

Two sets of minor intrusions occur sporadically in that part of the Gander Zone that was studied. Rare, foliated micro-diorites form steeply dipping sheets that mostly lie at low angles or sub-parallel to the regional foliation. Most are less than 1 m thick, and although they apparently crosscut local migmatitic fabrics in the Hare Bay Gneiss (e.g., Freshwater Bay), others are apparently included as enclaves elsewhere (e.g., Indian Bay). Similar in habit to syn-plutonic dykes, they apparently represent a localized phase of intermediate composition, temporally associated with the mobilization of the gneisses and intrusion of the granites.

Finally, unfoliated diabase dykes, up to 3 m thick, occur locally within the Hare Bay Gneiss and almost all the large granitic bodies. They are crosscut by the Newport Granite (Jayasinghe, 1978). Most dykes trend north-northeast and are sub-vertical in orientation.

STRUCTURAL GEOLOGY

Recent structural studies within the Gander Group (e.g., O'Neill, 1987; O'Neill and Knight, 1988; O'Neill and Lux, 1989; O'Neill and Blackwood, 1989) demonstrate a general increase in deformational complexity with rising metamorphic grade. An early, bedding-parallel fabric (S1) is folded around numerous small-scale isoclinal F2 folds, which are associated with a strong axial-planar S2 cleavage and northeast-trending subhorizontal mineral lineation. These structures are in turn refolded by upright, northeast-trending F3 folds, which become dominant within the Gander Group's higher grade, more highly deformed parts. The peak of low-pressure–high-temperature regional metamorphism is apparently synchronous with, or slightly later than this F3 folding (O'Neill and Lux, 1989). Data collected on reconnaissance traversing during the present study indicate that the dominant phase of folding and associated fabrics recognized within the Hare Bay Gneiss—here termed the Early Ductile structures—are broadly equivalent to the F3 folds farther west.

Early Ductile Structures

The dominant structures within the Hare Bay Gneiss are a series of mm- to km-scale folds whose steeply dipping to vertical axial planes trend northeast. Deformation associated with the folding is responsible for the regional tectonic fabric and is intense throughout much of the Hare Bay Gneiss. A well-developed sub-horizontal to shallowly plunging, northeast-trending mineral lineation is widespread, but locally has rotated into steep reclined orientations, often over distances of only a few centimetres (e.g., Windmill Bight, Figure 3a, b). Minor folds are typically highly curvilinear about the local lineation, and may display up to 180° of hinge curvature over a few millimetres (Figure 3a, b). Thus, the entire belt is characterized by variably plunging lineations, minor folds and complex changes in the senses of fold vergence (Figure 3a). In detail, most minor folds of this generation fold the mineral lineation about which they are curvilinear, a feature typical of progressive deformation in ductile shear zones (e.g., Holdsworth, 1990).

Small-scale isoclinal folds whose axes lie parallel to the mineral lineation are refolded by the regionally dominant fold set in many exposures (e.g., Plate 1). However, these structures are only preserved in metasedimentary gneisses or amphibolites, not in orthogneisses or granites. These early isoclines deform a still earlier bedding parallel fabric, suggesting that the regionally dominant fold set is pre-dated by at least two phases of deformation (cf. F3 folds in the Gander Group).

The Early Ductile deformation is clearly associated with high temperatures, as indicated by the widespread preservation of syn- to post-kinematic sillimanite needles (e.g., Indian Bay) suggesting upper amphibolite-facies conditions. Deformational fabrics are strongly recrystallized within the coarse-grained gneisses, whereas increased strain intensities in some localities have clearly induced the process of mobilization (e.g., Lockers Bay, Indian Bay). In other areas, notably western Freshwater Bay and Indian Bay, the same deformational phase has produced very different styles of folding within adjacent large-scale units of mobilized gneiss and less migmatized metasedimentary rock. In the latter units, the folds are similar to those shown in Figure 3a, whereas geometrically unpredictable, highly irregular and contorted structures (e.g., Plate 2) characterize the mobilized units. These observations suggest that the latter constitute a much less coherent rheology at the time of deformation. However, it would appear that the relative timing of mobilization and folding is variable, because some areas of such rocks show perfectly coherent patterns of folding (e.g., eastern Freshwater Bay).

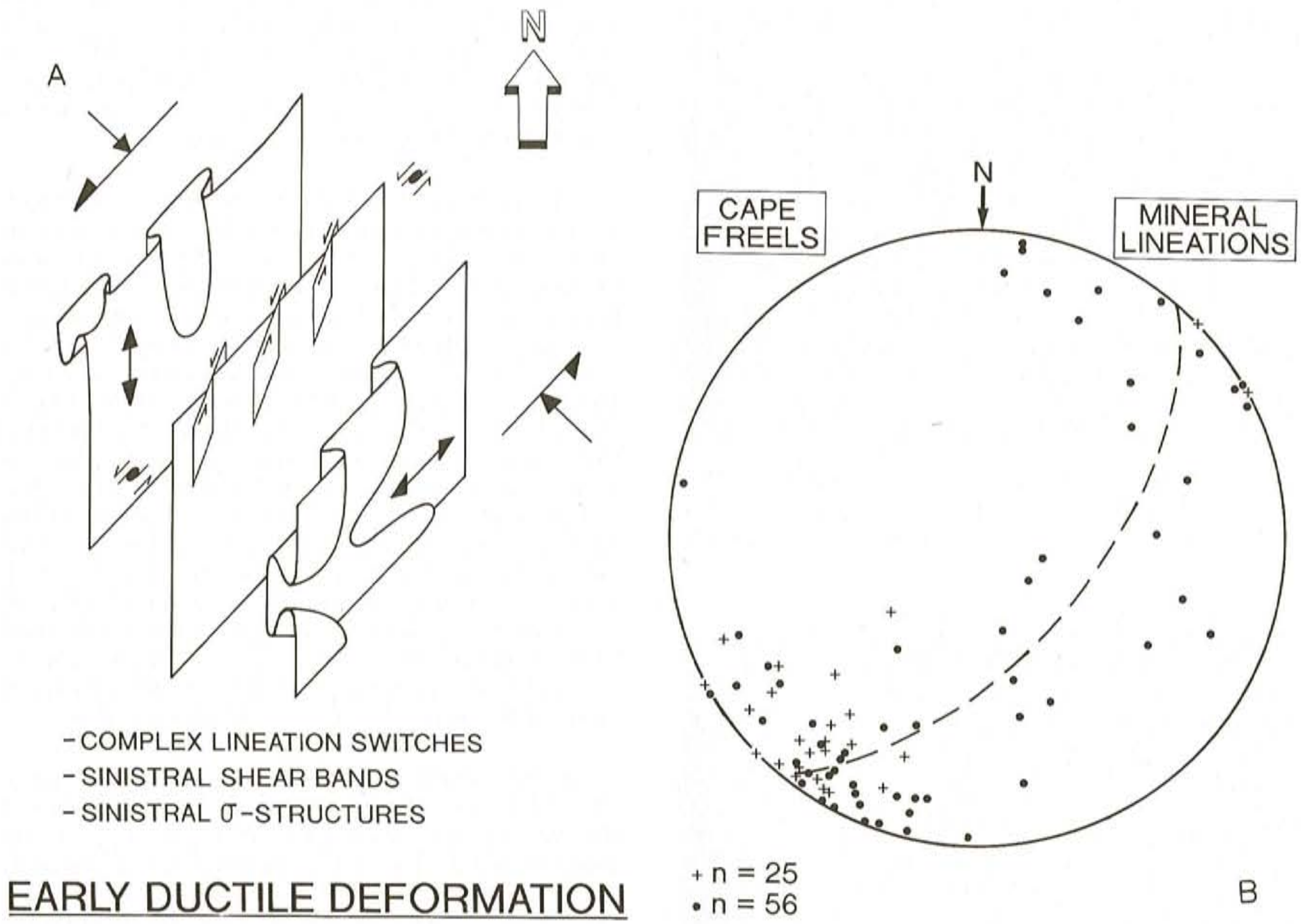

Figure 3. *a) 3-dimensional diagram summarizing the geometry of Early Ductile deformation structures in the northeast Gander Zone, Bonavista Bay. The two outer panels show the two extremes in orientation of the lineation and associated sheath folds, whereas the central panel shows the sinistral shear bands and σ-structures that occur throughout the region. b) Stereoplot of lineations from the Cape Freels–Windmill Bight area (for location see Figure 1). Solid dots are lineations from the Hare Bay Gneiss; crosses are from the Cape Freels Granite. Dashed line gives the mean regional foliation. Note the predominance of shallowly plunging northeast-southwest lineations, with a smaller group of steeply plunging lineations (cf. Figure 3a).*

Shear-sense criteria are abundant within the Hare Bay Gneiss, especially the more homogeneous mobilized gneisses and orthogneisses. They include: cm- to mm-spaced shear bands (Plate 3), asymmetric wrapping of metasediment–amphibolite enclaves in mobilized gneisses (Plate 4), σ-porphyroclasts and shearing of passive markers across strain gradients (e.g., dykes). All these features give sinistral senses of shear throughout the region. Note that in areas where minor folds are curvilinear about a shallowly plunging lineation, they predominantly display sinistral senses of vergence as they pass through the vertical (Figure 3a). Shear criteria in areas where the lineation has steep plunges give both northwest- and southeast-side-up senses of movement. Many shear bands carry thin streaks of leucosome (Plate 3), which, together with the evidence for sinistral shear during mobilized flow (Plate 4) suggest, once again, a close association between mobilization and deformation. Viewed as a whole (Figure 3a), the Early Ductile structural configuration is most readily interpreted as arising from a regional sinistral transpression which occurred, presumably, at upper-amphibolite facies.

Late Ductile Structures

These ductile structures are mostly restricted to localized shear zones and are immediately distinguishable from the earlier structures as they are usually associated with much lower grade, phyllonitic fabrics. Two principal shear zones are recognized, both of which are much disrupted by later brittle faulting; one is dextral and follows the trace of the Dover Fault, whereas the other is sinistral and is associated with the western contact of the Cape Freels Granite (Figure 4a). In addition, a number of small-scale, generally east-trending dextral phyllonitic shear zones cut the gneisses in several locations (Figure 4a).

The Dover Fault dextral shear zone affects rocks up to 1 km from the Gander–Avalon zone boundary. With

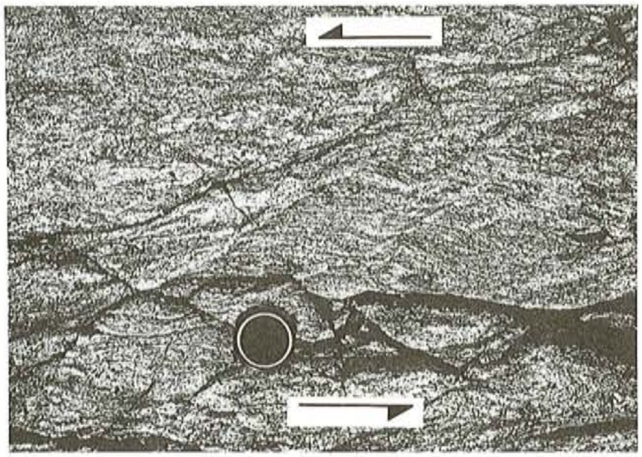

Plate 3. *Centimeter-spaced sinistral shear bands in tonalitic, mobilized Hare Bay Gneiss, Freshwater Bay. Note the thin streaks of leucosome that have formed along the shear planes.*

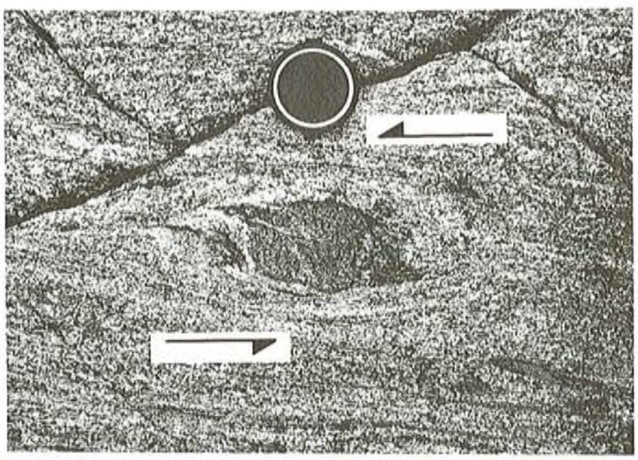

Plate 4. *Asymmetrically wrapped enclave of semi-pelite within deformed mobilized gneiss, Hare Bay Gneiss, Lockers Bay. Sinistral shear apparently occurred at, or near to the time of mobilization.*

proximity to the shear zone, the gneisses become increasingly epidote- and chlorite-rich and are green; this is due to retrograde metamorphism. Grain-size reduction fabrics are preserved in areas of higher strain. A zone (up to 300 m width) of dark green, chlorite–sericite phyllonite derived from the gneisses is present at the Gander–Avalon contact (Figure 4b). These almost always contain highly sheared pink veins of Dover Fault Granite.

The low-grade shearing deforms the larger Dover Fault Granite sheets (Figure 2). The biggest of these form resistant augen of lower strain, crosscut by networks of steeply dipping, conjugate sinistral and dextral phyllonitic shear zones (Figure 4b); these reach widths of a few cm. In the margins of the granite, and in the adjacent phyllonitic gneisses, lineations have sub-horizontal or gently plunging northeast-southwest orientations. Shear-sense criteria (shear bands, σ-structures, asymmetric sheath folds) all give dextral senses of shear (Figure 4b). Similar structures give dextral shear senses within the east-trending, sub-vertical shear zones (up to 50 m wide), which cut the gneisses in Lockers Bay, Indian Bay and Windmill Bight (Figure 4a). Fabrics and folds developed during the earlier higher grade metamorphism are strongly reworked and refolded within these shear zones.

The north-northeast-trending shear zone associated with the western margin of the Cape Freels Granite (Figure 4a) forms a belt at least 500 m wide, of greenschist-facies mylonites affecting both granite and adjacent gneisses. It is much disrupted by later faulting, and lower grade mylonitic gneisses are only well exposed in the Valleyfield coastal section; they are absent at the faulted contact at Cape Freels. Shear bands, asymmetric sheath folds, and σ-structures give sinistral senses of shear in surfaces oriented parallel to the shallowly plunging mineral lineation. Earlier folds and fabrics are strongly refolded and reworked, and are well preserved in metre-scale sinistral shear augen exposed in the Valleyfield section, as noted by Hanmer (1981). He has also described the marginal shear zone in the Cape Freels granite, which displays a spectacular series of protomylonitic to ultramylonitic S-C deformation textures. Low-grade sinistral and subordinate dextral shear bands are preserved within the western part of the granite up to 1 km from the contact, and overprint an earlier PFC foliation within the pluton.

At the southernmost outcrops of the Cape Freels Granite around Fox Bay, where it is crosscut by the undeformed Newport Granite (Jayasinghe, 1978), narrow, steeply northwest-dipping dextral reverse shear zones are abundant. These structures are associated with refolding of the earlier PFC fabric and may be related to dextral transpressive movements along the offshore extension of the Dover Fault (Figure 4a).

Late Brittle Structures

Complex linked systems of steeply dipping faults are widespread in the region and are concentrated in the vicinity of the Dover Fault and Cape Freels Late Ductile shear zones. Many larger faults have markedly controlled the local present-day physiography (e.g., Figure 2). Individual faults are often marked by narrow (< 1 cm) veins of epidotic cataclasite, or broader zones (<50 m) of breccia (Figure 5). Shear fibres and slickensides, where present, usually have shallow plunges, suggesting that strike-slip movements are dominant. In the Hare Bay–Dover area, the pre-existing arrangements of lithological units and phyllonite zones are highly disrupted by faulting on a cm to km scale (Figures 2 and 5). Three predominant fault orientations and displacement senses (as deduced from offsets) are recognized: east–east-northeast dextral, northeast-dextral, and north–north-northeast sinistral. These fracture patterns appear to best correspond to R (or Y), P and R' shears (*sensu* Tchalenko, 1970) associated with movements along a northeast-trending dextral fault zone. In well-exposed sections (Figure 5), distinct domains of R, P and R' faults are recognized, constituting an array of rotating fault blocks that are typical of brittle strike-slip deformation zones (e.g., Nur *et al.*, 1989). Within

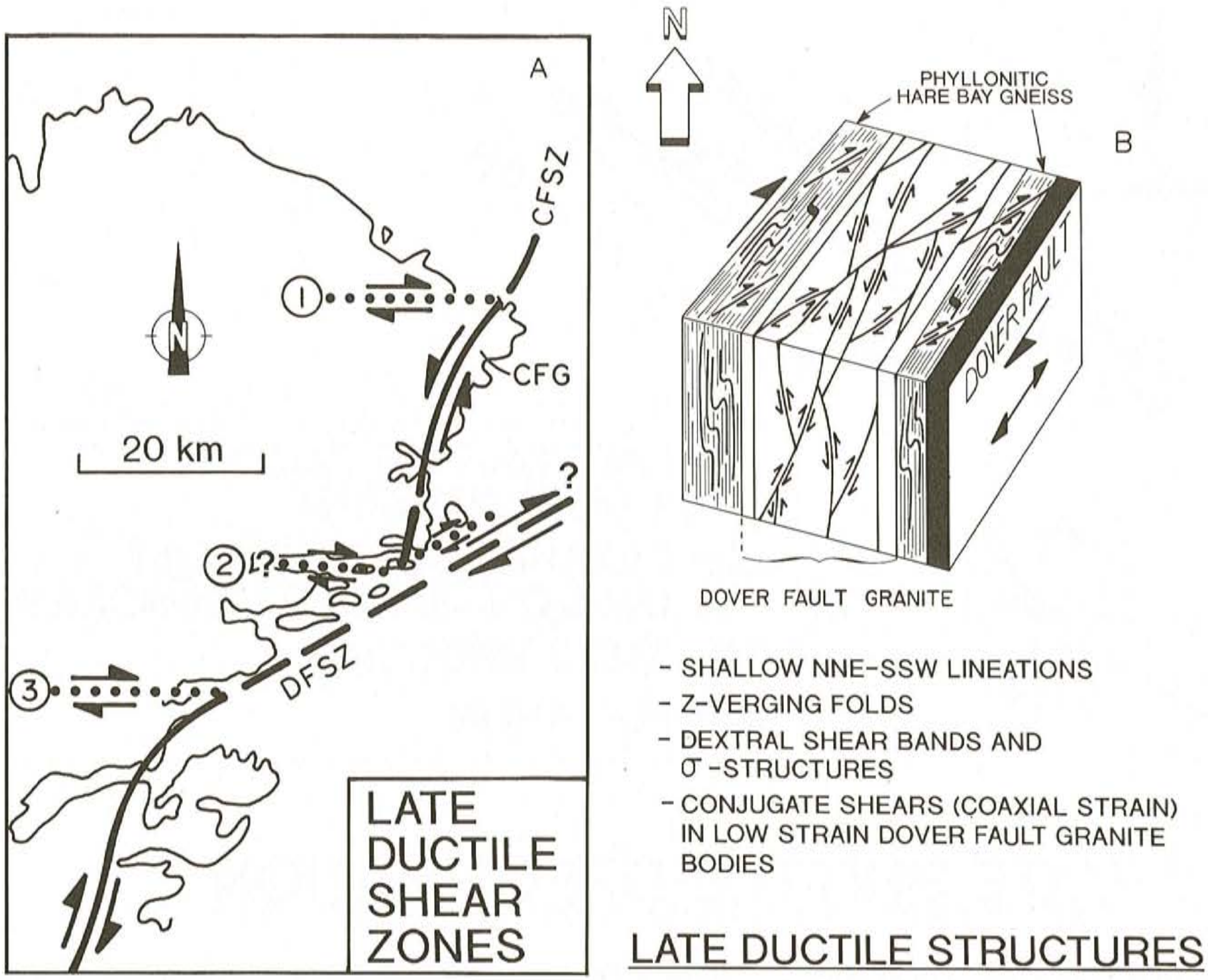

Figure 4. *a) Late Ductile shear zones in the Bonavista Bay area. DFSZ=Dover Fault shear zone; CFG=Cape Freels Granite; CFSZ=Cape Freels shear zone. The dotted lines show the orientations of minor shear zones of the same age in a number of locations; 1—Windmill Bight, 2—Indian Bay and 3—Lockers Bay. b) 3-dimensional diagram summarizing the geometry of Late Ductile structures along the Dover Fault shear zone. Where larger bodies of Dover Fault Granite occur (see Figure 2), a central zone of less-deformed coaxial strain in the granite separates highly non-coaxial phyllonites derived mostly from retrogressed Hare Bay Gneiss. The latter preserve abundant shear criteria including shear bands, σ-structures and dextrally verging folds. The central coaxial strain unit is absent in areas lacking large Dover Fault Granite bodies.*

these zones, extremely complex second-order fault-block arrays are developed in order to accommodate compatibility problems and fault-block shape changes during displacements along first-order (i.e., mappable) fault systems. Kinematic interpretations of fault patterns at the scale of individual exposures should be treated with caution, as complex localized systems of second-order transpression and transtension are to be expected (Wilcox *et al.*, 1973).

Similar fault arrays are associated with the Cape Freels Late Ductile shear zone, suggesting that the earlier sinistral movements are overprinted by regional Late Brittle dextral displacements.

STRUCTURAL AGES OF GRANITIC INTRUSION

All granites examined during the present study of the northeast Gander Zone are crosscut by brittle faults. The Newport Granite, the apparently youngest pluton studied, is crosscut by a complex fault system exposed on Frying Pan Island (Figure 1), as recognized by Blackwood (1977). A detailed analysis of these structures demonstrates that they have formed in association with dextral displacements along a northeast-trending master fault, which may be the northeast extension of the Dover Fault.

The unfoliated megacrystic biotite granites studied (Newport, Middle Brook, Deadmans Bay), together with a

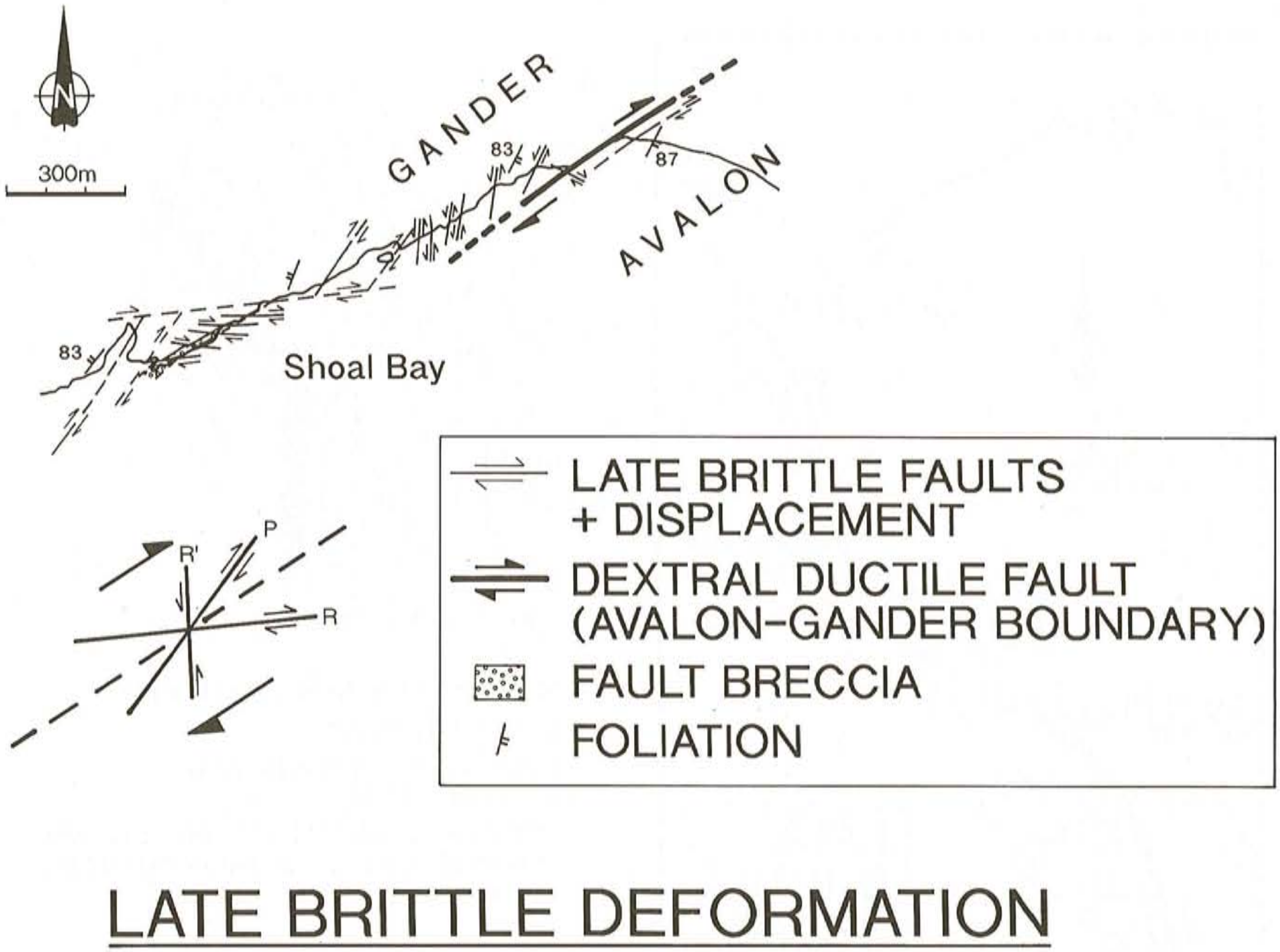

Figure 5. *Detailed map of the boundary of the Gander and Avalon zones (North Shoal Bay), showing late Brittle faulting patterns associated with dextral displacements along a presumed northeast-trending master fault. Note that the original Late Ductile dextral Dover Fault contact is preserved here (location 3 in Figure 2).*

number of small unfoliated two-mica granite bodies in the Indian Bay and Freshwater Bay areas, appear to postdate all ductile structures in the surrounding country rocks.

It is tentatively suggested that the majority of foliated granites within the northeast Gander Zone were intruded during deformation of the surrounding country rocks producing internal PFC and/or solid-state deformation fabrics (*sensu* Hutton, 1988). The earliest bodies (aplogranites, early members of sheeted granitic complexes, Freshwater Bay granite) contain strong solid-state S-C fabrics and folds that give sinistral shear-senses; it is proposed that they were intruded synchronously with the Early Ductile deformation. The Cape Freels granite carries an early PFC fabric, which is overprinted by low-grade solid-state fabrics, especially along its western margin. Fractured phenocrysts, flow folding and offsets along internal leucogranite sheets (Plate 5) all suggest sinistral shearing during emplacement of the granite, and this event is correlated with the later stages of the Early Ductile event. The Lockers Bay and Dover Fault granites

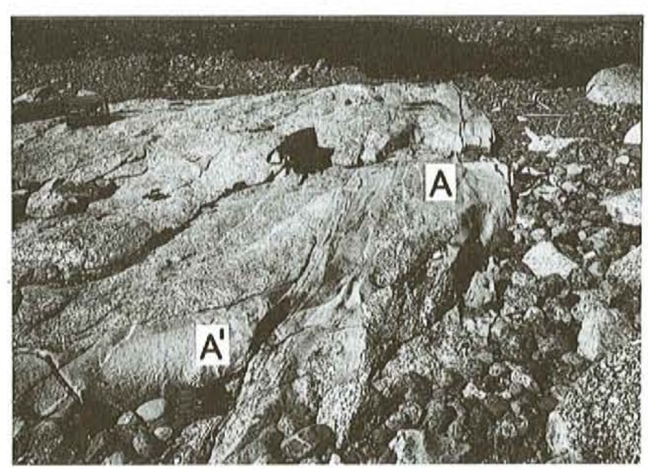

Plate 5. *Fine- to medium-grained leucogranite dykes of the Cape Freels Granite crosscutting the main granite, Cape Freels. Dyke A is offset in a sinistral sense to A' along a slightly later northeast-trending dyke.*

(Figure 2, Blackwood, 1977) are strongly deformed by greenschist-facies shearing associated with dextral transpressive Late Ductile movements along the Dover Fault shear zone (e.g., Figure 4b). Farther northwest, parts of the Lockers Bay, Freshwater Bay and sheeted granite complexes are deformed by narrow (<5 m) foliation-parallel phyllonitic shear zones displaying dextral and/or northwest-side-up senses of shear (S-C fabrics). A Late Ductile age of shearing seems likely based on textural similarity with the Dover Fault shear zone. The Dover Fault Granite does not appear to contain an earlier PFC fabric, based on field observations, and its intrusion is therefore proposed to have been post-Early Ductile, pre-Late Ductile deformation. In contrast, the Lockers Bay Granite carries a strong PFC S-fabric, which in several locations is folded by cm- to mm-scale folds with a consistent dextral sense of vergence. These folds are not associated with solid-state fabrics and they appear to represent early PFC structures. Many seem to have formed during magma flow around resistant enclaves of basic material (e.g., Freshwater Bay). Whereas these structures could be related to local flow within the magma, their consistent vergence over a wide area may indicate that the Lockers Bay Granite was emplaced during the initial stages of dextral Late Ductile movements.

NORTHWEST AVALON ZONE

INTRODUCTION

The rocks of the Avalonian succession in southwest Bonavista Bay comprise (in decreasing age) the Love Cove Group (Jenness, 1957), the Connecting Point Group (Hayes, 1948) and the Musgravetown Group (Hayes, op. cit.). Whereas the relative ages of these units are generally agreed upon, uncertainty exists as to the nature and significance of the original contact relationships of rocks assigned to the Love Cove and Musgravetown groups. Presently, many of the contacts of these three units are faults (Jenness, 1963; O'Brien, 1987; O'Brien and Blackwood, 1987). North of the study area, the Musgravetown Group passes conformably up into strata of probable early Cambrian age (O'Brien and Knight, 1988).

The present study includes examination of some of the rocks previously assigned to the western belt of the Love Cove Group. These are bounded to the northwest by the Dover Fault. Previous studies (e.g., Blackwood, 1977) have considered their southeast contact with supposedly younger sedimentary rocks of the Musgravetown Group to be a high-angle dislocation, the Howses Cove Fault. As will be described below, the present work provides new evidence that suggests that the western belt of supposed Love Cove Group in the study area is younger than and conformably overlies the local Musgravetown Group rocks.

MUSGRAVETOWN GROUP

Sedimentary rocks exposed along both shores of Content Reach (Figure 2) are here assigned to the Musgravetown Group. Those on the southeast and south shores have previously been placed in this group and were assigned to the Rocky Harbour and Crown Hill formations of Jenness (1963) by O'Brien and Knight (1988). The rocks cropping out on the northwest shore of Content Reach were originally mapped by Younce (1970) as Musgravetown Group, but all subsequent studies have placed them in the Love Cove Group, following Blackwood (1977).

Sandstone, shale and conglomerate of the Musgravetown Group along the southeast shoreline of Content Reach form a little deformed, right-way-up succession that can be divided into four lithological units (Blackwood, 1977; O'Brien and Knight, 1988; O'Brien and Blackwood, 1987, Figure 2). The structurally and stratigraphically highest unit overlies a prominent conglomerate horizon and crops out in the core of a major northeast-plunging syncline in Shatter Cove (see Figure 1). It comprises purplish-green siltstone and sandstone, with subordinate shale and, characteristically, purple- to buff-coloured, crossbedded sandstone, which contains pebbly horizons usually less than 1 m thick (Plate 6). These sandstone beds are highly veined with quartz in many exposures and often weather proud of the surface due to their competent nature. These sandstones and shales are identical in composition and appearance to the rocks immediately below those volcanic rocks on the shores of Content Reach, which are included in the Love Cove Group by Blackwood (1977).

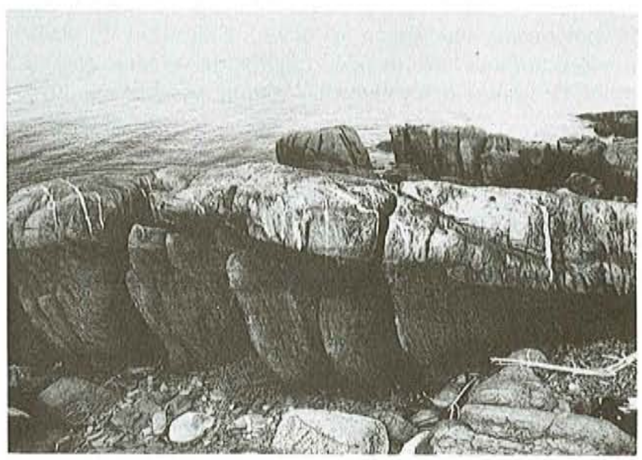

Plate 6. *Interbedded buff sandstone, purple-green siltstone and thin mudstone from the stratigraphically highest unit of the Musgravetown Group, southeast shore, Content Reach. Note the upright slatey cleavage in the siltstone and the quartz veining in the sandstone.*

Primary sedimentary structures are very well preserved in the Musgravetown Group rocks. These include crossbedding, graded-bedding, channels and ripple marks within the sandstones, mud-flake breccias, and spectacular mm- to cm-scale slump structures within many siltstone–mudstone units. Open upright folds with a moderate to weak cleavage (Plate 6) form the main tectonic structures in most exposures. Many exposed contacts with the Love Cove Group volcanic rocks are faults, but conformable, unfaulted boundaries are exposed at the southwest end of Content Reach and on Shoal Island (A and B on Figure 2). A narrow zone of interbanded volcanic rocks and silty sandstone, 1 to 2 m wide, occurs at the contact, and the sedimentary rocks consistently young upward into the overlying volcanic rocks. The Musgravetown Group rocks are more highly cleaved than in the exposures farther to the southeast, but they are otherwise identical. The so-called Howses Cove Fault (as shown by Blackwood, 1977) does not exist, although a small northeast-trending fault forms the contact between sedimentary and volcanic rocks on the coast (Figure 2).

LOVE COVE GROUP

The volcanic rocks in the study area, originally mapped as Love Cove Group, form the terminus of a 100-km-long belt, which is bounded to the northwest by the Dover Fault. Exposures in the area are intensely cleaved, colour-banded volcanic rocks, including acid to intermediate crystal tuffs, lithic tuffs, breccias, agglomerates and (rarely) rhyolite flows up to 25 m thick. Minor mafic horizons occur throughout the region. Way-up criteria are not preserved as the banding is apparently transposed into the steeply dipping tectonic cleavage; mm- to cm-scale isoclinal intrafolial folds of banding are common in areas of lower strain. Volcanic fragmentary material is strongly wrapped and often flattened by the tectonic foliation. A southeast to northwest increase in intensity in deformation occurs toward the Dover Fault and the rocks become increasingly phyllonitic. They still retain some primary lithological colour banding, but tend to take on a secondary pale green or brown colouration. In places, previous authors have mapped phyllonitic volcanic rocks as mylonitic granite (e.g., Hare Bay region; Blackwood, 1977).

INTRUSIVE ROCKS

Granites like those found in the Gander Zone are absent; however, late-stage pegmatoid veins, up to 20 cm wide, are preserved in a few locations around Shoal Bay and Lockers Bay. These crosscut most of the tectonic fabrics.

Narrow, undeformed dykes of greenish-black diabase occur in a few places in the study area. They are crosscut by late brittle faults, but postdate all other structures in the area. Similar dykes are found throughout the Gander Zone, where they pre-date the ?Devonian Newport Granite (e.g., Jayasinghe, 1978).

STRUCTURAL GEOLOGY

The intensity and complexity of deformation increases northwestward within the rocks of the Avalon Zone, and appears to be controlled by proximity to the Dover Fault. A single northeast-trending, steeply dipping slaty cleavage is moderately to weakly developed within the little-deformed clastic sedimentary rocks of the Musgravetown Group exposed on the southeast shore of Content Reach (Plate 6). It is associated with gentle to close, shallowly northeast- or southwest-plunging folds of km scale (e.g., Blackwood, 1978; O'Brien and Blackwood, 1987); minor folds are rare. Conglomerate horizons are little-deformed and original sedimentary imbrication fabrics are still preserved. There is no clear tectonic lineation in this region. The cleavage intensifies toward the overlying volcanic rocks (Love Cove Group of Blackwood, 1977) and, on the northwest side of Content Reach, open to tight minor folds are common, especially within more competent sandstone units; these folds consistently verge toward the anticline farther to the southeast (Figures 2 and 6). In the same exposures, a second set of open to tight folds ('Later Ductile' structures) deform the slatey cleavage (an 'Earlier' structure) and consistently display the reverse sense of vergence (e.g., antiform to the northwest, Figure 6). The intensity of strain rises sharply in the region around the contact between the Musgravetown and Love Cove groups. A steep, south-plunging lineation is developed on the Early cleavage planes a few tens of metres below the contact. Minor early folds tighten and their hinges become intensely curvilinear about the steeply plunging lineation (Figure 6). The Later folds also tighten locally, developing a fine axial-planar crenulation cleavage, and they can be mistaken for early structures in some exposures. However, they always fold the Early mineral lineation.

In the lower parts of the Love Cove Group, the Early steeply south-plunging lineation is prominent, and is commonly defined by highly elongate volcanic clasts. S-C fabrics and asymmetric wrapping of porphyroclasts give northwest-side-up senses of shear (Plate 7). Most minor Early fold axes lie parallel to the lineation, but rare examples of eye structures (Quinquis *et al.*, 1978) suggest that they possess a sheath-fold geometry (Figure 6). Later ductile folds are rare in the lower parts of the Love Cove Group.

The Early lineation gradually rotates anticlockwise (viewed northwest) through the vertical and round into a shallowly plunging or sub-horizontal, northeast-southwest orientation as the Dover Fault is approached (Figure 6). In the central part of the Love Cove Group, where the lineation plunges moderately northeast, asymmetric wrapping of volcanic clasts (e.g., Plate 8) consistently indicates a sinistral and northwest-side-up sense of shear (Figure 6). In the 200 to 600 m of rock nearest to the Dover Fault, Later Ductile folds, together with an associated steeply dipping crenulation fabric, become apparent. The folds are mostly on a scale of centimetres, or less, and are strongly curvilinear about a sub-horizontal northeast trend (Figure 6); they refold the early lineation. In the same zone, asymmetric wrapping fabrics now indicate dextral senses of shear (Figure 6) and it is proposed that this overprints the earlier sinistral displacement. Three important observations support this suggestion. First, the Late Ductile folds always show dextral senses of vergence as their hinges pass through the vertical (Figure 6). Secondly, a dextral Early movement is incompatible with a northwest-side-up sense of displacement, given the anticlockwise rotation of the mineral lineation (Figure 6). Finally, within a few hundred metres of the Dover Fault, volcanic rocks are intensely sheared, greenish-brown phyllonites, which strongly suggest the presence of a low-grade, high-strain zone (cf. Blackwood, 1977).

Thus, it is proposed that an Early phase of sinistral transpression, which developed during ?low greenschist-facies

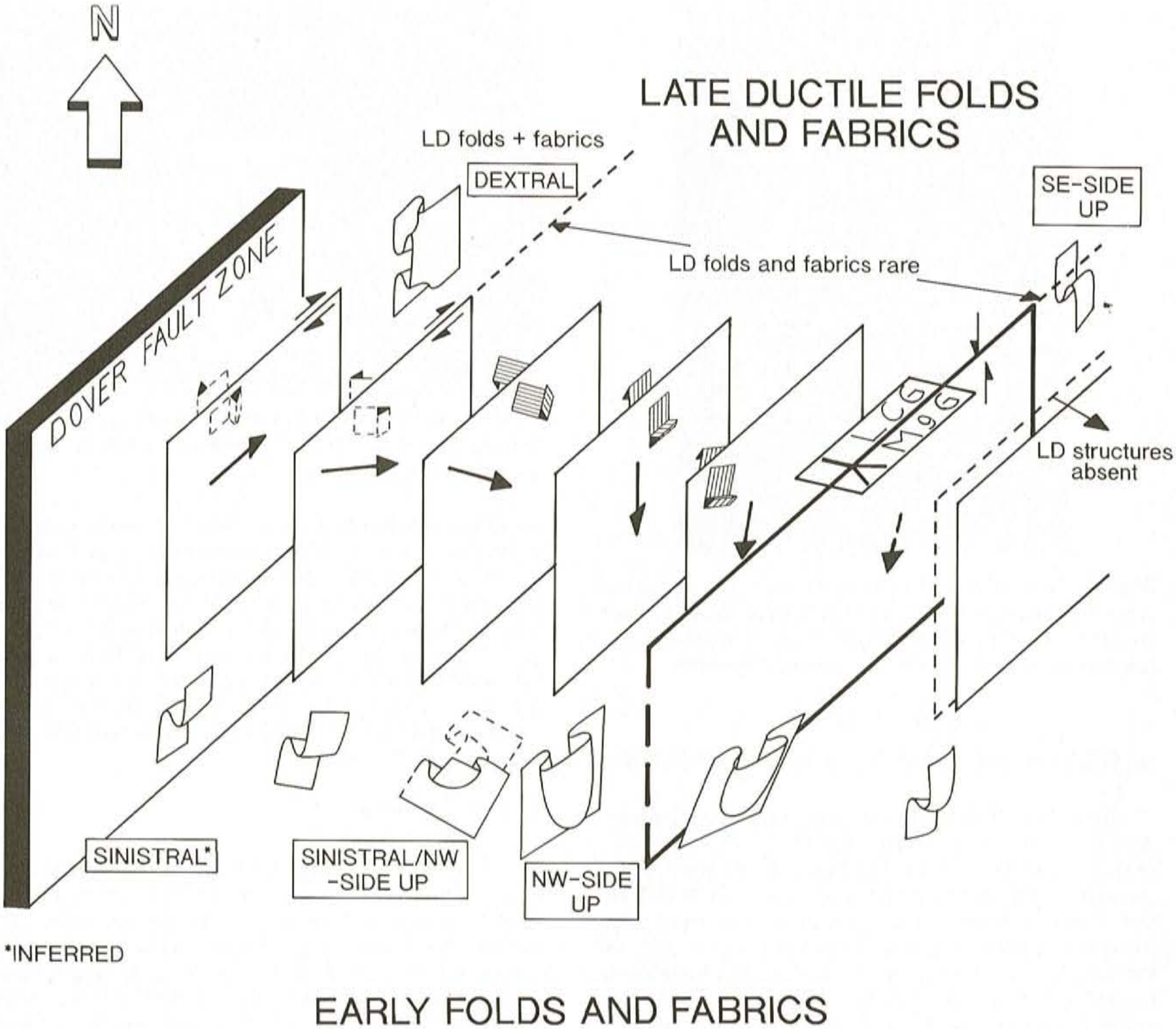

Figure 6. *3-dimensional diagram summarizing the structure of the northwest Avalon Zone, Bonavista Bay. The planes with solid arrows represent the regional tectonic cleavage and lineation respectively. Early and Late Ductile fold geometries are shown along the base and top of the diagram. Early shear sense is shown by the 3-D lined shear couple arrows; Late Ductile (LD) shear sense is shown by the solid-headed 2-D shear couple arrows. MgG and LCG = the Musgravetown and Love Cove groups respectively; note younging arrow across contact defined by thick line.*

metamorphism, is overprinted by dextral Later Ductile movements (?lower grade) in a narrow belt adjacent to the Dover Fault. The rotation of the lineation is probably a feature of the earlier deformation, reflecting an increasing component of sinistral shear toward the original northwest boundary of the Avalon Zone. Similar lineation patterns are widely recognized within transpression zones elsewhere (e.g., Sanderson and Marchini, 1984; Holdsworth, 1989; Holdsworth and Strachan, *in press*).

Faults ('Late Brittle' structures) are mostly northeast trending and have steep dips. They are particularly common along the contact of the Musgravetown and Love Cove groups and in the immediate vicinity of the Dover Fault. Many are associated with belts up to 100 m wide of greenish-grey rocks, which are commonly highly folded and/or brecciated. The folds have brittle deformation styles and are mostly steeply plunging with dextral senses of vergence. Minor fault offsets are also predominantly dextral. Thus, it is suggested that Late Ductile dextral movements were postdated by Late Brittle dextral faulting and associated minor folding. The actual age of these two sets of movements is discussed later.

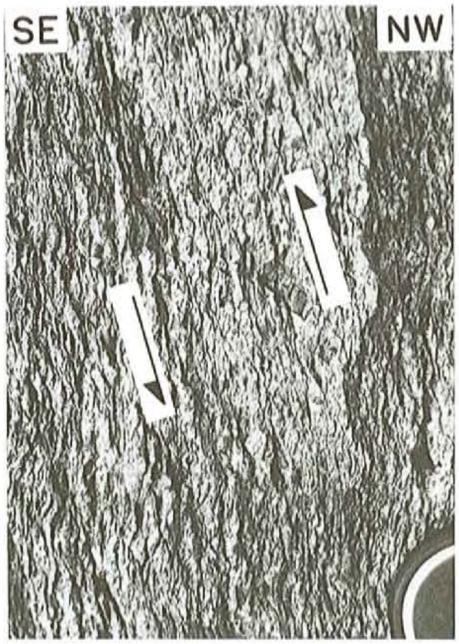

Plate 7. *Sheared crystal tuff of the Love Cove Group viewed in vertical surface parallel to steeply plunging lineation, south coast of Hare Bay. Centimetre-scale shear bands (an S-C fabric) give northwest-side-up senses of movement.*

DISCUSSION

NATURE OF THE GANDER–AVALON BOUNDARY

In the Hare Bay–Dover region (Figure 2), the Gander–Avalon boundary is most often marked by a Late Brittle fault. In three locations (1, 2 and 3 in Figure 2), brownish-green and grey phyllonites, interpreted to be derived from Love Cove Group volcanic rocks, are in contact with green phyllonites having pink sheared granitic layers that are interpreted to be derived from the Hare Bay Gneiss and Dover Fault Granite veins. The boundary is sharp and concordant and is interpreted as a ductile fault formed during the Late Ductile deformation. The most accessible exposure of the contact lies on the northwest side of a narrow peninsula northeast of the Hare Bay Municipal Park. The rocks here have been previously and incorrectly described as mylonitic Dover Fault Granite (e.g., Blackwood, 1977).

GANDER–AVALON CORRELATIONS

The present study confirms the fundamental differences in rock types, metamorphic grade and intrusive history that are apparent across the Gander–Avalon boundary. However, in the region close to the boundary, both zones preserve a three-phase kinematic history comprising: Early Ductile sinistral transpression (northwest-side-up), Later Ductile dextral transpression, and finally Later Brittle dextral faulting. The latter two phases are associated with displacements along the Dover Fault, with the main Gander–Avalon boundary being a ductile dextral fault. In the absence of any evidence to the contrary, it is here proposed that the earlier sinistral

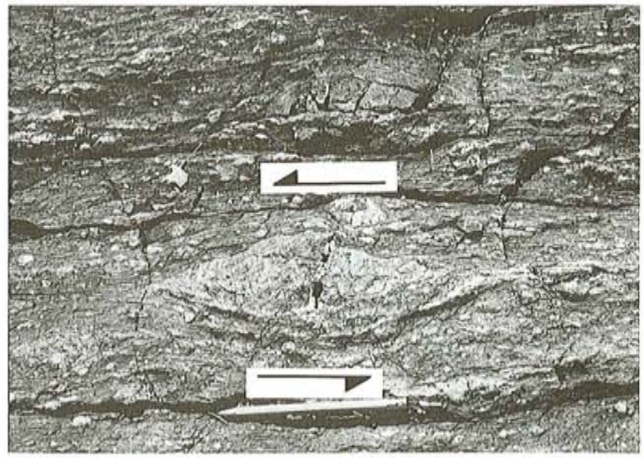

Plate 8. *Sheared volcanic breccia, Love Cove Group, 1 km west of location A in Figure 2. Asymmetric wrapping of clasts gives a sinistral sense of shear.*

events may also be correlatives. This structural linkage, first recognized by Caron and Williams (1988 a, b) pre-dates the Dover Fault, and may relate to the original juxtaposition of the Gander and Avalon zones. Thus, the Dover Fault may have reactivated an earlier sinistral boundary. The complete lack of other correlatable features across the boundary implies that lateral displacements are large, whereas the marked differences in metamorphic grade suggests that significant and probably rapid uplift of the Gander Zone has occurred (cf. Dallmeyer *et al.*, 1981).

TIMING OF EVENTS

The present study suggests that the Cape Freels Granite was intruded synchronously with the later stages of Early Ductile sinistral transpression in the Gander Zone. The Lockers Bay Granite appears to be slightly later, and is thought to have been intruded during the early stages of Late Ductile dextral movements. The unfoliated Middle Brook Granite appears to have been emplaced subsequent to all ductile deformation.

It is the author's view that much of the ductile deformation, metamorphism and plutonism in the Gander Zone occurred during a relatively short period. However, it is conceivable that the igneous protoliths of the earliest gneisses, the early isoclines and the migmatitic fabrics they fold in the metasedimentary rocks and the amphibolites, could be significantly earlier features.

If the correlation of events into the Avalon Zone is correct, all deformation in the Musgravetown and Love Cove groups in the study area is Paleozoic. However, the possibility that the Dover Fault, or its sinistral precursor, reactivated an earlier, deep-seated Avalonian structure cannot be discounted.

Geochronological studies to determine the age of principal orogenic phases in northeast Newfoundland are in progress. The magmatic and metamorphic character of the northeast Gander Zone is analogous in some respects to that of the Hermitage Flexure, and these similarities have led to the extrapolation of the Gander Zone into parts of southern Newfoundland (e.g., Colman-Sadd *et al.*, 1990). Given the widespread Silurian orogenesis in the latter area (e.g.,, Dunning *et al.*, 1990; O'Brien *et al.*, 1991) it is likely that a significant component of the geological history described here from northeast Newfoundland is Silurian (cf. Currie and Piasecki, 1989). The extent of Acadian (Devonian) ductile deformation in this part of the Appalachian Orogenic belt is uncertain; it is possible that the later stages of Late Ductile shearing are this age.

AGE OF BRITTLE FAULTING

Many of the Late Brittle faults appear to have formed preferentially within the regions affected by low-grade Late Ductile shearing, most obviously, the Dover Fault shear zone. This has led some authors (e.g., Caron and Williams, 1988a, b) to imply that significant amounts of faulting are simply continuations of the earlier ductile dextral movements as the fault zone passed through the brittle-ductile transition during uplift and erosion. Whereas this may have happened in some instances, regional field relationships suggest that much of the brittle faulting is significantly later and that the coincidence with earlier ductile shear zones is therefore a feature of reactivation. In particular, the intrusion of the unfoliated Newport Granite postdates ductile, but pre-dates brittle dextral movements along the Dover Fault Zone. This granite has an Rb–Sr whole-rock date of 332 ± 42 Ma, which has been interpreted as an intrusion age (Bell *et al.*, 1979). Whereas a high precision U–Pb date is clearly required, the existing date means that an Alleghanian age of brittle movement cannot as yet be discounted in the Bonavista Bay region.

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