Geology of the Area between Lockeport, Liverpool and Lake Rossignol, Shelburne and Queens Counties, Southwestern Nova Scotia

C. E. White

Introduction

The South Shore Nova Mapping Project was initiated in 2004 by the Nova Scotia Department of Natural Resources as a continuation of the Southwest Nova Project. The principal goals of the project are to produce a series of 1:50 000 scale geological maps of the area, describe and interpret the sedimentary, igneous, metamorphic and deformational history, and evaluate the economic potential. Reported here are results from 1:10 000 scale field mapping completed during the summer of 2004, including a preliminary bedrock geology map of the area between Lockeport, Liverpool and Lake Rossignol in Shelburne and Queens counties (Figs. 1, 2) and includes parts of NTS map areas 20P/10, 14, and 15 and 21A/02 and 03.

Details of the mapping program and methodology are similar to those in the Southwest Nova Project (Fig. 1), as summarized by White *et al.* (1999). Preliminary results since 1998 (covering all or parts of NTS map areas 21A/02 and 12, 21B/01 and 08, 21O/09 and 16, and 20P/05, 06, 11, 12, 13, and 14) were presented by White *et al.* (1999, 2001, 2003), Horne *et al.* (2000), White (2003), White and King (2002), and White and Barr (2004).

Map Units

Introduction

The earliest geological work on the meta-sedimentary rocks in the 2004 map area was undertaken by Bailey (1896) and Faribault (1914, 1915, 1918, 1920) and largely focused on structural and economic geology. Taylor (1967) subdivided the rocks in the present area into the Ordovician and earlier Goldenville and Halifax formations and noted that these units were intruded by the Devonian granodioritic Port Joli Pluton (later termed Port Mouton Pluton by Hope and Woodend, 1986). Hope and Woodend (1986), Hope (1987), and Hope *et al.* (1988) followed the subdivisions established by O'Brien (1986, 1988) and Waldron (1992) in the Meguma Group farther to the northeast, and subdivided the Goldenville Formation into the New Harbour and West Dublin members and the Halifax Formation into the Moshers Island and Cunard members. Although similar, the stratigraphic units established in the map areas to the southwest by White (2003) and White and Wasylik (2003) are used in this report, as they are shown to continue into the current map area. These stratigraphic units include the Late Neoproterozoic to Cambrian Goldenville Formation, consisting of the Green Harbour, Government Point, and Moshers Island members, and the overlying Cambrian to Early Ordovician Cunard member of the Halifax Formation. These units have been deformed and regionally metamorphosed, with grade ranging from biotite (greenschist facies) in the northeastern half of the map area to locally sillimanite-bearing migmatite (amphibolite facies) in the southwestern half. The metamorphic units are intruded by the Devonian Port Mouton Pluton (Hope and Wooden, 1986) and the gabbroic Late Triassic Shelburne Dyke.

Goldenville Formation

The Goldenville Formation is subdivided into two main units termed the Green Harbour and Government Point members, which are similar in distribution to the New Harbour and West Dublin members defined by Hope (1987). The Moshers Island member in the study area (Hope, 1987) and farther to the northeast in Queens and Lunenburg counties (O'Brien, 1986, 1988; Waldron, 1992) is defined as representing the base of the overlying Halifax Formation. However, based on field evidence (see below) the Moshers Island member is here interpreted to mark the top of the Goldenville Formation in the map area.

White, C. E. 2005: *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 129-144.

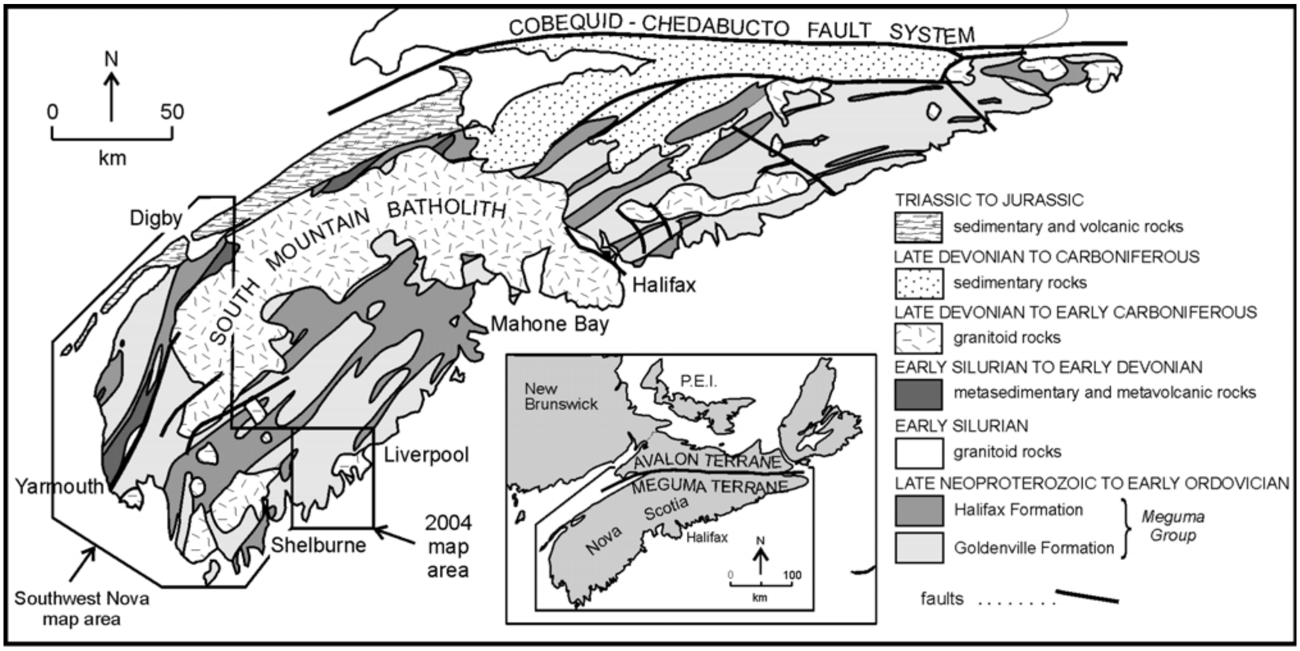

Figure 1. Simplified geological map of the Meguma Terrane, Nova Scotia, showing location of the mapped area related to the Southwest Nova Mapping Project and the 2004 map area.

Green Harbour Member

The Green Harbour member is the largest unit in the map area (Fig. 2) and consists of grey thick-bedded metasandstone that is locally interlayered with green, cleaved metasiltstone. Minor black slate interbeds are present. As metamorphic grade increases towards the pluton, the more pelitic beds are spotted first with biotite, followed by staurolite, cordierite, and andalusite. Migmatitic rocks are present near Summerville Beach. The metasandstone is light grey, thickly bedded and typically contains abundant elliptical calc-silicate lenses and beds. Original sedimentary structures are common, which aids in determining stratigraphic tops. Trace fossils are not common but large *Psammichnites* and *Phycodes*(?) grazing traces have been observed at the top of large metasandstone beds southwest of Little Port L'Hebert (Fig. 2). The Green Harbour member typically displays a uniform low aeromagnetic response throughout the area (King, 1997a, b, c, d, and unpublished data). The Green Harbour member is conformably overlain by the Government Point member near Blue Island, Western Head and Arnold, and also in Broad River (Fig. 2). The contact is marked by an increase in more pelitic interbeds and a thinning of the massive metasandstone beds and occurs over a 100 to 500 m interval. This contact is also marked by a higher positive aeromagnetic response.

Government Point Member

In areas of low metamorphic grade, the Government Point member is typically composed of grey, thinly bedded metasandstone, rhythmically laminated metasiltstone, and black slate. At higher metamorphic grade, around the western margin of the Port Mouton Pluton, the more pelitic beds in the member are composed of garnet-sillimanite schist/granofels. As in the Green Harbour member, calc-silicate nodules are very common in the metasandstone. Burrowing J-shaped trace fossils were observed in the metasandstone beds, and are typically deformed into elongate V-shaped features. A quartz-pebble conglomerate is exposed along the west side of Lockeport Harbour and forms deeply scoured channels in a 20 m-wide sedimentary slump structure that can be traced for 100 m along strike. The Government Point member is characterized by thin, alternating bands of high and low aeromagnetic signatures that reflect the high magnetite content of the interlayered pelitic beds. The Government Point member is best exposed along the shore northwest of Blue Island, in Lockeport Harbour, and in Broad River (Fig. 2).

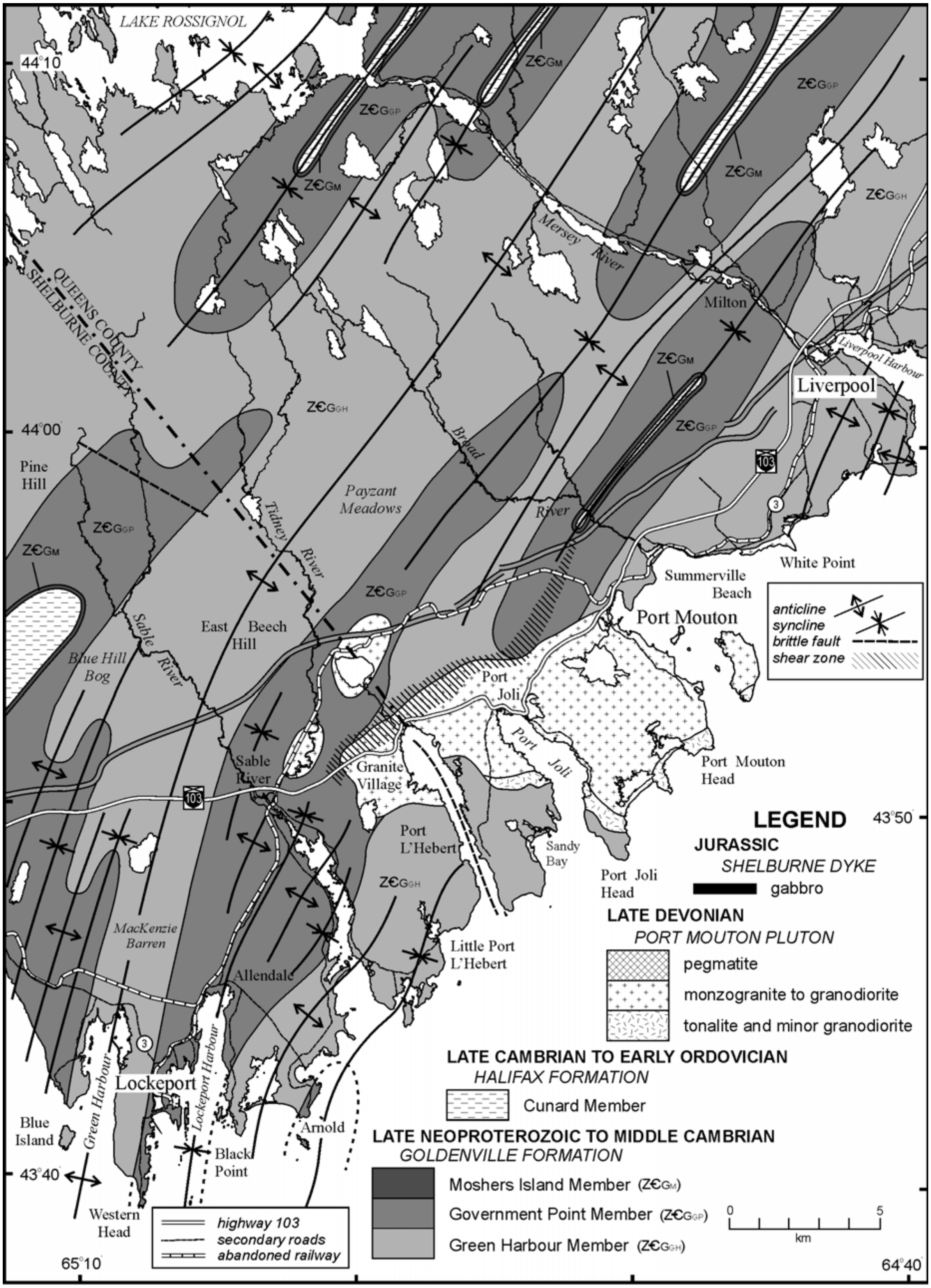

Figure 2. Simplified geological map of the area between Lockeport, Liverpool and Lake Rossignol, Shelburne and Queens counties, southwestern Nova Scotia.

Moshers Island Member

The Moshers Island member is a narrow (<100-300 m wide) unit of green to green-grey to grey, well laminated metasiltstone to slate interlayered with 1 to10 cm thick metasandstone beds. Toward the top of the member the metasiltstone is interlayered with rare black slate. A characteristic feature in this unit is thin (up to 10 cm wide), pink coticule beds and lenses that are more abundant toward the top of the unit. Locally these beds are so tightly folded that the limbs are non-existent and the coticule forms rods in the noses of minor folds. At higher metamorphic grades, as exposed in Broad River, the more pelitic beds are composed of andalusite ± staurolite ± cordierite schist. The contact with the underlying Government Point member appears to be gradational over several tens of metres, and marked by a decrease in the thickness of metasandstone beds. In Broad River, however, the lower part of the Moshers Island member is cut by a steep, bedding-parallel shear zone defined by tightly folded to rootless vertically-plunging quartz veins (see structure section). Along strike to the northeast similar quartz veins are present in the same stratigraphic horizon. The contact with the overlying Cunard member is abrupt and also marked by a bedding-parallel shear zone defined by tightly folded to rootless, steeply plunging coticule beds and quartz veins, also observed to the northeast. This unit is similar in its aeromagnetic signature to that of the Government Point member, although some of the green metasiltstone beds are extremely magnetic (50-100 SI units measured in the field).

The gradational relationship with rocks in the underlying Government Point member, the presence of abundant thin metasandstone beds, and the lack of abundant black slate supports the interpretation that the Moshers Island member in the present map area is more closely linked with the Goldenville Formation than the younger Halifax Formation.

Halifax Formation

Rocks typical of the Halifax Formation are exposed in the cores of five major, tightly folded synclines (Fig. 2). The Halifax Formation consists of black to rust-brown slate with thin beds and lenses of minor black metasiltstone. It locally contains abundant pyrite and pyrrhotite. With an increase in metamorphic grade toward the southeast (syncline near the mouth of Broad River), the slate becomes increasingly andalusite-rich and locally forms bands of chiastolite-bearing slate. This unit is typical of the Cunard Formation in southwestern Nova Scotia (Hope, 1987; Hope *et al.*, 1988; White *et al.*, 1999, 2001; Horne *et al.*, 2000). Like the Moshers Island member, the Cunard member in the map area is relatively narrow and its aeromagnetic signature is indistinguishable from that of the larger Government Point member.

Port Mouton Pluton

The Port Mouton Pluton (Hope and Wooden, 1986) occurs in the southeastern part of the study area (Fig. 2) and was extensively studied by Douma (1988, 1992). As a result, the main pluton was re-mapped on only a reconnaissance scale during the present study to confirm the lithological subdivisions and contact relations described by Douma (1988, 1992). In addition, a detailed structural study was conducted and integrated with unpublished data collected by Douma (1988). The two small plugs reported by Taylor (1967) west of the main pluton were not located during the study of Hope (1987), Hope and Wooden (1986), and Douma (1988) but due to extensive logging in the area and new aeromagnetic maps, these two bodies were confirmed to exist.

Based on cross-cutting features, Douma (1988, 1992) distinguished ten distinct units in the Port Mouton Pluton, which were involved in three distinct magmatic stages (Douma, 1992; Currie and Whalen, 1994; Clarke *et al.*, 2000). Foliated, biotite tonalite and granodiorite with minor synplutonic lamprophyric dykes dominated the early granitoid stage and occur as a continuous body along the southern contact of the pluton and as discontinuous bodies along the northeastern margin (Fig. 2). At the southern contact the igneous rocks locally contain numerous metasandstone screens whereas the contact in the north is associated with migmatitic country rocks (Summerville Beach area). Tonalite and granodiorite also occur as large blocks in units formed in the middle granitoid stage. The middle granitoid stage is dominated by biotite-muscovite monzogranite to granodiorite and occupies most of the remainder of the pluton. The northern contact with the country rocks is a large northeast-trending shear zone (see structure section). Late stage intrusions in the pluton range from biotite-muscovite tonalite to granite and occur in sheet-like pegmatitic and aplitic bodies cutting all earlier units, including the country rocks (Fig. 2).

Locally the tonalite in stage 1 and granodiorite in stage 2 display banding defined by alternating biotite-rich and biotite-poor layers and biotite schlieren. These features are interpreted to be related to magma flow (Douma, 1992; Currie and Whalen, 1994). The Port Mouton Pluton locally exhibits a very strong steep, northeast-trending tectonic foliation resulting from parallel alignment of biotite, and a lineation defined by elongate feldspar, quartz, and/or lens-shaped biotite aggregates (see structure section).

Attempts to date the Port Mouton Pluton using the conventional $^{40}Ar/^{39}Ar$ method on muscovite, biotite, and hornblende produced ages ranging from ca. 300 to 350 Ma that were attributed to either slow cooling (Keppie and Dallmeyer, 1995), thermal resetting (Reynolds *et al.*, 1987; Douma, 1988), or to have no chronological significance (Fallon *et al.*, 2001). Currie *et al.* (1998) reported magmatic monazite ages ranging from 368 ± 1 Ma (granodiorite) to 378 ± 3 Ma (tonalite) for the pluton. Clarke *et al.* (2000) established a U-Pb monazite age of 373 ± 1 Ma for the early and middle stages of the pluton. Fallon *et al.* (2001) reported $^{40}Ar/^{39}Ar$ laserprobe ages from the cores of muscovite at 373 ± 1 Ma, which suggest that the Port Mouton Pluton cooled rapidly following intrusion, whereas rims of some muscovite grains record ages as young as 315-325 Ma. These younger ages were interpreted to be either the result of reheating during the Alleghanian Orogeny or slow argon diffusion out of muscovite grain cores to rims that ceased at this time (Fallon *et al.*, 2001). Whole-rock and related isotope geochemistry implies a continental margin arc environment for the synplutonic lamprophyric dykes and by inference the remainder of the pluton (Tate and Clarke, 1995). However, Clarke *et al.* (2000) and Fallon *et al.* (2001) cited the mantle plume theory idea of Murphy *et al.* (1999) to account for the arc-like chemical signature in the Port Mouton Pluton and other plutons in the area.

Shelburne Dyke

The Early Jurassic tholeiitic Shelburne Dyke, based on aeromagnetic data, scattered outcrop and numerous float occurrences, extends across the middle part of the map area (Fig. 2). From the aeromagnetic data it is clear that the gabbroic dyke does not form one continuous sheet but appears to be offset by minor faults. In the northeastern part a small segment of the dyke appears to display an *en echelon* character. Although contacts with the country rocks are not exposed the dyke is finer grained towards the inferred margins compared to the centre.

Deformation and Metamorphism

Detailed $^{40}Ar/^{39}Ar$ studies on single grain muscovite and whole-rock samples from the Meguma Group indicate that regional greenschist facies metamorphism occurred from ca. 388-406 Ma and coincided with the Acadian Orogeny (Muecke *et al.*, 1988; Hicks *et al.*, 1999; Muir, 2000). In the map area, regional scale north- to northeast-trending folds with well developed axial planar cleavage and regional metamorphism that varies from greenschist facies in the northwest to amphibolite facies around the Port Mouton Pluton in the southeast are generally attributed to the Acadian Orogeny (e.g. Keppie, 1985).

Deformation

The identification and characterization of structural features in the map area are based on overprinting criteria and metamorphic grade. In areas where outcrop is sparse, aeromagnetic data are used to delineate the spatial extent of structural features. The area is divided into five structural domains with contrasting structural geometries (Figs. 3-7); they are similar in distribution to those defined by Hope (1987).

Domain I, in the southwestern part of the map area, comprises parts of the Jordan Bay-Green Harbour-Lockeport Harbour domains of Hope (1987) and extends from Blue Island to Black Point along the coast, northward to the area around the Shelburne Dyke (Fig. 3). In the western and eastern

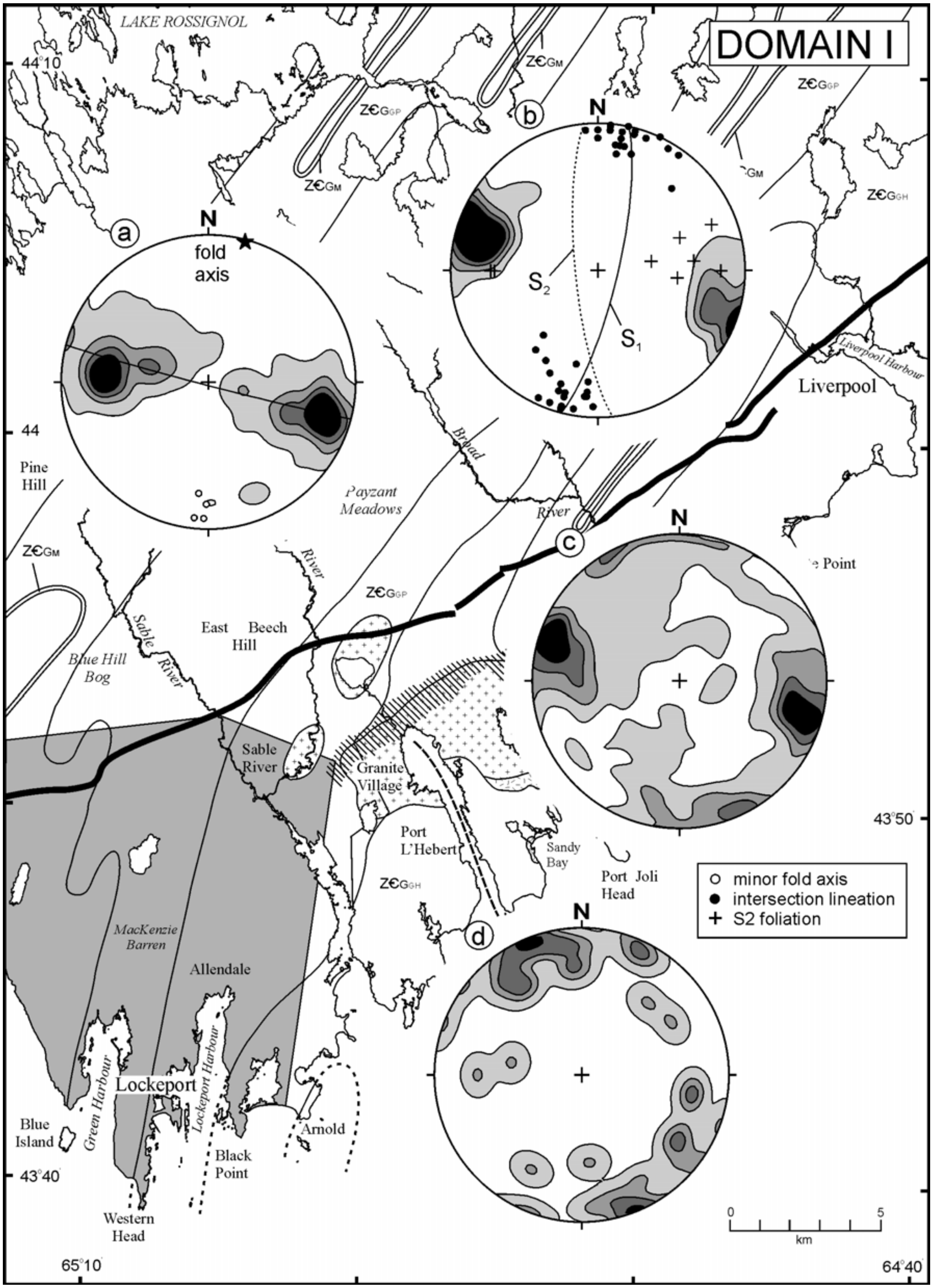

Figure 3. Equal area stereonets of structural data for Domain I (shaded grey area) in the map area. (a) Contoured poles to bedding and minor F_1 fold axes. (b) Contoured poles to foliation and bedding-cleavage intersection lineations, solid and dashed great circles show average orientation of S_1 and S_2, respectively. (c) Contoured poles to joints. (d) Contoured poles to quartz veins. Contours on stereonets at 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area.

part of the domain, the Government Point member is folded into several 5 to 500 m scale anticlines and synclines. The Green Harbour member is folded into a single anticline (Fig. 2). Poles to bedding (S_0) from domain I define a well developed girdle distribution with a near-horizontal, north-northeast-plunging fold axis (Fig. 3a). Poles to foliation (S_1) indicate a steep east dipping, north-northeast striking axial planar foliation (Fig. 3b). Minor F_1 folds are upright and horizontal to gently plunging southward (Fig. 3a). Intersection lineations (L_1) (bedding/foliation) are somewhat scattered but are generally subhorizontal or gently plunge to the north or south (Fig. 3b). Calc-silicate nodules typically are elongate parallel to the intersection lineation. Crenulation cleavages (S_2) are more common in the well cleaved to schistose lithologies and deform the schistosity and bedding. The crenulation cleavage strikes north with steep dips to the west (Fig. 3b) and the crenulation lineation (not plotted) is generally parallel to the minor fold axes. Although contoured poles to joints display a considerable amount of scatter, two clusters are evident (Fig. 3c). The main cluster indicates a prominent steep, north-to northeast-trending joint set that is parallel to the regional foliation and a second smaller cluster indicates a steep, northeast-to east-trending joint set (Fig. 3c). Contoured poles to quartz veins also display considerable scatter, although steep, northeast-trending quartz veins parallel to the minor joint orientations predominate (Fig. 3d).

Domain II, in the southern part of the map area, comprises the Sable River-Port L'Herbert domain of Hope (1987) and extends from Arnold to Sandy Bay along the coast, northward to southern contact with the Port Mouton Pluton (Fig. 4). Although outcrop is scarce, based on aeromagnetic data the Government Point member in the western part of the domain appears to be folded into a series of anticlines and synclines. The Green Harbour member, which makes up the remainder of the domain, is folded into a km-scale anticline and syncline (Fig. 2). Poles to bedding (S_0) define a well developed girdle distribution with a near-horizontal, southwest-plunging fold axis (Fig. 4a) and poles to foliation (S_1) indicate a steep east-dipping, northeast-striking axial planar foliation (Fig. 4b). In contrast to the regional fold axis orientation, minor F_1 folds are upright and plunge moderately southward (Fig. 4a). Intersection lineations (L_1) (bedding/foliation) are somewhat scattered but generally plung gently to moderately to the southwest (Fig. 4b). As in domain I, contoured poles to joints display a considerable amount of scatter, although the main cluster indicates a prominent steep, northeast-trending joint set that is parallel to the regional foliation in the domain (Fig. 4c). Contoured poles to quartz veins also display considerable scatter, although there is a predominance of steep, east-northeast-trending quartz veins parallel to those in domain I (Fig. 4d).

Domain III, in the southeastern part of the map area, comprises the St. Catherines River Bay domain of Hope (1987) in the area directly south of the Port Mouton Pluton in the Port Joli Head area and farther to the northeast in the White Point area (Fig. 4). In this area strike of bedding in the Green Harbour member is parallel to the contact of the pluton and the metasandstone is so injected with granite and pegmatite that most of the foliation has been obliterated by contact metamorphism (Hope, 1987). Poles to bedding (S_0) and foliation (S_1) indicate a vertical, northwest-striking average orientation for bedding and foliation (Fig. 4e, f). The distinctly different structural orientations in this domain compared to the regional structural patterns may be attributed to deflection by emplacement of the Port Mouton Pluton (e.g. Hope, 1987; Douma, 1988).

Domain IV, in the northern part of the map area, comprises the Northern-Broad River-Western Head domains of Hope (1987) and extends from the area north of the Shelburne Dyke and Port Mouton Pluton to Lake Rossignol (Fig. 5). The Goldenville and Halifax formations in this domain are folded into several regionally significant, doubly-plunging anticlines and synclines (Fig. 2) that are clearly portrayed on aeromagnetic maps (King, 1997a, b, c, d and unpublished data). Poles to bedding (S_0) define a well developed girdle distribution with a gently northeast-plunging fold axis (Fig. 5a). These data contrast with the obvious doubly-plunging attitude displayed on the aeromagnetic maps; however, minor F_1 folds are gently to moderately plunging toward the northeast and southwest (Fig. 5a). Poles to foliation (S_1) in Domain IV indicate a steep northwest-dipping, northeast- striking axial planar foliation (Fig. 5b).

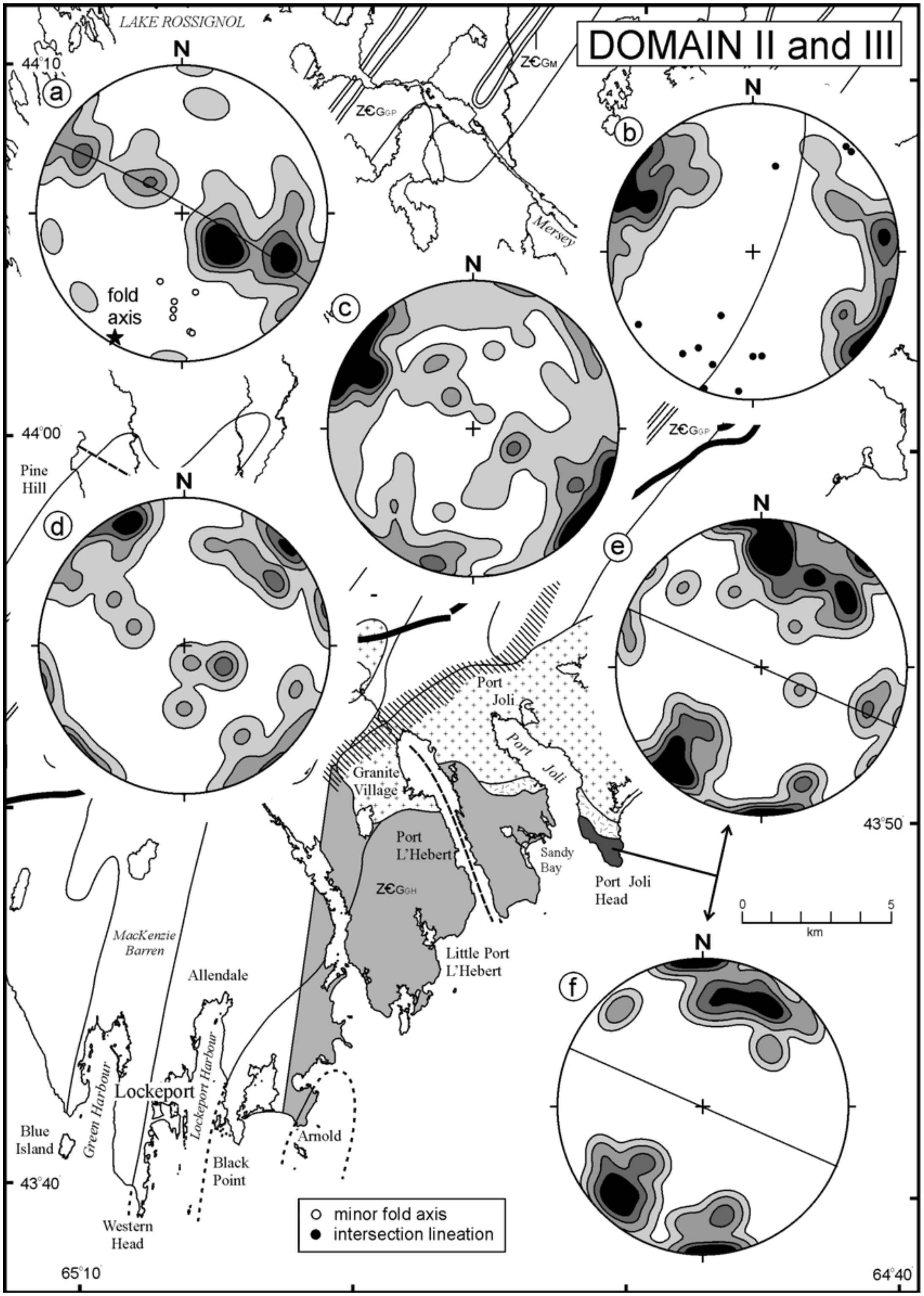

Figure 4. Equal area stereonets of structural data for Domain II and III (light and dark shaded areas, respectively) in the map area. Domain II: (a) Contoured poles to bedding and minor F_1 fold axes. (b) Contoured poles to foliation and bedding-cleavage intersection lineations, solid great circle shows average orientation of S_1. (c) Contoured poles to joints. (d) Contoured poles to quartz veins. Domain III: (e) Contoured poles to bedding, solid line shows average orientation of S_0 . (f) Contoured poles to foliation, solid line shows average orientation of S_1. Contours on stereonets at 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area.

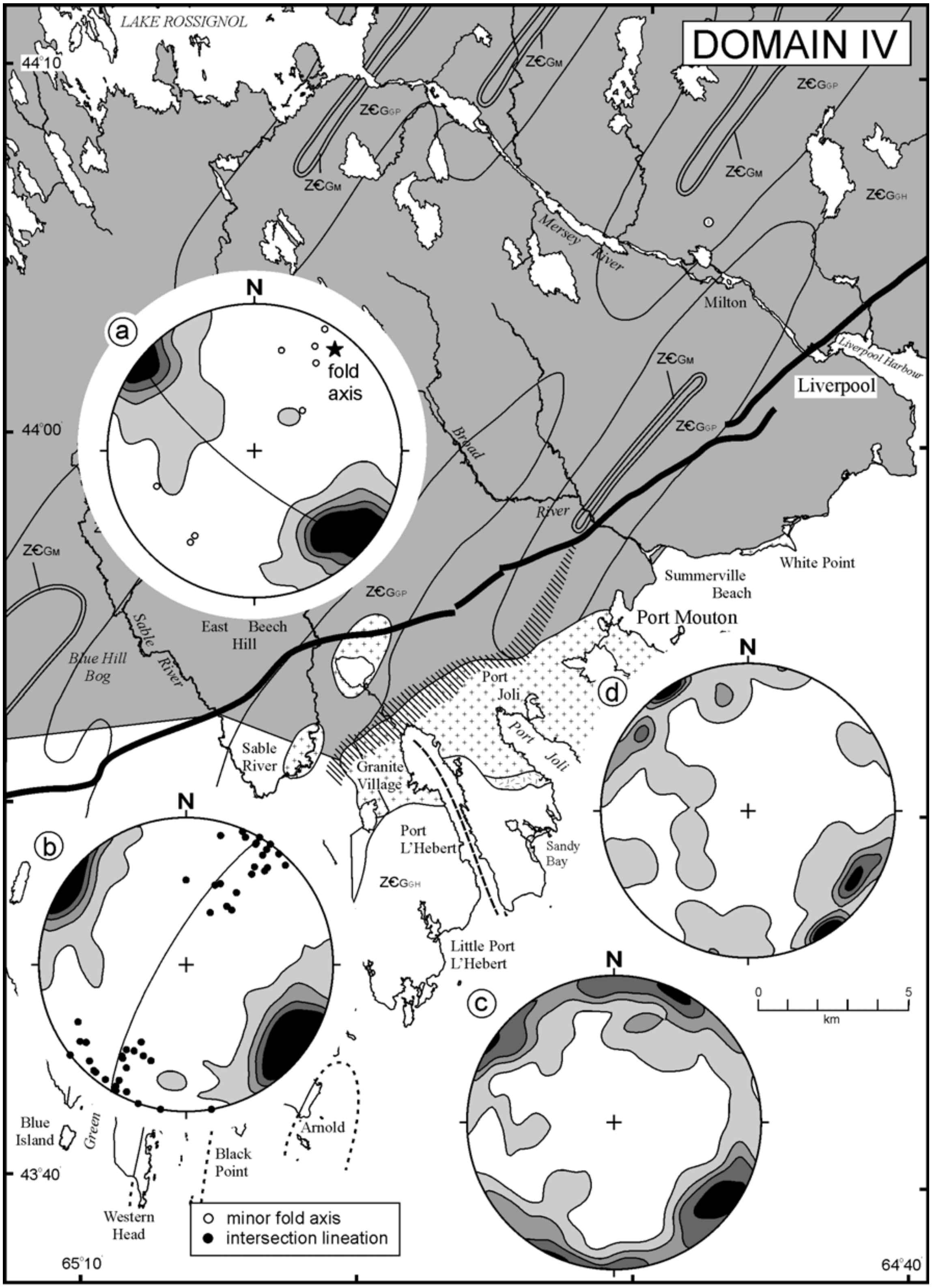

Figure 5. Equal area stereonets of structural data for Domain IV (shaded grey area) in the map area. (a) Contoured poles to bedding and minor F_1 fold axes. (b) Contoured poles to foliation and bedding-cleavage intersection lineations, solid great circle show average orientation of S_1. (c) Contoured poles to joints. (d) Contoured poles to quartz veins. Contours on stereonets at 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area.

Intersection lineations (L_1) (bedding/foliation) are somewhat scattered but generally display subhorizontal to moderate northeast-southwest plunge (Fig. 5b). Elongate calc-silicate and coticule nodules typically are parallel to the intersection lineation and minor fold axes. Contoured poles to joints display two prominent clusters. The main cluster indicates a steep, northeast-trending joint set that is parallel to the regional foliation and the second cluster indicates a steep, northwest-trending joint set that is orthogonal to the main set (Fig. 5c). Contoured poles to quartz veins also display considerable scatter, although steep, northeast-trending quartz veins parallel to those in domains I and II predominate (Fig. 5d).

Domain V comprises the main body of the Port Mouton Pluton (Fig. 6). As noted above it is locally banded and foliated. Contoured poles to banding define a well developed girdle distribution about an axis plunging moderately to the west (Fig. 6a). Because the Port Mouton Pluton is post-tectonic with respect to folding in the country rocks, it is unlikely that this girdle distribution is related to folding, but is more likely related to magmatic flow during intrusion. Contoured poles to foliation (S_1) indicate a steep northwest dipping, northeast-striking foliation (Fig. 6b), perpendicular to banding in the pluton but similar to the regional foliation orientations in domains I, II, and IV. Contoured poles to joints display considerable scatter, although the main cluster indicates a prominent steep, east-northeast-trending joint set (Fig. 6c), similar in orientation to those described by Douma (1988, 1992). Contoured poles to aplitic and pegmatitic dykes display considerable scatter, although they form two moderately well defined clusters. The main cluster indicates a north-south trend with a moderate dip to the east, whereas the other cluster indicates a steep, east-west orientation (Fig. 6d). These correspond to the orientations of pegmatite and aplite dykes, respectively (c.f. Douma, 1988, 1992). Quartz vein orientations, although scattered, display a moderately northwest-dipping, northeast-trending orientation (Fig. 6d).

Shear Zones and Faults

Several narrow (<2 m wide) shear zones have been documented in the Port Mouton Pluton (Maksaev, 1986; Douma, 1988, 1992; Currie and Whalen, 1994; Fallon *et al.*, 2001). Douma (1988, 1992) also documented a 0.5 km wide zone of ‘shear fabric’ in the granitic rocks along the northern margin of the pluton. New logging roads, ditch-digging, and new gravel pits and rock quarries along the northern margin of the pluton have better exposed this shear zone since the work of Douma (1988). This high-strain zone, herein termed the Granite Village shear zone, forms a wide (1 km) belt along the northern contact between the Port Mouton Pluton and the Goldenville Formation (Fig. 2). To the northeast, the shear zone thins to about a width of about 5 m and marks the boundary between the Government Point and Moshers Island members on the southeastern limb of the syncline exposed in Broad River. The contact between the Moshers Island and Cunard members is also marked by a shear zone which may be splay of the Granite Village shear zone. Due to lack of outcrop the shear zone could not be traced to the southeast. The shear zone is easily recognized in the granite and associated pegmatite by the presence of strong protomylonitic foliation and moderately developed mineral (stretching) lineation. However, recognition of the shear zone in the adjacent fine-grained metasandstone of the Goldenville Formation is not easy. Here the deformation has formed rectilinear laminations that look as if they are sedimentary in origin but upon closer inspection can be seen to contain extremely flattened, rootless isoclinal folds.

Contoured poles to the shear fabric indicate a steep, northeast-striking mylonitic foliation (Fig. 6e). This orientation is similar to the foliation in the pluton (Fig. 6b) and suggests that the two maybe related. Mineral lineations (elongate feldspar, quartz grains, and biotite patches) are steep, and minor folds in the protomylonite display shallow to moderate plunges to the southwest and northeast (Fig. 6e). In contrast, folded quartz veins in the shear zone in the Broad River area are steep and locally rootless. Kinematic indicators (asymmetric porphyroclasts and S-C fabrics) in the granite suggest southeast-side-up (granite up), dip-slip motion. Within the pluton, Currie and Whalen (1994) documented vertical and eastward movement with respect to the pluton margins. In contrast, the Granite Village shear zone exposed in Broad River displays dextral strike-slip sense of movement but more work is needed to verify this interpretation.

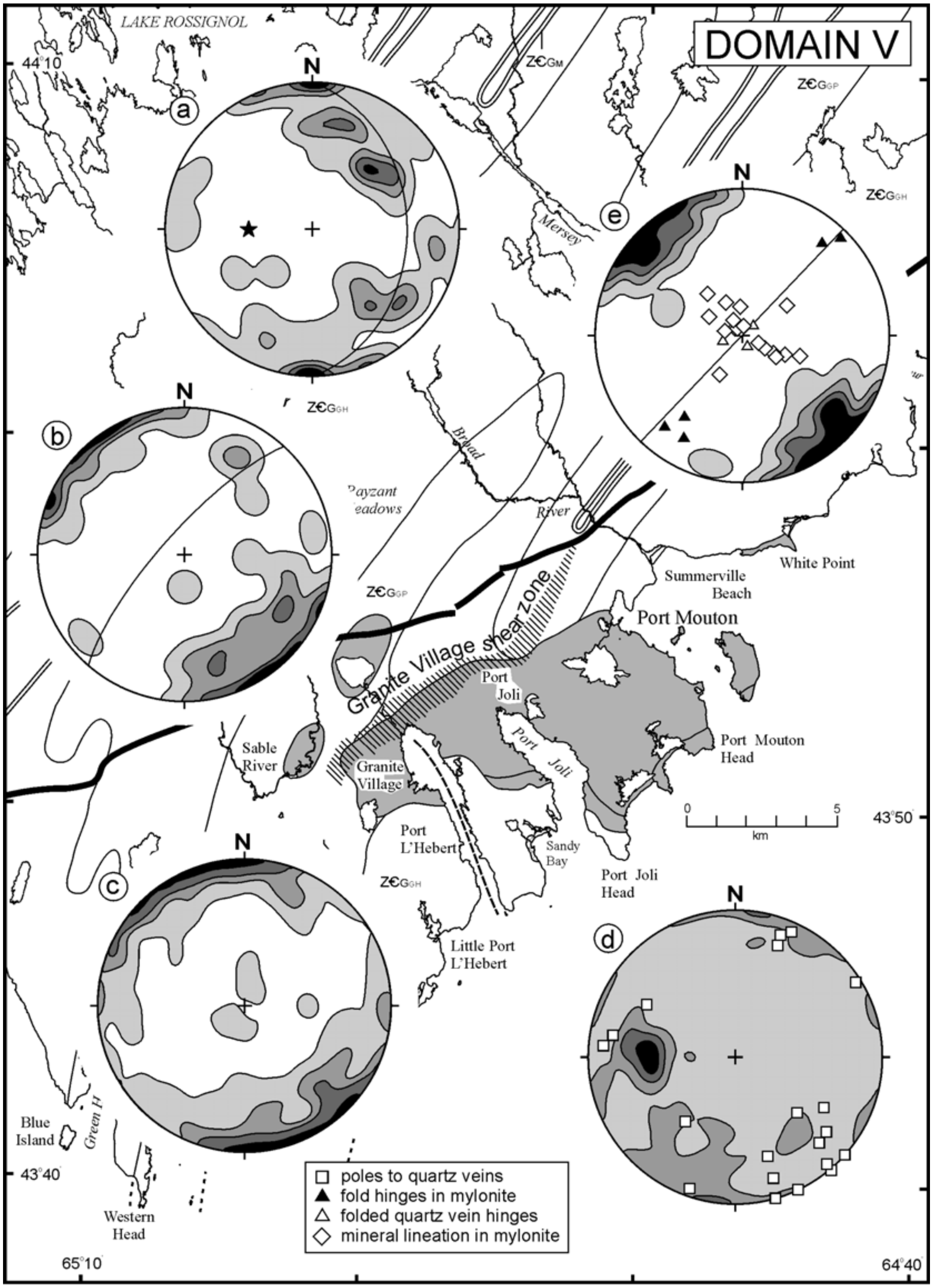

Figure 6. Equal area stereonets of structural data for Domain V (Port Mouton Pluton-shaded) in the map area. (a) Contoured poles to flow banding. (b) Contoured poles to foliation, solid great circle show average orientation. (c) Contoured poles to joints. (d) Contoured poles to pegmatite dykes, open squares are poles to quartz veins. (e) Contoured poles to mylonitic foliation, filled triangles are fold axes to minor folds, open triangles are fold axes to folded quartz veins, open diamonds are mineral lineations. Contours on stereonets at 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area.

Age of the shearing in the Port Mouton Pluton is unknown. Pegmatite dykes in the Granite Village shear zone are strongly deformed along with the host granite which suggests that deformation is younger than the pluton. However, within the pluton several pegmatitic dykes clearly cut the 'regional' foliation in the granite. If these pegmatitic dykes are similar in age to those in the north, then some mylonitization may have been synchronous with the main phase of plutonism. Currie and Whalen (1994) suggested that the deformation (mylonitization) was synchronous with emplacement and regional metamorphism and could be as young as 310-330 Ma. However, based on recent U-Pb data, the intrusive age of the pluton is well constrained at ca. 373 Ma (see Port Mouton Pluton section above). Although Fallon *et al.* (2001) suggested that the younger 315-325 Ma $^{40}Ar/^{39}Ar$ laserprobe ages from muscovite rims recorded reheating or slow cooling, it is possible that they record Alleghanian deformation that has been documented farther to the southeast (see White, 2003 for a summary).

No brittle faults were observed in outcrop in the map area. However, a northwest-trending fault is indicated by apparent offsets in aeromagnetic patterns in the Pine Hill area (Fig. 2). A brittle fault is inferred to exist in Port L'Hebert (Fig. 2) because bedding and foliation measurements on the west side of the harbour strike northeast and those on the east side strike northwest. In addition, the southern contact of the Port Mouton Pluton appears to be offset by approximately 2.5 km (Hope, 1987). Senses of movement along these faults are not known.

Pseudotachylyte veins occur at many locations throughout the area, especially in metasandstone of the Green Harbour member north of the Port Mouton Pluton. Pseudotachylyte veins have been reported in the West Dublin member (Government Point member) in the Broad River area (Hope, 1987). Many of the fractures that the veins occupy show evidence of microbrecciation along their margins and offsets up to 1-2 cm, suggesting that the veins represent *in situ* melts. In the Shelburne area farther to the southwest, similar veins have been interpreted to be associated with shallow faulting (Gareau, 1977).

Metamorphism

Based on pelitic lithologies in the Meguma Group, several metamorphic zones have been determined (Hope, 1987), similar to those defined in the map areas to the southwest (White, 1984; Bourque, 1985; Ross, 1985; Wentzell, 1985; Raeside and Jamieson, 1992). The lowest metamorphic grade rocks are in the biotite zone which is well exposed in the northeastern part of the map area (northeast of Mersey River). The biotite zone is characterized by the presence of prograde biotite, which gives the rock a spotted appearance. A typical mineral assemblage is biotite + chlorite + muscovite + quartz + plagioclase. Garnet zone rocks are similar to those in the biotite zone, except that they also contain tiny porphyroblasts of garnet and plagioclase compositions of An_{18} (Hope, 1987). This zone is well exposed in the northern and southern part of the map area. As metamorphic grade increases, cordierite appears with the same mineral assemblage as above. This area corresponds to the chlorite-cordierite zone of Hope (1987). Associated with this zone in the more aluminous rocks is rare chiastolite. Although well cleaved, rocks in the garnet and cordierite zones typically retain their original sedimentary textures but their mineral assemblage is metamorphic.

The staurolite zone is wide in the west but narrows around the Port Mouton Pluton. Most original sedimentary textures are obliterated in the pelitic lithologies. Typical mineral assemblage is staurolite + garnet + biotite + chlorite + muscovite + quartz + plagioclase. However, andalusite and cordierite are locally present and because of this, Hope (1987) termed this zone the staurolite-cordierite-andalusite zone. More work is needed to subdivide this zone. The andalusite zone (staurolite-absent zone of Hope, 1987) is marked by the disappearance of staurolite in the schist. This zone forms a wide concentric band around the Port Mouton Pluton. The typical mineral assemblage is andalusite + cordierite + garnet + biotite + muscovite + quartz + plagioclase.

The transition from the andalusite zone to the sillimanite zone is marked by the appearance of sillimanite as fibrolite. The sillimanite zone occurs adjacent to the Port Mouton Pluton up to a distance of 500 m from the margin of the pluton (Hope, 1987). As metamorphic grade increases, andalusite and garnet decrease in abundance. Along Summerville Beach, migmatitic rocks with anatectic textures are reported (Merrett, 1987), indicating that pressures and temperatures near granitic melt conditions were reached.

Because migmatite borders part of the northern margin of the Port Mouton Pluton and the sillimanite zone is concentric around the pluton, Hope (1987) speculated that these features were related to contact metamorphism by the pluton. However, she also concluded that the regional metamorphic grade in the area was at least at andalusite grade when the pluton was emplaced. In contrast, Currie and Whalen (1994) concluded that there is no obvious contact aureole around the pluton and that the ‘migmatite’ showed no evidence of partial melting. However, Currie and Whalen (1994) failed to offer an alternative explanation for the apparent association of these features with the pluton and therefore the conclusion of Hope (1987) seems more plausible.

Economic Geology

Significant beryl mineralization has been documented in the map area in association with pegmatite in the Port Mouton Pluton (Oldale, 1959; Taylor, 1967; MacDonald, 1988). Beryl appears to be associated only with tourmaline-bearing pegmatite, in most places as small disseminated grains, although crystals up to 10 cm long have been reported from Port Mouton Island (Hope *et al.*, 1988). Molybdenite was also reported in pegmatite veins that cut the Goldenville Formation and Port Mouton Pluton (Hope and Woodend, 1986). Pyrite, chalcopyrite, and magnetite occur along narrow zones parallel to schistosity in a biotite-muscovite schist along the east side of Jordan Bay (Hope and Woodend, 1986). Skarnoid calc-silicate nodules close to the pluton may contain pyrrhotite, chalcopyrite, and scheelite similar to those in the Digby area (Horne *et al.*, 2000) and the Barrington area (Mitchell, 2004). The only gold occurrence in the area was reported in quartz veins along Broad River by Faribault (1915). This occurrence was not confirmed during the present study.

From an industrial minerals perspective, the map area holds great potential. The local community is making use of sand and gravel to produce cement and asphalt. The Port Mouton Pluton has been quarried for aggregate in the making of Highway 103 and rip-rap used in building breakwaters.

Summary

A major result of the mapping during the summer of 2004 is the confirmation that stratigraphy in the Goldenville and Halifax formations is identical to that defined in the map area to the southwest (e.g. White and Wasylik, 2003) and farther northeast in Lunenburg counties (O’Brien, 1986, 1988; Waldron, 1992). In addition, the Moshers Island member is recognized as part of the upper-most Government Point member of the Goldenville Formation and not the lower Halifax Formation.

Regional folds trend north-south in the southern part of the map area with near horizontal fold axes, whereas folds in the northern part trend northeast with gentle southwest- and northeast-plunging fold axes. Folds in both areas have well developed axial planar cleavage. In the area south of the Port Mouton Pluton, bedding and foliation trend northeast, orthogonal to the regional fabric.

Peak amphibolite-facies regional metamorphism appears to have coincided with emplacement of the Port Mouton Pluton at ca. 373 Ma. If so, it is considerably younger than the ca. 400 Ma greenschist-facies regional metamorphism in the Meguma Group elsewhere in the Meguma terrane.

A major shear zone (Granite Village shear zone) marks the northern boundary of the Port Mouton Pluton and had steep, dip-slip movement with the granite up relative to the country rocks. The regional extent and age of this shear zone in unknown but based on muscovite rim ages, it may have been related to the Carboniferous Alleghanian Orogeny.

Acknowledgments

S. Barr, R. Raeside, R. Horne, and B. O’Brien are thanked for numerous discussions regarding the geology of southwestern Nova Scotia, and for the use of samples and unpublished information. S. Douma is thanked for providing her unpublished field books and field maps. Special thanks goes to T. Lawrence for providing enthusiastic assistance in the field. Tracy Lenfesty is thanked for help in the departmental library. Comments on various drafts of the manuscript by S. Barr were extremely helpful.

References

Bailey, L. W. 1896: Report on the geology of southwest Nova Scotia embracing the counties of Queens, Shelburne, Yarmouth, Digby and parts of Annapolis; Geological Survey of Canada, Annual Report, New Series, v. 19, part M, p. 1-154.

Bourque, A. D.1985: Migmatization and metamorphism associated with the Barrington Passage Pluton, Shelburne and Yarmouth counties, Nova Scotia; unpublished BSc Honours thesis, Acadia University, Wolfville, Nova Scotia.

Clarke, D. B., Fallon, R. and Heaman, L. M. 2000: Interaction among upper crustal, lower crustal, and mantle materials in the Port Mouton pluton, Meguma Lithotectonic Zone, southwest Nova Scotia; Canadian Journal of Earth Sciences, v. 37, p. 579-600.

Currie, K. L. and Whalen, J. B. 1994: A note on the occurrence of beryl in the Port Mouton pluton, southwestern Nova Scotia; *in* Current Research 1994-D, Geological Survey of Canada, p. 73-77.

Currie, K. L., Whalen, J. B., Davis, W. J., Longstaffe, F. J. and Cousens, B. L. 1998: Geochemical evolution of peraluminous plutons in southern Nova Scotia, Canada-a pegmatite-poor suite; Lithos, v. 44, p. 117-140.

Douma, S. L. 1988: The mineralogy, petrology, and geochemistry of the Port Mouton Pluton, Nova Scotia, Canada; unpublished M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Douma, S. L. 1992: Field relationships, mineralogy and structural features of the Port Mouton Pluton, southwestern Nova Scotia; Atlantic Geology, v. 28, p. 85-100.

Faribault, E. R. 1914: Greenfield and Liverpool Town map-areas, Nova Scotia; Geological Survey of Canada, Summary Report 1912, p. 372-382.

Faribault, E. R. 1915: Geology of the Port Mouton map-area, Queens County, Nova Scotia; Geological Survey of Canada, Summary Report 1913, p. 251-258.

Faribault, E. R. 1918: Investigations in western Nova Scotia; Geological Survey of Canada, Summary Report 1917, Part F, p. 17-20.

Faribault, E. R. 1920: Investigations in western Nova Scotia; Geological Survey of Canada, Summary Report 1919, Part F, p. 2-20.

Fallon, R. P., Reynolds, P. H. and Clarke, D. B. 2001: A comparative $^{40}Ar/^{39}Ar$ conventional and laserprobe study of muscovite from the Port Mouton pluton, southwest Nova Scotia; Canadian Journal of Earth Sciences, v. 38, p. 347-357.

Gareau, M. B. 1977: Pseudotachylytes of southwestern Nova Scotia; unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Hicks, R. J., Jamieson, R. A. and Reynolds, P. H. 1999: Detrital and metamorphic $^{40}Ar/^{39}Ar$ ages from muscovite and whole-rock samples, Meguma Supergroup, southern Nova Scotia; Canadian Journal of Earth Sciences, v. 36, p. 23-32.

Hope, T. L. 1987: Geology and metamorphism in the Port Mouton-Lockport area, Queens and Shelburne counties, Nova Scotia; unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Hope, T. L. and Woodend, S. L. 1986: Geological mapping and igneous and metamorphic petrology, Queens and Shelburne counties, Nova Scotia; *in* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 429-433.

Hope, T. L., Douma, S. L. and Raeside, R. P. 1988: Geology of the Port Mouton-Lockport area, southwestern Nova Scotia; Geological Survey of Canada, Open File 1768.

Horne, R. J., White, C. E., Muir, C., Young, M. D. and King, M. S. 2000: Geology of the Weymouth-Church Point area (NTS 21A/05 and 21B/08, southwest Nova Scotia; *in* Report of Activities 1999, eds. D. R. MacDonald and K. A. Mills; Nova Scotia Department of Natural Resources, Mines and Energy Branch Report ME 2000-1, p. 75-91.

Keppie, J. D. 1985: The Appalachian collage; *in* The Caledonide Orogen: Scandanavia and related areas; eds. D. G. Gee and B. A. Sturt; John Wiley, New York, p. 1217-1226.

Keppie, J. D. and Dallmeyer, R. D. 1995: Late Paleozoic collision, delamination, short-lived magmatisim, and rapid denudation in the Meguma Terrane (Nova Scotia, Canada): constraints from $^{40}Ar/^{39}Ar$ isotopic data; Canadian Journal of Earth Sciences, v. 32, p. 644-659.

King, M. S. 1997a: Meguma Terrane, enhanced (second vertical derivative) aeromagnetic digital data for NTS 21A/02, Liverpool, Queens and Lunenburg counties, Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Open File Map 97-023.

King, M. S. 1997b: Meguma Terrane, enhanced (second vertical derivative) aeromagnetic digital data for NTS 21A/03, Lake Rossignol, Shelburne, Yarmouth, Queens and Digby counties, Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Open File Map 97-024.

King, M. S. 1997c: Meguma Terrane, enhanced (second vertical derivative) aeromagnetic digital data for NTS 20P/14, Shelburne, Shelburne and Queens counties, Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Open File Map 97-032.

King, M. S. 1997d: Meguma Terrane, enhanced (second vertical derivative) aeromagnetic digital data for NTS 20P/15, Port Mouton, Queens and Shelburne counties, Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Open File Map 97-033.

MacDonald, D. 1988: Examination of a zoned pegmatite and host rocks at Port Joli, Nova Scotia; unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Maksaev, V. 1986: The origin of banding in the Mountain Island Granite, southern Nova Scotia; unpublished Internal Report, Dalhousie University, Halifax, Nova Scotia.

Merrett, D. 1987: The migmatites of Port Mouton; unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Mitchell, F. 2004; Metamorphic petrology of calc-silicate nodules from greenschist facies to migmatite grade, Liverpool-Pubnico area, Nova Scotia; unpublished B.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Muecke, G. K, Elias, P. and Reynolds, P. H. 1988: Hercynian/Alleghanian overprinting of an Acadian Terrane: $^{40}Ar/^{39}Ar$ studies in the Meguma Zone, Nova Scotia; Chemical Geology, v. 73, p. 153-167.

Muir, C. M. 2000: An $^{40}Ar/^{39}Ar$ study of the Goldenville, Halifax, White Rock and Torbrook formations of the Digby area, southwest Nova Scotia; unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Murphy, J. B., Van Staal, C. R. and Keppie, J. D. 1999: Middle to Late Paleozoic Acadian orogeny in the northern Appalachians: a Laramide-style plume-modified orogeny?; Geology, v. 27, p. 653-656.

O'Brien, B. H. 1986: Preliminary report on the geology of the Mahone Bay area, Nova Scotia; *in* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 439-444.

O'Brien, B. H. 1988: A study of the Meguma Terrane in Lunenburg County, Nova Scotia; Geological Survey of Canada, Open File 1823.

Oldale, H. R. 1959: Beryllium, Port Mouton, Queens County, Nova Scotia; Preliminary Report, Nova Scotia Department of Mines, 20P/15C 08-N-18(01).

Raeside, R. P. and Jamieson, R. A. 1992: Low-pressure metamorphism of the Meguma Terrane, Nova Scotia; Geological Association of Canada/Mineralogical Association of Canada Joint Annual Meeting, June 1992; Field Excursion C-5: Guidebook.

Reynolds, P. H., Elias, P., Muecke, G. K. and Grist, A. M. 1987: Thermal history of the southwestern Meguma Group, Nova Scotia, from $^{40}Ar/^{39}Ar$ and fission track dating study of intrusive rocks; Canadian Journal of Earth Sciences, v. 24, p. 1952-1965.

Ross, D. M. 1985: Structure and metamorphism of the Pubnico area, Yarmouth County, Nova Scotia; unpublished BSc Honours thesis, Acadia University, Wolfville, Nova Scotia.

Tate, M. C. and Clarke, D. B. 1995: Petrogenesis and regional tectonic significance of Late Devonian mafic intrusions in the Meguma Zone, Nova Scotia, Canada; Canadian Journal of Earth Sciences, v. 32, p. 1883-1898.

Taylor, F. C. 1967: Reconnaissance Geology of Shelburne map-area, Queens, Shelburne, and Yarmouth Counties, Nova Scotia; Geological Survey of Canada Memoir 349.

Waldron, J. W. 1992: The Goldenville-Halifax transition, Mahone Bay, Nova Scotia: relative sea-level rise in the Meguma source terrane; Canadian Journal of Earth Sciences, v. 29, p. 1091-1105.

Wentzell, B. D. 1985: The transition from staurolite to sillimanite zone, Port LaTour, Nova Scotia; unpublished B.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

White, C. E. 1984: Structure and metamorphism of the Jordan River valley, Shelburne County, Nova Scotia; unpublished B.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

White, C. E. and Barr, S. M. 2004: Age and petrochemistry of mafic sills in rocks of the northwestern margin of the Meguma Terrane, Bear River-Yarmouth area of southwestern Nova Scotia; *in* Minerals and Energy Branch, Report of Activities 2003; Nova Scotia Department of Natural Resources, Report 2004-1, p. 97-117.

White, C. E. and King, 2002: Preliminary bedrock geology of the Tusket map area (NTS 20P/13), southwestern Nova Scotia; *in* Minerals and Energy Branch, report of activities 2001; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Report ME 2002-1, p. 141-158.

White, C. E. and Wasylik, D. R. G. 2003: Preliminary bedrock geology map of the area between Baccaro Point and Sable River, Shelburne County (NTS 20P/06, 11, and 14); *in* Mining Matters for Nova Scotia 2003, Nova Scotia Department of Natural Resources, Minerals Resources Branch, Report ME 2003-2, p. 20.

White, C. E., Horne, R. J., Muir, C. and Hunter, J. 1999: Preliminary bedrock geology of the Digby map sheet, southwestern Nova Scotia; *in* Minerals and Energy Branch, report of activities 1998; Nova Scotia Department of Natural Resources, Mines and Energy Branch, Report 98-1, p. 119-134.

White, C. E., Horne, R. J., Tèniére, P. J., Jodrey, M. J. and King, M. S. 2001: Geology of the Meteghan River-Yarmouth area: a progress report on the Southwest Nova Scotia Mapping Project; i*n* Minerals and Energy Branch, Report of Activities 2000, Nova Scotia Department of Natural Resources, Mines and Energy Branch, Report 2000-1, p. 95-111.

White, C. E. and Barr, S. M. 2004: Age and petrochemistry of mafic sills of the northwestern margin of the Meguma terrane in the Bear River - Yarmouth area of southwestern Nova Scotia; *in* Mineral Resources Branch, Report of Activities 2003; ed. D. R. MacDonald; Nova Scotia Department of Natural Resources, Report 2004-1, p. 7-117.

White, C. E. 2003: Preliminary bedrock geology of the area between Chebogue Point, Yarmouth County, and Cape Sable Island, Shelburne County, southwestern Nova Scotia; *in* Mineral Resources Branch, Report of Activities 2002; ed. D. R. MacDonald; Nova Scotia Department of Natural Resources, Report 2003-1, p. 127-145.

White, C. E., Barr, S. M. and Gould, R. C. 2003: Gabbroic intrusions in the Meteghan-Yarmouth area (NTS 21A/04, 21E/01, 20P/13 and 20O/16) of the Meguma Terrane, southern Nova Scotia; *in* Mineral Resources Branch, Report of Activities 2002; ed. D. R. MacDonald;. Nova Scotia Department of Natural Resources, Report 2003-1, p. 147-162.