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GEOLOGICAL DEVELOPMENT OF THE AVALON ZONE, THE EASTERNMOST GANDER ZONE, AND THE DUCTILE DOVER FAULT IN THE GLOVERTOWN (NTS 2D/9, EAST HALF) MAP AREA, EASTERN NEWFOUNDLAND

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ABSTRACT

The eastern portion of the Glovertown (NTS 2D/9) map area comprises two contrasting domains, each characterized by profoundly different geological histories. Rocks in the east form part of the Avalon Zone, and include strata previously assigned to the late Precambrian Love Cove and Musgravetown groups. The Avalonian geological record in this area is of widespread shallow-marine to terrestrial sedimentation and volcanism, and subsequent low-grade regional metamorphism accompanying a relatively simple, slate-belt-style of deformation. In contrast, the Gander Zone to the west is represented by a sillimanite-grade gneiss complex (Hare Bay Gneiss) that is host to numerous granitic sheets, many of which are of regionally mappable dimensions. Almost all have been deformed to varying degrees with the surrounding gneisses.

Adjacent to their north-northeast-trending boundary, the Avalon and Gander zone rocks are affected by a zone of early ductile sinistral transpression, which is overprinted by lower grade ductile and subsequent brittle, dextral displacements. The early ductile deformational event in the Gander Zone is associated with a kilometre-scale, steep belt of focussed high-grade metamorphism, migmatization and granitic plutonism. In the northern half of the map area, an almost complete section of the later ductile, dextral mylonites is preserved within the ductile Dover Fault Shear Zone. In the southern part of the area, however, these mylonites are cut out by later dextral faults. The coarse-grained, K-feldspar porphyritic Terra Nova Granite postdates all but the youngest brittle movements along the Gander–Avalon zone boundary and in the adjacent country rocks.

INTRODUCTION

The eastern part of the Glovertown (NTS 2D/9) map area (Figures 1 and 2) is traversed by a complex, north-northeast-trending, steeply dipping tectonic zone, characterized by a reactivated transpressional deformational history. In the study area, as is the case elsewhere in the northeastern Newfoundland Appalachians (e.g., Blackwood, 1978; Holdsworth, 1991), this tectonic zone juxtaposes a lower Paleozoic, amphibolite-facies, granite–gneiss terrane to the west (Gander Zone; Williams, 1979) with a late Precambrian, greenschist-facies, terrestrial to shallow-marine, volcano-sedimentary terrane to the east (Avalon Zone; Williams, 1979). Evidence of any linkage between rocks on either side of this boundary prior to their initial juxtaposition is not apparent. Both regions, however, do share a common structural history related to movements along their mutual boundary. A broad zone of early ductile, sinistral transpression in both the Avalon and Gander zones is overprinted by lower grade ductile dextral displacements that form the boundary observed at the present day—the Dover Fault (Younce, 1970; Blackwood and Kennedy, 1975). Subsequent brittle, dextral faults disrupt and crosscut earlier ductile structures, including the Dover Fault. In the eastern

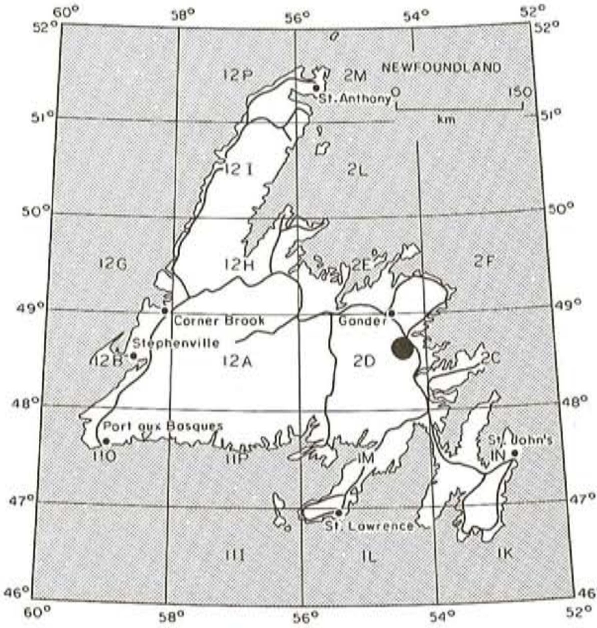

Figure 1. *Approximate location of the study area.*

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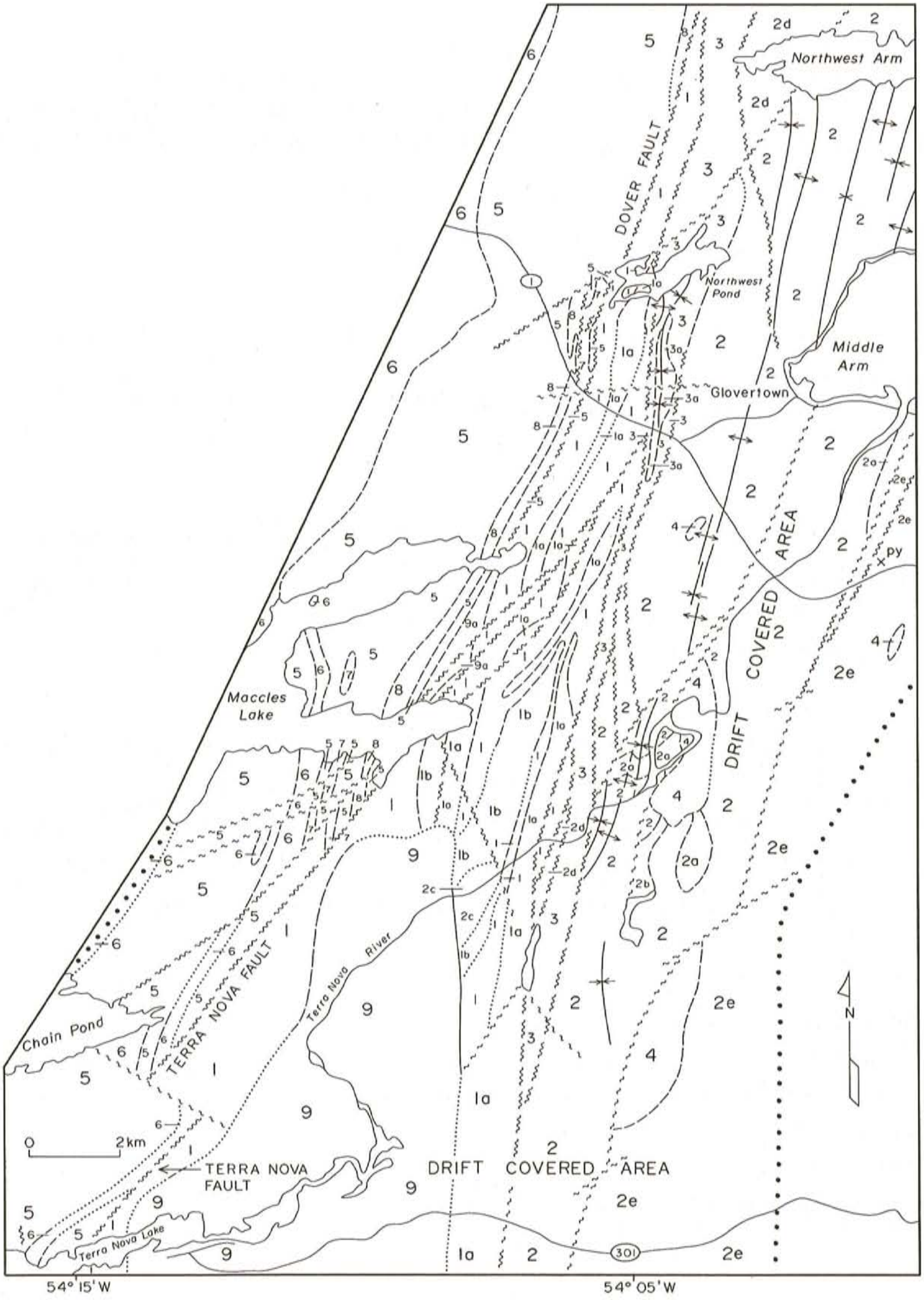


Figure 2. *Preliminary geological map of the eastern part of the Glovertown map area.*

LEGEND (for Figure 2)

DEVONIAN?

TERRA NOVA GRANITE

9 *Massive to very weakly foliated, pink, medium- to mainly coarse-grained, K-feldspar porphyritic, biotite ± hornblende granite; rare aplite;* **9a:** *coarse-grained, quartz-rich, biotite granite; minor pegmatite and graphic granite*

SILURIAN?

DOVER FAULT GRANITE (UNIT 8)

8 *Mylonitic, variably megacrystic to coarse-grained, K-feldspar porphyritic granite; ultramylonite; amphibolite; minor, weakly foliated granite*

7 *Foliated, fine-grained muscovite–biotite leucogranite; locally contains unseparated megacrystic granite sheets*

6 *Foliated, pink, grey and white, K-feldspar megacrystic biotite granite, locally intruded by minor unseparated leucogranite; contains minor metasedimentary rocks*

EARLY ORDOVICIAN OR EARLIER

HARE BAY GNEISS

5 *Unseparated metasedimentary gneiss and amphibolite, mobilized gneiss and orthogneiss*

LATE PRECAMBRIAN

4 *Unseparated gabbro and diabase*

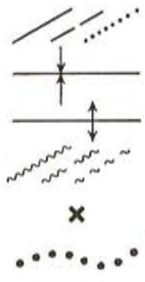
MUSGRAVETOWN GROUP

3 CROWN HILL FORMATION: *red, maroon and purple, planar-bedded and crossbedded sandstone; minor shale and pebble conglomerate;* **3a:** *volcanic breccia, aquagene tuff, red and green sandstone*

2 ROCKY HARBOUR FORMATION: *green and yellow, crossbedded sandstone; minor green conglomerate and red sandstone;* **2a:** *massive and flow-banded rhyolite; minor felsic pyroclastic rocks;* **2b:** *basalt, mafic tuff and associated metabasic rocks;* **2c:** *highly cleaved, green sandstone and hornfels;* **2d:** *undivided, red and green sandstone;* **2e:** *variably strained, mainly green, massive, thin-bedded and crossbedded sandstone and phyllite; contains unseparated flows and dykes of mafic composition and minor felsic tuff*

1 *Moderately to highly strained green, yellow, buff and white rhyolitic to dacitic tuff and volcanic breccia; phyllonite; sericite schist;* **1a:** *mainly moderately strained, red, maroon and pink felsic volcanic rocks; parataxitically banded rhyolite, ash-flow tuff and rheoignimbrite; minor unseparated tuffaceous sedimentary rocks;* **1b:** *basalt, mafic tuff and minor chlorite schist*

SYMBOLS



Geological contact (defined, approximate, assumed)..........

Axial trace of syncline..........

Axial trace of anticline..........

Fault (defined, approximate, assumed)..........

Mineral occurrence..........

Limit of geological mapping..........

part of the Gander Zone, widespread granitic magmatism and high-grade metamorphism are associated with the early, ductile, sinistral movements.

AVALON ZONE

The Avalon Zone rocks are disposed in continuous, north- to north-northeast-trending belts that are bounded, in most cases, by faults. Adjacent to the Gander Zone, there is an extensive tract of phyllonitic to moderately or weakly cleaved, low-grade, volcanic rocks (Unit 1; Figure 2), mapped by Jenness (1963) and subsequent workers as part of the late Precambrian Love Cove Group. This exclusively volcanic belt is bounded to the east by redbeds, which in turn are underlain by clastic sedimentary rocks of shallow-marine to terrestrial origin (Rocky Harbour and Crown Hill formations; Figure 2). Both of the latter units have been assigned by Jenness (1963) to the late Precambrian Musgravetown Group. The contact of the 'Love Cove' belt with the red clastic sedimentary unit at the top of the Musgravetown Group succession is faulted. However, several lines of evidence suggest that rocks previously assigned to the Love Cove Group, in this map area, are significantly younger than the type Love Cove Group, which underlies a thick and extensive succession of deep-marine turbidites (Connecting Point Group) farther to the east (O'Brien, 1987; O'Brien and Knight, 1988). It is likely that, within the study area, much of the volcanism is, in the broadest sense, coeval with Musgravetown Group sedimentation, although their exact stratigraphic relationship remains uncertain. Hence, the name 'Love Cove Group', previously used by Jenness (1963) and subsequent workers to designate these rocks, will not be employed here.

UNIT 1: UNNAMED VOLCANIC ROCKS

The westernmost of the Avalonian stratigraphic units is composed of inhomogeneously deformed, variegated volcanic rocks that lie in a northward-thinning belt bordered by the Gander–Avalon tectonic boundary and by redbeds of the Musgravetown Group (Crown Hill Formation). These rocks form part of a much more extensive volcanic belt that extends from the coast of Bonavista Bay southward, for a distance of approximately 100 km, to the Ackley Granite (Colman-Sadd *et al.*, 1990).

The volcanic flows and pyroclastic rocks represent a continuum of compositions ranging from rhyolite to dacite and, more rarely, andesite and basalt. Texturally, they vary from phyllonitic mylonites to moderately cleaved rocks, and in some areas, may carry only a weak fracture cleavage. There appears to be a general westward, albeit non-systematic, increase in deformation toward the Gander Zone, although the regional strain is inhomogeneous. A three-fold lithological division of this belt has been established; no internal stratigraphic order is implied. It remains possible that rocks with significantly different ages occur within this westernmost belt of Avalonian rocks.

Unit 1 is mainly composed of moderately to highly strained, green, yellow, buff and white, rhyolitic to dacitic tuff. These fine-grained rocks are, in many areas, spatially associated with subordinate amounts of monolithic and polylithic volcanic breccia (Plate 1). Adjacent to the Gander–Avalon zone boundary, the tuffs and flows are reduced to green phyllonites. Narrow zones of sericitic schist derived from the above rocks are locally developed throughout this belt. Primary banding is preserved, but in many cases, it has been transposed into parallelism with a single cleavage. In some localities, the tuffs are crosscut by highly cleaved and folded mafic dykes; in general, however, dykes are not particularly widely developed within this belt. Thermal metamorphism of Unit 1 tuffs in the aureole of the Terra Nova Granite has produced extensive areas of hornfels, which in the vicinity of Maccles Lake, have largely obliterated tectonic fabrics adjacent to the boundary with the Gander Zone.

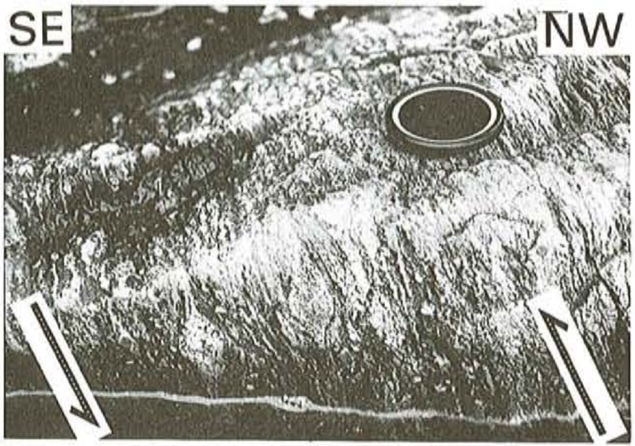


Plate 1. *Volcanic breccia of Unit 1, viewed toward the southwest, south shore of Maccles Lake (southeast arm). Note that asymmetric wrapping of the clasts in a steep surface oriented parallel to mineral lineation gives a northwest-side up sense of shear.*

A distinctive subunit (1a), consisting mainly of moderately strained, red, maroon and pink felsic volcanic rocks, comprises four semi-continuous bands that extend along much of the Unit 1 belt. A singularly significant lithological association within this subunit is parataxitically to flow-banded rhyolite, ash-flow tuff and rheoignimbrite, exposed near the southeast end of Maccles Lake (Plate 2). In that area, the latter rocks demonstrate a marked variation in strain. Over a distance of several metres, flows in which intricate, primary banding is preserved become progressively more deformed, until they are finally reduced to schists. Significantly, these texturally and compositionally distinctive volcanic rocks closely resemble the lithology most diagnostic of the Bull Arm Formation of the Musgravetown Group in the Bonavista Bay area, and in its equivalents elsewhere (O'Brien, 1987; O'Brien and Knight, 1988).

Less-common mafic volcanic rocks (subunit 1b) are mainly fine-grained and, in places, vesicular basaltic flows, which are largely confined to a northward-closing structure in the central portion of the study area. As way-up criteria are not preserved, the stratigraphic relation of these rocks

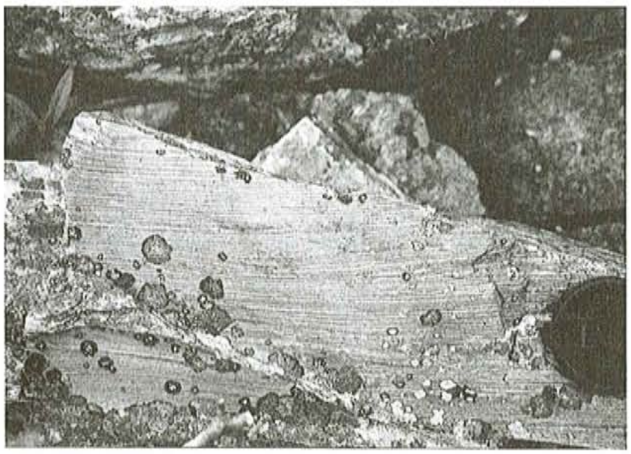


Plate 2. *Parataxitic banded rhyolite of subunit la, south shore of the southeast arm of Maccles Lake.*

to the other subunits remains equivocal. A smaller band of epidotized, mafic lithic tuff and coarser-grained, mafic breccia is faulted against subunit la rhyolite on the southeast arm of Maccles Lake.

In most previous accounts (e.g., Jenness, 1963; Blackwood, 1977; Hussey, 1979), the Unit 1 volcanic rocks and their along-strike equivalents have been included in the Love Cove Group. This unit is characteristic of the northwest Avalon Zone and traditionally is considered to occupy two separate belts separated by an intervening area of Musgravetown Group rocks. The volcanic rocks in question here, lie within the western Love Cove belt. Controversy has long surrounded the nature of this group's external contact relationships, and in particular, its contact with the Musgravetown Group. Jenness (1963) stated that the Love Cove–Musgravetown group contact was everywhere tectonic. However, on the basis of regional considerations, he assigned the Love Cove Group an older age and proposed that the two groups were separated by an angular unconformity. Younce (1970) disagreed, arguing that rocks previously assigned to the Love Cove Group throughout Bonavista Bay were, in part, deformed equivalents of the Musgravetown Group. Hussey (1979) subsequently contended that the Musgravetown Group conformably overlies the Love Cove Group, thus challenging Jenness's assertion that the Love Cove Group suffered regional deformation and metamorphism prior to Musgravetown Group deposition. Reusch and O'Driscoll (1987) inferred that the main western belt of the Love Cove Group was thrust eastward over the adjacent Musgravetown Group. Most recently, Holdsworth (1991) has presented evidence that supports a post-Musgravetown Group age for the western belt of Love Cove Group rocks in the Hare Bay–Dover area.

In the present study area, the boundaries of the unnamed Unit 1 volcanic belt are faulted. However, west of Glovertown, at Maccles Lake Brook and in the high ridges west of the Terra Nova River, the upper kilometre of the Musgravetown Group is observed to young consistently westward toward Unit 1. Moreover, significant volcanic intercalations occur in the uppermost part of the Musgravetown Group. Finally, texturally uncommon volcanic rocks, characteristic of the Musgravetown Group, are present within the Unit 1 succession. These three significant observations are consistent with the hypothesis that at least some of the Unit 1 volcanic rocks are broadly coeval with and possibly younger than some of the adjacent terrestrial sedimentary rocks of the Musgravetown Group. Until more conclusive data are available, the authors suggest that the name Love Cove Group be reserved for the volcanic rocks of demonstrable pre-Musgravetown Group age that conformably underlie the Connecting Point Group (cf. O'Brien and Knight, 1988; Knight and O'Brien, 1988). To date, such rocks have only been identified in the eastern Love Cove belt.

UNIT 2: ROCKY HARBOUR FORMATION

The most extensive Avalonian stratigraphic unit in the Glovertown area is composed of a monotonous succession of crossbedded, yellow-green sandstones, part of the Rocky Harbour Formation of the late Precambrian Musgravetown Group (Jenness, 1963). Within the study area, these sandstones pass conformably upward into the topmost red clastic sedimentary succession of that group, the Crown Hill Formation (Jenness, 1963). A few kilometres along strike to the northeast, in the adjacent St. Brendan's map area (NTS 11P/13; O'Brien and Blackwood, 1987), basal Rocky Harbour conglomerate lies disconformably upon volcanic rocks of the Bull Arm Formation.

The Rocky Harbour Formation forms structurally distinct but lithologically similar belts, separated by north-northeast-trending faults. The westernmost belt, which passes upward into the Crown Hill strata, is deformed by broad, open, regional anticlines and synclines, and is homoclinal over large areas. In contrast, rocks farther to the east appear to be characterized by generally higher, albeit inhomogeneous, bulk strain.

The principal rock types of the Rocky Harbour Formation are medium- to coarse-grained, green, yellow-green and buff, lithic sandstones. Typically, these exhibit well-defined, planar-, trough- and ripple-drift cross-stratification (Plate 3), although, in places, thin planar-bedded sandstones are predominant. The amplitude of crossbeds is variable and in many areas exceeds 50 cm. In several places, slumps and rip-ups are well preserved in these sandstones. Green pebble and cobble conglomerates, in places rich in green and, in one case, red, fine-grained felsite and flow-banded rhyolite clasts, are locally interbedded with the finer grained rocks. Subordinate amounts of red and maroon, fine-grained sandstone and, more rarely, granule conglomerate are interstratified with the other sandstones throughout the succession, most notably near the top of the formation. The red clastics are locally rich in coarse-grained, detrital muscovite.

A several-decametre-thick unit composed of interstratified felsite, rhyolite, and fine-grained felsic fragmental volcanic rocks (subunit 2a) occurs within the Rocky Harbour Formation near Grant Falls, on the Terra

Plate 3. *Crossbedded sandstones typical of the Rocky Harbour Formation, Musgravetown Group.*

Nova River. The variegated volcanic rocks overlie crossbedded sandstones, and are succeeded by thick-bedded sandstones having pebbly interlayers that are, in turn, overlain by a basalt flow and more cross-stratified sandstones. The latter rocks then persist to the top of the formation, attaining a thickness in the order of 1 km. Less continuous bands of rhyolitic flows and fine-grained, felsic tuffaceous rocks are more extensively developed in the eastern part of the Rocky Harbour Formation. Mafic plutonic rocks in the form of numerous dykes and narrow, sheet-like gabbroic bodies cut the eastern Rocky Harbour belt, whereas extrusive rocks of similar composition (subunit 2b) are rare.

At the top of the Rocky Harbour Formation, the yellow-green, crossbedded sandstone lithofacies becomes interbedded with pebbly volcanogenic sandstone and red-maroon tuffaceous sandstone. The contact with the overlying Crown Hill Formation is gradational over a few metres, and is drawn at the point in the succession where red sandstones become the predominant rock type.

UNIT 3: CROWN HILL FORMATION

A narrow but continuous band of red terrestrial clastic rocks overlies the Rocky Harbour Formation in the central portion of the study area and is mapped as part of the Crown Hill Formation of the Musgravetown Group (Jenness, 1963). The total thickness of the exposed red clastic succession in the study area is probably less than 500 m.

The lower part of this succession contains planar-bedded and poorly bedded, pale-red and bright-red sandstone, siltstone and shale. Locally, thin, buff and pale-green beds are intercalated with the redbeds. Polymictic, rounded-pebble and cobble conglomerate overlies the finer grained rocks in the northern part of the area. Their detrital assemblage includes red rhyolite, red and green dacite, red and green sandstone and shale and dark-green metabasic rocks. Some of the coarse-grained red sandstones are rich in detrital muscovite. The redbeds locally pass upward into grey-green and purple, pebbly sandstone, siltstone and mudstone that contain basaltic detritus in addition to intraformational sedimentary clasts. The latter are imbricated and, in places, display evidence of soft-sediment deformation; neptunian dykes are locally developed.

Spatially associated with the grey to purple rocks are coarse-grained, crudely bedded to massive volcanic and epiclastic breccias of probable laharic origin (subunit 3a). These fragmental rocks are composed of a green, pumice-rich, sandy matrix containing felsic volcanic blocks up to 50 cm diameter, and smaller, angular to thixotrophically deformed, intraformational rip-up clasts.

The thickness ($\leq$ 500 m) of Crown Hill Formation preserved in this area is significantly less than that exposed farther south in the type area (e.g., Jenness, 1963) but is comparable to thicknesses measured along strike to the north in vicinity of Deer Island (O'Brien and Knight, 1988). Within the study area, the stratigraphic top of the succession is not exposed; its contact with the adjacent dominantly volcanic belt (Unit 1; Figure 2) is tectonic. However, the presence of interbedded volcanic rocks near the top of the Crown Hill Formation, coupled with the observation that the Rocky Harbour–Crown Hill succession youngs regionally westward, suggests that some portion of the adjacent volcanic belt may be coeval with and, conceivably, in part younger than these terrestrial sedimentary rocks (see above).

UNIT 4: UNNAMED MAFIC INTRUSIONS

One relatively large and several smaller mafic plutons are intrusive into the Musgravetown Group within the map area (Figure 2). These poorly exposed intrusions are lithologically variable and include fine- and medium-grained gabbro, minor diorite and diabase. These are locally fractured, foliated and epidotized and are assumed to be pretectonic intrusions.

GANDER ZONE

Sillimanite-grade paragneisses and orthogneisses (Unit 5: Figure 2), part of the Hare Bay Gneiss of Blackwood (1977), are the predominant rock types within the Gander Zone in the map area. Elongate sheets of deformed megacrystic biotite granite (Unit 6: Figure 2) intrude the Hare Bay Gneiss and are very broadly synkinematic with respect to the regional high-grade metamorphism of the gneisses; their intrusion is associated with an early phase of ductile sinistral shear along the Gander–Avalon zone boundary (Holdsworth, 1991). Smaller elongate sheets of foliated muscovite–biotite granite (Unit 7; Figure 2), locally associated with the megacrystic bodies, crosscut both gneiss and megacrystic granite. A narrow, semi-continuous sheet of medium- to coarse-grained porphyritic biotite granite (Unit 8; Figure 2), intrusive into the Hare Bay Gneiss, is situated close to and sub-parallel with the Gander–Avalon zone boundary. Unlike the older granites, this body is everywhere deformed by dextral shearing.

UNIT 5: HARE BAY GNEISS

The Hare Bay Gneiss is most accurately portrayed as a gneiss complex, composed of three main components. These are, in order of relative age, (1) metasedimentary rocks and early amphibolites, (2) variably mobilized gneisses and (3) orthogneisses (cf. Holdsworth, 1991). Boundaries between individual components are, in most cases gradational, and interbanding of these units occurs on all scales. Thus, individual sub-divisions have not been mapped on a regional scale and are not distinguished on the accompanying map (Figure 2).

The metasedimentary rocks and early amphibolites, in essence banded paragneisses (cf. Blackwood, 1978), occur as screens and rafts on all scales, intimately intermingled with zones of mobilized gneiss, orthogneiss and granite. They are mostly banded metasedimentary rocks of psammitic, semipelitic and pelitic composition. Locally, they contain very minor amounts of pale-green, impure marble, which occurs as lensoid bodies up to 1 m across. Banded amphibolites form continuous interlayers or elliptical pods from a few centimetres to several tens of metres width. Contacts with adjacent metasedimentary rocks are sharp and, although tectonic strain has obliterated any vestige of discordance, an early intrusive origin for the amphibolites seems most likely (Holdsworth, 1991).

The mobilized gneisses are, in most cases, interpreted to have formed by the pervasive partial melting of extensive regions of semipelitic metasedimentary rocks. They are typically dark grey and coarse grained, and have a well-defined granodioritic leucosome. In most areas, the mobilized gneisses contain abundant, small schlieren and enclaves, which are derived from the parent sedimentary rock. Examples of highly deformed mobilized gneisses are well exposed in outcrops along the southern shore of the northeast arm of Maccles Lake (Plate 4).

The orthogneisses are grey to grey-pink rocks of granitic to granodioritic composition. In addition, pyroxene–hornblende-bearing dioritic orthogneiss is also locally present; for example, parts of the southeast arm of Maccles Lake. Its contacts are not exposed and thus its relation to other orthogneisses are not clearly understood. Bands of dioritic orthogneiss, less than 10 m thick, are also exposed in roadcuttings along Route 1.

In most cases, the orthogneisses are not derived from mobilization of the adjacent metasediments, and they may simply represent the earliest members of the granitic intrusive suite. However, in this discussion, they are defined separately, because at least some may prove to be older bodies (see, for example, Holdsworth, 1991, p. 112). Nevertheless, an apparent gradation between orthogneiss and granite does exist on all scales.

Within the shear zone associated with the Dover Fault (see below), the Hare Bay Gneiss is reduced to discoloured, dark-green, chlorite–sericite phyllonites containing numerous feldspar porphyroclasts and variable numbers of millimetre- to centimetre-scale, pink mylonitic lenticles. The latter appear to represent intensely deformed granite veins, and their presence may be used to distinguish these phyllonites from those derived from adjacent Avalon Zone volcanic rocks.

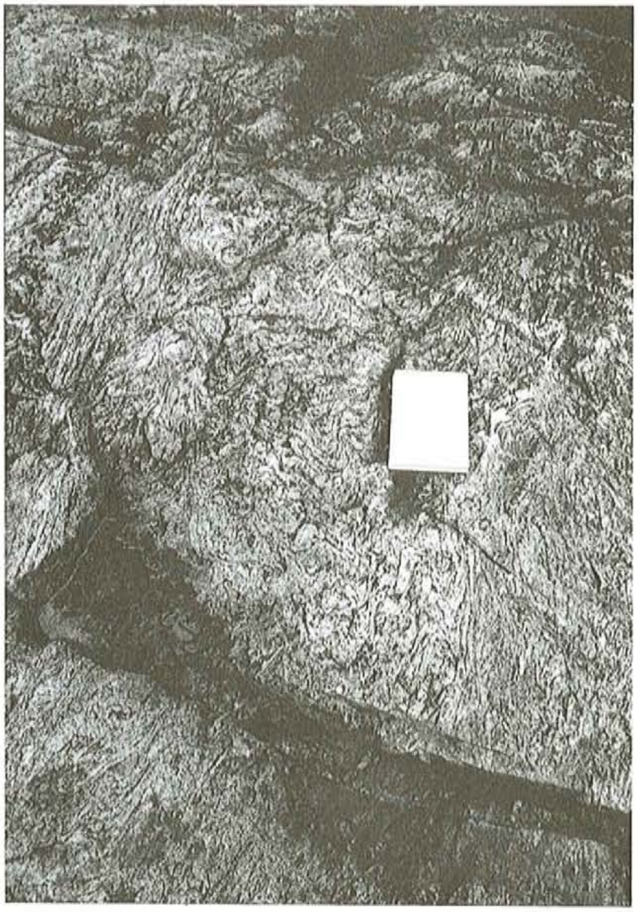


Plate 4. *Typical early ductile folds in mobilized, semi-pelitic Hare Bay Gneiss (Unit 5) outside of the Dover Fault Shear Zone, northeast arm of Maccles Lake.*

UNITS 6 and 7: MEGACRYSTIC BIOTITE AND TWO-MICA GRANITES

Megacrystic biotite granite (Unit 6; Figure 2) and intimately associated units of pink, two-mica granite (Unit 7; Figure 2) are here interpreted to represent the earliest intrusive bodies in the Gander Zone exposed within the study area. The megacrystic biotite granite intrusions are very similar to other sheets of this type observed around Bonavista Bay, most notably the Lockers Bay and Cape Freels granites (Blackwood, 1977; Jayasinghe, 1978). Like those in the study area, these latter granitic intrusions are closely associated with numerous sheets of two-mica granite.

In the study area, these granites are extensively developed within the tract of Hare Bay Gneiss south of Maccles Lake, where they form several composite, elongate, sheet intrusions. These bodies, which vary from a few centimetres to many tens of metres across, have been emplaced sub-parallel to the regional banding in the gneisses. In all cases, the presence of screens and elongate enclaves of gneiss is a common feature of the intrusions. Adjacent country rocks are often extensively and intimately sheeted with megacrystic granite on a centimetre- to metre-scale (Plate 5). A larger and more homogeneous body of foliated megacrystic biotite granite bounds the western margin of the Hare Bay Gneiss north of Maccles Lake. Near the community of Terra Nova, both megacrystic biotite and two-mica granites host large inclusions of medium- to coarse-grained diorite and gabbro. The diffuse nature of gabbro - granite contacts coupled with locally developed magma mixing textures (Plate 6) support the existence of a co-genetic mafic component to the granitic magmatism.

Plate 5. *Plan view of sheets of megacrystic biotite granite in metasedimentary paragneiss, Hare Bay Gneiss (Unit 5), south shore of Maccles Lake.*

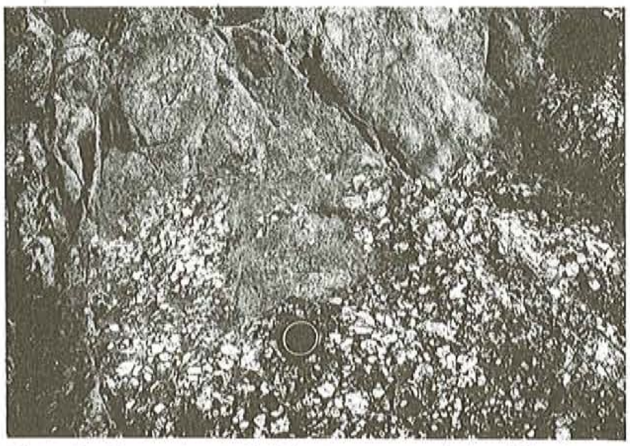


Plate 6. *Irregular and diffuse contact relationships between coexisting K-feldspar megacrystic biotite granite (light) and gabbro (dark).*

The megacrystic biotite and the two-mica granites contain strong magmatic-state foliations (cf. PFC fabrics as defined by Hutton, 1988), which are variably overprinted by solid-state fabrics. Shear-band foliations are abundant within these rocks and consistently indicate sinistral senses of displacement.

The eastern margin of what has been previously mapped as Maccles Lake Granite is also a foliated megacrystic biotite granite, associated with numerous sheets of two-mica granite. These rocks are presumably unrelated to the massive K-feldspar megacrystic granite that is typical of this pluton, suggesting that the presently defined Maccles Lake Granite is composite.

UNIT 8: DOVER FAULT GRANITE

The Dover Fault Granite is a narrow (≤500 m), elongate sheeted intrusion characterized by pink, variably megacrystic, biotite granite, which has been intensely deformed by ductile shearing associated with the adjacent ductile Dover Fault. This granite forms a semi-continuous body, well exposed between Route 1 and Maccles Lake (Figures 2 and 3); it is truncated by brittle faulting farther south. In all but one locality, the Dover Fault Granite is intruded into Hare Bay Gneiss; near Route 1, it is found in direct contact with volcanic rocks of the Avalon Zone.

Much of this intrusion is a very highly deformed mylonitic granite in which strongly wrapped feldspar porphyroclasts are the only surviving recognizable igneous component (Plate 7). A second textural type is found in the northern part of the study area where it lies immediately east of the mylonitic rocks. This second granite is characterized by weak to moderate solid-state strains and no magmatic foliation. Very rarely, narrow (<5 m) protomylonitic to mylonitic shear zones are developed. Areas of coarse-grained amphibolite and gabbro are locally associated with this low-strain granite. The faulted contact of massive and foliated rocks is exposed in a large quarry immediately north of Route 1. It is uncertain whether this less deformed granite is simply a slightly later, and therefore less-sheared body, or whether it represents low-strain regions within an otherwise strongly deformed sheeted complex.

The granite was originally emplaced as a series of sheets, sub-parallel to the regional banding in the Hare Bay Gneiss. In several areas, it is interlayered on a centimetre-scale with screens of dark, medium- to fine-grained amphibolite (Plate 8). Although these mafic units superficially resemble amphibolites of the Hare Bay Gneiss, they do not occur in the adjacent country rocks, and thus most likely represent intensely deformed coexisting mafic intrusions, emplaced synchronously with the granite.

MINOR INTRUSIONS

Minor intrusive bodies, unseparated on the accompanying map (Figure 2), include numerous sheets of pink granite, granite pegmatite and less-extensive granodiorite. These bodies, locally up to 20 m across, are found throughout the Hare Bay Gneiss, oriented parallel to, or at a low angle to, country-rock banding. At Terra Nova

Plate 7. *The σ-porphyroclasts (feldspar) in mylonitized granite, Dover Fault Shear Zone, Maccles Lake road. Note especially well developed, dextral shear-sense indicators below and right of pencil.*

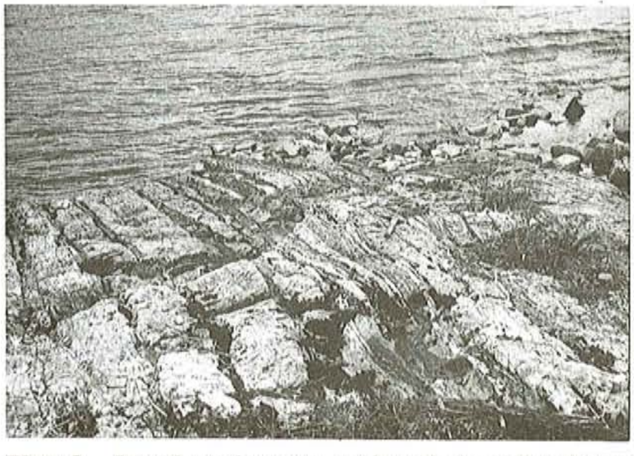


Plate 8. *Intersheeted granite, uniform dark amphibolite and metasedimentary screens, all mylonitized within the Dover Fault Shear Zone.*

Lake, the granites are cut by small dykes of unfoliated, dark grey-green diabase. Most of these are less than 1 m thick and all are crosscut by late brittle faults.

POST-DOVER FAULT INTRUSIONS

The youngest intrusive rocks in the study area, postdate all but latest brittle movements along the Gander–Avalon zone boundary and in adjacent country rocks. The largest of these is the Terra Nova Granite (Unit 9; Figure 2). This intrusion lies in the Avalon Zone portion of the study area, where it forms an irregular-shaped body with a rectilinear, north-trending eastern boundary. The diagnostic rock type of the Terra Nova Granite is pink to orange, coarse-grained, K-feldspar porphyritic, biotite–hornblende granite; a more medium-grained textural variant occurs locally. The granite is quartz-rich and in many places displays mantled feldspars, up to 5 cm in length. Although the granite is typically fresh and massive, it locally contains narrow alteration zones where a weak fracture cleavage has developed, and biotite is chloritized and feldspars are cloudy and hematitized.

The Terra Nova Granite truncates primary and tectonic layering in adjacent volcanic and sedimentary rocks. Cordierite porphyroblasts overprint the regional tectonic fabric in sedimentary rocks within its aureole. Variably cleaved hornfels locally occur as inclusions within the granite.

A probable apophysis of the main Terra Nova Granite forms a narrow and elongate, northeast-trending body (Unit 9a) situated between the northeast and southeast arms of Maccles Lake. Although petrographically similar, this granite is less texturally homogenous than the main body of Terra Nova Granite, containing coarse-grained quartz and extensive graphic or pegmatitic patches. It is mostly unfoliated, or contains a weak magmatic fabric, defined by feldspar laths aligned parallel to the regional banding. The granite is cut by small-scale brittle fractures and appears to predate very late brittle displacement along the Gander–Avalon zone boundary, along which it has been preferentially sited.

These intrusions are similar in many respects to other posttectonic granites spatially associated with the Gander–Avalon zone boundary elsewhere in Newfoundland (e.g., Ackley Granite, Dickson, 1983).

STRUCTURE OF THE GANDER–AVALON ZONE BOUNDARY

Along strike to the north, in the well-exposed region of western Bonavista Bay, three main deformational phases are recognized in the zone adjacent to the Avalon–Gander Zone boundary (Holdsworth, 1991). The earliest episode produced extensive high-strain zones, with associated sinistral sense of displacement that formed over a protracted period of time. The sinistral shear zones are viewed as broadly coeval with high-grade metamorphism, plutonism and migmatization in the eastern Gander Zone. These structures are progressively overprinted by greenschist mylonites developed within a dextral shear zone that defines the main Gander–Avalon zone boundary. Late brittle faulting disrupts this shear zone, and faults of this generation locally define the zone boundary.

In the Glovertown map area, the ductile dextral boundary is well preserved. This kilometre-wide zone of variably mylonitic and phyllonitic rocks, sited along the Gander–Avalon zone boundary, and derived from Hare Bay Gneiss and the Dover Fault Granite, is here termed the Dover Fault Shear Zone (DFSZ). From Maccles Lake northward (Figure 2), this ductile shear zone appears to be preserved more or less intact on the Gander Zone side of the boundary. South of Maccles Lake, however, a late, northeast-trending, brittle structure (the Terra Nova fault) excises a significant portion of the Gander Zone section (Figure 3), including the DFSZ. Thus, at Terra Nova Lake and Chain Pond (Figure 2), Avalonian volcanic rocks are faulted directly against gneisses and granites which, along strike and to the north, occur a considerable distance from the boundary. Within the study area, the ductile shear zone is best exposed along the northeastern and southwestern arms of Maccles Lake and also in a large quarry immediately northeast of Route 1.

DEFORMATIONAL FEATURES ASSOCIATED WITH THE DFSZ

The DFSZ is the most important and best exposed structure in the study area. For this reason, and also because its structures are directly related to movements along the Gander–Avalon zone boundary, it is described first.

Field observations indicate that the mylonites of the DFSZ formed under greenschist-facies metamorphic conditions and preserve chiefly primary, dynamic recrystallization textures. A characteristic set of minor structures have formed within the mylonites of the DFSZ, all of which indicate dextral strike-slip senses of movement (Figures 4 and 5). The same structures also overprint earlier structures in the Hare Bay Gneiss and associated granites for an additional 1 km west of the 1-km-wide zone of intense strain. The intensity of overprinting and retrogression increases progressively eastwards until most earlier structures are obliterated. It is clear that regionally, these ductile movements become increasingly focused along the Avalon–Gander zone boundary.

The DFSZ has a sub-vertical foliation, striking just east of north, upon which a ubiquitous south-plunging stretching lineation is preserved (Figures 4 and 5). Shear-band fabrics and σ-porphyroclasts consistently indicate dextral senses of shear. Open to tight curvilinear folds of the mylonitic foliation and lineation are abundant on millimetre to centimetre scale. Where axes plunge sub-vertically, folds consistently display dextral vergence (Figure 4). In addition, thin, competent horizons may develop sinistral, antithetic, brittle shears. These

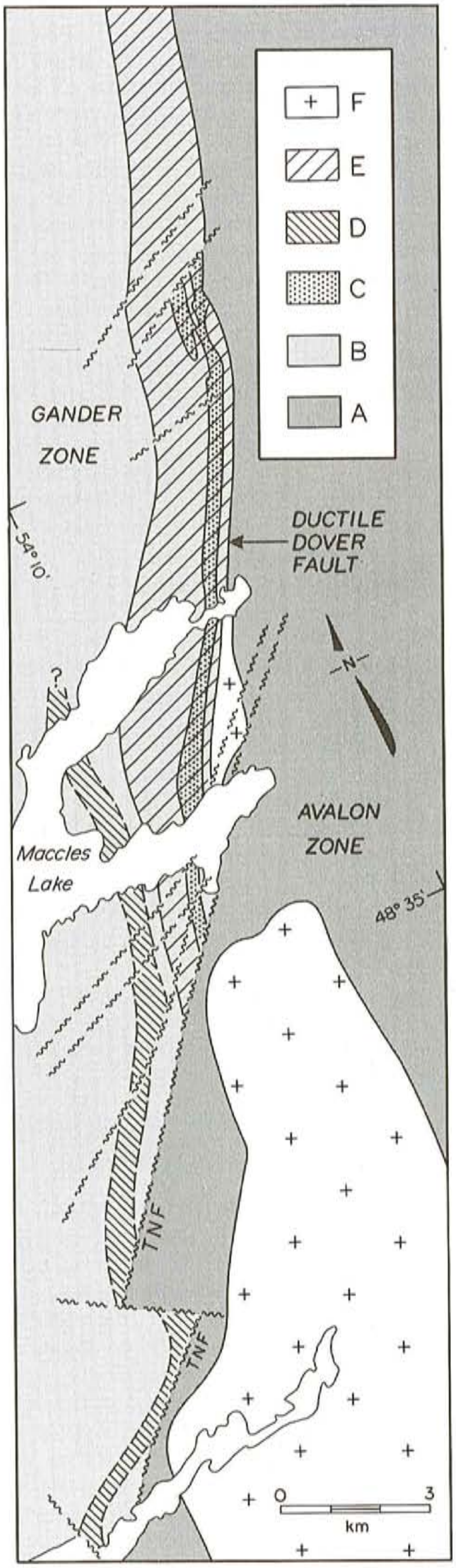
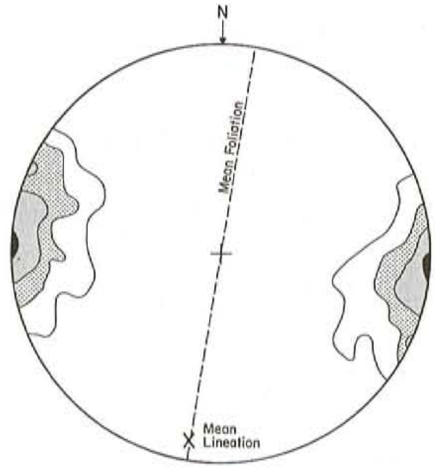
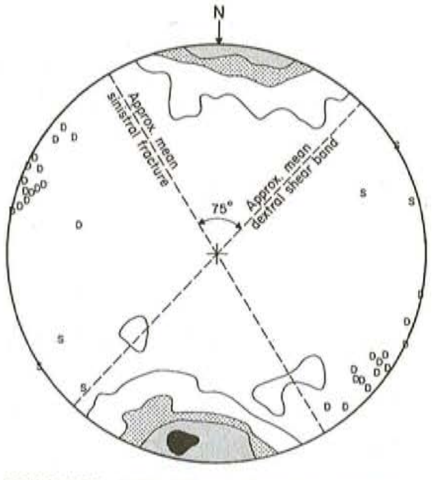


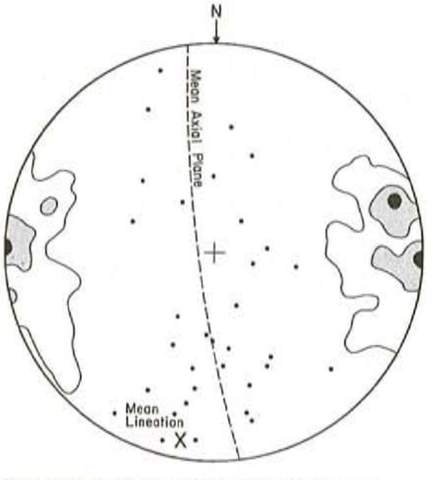
Figure 3. *Simplified map showing main structural components of the Gander–Avalon zone boundary. A = unseparated Avalon Zone; B = unseparated Gander Zone; C = Dover Fault Granite (Unit 8); D = sinistral shear zone; E = dextral shear zone; F = posttectonic Terra Nova Granite. Note that the Gander–Avalon zone boundary is the ductile Dover Fault in the northern part of the area and a later brittle fault (TNF = Terra Nova fault) in the south.*



CONTOURED DATA – Poles to lithological banding (n=109) (contours - 1%, 5%, 10%, 17.5%)



CONTOURED DATA – Mineral lineations (n=84) (contours - 1%, 5%, 10%, 20%)
D SYMBOLS – Poles to dextral shear bands (n=27)
S SYMBOLS – Poles to sinistral fractures (n=5)



CONTOURED DATA – Late ductile axial planes (poles) (n=33) (contours - 1.5%, 7.5%, 16%)
Dots - Late ductile fold axes (n=34)

Figure 4. *Stereonets showing structural data from the Dover Fault Shear Zone.*

are especially common within amphibolite screens within mylonitic Unit 8 granite. In well-exposed sections of the DFSZ, numerous foliation–parallel dextral faults are exposed. These are associated with small systems of rotating fault blocks, bounded by sinistral faults, which develop in areas where two dextral faults lie close together (F in Figure 5). These faults are everywhere crosscut by abundant late brittle structures and are thought to be part of the mylonitic structural suite. They may represent local zones of brittle failure within the mylonite zone, preferentially sited along the foliation.

In exposures of Avalon Zone volcanic rocks northeast of the DFSZ, a steep north-northeast-striking, slatey cleavage containing a steeply plunging stretching lineation is preserved. The cleavage lies at low angles to banding and is verging antiform to the east-southeast. Toward the Gander–Avalon zone boundary, the strain gradually increases, so that the cleavage and banding become parallel and the lineation rotates anticlockwise toward a shallower plunge (oriented west-northwest). In regions where the lineation plunge is steep, asymmetric wrapping of volcanic clasts gives northwest-side up and sinistral senses of shear (Plate 1). With proximity to the fault, where lineations have shallow plunges, only dextral shear senses are preserved. Although it has not be demonstrated in this area, a dextral over sinistral overprint is inferred, mainly on the basis of marked similarities with the Bonavista Bay coastal exposures (cf. Holdsworth, 1991).

The geometry and dextral kinematic shear sense of the DFSZ structures, together with the greenschist-facies metamorphic grade, indicate that these structures can be directly correlated with the late ductile structures associated with the Dover Fault farther north along the west coast of Bonavista Bay (Holdsworth, 1991). In that region, the ductile shear zone is highly disrupted by later brittle faults. Thus, exposures north of Maccles Lake in the present study area are particularly important, because they preserve the late ductile Avalon–Gander Zone boundary shear zone in its most intact form.

EARLIER DUCTILE DEFORMATION

The late ductile structures of the DFSZ, described above, overprint earlier folds and gneissic fabrics within the Hare Bay Gneiss. Unfortunately, good continuous sections through these rocks are not present in the study area. At Maccles Lake, the earlier structures are tight to isoclinal folds of the gneissic banding, which plunge sub-parallel to a moderate to strong, flat-lying, north-south stretching fabric (Plate 4). These structures closely resemble the early ductile folds recognized in the Bonavista Bay region (Holdsworth, 1991), which are thought to be equivalent to the regional F_3 folds of O'Neill (1991). On the coast of Bonavista Bay, such folds are associated with sinistral shear criteria. In the study area, however, no unambiguous evidence for this shear sense was observed in those locations where overprinting late, ductile shear bands or open folds are present.

A north-trending, ca. 1-km-wide, sinistral shear zone within the Gander Zone extends from the north shore of

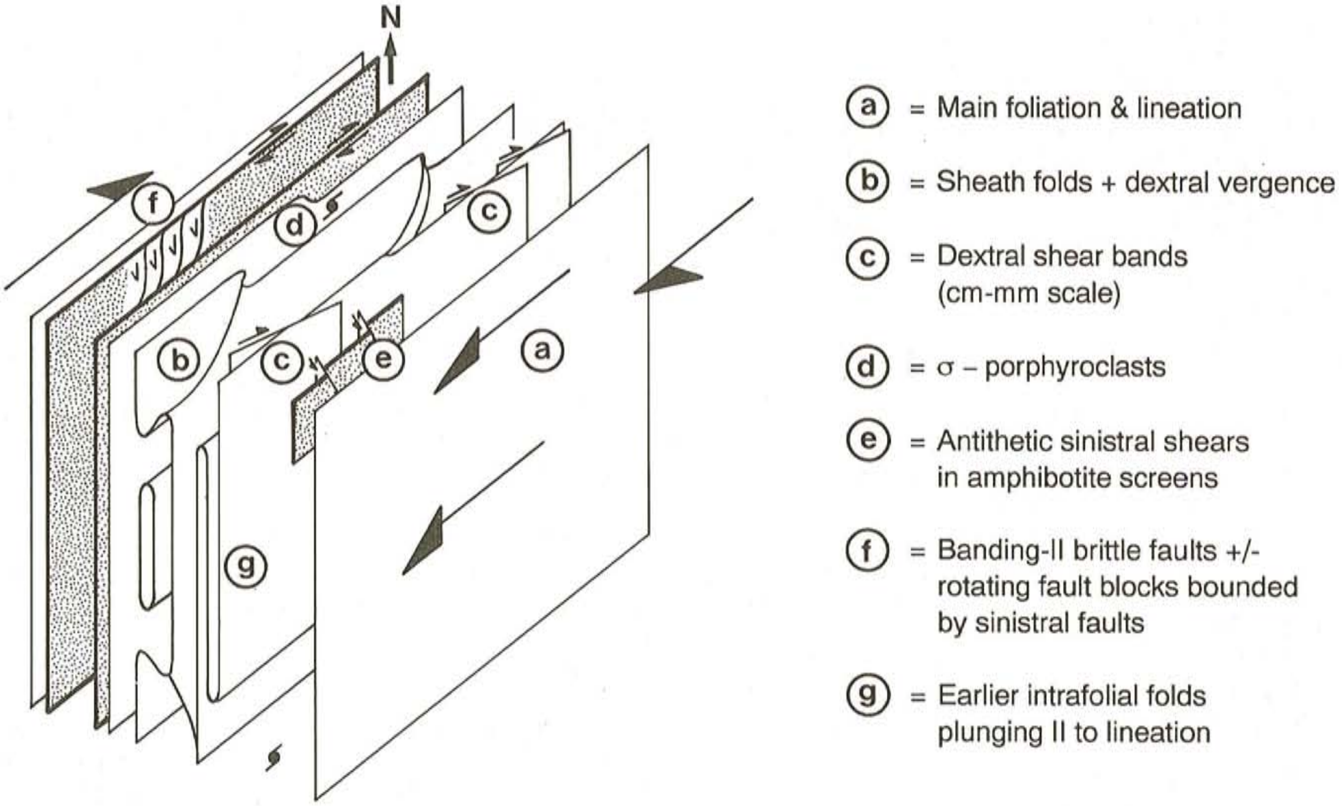


Figure 5. *A 3-dimensional summary diagram of minor structures associated with the Dover Fault Shear Zone (DFSZ). Compare with data in Figure 4. Note widespread evidence for dextral shear senses.*

Maccles Lake to Terra Nova Lake (Figures 2 and 3); its boundaries are not exposed. It is characterized by locally complex, polyphase deformation, attributed to protracted, progressive sinistral shear. In this area, protomylonitic to mylonitic Hare Bay Gneiss and granites containing sinistral σ-porphyroclasts are locally overprinted by one or two phases of sinistral shear bands or millimetre- to centimetre-scale folds. These structures rework the mylonitic foliations and deform the early, north-trending, subhorizontal lineation.

The most complex part of this shear zone is exposed on the islands in Terra Nova Lake, where later sinistral folds are seen to refold earlier, sinistral, shear-band fabrics. Belts of fine-grained ultramylonite, up to 15 m across, parallel the regional foliation and in many localities are focused in fine-grained, two-mica granite sheets. Adjacent megacrystic granite units display completely different levels of strain intensity and deformational complexity. For example, a megacrystic biotite granite, containing a single weak shear-band fabric, occurs adjacent to a variably mylonitic granite of similar composition, in which two phases of sinistral folds and C–S fabrics are preserved. In such situations, the less deformed body is thought to have been emplaced at a later stage in the deformation. This view is consistent with the intrusions having been focused within the shear zone, a feature recognized elsewhere in the Gander Zone (e.g., Holdsworth, 1991). Significantly, the megacrystic granite found at the eastern contact of the Maccles Lake Granite is also affected by sinistral shear.

The relative timing of the sinistral shear-zone structures and the early ductile and late ductile events is uncertain. Whereas earlier sinistral fabrics are associated with ductile deformation of feldspars, thus implying high temperatures, later features appear to be associated with lower grade, dynamic recrystallization textures similar to those seen in the DFSZ. It is conceivable that the sinistral shear zone was active throughout both events. Significantly, its north-south trend is similar to the late ductile, Cape Freels sinistral shear zone, which also overprints a zone of earlier high-grade sinistral shear (Holdsworth, 1991).

LATER BRITTLE STRUCTURES

Small-scale, late brittle structures within the DFSZ include conjugate sets of dextral and sinistral, steeply dipping to sub-vertical faults and brittle kinks and box folds of variable plunge (Plate 9). Many faults exhibit slickenfibres, which are everywhere shallowly plunging, suggestive of mostly strike-slip displacements.

Away from larger scale, late brittle faults, minor fractures with dextral and sinistral displacements occur in roughly equal numbers and normally display mutually crosscutting relationships. This suggests that they formed as conjugate sets. As the banding, in most cases, bisects the obtuse angle between the faults, the fractures are interpreted to indicate shortening at high angles and extension sub-parallel to the regional foliation. On average, dextral faults are northeast-

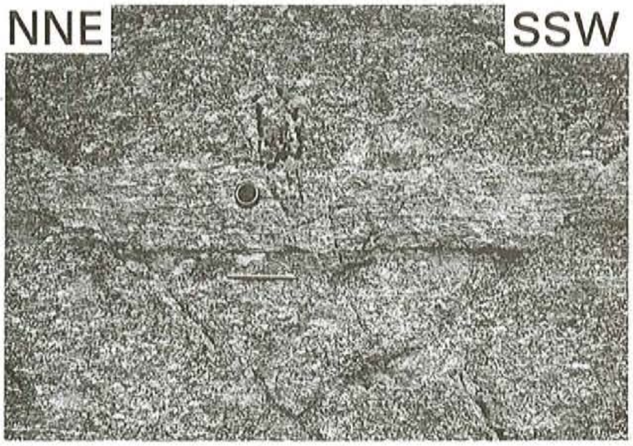


Plate 9. *Plan view of mutually crosscutting, late brittle dextral and sinistral conjugate fault sets, Terra Nova Lake.*

trending, whereas sinistral faults trend northwest. However, the considerable spread recorded in the data may be due to several orders of fault systems being present on various scales. In general, however, it appears that the conjugate faults accommodate shortening normal to the Gander–Avalon zone boundary by allowing extension along it.

The larger scale, late brittle faults are rarely exposed and, in most cases, are inferred from geological offsets or marked topographical features. Most faults trend northeast or east-northeast and have a dextral sense of displacement. The Gander–Avalon zone boundary south of Maccles Lake is marked by such late brittle faults. Clockwise changes in foliation strike (up to 50°), reflecting fault drag, may occur in zones several hundred metres either side of major dextral faults. Locally, asymmetric, Reidel-type, minor faulting patterns (cf. Tchalenko, 1970) are developed adjacent to the larger scale late brittle faults.

Late brittle folds are mostly small-scale features of little importance. However, marked changes in the strike in an area immediately north of Route 1 appear to result from a large-scale late brittle dextral folding. This structure produces a distinct kink in the Dover Fault. Centimetre-scale late brittle folds and faults of both dextral and sinistral shear sense are also locally common within the Avalon Zone volcanic rocks, particularly in regions adjacent to major faults (e.g., Terra Nova Lake).

The late brittle structures appear to reflect regional dextral displacements, with a possible component of east-northeast–west-southwest shortening being accommodated by the conjugate fault sets. Alternatively, these structures may be accommodating local stresses generated within the fault block regions between major fault strands. The late brittle fault system is similar to that observed farther north along the coast of Bonavista Bay (Holdsworth, 1991). It does not appear to be extensively developed in the region of the Gander–Avalon zone boundary between Maccles Lake and the northern boundary of the study area.

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