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FIELD TRIP GUIDEBOOK – B1

Geological Comparisons and Correlations Among Crustal Blocks in Eastern North America, Northwest Africa, and Western Europe

Leaders: Sandra M. Barr, Yvette D. Kuiper, Deanne van Rooyen, and Chris E. White

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FIELD TRIP GUIDEBOOK

TRIP B1. GEOLOGICAL COMPARISONS AND CORRELATIONS AMONG CRUSTAL BLOCKS IN EASTERN NORTH AMERICA, NORTHWEST AFRICA, AND WESTERN EUROPE

May 19 to May 23, 2022

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TRIP B1. Geological comparisons and correlations among crustal blocks in eastern North America, northwest Africa, and western Europe

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OVERVIEW OF THE FIELD TRIP (Fig. 1)

This 5-day post-conference field trip is part of International Geoscience Programme (IGCP) project 683 (https://igcp683.org/) led by Faouziya Haissen (Hassan II University, Casablanca, Morocco), Yvette Kuiper (Colorado School of Mines, USA), Pilar Montero (University of Granada, Spain), and Sandra Barr (Acadia University, Canada). IGCP 683 also organized a symposium during the conference. The symposium and field trip bring together geoscientists working in eastern North America, northwestern Africa, and western Europe to discuss potential correlations among crustal blocks with northwest African origin that are now dispersed across the three continents. Fragments of at least three of these blocks may occur in Nova Scotia and are the focus of this field trip and guidebook. Other areas (Avalonia in southern New Brunswick, the Penobscot Bay Inlier/Ganderia in coastal Maine, and Avalonia in southeastern New England) will be high-lighted during evening "virtual" field trips. These and other virtual field trips, including areas covering the Anti-Atlas and Meseta of Morocco, the SW Iberian massif in southern Spain, and Avalonia in Newfoundland, were presented during the IGCP 683 symposium that preceded the field trip and/or made available for viewing and download on the IGCP 683 website, together with this guidebook. All will be long-lasting valuable resources to those working on correlations between crustal blocks of eastern North America, northwestern Africa, and western Europe, and significant contributions of IGCP project 683.

The first two days of this field trip will highlight the unique geology of the Meguma terrane of Nova Scotia, the most easterly (outboard) crustal block of the northern Appalachian orogen. The Meguma terrane is of special interest in the context of the IGCP project 683, because its correlation with parts of NW Africa or Iberia has been proposed since the early 1970s (e.g., Schenk 1971, 1981). These models have been neither proven nor disproven in the intervening years (e.g., Letsch et al. 2018). Correlation with parts of Wales in the UK has also been proposed, with those areas together constituting the postulated domain of Megumia (e.g., Waldron et al. 2011). Participants in this field trip will visit key locations to examine the characteristic Cambrian–Ordovician turbiditic units of the Meguma terrane, including coticule horizons and trace fossils, and overlying Silurian–Devonian rift-basin sequences. The focus of days 1 and 2 is the stratigraphy in the Goldenville and Halifax groups, and the characteristics that enable the stratigraphic units to be recognized even at sillimanite grade. The manganiferous, coticule-bearing uppermost unit of the Goldenville Group is a key marker unit throughout the terrane. We will also visit a Mesozoic gabbro dyke that has been correlated with similar dykes in Iberia and Morocco. On Day 2 we view the lowermost exposed unit of the Goldenville Group, trace fossils of the High Head member (weather permitting), and evidence for a 30-million-year gap between the Halifax Group and base of the Rockville Notch Group (Sardian Gap of White et al. 2018), as well as the uppermost unit of the Halifax Group. Day 2 concludes with virtual field trips to Avalonia in southeastern New England by M.Thompson, and by Y. Kuiper and D. Murray, which will provide additional context for outcrops visited on this trip.

On Day 3, we cross the Cobequid-Chedabucto fault zone and view examples of the Avalonian rocks of the Cobequid Highlands of northern mainland Nova Scotia. The goal of days 3 and 4 is to demonstrate to participants the wide variation in rock types that are included in Avalonia. These days should lead to informed discussions of the big question of what defines Avalonia. The first stops in the Cobequids Highlands include some of the oldest rocks in Avalonia, interpreted to represent its Tonian passive margin at the time of Rodinia. Although many interpretations suggest that Avalonia was <u>not</u> part of Rodinia, the nature of these sedimentary rocks suggests that they formed on a passive continental margin, and not in an open ocean. In the Mount Ephraim block we will see the remnants of 755–730 Ma arc volcanic and plutonic rocks, ages represented in most other parts of Avalonia only by rare detrital zircon. Two evening virtual field trips on Day 3 visits the Penobscot Inlier, including Ganderian rocks of coastal Maine by D. Reusch and J. Strauss, and the Avalonian Caledonia terrane of New Brunswick by S. Johnson and A. Park. These virtual trips take us one step farther inboard than the live field trip and provide opportunities for additional discussion in the context of this field trip and IGCP 683.

On Day 4 we travel through the Mira terrane of southeastern Cape Breton Island where we see more typical Avalonian rocks that correlate closely with units in the type area for Avalonia in eastern Newfoundland. The goal of the day is to continue to explore the question of the definition of Avalonia by looking at some of the diverse belts of volcanic and sedimentary rocks that comprise the Mira terrane, which are very different from those in the Cobequid Highlands of Day 3. We visit outcrops of ca. 680 Ma, 620 Ma, and 575–570 Ma rocks, and see some of the overlying classic Cambrian stratigraphy considered by some workers to be an integral part of the definition of Avalonia.

On Day 5, enroute back to Halifax, we spend the morning in the Bras d'Or terrane, considered by some/many/most to be part of Ganderia. These stops provide an opportunity for comparison to the now-adjacent Avalonian rocks of similar age that we saw in the Mira terrane. The relationship between Ganderia and Avalonia, like that between Avalonia and Meguma, remains a topic of debate.

ACKNOWLEDGEMENTS

The material in this field guide draws on the work of many people. We acknowledge the pioneering work of Paul Schenk in establishing the importance of Meguma as an exotic component of the northern Appalachian orogen. We are grateful for the many important contributions of John Waldron over several decades of working in the Meguma terrane. We acknowledge Trevor MacHattie for his geochronological work in the Cobequid Highlands, and Teodoro Palacios and Sören Jensen for their microfossil and trace fossil work which have provided essential age constraints for Cambrian stratigraphy in Avalonia and Meguma. We also thank (in alphabetical order!) Barrie Clarke, Nick Culshaw, Rick Horne, Rebecca Jamieson, Shoufa Lin, Peter Reynolds, Rob Raeside, and Cees van Staal, all of whom have contributed immensely to our understanding of the geology of Nova Scotia. Many Acadia, Dalhousie, and St. FX University students, too numerous to mention individually, have contributed theses and/or worked as field assistants. We are grateful to those who contributed virtual field trip guides (Accotto, Azor, Expósito Ramos, Jabaloy-Sánchez, Johnson, Kuiper, Lowe, Martínez Poyatos, Mills, Montero, Murray, Park, Pérez-Cáceres, Reusch, Simancas, Strauss, Thompson) to the field trip, symposium and/or IGCP 683 website.

We thank staff of RMS Energy for permission to access their road network, and for facilitating opening of gates on a holiday weekend, and several Nova Scotian landowners for permission to access sites via their property. We thank Jason Loxton for his helpful editorial comments on the draft manuscript, and Amy Tizzard, Halifax 2022 Field Trip Committee Chair, for helping to keep planning and production on schedule.

SAFETY INFORMATION

General Information

The Geological Association of Canada (GAC) recognizes that its field trips may involve hazards to the leaders and participants. It is the policy of the Geological Association of Canada to provide for the safety of participants during field trips, and to take every precaution, reasonable in the circumstances, to ensure that field trips are run with due regard for the safety of leaders and participants. GAC recommends steel-toed safety boots when working around road cuts, cliffs, or other locations where there is a potential hazard from falling objects. GAC will not supply safety boots to participants. Some field trip stops require sturdy hiking boots for safety. Field trip leaders are responsible for identifying any such stops, making participants aware well in advance that such footwear is required for the stop, and ensuring that participants do not go into areas for which their footwear is inadequate for safety. Field trip leaders should notify participants if some stops will require waterproof footwear.

The weather in Nova Scotia in May is unpredictable, and participants should be prepared for a wide range of temperatures and conditions. Always bring suitable clothing. A rain suit, sweater, and sturdy footwear are essential at almost any time of the year. Gloves and a warm hat could prove invaluable if it is cold and wet, and a sunhat and sunscreen might be just as essential. It is not impossible for all such clothing items to be needed on the same day.

Above all, field trip participants are responsible for acting in a manner that is safe for themselves and their co-participants. This responsibility includes using personal protective equipment (PPE) when necessary (when recommended by the field trip leader or upon personal identification of a hazard requiring PPE use). It also includes informing the field trip leaders of any matters of which they have knowledge that may affect their health and safety or that of co-participants. Field Trip participants should pay close attention to instructions from the trip leaders and GAC representatives at all field trip stops. Specific dangers and precautions will be reiterated at individual localities. Be sure to ask if you have specific questions about personal comfort such as bathroom and snack breaks. Participants should be aware of and adhere to the GAC code of conduct. Any problems should be reported to Chris White, the designated safety officer for the trip.

Area-Specific Hazards

Some of the stops on this field trip are in coastal localities. Access to the coastal sections may require short hikes, in some cases over rough, stony, or wet terrain. Participants should be in good physical condition and accustomed to exercise. The coastal sections contain saltwater pools, seaweed, mud and other wet areas; in some places it may be necessary to cross brooks or rivers. There is a strong possibility that participants will get their feet wet, and we recommend waterproof footwear if you are disturbed by this possibility. We also recommend footwear that provides sturdy ankle support, as localities may also involve traversing across beach boulders or uneven rock surfaces. On some of the coastal sections that have boulders or weed-covered sections, participants may find a hiking stick a useful aid in walking safely.

Coastal localities present some specific hazards, and participants MUST behave appropriately for the safety of all. High sea cliffs are extremely dangerous, and falls at such localities could be fatal. Participants must stay away from cliff edges at all times, stay with the field trip group, and follow instructions from leaders. Coastal sections elsewhere may lie below cliff faces, and participants must be aware of the constant danger from falling debris. Please stay away from any overhanging cliffs or steep faces, and do not hammer any locations immediately beneath the cliffs. In all coastal localities, participants must keep a safe distance from the ocean, and be aware of the magnitude and reach of ocean waves. Participants should be aware that unusually large “freak” waves present a very real hazard in some areas. If you are swept off the rocks into the ocean, your chances of survival are negligible. If possible, stay on dry sections of outcrops that lack any seaweed or algal deposits, and stay well back from the open water. Remember that wave-washed surfaces may be slippery; avoid any area where there is even a slight possibility of falling into the water. If it is necessary to ascend from the shoreline, avoid unconsolidated material, and be aware that other participants may be below you. Take care descending to the shoreline from above.

Other field trip stops are located on or adjacent to roads. At these stops, participants should make sure that they stay off the roads, and pay careful attention to traffic, which may be distracted by the field trip group. Participants should be extremely cautious in crossing roads and ensure that they are visible to any drivers. Roadcut outcrops present hazards from loose material, and they should be treated with the same caution as coastal cliffs; be extremely careful and avoid hammering beneath any overhanging surfaces.

The hammering of rock outcrops, which is in most cases completely unnecessary, represents a significant “flying debris” hazard to the perpetrator and other participants. For this reason, we ask that outcrops not be assaulted in this way; if you have a genuine reason to collect a sample, inform the leaders, and then make sure that you do so safely and with concern for others. Many locations on trips contain outcrops that have unusual features, and these should be preserved for future visitors. Frankly, our preference is that you leave hammers at home or in the field trip vans.

Subsequent sections of this guidebook contain the stop descriptions and outcrop information for the field trip. In addition to the general precautions and hazards noted above, introductions for specific localities make note of specific safety concerns such as traffic, water, cliffs or loose ground. Field trip participants must read these cautions carefully and take appropriate precautions for their own safety and the safety of others.

Ticks

Lyme disease is a bacterial infection transmitted to humans and pets by a bite from a Blacklegged tick but not all ticks carry the bacteria. The Blacklegged tick has been found in all areas of Nova Scotia, especially in southwestern Nova Scotia. The tick that carries the bacteria can transmit Lyme disease only after it has filled itself with blood, which takes at least 24 hours. In most cases, the first symptom of Lyme disease is a rash near the tick bite that may look like a bull’s eye target. The bite is often painless, so you may not even know that you have been bitten. The rash usually appears between 7 to 10 days after the bite, but the range is between 3 and 30 days. Antibiotics are used to treat Lyme disease. Early treatment almost always results in full recovery. If you develop a fever, headache and/or joint pain after the field trip, it is best to see a doctor and inform them of your potential tick exposure. Some ticks are very small and you may not necessarily know you had one attached.

When possible, use insect repellent containing DEET. Follow manufacturer’s directions. Cover as much of your skin as possible when walking, working, or playing in areas where ticks are found. Wear enclosed shoes, tuck your shirt into your pants, and tuck your pant legs into your socks. Wear light-coloured clothing with a tight weave to see ticks more easily. Check yourself after walking in grassy or wooded areas. Inspect all parts of the skin, including arm pits, groin, and scalp. Remove ticks as soon as you find them. If attached remove by carefully grasping the tick with tweezers or fingers as close to the skin as possible. Gently and slowly pull the tick straight out. Do not jerk, twist, or squeeze it. Disinfect the site with soap and water, rubbing alcohol, or hydrogen peroxide to avoid other infections.

Additional Logistical Details Specific to this Field Trip

This field trip involves long drives as we traverse the province lengthwise. The drives are scenic, and many features of the geology can be noted from van windows. Some bathroom breaks are scheduled as noted below. Other bathroom breaks can be made en route on request, although some advance notice would be appreciated. Please be patient and kind throughout the trip – weather and unforeseen circumstances may require changes in plans.

Day 1: an initial lengthy drive – 2.5 hours. Bathroom break: Bridgewater. Subsequent bathroom breaks can be made en route on request with some advance notice. Field trip stops require walks of up to 400 m on both rocky and sandy beaches, and some clambering on outcrops.

Overnight at Comfort Inn, 96 Starrs Rd., Yarmouth (902-742-1119)

Day 2: the first stop requires a walk of 300 m on a sandy beach. Stop 2-2 requires a steep descent to the rocky shore at High Head, and a steep ascent after viewing the rocks. Participants may choose to wait in the vans. Once on the shore, some participants may choose not to clamber on the steep rock faces and some features of the rocks can be viewed without doing that activity.

Overnight at Old Orchard Inn, Greenwich (902-542- 5751)

Day 3: involves an initial lengthy drive (2.5 hours). Bathroom break: Debert. Stops are in quarries and at roadside outcrops. Only short walks of a few metres are required.

Overnight at Maritime Inn, 158 Main St, Antigonish (833-863-4400)

Day 4: involves an initial lengthy drive (2 hours). Bathroom break: St. Peters. Stop 4-5 requires a walk of about 500 m on a sandy and rocky shoreline.

Overnight at Holiday Inn, 300 Esplanade, Sydney (902-562-7500)

Day 5: Morning stops have short drives and short walks, followed by a drive of ~4 hours to the Halifax International Airport where the field trip ends between 5 and 6 pm.

PART I – GEOLOGICAL BACKGROUND

MEGUMA TERRANE

The Meguma terrane of Nova Scotia is the most easterly (outboard) element of the northern Appalachian orogen (Fig. 1). Work during the past 20 years resulted in extensive modification of previous terminology and led to new insights into its origin, evolution, and relationship to other peri-Gondwanan terranes. The Meguma terrane is composed of a thick (~13 km) succession of variably metamorphosed early Cambrian (Terreneuvian, although the base is not exposed and likely extends into the Ediacaran) to early Ordovician (Floian) turbiditic metasandstone and slate (Goldenville and Halifax groups), and a much thinner sequence of Early Silurian to Early Devonian slate, quartzite, and metavolcanic rocks (Rockville Notch Group), the latter group present only in the northwestern part of the terrane (Fig. 2). These rocks were deformed and metamorphosed during the Early to Middle Devonian and intruded by numerous, late syn- to post-tectonic, mainly Middle to Late Devonian, peraluminous granitic plutons (Fig. 2). The setting for this pre-granite orogenic event, commonly termed late Acadian or Neoacadian, is not yet well understood. Deformation continued during and after granite emplacement related to dextral transpressive accretion of the Meguma terrane against adjacent Avalonia along the Cobequid-Chedabucto (also known as Minas; Murphy et al. 2011) fault zone (Figs. 2, 3a). Subsequent Carboniferous motion in the fault zone and renewed transpression throughout the Meguma terrane (e.g., Culshaw and Dickson 2015) was related to transcurrent docking of Gondwana (Africa) outboard of Meguma terrane in the Alleghanian orogeny (Fig. 3b).

Based on detailed mapping (e.g., White 2010, 2013; White and Nickerson 2021) the Goldenville and Halifax groups have been divided into formations and members throughout the terrane (Fig. 4, 5). A major high-strain zone (Chebogue Point shear zone) and the South Mountain Batholith divide the onshore Meguma terrane into northwestern, southeastern, and eastern parts with broad similarities but also important stratigraphic differences (Figs. 2, 4). The formations of the Silurian-Devonian Rockville Notch Group, as well as two suites of mafic sills and dykes, occur only northwest of the shear zone (Fig. 4, 5). Age constraints from U–Pb dating and fossils indicate that the Halifax and Rockville Notch groups are separated by an unconformity representing a time gap of about 30 million years (Fig. 4), interpreted to represent the Sardian Gap (White et al. 2018). Because of potential confusion that results from using the word "Meguma" for both a supergroup and a terrane, in this field guide the term 'Meguma' is used only for the name of the terrane, and the term terrane is not repeated in every case.

Waldron et al. (2011) noted similarities in the Cambrian to Tremadocian lithological successions of the Meguma terrane and the Harlech Dome of North Wales, including the presence of Cambrian Series 3 (Miaolingian) manganese-rich sedimentary rocks. They proposed that both Meguma and North Wales are part of the "Megumia domain" that occupied a rift at the margin of Gondwana. However, deposition continued in the Halifax Group when rocks of the Harlech Dome were being uplifted and eroded, and the Meguma terrane lacks evidence for the Ordovician volcanism present in North Wales.

Age constraints on the Goldenville and Halifax groups are summarized on Figure 4. Macrofossils are rare; a metacarbonate bed near the top of the Goldenville Group yielded Middle Cambrian, Acado-Baltic trilobite fragments (Pratt and Waldron 1991), and rare graptolites in the upper part of the overlying Halifax Group (in the laterally equivalent Lumsden Dam and Bear River formations) indicate an Early Ordovician age (Cumming 1985; White et al. 2012; Pothier et al. 2015). Doyle (1979) reported acritarchs from the Halifax Group in the Bear River area (Bear River Formation of White 2010; Fig. 4), including *Acanthodiacrodium complanatum* and *Polygonium gracilis*, consistent with Tremadocian age. A maximum depositional age of 566 ± 8 Ma was indicated by the youngest detrital zircon grain in samples from the Goldenville Group east of Halifax (Krogh and Keppie 1990). Age constraints improved in recent years by the acquisition of additional detrital zircon age data (Waldron et al. 2009), the documentation of Cambrian trace fossils (Gingras et al. 2011), and acritarch identifications in the upper part of the Goldenville Group and throughout the Halifax Group (White et al. 2012).

Both the Cambrian–Ordovician and Silurian–Devonian successions were regionally metamorphosed to lower greenschist facies and locally to amphibolite facies (Hicks et al. 1999; White and Barr 2012a, b). They were deformed into north- and northeast-trending folds with associated axial planar cleavage during the early to middle Devonian, an event typically referred to as the Acadian or Neoacadian orogeny (van Staal 2007; White 2010). Because both of those orogenies were defined based on rocks and events in New England and hence cause confusion when applied to the Meguma terrane, we propose the new term "Kejimkujik" for the early to middle Devonian orogenic event in the Meguma terrane. They were intruded by abundant 385–357 Ma peraluminous granitoid rocks (e.g., Clarke et al. 1997; Reynolds et al. 2004; Moran et al. 2007; Bickerton et al. 2022), largest of which is the South Mountain Batholith (Fig. 2), with narrow, well developed contact metamorphic aureoles containing mineral assemblages characteristic of up to hornblende-hornfels facies (Mahoney 1996; White 2003). Upper Devonian–Carboniferous and Mesozoic rocks unconformably overlie the northern margin of Meguma terrane and are preserved locally elsewhere in the terrane (Fig. 2)

Psammitic rocks in both the Goldenville and Halifax groups are dominantly feldspathic wacke, with mineralogical compositions suggesting deposition in basins associated with active continental margin volcanic arcs (White and Barr 2010; Barr et al. 2022). Waldron et al. (2009) suggested on the basis of stratigraphic and isotopic differences and limited paleocurrent data that the northwestern and southeastern parts of the terrane may represent opposing sides of the continental rift basin in which the Goldenville and Halifax formations were deposited.

This field trip focuses on the northwestern (NW) and southeastern (SE) parts of the Meguma terrane (Figs. 2, 5–10). The distinctive, typically manganiferous beds of the correlative Bloomfield, Tupper Lake Brook, Moshers Island, and Beaverbank formations provide an age-constrained marker horizon at ca. 500 Ma throughout the terrane and are interpreted to be the uppermost unit of the Goldenville Group (Fig. 4). The underlying units have broad similarities but differ in detail among the NW, SE, and eastern parts of the terrane (Fig. 4). The thickest unit is the Church Point Formation in the NW area, with an estimated stratigraphic thickness of about 7.8 km, although the base is not exposed (Fig. 4). The oldest rocks are exposed in the core of an anticline on the coast between Yarmouth and Cape St. Mary (Figs. 7, 8), from which detrital zircon indicates a maximum depositional age of about 540 Ma (Waldron et al. 2009; Henderson 2016). The three age-equivalent formations (Moses Lake, Green Harbour, and Government Point) mapped SE of the Chebogue Point shear zone cannot be distinguished in the Church Point Formation NW of the shear zone. In the eastern area, the most extensive unit is the Taylors Head Formation, with lithological similarities and similar stratigraphic thickness to the Government Point Formation (Fig. 4). The underlying Tangier and Moose River formations appear to be age-equivalent to the upper part of the Green Harbour Formation (Fig. 4). The stratigraphic section is thinnest and least complete in the eastern area of the Meguma terrane.

The manganiferous Bloomfield, Tupper Lake Brook, Moshers Island, and Beaverbank formations are overlain by sulphidic rocks of the lowermost formation of the Halifax Group, named Acacia Brook/North Alton in the NW area and Cunard Formation in the SE and E (Fig. 4). The overlying age-equivalent Bear River, Lumsden Dam, Feltzen, and Glen Brook/Bluestone Quarry formations contain lower Ordovician fossils (White et al. 2012). The youngest units of the Halifax Group (Elderkin Brook and Hells Gate Falls) outcrop only in the Wolfville area (Fig. 10) where fossils indicate a minimum age of late Floian (ca. 470 Ma).

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AVALONIA

Introduction

Avalonia is a collage of diverse, mainly Neoproterozoic, terranes and belts (herein termed terranes for simplicity) with complex and apparently divergent tectonic settings and histories, isotopic compositions and temporal evolutions. They are linked together and have been defined by their similar lower Paleozoic cover rocks, comprising a generally shallow-marine platformal sequence dominated by fine-grained siliciclastic rocks (Keppie 1985; Landing 1996), although those rocks do not occur in all Avalonian terranes and some similar lower Paleozoic rocks may occur in non-Avalonian terranes (e.g., van Staal et al. 2021a, b). Avalonia extends from southern New England through Atlantic Canada, Wales and southern England into Belgium and central Europe; its European parts have been termed East Avalonia to distinguish them from its Appalachian parts, which are generally referred to as West Avalonia. However, contiguity of East and West Avalonia remains uncertain and some parts of East Avalonia are more likely part of Ganderia (e.g., Schofield et al. 2016; Waldron et al. 2019a, b; van Staal et al. 2021a, b).

In the northern Appalachian orogen, Avalonian rocks occur in southeastern New England (USA), the Caledonian Highlands of southern New Brunswick, the Cobequid and Antigonish highlands of northern mainland Nova Scotia, the Mira terrane of SE Cape Breton Island, and the Avalon platform of eastern Newfoundland (Fig. 1). Correlations among Neoproterozoic rocks in Avalonia are commonly ambiguous because the preserved record is fragmentary. Avalonia is interpreted to have begun docking with composite Laurentia (including Ganderia) in the latest Silurian to Early Devonian but convergence continued through the Devonian, and is generally considered to have been responsible for the long-lived Acadian orogeny (van Staal and Barr 2012; van Staal et al. 2009, 2012).

In addition to their Neoproterozoic and Cambrian rock record, some Avalonian terranes also contain Ordovician–Devonian igneous and sedimentary units (e.g., Hibbard et al. 2006). They include Silurian sedimentary rocks in the Cobequid and Antigonish highlands (e.g., Waldron et al. 1996) and offshore under the Grand Banks of Newfoundland (e.g., Durling et al. 1987), Silurian–Devonian alkalic plutonic and volcanic rocks in southeastern New England (e.g., Thompson et al. 2018), and Ordovician volcanic and plutonic rocks in the Antigonish Highlands. (Hamilton and Murphy 2004; Escarraga et al. 2012; Archibald et al. 2013; White 2018).

Unequivocal pre-Neoproterozoic basement has not been identified anywhere in West Avalonia. The oldest components so far identified are local sedimentary rocks of the western part of southeastern New England (Thompson and Bowring 2000; Thompson et al. 2012; Kuiper et al. 2022; Severson et al. 2022) and in the Cobequid Highlands in mainland Nova Scotia (Doig et al. 1993; Murphy et al. 1997, 1999; Murphy 2002; White et al. 2019a, b, 2020, 2022), which yielded Tonian maximum depositional ages based on youngest detrital zircon populations, but may be as young as Ediacaran. The oldest igneous rocks with ages of about 760 Ma occur the

Burin Peninsula in Newfoundland (Murphy et al. 2008) and in the Cobequid Highlands in Nova Scotia (White et al. 2022).

Cobequid Highlands (northern mainland Nova Scotia)

White et al. (2022) divided the Cobequid Highlands of northern mainland Nova Scotia into three fault-bounded areas which they termed the Jeffers, Bass River, and Mount Ephraim blocks (Fig. 11). The Jeffers block forms most of the northern and western Cobequid Highlands and consists mainly of intermediate to felsic volcanic, epiclastic, and minor plutonic rocks. Both volcanic and plutonic rocks in the western and eastern parts of the Jeffers block yielded U–Pb zircon ages of ca. 607 to 592 Ma, whereas the central area has older ages of ca. 630–625 Ma from both volcanic and plutonic units, as well as inherited ages in overlying Devonian conglomerate (Fig. 11). Due to time constraints, this field trip does not include the Jeffers block.

The Bass River block in the southern part of the Cobequid Highlands (Figs. 11, 12) contains quartzite, metawacke, ironstone, and minor calc-silicate rocks and marble of the Gamble Brook Formation with a maximum depositional age of 945 ± 12 Ma (White et al. 2022). These rocks are closely associated with undated subaqueous mafic volcanic rocks, quartz arenite, and ironstone of the Folly River Formation. The Gamble Brook Formation and probably the Folly Lake Formation were intruded by 615–600 Ma dioritic to granitic rocks of the Bass River plutonic suite (Keppie et al. 1998; Murphy 2002; Beresford 2014; White et al. 2022). The plutons of the Bass River suite are calc-alkalic and have petrological characteristics consistent with origin in a continental margin magmatic arc (Beresford 2014) but the Bass River block lacks volcanic rocks of similar age. Plutons are scarce in the Jeffers block to the north, and along with their host volcanic rocks tend to be older than those of the Bass River plutonic suite (Pe-Piper and Piper 2002; MacHattie et al. 2019; White et al. 2022). A sliver of orthogneiss (Economy River gneiss of Doig et al. 1993) along the Cobequid Fault west of the Bass River block (Fig. 11) is of similar age and composition to plutons of the Mount Ephraim plutonic suite of the Mount Ephraim block but its faulted contacts preclude it from providing age constraints on the Gamble Brook and Folly River formations. The subaqueous mafic volcanic rocks of the Folly River Formation have within-plate and MORB-like characteristics (such as light rare-earth element depletion), consistent with a rift to passive margin setting, but their age is not well constrained. Based on rock types, the metasedimentary and associated volcanic rocks are interpreted to represent a rift- to passive-margin setting, but whether they were all part of the same sequence remains uncertain.

The Mount Ephraim block in the eastern part of the Cobequid Highlands (Figs. 11, 13) includes quartzofeldspathic, semipelitic and pelitic gneiss and schist of the Mount Thom Formation, from which a paragneissic sample yielded youngest detrital zircon U–Pb ages of ca. 800 Ma. However, the result is equivocal because of the small number of zircon grains of that age in the sample, and hence the concordia age of 982 ± 16 Ma for a population of three zircon grains from the same sample that overlap within error may be a more robust indication of maximum depositional age of the formation (White et al. 2022). The Mount Thom Formation was deformed and metamorphosed prior to its intrusion by the comparatively undeformed Mount Ephraim plutonic suite which locally contains xenoliths of folded gneissic rocks. The Mount Ephraim plutonic suite consists of 752–730 Ma gabbroic/dioritic to granitic plutons which are comagmatic with ca. 752 Ma volcanic arc rocks of the Dalhousie Mountain Formation and the ca. 733 Ma dioritic Six Mile Brook pluton. Petrological characteristics of the Dalhousie Mountain Formation and Six Mile Brook pluton suggest that they formed in a continental margin magmatic arc (Vaccaro 2020; Vaccaro et al. 2020). The pre–750 Ma high-grade regional metamorphism and deformation and 752–730 Ma subduction-related magmatism recorded in the Mount Ephraim block are not known from elsewhere in West Avalonia (White et al. 2019a, b, 2022). The Mount Ephraim block also contains ca. 631 Ma subduction-related granitoid rocks of the Gunshot Brook pluton (Vaccaro 2020; Vaccaro et al. 2020), potentially tying these oldest known units to the main, Ediacaran arc phase recognised in the Jeffers block and elsewhere in West Avalonia. Van Staal et al. (2021a) suggested that the tectonothermal event responsible for deformation and metamorphism prior to ca. 760 Ma at may have been related to ophiolite obduction, consistent with the 760 Ma age of the ophiolitic Burin Group (Murphy et al. 2008).

In addition to the Mount Ephraim plutonic suite, the Mount Ephraim block also includes the Ordovician Eight Mile Brook plutonic suite along its southeastern margin (Fig. 13). The Eight Mile Brook plutonic suite consists of commingled syenite and gabbro that were traditionally interpreted to be Neoproterozoic (Donohoe and Wallace 1982; Pe-Piper and Piper 2005). However, three alkali–feldspar granite and syenite samples yielded U–Pb zircon LA-ICPMS) ages of ca. 480 Ma (White et al. 2019a), and their petrological characteristics are similar to those of the West Barneys River plutonic suite in the Antigonish Highlands (Escarraga et al. 2012; Archibald et al. 2013), providing an Ordovician link between these two parts of Avalonia.

No Cambrian rocks are known to be present in the Cobequid Highlands. The Neoproterozoic rocks are overlain by Silurian sedimentary rocks (Fig. 11), which are probably equivalent to the Arisaig Group of the Antigonish Highlands (MacHattie et al. 2014, 2019).

Metasedimentary units that may be equivalent to those of the Cobequid Highlands occur in the southeastern New England (SENE) part of West Avalonia (Fig. 1). They include quartzite and quartzofeldspathic, pelitic and calcareous rocks, a rock association similar to the Gamble Brook Formation. Transitional tholeiitic to alkalic volcanic rocks occur in the Blackstone-Westboro-Plainfield strata, also suggesting a rift to passive margin setting for these sedimentary rocks. The youngest detrital zircon populations from the oldest quartzite in these units is ca. 950 Ma and their detrital populations comprise zircons as old as Archean (Kuiper et al. 2022; Severson et al. 2022), suggesting that they formed part of an ancient continental landmass with an Archean component at the time of deposition. However, some quartzite units of the Westboro and Plainfield formations, and the North Attleboro Formation in SENE have Ediacaran maximum depositional ages (Hepburn et al. 2008; Thompson et al. 2012; Kuiper et al. 2022; Severson et al. 2022), indicating that similar facies were deposited at markedly different times in the same area, precluding firm correlations based on lithologies alone. Regardless, these metasedimentary units in parts of SENE and parts of the Cobequid Highlands suggest that rifting and formation of a Tonian passive margin was an integral part of the tectonic history of West Avalonia. Although the detrital zircon data indicate only maximum deposition ages, and the rocks could be Cryogenian or Ediacaran, the scarcity of young zircon grains in the Gamble Brook Formation seems most compatible with a dominantly Tonian age. Detrital zircon populations and Nd- and Hf-isotopic data suggest that the Tonian sedimentary rocks were sourced from a continent with Archean, Paleoproterozoic and Mesoproterozoic ages, with the dominant peaks lying between 1300 and 1000 Ma, consistent with Amazonian and/or Baltican sources (Murphy 2002; Barr et al. 2003; Thompson et al. 2012, 2022; Henderson et al. 2016; Kuiper et al. 2022; Severson et al. 2022).

Mira terrane (southeastern Cape Breton Island)

The Mira terrane (Barr and Raeside 1989) is the only part of Cape Breton Island which is unequivocally part of Avalonia (Hibbard et al. 2006). In contrast to the Cobequid Highlands described above, the Mira terrane correlates closely with the western part of the type area for Avalonia in Newfoundland in terms of rock types and ages (Barr et al. 1998).

Neoproterozoic rocks in the Mira terrane occur in three belts of mainly different ages (Fig. 14): ca. 680 Ma (Stirling), ca. 620 Ma (Sporting Mountain, East Bay Hills, and Coxheath Hills), and 575–550 Ma (Coastal). All three belts are dominated by mafic to felsic volcanic and volcaniclastic rocks and varying abundances of inter-stratified epiclastic and clastic sedimentary rocks. The Stirling belt is interpreted to represent an intra-arc or back-arc basin. In contrast, the ca. 620 Ma mainly volcanic, volcaniclastic, and plutonic rocks of the Coxheath Hills, Sporting Mountain, and East Bay Hills belts have lithological and chemical features typical of high-K calc-alkalic suites formed at continental margin subduction zones. However, the presence of plutonic rocks of this age in the Stirling belt indicates that these two belts were juxtaposed by that time. These composite dioritic to granitic ca. 620 Ma plutons are the most extensive plutons in the Mira terrane; their ca. 620 Ma age is well constrained by U–Pb zircon dates, both published and unpublished.

The ca. 575 Ma mainly tuffaceous volcanic rocks of Fourchu Group in the Coastal belt appear to be transitional between calc-alkalic and tholeiitic chemical affinity. They are inferred to represent magmas produced early in the development of a ca. 575 Ma northwest-dipping (present coordinates) subduction zone. High-level granitoid rocks are only a minor component of the belt. The other major component of the Coastal belt, the Main-à-Dieu Group, contains lava flows, tuffs, debris flows, and fine-grained epiclastic rocks interpreted to have been deposited in intra-arc basins developed adjacent to the stratovolcanoes represented by the tuffs and flows of the Fourchu Group (Barr 1993). The Main-à-Dieu Group is overlain by mainly clastic marine sedimentary rocks of Cambrian age (Barr et al. 1996, 2020).

Devonian plutons are a minor but important component in the Mira terrane. They are shallow intrusions with associated porphyry-type, greisen-hosted, and vein-hosted Cu-Mo-Pb-Ag-Bi mineralization (Barr and Macdonald 1992). Petrological characteristics suggest that they are subduction-related plutons, but no other evidence of a Devonian magmatic arc occurs in southern Cape Breton Island. The apparent arc-signatures could reflect the nature of their source rocks in the roots of a Neoproterozoic arcs, or they could be associated with a more outboard subduction zone relating to juxtaposition of Gondwana with Meguma (e.g., Moran et al. 2007). In any case, various studies have demonstrated that the Mira terrane has a rather cryptic but significant Devonian and younger thermal overprint (e.g., Willner et al. 2013b).\

The boundary of Mira terrane with the Bras d'Or terrane to the north is a "cryptic suture", buried beneath Carboniferous sedimentary rocks or located under water in Bras d'Or Lake (Fig. 8). On maps, it is rather arbitrarily placed at Carboniferous faults through the Boisdale Peninsula. The presence of clasts derived from both Mira terrane and Bras d'Or terrane units in a Middle Devonian conglomerate unit (McAdams Lake Formation) south of the inferred bounding faults shows that the two areas were in proximity by that time (White and Barr 1998). Magnetic and gravity models across the boundary suggest that the Mira terrane has been thrust under Bras d'Or terrane at the boundary (King 2002). To the east, the boundary has been traced across the Cabot Strait to Newfoundland, where is appears to merge with the Hermitage Bay Fault (Barr et al. 2014a).

GANDERIA – BRAS D'OR AND ASPY TERRANES

Ganderia in Cape Breton Island is represented by the Bras d'Or and Aspy terranes, separated by the Eastern Highlands Shear Zone (Fig. 15). The Bras d'Or terrane, like Mira, is dominated by Neoproterozoic and Cambrian rocks but they differ from those in Mira terrane in rock types, chemical and isotopic characteristics, and tectonomagmatic history, and hence Bras d’Or is interpreted to be part of Ganderia, not Avalonia (Barr et al. 1998; Hibbard et al. 2006; van Staal et al. 2021a, b). It contains fault-bounded blocks of Neoproterozoic low-pressure amphibolite-facies gneiss collectively known as the Bras d'Or Gneiss, and much more extensive belts of greenschist-facies (and in places amphibolite-facies) quartzite, marble, metawacke, and minor volcanic rocks, known collectively as the George River Metamorphic Suite (Raeside and Barr 1990; van Rooyen et al. 2019). The relationship between the two suites of metamorphic rocks is uncertain but it is most likely that they are the same rocks at different metamorphic grades (Barr et al. 2013), an interpretation consistent with results from the equivalent Brookville terrane of southern New Brunswick (Bevier et al. 1990; Barr et al. 2014b).

Both metamorphic suites in the Bras d'Or terrane were intruded by a large volume of Late Neoproterozoic (mainly ca. 560–540 Ma but some as young as 520 Ma) subduction zone-related dioritic, tonalitic, granodioritic, and granitic plutons (Fig. 15). Plutonic rocks are especially abundant in the eastern Cape Breton Highlands, where several plutons contain high-Al hornblende and magmatic epidote, indicative of crystallization at pressures of over 800 MPa (25 km depth) (Farrow and Barr 1992). These rocks are interpreted to represent the deep levels of an Andean-type continental margin subduction zone, whereas plutons (and in places co-magmatic volcanic rocks such as the Price Point Formation) in the southern part of the terrane represent higher level parts of the same subduction zone igneous assemblage. Post-orogenic Late Cambrian granitic plutons are also present, and Middle Cambrian to early Ordovician volcanic and sedimentary rocks are preserved in a down-faulted block known as the Bourinot belt in the Boisdale Hills (Fig. 15). In spite of some similarity to the Cambrian sequence on Mira terrane, the Bourinot belt seems firmly linked to Bras d’Or and hence Ganderia. Similar Avalonia-like Cambrian rocks also occur in Ganderia in southern New Brunswick (Fyffe et al. 2009).

Barr et al. (1998) proposed that Neoproterozoic rocks of the Bras d'Or terrane and its equivalents exposed in southern New Brunswick and locally in central and southern Newfoundland represent the "basement" on which Paleozoic rocks were deposited, and the Paleozoic rocks, which dominate the now-adjacent Aspy terrane in Cape Breton Island and other parts of Ganderia (van Staal et al. 2021b), were assumed to have been eroded from the Bras d’Or terrane. The mylonitic high-strain zone known as the Eastern Highlands Shear Zone that separates Bras d'Or and Aspy terranes in Cape Breton Island has a long and complex history (e.g., Lin 1995, 2001; Lin et al. 2004), and the original relationship between Bras d’Or and Aspy was likely as basement and cover (Chen et al. 1995). The Bras d'Or terrane appears to have been thrust to the northwest over the Aspy terrane, and much of the original terrane is likely missing - the part of Bras d’Or terrane now adjacent to Aspy was unaffected by and hence probably far away during the Silurian–Devonian events which are so prominently recorded in the Aspy terrane (Lin et al. 2007; Barr et al. 2018). These middle Paleozoic events are not generally recorded in Bras d'Or terrane rocks, except very near the Eastern Highlands Shear Zone, where $^{40}Ar/^{39}Ar$ dating revealed overprinting in Neoproterozoic rocks by younger thermal events interpreted to have been associated with Bras d’Or-Aspy terrane collision (Reynolds et al. 1989; Lin 2001).

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PART II – STOP DESCRIPTIONS

DAY 1 (Figs. 5, 6)

Drive from Halifax to Bridgewater, via Highways 102 and 103. Distance ~130 km, about 1.5 hours. From Bridgewater, follow Highway 331 to Dublin Shore (~20 km); turn left at Bells Cove Road, proceed about 700 m to shore at Bells Cove.

STOP 1-1: Dublin Shore – Goldenville Group - Halifax Group contact (Figs. 5, 6) (UTM Zone 20T 390683E 4902070N at stop 1a and 390700E 4901775N at stop 1b)

The contact between the Goldenville and Halifax groups was previously described as a "transition zone" of mixed metasandstone–slate units between the two units in some well exposed sections in the Lahave and Mahone Bay areas (O'Brien 1988). Some previous workers (e.g., Waldron 1987, 1992) placed the Goldenville-Halifax boundary at the base of the manganiferous Moshers Island Formation within that transition zone. However, during regional mapping, White (2010, 2013) found that the base of the Cunard Formation is a more prominent lithological boundary and easily recognized in the field, and hence he placed the boundary there (Fig. 4), This interpretation is also supported by the occurrence of manganiferous beds deeper in Goldenville Group stratigraphy, whereas they are absent from the Halifax Group (White 2010; White and Barr 2010). At this Dublin Shore location the actual contact is not accessible except at very low tide, but the differences between the two formations are clear from examining the Cunard Formation (Halifax Group) at location 1a and then walking ~400 m (access permitting) to view the underlying Moshers Island Formation (Goldenville Group) at location 1b.

Stop 1-1a: This location on the NE side of Bells Cove is in the Halifax Group a few metres stratigraphically above the contact with the Goldenville Group as defined by White (2010). The outcrop is black graphitic slate and pyrite-rich metasiltstone of the Cunard Formation, the lowermost unit of the Halifax Group according to White (2010). Bedding has shallow dip at this location as we are close to the crest of a regional northeast-plunging anticline. The rocks display multiple upright and open minor folds with well-developed steep axial planar cleavage. The metamorphic grade is greenschist facies (chlorite zone), and the typical mineral assemblage is chlorite + muscovite + quartz + plagioclase (albite) ± epidote.

Stop 1-1b: Southwest of the cove, pale grey to green metasiltstone and metamudstone are assigned to the Moshers Island Formation, the uppermost unit of the Goldenville Group. Except at very low tide, these seaweed-covered rocks are not safely accessible in this cove, but they can be viewed by walking in ~300 m on the driveway of a small cottage to the west (after obtaining permission from property owners).

At location 1b, rocks of the Moshers Island Formation appear coarser grained and less well cleaved than the overlying black slate. However, examination in thin section shows that the coarser grains are metamorphic and that the original grain size was very fine. Manganese-rich horizons (coticules) can be recognized by their distinctive pale pink/brown colour. In places they contain diagenetic concretions of manganoan carbonate rimmed or, in places, totally replaced by spessartine garnet, quartz, and ± ilmenite.

Return to vehicles and continue on Highway 331 approximately 8.5 km to Petite Rivière, cross bridge and turn left (south) at the crossroads onto Green Bay Road. Continue ~ 2km to the Canteen at Green Bay.

STOP 1-2: Green Bay - Government Point and Green Harbour formations (Figs. 5, 6) (UTM Zone 20T 385233E 4896736N)

In the terminology of White (2010), this locality is at the contact between the Government Point Formation (northeast of the canteen) and underlying Green Harbour Formation (southwest of the canteen), both part of the Goldenville Group. The contact is not exposed here but elsewhere the contact is gradational over 100–200 m. The Government Point Formation is well exposed on the shore area near the canteen. It consists of metasiltstone and subordinate slate and graded, ripple cross-laminated fine-grained metasandstone showing partial Bouma sequences. The total thickness of the Government Point Formation in this area is 1750 m.

The underlying Green Harbour Formation is best seen in outcrops on the rocky point at the south end of the beach (**~385435E, 4897060N**). It consists of massive metasandstone showing internal scour-and-fill structures, a variety of dewatering features, and rare grazing trace fossils. The metasandstone beds are deposits of high-concentration turbidity currents and do not show typical Bouma sequences.

Scattered carbonate nodules (concretions) and diffuse carbonate-cemented areas are visible on weathered surfaces in both the Government Point and Green Harbour formations. Some carbonate concretions are elevated in Mn content and contain minor spessartine garnet. Based on the mineral assemblage the regional metamorphic grade in this area is relatively low (chlorite zone).

Return to Petite Rivière, turn west on Highway 331 and continue about 10 km. Before Cherry Hill, turn left on Little Harbour Road. Drive ~250 m and park in the cleared area before it turns to go down to the wharf. Walk to the point on a rough trail (ask permission if buildings are occupied).

STOP 1-3: The Shelburne Dyke, Little Harbour, Cherry Hill (Figs. 5, 6) (UTM Zone 20T 381459E 4890528N)

The Shelburne Dyke extends across southern Nova Scotia and adjacent offshore areas to both the SW and NE. The dyke is part of the CAMP (Central Atlantic Magmatic Province; Cirilli et al. 2009) and has been speculated to correlate with the Messejana dyke in Spain (Dunn et al. 1998). The dyke has been very precisely dated using U–Pb in zircon at 201.364 ± 0.084 Ma (Davies et al. 2017), which means that it might be latest Triassic or it might be earliest Jurassic – the boundary on the 2021 time scale (Cohen et al. 2013, updated) is 201.3 ± 0.2 Ma. At this stop, the dyke is well exposed on the point beyond the small buildings. It is composed of medium-grained gabbronorite which consists primarily of labradorite and augite, with minor orthopyroxene and magnetite. The age of the dyke is almost identical to that of North Mountain Basalt but chemical differences indicate that this particular dyke was not the “feeder” for that basalt. At this location the dyke was emplaced along the contact between the Government Point Formation (exposed on the shoreline north of the dyke) and Green Harbour Formation (exposed on the shoreline south of the dyke but not accessible at this location).

Return to Highway 331 and continue west through Voglers Cove to Highway 103 (~15 km). Turn left and continue southwest on Highway 103 to Jordan Falls (~70 km). From the bridge over the Jordan River, proceed west on the highway for 5.6 km and turn left at Exit 25, the first Shelburne exit. Turn around where convenient and return to the highway, going east for 2.5 km, pulling far off on the shoulder or into the logging road network on the south side of the highway. The outcrops are in the cleared logging area.

STOP 1-4: Jordan Falls – cordierite-staurolite-andalusite-magnetite porphyroblastic metapelite (Figs. 5, 6) (UTM Zone 20T 317718E 4852806N)
These medium-grade metasedimentary rocks occur in the upper part of the Government Point Formation near its contact with the overlying Moshers Island Formation. It is located n the western limb of a large syncline. Bedding strikes 330 and dips at 10 degrees. The rocks contain porphyroblasts of cordierite, staurolite, andalusite, and magnetite, and less obvious biotite and garnet, which tend to be small and incorporated into the other metacryst phases. The rocks are highly magnetic. Randomly oriented andalusite metacrysts reach up to 15 cm in length and occur as vague, pale pink/purple patches with abundant inclusions on smooth surfaces. Spectacular hexagonal to round cordierite metacrysts are especially prominent on weathered surfaces. The matrix consists mainly of fine-grained plagioclase, quartz, and muscovite. Although the rocks appear to lack a fabric in outcrop, thin sections show that the metacrysts overgrew a string regional metamorphic fabric.

Because growth of these metacrystic minerals is governed by the availability of aluminum, iron, and magnesium, they are best developed in pelitic beds. Some layers are particularly rich in certain minerals, presumably reflecting subtle variations in the original compositional layering.

After the stop, continue east to Jordan Falls and turn around where safe to do so and continue southwest on Highway 103 for ~40 km. Stop 1-5 is ~2.2 km past the Barrington Passage exit (#29), and ~900 m east of where the highway crosses Barrington River.

STOP 1-5: Migmatite adjacent to the Barrington Passage Pluton (Figs. 5, 6) (UTM Zone 20T 292054E 4828046N)
These roadside outcrops are close to the contact with the ca. 373 Ma tonalitic Barrington Passage Pluton. Rocks of the Goldenville Group (Government Point Formation) have been brought close to or above the melting temperature depending on composition. The more psammitic beds are medium grained with abundant biotite that defines a subhorizontal foliation. Thin, 2–5 mm wide, quartz-feldspar layers and lenses parallel the foliation and are interpreted to be leucosome. Calc-silicate nodules are present in the psammitic layers. Biotite- and sillimanite-bearing pelitic layers with large muscovite porphyroblasts are interlayered with the psammitic lithologies. Quartz and feldspar-rich leucosomes are common in the pelitic layers. The outcrops are cut by muscovite-bearing, medium- to coarse-grained to pegmatitic, locally foliated, leucogranite, likely related to the 373 Ma Shelburne pluton located a few kilometres to the east.

Continue on highway 103 ~60 km to Yarmouth. Continue through Yarmouth on Starrs Road (Highway 3) for about 2 km to the lights at the T-junction (next to McDonalds). Turn right (north) on highway 1 for 475 m. At the "horse" (really) turn left (west) on Route 304. After

750 m turn left (southwest) on Grove Road (Route 304) for 2 km until T-junction with Overton and South Bar roads. Turn left (south) on South Bar Road (Route 304) and continue for 7 km until the road ends in the parking area near the lighthouse. Walk on the hiking trail to south to East Cape Forchu. Be cautious when climbing on the rock surfaces.

STOP 1-6: East Cape Forchu - White Rock Formation (Figs. 5, 7)
(UTM Zone 19T 728922E 4852956N)
Mafic metatuff occurs throughout the volcanic succession in the White Rock Formation in the Yarmouth area but forms a particularly thick unit in the Cape Forchu area. Typically, the mafic metatuff is greenish grey, fine to coarse grained, and well bedded. These rocks were originally crystal tuffs. They are completely recrystallized (lower amphibolite facies) and consist of plagioclase and amphibole (actinolite) crystals in a fine-grained recrystallized matrix of albite, actinolite, chlorite, epidote, quartz, and opaque minerals. The plagioclase crystals are interpreted to be of relict igneous origin, but the amphibole is metamorphic (MacDonald 2000). No glass shards or other volcanic characteristics have been preserved because of the grade of metamorphism.

Locally graded bedding is evident. In places, volcanic bombs, up to 25 cm long, have fallen into soft unconsolidated bedded ash so as to transect the uppermost laminae and bend downward those below. Later laminae arch over the bombs. Bomb-sag, like graded bedding, can be used for top determinations; the rocks young to the east, as do the rocks on the eastern side of the harbour.

In outcrops along the water's edge ~100 m east of the point, relict pillow structures are consistent with subaqueous conditions at times in the eruptive history.

Walk back along the trail to the car park area and ascend the steps to the lighthouse area. On the sloping outcrops of metatuff below the lighthouse, thin black "veins" of pseudotachylite are prominent. Pseudotachylite is generally produced by melting due to frictional heating on fault planes during cataclasis. Specific details of its origin here have not been investigated.

Retrace route to Yarmouth and Starrs Road.
Overnight at Comfort Inn, 96 Starrs Rd., Yarmouth, Nova Scotia, Canada B5A 2T5
(Telephone 902-742-1119)

DAY 2 (Figs. 5, 7–10)

From the Comfort Inn turn left to traffic lights on Starr Road and left again on highway 103. Drive ~17 km and take exit 33 to Port Maitland and Beaver River. Drive west ~2.3 km to highway 1. Turn right on highway 1 and continue north for 4.7 km. Turn left (west) onto Bartlett Shore Road and drive ~750 m to the end of the road. Walk about 300 m to outcrops on the beach to the south (outcrops are accessible only at low tide).

STOP 2-1: Bartletts Beach - lowest exposed Goldenville Group (Church Point formation) (Figs. 5, 7) (UTM Zone 19T 727840E 4877337N)
This outcrop is the lowermost exposed part of the Goldenville Group (Church Point Formation). The youngest detrital zircon grain from this outcrop yielded an age of 544 ± 18 (Waldron et al. 2009). The rocks are grey, medium- to thick-bedded metasandstone (feldspathic wacke) typical of the Church Point Formation. The metasandstone is typically very fine- to medium-grained and poorly sorted. Although the original mud matrix has recrystallized to a mixture of sericite, chlorite, and epidote, subangular to rounded sand-sized detrital grains are present still in many samples. Thin, conglomeratic lenses likely represent channel lag deposits. Clast lithologies consist of quartzite, metasiltstone/slate, and rare chert and basalt.

Return to Highway #1 and turn right (south) and travel 4.7 km to intersection with Richmond and Quaco roads. Turn right (west) on Quaco Road until T-junction at 1.4 km. Park on side of road and walk 250 m down trail to west (past mailboxes) toward beach. At beach, walk left (south) for 200 m until past thick metasandstone beds and on well laminated metasiltstone. This is the base of the High Head member. Continue walking for an additional 700 m until you reach a series of 5–6 thick metasandstone beds and a thin mafic sill/dyke. Trace fossils start here and continue to the south.

STOP 2-2: High Head - High Head member (Goldenville Group) (Figs. 5, 7, 8) (UTM Zone 19T 727620E 4870981N)
The High Head member occurs about 4.5 km above the lowest exposed units of the Church Point Formation seen at Stop 2-1. The stratigraphic thickness of the member is about 850 m, as measured by John Waldron and illustrated in Gingras et al. (2011). We will be looking at a section from about 375 m (true thickness) above the base to 650 m, in which trace fossils are most abundant.

The sedimentary strata of the High Head member are dominated by thinly bedded, planar laminated somewhat metamorphosed mudrocks, which dip ~55° to the southeast. Locally, a separate cleavage is discernible, dipping slightly more steeply than bedding. Very fine-grained metasandstone is locally interlaminated or interbedded with the slatey mudstone and display low-angle cross-lamination and rare bedding surfaces show low-relief, short wavelength (10–20 cm) undulations interpreted to represent ripple marks. Where present, thin (1–3 cm), graded metasandstone beds are sharp-based with rare, small load casts.

In the lower part of the section, sand beds are thicker (typically decimetre-scale) and more abundant. They show planar and cross-laminae organized in partial Bouma (1962) sequences, and are interbedded with metamudstone in up to metre-scale bedsets dominated by fine metasandstone. In the centre of the mudrock-dominated succession are several metre-scale bedsets of medium to fine-grained, graded metasandstone beds that display complete and partial Bouma (1962) sequences. Rare water-escape pipes are present. At the top of section very fine to fine-grained metasandstone reappears in very thin to medium thick (1–30 cm) graded beds with planar and cross-laminae in partial Bouma sequences, organized in bedsets 2–5 m thick.

At several points in the section, greenish-black mafic sills/dykes cut the sedimentary rocks. Based on the geometry of xenoliths and peperitic contacts in these dykes, White and Barr (2004) suggested that they were intruded soon after deposition, while the sediments were still wet.

The High Head member contains an important assemblage of trace fossils preserved in a deep-marine environment influenced by turbidite deposition (Gingras et al. 2011; Jensen et al. 2015). However, the depositional environment was also stabilized by biomats between turbidite-depositing events. The nature of the sedimentation (i.e., largely episodic) and the characteristics of the sedimentary environment (i.e., influenced by biomats) have led to excellent preservation of the trace-fossil assemblage. The trace fossil assemblage includes (in approximate order of abundance) *Planolites, Helminthopsis, Oldhamia, Chondrites, Gordia, Taenidium, Psammichnites gigas, Treptichnus, Phycodes, Lorenzinia, Palaeophycus,* and *Teichichnus*, as documented and illustrated in Gingras et al. (2011).

On the field trip we hope to access the High Head section at about midway in the section at the stratigraphically highest mafic sill/dyke. Here we will see peperitic textures on the margin of the sill. We will walk up-section (south) towards the metre-scale bedsets of metasandstone where the abundant trace fossil assemblages begin.

Retrace route to highway 1 and continue north 10.5 km to Mavillette. Turn left (west) on Cape St. Marys Road. For Stop 2.3 park in the area on the left at UTM Zone 19T 724356E 4885821N, just past the Mavillette beach road. For stop 2.3b, continue on Cape St. Marys Road until it ends in a parking area near the wharf. Clamber down rocks and follow walking trail toward the point.

STOP 2.3a: Cape St. Marys – Halifax Group and White Rock Formation (Figs. 5, 7) (UTM Zone 19T 723793E 4885461N)

Walk west at the top of the spectacular sandy beach to outcrops of the White Rock Formation. The section begins in metabasalt and goes down through slate and cross-bedded metasandstone units into mafic metatuff interbedded with quartzite. The basal 20 m of the White Rock Formation is dominantly volcanic (mafic metatuff underlain by felsic metatuff, dated at 442.9 ± 2.1 Ma by White et al. 2018). Underlying the felsic metatuff is a thin "diamictite" (pebbly phyllite) that has sharp contacts with both the metatuff and underlying bleached slate of the Bear River Formation of the Halifax Group. The diamictite has been interpreted previously to be a Late Ordovician glacial deposit (Schenk and Lane 1991). The underlying Bear River Formation consists of grey, well laminated to thinly bedded, cleaved metasiltstone, with minor, thin (<10 cm thick) slate beds and fine-grained, cross-laminated metasandstone beds (up to 20 cm thick). The Bear River Formation is not the uppermost unit of the Halifax Group, and so stratigraphic units are missing in this section. The contact is steeply inclined to the southeast and parallel to a second-generation foliation (S2) and transposed layering (S0) in the White Rock Formation. In the adjacent Bear River Formation, the contact is parallel to a penetrative crenulation cleavage (S2), but generally discordant to layering. Reverse-sense (White Rock Formation over Bear River formation) kinematic indicators occur close to the contact. The presence of crenulation cleavage and east-verging extended folds in the Bear River Formation suggest a complex deformational history for the reworking of the original contact, interpreted to have been an angular unconformity (Culshaw and Liesa 1997; Culshaw and Dickson 2015). All this section is in the northwestern part of the very wide (~5 km) Cape St. Marys shear zone (dated at ca. 320 Ma; Culshaw and Reynolds 1997).

STOP 2-3b: Cape St. Marys point (Figs. 5, 7)
(UTM Zone 19T 723496E 4884994N)
On the "point" section you can see the contact between the Bear River Formation of the Halifax Group and the overlying White Rock Formation (Rockville Notch Group) well exposed on the wave-cut platform. The basal 20 m part of the White Rock Formation is dominantly volcanic (mafic tuff underlain by felsic tuff). Underlying the felsic tuff is a thin "diamictite" (pebbly phyllite) that has sharp contacts with both the tuff and with the underlying bleached slate of the Bear River Formation. Below the bleached zone the Bear River Formation consists of grey, well laminated to thinly bedded, cleaved metasiltstone, with minor, thin (<10 cm thick) slate beds and fine-grained, cross-laminated metasandstone beds (up to 20 cm thick).

These outcrops are in the northwestern margin of the very wide (~5 km) Cape St. Marys shear zone as described by Culshaw and Liesa (1997) and Culshaw and Dickson (2015). The contact is steeply inclined to the southeast and parallel to a second-generation foliation (S2) and transposed layering (S0) in the White Rock Formation. The contact is parallel to a penetrative crenulation cleavage (S2), but generally discordant to layering in the adjacent slates of the Bear River Formation. The contact is interpreted to be a complexly deformed original angular unconformity (Culshaw and Liesa 1997). Note that the Bear River Formation is not the uppermost unit of the Halifax Group (Fig. 4), and so stratigraphic units are missing in this section.

This contact is the same as that exposed at Stop 2.3a located along the shore about 600 m to the northeast (UTM Zone 19T 723793E, 4885461N). At that location, the felsic tuff near the base of the White Rock Formation yielded a U–Pb zircon igneous crystallization age of 442.9 ± 2.1 Ma (White et al. 2018).

Be sure to look at the large boulders dumped in this area to protect the shoreline. Some are quarried from the Mavillette gabbro (age 426 Ma; Warsame et al. 2021) that forms a folded sill in White Rock Formation about 5 km north of here.

Return to Highway 1 and drive north to Meteghan. Turn right and drive north on Highway 101 to the Digby area (~100 km). Take exit 24 to Bear River and park on the side exit ramp ~20 m before the stop sign at the intersection with Highway 1 (road to Bear River).

STOP 2-4: Bear River exit ramp – Halifax Group, Bear River Formation (Figs. 5, 9)
(UTM Zone 20T 286991E 4943654N)
This outcrop is typical of the Bear River Formation which we also saw at Stop 2.3. It is characterized by grey, well laminated to thinly bedded, cleaved metasiltstone, with minor, thin

(<10 cm thick) slate beds and fine-grained, cross-laminated metasandstone beds (up to 20 cm thick). This outcrop is on the western limb of a major synclinal structure (Bear River syncline). Minor folding is displayed on various scales in this outcrop.

Numerous mafic intrusions occur in both the Goldenville and Halifax groups in western Nova Scotia (e.g., White and Barr 2004) and are quite abundant in this outcrop, forming both sills and dykes. They typically display chilled margins and, locally, peperitic relations with the host rocks. Early workers in the area (e.g., Smitheringale 1973) referred to these sills and dykes as “spilite” because of their intense alteration to albite and chlorite. They are the “type I sills” of Barr et al. (1983), interpreted to have intruded at approximately the same time or soon after deposition of their host sediments. In contrast, less abundant and generally larger gabbroic sills ("type 2") intruded not only the Goldenville and Halifax groups but also the Rockville Notch Group but not the South Mountain Batholith and hence are interpreted to be Devonian.

Return to Highway 101. Continue east to Coldbrook (110 km) and take Exit 13. Turn right (west) on Highway 1 for 2 km. Turn left (south) on English Mountain Road and continue for 3.8 km. Turn right (west) on Prospect Road and continue for 2.2 km. Turn left (south) at entrance to quarry and after 150 m park at quarry.

STOP 2-5: Tupper Lake Brook Formation, uppermost unit of the Goldenville Formation (Figs. 5, 10) (UTM Zone 20T 374528E 4987367N)

The Tupper Lake Brook Formation consists of banded maroon and green, thin- to medium-bedded metasiltstone to slate. Some of the thin metasiltstone beds display small-scale cross-lamination. Thin (<10 cm thick) metasandstone layers are rare and are typically very fine grained and poorly to moderately sorted. The composition of the metasandstone is dominantly feldspathic wacke (White 2010). These sediments may have been deposited from dilute silty to muddy turbidity currents. Towards the southern part of the quarry these rocks are more interlayered with thicker metasandstone beds that marks the transition into the underlying Church Point Formation.

In a quarry to the east, which we were not able to obtain permission to enter, the Tupper Lake Brook Formation locally contains 5 to 20 mm wide, ptygmatically folded, Mn-rich brown carbonate laminations and lenses, and proximal fractures are stained with steel-blue manganese. Within the contact metamorphic aureole of the South Mountain Batholith, these laminations and lenses are pink (converted to coticules) due to the presence of spessartine garnet.

Turn right (east) on Prospect Road and continue for 6 km to junction with Highway 12. Turn left (north) on Highway 12 for 150 m and turn right (east) on entrance ramp to Highway 101. Continue 5.6 km towards Wolfville, past Exit 12, stop at stretch of outcrop along south side of highway (just before water tower on north side of highway).

STOP 2-6: Hellgate Falls Formation, uppermost unit of the Halifax Group (Figs. 5, 10) (UTM Zone 20T 385617E 4990522N)

In this roadside (and hence noisy) outcrop rocks of the Hellgate Falls Formation are light to dark grey slate rhythmically interbedded with laminated to thinly bedded metasiltstone and light grey metasandstone. Thin lenses of cross-laminated metasandstone are common. Characteristic features of the Hellgate Falls Formation (which are present here) include abundant bioturbation textures and trace fossils. Many of the burrows are infilled with fine-grained white metasandstone that locally has a carbonate matrix. These trace fossils display a diverse assemblage of complex trails and based on the morphology, appear to be Early Ordovician. This age is confirmed by the presence of Floian acritarch species. Because this is the uppermost formation in the Halifax Group, the maximum thickness is uncertain but at least 1100 m are exposed.

Continue east on Highway 101 and take exit 11. Turn right (south) and continue 900 m to T-junction. Turn right (west) and continue for 3 km to T-junction at White Rock Road. Turn left (east) and continue for 2.3 km. Turn right (south) to T-junction at 500 m. Turn right (west) and continue for 1.2 km. Turn left (south) on Newtonville Road. Continue 3 km to T-junction. Turn left (east). After ~700 m, visit small quarry on north side of road.

STOP 2-7: (optional) North Alton Formation (Halifax Group) (Fig. 10)
UTM Zone 20T 391298E 4986994N
The North Alton Formation is stratigraphically equivalent to the Acacia Brook Formation in the Bear River area and Cunard Formation in the area southeast of the Chebogue Point shear zone (e.g., Stop 1-1). The rocks in this quarry are typical black to rust-brown slate with thin beds and lenses of minor black cleaved metasiltstone interbedded with cross-laminated, fine-grained, pyritiferous metasandstone. The slate contains abundant pyrite, arsenopyrite, and pyrrhotite that form beds and nodules up to 5 cm thick and may be a source of potential acid rock drainage issues. Several late Cambrian (Furongian) acritarchs were identified in samples from this quarry (White et al. 2012). The North Alton Formation is about 1000 m thick, although in areas of abundant folds it appears much thicker.

Retrace route to Greenwich.
Overnight at Old Orchard Inn
(Telephone 902-542- 5751)

<u>**DAY 3 (Figs. 11, 12, 13)**</u>

Depart Old Orchard Inn and follow Highway 101 to Windsor. Take exit #5 and Route 236 to Truro (~100 km, 1.5 hours). Join Highway 102 (north), and after 2 km, take left lane to merge with Highway 104 (TransCanada Highway) heading west. Continue for ~8 km and take Debert exit. After 1.4 km bear right, continue for 2.3 km and turn left (north) on Belmont Road. After 5.4 km turn right on Upper Belmont Road. After 6.3 km turn left on Patterson Lake (Folly Dam) road. After ~875 m, turn left (south) into quarry.

STOP 3-1: Frog Lake quarry - Gamble Brook Formation (Fig. 12).
(UTM Zone 20T 469041E 5039088N)

At the time of writing, the northeast wall of the Frog Lake quarry provides safe access to typical rocks of the Gamble Brook Formation. They include interlayered white quartzite, metawacke, and ironstone. Elsewhere, phyllite, calc-silicate rocks, and rare marble are also present. Their maximum depositional age is ca. 945 Ma, based on U–Pb dating of detrital zircon. These rocks may be correlative with similar sedimentary units in southeastern New England with similar maximum depositional ages (Thompson et al. 2012, 2014, 2022).

At this location the metasedimentary rocks are intruded by gabbroic rocks on the west and granodioritic/tonalitic rocks on the east. Although undated at this location, they are part of the Bass River plutonic suite, arc-related plutonic rocks that range from gabbroic/dioritic to granitic (Beresford 2014). These plutons form a significant component of the Bass River block and have yielded a range of ages but the most reliable are ca. 612–604 Ma (Fig. 12).

Retrace the route toward Belmont. From where the unpaved Upper Belmont Road intersects the paved Belmont Road, drive south 3.4 km. Turn left (east) onto Onslow Mountain Road, cross the bridge over the Chiganois River. After 6.3 km turn left (north) on the old Tatamagouche Road. Continue 10.8 km and park in cleared area on left to examine roadside outcrops of Stop 3.2a.

STOP 3-2a, b: McCallum Settlement area - Folly River Formation (Fig. 12)

The Folly River Formation is a distinctive unit but enigmatic in terms of its age. We have interpreted it to be similar in age to the Gamble Brook Formation because of their close association throughout the Bass River block (Fig. 12) and some lithological similarities, including the presence of ironstone in both formations, combined with the fact that both are intruded by the Bass River plutonic suite. However, the relationship remains equivocal. The two dominant lithological components of the Folly Lake Formation are subaqueous mafic volcanic rocks (stop 3.2a) interbedded with immature quartz-rich sandstone (stop 3-2b).

Dykes of fine- to medium-grained porphyritic gabbro and diorite are common throughout the Folly River Formation. Some clearly represent subvolcanic "feeders" to the basaltic flows and tuffs but others may be much younger and related to widespread Carboniferous bimodal igneous activity that dominates the Cobequid Highlands north of the Bass River block.

Stop 3.2a UTM Zone 20T 476165E 5040497N (Fig. 12)

The distinctive mafic volcanic rocks of the Folly River Formation are well exposed in outcrops along both sides of this logging road in the McCallum Settlement area. They consist of low-grade green to grey metabasalt with abundant epidote and quartz-carbonate veins. They include lapilli tuff and amygdaloidal basaltic flows. Some flows consist of angular clasts up to several centimeters in diameter that appear to have formed by autobrecciation, and pillow-like structures are common, indicating subaqueous eruptions.

Return to vehicles and continue north for about 750 m, bear right (east) at the branch road to the west, continue 40 m and park in the area of intersection with a logging road to the north. Walk about 50 m up the logging road to examine outcrop and float of Stop 3.2b.

Stop 3.2b UTM Zone 20T 476530E 5041192N (Fig. 12)
Outcrops in the area of stop 3.2b are mainly thick-bedded white-weathering sandstone typical of those interbedded with the metabasalt seen in stop 3-2a. They form prominent east-west, bedding-parallel ridges through the woods. They rarely exhibit cross-laminations and graded bedding, and locally are complexly folded on the outcrop scale, likely a result of slumping (soft-sediment deformation).

Return to vehicles and continue east about 2 km on the Old Tatamagouche Road to the intersection with the Old Truro Road. Turn right (south) and continue about 13.3 km. Cross bridge over North River, turn right (south) onto route 311 toward Truro. After 3.1 km, turn left (east) onto Mountain Lee Road and continue 5 km to traffic lights at intersection with Pictou Road. Turn left (north) onto Pictou Road for 300 m and turn right onto on ramp of Trans Canada Highway 104. Continue on Highway 104 about 21 km and take exit 18A (NOT 18) to Mount Thom. Turn left and go over the highway overpass (~250 m) to Highway 4 and turn right (east). After 7.6 km, turn left (north) onto the Weeks Quarry Road. Drive ~0.5 km and turn right into a small inactive quarry.

STOP 3-3: Eight Mile Brook Plutonic Suite (Fig. 13)
(UTM Zone 20T 502027E 5041915E)
Typical components of the Ordovician Eight Mile Brook Plutonic Suite can be safely examined in quarried boulders without approaching the quarry walls. They consist of co-mingled pink, equigranular, medium- to coarse-grained syenite to alkali-feldspar granite and black, medium- to coarse-grained monzogabbro. A sample of alkali-feldspar granite and a sample of quartz syenite from this quarry yielded U–Pb zircon (LA-ICPMS) ages of 477.7 ± 3.6 Ma and 479.7 ± 3.2 Ma, respectively (T. MacHattie, unpublished data; White et al. 2019a). They intruded the Mount Thom Complex and the Mount Ephraim plutonic suite (Fig. 13).

Return to and continue on Weeks Quarry Road about 750 m to the weigh station and drive into the quarry.

STOP 3-4: Mount Thom quarry – Mount Thom Formation (Fig. 13)
(UTM Zone 20T 501509E 5042750N)
In October 2021, the most accessible place to look at the metasedimentary rocks of the Mount Thom Formation was on the northwest wall of this active quarry (with permission and proper safety apparel). Overall, the formation consists of quartzofeldspathic, semipelitic and pelitic gneiss with minor calc-silicate gneiss and rare quartzite and amphibolite, and is cut by abundant gabbroic, dioritic, granitic, and pegmatitic dikes and sills related to the ca. 755–730 Ma Mount

Ephraim Plutonic Suite and Ordovician Eight Mile Brook Plutonic Suite and likely younger Carboniferous magmatism as well. The relationship of the metasedimentary rocks (schist, phyllite) of the Mount Thom Formation to those of the Gamble Brook Formation (Stop 3.1) is uncertain but they may be a higher-grade but equivalent unit. Dating of detrital zircon from a quartzofeldspathic paragneiss sample from this area yielded dates from 1969 ± 37 Ma to 1187 ± 19 Ma. The youngest three grains that overlap within error produce a concordia age of 1251 ± 10 Ma, indicating the maximum depositional age of the protolith (White et al. 2022). However, a similar sample from a quarry farther west in the Mount Thom Formation indicated a younger depositional age of 982 ± 16 Ma. That sample also contained three grains with ages of 806.0 ± 11.0 Ma, 793.0 ± 24.0 Ma, and 777.0 ± 13.0 Ma; although a concordia age could not be calculated, the presence of these grains suggests the possibility of an even younger maximum depositional age of ca. 800 Ma.

Continue on the road through the quarry and continue on the access road to the RMS Energy wind farm (gated 700 m from the quarry) to the first windmill 780 m from the quarry. Note that the windmills are located on hilltops and outcrops are rubbly and not impressive. It is the ages of these rocks that are amazing, not how they look in these outcrops.

STOP 3-5. Mount Ephraim – Mount Ephraim plutonic suite (Fig. 13)
(UTM Zone 20T 501714E 5043331N)
The Mount Ephraim plutonic suite consists dominantly of diorite to quartz diorite with textures that range from fine to coarse grained and equigranular to porphyritic. More felsic rocks represent a minor component of the suite and consist of medium- to coarse-grained, slightly porphyritic granodiorite to granite with phenocrysts of quartz and K-feldspar. Mingling between mafic and felsic rocks of the plutonic suite is common, indicating that they were comagmatic. U–Pb zircon ages from seven samples range from 755 M to 727 Ma (Fig. 13), with inherited populations as old as 767 Ma (White et al. 202). Unpublished chemical data show that the Mount Ephraim plutonic suite formed in a magmatic arc, and the Tonian ages show that this arc is the oldest yet dated in West Avalonia.

Rubbly outcrop at Stop 3.5 consists mainly of medium- to coarse-grained monzogranite. An outcrop of the same granite 500 m to the east yielded a concordia age of 754.5 ± 5.4 Ma based on seven zircon grains.

STOP 3-6. Dalhousie Mountain Formation (Fig. 13)
(UTM Zone 20T 503866E 5046342N)
The Dalhousie Mountain Formation consists of felsic ignimbrite, lithic-crystal tuff, and flows with abundant andesitic lithic tuff and minor basaltic lithic tuff and flows. Fine-grained, laminated volcanogenic siltstone and sandstone are interlayered with the volcanic rocks. The volcanic rocks are characteristically massive and lack a penetrative fabric. At this location, white-weathered dacitic lithic crystal tuff is the dominant component in rubble and sparse outcrop.

STOP 3-7. (optional) Dalhousie Mountain Formation (Fig. 13)
(UTM Zone 20T 502953E 5046690N)
A felsic crystal-lithic tuff was dated from this outcrop. It contained angular felsic lithic fragments with abundant embayed subhedral quartz and minor plagioclase crystals and yielded a concordia age of 752.9 ± 2.4 Ma (White et al. 2022). A somewhat older population of four grains produced a calculated concordia age of 767.2 ± 4.0 Ma, interpreted to represent an inherited component. The volcanic rocks have characteristics of a continental margin arc and are considered to be the extrusive counterparts of the Mount Ephraim plutonic suite.

STOP 3-8. Six Mile Brook Diorite (Fig. 13)
(UTM Zone 20T 504243E 5047816N)
The Six Mile Brook pluton is a small dioritic body intruded into the Dalhousie Mountain Formation (Fig. 13). It consists of medium- to coarse-grained, equigranular to porphyritic diorite to quartz diorite, with textural and mineralogical similarities to dioritic components of the Mount Ephraim plutonic suite and to mafic enclaves in the ca. 630 Ma Gunshot Brook pluton (Vaccaro 2020). A sample of fine- to medium-grained, equigranular quartz diorite from this outcrop produced a concordia age of 733.0 ± 2.2 Ma, which is interpreted to be the igneous crystallization age. A second 11-grain population yielded a calculated concordia age of 761.1 ± 5.0 Ma, which was interpreted to represent inheritance (White et al. 2022).

Retrace route past the Weeks Quarry and return to Highway 4. Turn left (east) for 8 km. Turn right and drive 350 m over the overpass and access the on ramp to Trans Canada Highway 104. Continue to Antigonish (about 75 km).

Overnight at Maritime Inn, 158 Main St, Antigonish
(Telephone: 833-863-4400)

DAY 4 (Fig. 14)

Depart Antigonish via Highway 104, crossing the Canso Causeway into Cape Breton Island. Continue on Highway 104 through Port Hastings and Port Hawkesbury to St. Peters. Turn south on Highway 247 through L'Ardoise.

STOP 4-1: Conglomerate at Point Michaud (Fig. 14)
(UTM Zone 20T 678434E 5049587N)
This locality is close to the L'Archeveque-Mira Bay fault system that separates the Stirling belt from the adjacent Coastal belt. The outcrop is a lens of polymictic conglomerate and pebbly arkose that forms part of the Gracieville Formation of Barr and White (2017), a mainly epiclastic unit that is a major component of the Stirling Group (Macdonald and Barr 1993; Barr et al. 1996). In addition to conglomerate the formation consists of lithic arenite, with abundant volcanic debris, and locally chert and dolostone. Elsewhere in the coastal section to the south and west, the conglomerate is interbedded with volcanic litharenite, laminated siltstone, and basaltic lapilli tuff. Clasts in the conglomerate are 5–20 cm in diameter, and include quartz–feldspar porphyry, tonalite, granodiorite, rhyolite, dacite, and minor grey quartzite. Two quartz–feldspar porphyry clasts, both with abundant embayed quartz, K-feldspar, and plagioclase phenocrysts in a cryptocrystalline quartzofeldspathic groundmass yielded U–Pb zircon LA-ICP-MS ages of 668.1 ± 3 Ma and 664.7 ± 3.1 Ma (Willner et al. 2013a). The Grand River pluton which intruded these rocks (Fig. 14) yielded a similar LA-ICPMS age but an older CA-TIMS age of ca. 682 Ma, and the latter is considered to be the igneous crystallization age (J. Crowley, written communication, 2021). These data corroborate the age of 681 +6/-2 Ma reported by Bevier et al. (1993) for a rhyolitic quartz-feldspar porphyry in the Stirling Group.

Return to Highway #4 via Grand River. Follow Highway to East Bay. Take Morley Road and stop at the entrance to a large quarry on the west (right) side of the road.

STOP 4-2: East Bay Hills Group - Morley Road Formation (Fig. 14)
(UTM Zone 20T 711940E 5096800N)
The East Bay Hills Group consists mainly of ca. 620 Ma volcanic and volcaniclastic rocks formed in an Andean-type subduction zone (Barr et al. 1996). The flow-banded rhyolite exposed in this quarry is typical of the Morley Road Formation and yielded an age of 623 ± 3 Ma. Age of the East Bay Hills Group is further constrained at 2 localities by cross-cutting plutons with ages of 625.2 ± 3.1 Ma and 619.4 ± 2.6 Ma (Barr et al. 2018).

If it is safe to do so, walk to the back wall of the quarry and examine the rhyolite where it shows spectacular columnar joints; otherwise, it can be examined in quarried blocks by the roadside.

Continue on Morley Road 2.6 km to the intersection with Grand Mira North Road. Turn left and drive 3 km to Route 327 in Marion Bridge. Turn right for 350 m, cross the bridge over the Mira River. Turn left after onto Trout Brook Road, and after 5.2 km turn right onto Bengal Road. Drive 1.5 km and stop at the roadside to view outcrops.

STOP 4-3: Canoe Brook Formation of the Mira River Group (Cambrian) (Fig. 14)
(UTM Zone 20T 720807E 5095007N)

The Canoe Brook Formation is a distinctive component of the Cambrian succession considered to be typical or characteristic of Avalonia. In the Mira terrane they are collectively called the Mira River Group (Barr and White 2017) and overlie the Ediacaran Main-à-Dieu Group (seen at Stops 4.4 and 4.5). This outcrop area displays rocks typical of the Canoe Brook Formation, including red-brown, carbonate-rich mudstone and siltstone, maroon siltstone containing grey-green reduction spots, and minor pink to red limestone. Landing (1991) recovered skeletal fossils from the Canoe Brook Formation along the Louisbourg Highway, which he attributed to the Cambrian Stage 3 (Geyer 2019) *Camenella baltica* Zone. He also reported the trace fossil *Teichichnus* and trilobite hash in the upper part of the formation. Hutchinson (1952) reported the Cabrian Stage 3 *Callavia* Zone trilobite *Strenuella strenua* from the Victoria Bridge area in rocks originally attributed to the MacCodrum Formation but now part of the Canoe Brook Formation (Barr et al. 1996). If you spot fossils here, please tell us!

Retrace route to Trout Brook Road. Turn right (east) and drive 8.5 km to Albert Bridge. Turn right on Route 22 (Louisburg Highway) and drive 15.6 km into the town of Louisburg. Turn left on Havenside Road and continue 3.3 km to the parking area at the end of the road.

STOP 4-4: Main-à-Dieu Group, Louisburg Lighthouse (Fig. 14)
(UTM Zone 21T 270657E 5087923N)

The exposures around the parking area and lighthouse display a variety of volcaniclastic rocks typical of the lower part of the Main-à-Dieu Group. If the weather is clear, you also will have a clear view of the fortress of Louisburg, a restored French fortress from the 1700s and a Canadian National Historic Site. The lighthouse area is also part of the park – no hammers or sample collecting!

This spectacular coastal area consists of varied lithic and crustal tuffs with ages of ca. 575 Ma, similar to many rocks in the Marystown Group of the Avalonian "type area" in Newfoundland. The outcrops are intruded by large mafic dykes of unknown age but perhaps related to the undated gabbro pluton at Baleine located 10 km farther east (Fig. 14).

Retrace route to Louisburg. Turn right on Louisburg Highway and after 970 m turn right onto Main-a-Dieu Road. Drive 15 km to Main-a-Dieu and turn left toward Bateston. After 3.7 km pull into small parking area on right.

STOP 4-5: Coastal section in the Main-à-Dieu Group (Fig. 14)
(UTM Zone 21T 276134E 5098554N)
Windsor, Horton, and Main-à-Dieu groups, coastal section, Mira Bay

A walk along the shore of Mira Bay displays outcrops of all these rock units. The first part of the section gives you an opportunity to see Carboniferous rocks of the Windsor and Horton groups and overlying glacial deposits. The underlying Main-à-Dieu Group (age ca. 570 Ma, based on a U–Pb zircon CA-TIMS date from rhyolite in this section; G. Layne and J. Crowley, unpublished data) is the youngest of the Neoproterozoic components of the Mira terrane. It consists of volcanic rocks, including basalt and rhyolite flows, varied (and commonly spectacular) lithic lapilli tuff, laminated ash tuff, and red clastic sedimentary sequences. The Main-à-Dieu Group in this section includes basalt and rhyolite flows, varied (and spectacular) lithic lapilli tuff, laminated ash tuff, and red clastic sedimentary sequences. It is a subaerial succession, likely formed during regional extension in this part of Avalonia. This section continues on Scatarie Island where the uppermost unit of the group, the Scatarie Island Formation, is overlain disconformably by the ca. 530 Ma (Terreneuvian) Bengal Road Formation, the lowest unit of the Mira River Group (Barr et al. 2020).

Continue on the Main-a-Dieu Road to Catalone and turn right on Route 22 into downtown Sydney.

Overnight at Holiday Inn, 300 Esplanade, Sydney, Nova Scotia
(Telephone 902-562-7500)

<u>DAY 5 (Fig. 15)</u>

From the Holiday Inn, follow Esplanade 100 m to merge with Highway 4. Follow Highway 4 through Sydney River and continue 21 km through Sydney Forks to East Bay. Turn right (north) for 2.7 km crossing the spit across East Bay to the intersection with the Eskasoni Road. Go straight on Bourinot Road, through the intersection with Beechmont Road at 5 km continuing straight for 2.1 km to intersection with Frenchvale Road, bear left and continue on Bourinot Road for 2.2 km. Park at roadside to examine outcrop at Stop 5-1.

STOP 5-1: Bourinot Road – Bourinot Group (Fig. 15)
(UTM Zone 20T 693761E 5103606N)
The Bourinot belt consists of the Bourinot Group, including middle Cambrian basaltic and rhyolitic volcanic flows and tuffs of the Eskasoni Formation, mainly quartz-rich siltstone and shale of the Dugald Formation and tuff and siltstone of the Gregwa Formation. Rhyolite from the Eskasoni Formation on Long Island yielded an age of 505 ± 3 Ma (White et al. 1994). The Bourinot Group is overlain by middle Cambrian shale and siltstone of the MacMullin Formation, shale and minor black limestone of the upper Cambrian MacNeil Formation, and light grey to black shale of the lower Ordovician McLeod Brook Formation (Hutchinson 1952; White et al. 1994; Landing et al. 1997). The Mount Cameron syenogranite in the northern of the Boisdale Hills yielded a Cambrian age of 509.3 ± 1.4 Ma and is considered related to the volcanic rocks of the Bourinot Group.

This stop includes basalt and interlayered quartz arenite in the lower part of the Eskasoni Formation. The quartz arenite sample yielded a maximum depositional age of ca. 515 Ma. Its detrital zircon population is mainly Ediacaran and consistent with derivation from surrounding metamorphic and plutonic units of the Boisdale Hills.

Like the Mira River Group in Mira terrane, the Bourinot Group and overlying units are Cambrian, but their younger ages (Cambrian Series 2 to Miaolingian) and presence of bimodal volcanic rocks have led to the interpretation that they formed during the rifting of Ganderia from Gondwana (Amazonia).

Continue on Bourinot Road 5.3 km to the intersection with Highway 223 at Boisdale. Turn right on Highway 223 and continue 12.3 km. Turn right (south) and drive ~100 m into an old quarry.

STOP 5-2: Frenchvale Road Metamorphic suite (Fig. 15)
(UTM Zone 20T 701829E 5113396N)
This retired quarry provides easy-to-access outcrops of quartzite and metawacke typical of the Frenchvale Road metamorphic suite (FRMS). The rocks are folded at outcrop scale and the muscovite-rich layers have a crenulation cleavage at high angle to the main foliation. Overall, the FRMS consists of marble, quartzite, and meta-psammite with minor amphibolite and andalusite-bearing metapelitic rocks. It is preserved in a narrow belt bounded by the Georges River fault on the east and intruded by Ediacaran plutonic rocks on the west (Fig. 15). Quartzitic layers in the metawacke from this quarry yielded a typical Ganderian detrital zircon population with ages

from 1.2 Ga to 2.1 Ga with the biggest peak at 1.7 Ga and smaller peaks at 1.5 Ga and 1.3 Ga and a possible maximum depositional age of ca. 800 Ma. This result is consistent with data from quartzite in the nearby Levatte quarry which yielded a typical Ganderian detrital zircon population with ages mainly between 1.0 and 1.6 Ga, and a maximum depositional age of ~967 Ma. The quartzite and associated marble are representative of the passive margin sequence inferred to have been formed on the edge of Ganderia at ca. 600 Ma when it was part of Amazonia.

Return to Highway 223, turn left and continue 180 m, and then turn right on Scotch Lake Road. Note spectacular marble quarry on left at 4.8 km (not a stop). At the intersection at 7.7 km, continue straight on Georges River Road. After 7.4 km to traffic light at Little Bras d'Or. Turn left onto Highway 105 (Trans Canada). Continue 24.5 km to the top of Kellys Mountain and pull into road on right.

STOP 5-3: Bras d'Or Gneiss - Kellys Mountain migmatitic gneiss and granite (Fig. 15) (UTM Zone 20T E= 691105 N= 5124661)

The core of Kellys Mountain consists of low-pressure gneissic rocks (part of the Bras d'Or Gneiss) intruded by granitic and dioritic rocks. In contrast the southwestern part of the mountain is relatively low- grade metasedimentary rocks (Glen Tosh Formation of the George River Metamorphic Suite). The gneiss contains the mineral assemblage cordierite–biotite–K-feldspar–plagioclase–quartz with accessory apatite, tourmaline, and Fe–Ti oxides and has an inferred semi-pelitic to pelitic protolith (Jamieson 1984). The Kellys Mountain gneiss records peak metamorphic conditions of 100–350 MPa and 580–700 °C, attributed to low-pressure contact metamorphism (Jamieson 1984). The rocks and the metamorphic conditions correlate well with those of the Brookville Gneiss in the Brookville terrane of southern New Brunswick (Barr et al. 2014b) and the units now 475 km apart are considered to be correlative.

END of Field Trip. Drive to Halifax airport (3.5 - 4 hours).

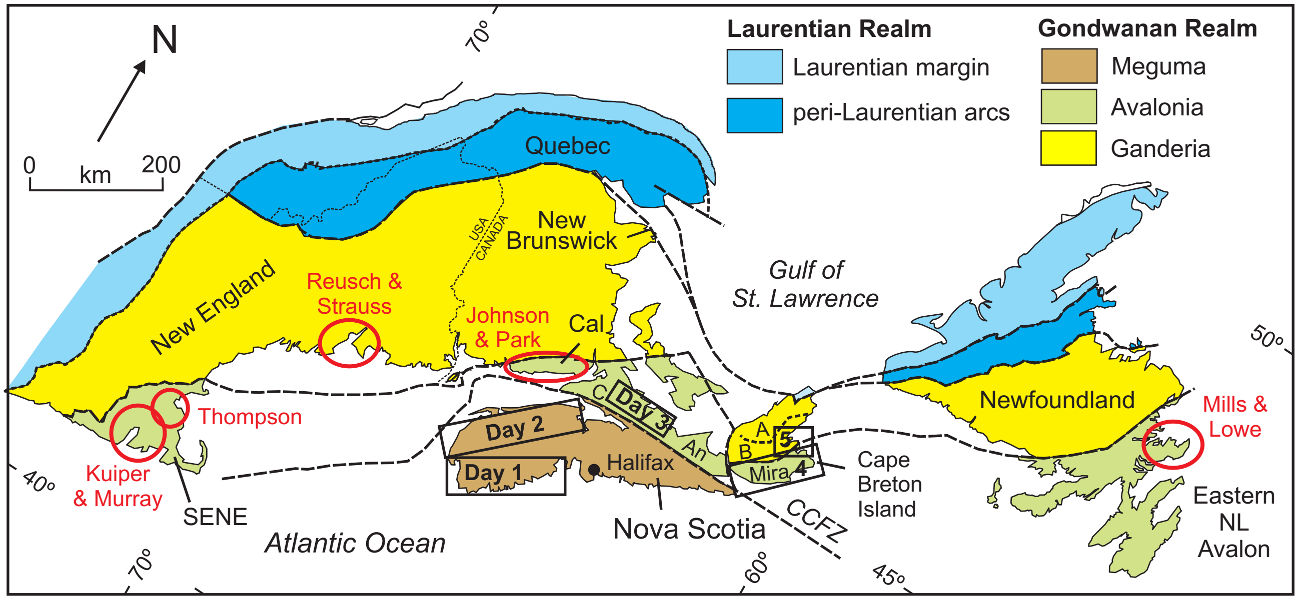

Fig. 1. Divisions of the northern Appalachian orogen (after Hibbard et al. 2006) showing the in-person field trip areas in Nova Scotia (boxes, days 1 to 5) and virtual field trip areas (red ellipses, labelled with guide author(s)). Abbreviations: A, Aspy terrane; An, Antigonish Highlands; B, Bras d'Or terrane; C, Cobequid Highlands; Cal, Caledonia Highlands; CCFZ, Cobequid-Chedabucto fault zone; NL, Newfoundland; SENE, southeast New England.

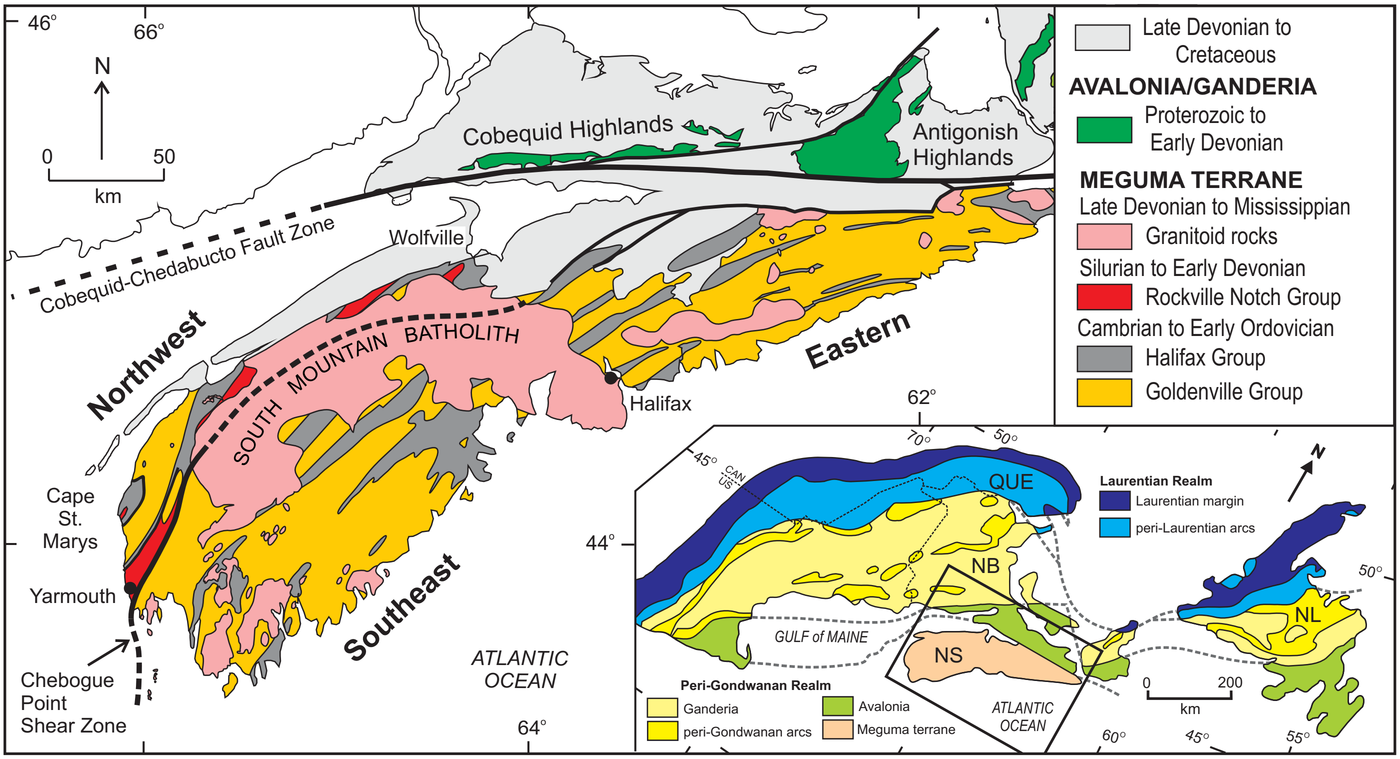

Fig. 2. Simplified geological map of the Meguma terrane showing the distribution of major rock units after White (2013 and in preparation). Inset map is after Hibbard et al. (2006).

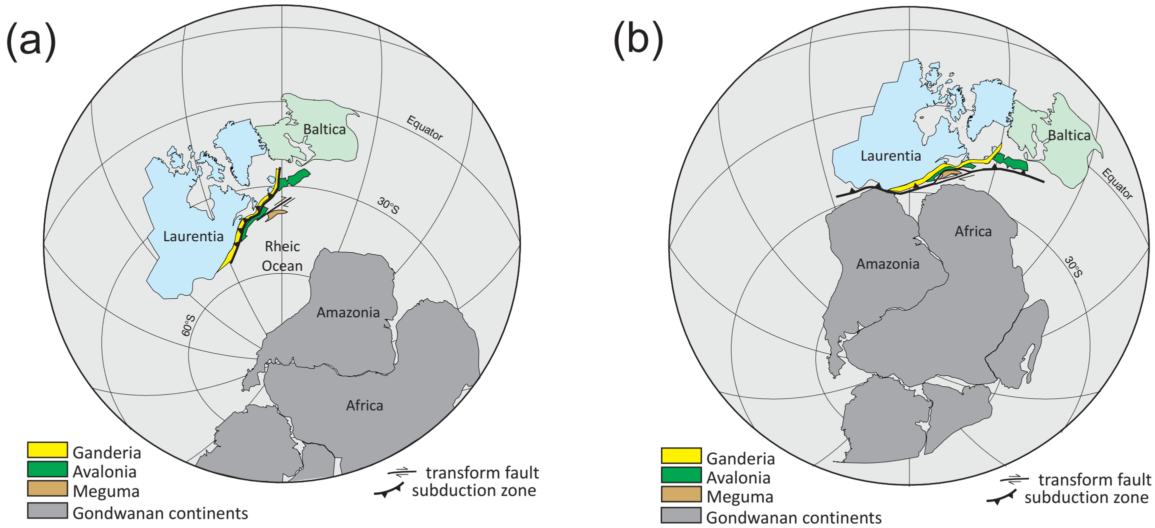

Fig. 3. Global reconstructions showing the location of the Meguma terrane in the (a) early Devonian (410 Ma) and (b) early Carboniferous (ca. 330 Ma), modified from van Staal et al. (2021b) The position of the Meguma terrane in (a) is at a minimum distance and could have been farther offshore.

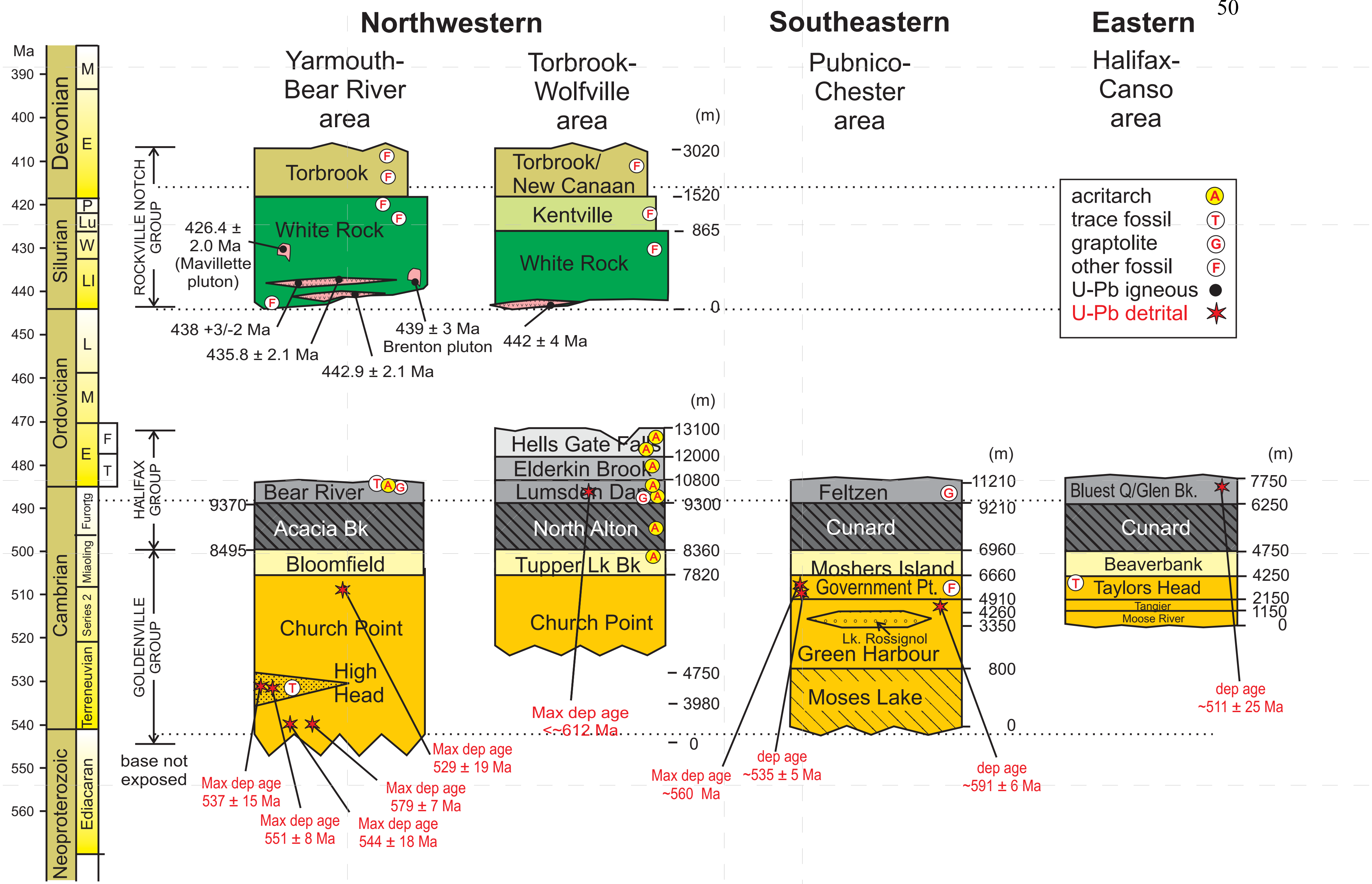

Fig. 4. Summary of Cambrian to Devonian stratigraphy in the Meguma terrane showing differences among the northwestern, southeastern, and eastern areas after White (2010, 2012), Barr and White (2012), and Barr et al. (in revisioned). Paleontological and U-Pb age data are from sources described in the text. All units are formations except High Head, Lake Rossignol, and Governor Lake which are members. Estimated stratigraphic thicknesses are shown in metres (m). Time scale is after Cohen et al. (2013, updated 2021). Abbreviations: Bk, Brook; E, Early; F, Floian; Furong, Furongian; L, Late; Lk, Lake; Ll, Llandovery; Lu, Ludlow; Miaoling, Miaolingian; M, Middle; P, Pridoli; Pt, Point; T, Tremadocian; W, Wenlock.

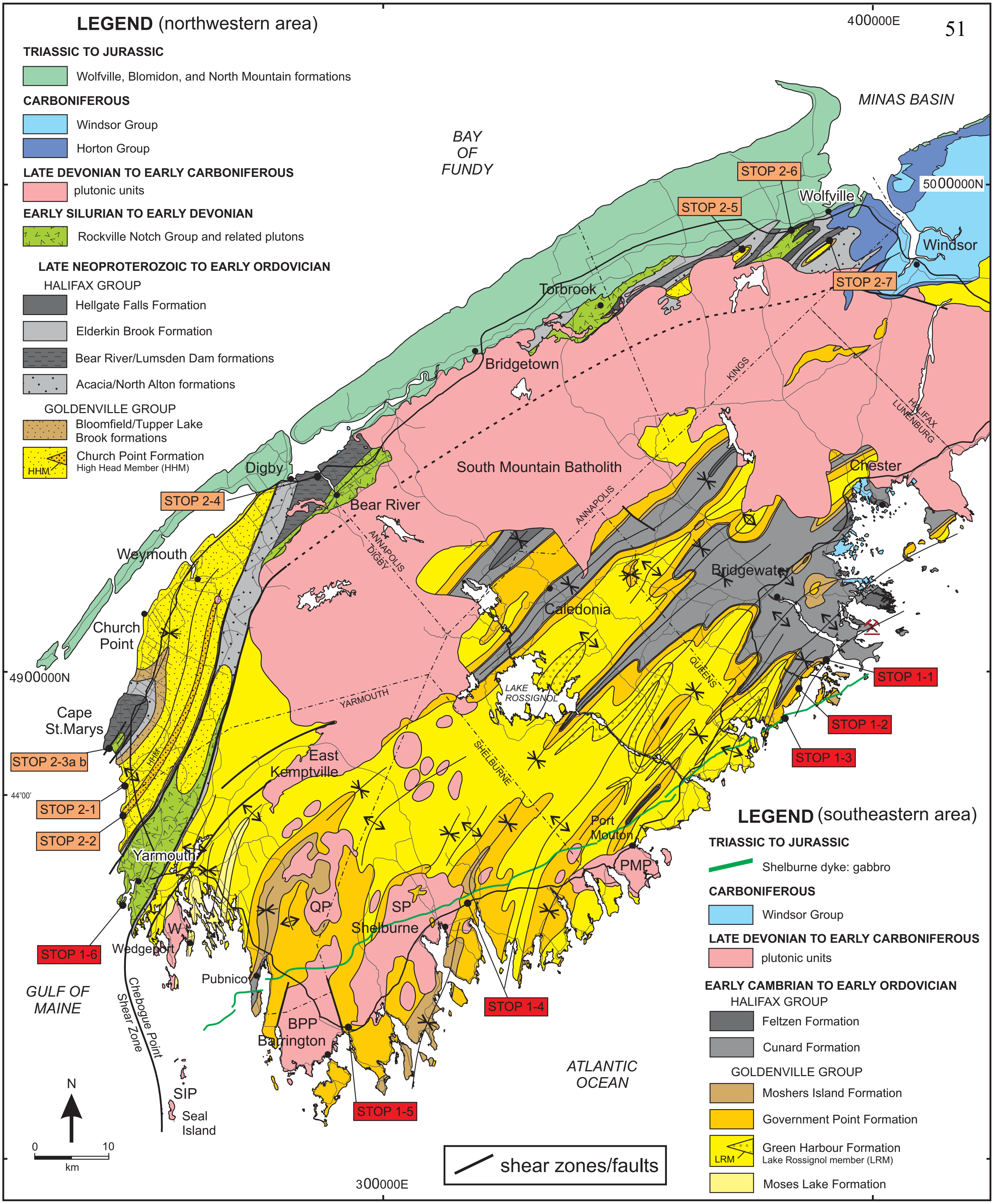

Fig. 5. Geological map of the northwestern and southeastern parts of the Meguma terrane showing approximate locations of field trip stops on Day 1 (1-1 to 1-6) and Day 2 (2-1 to 2-6). Geology is after White (2013) and White and Barr (2012). Pluton abbreviations: BPP, Barrington Passage, PMP, Port Mouton; QP, Quinan; SP, Shelburne; SIP, Seal Island; W, Wedgeport.

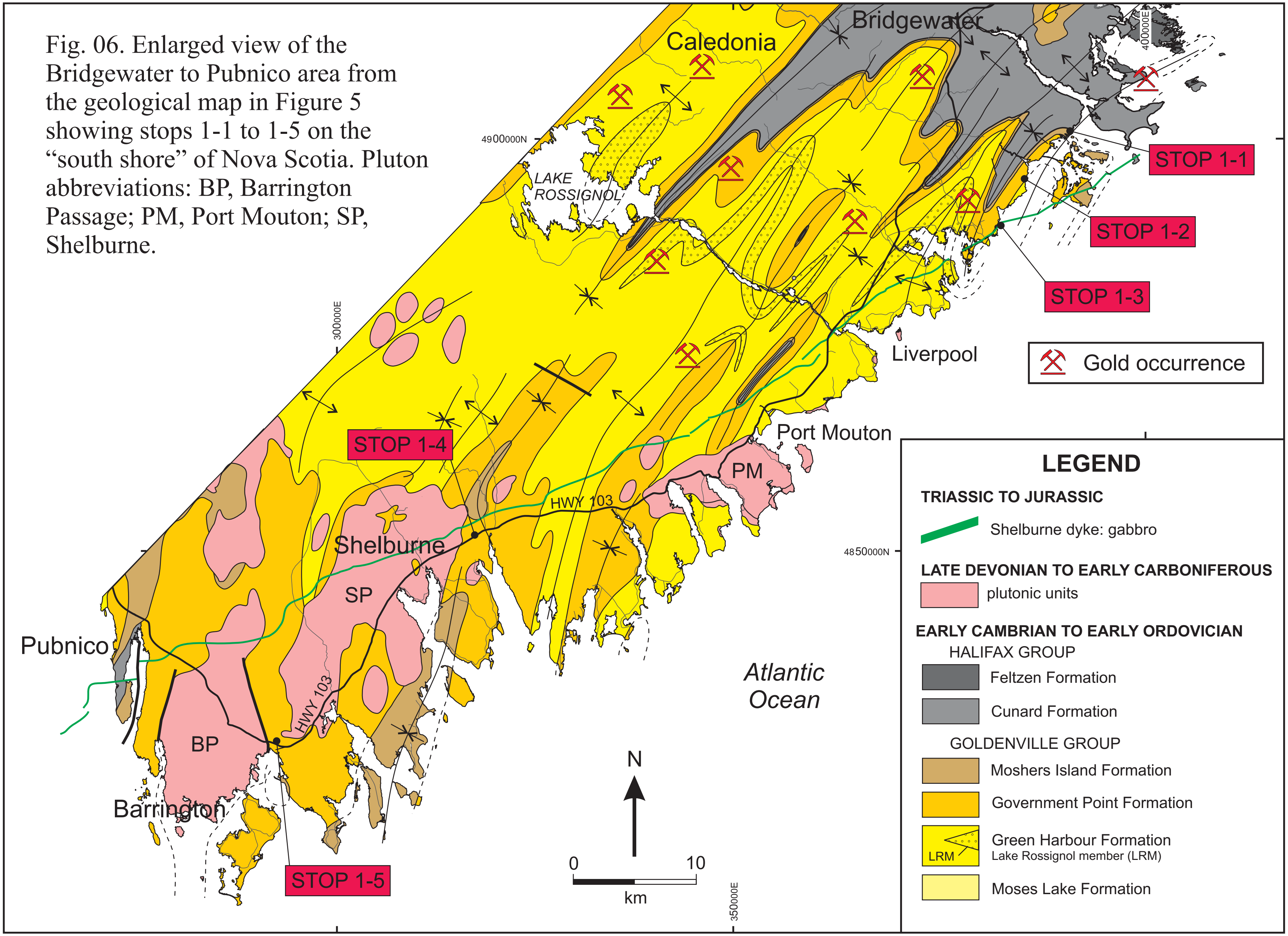

Fig. 06. Enlarged view of the Bridgewater to Pubnico area from the geological map in Figure 5 showing stops 1-1 to 1-5 on the "south shore" of Nova Scotia. Pluton abbreviations: BP, Barrington Passage; PM, Port Mouton; SP, Shelburne.

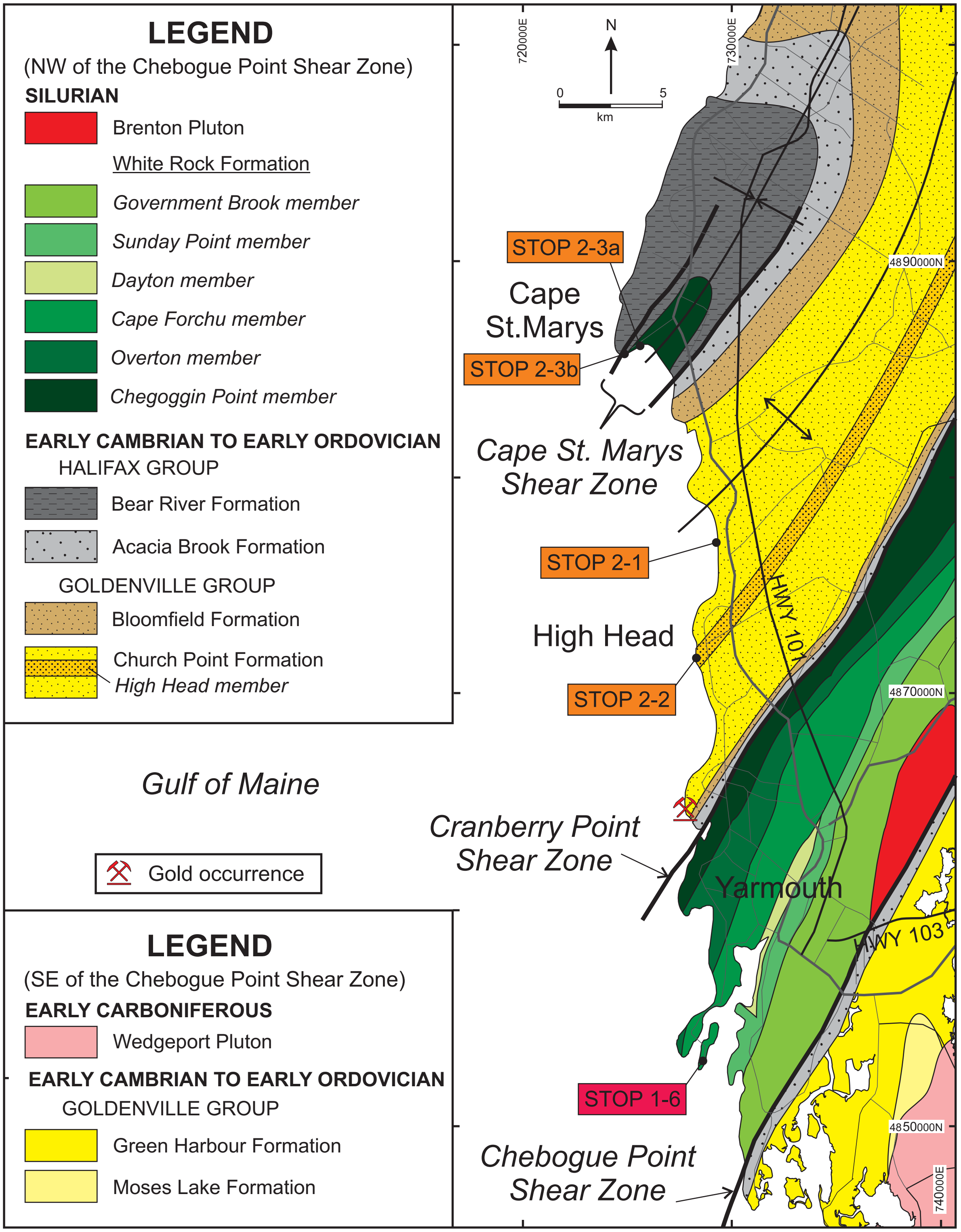

Fig. 7. More detailed geological map of the Yarmouth-Cape St. Marys area after White et al. (2001) and White (2012) showing stops 1-6 and 2-1, 2-1, and 2-3a and b.

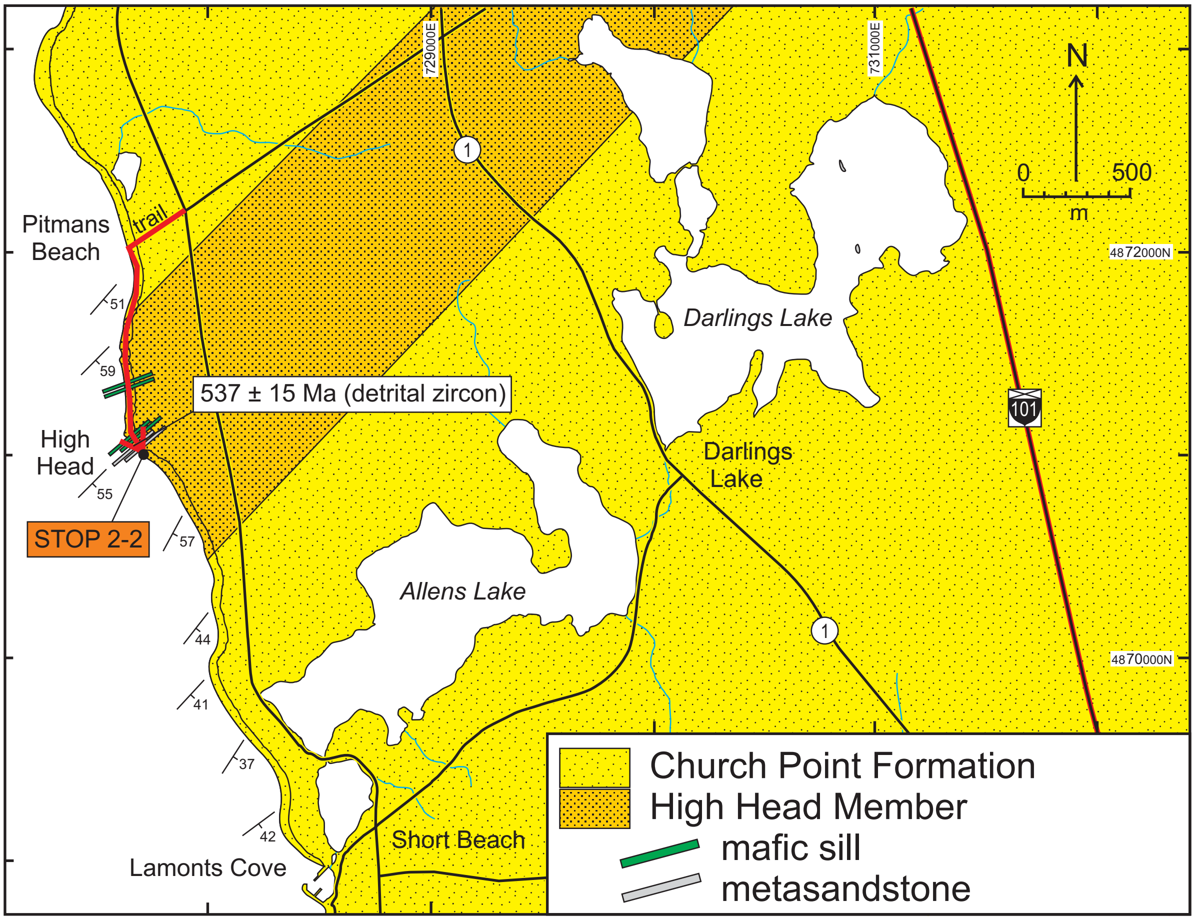

Fig. 8. Geological map of the High Head area showing details for Stop 2-2. Map is modified after Gingras et al. (2011).

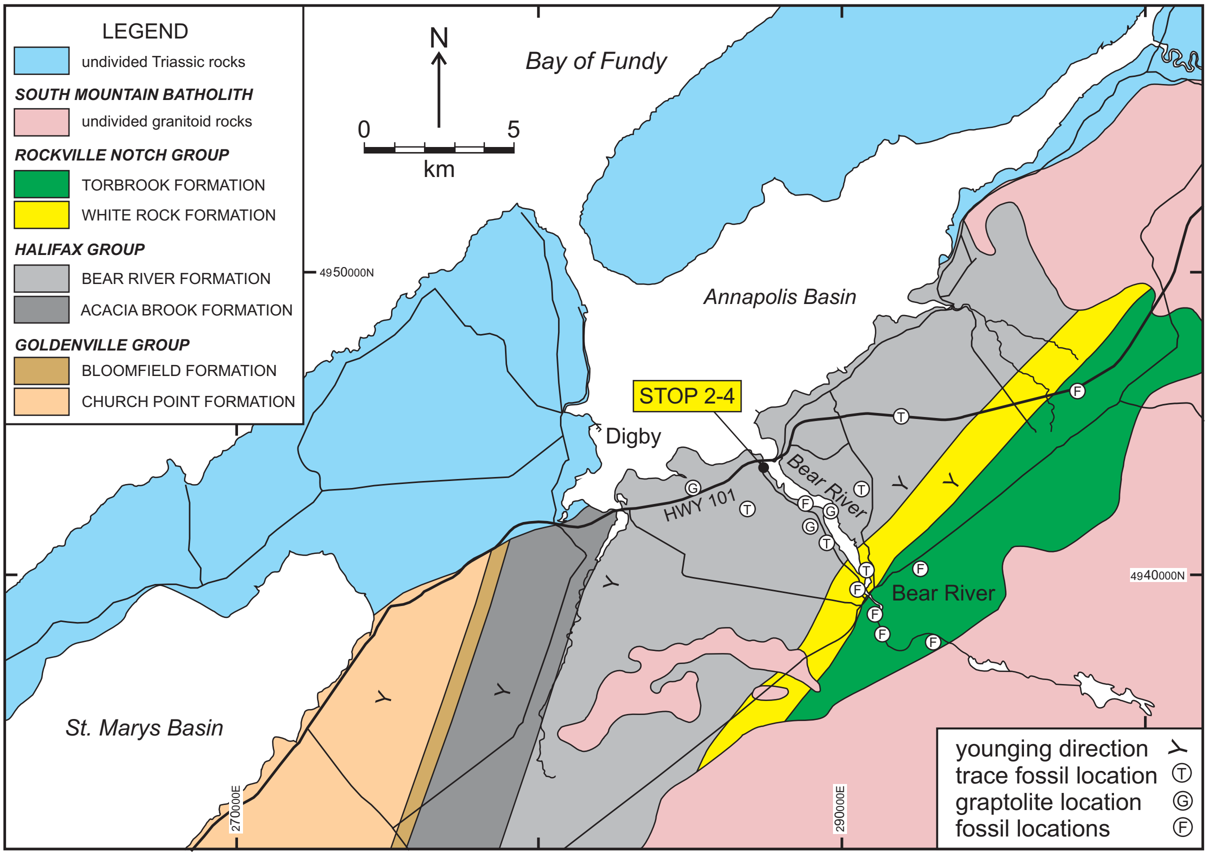

Fig. 9. Geological map of the Bear River area showing the location of stop 2-4. Map is modified from White et al. (1999) and White and Barr (2012).

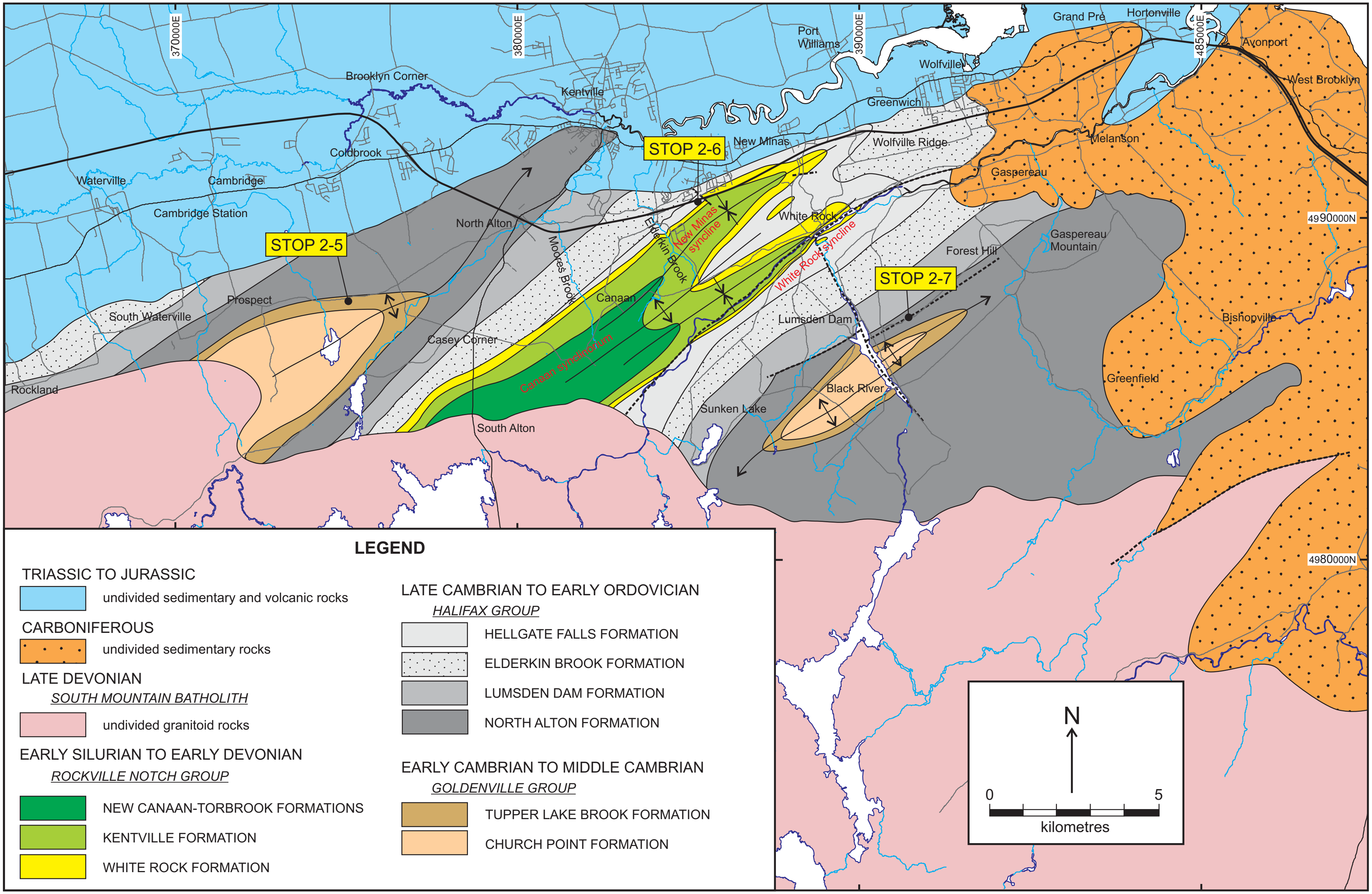

Fig. 10. Geological map of the Wolfville area showing more detail in the area of stops 2-5, 2-6, and 2-7. Map is modified from White and Barr (2012). Dashed lines are faults.

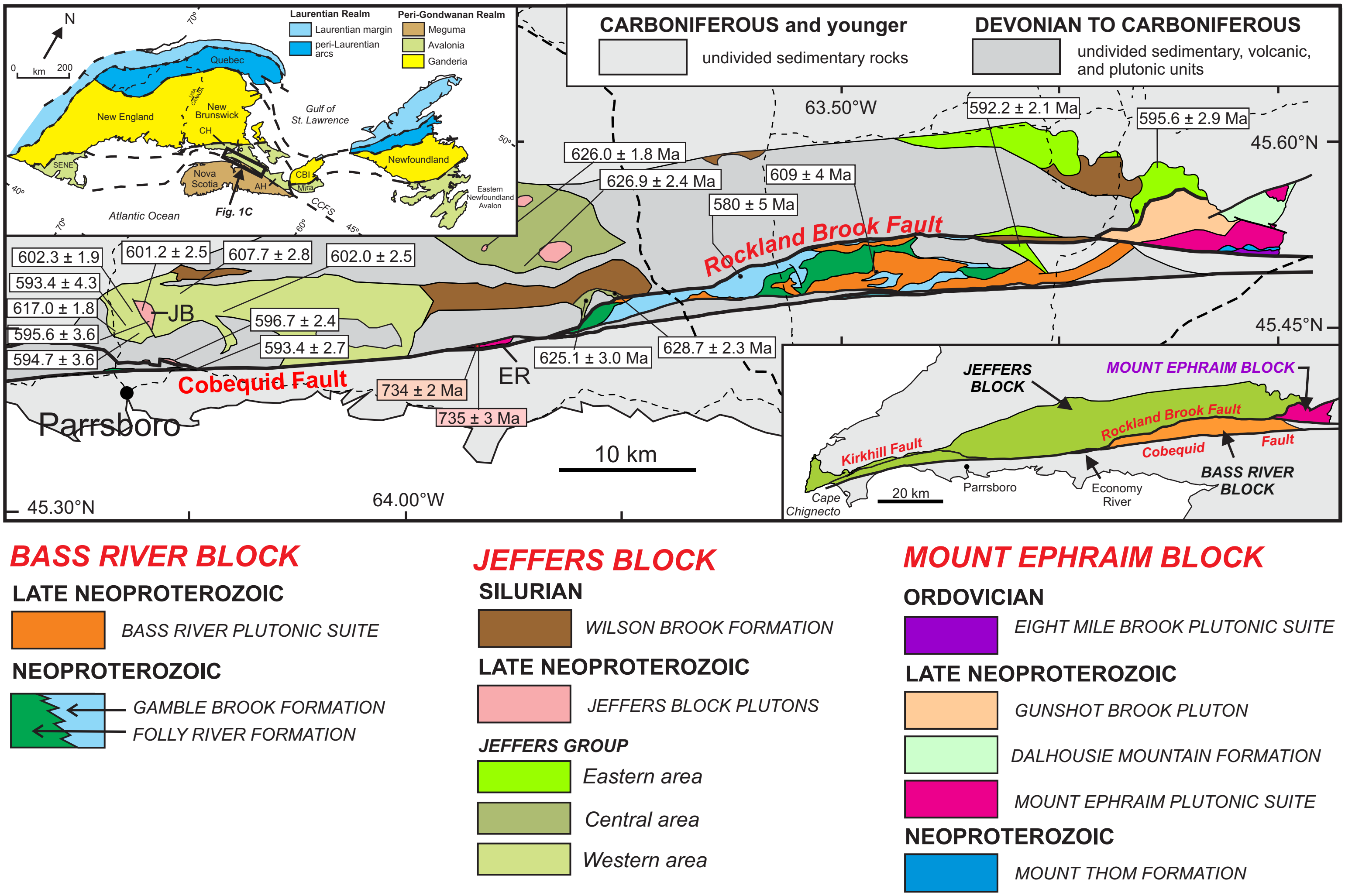

Fig. 11. Simplified geological map of the Cobequid Highlands of northern mainland Nova Scotia after White et al. (2022). The inset map on the upper left shows the location of the map area on a northern Appalachian realm and domain map after Hibbard et al. (2006). The inset map on the lower right shows the division of the Cobequid Highlands into Jeffers, Bass River, and Mount Ephraim blocks. U-Pb zircon ages are shown for units in the Jeffers block from White et al. (2022). Ages in the Economy River Gneiss (unit ER) are from Doig et al. (1991) and Henderson (2016). Ages in the Bass River and Mount Ephraim blocks are shown in Figures 12 and 13, respectively. JB is Jeffers Brook pluton.

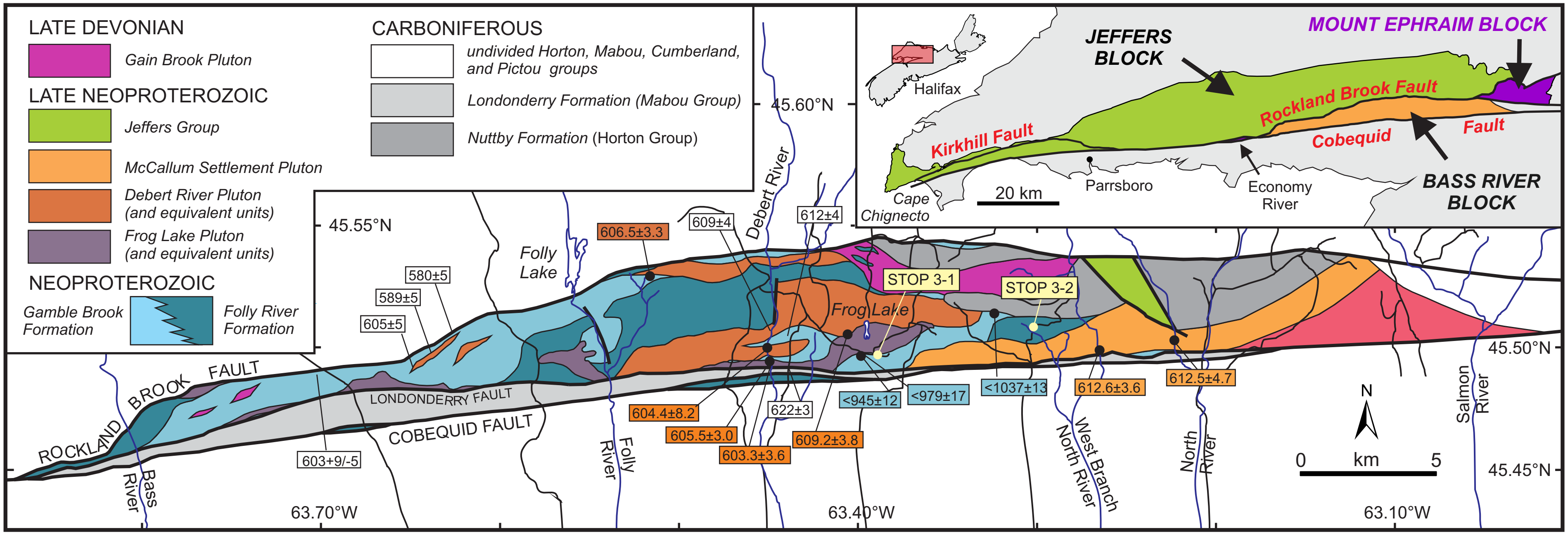

Fig. 12. Simplified geological map of the Bass River block modified from White et al. (2022) showing locations of stops 3-1 and 3-2. Also shown are ages and locations of dated samples in White et al. (2022). Orange boxes are plutonic samples and blue boxes are detrital zircon samples. Selected U-Pb dates from previous studies (Doig et al. 1991, 1993; Murphy et al. 1997) are shown in white boxes. Inset map on upper right shows the locations of the Bass River (orange), Jeffers (green), and Mount Ephraim (purple) blocks as defined by White et al. (2022).

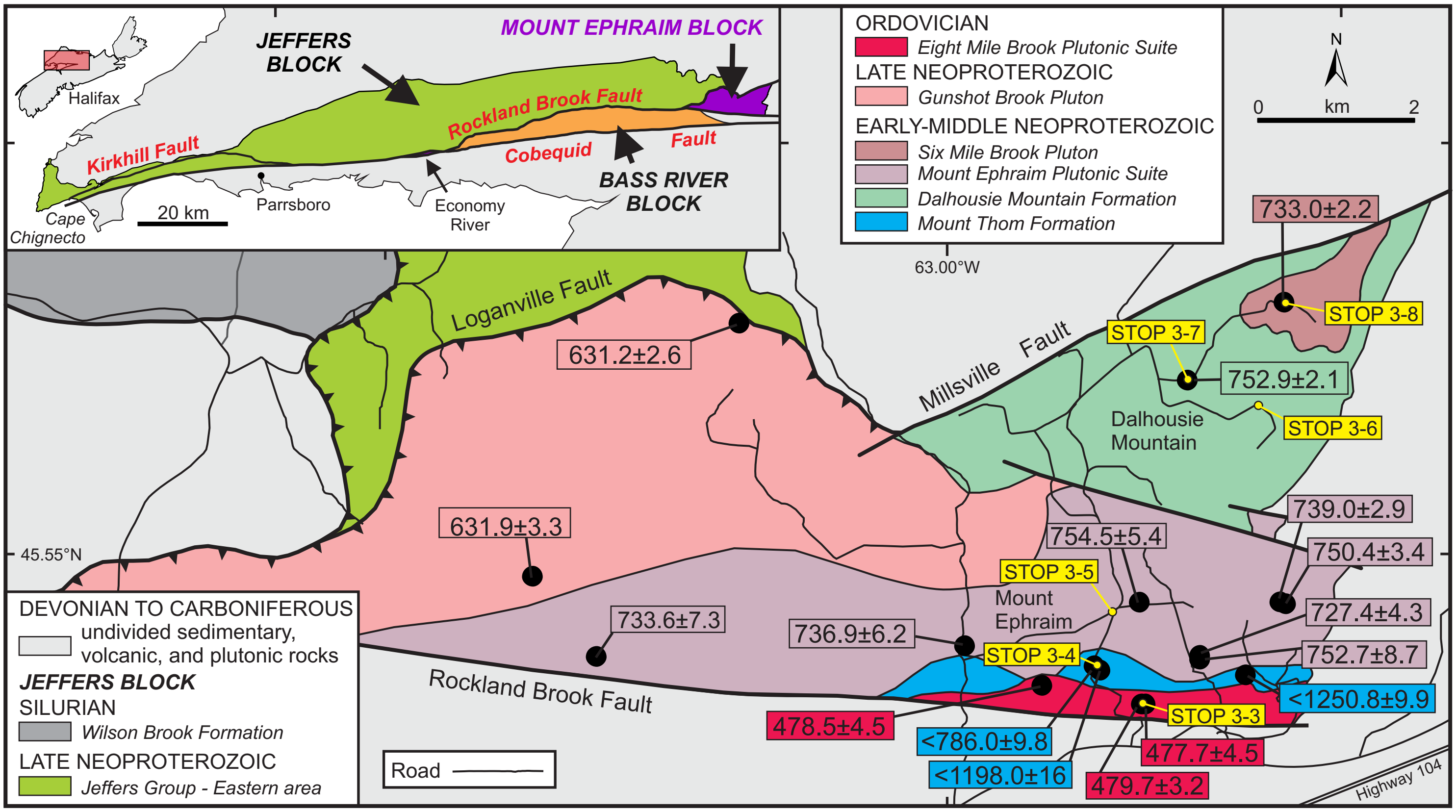

Fig. 13. Simplified geological map of the Mount Ephraim block modified after White et al. (2022) showing locations of stops 3-3, 3-4, 3-5, 3-6, 3-7, and 3-8. Also shown are ages and locations of dated samples from White et al. (2022). Inset map on upper left shows the locations of the Bass River (orange), Jeffers (green), and Mount Ephraim (purple) blocks as defined by White et al. (2022).

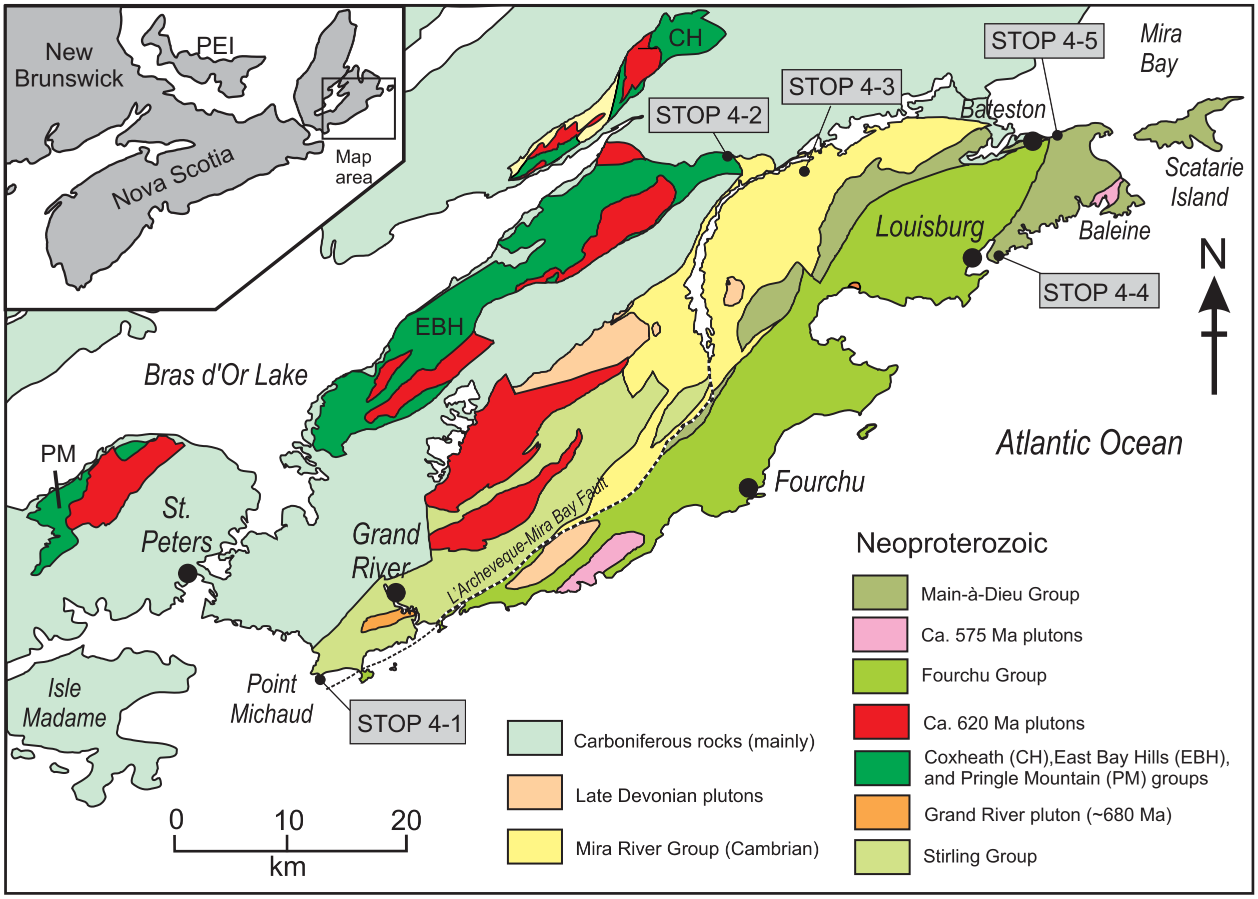

Fig. 14. Simplified geological map of the Avalonian Mira terrane of southeastern Cape Breton Island showing approximate locations of field trip stops on Day 4. Map is modified from Barr et al. (1996).

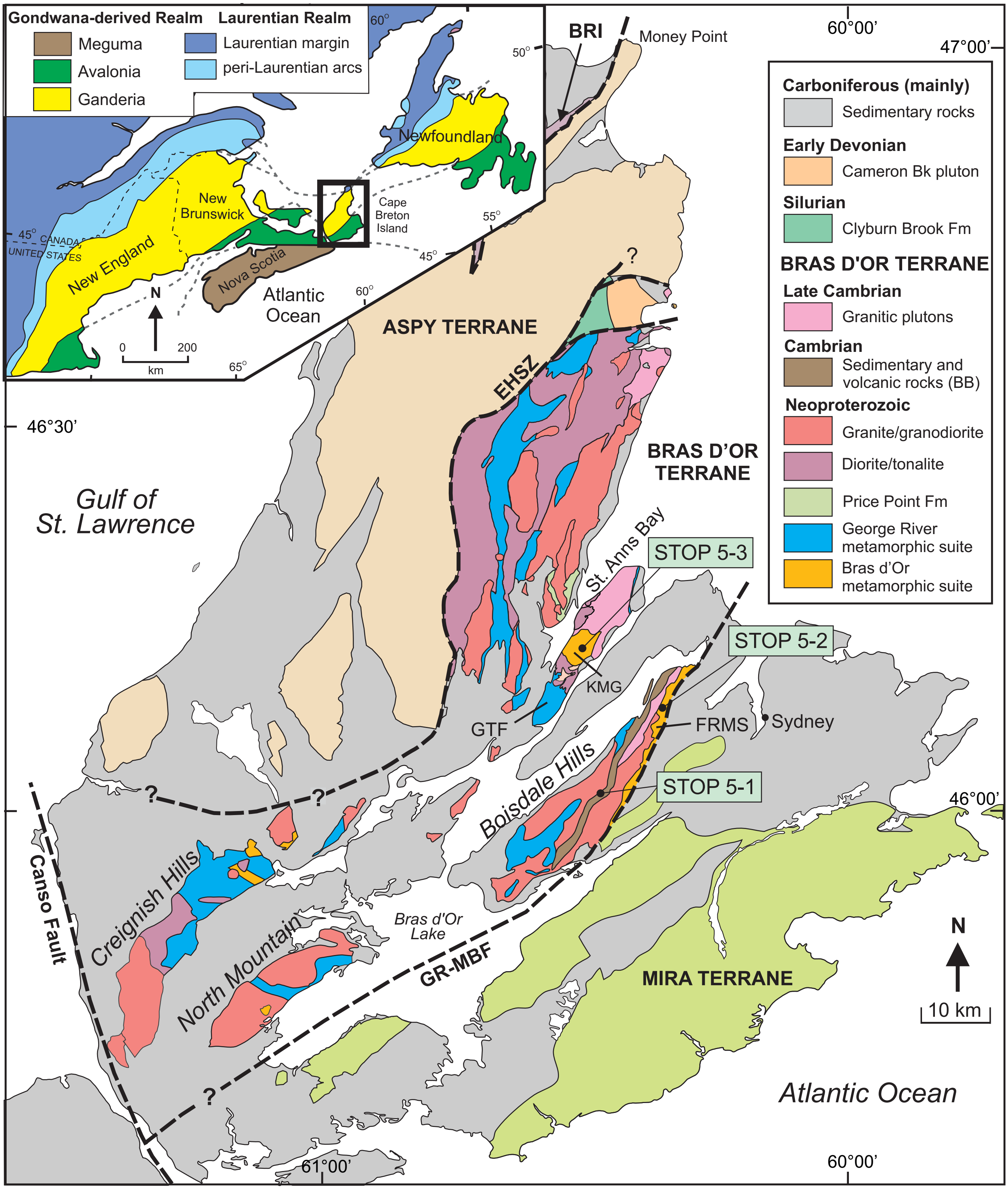

Fig. 15. Geological map of the Bras d'Or terrane after van Rooyen et al. (2019) showing the locations for stops on Day 5. Abbreviations: BB, Bourinot belt; EHSZ, Eastern Highlands Shear Zone; Fm, Formation; FRMS, Frenchvale Road metamorphic suite; GR-MBF, Georges River-MacIntosh Brook Fault; GTF, Glen Tosh Formation; KMG, Kellys Mountain Gneiss. Inset map shows terranes of the northern Appalachian orogen after Hibbard et al. (2006).

Notes