Preliminary bedrock geology of the Digby map sheet (21A/12), southwestern Nova Scotia

C. E. White, R. J. Horne, C. Muir and J. Hunter

Introduction

Southwestern Nova Scotia (i.e. Digby-Yarmouth-Shelburne area) is underlain by three principal rock assemblages: (1) Cambrian-Early Devonian metasedimentary and metavolcanic rocks, (2) mainly Late Devonian granitoid rocks, and (3) Mesozoic sedimentary and volcanic rocks (Fig. 1a). The Cambrian-Early Devonian metamorphic sequence and Devonian granitoid rocks are the characteristic units of the Meguma Terrane (Williams, 1979; Williams and Hatcher, 1983) (Fig. 1a). The metamorphic rocks were deformed and metamorphosed during the Acadian Orogeny, resulting in regional-scale folds and associated cleavage (Keppie, 1993). The age of deformation is constrained by $^{40}Ar/^{39}Ar$ age data at ca. 400-385 Ma (e.g. Muecke *et al.*, 1988; Hicks *et al.*, in press). Although granitoid rocks truncate regional fold structures, they are interpreted to be late syntectonic (e.g. Benn *et al.*, 1997). Middle Carboniferous deformation related to regional shear zones is recognized in the Yarmouth to Meteghan area, where it affects the metamorphic rocks (Culshaw and Liesa, 1997). Mesozoic sedimentary and volcanic rocks overlap older rocks with angular unconformity.

Southwestern Nova Scotia has been previously mapped on a reconnaissance scale (1:126 720) by Taylor (1967, 1969). Geological maps at 1:50 000 scale exist for the eastern part of NTS sheet 21A/12 (Smitheringale, 1973), the South Mountain Batholith (MacDonald, 1994) and the Shelburne area (Rogers, 1986). For the majority of the metasedimentary and metavolcanic rocks, however, no 1:50 000 scale geological maps are available for southwestern Nova Scotia, and published maps date back to those of Taylor (1967, 1969).

The results presented in this report represent the first stage of a five-year program of geological mapping in southwestern Nova Scotia, including parts of NTS sheets 21A/04, 05, 12; 21B/01, 08, 09; 20O/09, 16; and 20P/11, 12, 13, 14 (Fig. 1b). The principal goals of this project are to produce a series of 1:50 000 scale geological maps of the area, to describe and interpret the sedimentary, igneous, metamorphic, and deformational history of the Cambrian-Early Devonian metamorphic rocks, and to evaluate the economic potential of the area.

Geological mapping of the bedrock geology of the Digby area (NTS sheet 21A/12, Fig. 1) was completed during the summer of 1998. Mapping was undertaken at 1:10 000 scale, using orthophoto maps and colour air photos as base maps. The results have been digitally recorded using FieldLog® and AutoCAD® and plotted on 1:10 000 digital base maps, and a 1:50 000 scale compilation map has been generated. Over 400 samples have been collected from the area, including samples of Doyle (1979) and Mahoney (1996), which are on loan from the Geology Department of Acadia University, Wolfville. All samples were slabbed and about 200 were examined in thin section. Mineral occurrences of significance were verified in the field and new occurrences were also appropriately documented and sampled.

This report presents a summary of the results and conclusions from these studies, with emphasis on map units (stratigraphy), field relations and structural geology.

Map Units

Introduction

Taylor (1965, 1969) and Smitheringale (1973) subdivided the rocks in the present mapped area into formal units on the basis of lithology, paleontology, and comparison with similar lithologies elsewhere in Nova Scotia (e.g. Crosby, 1962). Metamorphic rocks include the Cambrian to Ordovician Meguma Group, consisting of the lower Goldenville Formation and the upper Halifax Formation, the Silurian White Rock Formation and the Early Devonian Torbrook Formation. Recently Schenk (1995a) elevated the Meguma Group to the rank of supergroup and elevated the Goldenville and Halifax formations to group status. Similarly, Schenk (1995b) combined the White Rock and Torbrook formations into the Annapolis Supergroup and elevated the formations to the rank of groups. All of these units were recognized during the present study; however, the traditional unit names

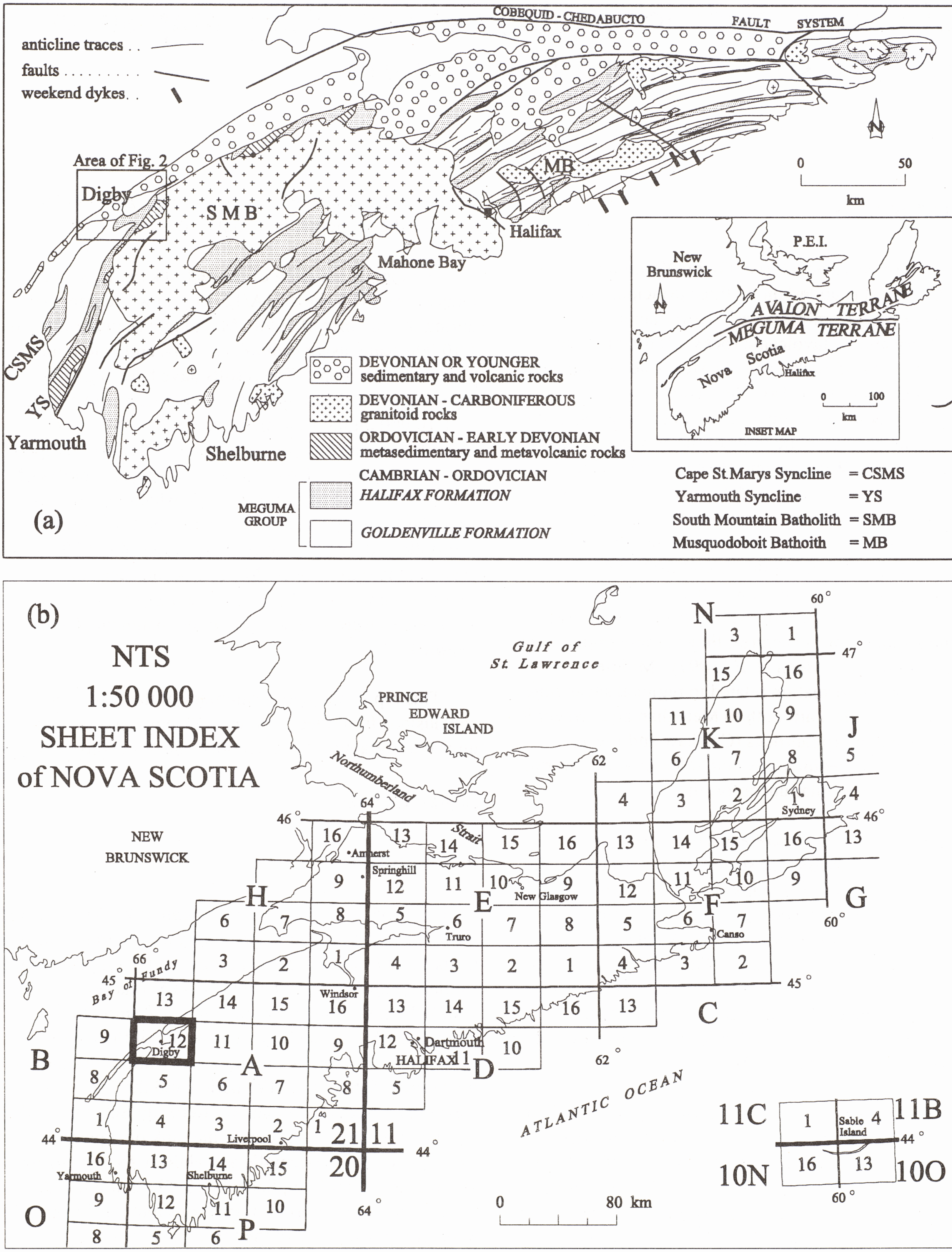

Figure 1. (a) Simplified geological map of the Meguma Terrane, Nova Scotia. Location of mapped area indicated as area of Figure 2. (b) National Topographic System (NTS) index map of Nova Scotia showing location of Figure 2.

assigned by Taylor (1969) and Smitheringale (1973) have been retained. In addition, the Halifax Formation has been divided into three new units which have been informally assigned member status. The metamorphic units are intruded by several suites of mafic sills (e.g. Doyle, 1979; Barr *et al.*, 1983). The Meguma Group, White Rock and Torbrook formations and mafic sills have been metamorphosed to chlorite grade as a result of regional greenschist facies metamorphism. Devonian granitoid rocks include part of the South Mountain Batholith and the Ellison Lake Pluton. Mesozoic units include the Triassic to Jurassic Wolfville, Blomidon and North Mountain formations.

Goldenville Formation

The Goldenville Formation occurs in the southwestern part of the mapped area (Fig. 2). It is poorly exposed, with outcrops limited to a few stream sections and logging roads. Distribution of this unit is more restricted than indicated previously (cf. Fig. 1a and Fig. 2), and the regional anticline and syncline shown by Taylor (1969) in the area of the Ellison Lake Pluton could not be confirmed. The Goldenville Formation consists of grey, massive to locally laminated or crosslaminated metasandstone and interbedded metasiltstone and slate. The metasandstone is typically fine grained, bedded on the metre scale, and has a poorly- to moderately-developed spaced cleavage. Carbonate and manganese concretions occur locally within metasandstone beds. Metasiltstone is typically green, massive to well laminated and well cleaved, and slate is dark grey and finely laminated. Stratigraphy (e.g. ratio of metasandstone to metasiltstone to slate) is highly variable, providing no obvious basis for stratigraphic subdivision of this unit within the mapped area. No fossils were observed, but a maximum age limit is provided by U-Pb 552 ± 5 Ma detrital titanite and 566 ± 8 Ma zircon (Krogh and Keppie, 1990). The contact between the Goldenville Formation and the overlying Halifax Formation is not exposed in the mapped area.

Halifax Formation

The Halifax Formation in the mapped area has been subdivided into three stratigraphic units, which are informally given member status here. From oldest to youngest, they are the Bloomfield, Acacia Brook and Bear River members.

Bloomfield Member

The lowermost part of Halifax Formation in the mapped area consists of a distinctive metasiltstone unit herein referred to as the Bloomfield member. This unit is exposed in a narrow, north-northeastward-trending belt at the contact between the Halifax and Goldenville formations in the southwestern part of the mapped area (Fig. 2). The distribution is well constrained for the northern three quarters of the unit (Fig. 2); however, projection of this unit to the southern map boundary is speculative, because no outcrop occurs in this area.

The Bloomfield member consists of distinctly banded maroon and green, very thinly bedded to medium bedded, locally crossbedded, metasiltstone to slate that locally displays a variegated texture (Fig. 3a). Metasandstone layers were not observed. Minor pink calcsilicate nodules occur locally. Contacts with adjacent units are not exposed, but the unit appears to be stratigraphically and structurally conformable with the underlying Goldenville Formation. A minimum stratigraphic thickness of 350 m is suggested from the exposed width.

Acacia Brook Member

The Acacia Brook member overlies the Bloomfield member and defines a north-northeastward-trending belt bounded by the Bloomfield member to the west and Acacia Brook to the east (Fig. 2). The northern part of this unit is well exposed; however, like the Bloomfield member, extension of the Acacia Brook member to the south is speculative, because exposure is limited in this area.

The Acacia Brook member consists mainly of light- to medium-grey, mainly planar laminated slate with minor, thin (<5 mm thick) laminations and lenses of well-cleaved, light grey metasiltstone. Crossbeds are commonly preserved. Metasandstone layers are rare. Locally the slate contains small (centimetre-scale), iron nodules (or weathered pyrite) and rust-brown (iron-rich?) laminations parallel to bedding horizons. No fossils were observed in this unit.

Contacts with the Bloomfield member are not exposed; however, based on regional-scale map patterns and structural similarities (see Structure and Metamorphism section), the contact is interpreted to be

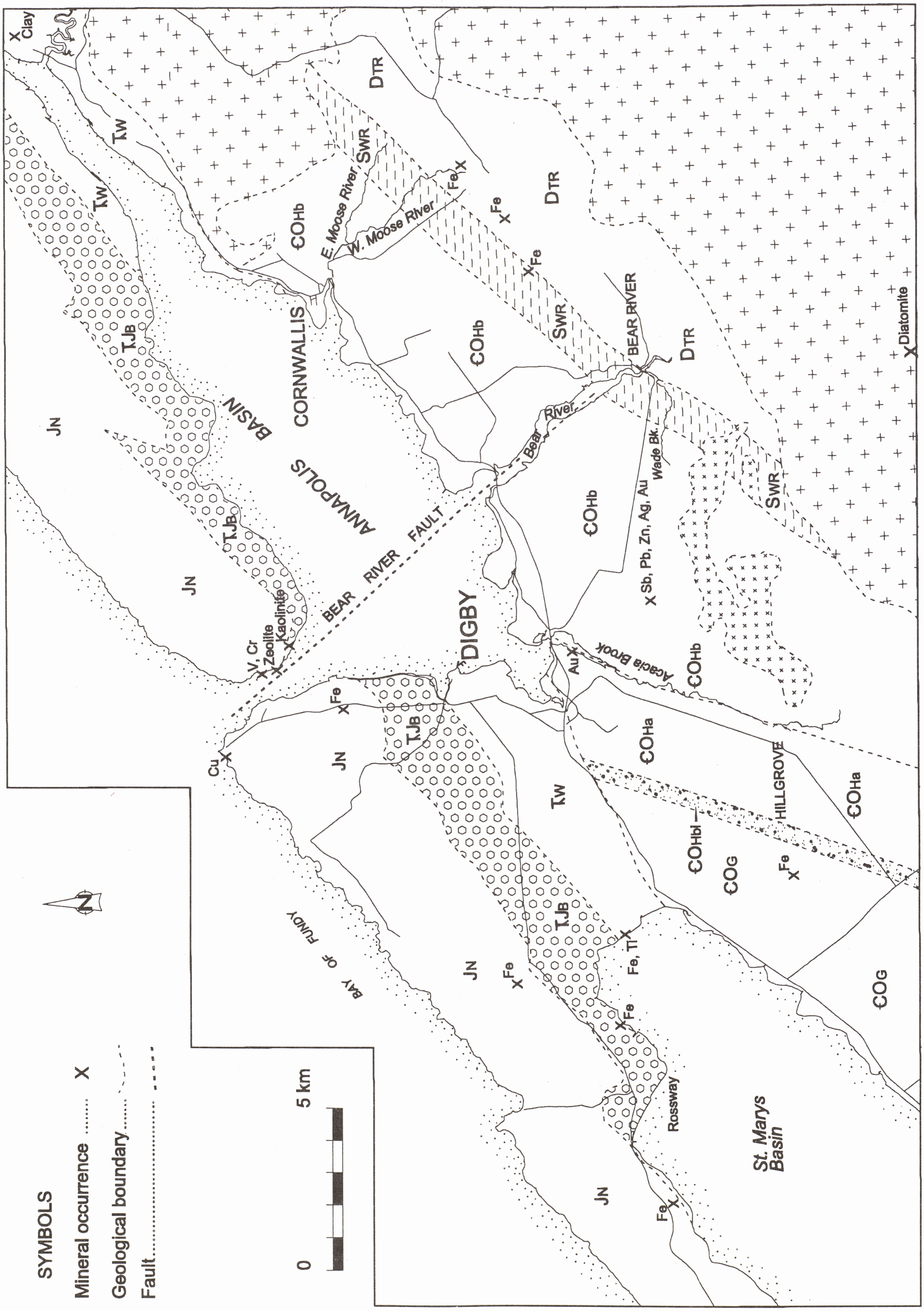

Figure 2. Preliminary geological map of the Digby area (21A/12).

LEGEND (Figure 2)

TRIASSIC TO JURASSIC

JN — ***NORTH MOUNTAIN FORMATION***: basalt and rare gabbroic dykes.

TJB — ***BLOMIDON FORMATION***: red to red-brown siltstone, sandstone, shale and minor claystone.

TW — ***WOLFVILLE FORMATION***: red to red-brown sandstone, arkose and minor conglomerate.

LATE DEVONIAN

SOUTH MOUNTAIN BATHOLITH: grey monzogranite to granodiorite.

ELLISON LAKE PLUTON: grey granodiorite.

EARLY DEVONIAN

DTR — ***TORBROOK FORMATION***: dark grey to black shale, siltstone and quartzite; minor limestone and 'iron formation'; locally cleaved; minor mafic sills and dykes.

SILURIAN

SWR — ***WHITE ROCK FORMATION***: grey shale, siltstone and quartzite; minor calcsilicate lenses and rare limestone; locally well cleaved; minor mafic sills and dykes.

CAMBRIAN TO EARLY ORDOVICIAN

MEGUMA GROUP

HALIFAX FORMATION:

ЄOHb — Bear River member: grey silty slate and cleaved metasiltstone with thin quartz arenite laminations; rare metalimestone nodules; abundant mafic sills and dykes.

ЄOHa — Acacia Brook member: grey slate with minor iron-rich laminations and nodules.

ЄOHbl — Bloomfield member: maroon and green, variegated metasiltstone.

ЄOG — ***GOLDENVILLE FORMATION***: light grey metasandstone and minor siltstone and slate

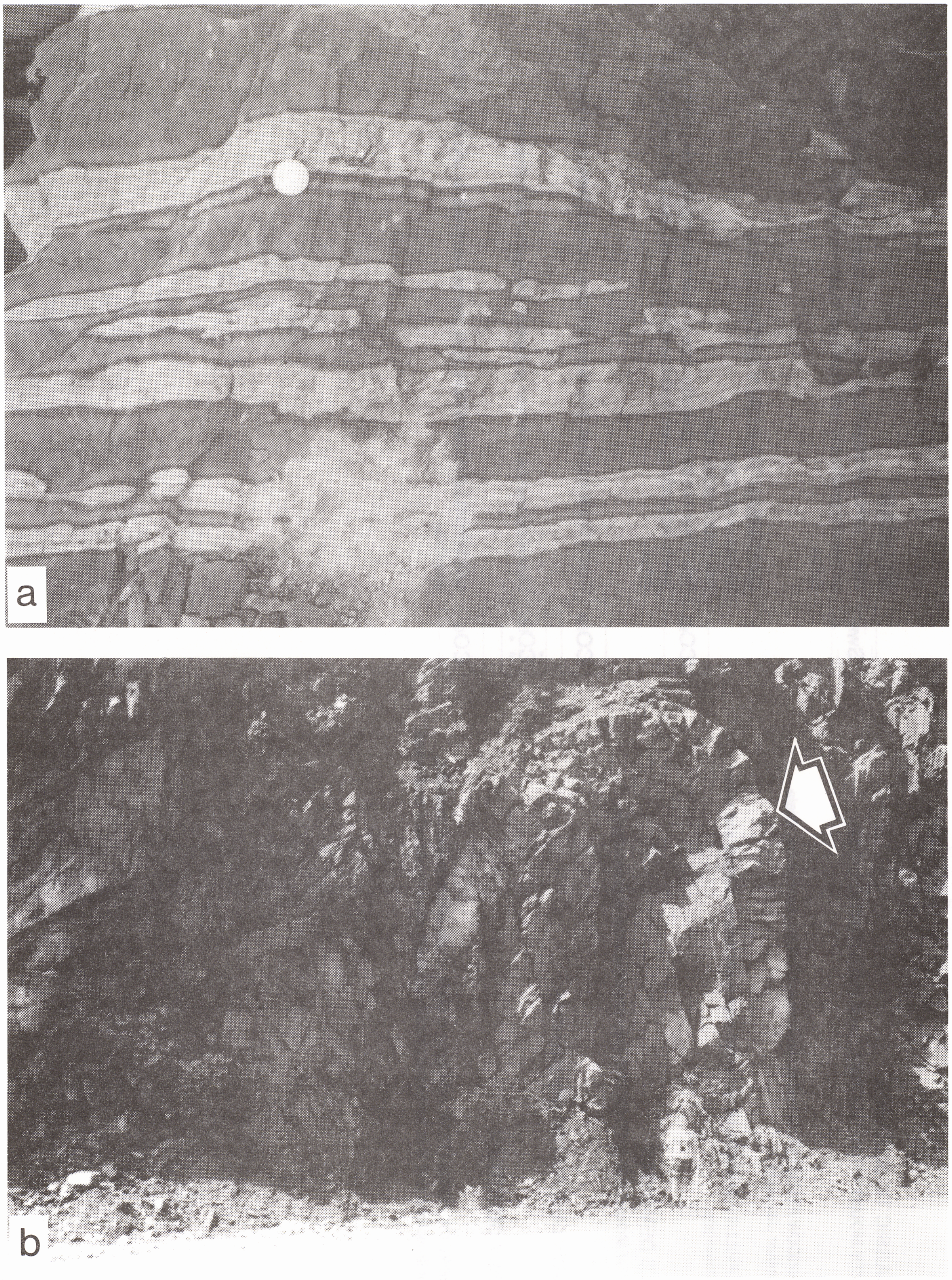

Figure 3. (a) Photograph of typical Bloomfield member, consisting of maroon (dark) and green (light), discontinuously banded (variegated) siltstone. Coin is 2.5 cm wide. (b) Photograph of typical Bear River member, consisting of silty slate, showing typical mesoscale fold found in this unit. Note folded Type I mafic sill, indicated by arrow. Person, in lower right of photograph, is 1.5 m tall, with hiking boots.

conformable with the Acacia Brook member. This interpretation is further supported by the general sedimentological similarity of these units; both consist mainly of planar laminated metasiltstone to slate. The contact with the overlying Bear River member was not observed and remains unclear. It coincides with Acacia Brook, which marks a prominent north-northeastward-trending linear feature. A faulted contact is suggested and supported by contrasts in structural style between the Bear River and Acacia Brook members (see Structure and Metamorphism section). A minimum stratigraphic thickness of 2200 m is suggested from the exposed width.

Bear River Member

The Bear River member is the uppermost and most extensive unit of the Halifax Formation in the area (Fig. 2). It is well exposed along brooks throughout much of the area; however, south of the Ellison Lake Pluton exposure is poor and distribution of this unit is speculative. The best continuous sections of this member are exposed along the lower part of Bear River.

The Bear River member consists of light- to dark-grey, banded to well laminated, cleaved silty slate, with minor, thin (<5 cm thick) metasiltstone and slate layers. A characteristic feature of this member is interlayered light grey, fine grained metasandstone that typically occurs as discontinuous, thin (<2 cm thick), lenticular crossbeds. Grey, massive, quartz-rich metasiltstone and metasandstone, forming layers up to 50 cm wide, are locally present. The metasiltstone typically contains abundant detrital muscovite. Rare, light grey metalimestone to silty metalimestone beds, lenses and nodules locally occur. Minor pyrite is common, occurring along laminae and fractures or as clusters of crystals. Pyrite beds up to 2 cm wide occur rarely.

Primary sedimentary structures are common and include cross- and graded-bedding, grooves, tool marks, ripple marks, small-scale slumping, and load casts. Fossil occurrences are generally sparse, although trace fossils and bioturbated layers are common. Early Tremadoc (earliest Ordovician) acritarch microfossils were reported by Doyle (1979) and specimens of the graptolite *Rhapdinopora flabelliforme* previously known as *Dictyonema flabelliforme* were observed within this unit (Smitheringale, 1973; this study) which are restricted to the Tremadoc (J. C. Russel, personal communication, 1999).

Contact with the overlying White Rock Formation is discussed below. Because of the numerous mesoscale folds in the Bear River member (Fig. 3b) (see Structure and Metamorphism section) a stratigraphic thickness could not be determined.

White Rock Formation

The White Rock Formation is well exposed in Bear River and Wade Brook (Fig. 2), where it has been studied in detail (e.g. Lane, 1975a, b, 1979; Doyle, 1979). It consists mainly of grey to dark grey slate and metasiltstone and minor light grey to white metasandstone. The slate is similar to the lithology in the underlying Bear River member and in isolated outcrops it is difficult to distinguish the two units. However, slates in the White Rock Formation are commonly darker, less laminated, and more silty than those in the Bear River member. The metasiltstone is laminated to massive, occurs in 5-20 cm thick beds, and cleavage is typically weakly to, locally, well developed. The metasandstone typically occurs as 1-10 cm thick, laminated to massive beds and discontinuous lenses. A characteristic feature of this formation is a thick (ca. 30 m), locally laminated and cross-stratified metasandstone layer. This layer is well exposed in Bear River, along a nearby road to the east and in Wade Brook, but appears to be discontinuous along strike. Rare, grey marble beds occur as thin (<15 cm thick) layers at the base of the formation, and thin (<3 cm thick) lenses of intraformational conglomerate, with a brown sandy matrix, locally occur near the top of the formation. Another feature of the White Rock Formation, not previously described in the area, is locally abundant pinkish-grey calcsilicate lenses.

Primary sedimentary structures are common and include crossbedding, grooves, tool marks, load casts and ripple marks. Fossil occurrences are sparse, although burrowing and grazing trace fossils and bioturbated layers are common. Ostracod fragments and calcareous oncolites have been recovered near the base of the formation, but no age was assigned to them (Lane, 1979). Upper Silurian vertebrate and crinoid remains have been collected near the top of the formation in addition to spore and chitinozoan microfossils (Blaise *et al.,* 1991; Bouyx *et al.*, 1997).

The contact between the White Rock Formation and the underlying Halifax Formation (Bear River member) is poorly defined. Smitheringale (1973) suggested that the base of the White Rock Formation should be placed at the bottom of the lowest 'quartzite' (cf. Doyle, 1979) or volcanic member (cf. Lane, 1979). In Wade Brook, the massive metasandstone sits with angular unconformity on slates of the Halifax Formation. In Bear River the base of the metasandstone is interlayered with black metasiltstone and a clear unconformity is not recognized. However, calcsilicate lenses typical of the White Rock Formation occur below the metasandstone along Bear River and continue down section to the limestone beds. We, in agreement with Lane (1979), place the contact between the White Rock and Halifax formations in this area at the base of the limestone. The presence of felsic tuff in the section could not be confirmed.

The upper contact between the White Rock and Torbrook formations is also problematic. Lane (1979) placed the upper contact just above the massive metasandstone based on the presence of Early Devonian fossils (Jensen, *in* Lane, 1979). However, fossils in this area have been reassigned to the Late Silurian by Blaise *et al.* (1991) and Bouyx *et al.* (1997). Our observations suggest the contact with the overlying Torbrook Formation is gradational and we place it above the intraformational conglomerate, where it occurs, and below the first occurrence of macroscopic Early Devonian fossils typical of the Torbrook Formation (see below). The exposed width of the White Rock Formation along Bear River suggests a stratigraphic thickness of approximately 1200 m.

Torbrook Formation

The Torbrook Formation occurs in a northeastward-trending belt between the White Rock Formation and the South Mountain Batholith. This unit is locally well exposed, particularly in the upper part of Bear River (Fig. 2). Outcrops of the Torbrook Formation were exposed temporarily during construction of a new penstock water pipeline in this area, which provided continuous sections through parts of the formation. These exposures, however, are now buried. The Torbrook Formation consists predominantly of metasiltstone and calcareous metasiltstone with minor slate, metasandstone, marble and rare ironstone. Most lithologies are poorly cleaved or lack cleavage. The metasiltstone is typically dark grey to black, but weathers pale grey. It is massive to well laminated, and commonly interlayered with thin (<2 cm thick), grey, laminated and crosslaminated metasandstone. In places the metasiltstone is pyrite-rich and weathers rusty-brown. Fossil-rich horizons are common within the metasiltstone. Dark grey slate is interlayered with the fossiliferous metasiltstone. White metasandstone beds become more abundant up section, range up to 2 m in thickness and are generally massive and locally crossbedded. Light grey, thin (<1 m) marble beds and nodules and thin (<10 cm) calcsilicate layers are interlayered with the metasiltstone. Ironstone, described as 'Iron Formation' by Woodman (1909) and Wright (1975), is exposed only in old mine trenches northeast of Bear River (Fig. 2). The ironstone consists of black, faintly laminated to massive, iron-rich sandstone. It was termed a chamositic sandstone by Doyle (1979).

Primary sedimentary structures are abundant and include crossbedding and ripple marks. The fossil assemblage includes brachiopods, corals, crinoids and pelecypods, and indicates an Early Devonian age (Smitheringale, 1973; Jensen, 1975a, b; Blaise *et al.*, 1991; Bouyx *et al.*, 1997).

The upper contact is not exposed due to intrusion of the South Mountain Batholith and therefore a reasonable estimate for the thickness of this unit is difficult to establish in the area.

Mafic Sills

Numerous mafic sills and rare dykes intruded the Halifax, White Rock and Torbrook formations (Smitheringale, 1973) and have generally been divided into two suites referred to as Type I and Type II (Doyle, 1979; Barr *et al.*, 1983; this study). Type I sills are restricted to the Halifax Formation. They are typically light grey, fine grained, thin (<2 m thick), vesicular, have narrow chilled margins, and are highly altered, with only relict igneous textures preserved and no igneous minerals. Phenocrysts displaying olivine morphologies are completely pseudomorphed by carbonate minerals, chlorite, and other secondary minerals. Type I sills are folded by F_1 folding (Fig. 3b) (see Structure and Metamorphism section) and soft-sediment deformational features are preserved along some of the sill contacts. These features suggest intrusion of the sills prior to deposition of the White Rock and Torbrook formations, as suggested by Doyle (1979) and Barr *et al.* (1983).

In comparison, Type II sills are dark grey to black, coarse grained, and generally wider and less abundant than Type I sills. Type II sills occur in the Halifax, White Rock and Torbrook formations and have not been observed in the South Mountain Batholith or Ellison Lake Pluton. Folded Type II sills were not observed; however, many of these sills are deformed and cleaved and no discordant examples have been observed, suggesting that these sills, like Type I sills, are folded by regional F_1

folding. Type II sills near the South Mountain Batholith are contact metamorphosed by the intrusion. Alteration is not as strong as it is in the Type I sills. Igneous textures and minerals are generally well preserved, with pyroxene only partially pseudomorphed by secondary minerals. Olivine, or evidence for former presence of olivine, was not observed.

A third set of mafic sills was recognized during this study. They are black, medium- to coarse-grained, uncleaved, unaltered and contain augite and pigeonite. These sills are texturally and mineralogically similar to basalts of the North Mountain Formation and are interpreted to be related to that formation. However, these sills are rare and were observed only in the Halifax Formation.

Devonian Plutonic Units

Plutonic units in the mapped area consist of the Ellison Lake Pluton and parts of the South Mountain Batholith (Fig. 2). A study of these units was not a priority of this project, because these units have been part of other detailed studies (Allen and Barr, 1983; MacDonald *et al.*, 1992; MacDonald, 1994; Ham, 1994).

The Ellison Lake Pluton is poorly exposed, therefore its distribution is based on limited outcrop, diamond-drill holes, trenching, boulder mapping and airborne radiometric data (Allen, 1982; Allen and Barr, 1983; Doyle, 1979). The South Mountain Batholith is better exposed, but outcrops are generally confined to streams and rivers (Ham, 1994). Both units consist of medium- to coarse-grained monzogranite and granodiorite with locally well-developed megacrysts of K-feldspar. The South Mountain Batholith has yielded U-Pb ages of ca. 370 Ma (monazite) (Clarke *et al.*, 1993; Harper, 1988). The Ellison Lake Pluton is generally similar in texture and mineralogy to the South Mountain Batholith and is interpreted to be of similar age (e.g. Allen and Barr, 1983; Ham, 1994).

Wolfville Formation

The Wolfville Formation is not well exposed in the mapped area, but its presence is confirmed from water wells along the shoreline of the Annapolis Basin (Trescott and Lin, *in* Doyle, 1979). Where exposed, this formation consists mainly of pink to red, coarse grained sandstone and conglomerate with minor interbeds of red to red-brown siltstone and shale.

The Wolfville Formation is interpreted to unconformably overlie the Meguma Group and the South Mountain Batholith (Fig. 2). Vertebrate faunal remains in exposures along the southern side of the Minas Basin (northeast of the mapped area) indicate a Middle to Late Triassic age for this unit (e.g. Olsen *et al.*, 1989). An estimate of the minimum thickness of the Wolfville Formation, based on exposed width, is approximately 450 m.

Blomidon Formation

The Blomidon Formation is better exposed than the Wolfville Formation and at Rossway, on Digby Neck, approximately 400 m of stratigraphy is exposed. This section represents the majority of the estimated 550 m stratigraphic thickness inferred from the exposed width of the unit. The Blomidon Formation consists mainly of red-brown to locally grey-green siltstone and minor sandstone and shale. Caliche nodules are locally common and evaporite beds have been reported at Rossway (Wade *et al.*, 1996).

Although the contact is not exposed in the mapped area, the Blomidon Formation is interpreted to conformably overly the Wolfville Formation based on borehole data (Jong, 1985; Wade *et al.*, 1996). Palynomorph assemblages within the Blomidon Formation indicate a mainly Late Triassic age, with the very top of the formation extending into the Jurassic (Wade *et al.*, 1996).

North Mountain Formation

The North Mountain Formation is well exposed along the coast of the Bay of Fundy, and consists of a succession of subaerial basaltic flows. In the Digby Neck area (Fig. 2), thick, coarse grained lower and upper flows are separated by seven or more thin amygdaloidal flows with abundant zeolites (e.g. Papezik *et al.*, 1988). The composite thickness is about 400 m (Wade *et al.*, 1996; this study). Coarse grained to pegmatitic gabbroic dykes, ranging in thickness from a few centimetres to approximately 5 m, are associated with the basalt. These dykes have been observed throughout the formation and are not restricted to any one flow.

A U-Pb (zircon) age of 202 ± 1 Ma (Early Jurassic) has been established for the pegmatitic gabbroic dykes (Hodych and Dunning, 1992) and provides a minimum age for the North Mountain Formation. The contact with the underlying Blomidon Formation is not exposed; however, siltstone close to the basalt appears to be metamorphosed and hydrothermally altered, consistent with a depositional contact.

Structure and Metamorphism of Cambrian to Early Devonian Rocks

Introduction

The Cambrian-Early Devonian stratified rocks (i.e. Meguma Group and White Rock and Torbrook formations) and Types I and II mafic sills were deformed during the Acadian Orogeny. This deformation resulted in regional-scale northeastward-trending folds with an axial planar cleavage and regional greenschist facies metamorphism (Taylor 1969; Smithingale, 1973). An apparent disconformity to local angular unconformity occurs between the Halifax and White Rock formations in the study area and similar observations have been documented in the Yarmouth area (e.g. Schenk, 1997). This pre-White Rock Formation deformation is interpreted to be minor and local in extent because contacts between these units are regionally conformable and folding of both units defines the first episode of regional deformation.

Folds

Previously published maps of the area showed that the dominant structures in the Cambrian-Early Devonian metamorphic rocks are regional-scale synclines in the Bear River and Hillgrove areas, separated by an anticline (Taylor, 1969; Smitheringale, 1973). Our observations do not support this earlier interpretation. Although stratigraphy is locally repeated within mapped units by mesoscale folds, regionally the mapped units systematically young from west to east with no apparent repetition (Fig. 2).

The character of regional folding varies throughout the mapped area and based on fold styles can be subdivided into three distinct structural domains. Domain I occupies most of the eastern part of the mapped area adjacent to the South Mountain Batholith and includes the White Rock and Torbrook formations. Domain II occupies the central part of the mapped area and includes the Bear River Member. Domain III comprises the western part of the area and includes the Acacia Brook and Bloomfield members of the Halifax Formation and the Goldenville Formation.

Domain I

A regional syncline was indicated in the Bear River area by Taylor (1969) and Smitheringale (1973), with the fold structure defined by repetition of the White Rock Formation in the area adjacent to the South Mountain Batholith. However, the southeastern limb of this fold was defined only on the basis of aeromagnetic contour patterns (Smitheringale, 1973, p. 41) and comparison with other synclines involving the White Rock and Torbrook formations to the northeast of the mapped area (e.g. Crosby, 1962; Smitheringale, 1973). In areas of fairly continuous outcrop (along Bear River and the exposed penstock trench) bedding on the northwestern limb of the 'syncline' steepens progressively toward the southeast, eventually becoming overturned and dipping to the northwest. Sedimentary 'way-up' structures in the contact aureole of the South Mountain Batholith are generally obliterated; however, lithologies appear to be more similar to those of the Torbrook Formation than the White Rock Formation. Hence, the existence of the 'Bear River Syncline' defined by Taylor (1969) and Smitheringale (1973) could not be confirmed in this study.

The structural data for this domain are consistent with a southeastward-dipping to overturned fold limb, with overturned poles to bedding plotting in the southeast quadrant of stereoplots (Fig. 4a). Cleavage is steep and strikes northeast, parallel to bedding (Fig. 4a). Intersection lineations are poorly developed, but plunge shallowly to the southwest (Fig. 4a). Only one mesoscopic fold was observed in the White Rock Formation.

Domain II

Folding within the Bear River member of the Halifax Formation is characterized by numerous mesoscale (metres to hundreds of metres in wavelength) folds which can be observed in roadcuts (Fig. 3b) and along stream sections. Similar folding was documented in this unit by Smitheringale (1973). Although local variation occurs in fold geometry, collectively, structural data for this area are systematic and indicate that folding is characterized by upright, horizontal folds trending northeast-southwest; stereoplots of poles to bedding (Fig. 4b) define a subvertical π girdle, indicating a subvertical fold profile plane; poles to cleavage (Fig. 4b) are steep, indicating that cleavage strikes roughly parallel to bedding and has a uniform trend throughout the area; bedding-cleavage intersection data (Fig. 4b) indicate that fold hinges plunge

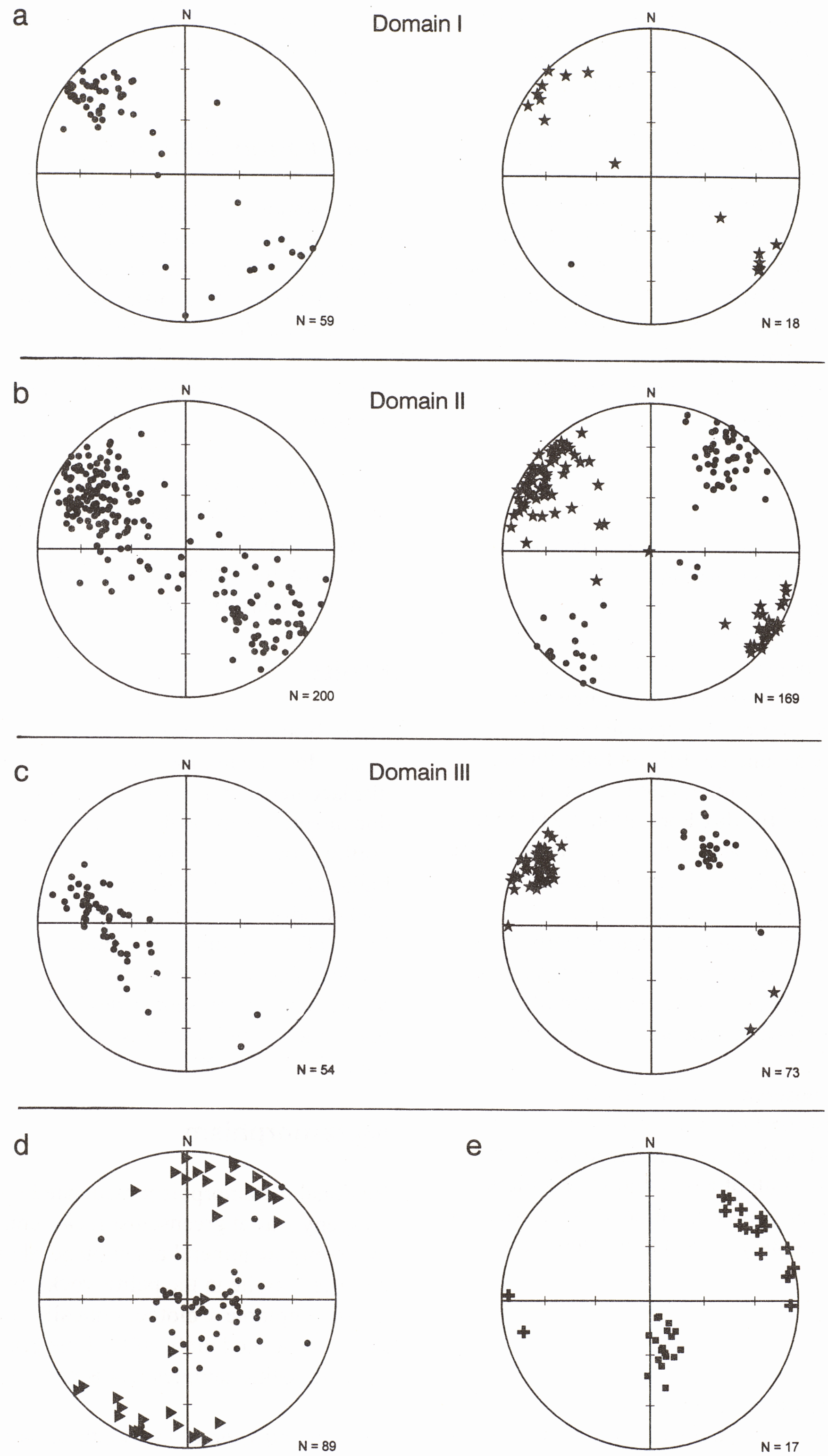

Figure 4. Equal area stereoplots of structural data for the Digby area. (a-c) Represent data for three structural domains defined within the area (see text); left streoplots represent poles to bedding, right stereoplots represent poles to cleavage (stars) and bedding-cleavage intersection lineations (filled circles). (d) Stereoplot of kink folds in the Digby area; filled triangles represent poles to axial planes and filled circles are fold hinges. (e) Stereoplot of crenulation cleavage data; crosses represent poles to crenulation cleavage (S_2) and filled squares represent crenulation lineation (L_2).

shallowly to the northeast and southwest. Structural data for the Type I sills parallel those for bedding and associated cleavage in the Bear River member.

The abundance of small-scale folds, general poor exposure, a lack of obvious vergence in mesoscale folds and the lack of stratigraphic marker horizons in the Bear River member inhibit construction of a cross-section through this unit. It is possible, and maybe probable, that the enveloping surface of mesoscale folds is shallow and that exposure of the Bear River member within the area represents only a thin stratigraphic interval. This interpretation is consistent with the uniform character of this unit over such a large area.

Domain III

Previous mapping in the Hillgrove area defined map patterns which implied a syncline in the Halifax Formation in the area, with the Goldenville Formation enclosing the southern part of the Ellison Lake Pluton and occurring along the southern part of the mapped area (Taylor, 1969). This interpretation is not, however, supported by our observations for several reasons. (1) Limited exposure around the Ellison Lake Pluton consists of spotted hornfels, interpreted here to represent contact metamorphosed Halifax Formation. (2) Bedding dips consistently to the east across the area, including the area underlain by the Goldenville Formation and the Bloomfield and Acacia Brook members (Fig. 4c). Bedding-cleavage relations and sedimentary structures indicate consistent, southeastward vergence (younging) across this section (Fig. 4c). (3) No repetition of stratigraphy was observed to support a regional fold.

Based on these observations, the Goldenville Formation and the Bloomfield and Acacia Brook members of the Halifax Formation in the mapped area form the southeastern limb of a regional scale anticline. Bedding-cleavage intersection lineation data indicate that the fold plunges moderately (~35°) to the northeast (Fig. 4c).

Kink Folds

Mesoscale kink folds are common in slaty units throughout the mapped area, especially in the Bear River member. These kink folds deformed both bedding and cleavage, with axial planes (S_2) typically west-northwestward-trending with steep fold hinges (Fig. 4d). Subhorizontal kink folds with shallow northeastward- and southwestward-plunging fold hinges (Fig. 4d) are also common, but these were not as often recorded in the field because of generally subhorizontal exposures.

Crenulation Cleavage

A crenulation cleavage (S_2) deforms axial planar cleavage related to regional folds (S_1) in the western part of the mapped area and is particularly well developed in the Bloomfield and Acacia Brook members, where this fabric is locally the dominant cleavage. A crenulation cleavage also occurs locally in the western part of the Bear River member and in slate intervals in the Goldenville Formation.

S_2 defines a systematic fabric which strikes south-southeast to north-northwest and dips steeply to the southwest (Fig. 4e). The crenulation lineation (L_2), defined by the intersection of S_1 and S_2, plunges steeply south-southeast (Fig. 4e).

Faults

Minor brittle faults are present throughout the mapped area. Most are not regionally significant, with small displacements of a few metres. Doyle (1979) documented both north-northeastward- and northwestward-trending, low-angle reverse and high-angle normal faults with vertical to steeply plunging slickensides. Horizontal slickensides are not common. Many of these faults were interpreted to be related to folding (Doyle, 1979); however, faults with similar orientations are present in the Mesozoic units and suggest that some of the faulting is post-Triassic (e.g. the Bear River Fault, Fig. 2).

Metamorphism

Regional metamorphism associated with the Acadian Orogeny was at greenschist facies conditions, with a peak metamorphic mineral assemblage of muscovite + chlorite + albite in the pelitic rocks and chlorite + albite + quartz ± epidote ± biotite, typically with abundant calcite, in the associated mafic sills. Fine grained biotite occurs in some pelitic samples, but is not common.

The intrusion of the South Mountain Batholith and Ellison Lake Pluton produced well-developed contact metamorphic aureoles that are superimposed on regional greenschist-facies mineral assemblages and textures. The first evidence of contact metamorphism in the pelitic rocks is the development of small, randomly oriented decussate biotite and muscovite grains in spotted slates. Original sedimentary structures are still well preserved. The mineral assemblage in these rocks are characteristic of the albite-epidote hornfels facies (e.g. Yardley, 1989). Closer to the intrusions, within a zone approximately 1000 m from the exposed contacts, cordierite and locally andalusite are developed and the rock displays a hornfelsic texture (Mahoney, 1996). Immediately adjacent to the intrusions andalusite is more abundant than cordierite and the rocks locally display a gneissic texture. The mineral assemblage in this part of the contact aureole is characteristic of the hornblende-hornfels facies (e.g. Yardley, 1989). This facies forms the greater part of the outcrop width of the aureole and continues up to the intrusive contacts. Better defining the contact metamorphism in the Bear River area is currently the subject of a B.Sc. honours thesis at Acadia University, Wolfville by Brian Campbell.

Economic Geology

Minor metallic mineral showings occur throughout the mapped area (Fig. 2). Pyrite and, locally, arsenopyrite commonly occur along bedding, fractures, and veins in many of the sedimentary rocks and sills in the Halifax, White Rock and Torbrook formations. Some veins contain arsenopyrite, chalcopyrite and pyrite with rare jamesonite, pyrrhotite, sphalerite and stibnite. These veins also have anomalous gold values (Nova Scotia Mineral Occurrence Database). Iron ore was mined (Wright, 1975) from hematite and magnetite rich layers in the Torbrook Formation. Minor chalcopyrite, chalcocite and malachite occur as stringers in the North Mountain Formation. Magnetite locally occurs finely disseminated in the basalt or concentrated in lenses, veins and along fractures. Zeolite minerals are common in vesicles and veins in the basalt. Kaolinite has been noted in sandstones along the contact between the basalt and the underlying Blomidon Formation (Nova Scotia Mineral Occurrence Database). A reported vanadium and chromium occurrence in the basalt was not verified (Nova Scotia Mineral Occurrence Database). Minor showings of clay, bog iron, and placer ilmenite and magnetite occur throughout the area.

In many localities in the Halifax Formation and a few in the North Mountain Formation the rocks are quarried for crushed stone and a few of the many sand and gravel deposits are presently being exploited. Many of the larger gabbroic Type II sills have potential as building stone.

Discussion and Preliminary Conclusions

The overall stratigraphy in the mapped area is broadly comparable to that documented elsewhere in the Meguma Zone (e.g. Crosby, 1962; Smitheringale ,1973). A significant contribution provided by this project to the understanding of the Meguma Group in the area is the subdivision of the Halifax Formation into three lithologically discrete members. The Bloomfield member represents the lowest unit and together with the overlying Acacia Brook member marks the transition from the Goldenville Formation to the Halifax Formation. The Bear River member represents the uppermost unit in the Halifax Formation and is characterized by abundant metasiltstone and metasandstone layers. The Bear River member contains earliest Tremodoc (Lower Ordovician) fossils, which suggests that the Acacia Brook and Bloomfield members, together with the Goldenville Formation may be Cambrian in age.

The Bloomfield and Acacia Brook members display lithologic similarities to the Moshers Island Member (Waldron, 1992; Schenk, 1995a, 1997) in the Mahone Bay area (Fig. 1). In the Mahone Bay area the Moshers Island Member is conformably overlain by sulphide-rich black slate of the Cunard Member (Waldron, 1992; Schenk, 1995a, 1997). Such sulphide-rich black slate is not present in the Bear River map area. The Bear River member may be a facies-equivalent unit to the Cunard Member, but the presence of the graptolite *Rhapdinopora flabelliforme* suggests that it is more similar to the younger Feltzen Formation of the Meguma Group (Schenk, 1997). The apparent lack of the Cunard Member, which is regionally extensive elsewhere in the Meguma Group (Waldron, 1992; Schenk, 1995a, 1997; Horne *et al.,* 1997), could reflect lateral facies variations or tectonic removal along a possible fault coincident with Acacia Brook.

Fossils in the upper part of the White Rock Formation indicate a Silurian age for most, if not all, of the formation. This age suggests a considerable time gap between the top of the Halifax Formation (Lower Ordovician) and deposition of the White Rock Formation, supporting the presence of an unconformity between the Halifax and White Rock formations in the area. The Torbrook Formation contains Early Devonian fossils and is in gradational contact with the underlying White Rock Formation.

Two prominent sets of mafic sills are present. Type I sills are restricted to the Meguma Group and are inferred to be penecontemporaneous with their host rocks and therefore Cambrian to Early Ordovician in age. Type II sills intruded the Meguma Group, White Rock and Torbrook formations, but predated the South Mountain Batholith, therefore they are Early to Middle Devonian in age. Based on limited data, both sets were interpreted to be tholeiitic transitional to alkalic, with the older sills more alkalic in character, and speculated to have been emplaced in a continental within-plate environment (Barr *et al.,* 1983). However, additional geochemical studies are required to verify these earlier results.

In contrast to Taylor (1969) and Smitheringale (1973), our mapping suggests that there is no repetition of stratigraphic units across the mapped area. Regional scale folding is characterized by a moderate to steep, eastward-dipping limb in the west (Domain III), a complexly folded middle zone representing a shallow, buckled limb (Domain II) and a moderately to steeply (locally over-turned), southeastward-dipping limb in the east (Domain I). The observed folding and distribution of map units may represent a regional monocline or the eastern limb of a regionally significant anticline. An added complexity in this model is the possible presence of a fault between the Acacia Brook and Bear River members of the Halifax Formation. A pronounced topographic linear feature marks this boundary, together with well-developed crenulation fabrics and a modest change in fold geometry (compare Figs. 4b and 4c) across this feature.

Kink folds and crenulation fabrics clearly define post-Acadian deformation, overprinting axial planar cleavage related to regional folds, and may be related to Middle Carboniferous deformation documented along the coastal section between Yarmouth and Meteghan (Culshaw and Liesa, 1997; Fig. 1). Culshaw and Liesa (1997) were able to define distinct shear zones along the coast, where exposure is excellent. Within the mapped area, definition of distinct shear zones is inhibited by poor exposure. However, the most intense crenulation development is confined to the Acacia Brook and Bloomfield members (Fig. 2), and, as noted above, may be related to a fault between the Acacia Brook and Bear River members. A shear zone in this area could represent along-strike extension of the shear zones in the Yarmouth Syncline (Fig. 1) defined by Culshaw and Liesa (1997) and Keppie and Dallmeyer (1995). Recognition of post-Acadian deformation in the mapped area supports the prediction of Culshaw and Liesa (1997) of inland extension of the deformation that they defined along the coast.

Mesozoic units unconformably overlie the Cambrian-Early Devonian metamorphic units and are tilted to the northwest.

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