

Geology of the Meteghan River-Yarmouth area: a Progress Report on the Southwest Nova Scotia Mapping Project

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Introduction

Mapping of the bedrock geology of the Yarmouth - Meteghan River area (NTS map areas 21A/01, 21A/04, 20O/16, 20O/13), southwest Nova Scotia (Fig. 1a), was initiated during the summer of 2000. This project represents the third year of a five-year program by the Nova Scotia Department of Natural Resources aimed at producing a series of 1:50 000 scale geological maps of the Digby-Yarmouth-Shelburne area (Fig. 1b). Details of the mapping program, previous geological investigations, and methodology were summarized by White *et al.* (1999), and preliminary results of the first two years (covering NTS map areas 21A/12, 21A/05, and 21B/08) were presented by White *et al.* (1999) and Horne *et al.* (2000).

Field Relations and Map Units

Introduction

Metamorphic rock units defined in the two previous map areas to the north (NTS 21A/12, 21A/05 and 21B/08) can be traced into the Meteghan River-Yarmouth map area. They include the Cambrian to Ordovician Meguma Group, consisting of the lower Goldenville Formation and the upper Halifax Formation, and the Silurian White Rock Formation (WRF) (Fig. 2). In contrast to the map areas to the north, outcrops characteristic of the Early Devonian Torbrook Formation were not observed. Also, in contrast to the WRF in the Digby - Weymouth areas, the WRF in the Yarmouth area includes abundant volcanic rocks, and is associated with plutonic units of similar Silurian age (e.g. Brenton Pluton). The metamorphic units are intruded by several suites of mafic sills (e.g. White *et al.*, 1999; Horne *et al.*, 2000), and both the sills and their host rocks have been deformed and regionally metamorphosed to varying degrees, ranging from greenschist facies (chlorite or biotite zone) to amphibolite facies (garnet or staurolite zone).

Exposure is generally good along the coast but is limited inland due to low topographic relief and extensive glacial deposits. High-resolution second derivative aeromagnetic and digital elevation model (DEM) data (Fig. 3) were used to help define map units inland.

Goldenville Formation

The Goldenville Formation occurs in the southeastern and central parts of the map area (Fig. 2). In the southeast and the northern part of the central area, it consists of grey medium- to thick-bedded metasandstone, locally interlayered with green, cleaved metasilstone and rare black slate, similar to the Goldenville Formation exposed to the north (e.g. Horne *et al.*, 2000). In the southern part of the central area, metamorphic grade is higher, and the metasandstone is muscovite-rich and interlayered with phyllite. Toward the stratigraphic top of the formation, the metasandstone becomes increasingly interlayered with black slate (Cheboque Point area, Fig. 2) or spotted phyllite (Cranberry Point area, Fig. 2).

A distinctive feature of the Goldenville Formation near High Head (Fig. 2) is a <1.0 km thick interval of mainly grey-green, cleaved metasilstone which contains abundant trace fossils (Fig. 4) and small (<2 mm) magnetite grains. A similar, <200 m thick, magnetite-bearing interval occurs nearby to the south, but lacks abundant trace fossils and is locally interlayered with metasandstone. Similar rocks with similar aeromagnetic response occur in the Salmon River area (Fig. 2 and 3) and may be the folded equivalents. These magnetite-bearing rocks occur about 5 km from the stratigraphic top of the Goldenville Formation. These intervals are distinct within the Goldenville Formation and may provide useful marker horizons in this area. The high magnetite content has resulted in a relatively high aeromagnetic signature with respect to the surrounding Goldenville Formation, allowing these units to be traced inland (Fig. 2 and 3).

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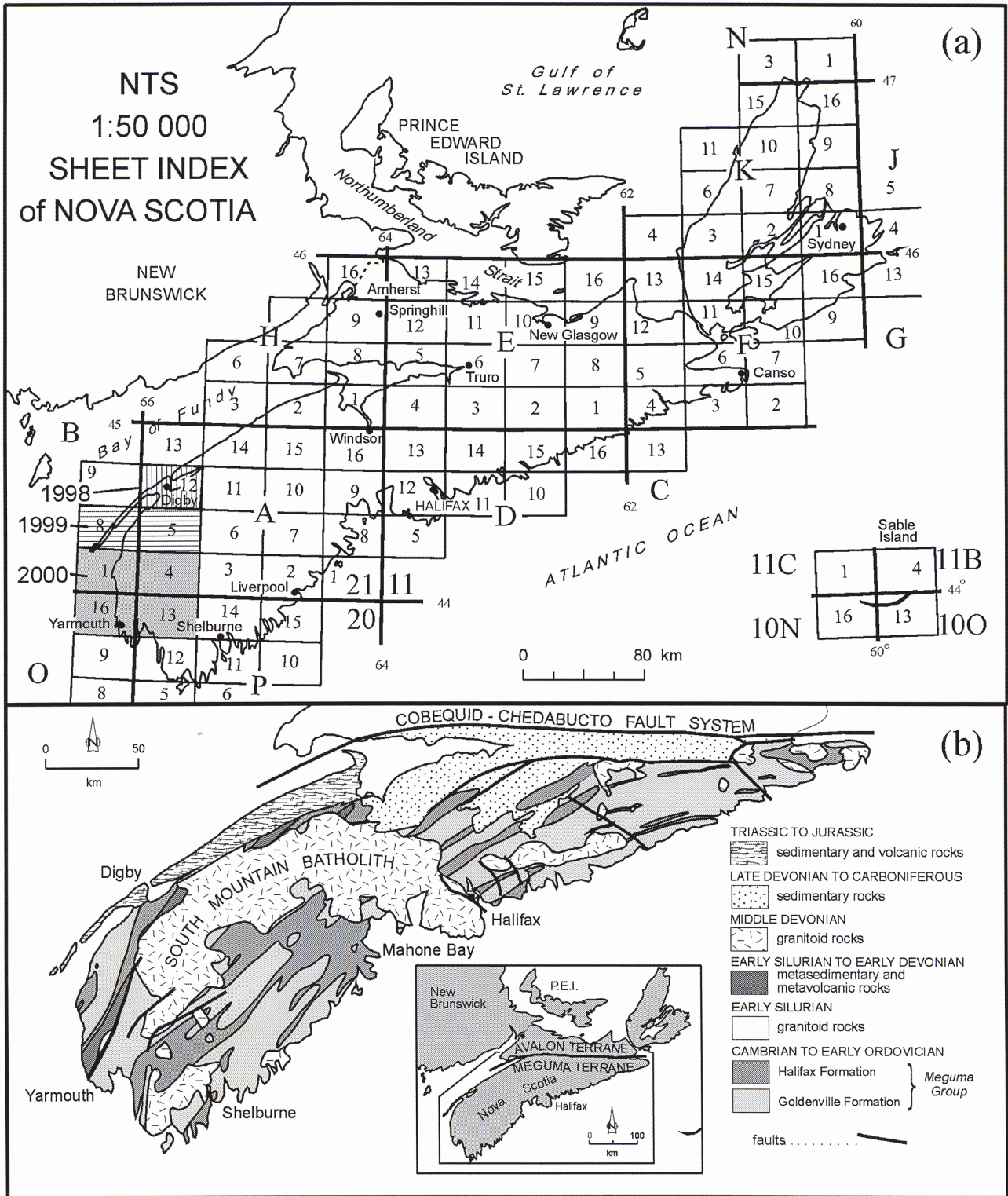


Figure 1. (a) National Topographic System (NTS) index map of Nova Scotia showing locations of mapped areas related to the Southwest Nova Scotia Mapping Project. (b) Simplified geological map of the Meguma Terrane, Nova Scotia.

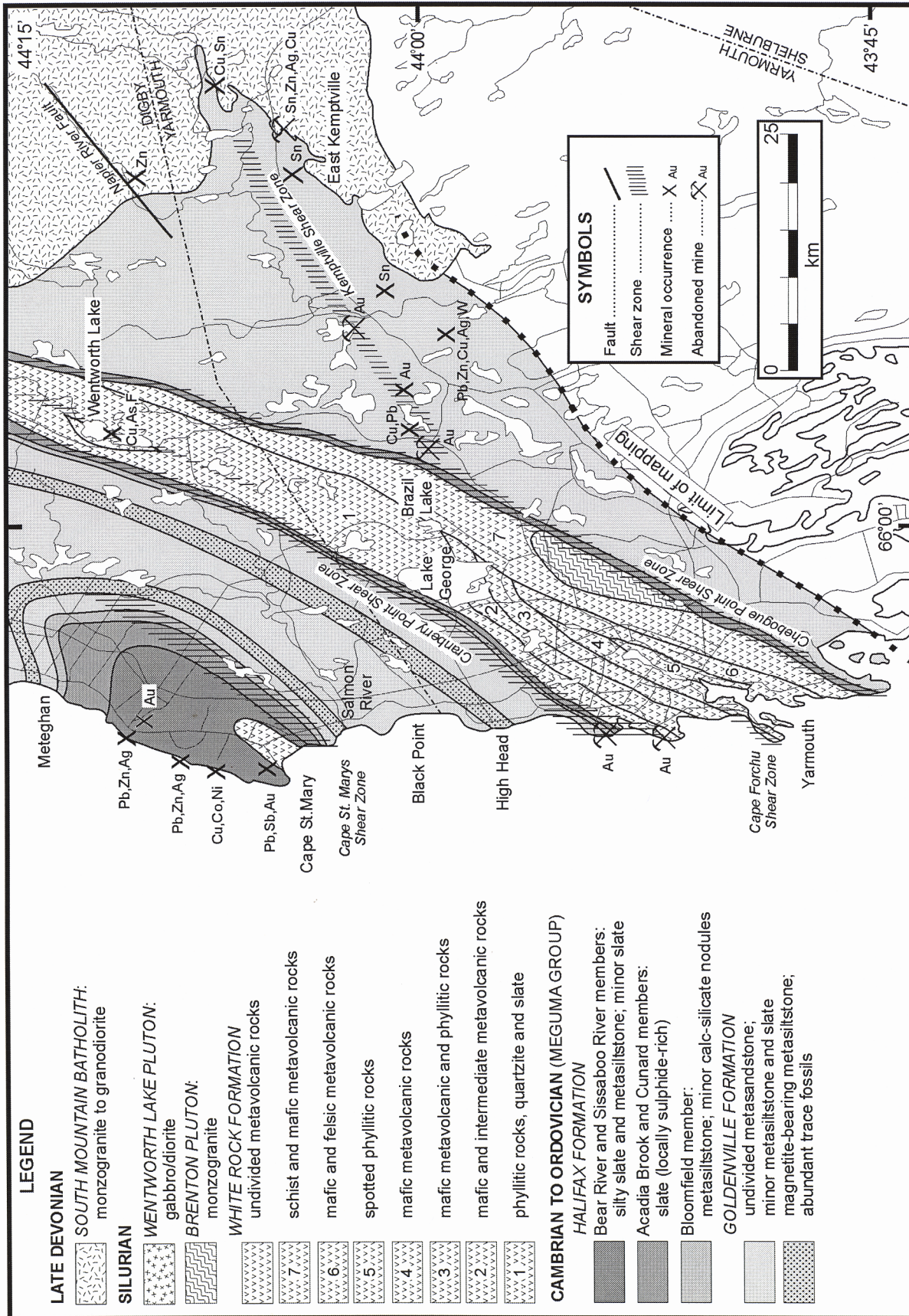


Figure 2. Simplified geological map of the Yarmouth - Meteghan River area (NTS map areas 21A/01, 21A/04, 200/16, 200/13), southwest Nova Scotia.

Halifax Formation

In the previously mapped areas to the north, the Halifax Formation was subdivided into three stratigraphic units including, from oldest to youngest, the Bloomfield, Acacia Brook/Cunard and Bear River/Sissiboo River members (White *et al.*, 1999; Horne *et al.*, 2000). Only the Bloomfield and Cunard members can be traced into the current map area; however, rocks characteristic of the Bear River/Sissiboo River member may be present in the Cape St. Marys area (Fig. 2), but more detailed mapping is needed to confirm the distribution of these units.

Bloomfield Member

In the Cheboque Point area (Fig. 2) the Bloomfield member consists of a thin (<20 m) unit of grey-green, well-laminated metasilstone and slate. The contact with the Goldenville Formation is abrupt and marked by a boudinaged mafic sill (<30 cm thick). Gradationally overlying the Goldenville Formation in the Cranberry Point area (Fig. 2), the Bloomfield member consists of a 200 m thick, locally well crenulated, phyllite to spotted phyllite. North of Salmon River (Fig. 2) the Bloomfield member consists of a 200 m thick, strongly sheared, uniform, greenish slate and metasilstone. The contact with the underlying Goldenville formation, consisting of metasandstone and minor metasilstone, is exposed and abrupt. The contact with the overlying Cunard member is gradational, defined by a 30 m wide zone with increasing black slate layers. Although well exposed along the coast, tracing the inland extent of the Bloomfield member is difficult due to poor outcrop control and lack of a significant aeromagnetic signature.

Cunard Member

Conformably overlying the Bloomfield member is black to rust-brown slate with minor (<10 to 50 cm thick) metasandstone layers of the Cunard member. Pyrite and pyrrhotite are common. This unit is typical of the Cunard member exposed to the north (Horne *et al.*, 2000) and elsewhere in the Meguma Group (e.g. Schenk, 1995). This unit corresponds to a high aeromagnetic signature which can be traced inland (Fig. 3).

White Rock Formation

Introduction

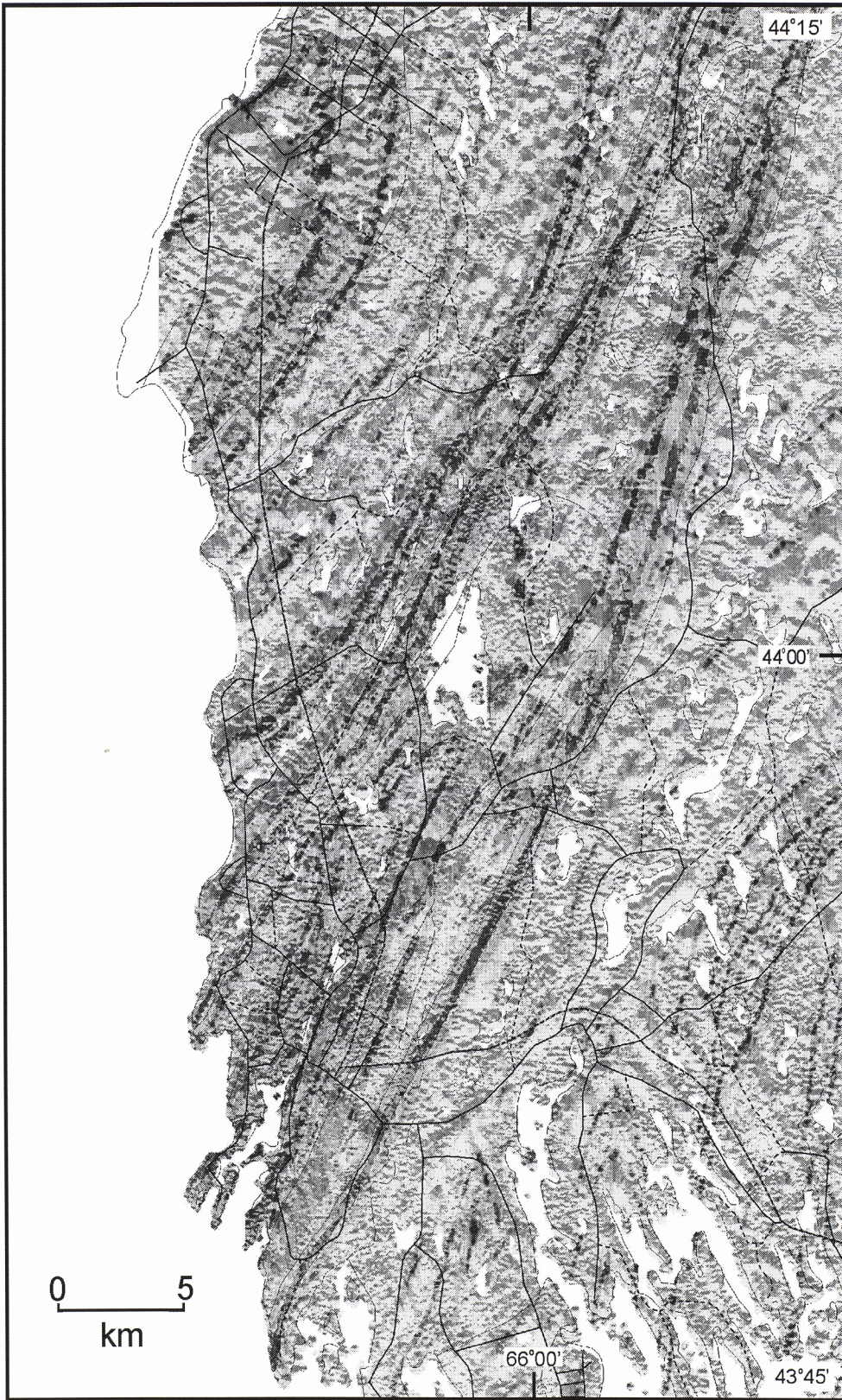
The White Rock Formation is well exposed in coastal sections in the Yarmouth and Cape St. Marys areas (Fig. 2) and is composed mainly of metavolcanic rocks,

in contrast to the entirely metasedimentary character of the unit in the northern map areas (e.g. White *et al.*, 1999; Horne *et al.*, 2000). Taylor (1965, 1967, 1969) interpreted the White Rock Formation in the Yarmouth area to occur in a syncline, as in the Bear River, Torbrook and Black River areas to the northeast, and subsequent workers did not significantly modify this interpretation (e.g. Lane, 1979; Hwang, 1985; Schenk, 1995, 1997; Culshaw, 1994; Culshaw and Liesa, 1997; MacDonald, 2000). Although the aeromagnetic data also suggest a synclinal structure, our mapping in the area indicates that the structure may be more complicated than a single syncline. In the Cape St. Marys area, the White Rock Formation was also interpreted to occur in a syncline and based on aeromagnetic data and limited field work this interpretation appears to be valid; however, more detailed mapping is needed for confirmation.

Due to deformation and greenschist- to amphibolite-facies metamorphism, many primary sedimentary and volcanic features within the White Rock Formation have been obliterated. However, in many cases the protolith can still be inferred and, where possible, the protolith name is used here. Geochemistry of mafic volcanic rocks in the White Rock Formation indicates an alkalic affinity and a within-plate tectonic setting and the felsic volcanic rocks have some characteristics similar to within-plate A-type granites (MacDonald, 2000).

Based on exposures along the coastal sections, the White Rock Formation can be subdivided into seven units. However, the lack of outcrop in some areas precludes extending, with confidence, many of these units inland. The combined DEM and high-resolution second derivative aeromagnetic data (Fig. 3) assist in tracing units from the coast into areas of lesser outcrop because in many places a reasonably good correlation occurs between rock type and magnetic signature. However, in some places where outcrop control is reasonably good, it is apparent that some geological units exhibit a change in magnetic signature along strike. Such changes make area-wide correlation of magnetic signature and rock unit difficult. In this preliminary report, emphasis is on the description of units based on coastal sections and on inland distribution of units for which outcrop data and magnetic signature are in agreement. Although the White Rock Formation in the Yarmouth area may have been originally folded into a regional syncline, based on the coastal exposures, the units of the White Rock Formation appear to be right-way-up and younging to the east, with no obvious repetition of units, suggesting that the syncline no longer exists.

Figure 3. Grey-scale calculated second derivative aeromagnetic image, gridded to a 75 m cell size, combined with the digital elevation model (DEM) with shading from the west at 45°.



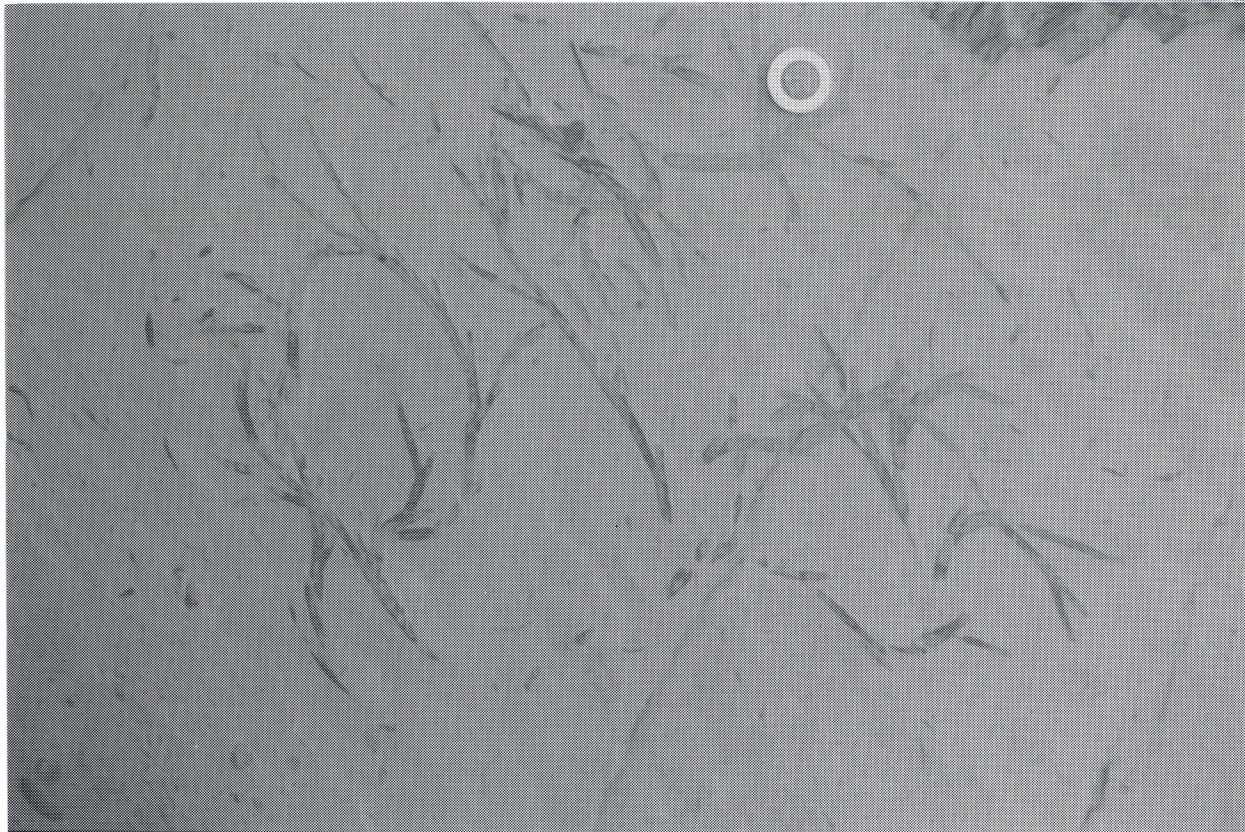


Figure 4. Photograph of the upper bedding plane surface of a horizontally laminated metasiltstone displaying large grazing and burrowing traces. Sample from the magnetite-bearing metasiltstone unit in the Goldenville Formation. Two-dollar coin for scale.

Unit 1

The stratigraphically lowest unit in the White Rock Formation is dominantly metasedimentary consisting of tuffaceous metasandstone, metasiltstone, slate and quartzite. It is exposed from Cranberry Head to Chegoggin Point (Fig. 2). The contact with the underlying Halifax Formation is not exposed. Unit 1 broadly corresponds to the basal metasedimentary and quartzite units defined by MacDonald (2000).

The lowest part of unit 1 consists of grey, well cleaved, tuffaceous metasandstone to metasiltstone. Small biotite and/or amphibole porphyroblasts (<2 mm in width) are abundant. Locally, elongate (up to 2 by 5 cm) amphibolite clasts are common. Calc-silicate beds (up to 20 cm thick) and lenses are common and typically display metamorphic zoning defined by varying amounts of amphibole and epidote. Upwards, this unit becomes interlayered with dark grey, laminated phyllite and slate, the latter containing trace fossils. The slate and phyllite grade upward into spotted metasiltstone which locally contains garnetiferous schist layers (up to 2 m thick) associated with sulphide-rich

metasandstone. Chloritoid is locally abundant. The spotted metasiltstone interval coincides with a high aeromagnetic signature that “pinches-out” inland (Fig. 3). At the top of this unit the spotted metasiltstone abruptly changes to thickly bedded, massive to well-laminated quartzite layers (Fig. 5). Based on drill core data and sporadic outcrops of quartzite, unit 1 can be traced to the Lake George area (Fig. 2).

Unit 2

Above the quartzite of unit 1 is a metavolcanic unit with minor tuffaceous metasandstone similar to the metavolcanic unit described by MacDonald (2000) which overlies the quartzite. The lower contact with the quartzite is well exposed at low tide at Chegoggin Point. At that location, dark green mafic crystal and lithic crystal tuff are interlayered with minor pink, intermediate to felsic crystal to crystal lithic tuff. About 100 m above the base of this unit, a quartzite similar to those in unit 1 occurs as large (up to 2 by 2 m) boudins in the mafic tuff. The mafic tuff coincides with a high aeromagnetic signature that can be traced to the Lake George area (Fig. 3). The remainder of the unit is



Figure 5. Photograph of massive quartzite (light) interlayered with thin amphibolite (dark) in the upper part of Unit 1. Backpack in centre for scale.

poorly exposed along the coast, with only rare inland outcrops, and displays a low aeromagnetic signature (Fig. 3). Interpreted to conformably overlie the mafic tuff is a sequence of light grey tuffaceous metasandstone interlayered with thinly bedded, spotted metasiltstone, metasandstone and actinolite-rich tuff. At the inferred top of this unit is a section of grey andesitic lithic to lithic crystal tuff.

Unit 3

Unit 3 is composed predominantly of mafic volcanic and metasedimentary rocks. The lower part of the unit is exposed inland along a string of discontinuous topographic highs where outcrops consist of amphibolitized mafic lithic tuff and flows. The contact with the andesitic tuff of unit 2 is not exposed but the highly deformed character of the most southeasterly outcrops of andesite suggests a tectonic contact. The middle and upper parts of the unit are well exposed along the coast near Overton and Cape Forchu West. The middle part of this unit consists of well laminated, spotted metasiltstone and metasandstone, locally interlayered with amphibole-rich tuffaceous metasandstone and mafic crystal tuff and flows. In the middle of this section is a rust-brown, 2 m wide,

massive quartzite layer. This quartzite differs from the quartzite in units 1 and 2 in its association with pillow basalt and the presence of rare brachiopod fossils. Calcisilicate lenses (20 cm thick) are common in the metasedimentary rocks and, like those in unit 1, typically display metamorphic zoning defined by varying amounts of amphibole and epidote. Also present are abundant trace fossils of *chondrites*. Up-section, the metasedimentary package is in sharp contact with a thick (<200 m) package of mafic lithic to lithic crystal tuff and associated flows interlayered with minor tuffaceous metasandstone. The top of unit 3 is marked by felsic crystal tuff with conglomeratic layers (Fig. 6) containing abundant elongate (up to 50 by 5 cm), mafic to felsic clasts.

This unit has a composite aeromagnetic signature and is therefore difficult to trace inland. In areas of good inland outcrop control (i.e. basaltic rocks at the base of this unit), the magnetic signature along strike varies between positive to negative amplitudes. Whether this is a result of the resolution of the aeromagnetic data or the magnetic character of the basaltic unit needs to be investigated further. This unit is equivalent to the mafic to felsic volcanic and metasiltstone unit defined by MacDonald (2000).

Unit 4

Unit 4 consists predominantly of mafic volcanic rocks and is best exposed along the northwestern shore of Yarmouth Harbour. The lower part of this unit is exposed at Cape Forchu West and consists of green to dark grey, massive mafic flows and lithic tuff. These are locally interlayered with minor tuffaceous metasandstone containing abundant small (<2 mm in length) amphibole porphyroblasts. The contact with unit 3 is sharp and marked by a narrow shear zone. The middle part of the unit consists of mafic lithic tuff interlayered with abundant tuffaceous sandstone (Fig. 7a). In contrast to the lower unit, this unit is thinly bedded to well laminated with original sedimentary and volcanic textures well preserved (Fig. 7b). In addition, many of the tuffaceous metasandstone layers contain calc-silicate lenses. The upper part of this unit consists of green, massive mafic flows and lithic to crystal lithic tuff. Locally the flows have pillow-like structures or brecciated flow tops. The associated lithic tuff contains abundant tuffaceous metasandstone and amygdaloidal basalt clasts. Locally plagioclase crystals (up to 1 cm in width) are abundant. The upper and middle packages are separated by a shear zone. In comparison to the stratigraphy defined by MacDonald (2000), the lower part of the unit corresponds to the mafic flows/tuff and conglomerate unit, whereas the middle and upper parts are broadly equivalent to uppermost mafic tuff and flows.

Unit 5

Unit 5 consists predominantly of metasedimentary rocks and is best exposed along the eastern shore of Yarmouth Harbour. The lower part of this unit contains thickly bedded metasandstone with abundant calc-silicate nodules interlayered with grey, biotite-spotted slate. Minor thin (<1 cm thick) limy beds are present. The middle part of the unit is mainly spotted slate interbedded with metasiltstone. Metasandstone layers and lenses are rare. Near the top of the unit, the metasedimentary rocks are interlayered with mafic lithic tuff and flows and tuffaceous metasandstone. The contact with unit 4 is not exposed but, because of a topographic linear, is interpreted to be a fault. This unit corresponds to the "black slate" in the upper unit of MacDonald (2000).

Unit 6

Above unit 6, in gradational contact, are mafic lithic tuff and flows interlayered with minor tuffaceous metasandstone. This unit is well exposed at Sunday Point. The metavolcanic rocks are very similar to the upper part of unit 4, but in contrast, many of the mafic layers in unit 6 contain peperite-like textures. In

addition, two distinctive felsic crystal tuff layers (< 100 m thick) exist in this unit that are not present in unit 4. The most westerly felsic layer can be traced several kilometres inland. The felsic crystal tuff has yielded a U-Pb zircon age of 438 ±3/-2 Ma, interpreted to be the time of crystallization of the tuff (J. Ketchum, unpublished data, cited by MacDonald, 2000). Because MacDonald (2000) interpreted the White Rock Formation to be folded into a syncline, this unit is similar to the mafic flows/tuff and conglomerate unit on the eastern limb of the syncline.

Unit 7

The stratigraphically highest unit in the White Rock Formation in the Yarmouth area is dominantly a mixture of metasedimentary and metavolcanic rocks. The metasedimentary rocks consist of biotite ± garnet ± staurolite-bearing phyllite and schist, locally interlayered with thin layers (<30 cm thick) of metasandstone and amphibolite. The metasedimentary rocks have a low areomagnetic signature. The metavolcanic rocks consist of green mafic to rare intermediate lithic tuff interlayered with tuffaceous metasandstone. They form a distinct belt in the centre of the metasedimentary unit, which is also defined by a strong areomagnetic signature. Large areas of medium- to coarse-grained amphibolite occur in this unit (i.e. Brazil Lake area) but because of lack of any primary features it difficult to ascertain the protolith. Quartzite layers are rare and have been observed interlayered with the amphibolite in the Brazil Lake area. These amphibolites have a low areomagnetic signature. This unit is equivalent to parts of the lower- most units defined by MacDonald (2000).

Intrusive Rocks

Mafic Sills

Compared to map areas to the north (e.g. White *et al.*, 1999; Horne *et al.*, 2000), mafic sills in the Goldenville and Halifax formations are not as abundant and, therefore, more difficult to subdivide into distinct suites (cf. White *et al.*, 1999). The sills are locally foliated, fine- to medium-grained and 1-2 m thick. The White Rock Formation contains numerous mafic sills that are typically foliated, medium- to coarse-grained and boudinaged parallel to foliation. Although the sills in the WRF are now composed of amphibolite, some display a phenocryst-rich or amygdaloidal zone near the upper contact, which suggests that they may represent mafic flows younging to the southeast, rather than sills. Cross-cutting mafic bodies (dykes) are rare. Geochemical work is in progress on the mafic sills.



Figure 6. Photograph of conglomerate layer in the upper part of Unit 3. Clasts are dominantly intermediate crystal tuff and tuffaceous sandstone. Hammer for scale.

Gabbroic and Dioritic Rocks

Small gabbroic and dioritic bodies outcrop in the Goldenville Formation near Sandford, in the Halifax Formation near Mavillette, and in the White Rock Formation near Wentworth Lake (Fig. 3). The intrusion near Sandford is well exposed along the coast and consists of relatively undeformed, homogeneous, medium-grained diorite. The age of the diorite is unknown but it clearly intruded metasandstone along the eastern margin and has a faulted contact on the south. Petrographic and petrochemical studies are in progress to further characterize this intrusion. The Mavillette Intrusion (Calder and Barr, 1982) is a small dyke-like body of medium-grained, ophitic gabbro. Locally it is coarse-grained, pegmatitic and strongly deformed. Like the Sandford intrusion, the age is unknown. The Wentworth Lake intrusion is well exposed on islands in Wentworth Lake. Contact relations with the surrounding staurolite and chloritoid-bearing metasedimentary rocks of the White Rock Formation are not exposed. The intrusion consists of unfoliated, medium- to coarse-grained diorite to quartz diorite (Ham and MacDonald, 1994). Toward the eastern margin, the diorite becomes increasingly deformed and grades into mylonite. There is no direct evidence for the age of this intrusion, although Ham and MacDonald (1994)

assigned a Middle Devonian or earlier age. Relatively fresh gabbroic sills occur in the Goldenville Formation in the Chebogue Point area and may be related to Early Mesozoic mafic dykes that occur in the Goldenville Formation and Carboniferous Wedgeport Pluton exposed farther east (Pe-Piper and Reynolds, 2000). Geochemical work is in progress on the gabbroic and dioritic intrusions.

Brenton Pluton

The Brenton Pluton (Taylor, 1967) is a narrow northeast-trending body in the southeastern part of the map area. It consists dominantly of a grey, medium-grained syenogranite to monzogranite (O'Reilly, 1976; MacDonald, 2000) that is typically strongly foliated and linedated. Locally, in the central parts of the pluton, the granite is unfoliated, massive and equigranular. The western contact is faulted against unit 7 of the White Rock Formation and the eastern contact is faulted against the Cunard member of the Halifax Formation. In contrast to previous work, no contact metamorphic aureole was observed (cf. Taylor, 1967; O'Reilly, 1976; Hwang, 1985). The Brenton Pluton has yielded a U-Pb crystallization age of ca. 439 Ma (Keppie and Krogh, 2000). Geochemistry of the granitic rocks suggests

some characteristics similar to within-plate A-type granites (MacDonald, 2000).

South Mountain Batholith

Because the geology of the South Mountain Batholith was part of an earlier detailed study (Ham and MacDonald, 1994), it was not remapped in detail during the present study. The batholith in the study area consists of medium- to coarse-grained monzogranite to leucogranite with locally well-developed megacrysts of K-feldspar. The South Mountain Batholith has yielded U-Pb crystallization ages of ca. 370 Ma (Clarke *et al.*, 1993; Harper, 1988).

Metamorphism

The Meguma Group, White Rock Formation and mafic sills were deformed during the Acadian Orogeny. This deformation resulted in regional scale northeast-trending folds with an axial planar cleavage. The regional deformation was accompanied by greenschist- to amphibolite-facies metamorphism that resulted in the southeastward increase in metamorphic grade from chlorite zone (Meteghan to Cape St. Marys), through biotite zone (Cape St. Marys to Cranberry Point), to garnet zone (Cranberry Point to Sunday Point) (Keppie and Muecke, 1979; O'Reilly, 1976; Hwang, 1985; Culshaw, 1994; Culshaw and Liesa, 1997). Recent studies by MacDonald (2000) further defined a staurolite zone along the southeastern contact between the White Rock and Halifax formations, indicating amphibolite facies conditions (Yardley, 1989). In addition, biotite is present in some areas within the chlorite zone. Whether this is a compositional feature of the original rock type or related to higher metamorphic grade is as yet unclear. Rocks of the Goldenville Formation southeast of the White Rock Formation have mineral assemblages characteristic of the chlorite and biotite zones, although locally contact metamorphism produced andalusite and cordierite-bearing assemblages. Associated with the deformation and metamorphism was the development of an axial planar penetrative slaty, to phyllitic, to schistose foliation.

Typical syntectonic metamorphic mineral assemblages in pelitic rocks include chlorite + muscovite + quartz + albite in the chlorite zone; biotite + chlorite + muscovite + quartz + albite in the biotite zone; garnet + biotite + chlorite + muscovite + quartz + albite + epidote ± chloritoid in the garnet zone; and staurolite + garnet + biotite + muscovite + quartz + plagioclase ± chlorite in the staurolite zone. Mafic volcanic rocks and sills in the chlorite and biotite zone typically retain their original igneous textures but their mineral assemblage is

metamorphic, including chlorite + epidote + actinolite ± quartz. In the garnet and staurolite zones original textures are typically obliterated and actinolite is replaced by hornblende (cf. Sarkar, 1978; MacDonald, 2000).

O'Reilly (1976) and Hwang (1985) reported evidence of a contact metamorphic aureole around the Brenton Pluton. However, the high metamorphic grade along the northern and western margins of the pluton is consistent with the regional amphibolite grade of metamorphism in unit 7 of the White Rock Formation (e.g. MacDonald, 2000).

The precise age of metamorphism is difficult to determine. A detailed $^{40}\text{Ar}/^{39}\text{Ar}$ study on single grain muscovite and whole-rock samples from the Meguma Group in the Digby area indicated that regional greenschist-facies metamorphism associated with the Acadian Orogeny occurred ca. 400 Ma (Muir, 2000). This age is similar to $^{40}\text{Ar}/^{39}\text{Ar}$ ages reported elsewhere in the Meguma Group (405-390 Ma, Muecke *et al.*, 1988; 395-388 Ma, Hicks *et al.*, 1999). However, the timing of amphibolite-facies metamorphism in the study area may be constrained by metamorphic monazite from the Brenton Pluton, which yielded a U-Pb age of 380 ± 3 Ma (Keppie and Krogh, 2000). Published $^{40}\text{Ar}/^{39}\text{Ar}$ muscovite and biotite ages from the Meguma Group, White Rock Formation and Brenton Pluton in the map area yielded considerably younger ages between 330 and 310 Ma (O'Reilly, 1976; Reynolds *et al.*, 1981; Dallmeyer and Keppie, 1987; Culshaw and Reynolds, 1997). An $^{40}\text{Ar}/^{39}\text{Ar}$ study on whole-rock samples from the Goldenville Formation northeast of the East Kemptville Mine yielded ages in the range 315 to 300 Ma (Keppie and Dallmeyer, 1995). These younger ages suggest a more complex tectonic history for the area than previously thought (e.g. Taylor, 1967, 1969; Lane, 1979; Hwang, 1985; Schenk, 1995, 1997), and may be related to a younger regional metamorphism or plutonism (e.g. Keppie and Dallmeyer, 1995), or to deformation related to shear zone development (e.g. Culshaw and Reynolds, 2000).

Deformation

Previous published maps of the area show the metamorphic rocks are deformed into a series of regional D_1 folds with the Goldenville Formation exposed in the Black Point anticline (Culshaw and Liesa, 1997) and the Halifax and White Rock formations are exposed in the Cape St. Marys and Yarmouth synclines (Taylor, 1967, 1969). The Cape St. Marys syncline is part of a larger synclinorium termed the Bear Cove synclinorium (Culshaw and Liesa, 1997). In



Figure 7a. Photograph of well layered mafic lithic and crystal tuff, interlayered with tuffaceous metasandstone in Unit 4. Beds are vertical and young to the south (right) and cleavage dips to the north (left). **Figure 7b.** Photograph of fine-grained andesitic bomb (light) in a mafic crystal tuff (Unit 4). Impact structures indicate stratigraphic top to the south (left side of photo). Knife for scale.

addition, several shear zones have been documented within the map area (Hwang, 1985; O'Reilly *et al.*, 1992; Ham and MacDonald, 1994; Keppie and Dallmeyer, 1995; Culshaw, 1994; Culshaw and Liesa, 1997). Our mapping generally agrees with this earlier interpretation; however, we differ in the interpretation of the present existence of the "Yarmouth syncline". Although the White Rock Formation in the Yarmouth area may have been originally folded into a regional syncline, and the presence of the Halifax Formation on either side of the White Rock Formation indicates a synclinal structure (Fig. 2), regionally the map units in the White Rock Formation systematically young from west to east with no apparent repetition of units. In addition, the aeromagnetic data combined with the preliminary stratigraphy in the Goldenville Formation on either side of the White Rock Formation do not appear to correlate (Fig. 3). The presence of major shear zones in the area may help explain some of the structural complexities but more detailed studies are needed to completely address this problem.

For descriptive purposes, the area is divided into three F_1 structural domains. Domain I comprises the Goldenville and Halifax formations in the Black Point anticline and Cape St. Marys synclinorium in the northwestern part of the map area (Fig. 8). The rocks in this zone are regionally metamorphosed to greenschist facies. Domain II includes all the White Rock Formation in the central part ("Yarmouth syncline") of the map area (Fig. 8). In this domain, metamorphism increases from greenschist facies in the east to amphibolite facies in the west. Domain III comprises the Goldenville and Halifax formations in the southeastern part of the map area (Fig. 8) where they are regionally metamorphosed to greenschist facies.

F_1 Folds

Poles to bedding in Domain I define a girdle distribution with a shallow, southwest-plunging fold axis (208/13) and poles to foliation define a well-developed cluster with a steep axial planar foliation that strikes northeast (Fig. 8). Intersection lineations (L_1), although somewhat scattered, have an average southwest plunge, similar to the calculated fold axis from bedding orientations (Fig. 8). However, intersection lineations also plunge to the northeast suggesting doubly plunging folds. Steep lineations are likely the result of re-orientation during younger deformation (cf. Culshaw and Liesa, 1997). Minor F_1 folds are not common and, where present, are restricted to the Bear Cove synclinorium and are upright subhorizontal folds (Culshaw, 1994; Culshaw and Liesa, 1997). The regional fold pattern indicates that the Black Point anticline and Cape St. Marys synclinorium are

moderately inclined to the northwest and plunge gently to the southwest with an overturned northwestern limb on the Black Point anticline (cf. Culshaw and Liesa, 1997).

Poles to bedding and volcanic layering in the White Rock Formation (Domain II) form a well defined cluster with an average bedding that strikes north-northeast and dips steeply to the east and also forms an incipient girdle distribution about a shallow southwest-plunging fold axis (194/14) (Fig. 8). Poles to foliation define a well developed cluster with an average orientation that strikes north-northeast with a vertical dip (Fig. 8). Intersection lineations (L_{1a}) parallel the long axis of elongate clasts (L_{1b}) and form a well developed, shallow, southwest-plunging cluster similar to the calculated fold axis from bedding orientations (Fig. 8). Minor F_1 folds are rare and restricted to the more pelitic rocks. They are steeply inclined and plunge gently to the south (Fig. 8).

Structural data in Domain III are similar to those in Domain I. Poles to bedding are somewhat scattered but still form a weak girdle distribution about a northeast-plunging axis and poles to foliation define a well developed cluster with a steep axial planar foliation that strikes northeast (Fig. 8). Average intersection lineations (L_1) form a shallow, southwest-plunging cluster; however, intersection lineations also plunge to the northeast suggesting doubly plunging folds.

F_2 Folds

Although minor F_2 crenulation fabrics are common in all rocks in the map area, mesoscopic-scale F_2 folds are more common in the White Rock Formation. Here, the foliation and bedding are locally deformed into upright, gently south-southeast-plunging F_2 folds (Fig. 8) with northeast-trending steep (S_2) axial planar foliation. The long axes of elongate clasts are parallel to the F_2 fold axis. The similarity in structural geometry between F_1 and F_2 folds suggests that deformation was coplanar.

Boundary Shear Zones

Numerous shear zones along lithological boundaries have been documented in the map area (Fig. 8) and are exposed mainly in coastal area. These include the Cape St. Marys, Cranberry Point, Cape Forchu and Chebogue Point shear zones of Culshaw (1994) and Culshaw and Liesa (1997). The Cape St. Marys, Cranberry Point and Chebogue Point shear zones have predominantly dip-slip displacement, although a significant strike-slip component is locally evident, whereas the Cape Forchu shear zone displays evidence for strike-slip motion (Culshaw and Liesa, 1997). The Cape St. Marys and

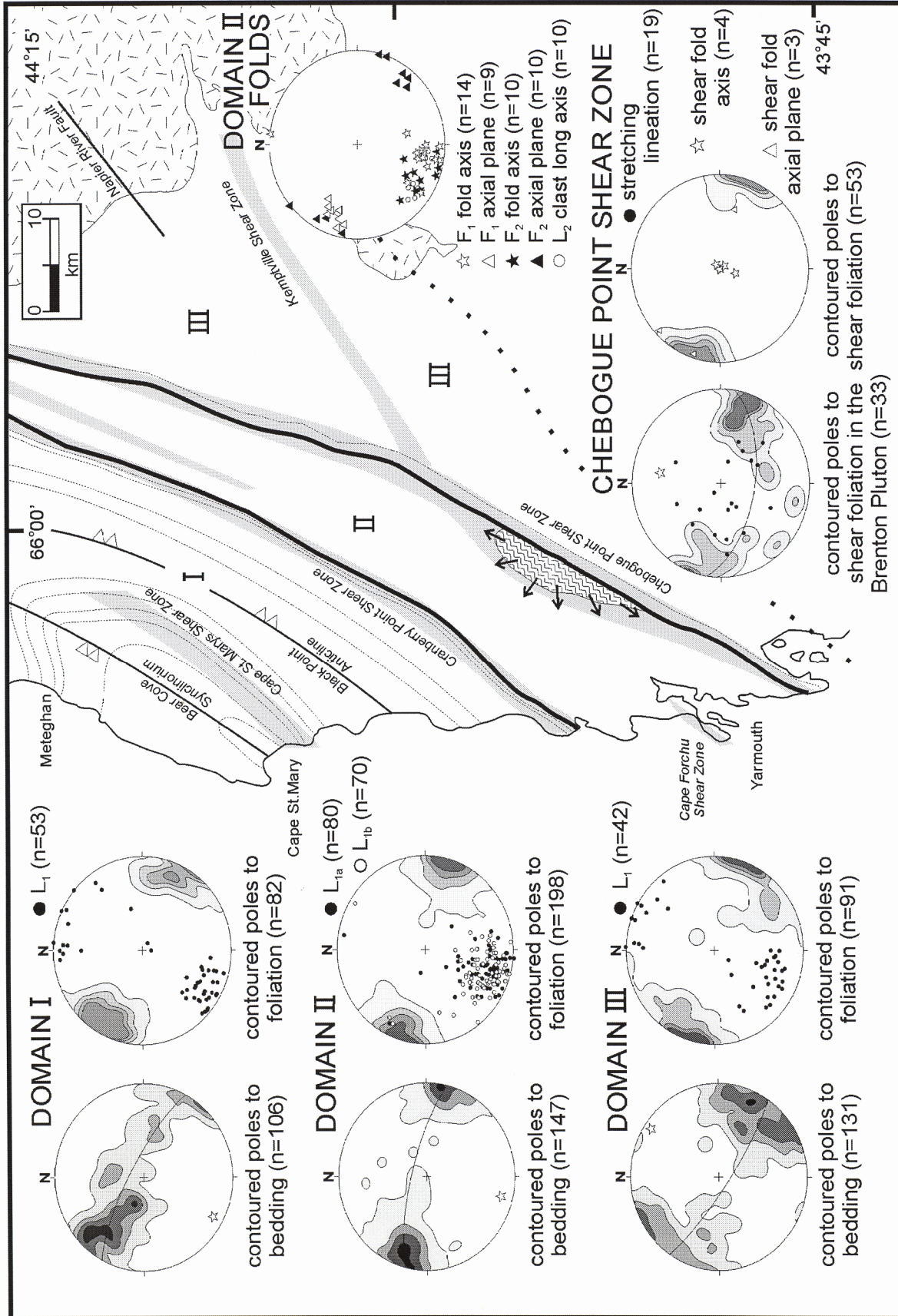


Figure 8. Stereographic projections displaying structural data from the map area. Units as in Figure 2. Contours on stereonets represent 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area. Arrows in Brenton Pluton represent stretching lineations. L terminology explained in text.

Cranberry Point shear zones have yielded ca. 320 Ma muscovite ages indicating a middle Carboniferous age for shear zone development (Culshaw and Reynolds, 1997). Our mapping has delineated several other shear zones, some of which may or may not correlate with those described above. Narrow, steeply dipping, northeast-trending shear zones occur in the Goldenville Formation southwest of the White Rock Formation (Ham and MacDonald, 1994), and locally display significant Sn-Cu-Au mineralization (O'Reilly, 1995).

The most significant shear zone is the Chebogue Point shear zone (Deerfield shear zone of Keppie and Dallmeyer, 1995). The Chebogue Point shear zone forms a wide belt along the southeastern contact between the White Rock and Goldenville formations, incorporating the majority of the Halifax Formation (Fig. 2). Inland the shear zone appears to encompass most of the Brenton Pluton and surrounding staurolite schist of the White Rock Formation. The shear zone juxtaposes chlorite and biotite grade zone of the Halifax and Goldenville formations and staurolite zone metamorphic rocks of the White Rock Formation (cf. Hwang, 1985). At Chebogue Point kinematic indicators suggest west-side-up dip-slip motion (Culshaw and Liesa, 1997), whereas Dallmeyer and Keppie (1987) and Keppie and Dallmeyer (1995) argued for dextral shear. This zone is strongly overprinted by younger brittle deformation that locally obliterates earlier deformational textures.

Poles to shear foliation form a well defined cluster with a steep, north-northeast trending orientation (Fig. 8). Rare folds in this zone are steeply plunging with axial planes subparallel to the average foliation (Fig. 8), suggesting a strike-slip motion. Poles to foliation in the Brenton Pluton form a well defined cluster with a foliation that strikes north-northeast and dips steeply to the northwest and also forms an incipient girdle distribution about a shallow north-plunging fold axis (Fig. 8). Isoclinal, infrafolial folds are rare. Stretching lineations appear to be scattered on the stereonet but in the field seem to have a very systematic "domal" distribution, plunging to the southwest, west, and northwest along the western margin and to the east and northeast on the eastern margin (Fig. 8). The domal stretching lineation pattern suggests a sheath-fold geometry.

The Kemptville shear zone (O'Reilly, 1995) is a northeast-trending mylonitic shear zone that is well developed in metasandstone of the Goldenville Formation. It can be traced from East Kemptville to Carleton where it appears to be truncated by the Chebogue Point shear zone (Fig. 2 and 8). The shear

zone is steeply dipping and records a dip-slip, southeast-side-up shear sense (Horne and White, 2000).

Economic Geology

Numerous tin, base metal, and precious metal occurrences are known in the map area (Fig. 2) and are described in the Nova Scotia Department of Natural Resources Mineral Occurrence Database for NTS map sheets 21A/01, 21A/04, 20O/16, 20O/13. The most significant mineral deposit in the area is the greisen-hosted East Kemptville Sn-Zn-Cu-Ag deposit in the South Mountain Batholith (e.g. Kontak, 1990). Smaller, granite-hosted deposits include the Li-Be-bearing pegmatite at Brazil Lake (e.g. MacDonald et al., 1992) and a copper showing in the dioritic Wentworth Lake intrusion (e.g. O'Reilly, 1978). The Goldenville Formation adjacent to the South Mountain Batholith is host to several Sn-Zn-Cu occurrences. The minerals typically occur in silicified and sericitized zones, or as statabound replacement associated with hydrothermally altered metasandstone, or in discordant vein systems (O'Reilly, 1995). The Goldenville Formation is also host to a large number of auriferous vein-quartz deposits associated with intense silica, sericite, carbonate and pyrrhotite alteration (O'Reilly *et al.*, 1992).

Many of these deposits share an association with shear zones or secondary structures related to shear zones (e.g. Kontak *et al.*, 1995; O'Reilly, 1995). During the past summer we delineated several new shear zones and extended many of the previously recognized ones (c.f. Ham and MacDonald, 1994). Two of the most notable are the Napier River fault (Horne and White, 2000) and the Kemptville shear zone (O'Reilly, 1995). The Napier River fault is poorly exposed; however, a prominent, northeast-trending linear is recognized that crosses the contact between the Goldenville Formation and South Mountain Batholith contact (Fig. 2 and 8). This zone is characterized by brecciation, intense silicification and epithermal textures similar to those described in the Tobeatic Fault Zone by Corey and Horne (1989). Preliminary assay results indicate elevated zinc levels. Several gold occurrences lie within the Kemptville shear zone (Fig. 2). Although some shear zones in the map area are known to be directly associated with mineral deposits, many have not been fully evaluated and provide excellent targets for future exploration.

Summary

The stratigraphy and map units defined in the map areas to the north (White *et al.*, 1999; Horne *et al.*, 2000) can

be traced into the present map area. The distribution of units is controlled by the Black Point anticline and the Bear Cove synclinorium (Culshaw and Leisa, 1997). Although the White Rock Formation in the Yarmouth area may have originally been folded into a syncline, the formation now appears to young to the east, with no obvious repetition of units, calling into question the presence of a syncline. The distribution of units in the White Rock Formation is more likely due to regional scale shear zones. The occurrence of a distinctive, trace fossil-rich, magnetite-bearing metasiltstone unit may provide a useful marker horizon in the Goldenville Formation.

Regional folds are northeast-trending, generally plunge gently to the southwest, and have a well developed axial planar cleavage. Although the area is cut by numerous unit-parallel Middle Carboniferous shear zones, the most significant is the Chebogue Point shear zone which juxtaposes biotite- and chlorite-zone rocks of the Meguma Group with staurolite-zone rocks of the White Rock Formation.

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