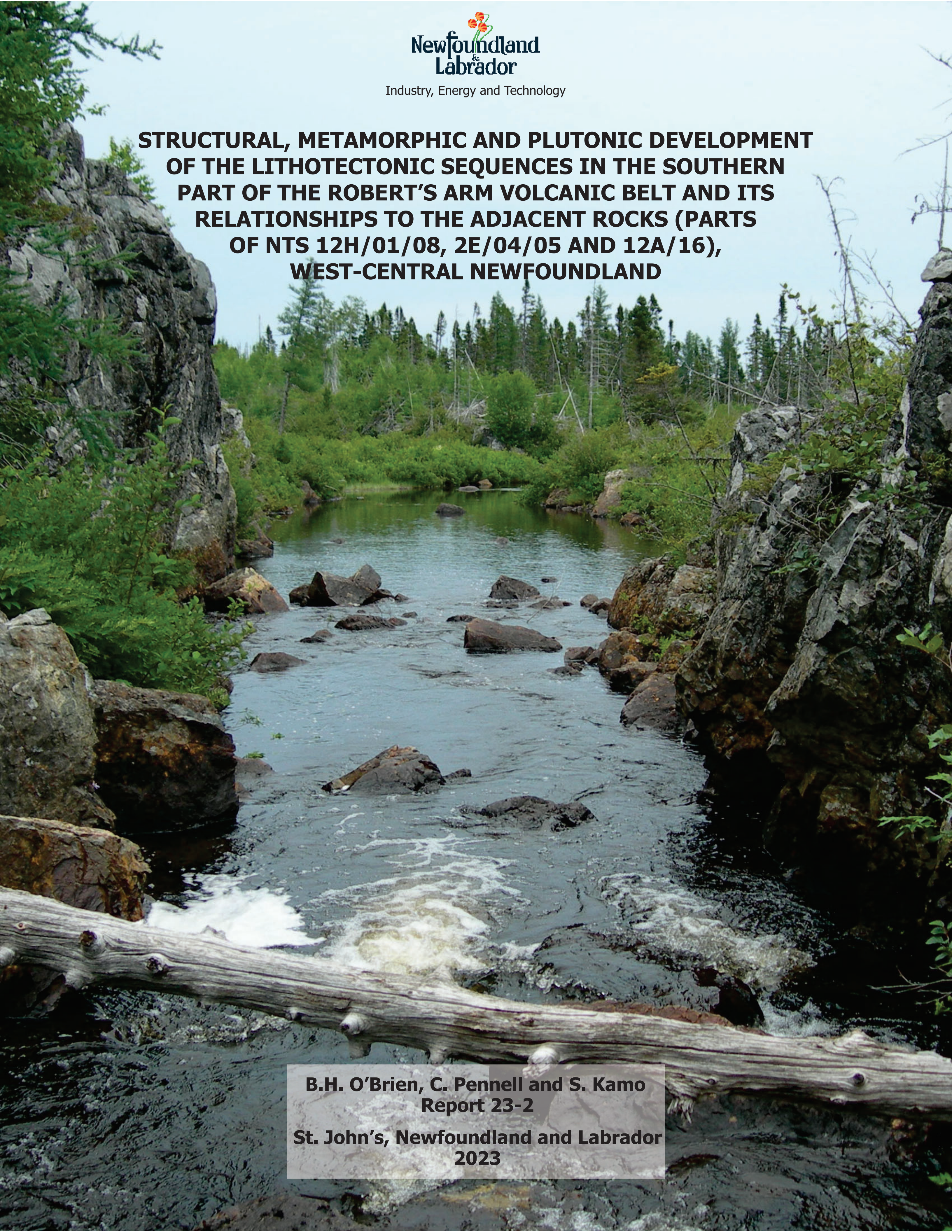

Newfoundland & Labrador
Industry, Energy and Technology

STRUCTURAL, METAMORPHIC AND PLUTONIC DEVELOPMENT OF THE LITHOTECTONIC SEQUENCES IN THE SOUTHERN PART OF THE ROBERT'S ARM VOLCANIC BELT AND ITS RELATIONSHIPS TO THE ADJACENT ROCKS (PARTS OF NTS 12H/01/08, 2E/04/05 AND 12A/16), WEST-CENTRAL NEWFOUNDLAND

B.H. O'Brien, C. Pennell and S. Kamo

Report 23-2

St. John's, Newfoundland and Labrador
2023

Industry, Energy and Technology

Mines

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Recommended citation:

O'Brien, B.H., Pennell, C. and Kamo, S.

2023: Structural, metamorphic and plutonic development of the lithotectonic sequences in the southern part of the Robert's Arm Volcanic Belt and its relationships to the adjacent rocks (parts of NTS 12H/01/08, 2E/04/05 and 12A/16), west-central Newfoundland. Government of Newfoundland and Labrador, Department of Industry, Energy and Technology, Geological Survey, St. John's, Report 23-2, 78 pages.

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ABSTRACT

Ordovician volcanosedimentary rocks in the southern Robert's Arm volcanic belt of west-central Newfoundland are regionally disposed in the northwest-dipping hangingwall sequence of the Silurian Red Indian Line thrust zone, and locally comprise part of the peri-Laurentian Notre Dame Subzone of the Dunnage Zone. Some of the most deformed and metamorphosed strata and sheared mafic–felsic intrusions are, however, tectonically situated near an older arc–arc collisional suture (Late Ordovician) located within the southeast part of the Robert's Arm thrust stack to the northwest of the Red Indian Line and the Badger Basin.

Strata, ranging from the Early to Late Ordovician, accumulated in volcanic arc or back-arc-related submarine depocentres that are partially preserved within four regional stratigraphical–structural basins. Ribboned ferruginous cherts and fine-grained volcaniclastic beds are commonly succeeded by coarsening-upward proximal turbidite sequences developed near the margins of small shortening basins.

In many places, these sedimentary rocks were deposited above calc-alkaline basalt lavas, tholeiitic basalt flows, or bimodal mafic–felsic pyroclastic strata. In general, different ages and types of sedimentary and volcanic rock formations comprise conformable lithostratigraphical successions, but these had originally formed in isolation at separate paleogeographic locations. Those of Middle and Late Ordovician age are present within several discrete structural tracts that together make up the main part of the southern Robert's Arm volcanic belt (SRAVB) in the area examined, in detail, for this report.

The disposition of the lithostratigraphical divisions located within the six regional structural tracts of the southern Robert's Arm volcanic belt was controlled by a Late Ordovician thrust-and-nappe complex. Constituent schist and gneiss belts had an original southwest inclination and were dynamically related to a period of orogen-parallel sinistral displacement (D1-O and D2-O). Within the northeastern segment of the area mapped in detail, they were overprinted by folds, cleavage and reverse faults related to the formation of a Silurian slate belt (D1-S and D2-S).

Dextral oblique-slip movements on northeast-dipping D1-S thrusts of probable Early Silurian age were initially focused on the area of the Red Indian Line; however, prior to the late Middle Silurian, they had evolved into more widespread D2-S northwest-dipping reverse faults, particularly in the Middle Ordovician strata of the Pennys Brook Formation in the western part of the peri-Gondwanan Wild Bight Group. Such greenschist-facies Silurian structures had also affected the tectonically adjacent Middle Ordovician olistostromal mélange in the Sops Head Complex, and had metamorphically downgraded the amphibolite-facies paragneiss that had developed at the base of the Annieopsquotch Accretionary Complex.

Regional metamorphism had accompanied Late Ordovician and Silurian plutonism in the southeastern SRAVB. An early syntectonic suite of sheeted metagabbroic and foliated granodioritic intrusions began to crystallize in paragneiss and ortho-amphibolite probably around the Ordovician–Silurian boundary. Similar plutonic rocks and allied dyke swarms continued to be emplaced into ductile shear zones in Ordovician host rocks during the Early Silurian.

Isotropic diorite, granodiorite, granite and syenite intrusions comprise a posttectonic Middle Silurian plutonic suite in the southern Robert's Arm volcanic belt and in younger strata within basins developed above adjacent tectonic terranes. Most of these concentrically zoned plutons were nested and later became offset by dilatant oblique-slip brittle faults. Cohesive zones of randomly oriented fault breccia were utilized during the ascent of radial swarms of composite mafic–felsic dykes through the posttectonic plutons and country-rock gneiss and schist.

The structurally lowest lithotectonic assemblage of the Annieopsquotch Accretionary Complex is found within the south-eastern SRAVB. It is argued in this report that the tectonic evolution of these schistose, gneissose and migmatitic rocks is better linked to the geological development of the terrestrial Silurian cover sequence in the adjacent Springdale Group basin than to the deep-marine Late Ordovician overstep sequence in the adjacent Badger Group basin.

1. INTRODUCTION

The area examined for this report is situated in the Appalachian Dunnage Zone in the middle part of the Central Mobile Belt of Newfoundland (Figure 1). It straddles the tectonic boundary separating the Ordovician stratified rocks of the southeast peri-Laurentian Notre Dame Subzone (metamorphic hinterland of composite Laurentia; *cf.* van Staal *et al.*, 2007) from those comprising the northwest composite peri-Gondwanan Exploits Subzone (mainly Victoria Arc, Exploits back-arc and the deep-sea Ordovician overstep sequences younger than the Dapingian Celtic Faunal Realm; *cf.* Williams, H. *et al.*, 1988; Williams, H., 1995; Harper *et al.*, 1996; Swinden *et al.*, 1997; Valverde *et al.*, 2006; Zagorevski *et al.*, 2010).

In north-central Newfoundland, a predominantly northwest-dipping arcuate thrust zone marked by various tracts of mainly pre-Sandbian olistostromal and post-Katian tectonic melange contains the regional Red Indian Line suture (Nelson, 1981; Blewett and Pickering, 1988; Lafrance, 1989; Thurlow *et al.*, 1992; Dec *et al.*, 1997; McConnell *et al.*, 2002; Zagorevski and McNicoll, 2011; O'Brien, 2012). Unbroken formations of Middle Ordovician (mainly Darriwilian) volcanic and sedimentary strata are widespread in adjacent parts of both the Notre Dame and Exploits subzones of the Dunnage Zone (O'Brien, 2003; Zagorevski *et al.*, 2007b).

REGIONAL GEOLOGY

Stratified rocks in the structurally lowest and youngest part of the peri-Laurentian Notre Dame Subzone progressively decrease in age toward the southeast and, in places, show an increase in regional metamorphic grade approaching the Red Indian Line (RIL). They comprise a southeast-directed fold-and-thrust belt having the opposite tectonic polarity of the Taconian and Salinic foreland belt of the Appalachian Mountains in western Newfoundland. In contrast, the structurally underlying rocks of the peri-Gondwanan Exploits Subzone generally become younger toward the RIL suture, which is the site of a regional stratigraphical-facing confrontation. Along their western margin, the Dunnage Zone rocks of the peri-Gondwanan realm are also disposed within a mainly northwest-dipping imbricate thrust stack of postulated Silurian age (*e.g.*, Williams, P. *et al.*, 1988; Elliot *et al.*, 1991; Kusky, 1996; Rogers *et al.*, 2005a, b; O'Brien, 2006; Zagorevski *et al.*, 2007a).

Volcanosedimentary strata in the Buchans–Robert's Arm volcanic belt (Swinden *et al.*, 1997) have been previously included within the more regionally extensive Annieopsquotch Accretionary Tract (AAT; Zagorevski *et al.*, 2006, 2015; Figure 2). Early Ordovician island-arc and ophiolitic rocks in the upper tectonic panel of this accretionary thrust stack were interpreted to have been affected by a late Middle Ordovician volcanic arc–microcontinent collision, governed by northwestward subduction (present coordinates; possibly Dapingian; *cf.* Lissenberg *et al.*, 2005; Hollis *et al.*, 2012). This occurred prior to the accumulation of the Darriwilian Red Indian Lake Group within the lower AAT. However, strata in the southeast part of the Buchans–Robert's Arm volcanic belt were postulated to have been tectonically underplated beneath the aforementioned rocks, initially, during a Late Ordovician episode of the Taconic Orogeny (Terminal TIII Sandbian phase; *ca.* 455 Ma; *cf.* van Staal, 2007).

In a regional study of the AAT complex in the Robert's Arm volcanic belt, Zagorevski *et al.* (2010, 2015) confirmed the presence of Floian felsic volcanic rocks in the upper part of the AAT thrust stack, but they had also documented occurrences of Darriwilian felsic volcanic rocks in the lower part of the AAT thrust stack. Recently, the younger volcanic strata have been mapped, in detail, throughout the structurally lower part of the Robert's Arm volcanic belt (O'Brien, 2009, 2016c), where they have been separated from other volcanic and sedimentary strata that have been presumed to range from the Middle to Late Ordovician. Although most of the complexly deformed and regionally metamorphosed Middle Ordovician felsic pyroclastic rocks in the southern Robert's Arm volcanic belt (SRAVB) have been historically included (with Early Ordovician rocks) in the peri-Laurentian Notre Dame Subzone, some have been assigned to the peri-Gondwanan Victoria Arc sequence of the Exploits Subzone (*e.g.*, Crooked Lake tuff in Zagorevski *et al.*, 2010a).

In the SRAVB, the structural hangingwall sequence of the highest and possibly oldest thrust fault includes Early Ordovician (Tremadocian) ophiolites and associated trondjhemite– tonalite–granodiorite metaplutonic suites (*e.g.*, Hall Hill and Mansfield Cove igneous complexes; Dunning *et al.*, 1987), although it may also include a Floian metagabbro in an ophiolite-hosted slice near South Brook (Zagorevski *et al.*, 2015). In contrast, the structural footwall sequence of the lowest and youngest thrust fault includes Late Ordovician sedimentary cover rocks of the Exploits Subzone that have long been held to comprise a Katian–Hirnantian–Llandovery piggy-back basin (*e.g.*, Nelson and Casey, 1979; Lash, 1994; Waldron *et al.*, 2012).

In Newfoundland, the Taconic II-accreted rocks of the Notre Dame Arc (NDA) and, in particular, the long-lived AAT sequence that lies regionally below it have been interpreted as being affected by synkinematic intrusion and regional metamorphism during successive Ordovician episodes of basin opening and closure in the peri-Laurentian arc complex (*e.g.*, van Staal *et al.*, 2009; Zagorevski *et al.*, 2015).

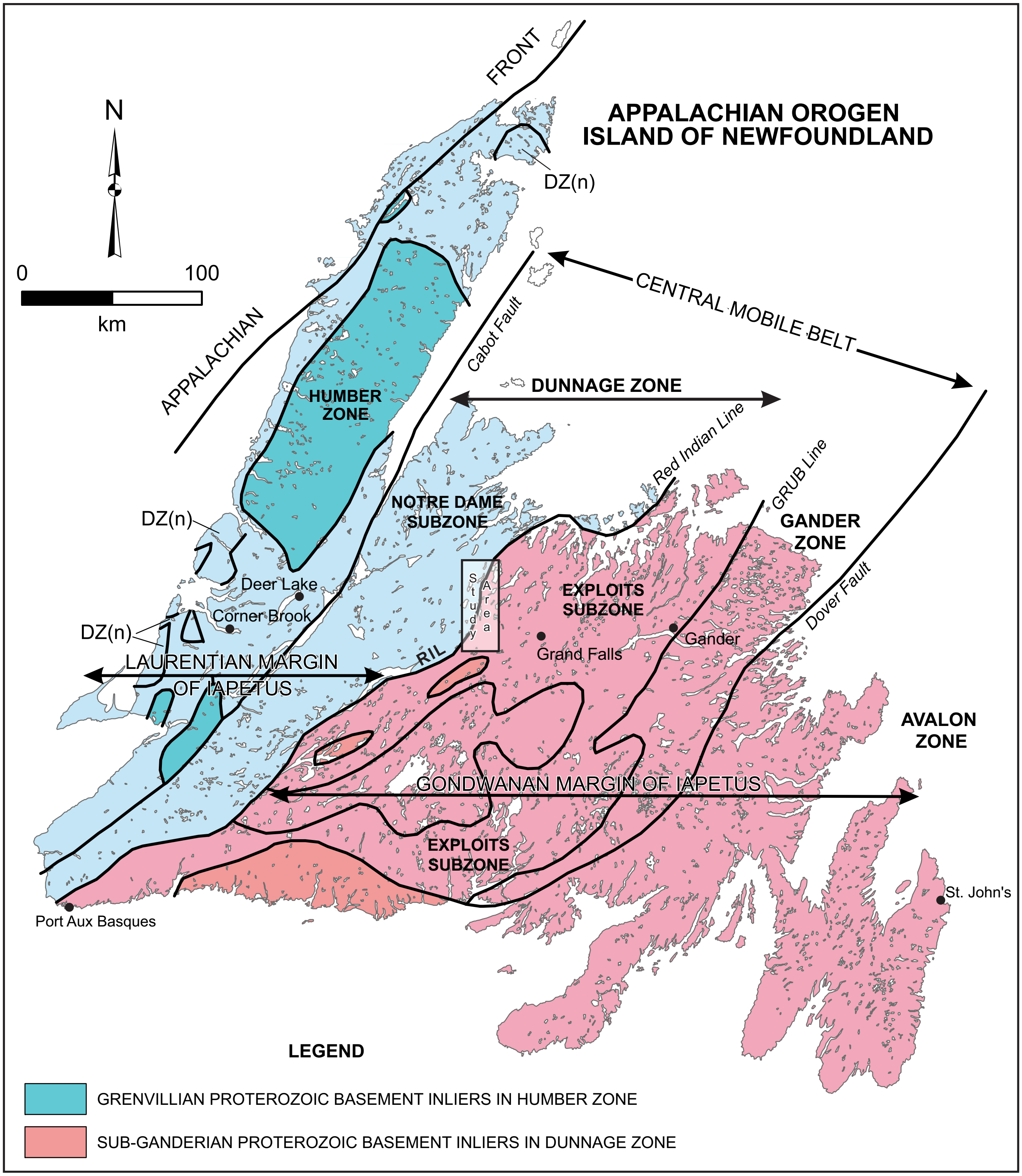


Figure 1. *Geological location of the study area in Newfoundland's Central Mobile Belt (mainly Appalachian Dunnage Zone). The area examined is shown on an interpretative paleotectonic map illustrating the Proterozoic basement inliers in the Humber and Dunnage zones and the regional tectonic boundary (Red Indian Line; RIL) separating the lower Paleozoic rocks that had developed on the peri-Laurentian margin of the proto-Altantic (Iapetus) Ocean from those originating on the opposing peri-Gondwanan continental margin. DZ(n) comprise allochthons of the Notre Dame Subzone of the Dunnage Zone lying above the rocks of the Humber Zone. Diagram is partly modified from O'Brien* et al. *(1996) and Sparkes* et al. *(2021).*

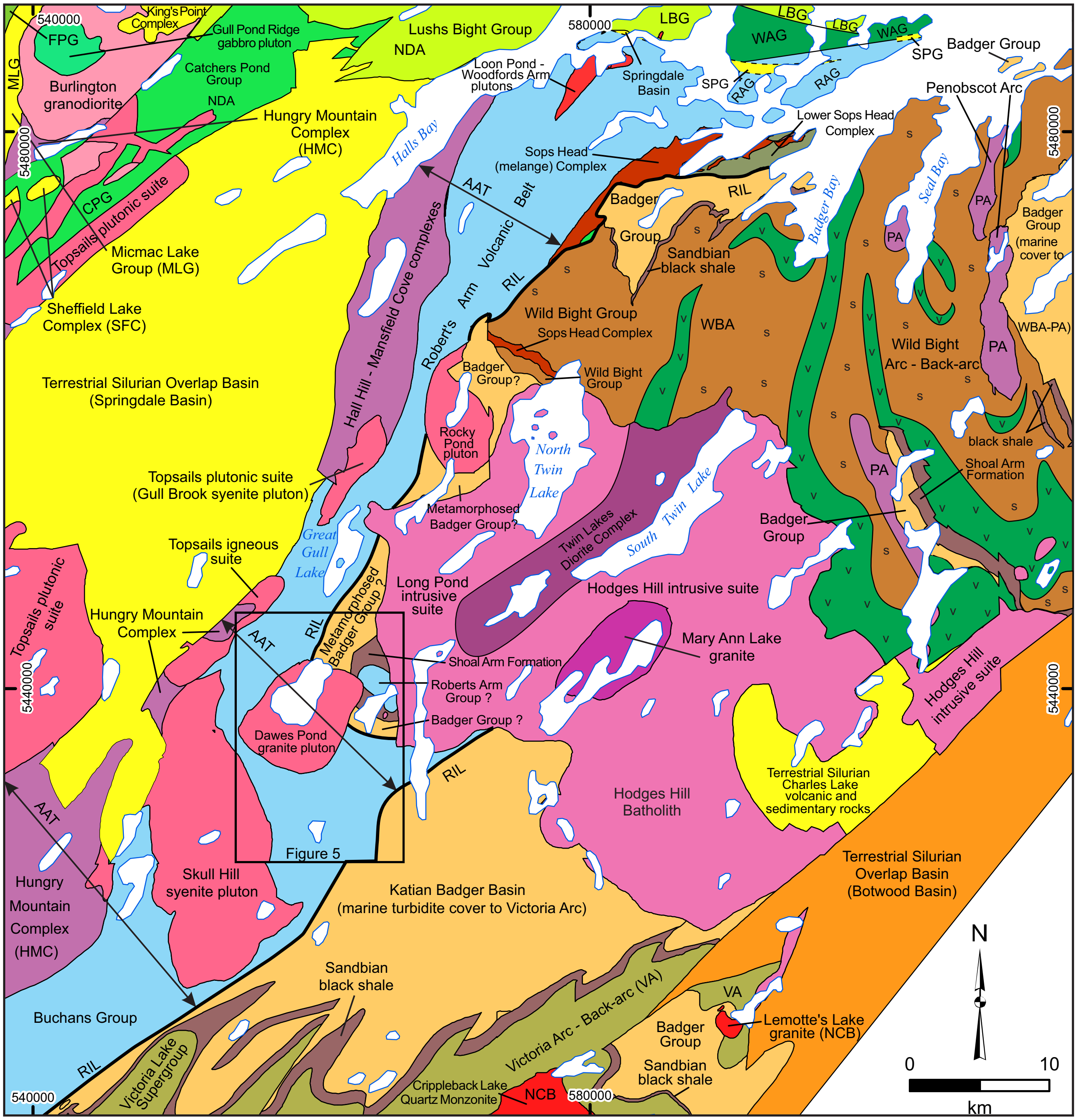


Figure 2. *Simplified geological and tectonic map of part of north-central Newfoundland showing the traditional Red Indian Line (RIL) boundary in the region southwest of the Notre Dame Bay coast (northwest side of the Badger Basin) and the location of a detailed study area (Figure 5) centred around Dawes Pond; also depicting the peri-Laurentian Early–Middle Ordovician strata of the Robert's Arm volcanic belt (AAT in blue;* cf. *Zagorevski* et al.*, 2010) lying between the overstep basins of the Silurian Springdale Basin and the Ordovician Badger Basin (*cf. *Dickson, 2000b, 2001). The peri-Gondwanan Middle Ordovician Wild Bight Arc (WBA; mainly sedimentary strata (s) in light brown and mainly volcanic strata (v) in light green) lies above the Early Ordovician Penobscot Arc (PA) complex but below a laterally extensive unit of Late Ordovician black shale present at the lithostratigraphic base of the Badger Basin. Note the local presence of Neoproterozoic sub-Ganderian basement (NCB; Crippleback Lake quartz monzonite and Lemotte's Lake granite) southeast of the Victoria Arc (VA;* cf. *Rogers* et al.*, 2006) and also several Siluro-Devonian plutonic complexes straddling the RIL, including posttectonic intrusions present in the Topsails, Skull Hill, Dawes Pond, Hodges Hill, Rocky Pond and Long Pond intrusive suites.*

TECTONIC LEGEND

NDA — Early to Middle Ordovician *Notre Dame Arc* (peri-Laurentian continental margin Tremadocian and Floian arc-related supracrustal rocks overlying the boninite-bearing Cambrian Lushs Bight Group and assigned to the Catchers Pond (CPG), Western Arm (WAG) and Flatwater Pond (FPG) groups of the Notre Dame Subzone)

AAT — Middle to Late Ordovician (Taconian) *Annieopsquotch Accretionary Tract* (subduction-related structural assemblage locally developed within the Buchans–Robert's Arm (BRA) volcanic belt and the overlying Hungry Mountain (HM), Hall Hill (HH) and Mansfield Cove (MC) metaplutonic complexes)

RIL — Late Ordovician to Early Silurian *Red Indian Line* (traditional boundary of the orogenic suture separating the BRA belt from a Late Ordovician cover basin of Badger Group turbidites and dormant peri-Gondwanan arc complexes; locally marked by the Middle Ordovician melange of the Sops Head Complex)

WBA — Middle Ordovician *Wild Bight Arc* (continental arc to back-arc volcanic rocks (V) and intercalated epiclastic turbidites (S) located in the middle-upper part of the peri-Gondwanan Wild Bight Group in the western part of the Exploits Subzone)

PA — Early Ordovician *Penobscot Arc* (primitive oceanic volcanic arc and arc ophiolite locally exposed in the lower part of the Wild Bight Group)

VA — Middle Ordovician *Victoria Arc* (ensialic volcanic arc and marine back-arc strata assigned to the uppermost part of the peri-Gondwanan Victoria Lake Supergroup)

NCB — *Neoproterozoic Crystalline Basement* (fragmented sub-Ganderian Late Precambrian gneiss, granite and volcanic arc complex inferred to have underlain the Early Paleozoic rocks of the sediment-rich Victoria Arc and those parts of the Penobscot Arc that were accreted to Ganderia in early Ordovician)

GEOLOGICAL LEGEND

INTRUSIVE ROCKS

Siluro–Devonian Posttectonic Plutonic Rocks(?)

- Hodges Hill intrusive suite; comprising a regional batholith composed of gabbro, diorite, tonalite, granodiorite, monzonite and granite plutons
- Topsails plutonic suite; posttectonic sheets and epizonal bosses of granodiorite, quartz monzonite and syenite; component of the Topsails Igneous Suite; includes older Rainy Lake plutonic complex
- Rocky Pond pluton; mainly composed of granodiorite, diorite porphyry and granite
- Gull Brook pluton; mainly composed of syenite and granite
- Dawes Pond pluton; mainly composed of granodiorite and granite
- Skull Hill pluton; mainly syenite, diorite, granite and quartz-feldspar porphyry

Late Ordovician–Silurian Syntectonic Plutonic Rocks

- Burlington granodiorite; including discrete Late Ordovician and Early Silurian intrusive phases of variably foliated granodiorite; sheeted metagabbro and diabase dyke swarms
- Gull Pond Ridge gabbro pluton; pillowed gabbro and comagmatic granodiorite; minor diorite and quartz-feldspar porphyry; gabbro intruded by Burlington granodiorite
- Twin Lakes diorite complex; banded amphibolite and metagabbro (having migmatitic paragneiss enclaves); mainly quartz diorite and lesser granodiorite

Ordovician Plutonic Rocks

- Late Ordovician or older Mary Ann Lake granite; mainly metamorphosed granite and schistose granodiorite (having paragneiss, migmatite and amphibolite enclaves); including a known Darriwilian granite
- Middle Ordovician Loon Pond–Woodfords Arm plutons; mainly pretectonic diorite, granodiorite, graphic granite and granophyre; including a known Floian granite; equivalent to felsic volcanic rocks within the upper structural part of the Robert's Arm volcanic belt
- Early Ordovician Hungry Mountain (HM), Hall Hill (HH) and Mansfield Cove (MC) metaplutonic complexes; mainly metagabbro, amphibolite gneiss, mylonite, metatonalite and granodiorite; swarms of composite quartz porphyry and diabase dykes; HH intruded by a known Tremadocian tonalite assigned to MC; included in the Annieopsquoch Accretionary Tract (AAT)
- Early Ordovician South Lake Igneous Complex; mainly flaser-banded metagabbro, schistose tonalite and swarms of sheeted diabase dykes; including a known Tremadocian gabbro pegmatite; equivalent to mafic and felsic volcanic rocks in the lower Wild Bight Group; included in the Penobscot Arc (PA)

Late Precambrian Plutonic Rocks

- Crippleback Lake and Lemotte's Lake felsic plutonic bodies; mainly quartz monzonite and granite in tectonic contact with adjacent stratified rock units; rare, Late Precambrian felsic pyroclastic strata intruded by rocks of the Crippleback pluton

STRATIFIED ROCKS

Terrestrial Silurian Overlap Sequences

- Silurian Micmac Lake Group, Kings Point Complex, Sheffield Lake Complex, Springdale Group and Charles Lake sequence; red conglomerate, hematitic basalt, ignimbrite, lahar, red mudstone and crossbedded sandstone located to the northwest of Red Indian Line (RIL); the Micmac Lake Basin occurs to the northwest of the Hungry Mountain Complex (HMC) and the Notre Dame Arc (NDA) and becomes wider adjacent to the Flatwater Pond Group (FPG) on the Baie Verte Peninsula; the Springdale Group is restricted to the Springdale Basin, is regionally situated above the NDA–HMC boundary, and pinches out toward the northeast above the rocks of the Robert's Arm volcanic belt (RAVB)

Legend for Figure 2.

Silurian Botwood Group; hematitic basalt and autobreccia, ash flows and flow-banded rhyolite, mud-cracked green and grey sandstone, and red micaceous sandstone located to the southeast of Red Indian Line (RIL) in the Botwood Basin; felsic volcanic rocks in the Charles Lake outlier are age equivalent of strata in the oldest part of the Springdale Group and may be older than some of the felsic volcanic rocks within the Botwood Basin

Notre Dame Subzone of the Dunnage Zone

Rocks that had probably accumulated above a Late Cambrian–Early Ordovician ophiolite basement to the west of the Micmac Lake Basin

Middle Ordovician Flatwater Pond Group; marine cover sequence composed of iron formation, banded chert, andesitic tuff, pillowed tholeiite, rhyolite flows, felsic tuff and volcaniclastic wacke; marked by conglomerate having detrital clasts of harzburgite, granodiorite, gabbro, rhyolite and quartzite; locally including Late Ordovician felsic pyroclastic strata and turbidites of the Black Creek sequence

Rocks that had probably accumulated above an older arc-ophiolite basement (Cambrian) to the west of the Springdale Basin

Early–Middle Ordovician Catchers Pond and lower Western Arm groups; marine cover sequences mainly composed of calc-alkaline basalt and arc-related tholeiitic pillowed basalt, bioclastic limestone, iron formation, flow-banded rhyolite, volcaniclastic wacke and laminated argillite

Rocks that had probably formed within the Cambrian arc-ophiolite basement immediately west of the Springdale Basin

Middle to Late Cambrian Lushs Bight Group; oldest known peri-Laurentian volcanic group in the Notre Dame Subzone; including sheeted dyke swarms, boninitic gabbros, boninite flows and younger arc-related tholeiitic basalts; rare lenses of peridotite, serpentinite and talc schist

Rocks that had probably accumulated above an Early Ordovician magmatic arc basement to the east of the Springdale Basin

Early–Middle Ordovician Buchans and Roberts Arm groups; comprising the main part of the Annieopsquotch Accretionary Tract (AAT) in the local study area; mainly lithotectonic sequences of variably mineralized mafic and felsic volcanic rocks and associated sedimentary rocks; together, having the longest known range of depositional age and preserving volcanic strata displaying the broadest range of rock types, compositional variations and petrochemical signatures known in the Notre Dame Subzone

Block-in-Matrix Melange Sequences of the Central Dunnage Zone

The Middle Ordovician Sops Head Complex has a lower unbroken formation typified by the Julies Harbour turbidite succession in western Badger Bay and an upper broken formation similar to that found within the Boones Point Complex and the Dunnage Melange near the Fortune Harbour Peninsula. The olistostromal block-in-matrix melange observed in all these units is inferred to have been originally covered by Sandbian graptolitic black shale

The upper part of the Sops Head Complex is composed of partially broken formations of alkaline and tholeiitic pillowed basalt, biogenic limestone and ribboned chert transitional to mud-matrix mixtite and pebbly mudstone; correlated with variably deformed strata found within the lowest structural part of the Robert's Arm volcanic belt near Burnt Pond (and locally assigned to the Burtons Harbour–Herring Cove division and the metamorphosed equivalent of the Julies Harbour division)

The lower part of the Sops Head Complex is composed of volcaniclastic wacke and sandstone turbidite overlain by pyritic siltstone turbidite, bedded chert and siliceous argillite transitional to polymictic boulder conglomerate and sandy debrite

Marine Ordovician Overstep Sequences

The basal Gull Island Formation of the Late Ordovician Badger Group is mainly made up of thick-bedded Katian sandstone turbidites and massive granular wackes displaying ripped-up argillaceous intraclasts and compacted calcareous nodules; a map scale lenticle of boulder conglomerate and pebbly wacke is marked by well rounded extraclasts of volcanic and plutonic rocks and fossiliferous Darriwilian limestone breccia. Badger Group strata are restricted to the southeast of the Red Indian Line (RIL) where they preserve a conformable stratigraphically gradational boundary with the youngest known part of the underlying Shoal Arm Formation; the Gull Island Formation is a partial correlative of the Point Leamington Formation and the Sansom Formation of the Badger Group

The Late Ordovician Shoal Arm Formation is mainly made up of red ferruginous radiolarian chert, grey manganiferous siltstone turbidite, green nodular phosphatic argillite, grey bioturbated and mottled chert, and graptolite-bearing black shale interbedded with silicified graphitic argillite; a conformable stratigraphical boundary is observable with underlying turbidite sandstone in the uppermost part of the Darriwilian Pennys Brook Formation; locally, in Badger Bay, the basal red chert of the Shoal Arm Formation lies in the Nemagraptus gracilis biozone of the earliest Sandbian; the Shoal Arm Formation is a partial correlative of other Sandian black shale-bearing units, including the widespread Lawrence Harbour Formation of central Newfoundland

Exploits Subzone of the Dunnage Zone

North of the Hodges Hill Batholith

The Early–Middle Ordovician Wild Bight Group (WBG) comprises an older Penobscottian intraoceanic arc sequence (PA) succeeded by a peri-Gondwanan immature continental margin arc sequence (WBA) and an overlying Exploits back arc sequence that directly onlapped the uplifted Penobscot Arc toward the east.

Fining-upward turbidite cyclothems in the slump-folded Pennys Brook Formation (S) of the upper Wild Bight Group are intercalated with calc-alkaline and tholeiitic pillow breccias (V), are intruded by similar types of gabbro laccoliths, and host basalt-dominant olistostromal deposits, all capped by a back arc sequence of mid-ocean ridge basalt, alkali basalt, limestone, mottled chert and spotted argillite

The oldest exposed Glovers Harbour Formation of the Wild Bight Group is composed of late Tremadocian boninite, calc-alkaline basalt and trondjhemitic rhyolite and, in Seal Bay Bottom, is observed to be disconformably overlain by a late Floian to late Darriwilian volcanic arc sequence composed of Omega Point iron formation, Sparrow Cove pillowed andesite, and Pennys Brook volcaniclastic turbidite; the South Lake Igneous Complex has been included with the Glovers Harbour Formation in the complex of PA rocks in the WBG

South of the Hodges Hill Batholith

The Cambro-Ordovician Victoria Lake Supergroup comprises several rock groups dominated by felsic and lesser mafic volcanic rock formations and constituent volcaniclastic strata; listed from east to west, the Middle Cambrian Tally Pond and Long Lake groups, the Late Cambrian Tulks Group, the latest Cambrian to earliest Ordovician Pats Pond Group (Penobscottian continental arc), and the early to late Middle Ordovician Noel Paul's Brook and Sutherlands Pond groups (VA); generally constituting pre-Late Ordovician ensialic volcanoplutonic arc sequences that become younger toward the RIL boundary; in the study area, the Victoria Lake Supergroup is mainly represented by the sedimentary strata of the Noel Paul's Brook Group

Legend for Figure 2 (continued).

OBJECTIVES

In the area surveyed, uncertainty remains about which tectonic elements (*cf.* O'Brien, 2008) comprise the constituent Ordovician assemblages within the high T–low P metamorphic belt in the lower part of the AAT. This report addresses certain characteristic aspects of Ordovician volcanism and sedimentation and Silurian metamorphism and deformation, as displayed by the lower AAT rocks within the southern Robert's Arm volcanic belt.

Evidence to be presented herein implies that amphibolite-facies regional metamorphism of the lower AAT assemblage did not affect the deep-sea Late Ordovician turbidites of the Badger Group and the underlying peri-Gondwanan strata in the adjacent part of the Exploits Subzone. Post-peak metamorphic uplift of the lower AAT assemblage, that began as slates initially formed in the overstep sequence of the outboard Exploits Subzone, continued as the low-grade strata of the Gondwanan Realm were being accreted to a Laurentian Margin schist and gneiss belt.

This report demonstrates that tectonic inversion of the Burnt Pond volcaniclastic turbidite basin (Julies Harbour metasedimentary schist) and its initial structural emplacement above imbricate thrust slices of late Darriwilian olistostromal mélange and early Sandbian black shale, occurred before the terrestrial development of the basal Wenlockian and younger Springdale caldera and was unrelated to the Katian–Hirnantian accumulation of Badger Group debris flows in the traditional RIL footwall sequence.

GLOSSARY OF STRATIGRAPHIC/STRUCTURAL NOMENCLATURES

Original Red Indian Line (RIL). This major orogen-scale tectonostratigraphic boundary in the Newfoundland Appalachians is situated within the lower Paleozoic Iapetan oceanic rocks of central Newfoundland. As defined by H. Williams and others (*ca.* 1988), and originally identified in map view, this boundary separated what was termed the Exploits and Notre Dame subzones of the Cambro-Ordovician Dunnage Zone. Tectonostratigraphic classification of RIL postdated recognition of the stratified rocks of the Buchans–Robert's Arm belt as being Ordovician and not Silurian (Dunning *et al.*, 1987) but it had predated the plate tectonic concepts of composite Ganderia and composite Laurentia (van Staal *et al.*, 2009) as some of the dynamic 3-D building blocks of the Newfoundland Appalachians. Recently, it has been suggested that the Red Indian Line be referenced to as the Mekwe'jit Line (*cf.* White and Waldron, 2022)

Traditional RIL boundary. Traditionally, RIL has been drawn at the northwest and northeast limit of the Exploits Subzone's Middle Ordovician strata that are found within the Victoria Lake, Wild Bight, Exploits and the Summerford groups or, alternatively, the conformably overlying Late Ordovician strata of the Shoal Arm Formation, the Lawrence Harbour Formation and the Badger Group. This boundary represents the local geological expression of the arcuate Red Indian Line in north-central Newfoundland.

Regional RIL boundary. The regional scale RIL has been traced throughout the Appalachian Mountains of eastern Canada and the United States (*e.g.*, Hibbard *et al.*, 2006; and others) and has been interpreted by other workers to extend, along strike, into the Caledonian Mountains of Ireland, Scotland and Norway (Roberts *et al.*, 2007; Chew and Strachan, 2013).

Red Indian Line thrust zone. This is a long-lived structural zone of mainly imbricate thrust and reverse faults in the central part of the Newfoundland Appalachians that had affected the Late Ordovician and older marine stratified rocks of both the Notre Dame and Exploits subzones, and that were focussed on the regional hangingwall and footwall sequences of the RIL of north-central Newfoundland. The thrust faults that deform the terrestrial strata of the adjacent Silurian and Carboniferous basins are not considered part of the RIL thrust zone.

Red Indian Line (orogenic) suture. As seen on deep seismic sections of the Newfoundland Appalachian crust and MOHO (*e.g.*, Quinlan *et al.*, 1992; and others), the RIL suture comprises a bipolar crustal-scale shear zone (northwest-dipping pro shears and southeast-dipping retro shears) separating, at surface, the opposing peri-Gondwanan and peri-Laurentian margins of the Cambro-Ordovician Iapetus Ocean, and spanning the interpreted extensional accretionary and collisional orogenic evolution (*cf.* Collins, 2002; Cawood *et al.*, 2009) of the Appalachian Central Mobile Belt.

Buchans–Robert's Arm (BRA) belt. A relatively narrow but laterally extensive belt (30 x 300 km) of mineralized Early to Middle Ordovician volcanic and associated sedimentary rocks recently described and discriminated from adjacent magmatic belts by Swinden and others (*ca.* 1997) and Zagorevski and others (*ca.* 2006). The BRA belt was distinguished, in part, by its unique isotopic and chemostratigraphic signature and was interpreted to lie within the eastern part of the peri-Laurentian Notre Dame Subzone. The BRA belt is geographically situated to the west of the Cottrell's Cove volcanic belt of central Notre Dame Bay and to the east of the Eastern ophiolite belt of western Notre Dame Bay.

Roberts Arm Group. This group of Ordovician stratified rocks occurs in the northern part of the Buchans–Robert's Arm belt and within the rocks assigned to the Robert's Arm volcanic belt, lying to the southeast of the Early Ordovician (*ca.* 480 Ma) Annieopsquotch ophiolite belt and the late Early Ordovician (478–473 Ma) arc plutonic rocks of the Hall Hill and Mansfield Cove igneous complexes. Some 55 km farther southwest, near Little Joe Glodes Pond, the oldest known rocks in the SRAVB are tectonically juxtaposed with the sheeted metatonalite, metagabbro and banded amphibolite bodies of the Early Ordovician Hungry Mountain Complex. This amphibolite facies metamorphic unit (uppermost AAT) was thrust above the weakly metamorphosed strata of the Buchans Group near the Buchans Mine town, and had also been emplaced above low-grade volcanic rocks within the age equivalent (*ca.* 471 Ma) part of the SRAVB. Such strata are probably older than many of the rocks comprising the type area of the Roberts Arm Group.

Esphenshade (1937) first mapped the extreme northeast part of the Robert's Arm volcanic belt (and some of its mineral deposits) in a small area near the coast line of Pilley's Island, Sop's Arm and Badger Bay for the Geological Survey of Newfoundland. There, he had erroneously assigned the well-exposed rocks of what would be subsequently called the Roberts Arm Group (and the overlying Lushs Bight Group) to what he locally termed the Pilleys Series (now defunct). In the northwest-dipping Robert's Arm part of this succession, Esphenshade (*op. cit.*) originally recognized what he deemed to be the older pillowed lava and basaltic strata of the original Crescent Lake Volcanics and the younger turbidite sandstone and other sedimentary strata of the original Crescent Lake Formation. These postulated Late Ordovician to Silurian volcanic rocks (and marine redbeds) were thought to have been stratigraphically underlain by the fossil-bearing Late Ordovician sedimentary strata that had been discovered in the Badger Bay area in the 1920s and 1930s (and subsequently correlated by S. Henry Williams (1991, 1995) with the Point Leamington Formation and Lawrence Harbour Formation, respectively). The Crescent Lake Volcanics and the Crescent Lake Formation are the only two, formally recognized, lithostratigraphical components of the Roberts Arm Group (*see* Lexicon of Canadian Stratigraphy, Volume VI, Atlantic Region, 1985).

The Ordovician Roberts Arm Group was redefined by Harold Williams (1963), who considered the lower boundary of the original two formations of the Roberts Arm Group to be everywhere faulted, in particular their lower contact with the underlying strata of the defunct lower "Badger Bay Series" (the conformable Middle to Late Ordovician lithostratigraphical succession of the Gull Island Formation of the Badger Group, the graptolitic Shoal Arm Formation and the Pennys Brook Formation of the Wild Bight Group). The original Crescent Lake Formation and the Crescent Lake Volcanics (Crescent Lake tholeiites) were remapped and extended inland to the southwest (Bostock, 1988), who assigned them to the Ordovician volcano-plutonic Roberts Arm Group, although he was uncertain about their primary depositional order. Bostock (1988) considered that the contact between the rocks of his Robert's Arm terrane and the underlying rocks of the Sops Head Complex to be a regional scale fault. The concept of the Red Indian Line as a fundamental terrane boundary had yet to have been formulated.

Cottrells Cove Group. This is an Early–Middle Ordovician volcanic and associated sedimentary rock group (Dec and others, *ca.* 1997) located to the north of the type area of the peri-Gondwanan Exploits Group of the Exploits Subzone. Viewed regionally, it is considered as a lateral equivalent of some of the peri-Laurentian rocks in the Buchans–Robert's Arm belt. In the most recent Lexicon of Canadian Stratigraphy for the Atlantic Region (1985), Paul Dean had included the basal Late Ordovician–Early Silurian Boones Point Complex with the overlying Moores Cove sedimentary and Fortune Harbour volcanic rocks of his Cottrells Cove Group and had correlated its olistrostromal and partially broken formations with those of the Sops Head Complex, which was observed to lie beneath the rocks of the Roberts Arm Group along strike farther west.

Badger Basin/basin. In this report, the name Badger Basin or Badger basin is locally used as a sedimentological–structural term to describe any shortened Late Ordovician and/or Early Silurian depocentre that had developed above the depositional substrate of the western and central Exploits Subzone. The marine deposits of the Badger basin are considerably older than the terrestrial Silurian deposits of the Botwood and Springdale basins and, in places, contain sediment derived from a local peri-Gondwanan source area within the extinct Victoria Arc and the adjacent Penobscot Arc (*see* Figure 2). The presence and distribution of individual depocenters (*i.e.*, discrete turbidite-hosted sub-basins) had possibly controlled the location of the present structural basins in which the strata of the Badger Group are disposed (*cf.* Arnott *et al.*, 1985; O'Brien 2012).

Badger retro-arc foreland basin. The Badger retro-arc foreland basin is an interpreted plate-tectonic feature located in the central part of insular Newfoundland and is thought to have originally developed on the scale of the Central Mobile Belt of the Appalachian Mountains (O'Brien, 2012). In contrast to a foredeep basin located near an accretionary wedge, accumulation of Badger basin sediment was postulated to have occurred in a synorogenic trough situated in a tectonically depressed region (on the back-arc side of a contemporaneous island-arc) and in front of an advancing or an encroaching interior thrust belt (*i.e.*, back-arc style as opposed to peripheral type).

Northern part of the Robert's Arm volcanic belt (NRAVB). The acronym NRAVB makes geographical reference to the first mapped and best exposed part of the Robert's Arm volcanic belt, including the type area of the Ordovician Roberts Arm Group and other components of Kerr's (1996) Robert's Arm exotic terrane complex and Thurlow's (1996) Spencer's Dock antiformal thrust stack. However, it excludes the Middle Ordovician rocks assigned to the Sops Head Complex.

Southern part of the Robert's Arm volcanic belt. The acronym SRAVB makes geographical reference to the relatively poorly exposed part of the base- metal–mineralized Robert's Arm belt mapped by the Geological Survey of Canada after Newfoundland's entry into the Canadian confederation. Situated to the northeast of the Buchans Group and the Red Indian Lake Group, and including stratified rocks other than those previously assigned to the Roberts Arm Group, it is a descriptive (non-lithostratigraphical) term initially used by Swinden and Sacks (1986) to describe the faulted complex of stratified rocks subsequently included in the 'subduction zone-generated' AAT (*cf.* Zagorevski *et al.*, 2006).

Rocks of southern Robert's Arm volcanic belt. This usage, which is more restrictive, refers to the marine Ordovician stratified rocks in the SRAVB outcropping in the region surveyed on 1:50 000 scale by Swinden and Sacks (1996) and Dickson (2000a, b, 2001), and systematically mapped on 1:25 000 scale by O'Brien (2009, 2016a–c), but it excludes the terrestrial strata mapped in detail at the margins of the adjacent Late Ordovician, Silurian and Carboniferous sedimentary basins. The SRAVB includes several tectonic panels composed of volcanic schist, paragneiss and migmatite that do not necessarily have their protoliths in the Ordovician volcanosedimentary strata and subvolcanic intrusions previously assigned to the original Roberts Arm Group. In the Burnt Pond area, alkali-basalt flows and siltstone turbidites similar to those recorded in the upper part of the Sops Head Complex have been previously assigned, correctly or not, to the SRAVB.

2. REGIONAL STRATIGRAPHY AND STRUCTURE OF THE SOUTHERN ROBERT'S ARM VOLCANIC BELT (SRAVB)

Fault-bounded tectonic panels of stratified rock units that range throughout much of the Ordovician are structurally intercalated and, in places, stratigraphically dismembered within regionally folded thrust stacks developed to the northwest and southeast of the traditional RIL (*e.g.*, Rogers *et al.*, 2005 a, b; O'Brien, 2016a, b, c; Figures 2, 3A). In the Notre Dame Subzone, even the structurally thickest and most extensive panels are, however, laterally discontinuous, and thus any one regional cross-section of the Robert's Arm volcanic belt is geologically incomplete.

In the SRAVB, the tectonic panels of mainly mafic extrusive rocks are generally composed of calc-alkaline island-arc lavas or, alternatively, tholeiitic back-arc and within-plate flows (Sarioglu, 2007). They are arranged in jasperite-, or limestone-, or wacke-bearing volcanic belts up to 25 km long (O'Brien, 2016, a, b, c). Different ages and types of mudstone-rich epiclastic sedimentary rocks are generally preserved within discrete turbidite basins separated by the adjacent volcanic rock sequences (Figure 3B).

In most tectonic panels within the SRAVB (shown, in part, in Figure 4), coarsening-upward turbidite sequences are generally coupled with different types and ages of volcanic rock formations. The marine volcaniclastic sedimentary strata are deposited above, or are individually tectonically linked to, several unique intervals of bimodal pyroclastic strata. These are typically situated on the faulted hangingwall side of a particular basin margin. The varying age and geochemistry of the subordinate intercalated felsic volcanic strata (G.R. Dunning and H.A.I. Sandeman, personal communication, 2020) point to tectonomagmatically discrete episodes of eruption within most of the sedimentary successions of the various structural basins shown in Figure 3B.

REGIONAL STRATIGRAPHY AND STRUCTURE

Swinden and Sacks (1986, 1996) and Swinden *et al.* (1997) employed the term Robert's Arm volcanic belt (RAVB) to include much of the marine volcanic and sedimentary strata previously assigned to the Ordovician Roberts Arm Group and, in particular, to rocks occurring northeast of the Ordovician Buchans Group in the SRAVB (*cf.* Kalliokoski, 1954; Williams, 1963; Dean, 1977; Kean and Jayasinghe, 1982; Evans *et al.*, 1994).

In the northern part of the SRAVB, between Great Gull Lake and Halls Bay, and in the west near Skull Hill and the valley of South Brook (Figures 2, 3B and 4), these are mainly phyllitic volcanic strata, low-grade slates and interbedded wackes that preserve abundant primary depositional features. However, farther south and east, higher grade metamorphic rocks were excluded from the Ordovician rock group but included in the SRAVB. The schist and gneiss belts outcropping near upper Burnt Pond, eastern Great Gull Lake, eastern Dawes Pond, upper Rocky Brook and southern Powderhorn Lake are tectonically juxtaposed with rocks to the northwest that were formerly assigned to the Roberts Arm Group. These amphibolite-facies metamorphic rocks are also faulted against anchizone (CAI<2; F.H.C. O'Brien, personal communication, 2000), and chlorite zone Late Ordovician turbidites of the type Badger Group located farther southeast near Badger Lake and Badger Brook (Dickson, 2001).

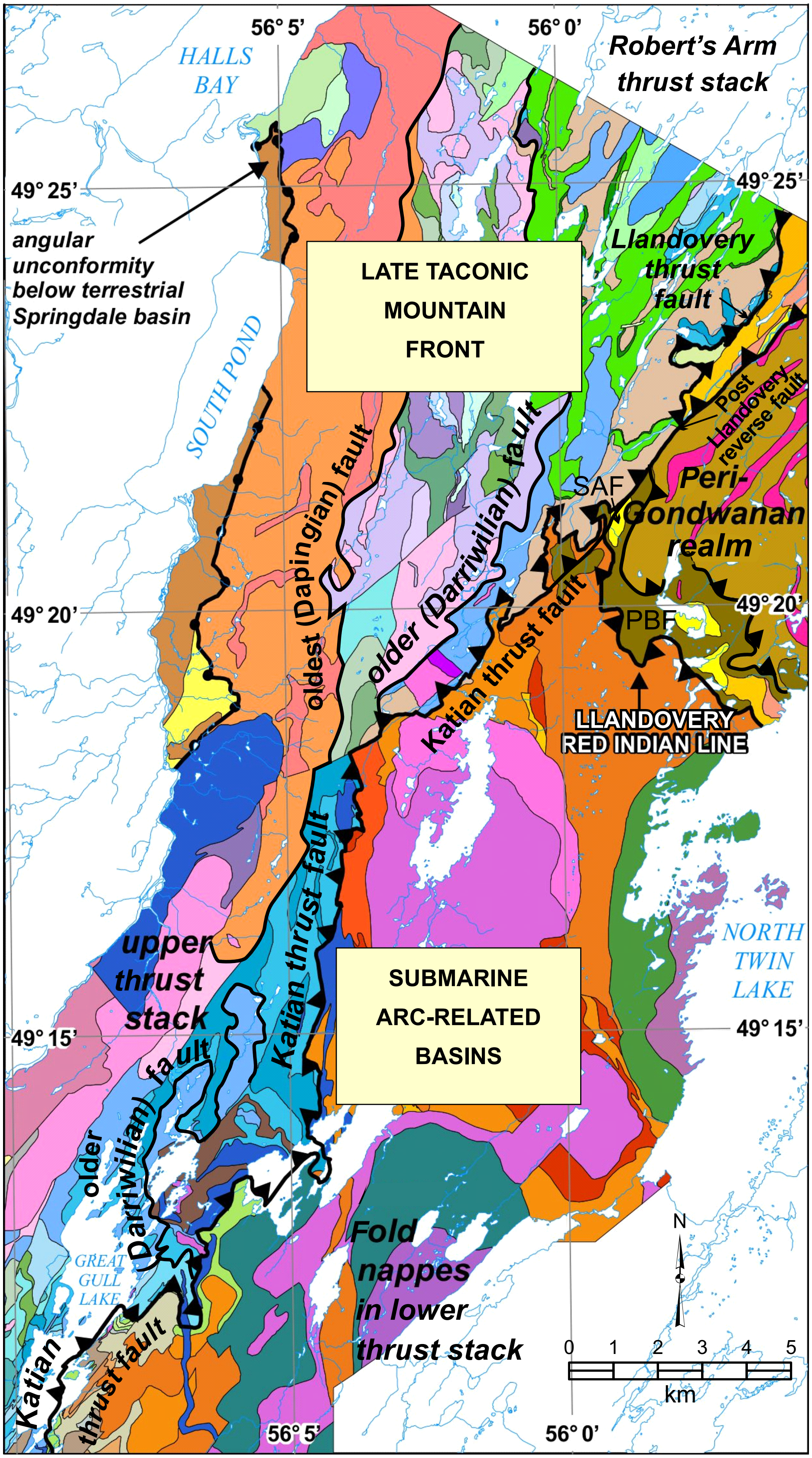


Figure 3A. *Lithotectonic sketch map showing the upper and lower segments of the Robert’s Arm (AAT) thrust stack in the Halls Bay–South Pond–Great Gull Lake area, highlighting the constituent volcanic arc and arc-related submarine basins and the folded thrust that marks the upper boundary of the lower AAT assemblage. Most of these structural–sedimentological basins are partly preserved in the fold nappes of the lower thrust stack. A postulated series of Dapingian, Darriwilian, Katian and Llandovery faults are depicted within the Robert’s Arm thrust belt in the region between Halls Bay and North Twin Lake. Undersea structures interpreted as forming a late Taconian mountain front occur in the upper AAT sequence and were developed in Early and Middle Ordovician plutonic and volcanic rocks; several regional fault blocks are present, one demarcated by a possible Dapingian fault at the structural base of the Hall Hill Complex (HHC) and another delimited by a possible Darriwilian fault at the structural base of the Gullbridge Tract (GT;* see *Figure 3B). The Middle Ordovician Iapetan arc-ophiolite suite of the Catamaran Brook Tract (CBT;* see *Figure 3B) was bounded by a probable Katian fault structure and may have originally lain to the present day southeast of the late Taconic mountain front. In the area west of North Twin Lake, the rocks of the Pennys Brook Formation of the Wild Bight Group, the Sops Head Complex and the Shoal Arm Formation are postulated to be bounded by folded Llandovery thrust faults at the Red Indian Line.*

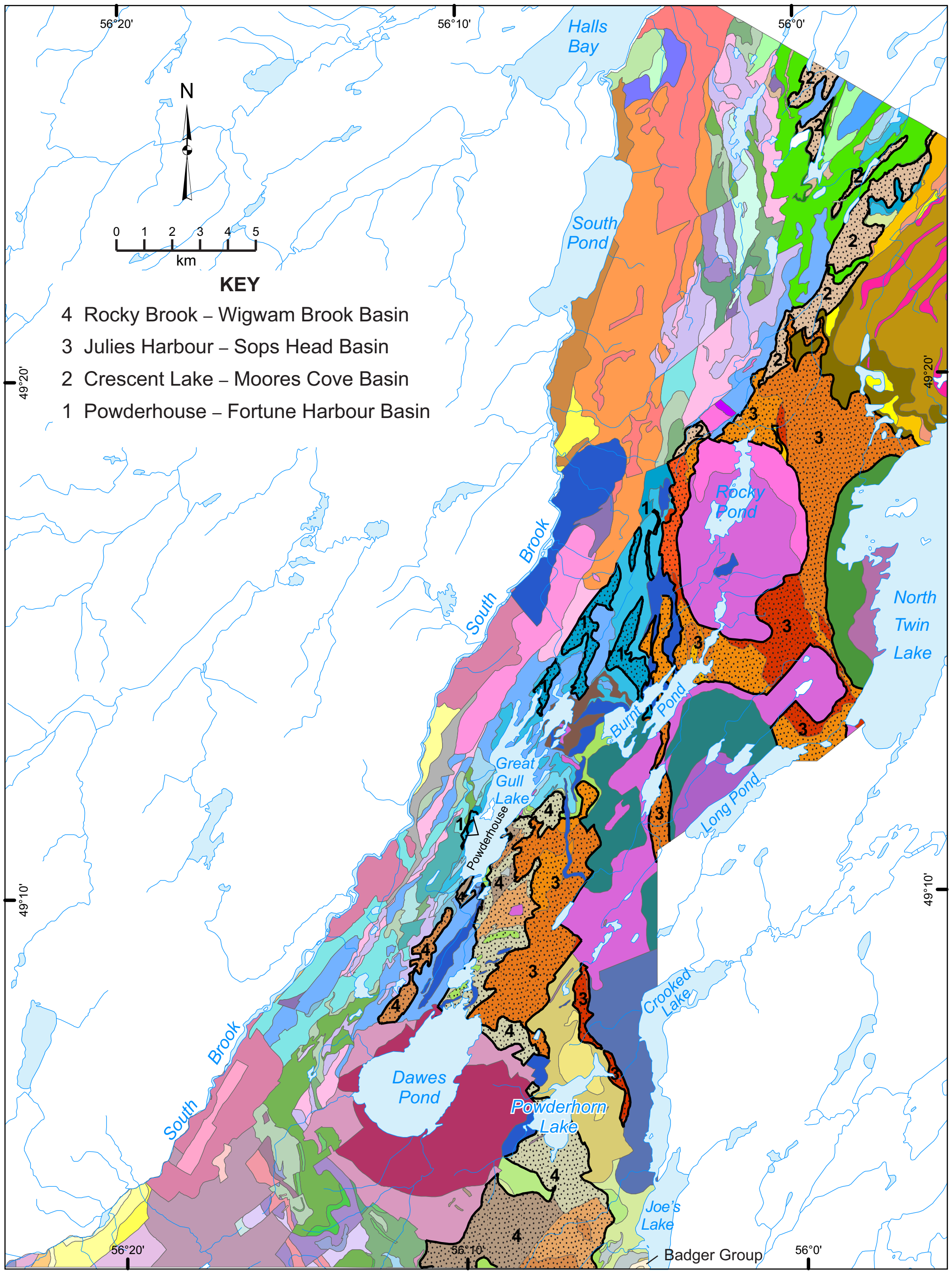


Figure 3B. *Lithotectonic sketch map showing the disposition of four regional stratigraphical–structural basins (screened pattern) located within the southern part of the Robert's Arm volcanic belt. From oldest to youngest, they are: Powderhouse–Fortune Harbour basin (1) of the Gullbridge volcanic belt, Crescent Lake–Moores Cove basin (2) of the South Brook volcanic belt, Julies Harbour–Sops Head basin (3) of the Herring Cove–Tommy's Arm volcanic belt, and Rocky Brook–Wigwam Brook basin (4) of the Catamaran Brook volcanic belt. Of these, the youngest two basins are situated within the lower AAT sequence of this report along with the structurally underlying rocks of Powderhorn Lake volcanic belt. Joes Lake strata in the Catamaran Brook volcanic belt (substrate of Basin 4) possibly comprised a late Darriwilian marine upland, at least in the vicinity of the olistostromal melange of the Sops Head Complex (SHC). However, in that part of the lower AAT lying seaward of the mountain front and closer to the Red Indian Line, continued uplift of the Sops Head Melange and the accreted Catamaran Brook Arc occurred after Late Ordovician thrust faulting of the Sandbian Shoal Arm Formation. The metamorphosed black pyritic mudstones of the Powderhorn Lake volcanic belt have unknown stratigraphical relations with age equivalent Late Ordovician grey mudstones in the Rocky Brook–Wigwam Brook basin or with the graptolitic slates at the bottom of the adjacent Badger Basin.*

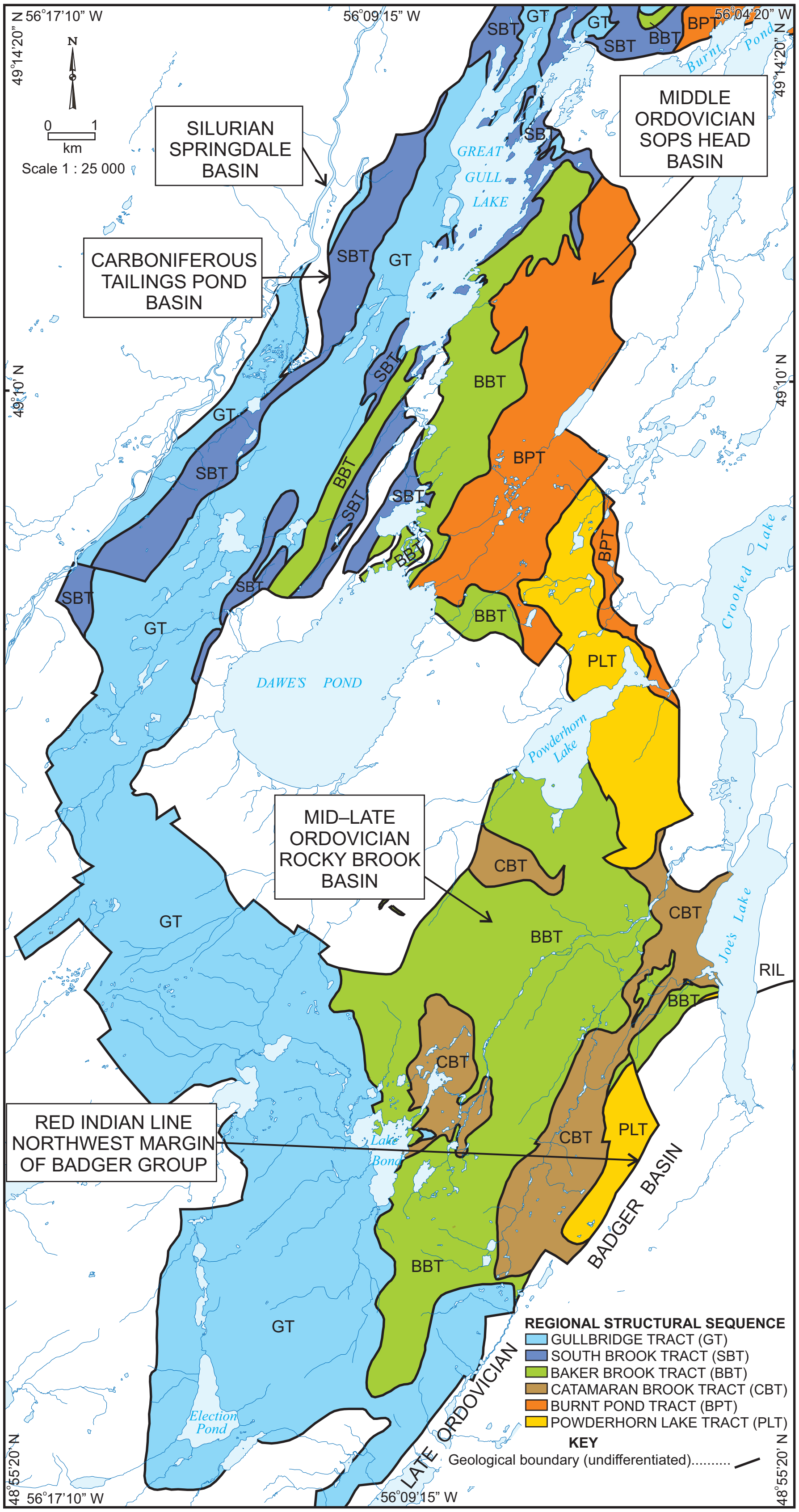


Figure 4. *Tectonic map illustrating the disposition and nomenclature of the six regional structural tracts that comprise the southern Robert's Arm volcanic belt (SRAVB). Listed from the structurally highest to lowest tracts, these are the Gullbridge Tract (GT), the South Brook Tract (SBT), the Baker Brook Tract (BBT), the Catamaran Brook Tract (CBT) and the Powderhorn Lake Tract (PLT). The Middle Ordovician Sops Head basin (Burnt Pond Tract; BPT) and the Middle to Late Ordovician Rocky Brook basin (Baker Brook Tract; BBT) are the largest sediment-dominated depocentres situated in the structurally lower part of the Robert's Arm thrust stack. The faulted margins of younger Ordovician, Silurian and Carboniferous basins are locally preserved within the study area and are also denoted in Figure 4. From oldest to youngest, the cover basins that lie tectonically adjacent to the SRAVB rocks are: 1) the Late Ordovician to Early Silurian Badger basin, 2) the Middle Silurian Springdale basin and 3) the Early Carboniferous Tailings Pond basin.*

TECTONIC ELEMENTS OF THE AAT THRUST STACK IN THE SRAVB

The AAT thrust stack within the SRAVB is composed of a lithotectonic sequence of probable Early, Middle and Late Ordovician stratified rock units disposed within six regional structural tracts (Figure 4). Listed from structural-top to bottom, in regional stacking order from northwest to southeast, these are:

1. Gullbridge Tract (GT; lithostratigraphic divisions of mainly Floian felsic and mafic volcanic rocks),
2. South Brook Tract (SBT; lithostratigraphic divisions of possible Dapingian–Darriwilian volcanic and intrusive rocks),
3. Baker Brook Tract (BBT; lithostratigraphic divisions of mainly Darriwilian–Sandbian felsic volcanic and interbedded sedimentary rocks),
4. Catamaran Brook Tract (CBT; lithostratigraphic divisions of mainly Darriwilian mafic volcanic rocks),
5. Burnt Pond Tract (BPT; lithostratigraphic divisions of mainly Darriwilian sedimentary rocks), and
6. Powderhorn Lake Tract (PLT; lithostratigraphic divisions of mainly Darriwilian felsic volcanic and Sandbian sedimentary rocks).

Strata within all six of these discrete structural tracts were tectonically stitched together by the oldest known intrusive suite of syntectonic ultramafic and mafic metaplutonic rocks in the SRAVB, most probably between the Sandbian and the Llandovery.

In the past, most workers had assigned at least some of the non-hornfelsed parts of the constituent lithostratigraphic divisions within each of these structural tracts to various parts of the Roberts Arm or Buchans groups (*e.g.*, Kalliokoski, 1954; Dean, 1977; Kean and Jayasinghe, 1982). Subsequently, there has been considerable debate over their relative stratigraphical position and whether or not younger unrelated rock groups are also present (*e.g.*, *see* Pope *et al.*, 1990; Rogers *et al.*, 2005a). Furthermore, in search of marker beds, many earlier workers attempted to correlate certain volcanic or sedimentary rocks present in each tract listed above with several of the better exposed lithological units present in the greenschist-facies rocks of the northern Robert's Arm volcanic belt near the coast of Notre Dame Bay [NRAVB; *see* Glossary]. Historically, the most common correlation was made with the generally northwest-dipping tectonic panels of turbidite sandstone in the original Crescent Lake Formation (*cf.* Espenshade, 1937; Williams, 1963) and the associated Crescent tholeiitic basalts (Bostock, 1988; Kerr, 1996; Zagorevski and McNicoll, 2011).

Occurring to the southeast of the known Early Ordovician volcanic rocks in the SRAVB thrust stack, the last named Middle Ordovician rock units had previously been tentatively identified (*e.g.*, Kalliokoski, 1954; Dean, 1977; Swinden and Sacks, 1996; Zagorevski *et al.*, 2015) within certain parts of the South Brook, Baker Brook and Catamaran Brook tracts of this report. This hypothesis was purported to be strengthened by their correlation with the Middle Ordovician tholeiitic basalts and turbidites of the Moores Cove Formation of the Cottrells Cove Group, situated in the RIL hangingwall sequence, farther northeast in central Notre Dame Bay (Dean, 1977; Dec *et al.*, 1997; O'Brien, 2003). The Early and Middle Ordovician strata in the Buchans, Roberts Arm and Cottrells Cove groups have been previously assigned to the most southeastern part of the peri-Laurentian Notre Dame Subzone of the Dunnage Zone (Williams, H. *et al.*, 1988).

After their tectonic stitching and pre-Wenlockian assemblage, the entire suite of regional metamorphic rocks in the SRAVB was thrust toward the southeast, and emplaced above relatively low-grade lithological units from the western part of the Exploits Subzone of the Dunnage Zone and its Late Ordovician overstep sequence. Traditionally, in the study area, the RIL suture has been drawn at the structural top of the Late Ordovician part of the Badger Group (*e.g.*, *see* Glossary, and Figure 2).

YOUNGER OVERSTEP BASINS

In places along the northwest margin of the SRAVB, a regional unconformity separates marine Ordovician rocks in the upper AAT from terrestrial strata assigned to the Middle Silurian Springdale Group, although this erosional surface is commonly displaced by various post-Springdale Basin fault structures or the basal conglomerate and the unconformity are seen to be upside-down (Bostock, 1988; Kerr, 1996; O'Brien 2016a; Figure 3A). Near South Brook, above the uppermost tectonic elements of the SRAVB, the basal part of the Silurian terrestrial succession is mainly composed of polymict conglomerate, red pebbly sandstone, autobrecciated basalt flows, flow-banded rhyolite, lahar and a welded ash tuff, locally dated by U–Pb TIMS (432.4 +1.7/-1.4 Ma in Coyle, 1992; Kings Brook sequence of O'Brien, *ibid.*). These latest Llandoverian–earliest Wenlockian strata are the oldest known rocks within the Springdale Group cover basin (Coyle and Strong, 1987; Chandler *et al.*, 1987). They are interpreted to have been unconformably overlain by presumed Carboniferous redbeds in a pocket basin, localized along South Brook (Tailings Pond sequence; O'Brien, 2016b).

Cambro-Ordovician rock units that were probably originally onlapped by the basal terrestrial succession of the Springdale Group (Zagorevski *et al.*, 2015; O'Brien, 2016a, b, c) include the Furongian and older primitive oceanic-arc rocks of the Lushs Bight Group, the Tremadocian ophiolites of the Hall Hill and Hungry Mountain intrusive complexes, and the Floian continental margin volcanic-arc rocks of the upper AAT within the Gullbridge structural tract (SRAVB) as well as the Boot Harbour, Pilley's Island and Triton terranes (NRAVB). Although an angular unconformity has not been locally preserved, these sub-Springdale basement rocks were previously interpreted to have been accreted to the composite peri-Laurentian Iapetan margin (Middle Ordovician and older Notre Dame Arc) during the Dapingian initiation of the Taconic III–Late Grampian orogenic episode in central Newfoundland and west Ireland (*cf.* van Staal *et al.*, 2007; Hollis *et al.*, 2012). Although geochronological data are lacking from SRAVB rocks to locally support this assertion, Floian volcanic detritus has been reported in Darriwilian conglomerate in the NRAVB (*e.g.*, Zagorevski *et al.*, 2015).

UPPER PART OF ROBERT'S ARM THRUST STACK IN THE SRAVB

In the SRAVB, the Gullbridge and South Brook structural tracts comprise the upper to middle part of the AAT (*cf.* Zagorevski *et al.*, 2006) and, regionally, they lie tectonically below the Tremadocian ophiolite relics observed in the Hall Hill and Hungry Mountain intrusive complexes (Figure 2). Constituent stratified units from both of these tracts are, however, complexly thrust faulted and are tectonically imbricated with each other at map scale (O'Brien, 2016a). It is possible that the structurally highest panel of the SBT (the South Brook Basalt of Swinden and Sacks, 1996) represents a tectonic sliver of the *ca.* 473 Ma Lloyds River ophiolite complex (*cf.* Zagorevski *et al.*, 2015), as it locally lies above the GT rocks and below the older ophiolites of the *ca.* 480 Ma Annieopsquash ophiolite belt. In contradistinction, Pope *et al.* (1990) and Pudifin (1993) favoured a correlation with certain basalts observed in the footwall of the former Gullbridge copper mine (their Gull Pond Basalt of the Roberts Arm Group).

All volcanic rocks herein assigned to the GT are thought to be Early Ordovician and coeval with the oldest dated rocks in the type areas of the Buchans and Roberts Arm groups (*cf.* Dunning *et al.*, 1987; Sparkes, 2020). Volcanic-arc rhyolite domes and Pb-mineralized pyroclastic rhyolite flows are interpreted to form the oldest exposed internal division, and these are stratigraphically overlain by a calc-alkaline pillowed basalt sequence having interstratified island-arc tholeiite (Sarioglu, 2007). A succeeding bimodal pyroclastic succession associated with Cu–Zn VMS mineralization is capped by a felsic volcanic-derived wacke unit that comprises the uppermost preserved sequence in the GT (Powderhouse division; Figure 3B). Felsic tuffs from the Powderhouse division have yielded Early Ordovician magmatic zircons dated by U–Pb SHRIMP at *ca.* 472 Ma (Zagorevski *et al.*, 2015), thus indicating a Floian depositional age.

In the SRAVB, most tectonic panels assigned to the SBT structurally underlie the rocks of the GT. They are commonly disposed in thrust-bounded structural domes that create tectonic windows through the overlying GT rocks (*e.g.*, O'Brien, 2016a, b). The mainly pillowed basalt flows comprising the SBT are thought to be Middle Ordovician (mainly Darriwilian) and to be considerably younger than the rocks of the Gullbridge Tract. Its carbonate-bearing back-arc and ocean-island basalts, succeeding chert-bearing island-arc tholeiites and dominant N-MORB, T-MORB and E-MORB pillow lavas (Sarioglu, 2007) have been correlated, in part, with the variably enriched tholeiites of the Skidder Basalt and its Cyprus-type copper prospects, both of which were intruded by a suite of *ca.* 465 Ma trondjhemite dykes (Pickett, 1988; Swinden *et al.*, 1997; Zagorevski *et al.*, 2006).

In the Red Indian Lake area of central Newfoundland, such rocks are overthrust by the Early Ordovician rocks of the Buchans Group and have been previously interpreted as comprising part of an oceanic supra-subduction zone (SSZ) back-arc ophiolite, albeit much younger than most obducted ophiolites in western Newfoundland. It has been proposed that the Skidder Basalt represents the oldest exposed formation of the Darriwilian Red Indian Lake Group (Zagorevski *et al.*, 2006).

In the northern SRAVB, the tholeiitic basalt succession of the Black Gull Island division of the SBT may also include possible equivalents of the original Crescent Lake Volcanics (the Crescent tholeiite belt of Bostock, 1988), particularly in localities where the Black Gull Island rocks were thrust directly above the Deer Pond division of the Crescent Composite Tract (CCT; O'Brien, 2016a). Internal lithostratigraphic divisions of the CCT include the oldest Deer Pond tholeiitic basalts, a younger unit of maroon siliceous argillite and interbedded felsic pyroclastic strata correlated with the early Darriwilian (*ca.* 467–466 Ma tholeiitic arc rhyolites of Zagorevski and McNicoll, 2011), and a succeeding coarsening-upward turbidite sequence of siltstone, sandstone and conglomerate (*i.e.*, the upper sedimentary unit of the Deer Pond division; O'Brien, 2016a; Crescent Lake–Moores Cove basin of this paper; Figure 3B).

The uppermost Deer Pond polymictic conglomerate contains outsized detrital clasts interpreted as being derived from the Hall Hill ophiolite, the Mansfield Cove tonalite, the volcanic-arc rocks of the GT, and the clastic limestones and within-plate basalts of the South Brook and Crescent Composite tracts. Such Notre Dame Subzone sedimentary rocks are lithostratigraphically distinct from the middle Darriwilian sedimentary strata of the Red Indian Lake Group (Zagorevski *et al.*, 2006; Coombs *et al.*, 2012) and, though relatively thick, these conglomerates are not known to be any younger than early Darriwilian in the Crescent Lake Formation of the Roberts Arm Group or in the Moores Cove Formation of the Cottrells Cove Group (O'Brien, 2003, 2012). However, it is the structurally underlying younger Ordovician lithotectonic sequences belonging to the AAT that are the main focus of this report.

LOWER PART OF THE AAT IN THE SRAVB

All of the lithostratigraphical divisions making up the youngest part of the SRAVB (Figure 5) lie structurally below Laurentian margin rocks assigned to the GT or the SBT. Listed from probably oldest to youngest, they are the Joes Lake division, the Eastern Baker Lake Brook division, the Julies Harbour division, the Powderhorn Brook division and the Rocky Brook division (*see* Master Legend, O'Brien, 2016). In the study area, these rocks are complexly deformed and regionally metamorphosed, crosscut by synmetamorphic mafic–felsic intrusive sheets, intruded by a variety of post-metamorphic plutons marked by nested cone sheets, and injected by radial swarms of minor intrusions along late fault structures marked by silicified cohesive gouges (Figure 5). Most of the Late Ordovician and older stratified rocks comprising the upper and lower AAT are locally present within a small thrust-and-nappe belt in the study area in the most southeastern part of the SRAVB.

In ascending order, the Joes Lake division of the Catamaran Brook structural tract is composed of a cupriferous tholeiitic pillowed basalt unit, a calc-alkaline basalt and basaltic andesite unit, and an interstatified rhyolite breccia–basalt tuff unit having a ferruginous argillite capstone. Such Joes Lake strata were intruded by voluminous subvolcanic bodies of quartz-feldspar porphyry and porphyritic gabbro. The uppermost bimodal pyroclastic strata in the Joes Lake division (including the Crooked Lake felsic tuff of Zagorevski *et al.*, 2010) are thought to be considerably younger than similar facies rocks in the GT.

The Eastern Baker Lake Brook division of the Baker Brook structural tract begins with a unit of metarhyolite tuff, interbedded with slumped hematitic argillite and locally includes a basal olistostrome dominated by banded rhyolite olistoliths. It is succeeded by a thick-bedded tuffaceous metawacke unit marked by laminated intervals of black sulphidic pelite scoured by rhyolite pebble conglomerate. The basal unit is interpreted to conformably overlie the Joes Lake succession; the upper unit may be partly correlative with the Eastern Felsic Tuff in the youngest preserved part of the Gullbridge mine sequence (Pope *et al.*, 1990).

The variably metamorphosed sedimentary strata of the Julies Harbour division of the Burnt Pond structural tract are partly composed of feldspathic sandstone turbidite overlain by phyllitic siltstone turbidite and banded sulphidic argillite. These contain rare tuffaceous lenticles of enriched tholeiitic basalt (Sarioglu, 2007), a feature that distinguishes the Julies Harbour turbidite basin from the Badger turbidite basin. Hornfelsic schist units distinguished by bands of cordierite–andalusite–magnetite–illmenite-schist also comprise part of the Julies Harbour division. These are thrust faulted against a Julies Harbour migmatitic paragneiss unit intruded by amphibolite dykes and granodioritic orthogneiss. Based on correlation of the migmatized amphibolite and paragneiss units exposed in the Burnt Pond–Powderhorn Lake area with those seen in the adjacent Twin Lakes–Middleton Lake area (Dickson, 2000a, b), deposition of the Julies Harbour turbidite succession in the BPT is interpreted to predate intrusion of the late Darriwilian Mary Ann Granite (463 +6/-4 Ma; G.R. Dunning, unpublished data, 2000).

The Powderhorn Brook division of the Powderhorn Lake structural tract is made up of an older metarhyolite unit composed of sphalerite-bearing volcanic breccia and graded crystal-lithic tuff, and a younger metapelite unit characterized by sulphidic cordierite–garnet–hornblende–andalusite–staurolite-schist. Although these regionally metamorphosed volcanic and sedimentary units are recumbently folded and thrust faulted, their original stratigraphically gradational boundary is locally preserved. The stratigraphical base of the Powderhorn Brook division is not exposed. The SRAVB strata from the Powderhorn Brook division crop out in a fault-bounded structural dome within the lowest preserved part of the AAT thrust stack (Figure 5).

The Rocky Brook division in the upper part of the Baker Brook structural tract contains some of the youngest known strata preserved in the SRAVB. The succession begins with a unit of flow-banded rhyolite, agglomerate and rhyolite autobreccia, and size-graded quartz-feldspar tuff and continues with a gradationally overlying unit of pebbly and sandy volcaniclastic wacke having abundant rip-up clasts of grey laminated mudstone. A succeeding unit of red siltstone turbidite is host to debris flows and slump sheets intruded by quartz-feldspar porphyry dykes and calc-alkaline gabbro sills. The uppermost preserved unit contains graded volcaniclastic wacke beds interstratified with ash-tuff layers and, based on the correlation with similar intervals in the Wigwam Brook Formation, is considered to be Late Ordovician (Zagorevski *et al.*, 2007b).

The Late Ordovician and older Rocky Brook stratigraphical succession is best developed and most complete where it is regionally right-side-up and northwest-dipping in the western part of the Baker Brook structural tract. In the vicinity of Lake Bond, such strata structurally underlie an older northwest-dipping and northwest-facing volcanosedimentary sequence (GT) from the Gullbridge structural tract (O'Brien, 2009). However, immediately beneath the thrust sheet carry-

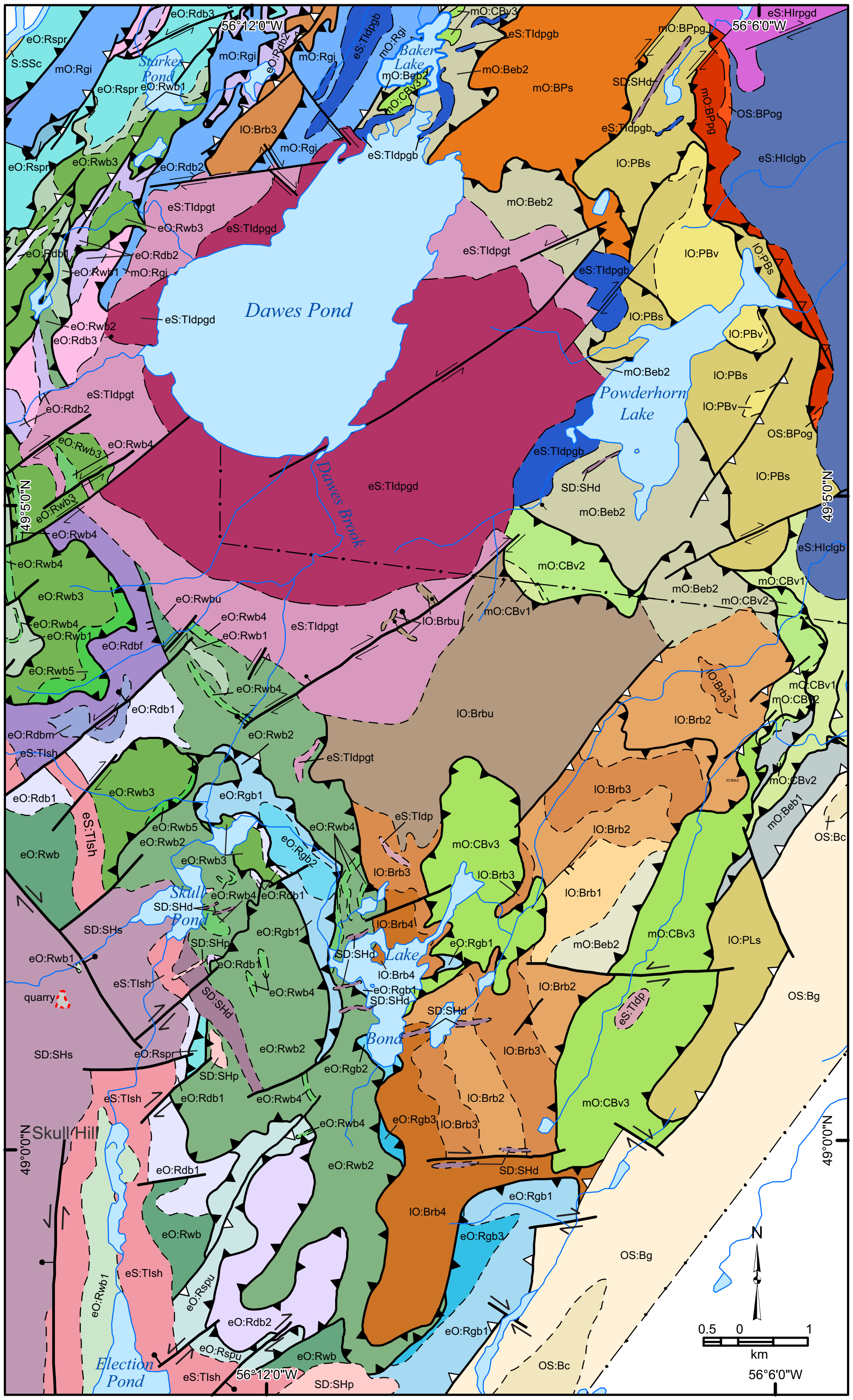


Figure 5. *Detailed geological map of the Dawes Pond–Lake Bond–Powderhorn Lake study area on 1:25 000 scale illustrating the disposition of the major rock units found in the most southeast part of the Robert's Arm volcanic belt (SRAVB). Internal lithostratigraphical boundaries and the contacts of intrusive units are dashed; different types and various ages of fault structures affecting or delimiting the SRAVB rocks are also depicted. The accompanying legend occurs on separate pages and describes only the rocks units that outcrop in the study area.*

LEGEND

POST-ORDOVICIAN INTRUSIVE ROCKS

Posttectonic Intrusions
Late Silurian to Early Devonian(?)

Skull Hill Quartz Syenite

SD:SHs Red to pink, medium-grained, isotropic, potassium feldspar porphyritic to equigranular syenite, light-grey to pink, medium-grained equigranular quartz monzonite, dark-red, fine-grained micrographic porphyry and hematitic granophyre; each intruded by conjugate dykes of porphyritic and aphanitic diabase, quartz porphyritic granite and aplite (Skull Hill Quartz Syenite, cf. Kean and Jayasinghe, 1982; Williams et al., 1985; Evans et al.,

Skull Hill porphyry

SD:SHp Quartz-feldspar porphyry and porphyritic hornblende–biotite microgranite (apophses and epipheses in Unit *SD:SHs*); satellite bodies of saussuritized felsic porphyry having abundant pyrite cubes, sericite and secondary albite; in the area southeast of Election Pond, later sheets of fresh gabbro intruded by fractured diabase dykes and offset aplite veins (possibly part of Unit 12a of Evans et al., 1994)

Skull Hill diorite

SD:SHd Dark-grey, medium-grained, equigranular diorite and subordinate, coarse-grained quartz-bearing gabbro occurring as satellite bodies and marginal sheets to the Skull Hill Quartz Syenite (predating units *SD:SHs* and *SD:SHp* in certain localities); in places, silicified pyritic diorite displaying hematite–carbonate–sericite pseudomorphs after plagioclase and having common antiperthite; includes part of Unit SD:gd of Swinden and Sacks (1996)

Topsails Igneous Suite
Early to Late Silurian(?)

eS:TI Intrusive rocks of the Topsails igneous suite (cf. Whalen, 1989), including plutonic and hypabyssal rocks of the Topsails intrusive suite (cf. Williams et al., 1985; Whalen and Currie, 1988)

Dawes Pond granite

eS:TIdpgt Mainly massive, isotropic, medium-grained, light-grey, potassium feldspar-phyric quartz monzonite having abundant biotite, titanite and ilmenite; minor, fine-grained, porphyritic biotite granite, high-silica granite and microgranitic porphyry; variably oriented enclaves of pyrhotite-bearing cordierite schist (Baker Brook structural tract of the Robert's Arm volcanic belt) in the southeastern part of the Dawes Pond granite and large accidental xenoliths of actinolite schist (Gullbridge structural tract) in the northwestern part of the map unit; all of the above plutonic rocks hosting swarms of minor intrusions, including subvertical sheets of quartz-feldspar porphyry, multiple diabase dykes, and aplite veins; Unit eS:TIdpgt rocks are complexly cross faulted and partially surround the Dawes Pond granodiorite (Unit eS:TIdpgd, see below)

Dawes Pond granodiorite

eS:TIdpgd Mainly massive, isotropic, medium-grained, light-grey to pink, hornblende–biotite granodiorite; a highly magnetic, coarse-grained, hornblende-rich granodiorite marked by copious cognate igneous xenoliths (or mafic restite) and having partially replaced enclaves of biotite-bearing epidiorite; along the margin of Unit eS:TIdpgd, near Powderhorn Lake, non-hornfelsed (unmetamorphosed) granodiorite back veined by porphyritic pillowed gabbro; unaltered sheets of equigranular quartz diorite crosscutting epidotized pillowed gabbro and glomerophyric gabbro having abundant magnetite and secondary titanite; many of the pre-granodiorite mafic intrusions located near the pluton margin are net-veined but unfoliated

Skull Hill Brook granodiorite

eS:TIsh Sporadically exposed, massive, light-grey, medium-grained, equigranular, hornblende–biotite granodiorite displaying commingling relationships with iron-oxide-rich gabbro; in places, granodiorite contains partially digested screens of coarse-grained, equigranular, isotropic gabbro transitional to fine-grained, xenocrystic or porphyritic gabbro; there, gabbros having abundant epidote–quartz veinlets are intruded by granodiorite dykes. In other areas, the granodiorite intrusions illustrates zones of pillowed to globular gabbro showing disaggregated chilled margins or displaying cuspate and lobate edges; in a few localities, gabbroic dykes belonging to Unit *eS:TIsh* display straight chilled margins where they crosscut granodiorite host rocks. Pyritic quartz-feldspar porphyry, similar to rocks in the adjacent body of Unit *SD:SHp*, intrudes Unit *eS:TIsh* granodiorite near Election Pond; southwest of Dawes Pond, Unit *eS:TIsh* granodiorite includes quartz-bearing net-veined diorite displaying iron-oxide–amphibole pseudomorphs after orthopyroxene phenocrysts, as seen elsewhere in Unit *SD:SHd* diorite

Topsails - Hodges Hill Plutonic Rocks
Early-Mid Silurian

Rocky Pond granodiorite

eS:HIrpgd Mainly massive, isotropic, light-grey, medium-grained, equigranular granodiorite having localized trains of biotite-bearing diorite fragments (possibly coarse-grained cognate xenoliths); subordinate, hornblende-bearing porphyritic granodiorite characterized by matrix-hosted calcite and disseminated epidote together with widespread pseudomorphs of saussurite after plagioclase and chlorite after amphibole; in places, hematite-rich, pyritic, quartz-phyric, potassium feldspar-bearing granodiorite hosting coarse pegmatite veins, particularly near its intrusive contact with country rock schist and older metamorphosed granite; locally, strongly jointed and fractured, pink to red, albite-bearing granodiorite developed in proximity to chlorite–epidote alteration zones marked by abundant kink bands, subhorizontal slickenlines and silicified fault gouge; along the western margin of the intrusion, abundant granodiorite sheets separating unmetamorphosed screens of quartz diorite and pyroxene-bearing hornblende porphyry (possibly related to Unit *S:HItlqd*)

Hodges Hill Intrusive Suite
Early Silurian and Younger?

Crooked Lake gabbro

eS:HIclgb Mainly massive, isotropic, dark-green, very coarse-grained, equigranular pyroxene gabbro emplaced into several of the structurally lowest tracts of the Robert's Arm volcanic belt; locally, grey-green, medium-grained, steeply dipping layered gabbro crosscut by composite sheets of quartz diorite and leucodiorite; subvertical swarms of flow-layered quartz-feldspar porphyry and en echelon porphyritic diabase dykes that extend from the margin of the Crooked Lake gabbro southwestward into its stratified host rocks; in the northwestern part of Unit *eS:HIclgb*, isotropic gabbro is locally silicified, bleached and intruded by veins of medium-grained granodiorite and fine-grained granite porphyry, particularly along east-northeast-trending systematic fractures in the gabbroic host rock; in contrast, near the lower reaches of Rocky Brook, the Crooked Lake gabbro is chilled against, and also intruded by, a small subvertical body of granodiorite that is similar to the Rocky Pond granodiorite (Unit *eS:HIrpgd*)

Legend for Figure 5.

Syn-metamorphic Intrusions

Late Ordovician – Early Silurian

Dawes Pond metagabbro

eS:TIdpgb Mainly grey-green, medium-grained granoblastic metagabbro; marginally foliated metagabbro sheets that crosscut and include screens of previously foliated and folded rocks (particularly as seen in flat-lying metabasites located at the tectonic base of the South Brook structural tract or in the tectonically underlying porphyroblastic metaturbidites of the Baker Brook structural tract); less common, regionally folded bodies of coarse-grained metapyroxenite locally illustrating relict clinopyroxene-rich cumulate bands at high angles to a secondary chloritic foliation; stratigraphically transgressive bodies of porphyritic mafic schist (having a penetrative dynamically recrystallized foliation and less common extension lineation) transitional to mafic granofelsic schist (having a poorly defined schistose foliation overgrown by granoblastic actinolite and biotite); a widespread, light-grey, highly sucrose, isotropic mafic granofels (statically recrystallized throughout on the microscopic scale despite being locally fabric retentive on the mesoscopic scale); associated minor intrusions, viz., conjugate sets of composite aphanitic and porphyritic diabase dykes intruded across gently-plunging open folds of porphyritic metapyroxenite sills; viz., epidotized diabase dykes and coeval quartz porphyry intrusions emplaced into fold hinge zones and intruded along vertical fault breccias made up of silicified porphyroclasts of metagabbro and host metasedimentary schist; post-schistosity fibrous veins in metagabbro filled by syntaxial growths of albite–epidote–ferroan carbonate–calcite–clinozoisite–titanite–spessartine–pennite–quartz ± sphalerite and arsenopyrite

Tower Hill felsic orthogneiss

OS:BPog Mainly granodioritic orthogneiss, schistose granodiorite, metaporphyritic amphibolite, and nebulitic granite in agmatite; dominantly, light-grey, medium-grained, well foliated quartz–plagioclase–hornblende–biotite gneiss having discontinuous dark-green layers of hornblende-bearing restite concordant with gneissosity; distorted podiform lenses of epidotized amphibolite within felsic orthogneiss; wispy-foliated granodiorite locally having a preferred alignment of zoned plagioclase phenocrysts; platey-foliated granodiorite having a ribboned shape fabric defined by flattened and dip-lineated grains of blue quartz; schistose granodiorite transitional to biotite-bearing mylonite in shear zones at the margins of country rock enclaves; folded granite dykes intruding across the metamorphic foliation in flaser-banded orthoamphibolites set in agmatite; granodioritic orthogneiss (and injection migmatite) hosting concordant leucogranite stringers and foliated diabase dykes that outline pinch-and-swell structures back veined by intrusive gneiss

SILURIAN AND OLDER STRATIFIED AND INTRUSIVE ROCKS

Terrestrial Strata Overlying Notre Dame Subzone (Dunnage Zone)

Post-Late Ordovician Regressive Overlap Sequence

Early to Late Silurian

Springdale Group

S:SSc Kings Brook conglomerate: Mainly boulder conglomerate, quartzose sandstone, volcaniclastic argillite and felsic porphyry; predominantly, light-grey, massive, clast-supported conglomerate marked by well-rounded cobbles and boulders of ignimbrite; light-grey, poorly stratified, granular to pebbly sandstone interbedded with conglomerate; subordinate, matrix-supported volcaniclastic argillite (lahar) marked by large angular blocks of porphyritic and aphyric rhyolite flows and bedded scoraceous tuff; in places, fine-grained lahar illustrating outsized fragments of slump-folded argillite and smaller clasts of laminated mudstone; minor, fine-grained, light-pink, quartz-feldspar porphyry dykes displaying flow-layered margins where crosscutting lahar and boulder conglomerate; rare, isotropic dykes of diorite porphyry intermingling with quartz-feldspar porphyry; rare, pink to red, poorly sorted, highly indurated beds of sandstone having subrounded clasts composed of partially preserved spherulites and embayed quartz prisms set in a hematite-rich matrix

ROCKS FORMED IN THE IAPETUS OCEAN

Dunnage Zone (Notre Dame Subzone)

Early to Middle Ordovician

Robert's Arm volcanic belt (northwest part)

Middle Ordovician(?)

South Brook structural tract (SBT)

mO:Rgi Black Gull Island pillowed tholeiite: Mainly pillow lava, ferruginous chert, pillow breccia and rare limestone; dark-grey, variably porphyritic, high-Fe or high-Mg tholeiitic basalts (Sarioglu, 2007), including titaniferous pillow lava, magnetic pillow breccia and mafic tuff; light-green, epidotized, chloritized and albitized basalt flows interstratified with dark-green laminated chert, locally intruded by stockworks of quartz–carbonate veins; pervasively silicified pillowed basalt transitional to chalcopyrite-bearing metabasite schist; chemostratigraphically, a dominantly arc tholeiite succession succeeded by a dominantly within-plate tholeiite succession; in probable ascending order, back arc basin basalt (BABB), transitional back arc basin basalt–ocean island basalt (Trans BABB–OIB), highly magnetic ocean island basalt (OIB), LREE-enriched mid oceanic ridge basalt (tholeiitic E-MORB), high Mg–low Si–low Ti mid oceanic ridge basalt (komatiitic E-MORB), transitional enriched mid oceanic ridge basalt–normal mid oceanic ridge basalt (T-MORB), normal island arc tholeiite (titaniferous IAT), and normal mid oceanic ridge basalt (N-MORB)

Lower Ordovician(?)

Gullbridge structural tract (GT)

eO:Rgbu Gull Brook Bridge anthophyllite schist: Mainly unseparated cordierite-bearing metamorphic rocks, sericitized volcanic rocks and volcaniclastic sedimentary rocks from the northwest part of the Robert's Arm volcanic belt that have been provisionally assigned to the Gull Brook Bridge division; cordierite−anthophyllite schist belt (Upadhyay and Smitheringale, 1972)

eO:Rgb3 Gull Brook Bridge tuff and jasperite: Mainly a regionally altered and mineralized sequence represented by a bimodal suite of pyroclastic volcanic rocks, siliceous argillite, volcaniclastic sandstone, and jasper-rich basalt; in probable ascending order, dark-grey, fine-grained, well stratified lavas of pillowed calc-alkaline basalt; light-green, massive to poorly stratified flows of porphyritic basaltic andesite displaying widespread silica–epidote–chlorite alteration zones and an extensive quartz vein stockwork; an interstratified pyroclastic sequence typically composed of medium-grained basalt breccia and fine-grained rhyolite tuff (interlayered on the scale of an exposure); angular outsized blocks of red chert and felsic tuff set in green chloritic basalt breccia; also, felsic volcanic breccia having large fragments of bedded mafic tuff and isolated intervals of hematitic pillow lava, all intruded by a gabbro sill complex; subordinate, rhyolite-dominant agglomerate marked by outsized bombs of coarse-grained basalt preserving chilled margins; locally, mafic and felsic pyroclastic strata transitional to cordierite−anthophyllite schist hosting recrystallized chalcopyrite−pyrite mineralization; felsic crystal-lithic tuff altered to black chloritic tuff near quartz vein arrays and gossan zones; chloritic mafic tuff illustrating disseminated sulphide grains replaced by hematite or jasper and crosscut by fresh diabase; at the top of the interval of bimodal eruptions, alternating thin-bedded felsic lithic tuff and fine-grained felsic crystal tuff interlaminated with black pyritic shard-bearing siltstone; minor, hematite-rich tholeiitic basalt associated with dark-green, medium-bedded, size-graded wacke rich in red jasper clasts; minor, light-grey, thin-bedded sandstone turbidite having detrital grains of rhyolite and embayed quartz; in the uppermost part of the subdivision, partially silicified and hematized basaltic pillow lavas intercalated with bright-red siltstone, dark-red chert, light-grey phyllite and quartz-feldspar crystal tuff selectively replaced by thin stratabound zones of orange jasperite

Legend for Figure 5 (continued).

eO:Rgb2 Gull Brook Bridge pumiceous wacke: Mainly greenish-grey, poorly sorted, medium-grained, crudely-stratified, pumice-rich granular wacke locally displaying erosional bases and pebbly lags; thick-bedded, vertically-graded, coarse-grained volcaniclastic wacke illustrating ubiquitous matrix replacement by hematite but preserving scoriaceous vitroclasts; light-grey, thick-bedded, medium-grained feldspathic sandstone injected by an anastomosing network of dark-pink quartz–hematite veins; an overlying thinly stratified interval of sandstone turbidite containing prominent resistant beds mostly replaced by disseminated jasper grains; subordinate, massive jasper veinlets crosscutting red siliceous siltstone and interbedded maroon chert; minor, variegated, green and red, ferruginous argillite; minor, very thin-bedded, partially hematized, quartz-feldspar crystal tuff; locally, in the upper part of the subdivision, clast-supported crystal-rich volcanic sandstone and rare rhyolite breccia

eO:Rgb1 Gull Brook Bridge basaltic andesite: Mainly dark-grey, plagioclase–porphyritic pillow lava and dark-green, size-graded pillow breccia comprising stratified flows of calc-alkaline basalt, basaltic andesite and andesite in the thickest and oldest part of the subdivision; a relatively thin overlying interval of felsic tuff and subordinate wacke having detrital clasts of green basalt and pink rhyolite; minor, komatiitic basalt flows in the upper part of the subdivision; locally succeeded by laminated beds of hematized quartz-feldspar crystal tuff and a banded hematite−magnetite iron formation up to a decimetre in thickness; near the stratigraphic top of Unit eO:Rgb1, a dark red sequence of pillowed calc-alkaline basalt and pervasively silicified basaltic andesite (Sarioglu, 2007)

Dawes Pond Brook division

eO:Rdbf Dawes Pond Brook rhyolite breccia: Mainly stratified felsic volcanic rocks, particularly chloritized rhyolite breccia; rocks assigned to Unit eO:Rdbf on the basis of their electromagnetic character and the overlying till composition

eO:Rdbm Dawes Pond Brook pillow lava: Mainly mafic volcanic rocks, including pillowed basalt; interpreted to comprise most or all of Unit eO:Rdbm on the basis of its aeromagnetic character and the overlying till composition

eO:Rdb3 Dawes Pond Brook calc-alkalic pillow breccia: Mainly dark-grey, plagioclase porphyritic, amygdaloidal, medium-grained, basaltic pillow breccia; very rare, light-grey, highly vesicular pillow lavas of aphanitic basaltic andesite; fresh basalt breccia passing into isotropic silicified basalt; massive pyritic basalt transitional to cordierite-bearing chlorite schist; in the vicinity of Starkes Pond, sphalerite-bearing protomylonitic basalt gradational to crenulated ultramylonite

eO:Rdb2 Dawes Pond Brook rhyodacite and aquagene tuff: Mainly thickly stratified lenticles dominated by felsic lithic tuff interbedded with felsic crystal tuff; size-graded rhyodacite breccia passing upward into felsic ash tuff and quartz-feldspar tuff; subordinate, coarse basalt breccia displaying bombs of vitric felsic tephra; subordinate, basalt breccia interbedded with felsic lithic tuff; minor, pillow lava gradational with aquagene tuff; locally, aquagene tuff passing vertically into vitreous felsic–mafic agglomerate having bombs of quench-textured basalt; minor, pyritic felsic breccia transitional to siliceous sericitic schist; in places, black chloritized tuff replaced by semi-massive pyrite

eO:Rdb1 Dawes Pond Brook rhyolite tuff and red mudstone: Mainly light-grey, fine-grained rhyolite tuff and less common rhyolite breccia making up the basal lenticle; size-graded beds of quartz-feldspar crystal tuff locally intercalated with basaltic lithic tuff; subordinate, red mudstone laminae within rhyolitic ash tuff; thin intervals of light-grey argillite, dark-grey phyllite, red siltstone and maroon chert interbedded with banded quartz-feldspar tuff; minor, black chloritic tuff and quartz–sericite schist displaying rare porphyroblasts of chalcopyrite and pyrite

West Lake Brook division

eO:Rwb Unseparated mafic to intermediate volanic strata and less common mafic to intermediate intrusive rocks; extrusive rocks are generally represented by a variably altered and mineralized sequence of pillowed basalt, basaltic andesite; unseparated units of gabbro and diorite that are regionally metamorphosed and inhomogeneously deformed

eO:Rwb5 West Lake Brook high-Mg gabbro: Mainly dark-grey, medium-grained, equigranular gabbroic laccoliths, locally chloritized and epidotized within propylitic alteration zones; in the mostly isotropic parts of these intrusions, systematically fractured, highly silicic gabbro; subordinate, marginally schistose pyritic gabbro (typically present where sheared country rocks having relict pillow structure are gradational with pervasively altered, chalcopyrite-bearing metabasite); subalkalic high-Mg gabbroic laccoliths marked by cooling joints related to the West Lake Brook continental flood basalts (CFB; see NAR-III group of Sarioglu, 2007)

eO:Rwb4 West Lake Brook calc-alkalic gabbro: Mainly light-grey, medium-grained equigranular gabbro gradational to dark-grey, fine-grained porphyritic gabbro near intrusive margins; subordinate, concordant bodies of highly conductive gabbro comprising a sill complex, particularly where altered country rocks host extensive stockwork zones (Unit eO:Rwb2; see below); minor, isotropic gabbro illustrating chlorite−epidote−calcite−pyrite−chalcopyrite−quartz veins; locally, cumulate layered gabbro transitional to lime-green metagabbro crosscut by foliated stringers of black chlorite and having structurally disaggregated folds of quartz veinlets; marginally schistose gabbro carrying arsenopyrite-bearing quartz veins near folded thrust faults; post-mineralization swarm of diabase dykes; calc-alkaline suite of gabbro sills having a composition between that of calc-alkaline basalt and island arc tholeiite (Trans CAB-IAT gabbro; cf. Sarioglu, 2007)

eO:Rwb3 West Lake Brook basaltic andesite: Mainly dark-green, porphyritic, fine-grained pillow lava interstratified with pillow breccia; light-green, massive, aphanitic, vesicular volcanic flows intercalated with subordinate volcanic breccia and lithic tuff; mafic to intermediate pillow lavas locally hosting chalcopyrite–sphalerite mineralization

eO:Rwb2 West Lake Brook arc tholeiite: Mainly dark-green, porphyritic, fine-grained pillow lava interstratified with pillow breccia; light-green, massive, aphanitic, vesicular basalt flows intercalated with subordinate volcanic breccia and lithic tuff; widespread alteration zones marked by lime green, net-veined basalt flows and chloritic lithic tuff

eO:Rwb1 West Lake Brook high alumina basalt: Mainly dark-green, porphyritic, fine-grained pillow lava interstratified with pillow breccia; light-green, massive, aphanitic, vesicular basalt flows intercalated with volcanic breccia; subordinate, quartz vein arrays and stringer stockworks structurally isolated from less altered basalts in other parts of the subdivision; minor, chloritized basalt displaying localized chalcopyrite–pyrite mineralization

Starkes Pond division

eO:Rspu Starkes Pond unseparated: Mainly large blocks and possible subcrop of flow-banded rhyolite; unexposed outcrop area assumed to be underlain by rocks of the Starkes Pond division

eO:Rspr Starkes Pond banded rhyolite: Mainly base-metal-mineralized coherent rhyolite flows and associated lava domes; dark-grey, massive, aphanitic rhyolite and light-grey, banded, quartz-phyric rhyolite, locally hosting sphalerite and galena mineralization; subordinate, chloritized spherulitic rhyolite intruded by dykes and sills of quartz-feldspar porphyry; minor, light-pink, flow-layered and flow-folded, vitric rhyolite illustrating a thixatropically deformed interval of light-grey ash tuff and parallel-laminated siltstone at the top of individual flow units

Legend for Figure 5 (continued).

Marine Strata Overlying Exploits Subzone (Dunnage Zone)
Post-Middle Ordovician Transgressive Overlap Sequence
Late Ordovician to Early Silurian(?)

OS:B Badger Group

OS:Bc Badger Brook conglomerate: Mainly polymictic conglomerate and pebbly wacke; predominantly light-grey, massive, siliciclastic conglomerate forming discontinuous lenticles within Unit OS:Bg (cf. Kean and Jayasinghe, 1982); subordinate, light-grey, thick-bedded, size-graded, pebbly to sandy wacke, locally capped by conglomerate or debrite horizons; minor, banded siliceous argillite having rare intercalations of thin-bedded gritty wacke; where polymictic conglomerate locally displays a scoured or erosional base and is vertically graded, well-rounded exotic magmatic and carbonate clasts comprise the majority of the boulders, cobbles and pebbles in the sandy matrix; in contrast, in places where conglomerate lenticles are mud matrix-supported and coarsen upward, intraformational clasts of laminated argillite and fine-grained wacke predominate; southern lenticle of Unit OS:Bc taken from Evans et al. (1994)

OS:Bg Badger Brook wacke: Mainly thick-bedded wacke, sandstone turbidite and laminated siltstone; predominantly light-grey, size-graded, gritty to granular wacke interstratified with medium-grained, planar-bedded sandstone turbidite; subordinate, light-grey laminated argillite interbedded with thin-bedded sandstone turbidite; minor, massive gritty wacke displaying isolated angular clasts of dark siltstone injected by sandstone dykelets or pebbly clastic intrusions; rare, centimetre scale intervals of dark-grey, thin-bedded siltstone turbidite; locally, debrite horizons illustrating slump-folded intraclasts of sandstone turbidite and rip-up clasts of parallel-laminated argillite

Dunnage Zone (lower AAT assemblage in SRAVB)
Middle to Late Ordovician

Robert's Arm volcanic belt (southeast part)

Middle to Late Ordovician(?)

Baker Brook structural tract (BBT)

Rocky Brook division

lO:Brbu Unseparated Rocky Brook succession; mainly poorly exposed sedimentary rocks that are stratigraphically undivided, including massive light-grey, coarse-grained tuffaceous wacke and thick-bedded pebbly wacke; in the southern part of the unit, exposures of light-grey thin-bedded sandstone turbidite and parallel laminated argillite

lO:Brb4 Light-grey, massive or thickly stratified, size graded, crystal-rich wacke interbedded with light-green, parallel-laminated, shard-rich argillite; minor, buff-weathered felsic ash tuff; rare, thin-bedded felsic lithic tuff

lO:Brb3 Rocky Brook argillite: Mainly grey siliceous argillite and maroon laminated chert interstratified with bright red, fine-grained siltstone turbidite; in places, porphyroblastic grey siltstone, nodular green argillite and concretionary maroon sandstone; subordinate, light-grey, thin-bedded sandstone turbidite having very thin resistant horizons of felsic lithic tuff; minor, light-grey quartz-feldspar crystal tuff interbedded with red laminated siltstone; pretectonic quartz-feldspar porphyry sills intruding light-grey, thin-bedded siltstone and light-green, finely-banded argillite

lO:Brb2 Rocky Brook wacke: Mainly greyish-green, thick-bedded gritty wacke hosting isolated sheets of pebbly sandstone; in places, individual beds of pebbly wacke grading to gritty and sandy wacke; subordinate, light-green, medium-bedded tuffaceous wacke displaying small argillite intraclasts; minor, thin-bedded sandstone turbidite, laminated siltstone and siliceous argillite intruded by calc-alkaline gabbro sills (Sarioglu, 2007); locally, poorly stratified debrite horizons having a black siliceous siltstone matrix and illustrating chaotically folded blocks of laminated argillite; in one locality near Rocky Brook, light-grey volcanic breccia displaying fragments of slump-folded ash tuff

lO:Brb1 Rocky Brook rhyolite: lenticle of dominantly light-grey to buff, massive rhyolite and rhyolitic agglomerate; subordinate intervals of very thick-bedded felsic breccia interstratified with quartz-feldspar crystal tuff

Late Middle Ordovician

Eastern Baker Lake Brook division

mO:Beb2 Eastern Baker Lake Brook metawacke: Mainly greyish-green, thickly-stratified, very coarse-grained, crystal-rich tuffaceous wacke having outsized clasts of felsic volcanic rocks; light-grey, massive pebbly wacke having basal conglomerate lags; blue quartz-bearing feldspathic wacke locally displaying angular fragments of slump-folded laminites and partially disaggregated argillaceous rip-up clasts; minor, thin-bedded intervals of felsic volcanic breccia, felsic lithic tuff and fine-grained volcaniclastic sandstone; rare, laminated intervals of black phyllite

mO:Beb1 Eastern Baker Lake Brook metarhyolite tuff: Mainly light-grey, felsic volcanic-derived granular to pebbly wacke having thin beds of quartz-feldspar tuff; subordinate, light-grey, thick-bedded, coarse-grained, poorly-sorted, crystal-rich wacke displaying thin interbeds of dark-grey siliceous sandstone; in ascending order, sandy olistostrome having abundant porphyritic and aphyric rhyolite olistoliths; massive crystal-rich packstone marked by abundant grains of resorbed quartz crystals and fractured feldspar prisms; in a few localities, succeeding intervals of laminated siliceous red argillite, thin-bedded maroon siltstone, and parallel-laminated grey sandstone; in the uppermost preserved part of the subdivision, felsic crystal tuff having black shale laminations transitional to quartz–pyrite schist and graphitic pelite; at the structural base of the unit near Joe's Lake, intraformational bands of sucrose metasedimentary schist and porphyroblast-rich granoblastic schist

Late Middle Ordovician

Catamaran Brook structural tract (CBT)

mO:CB *Joes Lake division*

mO:CBv3 Joes Lake pillowed tholeiite: Mainly dark-grey, thick-bedded pillow lavas, including normal mid oceanic ridge basalt and less common island-arc tholeiite (cf. Sarioglu, 2007); subordinate, light-grey interstitial chert; subordinate, pillow breccia interbedded with mafic tuff; minor, dark-green, massive basalt flows and equigranular gabbro sills; minor, malachite-bearing amygdaloidal basalt preserving seriate porphyritic and ophitic textures; locally, chloritic basalt transitional to light green, actinolite−biotite−cordierite schist, platey foliated metabasite and sucrose mafic granofels

mO:CBv2 Joes Lake basaltic−rhyolitic tuffs: Mainly bimodal pyroclastic strata overlying pillow lava and basalt flows; at the base of this subdivision, intercalated mafic lithic tuff, size-graded felsic lithic tuff, and phreatic agglomerate composed of polylithic volcanic fragments; in ascending order, poorly stratified coarse-grained volcanic breccia dominantly composed of rhyolitic blocks; rhyolitic agglomerate grading to felsic lithic tuff; succeeding felsic pyroclastic flows illustrating disaggregated folds of quartz-feldspar porphyry dykes; southwest of Powderhorn Lake, basaltic breccia associated with very thin-bedded mafic lapilli tuff and discontinuous graded beds of quartz-feldspar crystal tuff; in the uppermost preserved part of the map unit, fine-grained multicoloured sedimentary rocks, including light-grey to black siliceous argillite and black pyritic ribboned chert; locally dark-green, dark-red and dark-grey ferruginous siltstone underlying light-grey, parallel-laminated sandstone turbidite

Legend for Figure 5 (continued).

mO:CBv1	Joes Lake basaltic andesite: Mainly dark-grey, plagioclase-phyric, massive and pillowed, mafic to intermediate volcanic flows, including calc-alkaline basalt, basaltic andesite and less common andesite (cf. Sarioglu, 2007); subordinate, dark-green, fine-grained basalt locally displaying black chlorite aggregates near chalcopyrite–pyrite veinlets; minor, light-grey, very fine-grained, highly silicified basalt having abundant albite–carbonate–quartz veins; rare, pink and red jasper-bearing basalt hosting a stockwork of quartz–hematite veins; where altered and regionally metamorphosed, chloritic basalt passing gradationally into phyllonitic mafic schist having matrix-disseminated pyrite and jasper; locally, chloritic basalt transitional to net-veined sericitic metabasite showing leached zones adjacent to highly deformed and metamorphically recrystallized stringers of chalcopyrite, pyrite and quartz

Middle Ordovician?

Burnt Pond structural tract (BPT)
mO:BP Julies Harbour division

mO:BPpg	Julies Harbour migmatitic paragneiss: Mainly metasedimentary gneiss, amphibolite gneiss and migmatite; alternating porphyroblast-rich bands of light-grey, coarse-grained psammitic gneiss intercalated with dark-grey, medium-grained semipelitic gneiss; banded gneiss illustrating compositional layers preserving detached intrastratal isoclinal folds and possessing an attendant axial planar foliation; psammitic gneiss intruded by bodily rotated sills of foliated gabbro and having lozenge-shaped enclaves of metagabbro and garnetiferous amphibolite; migmatitic injection gneiss marked by restite pods composed of metagabbro and relict paragneiss; nebulitic migmatite and agmatite zones concentrated in the boudin necks of boudinaged folds of gneissosity; subordinate, tectonically straightened (platey) psammitic gneiss bounding discoidal lenses of folded lit-par-lit migmatitic gneiss and wrapping tectonic augen occupied by folds of boudinaged amphibolite dykes; platey hornfelsic gneiss displaying a dip-lineated shape fabric superposed on attenuated veins and relict bedforms; layered paragneiss transitional to fine-grained platey gneiss within small ductile shear zones (locally recrystallized to sucrose reworked gneiss and metasedimentary granofels); minor, paragneiss and amphibolite infiltrated by granodiorite gneiss and crosscut by foliated leucogranite; in places, metadolerite dykes back veined by folded lits of metamorphosed granodiorite emanating from orthogneiss and migmatitic paragneiss
mO:BPs	Julies Harbour phyllitic metaturbidite: Mainly phyllitic argillite, sulphidic siltstone and sandstone turbidite; in ascending order, light-grey, thick-bedded granular wacke, graded volcaniclastic sandstone and slump-folded sandstone turbidite; thin-bedded, siliceous, pyritic siltstone interstratified with thick-bedded, fine-grained nodular sandstone; thin-bedded mafic tuff (enriched tholeiitic basalt) interbedded with mottled sandstone turbidite; at the top of the sequence, widespread, laterally continuous beds of light-grey, fine-grained crosslaminated sandstone turbidite, dark-grey, thin-bedded siltstone turbidite, and light-green, parallel-laminated argillite; locally, thin-bedded sandstone, graded siltstone and siliceous argillite passing gradationally from slate into spotted phyllite near major fault zones

Early Late Ordovician and Older

Powderhorn Lake structural tract (PLT)
Powderhorn Brook division

lO:PBs	Powderhorn Brook metapelite: Mainly tectonically interlayered metasedimentary schists generally composed of dark-grey ferruginous pelite, light-grey siliceous semipelite and greyish-green sericitized granofels; subordinate, sulphidic cordierite–garnet–andalusite schist transitional to black laminated siltstone interstratified with thin-bedded pyritic sandstone; minor, graphitic schist having augened porphyroblasts of cordierite; locally, pelitic schist distinguished by dip-lineated cordierite porphyroblasts; minor, carbonaceous pelitic schist showing randomly oriented porphyroblasts of euhedral pyrite and chalcopyrite; intruded by numerous crosscutting bodies of fresh and highly altered gabbro
lO:PBv	Powderhorn Brook metarhyolite: Mainly light-grey, medium-grained quartz–sericite schist transitional to size-graded felsic crystal–lithic tuff; subordinate, andalusite-bearing felsic pyritic schist transitional to a gossan-forming, sphalerite-bearing rhyolitic breccia; where preserved, at the stratigraphic top of the subdivision, a gradationally conformable interval of thin-bedded metapelite interstratified with fine-grained crystal tuff and ash tuff

Legend for Figure 5 (continued).

ing the Black Gull Island pillowed basalt of the South Brook structural tract, the oldest part of the Rocky Brook division and the youngest known part of the Eastern Baker Lake Brook division are locally upside-down. At lower structural levels in the SRAVB thrust stack (within Belt 1), a relatively thick succession of the oldest and youngest subunits of the Rocky Brook division is present and occurs within a regional footwall syncline developed in the upper part of the BBT (Figure 6).

The main part of the Rocky Brook division in Belt 1 is disposed above a fault-modified refolded anticlinal nappe cored by older strata of the Joes Lake division and preserved relics of the basal subunit of the younger Eastern Baker Lake Brook succession (Belt 2). However, tectonic fragments of CBT and lower BBT rocks are locally exposed along the southeast margin of the Rocky Brook basin (Figure 6). Directly beneath overplated GT or SBT rocks at the northwest basin margin, detached panels of highly metamorphosed northwest-dipping Rocky Brook strata are seen to be structurally intercalated with small tectonic slivers of Joes Lake metabasalt and Eastern Baker Lake Brook metawacke.

RECENT GEOLOGICAL WORK IN THE SOUTHEASTERN SRAVB

In the study area, Swinden and Sacks (1996) assigned the Catamaran Brook–Baker Brook sequence, described above, to the oldest exposed part of their regionally northwest-facing Roberts Arm Group and considered them to be older than the rocks comprising the GT of this report. However, these authors were uncertain about the original stratigraphical position and the origin of the structurally underlying sequences represented by the Julies Harbour and Powderhorn Brook divisions of this report. Consequently, they excluded the last named metasedimentary and metavolcanic rocks from their peri-Laurentian Roberts Arm Group.

During subsequent geological mapping, Dickson (2001) had placed the structurally lowest metarhyolite of the Powderhorn Brook sequence of the SRAVB within a thrust-bounded dome and correlated it with the Early Ordovician felsic volcanic rocks in the main part of the Roberts Arm Group, as Dickson (*ibid.*) had locally defined and mapped it. The pelitic metasedimentary rocks in the upper part of the Powderhorn Brook sequence were correlated instead with the

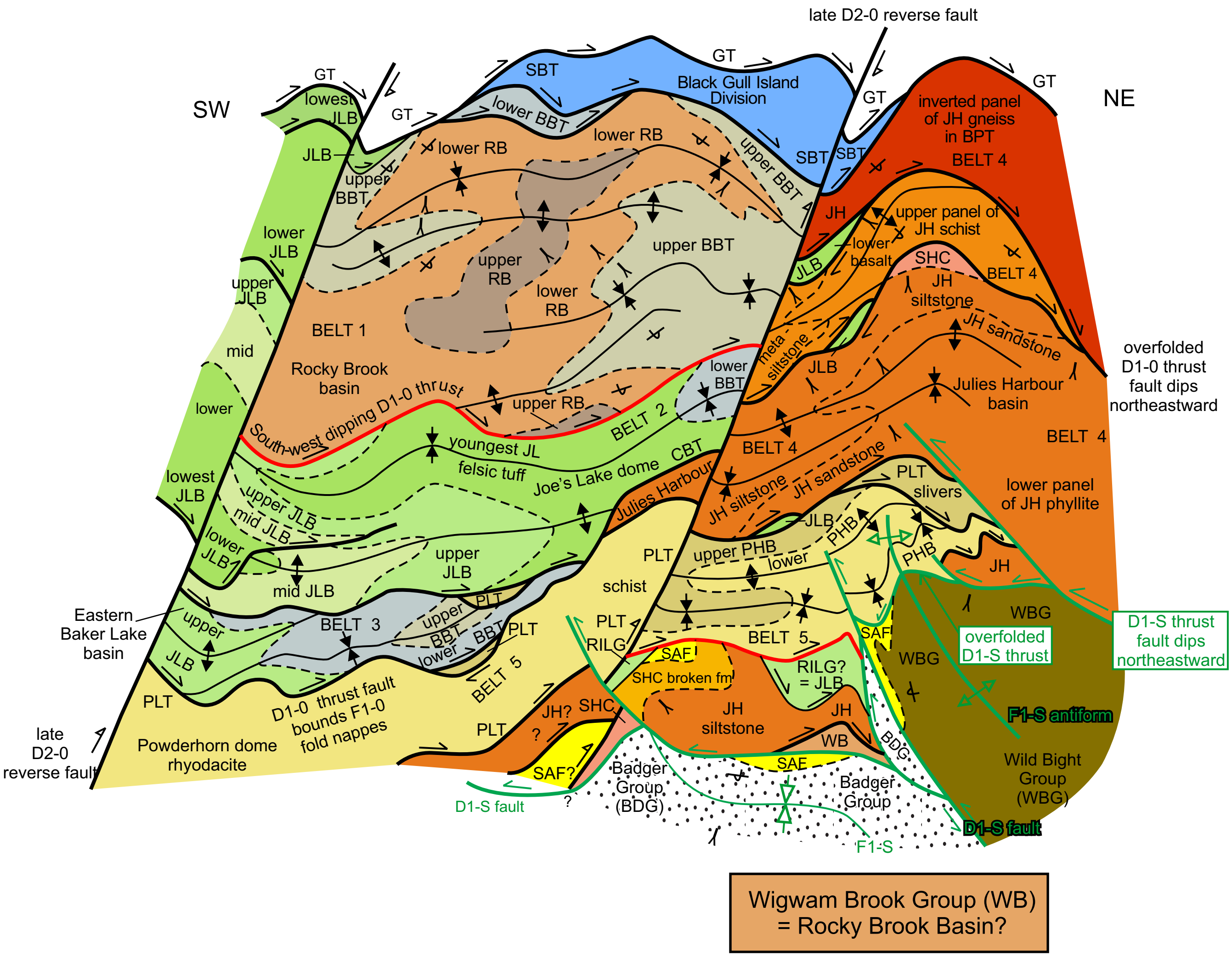


Figure 6. *Schematic southwest–northeast cross-section that depicts the regional stack of fold nappes and bounding thrust faults found within the southeast part of the SRAVB. Locally, five tectonostratigraphic belts are present and these contain representative rocks from most of the main structural tracts outlined in Figure 4. Note that, in the Exploits Subzone footwall sequence of the AAT, the early formed (D1-O) thrust faults are postulated to have had locally affected the graptolite-bearing Sandbian Shoal Arm Formation and the chlorite grade Sops Head Complex (as well as the schistose Late Ordovician strata in the structurally overlying Belt 5 of the SRAVB). In places, post-peak metamorphic (late D2-O) steeply southwest-dipping reverse faults offset the early-formed pre-peak metamorphic (D1-O) shear zones that had originally bounded the Middle and Late Ordovician strata within the SRAVB. Later back thrusts (D1-S) in the lower SRAVB assemblage also affect the Katian Badger Group and its substrate; such northeast-dipping structures are thought to be younger than the regional (F2-O) cross folds and late (D2-O) reverse faults in the SRAVB. Cross-section is not drawn to scale; red line represents the upper structural boundaries of the Catamaran Brook Tract and the Red Indian Lake Group.*

Late Ordovician black shale of the Shoal Arm Formation. However, farther north near Kippen's Pond, such graptolitic strata are observed to lie conformably above the Middle Ordovician strata of the Wild Bight Group (Exploits Subzone of the Dunnage Zone) and are in faulted contact with the Crescent Lake Formation of the Roberts Arm Group.

The migmatitic metaturbidite sequence herein assigned to the Julies Harbour division of the Burnt Pond structural tract was correlated by Dickson (2000a, b, 2001) with the siliciclastic turbidites of the Late Ordovician–Early Silurian Badger Group, which was mapped to crop out some 4 km farther east and to lie stratigraphically above the Late Ordovician black slates of the Shoal Arm Formation in that area. In contrast, Dickson (*ibid.*) assigned the structurally overlying Catamaran Brook–Baker Brook sequence to the Early Ordovician part of the Roberts Arm Group and, along a southwest-dipping thrust fault, placed these peri-Laurentian rocks above the metasedimentary schist and gneiss that he had assigned to the Badger Group (part of the Late Ordovician overstep sequence of the western Exploits Subzone). If correct, this would imply that the RIL suture would reside within the amphibolite-facies schist and gneiss belt (lower SRAVB) and be located much farther to the northwest than the traditional RIL boundary.

The entire Powderhorn Lake–Catamaran Brook–Baker Brook lithotectonic sequence was later correlated by Zagorevski *et al.* (2010, 2015) with strata in the Wigwam Brook Formation and other parts of the upper Victoria Lake Supergroup (Evans and Kean, 2002; Zagorevski *et al.*, 2007b) and the Wild Bight Group (O'Brien, 2001; MacLachlan *et al.*, 2001). Such rocks were deemed to represent part of their peri-Gondwanan Victoria Arc terrane which, farther southwest, lies structurally below the peri-Laurentian Red Indian Lake Group. In accord with Dickson's earlier work, they assigned the metasedimentary assemblage of the Powderhorn Brook pelitic schist (upper PLT) and the Julies Harbour psammitic gneiss (upper BPT) to hornfelsed parts of the Sandbian black shale and Katian turbidite succession (*see* Figure 2). Zagorevski *et al.* (2007b, 2010 and 2015) had placed all of the above-named stratified rocks beneath the main part of the Roberts Arm Group and, by definition, below their Taconic III-deformed Annieopsquotch Accretionary Tract. Thus, the RIL suture separating the peri-Laurentian Iapetan realm and the peri-Gondwanan Iapetan realm was postulated to be found within the metamorphic rock assemblage situated in the southeastern part of the SRAVB.

FOLD NAPPES IN THE LOWER PART OF ROBERT'S ARM THRUST STACK IN THE SRAVB

The lithostratigraphical divisions comprising the structural lower part of the SRAVB are disposed by paired regional folds within five vertically stacked nappe complexes. Listed below in tectonic order from highest to lowest, and not including the underlying panel of low-grade slate in the Katian Badger Group, thrust-bounded fold nappes occur in the following structural belts (Figure 6):

1) a structural basin in Belt 1 underlain by the Rocky Brook and upper Eastern Baker Lake Brook divisions,
2) a structural dome in Belt 2 underlain by the lower to upper Joes Lake and lower Eastern Baker Lake Brook divisions,
3) a structural basin in Belt 3 underlain by the uppermost Joes Lake division and the lower to upper Eastern Baker Lake Brook division,
4) a structural basin in Belt 4 underlain by the lower and upper turbidite units of the Julies Harbour division and the broken formation and mélange of the Sops Head Complex, and
5) a structural dome in Belt 5 underlain by the refolded recumbent folds of the lower and upper units of the Powderhorn Brook division.

In the southeast part of the SRAVB, the fault-bounded Powderhorn Lake, Catamaran Brook, Burnt Pond and Baker Brook structural tracts, each contain two or more nappe complexes and several imbricate thrust sheets. Small discontinuous thrust sheets of the Joes Lake division are underplated beneath right-side-up and inverted sections of the Black Gull Island division (SBT), locally separate an upper nappe complex (inverted) from a lower nappe complex within the Julies Harbour division (BPT) and, in places, lie structurally above the uppermost tectonic panel (horse) observed within the Powderhorn Brook division (PLT).

Fold nappes bounded by the earliest recognized thrust faults (D1-O) and overturned folds, bounded by later reverse faults (D2-O), were produced during two separate deformational events that occurred before, and during, peak regional metamorphism in the SRAVB, and which predated the emplacement of the oldest sheet intrusions of metapyroxenite and metagabbro. The earliest generation of nappe-forming F1-O folds were originally large recumbent structures that are now partly preserved within structural flat belts. In the southeast SRAVB, they have been mapped as closing (sideways) toward the southwest and the northeast.

A later generation of northwest- and southeast-plunging overturned folds overprinted all of the thrust-bounded tectonic panels and refolded their constituent recumbent folds. The younger train of upright to moderately inclined F2-O folds also developed in asymmetrical pairs and are bounded by southwest-dipping reverse faults and ductile shear zones that were located on the limbs of the secondary folds.

Generally, within the lower SRAVB, the younger strata of a particular lithostratigraphic division are locally observed to be upside down on the inverted limbs of overturned synclines beneath a bounding hangingwall thrust fault; whereas, older strata within the same division are commonly seen to be upside down on the inverted limbs of overturned anticlines above a bounding footwall thrust fault (*cf.* Figures 6 and 7). However, tectonically straightened zones of platy volcano-sedimentary rocks are also present along the early formed thrusts (D1-O) and the faulted margins of the refolded nappe complexes (D2-O).

Regardless, within the tectonic panels making up the various structural tracts in the southeast SRAVB (*see* above), most lithostratigraphic divisions were regionally disposed on the common fold limb and are consequently right-side-up. This is despite certain internal units having been displaced

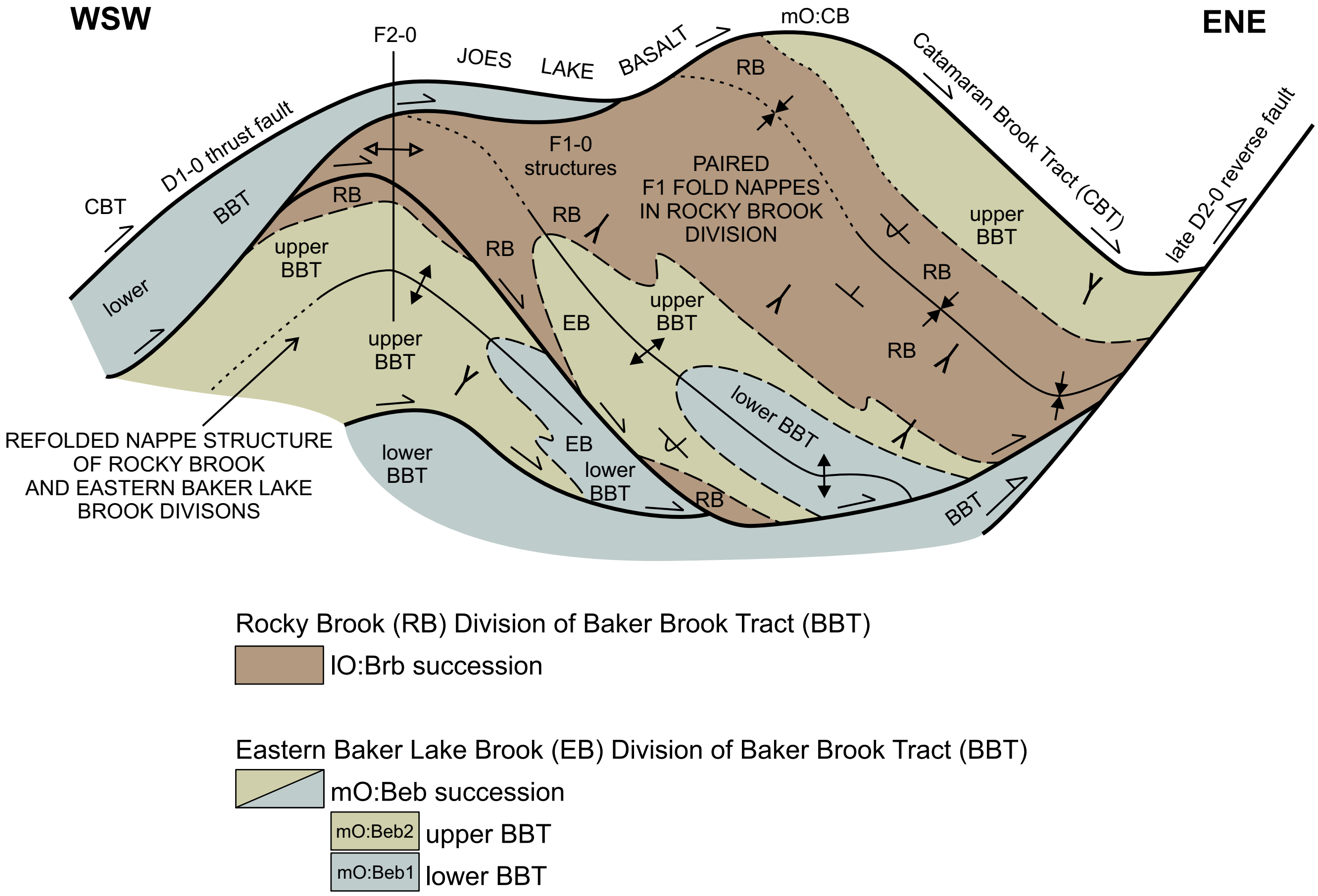


Figure 7. *Schematic west-southwest–east-northeast cross-section illustrating the refolded nappe structure of the Rocky Brook and Eastern Baker Lake Brook divisions of the Baker Brook Tract (BBT); the structurally overlying tectonic panel is represented by a sheared metabasalt from the Joes Lake division (mO:CB) and is denoted as Catamaran Brook Tract (CBT) on this diagram. Note that the early formed regional folds (paired F1-O nappes) are bounded by east-northeast-directed ductile thrust faults (solid arrows) and that both of these D1-O structures are overprinted by secondary (F2-O) folds and displaced by later southwest dipping (D2-O) reverse faults (open barbs). In places, where the lithostratigraphical subunits of these divisions were upside down, following D1-O thrusting and subrecumbent folding, regional D2-O deformation locally produced superimposed downward-facing structures in the lower SRAVB assemblage.*

by large ductile thrust faults and laterally transported as allochtonous sheets during regional southwest-over-northeast movement.

The primary nappes and thrust sheets outlined by the rocks of the Powderhorn Brook and Julies Harbour divisions were refolded to dip northeastward in some localities. They were later deformed by back thrusts and allied folds (D1-S) that display an antivergent northeast-over-southwest tectonic polarity (Figure 6). Strata belonging to the upper Wild Bight Group, the upper Shoal Arm Formation and the lower Badger Group were apparently deformed by these same northeast-dipping structures (probably during the Early Silurian) and were posttectonically intruded by epizonal sheets of coeval granite and gabbro during the Middle Silurian (*e.g.*, Sparkes *et al.*, 2021; *see* also section titled U–Pb ID-TIMS age of the Rocky Pond granodiorite in the SRAVB). These unmetamorphosed plutonic rocks were also emplaced into the amphibolite facies schist and gneiss belts of the lower SRAVB during or after a late Wenlock (Homerian) episode of terrestrial volcanism (*cf.* Dickson, 2000b, 429 ± 2 Ma; G.R. Dunning, unpublished data, 2000).

Near the intersection of the Buchans Highway and the Millertown Junction road, rock units lying beneath the Buchans and Red Indian Lake groups are, in part, probable correlatives of the Sops Head broken formations and black shale-hosted mélange, the Julies Harbour succession of sandstone and siltstone turbidite, and the Rocky Brook sequence of rhyolite tuff, red argillite and grey mudstone. Here, they appear to structurally underlie Powderhorn Brook and Joes Lake strata and to structurally overlie discontinuous thrust slices of Badger Group wacke and older graptolite-bearing black shale (Figure 6).

The northwest-trending D2-O structures in the SRAVB were themselves deformed and overprinted by a younger group of southwest-trending structural features; these were predominantly southeast-directed reverse faults and northwest-inclined major folds. Although they cannot be illustrated in the Figure 6 cross-section, the youngest group of reverse faults and allied overturned folds were inhomogeneously developed within upper and lower parts of the AAT in the SRAVB, and also throughout the northwest part of the Exploits Subzone. Northwest-dipping reverse faults of this age (and possibly younger structural features) form the upper boundary of a large homocline made up of Late Ordovician Badger Group strata near the outflow of Badger Lake (Figure 5; O'Brien, 2009).

3. REGIONAL METAMORPHISM, SYNTECTONIC INTRUSION AND MEGASCOPIC DEFORMATION

Regional metamorphism accompanied regional deformation throughout the Ordovician and Silurian evolution of the thrust-and-nappe belt in the AAT (Lissenberg *et al.*, 2005; Zagorevski *et al.*, 2006, 2007a). Related orogenic accretion is generally assumed to have begun after the late Early Ordovician phase of the Taconic II orogeny (*ca.* 475 Ma; early to mid-Floian; O'Brien and Dunning, 2014), as most volcanosedimentary strata in the area surveyed were deposited between the Early and Late Ordovician after the cessation of the regional Taconic II event in the northern segment of the Notre Dame Arc (Zagorevski *et al.*, 2006). In the northern part of the adjacent Buchans–Robert's Arm belt, certain Early and Middle Ordovician volcanic units residing in the upper and middle parts of the AAT were postulated to have been initially faulted as early as the late Middle Ordovician (probably Dapingian) and were locally uplifted and eroded in the Darriwilian (Zagorevski *et al.*, 2015).

INTRODUCTION

In the upper level thrust sheets of the SRAVB, Floian volcanic rocks from several divisions of the Gullbridge structural tract and the overlying Tremadocian metaplutonic rocks, from different parts of the Hungry Mountain and Hall Hill igneous complexes, are thought to have been originally onlapped by early Wenlockian strata assigned to the basal Springdale Group (Figures 2 and 3A). Thus, at least some of the regional deformation and metamorphism observed in SRAVB rocks had predated accumulation of terrestrial strata in the Springdale overstep basin and the emplacement of plutons that had crosscut from Ordovician basement to Silurian cover. Accordingly, metamorphic development of the southeast-directed thrust belt in the middle and lower part of the SRAVB has been ascribed to the Taconic III orogenic episode, which was previously interpreted to have been governed by the subduction zone underplating of the Middle Ordovician peri-Laurentian volcanic arc–back-arc complexes beneath Taconic II-accreted greenschist-facies metatectonites (*cf.* van Staal *et al.*, 2007).

In the southeastern SRAVB, regional dynamothermal metamorphism was coeval with several generations of major fold structures, fold-related faults, reverse shear zones, grain shape fabrics, mineral foliations and mineral lineations. Contractional deformation preceded and overlapped with the peak upper-amphibolite-facies metamorphism, which probably affected the stratified and intrusive rocks of the lower SRAVB during the Late Ordovician to Early Silurian (O'Brien and Dunning, 2008; also *cf.* Cawood *et al.*, 1994; Brem *et al.*, 2007 for the peri-Laurentian metamorphic rocks of the Notre Dame Arc).

REGIONAL SETTING

The peak metamorphic mineral assemblage observed in the generally fault-bounded belts of SRAVB schist and gneiss is spatially associated with a syntectonic intrusive suite composed of mainly massive hornblende amphibolite, banded garnet amphibolite, hornblende-bearing metatonalite gneiss, hornblende–biotite granodiorite and metadiabase, marginally schistose metapyroxenite, and hornblende- or actinolite-bearing metagabbro. The distribution of the various bodies of Tower Hill felsic orthogneiss (Unit OS:BPog; Figure 4) and Dawes Pond metagabbro (Unit eS:TIdpgb; Figures 3B and 5) shows that they were preferentially emplaced in the structurally lower part of the AAT. There, they intruded Buchan-type cordierite- and andalusite-bearing schistose and garnet- and sillimanite-bearing gneissose stratified rocks (Pennell, 2004) found within the nappe complexes of the Baker Brook, Catamaran Brook, Burnt Pond and Powderhorn Lake structural tracts (Figure 6).

Between 250–500 m from the plexus of these ultramafic and mafic sheet intrusions, the same SRAVB strata were never regionally metamorphosed above the biotite zone of the greenschist facies. Moreover, such phyllitic rocks were, only locally, contact metamorphosed to produce unfoliated hornfelses or were converted to isotropic sucrose granofels in the narrow thermal aureoles of the posttectonic Silurian plutons.

The regional setting of the plexus of the syntectonic intrusions and the site of peak regional metamorphism was the imbricate fault zone that had developed above the Powderhorn Brook metarhyolite and metapelite (Late Ordovician volcanic arc) in the Powderhorn Lake structural dome and the relict synclinal nappe of Julies Harbour metasandstone and metasiltstone (attenuated Middle Ordovician turbidite basin) within the overlying Burnt Pond structural dome (Figure 6).

In places, these rocks are directly tectonically overlain by highly deformed and metamorphosed parts of the eastern Baker Lake Brook metawacke (quartz–albite–sericite-schist in a right-side-up portion of the BBT), the lower Joes Lake tholeiitic basalt (cordierite–actinolite–green hornblende schist of the CBT) and the upper Rocky Brook argillite (cordierite–biotite–muscovite-schist in an inverted portion of the BBT). They occur as detached thrust slices at the top of the lower SRAVB assemblage above Belt 1 but are present also along some of the imbricate thrust faults within belts 2 and 4 (Figures 5 and 6).

D1-O, D2-O AND D2-OS EVENTS IN THE SRAVB

In the study area, SRAVB lithostratigraphic units, present in some schist and gneiss belts, became bounded by ductile thrust faults during the earliest recognizable regional deformation (D1-O) in the lower AAT nappe complex (Figure 8). The D1-O tectonic event probably began during the Late Ordovician after the cessation of Sandbian felsic volcanism. In places, mainly upside-down sequences of paragneiss and metasedimentary schist were structurally repeated by imbricate D1-O thrust faults, were refolded by steeply inclined to overturned F2-O folds, and were tectonically emplaced above underlying right-side-up phyllitic rocks to produce a 'hot-over-cold' geometry of metamorphosed strata, within the D1-O tectonic stack of F1-O fold nappes (Figure 6).

Stratified rock units in the Gullbridge and South Brook structural tracts of the upper SRAVB are less regionally metamorphosed than the migmatitic footwall sequence within the lower part of the SRAVB (*i.e.*, a 'hot-under-cold' geometry is present in Taconian schist to the northwest of the RIL suture in the study area). Thus, an inverted D1-O regional metamorphic gradient had not developed as a primary feature in the lower AAT, below the earlier fault-imbricated and overthrusted panels of older volcanic-arc and oceanic-island strata in the mid to upper part of the SRAVB.

At least some of the early regional metamorphism in the lower SRAVB was recorded by a widespread MS1-O cleavage and, in a few places, a fine-grained MS1-O schistosity. These occur within certain structural flat belts, predominantly in the southwest part of the study area, and are best preserved in rock units having a highly variable D1-O incremental strain. Beds deformed by subrecumbent F1-O minor folds and having an axial planar MS1-O foliation (or an attendant S1-O grain alignment fabric, marked by a low intersection angle with bedding) are transitional to phyllonites lying parallel to highly attenuated sedimentary layers and displaying a gently dipping MS1-O phyllitic foliation (black features in Figure 8).

The metamorphosed rocks contained within the D1-O thrust sheets were regionally folded and locally thrust faulted during the subsequent phase of D2-O deformation in the

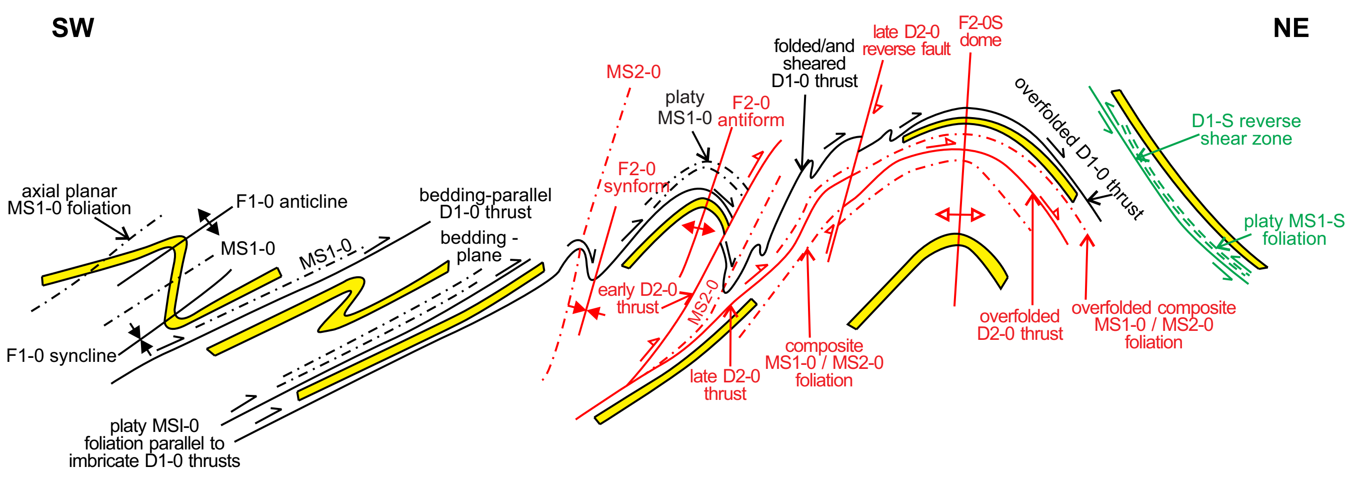


Figure 8. *Schematic southwest–northeast cross-section summarizing the individual geometrical characteristics of the D1-O and superimposed D2-O and D2-OS deformational and metamorphic features that typify the youngest part of the AAT thrust-and-nappe belt. Inhomogeneously deformed rocks of disparate regional metamorphic grade are present in the variably structurally reworked and tectonically remobilized D1-O thrust sheets now preserved in the southeastern SRAVB. Note that such contrasts in regional metamorphism were established prior to the development of the younger belts of MS1-S retrograde schist observed within the northeast-dipping (antivergent) D1-S thrust sheets preferentially developed in the eastern part of the study area. Bedding surfaces of SRAVB strata in yellow, D1-O metamorphic structures in black, D2-O and D2-OS metamorphic structures in red, and D1-S metamorphic structures in green.*

SRAVB (red features in Figure 8). In areas where the tectonic dip of the metamorphic rocks became steeper, and superimposed D2-O deformation was more penetrative, MS1-O foliation is still preserved within the hinge zones of intrastratal F2-O isoclinal folds and as inclusion trails within MS2-O index porphyroblasts (*see* accompanying photographic plates).

The superimposed MS2-O foliation is generally observed to be axial planar to widespread F2-O mesoscopic folds. The main MS2-O schistosity is commonly seen to be moderately southwest-dipping, although this is not the case everywhere throughout the lower SRAVB (Figure 9).

In areas where the SRAVB gneiss and schist belts were sharply bounded by imbricate D1-O fault zones, thrusting outlasted MS1-O metamorphism during the D1-O event (*see* parts of Figures 6, 8, 9 and 10). However, many of these faulted boundaries were tectonically reactivated during a later D2-O event, particularly in the northeast part of the area surveyed. Here, in some places, folded and sheared D1-O thrusts came to lie parallel to adjacent D2-O thrusts within what was to evolve into the hinge zones of some F2-OS domes. Moreover, in some localities, a composite MS2-O/MS1-O bed-parallel foliation (Figure 9) became over folded onto the northeast-dipping limbs of such fold structures (Figure 8; *see* the F3 crenulation folds of Pennell, 2004).

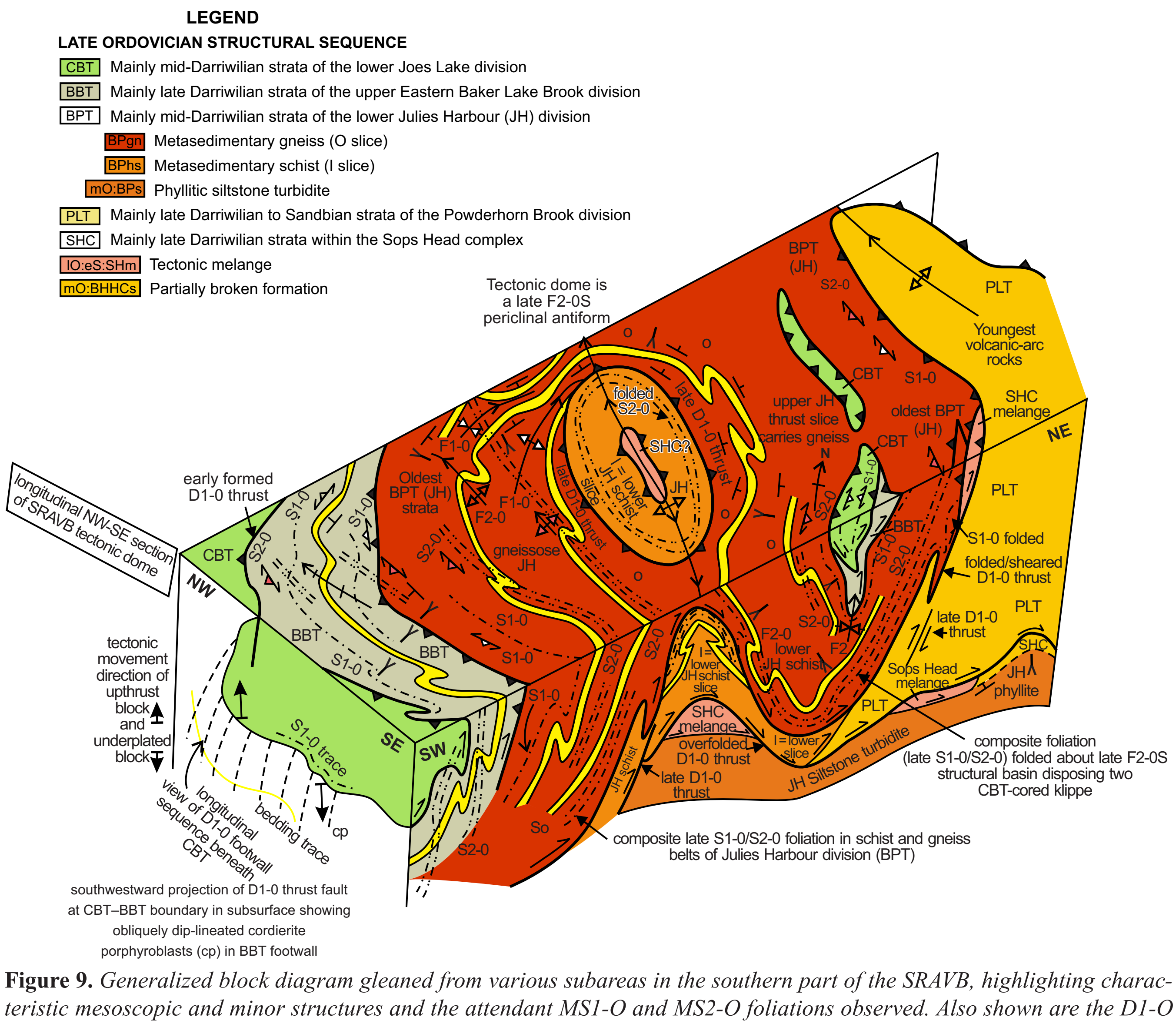


Figure 9. *Generalized block diagram gleaned from various subareas in the southern part of the SRAVB, highlighting characteristic mesoscopic and minor structures and the attendant MS1-O and MS2-O foliations observed. Also shown are the D1-O and D2-O effects in producing the Late Ordovician tectonic stacking pattern of certain thrust-bounded tectonic panels of Middle and Late Ordovician strata found within this region. Listed from structurally highest to lowest, CBT rocks are shown in green, BBT rocks in beige, BPT rocks in two shades of reddish-orange, PLT rocks in yellow and the SHC rocks in salmon, mustard and light orange.*

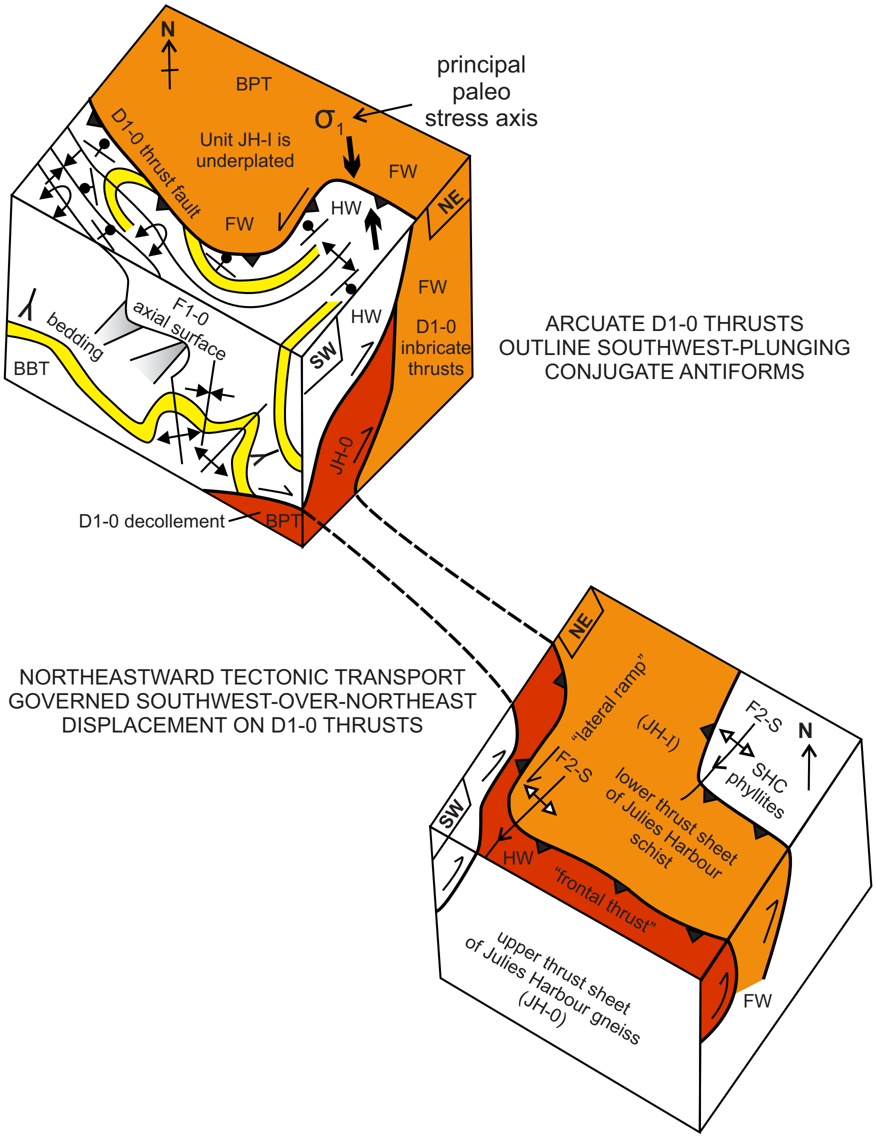


Figure 10. *Imbricate D1-O horseshoe thrusts as seen in a longitudinal-section constructed on the southwest-dipping flank of a D2-O tectonic dome. Such D1-O structures had mainly disposed the metasedimentary rocks of the Julies Harbour (JH) division of the Burnt Pond Tract (BPT). View is toward the northeast across these generally northwest–southeast trending D1-O fault structures. Southwest-dipping D1-O thrust faults having a southwest-over-northeast component of displacement separate upper gneissose (JH-O) and lower schistose (JH-I) thrust slices; as seen in one of the block diagrams, they place both of these tectonic panels of Julies Harbour metaturbidites structurally above the phyllitic metamorphic rocks of the Sops Head Complex (SHC). In the other block diagram, bedding planes are portrayed in highlighted yellow strata in the structurally overlying hangingwall sequence of the Baker Brook Tract (BBT). Note that oblique-slip frontal thrusts occur on the common limb of conjugate antiforms; whereas, sinistral and dextral lateral faults are located on the opposing fold limbs of the conjugate structures. These are mainly D1-O strike-slip thrusts that dip toward the northwest or the southeast; note the superimposed southwest-plunging F2-S cross folds. HW is hangingwall and FW is footwall; solid arrow indicates the D1-0 principal paleostress direction. A plan view and cross-section of this regional dome and the surrounding rock units are also illustrated in Figure 9.*

In certain areas, regional M2-O metamorphism appears to have lasted longer and persisted after the development of the F2-O domes and basins. For example, near the tectonic window at Burnt Pond, an amphibolite facies metamorphic assemblage (the cordierite–andalusite–magnetite-isograd; *cf.* O'Brien, 2016b) locally crosscuts downward-facing F2-O major folds of the MS1-O schistosity within structurally inverted parts of the lower AAT sequence (O'Brien, 2004).

In the aureoles of some of the larger sheets of the Dawes Pond metagabbro, amphibolite-facies index porphyroblasts had grown in the deformed country rocks of these intrusions, prior to the cessation of the D2-O deformation and the M2-O regional metamorphism. Along the intrusive contact of certain metagabbroic sheets, a hornblende schistosity formed at the pluton margin is seen to be concordant with an augened MS2-O shape fabric in its metasedimentary host rocks. Such metamorphic and intrusive rocks are typically situated on steeply dipping F2-O fold limbs within late formed D2-O shear zones, but had also developed in the hangingwall sequences of southwest-dipping, late D2-O reverse faults.

POSSIBLE LATEST ORDOVICIAN REGIONAL METAMORPHISM

Characteristic major structures and attendant minor structures have been simplistically portrayed in an interpretation of the three-dimensional regional distribution of selected rock units from the southeast SRAVB (Figure 9). They are deemed representative of the D1-O and D2-O features mapped throughout the study area. From its structural top to its base, the thrust stack depicted is locally composed of metamorphosed stratified rocks from the Joes Lake basalt of the CBT, the Eastern Baker Lake Brook wacke of the BBT, two tectonic panels of Julies Harbour metasedimentary gneiss and metasedimentary schist from the BPT, a discontinuous imbricate thrust slice of the Powderhorn Brook metarhyolite and metapelite from the PLT, and a thrust-bounded ellipsoidal dome made up of the phyllitic alkali basalt, the olistostromal mélange and the unbroken Julies Harbour formations of the Sops Head Complex.

M1-O Metamorphism in Relation to S1-O Cleavage, F1-O Folds and D1-O Faults

In the southeast SRAVB, relatively well-preserved D1-O thrust faults and related F1-O folds can be best appreciated when they are viewed in longitudinal sections of superimposed antiformal domes (Figure 10). Constructions of such northwest–southeast sections allow the viewer to look northeastward along the primary tectonic transport direction of the D1-0 structures. Consequently, the early formed frontal thrusts are generally still flat-lying but vary in the amount of dip and direction of fault inclination, particularly in areas where bedded strata were crosscut near possible ramps in the D1-O thrusts. Lateral ramps of D1-O thrust faults may be present in some of the stratified rocks of the PLT (O'Brien, 2016c) and are discernible within a longitudinal section of the broad crestal region of an antiformal dome near Powderhorn Lake (*see* inset in Pennell, 2004).

In thrust fault-bounded slices of some of the banded gneiss and layered schist belts in the BPT (Figures 9 and 10), tight to isoclinal F1-O folds of relict stratification are seen to be reclined and to plunge gently in the extension direction of the tectonically straightened rocks present at the structural base of these thrust sheets. In contrast, open F1-O folds of strata preserving primary bedforms developed as conjugate pairs within some of the larger tectonic panels between the bounding hangingwall and footwall thrusts. In some parts of the southeast SRAVB, minor F1-O folds and coeval D1-O thrust faults can be mapped around the superimposed F2-O domes and F2-O basins and are overprinted by MS2-O schistosity (Figure 9), suggesting that not all F2-O antiforms developed into F2-OS domes.

A slaty cleavage, defined by MS1-O white mica and chlorite, is present in the phyllitic turbidites of the Late Ordovician Rocky Brook division in the southwest SRAVB, near Lake Bond (O'Brien, 2009; Plate 1A). Locally, this foliation is axial planar to minor F1-O folds of bedding in a generally right-side-up Rocky Brook succession. The MS1-O foliation was overgrown by spotted MS2-O porphyroblasts of cordierite and andalusite and, farther east, within more altered Baker Brook rocks, it became grain-coarsened to form a pervasive MS1-O quartz–albite–sericite schistosity within certain D1-O tectonic panels.

Farther northeast in the SRAVB, structurally below the rocks of the SBT, the MS1-O metamorphism affected strata as old as the Deer Pond division of the Crescent Composite structural tract (CCT in O'Brien, 2016a; a partial correlative of the early Darriwilian Crescent Lake composite terrane of Zagorevski and McNicoll, 2011). Near the headwaters of the Tommy's Arm River, randomly oriented MS2-O cordierite porphyroblasts are observed to overgrow a MS1-O biotite foliation in the upper wacke and conglomerate unit; whereas, acicular aggregates of green hornblende crystals overgrow a strong MS1-O actinolite–chlorite foliation in inhomogeneously deformed parts of the older basalt unit. Deeper in the SRAVB nappe complex, within the CBT, gently dipping platy zones of net-veined MS1-O cordierite–actinolite schist (Plate 1B) are seen to pass abruptly into pillowed sequences of Joes Lake basalt.

In many locations in the SRAVB, sporadic index porphyroblasts, indicative of the amphibolite-facies metamorphism, overprint the regional MS1-O foliation in discontinuous belts of spotted metasedimentary schist. However, these are commonly transitional to belts of augened hornfelsic schist marked by variably flattened F2-O zones of closely packed MS2-O porphyroblasts, which still preserve a rotated internal MS1-O chlorite–muscovite foliation (Pennell, 2004). Such metamorphic rocks are most widespread in probable Middle Ordovician strata of the Julies Harbour division and the underlying probable Late Ordovician strata of the Powderhorn Brook division. The included foliation present in the synkinematically grown aluminosilicate porphyroblasts, within the Powderhorn Brook pelite is outlined by aligned grains of MS1-O muscovite, biotite and graphite (Plate 1C).

In a few places, Julies Harbour metasandstones and metasiltstones (Figures 5 and 9) are seen to be gradational with coarse porphyroblastic psammitic and striped semipelitic schists, intruded by voluminous swarms of gabbro dykes, particularly in the area between Tower Hill and South Burnt Pond (Figure 3B). They are interpreted as protoliths of a migmatitic paragneiss distinguished by ortho-amphibolite boudins, and having superimposed F2-O intrastratal folds (Plate 1D). The boudinage of the mafic dykes that had intruded and dilated these metasedimentary rocks occurred prior to D2-O regional deformation (Figures 6 and 8). This episode of ductile extension is indicative of an original late D1-O stretching along the MS1-O foliation and is possibly related to the upward rise of mafic magma along D1-O thrust faults.

POSSIBLE LATEST ORDOVICIAN–EARLIEST SILURIAN REGIONAL METAMORPHISM

In the structurally lowest tectonic panels of the SRAVB, in Late Ordovician and older stratified rocks, porphyroblasts of andalusite, cordierite, hornblende and garnet grew in a dynamically recrystallized matrix dominantly composed of quartz, biotite, muscovite, graphite, iron sulphide and iron

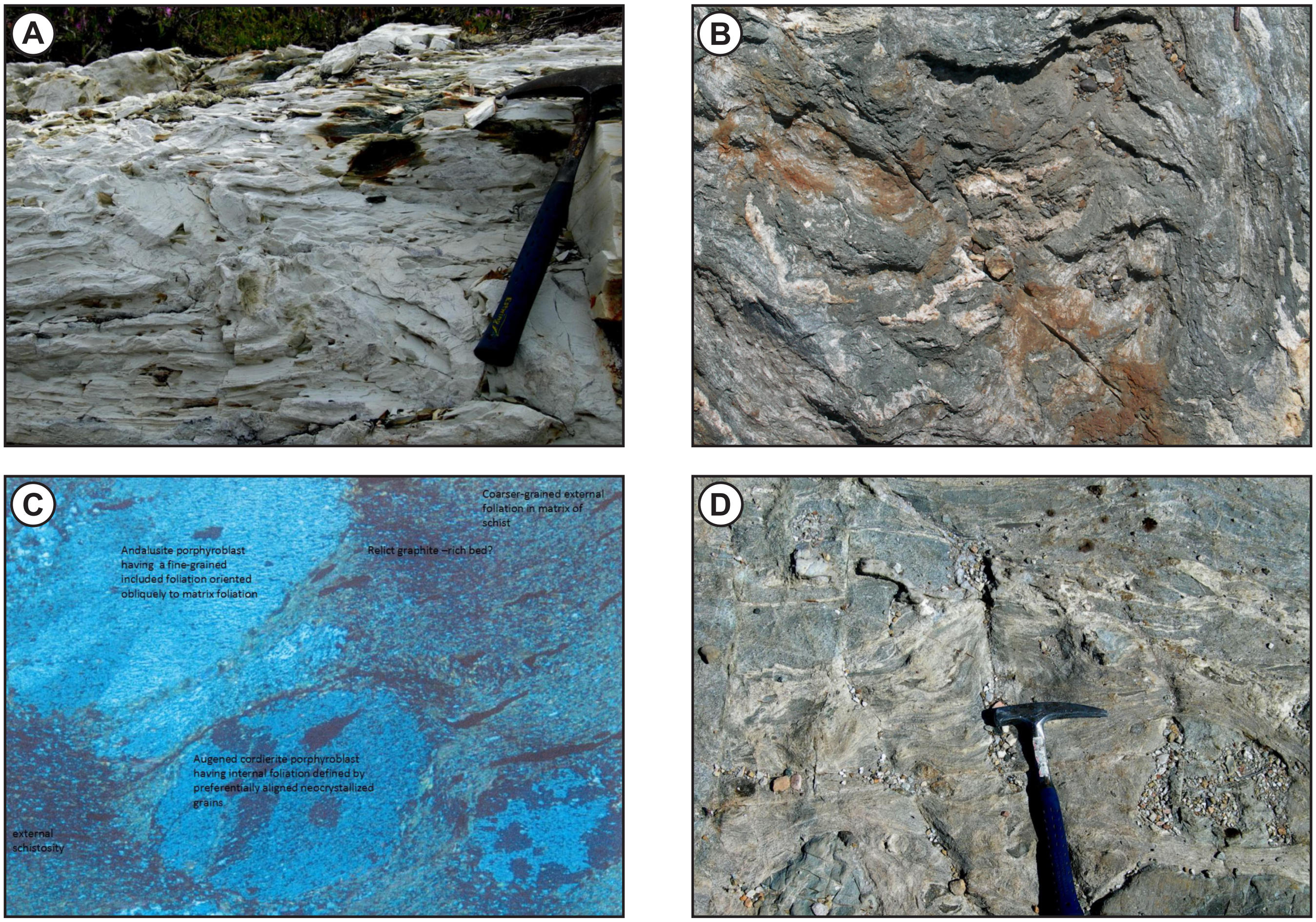


Plate 1. *A) Overturned syncline–anticline pair viewed looking down their gently northwest-plunging fold axes in a right-side-up sequence of thinly bedded Rocky Brook argillite. Gently northeast-dipping, axial planar MS1-O cleavage is present in the synclinal hinge zone (near end of hammer shaft). These generally flat-lying strata are situated structurally below the major D1 thrust forming the tectonic boundary with overlying phyllitic volcanic rocks of the Gullbridge Tract [E560296 N5431639]; B) Northwest-plunging F2-O folds are outlined by a gently dipping MS1-O porphyroclastic foliation (and albite–carbonate veins) in the oldest unit of the Joes Lake Basalt near Catamaran Brook Park. Asymmetric F2-O crenulation folds are present in the flat belts of MS1-O schist; whereas, a steeply northeast-dipping MS2-O composite foliation becomes penetrative on the long limbs of the upright to steeply inclined F2-O folds. A fine-grained (platy) MS2-O foliation had developed in places where minor F2-O antiforms tightened upwards, became tectonically attenuated and were displaced in small D2-O shear zones [E566746 N5433509]; C) A twinned andalusite porphyroblast illustrates an included MS1-O foliation that is oriented obliquely to a coarser grained MS2-O foliation in the schistose matrix of a sulphidic pelite and wacke sequence in the Powderhorn Lake Tract. The MS2-O matrix foliation transects a graphite-rich layer and forms augen around cordierite porphyroblasts having curved MS1-O inclusion trails; D) Plan view of the margin of a foliated sheet of light-grey granodiorite (top) in the Tower Hill Gneiss. The sill intrudes a dark-green net-veined gabbro (centre) that itself crosscuts isoclinal F2-O minor folds of MS1-O foliation in the paragneiss (near hammer). Boudins of finer grained amphibolites were bodily rotated during D2-O ductile shearing of paragneiss and indicate an earlier extension along the MS1-O foliation and the relict sedimentary layering [E566511 N5438306].*

oxide. Metamorphosed mafic volcanic strata in the CBT illustrate cordierite, brown biotite and green hornblende porphyroblasts set in a schistose matrix of actinolite, chlorite and sodic plagioclase. Metamorphosed felsic volcanic strata in the adjacent BBT contain large poikiloblastic crystals of andalusite, cordierite, biotite and sericite. Such metavolcanic rocks were probably metamorphosed in the lower amphibolite facies.

Metasedimentary rocks in the Powderhorn Brook, Julies Harbour, and Eastern Baker Lake Brook divisions have differing ages and thicknesses of black sulphidic pelite and grey siliceous pelite interstratified with biotite-bearing semipelite. They commonly contain coarse-grained garnet, andalusite and cordierite porphyroblasts. However, in some tectonic panels, these pelites also display relict staurolite and fresh andalusite prisms, rare sillimanite–fibrolite–garnet aggregates, and randomly oriented euhedral neoblasts of coarse biotite, set in a schistose matrix defined by aligned grains of muscovite and recrystallized graphite (*cf.* Swinden and Sacks, 1986; *see* also Pennell, 2004). Such metasedimentary rocks were probably metamorphosed in the mid to upper amphibolite facies.

Previous Work on Peak Metamorphism

In the lower part of the SRAVB, a staurolite–andalusite–cordierite–garnet assemblage has been previously reported by Swinden and Sacks (1996) within mica schist near Powderhorn Lake. Such amphibolite facies metamorphic rocks developed within a carbonaceous pelite unit enriched in recrystallized pyrite cubes (Unit OSms) that lay below the generally greenschist facies volcanic rocks of the Roberts Arm Group (Swinden and Sacks, *ibid.*). These authors provisionally supported Kalliokoski's (1954) original interpretation of these coarse-grained metasedimentary rocks as having formed in the thermal aureole of certain layered gabbros formerly assigned to the banded amphibolite-, migmatite-, and granodiorite gneiss-bearing Devonian Twin Lakes Complex. Most of these gabbro plutons were later included within the oldest observed part of the Early–Late Silurian Hodges Hill intrusive suite (*cf.* Dickson, 2000b). Emplacement of at least some of the plutons within the Hodges Hill batholith was assumed to postdate the terrestrial extrusion of adjacent Wenlockian rhyolite flows (Dickson, *ibid.*).

West of Powderhorn Lake, in a structurally overlying tectonic panel originally mapped as Crescent Lake Formation, some beds of Baker Brook wacke illustrate a schistose quartz–albite–sericite matrix but much smaller and more disseminated porphyroblasts of cordierite and andalusite. Fine-grained aggregates of muscovite needles were intergrown with these porphyroblasts and locally overprint the regional schistosity. By way of contrast, the highest grade pelitic schists in the lower SRAVB were probably regionally metamorphosed in the mid- to upper-amphibolite facies. These are found in several map units near the thrust faulted boundary separating the structurally overlying rocks of the Baker Brook and Burnt Pond tracts, from the structurally underlying rocks of the PLT (Figures 4 and 5).

According to Pennell (2004), most of the porphyroblastic minerals in the SRAVB schist and gneiss belts formed after the initiation of D1-O deformation and greenschist facies M1-O metamorphism, when they included the bed-parallel MS1-O foliation. Many more nucleated or became zoned and coarser grained during the D2-O regional deformation and amphibolite facies M2-O metamorphism, when such porphyroblasts were bodily rotated during growth and later distorted to yield porphyroclasts of garnet, quartz and andalusite. This dynamothermal metamorphism was argued to be unrelated to the posttectonic intrusion of the fractured and hydrothermally altered Early to Middle Silurian plutons of gabbro, diorite, granodiorite and syenite found in adjacent parts of the Hodges Hill intrusive suite (Pennell, 2004; O'Brien, 2009, 2016b, c; in this report, *see* U–Pb ID-TIMS age of the Rocky Pond granodiorite in the SRAVB).

M2-O Metamorphism in Relation to S2-O Cleavage, F2-O Folds and D2-O Faults

Regional M2-O metamorphism was ubiquitous and affected all stratified rock units present in the southeast SRAVB. In weakly deformed parts of the lower thrust sheets, M2-O porphyroblasts formed preferentially in epiclastic lithologies within phyllite belts; whereas, they grew best in particular grain size intervals within relict turbidite beds in the schist and gneiss belts (Plate 2D). Changing tectonic conditions during the M2-O metamorphic event resulted in an early stage D2-O transition from moderately southwest-dipping to gently southwest-dipping zones of variably penetrative MS2-O foliation (Figure 8). A subsequent D2-OS transition from composite flat-lying to northeast-dipping MS2-O foliation occurred prior to the late-stage development of a subvertical MS2-O platy foliation in late D2-O shear zones. Excellent examples of such phenomena are observable in metamorphic rocks from the Baker Brook, Catamaran Brook, Burnt Pond and Powderhorn Lake structural tracts.

In the lower part of the SRAVB, a strong M2-O regional foliation developed in each of several thrust sheets of Eastern Baker Lake Brook feldspathic schist, Joes Lake volcanic schist and Julies Harbour psammitic schist (Figure 5). These rocks are situated mostly on the southwest-dipping limbs of northwest- and southeast-plunging F2-O major folds (*e.g.*, Figures 5, 6, 8 and 9). There, the MS2-O foliation dips more steeply to the southwest than does the MS1-O foliation (Plate 1C; *see* also Figure 8). However, very gently dipping zones of MS2-O foliation (mainly quartz–cordierite–andalusite–hornblende–garnet–muscovite schist) are disposed farther northeast, particularly in a strongly deformed sulphidic pelite found in the Powderhorn Brook division (Plate 2F).

In such D2-O structural flat belts, dip-lineated L2-O cordierite porphyroblasts pitch gently on the bed-parallel MS2-O schistosity in the Powderhorn Brook pelite (Plate 2G). Moreover, gently plunging L2-O extension lineations occur adjacent to recumbent F2-O sheath folds overprinted by a weak crenulation cleavage within the crest of a major F2-OS dome (Plate 2H). However, in areas where the MS2-O schis-

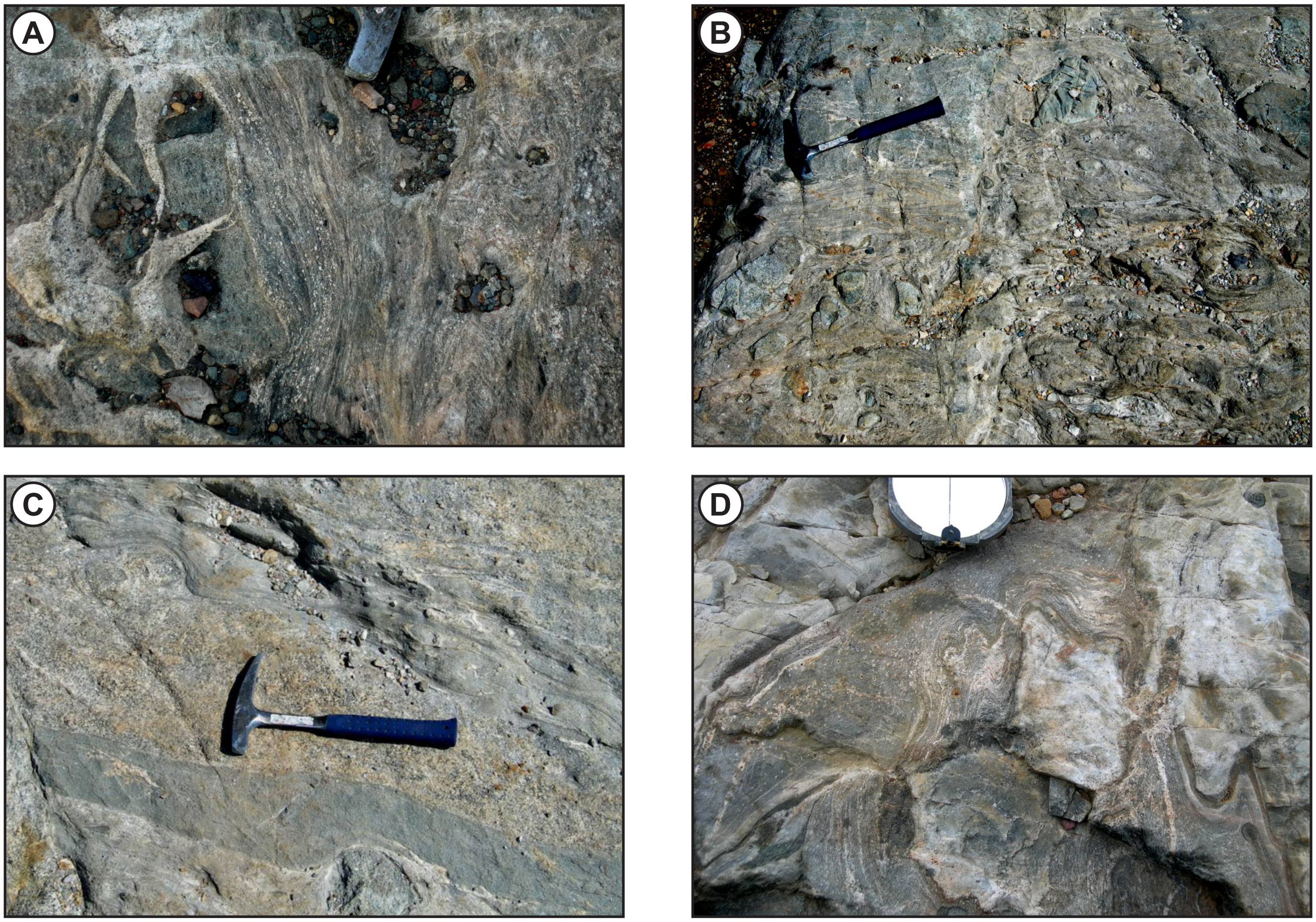


Plate 2. *A) Plan view of steeply plunging F2-O tight to isoclinal folds of bed-parallel MS1-O foliation locally preserved in intrafolial lithons between steeply dipping zones of platy MS2-O foliation (RHS near hammer head). Near the intrusive contact between dark-green gabbro and Julies Harbour migmatitic paragneiss (centre), light-grey granodiorite is back-veined from host rock paragneiss into the amphibole-bearing gabbroic intrusion. White plagioclase porphyroblasts in paragneiss adjacent to the intrusive contact have overgrown platy MS2-O foliation and intrafolial F2-O folds [E566548 N5438281]; B) Plan view of variably digested amphibolite pods (dark green) in migmatitic paragneiss that are tectonically augened by a fine-grained banded foliation to locally form a D2-O shape fabric (S>L). The platy MS2-O foliation overprints isoclinal F2-O folds of the bed-parallel MS1-O foliation and concordant amphibolite sills within a thrust sheet of Julies Harbour gneiss at Tower Hill. Agmatite zones had developed near vein-filled pressure shadows in the rotated tails of amphibolite boudins (below hammer) in host metasedimentary gneiss [E566511 N5438306]; C) Plan view of two intrusive sheets of light-grey, coarse-grained, weakly foliated granodiorite that separate and intrude two screens of banded and variably migmatized Julies Harbour paragneiss (middle and top of photograph). A younger metamorphosed diabase dyke (dark grey) displays chilled margins against the central granodiorite sheet (below hammer) and a rotated amphibolite pod within part of the injection migmatite (bottom); it is back veined by granodiorite lits emanating from the host migmatitic paragneiss [E566511 N5438306]; D) Northwest-plunging F2-O parasitic folds in a mesoscopic antiform located south of Burnt Pond (fold axes trending parallel to compass). A variably penetrative MS1-O foliation and concordant lit-par-lit quartz veinlets lie parallel to stratification in an interbedded psammite and semipelite sequence within a Julies Harbour schist belt. Reverse-graded porphyroblasts of euhedral chiastolites overgrow MS1-O schistosity, particularly in a narrow zone of high D1-O strain located near the base of this folded metamorphic layer (below compass). These D1-O structures are shortened by minor F2-O folds whose limbs were later thrust faulted and whose hinge zones were displaced and offset [E564876 N5449938].*

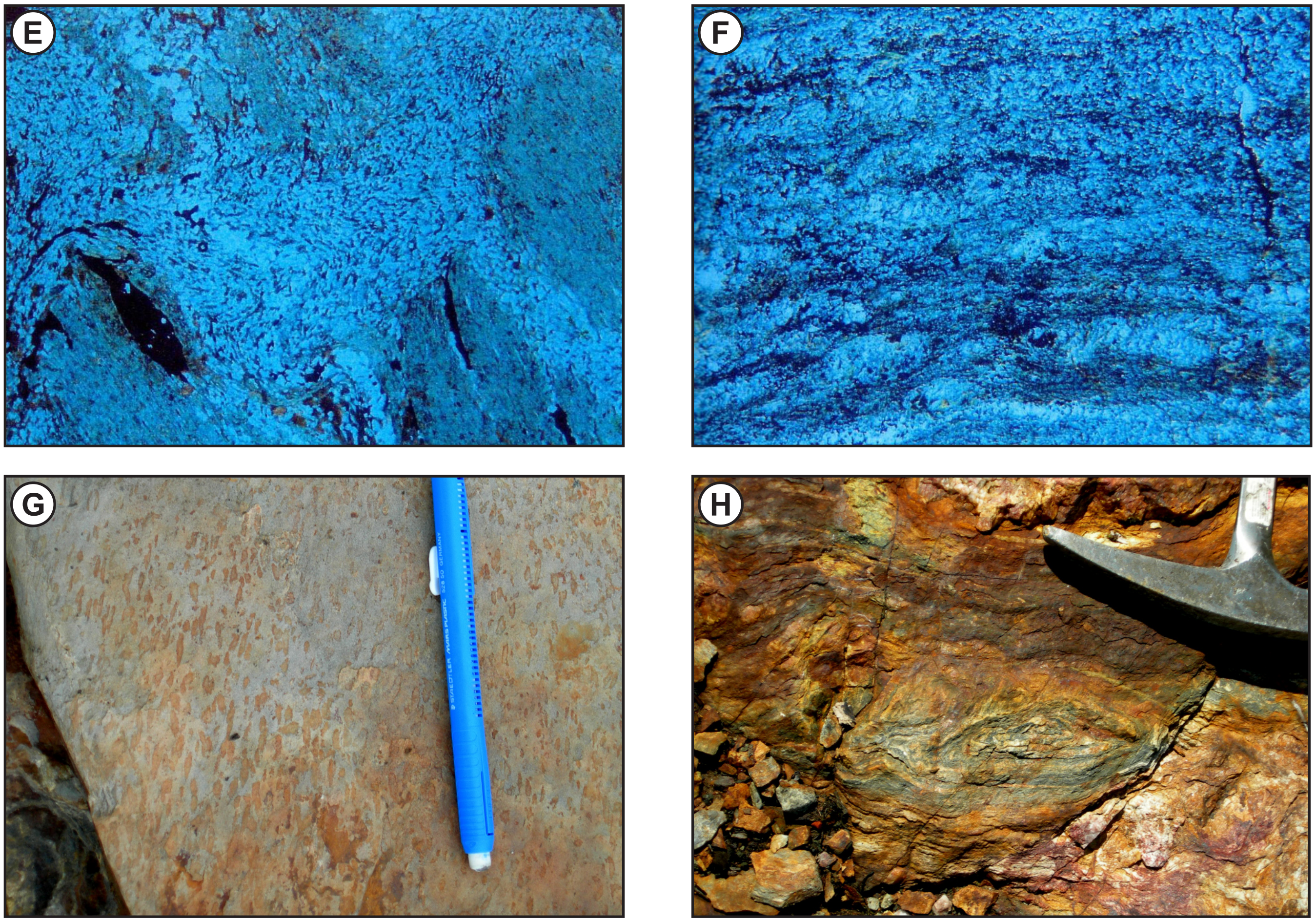


Plate 2. *E) Cordierite porphyroblasts showing an included MS1-O foliation that is finer grained and straighter than the MS1-O biotite foliation in the pelite matrix. The external MS1-O matrix foliation is crenulated by open to tight F2-O microfolds having axial planar graphite grains aligned within the neocrystallized MS2-O schistosity. Rock is located in the tectonically highest preserved part of the Powderhorn Brook pelitic schist, lying immediately beneath the structurally overlying Julies Harbour migmatitic gneiss near Tower Hill; F) Layer-parallel MS2-O schistosity within a pelite bed, preserves evidence of an incompletely transposed MS1-O foliation. The earlier foliation is folded within the quartzofeldspathic microlithons and, in places, is obliquely oriented to the differentiated phyllosilicate-rich layers making up the penetrative MS2-O schistosity. This Powderhorn Brook platy pelitic schist is situated on the northeast-dipping limb of the southeast-plunging F2-OS periclinal dome in the Powderhorn Lake Tract; G) Lineated cordierite porphyroblasts pitch in the dip direction of MS2-O schistosity in a gently inclined bed of Powderhorn Brook pelite; plan view looking down on a bedding plane. These M2-O cordierites display the L2-O mineral lineation which, in this location, plunges gently toward the southwest [E565232 N5441854]; H) Flat-lying composite MS2-O schistosity wraps around an eye-shaped F2-O sheath fold defined by quartz veinlets concordant with the MS1-O foliation in a sulphidic pelite assigned to the youngest part of the Powderhorn Brook division. Upright F2-OS crenulation folds overprint the strata-parallel MS2-O schistosity and plunge very gently to the south in the direction of the pre-existing L2-O extension lineation seen on the openly crenulated MS2-O foliation [E565279 N5438224].*

tosity is flat or dips gently northeastward, and the transposition of MS1-O into MS2-O foliation was locally incomplete, the coarser grained MS2-O schistosity is observed to be axial-planar to tight F2-O microfolds of a bed-parallel MS1-O fabric, within certain porphyroblast-rich pelite layers (Plate 2E).

In certain localities, schistose arc-basalts of the Joes Lake division dip gently and are situated directly above the structurally underlying rocks of the Powderhorn Brook pelite (Figure 5). Where the older volcanic rocks occur on the northeast-dipping limb of the above mentioned F2-OS dome, the Joes Lake schist is observed to have been overprinted by steeply dipping shear zones that had developed near some late D2-O reverse faults (*e.g.*, O'Brien, 2009). Near the outflow of Catamaran Brook, such metabasites illustrate subvertical platy zones of MS2-O actinolite schist within small northwest-trending shear zones (Plate 1D). Similarly, where the structurally underlying Julies Harbour metasedimentary gneiss of the BPT is locally mylonitized (and intruded by hornblende gabbro dykes), the latest MS2-O fabrics have a northwest strike, and dip very steeply toward the northeast (Plate 1A). The exact relationship of the late MS2-O foliation to the upright F2-OS crenulation cleavage is unknown.

Peak Metamorphic Assemblage

The migmatitic metasedimentary gneiss and metamorphosed gabbroic, tonalitic and granodioritic intrusions exposed at Tower Hill are characteristic of those observed throughout Unit mO:BPpg of the Julies Harbour division and Unit OS:BPog of the BPT (Plate 1D). These map units include previously dated intrusive bodies of latest Ordovician felsic orthogneiss and earliest Silurian schistose granodiorite (Figure 5; O'Brien and Dunning, 2008). The Julies Harbour paragneiss was intruded, sequentially, by various types of banded amphibolite sills and then by deformed and metamorphosed dykes of gabbro and granodiorite before the posttectonic emplacement of several plutons of similar composition assigned to the Hodges Hill intrusive suite (O'Brien, 2016b, c). West of North Twin Lake, the Julies Harbour paragneiss was crosscut by a Middle Silurian zoned pluton from the Topsails intrusive suite (*see* the unmetamorphosed Rocky Pond granodiorite in report section titled U–Pb ID-TIMS age of the Rocky Pond granodiorite in the SRAVB).

The relict bedding seen in Julies Harbour paragneiss contains a layer-parallel MS1-O foliation that, in places, outlines rootless F2-O isoclinal folds (Plates 1D and 2B). These are locally preserved in microlithons lying between the transposed porphyroblast-bearing melanosome of the main MS2-O gneissic banding. Rocks illustrating such M1-O and peak M2-O metamorphic features were later intruded by marginally foliated gabbro dykes that are older than, but probably broadly coeval with, the Late Ordovician gneissic granodiorite at Tower Hill (*see* below).

Tower Hill Orthogneiss

The Unit OS:BPog gneiss belts in the BPT are mainly composed of a banded plagioclase–hornblende intrusive gneiss initially metamorphosed during the regional amphibolite-facies event in the SRAVB. The protoliths of this gneiss were probably one or more of the pre-Wenlockian tonalite or granodiorite bodies underlying the study area. The orthogneiss located to the east of Powderhorn Lake at Tower Hill was affected by the M2-O metamorphism, which locally produced a segregated hornblende–biotite–muscovite–chlorite–plagioclase–alkali-feldspar–quartz foliation. In contrast, the host metasedimentary gneiss had recorded the effects of both the M1-O and M2-O phases of regional metamorphism.

The Tower Hill orthogneiss is observed to intrude variably digested bodies of podiform garnet–hornblende amphibolite as well as host migmatitic rocks correlated with the Julies Harbour metasedimentary gneiss. There, late D1-O boudinaged sills of flaser-banded amphibolite intrude along, and locally, crosscut MS1-O foliation; however, they are deformed by minor F2-O folds and are locally augened by platy MS2-O foliation (Plate 2B, C). Zones of M2-O agmatite developed preferentially in the D2-O rotated boudin necks of orthoamphibolite sills present within certain nebulitic belts of migmatite. The Tower Hill orthogneiss (syn- to post-peak MS2-O metamorphism) is the oldest known Ordovician syntectonic felsic intrusion in the study area.

Some foliated granodiorite intrusions in Unit OS:BPog were emplaced into fault-bounded panels of Julies Harbour metasedimentary gneiss marked by tight F2-O minor folds (Plate 2B). However, others were intruded into D2-O deformation zones typified by straightened paragneiss, boudinaged amphibolite and banded orthogneiss (Plate 2C). Late formed F2-O minor structures are outlined by folded granite veins that crosscut schistose gabbro and banded granodiorite dykes, and extend into adjacent wallrock zones of mylonitized paragneiss (Plate 2A).

A late-formed MS2-O schistosity is observed to dip steeply within weakly deformed granodiorite sheets bracketed, in relative age, by the above mentioned schistose gabbro dykes and a later northwest-trending swarm of foliated diabase dykes. The younger suite of metamorphosed mafic intrusions (Plate 2C) illustrates a characteristic pinch-and-swell structure, where such rocks had been emplaced into the gneissic parts of the Tower Hill granodiorite.

On Tower Hill (Figure 3B), migmatized amphibolites, agmatitic hornblendites and schistose hornblende gabbros are seen to be crosscut by granitic dykes, emanating from orthogneiss and migmatized Julies Harbour paragneiss (Plate 2A–C). However, similar migmatite zones have not been recognized in the underlying thrust sheet carrying the Powderhorn Brook metapelite and metarhyolite. All of these lower SRAVB rocks are, nevertheless, intruded by a regionally folded suite of later ultramafic and mafic dykes (Figures 9 and 11) assigned to the Dawes Pond metagabbro complex (Unit eS:TIdpgb).

SYNMETAMORPHIC INTRUSIONS WITHIN THE LOWER SRAVB

The structurally controlled emplacement of the synmetamorphic plutonic rocks, in the southeast SRAVB, began in D1-O with the sheeted intrusion of the banded-garnet–amphibolite dykes and hornblendites that are now preserved in Julies Harbour-type paragneiss boudins (Figure 12). It con-

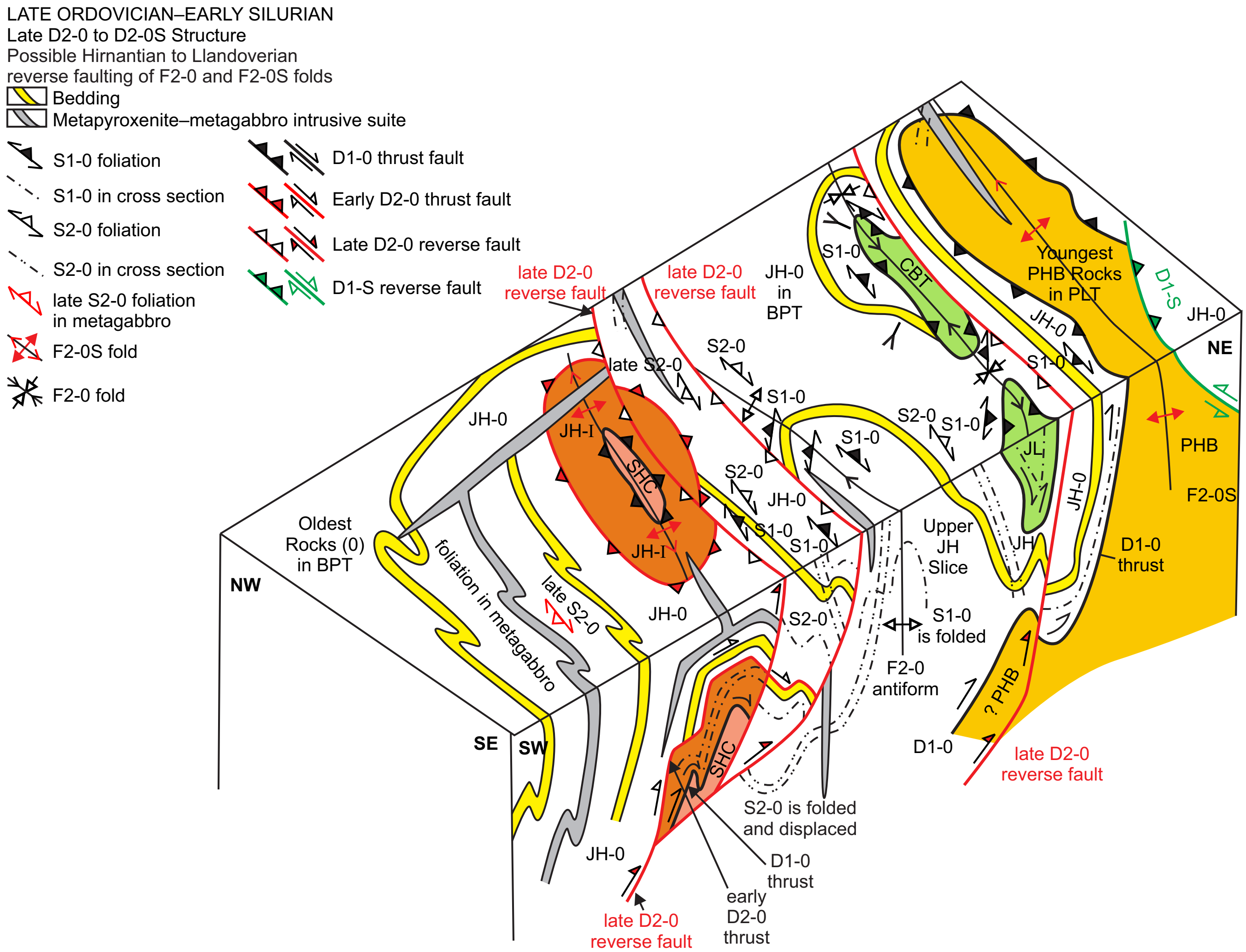
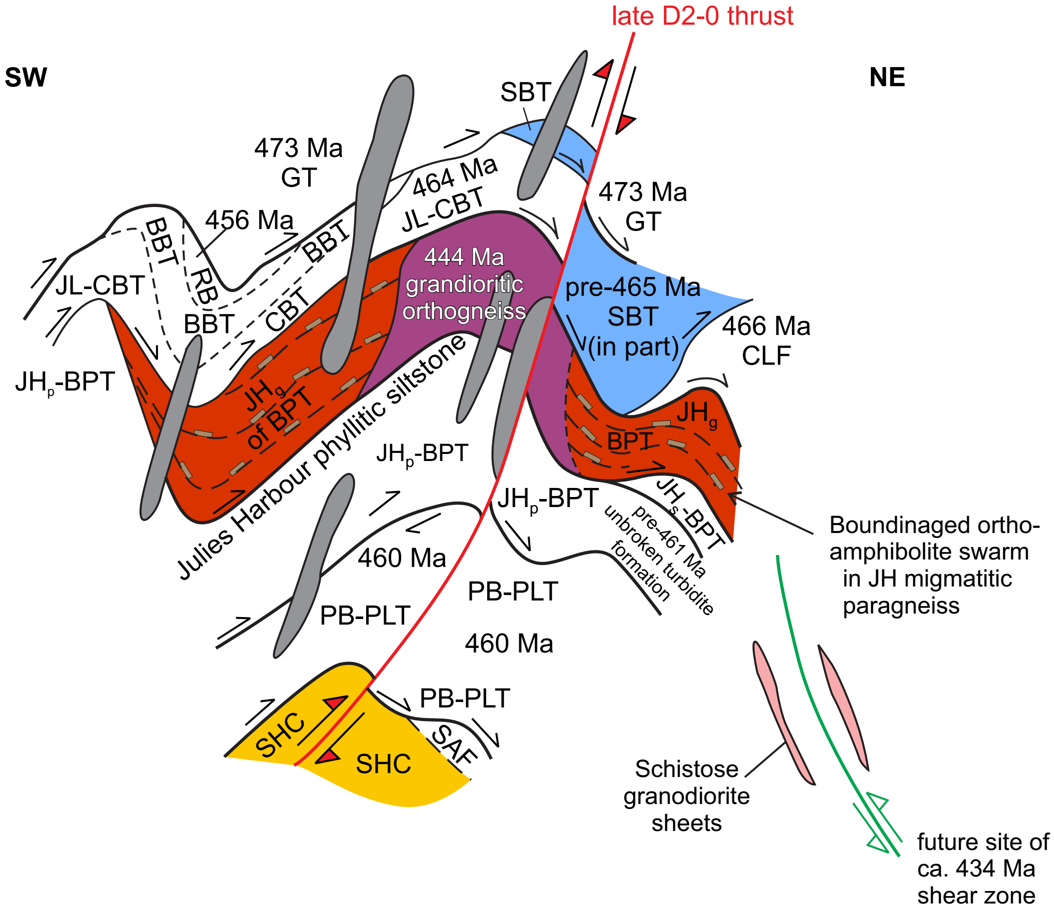


Figure 11. *Simplified SRAVB block diagram highlighting two domed thrust sheets of Julies Harbour metasedimentary rocks (labelled JH-O and JH-1 in the oldest observed part of BPT) that were intruded by deformed swarms of metagabbroic rocks. One such antiform within this folded SRAVB thrust stack is cored by Julies Harbour metasedimentary schist (labelled JH-1 in BPT and coloured light orange); in contrast, the other antiform is cored by Powderhorn Brook pelitic schist (labelled PHB in PLT and coloured yellow). These are separated by a regional synformal keel outlined, in part, by a tectonically overlying panel of Joes Lake volcanic rocks (labelled JL in CBT and coloured green). Tectonically underlying strata from the Sops Head Complex (labelled SHC and coloured pink) are also illustrated in the more complexly faulted antiform lying beneath JH-1. Note bedding planes (yellow strata) and various metagabbro bodies (blue-grey intrusions) depicted in the Julies Harbour lithotectonic sequence. Also protrayed are the regional trace of some D1-O thrust faults and the allied MS1-O metamorphic foliation, the axial trace of major F2-O folds and the attendant MS2-O foliation, some early-formed D2-O thrust faults, certain F2-OS domes and basins outlined by major D1-O and D2-O thrust faults, and several late D2-O reverse faults associated with the development of a late S2-O marginal foliation within some metagabbro dykes and adjacent country rocks.*

tinued with the subvertical Tower Hill-type swarms of amphibolitized gabbro, gneissic granodiorite and schistose diabase that were emplaced into the steeply dipping D2-O ductile shear zones in the lower SRAVB.

Rocks of the Dawes Pond metagabbro complex represent the youngest known component of the synmetamorphic intrusive suite in the SRAVB (Unit eS:TIdpgt; O'Brien, 2016c). Some of the constituent plutonic sheets in this complex may possibly be as old as the foliated Tower Hill granodiorite but are probably not as young as the unmetamorphosed granodiorite phase of the compositionally zoned pluton exposed near Dawes Pond. They have been correlated with metamorphosed Late Ordovician–Early Silurian intrusive rocks located farther south, near Buchans in the oldest part of the Topsails plutonic suite (*see* Rainy Lake Complex, Whalen and Currie, 1988; Master Legend in O'Brien, 2016).

Regional Tectonic Setting of Late Ordovician–Early Silurian Suite of Metapyroxenites and Metagabbros



Probable Ages of Syntectonic Ultramafic and Mafic Intrusions in SRAVB
- Maximum range of igneous crystallization is from post-456 Ma to pre-429 Ma
- Syn- to late D2-0 intrusive phase is mainly from post-443 Ma to pre-435 Ma
- Earliest known intrusive phase (ortho-amphibolite sills) is pre-444 Ma
- Latest known intrusive phase (composite metabasite dykes) is pre-435 Ma

Figure 12. *Schematic southwest–northeast cross-section of typical SRAVB rocks illustrating the tectonic setting of the D1-O, D2-O and D2-OS suite of syntectonic ultramafic and mafic intrusions (grey) observed in this part of the AAT. Structural symbols are the same as those shown in Figure 11. Estimated approximate age and abbreviations for units depicted in this part of the Robert's Arm thrust stack are as follows: GT=island arc-related volcanic rocks of the Gullbridge Tract; SBT=Black Gull Island tholeiitic basalt of the South Brook Tract; CLF=volcaniclastic strata of the Crescent Lake Formation; JL-CBT=tholeiitic and calc-alkaline basalt of the Joes Lake division of the Catamaran Brook Tract; RB=felsic volcanic-derived sedimentary rocks of the younger Rocky Brook division of the Baker Brook Tract; BBT=felsic volcanic-derived sedimentary rocks of the older Eastern Baker Lake Brook division of the Baker Brook Tract; JHg-BPT=migmatitic paragneiss, ortho-amphibolite and granodioritic orthogneiss of the Tower Hill Gneiss of the Burnt Pond Tract; JHs-BPT=hornfelsic schist of the Julies Harbour division of the Burnt Pond Tract; JHp-BPT=phyllitic siltstone turbidites and other unbroken formations of the Julies Harbour division of the Burnt Pond Tract; PB-PLT=graphitic pelitic schist and metarhyolite of the Powderhorn Brook division of the Powderhorn Lake Tract; SHC= tectonized olistostromal melange of the Sops Head Complex; SAF=graptolitic black slate and bioturbated chert of the Shoal Arm Formation.*

Late D2-O Syntectonic Intrusions

The synmetamorphic plutonic rocks observed in the SRAVB include the Baker Brook-type metapyroxenite dykes (Figure 5). In the past, the metapyroxenite body exposed at Baker Brook has been interpreted as a fault-bounded tectonic slice of part of the Ordovician Hall Hill ophiolite complex (Unit eOg of Swinden and Sacks, 1996). Alternatively, it has been assumed to be Early Ordovician and to have been in geological (intrusive) contact with rocks belonging to several discrete lithostratigraphic divisions within the Early Ordovician part of the Roberts Arm Group (Unit Ogb of Dickson, 2001).

Near the outflow of Baker Brook into Great Gull Lake, these layered ultramafic rocks crosscut open F1-O and close to tight F2-O folds in their metamorphosed country rocks (O'Brien, 2016c). In places, such intrusions were marginally foliated by a late MS2-O schistosity or they were openly buckled by late-formed F2-O fold structures. Subsequently, the layered pyroxenites were crosscut by unmetamorphosed composite diabase and quartz-feldspar porphyry dykes (*see* below).

Synmetamorphic intrusion in the SRAVB culminated with the relatively widespread injection of the Dawes Pond-type metagabbro bodies. This suite includes northwest-trending dykes intruded along steeply dipping F2-O fold limbs, or those emplaced near late D2-O reverse faults that obliquely offset F2-O fold axial surfaces, or those situated on the southwest-dipping flanks of F2-OS fold structures (Figure 11). Some of the relatively young intrusions in this suite are observed to have had occupied longitudinal or cross-strike fractures within certain F2-OS tectonic domes and, in places, they are seen to be sericitized and silicified. Coarse-grained pyrrhotite-bearing, nickel-rich gabbros were displaced by vertical shear fractures lying parallel to the northwest-trending MS2-OS crenulation cleavage (*e.g.*, Figure 11).

Relationships of Probable Late Ordovician–Early Silurian Intrusions in the Lower SRAVB Metamorphic Assemblage

The Dawes Pond metagabbro complex generally comprises a late D2-O to D2-OS intrusive suite in the SRAVB. These sheeted plutons were emplaced into host rocks of mainly Middle to Late Ordovician age that had been already regionally metamorphosed by latest Ordovician–earliest Silurian time (O'Brien and Dunning, 2008; G.R. Dunning, personal communication, 2009). Some of their host rocks were previously intruded by the Tower Hill tonalitic gneiss.

The schistose metapyroxenite and metagabbro bodies described below comprise part of the Tower Hill–South Burnt Pond–West Rocky Pond belt in the SRAVB (Figure 5). In this region, they typically intrude Unit OS:BPog orthogneisses within the Julies Harbour division. However, Dawes Pond-type metagabbros are also present in steeply dipping D2-O shear zones within the flanking metasedimentary and metavolcanic strata of the Gull Brook Bridge, Joes Lake, Eastern Baker Lake Brook and Powderhorn Brook divisions. Many metagabbro bodies in the Dawes Pond complex locally display a late MS2-O foliation and occupy structural positions along the crests and limbs of regional F2-O folds (Figure 11). They contain angular xenoliths of MS2-O foliated aplite dykes and L2-O lineated quartz veins.

The earliest known sheets of late syntectonic metagabbro had intruded the coarsely porphyroblastic metaturbidites of the BBT (MS2-O cordierite–andalusite–sericite–quartz schist). However, they had also intruded older volcanic rocks in a structurally overlying metabasite sequence (MS1-O cordierite–actinolite–albite schist) derived from the adjacent Black Gull Island basalt of the SBT. Consequently, such Dawes Pond metagabbros are interpreted to have been emplaced across the original D1-O thrust boundary separating these regional SRAVB structural tracts.

In contrast, later metagabbro bodies belonging to the Unit eS:TIdpgb intrusive suite had crosscut folded sills of cumulate-layered metapyroxenite hosted by lithostratigraphic units assigned to the Late Ordovician Rocky Brook argillite, the Middle Ordovician Eastern Baker Lake Brook metawacke and the Middle Ordovician Black Gull Island pillowed tholeiite (O'Brien, 2016c).

Some of the complex's mafic plutonic rocks have steeply dipping intrusive margins and are locally observed to be transitional to late MS2-O actinolite–biotite schist. Moreover, in places where dynamic recrystallization and static recovery were pervasive, extensive tracts of MS2-OS mafic granofels developed in certain gabbro-injected metabasite units or near gabbro intrusions emplaced into hornfelsic metasedimentary schist. Regardless, throughout the study area, they are observed to have been posttectonically intruded by probably Middle Silurian granodiorite plutons and hydrothermally altered diorite stocks, and by younger swarms of chloritized mafic dykes and epidotized quartz-feldspar porphyries.

Most intrusive sheets of Dawes Pond metapyroxenite and metagabbro that had been intruded across regional D1-O thrust faults were themselves displaced by younger northwest-dipping D2-S reverse faults and deformed by northeast-trending F2-S folds (*see* Silurian D1-S and D2-S description to follow), especially in the middle and upper parts of the SRAVB nappe complex (Figure 5). Although some of the Dawes Pond metagabbro bodies had probably been emplaced as cooling autokinematic sheets during late D2-O deformation (Figures 11 and 12), many of them were completely crystalline before reverse fault-related D2-S deformation of the oblate cordierite porphyroblasts that had developed in their country rocks (Plate 3D).

Based on regional considerations, the syn- and post-Late Ordovician metamorphic and syntectonic intrusive events in the SRAVB are postulated to have probably occurred between the latest Hirnantian stage and the late Llandoverian stage (*ca.* 443–435 Ma); *e.g.*, *see* Cawood *et al.* (1994), van Staal

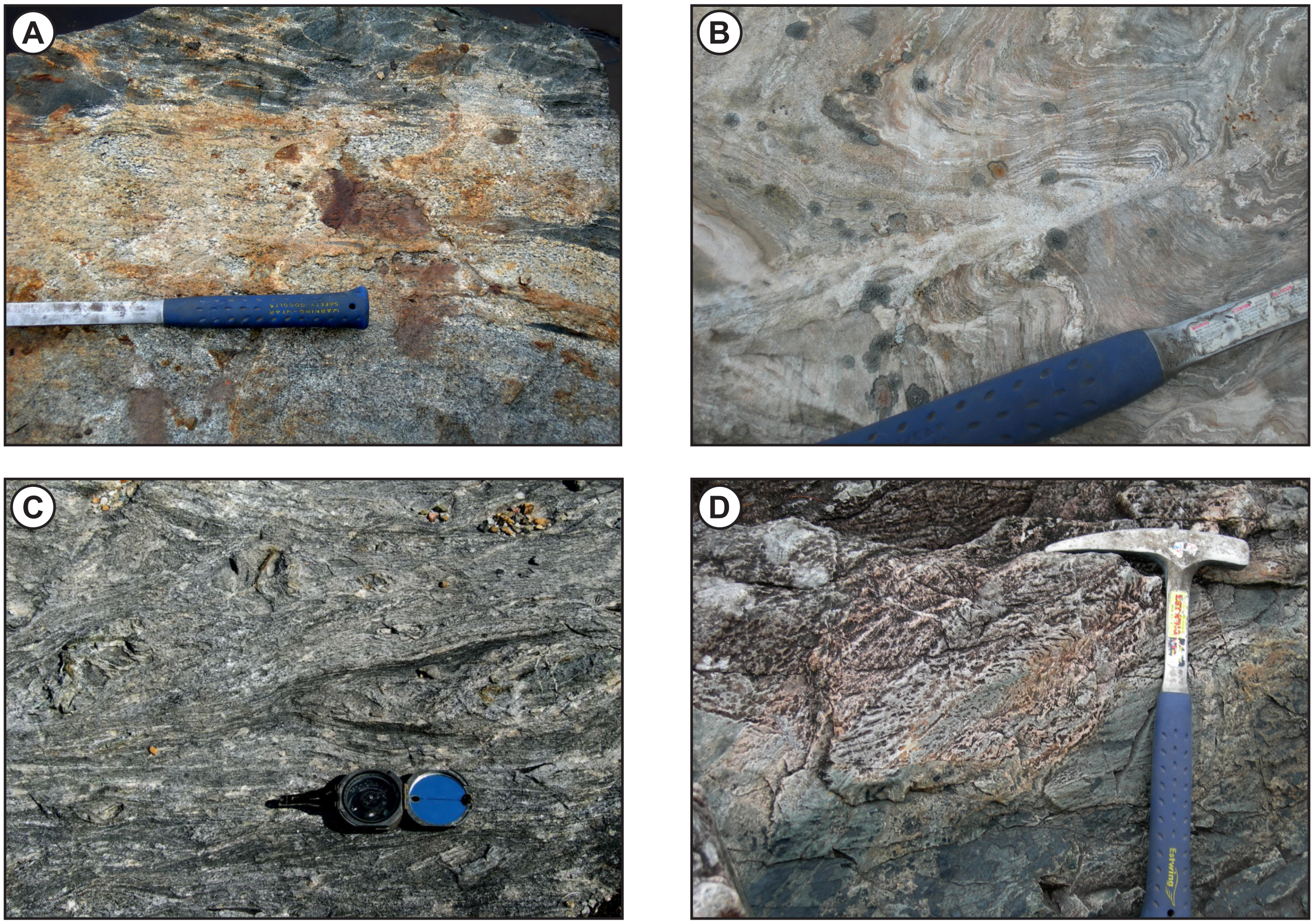


Plate 3. *A) Northwest–southeast longitudinal-section of a northeast-dipping D1-S shear zone developed within a foliated granodiorite, viewed looking down the foliation dip toward the northeast. The pink-weathered, light-grey granodiorite (under hammer shaft) invades and includes distorted xenoliths of coeval mafic dykes; it has been locally included in the youngest known part of the Unit OS:BPog intrusive suite. The stratified country rocks of this particular metamorphosed granodiorite (not shown in photograph) are amphibolite-facies metasedimentary rocks assigned to the Julies Harbour gneiss, although similar granodiorite sheets are present in the tectonically adjacent Powderhorn Brook pelite [E565067 N5443187]; B) A small reverse shear zone in Julies Harbour metasedimentary schist is occupied by a microgranitic dyke that dips gently toward the northeast and partially digests the country rock foliation. In places, along the original trace of this D1-S fault structure, a thrust had displaced the hinge and long limb of a tight F1-S fold in the adjacent hangingwall plate and placed it structurally above the limb of an open F1-S fold in the footwall plate. Note that the bed-parallel MS2-O schistosity defines such fault-related folds and lies parallel to a concordant microgranitic sill in the local footwall sequence. In the D1-S hangingwall sequence, an overprinted F2-O eye fold structure is preserved in the steeply pitching hinge zone of a northwest-closing F1-S synform [E564876 N5449938]; C) Tectonically straightened compositional bands of a reworked gneiss at Tower Hill (below compass) are made up of light-coloured MS1-S quartzofeldspathic layers (locally sucrose) and dark-coloured MS1-S layers of fine-grained actinolite (also enriched in phyllosilicates). These northeast-dipping D1-S structures bound lower stain zones composed of a folded lit-par-lit migmatitic paragneiss having relict boudins of amphibolite dykes. A structurally discordant MS2-O composite foliation in Julies Harbour paragneiss is preserved within the D1-S tectonic augen seen in the upper part of photograph [E566505 N5438424]; D) Reverse slip movement is interpreted to have occurred along the upper and lower bedding surfaces of upside-down strata located in the structurally highest part of the Late Ordovician Rocky Brook sequence near Great Gull Lake. This resulted in the formation of Z-shaped asymmetrical folds of the regionally northwest-dipping MS2-S cleavage, possibly indicating late D2-S flexural slip deformation. Within the internal parts of certain sandstone beds, where the foliation, being flexure, still lies gentler than the bedding, MS2-S cleavage is observed to wrap around flattened porphyroblasts of cordierite having large aspect ratios [E562338 N5448164].*

(1994), van Staal *et al.* (2008) and Brem *et al.* (2007) in the Canadian Appalachians; Tucker and Robinson (1990), Karabinos *et al.* (1998) and Dorais *et al.* (2012) in the New England Appalachians; Phillips *et al.* (2009), McConnell *et al.* (2010) and Chew and Strachan (2013) in the Irish and Scottish Caledonides; Andersen *et al.* (1998), Corfu *et al.* (2006), Nilsen *et al.* (2007), Roberts *et al.* (2007), Harper *et al.* (2008), Slagstad *et al.* (2013), Slagstad and Kirkland (2018) and Li *et al.* (2021) in the Scandinavian Caledonides for tectonic events of similar age near the Laurentia–Gondwana or the Laurentia–Baltica orogenic suture.

POSSIBLE SILURIAN (PRE-WENLOCKIAN) REGIONAL METAMORPHISM

In many localities in the eastern SRAVB, the peak metamorphic assemblage is typically defined by a composite MS1-O/MS2-O quartz–cordierite–andalusite–hornblende–garnet–muscovite porphyroclastic schistosity or, in places, a late MS2-O granoblastic to agmatitic gneissosity. In other nearby exposures, the highest grade assemblage, preserved in the amphibolite-facies metamorphic rocks, is characterized by randomly oriented MS2-O porphyroblasts of andalusite, sillimanite, cordierite, biotite and muscovite that had overgrown the greenschist-facies MS1-O foliation. These different textural types of metamorphic rocks reflect different stages of the regional amphibolite-facies metamorphism recorded in Late Ordovician and older strata in the study area. In any regard, such rocks had constituted an integral part of the southeast SRAVB assemblage before the onset of a lower grade (younger) phase of dynamothermal metamorphism described and discussed below.

In some localities, Dawes Pond-type metagabbroic intrusions and their schistose or gneissose host rocks are believed to have been affected by a Silurian phase of M1-S regional metamorphism and concomitant D1-S deformation. This retrogressive greenschist-facies event took place predominantly where the above-mentioned amphibolite-facies rocks were structurally reworked in thrust-related D1-S ductile shear zones (*cf.* Figures 6, 8, 11 and 12).

The youngest known syntectonic suite of plutonic rocks emplaced into the SRAVB schist and gneiss belts, are commonly situated where the host rocks, enveloping the metamorphosed intrusions of units OS:BPog and eS:TIdpgb, were inhomogeneously deformed by a series of northeast-dipping D1-S reverse shear zones. Preferentially developed, in parts of the lower SRAVB assemblage, these are geometrically distinguished from the D2-O imbricate thrust zones by their antithetic polarity (northeast-over-southwest D1-S displacement; *see* Figure 8).

In such tectonic settings, moderately to gently northeast-dipping sheets of a variably sheared granodiorite are seen to contain partially dismembered trains of deformed diabase dykes that carry a MS1-S actinolite–biotite–chlorite metabasite foliation. Such schistose granodioritic intrusions had been emplaced after the formation of the subvertical MS2-O foliation in orthogneiss at Tower Hill, and after the generation of the peak metamorphic assemblage in the lower AAT, but before the posttectonic emplacement of the adjacent Middle Silurian and younger plutonic rock units (O'Brien, 2016c). They are herein ascribed to a probable Early Silurian D1-S tectonothermal event that was mainly recorded in the eastern SRAVB.

On the northeast-dipping limb of the F2-OS Powderhorn Lake dome, the lithotectonic sequence of Powderhorn Brook sulphidic pelite, Julies Harbour hornfelsic semipelite and Joes Lake meta-andesite had its constituent amphibolite-facies MS2-O schists become reduced in grain size, within relatively fine-grained D1-S zones of neocrystallized M1-S phyllonite (Plate 3C). Furthermore, in some localities, this gently northeast-dipping M1-S actinolite–biotite–sericite foliation is observed to overprint and retrograde the cordierite–andalusite–garnet–hornblende assemblage in the Julies Harbour metasedimentary gneiss and hornfelsic schist belts. Elsewhere, in retrograded Joes Lake metavolcanic schist, the MS1-S metamorphism produced an actinolite–chlorite–albite assemblage; whereas, a MS1-S sericite–chlorite–graphite–albite assemblage was developed within retrograded Powderhorn Brook metapelite and Eastern Baker Lake Brook metawacke.

The regional MS1-S fabric comprises the sole metamorphic feature observed in intrusive sheets of sheared granodiorite concordantly emplaced into adjacent MS1-S phyllonite zones. It represents the youngest of the originally northwest-trending foliations formed in the older gneiss and schist belts, having grown during the MS1-S phase of retrogressive metamorphism in the lower SRAVB. Such post-peak metamorphic D1-S structures are well developed in a foliated Llandovery granodiorite dyke (O'Brien and Dunning, 2008) exposed near the summit of Tower Hill (Plate 3A).

Relationships of Syntectonic D1-S Intrusions in the Lower SRAVB

In the northeast part of the lower SRAVB due north of Powderhorn Lake (Figure 5), an intrusive phase of whispy-foliated granodiorite is seen to be transitional to schistose quartz-ribboned granodiorite and, locally, to banded ultramylonite (the Silurian D1-S suite of this report). Such plutonic rocks are host to a broadly coeval swarm of back-veined and assimilated diabase dykes (Plate 3A). Like the older Dawes Pond metagabbro, these layered synmetamorphic intrusions are also emplaced into the Tower Hill orthogneiss and the Julies Harbour migmatitic paragneiss. However, in contrast with the Unit OS:BPog orthogneiss, the syn D1-S granodiorite sheets are observed to intrude the structurally underlying thrust sheet of Powderhorn Brook pelitic schist. Relicts of these granodiorites and adjacent D1-S deformed country rocks are interpreted to comprise some of the large stoped enclaves and smaller accidental xenoliths seen in the posttectonic Crooked Lake gabbro of the Hodges Hill intrusive suite (Unit eS:HIclgb; O'Brien, 2016c).

Small intrusive bodies, mainly represented by gently inclined sheets of recrystallized granodiorite and granite, are observed to have been preferentially emplaced along minor D1-S thrust faults in lower SRAVB host rocks. Such magma-sealed thrusts displaced gently northeast-plunging F1-S folded zones developed in the adjacent hangingwall- and footwall metasedimentary sequences. In such locations, sideways-closing F1-S fold pairs, overprint steeply dipping zones of composite MS2-O/MS1-O schistosity (Plate 3B), yielding evidence of magmatic intrusion overlapping with D1-S ductile deformation. Within the gneiss and schist belts of the Burnt Pond and Powderhorn Lake structural tracts, northeast-dipping granodiorite dykes carrying the regional M1-S schistosity are known to have crosscut microgranitic sills and quartz veins that were deformed during the late D2-O event.

LATE-FORMED D2-S DUCTILE FAULTS

In the northern part of the SRAVB near Great Gull Lake, moderately northwest-dipping reverse faults are superimposed upon several northwest-plunging domes or adjacent structural basins. They serve to locally reorient these regional F2-O structures, particularly in areas near southwest-trending protomylonite zones (*e.g.*, near the former Gullbridge Mine and the Southwest Shaft).

Some of these ductile fault structures deformed the cordierite–anthophyllite schists typical of the GT, and elsewhere re-foliated Floian strata that were previously faulted but less hydrothermally altered. However, they are also mapped to offset the youngest known SRAVB rocks situated in the subjacent Gull Hill thrust-bounded structural dome (O'Brien, 2016c), where fault-related tectonic movements locally distorted the coarse porphyroblasts that had developed in Baker Brook cordierite–muscovite schist (Plate 3D).

As their relationship to the northeast-dipping D1-S reverse shear zones was not directly observed, it is possible that the above mentioned southwest-trending faults are simply regionally re-oriented examples of the D1-S structures described above. In this report, the southwest-trending reverse faults and northwest-dipping protomylonite zones have, however, been tentatively grouped with the D2-S structural features seen farther south in the SRAVB. These include the post D2-O reverse faults that had displaced the southeast- to southwest-plunging crossfolded F2-O domes of SRAVB gneiss and schist between Powderhorn Lake and Lake Bond, and those delimiting the tectonically adjacent homoclinal strata of the Badger Group in the area east of Skull Hill (O'Brien, 2009, 2016c).

4. U–Pb ID-TIMS AGE OF THE ROCKY POND GRANODIORITE IN THE SOUTHERN ROBERT'S ARM VOLCANIC BELT

Unit eS:HIrpgd granodiorite comprises part of the post-metamorphic Rocky Pond intrusive suite, a satellite body of the Topsails plutonic suite located at the headwaters of the Tommy's Arm River in the area west of North Twin Lake (Figure 13; O'Brien, 2016b). Rocks making up this circular plutonic complex were intruded posttectonically into Unit mO:BP metasedimentary rocks of the Julies Harbour division of the Burnt Pond structural tract (BPT). To the east, the Rocky Pond granodiorite was intruded by granite, granodiorite and quartz diorite sheets present at the western margin of the Siluro-Devonian Hodges Hill batholith.

TECTONIC SETTING

Along its southwest margin, the granodiorite unit of the Rocky Pond intrusive suite is emplaced through an antiformal thrust stack of Julies Harbour gneiss, schist and phyllite within the Burnt Pond window. There, this metamorphic assemblage lies above the alkali basalt, pyritic siltstone turbidite and pebbly mudstone of the upper Sops Head Complex (O'Brien, 2004; Sarioglu, 2007). At its northeast boundary, the granite unit of the Rocky Pond intrusive suite crosscuts a large klippen of Julies Harbour phyllite that is structurally underlain by the Julies Harbour metasedimentary gneiss and a small thrust slice of the Sops Head Complex (Unit mO:BHHCs, Figure 13; O'Brien 2016a, b). Farther north, near the western shore of North Twin Lake, the klippen carrying the Julies Harbour phyllite overlies the broken formations and olistostromal mélange of the Sops Head Complex; however, in places, it also tectonically overrides the Pennys Brook Formation of the peri-Gondwanan Wild Bight Group and the younger graptolitic slates of the Late Ordovician Shoal Arm Formation (*see* Figures 15 and 16B).

The purpose of obtaining a precise U–Pb ID-TIMS zircon date for the granodiorite intrusion (sample BOB-02-1) is to determine a younger limit on the time of peak metamorphism and early thrust-related deformation in this part of the regional map area (UTM Grid Zone 21, NTS 12H/8, Springdale, E571288, N5458770).

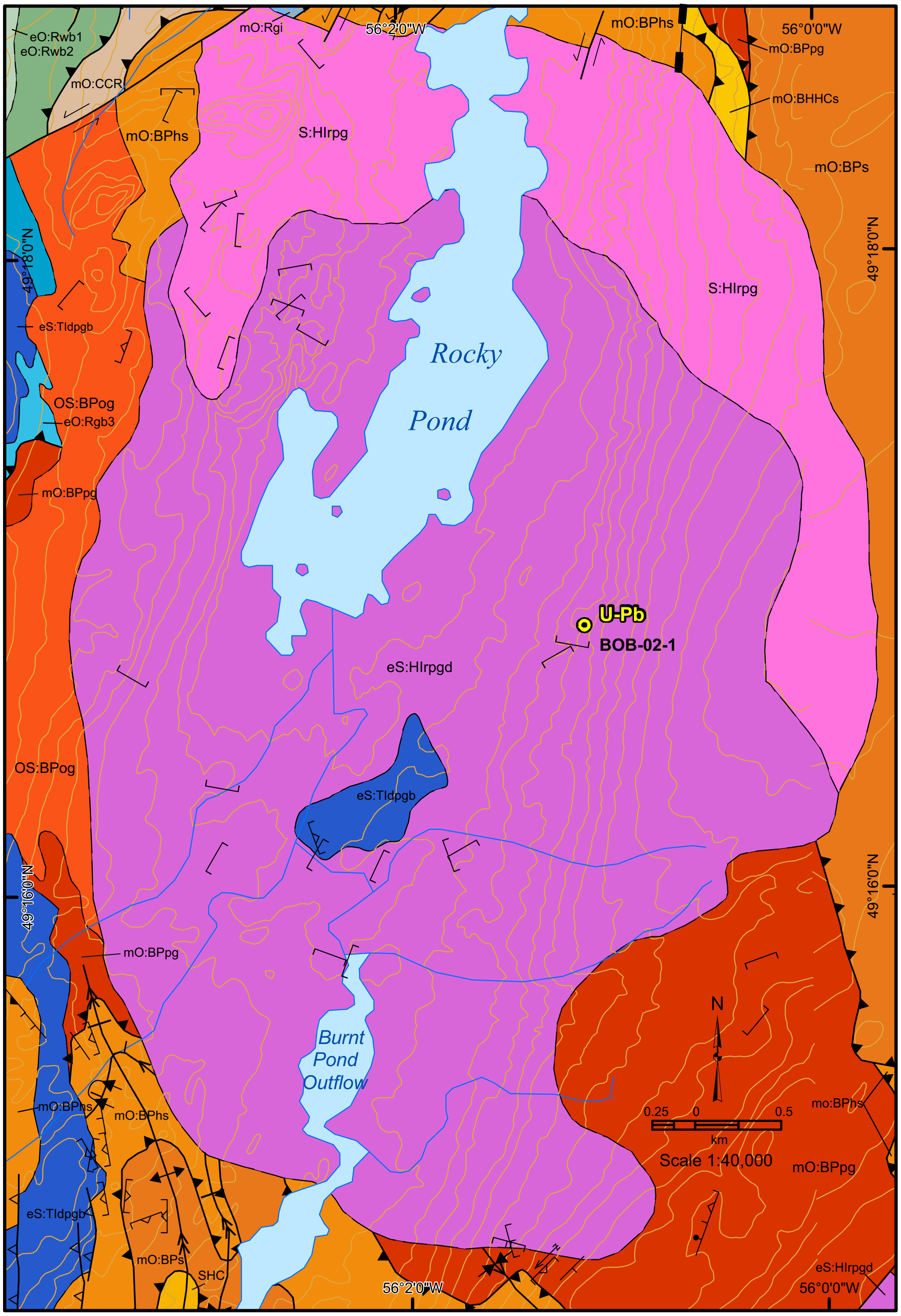


Figure 13. *Detailed geological map (drawn on 1:40 000 scale) of the Rocky Pond intrusive suite (Unit eS:HIrpgd and Unit S:HIrpg) and adjacent country rocks from both the upper and lower parts of the Robert's Arm thrust stack and the Sops Head Complex (SHC). Locally, the lower SRAVB metamorphic assemblage includes the Tower Hill felsic orthogneiss and banded amphibolite (Unit OS:BPog) of the Burnt Pond structural tract. Note the location of geochronology sample BOB-02-1 in the Early Silurian Rocky Pond granodiorite (Unit eS:HIrbgd) and the enclave of syntectonic Dawes Pond metagabbro (Unit eS:TIdpgb in blue) within that posttectonic intrusive map unit.*

LITHOLOGY OF THE ROCKY POND INTRUSIVE SUITE

An isotropic body of equigranular hornblende granodiorite (Unit eS:HIrpgd) comprises the main component of the nested pluton. In places, a coarse-grained biotite-bearing diorite is observed to be gradational with a quartz-phyric phase of the granodiorite. West of Rocky Pond proper, propylitic alteration zones are present in granodiorite invaded by late pegmatite veins; however, the dated specimen of BOB-02-1 granodiorite is relatively fresh.

Biotite quartz monzonite, porphyritic biotite leucogranite and rare granophyre (Unit S:HIrpg) form the outer intrusive ring of the compositionally zoned pluton. In some localities, altered veins of quartz-feldspar porphyry intrude the medium-grained equigranular quartz monzonite. Satellite bodies of pyritic porphyry dykes are widespread in adjacent country rocks.

Both the granodiorite and granite intrusions within the Rocky Pond pluton are crosscut by a northeast-trending swarm of aplite veins and multiple diabase dykes. Some of these minor intrusions were emplaced along northeast-trending subvertical zones of fluorite-bearing cohesive gouge that developed near late-stage, strike-slip faults.

ANALYTICAL PROCEDURES

The U–Pb analysis of single zircon crystals was by isotope dilution-thermal ionization mass spectrometry methods (ID-TIMS) at the Jack Satterly Geochronology Laboratory, University of Toronto. Zircon was separated from rock samples using standard heavy liquid and magnetic separation techniques.

All zircon grains have been air abraded (Krogh, 1982) to remove exterior surfaces that are likely to have undergone Pb loss. Zircon grains were rinsed in 8N HNO_3 at room temperature prior to dissolution. A mixed ^{205}Pb–^{235}U spike was added to the Teflon dissolution capsules during sample loading. Single zircon crystals were dissolved using ~0.10 ml of concentrated HF acid and ~0.02 ml of 7N HNO_3 at 200°C for 3–4 days. Samples were dried to a precipitate and re-dissolved in ~0.15 ml of 3N HCl overnight (Krogh, 1973). The U and Pb were isolated from the zircon using miniaturized ~50 ml anion exchange columns using HCl, dried in 0.05N phosphoric acid, deposited onto outgassed rhenium filaments with silica gel (Gerstenberger and Haase, 1997), and analyzed by a VG354 mass spectrometer using a Daly detector in pulse-counting mode. Dead time of the measuring system for Pb and U was 16 and 14 ns, respectively.

Corrections to the ^{206}Pb–^{238}U ages for initial ^{230}Th disequilibrium in the zircon have been made assuming a Th/U ratio in the magma of 4.2. All common Pb was assigned to procedural Pb blank. The laboratory blanks for Pb and U are usually less than 1.0 and 0.1 pg, respectively. Error estimates were calculated by propagating known sources of analytical uncertainty for each analysis including ratio variability (within run), uncertainty in the fractionation correction (0.038% and 0.015% (1s) for Pb and U, respectively, based on long-term replicate measurements of the standards SRM982 and CBNM72-6), and uncertainties in the isotopic composition and the amount of laboratory blank and initial Pb. The mass discrimination correction for the Daly detector

Table 1.. U–Pb ID-TIMS isotopic data for single zircon grains from granodiorite sample BOB-02-1, Rocky Pond intrusive suite, southern Robert's Arm volcanic belt, North Twin Lake area, Newfoundland

											Age (Ma)						
No.	Weight (ug)	U ppm	Th/U	Pbc (pg)	$^{206}Pb/^{204}Pb$ measured	$^{207}Pb/^{235}U$	2σ	$^{206}Pb/^{238}U$	2σ	Error Corr	$^{206}Pb/^{238}U$	2σ	$^{207}Pb/^{235}U$	2σ	$^{207}Pb/^{206}Pb$	2σ	% Disc
Z1	8	40	0.64	1.0	1388	0.5280	0.0057	0.06900	0.00041	0.474	430.1	2.5	430.5	3.8	432	21	0.5
Z2	7	34	0.71	0.8	1341	0.5256	0.0051	0.06896	0.00027	0.398	429.9	1.7	428.9	3.4	424	20	-1.5
Z3	7	57	0.65	1.7	1045	0.5260	0.0061	0.06891	0.00021	0.464	429.6	1.2	429.1	4.1	427	24	-0.7
Z4	8	51	0.65	0.7	2713	0.5252	0.0034	0.06883	0.00027	0.539	429.1	1.6	428.6	2.3	426	12	-0.7

Notes:
Zircon (Z) grains have been air-abraded (Krogh, 1982).
Th/U calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio and $^{207}Pb/^{206}Pb$ age assuming concordance.
Pbc is total common Pb assuming the isotopic composition of laboratory blank: assigned the isotopic composition of laboratory blank ($^{206}Pb/^{204}Pb$ = 18.49 ± 0.4%; $^{207}Pb/^{204}Pb$ = 15.59 ± 0.4%; $^{208}Pb/^{204}Pb$ = 39.36 ± 0.4%)
$^{206}Pb/^{204}Pb$ corrected for fractionation and common Pb in spike
Pb/U ratios corrected for fractionation, common Pb in the spike, and blank
Correction for ^{230}Th disequilibrium in $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ assuming Th/U of 4.2 in the magma
Disc is percent discordance for the given $^{207}Pb/^{206}Pb$ age
Error Corr is correlation coefficients of X-Y errors on the concordia plot
Decay constants are those of Jaffey *et al.* (1971): ^{238}U and ^{235}U are 1.55125 x 10^{-10}/yr and 9.8485 x 10^{-10}/yr
$^{238}U/^{235}U$ ratio of 137.88 used for $^{207}Pb/^{206}Pb$ model age calculations

is constant at 0.05% per atomic mass unit. Amplifier gains and Daly characteristics were monitored using the SRM 982 Pb standard. Thermal mass discrimination corrections are 0.10% per atomic mass unit for both Pb and U. Decay constants are those of Jaffey *et al.* (1971). VG Sector software was used for data acquisition. In-house data reduction software in Visual Basic by D.W. Davis was used. All age errors quoted in the text and table, and error ellipses in the concordia diagrams are given at the 95% confidence interval (Figure 14). Plotting and age calculations were done using Isoplot 3.31 (Ludwig, 2003).

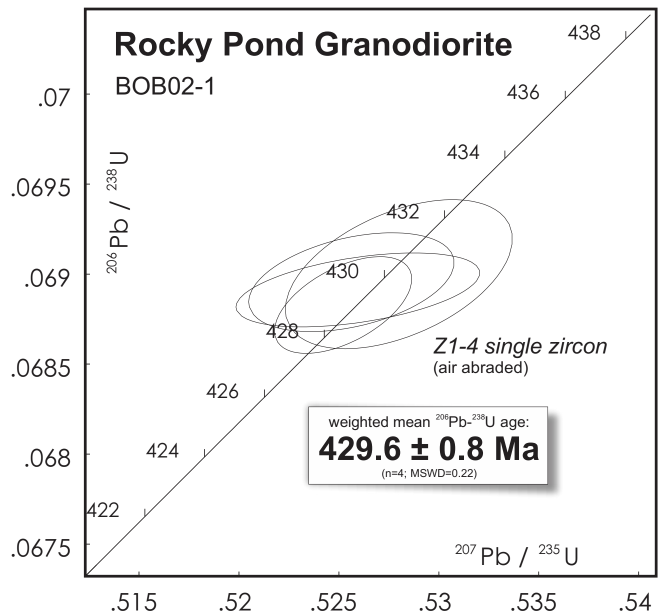


Figure 14. *Concordia diagram illustrating U–Pb ID-TIMS isotopic results obtained from single zircon crystals in Rocky Pond granodiorite sample BOB-02-1 [E571288 N5458770].*

U–Pb ISOTOPE RESULTS

Abundant euhedral, equant to 4:1 prismatic, clear, pale-brown, "gem-quality" zircon crystals containing numerous rounded, bubble-like melt inclusions were recovered for U–Pb isotopic dating. Four analyses of single, air-abraded zircon crystals gave concordant and overlapping data (results were obtained prior to the advent of chemical abrasion). The weighted mean ^{206}Pb–^{238}U age of 429.6 ± 0.8 Ma (MSWD= 0.22) is identical to the "concordia age" (Ludwig, 2003) of 429.6 ± 0.8 Ma (MSWD of concordance = 0.43). Zircon crystallization at 429.6 ± 0.8 Ma is interpreted as the best estimate for the time of granodiorite emplacement.

Implications of the Silurian (Wenlockian) Age for the Rocky Pond Granodiorite

Given that the dated granodiorite crosscuts stratified rocks that exhibit evidence of peak M2-O metamorphism and polyphase deformation, the 429.6 ± 0.8 Ma mean age is a lower limit for these tectonic events, at least in the North Twin Lake area. Furthermore, the Rocky Pond granodiorite is locally interpreted to postdate adjacent D1-S back thrusts within the Burnt Pond Tract (Figures 15 and 16). Also, because the Rocky Pond granite intrudes the Crescent Lake Formation of the Roberts Arm Group, the Black Gull Island basalt of the South Brook Tract, and the southeasterly adjacent Sops Head Complex, the Rocky Pond intrusive suite, as a whole, may provide a minimum Wenlockian (mid-Silurian) age on the timing of northwest-dipping D2-S reverse fault development along parts of the RIL suture.

5. COMPARISON OF SRAVB ROCKS WITH TECTONIC ELEMENTS OF THE RED INDIAN LINE IN THE NORTH TWIN LAKE–KIPPENS POND–SOPS LAKE AREA

Within the SRAVB in the area east of Gull and South brooks, the lower Early Ordovician rocks of the Hall Hill Complex and the upper Early Ordovician rocks of the GT outline part of a southwest-plunging F2-S oroclinal fold (Figure 15). In contrast, in the NRAVB near Crescent Lake and Robert's Arm, correlative GT rocks of the upper AAT complex form the northeast-plunging part of the same regional orocline (*see* inset in Figure 15).

Along the RIL thrust zone, rocks of the Sops Head Complex and the BPT Tract occur in highly attenuated and discontinuous thrust sheets situated between the Middle Ordovician Crescent Lake Formation of the peri-Laurentian Notre Dame Subzone and the Middle Ordovician Pennys Brook Formation of the peri-Gondwanan Exploits Subzone. They may possibly represent preserved tectonic elements of a paleogeographic realm within the middle part of the Iapetus Ocean (*see* Figure 15 legend) that may or may not belong to the Notre Dame Subzone of the Dunnage Zone.

The Crescent Lake volcanic and sedimentary divisions are conformable and comprise a regionally right-side-up, northwest-facing lithostratigraphic succession located at the structural base of the Roberts Arm Group in the type area. To the east of Sops Lake, the upper part of the Pennys Brook Formation is observed to be stratigraphically succeeded by the Sandbian Shoal Arm Formation and the Katian Badger Group (Figure 15).

The relationship between the volcanic and sedimentary formations of the Crescent Composite structural tract of the SRAVB to the type Crescent Lake Volcanics and Crescent Lake Formation in the NRAVB is unknown, although the former lie higher in the regional Robert's Arm thrust stack than the latter (Figure 15). However, in a few places, isolated tectonic panels of volcanic arc-related rocks from the CBT

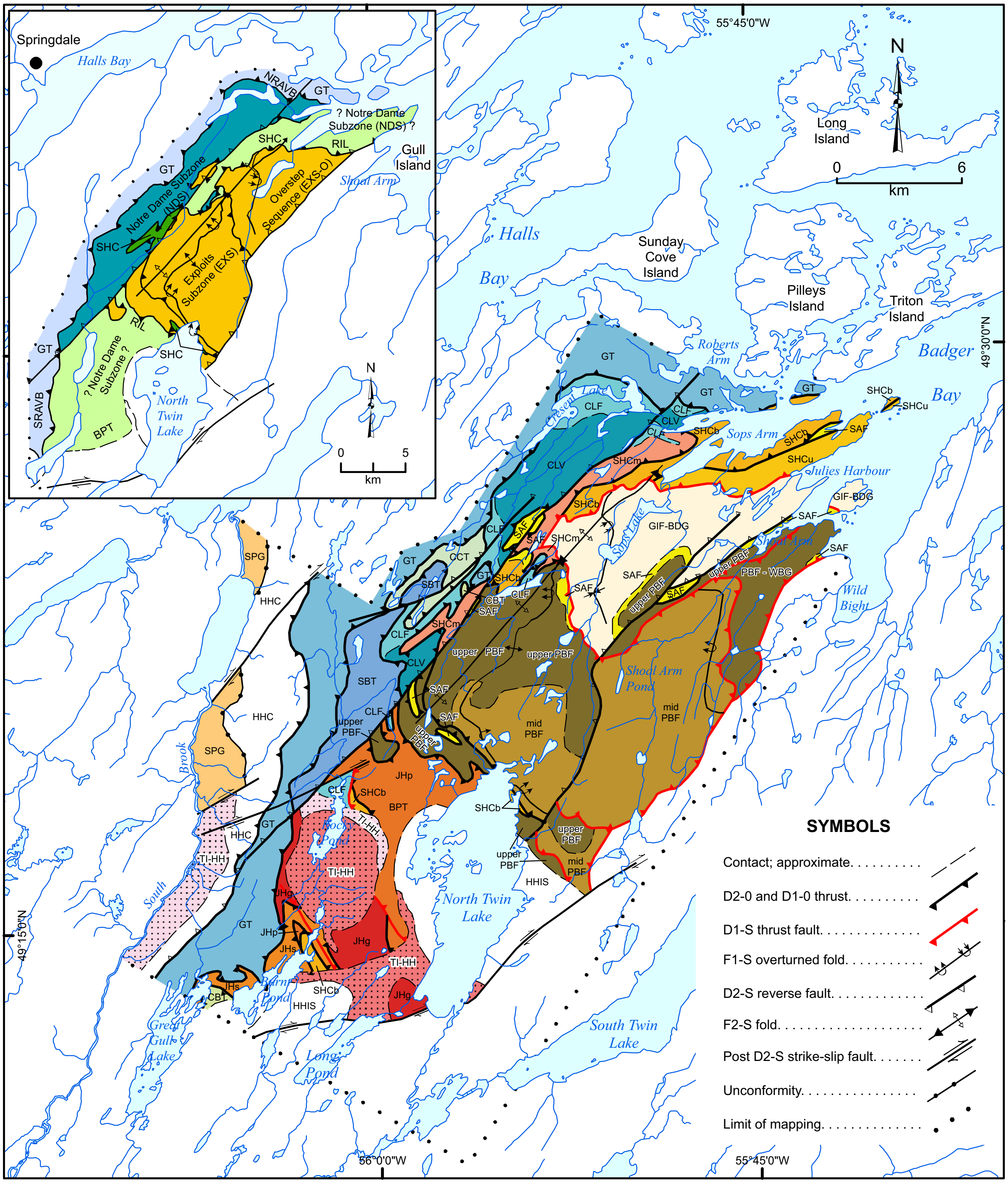


Figure 15. *Caption and Legend on next page.*

LEGEND

UNMETAMORPHOSED INTRUSIVE ROCKS

SILURIAN OR DEVONIAN

HHIS — Hodges Hill intrusive suite
Mafic plutonic rocks in the North Twin Lake and Long Pond areas of the Hodges Hill Intrusive Suite (mainly unseparated; (uncoloured units in Figure 15)

SILURIAN

TI-HH — Topsails–Hodges Hill intrusive suite
Older plutonic rock units of Hodges Hill Intrusive Suite (partial equivalents of intermediate to felsic intrusions within the Topsails Intrusive Suite)

- GBGT — Gull Brook granite
- RPG — Rocky Pond granite
- RPGD — Rocky Pond granodiorite

SILURIAN STRATIFIED ROCKS

SPG — Springdale Group

ORDOVICIAN STRATIFIED ROCKS

NOTRE DAME SUBZONE OF DUNNAGE ZONE
Upper SRAVB (some rocks probably assembled in early Middle Ordovician; listed in observed structural order)

- GT — Gullbridge Tract: Andesite, dacite and rhyolite
- CCT — Crescent Composite Tract: Tholeiitic basalt, ribboned chert and volcaniclastic wacke
- SBT — South Brook Tract: Tholeiitic basalt, pillow breccia and carbonate
- CLF — Crescent Lake Formation: Polymict conglomerate and volcaniclastic wacke
- CLV — Crescent Lake Volcanics: Pillowed tholeiitic basalt

PERI-LAURENTIAN TO MID-IAPETAN REALM
Lower SRAVB (rocks mainly sutured in Late Ordovician; listed in structural order)

- CBT — Catamaran Brook Tract: Joes Lake basalt and rhyolite
- BPT — Burnt Pond Tract (first juxtaposed with CBT in late Middle Ordovician?)
  - JHg — Julies Harbour gneiss
  - JHs — Julies Harbour schist
  - JHp — Julies Harbour phyllite
- SHC — Sops Head Complex
  - SHCm — block-in-matrix melange
  - SHCb — broken alkali-basalt formation
  - SHCu — unbroken turbidite formations

EXPLOITS SUBZONE OF DUNNAGE ZONE AND OVERSTEP SEQUENCES

RED INDIAN LINE (rocks initially sutured in Early Silurian)

- BDG — Badger Group
  - GIF — Gull Island Formation: Wacke, debrite and conglomerate
- SAF — Shoal Arm Formation: Chert and mudstone (unseparated)
- WBG — Wild Bight Group
  - PBF — Pennys Brook Formation
    - Upper PBF — ferruginous argillite and chert
    - Mid PBF — tuffaceous wacke and olistostrome

Figure 15. *Simplified regional geological map of the Burnt Pond–Rocky Pond–Kippens Pond–Sops Lake area drawn on 1:200 000-scale, between upper South Brook near Great Gull Lake and Crescent Lake, near the village of Robert's Arm. Note that the metasedimentary strata (and volcanic amphibolites) of the Burnt Pond Tract (BPT) may not necessarily be the statigraphical equivalent of the unbroken formations of the Middle Ordovician Sops Head Complex, although both units are disposed in the immediate hangingwall sequence of the Red Indian Line (RIL) fault zone.* See *Key to Symbols for Figure 15. Inset shows the general structural relationships of the peri-Gondwanan volcanic arc and back arc-related rocks of the Middle Ordovician Wild Bight Group (EXS; PBF-WBG) and the conformably overlying Late Ordovician overstep sequence of the Exploits Subzone (EXS-O; GIF-BDG) with the Late Ordovician and older rocks of the Robert's Arm volcanic belt (SRAVB and NRAVB) and the Middle Ordovician Sops Head Complex (SHC) and its possible metamorphic equivalents in the Burnt Pond Tract (BPT). The geological units portrayed in the coloured regional map are described in an accompanying legend. Uncoloured map units include parts of the Hodges Hill Intrusive Suite (HHIS) and the Hall Hill Complex (HHC).*

(Figure 15) were structurally emplaced below the Crescent Lake Formation and directly above the Sops Head Complex. Adjacent to the NRAVB in the area northwest of Sops Lake, Late Ordovician strata of the Gull Island Formation of the Badger Group locally occur below the Sops Head Complex in the structural footwall of the RIL suture. Farther south along this regional structure, in the area east of the Skull Hill pluton and adjacent to the SRAVB (Figure 2), similar Katian turbidites are seen below the partly broken formations of the Sops Head Complex, the Julies Harbour metasedimentary rocks of the BPT and other components of lower AAT assemblage and are well exposed in the structural footwall of the D2-S reverse fault located near Joes Lake and Badger Brook (O'Brien, 2009).

The lithotectonic sequence of GT, SBT and CCT volcanic rocks is disposed by probable Late Ordovician imbricate D1-O thrusts that outline a narrow arcuate train of tightly F2-O folded domes and basins. Late D2-O shear zones were occupied by southwest-dipping dykes of mylonitized granite in the underlying amphibolite-facies metamorphic rocks of the adjacent BPT (O'Brien, 2004). Tectonic slivers of arc-related turbidites from the Pennys Brook Formation, the overlapping black slate of the Shoal Arm Formation, and the block-in-matrix mélange and partly broken alkali basalt, ribboned chert and bioclastic limestone formations of the Sops Head Complex are also present within this relatively narrow tract of highly D2-O sheared and variably M2-O metamorphosed strata, although they are mostly seen to be out of primary depositional order (Figures 15 and 16). West of North Twin Lake, where strata of the Badger Group had been completely structurally excised, and immediately south of Burnt Pond, where the SBT and CCT lithotectonic sequences had been tectonically removed, the BPT metasedimentary rocks

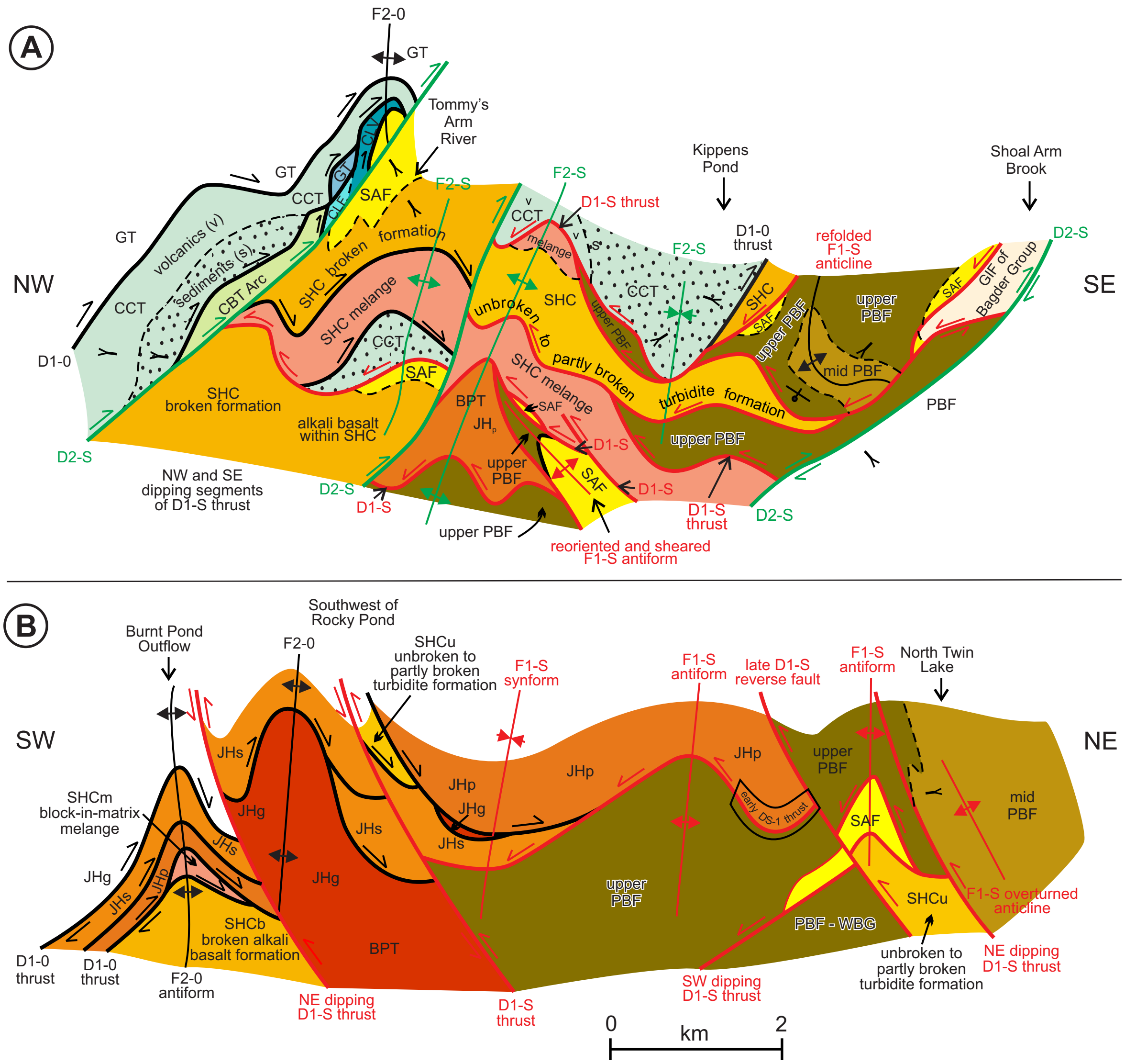


Figure 16. *Two regional cross sections of the Red Indian Line fault zone (based on the general geology shown on Figure 15), one oriented northwest–southeast (A) and the other southwest–northeast (B). The characteristic geometry of D1-O thrusts and F2-O folds (in black), F1-S folds and D1-S thrust-sense shear zones (in red), and F2-S folds and D2-S reverse faults (in green) are illustrated in rocks adjacent to RIL in the upper Tommy's Arm River–Kippens Pond–upper Shoal Arm Brook area (A) and in the Burnt Pond–Rocky Pond–North Twin Lake area (B). Dashed line indicates a primary lithostratigraphical boundary; bedding symbols and/or direction of younging arrows indicate the local stratigraphical facing direction. Their structural effect on the disposition of the graptolitic black slates of the Shoal Arm Formation (SAF in yellow) has been highlighted. Explanation of the abbreviations seen in Figure 16A: GT (Gullbridge Tract arc-related volcanic strata); CCT (Crescent Composite Tract tholeiitic basalts; polymictic conglomerates patterned), CBT (Catamaran Brook Tract arc-related volcanic strata); CLF (volcaniclastic sedimentary strata of the original Crescent Lake Formation); CLV (tholeiitic basalts of the original Crescent Lake Volcanics); BPT (Julies Harbour phyllitic siltstones (JHp) of the Burnt Pond Tract); SHC (unbroken to partly broken turbidite formations, broken volcanic and sedimentary formations, and pebbly mudstone and block-in-matrix melange of the Sops Head Complex); PBF (volcaniclastic turbidites, basalt breccias and cherts of the Pennys Brook Formation of the Wild Bight Group). As illustrated in Figure 16B, metamorphic rocks of the Burnt Pond Tract comprise various D1-O tectonic sequences labelled and abbreviated as JHg (Julies Harbour gneiss), JHs (Julies Harbour schist) and JHp (Julies Harbour phyllite); in places, these are tectonically juxtaposed with low grade rocks of the Sops Head Complex (SHCu and SHCb). The relative structural position of the slates of the Shoal Arm Formation (SAF) and the middle and upper members of the Pennys Brook Formation (PBF) of the Wild Bight Group (WBG) are also illustrated. Note that the BPT amphibolite facies metamorphic rocks were tectonically underplated beneath reverse fault-imbricated WBG (and SAF) strata during D1-S regional deformation; whereas, similar BPT metamorphic rock assemblages had been tectonically emplaced above SHC (and SAF) strata during regional D1-O/D2-O deformation. The folded D1-O thrust faults in the SRAVB rocks have a tectonic polarity opposed to the folded D1-S thrust and reverse faults in the Exploits Subzone rocks, although both are affected by similar northwest-dipping D2-S fault structures.*

are overthrust by the Joes Lake metabasalt in the northern part of the CBT (Figure 15).

Northeast-dipping D1-S reverse faults are nucleated near the traditional RIL suture within the Middle Ordovician Pennys Brook Formation of the Wild Bight Group (the tectonically uplifted part of the peri-Gondwanan Victoria Arc). They are best developed along the southwestern margin of the Wild Bight Group near the North Twin Lake exposures of the Sops Head Complex and also along the base of an adjacent klippen carrying older strata of the Pennys Brook Formation near the upper reaches of Shoal Arm Brook (Figures 15 and 16A, B). At this time, D1-S structures had also formed in the lower SRAVB metamorphic assemblage as northeast-dipping shear zones that were invaded by northeast-dipping sheets of deformed mafic and felsic intrusive rocks. Local host rocks included the F2-O folded trains of metasedimentary schist and gneiss in the Julies Harbour division between the North Twin Lake and Burnt Pond structural inliers of the Sops Head Complex.

Such pre-late Wenlockian structures had also affected some of the fossil-bearing sedimentary rocks in the Sandbian Shoal Arm Formation and the Katian Badger Group, a feature that distinguishes the D1-S shear zones from the late D2-O shear zones (Figures 15 and 16). In some locations, D1-S thrusts were locally folded to dip southwestward within sedimentary strata assigned to the Pennys Brook and Shoal Arm formations. They are interpreted to have been crosscut by later stage D1-S reverse faults that remain as northeast-dipping structures in adjacent parts of the Exploits Subzone. In other localities, M1-S phyllitic slates are observed to lie concordantly below composite M2-O/M1-O schists assigned to the lower SRAVB assemblage, particularly where rocks of the BPT lay both structurally beneath (Figure 16A) and structurally above (Figure 16B) low-grade rocks belonging to the Sops Head Complex or the Wild Bight Group.

All of these rocks were overprinted by large F2-S crossfolds and were displaced by northwest-dipping D2-S reverse faults (Figure 16A). Subsequently, the rocks comprising the Robert's Arm thrust stack were dextrally offset by a series of strike-slip faults that formed after the emplacement of the post-metamorphic plutonic rocks of the Topsails intrusive suite (Figure 15).

KINEMATIC EVOLUTION

A permissible regional kinematic analysis of the RIL suture and the RIL thrust zone in north-central Newfoundland is summarized below. A progressively increasing high T–low P regional dynamothermal metamorphism in the lower SRAVB assemblage culminated with D2-O deformation during the oblique convergence of the last accreted Powderhorn Lake Arc with the older Catamaran Brook Arc. Concomitant sinistral-oblique thrusting events around the Ordovician–Silurian boundary accompanied the tectonic underplating of the composite peri-Laurentian Iapetan margin (Figure 17) and gave rise to extensive tracts of hornblende garbenschiefer in the southeast part of the SRAVB. These movements produced southwest-dipping ductile fault structures in the lower Anneiopsquotch accretionary complex during an episode of mainly orogen-parallel displacement in the lower SRAVB thrust-and-nappe belt. The structural footwall rocks of the Middle Ordovician Sops Head Complex (Figure 17) may have served as a tectonic buttress to the lower SRAVB assemblage during D1-O and D2-O deformation when the convergence vector along the peri-Laurentian Iapetan margin was northward.

During later tectonic displacement along the RIL suture, an antivergent D1-S dextral oblique-slip thrusting event was accompanied by a low T–low P episode of regional metamorphism. A dynamic switch in the relative movements of the peri-Laurentian and peri-Gondwanan realms was controlled by the southward convergence of the colliding plate and first led to the northeastward under-thrusting of the SRAVB metamorphic assemblage and the southwestward overthrusting of the peri-Gondwanan slates of the Wild Bight Group. This Early Silurian accretionary event (post-early Hirnantian and pre-late Wenlockian) caused the northeast-dipping D1-S fault structures that had developed in the stratified rocks of the Badger Basin and the back-thrust and retrograded part of the AAT tectonic wedge. The plexus of the D1-S thrusts may have possibly been influenced by the inclination of the fossilized scar of the Darriwilian subduction zone that had governed the Exploits Subzone evolution of the Wild Bight Arc (MacLachan *et al.*, 2001) and the Victoria Arc (Zagorevski *et al.*, 2007b).

This was followed by a period of dextral-oblique slip D2-S reverse faulting that resulted in the primary northwest-dipping Silurian fault structures seen in the AAT and the western Exploits Subzone. This event occurred when the lower SRAVB metamorphic rocks became emergent and were structurally emplaced above the peri-Gondwanan volcanosedimentary sequence of the Wild Bight Arc and the Victoria Arc. Slaty cleavage arcs were generated during the west-over-east translation of the imbricate thrust sheets in the western part of the Exploits Subzone and along the RIL boundary as traditionally drawn.

6. DISCUSSION AND INTERPRETATION

Regional deformation and metamorphism of presumed late Taconian age in the peri-Laurentian Notre Dame Subzone of west-central Newfoundland has never been directly constrained by the geochronological dating of Taconic III accre-

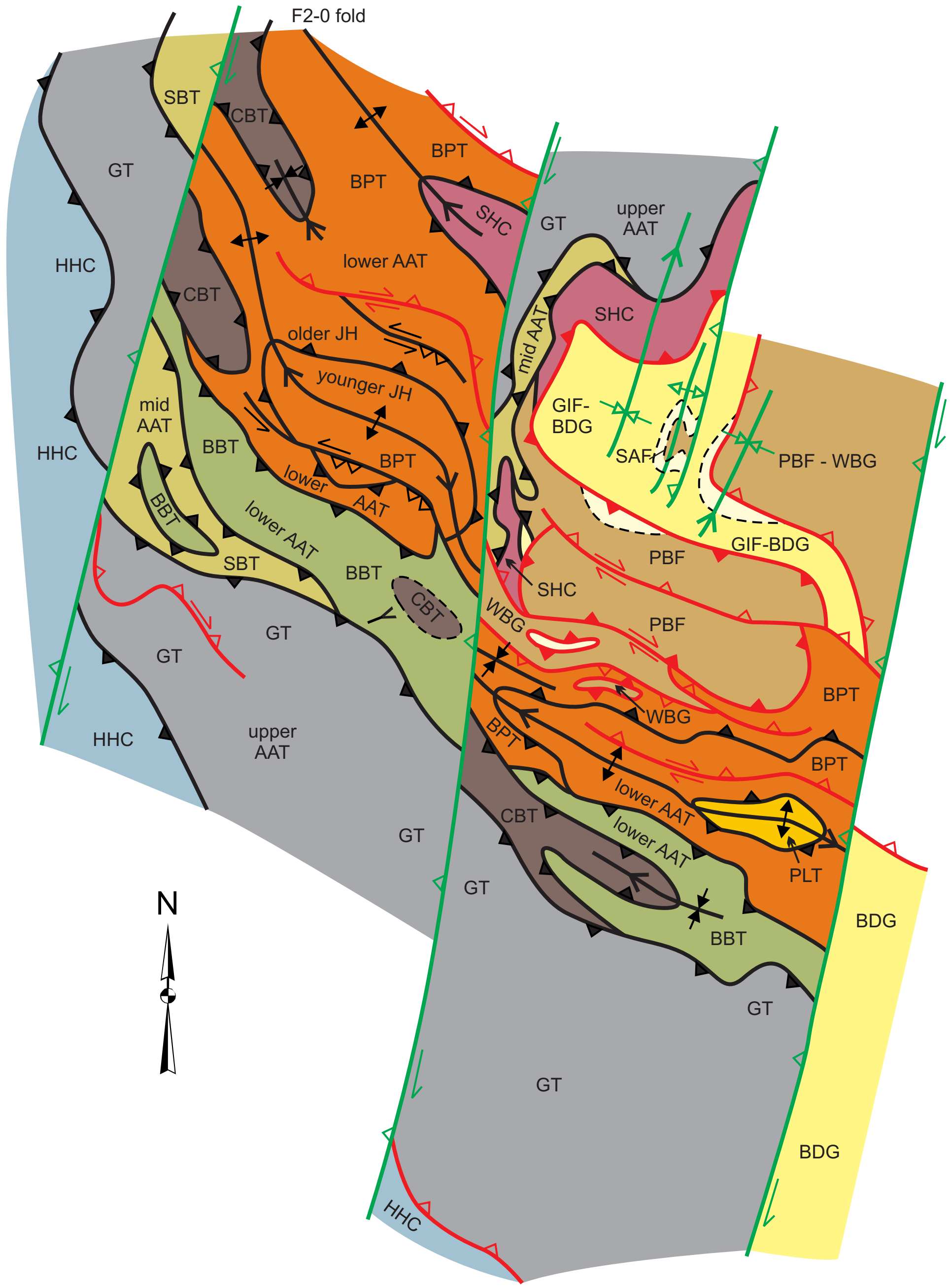


Figure 17. *Kinematic interpretation of the superimposed Ordovician and Silurian fold-and-thrust belts (D-O and D-S) observed in the southeast part of the Robert's Arm volcanic belt and the adjacent part of the Exploits Subzone. As portrayed by colour-coded structures in map view, the youngest of these sequentially accreted rock units are locally represented by the BBT–CBT–BPT–PLT lithotectonic sequence of the lower SRAVB and the WBG–SAF–BDG lithostratigraphic succession that of the Exploits Subzone and its overstep sequence (refer to Legend of Figure 15). Rocks of the lower SRAVB complex lie structurally below the upper and middle AAT rocks of the Notre Dame Subzone and are bounded by solid black D1-O thrusts and open black double-barbed D2-O reverse faults. Rocks of the western Exploits Subzone lie structurally beneath the lower AAT metamorphic assemblage and are bounded by solid red D1-S thrust and open-barbed D1-S reverse faults. All peri-Laurentian and peri-Gondwanan rock units were subsequently deformed by green coloured D2-S fold and fault structures. Note that D1-O thrusts, F2-O folds and sinistral-oblique D2-O reverse shear zones are drawn in solid black lines (single D1-O and double D2-O fault barbs); D1-S dextral oblique-slip thrusts (in solid red) and late D1-S reverse faults (having open red barbs); F2-S periclinal folds and D2-S dextral-oblique reverse faults are shown in green. The tectonic sketch map illustrated in Figure 17 is not drawn exactly to scale. Other rock unit abbreviations used in Figure 17 are for the Hall Hill Complex (HHC) and Gulbridge Tract (GT) of the upper AAT complex and the South Brook Tract (SBT) of the middle AAT complex. The Shoal Arm Formation (SAF) black slate is highlighted in cream, Gull Island Formation (GIF) sandstone turbidite of the Badger Group (BDG) in yellow, and epiclastic wacke of the Pennys Brook Formation (PBF) of the Wild Bight Group (WBG) in light brown.*

tionary events within the lower AAT, particularly in the region near the Red Indian Line boundary. Instead, the timing of the shut-off of Sandbian felsic volcanicity, as recorded above the adjacent peri-Gondwanan marine strata on the underplated convergent margin of the Exploits Subzone, has been employed as a tectonic proxy for the inferred timing of Late Ordovician accretion of the stratified rocks of the peri-Laurentian realm (*e.g.*, Valverde *et al.*, 2006; van Staal *et al.*, 2007, 2009; Zagorevski *et al.*, 2015).

Early in the Late Ordovician, a 'hard-rock' synmetamorphic accretionary event has been interpreted to have occurred between 455 and 450 Ma (Sandbian to Katian; formerly, mid to late Caradocian) in the lower SRAVB within the regionally northwest-dipping Annieopsquotch Accretionary Complex (AAC). Taconic III orogeny has been previously postulated to have affected the Darriwilian Red Indian Lake Arc in what would eventually become the regional hangingwall sequence of the RIL thrust zone (*cf.* Zagorevski *et al.*, 2015). A slightly younger Late Ordovician tectonothermal event may possibly have produced the M1-O metamorphism, S1-O foliation and related D1-O thrust faults seen in the Middle–Late Ordovician peri-Laurentian Rocky Brook–Wigwam Brook arc basin and underlying substrate of the Middle Ordovician Catamaran Brook Arc in the lower part of the Robert's Arm thrust stack.

During the latest Ordovician and earliest Silurian, D2-O orogenesis in the SRAVB culminated with the synmetamorphic collision of a tectonically underplated Late Ordovician rhyodacitic arc (the youngest known Iapetan Powderhorn Lake Arc) with the most outboard peri-Laurentian continental margin arc (*i.e.*, the Red Indian Lake–Catamaran Brook arc complex). Peak amphibolite-facies S2-O gneissosity predated the local development of ortho-amphibolite and para-migmatite within the lower SRAVB assemblage.

The regionally extensive high T–low P metamorphism produced fault-bounded gneiss and schist belts in the Middle and Late Ordovician volcanic arc–back-arc complexes in the immediate hangingwall sequence of the RIL. However, it also locally affected early Middle Ordovician suprasubduction zone ophiolite (Skidder Basalt–Black Gull Island Basalt) located higher in the middle part of the Robert's Arm thrust stack. Age equivalent Late Ordovician tectonomagmatic events have been described along major fault zones located farther northwest in the Dunnage Zone near the Grenvillian margin of Dashwoodsia (Brem *et al.*, 2007) and much farther southeast along the Iapetan margin of Ganderia (Valverde *et al.*, 2006).

In the study area, climactic M2-O metamorphism began after Sandbian Taconic III orogenesis in the AAT and the purported late Sandbian to late Katian D1-O event in the SRAVB. It formed tracts of nebulitic and injection migmatite possibly around *ca.* 445–443 Ma (G.R. Dunning, personal communication, 2008). Early stage SRAVB deformation had mainly ceased by the latest Ordovician but syntectonic plutonism and related regional metamorphism in the lower SRAVB may have continued into the early Llandovery (possibly into the *ca.* 443–438 Ma range).

The earliest phase of the succeeding Silurian Salinic orogeny predominantly affected the peri-Gondwanan volcanic island-arc complex that was accreted to the Powderhorn Arc. In this area, a northwest-dipping imbricate thrust belt had developed at the leading edge of the Middle Ordovician Wild Bight Arc (O'Brien, 2001, 2016a) and the Middle Ordovician Victoria Arc situated to the southwest (Rogers *et al.*, 2005b). A contemporaneous prograde regional metamorphism affected the Salinic and older greenschist-facies slates situated at the base of the AAT and below the RIL. The D1-S event followed the D2-OS cessation of the tectonic underplating of the peri-Laurentian continental margin arc complex by orogen-parallel displacement (*i.e.*, the general southwest-over-northeast Late Ordovician oblique thrusting seen in the lower SRAVB).

In the North Twin Lake area of the SRAVB, overfolded southwest-dipping D1-S thrust faults and concordant M1-S slaty cleavage developed beneath the SRAVB and formed in the Darriwilian rocks of the Sops Head mélange complex, the adjacent Darriwilian back-arc strata of the Wild Bight Group, and the overstepping late Sandbian and Katian turbidites of the Badger Group (Figure 18). In places, a D1-O/D2-O antiformal duplex in the lower SRAVB was tectonically juxtaposed against the underlying peri-Gondwanan arc complex along parts of the RIL imbricate thrust zone.

The D1-S episode of orogen-parallel displacement and dextral shearing was responsible for the structural emplacement of Wild Bight Group phyllites above the SRAVB gneiss belts, and bears witness to a tectonic switch in the relative movement directions of the peri-Laurentian and peri-Gondwanan plates near the RIL imbricate thrust zone. In certain localities, greenschist-facies M1-S metamorphism resulted in the retrogression of cordierite–andalusite–garnet–hornblende schist within northeast-dipping D1-S shear zones, particularly those late stage structures observed near postulated late Llandovery syntectonic intrusions in the SRAVB.

The retrogressive D1-S shear zones in the lower SRAVB metamorphic assemblage probably mark the late Early Silurian retro-wedging, structural uplift and tectonic emergence of the mid-Ordovician Wild Bight Arc–Victoria Arc. Some of the northeast-over-southwest reverse fault structures had displaced folded D1-S imbricate thrusts in Sandbian black graptolitic shale as well as concordant D2-O thrust faults in overlying SRAVB metasedimentary schist. Such D1-S structures are interpreted to be coeval with prograde greenschist-

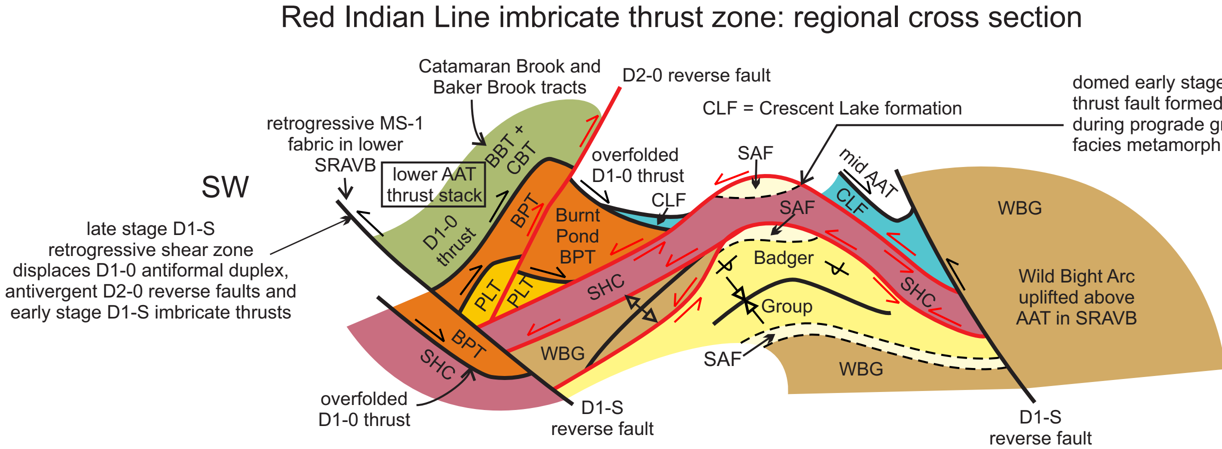


Figure 18. *Schematic cross-section of major lithological unis near the Red Indian Line, viewed looking northwestward, illustrating greenschist-facies underplating of SRAVB amphibolite facies rocks by movements related to early stage D1-S imbricate thrusts (folded to dip toward the northeast and southwest). Note that the lower AAT assemblage in the SRAVB locally comprised an antiformal duplex of imbricate D1-O thrust faults offset by southwest-dipping D2-O reverse shear zones prior to this event. Rocks of the lower and mid AAT complex were later structurally overplated by the tectonically uplifted strata of the Wild Bight Arc. This occurred when constituent gneiss and schist belts within the lower SRAVB belt were metamorphically retrograded (MS-1 event) during the formation of the late stage D1-S reverse shear zones (those inclined to the northeast). These had developed in the greenschist facies rocks of the Exploits Subzone throughout the North Twin Lake–Shoal Arm Brook area (Figure 15).*

facies metamorphism during the early-stage development of the Silurian slate belt observed in the western part of the Exploits Subzone.

The D2-S shortening event postdated early stage D1-S reactivation of the collision zone located below the M2-O migmatite tract in the lower SRAVB assemblage, and above the peri-Gondwanan Wild Bight Arc and the structurally overlying Sops Head mélange and pebbly mudstone tracts. It utilized northwest-dipping D2-S reverse faults to emplace these Mid-Iapetan Realm and Laurentian Realm rocks above the Sandbian–Katian–Hirnantian turbidite succession found in the western part of the Badger basin (Figures 15 and 17).

The early Salinic fault in the RIL imbricate thrust zone probably reactivated an older tectonic suture that had separated the green tuff-bearing Burnt Pond metaturbidite basin (the Late Ordovician migmatite belt) and the upper amphibolite-facies metavolcanic rocks of the Powderhorn Lake Arc. However, at lower Burnt Pond, the Late Ordovician collision zone appears to have involved phyllitic strata assigned to some of the partially broken alkali basalt formations of the mid-Iapetan or possibly peri-Gondwanan Sops Head Complex implying, if correct, the presence of a fundamental Laurentia–Gondwana suture within the lower SRAVB.

SRAVB RELATIONSHIP TO THE BADGER BASIN

Rapid uplift, surface erosion and deep dissection of the Sandbian–Katian suture zone and older (ophiolitic) Taconian schist in the outboard peri-Laurentian SRAVB has been historically interpreted as being coeval with the fore-deep accumulation of certain debris flows in the lower part of the Late Ordovician Badger Group in the Badger Belt (*e.g.*, Nelson and Casey, 1979; Nelson, 1981; Waldron *et al.*, 2012). However, the edifice of the Powderhorn Lake Arc (and the adjacent trench) would have restricted Sandbian dispersal of Taconic III detritus, unless the postulated Late Ordovician AAT subduction zone ceased to be active and the boundary of the lower SRAVB assemblage and the adjacent Sops Head Complex became tectonically transformed, in post-Sandbian time, into a transform fault margin (*cf.* Arnott *et al.*, 1985). Although the upper-amphibolite-facies metamorphism of Darriwilian metasedimentary gneiss and arc-related volcanic rocks near the Sandbian–Katian suture in the SRAVB postdated the marine subsidence of the Katian to Hirnantian part of the Badger turbidite basin, the cessation of northwest-directed subduction (subcretion) and the initiation of wrench fault uplift would permit re-sedimentation of detritus that had originated in peri-Laurentia during the Late Ordovician deposition of the Badger Group (above the yet to be accreted rocks of the peri-Gondwanan realm).

The Late Ordovician metamorphic, intrusive and structural events recorded in the lower SRAVB have not been recognized in the well-cleaved sedimentary strata of the Badger Group in any part of the Badger Belt. Nor did this particular episode of regional high T–low P metamorphism affect those Exploits Arc–Victoria Arc volcanic rocks that lie conformably beneath the Badger Group, indicating that the main part of the peri-Gondwanan Iapetan realm had yet to arrive at the Taconic III–Early Salinic accretionary complex.

The Katian–Hirnantian infill of the Badger Belt shortening basin contains characteristic outsized exoclasts that could indicate sedimentary reworking of late Darriwilian conodont-bearing carbonates originally deposited in the Middle Ordovician Sops Head Complex (and upper Wild Bight Group) and re-sedimentation of magmatic chromites from the complex's distinctive NMORB olistoliths, probably initially derived from subcreted Darriwilian parts of the peri-Laurentian volcano-plutonic arc complex. Isostatic or tectonic uplift may have triggered slumping and 'soft-rock' deformation of the late Katian (*ca.* 450–445 Ma) siliciclastic turbidites and the subsequent formation of debris flows carrying earliest Hirnantian biohermal carbonate reefs that had possibly once covered the southern emergent margin of the SRAVB.

In the oldest part of the Badger Belt basin, there is also evidence of an earlier episode of Katian uplift and erosion that had back stripped the adjacent calc-alkaline basalt-bearing peri-Gondwanan volcanic-arc and alkali basalt-dominant back-arc complex, its ophiolitic and tonalitic Penobscottian substrate, and their Sandbian black shale cover, *e.g.*, the late Dapingian–mid Darriwilian Wild Bight continental margin arc and the Tremadocian South Lake arc ophiolite (Figure 2; MacLachlan *et al.*, 2001; O'Brien, 2012). Fault-related thixatropic deformation of mudstone developed conformably above a shelly fossil-bearing Hirnantian turbidite succession located much farther east in the Badger Group and, although probably contemporaneous with some of the SRAVB metamorphic assemblage, it is confined to the early Llandovery marine trough of the Botwood Belt.

In this regard, the most outboard peri-Laurentian Red Indian Lake–Catamaran Brook arc complex and the subsequently accreted Powderhorn Lake Arc were still being tectonically buried in the lowest AAC, until at least the earliest Silurian. They could not be a source or catchment area for the peri-Laurentian detritus previously reported in the fossil-bearing Late Ordovician turbidites, particularly those lying adjacent to the SRAVB in the type area of the Badger Group.

The amphibolite-facies metamorphic rocks in the lower SRAVB are known to contain several Sandbian units having original grey and black mudstone, intercalated with pyritic felsic pyroclastic strata (partial time equivalents of the Shoal Arm Formation). However, Katian–Hirnantian metaturbidites (protoliths of the western Badger Group) have yet to be recognized in the lower AAT in association with such mudstones. It is possible that Badger Group strata were never deposited in this repetitively uplifted part of the Dunnage Zone.

SRAVB RELATIONSHIP TO THE SPRINGDALE BASIN

The dextral oblique-slip D2-S thrusting of the SRAVB metamorphic assemblage and the MS-2 slaty cleavage formation in the adjacent Middle Ordovician part of the Wild Bight Group developed during a mainly orogen-perpendicular episode of northwest-over-southeast tectonic movement and fault displacement (Figure 17). Possible Wenlockian overthrusting of volcano-sedimentary rocks in the upper part of the peri-Gondwanan Victoria Arc had placed such strata structurally above the Sandbian graptolitic shale of the Shoal Arm Formation and the Katian turbidites of the Badger Group (*ca.* 428 Ma; Sandeman, 2014). Lower greenschist facies D2-S deformation had also resulted in the tectonic emplacement of the D1-O/D2-O accreted Late Ordovician Powderhorn Lake Arc and the adjacent Middle Ordovician Sops Head Complex structurally above the low-grade rocks observed along the inverted margin of the Badger piggy-back basin.

It has been historically inferred that northwest-over-southeast thrusting of the Victoria Arc had caused the western part of the Middle Ordovician Exploits back-arc basin to close contemporaneously (*e.g.*, van Staal *et al.*, 2008). In places, within the eastern part of the Badger basin, this produced an Early Silurian Joeys Cove-type of olistostromal mélange near ductile thrust faults in the Summerford Group and other Exploits Subzone volcanic rocks (*e.g.*, Williams, P. *et al.*, 1988). However, the Early Ordovician rocks in the NRAVB were structurally emplaced above redbeds in the Springdale cover basin by later antivergent thrusts displaying southeast-over-northwest movement.

In contrast, in the area examined for this report, combined D1-S and D2-S thrust-related uplift and tectonic emergence of the D2-O belts of SRAVB metamorphic rocks appear to have been more directly related to the synvolcanic rifting and hypabyssal intrusion observed near the southeast margin of the terrestrial Springdale basin. This is supported by the early to mid-Silurian range of cooling ages obtained from the SRAVB schist and gneiss belts (S.P. Kelley, personal communication, 2011).

In the study area, the time period between climactic regional metamorphism and final (posttectonic) hydrothermal alteration of SRAVB rocks eclipsed the entire geological evolution of stratified rocks in the adjacent belts of the Badger Group and the Springdale Group.

7. SUMMARY AND CONCLUSIONS

Within the southeastern SRAVB, constituent AAT rocks were regionally deformed, variably metamorphosed and intruded by syntectonic plutonic rocks in the Ordovician and the Silurian, at least in the lower SRAVB assemblage.

D1-O EVENT IN THE SOUTHEASTERN SRAVB

The D1-O tectonothermal event is constrained by the depositional age of the upper Rocky Brook crystal tuff in the

BBT and the crystallization age of a crosscutting granodioritic to tonalitic gneiss that intrudes the Julies Harbour migmatitic paragneiss of the BPT. Thus, the timing of the regional D1-O deformation and M1-O metamorphism is locally bracketed between strata accumulation in the early Sandbian and migmatization in the latest Hirnantian (G.R. Dunning, unpublished data, personal communication, 2020). However, based on regional geological considerations, this Late Ordovician episode of deformation and metamorphism is most likely to be Katian (*see* Tectonic Setting). If correct, D1-O tectonism in the lower AAT was coeval with the deposition of certain debris flows in the tectonically adjacent Badger Basin, although this non-volcanic overstep sequence could not have subsided in advance of the lower SRAVB imbricate thrust belt and was not accreted to the youngest volcanic rocks of the Notre Dame Subzone until at least 15 Ma later in the Early Silurian.

D2-O EVENT IN THE SOUTHEASTERN SRAVB

The D2-O tectonothermal event was associated with the peak regional metamorphism and the development of the regional MS2-O gneissosity and the porphyroclastic MS2-O schistosity in parts of the lower SRAVB lithotectonic sequence. Local migmatization of paragneiss and intrusion of granite gneiss probably occurred in the latest Ordovician and certainly not later than the earliest Silurian (G.R. Dunning, unpublished data, 2008). The D2-O fold-and-thrust belt was governed by southwest-over-northeast (orogen-parallel) tectonic movements. Such shortening formed regional northwest- and southeast-plunging F2-O domes and basins that are outlined, in part, by elliptical D1-O thrust faults (F2-O to late F2-OS evolution). It also produced southwest-dipping reverse faults and sinistral shear zones (late D2-O to D2-OS evolution) that deformed the tectonic panels of porphyroblastic stratified rocks and had displaced the imbricate D1-O thrust faults in the lower SRAVB.

The syntectonic metapyroxenite and metagabbro suites that had intruded the lower SRAVB rocks were generally emplaced late during the regional D2-O event, which possibly lasted throughout a portion of the early Llandovery. However, D2-O deformation and M2-O metamorphism had ceased prior to the syntectonic intrusion of probable late Llandovery sheets of foliated granodiorite (G.R. Dunning, unpublished data, 2008). These were emplaced within retrograded schist zones in Julies Harbour gneiss and within northeast-dipping phyllonite zones in Powderhorn Brook schist. The late D2-O to D2-OS tectono-metamorphic features that had developed throughout the SRAVB were crosscut by posttectonic Middle Silurian plutons of gabbro, diorite, granodiorite, granite and syenite that have been locally assigned to the Topsails and Hodges Hill batholiths.

D1-S EVENT IN THE SOUTHEASTERN SRAVB AND BADGER BASIN

The D1-S tectonothermal event produced a synmetamorphic group of northeast-dipping back thrusts and reverse shear zones having a characteristic northeast-over-southwest tectonic polarity. Such antithetic fault structures overprinted the composite D1-O/D2-O tectono-metamorphic features in the SRAVB and developed during an attendant greenschist-facies (retrogressive) metamorphism of the amphibolite-facies metamorphic rocks that constitute the lower AAT lithotectonic sequence.

To the north and east of the detailed study area, the D1-S event has been recognized in the metasedimentary rocks of the Julies Harbour division of the BPT within a northern extension of the lower SRAVB lithotectonic sequence. In the vicinity of North Twin Lake, M1-S metamorphism has been assumed to be coeval with a lower greenschist facies regional metamorphic event observed throughout the western part of the Exploits Subzone and, particularly, in the RIL footwall sequence lying below the lower SRAVB. This tectonic event produced an early prograde stage of regional slaty cleavage and an associated series of northeast- and southwest-dipping thrust faults within a conformable Middle–Late Ordovician stratigraphic succession, including the Darriwilian part of the Wild Bight Arc–Victoria Arc. In the North Twin Lake–Kippens Pond–Sops Lake area (Figure 15), deformed units include the Pennys Brook Formation of the peri-Gondwanan Wild Bight Group, the graptolitic Shoal Arm Formation, the siliciclastic turbidites of the lower Badger Group, and the unbroken to broken formations of the Sops Head Complex.

The regional D1-S deformation and MS1-S metamorphism formed after the development of the domal antiformal culminations in the SRAVB imbricate thrust stack but were probably coeval with the southwest-directed fold nappes, northeast-dipping thrust faults and refolded klippen seen in the Pennys Brook Formation. It is possible that D1-S tectonism began near the end of the Llandovery during the Telychian substage (*cf.* Waldron *et al.*, 2012, 2014).

D2-S EVENT IN THE SOUTHEASTERN SRAVB AND BADGER BASIN

The D2-S tectonothermal event resulted in the regional development of northeast-trending F2-S periclinal fold structures, an attendant slaty MS-2 cleavage and dextral oblique-slip D2-S reverse faults. It resulted in the continued tectonic uplift of the Wild Bight Arc–Victoria Arc and the accreted Sops Head tectonic mélange belt. The D2-S shortening was governed by an east-directed translation of Exploits Subzone rocks during the tectonic inversion of the Badger Basin. The northwest-dipping reverse fault observed at the southeast margin of the SRAVB is a D2-S (possibly Wenlockian) fault structure that also deforms the chlorite-grade slates of the Badger Group near the outflow of Joes Lake into Badger Brook.

POST D2-S EVENTS IN THE NORTHWESTERN SRAVB AND THE SPRINGDALE BASIN

Near Gull Brook in the upper part of the AAT, undated bodies of posttectonic syenite and granite assigned to the Topsails Intrusive Suite were emplaced across the sub-Springdale unconformity developed above the Hall Hill Complex and had also crosscut the folded D1-O thrust fault separating the Hall Hill Complex from the structurally underlying volcanic rocks of the GT (*see* Figure 15). In this report, the Sheinwoodian substage of the early Wenlock has been estimated to range in age from 433.4 to 430.5 Ma and the Homerian substage of the late Wenlock to range from 430.5 to 427.4 Ma. To this point, the terrestrial stratigraphical succession of the Springdale Basin has been previously demonstrated to have evolved over most of this same time interval. For example, near Sheffield Lake, a Homerian syenite is known to intrude a Sheinwoodian ignimbrite at the northwest margin of the Springdale Basin (G.R. Dunning, personal communication, 2010).

The oldest known terrestrial felsic pyroclastic strata are displayed along the southwest margin of the Springdale Group and crop out in the lowest preserved part of this cover basin adjacent to the SRAVB (Chandler *et al.*, 1987; Coyle and Strong, 1987). Since these ash-flow tuffs have been previously dated at 432.4 +1.7/-1.4 Ma in the early Middle Silurian (Coyle, 1992), the D1-S event affecting the thrust sheets of Julies Harbour gneiss, Powderhorn Brook schist and Badger Group phyllite probably predated eruption of this basal Wenlockian epicontinental ignimbrite. It is also most likely that the D1-S episode of Silurian back thrusting (and the earlier D1-O and D2-O transpressional events) in the eastern part of the SRAVB predated the emplacement of the 429.6 ± 0.8 Ma Rocky Pond granodiorite into the lower AAT nappe complex. The northeast-trending strike-slip faults seen in the Rocky Pond intrusive suite and the Robert's Arm thrust stack offset the terrestrial Silurian strata of the Springdale Group and represent some of the youngest known brittle structures in the area surveyed.

ACKNOWLEDGMENTS

Funding for all field work and most laboratory studies associated with this project was provided by the Geological Survey of Newfoundland and Labrador, Department of Industry, Energy and Technology. BHOB acknowledges helpful information about the study area documented in two Memorial University theses, one by Chad Pennell supervised by Professor Tom Calon and the other by Kanan Sarioglu supervised by Professor George Jenner. Bryan Sparrow, Jeremy Squires, Chad Gidge, Peter Desveaux, Matt Clarke and Neil Stapleton are thanked for the GIS data assembly and map production.

Cees van Staal, Neil Rogers, Alex Zagorevski, Lawson Dickson and Scott Swinden are thanked for their geological insight and numerous field discussions. This paper is dedicated to the memory of Hank Williams, Peter Robinson, Frank Blackwood, Tom Calon and Steve Colman-Sadd.

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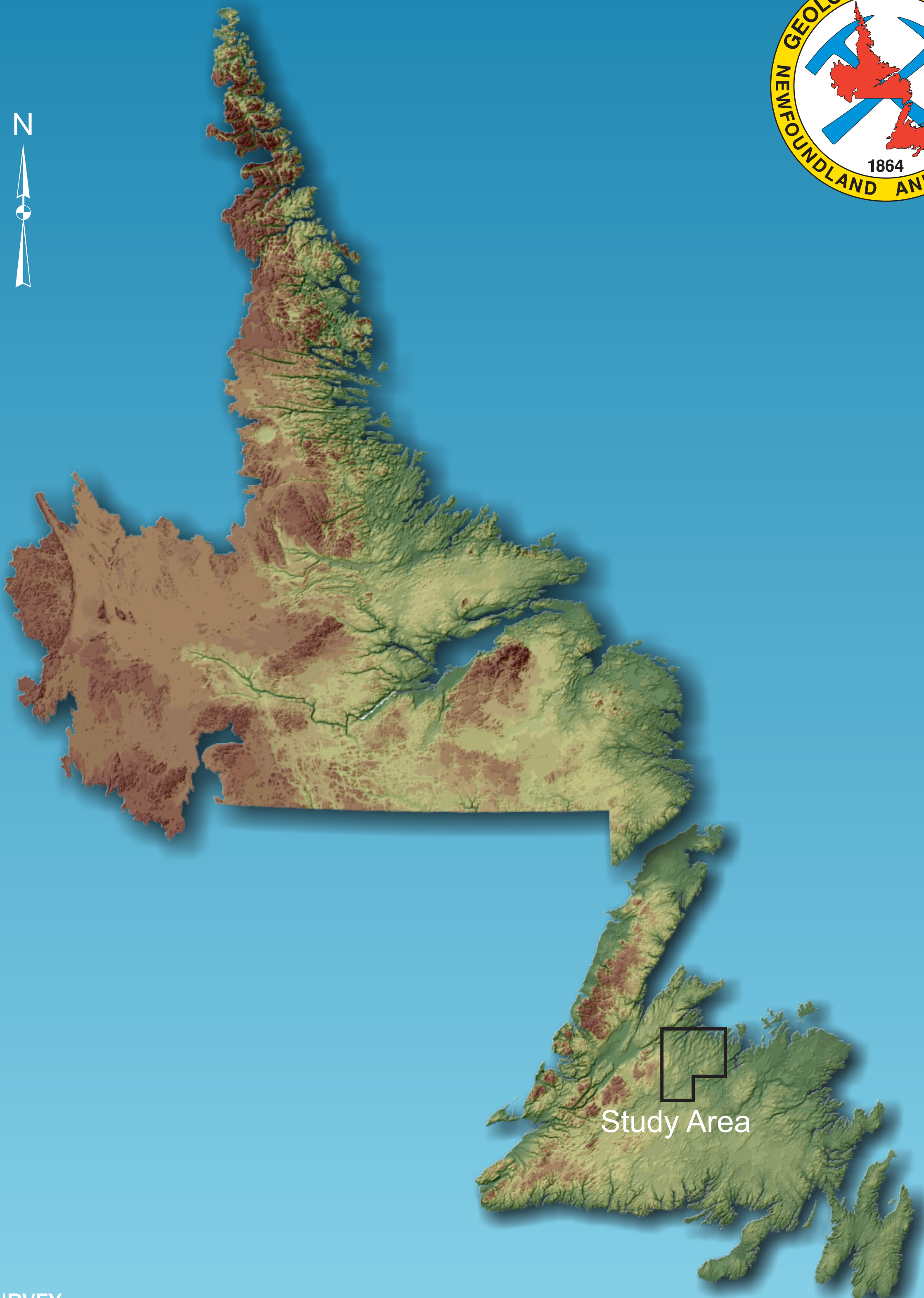

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