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TECTONIC RELATIONSHIPS ALONG THE MEELPAEG, BURGEO AND BURLINGTON LITHOPROBE TRANSECTS IN NEWFOUNDLAND

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ABSTRACT

During 1989, three 'Lithoprobe' deep seismic reflection transects were completed in western and central Newfoundland. The transects, named Meelpaeg, Burgeo and Burlington, span the Humber, Dunnage, Gander and Avalon tectonostratigraphic surface zones, and below them, the Grenville, Central and Avalon lower crustal blocks. New structural, kinematic and lithostratigraphic data are presented from surface boundaries along these transects. Data from central Newfoundland suggest that ophiolitic Dunnage crust was obducted over Gander clastic rocks during the Early or Middle Ordovician, resulting in the formation of a surficial mélange of ophiolite olistoliths in marine black shale at Cold Spring Pond, and probably elsewhere.

Subsequently, this boundary zone and a system of related zones along the Hermitage flexure became sites of ductile shearing movements directed toward the south and west, and also toward the north and east, parallel to the sinusoidal trend of the orogen in Newfoundland. In Bay d'Espoir, these movements occurred during the Silurian and were associated with large-scale syntectonic granitic plutonism.

Along the Baie Verte—Brompton Line, Ordovician obduction was followed by a complex sequence of sinistral and dextral transcurrent ductile movements, which also affected the Fleur de Lys Supergroup, and then by Acadian overthrusting of the Humber Zone over the Dunnage Zone, followed by minor reverse movements.

INTRODUCTION

The 1989 Lithoprobe seismic reflection lines cross all the major geological zones of western and central Newfoundland (defined by Williams *et al.* 1988) along three lines, the Meelpaeg (northwestern and southeastern), Burgeo and Burlington transects (Figure 1). The Meelpaeg transect and some of the relationships along its course have already been described (Williams *et al.* 1989b). This report describes new tectonic and lithostratigraphic relationships along the southeastern Meelpaeg transect based on 1989 fieldwork, and the surface boundary relationships along the Burgeo and Burlington transects. Figure 1 shows the tectonostratigraphic divisions and the courses of the transects, and is an update of Williams *et al.* (1989b). The 'Central Gneiss Terrane' (van Berkel and Currie, 1988) is separated from the Notre Dame Subzone and referred to here as the Dashwoods Subzone of the Dunnage Zone.

THE SOUTHEASTERN MEELPAEG TRANSECT

The northwestern and southeastern legs of the Meelpaeg transect are separated by a 13-km gap, underlain principally by granite of the North Bay intrusive suite (Colman-Sadd, 1985, 1986). From Great Burnt Lake (GBL in Figure 1), the southeastern leg follows a hydroelectric access road to Bay d'Espoir, then Routes 361 and 360 to Hermitage Bay and Routes 362 and 363 to English Harbour West. From northwest to southeast, it starts at the eastern margin of the northern Meelpaeg Subzone, then spans the southern Meelpaeg Subzone, the southeastern Exploits Subzone, the Gander Lake Subzone, and ends in the Avalon Zone (Figures 1 and 2). During 1989, lithostratigraphic and tectonic relationships were studied along the eastern boundary of the Meelpaeg and Exploits subzones in the Great Burnt Lake—Cold Spring Pond

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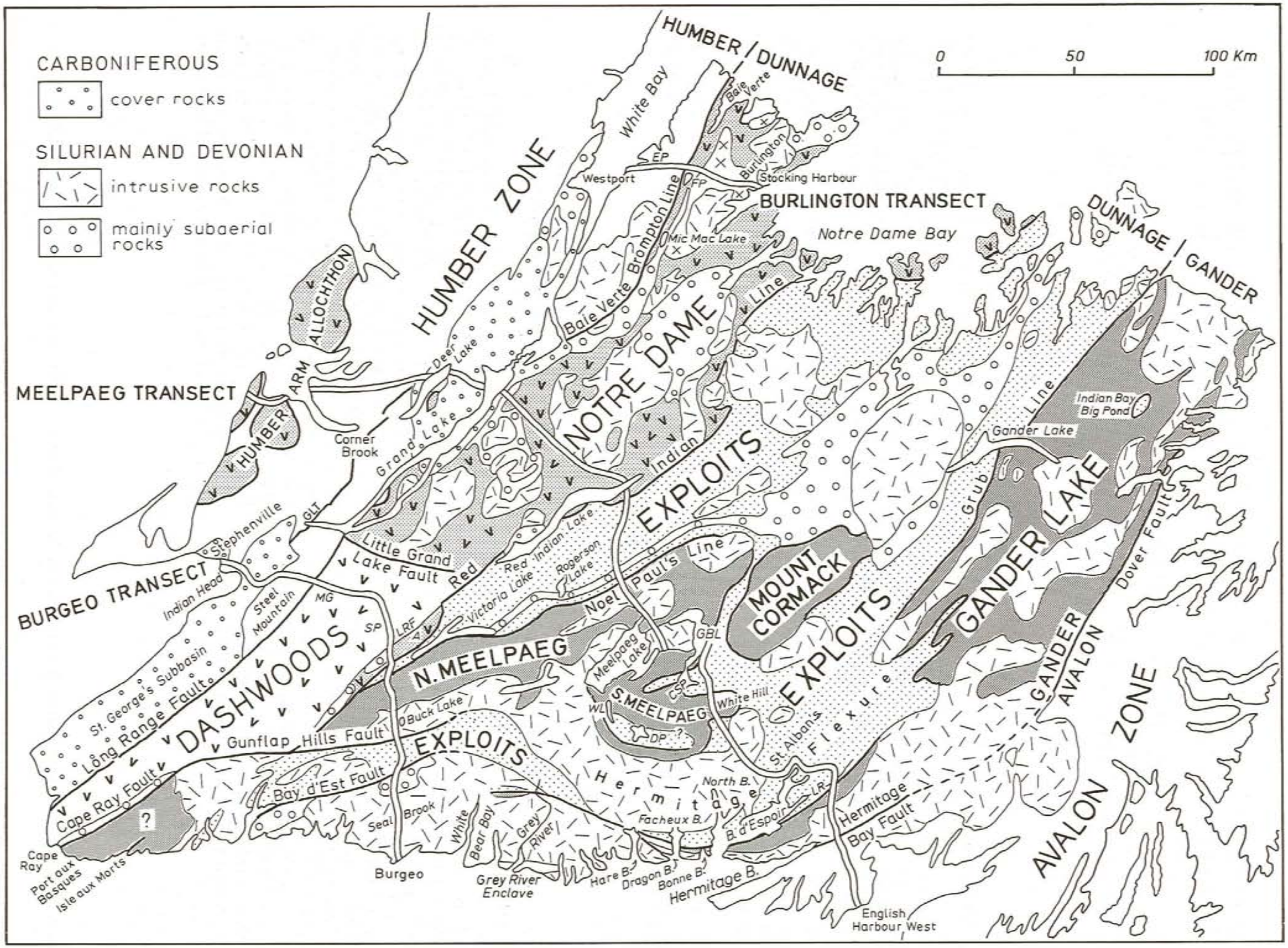

Figure 1. *Tectonostratigraphic subdivision of central Newfoundland and the courses of Lithoprobe transects. Modified after Williams* et al., *1988, 1989b. For clarity, intrusive rocks are omitted from the Dashwoods Subzone. Abbreviations: Southeastern Meelpaeg Transect, GBL–Great Burnt Lake, CSP–Cold Spring Pond, DP–Dolland Pond, WL–Wolf Lake, LR–Little River; Burgeo Transect, GLT–Grand Lake Thrust, MG–Main Gut complex, SP–Silver Pond complex, LRF–Lloyd's River Fault, A–Annieopsquotch Ophiolite Complex; Burlington Transect, EP–East Pond, FP–Flatwater Pond. The Burlington Granodiorite (Ordovician) is indicated by crosses.*

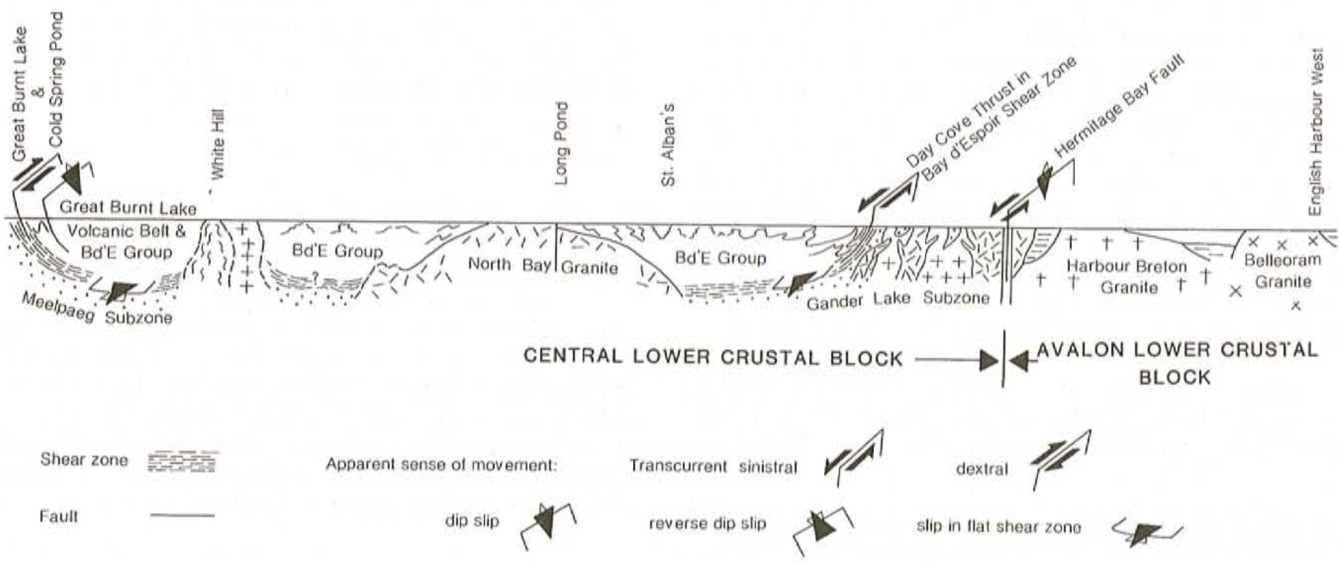

Figure 2. *Southeastern Meelpaeg transect: zonal subdivisions and schematic geological relationships. Abbreviations: Bd'E Group–Baie d'Espoir Group.*

region, and from the Exploits–Gander Lake boundary east of Bay d'Espoir through to the Gander Lake–Avalon boundary in Hermitage Bay.

Meelpaeg–Exploits Boundaries

Great Burnt Lake. East of Great Burnt Lake, a north–south-trending belt of low-grade, lower and middle Ordovician Exploits metasediments, volcanic rocks (Great Burnt Lake Volcanic Belt) and ophiolitic complexes separates mostly higher grade, Ordovician metaclastic rocks (Spruce Brook Formation) of the Mount Cormack and Meelpaeg subzones (Colman-Sadd and Swinden, 1984; Colman-Sadd, 1985).

Ophiolitic complexes are situated adjacent to the Mount Cormack Subzone boundaries, and fragments of ophiolitic rocks are locally present along the Meelpaeg boundaries. Below the dam at Great Burnt Lake, a suite of epidotic, metabasaltic pillow lavas and pillow breccias is interbedded with tuffs and bedded dark shales, all intruded by swarms of diabase dykes and sills. It may represent a conformable cover above an ophiolite suite, subsequently separated from it by faulting (Swinden, 1988). A body of trondhjemite, 1.25 km southeast of the dam, is intruded by gabbro and penetrated by tuffisite. This suite is unfoliated and is pervasively shattered on all scales. An ophiolitic fragment of serpentinized peridotite, chloritized and epidotized gabbro and mafic volcanic rocks occurs east of the transect, 7 km south of the dam (Swinden, 1988). Adjacent to its sheared margins, are competent mylonitic rhyolitic tuffs but also less competent silty shales, suggesting that original emplacement relationships have been modified by ductile and brittle faulting.

Along the northern Meelpaeg–Exploits boundary at Great Burnt Lake, both the Meelpaeg metamorphic and Exploits volcanic rocks, display layer-parallel mylonitic fabrics within a belt some 2-km wide. Confined to this belt in the Meelpaeg Subzone, a sheet of a spectacular megacrystic, mylonitic granite gneiss can be traced for some 70 km, along the eastern boundary of the Meelpaeg Subzone (Plate 1; Colman-Sadd and Russell, 1988; Colman-Sadd and Swinden, 1984, 1989). Where examined, the granite sheet appears to coincide with the zone of the highest shear strain within the mylonites.

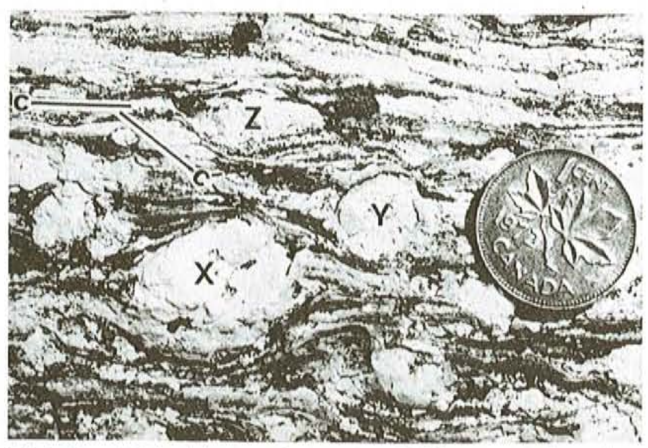

Plate 1. *Mylonitic granite gneiss. Feldspar porphyroclast (X) with a 'tail' of granulated and dynamically recrystallized feldspar aggregate, shear bands (c') and back-rotated mylonitic C-foliation (c) between porphyroclasts Y and Z indicated a dextral sense of shear. Above coin, a zone of very intense mylonitization. Thin white veinlets are syn-shearing segregation-type quartz veinlets. Plane of exposure parallel to intense stretching lineation, Great Burnt Lake.*

In the Meelpaeg mylonitic schists and in the mylonitic granite gneiss, mineral stretching lineation and rodding lineation within syn-shearing quartz veins (Plates 1 and 2; Piasecki, 1988b) are subhorizontal. Kinematic indicators, such as S-C foliations, shear bands, feldspar porphyroclasts with 'tails' (Plate 1; see also Berthé *et al.*, 1979; Gapais and White, 1982; Simpson and Schmid, 1983; Passchier and Simpson, 1986), collectively and consistently indicate low-angle to subhorizontal layer-parallel transport, parallel to the trend of the orogen in Newfoundland. In the steeply inclined rocks of the region, the apparent sense of motion is dextral transcurrent. In tuffs and pillow lavas of the Exploits Subzone, as in a quarry 2 km south of the Great Burnt Lake dam, stretching lineations are commonly vertical to steeply inclined; and S-C foliations and shear bands indicate dip-slip movements with downthrow to the east (Figure 2).

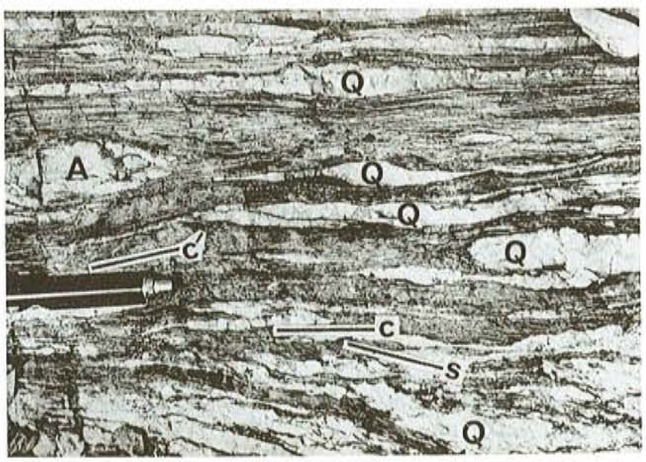

Plate 2. *A swarm of segregation-type, syntectonic quartz veins (Q) in mylonite derived from felsic tuff of the Isle Galet Formation. Above pencil, quartz vein slips on a shear band (c'). Along bottom, quartz veins aligned with the oblique mylonitic S-foliation (s) swing into the C-foliation (c). Quartz vein at centre right appears to be folded, the asymmetric 'drag' fold verging to the left. Quartz segregation (A) is imbricated. All the kinematic indicators point to a sinistral sense of shear. Plane of exposure parallel to stretching lineation. Bay d'Espoir Shear Zone, large quarry on transect 5.5 km south of River Pond.*

Cold Spring Pond. At Cold Spring Pond (CSP in Figure 1), a narrow, east–west-trending belt of Exploits Subzone separates the northern Meelpaeg Subzone from a smaller, southern 'satellite' (Colman-Sadd, 1984). The boundary of this southern Meelpaeg Subzone lies near Rocky Brook (the brook entering Cold Spring Pond near its southwestern corner), and in the area south of the brook.

Ophiolitic rocks in Rocky Brook were interpreted as emplaced in a complex fault zone (Colman-Sadd and Swinden, 1983, 1989; Colman-Sadd, 1984) and as representing a tectonic break between the Cold Spring Pond Formation (Exploits Subzone, Swinden, 1988) and the Spruce Brook Formation (Meelpaeg Subzone). The present work shows that serpentinized dunites in the brook are large blocks (olistoliths) within a chaotic, mylonitic mélange, some 500-m wide, for which the name, Cold Spring mélange, is proposed. The dunite blocks are accompanied by several large and innumerable small blocks of quartzite and metasiltstone within a matrix of homogeneous, unbedded black graphitic phyllonite (phyllosilicate-rich mylonite).

Along its northern margin, the mélange is separated from the Exploits Subzone by a 700-m-wide zone of Meelpaeg psammites and schists, probably representing a thrust slice. To the south and east, it borders a belt of mylonitic psammitic schists derived from the southern Meelpaeg Subzone, but which locally appear to contain slices(?) of psammites of Exploits Subzone affinity. This mylonitic belt contains a sheet of mylonitic granite gneiss, similar to that occurring at the eastern margin of the northern Meelpaeg Subzone at Great Burnt Lake. Subhorizontal lineations and kinematic markers consistently indicate transcurrent dextral movements.

In the Cold Spring mélange, predominant S-C foliations, shear bands, steep lineations and the alignment of small stretched olistoliths parallel with this lineation indicate dip-slip with downthrow toward the northeast. Fabrics of the transcurrent movements that dominate the more competent Meelpaeg psammites and the mylonitic granite gneiss, are only locally and weakly developed in the 'softer' Exploits phyllonites and talc-serpentine schists (Figure 2), suggesting that the transcurrent movements were earlier, and were subsequently overprinted in the less competent rocks by later ductile dip-slip movements.

An occurrence of dunite on top of a hill, 2 km south of Rocky Brook, and another nearby in metasediments permeated by granite, is thought to represent the same mélange in an area affected by imbricate(?) thrusting and faulting, and voluminous granite and migmatite intrusion.

Dolland Pond–Wolf Lake. The transect crosses the southern Meelpaeg Subzone west of White Hill (Colman-Sadd, 1984). Exposed here is a complex of migmatitic granite charged with blocks and schlieren of Meelpaeg-type metasediments and amphibolite, probably a diapir of Meelpaeg migmatitic granite that had penetrated through the Exploits cover.

Southwest of the transect, Meelpaeg metasediments, pervasively sheeted by syntectonic garnetiferous muscovite–leucogranite (Middle Ridge-type of Williams *et al.*, 1989a) extend to the margin of the North Bay Granite (Dickson and Delaney, 1984a,b). From Dolland Pond (DP) to Meelpaeg Lake (Figure 1), a layer-parallel ductile shear belt can be traced in psammitic and semipelitic mylonites and leucogranite-mylonites intruded by voluminous younger granite. In the region of Dolland Pond, the shear belt strikes east–west for some 40 km, dips gently northward, and its kinematic markers indicate dip–slip movements, both to the south (earlier ?) and to the north (later ?). South of Wolf Lake (WL), the mylonite belt swings northwest, its dip steepens to the northeast, and the sense of movement becomes predominantly sinistral transcurrent. The shear belt here contains a thick sheet of mylonitic granite gneiss similar to that at Great Burnt Lake and Cold Spring Pond.

Exploits–Gander Lake Boundary

At Bay d'Espoir, Exploits sedimentary and volcanic sequences (Baie d'Espoir Group) are structurally underlain by the Little Passage Gneiss, a belt of psammitic and semipelitic schists and migmatitic gneisses containing amphibolites associated with voluminous granitic plutons (Gander Lake Subzone). The boundary coincides with the Day Cove Thrust (Colman-Sadd, 1976, 1980), which marks the zone of the highest strain in a major ductile shear zone, the Bay d'Espoir Shear Zone (Piasecki, 1988a). The metamorphic grade jumps across this boundary from greenschist on the Exploits side to amphibolite in the Little Passage Gneiss. Along the transect, Exploits mylonitic felsic tuffs and phyllonitic schists (Isle Galet Formation) are exposed in a large quarry on Route 360, 5.5 km south of Little River (LR, Figure 1). Mylonitic schists of the Little Passage Gneiss begin 2 km farther south.

Northwest of the shear zone, chlorite–biotite-grade Exploits Subzone metasediments are folded by upright to overturned, open to tight F_1 folds with subhorizontal axes trending northeast–southwest and a pressure-solution to slaty axial surface cleavage, S_1. These are refolded by smaller, recumbent F_2 folds with flat-lying axial crenulation cleavage, S_2, and a penetrative subhorizontal crenulation lineation (Figure 2).

Within the zone of shearing, F_1 folds become isoclinal and overturned to the southeast with S_1 passing into the main mylonitic foliation (the mylonitic C-fabric). F_2 folds likewise become isoclinal and curvilinear, locally passing into sheath folds. S_2 cleavage becomes a schistosity and also merges into the mylonitic C-fabric. This composite C-fabric is folded by younger upright and inclined folds, giving rise to new crenulation lineations. This sequence of folding, apparently largely coeval with the shearing event, resembles the fold sequence within the sheared rocks in the Great Burnt Lake–Cold Spring Pond region (Colman-Sadd, 1985). The Bay d'Espoir mylonitic rocks contain abundant subhorizontal mineral stretching and rodding lineations, which are also parallel to lineations related to all the fold phases, and kinematic indicators (Plate 2). Along the shore of Bay d'Espoir, where the shear zone dips northwest much more gently than along the road transect, it is a gently inclined zone of overthrusting toward the southwest (Piasecki, 1988a). Traced southeastward into the higher grade rocks, the shear zone rotates into the subvertical in a belt of granitic intrusions adjacent to the Hermitage Bay Fault zone, the shear zone becoming a zone of sinistral transcurrent movement, as along the transect (Figure 2). This movement polarity is only locally reversed.

These observations on the Bay d'Espoir Shear Zone are remarkably consistent with the observations of Hanmer (1981). He interpreted the northeastern Gander Lake Subzone as a major zone of ductile shearing, having the same southerly sense of tectonic transport in zones of flat rocks, and sinistral transcurrent movements in the steep belt of the Hare Bay Gneiss adjacent to the Dover Fault, also invaded by syntectonic granitoids.

Syntectonic plutonism. The mylonitic schists of the Little Passage Gneiss contain a minor intrusive suite of muscovite–garnet–tourmaline granite (Middle Ridge type) and related pegmatite (Plate 3). Larger granitic bodies appear to the southeast, culminating in a regional belt of plutons adjacent to the Hermitage Bay Fault zone. Along the transect, the earliest intrusion is a biotite–hornblende tonalite phase of the Gaultois granite having pendants of mylonitic schists, migmatitic gneisses and amphibolites. It is cut by the leucogranite suite. Farther southeast, the tonalite is invaded by the main phase of the Gaultois granite, a coarse, inhomogeneous biotite-granodiorite with schlieren of migmatitic gneiss and nebulitic granite. On the transect, 5 km from the Hermitage Bay Fault, the Gaultois granite is intruded by variably foliated, equigranular muscovite and muscovite–biotite granite, only locally garnetiferous, which is in turn cut by pink muscovite–biotite granite. All these granitoids have variably developed foliar and linear fabrics of the same attitude and orientation as those in the shear zone mylonites; and locally they develop mineral stretching lineations sufficiently intense to become L-tectonites, indicating syn- to late-tectonic emplacement into the active shear zone. Late slickenside lineations also tend to follow this direction, suggesting prolonged, waning simple shear strain extending into the phase of granite cooling and uplift.

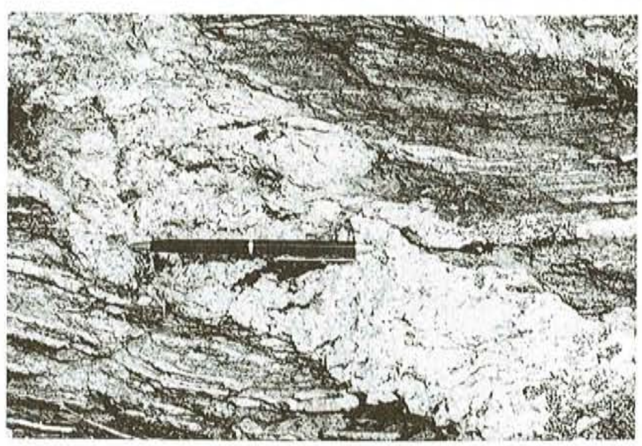

Plate 3. *Late syntectonic pegmatite. A pegmatite member of the muscovite-garnet leucogranite suite (Middle Ridge type) cuts the mylonitic C-fabric (schistosity with swarm of concordant quartz veinlets) of a Little Passage Gneiss mylonite, but is cross-foliated in parallelism with the mylonite foliation. Bay d'Espoir Shear Zone, quarry on transect at map reference 051938 on 1:50,000 sheet 1M/13.*

Bay D'Espoir Shear Zone and the Hermitage Flexure. As the Bay d'Espoir Shear Zone is traced westward along the Hermitage Flexure (Figure 1), it remains steep throughout, its stretching lineation remains subhorizontal, and the layer-parallel shear zone follows the course of the flexure through

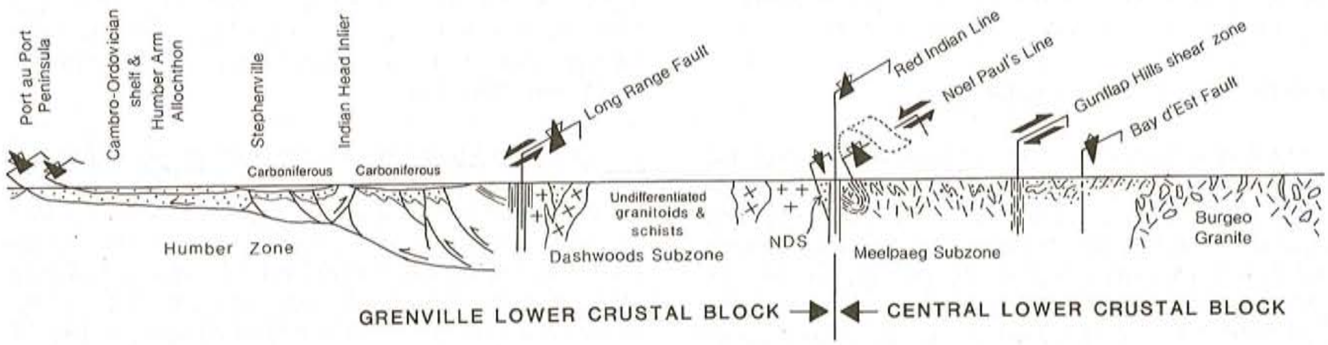

Figure 3. *Burgeo transect: zonal subdivisions and schematic geological relationships. Structural symbols as in Figure 2. Abbreviations: NDS–Notre Dame Subzone.*

east–west in Facheux Bay to west–northwest in Hare Bay and Grey River. However, the apparent sense of shear transport in both the metasedimentary rocks and the syntectonic leucogranite suite becomes progressively reversed from dominantly sinistral in Bay d'Espoir through both sinistral and dextral in Bonne Bay to dominantly dextral west of Bonne Bay.

The Dragon Bay mylonite zone (Blackwood, 1985), is a steep zone of subhorizontal, mainly dextral transcurrent movement in mylonitic McCallum granite, which intrudes the Little Passage Gneiss sheeted with muscovite–garnet leucogranite. It converges with the Bay d'Espoir Shear Zone in Hare Bay, from whence a wide, anastomosing belt of dominantly dextral transcurrent shear extends into the Burgeo Granite at least as far as White Bear Bay (Blackwood, 1983; O'Brien and Tomlin, 1983), where large screens of Meelpaeg and Exploits mylonites are engulfed by younger granite (Figure 1).

Hermitage Bay Fault Zone

At the transect, the Hermitage Bay Fault (Kennedy *et al.*, 1982) is represented by a subvertical breccia zone, in contrast with the Dover Fault zone, where the fabrics of a complex sequence of ductile movements are only partly overprinted by brittle movements. However, mylonites are present in the fault zone 20 km to the northeast of the transect. Within a 1-km-wide zone of shattered and altered rocks on both sides of the fault, relationships within fracture systems indicate subhorizontal, sinistral transcurrent movements, and also subvertically directed movements with downthrow to the east (Avalon side down). These are taken to be the major movements (Figure 2). Less common relationships between minor fractures indicate reversals in the sense of the subvertical slip and also southeast-directed movements on subhorizontal fractures. These probably represent subsequent minor movements.

Granites at the head of Hermitage Bay were first interpreted as a single pluton straddling the Gander–Avalon Boundary (the Straddling Granite of Blackwood and O'Driscoll, 1976; Colman-Sadd *et al.*, 1979). Our observations support the geochemical and isotopic evidence quoted by Elias and Strong (1982) for different granites on opposite sides of the Hermitage Bay Fault. The granite on the Gander side is a muscovite granite, foliated and locally lineated in parallelism with the fabrics in the Bay d'Espoir Shear Zone. The granite on the Avalon side contains no muscovite and no ductile fabrics.

THE BURGEO TRANSECT

The Burgeo transect extends from Stephenville, eastward to the Trans-Canada Highway and then follows Route 480 to Burgeo (Figures 1 and 3). It spans the Humber Zone, the Dashwoods, Notre Dame and the western Exploits subzones of the Dunnage Zone, the northern Meelpaeg Subzone of the Gander Zone, the southern Exploits Subzone and the Burgeo Granite batholith. From northwest to southeast, it crosses the major tectonic boundaries of the Long Range Fault, Red Indian and Noel Paul's lines, and the Gunflap Hills Fault (the Meelpaeg–southern Exploits boundary).

Humber Zone

Through much of the Humber Zone, the transect crosses glacial deposits covering thin, flat-lying Carboniferous sediments of the St. George's Subbasin. Below the Carboniferous are Cambro–Ordovician platformal sediments and the Grenville basement of the Appalachian foreland involved in Taconian–Acadian thrusting (Figure 3; Williams, 1985; Cawood and Williams, 1988; Williams and Cawood, 1989). From west to east, the regional cleavage and axial-planar to thrust-related folds increase in intensity, as does metamorphism, from anchizonal to chlorite–muscovite grade. In this region, most Taconian and Acadian deformations share an east over west polarity. Across the Grenville basement, the transect is within the Steel Mountain anorthosite and related mafic rocks and gneisses (the Steel Mountain Terrane of Currie, 1987), correlatives of the Indian Head Inlier to the west (Figures 1 and 3).

Humber–Dunnage Boundary

The surface extent of the Humber Zone is delimited by the Long Range Fault, a steep, major lineament having a complex history of ductile to brittle movements. In the fault zone at Grand Lake, earlier complex mylonitic fabrics, which locally indicate sinistral transcurrent slip and also vertical movements, are overprinted by vertical, brittle movements downthrown to the west. In the vicinity of this lineament, the Grenville basement exhibits Paleozoic reworking. Its regional northwesterly trending fabrics swing into the northeasterly Appalachian trend, and its original high-amphibolite–granulite facies assemblages are retrogressed to greenschist–amphibolite facies. Along the transect, the coarse anorthosite has recrystallized to a finer grained rock, gabbros are amphibolitized, and the rocks have developed networks of small anastomosing shear zones. At Grand Lake, between the Grand Lake Thrust (GLT) and the Long Range Fault (Figure 1), retrograded Grenville gneisses having an allochthonous cover sequence correlatable with the Fleur de Lys Supergroup, are imbricated by ductile thrusts having a westward displacement. The original position of this cover must have been to the east of the present Long Range Fault (Currie, 1987).

Dashwoods Subzone Boundaries

The Dashwoods Subzone is synonymous with the Central Gneiss Terrane of van Berkel and Currie (1988). It comprises amphibolite- to granulite-facies psammites invaded by voluminous, Ordovician syn- and late-tectonic tonalitic and granitic plutons (463 to 455 Ma, Dunning, 1987; Currie *et al., in preparation)* and by early Silurian posttectonic mafic plutons (434 to 431 Ma, Dunning *et al.*, 1988). Its northern boundary is the northward-dipping Little Grand Lake Fault. Along this fault, early ductile shearing was followed by late, low-angle, north over south movements with low-grade, upper crustal volcanic rocks of the Notre Dame Subzone, thrust upon deeper crustal rocks of the Dashwoods Subzone (see also van Berkel and Currie, 1988; Currie and Piasecki, 1989).

Across the Dashwoods Subzone, the transect crosses foliated tonalitic–granitic intrusions, and two posttectonic early Silurian gabbro complexes, the locally layered Main Gut Gabbro (MG) adjacent to the Long Range Fault, and the Silver Pond Gabbro (SP) adjacent to the Lloyds River Fault (LRF) and related brittle faults bounding the Annieopsquotch Ophiolite Complex (A) (Figure 1; van Berkel and Currie, 1986; Dunning, 1987).

Along the transect, the eastern margin of the Dashwoods Subzone is the unexposed Lloyd's River Fault. It coincides with a narrow belt of down-faulted Silurian red beds and rhyolitic volcanic rocks (Chandler and Dunning, 1983), exposed in a hill with a microwave tower. Southwestward, the same lineament is marked by the outcrop of the Devonian Windsor Point Group along the Cape Ray Fault zone (Kean, 1983).

Notre Dame–Western Exploits Boundary

This boundary, the Red Indian Line (Williams *et al.*, 1988, 1989b), approximately corresponds with the boundary between the Grenville and Central Lower Crustal blocks (Keen *et al.*, 1986; Marillier *et al.*, 1989). At the transect, the Red Indian Line is obscured by mafic intrusions. Northeast of the transect, it follows the contact of the Annieopsquotch Ophiolite Complex (Notre Dame) and the Cambrian to Middle Ordovician (Dunning *et al.*, 1986, 1987) Victoria Lake Group (western Exploits). The latter comprises felsic volcanic rocks, tuffs and mafic pillow lavas and intercalated red shales, dykes and sills. Farther northeast at Red Indian Lake, the Red Indian Line is marked by isolated occurrences of red Silurian sandstones on its western side (Williams *et al.*, 1988, 1989b).

Western Exploits–Meelpaeg Boundary

Noel Paul's Line, the Exploits–Meelpaeg boundary, separates low-grade rocks of the Exploits Subzone from higher grade rocks of the northern Meelpaeg Subzone. Noel Paul's Line is not well exposed on the transect and its kinematics are complex. Along the transect, the Rogerson Lake Conglomerate, which appears to be a subaerial infill of a probably Silurian lineament at or near Noel Paul's Line, exhibits the fabrics of northwesterly overthrusting; but 1 km farther south, the first exposure of Meelpaeg granite–mylonite has a fabric of subhorizontal, sinistral transcurrent movement.

At Victoria Lake, Noel Paul's Line is a layer-parallel, southeast-dipping ductile shear zone 1-km wide, along which Meelpaeg granite–mylonites are thrust northwest over mylonitic Victoria Lake Group volcanic rocks. However, the removal of the effect of a subsequent regional antiform restores a sense of northwest thrusting of Exploits over Meelpaeg subzones (Williams *et al.*, 1989b).

Southwest of the Burgeo road, the Red Indian Line converges with Noel Paul's Line, and the same southeast- over northwest-overthrusting polarity characterizes the shear zone for 40 km southwest to the Gunflap Hills.

Northern Meelpaeg Subzone

On the transect, Meelpaeg Subzone rocks are variably foliated, steeply inclined granitoids. The earliest, grey nebulitic granites enclose rare screens or pendants of migmatitic metasediments associated with up to 20 percent amphibolite (dykes?). The metasediments bear syn- and post-tectonic sillimanite. These rocks were folded before intrusion of voluminous biotite–muscovite–garnet leucogranite and related tourmaline–beryl pegmatites (Middle Ridge type). This suite, dated at 418 $\pm$ 2 Ma (Currie *et al., in preparation)*, cuts the nebulitic granite but is itself cross-foliated in parallelism with the foliation in the latter. At Buck Lake (Figure 1), psammitic schists having calc-silicate ribs similar to those in the Little Passage gneisses are intruded by

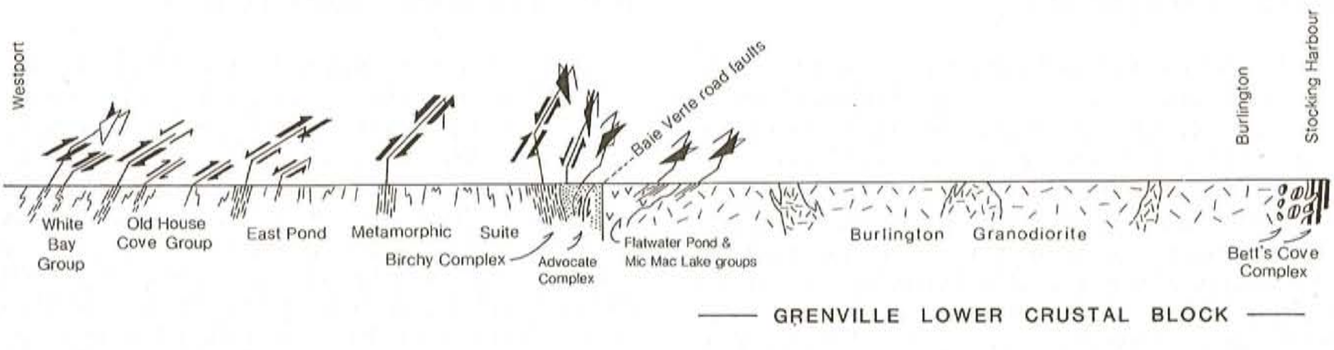

Figure 4. *Burlington transect: zonal subdivisions and schematic geological relationships. Structural symbols as in Figure 2. Thickness of the symbols for transcurrent movements (arrows) indicates the relative frequency of these fabrics.*

leucogranite, then cut by the xenocrystic Buck Lake granite. Throughout the transect, the granites have weak, subhorizontal mineral lineations, and an apparent 'memory' of small-scale sinistral strike-slip movements.

Meelpaeg–Southern Exploits Boundary

The Gunflap Hills Fault (Chorlton, 1980; O'Brien, 1983) separates the northern Meelpaeg Subzone from the southern Exploits Subzone (Figures 1 and 3). At Gunflap Hills, this fault forms a 2-km-wide, subvertical zone of intense, layer-parallel ductile shear with subhorizontal sense of dextral transcurrent movement. At the transect, a ductile Meelpaeg granite–mylonite has the same sense of movement, but the shear zone is partly cut out by brittle faulting, with a sharp metamorphic break between the Meelpaeg amphibolite-facies mylonites and the Ordovician Bay du Nord Group in biotite–chlorite grade (Exploits Subzone, O'Brien *et al.*, 1986). Adjacent to the Gunflap Hills Fault, Bay du Nord Group phyllitic shales and sandstones are inverted in a zone 5-km wide, and their earliest recumbent folds are refolded by small upright, highly curvilinear folds, which may be related to a late phase of subvertical movement of the Gunflap Hills Fault.

Within the Exploits Subzone, the Bay d'Est Fault, a zone of vertical movements late in the structural sequence and locally mylonitic (Chorlton, 1980; O'Brien, 1987), juxtaposes the Ordovician Bay du Nord Group with crossbedded and locally pebbly sandstones of the Silurian La Poile Group. At the transect, a tonalite containing xenoliths of sheared volcanic rocks occurs on the Exploits side of the Bay d'Est Fault.

Farther south along the transect, La Poile sandstones are intruded by the Burgeo Granite, a composite, largely syntectonic, Silurian (ca. 429 Ma to 415 Ma) intrusion of batholithic dimensions (Dickson *et al.*, 1989; Dunning *et al.*, 1988).

THE BURLINGTON TRANSECT

The Burlington transect follows Route 411 from Westport to the Baie Verte road (Route 410) and then Route 413 to Burlington and Stocking Harbour (Figures 1 and 4). It crosses the Fleur de lys Supergroup of upper Hadrynian to lower Ordovician clastics, the Humber–Dunnage boundary (Baie Verte–Brompton Line) and Dunnage volcanic rocks and plutons farther east (Williams and St. Julien, 1982; Hibbard, 1983).

Tectonic Base of the Fleur de Lys Supergroup

The Fleur de Lys Supergroup is exposed in large-scale anticlinoria and synclinoria. In the deepest tectonic level, Fleur de Lys turbidites in amphibolite facies (Old House Cove group) are tectonically underlain by the East Pond Metamorphic Suite, a migmatitic 'infrastructure' of schists interbedded with metaconglomerate. Granitic gneisses near the metaconglomerate were interpreted as reworked Grenville basement (Hibbard, 1983). However, the gneisses may have been derived by migmatization and deformation of the conglomerate and adjacent schists (Piasecki, 1987), implying that, at least along the transect, Grenville basement may lie below the present level of exposure. The tectonic zone separating the Old House Cove group from the East Pond Metamorphic Suite (Hibbard, 1983), is a layer-parallel ductile shear zone some 1.5-km wide (Piasecki, 1988b). It shows a polyphase sequence of orogen-parallel movements, having apparently south-directed overthrusting, followed later by north-directed overthrusting in gently inclined rocks, and related sinistral and dextral movements in steep rocks (Figure 3).

Tectonic Zones Internal to the Fleur de Lys Supergroup

The whole outcrop of the Old House Cove group crossed by the transect contains abundant S-C foliations and shear bands indicating penetrative internal strike–slip with an apparent dextral (dominant), and sinistral (minor) sense of displacement (Figure 4). Locally, related minor mylonitic zones are present. To the west, the boundaries of the White Bay Group and internal boundaries between its subdivisions (Pidgeon Island and Garden Cove formations) are zones of shearing, again with predominantly dextral sense of transcurrent movements in steep rocks, and north-directed overthrusting in gently inclined rocks.

Humber–Dunnage Boundary

The Humber–Dunnage boundary, the Baie Verte–Brompton Line, is a complex zone of polyphase ductile to brittle movements. Along the transect, the eastern flank of the Fleur de Lys Supergroup is a subvertical mylonite zone 2.5-km wide. Intensely mylonitic greenschist-facies phyllonites of the Rattling Brook Group and the Birchy Complex lie within this zone. The belt of highest shear strain abuts a 1-km-wide sheared serpentinite (Advocate Complex), locally replaced by talc-serpentinite and carbonate. Mylonite fabrics in the ultramafic rocks and westward, indicate that earlier phases of both dextral and sinistral transcurrent transport were followed by a late, major phase of overthrusting to the east (west over east movements), a common movement polarity along the whole boundary northeast of Mic Mac Lake.

Along the transect, the Advocate Complex is bounded to the east by the Baie Verte Road fault system. This fault system is marked by a sharp break in tectonic and metamorphic intensity between strongly foliated and sheared mid-greenschist Ordovician mélanges and ophiolitic rocks in the west, and weakly deformed low-greenschist Middle Ordovician Flatwater Pond and Silurian Mic Mac Lake groups in the east.

South of Flatwater Pond (FP), tectonic slices of the Mic Mac Lake Group volcanic rocks are thrust toward the east, indicating that the late east over west movements are Silurian or later (Acadian). However, along the transect north of Flatwater Pond, a 3.5-km-wide zone of volcanic rocks (Flatwater Pond and Mic Mac Lake groups) and the margin of the Burlington Granodiorite, contain minor ductile shear zones with an east over west sense of dip–slip movement. These probably indicate a late phase of Acadian shearing.

Notre Dame Subzone

Across this subzone, the transect is largely in the Middle Ordovician Burlington Granodiorite, a weakly foliated, sphene-rich, feldspar-porphyritic hornblende-granodiorite of near batholithic dimensions, with later, more leucocratic phases in its central and eastern regions. Along its western flank, the granodiorite is cut by felsic dykes, feeders to unconformably overlying Silurian Mic Mac Lake volcanic rocks. Between Burlington and Stocking Harbour, the Burlington Granodiorite agmatizes a south–southeast-trending sheeted dyke complex and a related diabase–gabbro (Betts Cove Complex). The granodiorite has been fluidized, resulting in common tuffisite along its joints, and is cut by a swarm of diabase dykes.

DISCUSSION AND OVERVIEW

Dunnage–Gander Boundary Relationships in South-Central Newfoundland

An allochthonous Dunnage Zone above the Gander Zone in central Newfoundland has been proposed previously (e.g., Colman-Sadd and Swinden, 1984; Karlstrom, 1983; Piasecki, 1988a; Williams *et al.*, 1988, 1989b). The Cold Spring mélange heralds the first docking of the ophiolitic Dunnage crust over the clastic rocks of the Gander Zone. Its unbedded, homogeneous black graphitic matrix is characteristic of the matrices of all early to middle Ordovician mélanges in Newfoundland (Williams, 1973, 1977a,b; Williams and Smyth, 1983; Pajari *et al.*, 1979; Smyth and Schillereff, 1982; Hibbard, 1983; Hibbard and Williams, 1979). Thus, by inference, the Cold Spring mélange reasonably constricts earliest obduction to the Early or Middle Ordovician. Other fragmental ophiolitic occurrences at Exploits–Meelpaeg and Exploits–Mount Cormack boundaries (Colman-Sadd, 1984, 1989; Willams *et al.*, 1988) may also represent ophiolitic mélanges.

The orogen-parallel movements are later: they follow the Dunnage–Gander boundary zone, modify the mélange, and in Bay d'Espoir are associated with syntectonic Silurian granites *(ca.* 421 Ma, Dunning *et al., in press).* The re-activation of this boundary at the Great Burnt Lake–Cold Spring Pond region may, or may not be of the same age. The west over east (dip–slip) movements in the latter region are later still.

The Dunnage–Gander tectonic boundary can be considered as initially subhorizontal and subsequently domed, exposing the tectonic windows of the Mount Cormack and Meelpaeg subzones. The ductile shear boundaries at Great Burnt Lake and Bay d'Espoir appear to be tectonically equivalent, and probably coeval. The former records an apparent dextral sense of movement that is consistent with the orogen-parallel, sinistral movement at the opposite side of the Exploits Subzone in Bay d'Espoir (Figure 2). However, fabric relationships within the Bay d'Espoir Shear Zone in Bonne Bay (Figure 1) suggest that this large-scale, southward-directed Silurian(?) movement of the Dunnage Zone over the Gander substrate (Currie and Piasecki, 1989) progressively deviates through some 60°, along the present course of the Hermitage Flexure. Back-movements along the Hermitage Flexure (dextral) and in the Dolland Pond shear belt (northerly dip–slip) may reflect a relaxation of this regime. A system of dextral transcurrent shear zones extending from south-central Newfoundland toward Cape Ray, such as the Dragon Bay shear zone, the shear belt within the Grey River Enclave, the Gunflap Hills and the Isle aux Morts shear zones (Figure 1; Piasecki, 1989) also may be related to the back-movements on the Bay d'Espoir Shear Zone. More data, and especially more control on the timing of these events, are critical to elucidate the accretionary history.

Noel Paul's Line appears to be a continuation of the major lineament of the Cape Ray Fault (Brown, 1977; Wilton, 1983), albeit displaced by the Gunflap Hills Fault (Figure 1). Along Noel Paul's Line, the dominant mylonite fabrics are those of northwesterly overthrusting. They appear to relate to the first deformation in host metasediments, and are probably earlier than the transcurrent movements at Great Burnt Lake, which appear to relate to the second deformation (Williams *et al.*, 1989b). If the transcurrent fabric at Noel Paul's Line between Victoria Lake and the Burgeo road is not the overthrusting fabric rotated in a large fold, then it resembles the Silurian movements at Bay d'Espoir (cf. Figures 2 and 3). This further suggests a polyphase movement history along Noel Paul's Line, which may be comparable with that in the Cape Ray Fault zone (Piasecki, 1989). The early overthrusting on Noel Paul's Line invites comparison with pre-Mid Devonian movements with the same sense of transport in the Cape Ray Fault zone, and the transcurrent movements with Silurian transcurrent movements at the Bay d'Espoir region; the overthrusting in the Rogerson Lake Conglomerate on the Burgeo road may correspond with post-Mid Devonian northwesterly overthrusting in the Cape Ray Fault zone. However, the regional history of ductile shearing movements is likely to be more complex, since in the Cape Ray Fault zone, pre-middle Devonian overthrusting may have been preceded by transcurrent movements (Williams, 1989b).

Humber–Dunnage Boundary Relationships

Obduction of the Dunnage Zone over the Appalachian miogeocline (Humber Zone) is recorded by the formation of the Coachman's mélange in Baie Verte (Figure 1) during the Early Ordovician (Williams, 1977b). In this mélange, and in nearby sheared turbidite-like metasandstones, kinematic markers indicate a sense of southeast- over northwest-overthrusting movements, but it is uncertain whether these relate to Ordovician movements, or to a later phase. The transcurrent movements within the Fleur de Lys Supergroup and the Advocate Complex, the subsequent east over west overthrusting, and the local(?) west over east movements along the western flank of the Burlington Granodiorite are all most probably Acadian in age.

Dashwoods Subzone

The nature of the Dashwoods Subzone remains enigmatic. Within its metasediments, layer-parallel belts of mylonite with fabrics of transcurrent movements contain lenses of serpentinite and gabbro (Piasecki, 1988b; Fox and van Berkel, 1988). These may represent metamorphosed and dismembered ophiolitic complexes or mélanges. They imply the presence of either a number of small miogeoclinal blocks comingled with ophiolites, or a single Humber–Dunnage boundary that was imbricated before voluminous Ordovician syn- to late-tectonic plutonism and the subsequent emplacement of posttectonic, Silurian mafic plutons.

Burgeo Granite

The Silurian crystallization ages for the syn- and post-tectonic phases of the Burgeo Granite (*ca.* 429 Ma and 415 Ma), are thought to bracket the deformation in its host metasediments (Dunning *et al.*, 1988), and date the orogen-parallel movements in the Bay d'Espoir and related shear zones that affect the granite. Of particular significance are ophiolitic(?) to migmatitic and gneissic enclaves in the granite. At the transect 2.5 km south of Seal Brook (Figure 1), a hybrid, agmatitic granodiorite contains enclaves of psammitic gneiss intimately interbanded with thin, concordant amphibolite, a rock type similar to the Port aux Basques Gneiss. The enclaves suggest emplacement of the batholith into an assembled continental-type crust such as the Gander Zone and ophiolitic crust of the Dunnage Zone.

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