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A RECONNAISSANCE STRUCTURAL STUDY ALONG THE GANDER–AVALON ZONE BOUNDARY BETWEEN TERRA NOVA LAKE AND THE ACKLEY GRANITE, NEWFOUNDLAND

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ABSTRACT

The Gander–Avalon zone boundary has been re-examined in the region between Terra Nova Lake and the northeastern edge of the Ackley Granite, near Island Pond West.

The Avalon Zone nearest to the boundary comprises volcanic rocks intruded by a series of northerly trending granite bodies that were emplaced prior to deformation of the country rocks. Adjacent to the Gander Zone, all of the Avalonian rocks are overprinted by low-grade ductile dextral shearing that resembles the deformation associated with the Dover Fault in regions farther to the northeast.

The Gander Zone comprises migmatized Hare Bay gneisses, including early granitic units, and various later deformed granite sheets. A 2-km-thick K-feldspar megacrystic biotite granite sheet can be traced southward from Terra Nova Lake and appears to be continuous along the entire length of the boundary with the Avalon Zone. Gneisses and granites are affected by a long-lived ductile sinistral shearing that, in its later stages, produced proto- to ultramylonitic textures in the megacrystic granite sheet nearest to the Gander–Avalon zone boundary.

The Gander–Avalon zone boundary can be traced as narrow, sharply defined ravine features through much of the study area. Its topographic character, together with the sharp mis-match in ductile shear sense either side of the boundary, is consistent with the contact being a steeply dipping brittle fault. It is proposed that this structure is the continuation of the Terra Nova Fault. Thus, from the south shore of Maccles Lake southward to the Ackley Granite, an earlier boundary (the ductile Dover Fault) and part of the eastern Gander Zone is missing. The age of brittle movement is uncertain, but a Devonian or younger age seems likely, based on relationships seen in along-strike equivalent areas around Bonavista and Hermitage bays.

INTRODUCTION AND REGIONAL SETTING

It is generally accepted that the Gander–Avalon zone boundary (Figure 1) forms one of the most prominent tectonic discontinuities in the Newfoundland Appalachians. Along this boundary, the lower Paleozoic, amphibolite-facies gneisses and granites of the Gander Zone to the west are juxtaposed with late Precambrian, greenschist-facies volcanic, sedimentary and plutonic rocks of the Avalon Zone to the east (Blackwood and Kennedy, 1975; Blackwood, 1977, 1978; Williams, 1979). Recent studies (e.g., Caron and Williams, 1988; Holdsworth, 1991; O'Brien and Holdsworth, 1992) in the region between Bonavista Bay and Terra Nova Lake (Figure 1) have demonstrated that the north-northeast-trending, subvertical boundary is a broad tectonic zone characterized by a complex, reactivated transpressional and strike-slip history of displacement. A definitive geological link between the Gander and Avalon zones prior to their juxtaposition along this tectonic zone has not been identified, but a common kinematic history of displacements along their mutual boundary is now recognized. These displacements have been grouped into three deformational phases (cf. Holdsworth, 1991): Early Ductile, Late Ductile, and Late Brittle.

An Early Ductile phase of sinistral transpression is responsible for the earliest recognized juxtaposition of the two terranes along this boundary, probably during the Silurian (O'Brien *et al.*, 1991). On the Gander Zone side, a broad (ca. 20 km) shear zone was developed and acted as a focus for high-grade metamorphism, regional migmatization and widespread syntectonic granitoid intrusion. The shear zone fabrics postdate at least two earlier deformation events recognized in the western part of the Gander Zone outcrop (Holdsworth, unpublished data). The greenschist-facies, sinistrally transpressive, high-strain zone on the Avalon side

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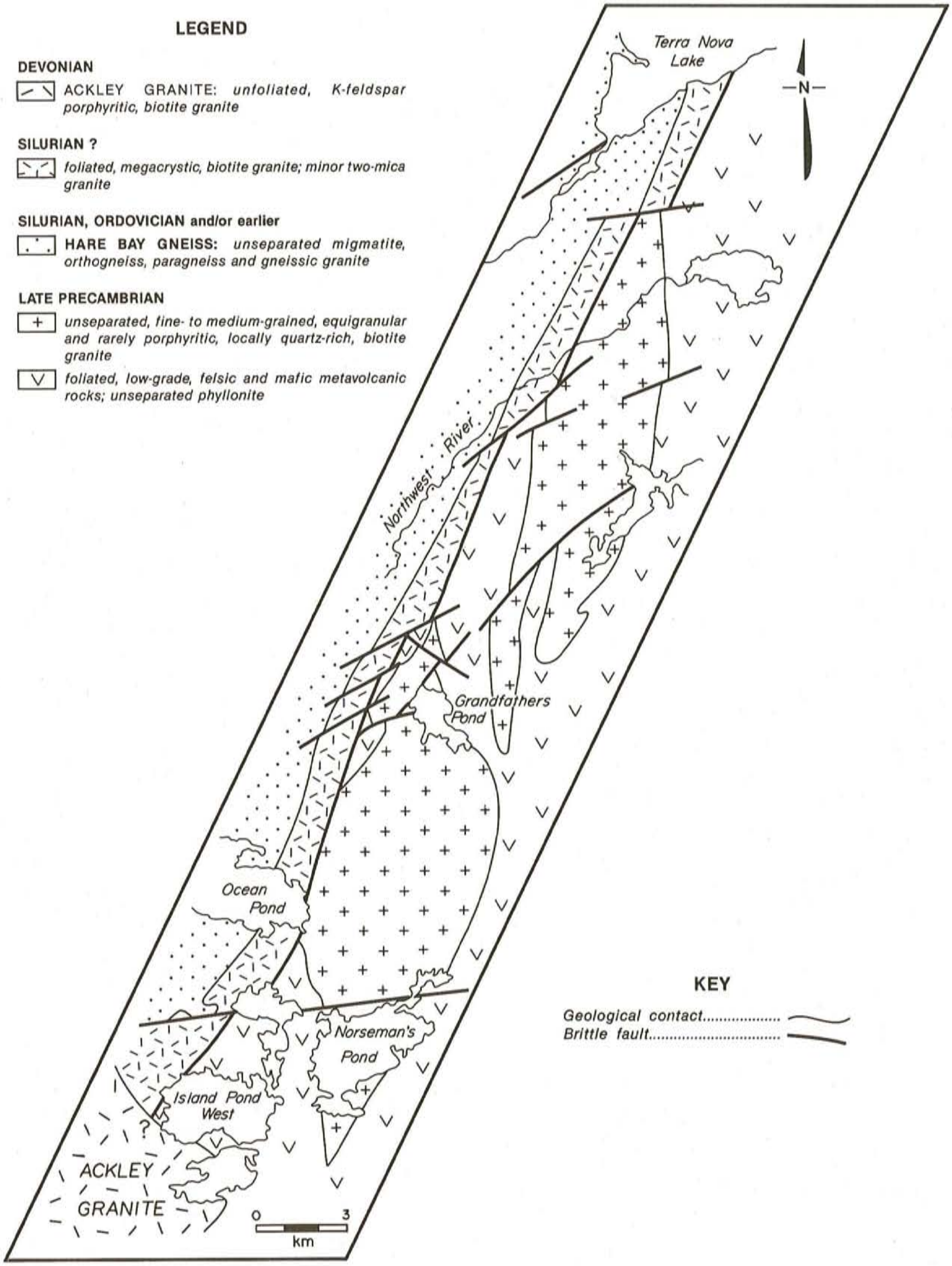

Figure 1. *Simplified geological map of the Gander–Avalon zone boundary in northeastern Newfoundland.*

is narrower ($\leq$ 2 km) and is synchronous with the primary cleavage recognized in the volcanic and sedimentary rocks away from the boundary.

A Late Ductile conjugate strike-slip shear zone system formed at low greenschist-facies conditions, overprinting earlier structures. The most prominent shear zone forms the main Gander–Avalon contact seen at the present day, the ductile Dover Fault (Younce, 1970; Blackwood and Kennedy, 1975). Mylonites are associated with this north–northeast-trending shear zone and are best preserved on the Gander Zone side, especially around Maccles Lake (Figure 1; O'Brien and Holdsworth, 1992), where a 3-km-wide zone of mylonite is exposed. In the Bonavista Bay area, some of the later Gander Zone granites near the northeast–southwest-trending boundary with the Avalon Zone (e.g., Lockers Bay Granite) are thought to have been intruded synchronous with dextral shear and these may record the onset of displacements along the Dover Fault (Holdsworth, 1991; see also Holdsworth *et al., this volume*). There are also several north- to north–northeast-trending sinistral shear zones that are thought to be broadly contemporaneous with the ductile Dover Fault, including the Cape Freels sinistral shear zone (Holdsworth, 1991; Holdsworth *et al., this volume*) and a kilometre-wide zone between Maccles and Terra Nova lakes (O'Brien and Holdsworth, 1992).

Late Brittle dextral fault systems severely disrupt the pre-existing boundary and crosscut all other geological features, including the youngest granite plutons (Blackwood, 1977; Holdsworth, 1991). Most of the present day Gander–Avalon zone contacts are brittle faults, and in the region between Maccles Lake and Terra Nova Lake (Figure 1), such faults cut out a large segment of Gander Zone rocks that would have lain nearest to the pre-existing boundary (O'Brien and Holdsworth, 1992).

GEOLOGY ALONG THE TERRA NOVA LAKE–ISLAND POND WEST CORRIDOR

This report summarizes the findings of a helicopter-based reconnaissance that extends this study along the Gander–Avalon boundary southward from Terra Nova Lake to Island Pond West, an along strike distance of about 45 km (Figures 1 and 2). The boundary crosses part of the Bay du Nord Wilderness area in the region previously mapped by Jenness (1963) and Reusch and O'Driscoll (1987). The primary aim of this study was to elucidate the kinematic histories that are preserved in the deformed Gander and Avalon zone rocks that occur adjacent to their mutual boundary as far south as the Ackley Granite (Figure 1). Attempts to investigate the relationships of the latter pluton to the terrane boundary were thwarted by lack of exposures in the critical area.

Much of the boundary region is very poorly exposed. The areas with the most exposure lie in the regions (from north to south): immediately north of Northwest River; north and west of Grandfathers (or Sams) Pond; southeast of Ocean Pond; and northwest of Island Pond West (Figure 2). Our study broadly confirms the location of the Gander–Avalon boundary as mapped by Reusch and O'Driscoll (1987) except in the region around Island Pond West. There, the contact is placed about 2 km farther to the southeast (compare our Figure 2 with Figure 1 of Reusch and O'Driscoll, 1987).

AVALON ZONE

In the region of the Gander–Avalon zone boundary, the Avalon Zone rocks comprise a thick sequence of highly cleaved to phyllonitic greenschist-facies volcanic rocks that are intruded by several north–south elongate deformed granite bodies (Figure 2). Previous workers (Jenness, 1963; Reusch and O'Driscoll, 1987) have assigned the volcanic rocks to the late Precambrian Love Cove Group, placing them in a western belt that runs from Bonavista Bay southward to the Ackley Granite. However, recent studies of this volcanic belt north of Terra Nova (Holdsworth, 1991; O'Brien and Holdsworth, 1992) suggest that they are significantly younger than the Love Cove Group of the type area and that they are broadly coeval with the deposition of the younger late Precambrian Musgravetown Group units, which crop out immediately east of the volcanic rocks described here. The age of the crosscutting granites is unknown, although Reusch and O'Driscoll (1987) have suggested that they resemble the Swift Current Granite, one of the plutons thought to be broadly equivalent to the final phases of late Precambrian volcanism in the Avalon (e.g., O'Brien *et al.*, 1990). In addition, Reusch and O'Driscoll (1987) recognized units of quartzite, which overlie the volcanic rocks and contain clasts resembling the nearby Avalon Zone granites. If these quartzites are part of the earliest Cambrian Random Formation (Walcott, 1900; Anderson, 1981), then this observation is consistent with the granites being Precambrian.

Volcanic Rocks

The volcanic rocks form part of a thick, texturally diverse sequence of tuffs and rhyolitic lavas. Those examined during the present study are predominantly fine-grained, pink-grey, crystal tuffs of acidic to intermediate composition (Plate 1), in which compositional banding or bedding is poorly developed. Most crystals are of pink feldspar and/or quartz. Dark-green, fine-grained mafic units, up to 1 m thick, form a subordinate rock type. Poorly sorted, grey-green agglomerates and breccias are well developed in some local areas (e.g., 2 km north of Island Pond West). All the rocks studied carry a strong cleavage that intensifies toward the Gander–Avalon zone boundary, close to which the volcanic rocks are often pale- to dark-green phyllonites. Examples of these are exposed in the road-bed along the southern shore of Terra Nova Lake.

Granites

Reusch and O'Driscoll (1987) identified two major and numerous minor granite intrusions that cut the volcanic rocks on the Avalon Zone side of the boundary (Figure 2). At least two types, which appear to be gradational variants, were

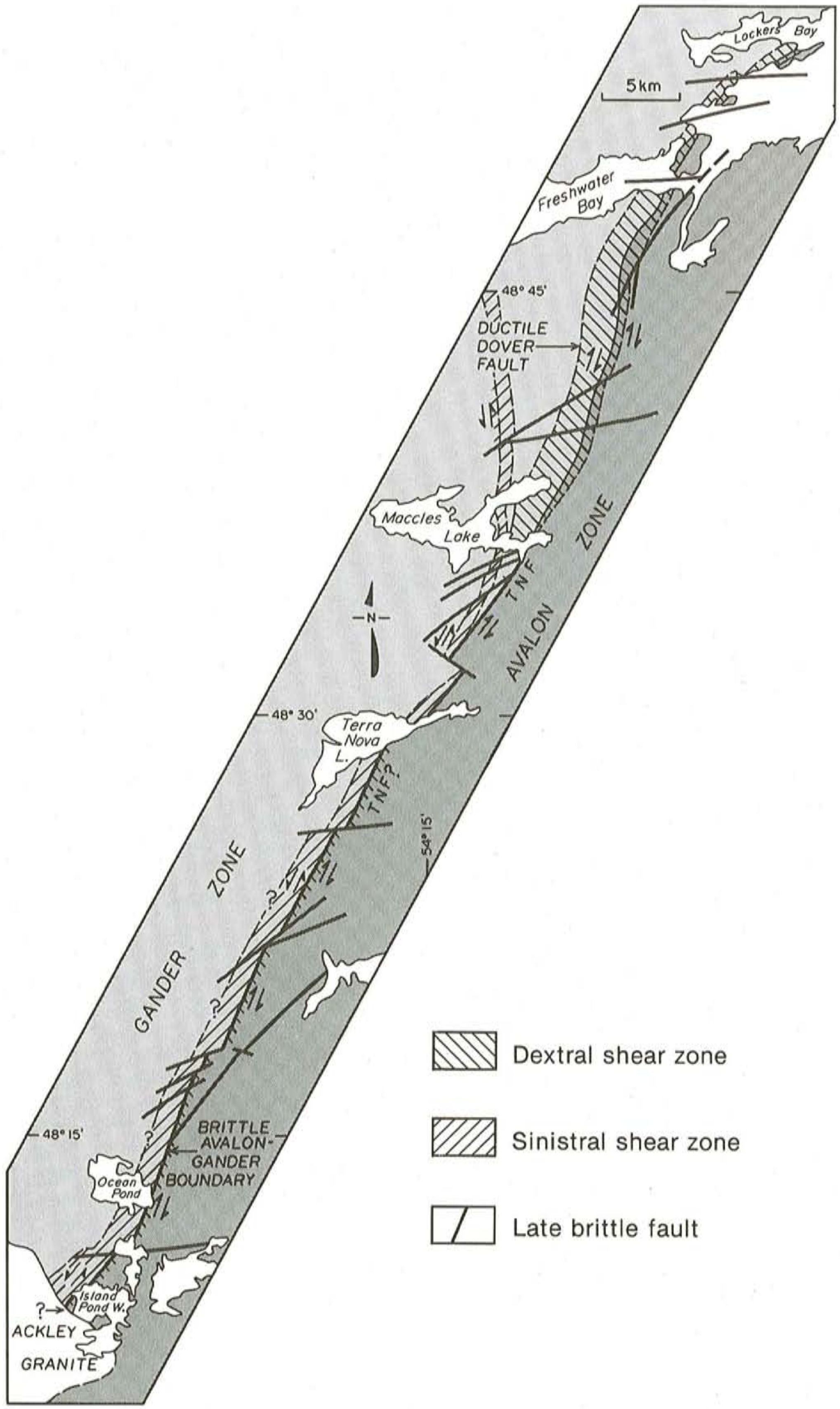

Figure 2. *Simplified geological map of the Gander–Avalon zone boundary region based on present study and Figure 1 of Reusch and O'Driscoll (1987).*

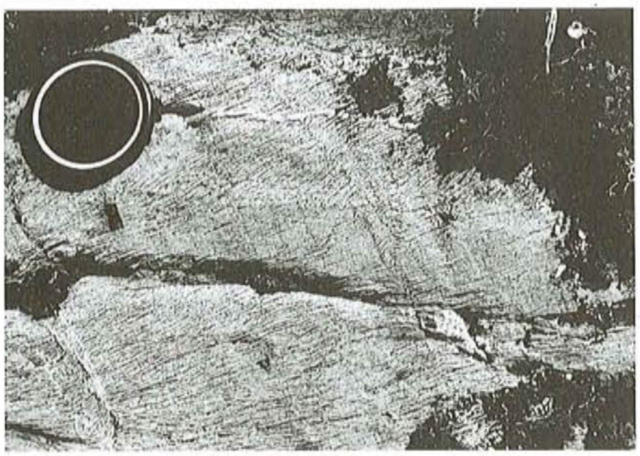

Plate 1. *Bedded, pale-coloured tuffs of the Avalon Zone viewed in plan; north is to the left. An early bedding-parallel fabric is strongly overprinted by a local secondary crenulation cleavage formed during dextral shear associated with deformation along the nearby boundary with the Gander Zone. Locality 2 km northwest of Grandfathers Pond.*

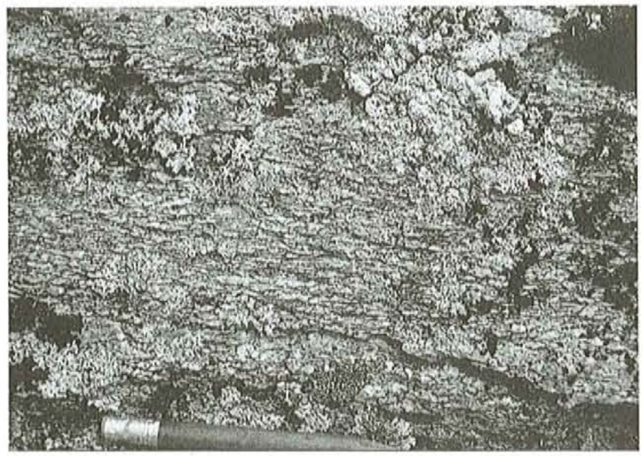

Plate 2. *Dextral shear bands in proto-mylonitic biotite granite, Avalon Zone; north is to the left. Locality 1 km northwest of Grandfathers Pond.*

observed during the present investigation. The first is a coarse-grained, locally porphyritic, pink granite, notably rich in quartz; the second is a fine- to medium-grained biotite granite (Plate 2). Both types are remarkably uniform in texture and composition within individual exposures, a characteristic that is significantly different to the granites in the Gander Zone. Exposed granite margins are sharp and steeply dipping and are often marked by a zone of granite dykes that cut tuffaceous rocks near the main contacts. On a large scale, the granites trend north–south, subparallel to the regional banding in the volcanic rocks and slightly anticlockwise of the Gander–Avalon boundary (Figure 2). All of the granite bodies studied carry moderate to strong solid-state fabrics (e.g., Plate 2) oriented subparallel to the penetrative cleavage in the adjacent country rocks. Increasing amounts of mylonitization and retrogression are observed on approaching the contact with the Gander Zone. All the granites are terminated at this boundary. Locally, granite veins and volcanic rocks are mylonitized together in the same outcrops (e.g., in the road exposures south of Terra Nova Lake), suggesting that these intrusions are pretectonic with respect to ductile deformation along the Gander–Avalon zone boundary.

GANDER ZONE

In the area studied, the Gander Zone in a 2- to 3-km-wide corridor nearest to the Avalon Zone can be divided into two units. The first of these is a mixed assemblage of migmatites, gneisses and granites similar to the Hare Bay Gneiss exposed in the type area to the north (Blackwood, 1976, 1977, 1978). The second unit, lying to the east, is a distinctive 1- to 2-km- wide sheet of K-feldspar megacrystic biotite granite that runs parallel to the Gander–Avalon boundary through the whole area (Figure 2). Reusch and O'Driscoll (1987) equated this intrusion with the Dover Fault granite recognized by Blackwood (1977). However, it is more likely that it is a southward continuation of the megacrystic granite, which forms the prominent string of islands in Terra Nova Lake, and continues northward, as a foliation-parallel sheet, to Maccles Lake (Figure 1). In that area, the granite lies several kilometres west of the Dover Fault and is flanked on both sides by the Hare Bay Gneiss (see O'Brien *et al.*, 1991; O'Brien and Holdsworth, 1992).

Hare Bay Gneiss and Associated Rocks

The Hare Bay Gneiss studied in the area has three thoroughly interlayered components: metasedimentary rocks, mobilized gneisses (paragneisses and orthogneisses) and early granite gneisses. All of these units have been subsequently crosscut by numerous granite sheets, that have undergone varying degrees of deformation together with the country rocks.

The metasedimentary rocks comprise interbanded psammites, semipelites and pelites, together with local boudinaged layers of amphibolite. The pelites and semipelites locally contain sillimanite and are characteristically rusty orange weathering. They are variably migmatized and pass gradationally into coarse-grained mobilized gneisses (Plate 3) that appear to represent local partial melts. All these rocks are crosscut by locally abundant sheets of distinctive granite gneiss (Plate 4) that range in thickness from a few centimetres to several metres. These early bodies clearly crosscut the banding in the metasediments, but they are deformed with the country rocks by folds on a centimetre to metre scale. The later granites crosscut these structures. The K-feldspar phenocrysts in the granite gneisses display strong ductile deformation and albitic rims (e.g., Plate 4) indicative of high-temperature deformation (Simpson, 1985) producing their characteristic augen texture.

The later granite bodies intrude across the metasedimentary and granitic gneisses and crosscut folds in

Plate 3. *Asymmetric restite pod in mobilized gneisses in the Gander Zone indicating sinistral senses of shear at high temperatures; south is to the left. Locality 2 km north of Island Pond West.*

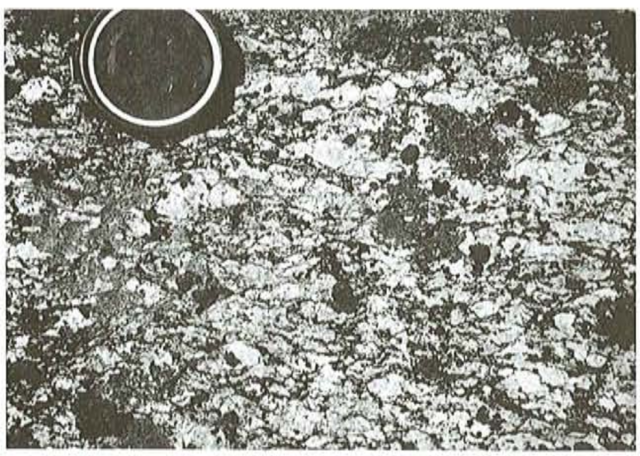

Plate 4. *Weakly deformed early granitic gneiss, Gander Zone. Note the weak sinistral shear band fabric and pale albitic rims around the K-feldspar phenocrysts. Locality 4 km west of Grandfathers Pond.*

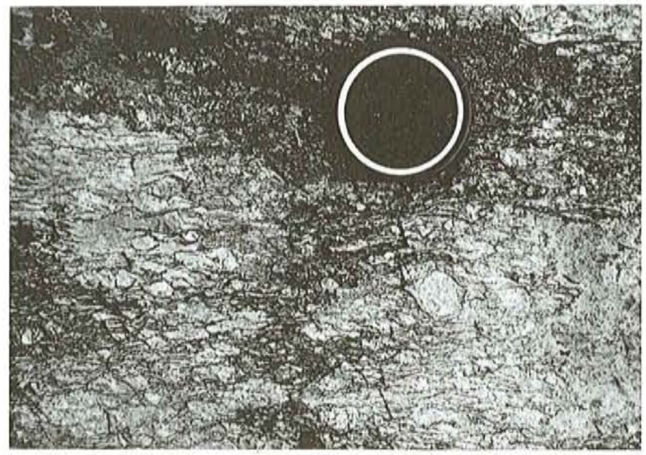

Plate 5. *Mylonitic K-feldspar megacrystic biotite granite with sinistral-wrapping textures and shear bands, Gander Zone; northeast is to the right. Locality just southeast of Northwest River.*

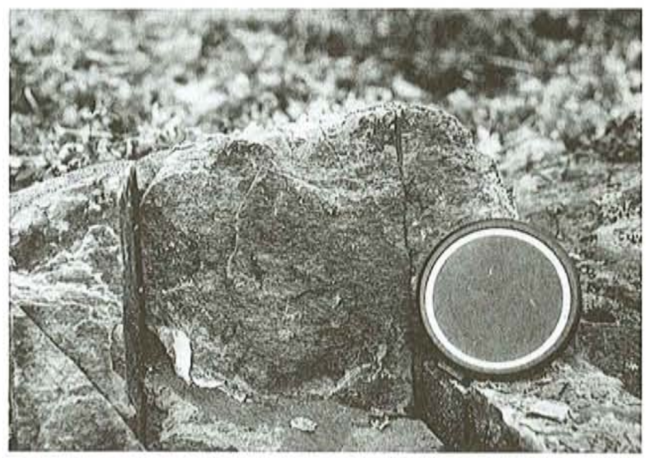

Plate 6. *Subhorizontal stretching lineation in pink, two-mica granite sheet, Gander Zone. Same locality as Plate 5.*

these rocks. They include discontinuous sheets of K-feldspar megacrystic biotite granite, fine- to medium-grained, pink and grey, two-mica granites and muscovite pegmatites. All of these rocks have been deformed heterogeneously in the solid state, together with the surrounding country rocks, but are not folded.

Foliated Megacrystic Granite

Sheets of K-feldspar megacrystic biotite granite (Plate 5), together with subordinate amounts of fine-grained two-mica granite (Plate 6) form a composite intrusion up to 2 km wide and lie parallel to the Gander–Avalon zone boundary throughout the entire study area. This intrusion is restricted to the west side of the boundary; no unequivocal veins of megacrystic granite are found in the adjacent Avalonian rocks. In all exposures, the granites carry a strong solid-state fabric, displaying well-defined proto-mylonitic to, locally, ultramylonitic textures (e.g., Plates 5 and 6). There is a considerable amount of retrogression associated with mylonitization. This has formed chlorite and epidote, which impart a dark green colour seen in fresh surfaces, especially in regions nearest to the Avalon Zone. In weathered surfaces, the granites may display a distinctive orange colouration. Sheeting of granite can usually be seen in single exposures. These sheets lie parallel to the regional foliation. Individual sheets range in thickness from a few centimetres to several tens of metres or more. In places, thin screens of schistose pelitic metasediment separate individual intrusive units, whereas elsewhere, granite–granite contacts are defined by slight changes in composition, colour and/or grain size.

STRUCTURE

AVALON ZONE

Throughout the study area, a steeply dipping, north–south-trending penetrative cleavage is developed in

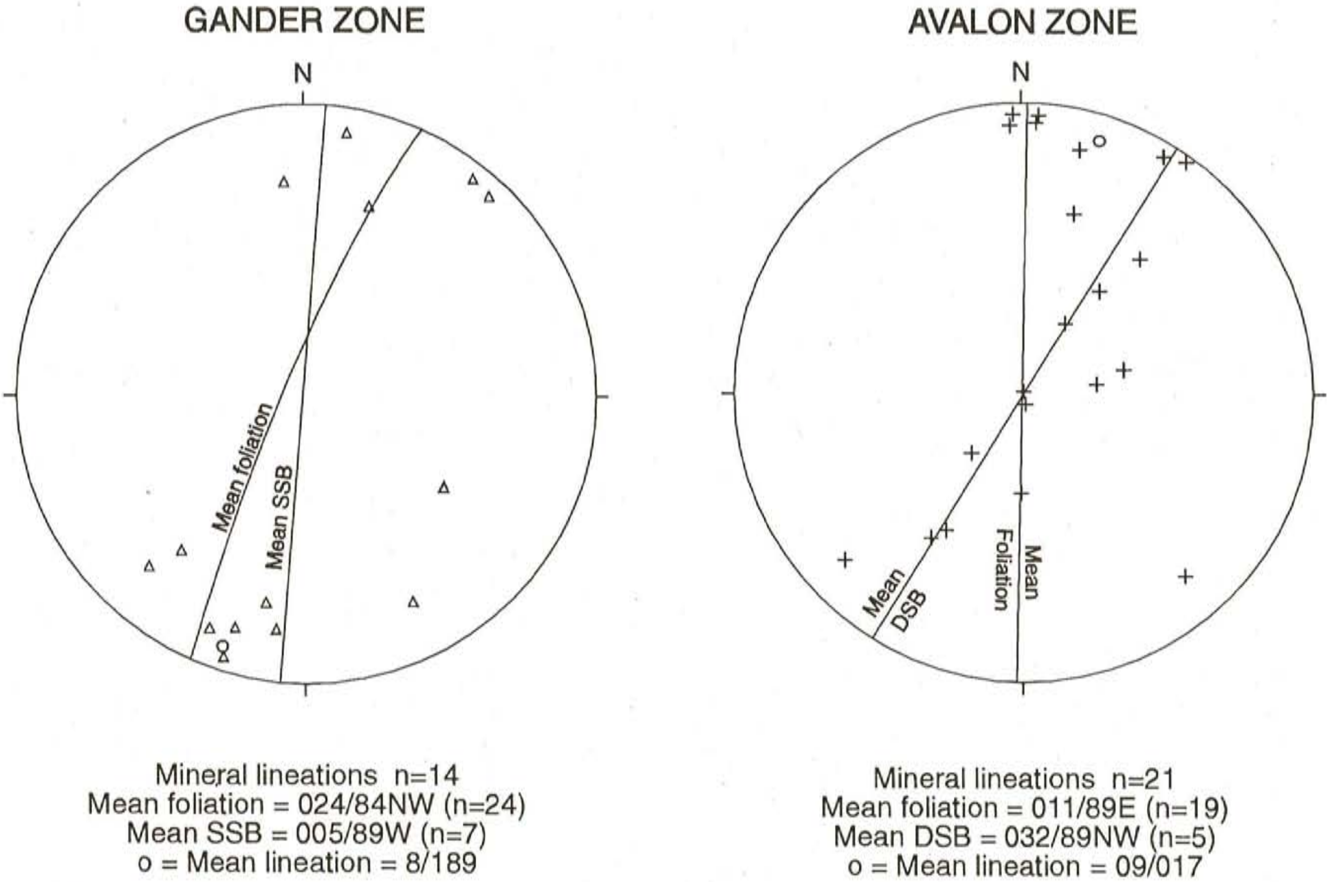

Figure 3. *Summary stereonets showing ductile deformation fabric relationships in the Avalon and Gander zones in the study area.*

both the volcanic and granitic rocks of the Avalon Zone (Figure 3). This fabric intensifies westward, becoming phyllonitic in the exposures nearest to the Gander Zone. In the kilometre-wide section closest to the boundary, asymmetric shear band fabrics (e.g., Plates 2 and 7) are abundant, together with dextrally verging minor folds and locally, an associated crenulation cleavage (e.g., Plates 1 and 7). The shear bands lie 10 to 30° clockwise of banding, whereas the crenulation fabric strikes anticlockwise of banding; this relationship indicates dextral senses of shear. The mineral lineations associated with these structures have mainly shallow north-northeast or south-southwest plunges. Traced eastward away from the boundary, the lineations appear to steepen, a plunge pattern also recorded in the same rocks along strike in the Bonavista Bay area (Holdsworth, 1991). In the granite units, a slightly different pattern emerges. Nearer to the Gander Zone, a strong dextral shear band fabric is developed (Plate 2). Lineations within most exposed surfaces lie within C-surfaces and are shallowly plunging. Traced away from the boundary, the shear band fabric containing shallow lineations, weakens and a steeply plunging (?earlier) lineation appears within the main cleavage. This accounts for the apparent spread in data shown in Figure 3 and suggests that the dextral fabrics may overprint an earlier deformation. The dextral features are comparable to the Late Ductile deformation recognized along strike and to the northeast in the Avalon Zone rocks nearest to the Dover Fault Zone (e.g., Holdsworth, 1991; O'Brien and Holdsworth, 1992).

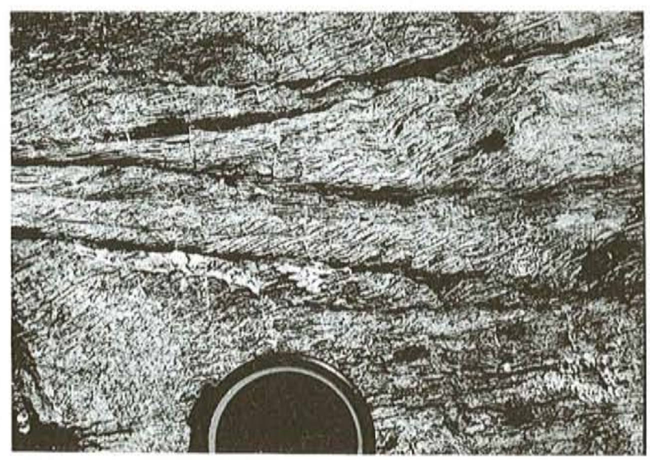

Plate 7. *Dextral shear bands cutting local secondary cleavage (cf. Plate 1) in pale felsic tuffs of Avalon Zone near the boundary with the Gander Zone.*

Brittle deformational features postdate all other structures and include centimetre- to metre-scale kink and box folds and faults. Fold plunges and vergence are variable and no consistent sense of movement is indicated. Several narrow northeast- and east-trending ravines appear to be sited along large-scale brittle faults. Geological offsets suggest mostly dextral senses of movement and in several locations, these structures appear to displace the Gander–Avalon zone boundary itself (Figure 2).

GANDER ZONE

About 3 km west of the boundary, the foliation in the gneisses and granites is irregular due to widespread close-to-tight folding of the metasediments and early granite gneisses. The folds display dominantly sinistral senses of vergence and deform an earlier high-temperature S–C fabric defined by the σ-shaped wrapping of K-feldspar phenocrysts in the granite gneiss sheets (Plate 4). Asymmetric wrapping of restite pods in units of mobilized gneiss (Plate 3) also suggests that migmatization of the country rocks was occurring during sinistral displacements. All of these structures are associated with shallowly north-northeast- or south-southwest-plunging mineral lineations.

The variably mylonitic fabrics in the granites adjacent to the boundary appear to be associated with retrograde, chlorite-grade mineral assemblages, which suggests that the fabrics are later, low-temperature phenomena. Lineations are shallowly plunging (e.g., Plate 6) and asymmetric fabrics are developed, including σ-wrapping of K-feldspar megacrysts and shear bands (e.g., Plate 5). The latter consistently lie anticlockwise of the main foliation (Figure 3). Nearly all of these features give a sinistral sense of displacement, although in isolated pods of lower strain (e.g., south of Ocean Pond), conjugate dextral and sinistral shear zones are preserved. Later brittle structures are restricted to a few small-scale faults, which in many places are associated with kink and box folds.

The widespread and apparently long-lived history of ductile sinistral displacements is characteristic of the eastern Gander Zone, particularly in the south Maccles Lake–Terra Nova area (Figure 1; O'Brien and Holdsworth, 1992). The strong lithological and structural similarities suggest that the region can be correlated directly with the easternmost parts of the Gander Zone immediately along strike to the northeast.

NATURE OF THE GANDER–AVALON ZONE BOUNDARY

The Gander–Avalon boundary is nowhere exposed in the region between Terra Nova Lake and the supposed outcrop of the Ackley Granite. It has a marked topographic expression, however, which can be easily seen on air photographs. The boundary feature is offset tens to hundreds of metres dextrally along ravines that are likely to mark the traces of later northeast- and east-trending faults (Figure 2). It appears, therefore, that the boundary is a sharply defined brittle fault, which trends north-northeast (Figure 2). This interpretation is consistent with the fundamental differences in trend and shear sense of the ductile fabrics that are preserved on either side of the boundary. Specifically, the Avalon Zone fabrics trend just east of north and are dextral, whereas the Gander Zone fabrics have a more northeasterly trend and are sinistral (see Figure 3). The relationships seen in this area are analogous to those documented north of Terra Nova Lake (Figure 1; O'Brien and Holdsworth, 1992). In that region, a long-lived ductile sinistral shear zone, associated with a linear megacrystic granite body, is juxtaposed by the Late Brittle (cf. Holdsworth, 1991) Terra Nova Fault against Avalonian volcanic rocks. The north-northeast-trending sinistral shear zone can be traced 15 km north to the shores of Maccles Lake where it lies several kilometres west of the dextral Gander–Avalon boundary. Traced southward from Maccles Lake, the Terra Nova Fault appears to cut obliquely clockwise relative to the regional banding to the west, effectively removing up to 3 km width of section from the easternmost part of the Gander Zone (O'Brien and Holdsworth, 1992). Our observations suggest that this fault, or a subparallel structure, continues southward defining the Gander–Avalon zone boundary at least as far as the Ackley Granite. However, in this region, the Terra Nova Fault parallels the structural grain in the Gander Zone, and cuts clockwise across banding to the east in the Avalon Zone (Figure 2). No evidence was found to preclude the possibility that the Late Brittle displacements that define the Gander–Avalon zone boundary along the mapped corridor postdate the emplacement of the Ackley Granite. Their relationship to the brittle Hermitage Bay Fault (Blackwood and O'Driscoll, 1976), which lies along strike in southern Newfoundland, is unknown; they may be coeval.

In conclusion, these findings suggest that the Gander–Avalon boundary from the south shore of Maccles Lake southward to the Ackley Granite is a Late Brittle fault (sensu Holdsworth, 1991). It is suggested that this fault has obscured the presumed original contact, the ductile Dover Fault. The magnitude, sense and age of brittle displacement is uncertain, although a Devonian or possibly later age for the dextral sense of movement seems likely.

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