GAC
Newfoundland
and Labrador

GEOLOGICAL ASSOCIATION of CANADA
NEWFOUNDLAND and LABRADOR SECTION

2021 FALL FIELD TRIP
October 23

FROM THE ROOF TO THE BASEMENT: A TOUR OF STRUCTURES, SEDIMENTARY ROCKS AND EPITHERMAL SYSTEMS OF THE NORTHEASTERN AVALON

Greg Sparkes, Luke Beranek and Andrea Mills

GEOLOGICAL ASSOCIATION of CANADA
NEWFOUNDLAND and LABRADOR SECTION

FALL FIELD TRIP 2021

FROM THE ROOF TO THE BASEMENT: A TOUR OF STRUCTURES, SEDIMENTARY ROCKS AND EPITHERMAL SYSTEMS OF THE NORTHEASTERN AVALON

Greg Sparkes[1], Luke Beranek[2] and Andrea Mills[1]

[1]Geological Survey of Newfoundland and Labrador
Department of Industry, Energy and Technology
P.O. Box 8700, St. John’s, NL, A1B 4J6

[2]Department of Earth Sciences
Memorial University of Newfoundland and Labtador
St. John’s, NL, A1B 3X5

October 23, 2021

CONTENTS

FIGURES

FIGURES

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.

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.

SPECIFIC HAZARDS

Some stops on this field trip are in coastal localities. Access to the coastal sections normally requires short hikes, in some cases over rough, stony or wet terrain. There is a strong possibility that participants will get their feet wet, and we recommend waterproof footwear. We also recommend footwear that provides sturdy ankle support, as localities may also involve traversing across beach boulders or uneven rock surfaces. Coastal localities present some specific hazards, and participants MUST behave appropriately for the safety of all. Participants must stay clear of the cliff edges at all times, stay with the field trip group, and follow instructions from leaders. 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. 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. 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. Roadcut outcrops present hazards from loose material, and should be treated with the same caution as coastal cliffs. Other outcrops may be in disused quarries or excavations, or may require short hikes from roads across possibly uneven and/or wet terrain. Weather is unpredictable in this area and participants should be prepared for a wide range of temperatures and conditions. Always take suitable clothing. A rain suit, sweater, sturdy footwear are essential at almost any time of the year.

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. The trip visits some 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, the introductions for specific localities make note of specific safety concerns such as traffic, water, cliffs or lose ground. Field trip participants must read these cautions carefully and take appropriate precautions for their own safety and the safety of others.

INTRODUCTION

REGIONAL SETTING OF THE AVALON ZONE

The Avalon Peninsula is the type area for the microcontinent Avalonia, one of the peri-Gondwanan terranes accreted to the Laurentian margin by the latest Silurian as the result of closure of the Acadian seaway between composite Laurentia and Avalonia (*e.g.*, Wilson, 1966; Nance *et al.*, 2008; van Staal and Barr, 2012; Mills *et al.*, 2020). Avalonia is a collage of fault-bounded Neoproterozoic, partly juvenile arc-related volcano-sedimentary belts that underwent latest Neoproterozoic orogenesis and denudation, prior to deposition of an overstepping Cambrian–Ordovician platformal sedimentary succession (van Staal and Barr, 2012; Landing *et al.*, 2004). The Avalon terrane in Newfoundland extends offshore to the eastern edge of the continental margin (Haworth and Lefort, 1979; Miller and Singh, 1995; *see* also Lilly 1965; 1966), and is tectonically juxtaposed with Ganderia to the west and northwest by the Dover and Hermitage Bay fault zones, respectively (Figure 1) (Blackwood and Kennedy, 1975; O'Brien *et al.*, 1996).

Fragments of Avalonia occupy much of the eastern margin of the Appalachian–Cadomian orogeny and are interpreted to continue from the northeastern U.S. through Atlantic Canada (West Avalonia) and into Wales and southern England to Belgium and central Europe (East Avalonia) (Murphy *et al.*, 1999; van Staal *et al.*, 2020). Most areas designated as Avalonia consist of a collage of Neoproterozoic terranes having complex and differing tectonic settings and histories (van Staal *et al.*, 2020). They are linked by their similar lower Paleozoic cover rocks that comprise a shallow-marine platformal sequence comprising mainly fine-grained siliciclastic rocks having an Acado-Baltic faunal assemblage (Boyce, 1988; Myrow, 1995; Landing, 2004).

Several major tectonomagmatic events punctuate the Neoproterozoic evolution of Avalonia in Newfoundland (Figure 2). Tonian magmatic remnants are preserved in the ophiolitic Burin Group (*ca.* 760 Ma; Krogh *et al.*, 1988; Murphy *et al.*, 2008) and as the *ca.* 730 Ma Hawke Hills tuff (formerly the lowermost unit of the Harbour Main Group) of the central Avalon Peninsula (*see* Israel, 1998; O'Brien *et al.*, 2001). After an apparent 50 million year hiatus, Cryogenian magmatism occurred, including the 680–670 Ma calc-alkaline volcanic Tickle Point Formation and correlative plutonic rocks of the Furby's Cove Intrusive Suite on the Connaigre Peninsula (Swinden and Hunt, 1991; O'Brien *et al.*, 1996). Another hiatus of at least 30 million years occurred prior to the onset of the main Ediacaran-arc phase (*e.g.*, Murphy *et al.*, 1999), which is considered to be one of the hallmarks of Avalonia. Geochronology has bracketed the largest and probably longest-lasting arc-related magmatic event to between 640 and 565 Ma, and is interpreted as an Andean-style arc (Thompson, 1993; Barr and White, 1996; Barr *et al.*, 1998; Murphy *et al.*, 1999; Nance *et al.*, 2002; Thompson *et al.*, 2014) and arc-adjacent basins (Hughes and Brückner, 1971; van Staal *et al.*, 2020). This generalization should be viewed with caution because this event was short-lived in most parts of West Avalonia, and no one area preserves evidence that this event was in fact a continuum (van Staal *et al.*, 2020). Vestiges of the main Avalonian arc in Newfoundland include parts of the composite Harbour Main Group (*see* O'Brien *et al.*, 2001) and the Holyrood Intrusive Suite (*ca.* 630–620 Ma; Krogh *et al.*, 1988) on the Avalon Peninsula, parts of the former Love Cove Group (now the more spatially restricted Broad Island Group; Mills *et al.*, 2020) in the Eastport area (*see* also Dec *et al.*, 1992), the Simmons Brook Intrusive Suite and Connaigre Bay Group on Connaigre Peninsula (O'Brien *et al.*, 1995), and the Peter Brook granite (Sparkes and Dunning, 2014) on the south-

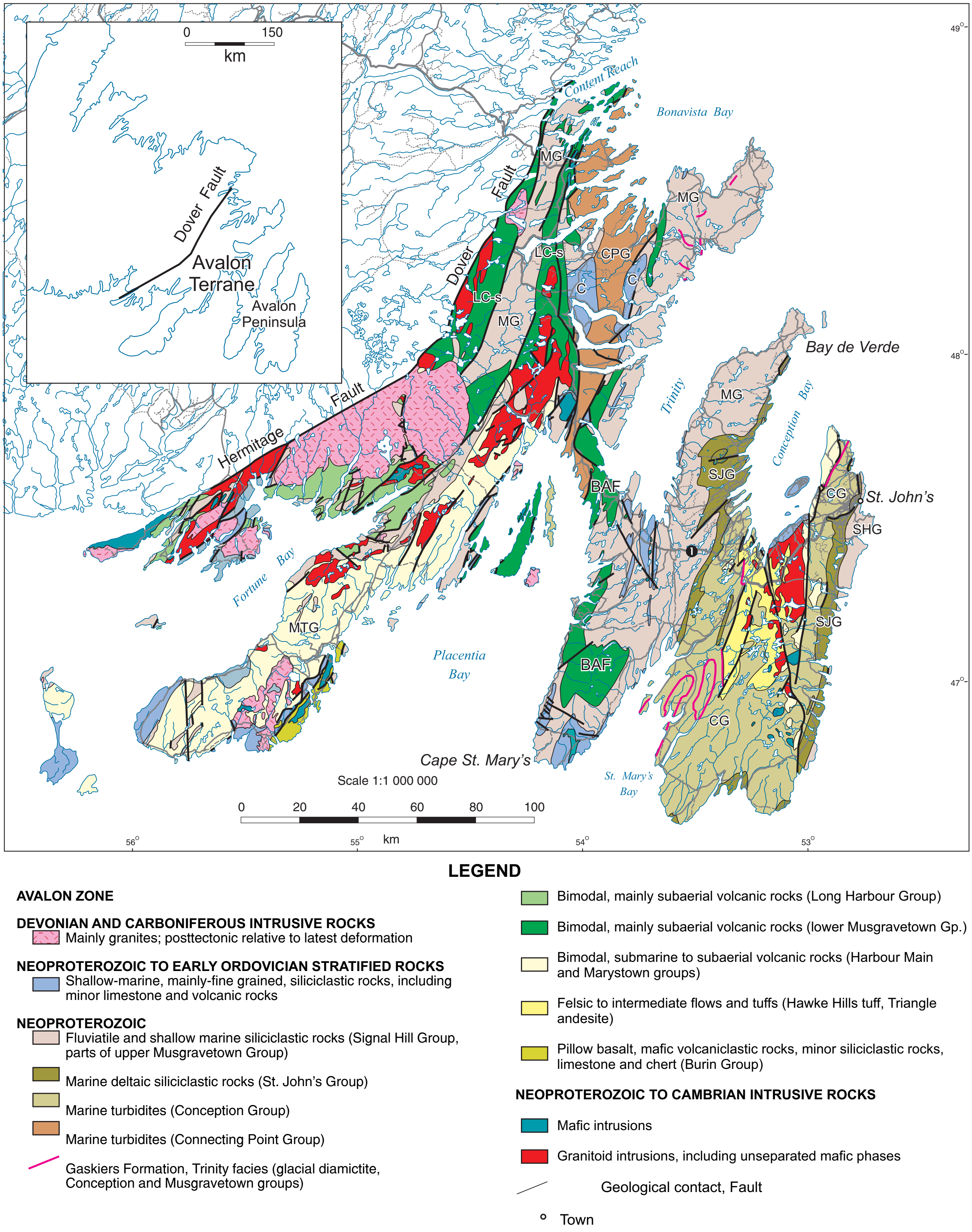


Figure 1. *Simplified geology map of the Avalon Terrane in Newfoundland (modified from King, 1988).*

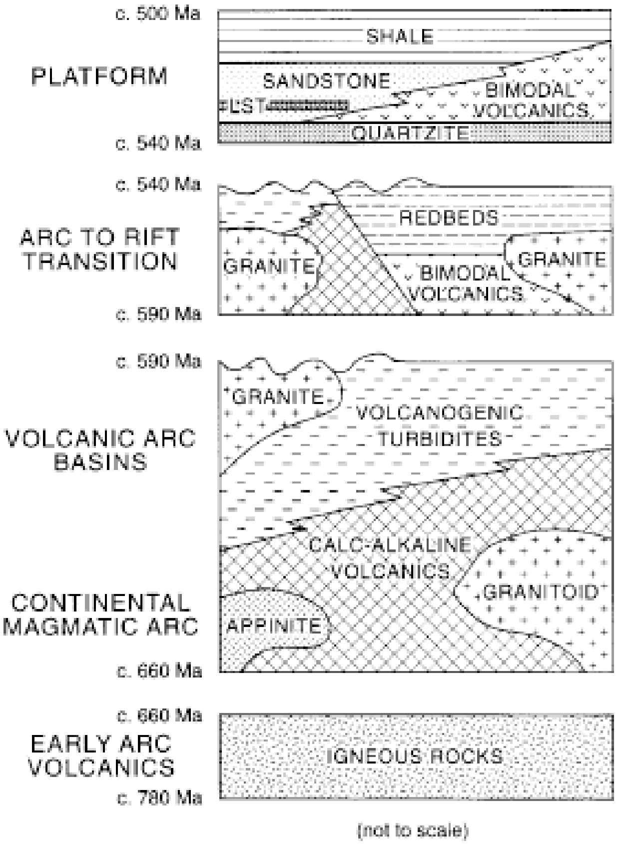


Figure 2. *Interpretive tectonostratigraphic column for the Neoproterozoic to Cambrian rocks of the Avalon Terrane in Newfoundland (from Murphy* et al.*, 1999).*

ern Burin Peninsula. Bimodal, alkaline magmatism followed at *ca.* 580 Ma in the Bonavista area (Mills and Sandeman, 2021), *ca.* 568–552 Ma (O'Brien *et al.*, 1995) on the Connaigre Peninsula (Long Harbour Group), and at *ca.* 569 Ma in the Eastport area (Mills *et al.*, 2020). Alkaline magmatism also occurs in the Conception Bay South area on the Avalon Peninsula (Colliers peninsula; Nixon and Papezik, 1979), and, dated at *ca.* 606 Ma (Krogh *et al.*, 1988), may be the oldest alkaline magmatism within the Avalon terrane of Newfoundland.

GEOLOGICAL SUMMARY OF THE AVALON PENINSULA

The east-central part of the Avalon Peninsula is cored by a broad, north-south elongated periclinal dome (Holyrood Horst) of late Neoproterozoic, primarily subaerial volcanic and plutonic rocks that have historically been assigned to the Harbour Main Group and Holyrood Intrusive Suite, respectively (King, 1988a, 1990; O'Brien and O'Driscoll, 1996; O'Brien *et al.*, 1997, 1998; *see* Figures 1 and 3). These low-grade rocks typically lack a penetrative deformation fabric, and have yielded a variety of late Neoproterozoic U–Pb zircon ages (Krogh *et al.*, 1988; Sparkes *et al.*, 2005), most of which fall between 640 and 580 Ma. This volcanoplutonic core contains outliers of marine siliciclastic rocks and is flanked by a younger, shoaling-upward succession of marine, deltaic and fluviatile siliciclastic rocks (Conception, St. John's and Signal Hill groups, respectively; *e.g.*, King, 1988), thought to be concentrically disposed around the older succession.

Locally, the base of the marine succession is unconformable on the earlier volcanoplutonic rocks. The estimated minimum total composite thickness of the stratified succession (Conception, St. John's and Signal Hill groups) is in the range of 7 to 10 km (*e.g.*, King 1988a). Tuff beds in the upper Conception Group (Mistaken Point Formation) have been dated at 565 Ma (Benus, 1988; Matthews *et al.*, 2020) and 566 Ma (Canfield *et al.*, 2020); the age of the base of this flanking marine succession is largely unconstrained, but predates deposition of glacial diamictite of the *ca.* 580 Ma Gaskiers Formation (lower Conception Group; *see* Pu *et al.*, 2016).

A shale-rich cover of early Cambrian to earliest Ordovician age lies with pronounced angular discordance on various levels of the folded and faulted Proterozoic succession (Hutchinson 1962). The lower Paleozoic paleontology has been reviewed by Hutchinson (1962), Bergstrom (1976), Anderson (1981), Bengston and Fletcher (1983), Ranger *et al.* (1984), Boyce (1988) and Landing (1996).

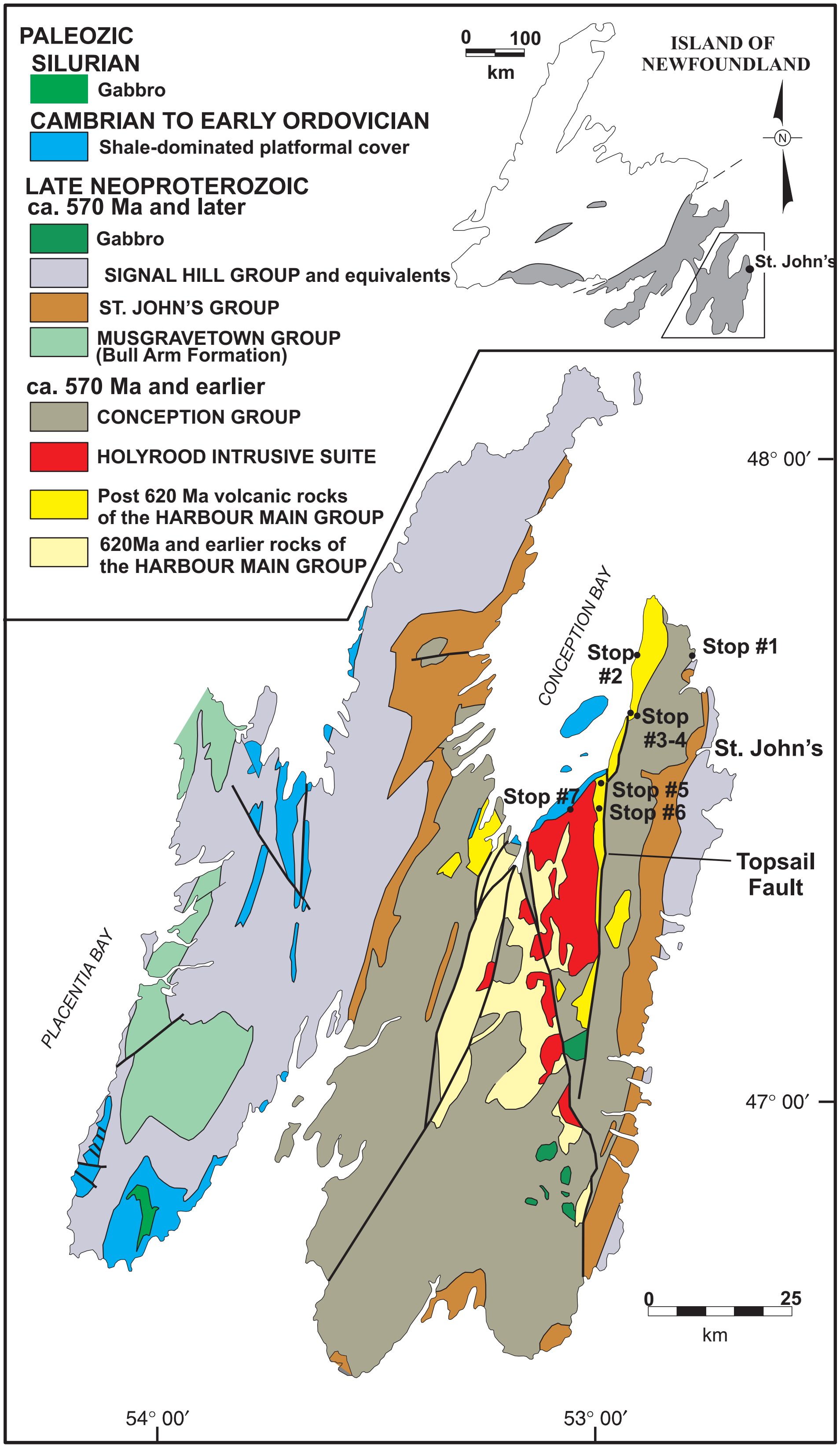


Figure 3. *Simplified geology map of the Avalon Peninsula (modified from King, 1988; from O'Brien* et al.*, 1996).*

Early Silurian mafic sills and related intrusions are emplaced into this Cambrian cover in the southwestern part of the Avalon Peninsula (Greenough *et al.*, 1993; *see* also Hodych and Buchan, 1998). Diabase of Mesozoic age (*ca.* 201 Ma; Hodych and Hyatsu, 1980) intruded the Proterozoic succession, and coincides with a 110-km-long magnetic lineament that trends northeasterly across the southeastern Avalon Peninsula (*see* also Papezik and Hodych, 1980). A regional magnetic high of similar orientation parallels the south shore of Conception Bay, locally coinciding with exposure of posttectonic diabase, possibly of similar age.

TRIP ITINERARY

This field trip will start out in some of the youngest units of the eastern Avalon Peninsula (Signal Hill Group; King, 1990) and as we make our way westward we gradually move down through the largely siliciclastic-dominated rocks of the region that lie east of the regionally extensive Topsail Fault (Stops 1-4). Then we move across the fault into the "basement" volcanic and plutonic rocks to examine the hydrothermal alteration and structures developed in the area west of the Topsail Fault (Stops 5-7).

FIELD TRIP STOPS

STOP 1: FLAT ROCK THRUST

Directions: *Leave St. John's* via *Route 20 (Torbay Bypass Road), continue past the exit for Route 21, and then turn right, taking the Torbay exit. Turn left at the sign for Flatrock, turning onto Windgap Road. Proceed along the road to the parking lot for St. Michael's Church; from here we will proceed on foot along the route highlighted in red.*

(The following is summarized from Calon 2005.)

This stop highlights the field relationships that define the east-vergent Flat Rock thrust and constrain the significance of late Ediacaran(?) crustal shortening, exhumation, and syn-tectonic deposition in the northeast Avalon Peninsula. The Flat Rock thrust at this stop is exposed in a steep cliff face at the mouth of Piccos Brook (Figure 4); excellent exposures of the fault are accessible by foot traverse along Piccos Brook immediately to the west. The Flat Rock thrust near Piccos Brook is a ~1 km-long, northeast-trending fault zone with roof and floor thrusts that are separated by a shale duplex. Conception Group (Torbay Member, lower Drook Formation) strata comprise the hangingwall of the fault and consist of interbedded, fine-grained sandstone and siltstone units that are the oldest exposed rocks in the Flatrock area. St. John's Group (Fermeuse Formation) strata in the shale duplex are penetratively deformed black shale units with cleavage steeper than the dips of enclosing roof and floor thrusts. Signal Hill Group strata (Piccos Brook Member, upper Flatrock Cove Formation) comprise the footwall and are characterized by red breccia and sandstone units of probable alluvial fan origin. Signal Hill Group strata adjacent to the shale duplex are altered grey-green and likely indicate fluid migration along the floor thrust.

The estimated throw on the Flat Rock thrust at this location is ~3500 m based on the interpreted stratigraphic offset between the Drook and Flatrock Cove formations (*see* Figure 5). Whereas the underlying parts of the Signal Hill Group in the Flatrock area (*e.g.*, Cuckold Formation) show evidence for the exhumation of felsic igneous rocks and Avalonian arc infrastructure, red breccia and sandstone units of the Piccos Brook Member contain fine-grained, sedimentary lithic fragments and probably demonstrate provenance from uplifted Conception Group strata in the hangingwall. The Piccos Brook Member was likely a syntectonic unit in the foreland of the east-vergent thrust system and eventually imbricated and overridden by advancing thrust sheets. At Red Head, ~1 km north of this stop, folded Conception Group strata are unconformably overlain by Piccos Brook Member breccia units (Lilly unconformity; Anderson *et al.*, 1975). These relationships indicate that uppermost Piccos Brook Member deposition post-dates the timing of thrust-related deformation.

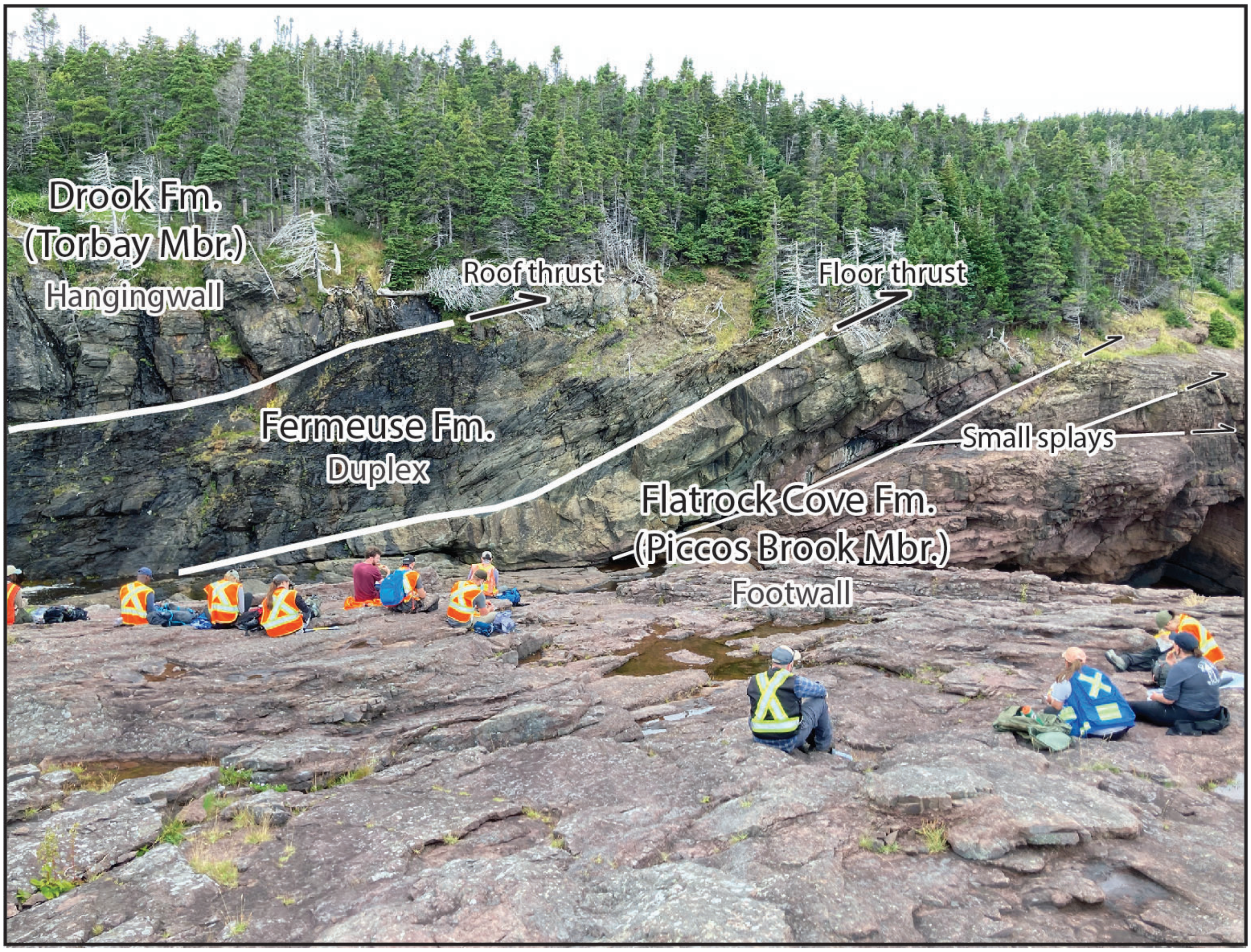


Figure 4. *North-facing view of Flat Rock thrust zone exposed in cliffside at the mouth of Piccos Brook. At this stop, the fault zone consists of east-vergent roof and floor thrusts that are separated by a shale duplex. Left side of photo: Hangingwall strata of the Conception Group (Torbay Member, Drook Formation) overlie penetratively deformed Fermeuse Formation rocks in the shale duplex. Right side of photo: Footwall strata of the Signal Hill Group (Piccos Brook Member, Flatrock Cove Formation) are beneath the floor thrust and cut by small splays. Signal Hill Group strata adjacent to the shale duplex are altered grey-green and likely indicate fluid migration along the floor thrust.*

The absolute ages of the Flat Rock thrust, potentially equivalent east-vergent deformation features (*e.g.*, Red Head Cove fault, Blackhead syncline, Bay Bulls syncline, Knobby Hill anticline and syncline), and deposition of syntectonic sedimentary successions in northeastern Avalon are uncertain, but generally assigned to the late Ediacaran "Avalonian orogeny". For example, Calon (2005) summarized the significance of Flatrock Cove Formation growth strata and their relationship to the rise of the Knobby Hill anticline south of Flatrock. The timing of the Flat Rock thrust must postdate the deposition of the Drook Formation in the hangingwall (570 Ma in southern Avalon, Pu *et al.*, 2016). The youngest detrital zircon grains in Piccos Brook Member (*e.g.*, Langor 2017) and underlying Signal Hill Group strata near Flatrock are *ca.* 565 Ma (Hutter and Beranek, 2017), but likely overestimate the true depositional age of syntectonic sedimentation.

Geology of the Flat Rock Area

Tom Calon, Trevor Rice, Bradley Evans, Jason Flight

Department of Earth Sciences, Memorial University of Newfoundland

Flat Rock Cove Lithostratigraphy

Group	Formation	Member	Lithology	
Signal Hill	Flat Rock Cove	Piccos Brook	red mudstone, cross-bedded sandstone and (laminated) breccia; coarsening upwards into massive breccia; unconformable succession	
		Knobby Hill	grey thick-bedded arkosic cross-bedded sandstone and pebble to cobble conglomerate consisting of five northeastward thickening unconformable sequences KA-KE	
	Cuckold	Skerries Bight	red sandstone and pebble conglomerate	*Wind Gap Unconformity*
		Cape Spear M	pebble to cobble conglomerate with exotic marker (M) of rhyolite and quartz-sericite schist clasts, subordinate coarse sandstone	four unconformable sequences of conglomerate and sandstone; may correlate with Blackhead Formation Sequences CA-CD
		Cabot Tower	coarse-grained, yellow-red sandstone, coarsening upwards to pebble conglomerate	
	Quidi Vidi		medium-grained red sandstone, sub-ordinate mudstone and mud-flake breccia	
	Gibbett Hill		fine to medium-grained green tuffaceous sandstone, laminated siltstone, and shale	
St. John's	Renews Head		dark grey shale, siltstone and fine-grained sandstone with two marker units of white/tan cross-laminated sandstone	
	Fermeuse		thin-bedded grey to black shale, subordinate sandstone, penetratively cleaved	
Conception	Drook	Mannings Hill	medium- to thick-bedded siliceous shale, siltstone, and laminated and massive (arkosic) sandstone	
		Bauline Line	mixtite; thick massive beds with clasts (rhyolite) up to 20 cm in unsorted siliceous matrix; packages of massive and laminated arkosic sandstone; interlayered with the top of the Torbay Member	
		Torbay	fine-grained thinly laminated green to grey siliceous sandstone and siltstone with minor tuff	

Symbols

bedding (normal/top undetermined, overturned, vertical)

cleavage
minor fold
mineral lineation

marker units in Renews Head Formation
veins, subvertical

Wind Gap Unconformity
observed/inferred contacts
faults
Flat Rock Thrust (teeth in HW)
anticline, locally overturned
syncline

roads & Trails
Piccos Brook
103.2 elevation of ponds (in m asl.)
x critical outcrops for contacts

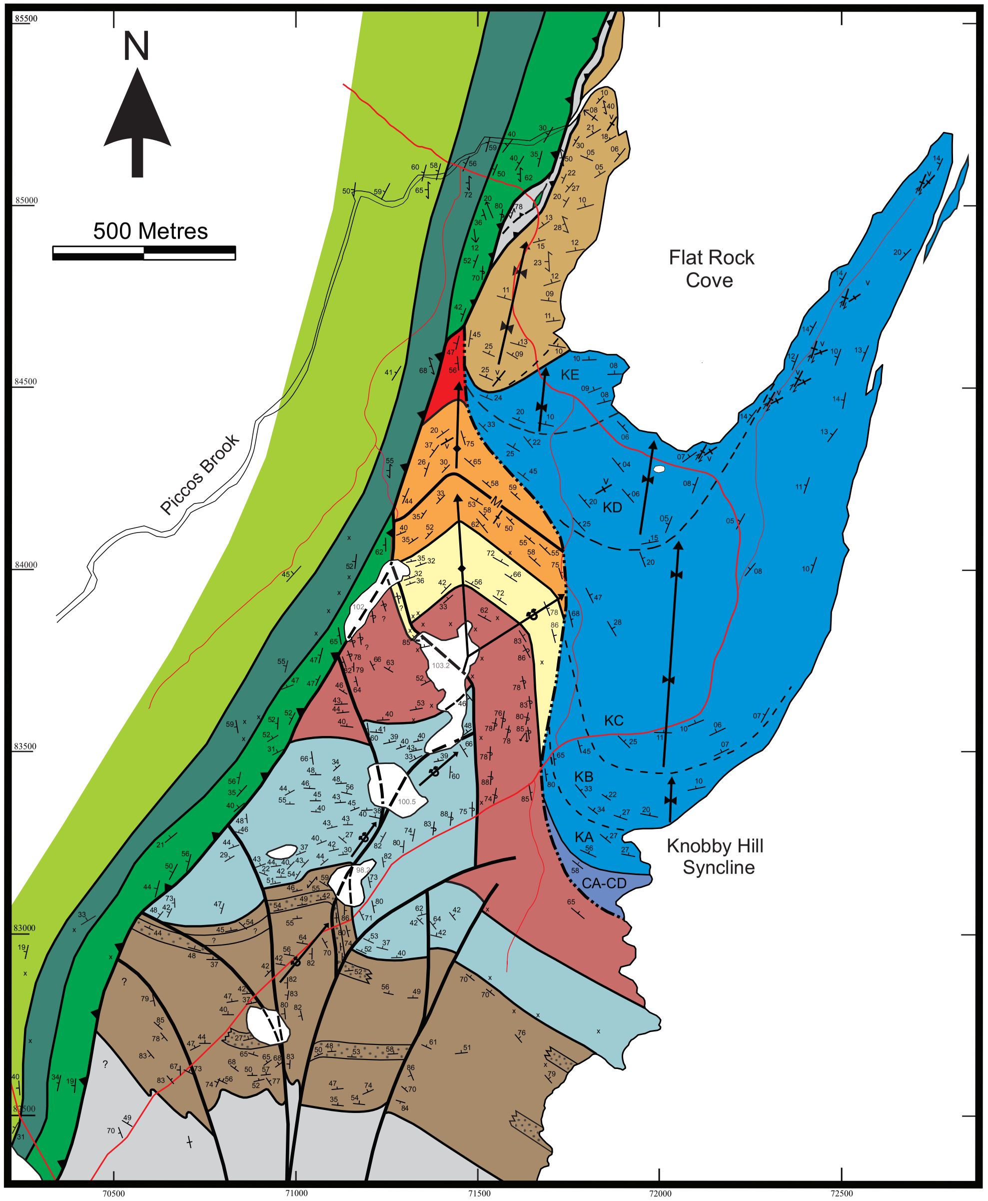


Figure 5. *Geology map and legend of the Flatrock area (from T. Calon and students).*

STOP 2: BAULINE – HORSE COVE COMPLEX

***Directions:** Leave the church parking lot by turning left onto Windgap Road. Proceed to the intersection with Route 20 (Torbay Bypass Road), and turn left at the intersection. Proceed along Route 20 to the intersection with Route 21 (Bauline Line), turning right at the intersection. Proceed along Route 21 to the town of Bauline; continue on to the waterfront, and turn left onto the road just before the wharf to get to the parking area.*

This stop highlights the variably developed high-strain zone occurring along the trace of the regional-scale Topsail Fault that is exposed intermittently along the eastern coastline of Conception Bay. This zone, referred to as the Horse Cove Complex (Figure 6; G.W. Sparkes, 2006; St. Phillips Formation of King 1990; *see* also Skipton *et al.*, 2013) is host to a prominent swarm of mafic and felsic dykes, hosted within submarine volcaniclastic and mafic volcanic rocks, and lesser diorite and granodiorite along the eastern coastline of Conception Bay.

(The following is summarized from Skipton 2011.)

This stop highlights the mafic- to felsic-dyke swarm within the Horse Cove Complex; detailed mapping has identified eight dyke units, ranging from mafic-to-felsic in composition. Magmatism within the area is been bracketed between 580.6 ± 2.0 Ma (feldspar porphyry dyke) to 578.4 ± 2.3 Ma (andesite dyke); indicating magmatic activity occurred over a maximum period of 6.5 million years. Dating of the granodiorite host rock yielded an age of 625 ± 1.4 Ma, indicating a potential correlation with the regionally extensive Holyrood Intrusive Suite farther to the southwest (*see* Stop #7).

Based on lithogeochemistry, the feldspar porphyry and rhyolite dykes are of volcanic arc affinity, whereas the mafic to intermediate dykes comprise calc-alkaline and tholeiitic rocks having compositions that range from OIB-like to E-MORB-like, to LREE-enriched, subduction-related calc-alkaline basalt and andesite.

A northeast-southwest striking, west dipping, cleavage is prominent at this stop, and is generally more pronounced towards the west. Localized zones of shearing are noted (2–5 m in width), some of which contain attenuated blocks of granodiorite within strongly sheared mafic-to intermediate rocks. Local, meter-scale, dextral offsets of some dykes are also noted.

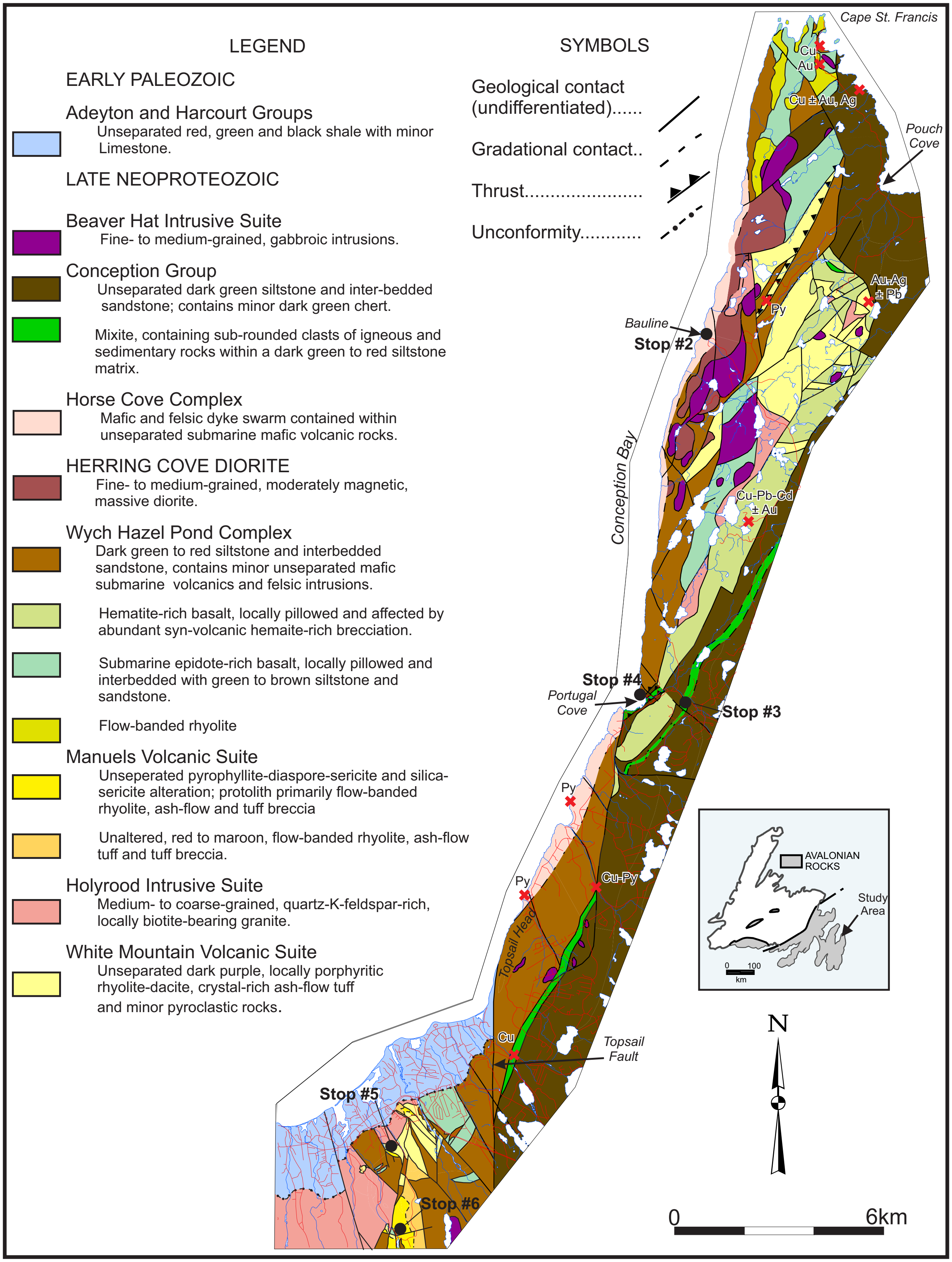


Figure 6. *Regional geology map of the eastern coast of Conception Bay (modified from Sparkes, 2006; modified in part from Hsu, 1976 and King, 1990.*

STOP 3: DIAMICTITE (BAULINE LINE MEMBER; OR POSSIBLE GASKIERS EQUIVALENT)

Directions: *Leave Bauline and proceed back along Route 21 to the intersection with the Bauline Line Extension, turning right at the intersection. Continue on to the intersection with route 40 (Portugal Cove Road), turning right at the intersection, and proceed to the parking lot of the Whale's Back Convenience (located on the right). From here we will proceed on foot to the outcrop down the road.*

This will be a short stop to investigate the matrix-supported conglomerate of the Bauline Line Member of the Drook Formation (King 1990). The matrix of the rock is dark green-grey and appears structureless, or massive, at this location. The rock is commonly described as a mixtite (King, 1990), owing to the mixture of its constituent materials, which range from mud/clay and silt/sand in the matrix, but also includes pebbles, cobbles and boulders. The larger clasts range from subangular to rounded and include common volcanic and plutonic clasts that are extra-basinal with respect to the Conception Group. This distinctive regional marker unit was assigned to the Drook Formation (mid-Conception Group), but may be correlative to the Gaskiers Formation (lower Conception Group; Williams and King, 1979). Rocks of the Gaskiers Formation were first described by Brückner (1969), who speculated that these mixed rocks may be ancient 'tillites' of glacial origin. Brückner and Anderson (1971) documented the presence of glacial striae on the surfaces of clasts from the Gaskiers Formation, confirming Brückner's (1969) suggestion that these rocks are indeed glacial products. Gravenor (1980) reported chatter marks on garnets isolated from rocks of the Gaskiers Formation, further substantiating the influence of glaciers. Age dating by U–Pb geochronology (zircon) has constrained the timing of deposition of both the Gaskiers Formation at its type locality and the correlative Trinity facies on Bonavista Peninsula to *ca.* 580 Ma (Pu *et al.*, 2016). Other possible correlatives occur sporadically across the Avalon terrane in Newfoundland, and, in addition to the Gaskiers Formation on southeastern Avalon Peninsula (Williams and King, 1979; King, 1990) and the Trinity facies of the Musgravetown Group on Bonavista Peninsula (Normore, 2011; Pu *et al.*, 2016), also include diamictite of the Big Head Formation (Musgravetown Group) on southwestern Avalon Peninsula (Brückner, 1977; Mills and Sandeman, 2021), and submarine outcrops on the Virgin Rocks Shoal located ~200 km southeast of St. John's (Lilly, 1965, 1966). Although thought to be of shorter duration than the preceding Sturtian and Marinoan glacial events (Hofmann and Li, 2009), Ediacaran glaciation (*ca.* 635–541 Ma) has now been reported from many ancient landmasses including Amazonia, Australia, Baltica, Laurentia, North China and Tarim cratons (Le Heron *et al.*, 2019) and is recognized as a significant global event in Earth's history.

STOP 4: PORTUGAL COVE THRUST

Directions: *From Stop #3, proceed along Portugal Cove Road to the ferry terminal (turn right when leaving the store parking lot). Turn right onto Ferry Terminal Road, keeping to the extreme right-hand lane and continue on to the breakwater to park.*

(The following is summarized from Calon, 1993.)

- Topsail Fault passes under the waters of the bay to the west, separating the late Precambrian rocks from the Cambro-Ordovician successions of sandstone, shale and iron formation at Topsail, 10 km south of here.

- Miller (1983) interpreted the Topsail Fault as a high-angle, normal fault, with an estimated downthrow of the western block in the order of 7–10 km.

- This area is interpreted by Calon (1993) to occur along a high-angle reverse fault, and includes imbricated and folded siliciclastic sediments. Evidence of reverse motion comes from slickenlines, the vergence and asymmetry of the fold geometry, cleavage, etc.

- On the opposite side of the cove, the Dogberry Hill fault structurally juxtaposes the diamictite (Stop #3) with the Horse Cove Complex (Stop #2).

- The cliff face north of Portugal Cove provides a section through a small imbricate stack of thrust sheets containing a turbiditic sequence of siliceous sandstones and interbedded shales with minor mafic ash beds, locally intruded by mafic dykes (Figure 7A, B).

- The interbedded red siltstone and grey sandstone here contains local outsized clasts, many of which are felsic, and, less commonly, mafic volcanic rocks and, like clasts of the diamictite at Stop 3, are considered extra-basinal with respect to the Conception Group.

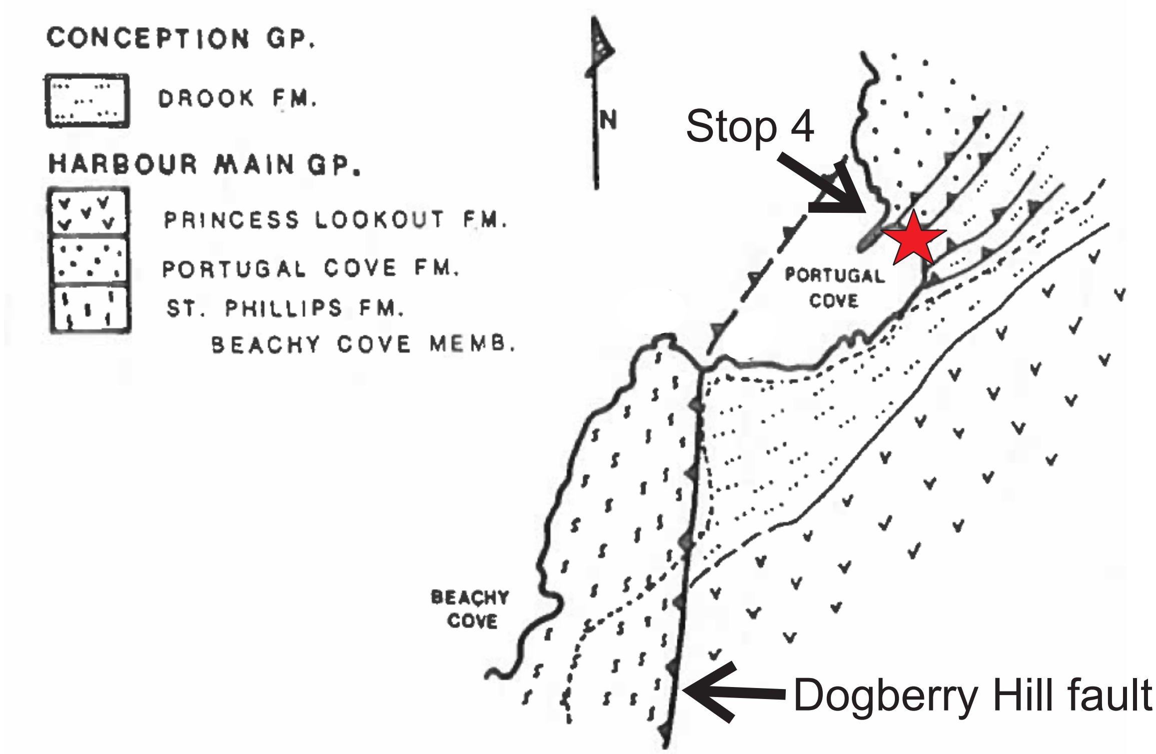


Figure 7A. *Schematic geological map of the Portugal Cove area showing main stratigraphic and structural relationships (after Calon, 1993).*

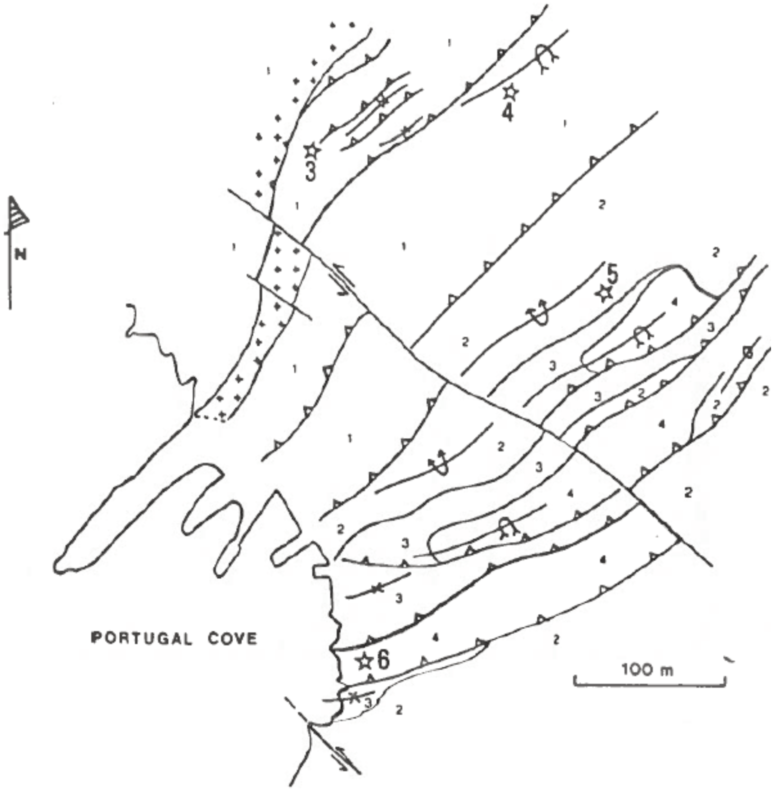


Figure 7B. *Geological map of the area around the town of Portugal Cove. Symbols: 1 – Portugal Cove Formation; 2 – Green siltstone–sandstone unit; 3 – Red sandstone unit; 4 – Mixtite; +++ = gabbro dyke. Units 2–4 form the basal part of the Conception Group (after Calon, 1993).*

STOP 5: STEEP NAP ROAD PROSPECT: Au–Ag-BEARING, LOW-SULPHIDATION-STYLE VEINS AND BRECCIAS

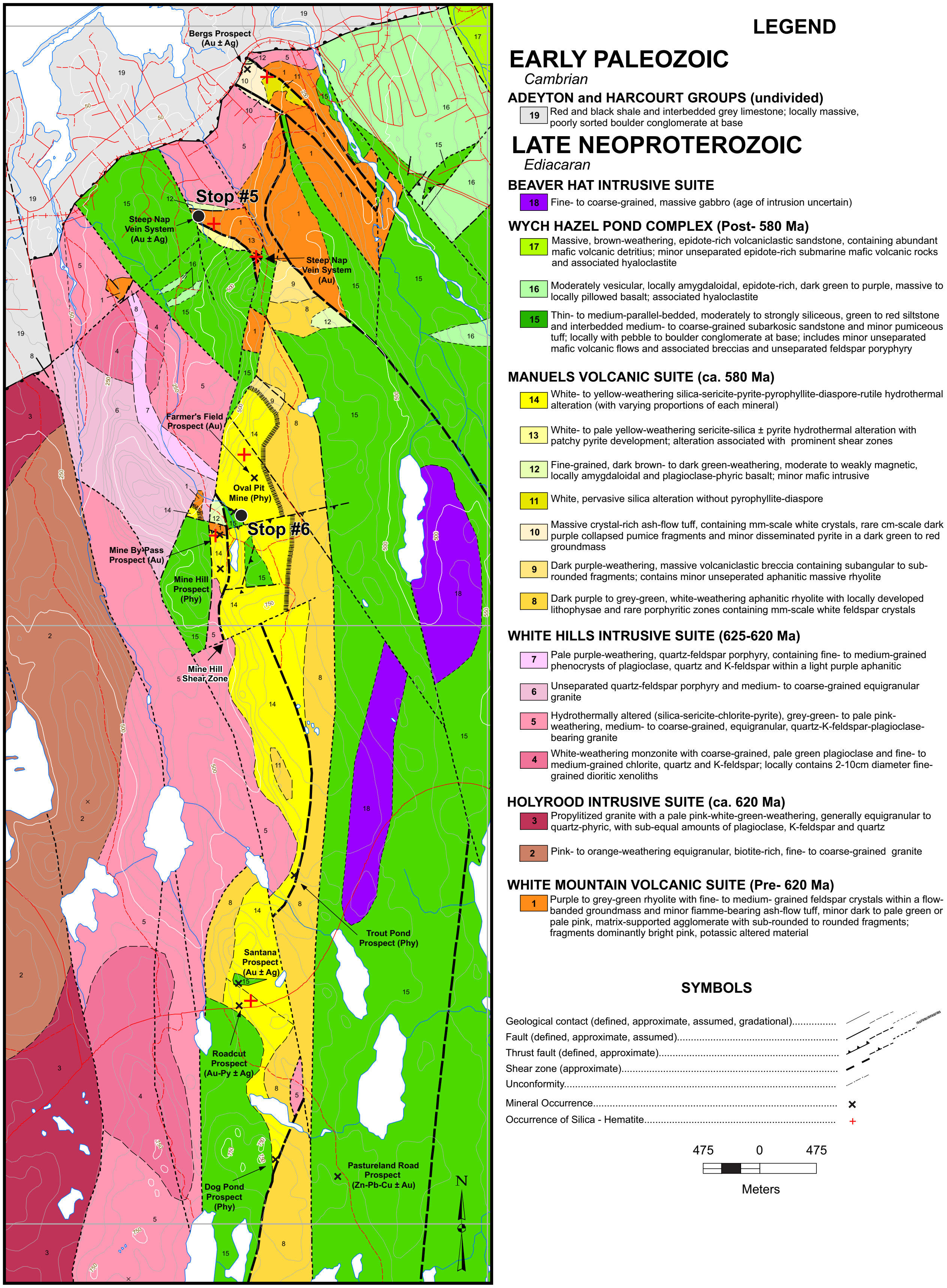
***Directions:** Leave the ferry terminal and turn right onto Portugal Cove Road. Continue along Route 41 to the intersection with Route 50 (St. Thomas Line), turning right at the intersection onto St. Thomas Line. Continue along St. Thomas Line to the intersection with route 60 (Topsail Road), turning right at the intersection. Proceed along Topsail Road, turning right onto the Conception Bay highway. Proceed along the Conception Bay highway, past the Dominion, turning left at CBS Vinyl Windows and Doors, onto Anchorage Road. Continue driving until you have passed under the Conception Bay Bypass and turn left at the intersection onto Chute Place; the stop is located on your right.*

(The following is modified from O'Brien *et al.*, 2012)

The blasted outcrop on the south side of the road forms part of the Steep Nap prospect. Discovered in 1995, the prospect consists of gold-bearing hydrothermal quartz–hematite–adularia veins in pyroclastic and hydrothermal breccias (O'Brien *et al.*, 1998; Mills *et al.*, 1999). The veins in this exposure have many of the characteristics of low-sulphidation (adularia–sericite) epithermal gold mineralization: *e.g.*, adularia- and chalcedony-bearing; crustiform and colloform textures; low silver/gold ratio (generally <10/1); chalcedonic recrystallization and carbonate replacement textures.

We are located about 3 km to the north of the Oval Pit pyrophyllite mine (*see* Stop #6), and about 1.25 km SSW of the Berg's prospect (Figure 8). The largest veins in this outcrop have returned assays of 3.3 g/t Au and 20 g/t Ag (Mills *et al.*, 1999). This 60 m long outcrop of felsic pyroclastic rocks contains at least 100 veins, ranging in size from 1 mm up to 1.7 m; most are less than 2 cm wide. Several types of breccia are also exposed. The main auriferous material forms a 1.7 m wide composite vein composed of crustiform bands of adularia–quartz–chalcedony and minor hematite. Very little sulfide mineralization is present in any of the veins. The largest auriferous veins have been traced along strike for more than 550 m. Samples collected from trenches excavated by Rubicon Minerals Corporation have locally assayed up to 9.23 g/t Au (B.A. Sparkes, 2003).

Sericite, chlorite, and hematite are the main wall-rock alteration phases; there is also evidence of some potassic and silica alteration. Most (although not necessarily all) of the more intense sericite alteration is post-veining, and related to brittle deformation. Less intense but more pervasive sericite alteration is present in the northern half of the outcrop. Chlorite alteration is mainly confined to thin halos around preveining fractures and veinlets. A more extensive area of chloritic alteration (*ca.* 2 m wide) is developed



LEGEND

EARLY PALEOZOIC

Cambrian

ADEYTON and HARCOURT GROUPS (undivided)

19	Red and black shale and interbedded grey limestone; locally massive, poorly sorted boulder conglomerate at base

LATE NEOPROTEROZOIC

Ediacaran

BEAVER HAT INTRUSIVE SUITE

18	Fine- to coarse-grained, massive gabbro (age of intrusion uncertain)

WYCH HAZEL POND COMPLEX (Post- 580 Ma)

17	Massive, brown-weathering, epidote-rich volcaniclastic sandstone, containing abundant mafic volcanic detritius; minor unseparated epidote-rich submarine mafic volcanic rocks and associated hyaloclastite
16	Moderately vesicular, locally amygdaloidal, epidote-rich, dark green to purple, massive to locally pillowed basalt; associated hyaloclastite
15	Thin- to medium-parallel-bedded, moderately to strongly siliceous, green to red siltstone and interbedded medium- to coarse-grained subarkosic sandstone and minor pumiceous tuff; locally with pebble to boulder conglomerate at base; includes minor unseparated mafic volcanic flows and associated breccias and unseparated feldspar poryphyry

MANUELS VOLCANIC SUITE (ca. 580 Ma)

14	White- to yellow-weathering silica-sericite-pyrite-pyrophyllite-diaspore-rutile hydrothermal alteration (with varying proportions of each mineral)
13	White- to pale yellow-weathering sericite-silica ± pyrite hydrothermal alteration with patchy pyrite development; alteration associated with prominent shear zones
12	Fine-grained, dark brown- to dark green-weathering, moderate to weakly magnetic, locally amygdaloidal and plagioclase-phyric basalt; minor mafic intrusive
11	White, pervasive silica alteration without pyrophyllite-diaspore
10	Massive crystal-rich ash-flow tuff, containing mm-scale white crystals, rare cm-scale dark purple collapsed pumice fragments and minor disseminated pyrite in a dark green to red groundmass
9	Dark purple-weathering, massive volcaniclastic breccia containing subangular to sub-rounded fragments; contains minor unseperated aphanitic massive rhyolite
8	Dark purple to grey-green, white-weathering aphanitic rhyolite with locally developed lithophysae and rare porphyritic zones containing mm-scale white feldspar crystals

WHITE HILLS INTRUSIVE SUITE (625-620 Ma)

7	Pale purple-weathering, quartz-feldspar porphyry, containing fine- to medium-grained phenocrysts of plagioclase, quartz and K-feldspar within a light purple aphanitic
6	Unseparated quartz-feldspar porphyry and medium- to coarse-grained equigranular granite
5	Hydrothermally altered (silica-sericite-chlorite-pyrite), grey-green- to pale pink-weathering, medium- to coarse-grained, equigranular, quartz-K-feldspar-plagioclase-bearing granite
4	White-weathering monzonite with coarse-grained, pale green plagioclase and fine- to medium-grained chlorite, quartz and K-feldspar; locally contains 2-10cm diameter fine-grained dioritic xenoliths

HOLYROOD INTRUSIVE SUITE (ca. 620 Ma)

3	Propylitized granite with a pale pink-white-green-weathering, generally equigranular to quartz-phyric, with sub-equal amounts of plagioclase, K-feldspar and quartz
2	Pink- to orange-weathering equigranular, biotite-rich, fine- to coarse-grained granite

WHITE MOUNTAIN VOLCANIC SUITE (Pre- 620 Ma)

1	Purple to grey-green rhyolite with fine- to medium- grained feldspar crystals within a flow-banded groundmass and minor fiamme-bearing ash-flow tuff, minor dark to pale green or pale pink, matrix-supported agglomerate with sub-rounded to rounded fragments; fragments dominantly bright pink, potassic altered material

SYMBOLS

Geological contact (defined, approximate, assumed, gradational)................

Fault (defined, approximate, assumed)...

Thrust fault (defined, approximate)...

Shear zone (approximate)...

Unconformity..

Mineral Occurrence.. ×

Occurrence of Silica - Hematite.. +

Figure 8. *Regional geological map of the eastern side of the Holyrood Horst.*

adjacent to (west of) the widest vein. Hematite alteration occurs sporadically throughout the outcrop, both as early remobilization halos and later patches and halos around late veinlets and fractures.

The presence of crustiform textures with chalcedonic silica and K-feldspar in the form of adularia indicate the mineralized veins formed during boiling of near-neutral pH fluids associated with episodic pressure release. Neutral fluids rose into a zone of increased permeability, in this case created by faults. Confining pressure was reduced as fluids neared the paleosurface; the fluid boiled, CO_2 was given off; the resultant drop in pH and temperature led to low-T, K-feldspar formation (adularia), and metal precipitation from silica gels. The system gradually sealed, pressure built up and boiling stopped; renewed fracturing broke the sealed cap in the system, and the process repeated.

The early cockade-textured hydrothermal breccia reflects hydraulic fracturing and tectonic brecciation synchronous with boiling; this is evident from crustiform-banded adularia and chalcedonic silica in the matrix. Breccias also formed during later stage hydrothermal activity in the same system. These are Au–Ag-bearing only where they contain mineralized adularia-bearing vein fragments.

Vein features preserved here demonstrate that these rocks formed within the boiling level of a low-sulphidation epithermal system at an approximate depth suitable for precious metal deposition. An exploration diamond drilling program, completed by Rubicon Minerals Corporation in 2005, intersected broad mineralized intervals (up to 45 m in core length) of veins, vein-stockwork and hydrothermal breccias. Mineralized intersections were obtained in 5 of the 7 holes drilled, with the best result assaying 1.9 g/t Au over 0.7 m (B.A. Sparkes, 2005).

STOP 6: OVAL PIT PYROPHYLLITE MINE

Directions: *(Trinity Resources Oval Pit Mine property) Head back to the intersection of Anchorage Road and Chute Place, and continue straight through the intersection. Continue on Anchorage Road until the intersection with Minerals Road, tuning left at the intersection. Proceed along the road to the mine entrance, stopping at the Mine office.*

EXERCISE EXTREME CAUTION!
PLEASE KEEP AWAY FROM THE EDGE OF THE OPEN PIT.

(The following is modified from O'Brien *et al.*, 2012.)

The view from the top of the pit shows a number of features including the outline of the pyrophyllite-diaspore ore zone, the unconformably overlying sedimentary rocks, which are rich in detrital altered clasts, and some of the larger scale structures affecting the alteration system. The most notable of these is a steep reverse fault that juxtaposes the alteration zone (in the south pit extension) with the sedimentary succession. The structure has about 60 m of vertical throw. The same structure has a significant component of subhorizontal displacement. Vertical and horizontal displacement of the ore zone along this fault is mimicked in the overall shape of the open pit, particularly the southwest extension.

The pyrophyllite deposits of this area were discovered in 1898 and were first mined in the period from 1903 to 1905, with approximately 7750 tons of hand-picked ore shipped from a quarry near Johnnies Pond (presumably at or near the site of the Mine Hill deposit; Vhay 1937). Pyrophyllite ore was produced intermittently in the mid-1930s and 1940s by the Industrial Minerals Company of Newfoundland, mainly from the area around Mine Hill, but also from the Trout Pond and Dog Pond prospects, located farther south (Figure 8). Mining of the Oval Pit pyrophyllite deposit was carried out from 1956 to 1996 (*e.g.*, Lee, 1958), first by Newfoundland Minerals Ltd. and eventually, by Armstrong World Industries Canada Ltd. Exploration drilling of all deposits was carried out over this interval. Until now, pyrophyllite from this deposit has been traditionally used exclusively for ceramic applications, and was shipped in bulk to U.S. ceramics plants. The deposit is now owned and operated by Trinity Resources. The owners produce a variety of high-end pyrophyllite products, including fillers and whiteners for paper, plastic and paint, plus a number of specialty ceramic uses; this product is milled and packaged on-site.

The earliest geological study of the pyrophyllite deposits was carried out by Buddington (1916). A detailed study of the Mine Hill, Trout Pond and Dog Pond prospects was carried out by Vhay (1937). A number of investigations followed the development of the Oval Pit Mine (*e.g.*, Keats, 1970; Papezik and Keats, 1976; Papezik and Hume, 1984). The most recent geological mapping of this region is that of Hayes and O'Driscoll (1989, 1990), Hayes (1997), O'Brien *et al.* (1997, 1998, 2001) and G.W. Sparkes (2005).

A well-exposed section through an extensive advanced argillic hydrothermal system is preserved in the Oval Pit Mine and in the immediate surrounding area. Alteration can be subdivided from east to west into subzones of argillic, advanced argillic and massive silica alteration. The argillic zone is characterized by the presence of silica and sericite, with or without pyrophyllite, and the common occurrence of hydrothermal hematite. The advanced argillic zone contains subzones of massive pyrophyllite, sericite and diaspore, with minor barite and rutile (*e.g.*, Oval Pit), and of silica, pyrophyllite and sericite, locally with 5 to 10% pyrite. Smaller zones of massive silicic alteration are mainly in the form of metre-scale pods of high-grade silica, containing less than 5% sericite and/or pyrophyllite. Locally, pyrite forms the matrix of associated silica breccias. No large or continuous zone of silicic alteration has been identified at surface. The zones of silicic alteration are irregularly distributed in detail, but appear to be located mainly to the northeast of the advanced argillic zone. The original distribution of silica and pyrophyllite within the advanced argillic alteration zone indicate that they are essentially contemporaneous. Pyritic rocks intimately associated with the pyrophyllite are not typically anomalous in gold, although values up to 0.8 g/t have been noted locally. The highest gold values noted to date are associated with hydrothermal breccias at the edge of the advanced argillic zone.

To the west, is a zone of relatively high strain, which is due, in part, to the Mine Hill Shear Zone (*cf.* Sparkes *et al.*, 2005; Figure 9A, B), which is regionally coincident with both the main area of advanced argillic alteration and the boundary between 620–625 Ma magmatic rocks to the west and the younger *ca.* 584 Ma volcanic rocks to the east. Locally, pyritic granite intrudes the volcanic sequence on the south side of Mine Hill; this phase has been dated at 619 ± 1 Ma (G.W. Sparkes, 2005), indicating that the host to the alteration west of the high strain zone is part of the older, pre-620 Ma volcanic sequence. Ar–Ar dating of sericite from the high strain zone provides an age of 537 ± 3.0 Ma, which is inferred to represent the youngest recorded deformation along this structural boundary (G.W.Sparkes 2005).

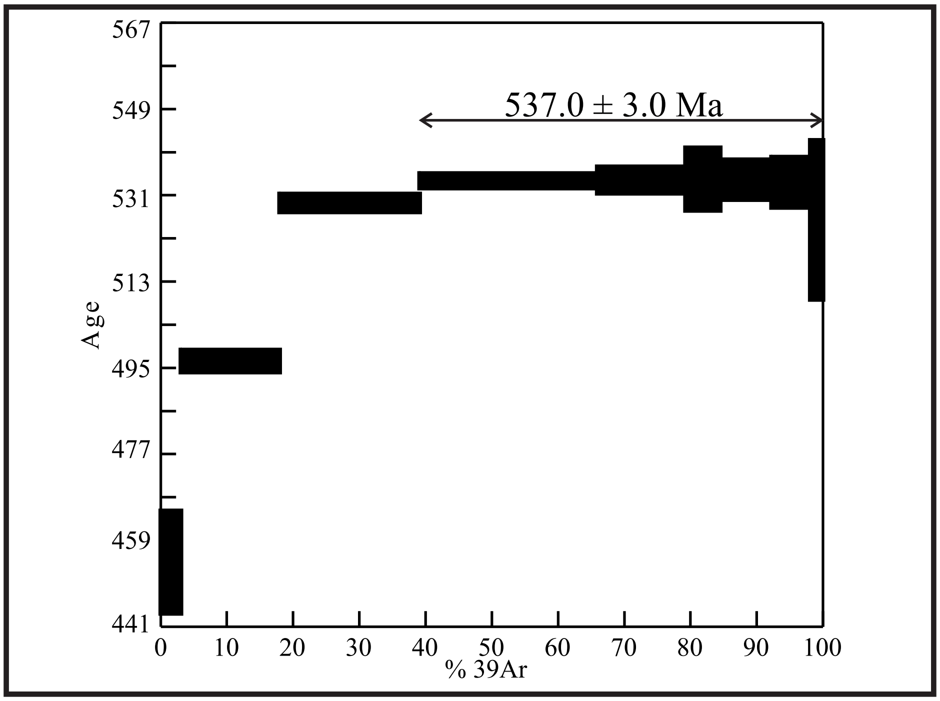


Figure 9A. *Step-heating ^{40}Ar–^{39}Ar spectra for sericite from foliated advanced argillic alteration, Mine Hill.*

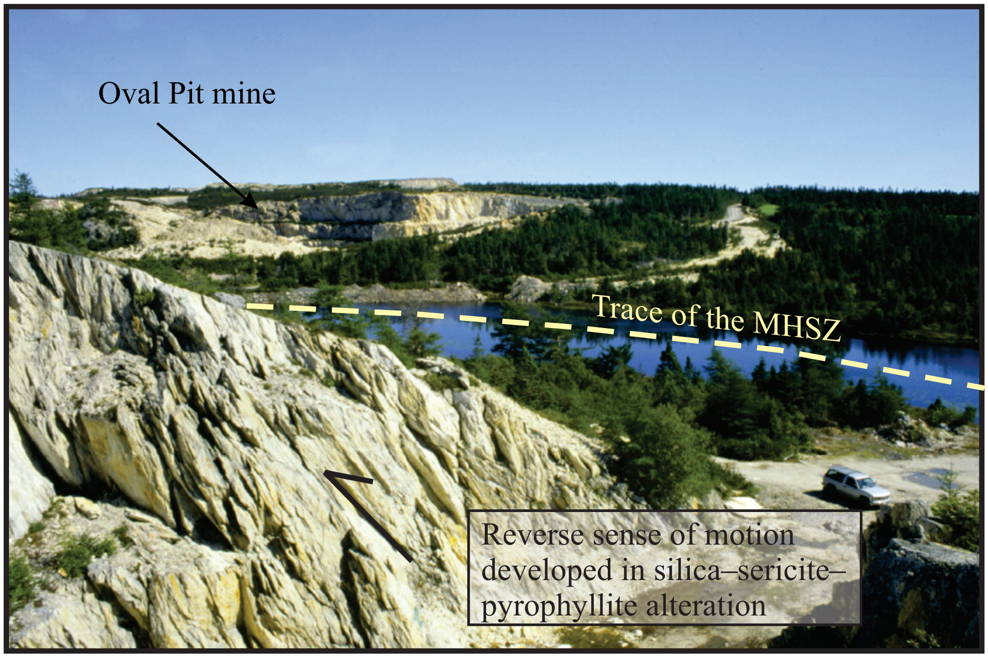


Figure 9B. *Mine Hill shear zone exposed in foreground with the Oval Pit mine in the background. Note the reverse sense of motion within the alteration. Viewed looking towards the northeast from Mine Hill.*

STOP 7: HOLYROOD GRANITE

Directions: *Proceed back along Minerals Road, past the intersection with Anchorage Road, continuing on to the intersection with Route 2 (Conception Bay South Bypass), turning left onto the bypass. Continue along the bypass until reaching the exit for Legion Road. Take the exit for Legion Road, turning left at the intersection, and proceed along Legion Road to the intersection with Kelliview Avenue. Turn right at the intersection and proceed on Kelliview Avenue to the intersection with Red Bridge Road, and turn right at the intersection. Proceed along Red Bridge Road until reaching the second quarry located on your left.*

EXERCISE EXTREME CAUTION!
PLEASE KEEP AWAY FROM THE WALLS OF THE QUARRY

Our final stop is located within the plutonic "basement" rocks that were located just to the west of our previous stop at the Oval Pit Mine. We have now moved west into the main body of the Holyrood Intrusive Suite (Figure 10). In this quarry, the Cambrian unconformity is preserved in upper portions of the workings; this unconformity signifies a gap of some 80 million years. At this stop, the plutonic rocks of the Holyrood Intrusive Suite display well-developed magmatic breccia textures, associated with the interaction of 3–4 plutonic phases exposed along the quarry wall. These phases are inferred to be essentially comagmatic, based on the regional U–Pb dating of the Holyrood Intrusive Suite conducted to date. If you look closely, rare sedimentary xenoliths are also locally exposed in some of the granite blocks on the quarry floor, and these may potentially be correlative with the older (>620 Ma) turbidites mapped along the western margin of the intrusion (Figure 10). These older turbidites occupy a lower stratigraphic position than the Conception Group and have been informally referred to as the 'mis-Conception Group'; they may be correlative to the older Connection Point Group of the western Avalon terrane in Newfoundland (*see* Figure 1).

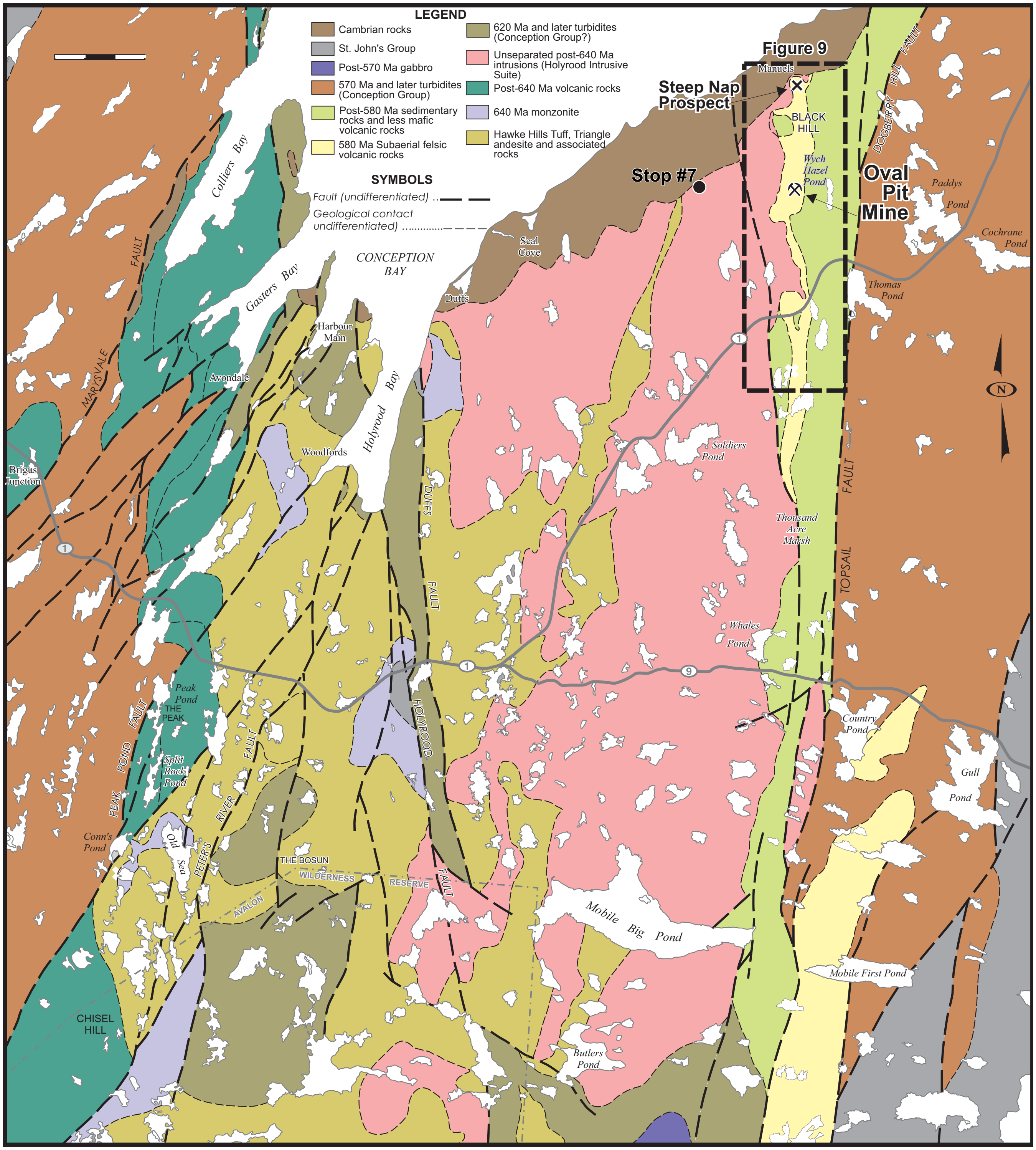


Figure 10. *Simplified geological map of the eastern Avalon Holyrood Horst, and surrounding units (modified from O'Brien* et al.*, 2001).*

REFERENCES

Anderson, M.M.

1981: The Random Formation of southeastern Newfoundland: A discussion aimed at establishing its age and relationship to bounding formations. American Journal of Science, Volume 281, pages 807-830.

Anderson, M.M., Brückner, W.D., King, A.F. and Maher, J.B.

1975: The Late Proterozoic “H.D. Lilly Unconformity” at Red Head, northeastern Avalon Peninsula, Newfoundland. American Journal of Science, Volume 275, pages 1012-1027.

Barr, S.M., Raeside, R.P. and White, C.E.

1998: Geological correlations between Cape Breton Island and Newfoundland, northern Appalachian orogeny. Canadian Journal of Earth Sciences, Volume 35, pages 1252-1270.

Barr, S.M. and White, C.E.

1996: Contrasts in late Precambrian-early Paleozoic tectonothermal history between Avalon Composite Terrane *sensu stricto* and other peri-Gondwanan terranes in southern New Brunswick and Cape Breton Island, Canada. Geological Society of America Special Papers, Volume 304, pages 95-108.

Bengston, S. and Fletcher, T.P.

1983: The oldest skeletal fossils in the Lower Cambrian of southeastern Newfoundland. Canadian Journal of Earth Sciences, Volume 20, pages 525-536.

Benus, A.P.

1988: Sedimentological context of a deep-water Ediacaran fauna (Mistaken Point, Avalon Zone, eastern Newfoundland). Abstract. *In* Trace Fossils, Small Shelly Fossils and the Precambrian–Cambrian Boundary, The University of the State of New York, Bulletin 463, pages 8-9.

Bergstrom, J.

1976: Lower Palaeozoic trace fossils from eastern Newfoundland. Canadian Journal of Earth Sciences, Volume 13, pages 1613-1633.

Blackwood, R.F. and Kennedy, M.J.

1975: The Dover Fault: Western boundary of the Avalon Zone in northeastern Newfoundland. Canadian Journal of Earth Sciences, Volume 12, pages 320-325.

Boyce, D.

1988: Cambrian trilobite faunas of the Avalon Peninsula, Newfoundland. Trip A8. Field trip guide-book, GAC-MAC-CSPG Annual Meeting, St. John’s, Newfoundland, 77 pages.

Brückner, W.D.

1969: Geology of eastern part of Avalon Peninsula, Newfoundland – A summary. American Association of Petroleum Geology, Memoir 12, pages 130-138.

1977: Significance of new tillite finds for east-west correlation of Proterozoic Avalon-zone formations in southeastern Newfoundland (Canada). Estudio Geologico, Volume 33, pages 95-102.

Brückner, W.D. and Anderson, M.M.

1971: Late Precambrian glacial deposits in southeastern Newfoundland – A preliminary note. Geological Association of Canada, Proceedings, Volume 24, No. 1, pages 95-102.

Buddington, A.F.

1916: Pyrophyllitization, pinitization and silicification of rocks around Conception Bay, Newfoundland. Journal of Geology, Volume 24, pages 130-152.

Calon, T.

1993: Stratigraphy and structure of Avalon Zone around Conception Bay. Atlantic Uiversities Geology Conference, Memorial University of Newfoundland, St. John's, October 21-24, 1993, unpublished Field Trip Guide, 24 pages.

2005: Late Precambrian sedimentation and related orogenesis of the Avalon Peninsula, eastern Avalon Zone. Atlantic Universities Geology Conference, unpublished Field Trip Guide, 35 pages.

Canfield, D.E., Knoll, A.H., Poulton, S.W., Narbonne, G.M. and Dunning, G.R.

2020: Carbon isotopes in clastic rocks and the Neoproterozoic carbon cycle. American Journal of Science, Volume 320, pages 97-124. DOI 10.2475/02.2020.01

Dec, T., O'Brien, S.J. and Knight, I.

1992: Late Precambrian volcaniclastic deposits of the Avalonian Eastport basin (Newfoundland Appalachians): Petrofacies, detrital clinopyroxene and paleotectonic implications. Precambrian Research, Volume 59, pages 243-262.

Gravenor, C.P.

1980: Heavy minerals and sedimentological studies on the glaciogenic Late Precambrian Gaskiers Formation of Newfoundland. Canadian Journal of Earth Sciences, Volume 17, pages 1331-1341.

Greenough, J.T., Kamo, S.L. and Krogh, T.E.

1993: A Silurian U–Pb age for the Cape St. Mary's Sills, Avalon Peninsula, Newfoundland, Canada: Implications for Silurian orogeny in the Avalon Zone. Canadian Journal of Earth Sciences, Volume 30, pages 1607-1612.

Haworth, R.T. and Lefort, J.P.

1979: Geophysical evidence for the extent of the Avalon zone in Atlantic Canada. Canadian Journal of Earth Sciences, Volume 16, pages 552-567.

Hayes, J.P.

1997: Geological setting and genesis of the eastern Avalon High-alumina belt. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 172 pages.

Hayes, J.P. and O'Driscoll, C.F.

1989: The geology of the eastern Avalon high-alumina belt, Avalon Peninsula, Newfoundland. Government of Newfoundland and Labrador, Department of Mines, Geological Survey, Map 89-149.

1990: Regional setting and alteration within the eastern Avalon High-alumina belt, Avalon Peninsula, Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 90-1, pages 145-155.

Hodych, J.P. and Buchan, K.L.

1998: Palaeomagnetism of the *ca.* 440 Ma Cape St. Mary's sills of the Avalon Peninsula of Newfoundland: Implications for Iapetus Ocean closure. Geophysical Journal International, Volume 135, pages 155-164.

Hodych, J.P. and Hayatsu, A.

1980: K-Ar isochron age and paleomagmetism of diabase along the trans-Avalon aeiromagnetic lineament – evidence of Late Triassic rifting in Newfoundland. Canadian Journal of Earth Sciences, Volume 17, pages 491-499.

Hoffman, P.F. and Li, Z-X.

2009: A Palaeogeographic context for Neoproterozoic glaciation. Palaeogeography, Palaeoclimatology, Palaeoecology, Volume 277, pages 158-172.

Hsu, E.Y.C.

1975: Pouch Cove–St. John's. Government of Newfoundland and Labrador, Department of Mines and Energy, Mineral Development Division, Map 7836.

Hughes, C.J. and Bruckner, W.D.

1971: Late Precambrian rocks of eastern Avalon Peninsula, Newfoundland - a volcanic island complex. Canadian Journal of Earth Sciences, Volume 8, pages 899-915.

Hutchinson, R.D.

1962: Cambrian stratigraphy and trilobite faunas of southeastern Newfoundland. Geological Survey of Canada, Bulletin 88, 156 pages.

Hutter, A. and Beranek, L.P.

2017: Magmatic evolution of the Avalonian arc system revealed by Ediacaran strata in eastern Newfoundland: New results from laser ablation split-stream (LASS) detrital zircon U-Pb geochronology and Hf isotope geochemistry. Geological Society of America, Abstracts with Programs, Volume 49, No. 6. doi: 10.1130/abs/2017AM-303466

Israel, S.

1998: Geochronological, structural and stratigraphic investigation of a Precambrian unconformity between the Harbour Main Group and Conception Group, east coast Holyrood Bay, Avalon Peninsula, Newfoundland. Unpublished B.Sc. (Honours) thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 78 pages.

Keats, H.F.

1970: Geology and mineralogy of the pyrophyllite deposits south of Manuels, Avalon Peninsula, Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 77 pages.

King, A.F.

1988a: Geology of the Avalon Peninsula, Newfoundland. Government of Newfoundland and Labrador, Department of Mines, Mineral Development Division, Map 88-01, scale 1:250 000.

1988b: Late Precambrian sedimentation and related orogenesis of the Avalon Peninsula, Eastern Avalon Zone. Geological Association of Canada-Mineralogical Association of Canada-Canadian Society of Petroleum Geologists, Annual Meeting, Field Trip A-4, Guidebook. St. John's, Newfoundland, 84 pages.

1990: Geology of the St. John's area. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 90-2, 88 pages.

Krogh, T.E., Strong, D.F., O'Brien, S.J. and Papezik, V.S.

1988: Precise U–Pb zircon dates from the Avalon Terrane in Newfoundland, Canadian Journal of Earth Sciences, Volume 25, pages 442-453.

Landing, E.

1996: Avalon: Insular continent by the latest Precambrian. *In* Avalonian and Related PeriGondwanan Terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America, Special Paper 304, pages 29-63.

2004: Precambrian–Cambrian boundary interval deposition and the marginal platform of the Avalon microcontinent. Journal of Geodynamics, Volume 37, pages 411-435.

Langor, V.

2017: Physical stratigraphy and provenance of the Piccos Brook Member, Flatrock Cove Formation, Flatrock, Newfoundland: Unpublished B.Sc. honours thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 60 pages.

Lee, B.W.

1958: Newfoundland Minerals Ltd, Manuels area, Conception Bay, Newfoundland, report on pyrophyllite zone at Mine Hill and 10 diamond drill hole records. Unpublished internal report, Newfoundland Department of Mines, Agriculture and

Resources, Mineral Resources Division. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey file 001N/07/ 0052.

LeHeron, D.P., Hogan, K.A., Phillips, E.R., Huuse, M., Busfield, M.E. and Graham, A.G.C.
2019: An introduction to glaciated margins: The sedimentary and geophysical archive. Geological Society, London, Special Publications, Volume 475, pages. 1-8.

Lilly, H.D.
1965: Submarine examination of the Virgin Rocks area, Grand Banks, Newfoundland: Preliminary note. Bulletin of the Geological Society of America, Volume 76, pages 131-132.

1966: Late Precambrian and Appalachian tectonics in the light of submarine exploration on the Great Banks of Newfoundland and in the Gulf of St. Lawrence – preliminary views. American Journal of Science, Volume 264, pages 569-574.

Matthews, J.J., Liu, A.G., Yang, C., McIlroy, D., Levell, B. and Condon, D.J.
2020: A chronostratigraphic framework for the rise of the Ediacaran macrobiota: New constraints from Mistaken Point Ecological Reserve, Newfoundland. Geological Society of America Bulletin, 13 pages. doi.org/10.1130/B35646.1

Miller, H.G. and Singh, V.
1995: The Avalon Terrane of Newfoundland: Geophysical correlations from onshore to offshore as evidence for Precambrian to Tertiary structural evolution. Tectonophysics, Volume 242, pages 183-197.

Miller, H.G.
1983: A geophysical interpretation of the geology of Conception Bay, Newfoundland. Canadian Journal of Earth Sciences, Volume 20 pages 1421-1433.

Mills, A.J., Dunning, G. and Sandeman, H.
2020: Age-constrained arc- to rift-magmatism in northwestern and central Avalon Terrane, Newfoundland, and implications for lithostratigraphy. Canadian Journal of Earth Sciences. doi: 10.1139/cjes-2019-0196

Mills, J., O'Brien, S.J., Dubé, B., Mason, R. and O'Driscoll, C.F.
1999: The Steep Nap Prospect: A low-sulphidation, gold-bearing epithermal vein system of Late Neoproterozoic age, Avalon Zone, Newfoundland Appalachians. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Report 99-1, pages 255-274.

Mills, A.J. and Sandeman, H.
2021: Lithostratigraphy and lithogeochemistry of alkaline basaltic rocks of the Bonavista Peninsula: Implications for interpretation of the Musgravetown Group. Atlantic Geology, Volume 57, pages 207-234.

Murphy, J.B., Keppie, J.D., Dostal, J. and Nance, R.D.
1999: Neoproterozoic – early Paleozoic evolution of Avalonia. Geological society of America, Special Papers, Volume 336, pages 253-266.

Murphy, J.B., McCausland, P.J.A., O'Brien, S.J., Pisarevsky, S. and Hamilton, M.A.
2008: Age, geochemistry and Sm-Nd isotopic signature of the 0.76 Ga Burin Group: Compositional equivalent of Avalonian basement? Precambrian Research, Volume 165, pages 37-48.

Myrow, P.M.
1995: Neoproterozoic rocks of the Newfoundland Avalon Zone. Precambrian Research, Volume 73, pages 123-136.

Nance, R.D, Murphy, J.B. and Keppie, J.D.
2002: A Cordilleran model for the evolution of Avalonia. Tectonophysic, Volume 352, pages 11-31.

Nance, R.D., Murphy, J.B., Strachan, R.A., Keppie, J.D., Gutierrez-Alonso, G., Fernandez-Suarez, J., Quesada, C., Linnemann, U., D'Lemos, R. and Pisarevsky, S.A.
2008: Neoproterozoic–Early Palaeozoic tectonostratigraphy and palaeogeography of the peri-Gondwanan terranes: Amazonian v. West African connections. *In* The Boundaries of the West African Craton. *Edited by* N. Ennih and J.-P. Piegeois. Geological Society of London, Special Publications, Volume 297, pages 345-383.

Nixon, G.T. and Papezik, V.S.
1979: Late Precambrian ash flow tuffs and associated rocks of the Harbour Main Group near Colliers, eastern Newfoundland: Chemistry and magmatic affinities. Canadian Journal of Earth Sciences, Volume 16, pages 167-181.

Normore, L.S.
2011: Preliminary findings on the geology of the Trinity map area (NTS 2C/06), Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 11-1, pages 273-293.

O'Brien, S.J., Dube, B., O'Driscoll, C.F. and Mills, J.
1998: Geological setting of gold mineralization and related hydrothermal alteration in Late Neoproterozoic (post-640Ma), Avalonian rocks of Newfoundland, with a review of coeval gold deposits elsewhere in the Appalachian Avalonian Belt. In Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Report 98-1, pages 93-124.

O'Brien, S.J., Dunning, G.R., Dubé, B., O'Driscoll, C.F., Sparkes, B., Israel, S. and Ketchum, J.
2001: New insights into the Neoproterozoic geology of the central Avalon Peninsula (parts of NTS map areas 1N/6, 1N/7 and 1N/3), eastern Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Report 2001-1, pages 193-205.

O'Brien, S.J., King, A.F. and O'Driscoll, C.F.
1997: Late Neoproterozoic geology of the central Avalon Peninsula, Newfoundland, with an overview of mineralization and hydrothermal alteration. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Report 97-1, pages 257-282.

O'Brien, S.J., O'Brien, B.H., Dunning, G.R. and Tucker, R.D.
1996: Late Neoproterozoic Avalonian and related peri-Gondwanan rocks of the Newfoundland Appalachians. *In* Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America, Special Paper 304.

O'Brien, S.J. and O'Driscoll, C.F.
1996: Preliminary investigation of Neoproterozoic (Avalonian) rocks, northeastern Holyrood (NTS 1N/6) map area: Notes on geology, mineralization and mineral exploration potential. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey, Report 96-01 pages 19-23.

O'Brien, S.J., O'Driscoll, C.F., Greene, B.A. and Tucker, R.D.
1995: Pre-Carboniferous geology of the Connaigre Peninsula and the adjacent coast of Fortune Bay, southern Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 95-1, pages 267-297.

O'Brien, S.J., Sparkes, G.W., Dunning, G., Dubé, B. and Sparkes, B.
2012: Neoproterozoic epithermal gold mineralization of the northeastern Avalon Peninsula, Newfoundland. Unpublished GAC-MAC Field Trip Guidebook A5, 35 pages.

Papezik, V.S. and Hodych, J.P.
1980: Early Mesozoic diabase dikes of the Avalon Peninsula, Newfoundland: Petrochemistry, mineralogy, and origin. Canadian Journal of Earth Sciences, Volume 17, pages 1417-1430.

Papezik, V.S. and Keats, H.F.

1976: Diaspore in a pyrophyllite deposit on the Avalon Peninsula, Newfoundland. Canadian Mineralogist, Volume 14, pages 442-449.

Papezik, V.S. and Hume, W.D.

1984: The pyrophyllite deposit on the Avalon Peninsula, Newfoundland. *In* The Geology of Industrial Minerals in Canada. *Edited by* G.R. Guillet and W. Martin. Canadian Institute of Mining and Metallurgy, Special Volume, Volume 29, pages 9-11.

Pu, J.P., Bowring, S.A., Ramezani, J., Myrow, P., Raub, T.D., Landing, E., Mills, A., Hodgin, E. and Macdonald, F.A.

2016: Dodging snowballs: Geochronology of the Gaskiers glaciation and the first appearance of the Ediacaran biota. Geology, Volume 44 (11), pages 955-958; Geological Society of America, Data Repository item 2016326; doi: 10.1130/G38284.1, 4 pages.

Ranger, M.J., Pickerill, R.K. and Fillion, D.

1984: Lithostratigraphy of the Cambrian? - Lower Ordovician Bell Island and Wabana groups of Bell, Little Bell and Kellys islands, Conception Bay, eastern Newfoundland. Canadian Journal of Earth Sciences, Volume 21, pages 1245-1261.

Skipton, D.R.

2011: Geology, geochemistry and tectonic importance of the Horse Cove Complex: A Late Neoproterozoic igneous complex in the eastern Avalon Zone, Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John’s Newfoundland, 311 pages.

Skipton, D.R., Dunning, G.R. and Sparkes, G.W.

2013: Late Neoproterozoic arc-related magmatism in the Horse Cove Complex, eastern Avalon Zone, Newfoundland. Canadian Journal of Earth Sciences, Volume 50, pages 462-482.

Sparkes, B.A.

2003: Second year assessment report on geological and geochemical exploration for licence 8171M on claims in the Manuels area, on the Avalon Peninsula, Newfoundland. Newfoundland and Labrador Geological Survey, Assessment File 1N/10/0744, 2003, 76 pages.

2005: Fourth year assessment report on diamond drilling exploration for licence 10766M on claims in the Conception Bay South area, on the Avalon Peninsula, Newfoundland. Newfoundland and Labrador Geological Survey, Assessment File 1N/0765, 2005, 262 pages.

Sparkes, G.W.

2005: The geological setting, geochemistry and geochronology of host rocks to high- and low-sulphidation style epithermal systems of the eastern Avalon high-alumina belt, Eastern Avalon Zone, Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John’s Newfoundland, 313 pages.

2006: Late Neoproterozoic geology of the east coast of Conception Bay, Newfoundland Avalon Zone. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 6-1, pages 265-279.

Sparkes, G.W. and Dunning, G.R.

2014: Late Neoproterozoic epithermal alteration and mineralization in the western Avalon Zone: A summary of mineralogical investigations and new U–Pb geochronological results. *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 14-1, pages 99-128.

Sparkes, G.W., O’Brien, S.J., Dunning, G.R. and Dubé, B.

2005: U–Pb geochronological constraints on the timing of magmatism, epithermal alteration and low-sulphidation gold mineralization, eastern Avalon Zone, Newfoundland. *In* Current Research. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Survey, Report 05-1, pages 115-130.

Swinden, H.S. and Hunt, P.A.
1991: A U–Pb zircon age from the Connaigre Bay Group, southwestern Avalon Zone, Newfoundland: Implications for regional correlations and metallogenesis. *In* Radiometric Age and Isotopic Studies, Report 4. Geological Survey of Canada Reports, Volume 90-2, pages 3-10.

Thompson, M.D.
1993: Late Proterozoic stratigraphy and structure in the Avalonian magmatic arc, Southwest of Boston, Massachusetts. American Journal of Science, Volume 293, pages 725-743.

Thompson, M.D., Ramezani, J. and Crowley, J.L.
2014: U–Pb zircon geochronology of Roxbury Conglomerate, Boston Basin, Massachusetts: Tectono-stratigraphic implications for Avalonia in and beyond SE New England. American Journal of Science, Volume 314, pages 1009-1040.

van Staal, C.R. and Barr, S.M.
2012: Lithospheric architecture and tectonic evolution of the Canadian Appalachians and associated Atlantic margin. Chapter 2. *In* Tectonic Styles in Canada: The LITHOPROBE Perspective. *Edited by* J.A. Percival, F.A. Cook and R.M. Clowes. Geological Association of Canada, Special Paper 49, pages 41-95.

van Staal, C.R., Barr, S.M., McCausland, P.J.A., Thompson, M.D. and White, C.E.
2000: Tonian-Ediacaran tectonomagmatic evolution of West Avalonia and its Ediacaran-Early Cambrian interactions with Ganderia: An example of complex terrane transfer due to arc-arc collision? *In* Pannotia to Pangea. *Edited by* J.B. Murphy and R.A. Strachan. Geological Society of London, Special Paper.

Vhay, J.S.
1937: Pyrophyllite deposits of Manuels, Conception Bay, Newfoundland. Government of Newfoundland and Labrador, Department of Natural Resources, Geological Section, Bulletin Number 7, 33 pages.

Williams, H. and King, A.F.
1979: Trepassey map area, Newfoundland. Government of Newfoundland and Labrador, Department of Mineral Development, Geological Survey, Memoir 389, pages 1-24.

Wilson, J.T.
1966: Did the Atlantic close and then re-open? Nature, Volume 211, pages 676-681.