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Field Trip B1

Accretion of peri-Gondwanan terranes, northern mainland Nova Scotia and southern New Brunswick

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ACCRETION OF PERI-GONDWANAN TERRANES, NORTHERN MAINLAND NOVA SCOTIA AND SOUTHERN NEW BRUNSWICK

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ITINERARY

The trip begins when we depart from the Student Union building on the Dalhousie University campus at 6:00 pm on Wednesday (May 18th), en-route to St. Francis Xavier University in Antigonish, and officially concludes at approximately 5 pm in Saint John on Saturday (May 21st). For those flying out of Halifax on Sunday, at least one of the vans will be returning to Halifax on Saturday evening. The drive from Saint John to Halifax is about 4.5 hours so we don't expect to arrive until very late in the evening. Participants are responsible for their own accommodations in Halifax and/or Saint John before and after the trip.

Accommodations on Wednesday (Antigonish), Thursday (Stellarton) and Friday (Saint John), the evening meal on Thursday, breakfasts on Thursday and Friday mornings and bagged lunches for all 3 days are included. Anyone with food allergies should let the trip leaders know ahead of time so appropriate meal arrangements can be made.

Day 1: (Thursday) Meet for breakfast on campus at Saint Francis Xavier University (time to be arranged Wednesday evening). Visit field stops in the Antigonish area. Depart at approximately 5 pm for the Heather Motel in Stellarton (maximum 1 hour drive). Dinner at the Heather Motel.

Day 2: (Friday) Meet for breakfast at Heather Motel (time to be announced) and then depart for the Cobequid Highlands field stops. Mid-afternoon depart for Saint John, New Brunswick (approximately 3.5 - 4 hour drive). Arrive at the Coastal Inn Fort Howe in Saint John in the early evening. Meet for dinner in the city (time and location will be discussed when we arrive).

Day 3: (Saturday) Meet for breakfast (location and time to be announced). Depart Coastal Inn on foot to examine outcrops in the city of Saint John for Stop 3-1. Return to Coastal Inn and drive to the Pocologan – St. George area for the remainder of Day 3 field stops. In the late afternoon we return to Coastal Inn (Saint John). Van(s) depart for Halifax.

SAFETY

For safety reasons field trip participants are advised to take note of the following precautions. Most of the field stops are road side or coastal but some will involve light hiking. Participants are advised to wear appropriate clothing and footwear that will include gear suitable for both wet and cold conditions. Participants are also reminded that safety goggles are recommended when hammering any outcrop and before doing so, please check that no one is standing too close. Please be aware of the following specific safety hazards on this trip:

Day 1 Stops 1-1 to 1-8 will be on the shore of the Northumberland Strait. Rock outcrops on the coast are generally covered with seaweed and are very slippery. Please use caution and common sense when traversing the shoreline exposures and make sure to secure good footing.

Day 2 Stops are mostly located along woods roads, with the exception of stop 2-1 and 2-6 which will be in quarries. The Weeks quarry (Stop 2-1) is an active quarry, therefore, use extreme caution, avoid moving quarry equipment and follow the instructions given by the field trip leaders. Pay special attention to loose rocks on the higher quarry walls and participants are urged to examine rocks in loose blocks on the quarry floor. Hard hats are required when examining quarry faces.

Also be aware of slippery rock surfaces in the river bed at Stop 2-7. On woods roads stay on the shoulder of the road and watch for speeding logging trucks, especially at Stops 2-8 and 2-12 where there are blind corners. At road side outcrops please heed traffic and watch for falling rocks at stops 2-11 and 2-12, at which there are rather loose cliff faces.

Day 3 Stops will largely be along major highways, arterial roads and city streets which receive a lot of vehicle traffic; therefore, be extremely careful when examining these road-cuts. Park in a safe manner and do not cross the road to examine outcrops. Stop 3-1 in the City of Saint John will take us through heavy traffic areas; participants are urged to be aware of traffic, stay on the sidewalks, and cross only at pedestrian crossings. Stops 3-2 to 3-5 (inclusive) are on woods roads.

Please watch for logging trucks and other traffic and be wary of falling rocks when approaching cliff faces. Take special care on the outcrops along the shore at stops 3-6 and 3-7. The rocks are very slippery and seaweed covered so use caution and secure good footing before moving along the outcrop. Please be aware of the fishing boats and activities at the wharf on stop 3-7.

INTRODUCTION

The diverse geology of the Maritime Provinces of Canada is a reflection of its location within the northern Appalachian orogen, which has long been recognized as a collage of distinct tectonostratigraphic zones or terranes (e.g., Williams 1979). These terranes record a protracted (ca. 250 Ma) Paleozoic accretionary history involving major oblique collisional events which marked the sequential docking to Laurentia of non-Laurentian outboard terranes and microcontinents, including Gander, Avalon, Meguma, and perhaps others (Fig. 1). These events culminated in the collision of the Gondwanan and Laurentian continents as the intervening Iapetus and Rheic oceans closed (e.g., van Staal *et al*. 1998, 2004a).

Rocks in southern New Brunswick, northern mainland Nova Scotia, and central and southern Cape Breton Island (Fig. 2) mainly record the mid-Paleozoic convergence of Gander and Avalon, and possibly other separate intervening terranes, which culminated in the late Silurian - early Devonian Acadian Orogeny. This event is now recognized as distinct from a younger mid-Devonian orogenic event termed the Neo-Acadian Orogeny, which is the dominant event recorded in the Meguma terrane of southern Nova Scotia (van Staal *et al.* 2004a). On-going oblique convergence and strike-slip motion along boundaries between the previously assembled terranes is recorded in diverse and protracted tectonism during the Late Devonian to Permian. The ultimate docking of Gondwana (Africa) resulted in the Late Carboniferous to Permian Alleghanian Orogeny, the effects of which were felt in coastal southern New Brunswick and along strike in the Cobequid and Antigonish Highlands and southern Cape Breton Island.

Many aspects of this history are controversial. Perhaps most fundamental is the definition and extent of Avalon Zone, Avalonia, or “Composite Avalon”, as it is variously called. In southern New Brunswick, some workers (e.g. Park and Whitehead 2003; Robinson *et al*. 1998; Tucker *et al*. 2001) place the boundary far inboard at the Norumbega-Fredericton fault system, so that the outboard areas termed the St. Croix, Mascarene, New River, Kingston, Brookville and Caledonia belts or terranes are all included in Avalon Zone, Avalonia, or Composite Avalon. Other workers include the St. Croix, Mascarene, New River and Kingston terranes in Gander (or Ganderia) and place the Gander-Avalon boundary between the Kingston and Brookville terranes (e.g., Fyffe *et al*. 1999), or at the boundary between Caledonia and Brookville terranes (White *et al*. 2001; Barr *et al*. 2002). In the latter interpretation, the Caledonia terrane and similar areas in the Cobequid and Antigonish Highlands and southeastern Cape Breton Island have been termed Avalon terrane *sensu stricto*, to distinguish them from the broader area of Avalon Zone, Avalonia, or Composite Avalon. Whether the Brookville terrane is part of Gander, or Avalon, or a separate microcontinental block (“Bras d’Oria”) is also controversial (Barr and White 1996; King and Barr 2004). To further complicate the interpretations, some workers think that the components of Avalon Zone, Avalonia, or Composite Avalon, however broadly defined, docked as a single microcontinent or “composite terrane”, whereas others (e.g., Barr *et al*. 2002) consider them to have been separate peri-Gondwanan fragments that docked sequentially.

The controversy extends to Cape Breton Island, where the Avalon-Gander boundary has been variously placed at the Mira-Bras d’Or boundary (the nature of which is obscured by Devonian and younger rocks; King 2002), the Bras d’Or - Aspy boundary (Eastern Highlands Shear Zone), the Aspy - Blair River Inlier boundary (Wilkie Brook - Red River faults), or even in the Gulf of St. Lawrence north of Cape Breton Island, with all of the island in Avalon (Williams 1978; Keppie *et al*. 2000).

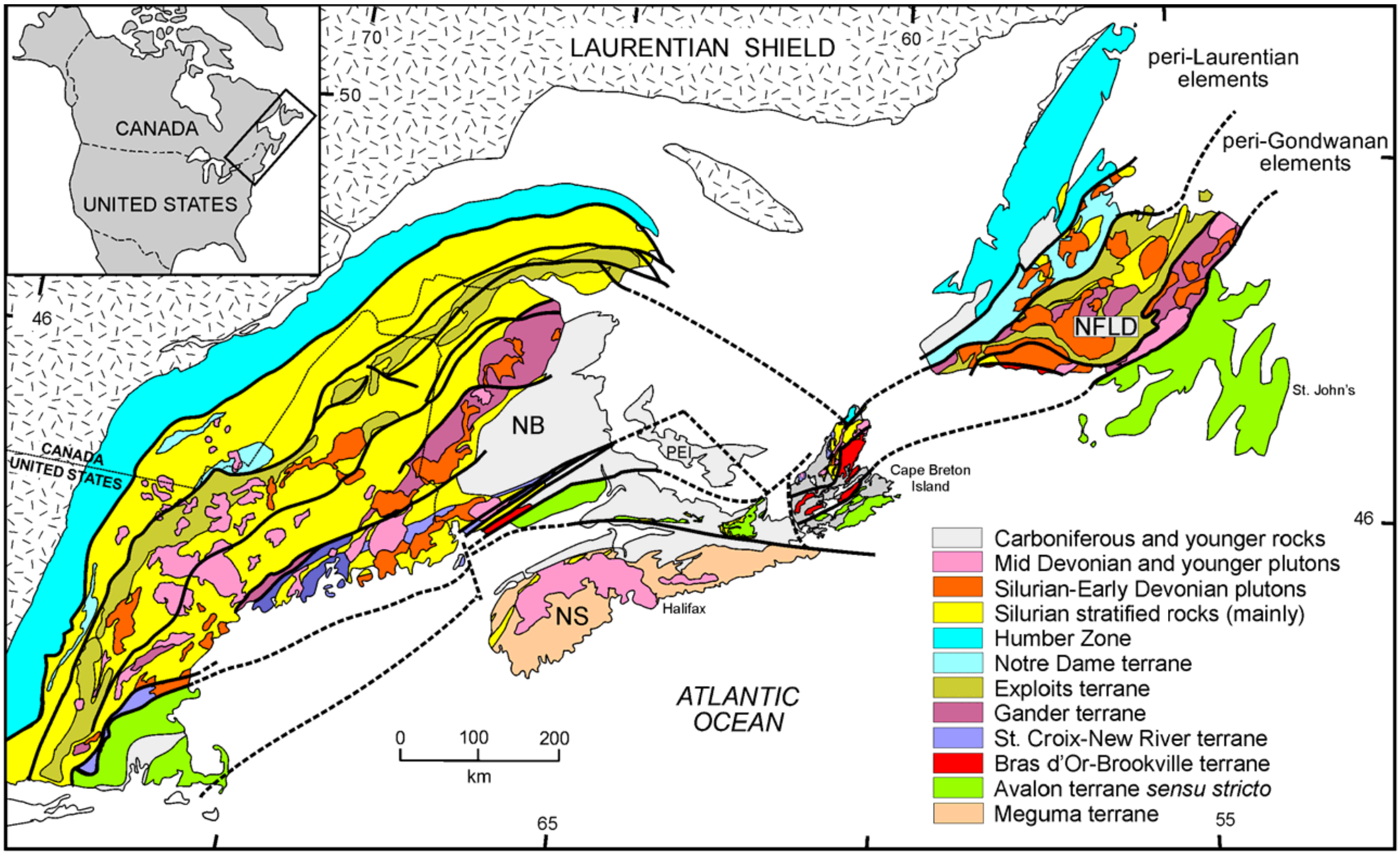


Figure 1. *A simplified geological map showing terranes in the northern Appalachian orogen, modified after van Staal et al. (1998) and Hibbard et al. (in press).*

In contrast to the complexity and controversy in southern New Brunswick and Cape Breton Island, general agreement exists that both the Antigonish Highlands and Cobequid Highlands are entirely part of the Avalon terrane *sensu stricto*. One explanation is that these areas originated farther inboard (i.e. east in present coordinates) within Avalon terrane *sensu stricto*, and have been brought into their present position by dextral offset on the Canso fault system (Fig. 2). Although the boundary is now marked by a major fault (Cobequid-Chedabucto fault system), the extent of Avalon to the south is also controversial, with some workers interpreting the Meguma terrane to have formed on Avalonian crust in contrast to the traditional view that Meguma terrane was exotic and tectonically placed over Avalon terrane in the Devonian (Murphy *et al*. 2004a).

Not surprisingly, with dispute about whether or not the areas termed Avalon Zone, Avalonia, or Composite Avalon docked as a single microcontinent or as separate terranes, the polarity of subduction between “Ganderia” and “Avalonia” is controversial. Some workers (e.g., van Staal *et al*. 2004a; Barr *et al*. 2002) suggested that the oceanic rocks were subducted beneath Ganderia to the northwest; however, evidence from Maine and southwestern New Brunswick has been interpreted to contradict this idea, suggesting evolution of the area above a southeast-dipping subduction zone (Tucker *et al*. 2001; McLeod 2004). If the interpretation of Barr *et al*. (1998, 2002) is correct, then no Avalon terrane *sensu stricto* is present in Maine (Fig. 1).

The Avalonian microcontinent (or possibly the Bras d’Oria microcontinent; Barr *et al*. 2002) probably arrived at the margin of Ganderia in the Silurian, marking the onset of the Acadian Orogeny (van Staal *et al.* 2004a). This event likely produced the voluminous plutons of Late Silurian to Early Devonian age (ca. 423-390 Ma) in southern New Brunswick. The cause of the Neo-Acadian orogeny in the mid Devonian (ca. 400 – 390 Ma) and subsequent voluminous pluton emplacement (ca. 380-370 Ma) in the Meguma terrane has been attributed to the accretion of Meguma to Avalon (van Staal *et al*. 1998), however, no evidence for this deformation has yet been documented in Avalon. This model is further complicated by the suggestion that Meguma and Avalon were contiguous throughout the Paleozoic (e.g. Murphy *et al*. 2004a) hence in this scenario their collision could not be responsible for Neo-Acadian orogenesis. Murphy *et al.* (1999) attributed the voluminous magmatism at ca. 380-370 Ma in the Meguma terrane and at ca. 360-355 Ma in the Cobequids Highlands to passage of the area over a mantle plume, although some believe this model does not adequately explain magmatism at ca. 375 Ma in Cape Breton Island and at ca. 367-360 Ma in southern New Brunswick. The late Paleozoic closure of the Rheic Ocean during final amalgamation of Gondwana with Laurentia and its collage of accreted terranes resulted in the Alleghanian Orogeny, the effects of which were mostly concentrated in the Meguma terrane, along the Cobequid - Chedabucto Fault Zone in Nova Scotia and throughout coastal southern New Brunswick (e.g., Nance 1987).

As indicated by the title, on this trip we examine terranes in northern mainland Nova Scotia and southern New Brunswick that are associated with the eastern (peri-Gondwanan) margin of the Iapetus Ocean. We will investigate the timing and mode of Mid-Paleozoic accretion of peri-Gondwanan terranes and their significance for the Acadian and Neo-Acadian orogenies. Specific emphasis will be placed on the nature of the boundaries between Neoproterozoic terranes and their relationships with Cambrian through Carboniferous cover sequences in the Antigonish and Cobequid highlands in Nova Scotia and along a southern New Brunswick transect. In contrast to the Avalonian rocks of the Antigonish and Cobequid highlands, Neoproterozoic and Early Paleozoic rocks in southern New Brunswick have been variously allied with both the Ganderian and Avalonian microcontinents, or regarded as separate from either (Brookville terrane).

While most authors are in agreement on the affinity of the most outboard and inboard of these belts, what lies between has been the subject of considerable debate. Numerous models have been invoked to explain the relationships and interactions among these belts in southern New Brunswick; however they remain controversial. Hence discussion on this trip is likely to be lively. The trip is a companion to the Special Session "Assembling Avalon and other peri-Gondwanan terranes".

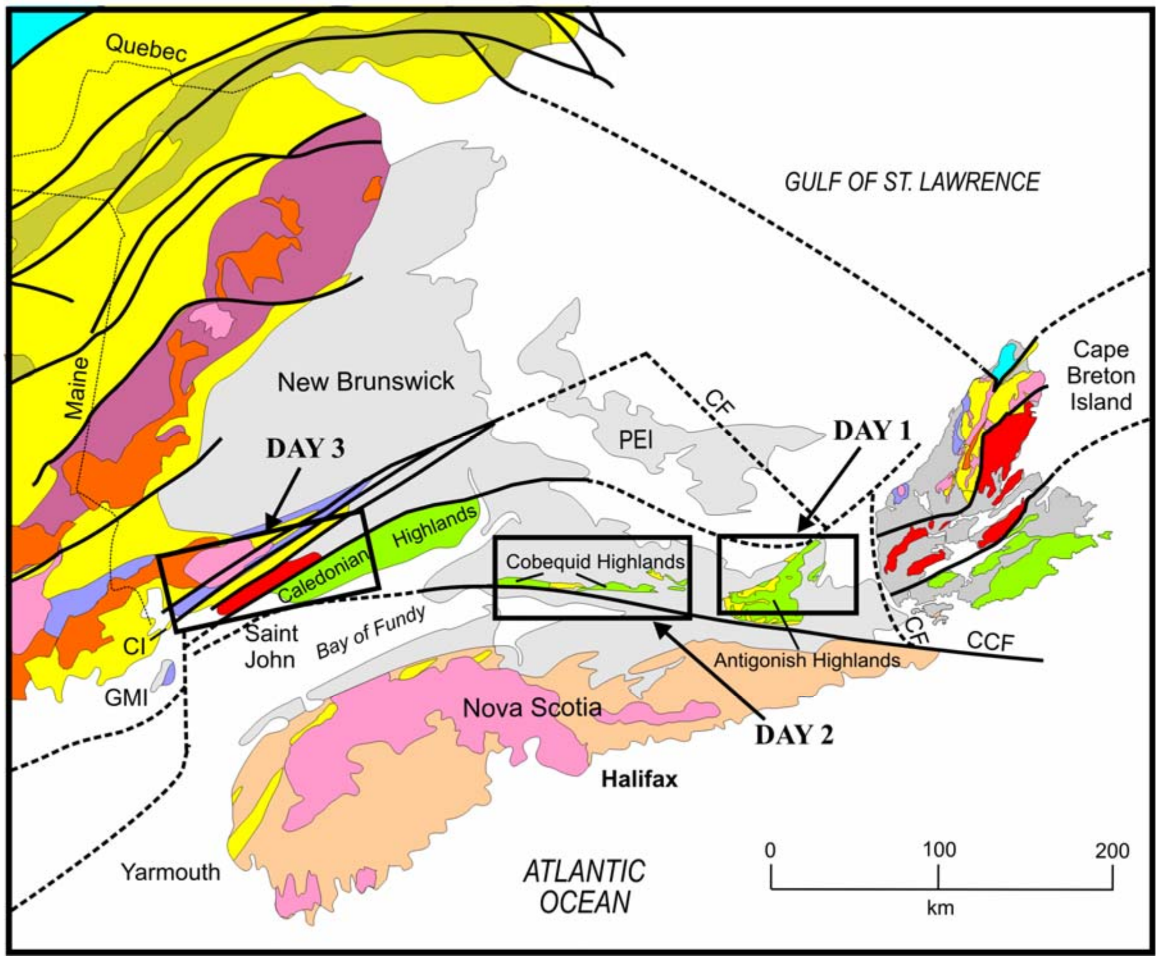


Figure 2. *A more detailed view of figure 1 showing the Maritime Provinces and the locations for Days 1, 2, and 3 of this field trip. Legend as in Fig. 1. GMI – Grand Manan Island; CI – Campobello Island; CCF – Cobequid Chedabucto Fault; CF – Canso Fault.*

DAY ONE
EVOLUTION OF THE RHEIC OCEAN - ANTIGONISH HIGHLANDS

Leader: J. Brendan Murphy

PURPOSE

Day one of the field trip concentrates on the Neoproterozoic and Paleozoic evolution of the Antigonish Highlands which preserves evidence of its early (Neoproterozoic-Cambrian) Gondwanan history, its drift from Gondwana and accretion to Laurentia (Ordovician-Silurian) and the effects of closure of the Rheic Ocean in the Carboniferous.

GEOLOGIC SETTING

Neoproterozoic rocks

The Antigonish Highlands (Fig. 1-1a) are predominantly underlain by Neoproterozoic rocks of the ***Georgeville Group***, which record the progressive development of a sedimentary basin in an arc regime (Murphy and Keppie 1987; Murphy *et al*. 1990). The stratigraphically lowest rocks of the Georgeville Group occur in the northern and southern parts of the highlands, whereas the stratigraphically highest rocks occur in the central highlands. Geochronological evidence (below) indicates that all formations in the Georgeville Group were deposited penecontemporaneously (Fig. 1-1b).

The Georgeville Group is divided into seven formations. Of these, three occur in the coastal fault block (**Stops 1-1 and 1-2,** Fig. 1-2) and the other four crop out in fault blocks inland. The lowest unit exposed in the coastal fault block is the Chisholm Brook Formation. It consists of interlayered calc-alkalic mafic to intermediate flows, tuff, marble and mudstone in the west, and flows and tuff pervasively intruded by dykes in the east (Fig. 1-2). The overlying Morar Brook Formation is made up mainly of black porcelainous mudstone interbedded with thin siltstone and chert horizons and rare thin limestone and conglomerate beds. These rocks are overlain conformably by the Livingstone Cove Formation containing conglomerates interbedded with the black mudstone and siltstone. The conglomerate horizons typically have channeled bases and the clasts are generally supported by a sandy volcaniclastic matrix exhibiting not obvious grading. Pebbles in the conglomerates are predominantly of volcanic origin with some of granite and locally derived black mudstone. The youngest detrital zircon from the formation yields 613 ± 5 Ma (single zircons, TIMS, Keppie *et al*. 1990, 1998) and provides a maximum depositional age for the formation. In addition to a late Neoproterozoic detrital zircon population (0.61-0.62 Ga), other single grain detrital zircon analyses yield populations of ca. 1.1 to 1.2 Ga, 1.5 Ga, 1.8-2.0 Ga and 2.6 Ga, which is interpreted to reflect derivation from the Amazonian craton of Gondwana (single zircon, TIMS; Keppie *et al.* 1998).

The central part of the highlands is dominated by the Maple Ridge Formation (correlated with the Morar Brook Formation), which consists mainly of black and green slate interbedded with greywacke and minor basalt. It is conformably overlain by the James River Formation (regarded as a facies equivalent of the Livingstone Cove Formation). At the base, this formation is mainly volcaniclastic conglomerate, greywacke and slate, grading upwards through green wacke, slate and minor basalt into predominantly green laminated slate at the top. This formation is, in turn, conformably overlain by submarine mafic volcanic rocks interbedded with some greywacke, slate and rare rhyolite flows of the Clydesdale Formation. The mafic rocks have within plate, tholeiitic affinities (Murphy *et al*. 1990), thought to reflect rifting in a volcanic arc environment. This formation grades up into the South Rights Formation consisting mainly of slate with minor greywacke and basalt.

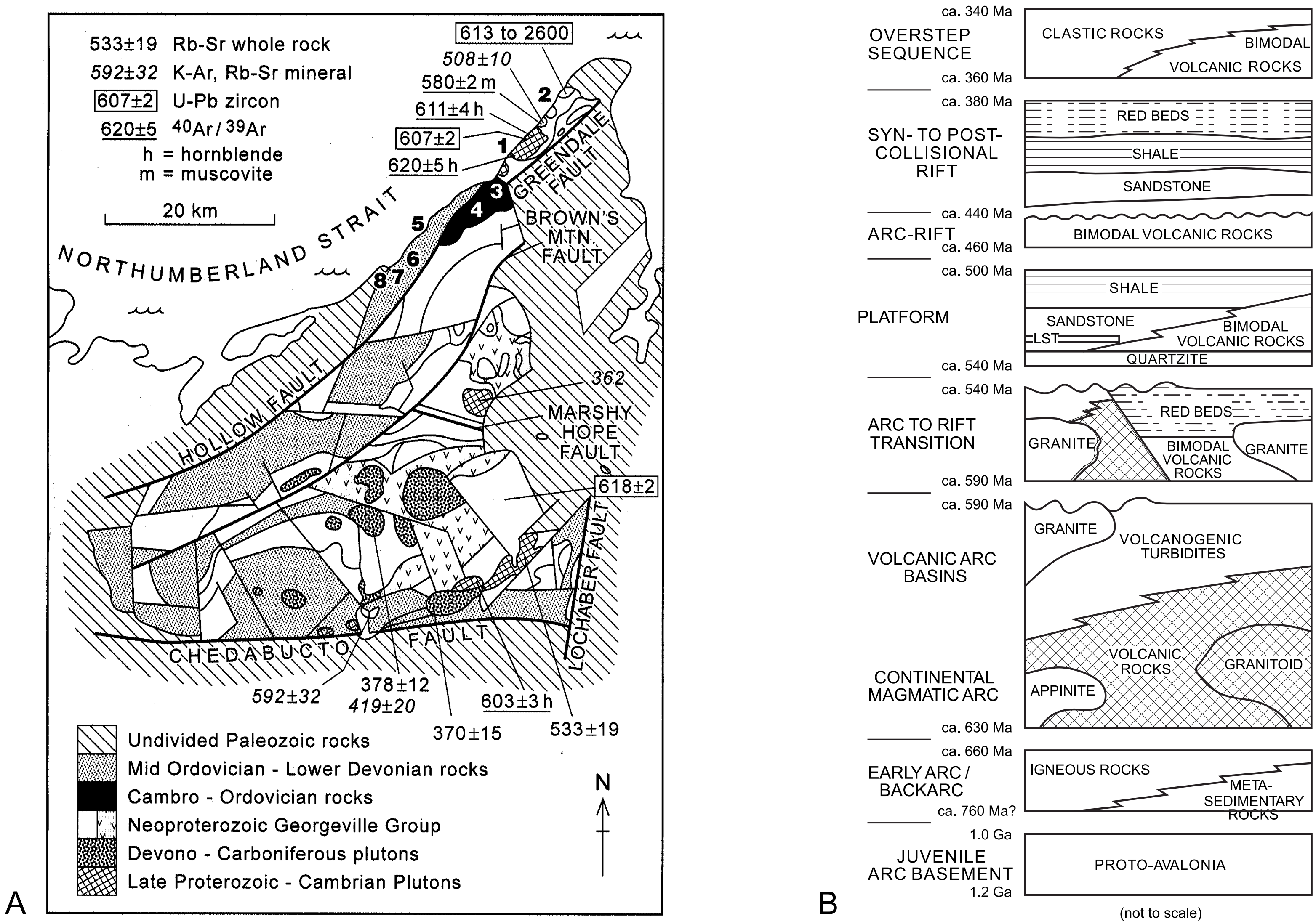


Figure 1-1. *a) Summary of the geology of the Antigonish Highlands and general location of field stops. For details see Murphy et al. (1991). b) Tectonostratigraphy of the Antigonish Highlands (modified from Murphy et al., 1991; Murphy and Nance 2002). Arisaig Group is 440-380 million years old and is classified as a syn-to post collisional rift basin.*

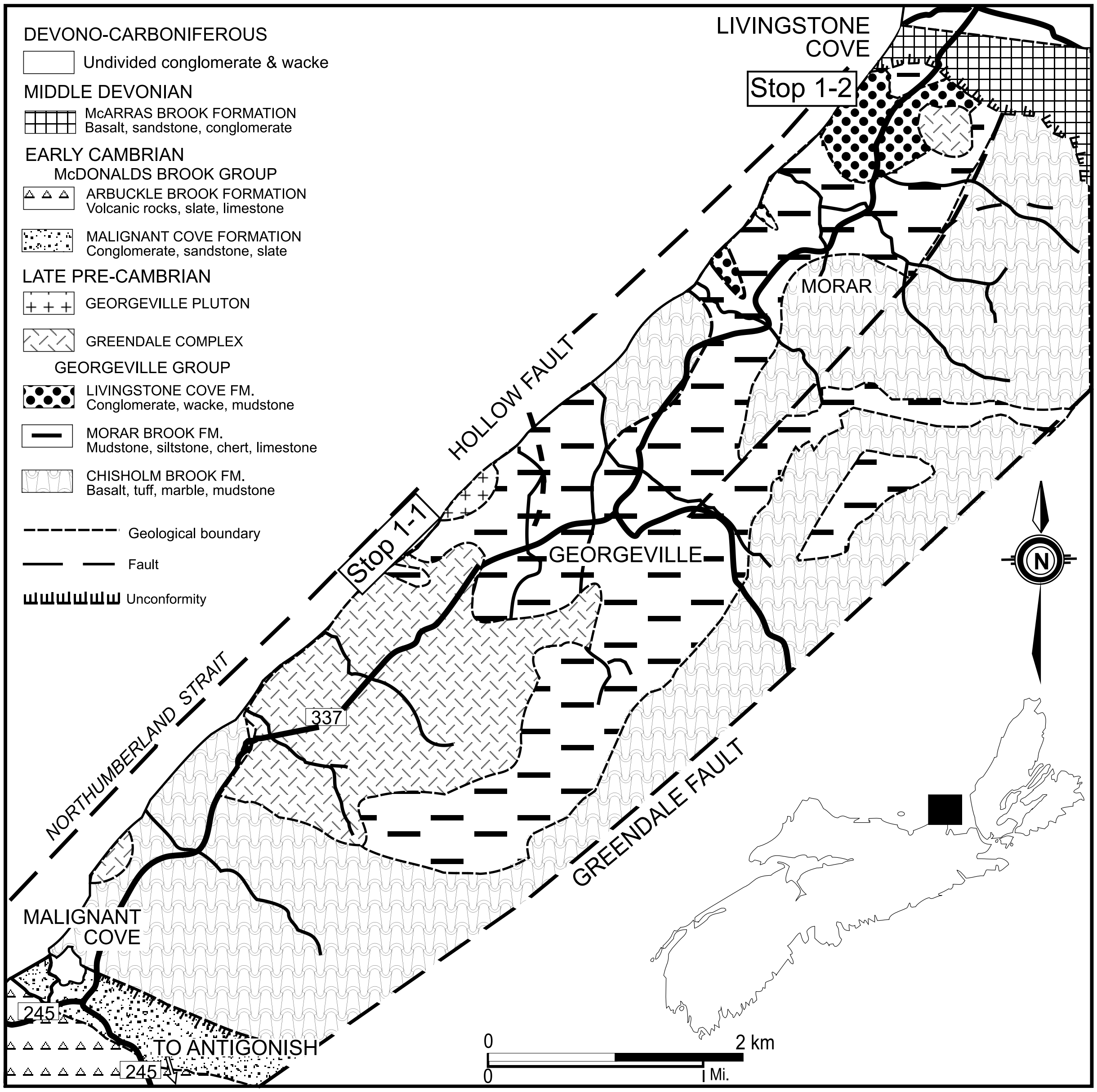


Figure 1-2. Summary geological map of the coastal block between the Greendale and Hollow Faults, emphasizing Neoproterozoic rocks of the Georgeville Group, Greendale Complex and Georgeville Granite. General location for Stops 1-1 and 1-2.

In the southern highlands, turbidites of the James River and South Rights River formations overlie the Keppoch Formation, which consists of a thick interlayered sequence of felsic, intermediate and mafic volcanic rocks with minor subaerial to shallow marine sedimentary rocks. The felsic and intermediate volcanic rocks have arc compositions, whereas the mafic rocks consist of low-Ti calc-alkalic and high-Ti tholeiitic flows. The upper part of Keppoch Formation contains interlayered volcanics and turbidites suggesting that the contact is transitional.

The environment of deposition of the Georgeville Group is inferred to have been a quiet, deep-water basinal area into which arc-derived volcaniclastic flysch deposits entered by mass flow with detritus supplied by erosion of rapidly rising volcanic highlands. The marble horizons are deduced to have been deposited in shallow seas fringing volcanic islands.

The Georgeville Group was deformed first by northwest-southeast, tight to isoclinal, recumbent folds with a weak axial planar cleavage defined by chlorite, sericite and biotite and refolded by northeast-southwest and east-west upright folds. The deformation, which is less intense in the southern highlands, was accompanied by lower greenschist-facies metamorphism. In contrast, throughout most of the Antigonish Highlands, the main structural fabric is generally only a weak S_1 cleavage which is parallel or sub-parallel to bedding, except in the hinges of rarely preserved F_1 folds (Murphy *et al*. 1991). Intrusion of the "appinitic" mafic to intermediate Greendale Complex occurred during the later stages of deformation (Murphy and Hynes 1990; Murphy *et al*. 2001). The Greendale Complex (Fig. 1-1a, Fig. 1-2) has yielded ages of 607 $\pm$ 2 Ma (U-Pb, titanite, Murphy *et al.* 1997) and 611 $\pm$ 4 Ma (^{40}Ar/^{39}Ar, hornblende, Keppie *et al*. 1990). These age data suggest a limited time gap between deposition, deformation and intrusion of the Georgeville Group indicating that it was probably deposited synorogenically in a strike-slip basin within an ensialic volcanic arc regime. The anomalous structural complexity of the Georgeville Group compared to coeval Avalonian sequences is consistent with strike-slip related deformation and basin inversion in an arc setting (Murphy *et al*. 1992). Emplacement of the Greendale Complex may be spatially and temporally associated with strike-slip movement along the Hollow-Greendale fault system.

The Georgeville Group is post-tectonically intruded by the Georgeville Granite, which is a semi-circular epizonal body, ca. 1.5 km across that is excellently exposed along the shoreline section of the Northumberland Strait (Figs. 1-2, 1-3). The pluton consists of a central stock predominantly consisting of 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. The granite consists of medium-grained quartz, microcline perthite and albite (An ~ 0) with subordinate mafic phyllosilicate minerals and a wide range of accessory minerals including zircon, titanite, rutile, euxenite, cassiterite and pyrite (Murphy *et al*. 1998). Small pegmatitic pods (generally ca. 0.4 m in diameter) are common throughout the exposed granite and consist mainly of quartz and microcline ($\pm$ amazonite). The granite is characterized by high SiO_2 (between 71-80%), Th, Nb, Y and Zr, very low CaO, TiO_2, MgO, FeO, MnO and most notably, extreme LREE depletion. Many, but not all, geochemical and mineralogical features resemble A-type, within plate granites. ^{40}Ar/^{39}Ar (muscovite) data yielded a plateau age of 579.8 $\pm$ 2.2 Ma suggesting intrusion about 20 million years after arc-related magmatism had ceased in the Antigonish Highlands (Murphy *et al*. 1998).

Cambrian-Early Ordovician rocks

Cambrian-Early Ordovician rocks unconformably overlie the Georgeville Group (Figs. 1-1a and 1-4) and occur only in the northern most Antigonish Highlands **(Stops 1-3 and 1-4).** The contact is an unconformity in some localities; in others, it is a low-angle fault. Cambrian-Early Ordovician rocks are divided into two groups that are related by lateral facies variations: the predominantly sedimentary Iron Brook Group and the predominantly volcanic McDonalds Brook Group (Keppie and Murphy 1988) (Fig. 1-4). Red fluviatile conglomerate, sandstone and slate occur at the base of each group (Black John and Malignant Cove formations). In the Iron Brook Group, redbeds of the Black John Formation are conformably overlain by interbedded red and green slate and fossiliferous pink limestone of the Little Hollow Formation.

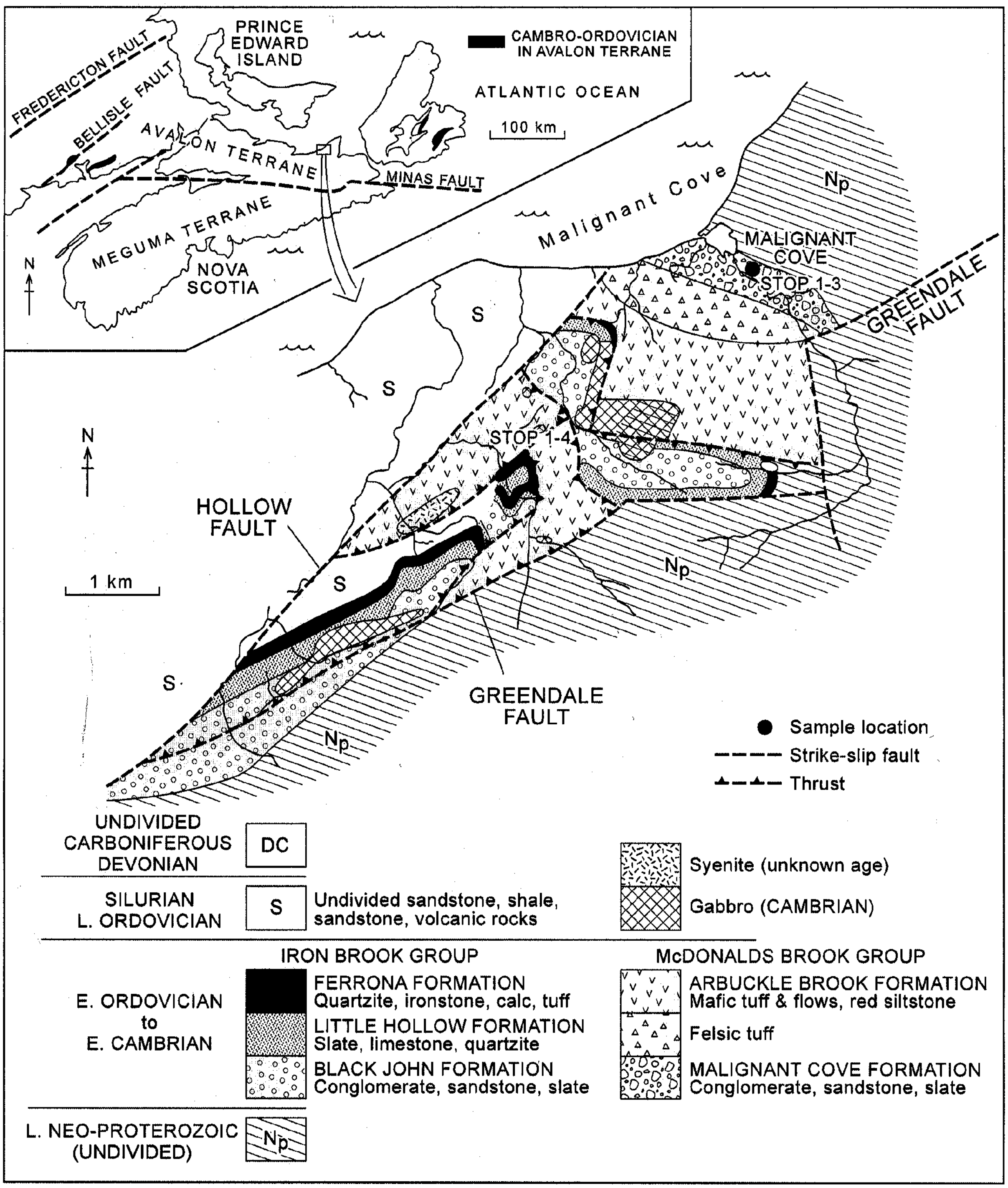


Figure 1-4. *Simplified geological map of the Cambro-Ordovician rocks of the Antigonish Highlands showing the locations of fields stops 1-3 and 1-4 (modified after Murphy et al. 1991). Inset shows the distribution of Cambrian rocks in Nova Scotia.*

The limestones have yielded a late Early Cambrian fauna of trilobites and paraconodonts (Landing and Murphy 1991). The Little Hollow Formation is concordantly overlain by interbedded quartzite, lateritic ironstone and calcareous tuff of the Ferrona Formation which has yielded some inarticulate brachiopods: *Obolus (lingulobus) spissa* and *Lingulella(?)* of late Cambrian-early Ordovician age. This suggests that a diastem is present in the succession here during the middle Cambrian. In the McDonalds Brook Group, the basal redbeds of the Malignant Cove Formation are overlain by a thick sequence of bimodal volcanic rocks with thin interbedded units of red slate, siltstone and fossiliferous limestone of the Arbuckle Brook Formation (Fig.1-4). Many of the dykes in older rocks are feeders to these volcanic rocks. Recent paleontological evidence (Landing and Murphy 1991) suggests that many of the above formations may be directly correlated with Eocambrian and Cambrian strata in the Avalon Peninsula of Newfoundland.

The stratigraphy suggests a transition from a subaerial to shallow marine environment of deposition. The mafic rocks have alkalic, within plate, extensional characteristics and are interpreted to be related to local rifting (Murphy *et al*. 1985). Felsic volcanic rocks are attributed to crustal anatexis associated with ascending mafic magma. The limited occurrence of Cambro-Ordovician sequences within Nova Scotia and the fault-bounded nature of the Antigonish sequence, together with the geochemistry of the volcanic rocks, indicate a local pull-apart basin tectonic environment, probably associated with dextral transpression during the latest stages of the Avalonian-Cadomian Orogeny. The presence of a cosmopolitan Avalonian (formerly Acado-Baltic) fauna in the pink limestones (Landing 1996; Landing and Murphy 1991) indicates a connection to open seas. These Cambro-Ordovician rocks are similar to those in other areas of the Avalon Terrane in Atlantic Canada and Britain (Keppie and Murphy 1988; Landing and Murphy 1991) and, together with paleomagnetic data, suggest that the Avalon Terrane faced an open ocean along the northern Gondwanan margin in Early Cambrian time (Keppie 1985).

The Cambrian to Early Ordovician rocks were affected by greenschist-facies metamorphism, which is most intense in the centre of the basin and dies out at the margins. Some parts of the Iron Brook and McDonalds Brook formations were also deformed by recumbent F1 folds with a penetrative axial plane cleavage defined by chlorite, muscovite and biotite, and accompanying thrusts, and then refolded by F_2 folds. The deformation is Early Ordovician to mid Ordovician in age, and predates deposition of the Dunn Point Formation and Arisaig Group. The underlying Georgeville Group rocks are virtually unaffected by this deformation, indicating that Cambrian-Early Ordovician sequences are separated from Neoproterozoic sequences by a décollement surface that lies close to, or at, the contact between them. The deformation is inferred to be the result of sinistral northeast-southwest strike-slip faulting in which the Cambrian pull-apart basin became the locus of compression. This time coincides with a major break in the stratigraphy in many areas of the Avalon Terrane, between Arenig and latest Ordovician times, and may be related to the sinistral accretion of Avalon with cratonic North America.

Mid Ordovician-Early Devonian rocks

Mid Ordovician-Early Devonian rocks (Figs. 1-1a and 1-5) predominantly occur at the extremities of the Antigonish Highlands and are traditionally assigned to the Arisaig Group, as described in detail in Boucot *et al*. (1974). These rocks unconformably overlie Cambrian to Early Ordovician and Neoproterozoic sequences.

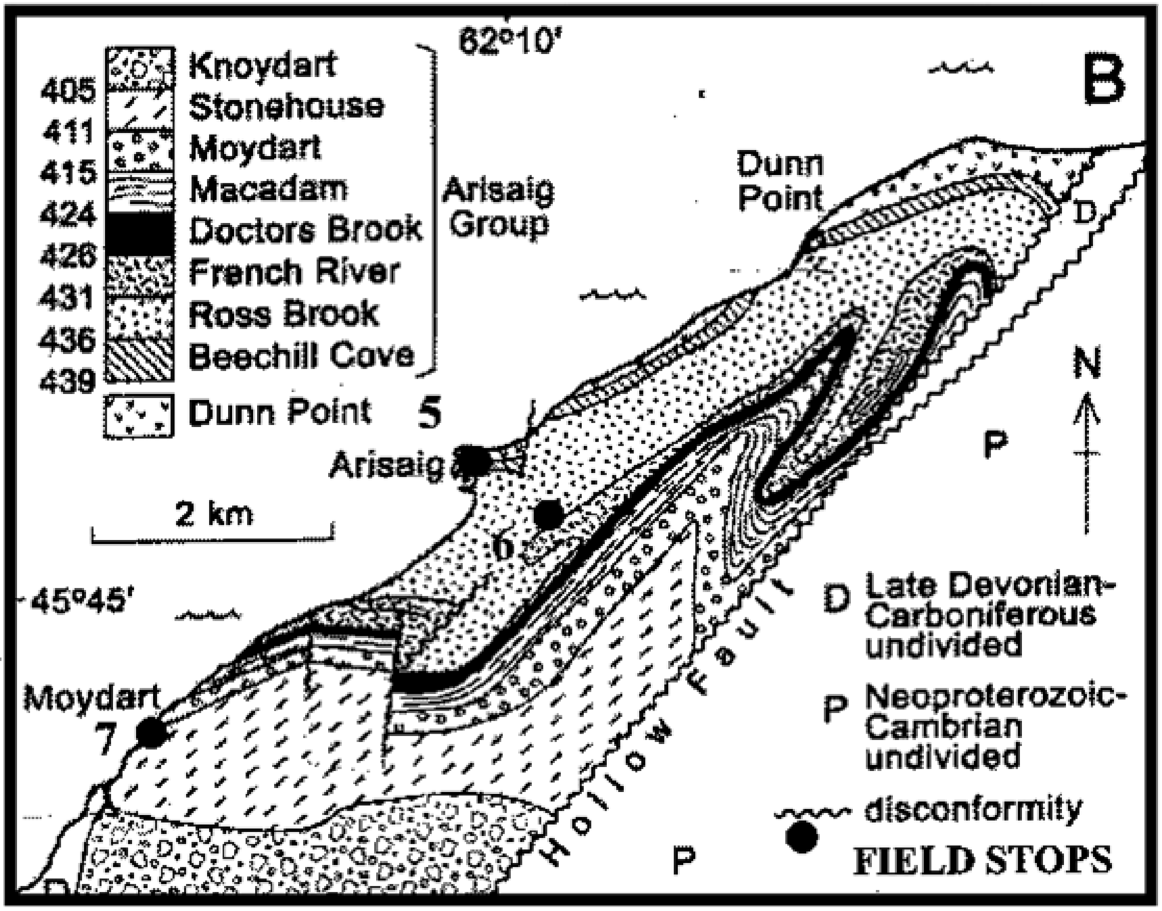


Figure 1-5. *Geological map highlighting the geology of the Arisaig Group showing the locations of field stops 1-5 to 1-7. Stop 1-5 is the location of the dated sample in the Dunn Point Formation. Stops 1-6 and 1-7 are locations of samples analyzed for detrital zircons in the French River and Stonehouse formations. Modified from Boucot et al. (1974).*

The lowest strata in this sequence consist of fluviatile red clastic sedimentary rocks and interlayered bimodal volcanic rocks (Dunn Point and Bears Brook formations, **Stop 1-5**) overlain by a thick sequence of fossiliferous, shallow marine siliciclastic rocks and minor rhyolite with red clastic sedimentary rocks towards the top of the sequence (Fig.1-5).

Geochemical and Sm-Nd isotopic studies for the Dunn Point Formation indicate that the mafic rocks are Fe-Ti rich tholeiites and the felsic rocks were derived by anatexis of typical Avalonian crust, therefore, the formation has been interpreted to reflect a local intra-continental extensional environment (Keppie *et al*. 1979; Murphy 1987b; Murphy *et al*. 1996b). Until recently, the only published age data for the volcanic rocks yielded an imprecise Rb-Sr whole rock isochron age of 421 ± 15 Ma (Fullagar and Bottino 1968, recalculated in Keppie and Smith 1978). The Late Silurian date is considered unreliable, however, as these rocks are disconformably overlain by clastic rocks of the Beechill Cove Formation that contain earliest Llandovery fossils (e.g., Boucot *et al*. 1974; Pickerill and Hurst 1983).

On the basis of field relationships and regional lithostratigraphic correlations (Chandler *et al*. 1987), the Dunn Point Formation had been assumed to be latest Ordovician-earliest Silurian age and part of the Arisaig Group (Murphy 1987a; Murphy *et al*. 1991). This assumption implied that Dunn Point volcanism occurred during or immediately following accretion of Avalonia to Laurentia, and therefore likely reflected local extension and basin development related to oblique collision between Avalonia and Laurentia after closure of the Iapetus Ocean (e.g., Murphy 1987a, 1987b).

However, recent U-Pb zircon (TIMS) data from a rhyolite yielded a concordant age of 460.0 ± 3.4 Ma for the Dunn Point Formation, indicating a 20 million year gap between the deposition of the Dunn Point and Beechill Cove formations (Hamilton and Murphy 2004). This age difference implies that the Dunn Point Formation should no longer be considered part of the Arisaig Group and requires that the tectonic significance of the formation be re-evaluated.

The age data also provide a simple reconciliation of the apparently conflicting paleomagnetic data and inferred paleolatitude for Avalonia in the Ordovician-Silurian. Hodych and Buchan (1998) determined a paleolatitude of 32°S ± 8° for the Cape St Mary's gabbro sills in the Avalon terrane of Newfoundland, the age of which is tightly constrained by U-Pb dating of baddeleyite at 441 ± 2 Ma (Early Silurian, Greenough *et al*. 1993). A southerly paleolatitude was also established for the Dunn Point volcanic rocks by Van der Voo and Johnson (1985) and a primary (pre-folding) paleolatitude of 41°S ± 8° was refined and confirmed by Johnson and Van der Voo (1990). Though these units were thought then to be broadly coeval, our data indicate that the Dunn Point volcanic rocks are 20 million years older than the Cape St Mary's sills, and thus these data can be reconciled by 10 degrees northward movement of Avalonia during this interval. As Laurentia lay at a paleolatitude of about 20^{o}S between 460 and 440 Ma (e.g. MacNiocaill and Smethurst 1994), this implies that Avalonia was located about 1700-2000 km south of the Laurentian margin at 460 Ma, with a latitudinal component of the convergence rate between Avalonia and Laurentia from 460 to 440 Ma of about 5.5 cm/yr (see also Johnson and Van der Voo 1990).

Lying this distance off the Laurentian margin at 460 Ma, Avalonia was the key tectonic element defining the southern margin of the Iapetus Ocean and the northern margin of the Rheic Ocean (e.g. Torsvik *et al*. 1996). The Arenig-Llandeilo northward drift of Avalonia relative to Gondwana is consistent with the presence of an ocean ridge system between Avalonia and Gondwana, implying that the trailing (southern) edge of Avalonia was a passive margin. In contrast, voluminous Late Tremadoc-Caradoc arc (e.g. Popelogan-Victoria) and back arc (Tetagouche-Exploits) complexes in Newfoundland, New Brunswick and Maine and the ensialic arc-magmatism recorded by correlative Avalonian rocks in Britain and Ireland (Lake District-Leinster volcanic arc) suggest that Iapetan oceanic crust was subducted beneath the northern margin (e.g. van Staal *et al*. 1998).

Thus, the tectonic environment of the Dunn Point Formation is reinterpreted in terms of an ensialic microplate floored by Avalonian crust, bordered to the north by the Iapetus Ocean and to the south by the Rheic Ocean. The Dunn Point volcanism probably developed on the Avalonian microcontinent outboard from both Laurentia and Gondwana, possibly in a rifted arc setting (Fig. 1-6) analogous to the modern Taupo Zone in northern New Zealand.

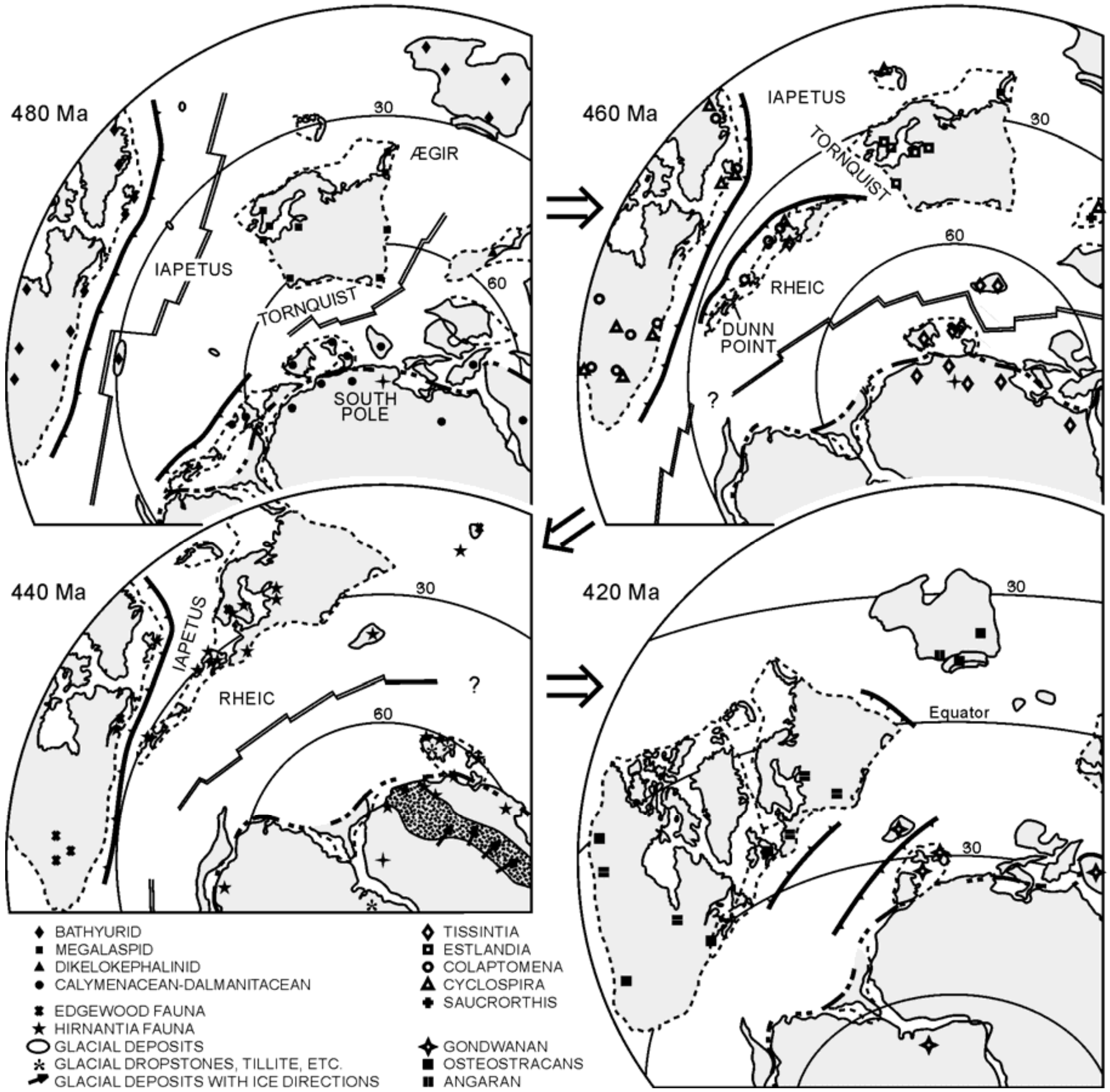


Figure 1-6. *Early Ordovician, middle Ordovician and late Ordovician reconstructions showing the relative positions of Gondwana, Laurentia, Baltica, and peri-Gondwanan terranes (including Avalonia). Reconstructions based on Cocks and Torsvik (2002); Fortey and Cocks (2003).*

Age	Formation	Thickness	General geology
LOWER DEVONIAN	Knoydart Formation	360 m	Greyish red mudstone, siltstone & fine-grained wacke
	Stonehouse Formation	411 m	Bluish grey calcareous wacke
UPPER SILURIAN	Moydart Formation	119 m	Greenish grey mudstone, wacke & siltstone
	McAdam Brook Formation	107 m	Grey mudstone, wacke, shale & calcareous wacke
	Doctors Brook Formation	85 m	Black shale
	French River Formation		Bluish grey, fine-grained wacke
LOWER SILURIAN	Ross Brook Formation	360 m	Dark grey mudstone & shale
	Beechill Cove Formation	80 m	Greenish & bluish grey wacke & siltstone

Figure 1-7. *Stratigraphy of the Arisaig Group (based on Boucot et al., 1974).*

The 460 Ma age for the Dunn Point volcanic rocks also has important implications for its relationship with the overlying earliest Llandovery clastic sedimentary rocks of the Beechill Cove Formation, which form the base of the redefined Arisaig Group. A summary of the stratigraphy of the Arisaig Group is shown in Figure 1-7. The Beechill Cove Formation consists of shallow marine conglomerate at the base overlain by sandstone and siltstone that contain early Llandovery fossils (Boucot *et al*. 1974; Pickerill and Hurst 1983). The Beechill Cove Formation is about 80 m thick and is conformably overlain by ca. 360 m of middle to late Llandovery black shale, muddy siltstone, tuff and arenaceous limestone of the Ross Brook Formation (Hurst and Pickerill 1986), followed by Wenlockian-Ludlovian strata (French River and Doctors Brook formations, collectively 85 m and McAdam Brook, 107 m) consisting of green-grey mudstone, siltstone and sandstone that were deposited in a near-shore environment (**Stop 1-6**; Boucot *et al*. 1974).

The overlying Late Ludlovian Moydart Formation (119 m thick) consists of green interbedded siltstone, shale, mudstone and limestone overlain predominantly by red mudstone with caliche concretions. The sequence was interpreted to reflect progressive shallowing and eventual subaerial exposure (Waldron *et al*. 1996). These strata are conformably overlain by the Pridolian Stonehouse Formation (411 m thick) which consists of fossiliferous interbedded mudstone, shale with minor siltstone and sandstone **(Stop 1-7)**, followed by about 360 m of interbedded red and green, coarse-to fine-grained clastic rocks of the Knoydart Formation, indicative of deposition in deltaic and fluviatile environments (Boucot *et al*. 1974).

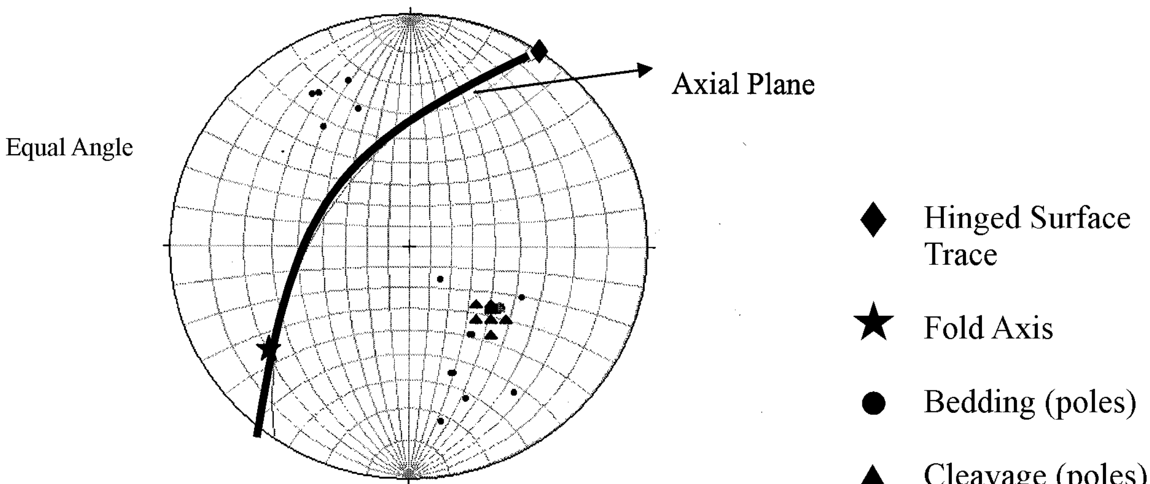
In contrast to the Dunn Point Formation, geochemical and isotopic studies of the Arisaig Group sedimentary rocks indicate they are not derived from the underlying, juvenile Avalonian basement (Murphy *et al.* 1995, 1996a, 2004b). Instead, these data are consistent with derivation from ancient continental crust. Unlike Avalonian basement which is characterized by isotopically juvenile crust, all Arisaig Group sedimentary rocks are characterized by strongly negative $\varepsilon_{Nd(t)}$ (from -4.8 to – 9.3, t = 430 Ma) and T_{DM} ages > 1.5 Ga with an overall trend towards increasingly negative ε_{Nd} values from the base to the top of the group. U-Pb dating of detrital zircons from the Arisaig sedimentary rocks indicate that these strata contain abundant Neoproterozoic-Early Cambrian zircons (ca. 620-520 Ma), and lesser abundances at about 900-1200 and 1500 to 2200 Ma. Archean zircons are very minor (Murphy *et al*. 2004b).

The Early Devonian Stonehouse Formation sample contains Late Silurian and Early Ordovician zircons, and in comparison to the Silurian samples, less abundant Cambrian (ca. 510-520 Ma), Neoproterozoic (550-610 Ma; 834 Ma) zircons and subordinate Mesoproterozoic (1000-1200 Ma and 1400 to 1600 Ma) and Paleoproterozoic (2000 to 2100 Ma) zircons. There are no Archean zircons in any of the Early Devonian samples. Some Arisaig sedimentary rocks contain detrital zircons with ages similar to the depositional age, suggesting that basin formation was broadly coeval with active volcanism in the orogen.

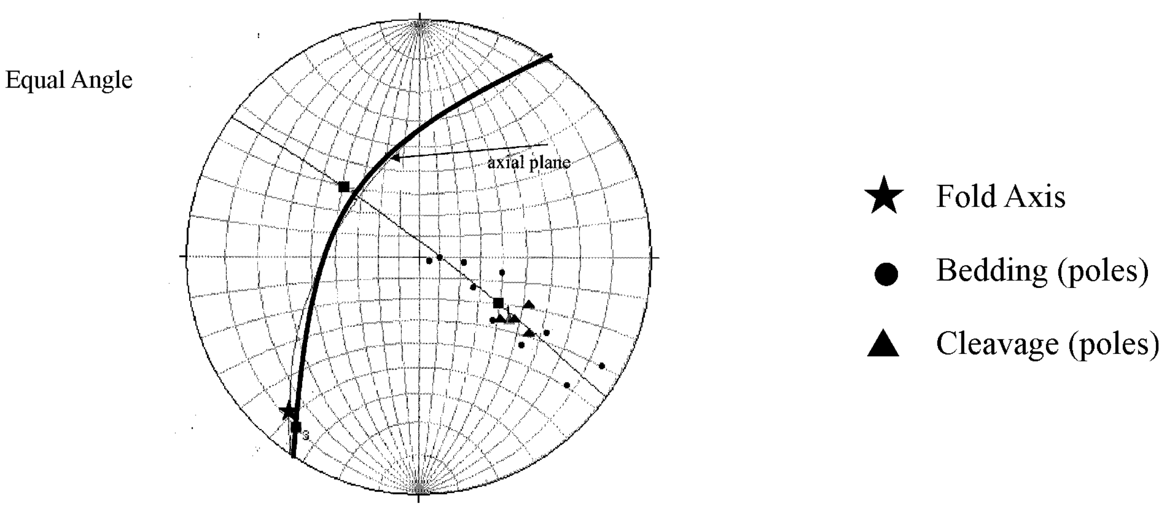
Waldron *et al.* (1996) interpreted the subsidence history of the Arisaig Group as an initial phase of rapid subsidence and extension (30% to 60%) in the Early Llandovery followed by thermal relaxation and slower subsidence rates in the Wenlockian and Ludlow. The vastly increased subsidence rates and accommodation space in the Pridoli (as represented by the Stonehouse Formation) is attributed to loading of the Avalonian margin due to interaction with a neighbouring terrane (Waldron *et al*. 1996). This coincides with a change in paleocurrent direction from NE-SW to SE-NW (Boucot *et al.* 1974; Waldron *et al*. 1996) and could reflect loading from the Gander-Laurentian margin to the north or from the Meguma terrane to the south.

Contrary to previous syntheses (e.g., Murphy *et al*. 1991) the 20 million year age gap between the Dunn Point Formation and Arisaig Group is now interpreted to represent the time during which Avalonia collided with Laurentia-Baltica, implying accretion by the Early Llandovery (Murphy *et al*. 1995). The Early to Middle Silurian Arisaig strata are inferred to have been deposited adjacent to the trailing edge of Avalonia in an intra-continental basin that was generated following oblique collision between Avalonia and Laurentia-Baltica (Murphy *et al*. 1996b). A comparison between the U-Pb detrital zircon data and the age of tectonothermal events in potential source areas, together with regional geologic and isotopic data, suggest that Silurian strata of the Arisaig Group were primarily derived from Baltica, but with increasing input from Laurentia by the time of deposition of the upper (early Devonian) strata (Murphy *et al*. 2004b).

The Arisaig Group was deformed in the middle Devonian into regional NE to NNE trending folds during the Acadian orogeny (**Stop 1-6**; Figs. 1-3, 1-8; Braid and Murphy, under review), prior to deposition of the unconformably overlying mafic volcanic and interbedded red clastic strata of the Middle Devonian McArras Brook Formation **(Stop 1-7).** The observed structural features are consistent with fold propagation associated with ramp-flat thrust fault geometry and coeval local extension recorded by a set of conjugate normal faults. Many outcrop-scale folds have sheared limbs and show evidence of a complex progressive deformation. Folding was predominantly accomplished by bulk rotation and flattening above thrust fault tips; flexural mechanisms were not important. Bedding data around outcrop-scale folds, however, reveal a simple geometry dominated by conical rather than cylindrical folds. The axial plane, fold and conical axis orientations show high variability, but are consistent with progressive deformation related to coeval dextral strike slip movement along the Hollow Fault. Taken together, these data indicate that fold mechanisms and geometry in the shallow crust during the Acadian orogeny may be related to dextral strike-slip along major faults and co-genetic upward-propagating thrusts that rotated and flattened overlying strata.



a.



b.

Figure 1-8. *Stereographic projections of structural data around the regional syncline from Braid and Murphy, under review (a) to the north of the Hollow Fault, (b) structural data around French River anticline.*

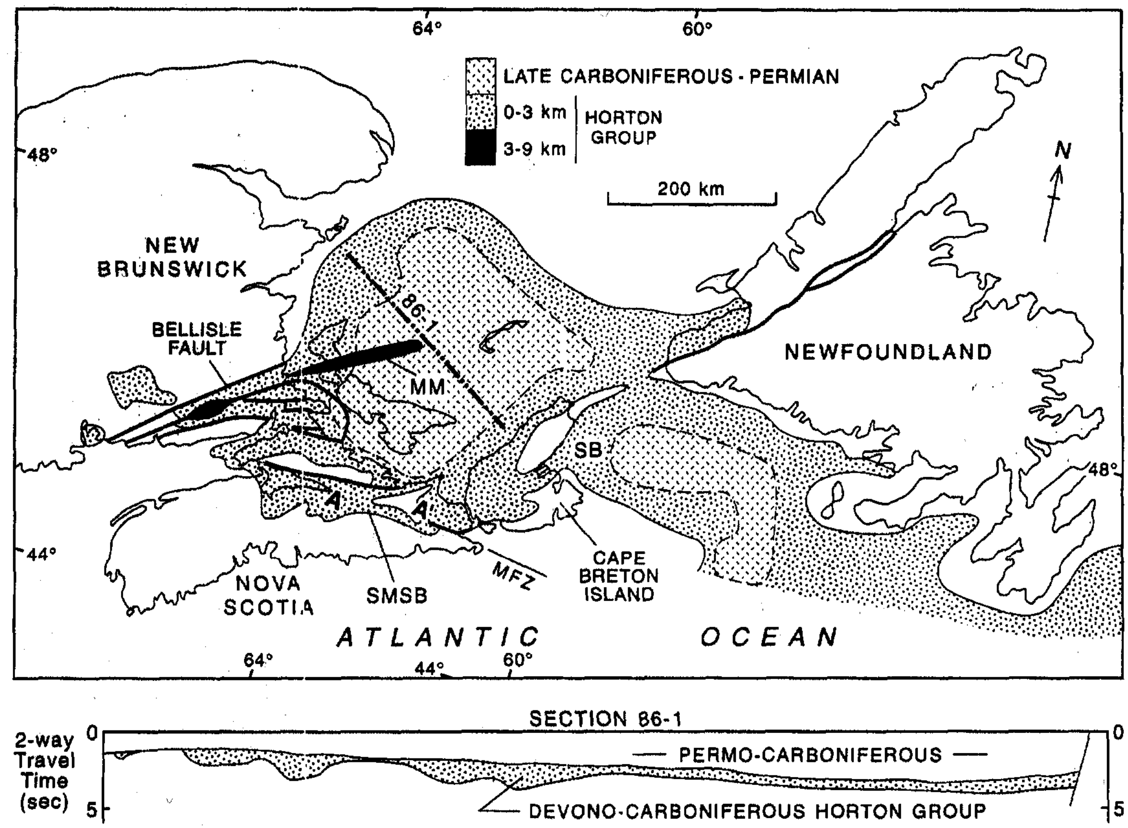


Figure 1-9. *Distribution and thickness of Late Devonian-Permian strata in the Maritimes Basin (after Durling and Marillier 1993). Seismic section from Marillier et al. (1989).*

Middle Devonian-Late Carboniferous rocks

Middle Devonian-Late Carboniferous strata are deposited in the Merigomish sub-basin (Fralick 1980) within a broad northeast-trending trough, which extends from the Antigonish Highlands in the southeast to the Cobequid Highlands in the northwest. The sub-basin is located along the southern flank of the composite Maritimes Basin, which is the dominant Late Paleozoic depocentre in Atlantic Canada (Fig.1-9, 1-10).

These strata were deposited between the Acadian and Alleghanian during regional tectonic events associated with the destruction of the Rheic ocean, development of the Appalachian orogen and amalgamation of Pangea (e.g., Williams and Hatcher 1983; Keppie 1985).

Along the Northumberland Strait, near Knoydart **(Stop 1-8)**, mid-to-late Devonian mafic volcanic rocks and continental clastic sediments of the McArras Brook Formation were deposited during an episode of regional intra-crustal extension. During this time in the neighbouring Cobequid Highlands, the intrusion of Late Devonian plutonic rocks associated with regional shear was accompanied by unroofing of the highlands (see Pe-Piper and Piper, Day 2).

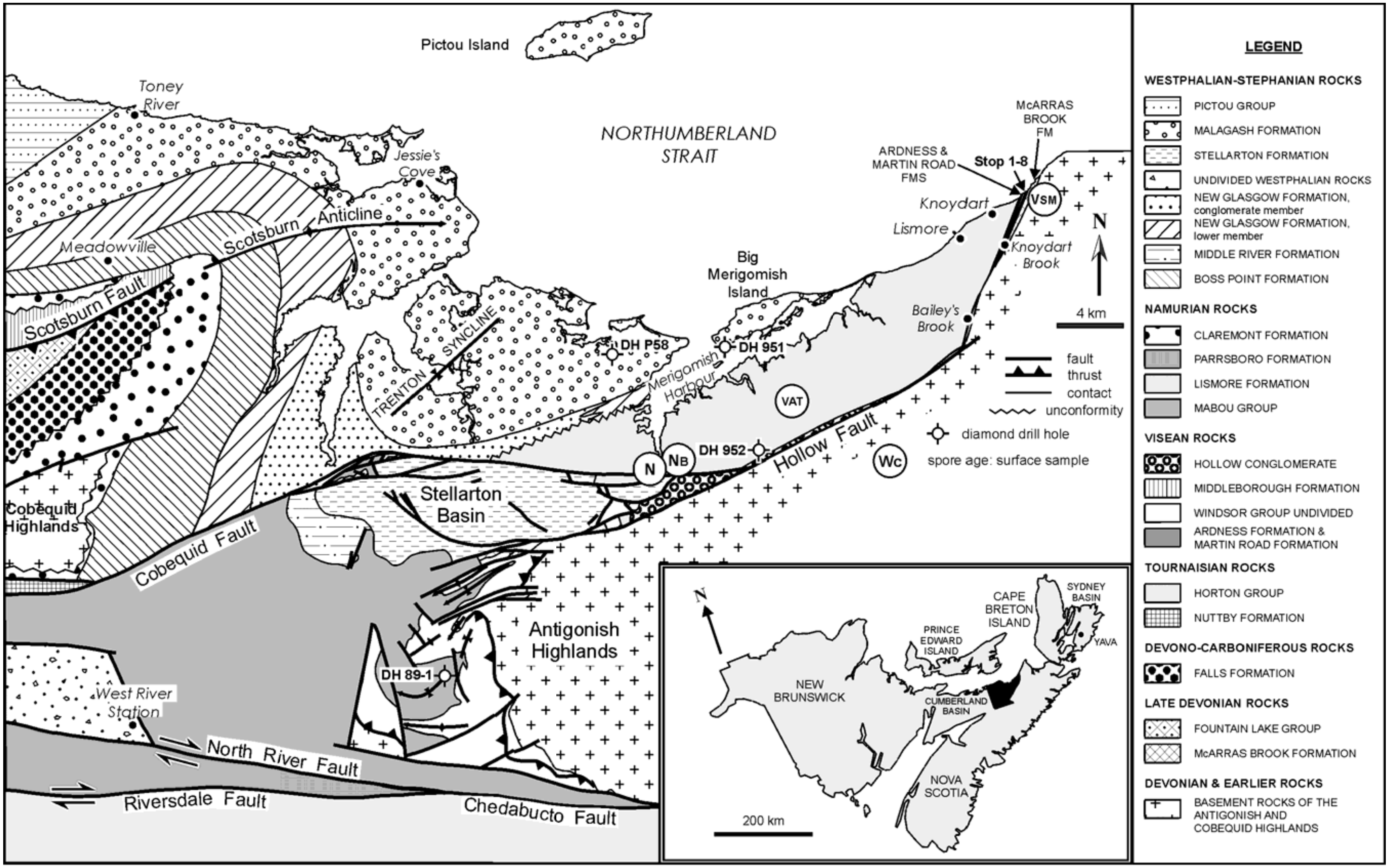


Figure 1-10. *Geological map of the Merigomish and Stellarton sub-basins (after Chandler et al. 1997; Waldron 2004).*

In the Late Devonian - Early Carboniferous, continental clastic rocks of the Horton Group were deposited in a series of rift basins (McCutcheon and Robinson 1987; Martel and Gibling 1991) that overstepped the Avalon-Meguma terrane boundary. The clastic rocks were locally derived from adjacent highland areas (Hamblin and Rust 1989; Gibling 1995; Murphy *et al*. 1995).

During the Viséan, a marine incursion deposited limestone, evaporitic and clastic rocks of the Windsor Group under hot semi-arid to arid conditions (Chandler *et al*. 1997). Within the Merigomish sub-basin, the Windsor Group is divided into continental clastic rocks of the Martin Road Formation overlain by laminated limestone of the Ardness Formation **(Stop 1-8)**. Renewed movement along the Hollow Fault, which defines the southern flank of the Merigomish sub-basin, resulted in the deposition of the late Viséan-early Namurian Hollow Conglomerate as a braided alluvial fan (Fralick 1977; Chandler *et al*. 1997). This was followed by deposition of the Lismore Formation, which is the lowermost formation in the Mabou Group exposed in the Merigomish sub-basin (Fralick 1980; Chandler *et al*. 1997).

Paleontological evidence suggests the Namurian Lismore Formation lies disconformably on the limestone of the Ardness Formation (Keppie *et al*. 1978). The Ardness limestone contains Viséan C to E1 spores. Spore samples from the directly overlying Lismore Formation red beds (Fig.1-11) suggest a Viséan AT age (upper Viséan, Utting 1987), which represents the boundary between the Windsor and Mabou groups. Further up-section, the Lismore Formation has yielded early Namurian and Namurian B spore assemblages (Chandler *et al*. 1997).

The Lismore Formation is part of the Mabou Group, a continental sequence deposited following the marine Windsor Group (Fralick 1980; Fralick and Schenk 1981; Chandler *et al*. 1997). Gibling (1995) suggested that the regression was perhaps related to sea-level lowering during the Gondwanan glaciation or to the transpressive collision of the North American continent and the African part of Gondwana. Geochemical and isotopic analyses of the Lismore Formation (Stevens *et al*. 1999) suggest predominant derivation from underlying Arisaig Group strata, although the upper part of the formation has increased input from Cobequid Highland lithologies, reflecting uplift of the highlands during Lismore Formation deposition.

The Lismore Formation is unconformably overlain by the Westphalian A to B? New Glasgow Formation of the Cumberland Group (Chandler *et al*. 1997). During the early Westphalian, reactivation of the Cobequid-Hollow Fault system resulted in the formation of the Stellarton Basin (Yeo and Ruixiang 1987; Waldron 2004) and associated Westphalian A to D sedimentation (Naylor *et al*. 1989; Chandler *et al.* 1997).

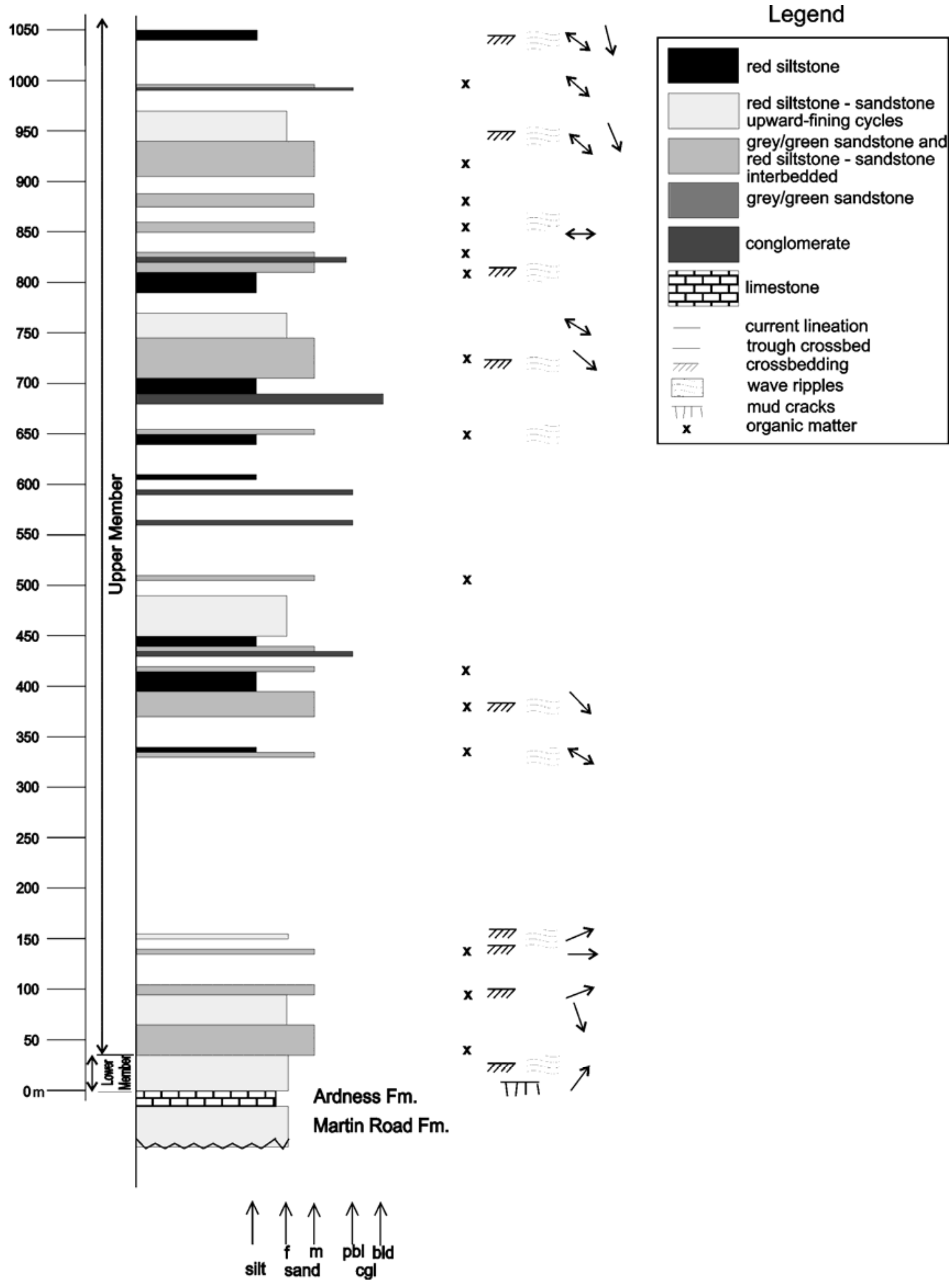


Figure 1-11. *Measured stratigraphic section (1050 m) of the Lismore Formation, as shown at Stop 1-8. LM = Lower Member (after Stevens et al. 1999). Arrows indicate paleocurrent direction (see also Fralick 1977, 1980).*

ROAD LOG

The outcrops we visit on Day 1 are located along the shore of the Northumberland Strait, north of Antigonish (Figs. 1-2, 1-3). They may be reached by driving north along Nova Scotia highway 245 from Antigonish to Malignant Cove, which is located at the junction with Nova Scotia highway 337. To reach Stop 1-1, proceed 5 km east on highway 337 to a road on the north side of the road leading to the Georgeville Quarry (Fig. 1-2). This road has a metal bar-type gate at its entrance. Park by the gate and walk down the road to the shore. Proceed east along the shore about 50 m to the first outcrops - this is Stop 1-1A (Fig. 1-3).

Stops 1-1A to 1-1P are located northeast of here, along the shore, and may be completely traversed only at low tide. At the end of the traverse, walk up the track along the brook between Stops 1-1N and 1-1P back to highway 337 and then back to the starting point. Resume driving northeast along Nova Scotia 337 to Livingstone Cove (Fig. 1-2). Park near the Livingstone Cove Pier and walk 500 m southwest along the shore to reach Stop 1-2.

To reach Stop 1-3, return to Malignant Cove along Nova Scotia 337 (Fig. 1-2). Stop 1-3 is located at Malignant Cove (Fig. 1-4), about 100 m south of the junction of highways 345 and 337. Park in the parking spaces by the side of the road and follow the short footpath to the outcrops in Malignant Brook, which runs along the eastern side of the road. From here, drive southeast along highway 245 to Arisaig (Fig. 1-1a), where you take the turn down to Arisaig Pier for Stop 1-5 (Fig. 1-5). Return onto route 245, proceed west about 700 m and turn left along MacDonald Brook road (just past the entrance to the picnic park). Proceed about 1.2 km along the road until exposures on both sides of the gorge (Stop 1-6). Return onto highway 245. Proceed 6 km to McArras Brook, walk down access road parallel to brook, eastern side until coastline, walk 500 meters along coast (to northeast) until you reach the contact (Stop 1-7). The contact is also exposed on McArras Brook 200 m from its mouth. Return to highway 245, proceed 4 km, park at edge of road and proceed 800 m across open fields to shore (Stop 1-8).

STOP DESCRIPTIONS

STOP 1-1: Neoproterozoic Chisholm Brook and Morar Brook formations (part of Georgeville Group), intruded by Greendale Complex and alaskite on the shore north from the Georgeville Quarry, Northumberland Strait (Fig. 1-3).

Stop 1-1A

Two phases of the syn- to post- tectonic Greendale Complex may be observed; plagioclase-rich and hornblende-rich gabbro, with a sharp contact between them. The plagioclase crystals enclose enclaves of matrix and so is a late crystallizing mineral, probably of metasomatic origin. Igneous hornblendes from the Greendale Complex have been dated at 607 ± 2 Ma (U-Pb, titanite, Murphy *et al.* 1997) and 611 ± 4 Ma and 620 ± 5 Ma (^{40}Ar/^{39}Ar, hornblende, Keppie *et al.* 1990).

Stop 1-1B

A basalt xenolith in the gabbro shows evidence of increasing contamination towards the contact. The basalt consists of albite, epidote, prehnite and actinolite. The amphibole increases in size towards the contact with the gabbro. Coarse pegmatites with sinuous contacts and a microgranite dyke represent a late felsic stage.

Stop 1-1C
A fault slice containing metasomatized marble and interbedded impure serpentinized marble and basalt. These rocks are thought to comprise part of the Chisholm Brook Formation.

Stop 1-1D
Intrusive contact between late pegmatitic felsic phase of the intrusive body and marble and tuff of the country rocks. The pegmatite contains large crystals of amphibole (up to 8 cm) sometimes enclosing plagioclase cores, in a matrix of orthoclase, quartz and plagioclase. The pegmatite is cut by an aplitic dyke. Host rocks show evidence of contact metamorphism.

Stop 1-1E
Contact between Chisholm Brook and Morar Brook formations. Interbedded tuff and agglomerate of Chisholm Brook Formation grade conformably up into black, thinly laminated mudstone of the Morar Brook Formation. The bedding is overturned.

Stop 1-1F
Morar Brook Formation: slump folds. Although this fold is probably related to deformation, large scale isoclinal folds affect the volcanic rocks and therefore have a hard-rock component.

Stop 1-1G
Leucocratic diorite intrusive sheet containing xenoliths of country rock. Both contain large stage metasomatic plagioclase porphyroblasts. The eastern contact of the sheet is broadly concordant. Load casts in the mudstone/siltstone host rock indicate overturned bedding.

Stop 1-1H (Optional): Morar Brook Formation: interbedded mudstone, siltstone, marble and chert. Note the minor intrusive, which alternates from a sill to a dyke.

Stop 1-1J (Optional): Morar Brook Formation: An example of a northeast-southwest, upright, F_2 fold.

Stop 1-1K (Optional): Intrusive contact between post-tectonic “alaskite” stock of the Georgeville Granite and mudstones of the Morar Brook Formation showing contact metamorphism. The alaskite consists of quartz, plagioclase and microcline with minor chlorite and amazonite. $^{40}Ar^{39}/Ar$ (muscovite) data yields a plateau age of 579.8 $\pm$ 2.2 Ma (Murphy *et al.* 1998).

Stop 1-1L (Optional): Morar Brook Formation: An example of an easterly facing, isoclinal F_1 fold with a poorly developed fracture cleavage.

Stop 1-1M (Optional): Coarse pegmatite associated with the alaskite.

Stop 1-1N (Optional): Thin veins of alaskite intruding the mudstones are undeformed, indicating their post-tectonic age.

Stop 1-1P (Optional): Chisholm Brook Formation: tuff, basalt flows and mudstone intruded by numerous, comagmatic mafic dykes. Typical mineralogy is albite, epidote, actinolite and chlorite. These rocks probably underlie the Morar Brook Formation.

STOP 1-2: Neoproterozoic Livingstone Cove Formation (part of the Georgeville Group) unconformably overlain by Middle Devonian McArras Brook Formation.

Overturned, gently dipping mudstone, siltstone and volcaniclastic conglomerate of the Livingstone Cove Formation is here cut by numerous mafic dykes. Pebbles from these conglomerates contain zircons, the youngest dated at 613 ± 5 Ma, and with populations of ca. 1.1-1.2 Ga, 1.5 Ga, 1.8-2.0 Ga and 2.6 Ga (Keppie *et al*. 1998). On its northern margin, the Livingstone Cove Formation is unconformably overlain by red conglomerate and sandstone of the McArras Brook Formation. This unconformity is well exposed on the shore, in places cut by minor transverse faults. Farther north along the shore, amygdaloidal basalt within the McArras Brook Formation crops out truncated by a fault (Fig. 1-2).

STOP 1-3: Latest Neoproterozoic or Early Cambrian Malignant Cove Formation at Malignant Cove.

See Fig. 1-1a and 1-4. The Cambrian rocks in the northern Antigonish Highlands occur in a small fault-bounded, pull-apart basin produced by dextral strike-slip movements. They have been divided into two laterally equivalent groups: the mainly sedimentary, 225 m thick Iron Brook Group and the predominantly volcanic, 500 m thick McDonalds Brook Group (Murphy *et al*. 1985; Keppie and Murphy 1988).

The Malignant Cove Formation is the oldest formation in the McDonalds Brook Group. It conformably underlies the Arbuckle Brook Formation, which is dominated by volcanic rocks some of which contain limestone clasts that yield late Early Cambrian fossils (Landing and Murphy 1991). The base of the Malignant Cove Formation is not exposed but is inferred to be an unconformity. The formation consists of about 250 m of red, fluviatile conglomerate, breccia, sandstone and slate. The conglomerates are generally well sorted and contain pebbles of mafic and felsic volcanic rocks, sericitic shale, quartzite, red siltstone, jasper and perthitic feldspars. The matrix consists of quartz, sericite, chlorite, and minor biotite.

Conglomerate from the Malignant Cove Formation that was sampled for U-Pb detrital zircon analyses (LA-ICPMS, Murphy *et al*. 2004c) indicate an overwhelming dominance of Neoproterozoic zircons (56 in a total of 62) with a continuous cluster spanning from 585 ± 5 Ma (age of the youngest zircon dated in this sample) to 676±8 Ma. In the cumulative probability plot, there are relative peaks at *c*. 588, 600, 612, 626, 644 and 664 Ma. An older Neoproterozoic cluster (6 analyses) features three concordant analyses at 707-715 Ma and three discordant (6-8% discordance) analyses with older $^{207}Pb/^{206}Pb$ ages (756-764 Ma). Of the remaining six analyses five are Mesoproterozoic at *c*. 1023, 1154, 1218, 1542 and 1608 Ma and one is Paleoproterozoic (1938 Ma).

The vast majority of zircons can be readily derived from underlying Georgeville Group rocks. The sample is dominated by zircons derived either from the main phase of Avalonian magmatism (*c*. 635-570 Ma), or from the early arc phase (750-670 Ma). The lack of Cambrian zircons may reflect the fact that the Malignant Cove Formation underlies the oldest Cambrian volcanic units in the Antigonish Highlands. The Mesoproterozoic and Paleoproterozoic zircons in both samples could readily be derived by recycling of such zircons from the underlying Neoproterozoic sedimentary units. In contrast to the late Neoproterozoic rocks, therefore, there is nothing in the new data that requires laterally extensive drainage systems.

STOP 1-4: Cambro-Ordovician Iron Brook Group deformed by Middle Ordovician structures on East Doctors Brook, Doctors Brook (Optional)

Stop 1-4A McDonalds Brook Group: Arbuckle Brook Formation: High $Ti0_2$, alkalic, within-plate basalts containing albite, epidote and chlorite.

Stop 1-4B Iron Brook Group - Ferrona Formation: interbedded quartzite and ironstone containing inarticulate brachiopods. Some of the ironstones are oolitic-pisolitic and contain irregular grains of quartz and jasper. Petrographically, some ironstone may be seen replacing a variety of rock types including quartzite, shale, mudstone and tuff. The contact between the Ferrona and Arbuckle Brook Formations at this locality is not exposed. It is interpreted to be a thrust contact on the basis of map patterns.

Stop 1-4C Iron Brook Group - Little Hollow Formation: highly altered, calcareous tuff. Note the two fabrics.

Stop 1-4D Iron Brook Group - Little Hollow Formation: interbedded slate and nodular pink limestone containing brachiopods, trilobites and paraconodonts of late Early Cambrian age (Landing and Murphy 1991).

Stop 1-4E Iron Brook Group - Little Hollow Formation: northeast-southwest, Acadian, upright F_2 folds deforming slatey cleavage in red slates.

STOP 1-5: Middle Ordovician Dunn Point Formation and Earliest Silurian Beechill Cove and Ross Brook formations at Arisaig

See Figs. 1-5 and 1-7. In the Arisaig area, the succession starts with 90 to 210 m of subaerial, bimodal, tholeiitic (-alkalic), within-plate, rift or anorogenic basalts, rhyolites and ignimbrites and interbedded laterites of the Dunn Point and McGillivray Brook Formations. The geochemistry is indistinguishable from the correlative Bears Brook Formation to the south of the Hollow Fault. The rhyolites have yielded a middle Ordovician age of 460 ± 2 Ma. These are unconformably overlain by shallow marine conglomerate, sandstone and siltstone of the Early Llandovery Beechill Cove Formation that grades upwards into Mid-Late Llandovery black shales, muddy siltstone, tuff and arenaceous limestone of the Ross Brook Formation. These formations are followed by shallow marine siltstone, shale and limestone of the rest of the Arisaig Group (Fig. 1-7). The total thickness of the Arisaig Group is about 1800 m. It passes upwards into 1,000 + metres of generally non-marine silty mudstone, marl, sandstone and conglomerate of the Early Devonian Knoydart Group. The Ordovician to Early Devonian rocks were deformed during the late Early-Middle Devonian Acadian Orogeny by northeast-southwest, upright to asymmetric, gently to steeply plunging folds, which also refolded the Iron Brook and McDonalds Brook Groups. The accompanying metamorphism is sub-greenschist facies.

Stop 1-5A

Contact between Beechill Cove and Dunn Point formations. Here, conglomerate, assigned to the base of the Beechill Cove Formation by Boucot *et al.* (1974) lies disconformably upon rhyolite capped by lenses of laterite of the Dunn Point Formation. The McGillivray Brook Formation is absent. Most of the pebbles are rhyolite and ignimbrite presumably derived from the McGillivray Brook Formation. Some jasper pebbles are also present. Rapid changes in thickness of the conglomerate suggest deposition in channels. The rhyolite is made up of quartz and feldspar phenocrysts set in a devitrified glass matrix, with variable degrees of alteration of albite, sericite and hematite.

Stop 1-5B

Dunn Point Formation: Basalt flows interbedded with laterite horizons and overlain by rhyolite flows. The basalts are generally vesicular, particularly towards their tops, and grade upwards from spheroidally weathered basalt, through a rubbly laterite/basalt mixture into a blocky indurated red laterite, capped by small irregular lenses of bedded laterite. This sequence is interpreted as an undisturbed red lateritic soil profile, with the bedded laterite being deposited by wind. In places, the basalt flows have incorporated pieces of the underlying laterite in their basal portions. The intimate association of vesicles with laterite trains suggests that the laterites were soft and wet at the time of extrusion. The basalts are generally aphyric and consist of plagioclase, epidote, chlorite, calcite, opaques and rare clinopyroxene relics. Vesicles are filled with quartz, chlorite and prehnite. The basalts are tholeiitic with some alkaline tendencies and were extruded during an anorogenic or rifting period within a continental plate (Keppie *et al*. 1979; Murphy 1987b).

Stop 1-5C
Dunn Point Formation: Basalt and rhyolite flows. The rhyolite flows show a variety of features, such as flow banding and auto- brecciation.

Stop 1-5D (Optional) Ross Brook Formation, Middle Member: Grey shale with some thin argillaceous siltstone. The shale is generally parallel-laminated and in places bioturbated. The siltstone displays parallel-lamination, cross-bedding and load casts. Fossils include brachiopods, the diagnostic Early Silurian, shallow marine *Eocoelia hemisphaerica* among them, pelecypods, worm burrows and trails. Suspension-feeding bivalves are often preserved in their life positions. These rocks were deposited in a shallow marine shelf environment, which was generally quiet with clear water and only a few storm-generated currents. The shale has been deformed by variably oriented late folds.

STOP 1-6 Wenlockian-Ludlovian Arisaig Group at MacDonald Brook Road
Typical stratigraphy and style of deformation exhibited by strata of the French River, Doctors Brook, and MacAdam formations. Note the ironstone layer, cleavage-bedding relationships and the style of folding (see Figs. 1-5 and 1-7).

STOP 1-7 Late Silurian-Early Devonian Stonehouse (Arisaig Group), Middle Devonian McArras Brook Formation and Carboniferous (Viséan) Martin Road and Ardness formations on shoreline, near McArras Brook

Stop 1-7A
Angular unconformity between cleaved siltstone, shale and mudstone of the Late Silurian-Early Devonian Stonehouse Formation and overlying Middle Devonian amygdaloidal basalt of the McArras Brook Formation. The contact has been “fault-modified”. In McArras Brook, a 5 m conglomerate lies beneath the basalt flow and unconformably above red silty mudstone and sandstone of the Early Devonian Knoydart Formation. The McArras Brook Formation consists of interbedded red conglomerate, sandstone, shale and basalt. The basalts are generally composed of plagioclase and augite phenocrysts set in a matrix of plagioclase, clinopyroxene and opaques variable replaced by chlorite, actinolite, calcite and quartz. Geochemically they are tholeiitic and within-plate (Dostal *et al*. 1983) and are attributed to rifting associated with the Magdalen pull-apart basin during the transpressive phase of the Acadian Orogeny. Concretionary limestone nodules are characteristically scattered throughout the shaley beds. Pebbles in the conglomerate are usually coated with a hematitic staining and comprise mainly red sandstone and siltstone derived from the underlying Knoydart Formation. The unconformity between the Early Devonian Knoydart Formation and Middle Devonian McArras Brook Formation represents the time interval during which the first phase of the Acadian Orogeny deformed the rocks. The McArras Brook Formation is interpreted as subaerial molasse.

Stop 1-8 Late Devonian - Carboniferous strata near Knoydart Point

Stop 1-8A Unconformity between Viséan Martin Road Formation (Windsor Group) and Middle Devonian McArras Brook Formation.

At the contact on the shore, conglomerate and sandstone of the Martin Road Formation may be seen resting upon a basalt flow capped by thin lenses of limestone. Tracing the unconformity to the east in the cliff, it rests at progressively higher stratigraphic levels in the McArras Brook Formation until on the headland 100 m east of the contact it rests above another higher basalt flow. Paleocurrent directions are towards the southeast in the Martin Road Formation and towards the west in the McArras Brook Formation. Carbonaceous plant debris is locally abundant in the Martin Road Formation. Concretionary barite with copper mineralization occurs in the middle of the formation (Keppie *et al*. 1978). Geochemical analyses of the Martin Road clastic rocks indicate derivation from the underlying Arisaig Group, implying that the unconformity between the Martin Road and McArras Brook has local significance (Murphy 2001).

Stop 1-8B Contact between Viséan Ardness Limestone and underlying Martin Road Formation, Windsor Group (See Fig.1-11).

The base of the Ardness Formation is defined at the base of the Ardness Limestone. At the easternmost exposed contact, a fault complicates the section. Farther west, where this same contact is exposed, repeated by local high angle faults, it is concordant and conformable.

Stop 1-8C Conformable contact between Viséan Ardness Formation (Windsor Group) and overlying Namurian Lismore Formation (Mabou Group).

The succession grades conformably upwards from limestone into wacke, mudstone, siltstone and shale of the Lismore Formation. A measured section is shown in Fig. 1-11 (Stevens *et al*. 1999). The geochemical and isotopic data indicate that the Lismore Formation may be subdivided into two geochemical groupings (Stevens *et al*. 1999). This subdivision is primarily reflecting varying contributions from accessory phases, clay minerals or rock fragments and occurs 115 meters above the base of the upper member.

The data from the lower grouping shows an important contribution from underlying Arisaig Group rocks and relatively minor contributions from Late Devonian granitoid rocks of the adjacent Cobequid Highlands and possibly metasedimentary rocks from the Meguma Terrane to the south. The data from upper grouping reveal a more important contribution from the Cobequid Highlands granitoid rocks. This variation in geochemistry is thought to constrain the age of renewed motion and uplift along the faults along the southern flank of the Maritimes Basin and, more generally, suggests that geochemical and isotopic data from continental clastic rocks may help constrain the age of tectonic events that influence deposition of basin-fill rocks.

DAY TWO
BLOCKS AND THEIR BOUNDARIES – NEOPROTEROZOIC AVALON TERRANE ROCKS OF THE COBEQUID HIGHLANDS

Leaders: Georgia Pe-Piper and David J.W. Piper

PURPOSE

Day 2 of the fieldtrip examines representative Neoproterozoic rocks from the two major blocks of the Avalon terrane in the Cobequid Highlands. Emphasis is on the nature of the boundary between the Jeffers and Bass River blocks and the character of the principal rock types within each block. For logistical reasons, this part of the fieldtrip concentrates on the southeastern part of the Cobequid Highlands. Localities elsewhere in the Cobequid Highlands are well described in previous field guides (Donohoe and Wallace 1980, 1985; Donohoe *et al*. 1992; Wallace 1998). Bedrock maps are those of Donohoe and Wallace (1982) and Pe-Piper and Piper (2005); aeromagnetic maps are those of Kiss *et al.* (1989).

INTRODUCTION

The Cobequid Highlands consist of Avalonian Neoproterozoic rocks, Silurian to Lower Devonian sedimentary rocks and widespread latest Devonian to early Carboniferous plutons and their volcanic equivalents. The Cobequid Highlands (Fig. 2-1) lie north of the Cobequid - Chedabucto fault zone, the term applied to a series of faults, with a wide range of ages, that mark the upper crustal expression of the crustal scale Minas Geofracture (Keppie 1982) between the Avalon and Meguma terranes. Areas affected by Late Paleozoic strike-slip motion on this system within and adjacent to the Cobequid Highlands are termed the Cobequid Shear Zone. The Cobequid Fault, which marks the southern margin of the Cobequid Highlands horst, is part of the Cobequid Shear Zone that was reactivated as a basin-margin fault in the Triassic (Withjack *et al*. 1995) and as a dextral shear in the mid Cretaceous (Pe-Piper and Piper 2004).

Within the Cobequid Highlands, Neoproterozoic rocks occur in two distinct blocks with quite different geology, the ***Bass River*** and ***Jeffers*** blocks, separated by the Rockland Brook Fault (Fig. 2-1). These two blocks consist principally of Late Neoproterozoic rocks. Not included in either block is the ***Economy River Gneiss***, a granodioritic orthogneiss that has yielded a U-Pb zircon age of 734 Ma (Doig *et al*. 1993) and is geochemically distinct from other Neoproterozoic granodiorite units.

The western part of the Rockland Brook Fault was last active in the Early Carboniferous (Pe-Piper *et al*. 2004) and this late Paleozoic movement appears to have continued westward in the Kirkhill Fault. The northern margin of the Cobequid Highlands is largely fault-bound, with minor overstep of Upper Carboniferous rocks of the Cumberland Basin. A series of faults striking E-W has been mapped between the Rockland Brook Fault and the northern margin of the Cobequid Highlands, resulting in E-W trending outcrop belts of Neoproterozoic, Silurian and Devonian-Carboniferous rocks (Fig. 2-2).

The Late Neoproterozoic rocks of the Cobequid Highlands, particularly those of the Jeffers block, show similarities to rocks of comparable age in the Antigonish Highlands (Murphy *et al*. 1992), as do the Silurian sedimentary rocks. These two highland areas are separated by Carboniferous rocks of the Stellarton Basin. Much of the Cobequid Highlands is underlain by

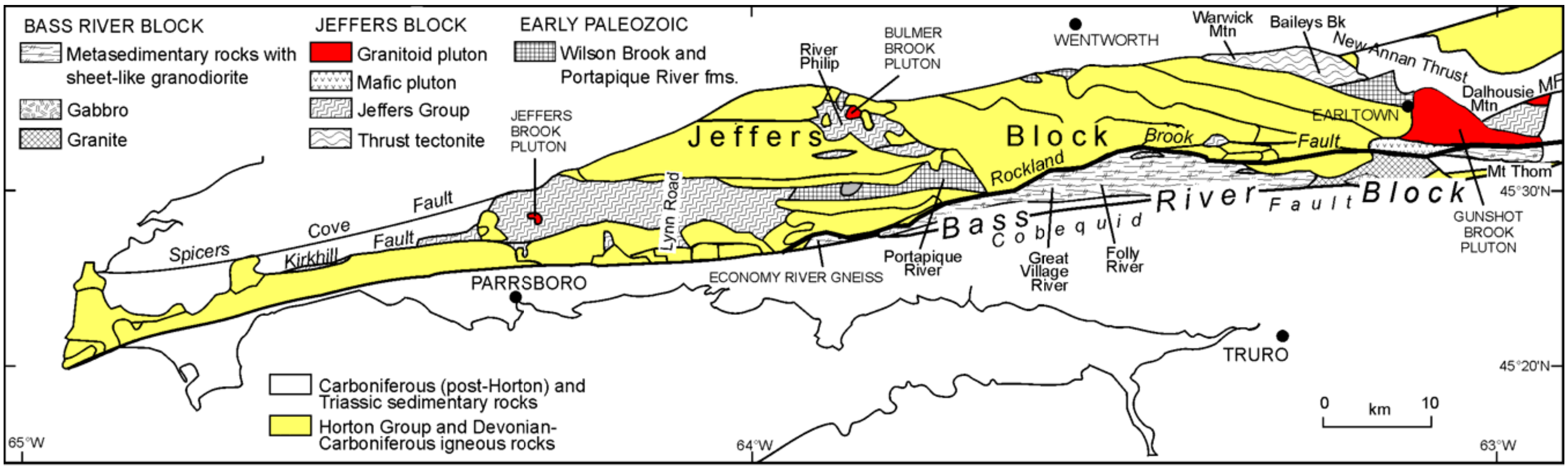


Figure 2-1. *Summary geological map of the Cobequid Highlands to illustrate Neoproterozoic and Lower Paleozoic rocks and faults inferred to have been active in the Late Neoproterozoic.*

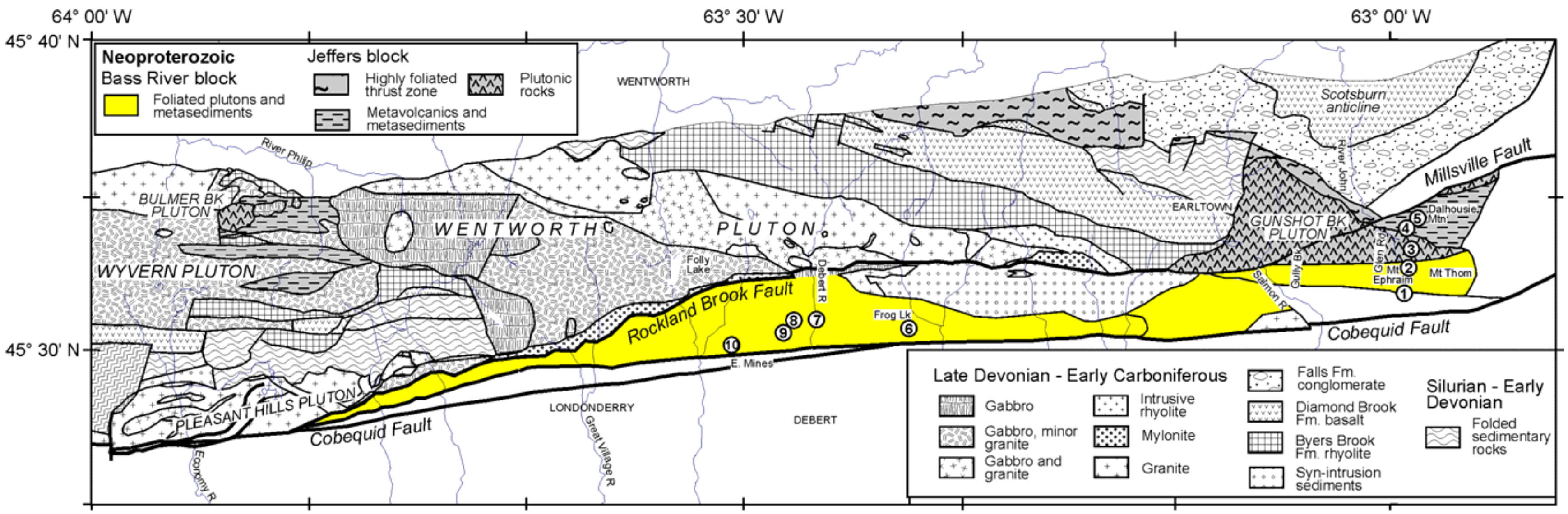


Figure 2-2. Geological map of the eastern Cobequid Highlands, showing locations of stops.

latest Devonian - earliest Carboniferous granite and gabbro plutons and their extrusive equivalents, the Fountain Lake Group. Terrestrial fluvial and lacustrine sediments accumulated in small basins of mid Devonian to early Carboniferous age.

The Cobequid Highlands provide little evidence for geologic history from the Cambrian to the Early Devonian. The only known Lower Paleozoic rocks are marine and littoral sedimentary rocks of the Arisaig Group of Silurian to Early Devonian age, assigned to the Wilson Brook and Portapique River formations. Middle to Late Devonian rocks show a completely different tectonic setting, comprising terrestrial sediments in fault-bound basins. Late Paleozoic igneous activity (both plutons and volcanic rocks) is concentrated at the Devonian – Carboniferous boundary, from 365 to 350 Ma. A spotted hornfels near Parrsboro has yielded Ar/Ar dates of uncertain significance of 465 Ma on muscovite and 511 Ma on biotite (J. Nearing, pers. comm. 1996), but otherwise there is no evidence of early Paleozoic igneous activity.

THE BASS RIVER BLOCK

The Bass River block (Nance and Murphy 1990) consists of a series of fault slices of Neoproterozoic shelf siliciclastic sedimentary rocks (***Gamble Brook Formation***: Stops 2-6, 2-10), tectonically juxtaposed with ocean-floor basalt and a thin cover of pelagic sedimentary rocks and fine-grained turbidites (***Folly River Formation***: Pe-Piper and Murphy 1989; Stop 2-7), and intruded by a series of plutonic rocks. The Gamble Brook Formation contains detrital zircon grains as young as 1183 Ma (Keppie *et al*. 1998), thus placing a maximum age on the formation. Individual plutons are difficult to define because of the tectonic dismemberment of the Bass River block, but three principal plutonic rock types are distinguished: the ***Frog Lake gabbro/diorite*** unit (Stops 2-2, 2-6), the ***Debert River granodiorite*** unit (Stops 2-1, 2-8, 2-10) and the ***McCallum Settlement granite*** unit (Pe-Piper *et al*. 1996). The first two units occur principally as sheets tens to hundreds of metres thick within the Gamble Brook Formation, with structures indicating emplacement during shearing (Pe-Piper *et al*. 1996). Geochronology by $^{40}Ar/^{39}Ar$ on hornblende (Keppie *et al*. 1990) and U-Pb on zircon (Doig *et al*. 1991) showed that the Frog Lake gabbro/diorite is about 622 Ma and the Debert River granodiorite 609 - 605 Ma. Poor quality U-Pb and Rb-Sr ages of ca. 575 Ma (Doig *et al*. 1991) have been obtained from the McCallum Settlement granite unit, which cuts the Debert River granodiorite. In addition, small bodies of the geochemically distinct ***Glen Road*** and ***Gully Brook granite*** units (Stop 2-2) have been recognised in the Mount Thom area (Pe-Piper *et al*. 2002).

In the last century, some authors distinguished certain lithologies within the Bass River block (termed the "Bass River complex") as possible "basement" rocks of the Avalon terrane. They include the Great Village River Gneiss (Cullen 1984) and the "Mount Thom complex" (Meagher 1995), from which Gaudette *et al*. (1984) reported a 934 ± 82 Rb/Sr isochron from granitic gneiss. Doig *et al*. (1991) reported Late Neoproterozoic U-Pb zircon ages in the Great Village River Gneiss of 589 Ma from an amphibolite, with a protolith interpreted as Folly River Formation on the basis of whole-rock chemistry, and 580 Ma from granitic gneiss, probably of McCallum Settlement granite protolith. Nearing *et al*. (1996) dated amphibole from mylonite near the Rockland Brook Fault as 601 Ma by $^{40}Ar/^{39}Ar$. As argued by Pe-Piper *et al*. (1995) and Murphy *et al*. (2001, p. 48-49), we interpret both the Mount Thom complex and the Great Village River gneiss as having protoliths consisting of middle Neoproterozoic sedimentary and volcanic rocks and Late Neoproterozoic plutons, similar to those exposed elsewhere in the Bass River block. Metamorphism of the Bass River block is of greenschist facies, with sparse evidence locally of higher grades adjacent to mafic and intermediate plutons. The principal deformation and metamorphism took place during Late Neoproterozoic transpressional motion on the Rockland Brook Fault, when the rocks underwent thermo-mechanical softening as a consequence of emplacement of Frog Lake gabbro and Debert River granodiorite (Pe-Piper *et al*. 1995, 1996, 2002).

Pe-Piper *et al*. (1996) interpreted the sequence in the Bass River block as having formed by tectonic accretion at a convergent plate margin, with the plutonic rocks emplaced along shear zones during oblique convergence. Murphy (2002) showed from sedimentary geochemistry that the Gamble Brook Formation formed in a rifted arc environment. Pe-Piper *et al*. (1996) interpreted contacts between the Gamble Brook Formation and the Folly River Formation as tectonic; Murphy *et al*. (1988) interpreted the relationship as unconformable.

THE JEFFERS BLOCK

The Jeffers block consists principally of the ***Jeffers Group***, a series of volcanic and volcaniclastic sedimentary rocks at least several hundred metres thick (Pe-Piper and Piper 1989). In the western Cobequid Highlands, the ***Gilbert Hills Formation*** (Stops 2-11, 2-12) of principally andesite and dacite is overlain by turbidites (sandstone and argillite) of the ***Cranberry Lake Formation*** (Stop 2-13). Jeffers Group rocks are also recognised in the River Philip area (Fig. 2-2) (Pe-Piper *et al*. 1994). At Warwick Mountain and in Baileys Brook (Fig. 2-1) Jeffers Group rocks were included in the ***Warwick Mountain Formation*** of Donohoe and Wallace (1982). Here, they are tectonically intercalated with Carboniferous sedimentary and igneous rocks in the hanging wall of the New Annan Thrust (Piper and Pe-Piper 2001). In the eastern Cobequid Highlands, at Dalhousie Mountain, Jeffers Group rocks have been termed the ***Dalhousie Mountain Formation*** (Murphy *et al*. 1988, 2001; Stops 2-4, 2-5). The formation consists of abundant tuffaceous turbidites and argillites with interbedded felsic and mafic volcanic rocks. The Jeffers Group can be readily recognized because the volcanic rocks are geochemically distinct from younger Devonian-Carboniferous volcanic rocks (Pe-Piper *et al*. 1994) and, except for lacustrine turbidites in the Horton Group, no other turbidites are known from the Cobequid Highlands. The age of the Jeffers Group is Late Neoproterozoic based on a U-Pb age on zircon of 630 ± 2 Ma from a rhyolite in the Gilbert Hills Formation (Murphy *et al*. 1997) and by cross-cutting plutonic rocks of two common geochemical types: the ***Jeffers block granodiorite*** unit and the ***Gunshot Brook granite*** unit (Stop 2-3).

In the western Cobequid Highlands, the Jeffers Group is cut by the Jeffers Brook Pluton (Pe-Piper 1988) with an $^{40}Ar/^{39}Ar$ age of 605-607 Ma (Keppie *et al*. 1990). The Bulmer Brook Pluton cuts the Jeffers Group in the River Philip area. South of Dalhousie Mountain, the Dalhousie Mountain Formation is intruded, with an undeformed igneous contact, by the Gunshot Brook Pluton, which has a U-Pb age of 605 Ma (R. Doig, in Murphy *et al*. 2001). Smaller intrusive bodies in this area have been termed the River John gabbro, tonalite and granodiorite units (Pe-Piper *et al*. 2002; Stop 2-3).

Deformation of the Jeffers Group in the type area involved thrusting and produced recumbent isoclinal folds (Donohoe and Wallace 1985; Pe-Piper and Piper 1989; Stops 2-11, 2-12). The Dalhousie Mountain Formation and the Jeffers Group in the River Philip area are both folded and cleaved. Elsewhere, such as in Bailey Brook, strata are almost undeformed. The Jeffers Brook Pluton shows synmagmatic deformation features near its southwestern margin, much of the pluton shows a weak ductile solid-state foliation, and mafic enclaves tend to be flattened. Such rapid changes in degree of deformation suggest that deformation was related to regional shear. In the Mount Thom area, the Jeffers block shows a major shear zone contact with the Bass River block that has been unaffected by late Paleozoic deformation (Pe-Piper *et al*. 2002; Stop 2-3). The great thickness of mylonitic granite suggests that this shear zone may have been synchronous with the 605 Ma Gunshot Brook Pluton. To the west, the contact between the two blocks along the Rockland Brook Fault experienced major late Paleozoic reactivation.

GEOCHEMICAL CHARACTERISTICS OF THE PLUTONIC ROCKS

A wide range of plutonic rocks are found in the Cobequid Highlands, both of Neoproterozoic and Late Paleozoic age. In many cases, petrographic features in hand specimen and even thin section are insufficient to discriminate between different units of plutonic rocks. We have found that whole rock geochemistry provides a reliable and consistent method of discriminating in the first instance between Neoproterozoic and Late Paleozoic plutonic rocks, and allow the further discrimination of different igneous suites among the Neoproterozoic rocks (Fig. 2-3).

BASS RIVER BLOCK

On the south side of the Rockland Brook Fault, three plutonic rock types are recognised in the central Cobequid Highlands: the Frog Lake gabbro, the Debert River granodiorite and the McCallum Settlement granite (Fig. 2-3). In the eastern Cobequid Highlands, no equivalents of the McCallum Settlement granite have been found, but two undated geochemically distinctive granites, Glen Road and Gully Brook, are found. They are geochemically quite different from late Paleozoic granites, but no definite correlation can be made with Neoproterozoic plutonic suites. The Mount Thom Complex appears to consist of gneissose Debert River granodiorite and tectonic intercalations of Gamble Brook Formation metasedimentary rocks, similar to "Great Village River Gneiss" of the central Cobequid Highlands (Pe-Piper *et al*. 1995).

Frog Lake gabbro/diorite: The gabbro/diorite consists principally of plagioclase and hornblende. Most has 47-55% SiO_2, TiO_2 in the range 1.3-1.6%, Y 18-30 ppm, Nb < 15 ppm and Zr <135 ppm, and overall has a subduction-related trace element signature. In places, the Frog Lake gabbro/diorite has higher TiO_2 and is more alkalic in character. Nevertheless, it contrasts with Devonian-Carboniferous gabbro which has high contents of Y (>35 ppm), Zr (>200 ppm), and Ti (>1.8%).

Debert River granodiorite: This rock type ranges from 59-69% SiO_2, with moderate levels of Ba (600-900), Y (40-50 ppm), Zr (220-280) and Nb (15-18 ppm). At Lower Mount Thom and the Mount Ephraim quarry, granitic gneiss with 71- 72% SiO_2 has similar trace element characteristics to the Debert River granodiorite.

McCallum Settlement granite: This granite has a narrow range of compositions with 73% SiO_2, 31-34 ppm Nb, 17-19 ppm Y, and 125- 220 ppm Zr. It has geochemical characteristics suggesting a within-plate or A-type character (Pe-Piper *et al*. 1996).

Glen Road granite: Granite from Glen Road has >76% SiO_2, low Ba (<150 ppm), and Y and Nb < 7 ppm.

Gully Brook granite: Granite from Gully Brook and from Mount Thom has about 74% SiO_2, low Y and Nb, but high Ba (>800 ppm).

JEFFERS BLOCK

On the north side of the Rockland Brook Fault, most plutonic rocks geochemically resemble the Jeffers Brook pluton, notably in their much lower abundances of high field strength elements. The dominant rock type in the eastern Cobequid Highlands is the Gunshot Brook granite, but lesser amounts of gabbro, tonalite and granodiorite are also found, particularly in the south of the area.

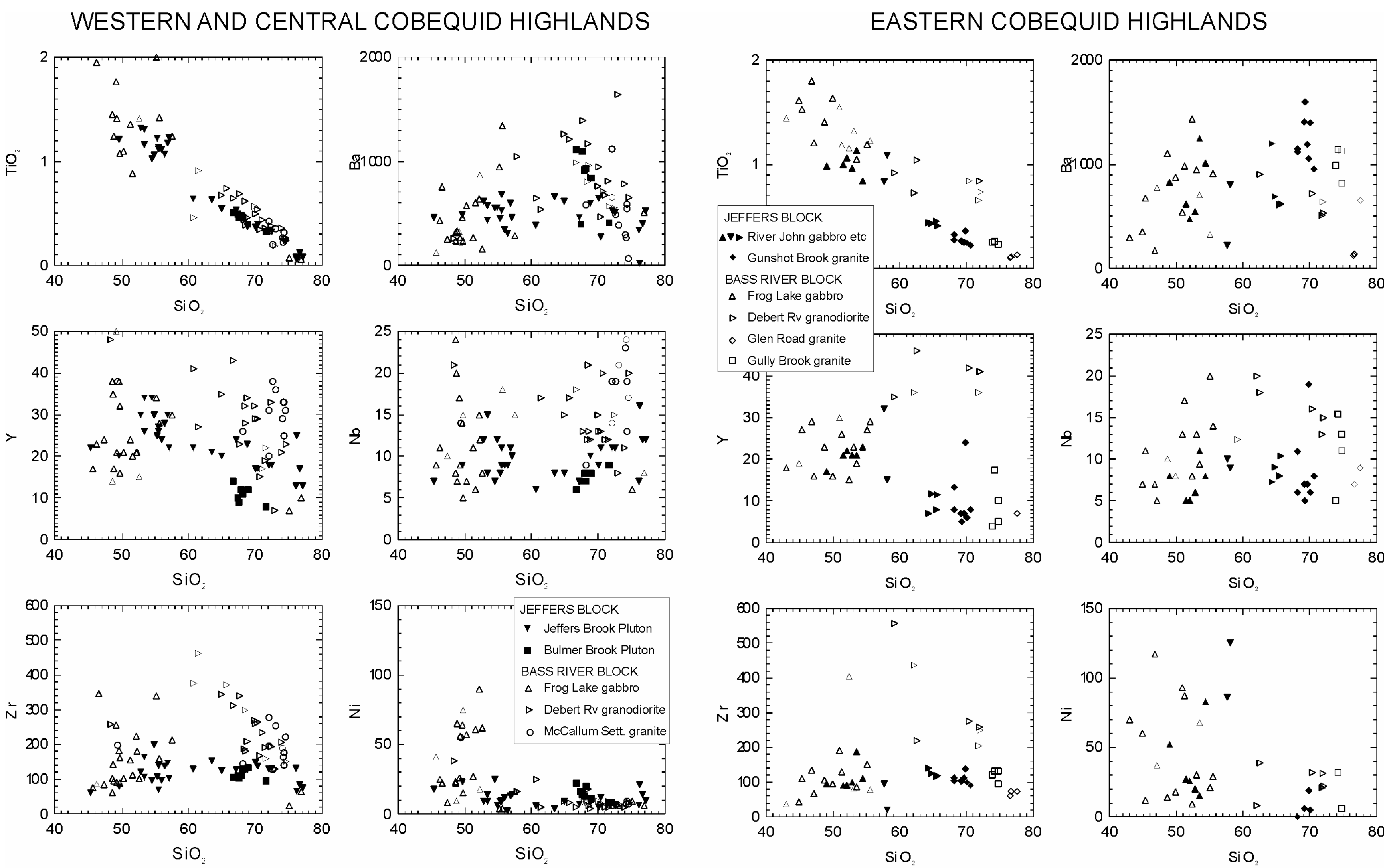


Figure 2-3. Selected element plots against silica for Neoproterozoic plutonic rocks of the Cobequid Highlands.

Jeffers block granodiorite: Most granodiorite ranges from 54-73% SiO_2 thus showing a much wider compositional range than the Debert River granodiorite. For the same SiO_2 content, the Jeffers block granodiorite has lower abundances of Y, Nb, Zr, Ba and K than the Debert River granodiorite.

Gunshot Brook granite: This granite has typically 68% - 69% SiO_2, Ba > 950 ppm, both Y and Nb < 10 ppm, Zr < 120 ppm and Ga < 20 ppm. It is quite unlike any Devonian-Carboniferous granites of the Cobequid Highlands, which have generally higher SiO_2, much higher Y and Nb, rather higher Ga and Zr, and much lower Ba. It also differs from the McCallum Settlement granite in being lower in SiO_2, Y, Nb and Zr.

River John gabbro: This gabbro has 50-52% SiO_2, Zr 90-110 ppm, Y 20-22 ppm, Nb 5-6 ppm and TiO_2 0.9-1.1%. It is quite different from Devonian-Carboniferous gabbros of the Cobequid Highlands.

River John tonalite: Tonalite with ca. 56% SiO_2 is similar to the Debert River granodiorite, but has lower Y (<32 ppm) and Zr (<100 ppm). Trace element patterns are similar to the River John gabbro.

River John granodiorite: Granodiorite found in the headwaters of the West Branch River John with 63-65% SiO_2 appears transitional in geochemistry between the River John tonalite and the Gunshot Brook granite.

THE ROCKLAND BROOK FAULT

The Rockland Brook Fault (Miller *et al*. 1995) separates the Bass River block from the Jeffers block. In the western Cobequid Highlands, it is either represented by the Kirkhill Fault, or merges with the Cobequid Fault and no rocks of the Bass River block are known in this region. In the central Cobequid Highlands, the Rockland Brook Fault was a major zone of Famennian-Tournaisian strike-slip motion and the principal pathway from intrusion of the late Paleozoic Pleasant Hills and Wentworth plutons (Pe-Piper *et al*. 1998). Farther east, this motion was largely taken up on the Millsville Fault, which was a major relief feature in the early Carboniferous (Chandler *et al*. 1994). Where exposed, no significant cataclasis is seen along the eastern part of the Rockland Brook Fault, which we interpret as an Avalonian suture that was **not** reactivated in the late Paleozoic. In the later Carboniferous rocks north of the Stellarton graben, the Rockland Brook Fault has no apparent surface expression. Motion appears to have been taken up on four subparallel ENE-trending faults: the Hollow Fault on the south side of the Stellarton basin, the Cobequid Fault, the Millsville Fault, and the Scotsburn Fault (Fig. 2-1). Devonian-Carboniferous igneous rocks are found near the Cobequid Fault and its splays south of Lower Mount Thom and probably on the Millsville Fault, but are absent on the eastern part of the Rockland Brook Fault.

REGIONAL COMPARISONS OF THE PRECAMBRIAN ROCKS

Comparisons of the Avalonian tectonic and igneous events (Fig. 2-4) can be made between the blocks of the Cobequid Highlands and the Caledonia terrane of southern New Brunswick, the Georgeville block of the Antigonish Highlands, and the Mira terrane of southern Cape Breton island. In most of these areas, there is a long and complex history of Late Neoproterozoic igneous activity. No volcanic rocks are known from the Cobequid Highlands of similar age to the 680 Ma Stirling Group of the Mira terrane. The oldest volcanic rocks are the

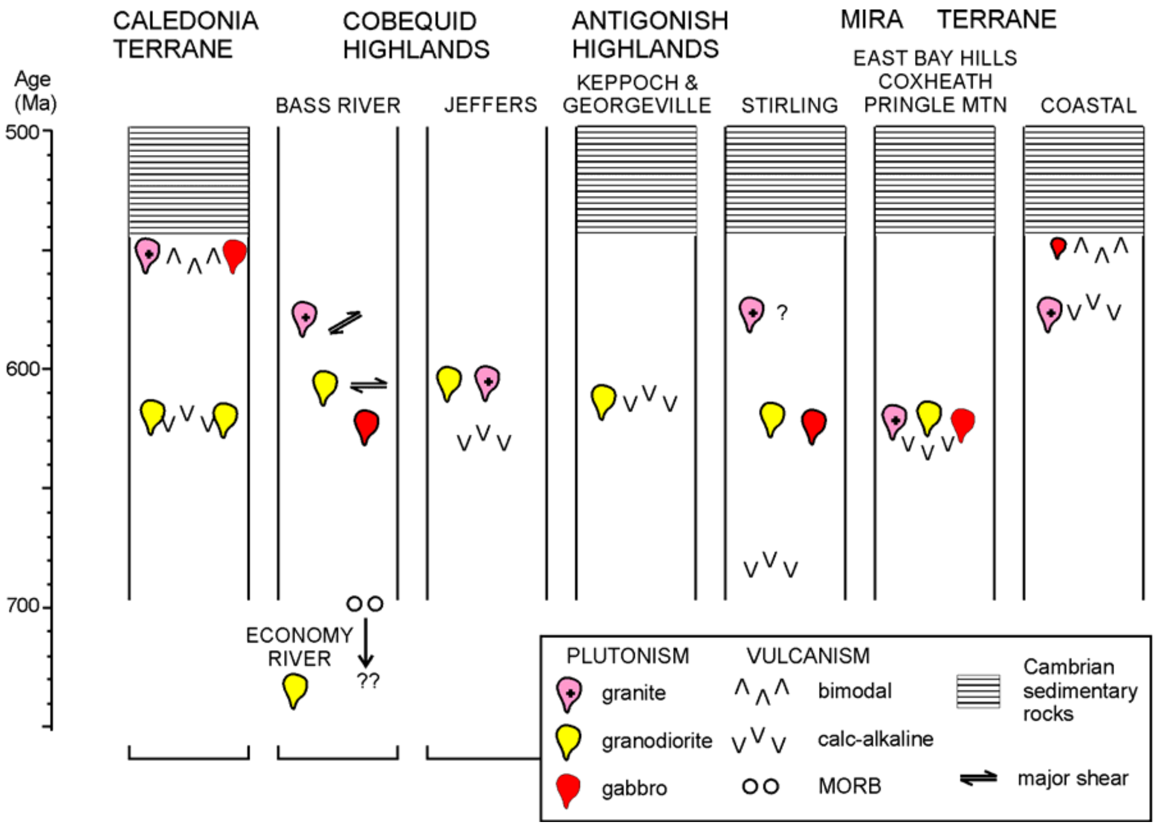


Figure 2-4. *Comparison of Neoproterozoic events in the Cobequid Highlands with those in adjacent parts of the Avalon terrane (from Pe-Piper and Piper 2003).*

630 Ma Jeffers Group, which are a little older than the ca. 620 Ma volcanism of the Mira terrane (East Bay Hills, Coxheath, and Pringle Mountain groups) and the 615-610 Ma Keppoch Formation in the Antigonish Highlands, but may be of similar age to the Broad River Group of the Caledonia terrane. In the Bass River block, the 622 Ma Frog Lake gabbro is of similar age to widespread dioritic to granodioritic plutons in the Caledonia and Mira terranes. Similar plutonism in the Antigonish Highlands is regarded as being a little younger (618-611 Ma) and the 609-605 Ma Debert River granodiorite of the Bass River block is younger still. The 605-607 Ma plutons of the Jeffers block are of similar age to the Debert River granodiorite. Metamorphism (590-600 Ma) and intrusions (580 Ma) in the “Great Village River Gneiss” and the McCallum Settlement granite (ca. 575 Ma) are a little older than the Fourchu and Main -A-Dieu volcanics and associated plutons of the Mira terrane (ca. 575-560 Ma) and the Coldbrook Group volcanics and the younger plutons of the Caledonia terrane (560–550 Ma).

The closest regional similarities are between the Jeffers block of the Cobequid Highlands and the Georgeville block of the Antigonish Highlands (Fig. 2-4). The Bass River block, which lacks volcanic rocks related to plutonism, appears to be at a deeper crustal level than either of these blocks or the Caledonia and Mira terranes. From its present geometry, it might have been the most inboard of these peri-Gondwanan terranes.

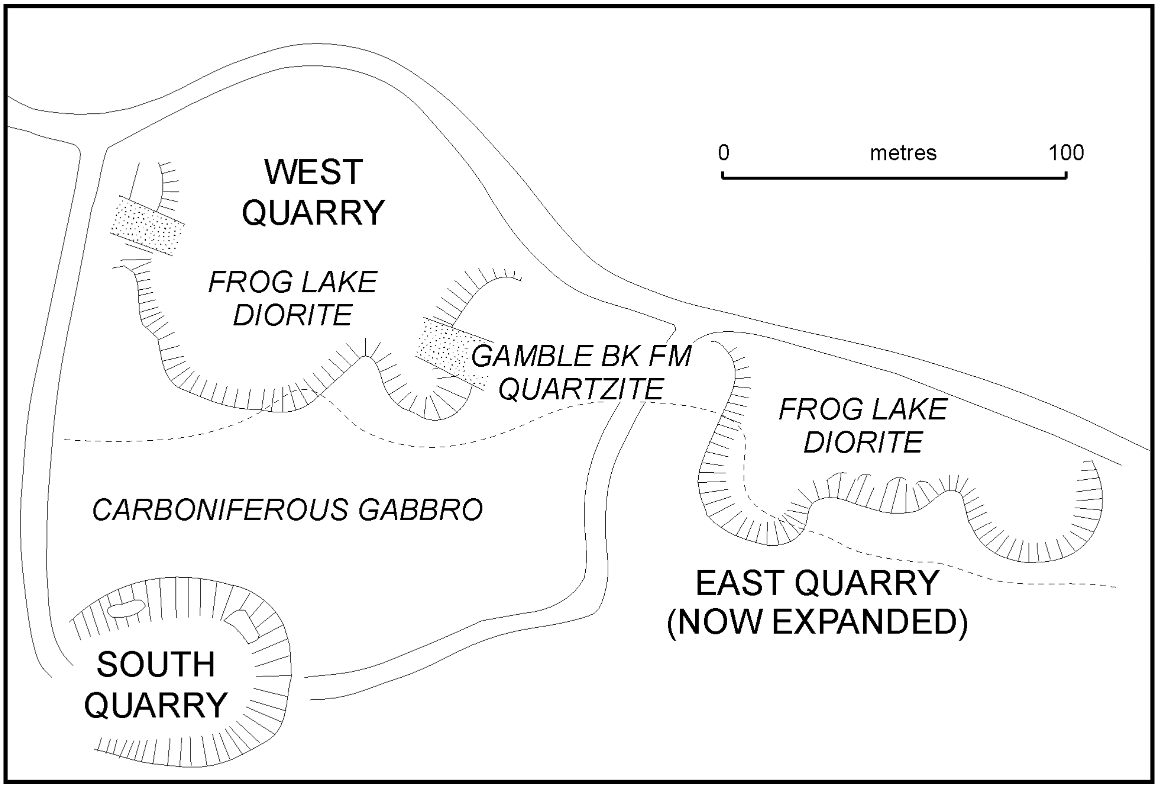


Figure 2-5. *Map of the Frog Lake quarries in 1989, prior to the expansion of the East Quarry.*

ROAD LOG

All of the field stops are located along woods roads to the north of the Trans-Canada Highway (Highway 104) (Fig. 2-2). Stops 2-1 to 2-5 in the Mount Thom area can be reached by taking Exit 20 from the Trans-Canada Highway at Saltsprings and joining old Highway 4. Drive west on Highway 4. At 8.6 km from the exit ramp is the turnoff to Stop 2-1 (Weeks Quarry) on the right. 2.4 km farther west on Highway 4, turn right onto the unpaved Glen Road. 2.0 km up Glen Road, turn right onto snowmobile trail 556 at the south end of Bezanson Lake. Stop 2-2 is 2.5 km east along this trail, at a Y-junction. At this Y-junction, turn left (north) onto trail 552-E. Stops 2-3 are along this trail: 2-3A at 0.7 km from Stop 2-2, 2-3B at 0.8 km, 2.3C at 1.0 km, 2-3D at 1.1 km. At 2.1 km north of Stop 2-2, bear left at the Y-junction. Stop 2-4 is 0.8 km beyond this Y-junction and stop 2-5 is 1.1 km. Then drive back along the same route to Glen Road and rejoin Highway 4. At 5.4 km along Highway 4, turn left to the Trans-Canada Highway at Exit 19.

Stops 2-6 to 2-10, in the Debert area (Fig. 2-2) can be reached by leaving the Trans-Canada Highway at Exit 13 (Debert). At 0.2 km from the exit is a Tim Horton's; at 1.2 km from the exit, bear right at the Y-junction towards Belmont and at 4.7 km from the exit turn left (north) towards Belmont. Drive through Belmont. At the Y-junction at 9.4 km, follow the paved road to the left, but at the next junction at 10.4 km, take the unpaved road to the north (straight ahead). Shortly after the road crosses the Cobequid Fault line, there is a road junction at 16.9 km. The right hand road is signed as Farm Lake Road. Take the left hand road towards the Frog Lake quarries, bearing right between piles of aggregate and parking at the entrance to the West Quarry (Stop 2-6) at 18.1 km. From here, follow the woods road to the northwest. At 3.3 km from Stop 2-6 is a narrow bridge that is difficult to cross. At 4.1 km on the south side of the road is the entrance to an old quarry in Debert River granodiorite and at 5.1 km cross the Debert River (Stop 2-7). Three roads radiate from west end of the Debert River bridge: take the middle road. At 1.3 km from the Debert River bridge, this road joins a new woods road. Park on the old road and walk 100 m down the new road to the left (south) to Stop 2-8.

Return to vehicles and drive down this new road to the south. At 2.0 km from the Debert River bridge, park on west side of road for Stop 2-9. Then continue south along this road, bearing left at the junction at 7.8 km from the Debert River bridge, and right at the junction at 9.5 km. At 10.2 km, arrive at the junction of the Upper Debert River Road and the East Folly Mountain Road. Continue straight along the East Folly Mountain Road. Go across the cross-roads at 11.9 km and continue to the next cross-roads at 12.4 km: go right here (to north) and continue uphill to the powerlines at 14.3 km (Stop 2-10). Return along the same road, turn left (east) at the first crossroads at 1.9 km from the powerlines, go right (south) at the next crossroads at 2.4 km down Reid Road, and at 8.0 km reach the junction with Plains Road. Turn right onto Plains Road and drive west, crossing old Highway 4 at 11.1 km, and go straight at the junctions at 13.4 km and 15.8 km to reach the on-ramp of the Trans-Canada Highway at 16.3 km. At this point, take the Trans-Canada Highway northwards towards New Brunswick.

If weather or other circumstances such as washed out woods roads so dictate, optional Stops 2-11 to 2-13 may be visited. They are located on Lynn Road (Fig. 2-1), in the Jeffers Block of the western Cobequid Highlands. In this case, do not join the Trans-Canada Highway, but continue under the bridge and on to Great Village. In Great Village, make a sharp turn to the right onto Highway 2. Drive west along Highway 2 through Bass River, Economy and Five Islands and turn right (north) onto Lynn Road at the county line immediately west of Lower Five Islands. At 3.2 km from Highway 2, Stop 2-11 is on the west side of the road. Stop 2-12 is at 3.8 km from the highway on the west side of the road (care - blind corner), and Stop 2-13 is at 6.6 km on the east side of the road. Then continue north along Lynn Road through East Mapleton to the junction with Highway 2. Turn right (northeast) on Highway 2 and pass through Springhill, then take the Highway 142 connector to the Trans-Canada Highway.

STOP DESCRIPTIONS

STOP 2-1 [*optional: depends on state of quarry*]. Weeks quarry. **Pay attention to loose rock on quarry walls and moving quarry equipment.**
Examine rocks in loose blocks on quarry floor. The main active quarry exposes variably deformed and rather inhomogeneous Debert River granodiorite. Small screens of Gamble Brook Formation metasediment are metamorphosed to biotite schist. Minor gabbro bodies are also present: at least some resemble Carboniferous gabbro in their geochemistry and have locally produced hybrid tonalites.

STOP 2-2 [*optional alternate to stop 2-1*] **Bass River block**.
On northwest side of clearing, Frog Lake diorite shows a mineral fabric (? is it pre-full crystallisation) in contact with Gully Brook granite.

STOP 2-3 At this stop, we walk through a major mylonite zone in the Neoproterozoic plutonic rocks, marking the southern margin of the Jeffers block and the Gunshot Brook granite. This mylonite zone, with more mafic rocks of the River John suite, may be a magma source zone analogous to the relationship of the Carboniferous Rockland Brook fault to the Wentworth pluton.

Stop 2-3A On the east side of road is a series of outcrops in foliated to mylonitic granodiorite, with some diorite at the north end of the outcrop (River John gabbro, tonalite and granodiorite).

Stop 2-3B the east side of road is an outcrop of mylonitic River John granodiorite.

Stop 2-3C 200 m farther north, at junction of woods road to east. On west side of road is an outcrop of granodiorite showing little deformation.

Stop 2-3D At 100 m farther north of the junction, at the small pond on the east side of the road, is the first small outcrop of Gunshot Brook granite, of interest only for its lithology. In the brook to the ENE, there are extensive outcrops of Gunshot Brook granite showing an irregular intrusive contact with Dalhousie Mountain Formation to the north.

STOP 2-4 Jeffers block, Dalhousie Mountain Formation
Outcrops on west side of road just NE of a slow bend showing intermediate lavas and pyroclastic rocks of the Dalhousie Mountain Formation, cut by a dyke.

STOP 2-5 (Optional) Jeffers block. Small clearing on SE side of road with various andesite to dacite lavas and pyroclastic rocks of the Dalhousie Mountain Formation. 100 m to the north is a road junction with further outcrops and a chance to turn vehicles around.

STOP 2-6 Frog Lake quarries (Fig. 2-5) **Bass River block**. The most interesting features are in the West Quarry, where Frog Lake diorite is in contact with a vertical sheet of Gamble Brook Formation quartzite and is cut by a Carboniferous gabbro dyke. **Pay attention to loose rocks on the higher quarry walls.** The diorite is inhomogeneous, with pervasive veining by different diorite and tonalite phases, with oriented phenocrysts and felsic segregations. Dioritic hornblendite pegmatites are common. Country rock shows local metasomatic growth of hornblende and is surrounded by a selvage of leucogranite that extends into the diorite as granitic pegmatite.

STOP 2-7 Debert River bridge; Folly River Formation, Bass River block
Outcrop is in the Debert River, from the bridge to 100 m to the north. The river can be accessed on the west side of the bridge. **Pay attention to wet, slippery rock surfaces.** The Folly River Formation consists of basalt with interbedded fine-grained turbidites and thin red chert beds and nodules, cut by mafic dykes. The rocks have undergone greenschist facies metamorphism and are post-tectonically cut by the Shatter Brook pluton of McCallum Settlement granite.

STOP 2-8 Debert River granodiorite, Bass River block
Outcrop on east side of woods road in Debert River granodiorite, Bass River block. **Watch out for speeding logging trucks coming round the blind corner: park on old road 100 m north of the outcrop.** It shows characteristically inhomogeneous Debert River granodiorite with mafic enclaves and shear along the finer-grained granodiorite.

STOP 2-9 (Optional) Carboniferous gabbro shows very inhomogeneous strain related to Carboniferous deformation along the Rockland Brook Fault. Similar gabbro was seen in dykes at Stop 2-7. The largest gravity anomaly in the Cobequid Highlands is located in this area.

STOP 2-10 Bass River block; Gamble Brook Formation and Debert River granodiorite
Park beneath powerlines and walk 100 m east along the clearing, where there are low outcrops of Gamble Brook quartzite with lit-par-lit intrusion of Debert River granodiorite.

STOP 2-11 (Optional) Jeffers block; Horton Group
High rather loose cliff outcrop on west side of road: **pay attention for speeding traffic and falling rocks**. Preferably examine rocks in fallen blocks. At the south end of the outcrop are black shales and thin-bedded siltstones of the Horton Group. This marks the northern edge of the Cobequid Fault zone in this area, with intermittent outcrops in fault zone rocks including Horton Group and Carboniferous microgranite for several hundred metres to the south. At the north end of the outcrop, cleaved andesite (locally vesicular) of the Gilbert Hills Formation outcrops.

STOP 2-12 (Optional) Jeffers block; Gilbert Hills Formation
High rather loose cliff outcrop on west side of road, with lower outcrop with fewer hazards at north end of outcrop. **Note that this is a blind corner: pay attention for speeding traffic and falling rocks**. The outcrops show cleaved intermediate volcanic rocks, with the degree of deformation increasing northward.

STOP 2-13 (Optional) Jeffers block; Cranberry Lake Formation
Laminated argillite and fine-grained turbidite sandstone outcrop in a low cliff on the east side of the road.

DAY THREE
PERI-GONDWANAN TERRANE EVOLUTION IN SOUTHERN NEW BRUNSWICK

Leaders: Sandra Barr, Susan Johnson and Chris White

PURPOSE

On Day three we concentrate on the similarities and differences among Neoproterozoic - Early Paleozoic peri-Gondwanan terranes and Late Ordovician to Early Silurian cover rocks in southern New Brunswick and what these rocks tell us about the accretionary history of the area.

INTRODUCTION

Southern New Brunswick is characterized by several narrow, fault-bounded, northeast-trending belts of rocks of contrasting composition and age that record a complex history of Late Neoproterozoic and Paleozoic extensional and accretionary tectonic events. From northwest to southeast, these belts of rock have been named St. Croix, Mascarene, New River, Kingston, Brookville, and Caledonia terranes (Fig. 3-1), although not all of the trip leaders are completely comfortable with the terrane terminology. Furthermore, all of the leaders recognize that the Late Ordovician to Late Silurian volcanic, sedimentary, and plutonic rocks of the Kingston and Mascarene terranes likely represent dissected cover sequences on the New River and St. Croix terranes, and therefore are not likely to be separate terranes with distinct Neoproterozoic basements.

The St. Croix terrane records a Lower Paleozoic stratigraphic and structural history similar to that in the Miramichi Group in northern New Brunswick, and consequently has been included in the Gander Zone or Ganderia (Fyffe and Fricker 1987; van Staal and Fyffe 1991; van Staal *et al*. 1998). In this interpretation, the boundary between the Gander and Avalon zones is placed at the Falls Brook - Taylor Brook Fault or concealed beneath the Mascarene cover sequence and Silurian - Devonian plutonic rocks of the Saint George Batholith (Fyffe *et al*. 1992; Whalen *et al.* 1994, 1996; Currie 1984, 2003; Currie and McNicoll 1999; Johnson 2001).

However, not all workers accept this interpretation. The St. Croix terrane is alternatively considered to be part of Avalon Zone (or Composite Terrane), rather than Gander (or Medial New England) Zone (e.g., Robinson *et al*. 1998; Tucker *et al*. 2001), and the Avalon - Gander boundary placed at the Fredericton Fault (e.g., Park and Whitehead 2003).

Another alternative viewpoint (Barr and White 1996; Barr *et al.* 2002, 2003; King and Barr 2004) is that the Neoproterozoic and Lower Paleozoic terranes in southern New Brunswick were all initially peri-Gondwanan, but only the Caledonia terrane is part of the Avalon Zone as originally defined by Williams (1978, 1979). The Brookville and New River terranes are interpreted to be basement terranes distinct from Avalon, and possibly (but not necessarily) linked to Ganderia, which includes the St. Croix terrane, as well as the Miramichi terrane of northern New Brunswick (van Staal *et al.* 1998). Hence, these workers draw the Avalon boundary at the Caledonia - Clover Hill Fault.

A further complication is the recognition, as described below, that the New River terrane consists of contrasting parts, some of which may include stratigraphic and plutonic units characteristic of Avalon terrane *sensu stricto* (Johnson 2001).

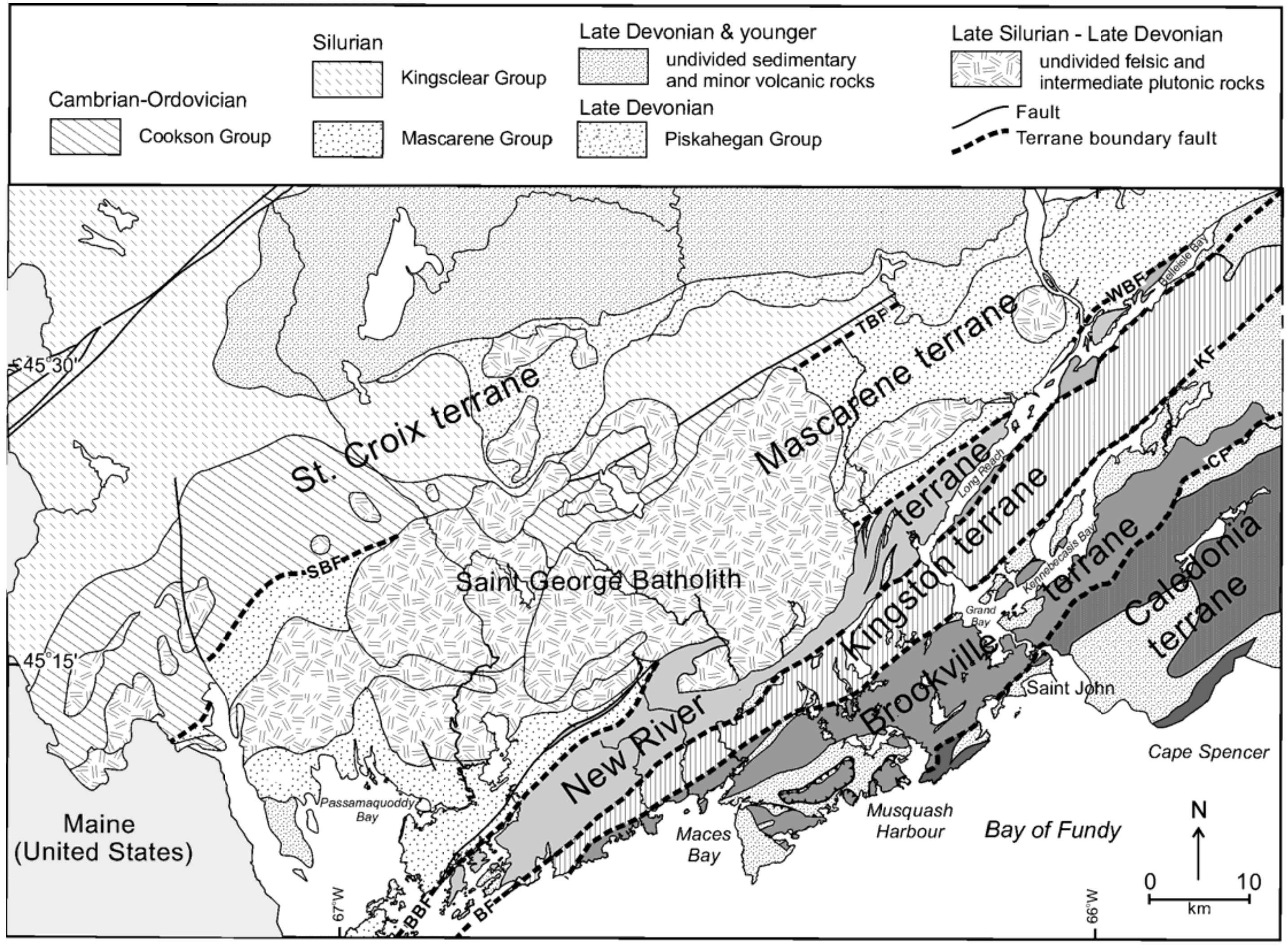


Figure 3-1. *Geological belts and/or terranes in southern New Brunswick after King and Barr (2004). Details of the controversies surrounding these belts are explored in the text. Abbreviations not shown in legend: BBF, Back Bay Fault; BF, Belleisle Fault; SBF, Sawyer Brook Fault; TBF, Taylor Brook Fault; WBF, Wheaton Brook Fault. Geology has been modified from New Brunswick Department of Natural Resources (2000).*

Hence it is obvious that the significance of the similarities and differences among terranes in southern New Brunswick remains uncertain and consensus on the topic has yet to be reached. Although questions remain, we think that we are moving closer to an understanding of the timing and mechanisms of terrane amalgamation in southern New Brunswick. The characteristics of the terranes are summarized below to provide background for the field trip. Due to time constraints it will not be possible to examine the St. Croix terrane on this trip, and therefore, it is not included in the descriptions below. Stop locations for day 3 are shown on Figure 3-2.

BACKGROUND: NEOPROTEROZOIC – CAMBRIAN TERRANES AND THEIR BOUNDARIES

Caledonia terrane: The Caledonia terrane includes mainly Neoproterozoic and Cambrian rocks exposed south of the Caledonia-Clover Hill Fault (Fig. 3-1). The fault is a Carboniferous feature, but has been interpreted to mark the approximate location of a cryptic suture between the Caledonia and Brookville terranes (White *et al.* 2001). Neoproterozoic volcanic and sedimentary rocks of the Caledonian Highlands are divided into two groups (Bevier and Barr 1990; Barr *et al*. 1994; Barr and White 1999). The older ***Broad River Group*** is exposed mainly in the northeastern and southern parts of the Caledonian Highlands and is inferred to be unconformably overlain by the ***Coldbrook Group***, which occupies most of the central and southwestern parts of the highlands (Fig. 2).

The Broad River Group is comprised of low-grade schistose and phyllitic, mainly intermediate and felsic crystal and lithic crystal tuff and less abundant felsic flows, mafic tuffs and flows, and volcanogenic sedimentary rocks with a total thickness of > 7 km (Barr and White 1999). Bevier and Barr (1990) and Barr *et al*. (1994) reported U-Pb (zircon) ages of ca. 618 Ma and 613 ± 2 Ma for the Broad River Group. The group is intruded by a related suite of compositionally expanded gabbroic to granitic plutons, components of which have yielded U-Pb (zircon) ages of 625 ± 5 Ma, 625 ± 1 Ma, 616 ± 3 Ma, and 615 ± 1 Ma (Bevier and Barr 1990; Watters 1993; Barr *et al*. 2000). Petrochemical features of the Broad River Group and associated plutons are clearly indicative of origin in a continental margin magmatic arc (Barr and White 1999). The rocks commonly exhibit a strong foliation with well-developed slatey cleavage. The main regional deformation was accompanied by greenschist facies metamorphism (Ruitenberg *et al*. 1979; Barr and White 1999). Regional metamorphism and penetrative deformation in the Broad River Group pre-dated deposition of the Coldbrook Group, which is relatively undeformed and unmetamorphosed. Dallmeyer and Nance (1994) reported $^{40}Ar/^{39}Ar$ (whole-rock phyllite ages) for the Broad River Group, which suggest that it subsequently underwent a Silurian to Devonian thermal event.

Late Neoproterozoic volcanic and sedimentary rocks of the Coldbrook Group are divided into a lower sequence of intermediate volcanic rocks, volcanogenic tuff, tuffaceous conglomerate, and laminated cherty siltstone with minor basaltic lenses and layers; and an overlying sequence comprised mainly of subaerial bimodal rhyolitic and basaltic volcanic rocks and red sandstone and conglomerate. The total thickness of the group is estimated to be over 10 km. Dacite in the lower sequence has been dated by U-Pb (zircon) at 554 +14 -1 Ma (Barr *et al.* 1994). Rhyolite and rhyolite tuff from the upper package yielded ages of 548 ± 1 Ma, 559 ± 5 Ma, 555.5 ± 3.1 and ca. 560 Ma (Bevier and Barr 1990; Barr *et al.* 1994; Miller *et al.* 2000; B. Miller, unpublished data). An associated suite of mainly gabbroic and granitic plutons, with few intermediate components, have yielded U-Pb (zircon) ages of 551 ± 5 Ma, 550 ± 1 Ma, and 557 ± 3 Ma. Based on petrological characteristics, the plutons are considered to be cogenetic with the basalt and rhyolite in the upper part of the group (Barr and White 1999).

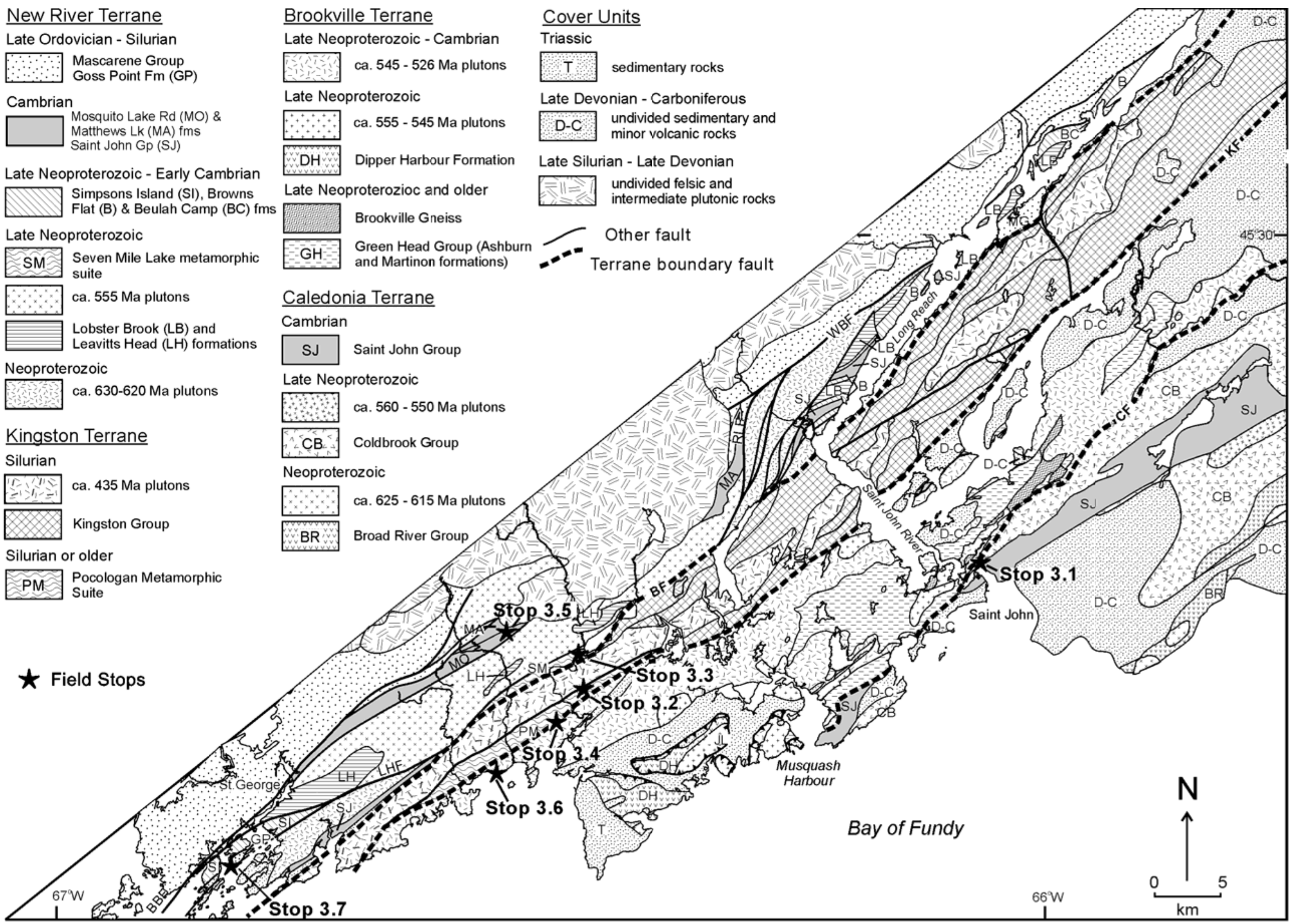


Figure 3-2. *Geological map of the Saint John - St. George area after King and Barr (2004), showing field trip stops on Day 3. Abbreviations as in Figure 3-1. Faults in the New River terrane: LHF, Letang Harbour Fault; RLF, Robin Hood Lake Fault.*

The Coldbrook Group is succeeded by Lower Cambrian to Lower Ordovician platformal sedimentary rocks of the ***Saint John Group*** (e.g. Hayes and Howell 1937; Tanoli and Pickerill 1988). Barr and White (1999) established that the upper volcanic units of the Coldbrook Group are gradationally and conformably overlain by (and in part equivalent to) red clastic sedimentary rocks that comprise the basal unit of the Ratcliffe Brook Formation of the Saint John Group (Tanoli and Pickerill 1988). The upper Coldbrook Group and lower part of the Ratcliffe Brook Formation are equivalent to the uppermost Neoproterozoic to Earliest Cambrian Rencontre Formation of Landing (1996) as shown in Figure 3-3 below. The Rencontre Formation is the lowest unit of the Avalonian cover sequence, indicative of the initial rift deposits that accumulated in down-dropped, fault-defined basins within Avalon (Landing 1996; Landing and Westrop 1998).

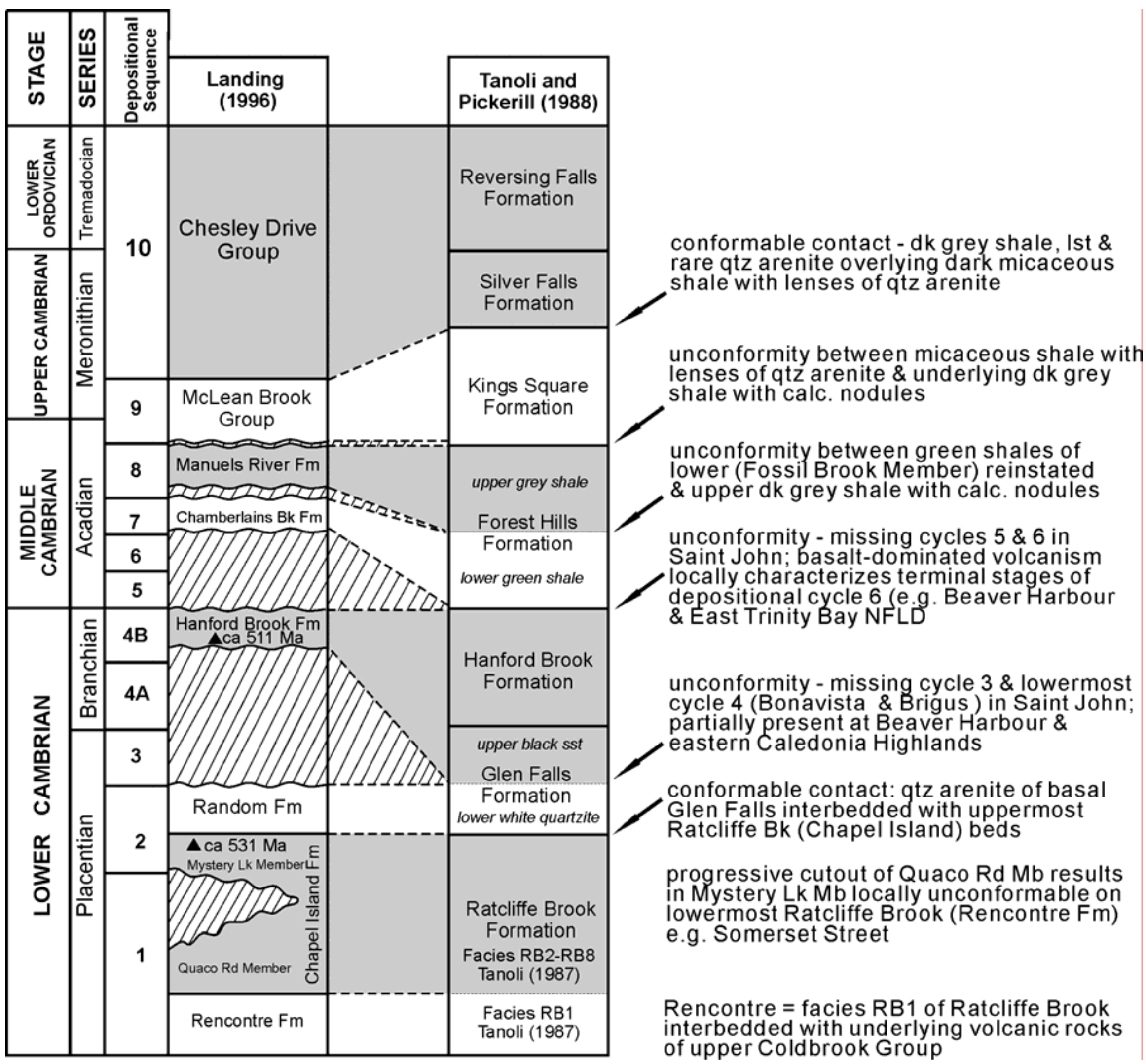


Figure 3-3. *Revised stratigraphy of the Cambrian Saint John Group showing major revisions and depositional sequences after Landing (1996).*

Although Landing (1996) and Landing and Westrop (1998) argued on lithostratigraphic grounds that the Saint John Group should be abandoned, the term is firmly established and it is unlikely that the revised nomenclature will be adopted. Nonetheless, they demonstrated that the Saint John Group contains several major unconformities that represent large intervals of time. A compromise is possible by retaining the terminology but acknowledging the stratigraphic gaps as illustrated by Johnson (2001) and shown in Figure 3-3.

Also included in the Caledonia terrane are high-P/low-T metamorphic rocks of the ***Hammondvale Metamorphic Suite***, which occur in a fault-bounded area on the northwestern margin of the terrane. The suite consists dominantly of albite-muscovite schist, with minor interlayered calc-silicate rocks, marble and amphibolite. Pressure-temperature estimates indicate peak metamorphic conditions at 9.5-12 kbar and 580-420^{o}C (White *et al*. 2001). Muscovite from the schist yielded ^{40}Ar/^{39}Ar cooling ages of 617-603 Ma (White *et al*. 2001). Rocks of the Hammondvale Metamorphic Suite were previously interpreted to be high-grade parts of the Green Head Group of the adjacent Brookville terrane (Ruitenberg *et al.* 1979); however, we believe their composition and muscovite cooling ages are more compatible with the Caledonia terrane.

The Hammondvale Metamorphic Suite is interpreted to represent an accretionary complex formed in the forearc area of a southeast-dipping subduction zone in which the ca. 625-615 Ma arc magmatism of the Broad River Group was generated (White *et al*. 2001). The accretionary complex was likely exhumed by earliest Cambrian time, as its ^{40}Ar/^{39}Ar ages closely match those of detrital muscovite in Early Cambrian clastic rocks of the Saint John Group reported by Dallmeyer and Nance (1990), suggesting that it was likely the source (White *et al.* 2001). Barr and White (1999) emphasized that although subduction ceased in the Caledonia terrane by ca. 600 Ma it does not necessarily imply that Caledonia had collided with the now-adjacent Brookville terrane, as there is little evidence of such an event in the latter. However, alternative interpretations as to the timing of amalgamation between the two terranes have been proposed (e.g., Currie and McNicoll 1999; Landing 1996; Johnson 2001; Currie 2003).

Brookville terrane: The Brookville terrane is composed of Neoproterozoic and Cambrian rocks that are divided into four major units; the Green Head Group, Brookville Gneiss, Dipper Harbour Formation and Golden Grove Plutonic Suite (White 1996; White and Barr 1996; White *et al*. 2002). Rocks that characterize the terrane are confined to the area between the Caledonia - Clover Hill Fault on the southeast and the Kennebecasis Fault on the northwest (Fig. 3-1). Much of the northeastern part of the Brookville terrane is concealed beneath Late Devonian to Carboniferous strata of the Maritimes Basin, but rare inliers occur in the Moncton area.

The oldest rocks in the terrane are platformal sedimentary rocks of ***Green Head Group***. The group consists of the Ashburn Formation (dominantly marble with minor metaclastic rocks) and the Martinon Formation (dominantly metasiltstone with minor meta-calc-silicate rocks, quartzite, metaconglomerate and marble); the two units are interpreted to be lateral facies equivalents (White 1996; White and Barr 1996). Based on locally preserved stromatolites, Hofmann (1974) suggested that the Green Head Group is Neohelikian (Mesoproterozoic) in age, but a more recent assessment suggests a minimum age of ca. 750 Ma (H. Hofmann, written comm. 1991). An early Neoproterozoic or late Mesoproterozoic age for the Green Head Group is supported by a ca. 1230 Ma age for the youngest detrital zircon grains from the unit, which provide a maximum age for deposition (Barr *et al.* 2003).

The Green Head Group is in tectonic contact along the MacKay Highway Shear Zone with the ***Brookville Gneiss***, a locally migmatitic paragneiss with sheets of granodioritic to tonalitic orthogneiss, minor calc-silicate and marble layers, and rare quartzite and amphibolite (Nance and Dallmeyer 1994; White 1996). Paragneiss comprises about 75% of the Brookville Gneiss, and contains detrital zircons indicating a maximum depositional age of ca. 640 Ma (Bevier *et al.* 1990). The orthogneiss has an igneous crystallization age of 605 $\pm$ 3 Ma and was metamorphosed to amphibolite facies at 564 $\pm$ 6 Ma (Bevier *et al.* 1990; Dallmeyer *et al.* 1990). Providing that the Mesoproterozoic to Early Neoproterozoic age for the Green Head Group is correct, these dates suggest that the Brookville Gneiss is younger than the Green Head Group, therefore cannot be its basement.

The original relationship between the Brookville Gneiss and Green Head Group is a topic of debate. Currie (2003) suggested that the relationship was originally intrusive and that the ca. 605 Ma orthogneiss age and volcanic rocks of similar age in the Broad River Group provide a magmatic link between the Brookville and Caledonia terranes by this time. However, this link is tenuous given the many differences between the two terranes in terms of previous and subsequent stratigraphic, igneous and metamorphic histories. The ca. 564 - 540 Ma deformation and amphibolite-facies metamorphism in the Brookville Gneiss may have been related to juxtaposition of the Brookville Gneiss and Green Head Group along the MacKay Highway Shear Zone, as well as to intrusion of both units by Late Neoproterozoic to Early Cambrian gabbroic to granitic plutons of the ***Golden Grove Plutonic Suite*** (White *et al.* 2002). The ages of intrusion are well constrained by ten U-Pb (zircon) ages and several ^{40}Ar/^{39}Ar cooling ages, which indicate the suite ranges from ca. 550 – 525 Ma (Dallmeyer and Nance 1992; White 1996; Currie and Hunt 1991; Currie and McNicoll 1999; White *et al.* 2002).

Based on age and composition the plutons of the Golden Grove Plutonic Suite can be divided into two groups. The older group consists of ca. 555 – 540 Ma syenogranitic to monzogranitic intrusions and spatially and temporally associated volcanic rocks of the Dipper Harbour Formation. Like volcanic and plutonic rocks of similar age in the Caledonia and New River terranes, these rocks have continental, within-plate geochemical signatures, but other differences suggest that making links among these units is equivocal (White *et al*. 2002; Barr *et al.* 2003**)**. The younger suite comprises mostly granodioritic plutons that range in age from ca. 540 – 526 Ma and constitute a calc-alkalic, I-type granitoid suite typical of continental margin subduction (White 1996; Eby and Currie 1996; White *et al*. 2002). These data suggest that the Brookville terrane was undergoing continental extension in the latter part of the Neoproterozoic (ca. 550 Ma), which quickly developed into a continental margin subduction zone that lasted into the Tommotian stage of the Early Cambrian.

The boundary between the Brookville terrane and the Kingston terrane to the west is defined by the Kennebecasis Fault (Fig.3-1), a northeast-trending brittle fault that shows evidence for a prolonged history of movement and reactivation (e.g., Park *et al*. 1994). The Kennebecasis Fault, and hence the boundary, is defined by a single, brittle, northeast-trending fault over much of its length, with the exception of the Pocologan area where the fault is part of a complex zone of sub-parallel faults bounding mylonitic rocks. The mylonitic rocks were named the “Pocologan mylonite zone” by Rast and Dickson (1982), and described as a 2 km-wide zone of dextral strike-slip of uncertain regional tectonic significance (Rast and Dickson 1982; Park *et al*. 1994). Barr and White (2001) recognized two distinct mylonite units occupying separate fault splays. The most southeasterly splay is occupied by the Pocologan Harbour granitoid suite, a unit of mylonitic granitoid rocks that is essentially the deformed margin of the adjacent McCarthy Point Granodiorite and other plutonic units of the Brookville terrane (Barr and White 2001; White *et al.* unpublished data). An Early Cambrian age (528 +4/-3 Ma, U-Pb zircon) for the pluton provides a maximum age for deformation in this part of the zone (Barr *et al*. 2001).

In the Pocologan area, the brittle Kennebecasis Fault is interpreted to separate mylonitic rocks of the Pocologan Harbour Granitoid Suite from the Pocologan Metamorphic Suite (Fig. 3-4). The Pocologan Metamorphic Suite is interpreted to be part of the Kingston terrane, and, therefore, is described below with that belt, although not all of the authors are convinced of this interpretation.

New River terrane: The New River terrane comprises an attenuated lozenge-shaped belt of Neoproterozoic and Cambrian volcanic, plutonic, and sedimentary rocks located west of the Belleisle Fault (Fig. 3-2) (Johnson and McLeod 1996; Johnson 2001). The terrane separates Silurian rocks of the Kingston terrane from rocks of similar age in the Mascarene Group to the west. It extends for a distance of over 100 km, from Head Harbour Passage in the Bay of Fundy northeast to Belleisle Bay. Johnson (2001) postulated that the New River terrane is composite, based on differences in the Neoproterozoic and Cambrian rocks in the Long Reach, Pocologan River and Beaver Harbour areas. These distinctions were interpreted to reflect wide geographic separation during deposition, rather than deposition on separate basement blocks, although alternative interpretations are possible (e.g., Bartsch 2005).

The ***Long Reach block*** in the northeastern part of the terrane is confined to the triangular area bounded by the north-trending Robin Hood Lake Fault (Fig. 3-2) and northeast-trending Belleisle and Wheaton Brook faults. The Long Reach area occupies a flexure within the Belleisle Fault Zone, as the Belleisle and Wheaton Brook faults merge into a single fault to the northeast in Belleisle Bay. The Long Reach area is characterized by plutonic rocks with ages of ca. 629 - 625 Ma, volcanic rocks with ages of ca. 555 - 545 Ma, and shallow marine clastic rocks containing Avalonian fauna, and hence shows similarity to the Caledonia terrane. The oldest magmatism is represented by the Brittain Creek and Lingley plutons for which Currie and McNicoll (1999) reported U-Pb zircon ages of 625 ± 2 Ma and 629.3 ± 0.9 Ma. Limited chemical data indicate that the ca. 629 - 625 Ma plutonic rocks form a subalkalic suite that ranges in composition from leucogranite to quartz diorite (Johnson 2001; Johnson and Barr 2004). Their tectonic setting is ambiguous; however, the compositionally expanded nature of the Brittain Creek - Lingley plutons is consistent with formation in a continental margin subduction zone, like coeval to somewhat younger rocks in the Caledonia terrane.

The younger, mainly bimodal volcanic sequence in the Long Reach area is divided into the Lobster Brook Formation and overlying laterally equivalent Browns Flat and Beulah Camp formations. The Lobster Brook Formation consists mainly of rhyolitic tuffs and felsic agglomerate that yielded a U-Pb zircon age of 554 ± 6 Ma. Rhyolitic to dacitic pyroclastic rocks, basaltic tuffs, and flows and red epiclastic rocks make up the Browns Flat and Beulah Camp formations. The chemical data for the ca. 555 Ma sequence as a whole appear to indicate formation in a within-plate setting (Johnson and Barr 2004). The Browns Flat and Beulah Camp formations are disconformably overlain by Cambrian rocks that are directly comparable to the Saint John Group in the Caledonia terrane (e.g., Tanoli and Pickerill 1988; Landing and Westrop 1996).

In contrast to the southwestern part of the terrane, the boundary with the Mascarene Group in the Long Reach area is marked by a single fault, referred to as the Wheaton Brook Fault. McCutcheon (1981) presented evidence for major northwest-directed thrusting on the fault, which was supported by Johnson (2001) based on a very intense shallow, penetrative fabric in the Lingley Intrusive Suite adjacent to the fault. However, the lack of strong fabric or isoclinal folding in the adjacent Silurian rocks that one would expect along the sole of major thrust supports the interpretation of Currie (1984, 1988) that the juxtaposition of relatively unmetamorphosed Neoproterozoic rocks against hornfelsed Late Silurian rocks of the Mascarene Group on the opposite side of the fault is indicative of subsequent transcurrent movement.

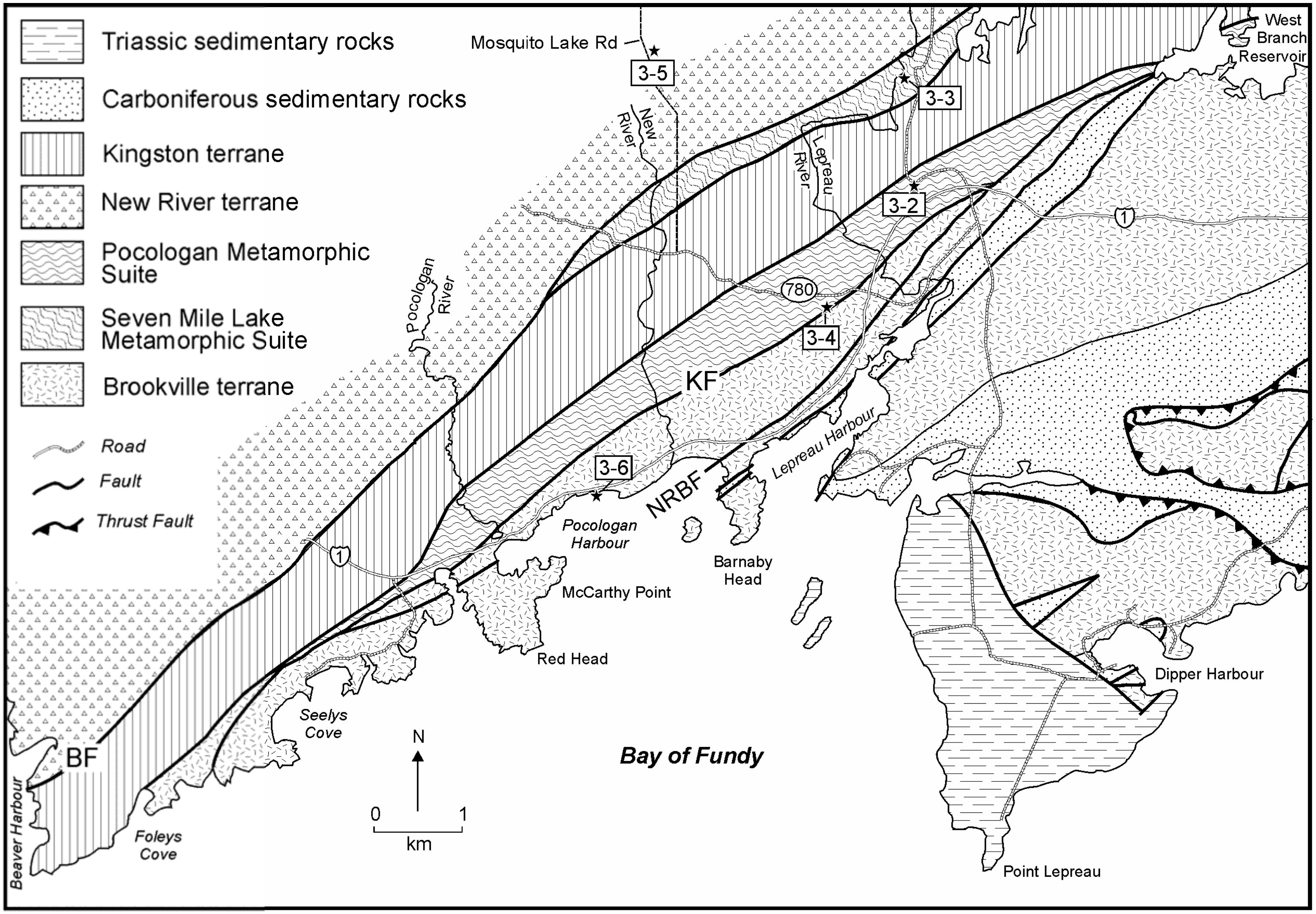


Figure 3-4. *Geological map of the Pocologan area showing terranes and more detailed locations for stops 3-2 to 3-6. Abbreviations not in the legend: BF, Belleisle Fault; KF, Kennebecasis Fault; NRBF, New River Beach Fault*

The timing of major transcurrent motion is difficult to assess, although it obviously post-dated the Late Silurian rocks on the west side of the fault. The latest significant movement on the Wheaton Brook Fault appears to pre-date emplacement of the Late Devonian Mount Douglas Granite.

The southwestern part of the New River belt is divided into two fault-bounded sequences. The western sequence consists of Late Neoproterozoic plutonic and related volcanic rocks of the Ragged Falls Intrusive Suite, Leavitts Head Formation, Early Cambrian bimodal volcanic and sedimentary rocks of the Simpsons Island Formation, and late Early Cambrian volcanic and sedimentary rocks of the Mosquito Lake Road and Matthews Lake formations (Currie 1987; Johnson and McLeod 1996; Johnson 2001; Bartsch 2005). Syenogranite and granodiorite from the Ragged Falls Intrusive Suite yielded U-Pb (zircon) ages of 555 ± 10 Ma (Currie and Hunt 1991) and 553 ± 2 Ma (McLeod *et al*. 2003), respectively, and a nearly identical age of 554 ± 3 Ma was obtained from felsic crystal tuff within the Leavitts Head Formation (McLeod *et al.* 2003). On the basis of chemical characteristics the Ragged Falls Intrusive Suite was interpreted to have formed in an extensional setting by Barr *et al.* (2003). Additional chemical data reported by Bartsch (2005) suggest it may have formed in a continental margin volcanic-arc setting.

The Leavitts Head Formation is in faulted contact with bimodal volcanic and sedimentary rocks of the Simpsons Island Formation (Fig. 3-5). The latter formation consists of mafic and felsic breccias, flows, and pyroclastic rocks, and minor intermediate tuffs, flows and red to grey siliceous fine-grained sandstone, thin-bedded siltstone, quartzite, and red arkosic sandstone. A recent U-Pb age of 538.4 ± 4.4 Ma for rhyolite in the sequence demonstrates that the formation is Early Cambrian in age (Barr *et al*. 2003). The new age date is significant as the Simpsons Island Formation is lithologically similar to the Browns Flat and Beulah Camp formations in the Long Reach area, which based on their stratigraphic position are likely similar in age. Before its age was determined, the Simpsons Island Formation was thought to conformably underlie the Late Ordovician Goss Point Formation (Johnson and McLeod 1996); recent mapping in the area has suggested that the contacts are faulted (Bartsch 2005).

Strongly deformed to mylonitic late Early Cambrian rocks of the Mosquito Lake Road and Matthews Lake formations occupy a fault sliver on the northwestern margin of the Ragged Falls Intrusive Suite (Johnson and McLeod 1996; Johnson 2001). Rhyolite breccia in the Mosquito Lake Road Formation yielded U-Pb (zircon) age of 514 ± 2 Ma (McLeod *et al*. 2003). The Mosquito Lake Road Formation contains rhyolitic tuffs, breccias, and flows, quartz-rich feldspathic wacke, laminated siltstone, volcaniclastic wacke and conglomerate. Sedimentary rocks in the formation locally contain thin magnetic iron-rich laminations and rare garnet-rich “layers”. Quartzite-pebble conglomerate overlying the rhyolite breccia was assigned to the Matthews Lake Formation, a unit of light grey to white, thick-bedded, granular quartzite and intraformational quartzite pebble conglomerate, laminated phyllitic siltstone and sandstone, dark grey graphitic slate, volcanogenic sandstone and minor calc-silicate rocks, which is exposed along strike to the northeast. Johnson and McLeod (1996) interpreted the quartzite-pebble conglomerate overlying the dated volcanics in the Mosquito Lake Road Formation to be in the same stratigraphic position as similar quartzite-pebble conglomerate and quartzite at Matthews Lake about 3 kilometres to the northeast. A direct correlation is hindered by the absence of Mosquito Lake Road volcanic rocks in the Matthews Lake area due to faulting. If the correlation is correct it suggests an Early - Middle Cambrian age for the Matthews Lake Formation.

The second fault-bounded sequence in the southwestern part of the terrane occurs between the Belleisle and Letang Harbour faults in the ***Beaver Harbour block***. The main units in this fault block are Neoproterozoic granitoid rocks, Early to Middle Cambrian fossiliferous

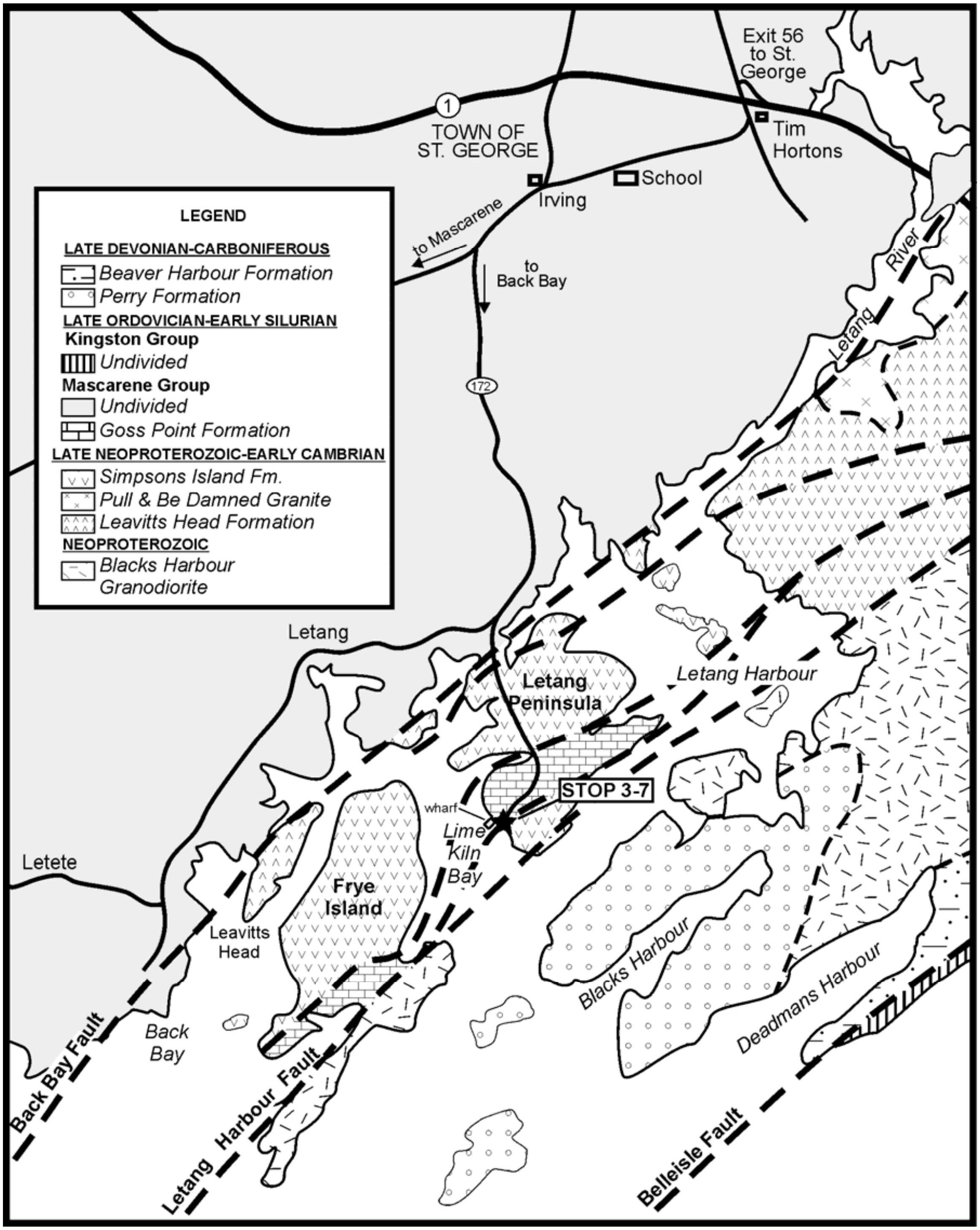


Figure 3-5. *Geology of the Letang Harbour area showing more detailed location for Stop 3-7 in the New River terrane.*

sedimentary rocks and a variety of Lower Paleozoic (Silurian?) and Late Devonian to Carboniferous units (Bartsch 2005). The granite and granodiorite are part of the “Blacks Harbour Granite” of Helmstaedt (1968) (Fig.3-5), for which an age of 620 ± 1.5 Ma (U-Pb zircon) was recently reported (Barr *et al.* 2003).

Early and Middle Cambrian rocks occur in the Buckmans Creek area and comprise a sequence of red and green siltstone, shale and sandstone, pink limestone, mafic breccia, nodular limestone, and grey siliciclastic mudstone. Helmstaedt (1968) discovered trilobites in the upper part of the sequence which correlate with the upper Chamberlains Brook – Manuals River interval of the Avalonian cover sequence in Newfoundland (Landing 1996, p.48). This interval is time-equivalent to the marine clastic rocks of the Forest Hills Formation in the Saint John area. A fossiliferous pink limestone was recently discovered downsection of the Helmstaedt (1968) fossil locality and is currently being assessed. Preliminary results indicate a late Early Cambrian (lower Branchian) assemblage, possibly correlative with the Brigus Formation in Newfoundland (E. Landing, personal communication 2004). Rocks of this age are missing and or significantly thinned in areas representing the marginal platform of Avalon, such as in the Saint John area (Saint John Group) (Landing 2004). In the Saint John Group this time interval corresponds to a depositional hiatus between the Glen Falls and Hanford Brook formations (Fig. 3-3).

Johnson (2001) argued that the correlation of Cambrian depositional sequences in the Beaver Harbour and Long Reach blocks with those in the Avalon terrane *sensu stricto* in Newfoundland by Landing (1996), suggested a link between these areas and the Caledonia terrane in Cambrian time. This interpretation is supported by geochemical and radiometric data which indicate that the Caledonia and New River terranes experienced corresponding pulses of magmatic activity at ca. 620-630 and ca. 560-550 Ma (e.g., Currie and McNicoll 1999), although alternative explanations of these data have been made (Barr *et al*. 2003; Bartsch 2005).

The apparent lack of correlatives for the ca. 514 Ma Mosquito Lake Road and Matthews Lake formations in the Avalon terrane led Johnson (2001) to speculate on a possible link with Cambrian rocks in the St. Croix (Gander) terrane in Maine, thereby indicating that the New River terrane is composite. SHRIMP analyses of detrital zircon grains from Cambrian arenite in the Matthews Lake Formation, the Baskahegan Lake and Calais formations in the St. Croix (Gander) terrane in Maine, and the Ellsworth Schist that lies east of the St. Croix terrane in Maine indicate similar detrital zircon populations (van Staal *et al*. 2004b). All contain abundant Early Cambrian and Late Neoproterozoic zircon populations as well as important contributions of Mesoproterozoic (1.2 – 1.6 Ga) and Early Paleoproterozoic (2.0 – 2.3 Ga) zircon grains. The Matthews Lake Formation at Matthews Lake showed that a single population of zircon grains dated at 539.4 ± 4.5 dominates the sample (40% of the analyses) (V. McNicoll, written communication 2002). These data constrain the age of the Matthews Lake Formation to <539 Ma. Other significant contributions include zircon grains of Mesoproterozoic (1535-1160) and Neoproterozoic (900-650) ages. Most striking is the similarity between the Matthews Lake Formation and quartzite in the Ellsworth Schist. Both show a significant cluster around ca. 550-540 Ma (V. McNicoll, written communication 2002). This suggests that the Matthews Lake Formation may be more directly related to the rocks east of the St. Croix (Penobscot) terrane in Maine.

The Ragged Falls Intrusive Suite is bounded to the east by a major belt of mylonitic rocks that lie along the Belleisle Fault southwest of Seven Mile Lake (Seven Mile Lake Mylonite Zone of Garnett and Brown 1973). These mylonitic and cataclased granitoid and volcaniclastic rocks occupy an area over 700 metres wide and > 10 km long. Barr and White (2001) referred to this zone as the ***Seven Mile Lake Metamorphic Suite*** (Fig. 3-4). The suite is interpreted to be linked to the granitoid rocks in the New River terrane and contrasts sharply with the adjacent rocks of the Kingston Group, which do not appear to be as strongly deformed.

The mylonite zone at Seven Mile Lake on the eastern margin of the New River terrane is mirrored on its western side by the Saint George – Wheaton Brook Mylonite Zone (Currie 1987). The Saint George – Wheaton Brook Mylonite Zone separates the Cambrian Mosquito Lake Road Formation from the Mascarene Group, but may not mark the western extent of Neoproterozoic – Cambrian rocks in the area, as probable Neoproterozoic granitoid rocks are tectonically interleaved with Mascarene strata west of the mylonite zone.

BACKGROUND: LATE ORDOVICIAN AND SILURIAN SEQUENCES

Kingston terrane: Barr *et al*. (2002) defined the Kingston terrane as a belt of mainly Silurian metamorphosed volcanic, volcaniclastic, sedimentary and granitic rocks between the Kennebecasis and Belleisle faults. These rocks comprise the easternmost exposures of Silurian rocks in southern New Brunswick and separate the Neoproterozoic and Cambrian rocks of the Brookville terrane from those of the New River terrane (Barr *et al*. 2002). The Kingston terrane is exposed for a distance of more than 75 km (Fig. 3-1) and continues to the northeast in the subsurface beneath Late Devonian to Carboniferous units. The strong magnetic signature associated with the terrane continues farther to the northeast across the Northumberland Strait (e.g., Miles *et al*. 2000). To the southwest, the magnetic signature can be traced offshore toward Campobello Island (Fig. 2), where felsic volcanic and sedimentary units underlying the Quoddy Formation have been correlated with those of the Kingston terrane (McLeod and Rast 1988; McLeod *et al*. 2001).

In the Kingston terrane, volcanic, volcaniclastic and clastic sedimentary rocks of the Kingston Group are intruded by high-level comagmatic granitoid plutons and abundant mafic sheets (Grant 1971; O'Brien 1976; Ruitenberg *et al.* 1979; Barr *et al*. 2002). The great quantity of mafic sheets, especially in areas of granitoid host rocks, led to the previous interpretation of the Kingston belt as a bimodal dyke swarm (Kingston Complex or Kingston Dyke Complex; Eby and Currie 1993; Schreckengost and Nance 1996; Currie 2003). The Kingston Group is divided into five formations named, from base to top, Raymond Mountain, Bayswater, Waltons Lake, Westfield, and Williams Lake. The formations consist of varying proportions of dacitic and rhyolitic crystal and lithic-crystal lapilli tuff, with less abundant basaltic to andesitic flows and tuffs, rare dacitic and rhyolitic flows and minor volcanogenic sedimentary rocks. On Campobello Island rocks of the Kingston Group are assigned to the Nancy Head Formation and overlying Quoddy Formation (McLeod *et al*. 2001). Megascopic structural patterns indicate that the succession on Campobello Island lies near the top of the Kingston Group regionally (McLeod 1979; McLeod and Rast 1988).

Plutons associated with the Kingston Group are characterized by fine grain size and granophyric and locally porphyritic textures, consistent with high-level emplacement. The mafic sheets have amphibolite mineralogy and have been regionally metamorphosed together with their host rocks to upper greenschist facies - lower amphibolite facies in the late Silurian - early Devonian (Nance and Dallmeyer 1993; Barr *et al*. 2003). U-Pb (zircon) ages for the Bayswater and Westfield formations, respectively, are 436 ± 3 and 442 ± 6 Ma (McLeod *et al*. 2003; Barr *et al*. 2002). Similar ages of 435.5 ± 1.5, 437 ± 10, and 437 ± 3 for the Sand Point, West Branch Reservoir and Centreton granites, along with chemical similarities, indicate a comagmatic suite (Barr *et al*. 2002; McLeod *et al*. 2003). A minimum age for the mafic dykes is provided by $^{40}Ar/^{39}Ar$ (hornblende) cooling ages of ca. 416 to ca. 390 Ma, which are interpreted to represent cooling after greenschist- to lower amphibolite-facies metamorphism (Nance and Dallmeyer

1993). The Kingston Group and associated granitoid rocks appear to be calc-alkalic and formed in a continental margin volcanic arc (Barr *et al*. 2002). In contrast, the mafic sheets have an overall continental tholeiitic character, but some show strong arc tendencies suggesting they were emplaced in an extensional setting within the slightly older arc (McLeod *et al.* 2001; Barr *et al.* 2002).

In the Pocologan area of the Kingston terrane, mylonitic and high-grade metamorphic rocks in a 40 km^2 lens-shaped fault-bounded area have been termed the ***Pocologan Metamorphic Suite***. This assemblage of metapelite, semi-pelite, calc-silicate rocks, amphibolite and granite is interpreted to have formed in the forearc area outboard of the Kingston arc in the early Silurian. Pressure and temperature estimates from metamorphic assemblages in muscovite-biotite-garnet-staurolite schist, calc-silicate rocks and garnet-bearing orthogneiss indicate that, in places, peak pressure and temperature conditions were at least 9.7 kbar at 560^{o}C, although some parts of the metamorphic suite reached only greenschist-facies conditions (White *et al*. unpublished data). Age of this greenschist- to amphibolite-facies metamorphism is constrained by ca. 435 Ma U-Pb igneous crystallization ages from igneous components and $^{40}Ar/^{39}Ar$ amphibole cooling ages after amphibolite-facies metamorphism in the adjacent Kingston arc. Near-plateau $^{40}Ar/^{39}Ar$ muscovite ages from two samples in the Pocologan Metamorphic Suite are much younger (~345-342 Ma) and are interpreted to represent the minimum cooling age following a major mylonitization event that produced the dominant fabric in most parts of the metamorphic suite. Lower temperature parts of the spectra indicate thermal disturbance at ca. 315-320 Ma, interpreted to represent ongoing transpressive motions outboard of the Pocologan Metamorphic Suite during juxtaposition of the Avalon and Meguma terranes.

The Pocologan Metamorphic Suite is linked to the Kingston terrane on the basis of lithological similarities and the presence of a mylonitic granite sheet which yielded an igneous age (435 ±-5 Ma) similar to that of the Kingston Group and associated granite (Miller *et al*. 2000; Barr *et al*. 2002). The interpretation of Barr *et al*. (2002) and White *et al*. (unpublished data) that the Pocologan Metamorphic Suite is an Early Silurian forearc or accretionary prism that developed between the New River and Brookville terranes is consistent with the model of Fyffe *et al*. (1999), who suggested that the Mascarene Group represents the back-arc associated with the Kingston arc and thereby implying a northwest-dipping subduction zone beneath the New River terrane. An alternative interpretation was recently proposed by McLeod (2004), who suggested that Early Silurian volcanic rocks in the Mascarene Group also formed in an arc environment, and hence that Early Silurian arc-volcanic rocks occur on both sides of the New River terrane. He suggested that the spatial and temporal distribution of arc, back-arc, and within-plate volcanic rocks are more consistent with a southeast-dipping subduction zone in the Early Silurian, as previously proposed by Tucker *et al*. (2001).

Park *et al* (1994) tentatively proposed a Late Silurian to Early Devonian age for the major deformation event that produced the shear zone in the Pocologan mylonite zone based on the assumption that the deformation was coeval with metamorphism in the Kingston belt, for which the main foliation was dated at ca. 415-390 Ma ($^{40}Ar/^{39}Ar$ amphibole; Nance and Dallmeyer 1993). However, McLeod *et al*. (2001) has shown that the amphibolite-facies metamorphism in correlative rocks on Campobello Island post-dated the main deformational event, which they suggested occurred in the Llandovery soon after deposition of the ca 435 Ma Kingston Group and the lower part of the Mascarene Group. In contrast, White *et al*. (unpublished data) considered that the metamorphism was associated with burial during subduction and subsequent collision with the Brookville terrane, and that the rocks were mylonitized by subsequent transcurrent motion that may have continued through to the Carboniferous when the Pocologan Metamorphic Suite was uplifted and cooled below the closure temperature of muscovite.

The boundary between the Kingston and New River terranes is presently defined by the Belleisle Fault, a major structural feature in southern New Brunswick on which several types and ages of movement are postulated, the latest of which was brittle (e.g., Williams 1979; Garnett and Brown 1973).

Mascarene Group: The Mascarene Group consists of Late Ordovician to Late Silurian volcanic and sedimentary rocks that are distributed among several fault-bounded blocks between the St. Croix and New River terranes (Figs 3-1, 3-5). Each of the blocks exhibits distinct stratigraphic and structural features, but all of the blocks contain similar faunal assemblages, suggesting that they were once part of a composite marine basin (Fyffe *et al*. 1999 and references therein). The basin was geographically extensive, its contents stretching for a distance of 150 km in southern New Brunswick and continuing another 150 km southwest as the Coastal Volcanic belt in Maine (Berry and Osberg 1989; Tucker *et al*. 2001). On the basis of fossil evidence the Mascarene Group was previously thought to span the Silurian and Early Devonian (Berry and Boucot 1970); however, recent U-Pb data have demonstrated that much of group is significantly older than suggested by the fossils. Felsic volcanic rocks in the Letete and Waweig formations, assigned a Pridolian (Late Silurian) age based on fossil evidence, yielded U-Pb (zircon) ages of 437 ± 7 Ma and 438 ± 4 Ma, respectively (Miller and Fyffe 2002). Significantly, these ages are identical to those obtained for the Kingston Group and associated granitoid plutons.

Late Ordovician-Silurian strata of the Mascarene Group are tectonically interleaved with Neoproterozoic-Lower Paleozoic rocks of the New River terrane near their boundary (Johnson and McLeod 1996; Johnson 2001). Whereas direct stratigraphic evidence exists that the Mascarene Group received detritus from the Cookson Group, indirect evidence suggests that the New River terrane provided detritus as well. Detrital zircon data for igneous pebbles collected from Early Silurian conglomerate that also contains Cookson Group sedimentary clasts show a wide range of Neoproterozoic ages (ca. 705-531 Ma). The most abundant zircon population (62%) ranges from 588-531 Ma, which is compatible with a New River terrane source (Fyffe *et al*. 2001). Other ages represented in the data set include 1567–1099 Ma (6%), 705-672 Ma (6%), 630-621 Ma (4%), 605-603 Ma (4%), 526-489 Ma (15%) and 479-461 Ma (4%).

The unconformable relationship between Silurian rocks in the Coastal Volcanic Belt and the Cambrian Ellsworth Schist in Maine (Berry and Osberg 1989) provides additional evidence in support of a basement – cover relationship between the New River terrane and the Mascarene Group. In addition mafic dykes similar to some of those in the Kingston terrane also occur in the New River terrane (Pull and be Damned Complex of Currie 1987) and farther west in the Mascarene Group. The chemistry of the dykes indicates a similar source, suggesting that this magmatism may have developed in the New River terrane (McLeod *et al*. 2001). The implications of these data are that the Mascarene Group was deposited as a cover sequence on both the New River and St. Croix terranes, indicating that they were together by at least Late Ordovician time. In the Late Silurian to Late Devonian, the St. Croix and New River belts along with their Mascarene Group cover were intruded by voluminous synorogenic to postorogenic intrusions of the Saint George Batholith (McLeod 1990).

ROAD LOG

The day begins at the Coastal Inn Fort Howe, located at the intersection of Portland and Main streets in Saint John. Stop 3-1 is a walking stop in which we view sections on Somerset and Main streets in the City of Saint John, which will take approximately 2 hours. The stop begins and ends at the Coastal Inn. From the Coastal Inn, proceed across Fort Howe and down Somerset Street. Follow detailed walking directions see below under Stop 3-1. Return to hotel parking lot for the drive to Stop 3-2 in the Lepreau area, approximately 40 km west of Saint John (Figs. 3-2, 3-4).

From the hotel parking lot turn right onto Portland Street and then left at the stop sign onto Hilyard Street. Proceed past Brennan's Funeral Home and Royal Lepage to the traffic lights. Turn right at the first set of lights and then left at the next set of lights, following road signs to Highway 1 (west) toward St. Stephen. Proceed west on Highway 1 through Saint John, across the Harbour Bridge (toll is 25 cents), and continue on Highway 1 to the Lepreau exit (Exit 86). Take exit ramp onto Seven Mile Lake Road and drive north to stops 3-2 and 3-3. Retrace route south on Seven Mile Lake Road, cross over the highway and turn right onto old Highway 1. Drive a few kilometres and stop at the Petro-Canada Service Station in Lepreau for a rest stop prior to lunch break. Drive a short distance west on old Highway 1 to Lepreau Falls for lunch.

Return to vehicles and drive north on route 780. Turn west on Spear Road. Park at end of paved road and walk up woods road to Stop 3-4. Return to route 780 and continue west to Stop 3-5 on the Mosquito Lake Road. You are driving through the Kingston belt and most of the outcrops along the road are massive to amphibolitic mafic sheets. Turn right (north) onto the logging road to Mosquito Lake and drive approximately 5.5 km. Outcrops on the east (right) side of the road are Stop 3-5.

Return to route 780 and retrace route back to Highway 1 through the Kingston terrane. Proceed west on Highway 1, passing the turn-offs to Haggertys Cove Road and New River Beach Provincial Park. Turn left toward the shore at Pocologan Crossroad, located just west of the Seaview motel and restaurant. After 100 m, turn right (west) on the Pocologan Road for 700 m. Park vehicles on roadside and follow path to the rocky shoreline (Stop 3-6).

Retrace your route to Highway 1 and continue west to St. George (Exit 56). Travel south along Route 172 and turn left onto Lime Kiln Road. Follow road to wharf. Stop 3-7 is the shoreline exposures on both sides of the wharf.

STOP DESCRIPTIONS

STOP 3-1: Boundary between the Caledonia and Brookville terranes

The section begins in marble of the Brookville terrane (Green Head Group) and proceeds into rocks of the Caledonia terrane. The latter terrane is characterized by the following; grey-green dacite (Coldbrook Group), red conglomerate, arkosic sandstone and siltstone (Ratcliffe Brook Formation), and finally quartz arenite, siltstone and shale (Saint John Group). Faults are numerous, both between and within units. The U-Pb zircon of age 554+14/-1 Ma that was reported for the dacite unit in the Coldbrook Group was collected from the Somerset Street section (Barr *et al.* 1994). This dacite unit is assigned to the McBrien Lake Formation, which is part of the lower Coldbrook Group (Barr and White 1999).

The sedimentary parts of this succession have been redefined in recent years by E. Landing and co-workers. According to these workers (e.g., Landing and Westrop 1998, pp. 55-58), the red clastic rocks belong to the Late Neoproterozoic - Early Cambrian Rencontre and Chapel Island formations (equivalent to the Ratcliffe Brook Formation), a characteristic unit of the Avalon zone. At this locality the Rencontre Formation is overlain unconformably by marine siliciclastic rocks of the upper member of the Chapel Island Formation (green and minor red, purple and dark grey shale and sandstone) due to a progressive westerly cut-out of the lower member. Note that the upper part of the Chapel Island Formation contains quartz arenite beds, indicating a conformable contact with the overlying Random (Glen Falls) Formation, which consists of massive quartz arenite. Zircons from an ash bed in the Chapel Island Formation in the Somerset Street section yielded an age of 530.7 ± 0.9 Ma (Isachsen *et al*. 1994).

Above the "white quartz arenite" is a fossiliferous "black sandstone", assigned by Landing to the Hanford Brook Formation, with a major unconformity separating these two parts of the former "Glen Falls Formation" (this unconformity is apparently comparable to that between the Random and Brigus Formation on the Burin Peninsula of Newfoundland). The overlying sedimentary succession in the Saint John area extends into the Lower Ordovician.

0 m - From the Coastal Inn, walk up the sidewalk on Simonds Street past marble and dolostone outcrops of the Ashburn Formation (Green Head Group). The marble is in places crystalline and in places contains fine mylonite bands.
100 m - Turn right onto Magazine Street, past outcrops of marble, dolostone, minor meta-siltstone and mafic dykes.
200 m - Turn right onto the road up to Fort Howe. Continue walking across Fort Howe, noting marble outcrops and a spectacular view of Saint John Harbour.
500 m - Turn left onto Kitchen Street sidewalk.
550 m - Turn right onto Barker Street sidewalk and cross Somerset Street at lights.
600 m - Turn right and walk down Somerset Street sidewalk, passing outcrops of grey dacite of the lower part of the Coldbrook Group. The contact between the dacite and marble (Brookville terrane) is not exposed but you will see it later in the Main Street section.
900 m - Redbeds of the Rencontre (Ratcliffe Brook) Formation.
950 m - Intersection with Paradise Row. Cross Somerset Street at the lights and walk along Paradise Row sidewalk past Brenan's Funeral Home.
1200 m - Turn right onto entrance ramp to Main Street (**please stay on the sidewalk!**). Examine outcrops along this 600 m section, which begins in the Saint John Group, pass through redbeds (conglomerate, arkosic sandstone and siltstone) of the Rencontre (Ratcliffe Brook) Formation, grey-green dacite of the lower part of the Coldbrook Group, and finish in marble of the Green Head Group. Note the abundance of faults!
1800 m - Finish at Simonds Street intersection opposite Coastal Inn.

STOP 3-2: Pocologan Metamorphic Suite

Road cuts at this stop consist of fine-grained biotite schist and felsic granitoid rocks of the Pocologan Metamorphic Suite. The pink protomylonitic granite in this outcrop has been dated at ca. 435 Ma. We think that this granite, as well as the mafic dyke in this outcrop, are related to those in the Kingston Group, and hence provide a link between the Kingston Group and the Pocologan Metamorphic Suite, which some of us interpret to be an accretionary complex on the trench side of the Kingston arc. The distinctive muscovite-biotite-garnet-staurolite schist, calc-silicate rocks and garnet-bearing orthogneiss that characterize the Pocologan Metamorphic Suite are not present in this outcrop. If time permits at the end of the day, we can stop to see these lithologies in an outcrop along highway #1 en route back to Saint John.

STOP 3-3: Mylonitic granitoid rocks of the Seven Mile Lake Metamorphic Suite

Mylonitic rocks that separate the Silurian Kingston Group from Neoproterozoic granitoid rocks of the New River terrane lie within the Seven Mile Lake mylonite zone of Garnet and Brown (1973). Most of these metamorphic rocks appear to have a granitoid protolith and are therefore interpreted as the mylonitic margin of the Ragged Falls Intrusive Suite. These rocks record evidence of both ductile and subsequent brittle deformation and probably had a protracted and complex history. The brittle deformation may be related to movement on the Belleisle Fault, which juxtaposed the highly deformed, mylonitic rocks against much less deformed rocks of the Kingston Group.

STOP 3-4: Contact between the Pocologan Metamorphic Suite and the Pocologan Harbour granitoid belt

The northern part of the outcrop is the Pocologan Metamorphic Suite (Kingston terrane) and the southern part is the Pocologan Harbour granitoid belt (Brookville terrane). The contact here is a brittle fault (typically hidden under the mud) which some of us interpret to be the Kennebecasis Fault. The granitoid rocks are mylonitic, but relatively homogeneous, in contrast to the banded, higher grade rocks of the Pocologan Metamorphic Suite.

STOP 3-5: New River terrane - Mosquito Lake Road and Matthews Lake formations

This large outcrop is typical of high strain zones in the Mosquito Lake Road and Matthews Lake formations in the New River terrane. The main foliation is evident as east-northeast-trending flattened, stretched, and boudinaged clasts within the conglomerate and felsic breccias. A strongly developed second cleavage trending northeast is best developed within finer grained sedimentary rocks at the southern end of the outcrop. Interbedded volcaniclastic wacke and siltstone in this outcrop locally contain strongly magnetic beds and rare garnet. Biotite and locally cordierite porphyroblasts are developed in the pelitic rocks here, due to the close proximity of the Late Devonian Mount Douglas Granite.

At the north end of the outcrop, rhyolite tuff and breccia are overlain by quartzite-pebble conglomerate assigned to the Matthews Lake Formation. Rhyolite tuff near the contact yielded a late Early Cambrian U-Pb (zircon) age of 514 ±2 Ma. Detrital zircon grains from massive white quartzite in the Matthews Lake Formation about 3 km east along strike yielded a single dominant population of zircons (40%) dated at 539.4 ± 4.5 Ma. The lack of ca. 514 Ma zircons in the sample suggests that the conglomerate at this outcrop is not in the same stratigraphic position as the one at Matthews Lake, which may actually underlie the Mosquito Lake Road volcanic rocks at this locality. The formations are interpreted to be in part laterally equivalent.

STOP 3-6: Pocologan Harbour granitoid belt (deformed Brookville terrane granitoid rocks)

Outcrops along the coast through Pocologan belong to the Pocologan Harbour granitoid belt. The protolith is interpreted to be mainly the McCarthy Point Granodiorite; which at McCarthy Point has yielded an age of 528 ± 2 Ma. The granodiorite here is cut by a deformed mafic dyke. The mylonitic foliation in this outcrop has a shallow dip, although the lineation remains subhorizontal. About 30 m to the west, the Penn Island Granite is exposed. In less deformed areas outside the mylonite zone it is clear that the granite cuts the granodiorite. These plutonic rocks are typical of the Golden Grove Plutonic Suite of the Brookville terrane. The mafic dyke cuts both of the granitoid units.

STOP 3-7: Contact between the Simpsons Island Formation (New River terrane) and the Late Ordovician - Silurian Mascarene Group

Shore exposures on the north side of the wharf are spectacular limestones and marbles of the Goss Point Formation, the oldest rocks in the Mascarene Group. Nowlan *et al.* (1997) reported conodonts from this unit, sampled farther up the shore, which indicate a Caradocian to Ashgillian age. Donohoe (1973) conducted structural analyses of the Late Ordovician and Early Silurian rocks in the Mascarene Group and found that these rocks underwent two major fold-generating events (D_1 and D_2), which produced isoclinal to tight upright, steeply plunging folds. These events were followed by D_3 and D_4 that produced kink band deformation important only on an outcrop scale. In the parking lot, the limestone is interbedded with light grey argillite and tuffaceous sedimentary rocks in the low bank.

On the south side of the wharf, massive mafic agglomerate and coarse mafic tuffaceous rocks of the Simpsons Island Formation outcrop along the shore. The ca. 539 Ma age for the Simpsons Island Formation indicates it is Early Cambrian age (Barr *et al.* 2003). Due to the faulted nature of most contacts and its lithological similarity to volcanic rocks in the Mascarene Group, the Simpsons Island Formation was previously assumed to be part of the Late Ordovician –Silurian Mascarene succession (see Johnson and McLeod 1996, pp. 153-156). The faulted contact between the limestone (Mascarene Group) and mafic volcanic rocks (Simpsons Island Formation) is located in the cove on the south side of Lime Kiln Road. In contrast to the limestone, the Simpsons Island Formation displays only a single northeast-trending, steeply dipping cleavage that is axial planar to upright, gently plunging folds. The contact between the two sequences is not exposed but the contrast in deformation suggests that it is most likely a brittle fault.

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