# Preliminary Geology of the Antigonish Highlands, Northern Mainland Nova Scotia

*C. E. White*

## Introduction

Bedrock mapping continued through the summer of 2011 in the Antigonish Highlands (Highway 104 to Malignant Cove) in northern mainland Nova Scotia (Fig. 1). This work completed the bulk of bedrock mapping in the Antigonish Highlands Mapping Project, with the exception of the northernmost part (Georgeville block of Murphy *et al*. 1991). Background information on the goals of this project, a summary of previous geological investigations in the area, methodology, and preliminary results from the southern Antigonish Highlands (Cobequid-Chedabucto Fault to Highway 104) were summarized by White *et al*. (2011). This report combines those results with the new work in 2011 to present a revised interpretation of the geology for the entire highlands (Fig. 2). It also incorporates changes in the distribution of units in the southern highlands, which resulted from student thesis projects by Archibald (2012) and MacFadzen (2012). The new map leads to enhanced understanding of the stratigraphy, structure, metamorphism, age and economic potential of the Antigonish Highlands.

## Field Relations and Map Units

### Introduction

Many of the volcanic, sedimentary and plutonic units recognized in the southern Antigonish Highlands can be traced into the northern highlands, including the Late Neoproterozoic Georgeville Group and related plutonic units, Late Neoproterozoic Bears Brook formation, and the Silurian Arisaig Group. However, several additional stratigraphic units occur in the northern

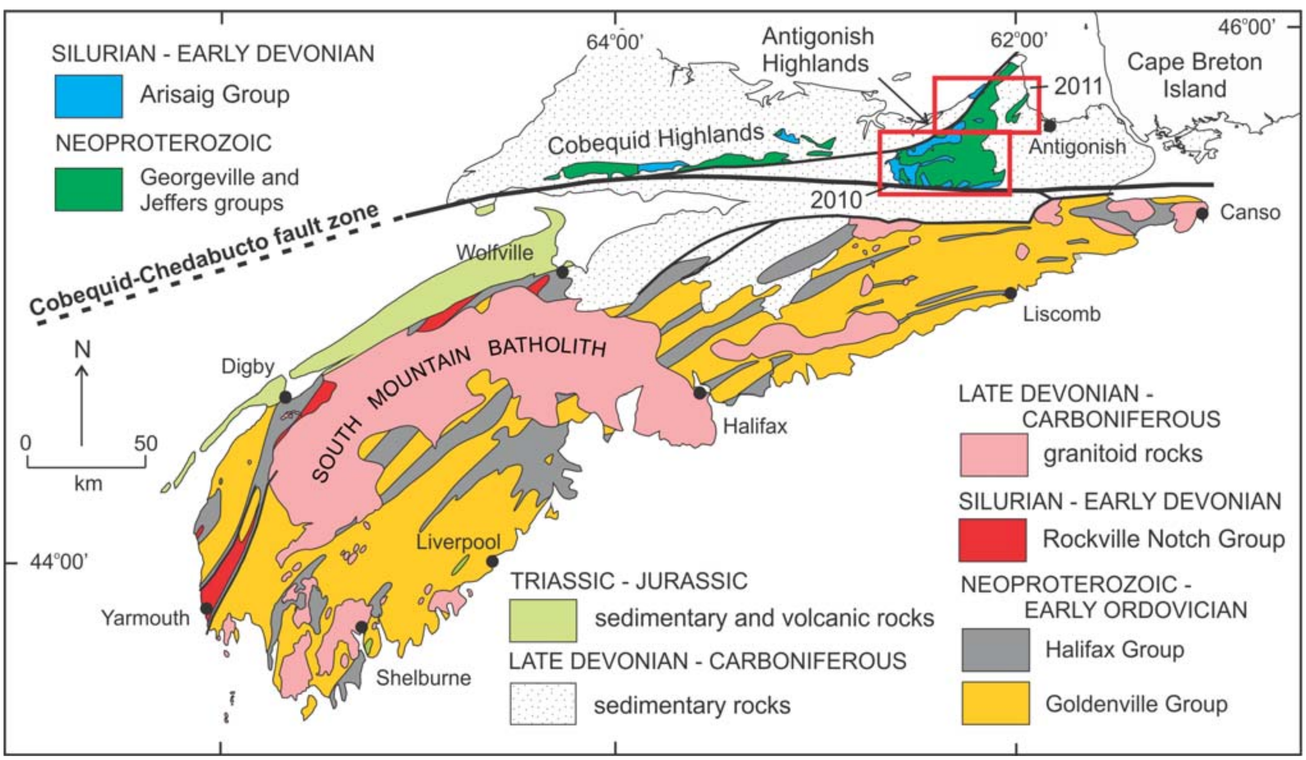


**Figure 1**. Simplified geological map of southern Nova Scotia, showing the location of the 2010 and 2011 map areas (red boxes) in the Antigonish Highlands.

White, C. E. 2013: *in* Mineral Resources Branch, Report of Activities 2011; Nova Scotia Department of Natural Resources, Report ME 2012-001, p. 75-91.

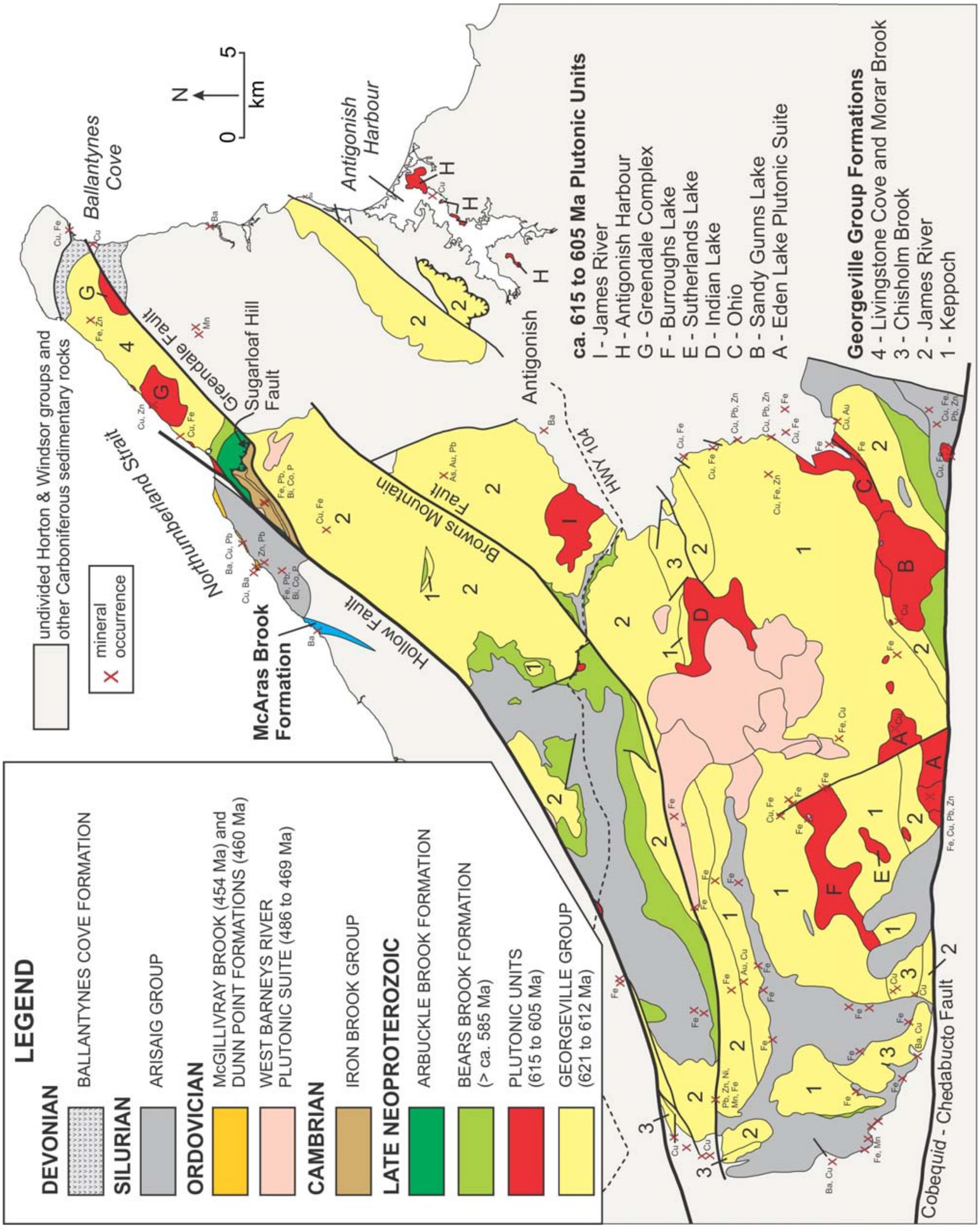


**Figure 2**. Simplified geological map of the Antigonish Highlands based on White *et al*. (2011) and the results presented in this report.

highlands, some previously recognized and some new (White and Barr, 2012; White *et al*., 2012). Previously recognized units include the Cambrian to Ordovician Iron Brook and McDonalds Brook groups of Murphy *et al*. (1991) and Horton Group-equivalent units of Benson (1974) and Keppie *et al*. (1978), although their distribution and age have been revised. As in the southern highlands, previous unit names are retained insofar as possible; however, follow-up studies of geochronology, geochemistry and petrography are likely to necessitate further changes in terminology.

## Stratigraphic Units

### *Keppoch Formation*

The Keppoch Formation of the Georgeville Group (Murphy *et al*., 1991) makes up the core of the southern Antigonish Highlands but is limited in its distribution in the northern highlands (Fig. 2). In both areas the formation consists of pink to grey, rhyolitic to dacitic lapilli tuff with abundant crystal and lithic fragments. Locally, outcrops display well defined flow banding. Varied gabbroic, and to a lesser extent granitic, porphyry dykes and sills are common. An indication of the age of the Keppoch Formation is given by a U-Pb zircon age of 618 ± 2 Ma reported by Murphy *et al*. (1997) for a rhyolite "flow" in the southern highlands. The dated unit was re-interpreted to be a high-level granitic porphyry dyke or sill by White *et al*. (2011) and, if so, provides a minimum age for the formation.

### *James River Formation*

The James River Formation is the most widespread unit in the Georgeville Group (Fig. 2). It consists of light green to green-grey to locally maroon, well laminated to thinly bedded, cherty siltstone (Fig. 3a), locally interbedded with minor grey to red fine- to coarse-grained sandstone and minor rhyolitic lapilli tuff. Granule to pebble conglomeratic beds are locally common (e.g. Murphy *et al*., 1991) but generally have a re-worked volcanogenic appearance. Brown carbonate-rich sandstone beds with rip-up clasts noted in the southern highlands were not observed in the north. Murphy *et al*. (1991) assigned different formation names (South Rights, Clydesdale, James River and Maple Ridge) to rocks of this unit in different geographical areas of the highlands, largely based on differences in sedimentary characteristics. However, during the present study the distinctions among these formations were not recognized consistently and hence all are assigned to a single formation, James River, following White *et al*. (2011). The James River Formation forms the flanks of the southern highlands and the core of the northern highlands (Fig. 2). The contact with the underlying Keppoch Formation is conformable and gradational over 5 to 100 m (Murphy *et al*., 1991; White *et al*., 2011). Other than laminations, rare slump folds and graded bedding, sedimentary structures are not common. This unit was interpreted previously to represent a marine turbidite fan deposit (e.g. Murphy *et al*., 1991). However, the lack of sedimentary structures typical of Bouma (1962) sequences and the presence of abundant volcanic and volcanogenic rocks suggest instead deposition in a shallow restricted basin environment. It is similar to units elsewhere in the Avalon terrane, which are interpreted to be caldera lake-fill deposits (e.g. Barr *et al*., 1996; Barr and White, 1999). Fine- to coarse-grained gabbroic sills and dykes are common in the James River Formation.

### *Chisholm Brook Formation*

The type locality for the Chisholm Brook Formation is located in the Georgeville block (Murphy *et al*., 1991), not yet mapped in the current study. However, a package of green, amygdaloidal basaltic flows and lapilli tuff, interlayered with grey, well laminated cherty siltstone and rare quartzite in the southern Antigonish Highlands (Fig. 2) was assigned to that formation by White *et al*. (2011) based on its similarity to the type locality described by Murphy *et al*. (1991). The Chisholm Brook Formation is interpreted to be a lateral equivalent of the James River Formation (White *et al*., 2011). Varied gabbroic dykes and sills are common, as in the other formations described above.

### *Morar Brook and Livingstone Cove Formations*

As for the Chisholm Brook Formation, the type areas for the Morar Brook and Livingstone Cove formations as defined by Murphy *et al*. (1991) are located in the Georgeville block (Fig. 2). In that area the Morar Brook Formation conformably overlies the Chisholm Brook Formation and is in turn conformably overlain by the Livingstone Cove Formation (Murphy *et al*., 1991). Where observed during reconnaissance work in the Georgeville block as part of the present project, the Morar Brook Formation consists of dark grey, laminated cherty siltstone similar to that in the James River Formation; however, it also contains limestone and conglomeratic beds (Figs. 3b, c). The conglomerate beds consist of well rounded volcanic, sedimentary and granitic clasts and do not have the 'volcanogenic' appearance characteristic of the conglomerate layers in the James River Formation.

Rocks of the Livingstone Cove Formation were not observed during the present study, but according to Murphy *et al*. (1991) the formation consists mainly of conglomerate. Detrital zircon U-Pb ages from the Livingstone Cove Formation range from 621 to 612 Ma (Keppie *et al*., 1998), providing a maximum age for deposition.

***Bears Brook Formation***

The Bears Brook Formation of Maehl (1961) crops out mainly along the northern flank of the southern highlands and the western flank of the northern highlands (Fig. 2). The formation consists of red to red-brown to maroon conglomerate and arkosic sandstone and siltstone with minor grey cherty siltstone and tuff (Fig. 3d), as described in more detail by White *et al*. (2011). The contact with the underlying James River Formation appears to be conformable. The maximum age of the formation is 593 ± 10 Ma, based on the U-Pb age of the


**Figure 3**. (a) Thinly to thickly bedded "cherty" siltstone from the James River Formation. Thick bed in centre of photograph is about 20 cm wide. (b) Marble and calc-silicate rock (dark) of the Morar Brook Formation. (c) Conglomerate in the Morar Brook Formation. (d) Conglomerate and arkosic sandstone in the Bears Brook Formation.

youngest detrital zircon reported by Murphy *et al*. (2004a).

The Malignant Cove Formation (name now abandoned), previously included in the basal part of the Cambrian succession in the northern Antigonish Highlands, is here interpreted to be part of the Bears Brook Formation (Fig. 2), based on similarity in lithologies and the presence of detrital zircon grains no younger than 585 ± 5 Ma (Murphy *et al*., 2004b), the same age within error as the youngest zircon grain in the Bears Brook Formation as noted above. The minimum age is constrained by the Early Silurian age of the Arisaig Group, which unconformably overlies the Bears Brook Formation.

***Iron Brook Group***

The Iron Brook Group is exposed in a small area in the northern Antigonish Highlands bounded by the Hollow Fault on the northwest, Greendale Fault on the south, and the Sugarloaf Hill Fault on the northeast (Fig. 2). Murphy *et al*. (1991) subdivided the Iron Brook Group into three units (from oldest to youngest): (1) Black John Formation, (2) Little Hollow Formation, and (3) Ferrona Formation. These units are retained in the current work but are modified.

The lowermost unit of the Black John Formation is red to red-brown arkosic conglomerate and siltstone that sits with apparent angular unconformity on strongly foliated red to pink rhyolitic to dacitic lithic tuff. The tuffaceous rocks dip southeast at 70–75°, whereas the overlying conglomerate and siltstone dip northwest at 75–85° and are right-way-up. The volcanic rocks were previously included in the Black John Formation (Landing and Murphy, 1991; Murphy *et al*., 1991), but because of the presence of an angular unconformity, the volcanic rocks are re-interpreted to be part of the James River Formation. These strongly foliated volcanic rocks mark the location of the Greendale Fault (Fig. 2).

Upsection in the Black John Formation, the conglomeratic beds become thinner and red to grey siltstone predominates. Near the top of the unit the red siltstone is interbedded with black slate, and minor quartz arenite. Landing and Murphy (1991) abandoned the “Black John Formation” designation and assigned this succession to the Rencontre, Chapel Island, Random and Cuslett formations. However, these units are not mappable based on the available outcrops and hence the name Black John Formation is retained for the whole sequence. Microfossils collected from near the top of the formation are similar to fossils in the Lower Cambrian Chapel Island Formation in Newfoundland (Landing and Murphy, 1991). Preliminary results from acritarchs in samples from the same locality in the Black John Formation also suggest a similar age (S. Jenson, written communication, 2012).

The Little Hollow Formation is conformable with the underlying Black John Formation and consists of red to pink siltstone, slate and fossiliferous vuggy limestone (Fig. 4a). The red siltstone is similar in appearance to that in the underlying Black John Formation. In drill core from the Doctors Brook area, the upper red limestone and slate were reported to be interbedded with carbonate-rich tuff (Ells, 2007), but more detailed petrographic descriptions were not provided. Trilobites, brachiopods and microfossils have been recovered from the limestone and are assigned to the late Early Cambrian *Callavia* Zone (Landing *et al*., 1980).

The overlying Ferrona Formation appears to be lithologically heterogeneous. In places, the lowest unit consists of grey, thinly bedded siltstone and fine-grained micaceous quartz arenite that conformably overlie pink limestone of the Little Hollow Formation. From drill core descriptions (e.g. Ells, 2007), the basal units of the Ferrona Formation consist of “quartzite” interbedded with ironstone and grey to red siltstone. The same lithologies were observed in the old ironstone exploration trenches (Fig. 4b), but there some of the ironstone is hosted in pebble- to cobble-conglomerate and arkosic sandstone interlayered with quartz arenite (quartzite of Murphy *et al*., 1991 and Ells, 2007), limestone and pumice-rich lithic tuff. Upsection, grey micaceous sandstone and siltstone are predominant, with rare lithic tuff beds. No ironstone beds were observed upsection. Many of the ironstone beds contain fragmentary inarticulate brachiopods identified as *Obolus (lingulobus) spissa* and *Lingulella*? sp., which are probably of Early Ordovician age (Williams, 1914; Landing and Murphy, 1991; Murphy *et al*., 1991).

Benson (1974) and Murphy *et al*. (1991) showed a small inlier of Silurian Beechill Cove Formation lying unconformably on the Cambrian-Ordovician rocks. However, these grey micaceous sandstone and siltstone beds are identical to those associated with the ironstone. In addition, they are cut by fine-grained gabbroic sills not seen anywhere in Silurian units of the Antigonish Highlands (see below). The Silurian age was assigned by Benson (1974) based on the presence of brachiopods and crinoids, but according to Benson (1974, page 75) these fossils collected in Iron Brook were "indeterminate" and no species name was assigned. In addition, Benson (1974) noted that his collection of brachiopods associated with the Iron Brook Group ironstone beds were also indeterminate. Therefore, based on field observations noted above, the previously mapped Silurian strata in this area are here included in the upper part of the Ferrona Formation.

### *Arbuckle Brook Formation*

The Arbuckle Brook Formation consists of basaltic to dacitic lithic tuff, cherty siltstone and basalt flows that locally display hyaloclastic texture. It was previously included in the upper part of the McDonalds Brook Group (Landing and Murphy, 1991; Murphy *et al*., 1991) and divided into a lower member consisting of rhyolite and conglomerate, and an upper member characterized by mafic volcanic rocks and Cambrian sedimentary rocks. Parts of the lower member are now included in the Bears Brook Formation (see above), whereas the upper part constitutes most of the Arbuckle Brook Formation as defined here. The lower contact of the Arbuckle Brook Formation with the Little Hollow Formation was observed in several places and is brecciated by a low-angle fault. Based on these observations and the presence of cherty siltstone similar to those in the James River Formation, the Arbuckle Brook Formation is currently considered to be Late Neoproterozoic. However, based on the presence of similar volcanic rocks observed during this study in the Ferrona Formation, the Arbuckle Brook Formation could be as young as Ordovician. Additional mapping is required in this area to clarify these relationships.

### *Dunn Point and McGillivray Brook Formations*

The Dunn Point and McGillivray Brook formations in the northern Antigonish Highlands are well exposed along the shoreline of the Northumberland Strait, and are not recognized to occur elsewhere (Fig. 2). They consist of rhyolitic and basaltic flows and lithic tuff interbedded with conglomerate, sandstone and minor shale (Fig. 4c, d). Two samples from rhyolitic flows in the Dunn Point and McGillivray Brook formations yielded U-Pb ages of 460 ± 3.4 Ma and 454 ± 0.7 Ma, respectively (Hamilton and Murphy, 2004; Murphy *et al*., 2012). Based on its radiometric age, a 10 million year gap appears to exist between the McGillivray Brook Formation (ca. 454 Ma; Murphy *et al*., 2012) and the overlying Silurian (<ca. 443 Ma) Arisaig Group. However, in the section examined during the present study, the contact appears conformable.

### *Arisaig Group*

The Beechill Cove Formation is considered to be the lowermost unit of the Arisaig Group, consistent with Benson (1974) and Boucot *et al*. (1974). It consists of light grey, poorly to well sorted, fine- to coarse-grained, thinly to thickly bedded, quartz- to feldspathic arenite. Polymictic to quartz pebble conglomerate beds with abundant detrital muscovite are common. During this study, an angular unconformity to nonconformity was observed in several places between the Beechill Cove Formation and underlying rocks of the Bears Brook and James River formations.

The Ross Brook Formation conformably overlies the Beechill Cove Formation and consists of black to grey fossiliferous siltstone and shale. The overlying French River Formation consists predominantly of siltstone and minor shale. Benson (1974) showed the French River Formation to be conformably overlain by shale, siltstone, sandstone and minor limestone of the McAdam Formation (Fig. 5a), although Boucot *et al*. (1974) mapped the intervening Doctors Brook Formation, consisting

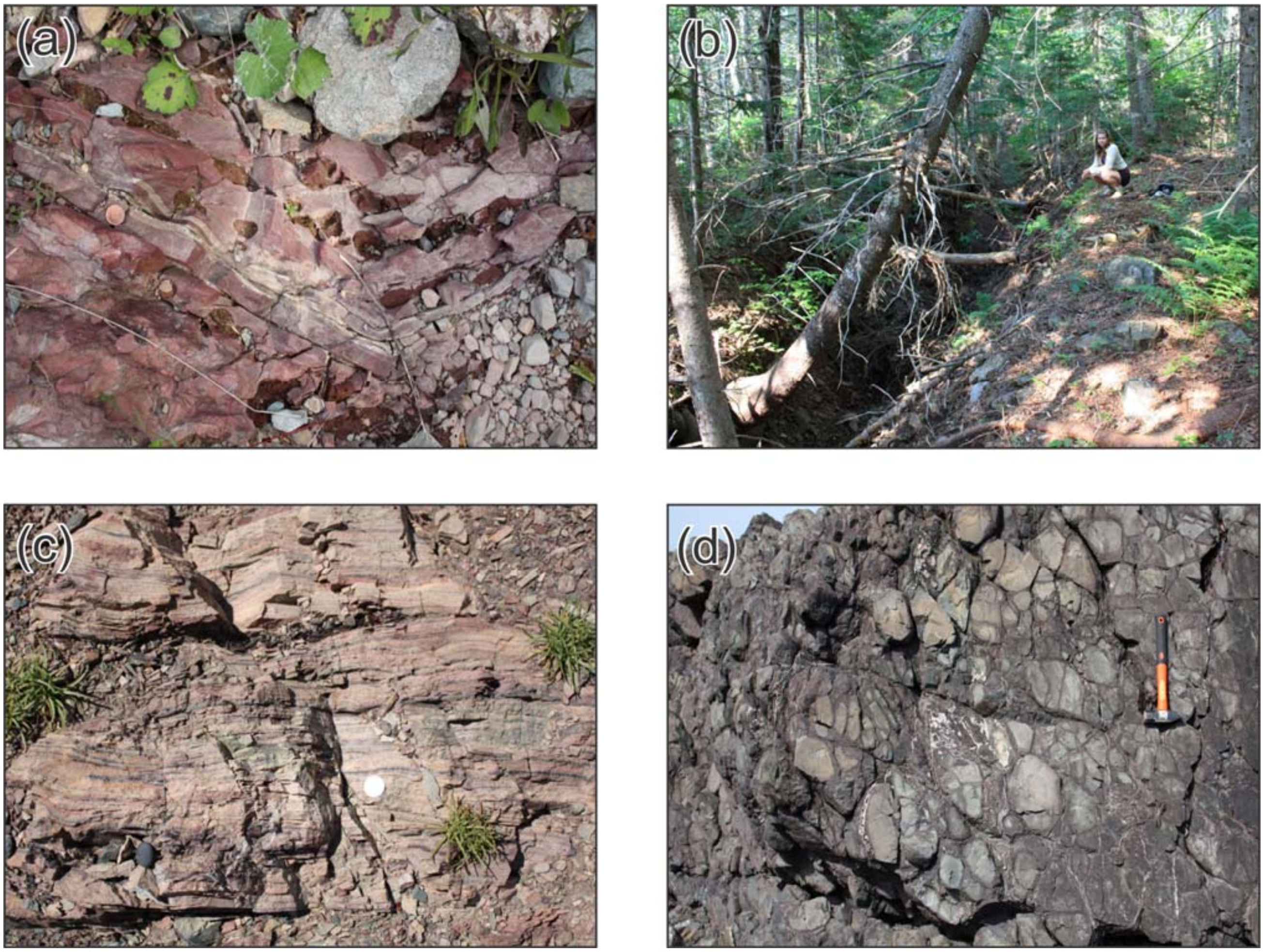


**Figure 4**. (a) Pink to red siltstone and limestone beds of the Little Hollow Formation. (b) Exploration trench in ironstone beds in the Ferrona Formation. (c) Flow-banded rhyolite in the Dunn Point Formation. (d) Pillowed basalt flow in the Dunn Point Formation.

of shale and carbonate nodules. Overlying the McAdam Formation is the Moydart Formation, which consists of a lower green mudstone and siltstone package and an upper red carbonate unit. The ironstone bed that was mined during the 1900s was included in the base of the McAdam Formation by Benson (1974), whereas Boucot *et al*. (1974) included the ironstone in the French River Formation. The current mapping could not distinguish between the two formations. In contrast to underlying units, no volcanic rocks, dykes, or sills were observed in the Arisaig Group anywhere in the Antigonish Highlands.

### *Late Devonian to Carboniferous Units*

Some parts of the Late Devonian to Carboniferous McAras Brook, Horton, Windsor and Mabou groups were mapped during this study (Fig. 2), and the locations of contacts have been slightly modified from previous maps and reports (e.g. Keppie *et al*., 1978; Giles, 1982; Boehner and Giles, 1982, 1993; Murphy *et al*., 1991). In addition, the succession of basalt and rhyolite flows interbedded with volcaniclastic conglomerate and minor shale in the northern Antigonish Highlands (Fig. 2) have been removed from the McAras Brook Formation of earlier workers and assigned a new name, Ballantynes Cove formation. Shale samples from this area previously yielded late Famennian palynomorphs (Keppie *et al*., 1978; Martel *et al*., 1993), and the associated rhyolite has yielded a U-Pb zircon age of 370 ± 1.5 Ma (Dunning *et al*., 2002). Hence, these rocks are Devonian, not Carboniferous. In contrast, the name McAras Brook Formation has been retained for basalt and interbedded sedimentary rocks in the McAras Brook area (Fig. 2). These rocks are considered to be Carboniferous based on the reported presence of a Late Visean spore assemblage collected just above the highest basalt unit (Barss, 1977). This interpretation is supported by the facts that (1) the sedimentary rocks in this formation are poorly indurated (Fig. 5b) compared to those in the Ballantynes Cove formation and (2) the basalts in the two formations display differences in texture and chemical characteristics (Pe-Piper and Piper, 1998).

## Plutonic Units

### *Late Neoproterozoic Plutons*

Field relations and ages of plutonic units in the southern Antigonish Highlands were summarized by White *et al*. (2011) and are only briefly reviewed here. Plutonic units in that area include the Late Neoproterozoic (ca. 592 Ma; K-Ar hornblende; Wanless *et al*., 1967) Eden Lake plutonic suite which consists of bodies of quartz diorite, tonalite (gradational to granodiorite), syenogranite and alkali-feldspar granite (Escarraga, 2010). The Sutherlands Lake pluton, farther to the northwest (Fig. 2), consists of grey, medium-grained quartz diorite similar to rocks of the Eden Lake plutonic suite and is likely of similar age. The ca. 615 Ma Lorne Station granite is cut by numerous fine-grained gabbroic dykes and is very similar to the granitic parts of the Eden Lake plutonic suite (White *et al*., 2011). The ca. 605 Ma Sandy Gunns Lake pluton consists of quartz diorite, alkali-feldspar granite and syenogranite (Escarraga, 2010). The quartz diorite and alkali-feldspar granite locally display co-mingling textures, indicating that they were comagmatic. The ca. 606 Ma Ohio pluton (Murray, 2011) is mainly a pink to pale grey, medium-grained granodiorite. All these units, except the Lorne Station granite, which forms an outlier surrounded by younger Carboniferous rocks, intruded the Georgeville Group (White *et al*., 2011).

The petrography and geochemistry of the Indian Lake pluton (Fig. 2) were studied by MacFadzen (2012), who showed that the pluton consists of a calc-alkaline suite of medium-grained quartz diorite and medium-grained monzogranite gradational to granodiorite and tonalite. Both the monzogranite-granodorite-tonalite and quartz diorite contain abundant cogenetic dioritic inclusions. The Indian Lake pluton is not reliably dated, but based on petrological similarities it is interpreted to be of similar age to the ca. 606 Ma Ohio pluton (MacFadzen, 2012). The Burroughs Lake pluton in the western part of the southern highlands (Fig. 2) consists mainly of pink to locally purple, feldspar to feldspar-quartz porphyry with crystals up to 1 cm in diameter. A nonconformable contact with the overlying Beechill Cove Formation of the Arisaig Group is well exposed at one location in a quarry. The pluton yielded a U-Pb (zircon) crystallization age of ca. 615 Ma (unpublished data). This age confirms that the rocks of the Keppoch Formation intruded by the pluton are Neoproterozoic (Fig. 2).

The James River pluton of Murphy *et al*. (1991) is located in the southern part of the northern Antigonish Highlands (Fig.2). It consists of pink, medium-grained monzogranite to granodiorite with rare enclaves of medium-grained quartz diorite. Near the western margin of the pluton, granite porphyry enclaves and miarolitic cavities are common. Locally the pluton appears to grade into flow-banded porphyritic rhyolite. It intruded the James River Formation (Fig. 2) and is unconformably overlain along its southeastern margin by the Horton Group (e.g. Boehner and Giles, 1993). Based on petrological similarities with the Ohio pluton, the James River pluton is considered to be Late Neoproterozoic.

In mapping the Carboniferous Antigonish Basin, Boehner and Giles (1982, 1993) recognized that areas of elevated topography along the southeastern shore of Antigonish Harbour are underlain by granite and microgranite, and used the term Antigonish Harbour pluton for these granitoid rocks. That name is retained here. The pluton consists of pink, medium- to coarse-grained, syenogranite to monzogranite with abundant miarolitic cavities and porphyritic granodiorite (Fig. 5c). It is cut by numerous aplitic dykes. In places pseudotachylite veins are common (Fig. 5d). The most southwestern body (Fig. 2) is more syenitic in composition than the rest of the pluton.

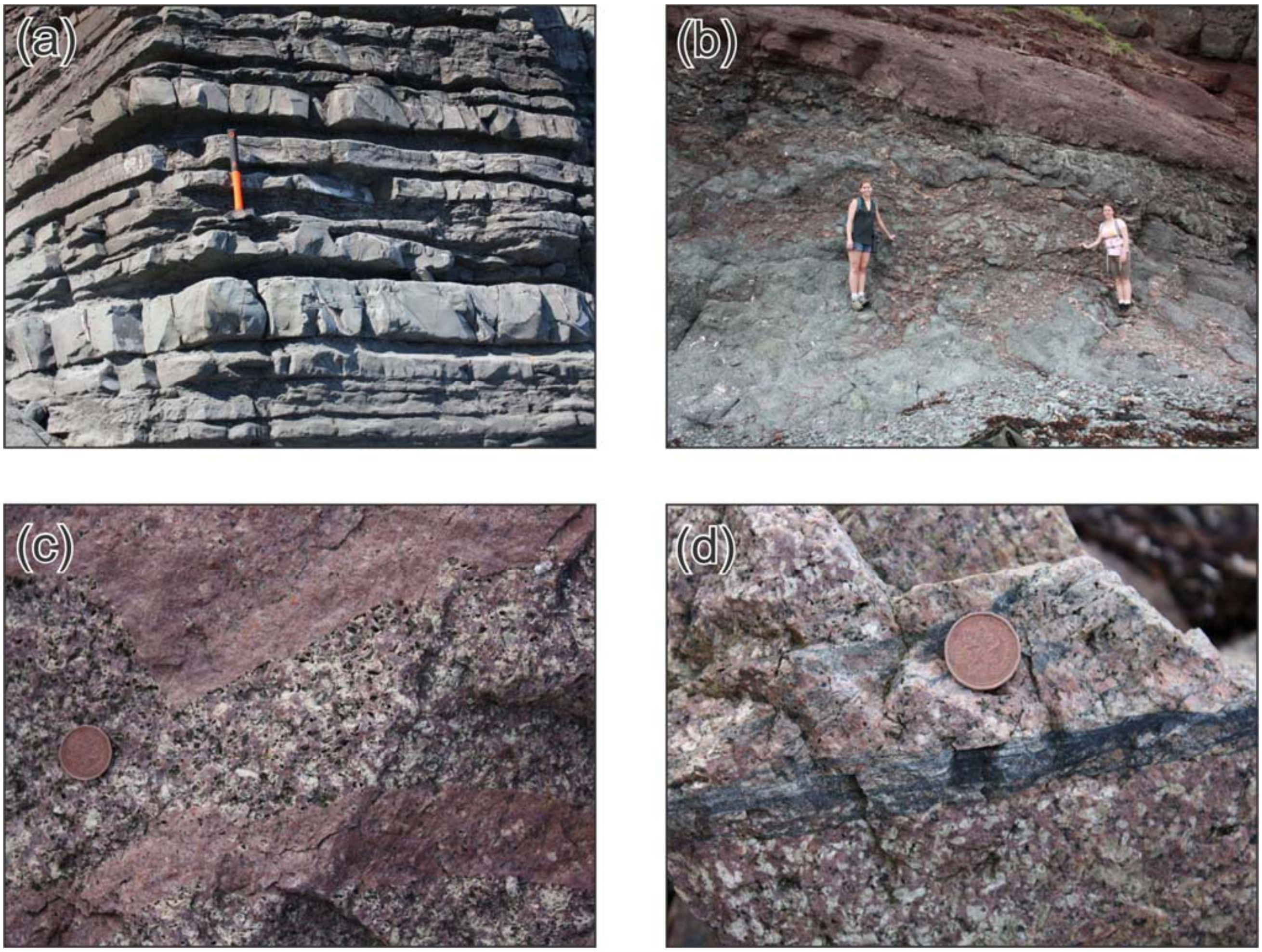


**Figure 5**. (a) Well bedded fine-grained sandstone (pale grey) and fossiliferous limestone (eroded layers) in the McAdam Brook Formation of the Silurian Arisaig Group. (b) Peperitic basalt and coarse-grained poorly sorted sandstone and conglomerate of the McArras Brook Formation. (c) Typical example of the porphyritic granodiorite in the Antigonish Harbour pluton cut by aplitic- to medium-grained syenogranite. (d) Pseudotachylite vein in porphyritic granodiorite in the Antigonish Harbour Pluton.

Rocks intruded by the plutons are not exposed. The plutons are overlain nonconformably by carbonate rocks of the Gays River Formation (e.g. Boehner and Giles, 1982). Zircon grains from the monzogranite yielded a preliminary U-Pb age of ca. 609 Ma (unpublished data).

The Greendale Complex of Murphy *et al*. (1991) is located in the Georgeville block and was not mapped in detail during the present study. Based on previous descriptions, it varies in texture from fine grained to pegmatitic and is composed of hornblende gabbro and minor leucogranite (Murphy *et al*., 1991, 1997). A pegmatitic sample previously yielded a U-Pb (titanite) age of 607 ± 3 Ma and an upper intercept age of 606.6 ± 1.6 Ma (Murphy *et al*., 1997). The Greendale Complex intruded the Morar Formation, based on the presence of large marble, calc-silicate, and metasiltstone xenoliths. Also present in the Georgville block is the small Georgeville pluton, a small (ca. 1.5 km across) epizonal body that is exposed along the shoreline of the Northumberland Strait to the northwest of the Greendale Complex. The pluton consists leucocratic, medium- to coarse-grained alkali-feldspar granite and pegmatite intruded by steep to moderately dipping aplite and pegmatite dykes. Intrusive contacts with the Georgeville Group host rocks are sharply defined, and the host rocks show development of spotted hornfels, which overprints regional tectonic fabrics. Many, but not all, geochemical and mineralogical features resemble A-type, within-plate granites. Muscovite yielded a $^{40}Ar/^{39}Ar$ plateau age of 579.8 ± 2.2 Ma, interpreted by Murphy *et al*. (1998) as the age of intrusion.

### *West Barneys River Plutonic Suite*

The West Barneys River plutonic suite (Fig. 2) consists of gabbroic rocks and medium- to coarse-grained syenite to alkali-feldspar granite, which crop out over an area of about 100 km$^2$ in the central part of the southern Antigonish Highlands. Based on the work of Escarraga (2010), Archibald (2012) and MacFadzen (2012), the suite is subdivided into five intermediate to felsic plutons (Laggan, Brora Lake, Leadbetter Road, Mount Adam and Haggarts Lake), two mafic plutons (Garden River and Duck Ponds), and a large, heterogeneous pluton (Poor Farm Brook composite pluton) that contains all of the rock types seen in the other plutons but too closely associated to be subdivided into separate bodies. Magma mixing and mingling textures indicate a co-magmatic relationship between the intermediate to felsic and mafic rocks. Intermediate to felsic rocks are mainly hypersolvus and in some cases show interstitial granophyre indicative of shallow emplacement. Geochemically, intermediate and felsic rocks are dominantly alkaline and have characteristics of within-plate, A-type granitoid suites (Archibald, 2012; Escarraga *et al*., 2012). Gabbroic rocks are dominantly inequigranular (locally porphyritic) and are transitional from tholeiitic to alkalic and have compositions characteristic of continental within-plate mafic rocks (Escarraga, 2010; Escarraga *et al*., 2012; Archibald, 2012). Additional U-Pb zircon dating has shown the suite ranges in age from ca. 485 to 465 Ma (unpublished data).

### *Other Syenitic Plutons*

A small body of fine- to coarse-grained syenite in the northern Antigonish Highlands is here named Mount MacDonald (Fig. 2). Coarse-grained granite with K-feldspar crystals rimmed by plagioclase appears to form dykes in the syenite. Based on the presence of xenoliths of cherty siltstone, the pluton it is interpreted to have intruded the James River Formation. Elsewhere in the northern highlands, smaller bodies and dykes of similar syenite intruded the James River Formation as well as Bears Brook Formation, Arbuckle Brook Formation and Iron Brook Group. A small, fault-bound syenite at Malignant Cove is considered also to be related to this suite. The absolute age of these syenitic rocks is unknown, but based on petrological similarities to the syenitic rocks in the West Barneys River plutonic suite they are likely to be Ordovician.

### *Dykes and Sills*

All of the pre-Silurian rock units of the Antigonish Highlands are cut by mafic and felsic dykes and sills. The mafic dykes range in texture from fine- to coarse-grained, depending on size, with well developed chilled margins. Some are porphyritic with phenocrysts of plagioclase. They range in composition from monzogabbro to gabbro to quartz gabbro but are mainly monzogabbro (e.g. Archibald 2012). The felsic dykes and sills are typically fine grained or porphyritic with phenocrysts of quartz and K-feldspar and less abundant plagioclase. They range in composition from alkali-feldspar granite to quartz syenite and monzogranite. Many of these dykes and sills appear similar to rock types present in the West Barneys River plutonic suite. Many of the sills were previously interpreted as flows and considered part of the stratigraphic sequence (e.g. Maehl, 1961; Murphy, 1987; Murphy *et al*., 1991), but their intrusive character is typically based on chilled margins and the presence of xenoliths of the host rocks.

# Deformation

## Introduction

The Antigonish Highlands is divided into three main structural zones. Zone 1 comprises the area north of the Cobequid-Chedabucto Fault and south of Highway 104 where the outcrop pattern defines a domal structure with the older rocks of the Keppoch Formation forming the core surrounded by the younger rocks of the James River, Chisholm Brook and Bears Brook formations (White *et al*., 2011). Zone 2 is the northern part of the Antigonish Highlands and comprises the area south of the Hollow Fault and north of Highway 104, whereas Zone 3 is in the extreme northern part of the Antigonish Highlands and comprises the area north of the Hollow Fault.

## South of the Hollow Fault and North of Highway 104

Poles to bedding orientation from the James River Formation south of the Hollow Fault and north of Highway 104 display considerable scatter but have a moderately developed girdle distribution indicating folding about a fold axis with a shallow plunge to the southwest (Fig. 6a). No minor folds were observed in the field. Poles to foliation are less scattered and reflect a steep, east-striking foliation (Fig. 6a). The (bedding/foliation) intersection lineations ($L_1$) are scattered in the James River Formation but generally plunge northeast or southeast at shallow to moderate angles (Fig. 6a). This set of structures is consistent with the regional northeasterly trend of the James River Formation. This scatter in bedding, cleavage and lineation data suggests that these structural features might have been re-oriented in a later event. A similar pattern is observed in the James River Formation in the southern highlands (White *et al*., 2011).

Few structural data were obtained from the Bears Brook Formation in the northern highlands compared to the south because of its limited distribution. Available data for bedding orientations have poles that form a cluster indicating that the average orientation strikes northeast with a moderate dip to the northwest (Fig. 6b). This is similar to the main cluster of bedding poles in the James River Formation (Fig. 6a) and suggests the Bears Brook and James River formations were folded together, a structural pattern similar the southern highlands (White *et al*., 2011).

Contoured poles to bedding in the Arisaig Group north of Highway 104 and south of the Hollow Fault define a moderately developed girdle distribution indicating a fold axis with a shallow plunge to the west (Fig. 6c). A similar pattern was obtained from bedding in the Arisaig Group in the southern Highlands (White *et al*., 2011), suggesting that all the rocks in the Arisaig Group south of the Hollow Fault were folded together. Poles to foliation in the north are axial planar, but based on the calculated girdle distribution of bedding appears to be slightly oblique to a ‘normal’ axial planar cleavage (Fig 6c). Intersection (bedding/ foliation) lineations ($L_1$) have shallow plunges to the west-southwest (Fig. 6c).

Bedding in the Iron Brook Group displays considerable scatter in orientation, although a plot of poles to bedding shows a moderately well defined girdle distribution, indicating a fold axis with shallow plunge to the southwest (Fig. 6d). Poles to foliations also display scatter, but a steep, northeast-striking, axial planar foliation is evident. Intersection (bedding/foliation) lineations ($L_1$) have shallow plunges to the southwest, similar to the calculated fold axis (Fig. 6c). Minor folds also have shallow southwest plunges (Fig. 6d).

## North of the Hollow Fault

On average, bedding in the Dunn Point and McGillivray Brook formations strikes east-northeast and dips about 75° to the south-southeast. Poles to bedding do not define a girdle distribution (Fig. 6e). The few poles to bedding in the southeastern quadrant are from vertical to overturned bedding observed in the field. This may indicate that these units were not folded or the formations are on the northwest limb of a regional syncline. The only minor folds observed are related to flow textures in the rhyolite.

In contrast, poles to bedding in the overlying Arisaig Group define a girdle distribution, indicating a fold axis with a shallow plunge to the southwest, although the majority of bedding measurements have a shallow dip to the south-southeast (Fig. 6f). These orientations are similar to the bedding in the underlying Dunn Point and McGillivray Brook formations but not as steep. The cleavage is not well defined, but where present it appears to be steep, northeast-striking and axial planar to the fold, indicated by the distribution of poles to bedding (Fig. 6f). Intersection (bedding/foliation) lineations ($L_1$) and minor fold axes are similar to the calculated fold axis and generally have a shallow plunge to the southwest (Fig. 6f). Taken together, the data suggest that the Dunn Point and McGillivray Brook formations, and the Arisaig Group north of the Hollow Fault, were folded together.

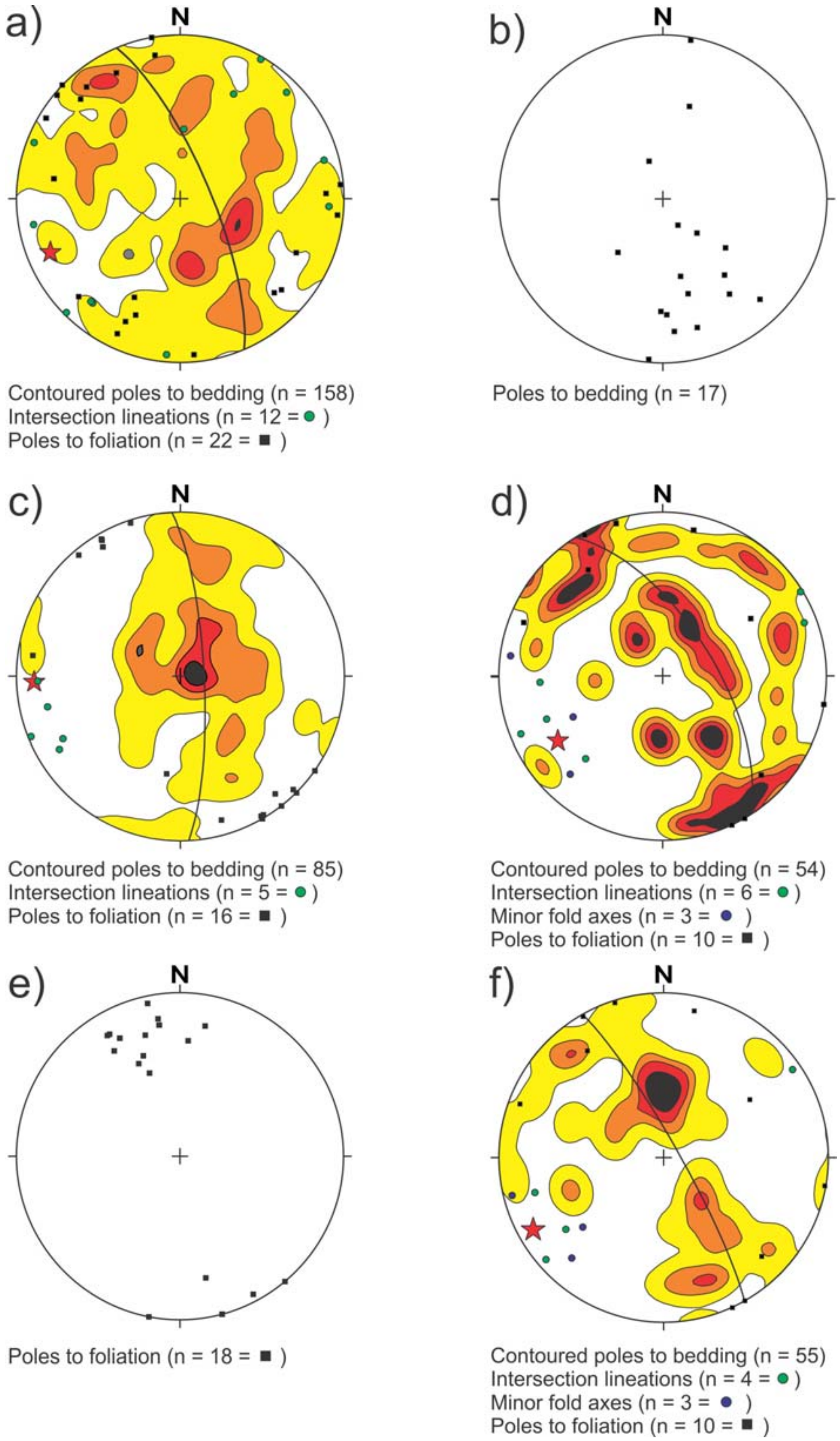


**Figure 6**. Equal-area stereonets of structural data from the map area. (a) Contoured poles to bedding in the James River Formation. (b) Poles to bedding in the Bears Brook Formation. (c) Contoured poles to bedding in the Arisaig Group south of the Hollow Fault. (d) Contoured poles to bedding in the Iron Brook Group. (e) Poles to bedding in the Dunn Point and McGillivray Brook formations. (f) Contoured poles to bedding in the Arisaig Group north of the Hollow Fault. Solid great circle shows average orientation of planar features and the red star shows the calculated average fold axis. Contours at 1, 3, 5 and greater than 7% per 1% area; darkest shading indicates highest contour area.

## Faults

As in the southern highlands, many of the faults previously defined in the northern highlands (e.g. Murphy *et al*., 1991) are re-interpreted as unconformities (contacts between older units and Silurian units) or have been removed from the map because of lack of evidence for their existence (Fig. 2). In contrast to some faults in the southern highlands, no mylonite or protomylonite zones were recognized on faults in the northern highlands. Four main faults are recognized: Browns Mountain Fault, Hollow Fault, Greendale Fault and Sugarloaf Hill Fault (Fig. 2), as described below.

The Browns Mountain Fault (Benson, 1974) is a vertical curvilinear feature that trends northeast across the central part of the map area (Fig. 2). It does not display a major topographic lineament but is defined by zones of highly fractured rock and breccia and is marked by a major change in aeromagnetic patterns (King, 2005). Although being a major fault, it does not juxtapose significantly different formations, as it is contained within the James River and Bears Brook formations. It has been interpreted to also mark a change in deformational style (Murphy *et al*., 1991), but this was not confirmed during this study. Murphy *et al*. (1991) argued that this fault was active in the Late Neoproterozoic. However, it also cuts the Windsor Group and younger (?) rocks (Fig. 2), suggesting significant post-Carboniferous movement. The tectonic significance or sense of movement of this fault remains unknown.

The Hollow Fault (Benson, 1974) is parallel to the Browns Mountain Fault, but lies farther to the northwest (Fig. 2). It is marked by a major topographical feature. On the northern side of the fault are rocks of the Carboniferous Mabou Group and Silurian Arisiag Group, whereas south of the fault are the Livingstone Cove and Morar Brook formations and related plutons, the Iron Brook Group, and the Arisaig Group (Benson, 1974; Murphy *et al*., 1991; White and Archibald 2011; White *et al*., 2011). Like the Cobequid-Chedabucto fault zone, this fault has been interpreted to be a major crustal feature (Murphy *et al*., 1991, 2001). The Hollow Fault is poorly exposed except where it intersects the coastline at Georgeville (Fig. 2). Based on field observations in that area, Murphy *et al*. (2001) suggested that the fault had significant Late Neoproterozoic dextral strike-slip movement but recognized evidence for repeated motion as young as Paleozoic.

The Greendale Fault (Murphy *et al*., 1991) is a splay of the Hollow Fault (Fig. 2). In places it is marked by considerable topographic relief where it separates the Late Neoproterozoic Livingstone Cove, Morar Brook, Bears Brook and Arbuckle Brook formations and related plutons, as well as the Cambrian to Ordovician Iron Brook Group on the north side of the fault from the James River Formation and Devonan to Carboniferous rocks of the Horton Group and Ballantynes Cove formation on the south (Fig. 2). The fault is poorly exposed except in new washouts along the fault scarp south of the Iron Brook Group. In this area the fault is a zone 100 m wide consisting of well cleaved rocks with cleavage striking northeast and dipping 70-75° to the southeast. No mineral/stretching lineation or kinematic indicators were observed. Clasts in the zone are flattened parallel to the foliation. Breccia zones, 1-2 m wide, are parallel to the foliation.

Sugarloaf Hill is a new name for a low-angle fault that is well exposed on the slopes of Sugarloaf Hill, where volcanic rocks of the Arbuckle Brook Formation are topographically higher than the rocks of the Little Hollow Formation (Fig. 2). The Arbuckle Brook Formation is in the hanging wall and the Iron Brook Group is in the footwall. It is marked by a zone of friable basaltic tuff and breccia of the Arbuckle Brook Formation and sheared red limestone of the Little Hollow Formation of the Iron Brook Group. No kinematic indicators were observed. Although thrust faults were previously recognized in the area (e.g., Murphy *et al*., 1991), volcanic rocks of the Arbuckle Brook Formation were interpreted previously to be interlayered with limestone of the Little Hollow Formation (Landing and Murphy 1991; Murphy *et al*., 1991).

## Metamorphism

Regional metamorphism throughout the Antigonish Highlands is low grade, up to a maximum of chlorite zone of the greenschist facies. The metamorphic mineral assemblage is chlorite + white mica + albite + epidote in the pelitic rocks. Intrusion of the Barneys River plutonic suite produced a narrow, poorly preserved contact metamorphic aureole that is superimposed on regional greenschist-facies mineral assemblages and textures. In the aureole, rounded cordierite grains are present, and the groundmass texture is hornfelsic (White *et al*., 2011; Archibald 2012). A thin contact metamorphic aureole with cordierite spots also was observed at the margin of the James River Pluton. No higher grade contact metamorphic minerals were observed. The presence of cordierite is characteristic of the hornblende-hornfels facies of metamorphism (e.g. Yardley, 1989).

## Economic Geology

The Antigonish Highlands has an early history of iron mining and exploration for copper, lead and zinc. Other than the iron, no economic value was placed on the area. A summary of the mining history is provided by White *et al*. (2011). The Nova Scotia Department of Natural Resources Mineral Occurrences Database for NTS map sheets 11E/09, 11E/16, 11F/12 and 11F/13 contains a complete summary of mineral occurrences and former mines in the map area.

Mapping during 2011 in the northern highlands confirmed many of the earlier mineral occurrences and indicated some previously unreported occurrences (Fig. 2). A previously unreported occurrence of chalcopyrite and malachite was observed in thin (1-3 cm wide) pseudotachylite veins in the Antigonish Harbour pluton. Analyses of these samples, using a portable X-5000 XRF (portable XRF) manufactured by Innov-X, yielded anomalous copper concentrations (up to 8750 ppm) with small amounts of zinc (up 167 ppm). The age of the pseudotachylite and associated mineralization is unknown.

Analyses of ironstone samples from the Iron Brook and Arisaig groups (Fig. 7), using the portable XRF, yielded anomalous levels of bismuth (512 ppm), cerium (335 ppm), cobalt (200 ppm), vanadium (283 ppm), lead (475 ppm) and phosphorous (up to 32 500 ppm). Although most of the ironstone in the Iron Brook Group yielded consistent lead and cobalt levels, some ironstone beds in the Arisaig Group yielded lead and cobalt concentrations up to 2900 and 450 ppm, respectively.


**Figure 7.** Rock slabs displaying various textures in the ironstone beds. (a, c, and d) Samples from the Iron Brook Group. (b) Sample from the French River Formation (Arisaig Group).

Also important is the occurrence of anomalous zinc levels (up to 3000 ppm) in the syenitic and gabbroic rocks in the northern highlands. These rocks are likely related to the West Barneys River plutonic suite, which also contains high zinc (White *et al*., 2011). Along with the elevated Zn, the syenitic and gabbroic rocks are relatively high in Ba, Ga, Zr, Y and V (unpublished data, portable XRF)

Rocks of the northern highlands continue to be a local source of aggregate, especially the cherty siltstone in the James River Formation.

## Summary

Detailed 1:10 000 scale bedrock mapping has greatly enhanced the understanding of the geology in the Antigonish Highlands. The James River and Bears Brook formations in the southern Antigonish Highlands are present also in the northern highlands. In the southern highlands, U-Pb data show that the Burroughs Lake pluton has an age of ca. 615 Ma, consistent with the Neoproterozoic age inferred for its host rocks of the Keppoch Formation.

The former Malignant Cove Formation is now included in the Late Neoproterozoic Bears Brook Formation, based on similar lithologies and detrital zircons that predate ca. 585 Ma. The Arbuckle Brook Formation, based on its lithological characteristics, is now considered to be Late Neoproterozoic in age and hence part of the Georgeville Group.

The redefined Iron Brook Group in the northern Highlands consists of a fault-bounded package of Early Cambrian sedimentary rocks unconformably overlain by Early Ordovician sedimentary and volcanic rocks with minor ironstone beds. Rocks representing the Middle and Late Cambrian part of the stratigraphy appear to be missing.

The Ordovician West Barneys River plutonic suite is exposed over a large area in the southern Antigonish Highlands. It consists of syenite to alkali-feldspar granite and tholeiitic transitional to alkalic gabbro formed in an extensional setting. All of the Late Neoproterozoic and Cambrian to Ordovician rocks in the highlands are intruded by a suite of mafic and felsic sills and dykes that are interpreted to be related to the West Barneys River plutonic suite, based on their compositions.

South of the Hollow Fault, an unconformity separates the Silurian Arisaig Group from the underlying Neoproterozoic rocks of the Keppoch, James River, Chisholm Brook and Bears Brook formations, whereas north of the Hollow Fault, the Arisaig Group conformably overlies the mid- to late-Ordovician Dunn Point and McGillivray Brook formations. Volcanic rocks equivalent to the Dunn Point and McGillivray Brook formations have not been recognized south of the Hollow Fault. In contrast to older units, no volcanic rocks, dykes or sills were observed in the Dunn Point and McGillivray Brook formations or in the Arisaig Group.

The Early Ordovician Ferrona Formation of the Iron Brook Group and the French River/McAdam Brook formations of the Arisaig Group locally contain ironstone beds with elevated Pb, Bi, Co and P. The syenite and gabbro in the West Barneys River plutonic suite, as well as the related dykes and sills, are elevated in zinc and other metals and likely provide an excellent target for exploration.

These new field observations, petrological data and ages have dramatically changed the previously published geological map of the Antigonish Highlands and hence our understanding of the tectonic evolution of this part of Avalonia.

## Acknowledgments

S. Barr, G. O'Reilly, G. DeMont and B. Murphy are thanked for numerous discussions regarding the geology of the Antigonish Highlands. Thanks to the numerous aggregate companies for allowing access to restricted quarrying operations. Special thanks to T. Lenfesty and J. Brenton for providing eager and enthusiastic help in the departmental library. Comments and edits on the draft manuscript by S. Barr were helpful.

## References

Archibald, D. B. 2012: Field relations, petrology, and tectonic setting of the Ordovician West Barneys River plutonic suite, southern Antigonish Highlands, Nova Scotia; M.Sc. Thesis, Acadia University, Wolfville, Nova Scotia, 259 p.

Barr, S. M. and White, C. E. 1999: Field relations, petrology, and structure of Neoproterozoic rocks in the Caledonian Highlands, southern New Brunswick; Geological Survey of Canada, Bulletin 530, 101 p.

Barr, S. M., White, C. E., and Macdonald, A. S. 1996: Stratigraphy, tectonic setting, and geological history of Late Precambrian volcanic-sedimentary-plutonic belts in southeastern Cape Breton Island, Nova Scotia; Geological Survey of Canada, Bulletin 468, 84 p.

Barss, M. S. 1977: Report on samples submitted for age determinations by D. Keppie, Nova Scotia Department of Mines, NTS 11E/9, 11F/13; Unpublished Eastern Petroleum Geology Subdivision Report, Report No. EPGS-PAL, 14-77 MSB.

Benson, D. G. 1974: Geology of the Antigonish Highlands, Nova Scotia; Geological Survey of Canada, Memoir 376, 92 p.

Boehner, R. C. and Giles, P. S. 1982: Geological map of the Antigonish Basin, Nova Scotia; Nova Scotia Department of Mines and Energy, Map 1982-002, scale 1:50 000.

Boehner, R. C. and Giles, P. S. 1993: Geology of the Antigonish Basin, Antigonish County, Nova Scotia Department of Natural Resources, Memoir 8, 109 p.

Boucot, A. J., Dewey, J. F., Fletcher, R., Fyson, W. K., Griffin, J. G., Hickox, C. F., McKerrow W. S. and Ziegler, A. M. 1974: Geology of the Arisaig area, Antigonish County, Nova Scotia; Geological Society of America, Special Paper 139, 191 p.

Bouma, A. H., 1962: Sedimentology of some Flysch Deposits: a Graphic Approach to Facies Interpretation; Elsevier, Amsterdam, 168 p.

Dunning, G. R., Barr, S. M., Giles, P. S., McGregor, D. C., Pe-Piper, G. and Piper, D. J. W. 2002: Chronology of Devonian to early Carboniferous rifting and igneous activity in southern Magdalen Basin based on U–Pb (zircon) dating; Canadian Journal of Earth Sciences, v. 39, p. 1219–1239.

Ells, K. 2007: The origin of Cambrian-Ordovician oolitic ironstones, Iron Brook Group, Antigonish Highlands, Nova Scotia; B.Sc. honours thesis, St. Francis Xavier University, Antigonish, Nova Scotia, 66 p.

Escarraga, E. A. 2010: Field relationships, petrology, age, and tectonic setting of previously inferred Devonian-Carboniferous granitic plutons in the Antigonish Highlands, Nova Scotia; M.Sc. thesis, Acadia University, Wolfville, Nova Scotia, 198 p.

Escarraga, E. A., Barr, S. M., Murphy, J. B. and Hamilton, M. A. 2012: Ordovician A-type plutons in the Antigonish Highlands, Nova Scotia; Canadian Journal of Earth Sciences, v. 49, p. 329–345.

Giles, P. S. 1982: Geological map of the Eureka area, central Nova Scotia (11E/07D and 11E/10A); Nova Scotia Department of Mines and Energy, Map ME 1982-003, scale 1:50 000.

Hamilton, M. A. and Murphy, J. B. 2004: Tectonic significance of a Llanvirn age for the Dunn Point volcanic rocks, Avalon terrane, Nova Scotia, Canada: implications for the evolution of the Iapetus and Rheic Oceans; Tectonophysics, v. 379, p. 199–209.

Keppie, J. D., Davis, D. W. and Krogh, T. E. 1998: U–Pb geochronological constraints on Precambrian stratified units in the Avalon Composite Terrane of Nova Scotia, Canada: tectonic implications; Canadian Journal of Earth Sciences, v. 35, p. 222–236.

Keppie, J. D., Giles, P. S. and Boehner, R. C. 1978: Some Middle Devonian to Lower Carboniferous rocks of Cape George, Nova Scotia; Nova Scotia Department of Mines, Paper 1978-004, 37 p.

King, M. S. 2005: Airborne magnetic calculated second vertical derivative map for parts of NTS 11E/09, Merigomish area, Nova Scotia; Nova Scotia Department of Natural Resources, Open File Map ME 2005-45, scale 1:50 000.

Landing, E. and Murphy, J. B. 1991: Uppermost Precambrian(?)-Lower Cambrian of mainland Nova Scotia: faunas, depositional environments, and stratigraphic revision; Journal of Paleontology, v. 65, p. 382–396.

Landing, E., Nowlan, G. S. and Fletcher, T. P. 1980: A microfauna associated with Early Cambrian trilobites of the Callavia Zone, northern Antigonish Highlands, Nova Scotia; Canadian Journal of Earth Sciences, v. 17, p. 400–418.

MacFadzen, A. L. 2012: Petrology of the Indian Lake and Leadbetter Road plutons, Antigonish Highlands, Nova Scotia; B.Sc. honours thesis, Acadia University, Wolfville, Nova Scotia, 82 p.

Maehl, R. H. 1961: The older Paleozoics of Pictou County, Nova Scotia; Nova Scotia Department of Mines, Memoir 4, 112 p.

Martel, A. T., McGregor, D. C. and Utting, J. 1993: Stratigraphic significance of Upper Devonian and Lower Carboniferous miospores from the type area of the Horton Group, Nova Scotia; Canadian Journal of Earth Sciences, v. 30, p. 1091–1098.

Murphy, J. B. 1987: Petrology of Upper Ordovician-Lower Silurian rocks of the Antigonish Highlands, Nova Scotia; Canadian Journal of Earth Sciences, v. 24, p. 752–759.

Murphy, J. B., Anderson, A. J. and Archibald, D. A. 1998: Alkali feldspar granite and associated pegmatites in an arc-wrench environment: the petrology of the Late Proterozoic Georgeville Pluton, Antigonish Highlands, Avalon Composite Terrane, Nova Scotia, Canada; Canadian Journal of Earth Sciences, v. 35, p. 110–120.

Murphy, J. B., Fernández-Suárez, J., Jeffries, T. E. and Strachan, R. A. 2004b: U-Pb (LA-ICP-MS) dating of detrital zircons from Cambrian clastic rocks in Avalonia: erosion of a Neoproterozoic arc along the northern Gondwanan margin; Journal of the Geological Society, London, v. 161, p. 243–254.

Murphy, J. B., Hamilton, M. A. and LeBlanc, B. 2012: Tectonic significance of Late Ordovician silicic magmatism, Avalon terrane, northern Antigonish Highlands, Nova Scotia; Canadian Journal of Earth Sciences, v. 49, p. 346–358.

Murphy, J. B., Keppie, J. D., Davis, D. and Krogh, T. E. 1997: Regional significance of new U-Pb age data for Neoproterozoic igneous units in Avalonian rocks of northern mainland Nova Scotia, Canada; Geological Magazine, v. 134, p. 113–120.

Murphy, J. B., Keppie, J. D. and Haynes, A. J. 1991: The geology of the Antigonish Highlands, Nova Scotia; Geological Survey of Canada, Paper 89-10, 115 p.

Murphy, J. B., Keppie, J. D., Stacey, J. and Trainor, R. 2001: Deciphering the Neoproterozoic history of the Hollow Fault, Avalon terrane, mainland Nova Scotia; Journal of Structural Geology, v. 23, p. 1067–1077.

Murphy, J. B., Pisarevsky, S. A., Nance, R. D. and Keppie, J. D. 2004a: Neoproterozoic-early Paleozoic evolution of peri-gondwanan terranes; implications for Laurentia-Gondwana connections; *in* The Avalonian-Cadomian Belt and Related Peri-Gondwanan Terranes; International Journal of Earth Sciences, v. 93, p. 659–682.

Murray, D. 2011: Petrographic and chemical characterization of the Neoproterozoic Ohio Pluton of the Antigonish Highlands, Nova Scotia; B.Sc. thesis, St. Francis Xavier University, Antigonish, Nova Scotia, 41p.

Pe-Piper, G. and Piper, D. J. W. 1998: Geochemical evolution of Devonian-Carboniferous igneous rocks of the Magdalen Basin, eastern Canada: Pb- and Nd-isotope evidence for mantle and lower crustal sources; Canadian Journal of Earth Sciences, v. 35, p. 201–221.

Wanless, R. K., Stevens, R. D., Lachance, G. R. and Edmonds, C.M. 1967: Age determinations and geological studies; K-Ar isotopic ages; Geological Survey of Canada, Report 7, 120 p.

White, C. E. and Archibald, D. B. 2011: Preliminary geology of the southern Antigonish Highlands, northern mainland Nova Scotia; Nova Scotia Department of Natural Resources, Mineral Resources Branch, Open File Illustration ME 2011-001.

White, C. E., Archibald, D. B., MacHattie, T. G., and Escarraga, E. A. 2011: Preliminary geology of the southern Antigonish Highlands, northern mainland Nova Scotia; *in* Mineral Resources Branch, Report of Activities 2010, ed. D.R. MacDonald; Nova Scotia Department of Natural Resources, Report ME 2011-001, p. 145–164.

White, C. E. and Barr, S. M. 2012: The essential role of modern bedrock mapping in tectonic interpretations: an example from the Antigonish Highlands, northern mainland Nova Scotia, Canada; *in* Northeastern GSA Section Meeting, Abstracts with Programs 44-2, March 18-20, p. 88.

White, C. E., Barr, S. M., Archibald, D. B., Voy, K. E., MacHattie, T. G., Escarraga, E. A. and McFarlane, C. R. M. 2012: A new geological interpretation of the Antigonish Highlands, northern mainland Nova Scotia; presented at Atlantic Geoscience Society 38th Annual General Meeting; abstract in Atlantic Geology, v. 48, p. 51.

Williams, M. Y. 1914: Arisaig-Antigonish District; Geological Survey of Canada, Memoir 60, 173 p.

Yardley, B. W. D. 1989: An Introduction to Metamorphic Petrology; Longman Scientific and Technical, Harlow, 248 p.