Mafic and Felsic Intrusions in Carboniferous Rocks of Central Nova Scotia[1]

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Introduction

Central Nova Scotia, including NTS map areas 11E/06, 11E/07 and the southern portion of 11E/10 and 11E/11, is underlain predominantly by sedimentary rocks of Carboniferous age (Fig. 1). Several workers have indicated that small intrusion of mafic and felsic composition are hosted by these rocks but little attempt has ever been made to determine their age and contact relations relative to their hosts. It is known that the plutons show an association, spatially at least, with regional and secondary-scale faults belonging to the Cobequid-Chedabucto Fault Zone (CCFZ) but whether or not the plutons actually intrude their hosts or are pre-Carboniferous in age and simply brought into their current position by faulting is not known.

There is an important economic implication to answering this question of age. Northern Nova Scotia and, in particular, the CCFZ and Carboniferous units it deforms, shows many of the features typical of a terrain hosting the much sought-after iron oxide-copper-gold (IOCG) type of mineral deposits. Foremost among these features are the presence of several small examples of these deposits (e.g. Mt. Thom Cu-Co-Au prospect and Copper Lake Cu-Fe-Au mine) and an abundance of deposits of iron oxide, ankerite and siderite, many of which were mined for iron in the 19th Century (e.g. Londonderry, Bridgeville). Currently, the CCFZ is undergoing exploration by several companies for IOCG deposits, and the ability to define if any of these intrusions played a role in the formation of these deposits will aid in further refinement of a metallogenetic model for IOCG deposits in Nova Scotia. With this aim in mind, several of the mafic and felsic intrusions were examined and sampled in 2005 as part of the Targeted Geoscience Initiative, Phase 2 (TGI-2), a joint federal-provincial agreement to help stimulate petroleum and mineral exploration in central Nova Scotia. The mapping had two components:

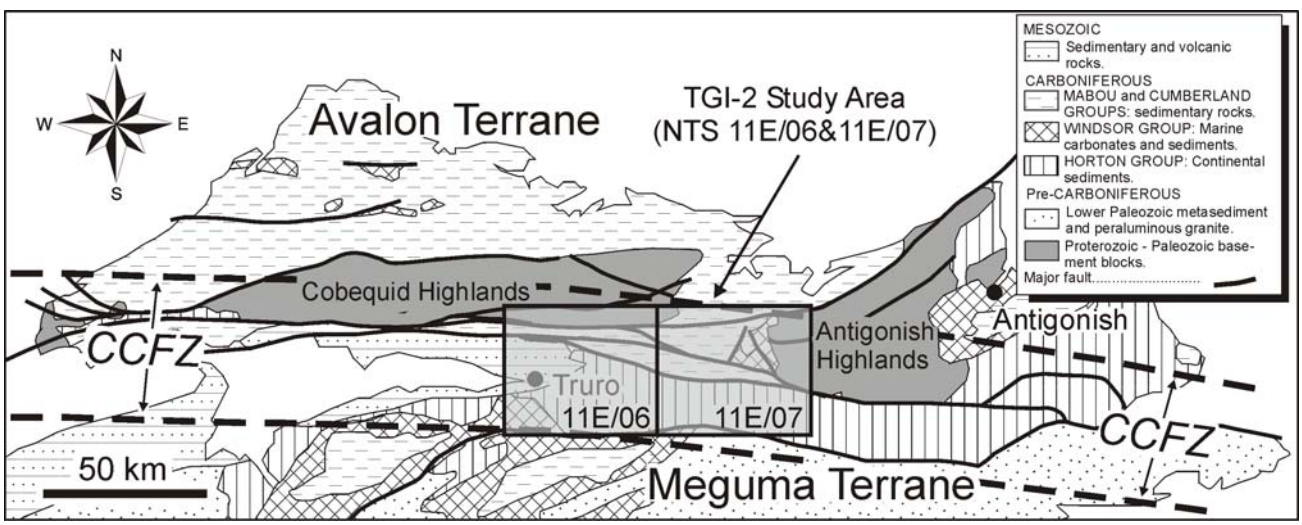

Figure 1. Geology of northern Nova Scotia along the Cobequid-Chedabucto Fault Zone (CCFZ) showing location of the TGI-2 study area.

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(1) definition of field relations described herein, and (2) sampling for absolute age dating, carried out jointly with D. J. Kontak. A report on the results of age dating is introduced by Naylor *et al.* (2005) and will be presented in more detail when the analytical work is completed.

Geology of Central Nova Scotia

The Cobequid-Chedabucto Fault Zone and the Evolution of Carboniferous Basins

From an economic standpoint, the Carboniferous sedimentary and marine strata of Nova Scotia are of the greatest importance, as these units have provided most of the industrial and metallic mineral resources of the province since European settlement some four centuries ago. These include the vast coal deposits for which the province is famous, as well as huge resources of gypsum, limestone and building stone. As well, the Carboniferous units are host to many significant deposits of base metals, Ba, Cu, and the once economically significant iron-oxide vein deposits, of which the Londonderry Iron District is most notable.

The CCFZ is perhaps the single most important geological feature in the province and is the main governing factor behind the evolution of the Carboniferous basins. This system of regional, crustal scale, transpressional, strike-slip and thrust fault structures governed formation of most of the basins into which sediments were deposited during the latter stages of the middle Paleozoic Acadian Orogeny. The faults also served as channelways allowing the rise of mantle-derived plutons of gabbro-diorite and related A-type granitic plutons. Attending the plutons was a very widespread and pervasive hydrothermal alteration event, characterized by K-Na-Fe-Si-CO_2 alteration. More importantly, the fault structures and associated hydrothermal alteration are associated with formation of many of the province's mineral deposits. Carbonate-hosted base metal and barite deposits at Walton, Gays River, Smithfield, Jubilee and Brookfield all had a significant component of structural control in their formation. Likewise several interesting deposits of iron-oxide-copper-gold (IOCG) and related iron-oxide deposits, such as were mined in the former iron-mining districts, all have a direct structural association to the CCFZ.

Pre-Carboniferous Basement Rocks

Avalon Terrane

The Carboniferous rocks of northern Nova Scotia represent basin-fill deposits of sediment adjacent to and along the flanks of highland blocks of Precambrian and lower Paleozoic crystalline basement. The highland blocks developed by dextral, strike-slip and thrust faulting along sutures of the CCFZ (Pe-Piper *et al*., 2004). Formation of the CCFZ began in the lower Paleozoic but, by far, most movements occurred related to the docking of the Avalon and Meguma terranes during the Devonian Acadian Orogeny. The Cobequid Highlands underlie the western end of the CCFZ and is a horst structure consisting of arc volcanics, plutonic rocks and associated lower Paleozoic sedimentary rocks (Pe-Piper and Piper, 2002). Part and parcel of the highland formation was emplacement of a voluminous series of gabbroic and A-type granitic magmas and their extrusive equivalents during the very latest Devonian and into the early Carboniferous (Pe-Piper *et al.*, 2004). Movement along the faults continued episodically into the late Carboniferous, as did intrusion of volumetrically lesser amounts of mafic magma and attendant hydrothermal alteration.

The Antigonish Highlands are geologically similar to the Cobequid Highlands except that they are dominated by lower Paleozoic volcanic and turbidite sequencess intruded by granodioritic and granitic plutons of intermediate composition (Benson, 1974a; Murphy *et al.*, 1991). Plutons and plugs of mafic composition are also present throughout the Antigonish Highlands, especially close to the CCFZ (Benson, 1974b).

Meguma Terrane

The CCFZ marks the tectonic boundary between the Avalon Terrane to the north and the Meguma Terrane to the south (Fig. 1). The Meguma Terrane consists predominantly of the lower Paleozoic

turbiditic metasediments of the Cambro-Ordovician Meguma Group. The Meguma Group consists of the metawacke-dominated Goldenville Formation and conformably overlying slate-dominated Halifax Formation.

A cogenetic suite of peraluminous granitic rocks of the late Devonian age intrude the Meguma Group. These granites range in composition from tonalite to highly evolved leucogranite but, volumetrically, granodiorite is the most important phase. The Meguma Terrane, although not a highland of the same dimensions as the Cobequid and Antigonish highlands, still served as a basement providing sediment for transport and infilling of the Carboniferous basins after the Acadian Orogeny.

The Carboniferous Succession

Horton Group

The Carboniferous sequence in central Nova Scotia began with deposition of large amounts of clastic continental alluvium in graben and half-graben basins adjacent to sutures of the CCFZ. These sediments have been assigned to the Horton Group, consisting mostly of coarse sandstone, siltstone and conglomerate (Benson, 1967a).

The Horton Group type section was defined by Bell (1929) from the Horton Bluff area near Windsor, where it consists of the Horton Bluff Formation and conformably overlying Cheverie Formation. This nomenclature has been retained for the Horton Group in the TGI-2 study area (Naylor *et al.*, 2005). Horton Group rocks are mostly confined to the St. Mary's Graben, which underlies the southern portion of NTS map areas 11E/06 and 11E/07, and is a rectangular structure 130 km long by 15 km wide that is almost entirely bounded by major splay faults of the CCFZ. Within the graben, Benson (1967a, 1974a) subdivided the Horton Group into three units he felt were equivalent to the Craignish, Strathlorne and Ainslie formations, defined on Cape Breton. In general, the Craignish Formation is equivalent to the Horton Bluff Formation, and the Strathlorne and Ainslie Formations to the Cheverie Formation.

Mapping as part of the TGI-2 project has shown that within the eastern half of the graben, and especially underlying the area south of Lorne, the rocks belong to a middle member of the Horton Bluff Formation. They consist of grey to dark grey shale and siltstone, alternating with thin bands of grey to green mudstones. Conformably overlying these rocks is an upper member of the Horton Bluff Formation which consists of light- to medium-grey quartz arenite beds, interbedded with grey shale, mudstone, nodular dolostone and minor conglomerate. Overlying the Horton Bluff Formation are grey to green sandstones of the Cheverie Formation with local conglomerate interbedded with maroon and grey mudstone. The fossil assemblage within the Horton Group indicates it is Tournaision in age (earliest Carboniferous stage) and deposition was continental in origin. The uppermost Horton Group strata are latest Tournaisian (Bell, 1929).

Windsor Group

The continental sediments of the Horton Group are overlain by a sequence of marine sediments with interbedded evaporite sequences known as the Windsor Group. Incursions of continental sediments are also known in the Windsor but are minor. Although the contact of the Horton and Windsor groups appears to be conformable, fossil evidence suggests a depositional hiatus between the two. The uppermost Horton Group rocks have Tornaisian fossil assemblages while the lowermost Windsor Group beds are mid-Viséan (Calder, 1998).

Most of the Windsor Group rocks in the TGI-2 study area are confined to the Eureka area (NTS 11E/07). Giles (1982) mapped these rocks and applied local names to formations found therein. However, for the purposes of keeping things simple in this report, the more established names assigned to these same Windsor Group units in the Shubenacadie and Musquodoboit Carboniferous basins (Giles *et al.*, 1979) are used here.

The oldest Windsor Group rocks known in the study area belong to the Gays River Formation which consist of a carbonate buildup (bank) of partly laminated limestone and lesser dolostone best developed in areas where the Windsor Group directly onlaps pre-Carboniferous basement. The unit is usually thinly bedded but locally contains thick beds. The Gays River Formation is the lateral equivalent to the finely laminated limestone of the

Macumber Formation, which marks the beginning of the Windsor Group succession at many other locales in the province. At Bridgeville, these Gays River Formation rocks, and their immediately underlying pre-Carboniferous crystalline basement rocks, host most of the deposits of hematite previously mined at the Bridgeville Iron Mines (Wright, 1975).

Conformably overlying the Gays River Formation are thick units of gypsum and anhydrite of the Carroll's Corner Formation, termed the Bridgeville Formation by Giles (1982). The Carroll's Corner Formation is a thick succession of poorly stratified anhydrite and gypsum with minor, irregular beds of limestone and dolostone. In the Eureka basin, rocks of the Carroll's Corner Formation are found immediately above the Gays River Formation along the eastern margin of the basin and its contact with pre-Carboniferous rocks of the Antigonish Highlands.

Disconformably above the Carroll's Corner Formation is the MacDonald Road Formation or Forbes Lake Formation of Giles (1982). The MacDonald Road Formation consists predominantly of maroon to pale greyish-red shale, mudstone and paraconglomerate. Minor limestone beds are also present. Cyclic repetition of these rocks is characteristic.

Conformably overlying the MacDonald Road Formation are the maroon to reddish-brown mudstone, fine-grained sandstone and intercalated sheets of limestone and grey, fossiliferous mudstone and shale of the Green Oaks Formation. Some beds of anhydrite and gypsum are present. Giles (1982) refers to these rocks as the Churchville Formation.

Mabou Group

The Mabou Group was described and introduced as a replacement for the Canso Group by Belt (1964, 1965). Many early maps of central Nova Scotia use the term Canso Group (Benson, 1967; Donohoe and Wallace, 1982). The Mabou Group consists of a succession of fine-grained, red and grey, fluvial and lacustrine strata which overlie the Windsor Group. Mabou Group rocks underlie substantial portions of NTS map areas 11E/06 and 11E/07. Although it is poorly established, the Mabou Group is considered to be a lateral equivalent to the Londonderry Formation, although the latter only occurs as fault bounded blocks along major splays of the CCFZ. The relationship between the Mabou Group and the Londonderry Formation is important considering that the substantial hematite and ankerite vein systems that constitute the Londonderry iron deposits are hosted by Londonderry Formation rocks, so it is unfortunate that a better defined relationship has not been established.

Cumberland Group

The upper Carboniferous or, coal-bearing, rocks in Nova Scotia have been referred to under several group names including Riversdale, Morien, Stellarton and Pictou. Ryan *et al.* (1991) proposed an expanded definition of the Cumberland Group to include all the typically heterogeneous sandstone, mudrock and conglomerate stratigraphically above the Mabou Group. In the TGI-2 project area the Cumberland Group consists of the Boss Point, Parrsboro, Totten Brook, Chiganois River, Cross Road and Debert formations. In the area studied for this report only rocks of the Boss Point, Parrsboro, Chiganois and Cross Road formations are found.

Plutonic Rocks Hosted by Carboniferous Strata

Mafic Plutons

A review of the available geology maps, literature and mineral exploration assessment files (Fletcher, 1892, 1902a, 1902b, 1902c, 1902d; Benson, 1967b, 1974b; Mersereau, 1974; Giles, 1982; Black, 1995, Rankin, 1997) shows that the Carboniferous rocks along the CCFZ in central Nova Scotia host numerous, small igneous intrusions and dykes. Most of the intrusions are mafic in composition and several were examined in 2004 as part of the TGI-2 project. A description of each site visited follows.

Moiche Hill Gabbro and Carbonate Breccia Complex

Fletcher (1892, p. 150P) and Benson (1967a, p. 36) make reference to a mixed sequence of gabbro and limestone at Moiche Hill (referred to as Robert

Gordon's Hill by Fletcher) near Glengarry Station (Fig. 2). The geology map of this area by Fletcher (1902a) shows a small quarry on the site where lime was extracted by the local farmers for agricultural purposes. It is clear from the brief description of Fletcher (1892) that he considered the carbonate exposed here to be layers of limestone enveloped in reddish "trap". A lifetime resident of the area confirmed that early settlers used to periodically visit this site, where they would fill the pit with hardwood then blow large blocks of the mixed limestone and gabbro into it and start a fire. After the blocks were cooked they would crush them, mix them with the ash, and spread the mixture on their fields.

Traverses across Moiche Hill, and along Middle River of Pictou where it follows the base of the hill, quickly showed that much of the hill is underlain by a fragmental gabbroic pluton (Fig. 2). Outcrops of dark grey to purplish gabbro are exposed in the old quarry and along the crest of the hill west from the quarry to the Glengarry Station Road. In addition, the hillside itself is draped by a substantial talus consisting of more than 80% gabbro boulders. Outcrops and rubble crop of the gabbro found along the road leading north toward Marshdale indicate that the complex extends at least that far to the northeast. Toward the west, one probable outcrop of gabbro occurs along the road leading north from Glengarry Station, a short distance north of the bridge over Middle River of Pictou (Fig. 2).

The area surrounding the Moiche Hill gabbro is underlain by maroon to light grey sandstone and siltstone of the Carboniferous Mabou Group. Outcrops of these sediments are found along the

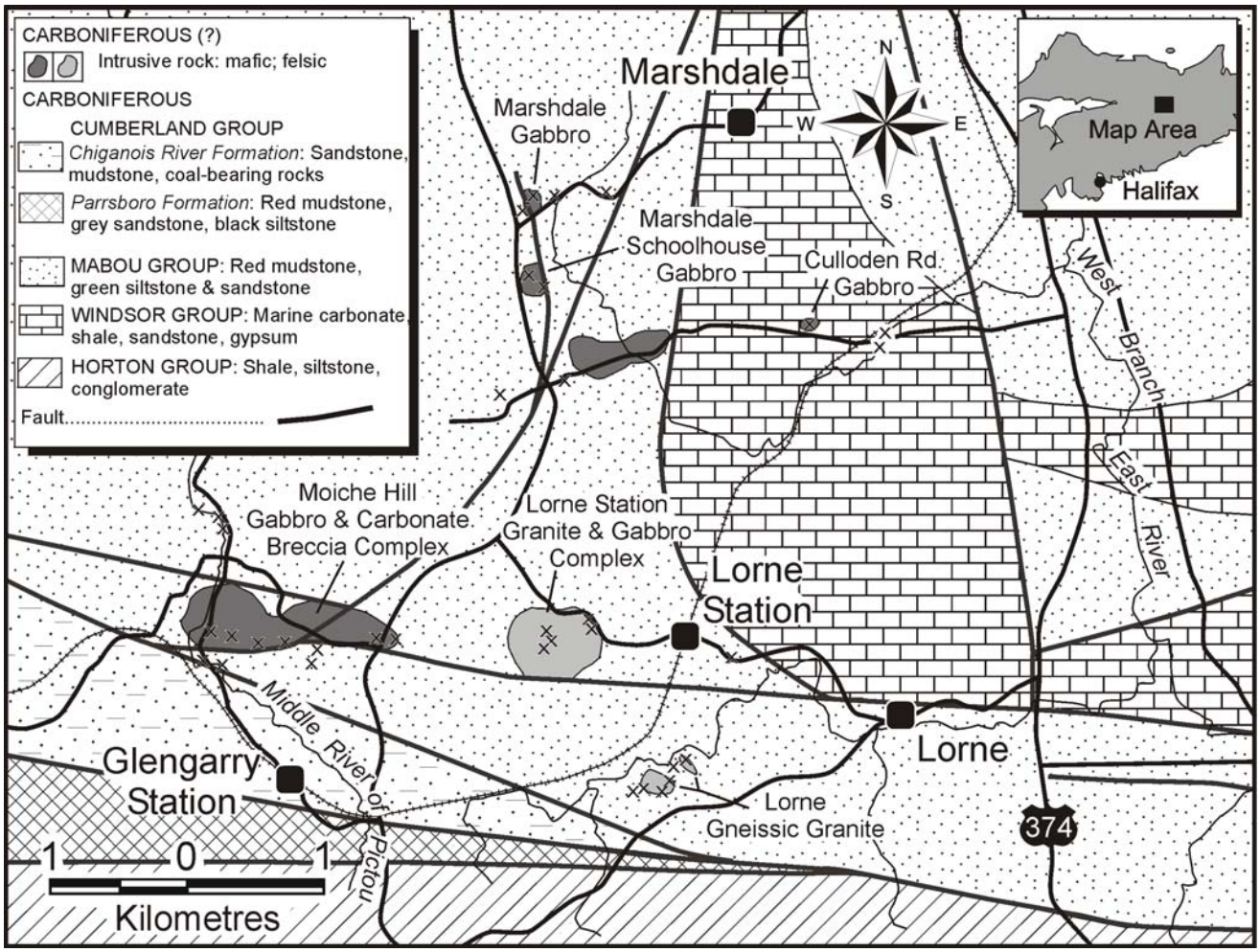

Figure 2. Geology of the Lorne-Marshdale area, southern Pictou County, showing igneous intrusions examined as part of the TGI-2 Project.

Middle River of Pictou and along several roads that encircle the hill. In addition, outcrops of Mabou Group redbeds were found during traverses of the southeastern face of the hill, immediately north of the now abandoned site of the old Glengarry railway station.

It is clear from the gabbro outcrops, and from the abundant gabbro boulders that drape the hill, that the intrusion is mostly brecciated. This especially holds for the pluton's southern contact. The gabbro is fine- to medium-grained and grey to greenish-grey in colour. In places it is porphyritic with fine laths of plagioclase. Evidence of brecciation is ubiquitous, as is the occurrence of minor amounts of fracture-controlled specularite. Outcrops and large boulders are mildly magnetic. The gabbro exposed in the 50 m long, by 3-5 m deep, pioneer era quarry is also brecciated. The distribution and frequency of blocks of brecciated sediment in the southern part of the quarry suggests that area may be underlain by Mabou Group rocks. although they are not exposed.

The 2-3 m high outcrop faces along the eastern edge of the quarry expose totally recrystallized carbonate (marble) interlayered with lenses of brecciated gabbro and fragments of broken red sediment. A planar layering obvious within the carbonate trends 074° Az, dipping 84° south, and appears to be extensional in origin. In addition, carbonate-filled extensional fractures are present in many of the larger breccia fragments of both gabbro and sediment.

There is no evidence to suggest that the carbonate exposed in the quarry is a recrystallized version of what was originally Carboniferous limestone. The distribution of the carbonate in the pit, its intimate interlayering with gabbro, and its totally recrystallized (marble) condition all strongly suggest that the carbonate is hydrothermal in origin and localized along the brecciated contact of the gabbro intrusion with the Mabou Group country rock. The alignment of brecciated outcrops of gabbro and sediment along the southern and southeastern contact of the intrusion indicates that a northeast-trending fault passes through this area and continues north toward Marshdale (Fig. 2).

A sample from of the Moiche Hill gabbro has been submitted for Ar^{40}/Ar^{39} dating.

Marshdale and Marshdale Schoolhouse Gabbros

Two small intrusions of dark green, medium- to coarse-grained gabbro are found at Marshdale, Pictou County (Fig. 2). One, named here the Marshdale gabbro, is exposed in an aggregate quarry opened in the mid-1960s to provide construction material for the Harvey Venoit Causeway joining New Glasgow and Pictou. The other, now named the Marshdale Schoolhouse gabbro, outcrops as a small knoll behind the site of the former Marshdale schoolhouse, a few hundred metres south on the road to Glengarry from the Marshdale intersection (Fig. 2). Fletcher (1892, p. 150P; 1902) reports the area behind the school had several prospect pits dug in search of specularite occurring within gabbro. Benson (1967b), on his geology map of the area, indicates a small dyke of gabbro at the site of the Marshdale Schoolhouse gabbro but does not show the existence of the Marshdale gabbro intrusion immediately to the north.

It is possible the two gabbros are actually one pluton but the existing outcrop distribution will not allow a firm answer on this. Second derivative aeromagnetic data (Geological Survey of Canada) over this area shows the presence of two low-amplitude magnetic anomalies, corresponding with each area of gabbro outcrop. This suggests that two separate plutons exist, although they still may be connected at depth.

The distribution of outcrops at the Marsdale quarry indicates that the pluton has a minimum size of 90 m long by 70 m wide. A prominent 10 m high spire of gabbro remains at the north end of the quarry and represents the original height of the outcrop knoll prior to quarry construction. Much of the gabbro occurs as a dark green, coarse-grained, hypidiomorphic, granular textured rock consisting of hornblende, pyroxene and plagioclase. Minor amounts of sphene and hematite are present. Lighter coloured, metre scale patches occur within the gabbro and may represent portions of more differentiated gabbro or metasomatic alteration zones. These light coloured patches are more plagioclase-rich and commonly contain disseminations of specularite, pyrite and lesser chalcopyrite.

Considerable loose gabbro rubble lies about the pit and among the rubble occur large boulders showing an intrusive contact of the gabbro with an odd textured, fine-grained, light-to dark-green, layered rock (Fig. 3). Geology maps (Benson, 1967b; Giles, 1982) show the Marshdale area to be underlain by red to green siltstone and sandstone of the Mabou Group. An outcrop of typical Mabou Group, very friable red siltstone is found on the north side of the Marshdale-Hopewell Road about 200 m east of the quarry. On the west side of the Marshdale-Glengarry Road, immediately opposite the Marshdale intersection, which is 100 m west of the quarry, rubble crop of mixed grey to red siltstone and mudstone is found (Fig. 2). On entering the quarry, however, a bank along the left-hand side of the road that skirts the west edge of the pond at the centre of the pit exposes several outcrops of the odd textured rock mentioned above. The rock is light green to dark green, with a pronounced layering and very fine grain size. At first glance it resembles rhyolite, but the presence of numerous light coloured, spherical alteration blebs, encircled by mottled, calc-silicate and porcelain alteration, suggests it is actually a highly altered rock developed by heat and escaping fluids during intrusion of the gabbro. The rock occurs in the contact zone of the gabbro and the ubiquitous presence of breccia indicates the contact is highly faulted. The overall composition and texture of the thermally and metsomatically altered contact rock is markedly different than the much softer and more friable Mabou Group red siltstone and mudstone found a couple of hundred metres to the east. Outcrops of interbedded green and grey, laminated siltstones found to the south along the west end of the Culloden Road (Fig. 2), however, may easily represent a non-altered protolith of the contact rock.

Figure 3. Photograph of altered and deformed contact rock from the Marshdale gabbro intrusion.

Veins of white calcite, some with quartz, intrude the gabbro and many of these carry well formed crystals of pyrite and chalcopyrite. In fact, euhedral crystals of chalcopyrite are present and this marks the only location in the province where I have observed this mineral in euhedral form. Specularite also occurs with the sulphides in some of these veins, and also separately, sometimes in significant amounts speckled throughout the matrix of the brecciated contact rock.

A sample of the Marshdale gabbro has been submitted for Ar^{40}/Ar^{39} dating.

The Marshdale Schoolhouse gabbro occurs as a small knoll in the woods behind the location of what was once the Marshdale School (Fletcher, 1902a; Fig. 2). The school was located on the east side of the Marshdale-Glengarry Road, 380 m south toward Glengarry from the Marshdale intersection. The school was lost in a fire in 1936 and a portion of what remained of the structure was incorporated into one of the nearby homes. A small pond is found in the woods immediately to the east of the road and pits, trenches and outcrops of gabbro are found to the east and north of the pond. Fletcher (1892) indicated that the pits were dug on the gabbro in quest of iron from the large patches of specularite that occur in the rock. An examination of the property shows that several small pits and trenches are present, and it also appears as if the pond itself is man-made and the result of nature reclaiming what was once a pit related to the past prospecting. Loose gabbro litters the area and much of it is mineralized with specularite. The distribution of pits and outcrop suggests that the gabbro intrusion is elongate toward the north with a minimum size of 110 m by 60 m. The second derivative aeromagnetic data (Geological Survey of Canada) for this area suggest the pluton is more circular and slightly larger.

The Marshdale School gabbro is similar in composition and texture to the pluton exposed in the Marshdale quarry. Most of the pluton is coarse grained, but there is an apparent fining of the grain size toward the road (west) suggesting that the contact is being approached in that direction. Unfortunately, the country rock to the pluton is not exposed and none was noted in the abundant loose rubble that litters the prospect. This pluton is thought to be hosted by Mabou Group sediments but no inferences on the contact relations of these rocks with this particular gabbro intrusion can be made.

As far as tonnage and amount of massive iron-oxide are concerned, there is not a substantial abundance of specularite within the gabbro, but there are some fairly spectacular specimens of the mineral to be found. Gabbro containing large patches and blades of specularite 3-4 cm in length are common. Most of the specularite occurs within veins and along fractures, but some occurs as patches and segregations within the gabbro suggesting it crystallized by way of direct metasomatic alteration processes within the gabbro as opposed to post-crystallization precipitation along fractures and fault planes.

Culloden Road Gabbro

A small intrusion of gabbro outcrops in a farmer's field on the north side of the Culloden Road south of Marshdale (Fig. 2). The Culloden Road leads west from Highway #374 about halfway between the village of Hopewell and the community of Lorne. The field is about 2 km west of the highway, on the north side of the road, a few hundred metres west of the railway crossing. The gabbro consists of a single, prominent outcrop surrounded by trees that were left for livestock to shelter from the sun. The outcrop measures 5 m by 5 m, and is surrounded by abundant gabbro rubble, most of which has angular, sharp edges (Fig. 4). The rock is medium grey and, for the most part, is shot through with a stockwork of cream coloured quartz-calcite veins. The veins appear to be filling closely spaced extensional fractures and tension gashes.

The gabbro appears to be highly silicified and carbonitized. The veins occupy a variety of orientations but most trend 073° Az and are vertical to steeply dipping toward the south. The outcrop also contains several flat-lying shear zones which crenulate and offset the quartz-calcite stockworks. Pyrite, pyrrhotite, specularite and minor chalcopyrite occur within the quartz-calcite veins and, to a lesser extent, as disseminations throughout the gabbro.

No country rock outcrops occur near the gabbro so direct inferences cannot be drawn as to the contact relations. This area is mapped by Giles (1982) as being underlain by maroon to reddish-

Figure 4. Outcrop of gabbro intruded by extensional calcite-quartz veins on the Culloden Road.

brown mudstone and sandstone of the Green Oaks Formation (called Churchville Formation by Giles), which occupies the upper part of the Carboniferous Windsor Group. Boulders of these rocks abound in the road gutters and rock piles throughout the Culloden Road area and an outcrop of very friable, red mudstone is exposed on Cameron Brook where it meets Culloden Road about 500 m east of the gabbro.

It is interesting to note that Fletcher (1892) makes frequent mention of clusters of gabbro boulders, often highly veined with calcite and quartz, being found along the trace of the Chedabucto Fault from Glengarry east to Sunnybrae. Many of these boulder clusters are found along the north scarp of the St. Marys Graben, an area underlain by Carboniferous Horton Group rocks. Some of the clusters, however, occur in areas underlain by rocks belonging to the younger Windsor and Mabou groups. The Culloden gabbro would be one such occurrence. A sample from this outcrop has been submitted for Ar^{40}/Ar^{39} dating.

Centredale Gabbro Intrusions

Three gabbro plugs are found in Mabou Group rocks in the Centredale-Elgin area east of Lorne, Pictou County (Fig. 5). Outcrops of the Elgin and Centredale plugs are indicated as single diabase outcrops on Giles (1982). Benson (1967b) indicates a diabase outcrop at Centredale but not the one at Elgin. The largest, and easternmost of the three plugs, is found between Centredale and Archibalds Brook but it has no known outcrops. Its existence is inferred by the presence of a strong magnetic anomaly that underlies the area. Similar, but lower amplitude, magnetic anomalies underlie the Centredale and Elgin plugs.

Benson (1967b) mapped the Centredale area as being underlain by Windsor Group sediments. Giles (1982), based on spore data, felt that the rocks south of the Centredale Fault actually belonged to the Mabou Group (Fig. 5). Any examination of the section between the Centredale Fault and the Chedabucto Fault, about a kilometre and a half to the south, will quickly reveal that these rocks are indeed highly faulted and several faults parallel to the main bounding faults also probably exist.

The westernmost of the three gabbro plugs outcrops along a stream that parallels the road leading from Elgin to Centredale (Fig. 5). Measuring from the Centredale intersection, drive 1 km west toward Elgin. At that point the stream is immediately north of the road. Walk upstream along the stream to where it swings to the north and about 50 m farther upstream is an outcrop of coarse grained, dark green gabbro on the west bank. This gabbro is similar in texture and composition to the gabbro exposed in the Marshdale quarry several kilometres to the northwest. Immediately to the west of the outcrop on the stream is a prominent west-trending knoll. A second gabbro outcrop is found about another 100 m west along this knoll. A considerable amount of gabbro float litters the stream and along the trend of the knoll, suggesting that gabbro underlies much of this area. How far it extends to the west is not known, but it is felt that the extent of the magnetic anomaly in the Geological Survey of Canada aeromagnetic survey over this area provides some idea, and this information was used in defining the size of the pluton in Figure 5.

Although the contact of the gabbro with the Mabou Group sediments is not exposed, about 20 m downstream from the gabbro outcrop on the

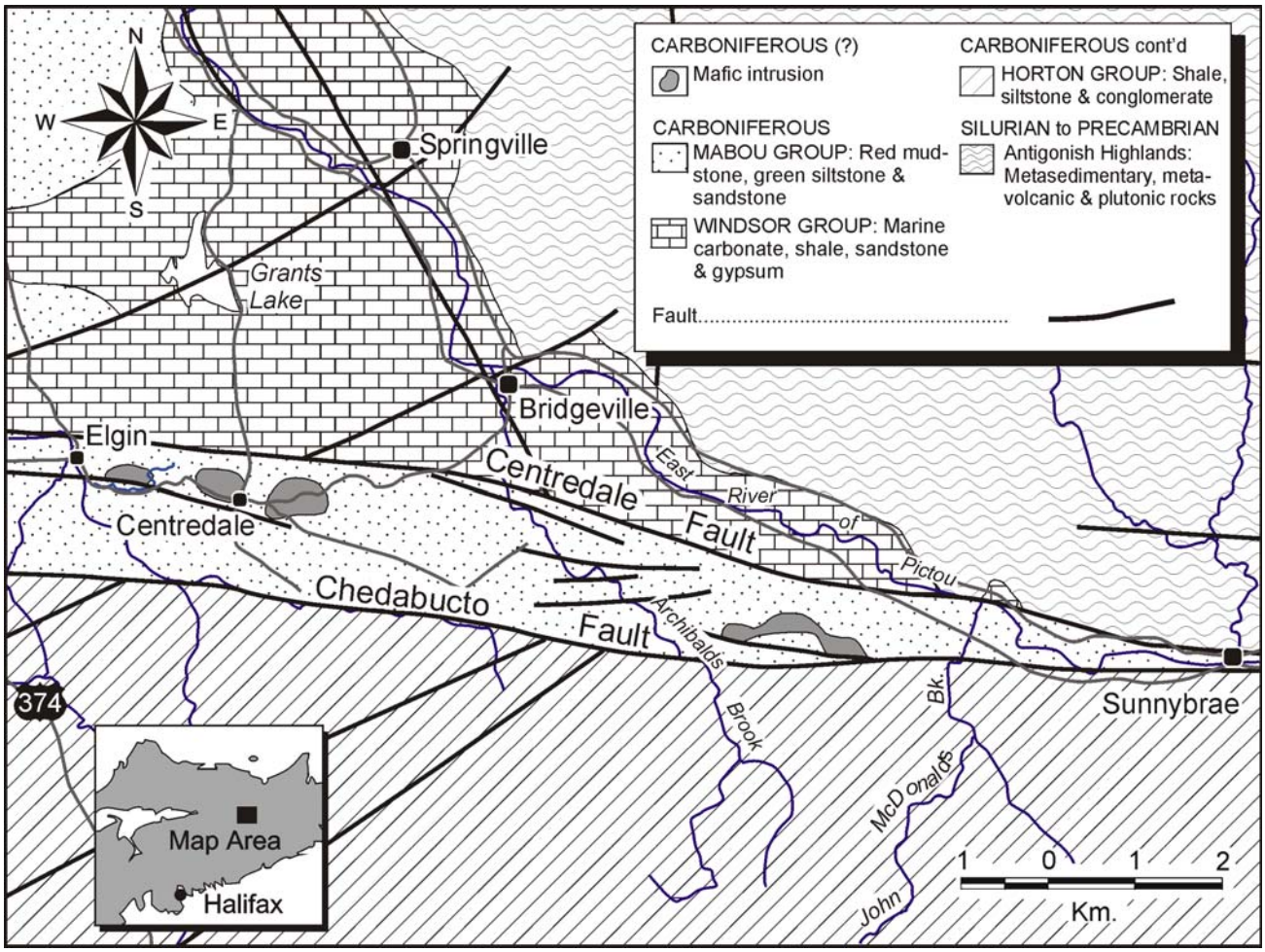

Figure 5. Geology of the Centredale-Sunnybrae area of Pictou County showing the location of gabbro intrusions examined in 2004.

brook is found an outcrop of highly deformed and thermally altered calcareous siltstone. This suggests, but does not prove conclusively, an intrusive relationship between the gabbro and the Mabou Group. The outcrop contains disseminated pyrite and is also intruded by veins of pinkish gypsum.

The gabbro at Centredale underlies the area northwest of the intersection of the Elgin and Grants Lake Roads (Fig. 5). A large outcrop of dark green, coarse-grained gabbro is exposed on the north bank of a brook about 40 m west from the Centredale intersection and on the north side of the road to Elgin. Texturally and compositionally, this gabbro is identical to the intrusion at Elgin and Marshdale. This intrusion is recorded as a single outcrop by Benson (1967b) and Giles (1982) who infer it may simply be a small dyke. However, the brook for at least 200 m west from the Centredale intersection consists almost entirely of gabbro boulders. As well, gabbro constitutes 70-90% of the float for 200-300 m northwest from the intersection which corresponds with a small topographic high in that area. The distribution of the gabbro float and the configuration of the magnetic anomaly in the aeromagnetic data in this area suggest that the gabbro plug is roughly circular with a diameter in the order of 200 m or more.

The contact of the gabbro with the surrounding Mabou Group sediments is not exposed, nor are there any Mabou Group outcrops close by. The only suggestion of an intrusive relationship are the presence of float of bleached and thermally altered sediment mixed with gabbro float on the periphery of the intrusion. Outward from the known area of

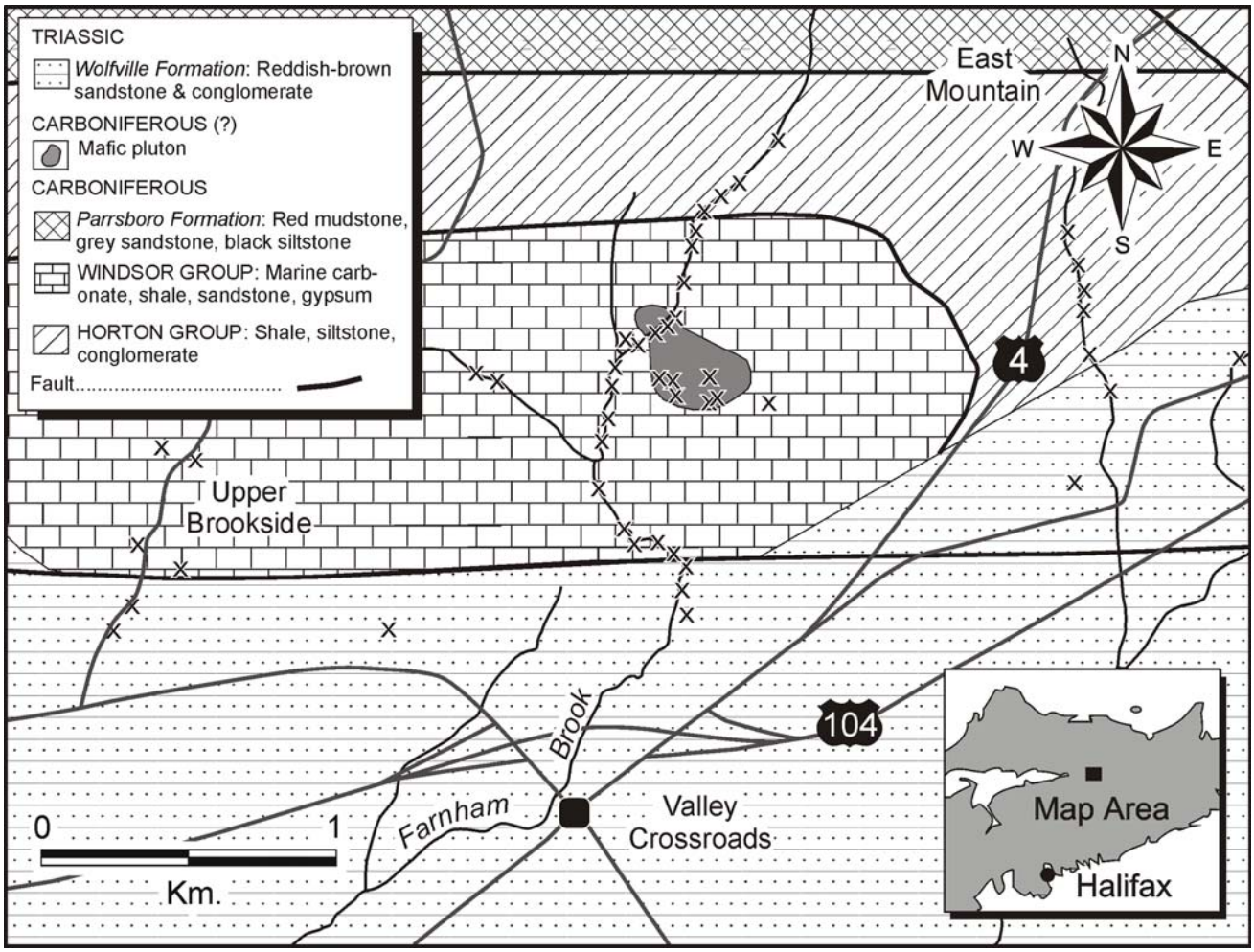

Figure 6. Geology map of the East Mountain area, north of Truro, showing the East Mountain gabbro intrusion.

the intrusion, the frequency of this altered-sediment float decreases until there is only the red-maroon sandstone and siltstone typical of the Mabou Group.

A sample of the Centredale gabbro has been submitted for an Ar^{40}/Ar^{39} age determination.

The easternmost of the three Centredale gabbros is not known to outcrop. However, the magnitude of the magnetic anomaly over that area in the Geological Survey of Canada aeromagnetic surveys strongly suggests a gabbro intrusion is present (Fig. 5). The magnitude of the anomaly suggests the pluton will be similar to the two intrusions to the west at the Centredale intersection and near Elgin, but slightly larger.

East Mountain Gabbro

Two currently producing aggregate quarries have been developed in a gabbro intrusion on the southwest end of East Mountain (Fig. 6). Fletcher (1902c) indicates a mafic intrusion in this area on his geology map, and Donohoe and Wallace (1982) indicate two outcrops of diabase in the area immediately to the east of the present-day quarries. However, the previous mapping preceded construction of the quarries. Donohoe and Wallace (1982) also indicate the area surrounding the intrusion as being underlain by Horton Group sediments and a block of Windsor Group limestone underlies the area immediately to the west. They show a fault separating the two units. Mapping done as part of the TGI-2 project (Naylor *et al.*, 2005) shows that, in fact, the Windsor Group is more extensive and actually underlies much of the southwest end of East Mountain, including the area surrounding the gabbro. The extent of the gabbro intrusion provided in Figure 6 is based on outcrop as well as the footprint of a low amplitude magnetic anomaly in Geological Survey of Canada aeromagnetic data that cover this area.

The gabbro typically has a purple-grey colour and is texturally inhomogeneous. For the most part, the gabbro is fine- to medium-grained, with large portions that are massive and somewhat resemble volcanic rock. Several zones within the gabbro are porphyritic due to the presence of fine plagioclase laths. Throughout the quarries are found several pods consisting of an abundance of plagioclase and light coloured tremolite. These pods are gradational in the massive and porphyritic portions of the gabbro and are believed to be the result of metasomatic processes in the melt prior to crystallization. Veins of jasper and a reddish carbonate also intrude the gabbro.

The contact of the gabbro with the enclosing Windsor Group sediments is not exposed, but gabbro outcrops on Farnham Brook are found within a few metres of Windsor Group limestone outcrops (Fig. 6). The limestone outcrops show thermal upgrading to marble, the degree of which decreases away from the gabbro, indicating that an intrusive relationship is almost certain.

A sample of the East Mountain gabbro has been submitted for an Ar^{40}/Ar^{39} age determination.

Salmon River Gabbro

A gabbro dyke is exposed on the east bank of the Salmon River about 1 km north of where it joins with the Black River (Fig. 7). Fletcher (1892, p. 152P) was first to make mention of the dyke and the fact that the sedimentary country rock adjacent to it is considerably altered. He also noted the increased occurrence of veins of ankerite and specularite near the dyke. Fletcher (1902d) indicates the dyke on his map of this area, as do Donohoe and Wallace (1982). The latter interpret the gabbro as a lens-like body adjacent to the Riversdale Fault, which traverses this area.

The contact of the gabbro with the enclosing siltstone and sandstone of the Carboniferous Boss Point Formation is well exposed here (Fig. 8). There is strong evidence that an intrusive relationship exists. As was first noted by Fletcher (1892), there is considerable bleaching and annealing of the sedimentary country rock (Boss Point Formation) adjacent to the gabbro. This alteration extends into the sediment for 8-10 m away from the contact, and is also accompanied by minor brecciation in some areas and production of secondary specularite, ankerite and minor barite. Areas of more pronounced bleaching and alteration are also associated with increased magnetism. The contact trends 030° and dips 48° east. There is also a pronounced fining of the grain size within the gabbro toward the contact, which is suggestive of chilling. Within a few metres into the dyke, the grain size increases to a coarse size and remains so for the remainder of the exposed width of the

intrusion. Existing outcrops indicate that the gabbro has a minimum thickness of 30 m, and the fact that the gabbro outcrops farthest away from the contact are still coarse grained suggests that this dyke may be of considerable thickness.

A very pronounced magnetic anomaly underlies the hilly area between the dyke exposure and Black River about 1 km to the south (Fig. 7). Sedimentary rock is to be found along Salmon River south of the dyke outcrops, but there is no outcrop at all to be found on the hills above the river, in the area underlain by the magnetic anomaly. The magnitude of the anomaly suggests that a gabbro intrusion of considerable size either underlies the hill or is close to surface there. It is interesting to note that clusters of gabbro boulders occur in the woods along a trend of 030° Az, which corresponds to the strike extension of the dyke exposed on the river. It appears unlikely that the dyke, as exposed on the river, is the sole source of the sizable magnetic anomaly. It is more likely the dyke is merely the northwestern edge of a much larger intrusion that extends to the southeast and underlies the hill between Salmon River and Black River. Alternatively, the dyke is merely an offshot intrusion from a much larger body that underlies the entire hill.

John McDonald Brook Gabbro

Fletcher (1892, p. 35P and 149P) makes clear mention of the presence of “reddish and greenish massive felsite, trap, syenite and diorite, granular and compact, of serpentinous diorite-breccia” along John McDonald’s (Ogg) Brook and surrounding fields near Sunnybrae (Fig. 5). Several traverses in

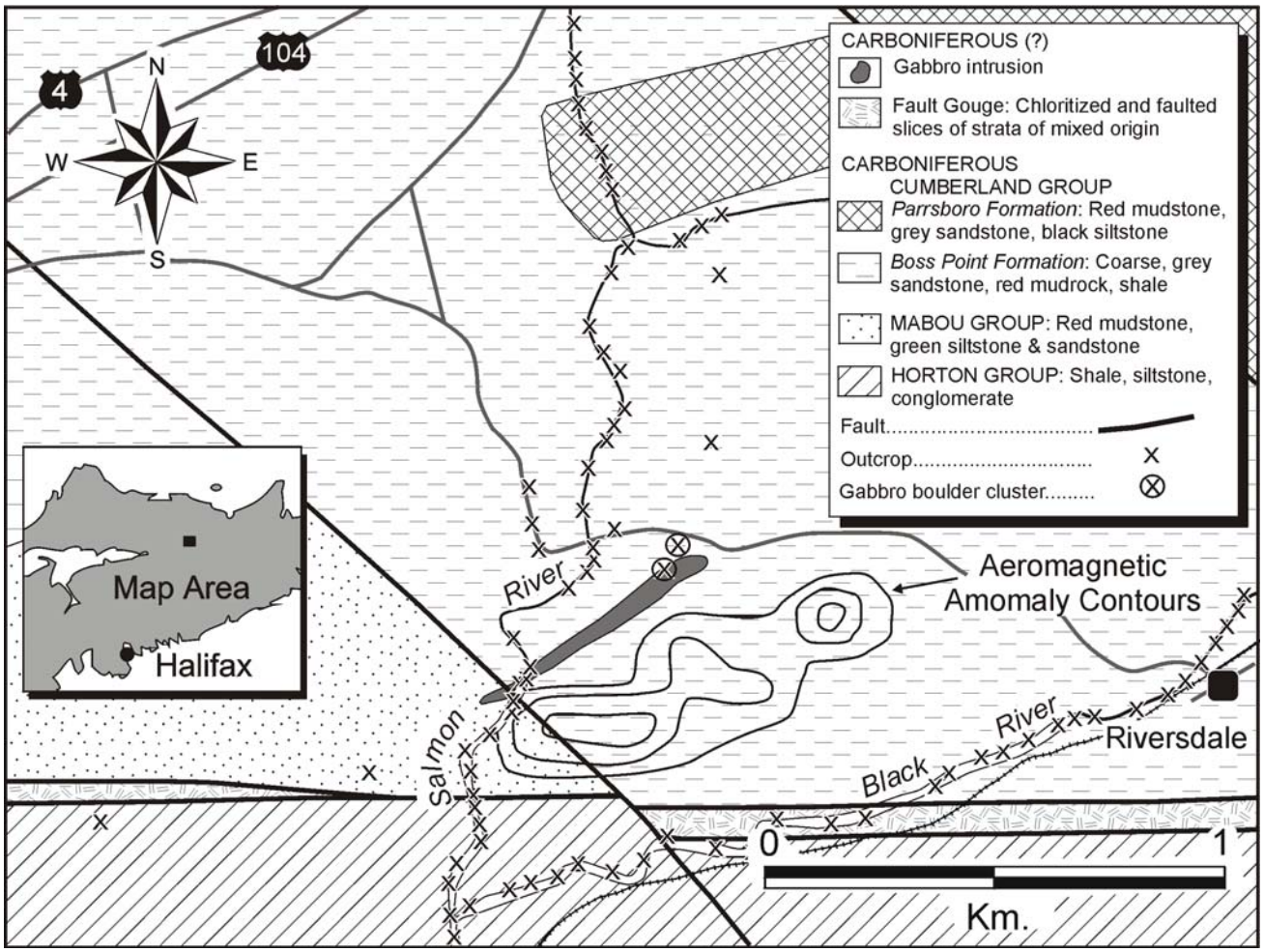

Figure 7. Geology map of the junction of the Salmon and Black rivers in eastern Colchester County, showing the location of the Salmon River gabbro.

this area failed to turn up outcrops of these rocks and, in some instances, it was found the felsite and syenite he reported were actually probably highly silicified and deformed (mylonitized) Horton Group slate. However, it is clear from outcrops that the major east-west Chedabucto Fault passes through the brook a couple of hundred metres south of the bridge on the Sunnybrae Road and forms the contact of the red-maroon siltstone and sandstone of the Mabou Group to the north with older grey slate of the Horton Group, which constitute the St. Mary's Graben to the south. Outcrops in the brook south of this structure are very considerably faulted and deformed and contain an abundance of ankerite specularite veins and associated hydrothermal alteration.

A pronounced magnetic high, elongate east-west for 1.5 km, underlies the trace of the Chedabucto Fault Zone a short distance west of John McDonald's Brook (Fig. 5). This area is found along the north-facing scarp of the St. Mary's Graben and, although no outcrops of gabbro are known, contains common boulders of coarse-grained gabbro highly veined with calcite and quartz and very much resembling the gabbro found at the Culloden Road intrusion. Boulder clusters of highly veined gabbro are common along the north face of the St. Mary's Graben in this region (Fletcher, 1892), and likely reflect the presence of many small intrusions or dykes emplaced along the major fault structures that mark this boundary. In all likelihood, the strong magnetic anomaly west of John McDonald's Brook represents an intrusion of this composition. Unfortunately, the contact relations of the pluton with its enclosing country rocks are not known, although Fletcher (1892) reports dykes and minor intrusions of such rocks in the Horton Group sediments.

Mount Thom Gabbros

Two complexes consisting of mixed mafic rock, metasediment and granite gneiss occur along the trace of the major, east-west Weatherby Brook Fault south of Steele Run near Mt. Thom (Fig. 9). The complexes correspond to an elongate magnetic high and diamond-drilling associated with exploration of the Mt. Thom Cu-Co-Au prospect, immediately to the north on the north side of Steele Run, has shown the anomalies are underlain by a mixed complex of gabbroic intrusive rock, slate, possible metavolcanics, minor granite gneiss and pegmatite (Mersereau, 1971). An examination of the diamond-drillholes (e.g. DDH-10; Mersereau, 1971) shows the rocks are indeed a mixture of rock types and their relationships are very much complicated by the high degree of faulting that has affected them. In addition, considerable hydrothermal alteration and injection of ankerite

Figure 8. Intrusive contact of the Salmon River gabbro with Boss Point Formation sediments exposed on Salmon River.

and calcite veins has overprinted the rocks and further complicates recognition of their relationships. It is clear, however, that examples of the reported rock types do exist except for perhaps the metavolcanic rocks, which may just be deformed intervals of fine-grained gabbro.

The fact that these rocks occur within or adjacent to a major fault structure, suggests that they may just be fault slices of lower Paleozoic basement rock brought into their current position tectonically. As such, they may be older than the surrounding Carboniferous Mabou and Cumberland group sediments.

Felsic Plutons

Mt. Thom Granite

Exploration of the Mt. Thom Cu prospect by Esso Minerals in the early 1970s recognized the presence of granite, granite breccia and granite porphyry in diamond-drill core and outcrop (Mersereau, 1971). The granite is found within a very highly faulted zone exposed along an unnamed brook that flows north into Steele Run (Fig. 9). The main Mt. Thom mineralized showing is found immediately to the north, on the north side of Steele Run. A diamond-drill hole (Mersereau, 1971; DDH #43) was collared to drill north under some outcrops of the pinkish granite exposed on the brook, where the brook meets the powerline that passes through the Mt. Thom region (Fig. 9).

An examination of the drill core from DDH #43, and mapping along the brook between the powerline and Steele Run, shows that granite is present and that the section is clearly within a major fault zone and, in fact, may be at the at the junction of two major faults. The east-west Weatherby Brook Fault is known to pass through this area and serves to separate Mabou Group

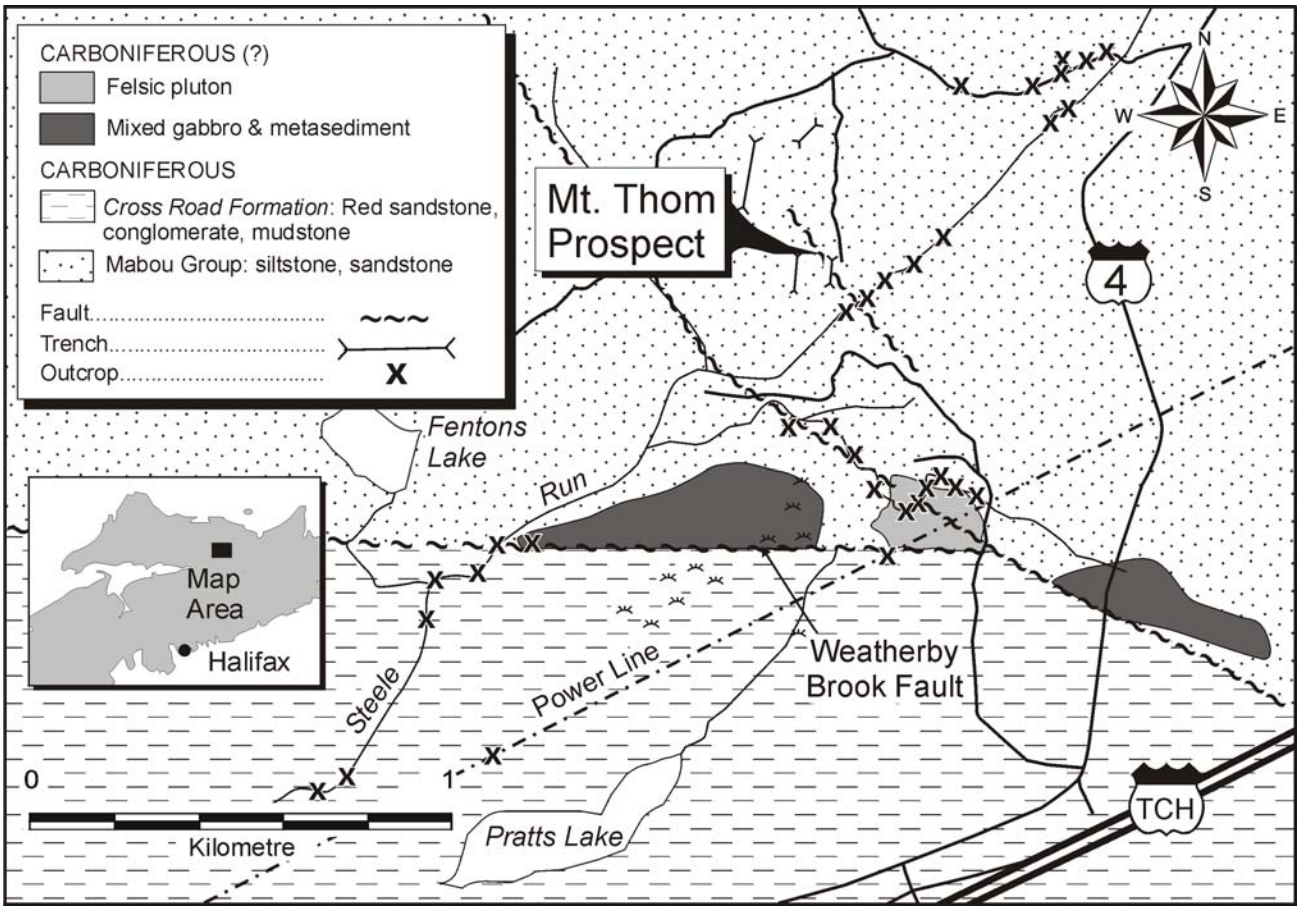

Figure 9. Geology of the Mount Thom Cu-Co-Au prospect and surrounding area showing the location of felsic and mafic intrusions along the Weatherby Brook Fault.

siltstone and sandstone to the north from the conglomerate and maroon sandstone of the Cumberland Group to the south. In addition, exploration geologists with Esso concluded that a northwest-trending fault crossed the Mt. Thom property and its trace would pass through the area of the unnamed brook. Regional mapping carried out as part of the TGI-2 project provides support for the existence of such a northwest-trending fault (Naylor *et al.*, 2005).

Although the contact relations of the granitic rocks in this area are very complicated and, in many cases, obliterated by faults, there is still evidence that the felsic rocks actually intrude Carboniferous Mabou Group sediments. Within the top 55 m (181 ft.) of DDH #43 there are several intersections of mixed granite-pegmatite dykes, some of which have sharp intrusive contacts with highly faulted and hydrothermally altered sediments. A granite porphyry breccia extends from 13 m to a depth of 45 m, and contains so many fragments of sediment that Esso geologists logged it as granitized sediment. Pegmatitic granite is found at 46, 53 and 55 m depths. From 72-73 m a fine-grained pink aplitic phase is in intrusive contact with a fine-grained greenish siltstone, probably of the Mabou Group (Fig. 10).

Outcrops of pinkish granite, porphyritic granite and brecciated granite are found locally along the unnamed brook north of where it crosses the powerline (Fig. 9). As is the case with the diamond-drill core of DDH #43, subsequent faulting has obliterated much of the original contact relations. In several places, however, one can see a fining of grain size in the granite toward contacts with the country rock sediment, suggesting chilling during intrusion. Furthermore, the compositional variability of the granite is worthy of consideration. Examples of fine-grained aplite, fine- to medium-grained granite and granite porphyry, and pegmatite are all present. This suggests that greatly varying conditions prevailed during emplacement of the felsic melts, and/or there were multiple injections. If the granite was simply the result of tectonic emplacement of fragments of previously crystallized Cobequid Highlands plutons, one would not expect such textural variation, unless there was the fortuitous situation where the pluton

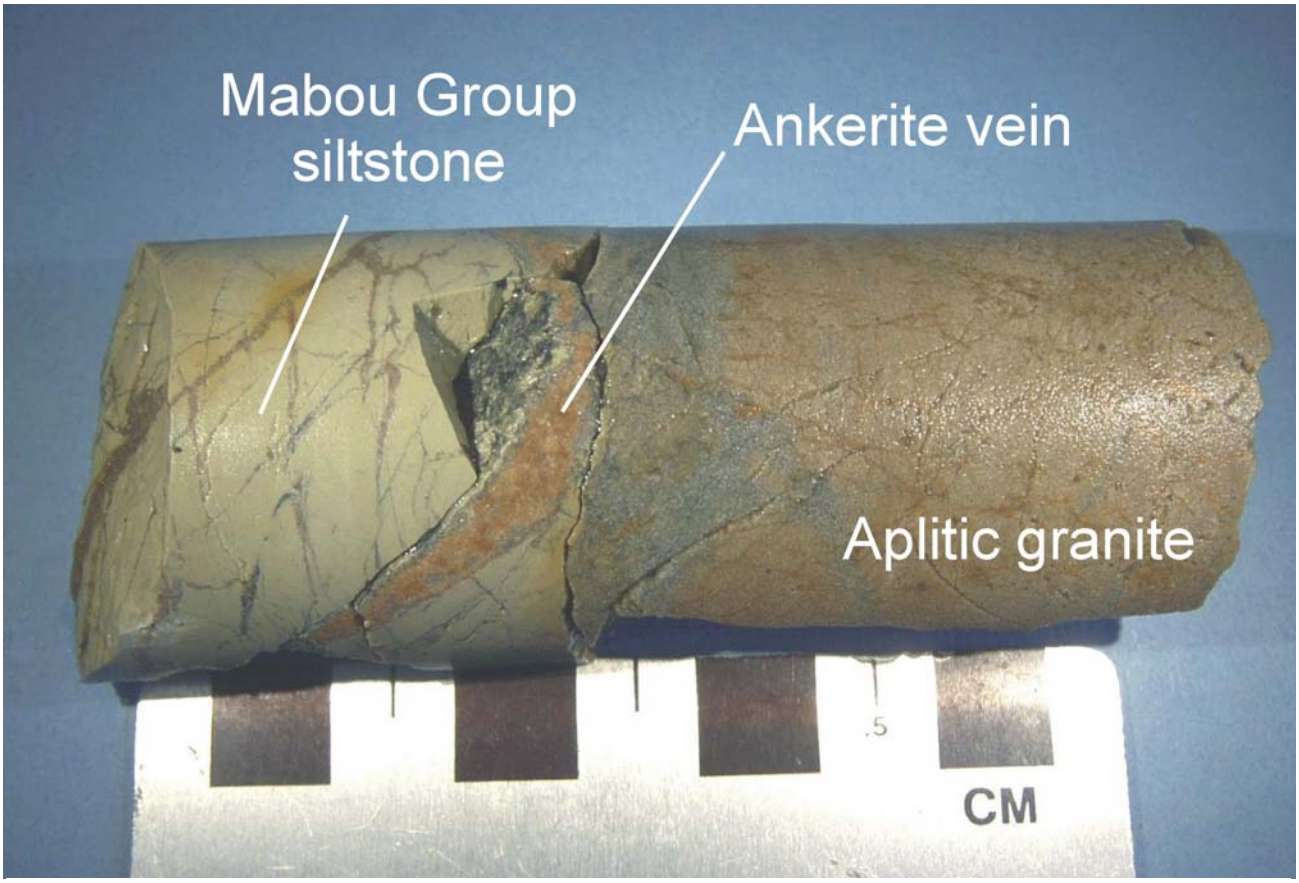

Figure 10. Photograph of a sample of diamond-drill core from DDH #43 of Esso Resources Canada from the Mount Thom prospect showing the contact of fine-grained, pink, aplitic granite with Mabou Group siltstone.

from which the fault wedges originated was itself texturally variable and inhomogeneous in composition. That situation is possible, but unlikely. It is more likely that a late-stage, felsic melt was emplaced into an active fault zone and the resultant variability of texture and composition is indicative of the changing physical and chemical conditions typical of such a situation.

Lorne Gneissic Granite

A currently producing aggregate quarry has exposed a small pluton of gneiss of hybrid composition that has a pronounced planar fabric trending 082° and dipping 78° north (Fig. 2). Fletcher (1892, p. 149P) made note of "many large blocks of green-grey, white veined gneissic diorite, the veins being compact or granular felsite." Benson (1967b) showed a single outcrop of granite in his geology map of the area.

The current quarrying operation has exposed the entire pluton. Most of the pluton has an overall monzonitic composition but portions of a more mafic dioritic composition are found, as well as pinkish rapikivi-textured granite and alaskite zones. Generally, the zones of rapikivi granite occur as monzonite in which layers of pink, K-feldspar-rich granite occur parallel to the well developed gneissic fabric. This gives the rock an overall pinkish granite look.

The contact of the pluton with the enclosing Mabou Group sediments is well exposed and the contacts are roughly parallel to the planar fabric within the pluton. This suggests that the fabric within the pluton may have developed in response to emplacement of the body into its current position. Furthermore, the degree and intensity of the planar fabric clearly increases toward the contact with the sediments. It is important to note, however, the presence of ductile deformational textures within the pluton, things like mylonitic zones, rolling of K-feldspar and quartz phenocrysts. By contrast, the contacts for the most part are fault breccias with slickensided fracture surfaces which are indicative of more high level, brittle deformation.

Evidence of hydrothermal alteration and associated specularite and sulphide mineralization abound throughout the quarry and especially toward the more deformed contact zones. In addition, the brecciated Mabou Group contact rocks are also hydrothermally altered and, in places, actually healed due to influx of carbonate and quartz into the breccia matrix. Much of the specularite mineralization is secondary and occurs filling fractures and as disseminations throughout breccia, but there are also examples of large blades of the mineral occurring within and adjacent to layers of rapikivi granite, suggesting a metasomatic origin related to the formation of the granitic layers.

Since all the observed contacts of the pluton are faults, no conclusion can be made as to whether the gneiss actually intrudes the Mabou Group or was simply brought into position by subsequent faulting. It must be said that the forces necessary to raise the pluton to a gneissic character are far more than would seem to be available at its current level of exposure. This would suggest the gneiss formed at greater depth and was brought into its current position by faults. This is not to say the pluton is not Carboniferous in age, just that it was not likely intruded to this level. A sample of the pluton is currently being age dated and this may further shed light on this aspect of its development.

Lorne Station Granite and Gabbro Complex

About 1 km northwest of the Lorne Gneiss is another operating aggregate quarry, just west of Lorne Station (Fig. 2). Benson (1967b) indicates a few outcrops of granite adjacent to the road. In the woods west of these outcrops and at the top of a prominent topographic high the current quarry operation has exposed a fairly substantial face within a mixed pink granite and gabbro complex. The rock consists of pink, medium-grained granite intruding greenish, fine-grained and somewhat altered gabbro. The rocks here very much resemble those found in the quarrying operations in the Cobequid Mountains in the area of Mt. Thom and Six Mile Brook west of Scotsburn and Saltsprings, Pictou County. Unfortunately, the quarry has yet to expose any of the Carboniferous country rock known to surround this topographic high, so no conclusions can be made as to the geological relations. However, the similarity of these rocks, compositionally and texturally, to those in the quarry operations in the Cobequids to the north, suggest the rocks here represent a basement block brought into its current position by faulting.

Trafalgar Granite

Fletcher and Faribault (1901) indicate a small intrusion of syenite outcropping on the West River St. Mary's just downstream from Trafalgar, Pictou County. Benson (1967b) also indicates the intrusion on his geology map as do Giles *et al.* (unpublished map) on their map of the Liscomb Complex. The section was examined in 2004 (Fig. 11) and the rock was found to be a muscovite-bearing monzogranite and, although deformed and with a weak planar fabric, resembles granitic phases typically found within the Meguma Zone. There is apparently no evidence to support calling the rock a syenite, as was done by Fletcher and Faribault (1901). Evidence suggests the entire block of granite is fault-bounded and is almost, if not entirely, surrounded by Horton Group clastic sedimentary rocks. The Horton Group shows no evidence of the thermal effects of intrusion. It appears the granite is merely a faulted-in remnant from one of the monzogranite plutons in the Liscomb Complex, which underlies a large area to the south.

Summary

The Carboniferous rocks of central Nova Scotia are host to several plutons of mafic and felsic

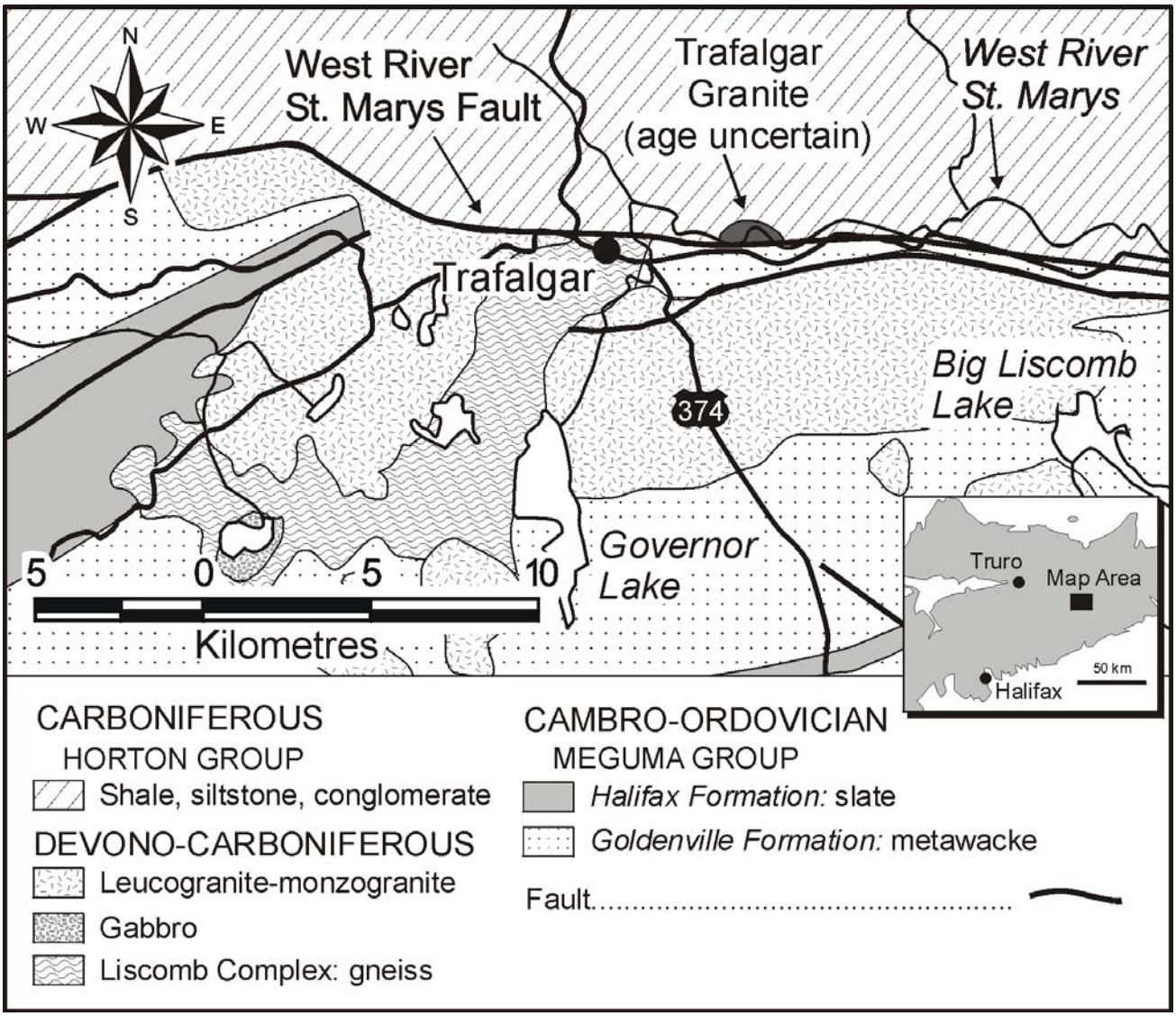

Figure 11. Geology of the Trafalgar area of northwest Guysborough County showing the location of a fault-bounded outlier of granite along the West River St. Marys Fault.

composition. There is an obvious spatial association between the plutons and fault splays related to the regional Cobequid-Chedabucto Fault Zone. This suggests that faults have played a role in emplacement of the plutons, albeit by serving as host to melts rising along the faults, or by tectonically dislodging portions of older intrusive rock and bringing them into their current position by the movement of the faults themselves. Unfortunately, the original contact relations of the plutons with their enclosing country rocks are complicated or, in some cases, completely obliterated by subsequent movements along the fault zones.

Fletcher (1902 a and b), in geology maps of southern Pictou County and eastern Colchester County, indicates numerous small mafic and felsic intrusions in the Carboniferous rocks. Fletcher (1892) makes frequent mention that at least some of these intrusions intrude their enclosing host rocks, as opposed to simply being faulted into place along faults related to the CCFZ. At some of the sites (Limerock and John McDonald Brook) it was found that highly bleached and altered sandstone units were mistakenly identified as felsite. However, there are many sites at which mafic and felsic intrusive rocks are definitely present. Field examinations in 2004 have shown that some of these plutons are emplaced along fault structures and have had their contact relations obliterated, or so complicated by post-emplacement fault movements, that their origin still remains a mystery (e.g. Lorne Gneissic Granite, Lorne Station Granite and Gabbro Complex). At some sites though, intrusive relations are present that indicate the plutons actually intrude their enclosing sediments (e.g. Moiche Hill Gabbro and Carbonate Breccia, Centredale Gabbro, Marshdale Gabbro, Salmon River Gabbro and East Mountain Gabbro, Mt. Thom Granite).

The observed field relations indicate mafic intrusions definitely intrude Carboniferous sediments of the Windsor Group (East Mountain Gabbro), Mabou Group (Moiche Hill, Marshdale, Centredale gabbros and Mt. Thom granite) and Boss Point Formation (Salmon River Gabbro). The youngest Carboniferous rocks observed to be intruded belong to the Boss Point Formation.

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