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LOWER PALEOZOIC CARBONATE ROCKS OF THE NORTHERN CLOSURE OF THE NORTH BROOK ANTICLINE AND THE SPRUCE PONDS KLIPPE, GEORGES LAKE (12B/16) AND HARRYS RIVER (12B/9) MAP AREAS: COLLECTED THOUGHTS ON UNCONNECTED ROCKS

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ABSTRACT

Klippen of lower Paleozoic carbonate rocks occur just to the north of the North Brook Anticline, where they form the caps of rounded hills, surrounded by valleys and lower ground of recessively weathering slates, some of inconclusive stratigraphic affinity. Detailed mapping of the klippen suggests that they are erosional parts of a once contiguous thrust sheet, which was emplaced above shaly, but not always intact, rocks of the western Newfoundland Taconian foreland basin. The klippen and Taconian flysch are deformed about north- to northeast-trending and plunging folds, which are associated with a mainly east-dipping, regionally penetrative slaty cleavage; east-trending folds predate this northeast folding.

The klippen, collectively called the Spruce Ponds klippe, consist of Late Cambrian to Middle Ordovician carbonates of the Berry Head Formation, Port au Port Group, and the St. George and Table Head groups. The carbonate rocks are finely recrystallized, although they still show microscopic fabrics and sedimentary structures.

Slates in the footwall to the thrust sheet are generally difficult to divide but can be separated locally into: 1) the American Tickle Formation of the Goose Tickle Group, including the Daniel's Harbour Member, a thin limestone conglomerate unit; 2) broken formation of the Goose Tickle Group, and 3) slates, possibly related to the Green Point Formation of the Cow Head Group. Other slaty, rocks intercalated with quartz arenite as well as conglomerate, sandstone and minor volcanic rocks have strong affinities to the Irishtown Formation and perhaps the Blow Me Down Brook Formation or the Howe Harbour member of the Goose Tickle Group.

Lower Paleozoic carbonates deformed in the North Brook Anticline occur structurally beneath the slates. Although the anticline appears to be a large open structure, internally it is the host to numerous small folds and a number of shear zones, some of which are interpreted as thrust faults.

INTRODUCTION

Lower Paleozoic carbonate rocks and slates of the North Brook Anticline and a number of structurally overlying thin-skinned thrust slices to the north (Figure 1) straddle the boundaries of Georges Lake (NTS 12B/16) and Harry's River (NTS 12B/9) map areas. These rocks have most recently been included in the 1:100 000 and 1:250 000 maps of Williams (1985) and Williams and Cawood (1989), respectively, and are shown on the older reconnaissance maps of Walthier (1949). Walthier's map (*op. cit.*) illustrated Lower Paleozoic carbonate rocks in the North Brook Anticline area, which he called the Robairs Brook Anticline, and in a structurally separate block now defined as klippen, which he called the Spruce Brook horst. Williams (1985) defined and named the North Brook Anticline and connected the northern klippen to the structure, placing most of their strata in the Table Head Group. Later, Williams and Cawood (1989) illustrated the northern klippen as several blocks surrounded by mélange and separate from the North Brook Anticline, and assigned them a Cambro-Ordovician age.

The area is accessible by truck along Loggers School Road, west from the Trans-Canada Highway, a distance of at least 22 km. Numerous main and subsidiary gravel logging roads and skidder trails form a network throughout the area and include a southern branch to the community of Gallants on the banks of Harrys River. The terrain is typically one of

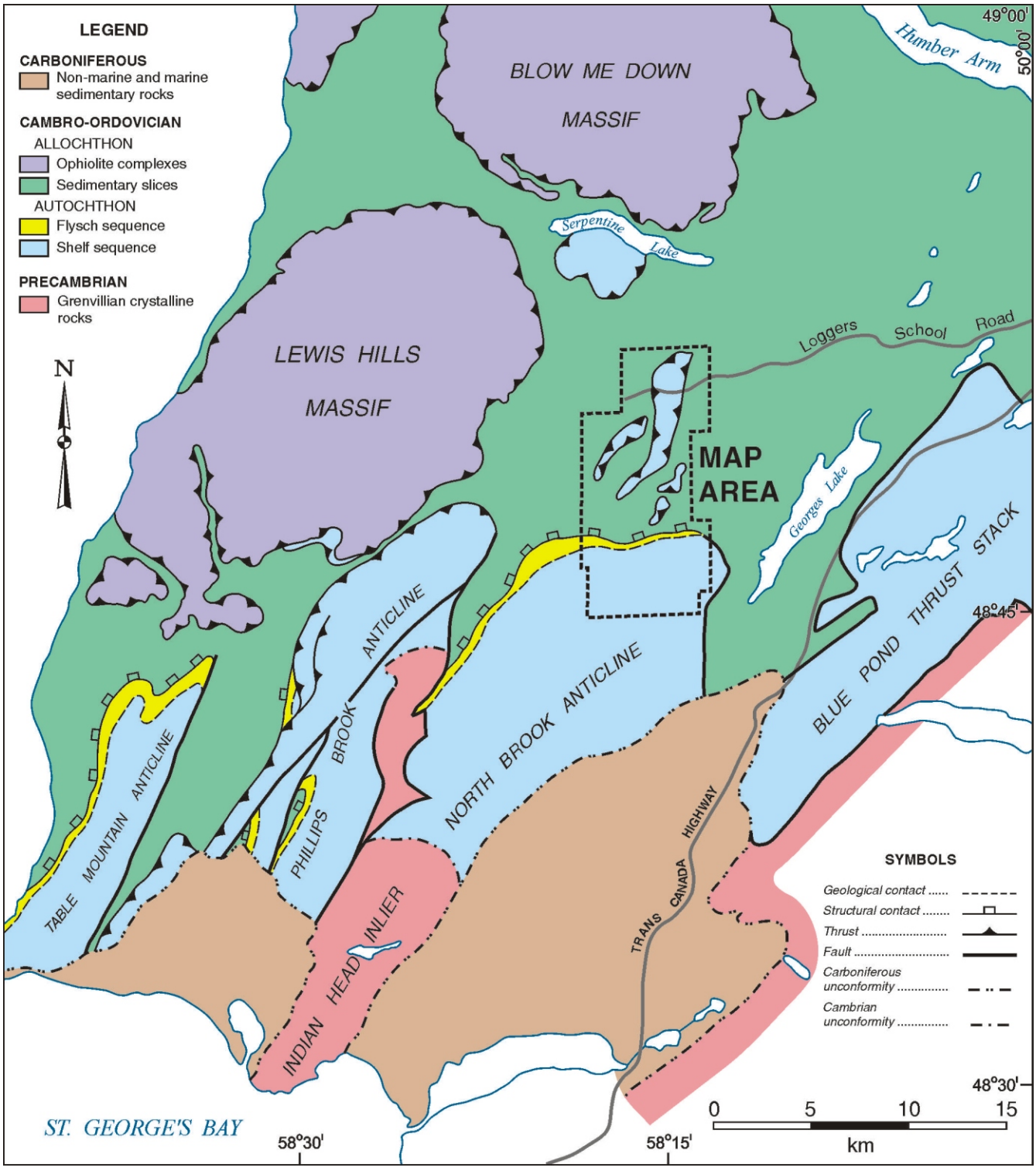

Figure 1. *Simplified regional geological map of the North Brook Anticline area showing the main geological terranes of the region and outlining the map area of the Spruce Ponds klippe (based on Williams and Cawood, 1989).*

gentle rolling hills and steep valleys and local scarps. Much of the area is now covered with silvacultured second-growth forest and low shrub but there are also extensive areas of bog, particularly where slate subcrops on low-angle slopes.

GEOLOGY

Carbonate rocks of the map area occur in the northern part of the North Brook Anticline and in a number of topographically separate carbonate klippen that outcrop north of the anticline (Figure 2). The latest mapping, supported by macrofossil collections, shows that carbonate rocks of the klippen are erosional remnants of a single klippe that is here informally called the Spruce Ponds klippe. The carbonate rocks in the map area comprise the top of the mainly Cambrian Port au Port Group and overlying Ordovician strata of the St. George and Table Head groups. These rocks are stratigraphically overlain by intact and broken formation of slates and thin sandstones of the Goose Tickle Group, including a thin limestone conglomerate correlated with the Daniel's Harbour Member, and by broken formation derived from dominantly shaly rocks, and placed by Williams and Cawood (1989) in the basal mélange of the Humber Arm Allochthon. The slate terrane contains rocks of the Goose Tickle Group, mélange derived from the Green Point Formation, and sequences of Irishtown Formation slates and meta-quartz arenite. It also includes slates hosting dismembered boudins of competent rocks that include meta-quartz arenite and conglomerate and pebbly sandstone containing mafic volcanic pebbles. The meta-quartz arenite probably belongs to the Irishtown Formation and coarser clastics may belong to the Blow Me Down Brook Formation. Adjacent to the eastern margin of the Spruce Ponds klippe is a long narrow, north-trending belt of ultramafic rock that is separated from the carbonate rocks by a narrow zone of slate.

CARBONATE ROCKS OF THE NORTH BROOK ANTICLINE AND THE SPRUCE PONDS KLIPPE

The carbonate succession at the northern edge in the North Brook Anticline, consists of a simple stratigraphic succession of limestones and dolostones of Late Cambrian to Middle Ordovician age. Coincidently, this is essentially the same succession mapped in the Spruce Ponds klippe, where the oldest rocks belong to the Berry Head Formation of the Port au Port Group.

Berry Head Formation

The Late Cambrian Berry Head Formation, Port au Port Group, is dominated by a lower unit of buff- to yellow-weathering, light to dark grey, thick-bedded dolostone associated with rare limestone. It is overlain by an upper member of dolostone and dololaminite intercalated with stylonodular, burrowed, stromatolitic, and laminated limestone similar to that occurring in the nearby Phillips Brook Anticline (Figure 1; Knight and Boyce, 2000). The dolostones are mainly featureless and unfossiliferous, but locally contain chert and display thin bedding and lamination. The gastropod Sinuopea occurs rarely in some of the limestone beds of the upper member.

St. George Group

The Berry Head Formation is conformably overlain by the St. George Group, which retains its four-fold stratigraphic character defined elsewhere in western Newfoundland (Knight and James, 1987). The Watts Bight Formation, like the formation in the adjacent Phillips Brook Anticline, is largely a dark-grey, bioturbated and thrombolitic, dolomitic and cherty limestone containing some interbeds of dololaminite. Tan-grey, finely sucrosic dolostone has unevenly replaced the limestone and grey grainstone is common in the upper part of the formation.

The overlying Boat Harbour Formation is composed, typically, of metre-scale sequences of bioturbated dolomitic limestone capped by laminated limestone and/or dololaminite. Beds of thrombolitic and stromatolitic limestone occur locally. Prominent laminated limestone marks the top of the formation as is seen elsewhere in western Newfoundland. The most obvious fossils are dolomitized gastropods; trilobite fragments, the latter are present but are difficult to recover because of limestone recrystallization.

Limestones of the overlying Catoche Formation are largely dark-grey, medium- to thick-bedded, dolomite-mottled and bioturbated, lime mudstones. Scour-based lenses of skeletal–intraclastic grainstone occur throughout. Interbeds of stylonodular and locally ribbon-bedded, dolomitic lime mudstone also occur, and chert is fairly common. A pronounced marker of large thrombolitic mounds, associated with grainstones, is present locally in the Spruce Ponds klippe; only a few, small thrombolite mounds have been noted in the formation in the anticline. Macluritid and murchisonid gastropods are the most obvious fossils but a few silicified opercula straight cephalopods, e.g., rostroconch *Euchasma blumenbachii* (Billings, 1839) and rare crinoid and trilobite fragments have also been recovered.

The Catoche Formation is capped by the Costa Bay Member, a clean, light-grey to off-white limestone, 10 m thick, that comprises intraclastic grainstone and skeletal mudstones containing ostracodes and gastropods.

The Costa Bay Member is conformably overlain by the Aguathuna Formation. The base of the formation is locally marked by a stromatolitic limestone bed, a basal marker also

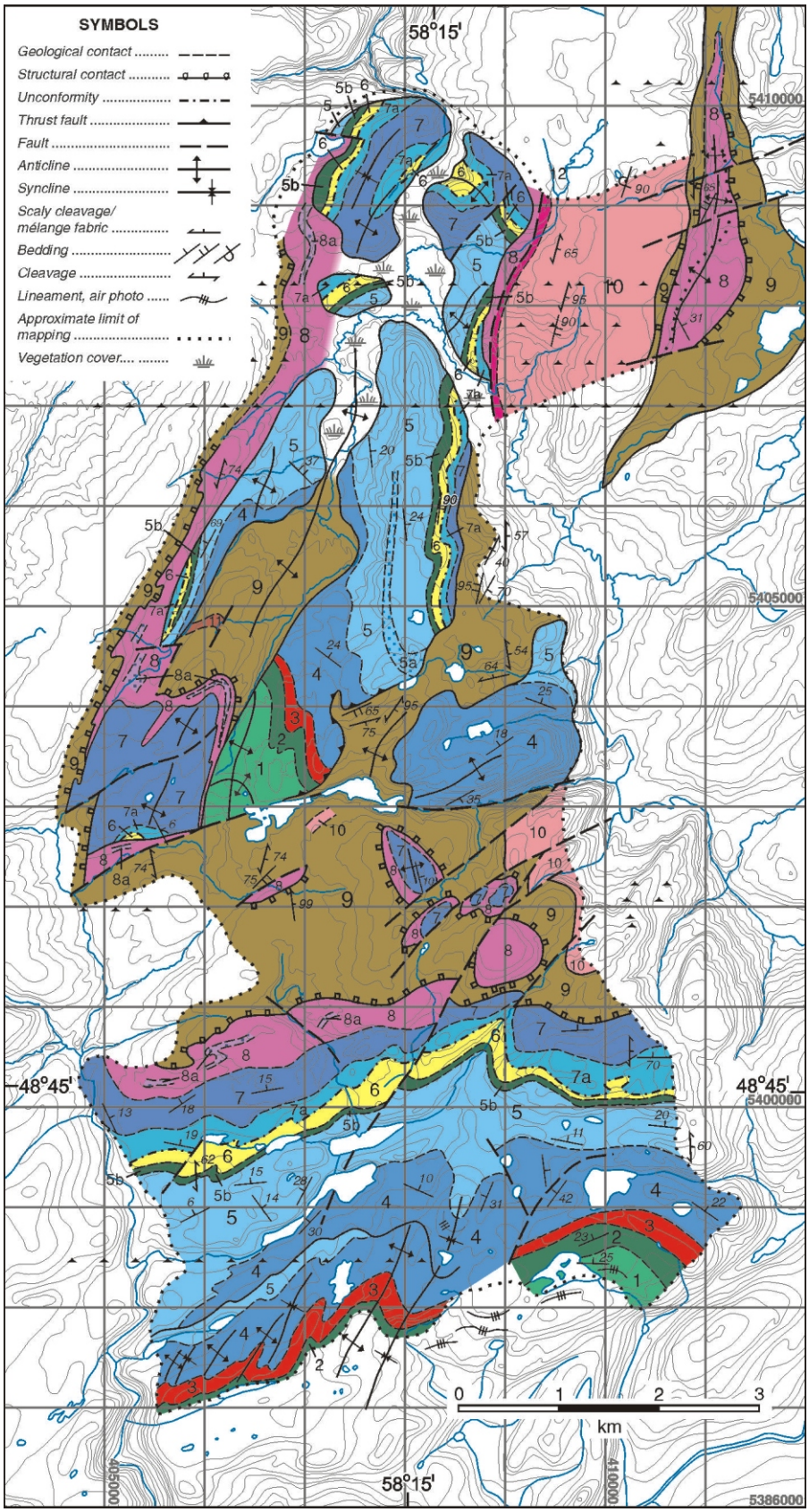

Figure 2. Caption and legend on facing page.

Figure 2. *Geological map of the Spruce Ponds klippe and the northern part of the North Brook Anticline.*

present in the adjacent Phillips Brook Anticline. The Aguathuna Formation consists of metre-scale parasequences of interbedded, burrowed and stromatolitic limestone, lime grainstone, lime mudstone and bioturbated dolostone, which are interbedded with dololaminite, argillaceous dololaminite and laminated limestone. Many of the limestones are clean, commonly light grey and range from peloidal mudstones through wackestones to packstones and grainstones; a few skeletal grains are also visible. There are also rare beds of oolitic grainstone and dark-grey, bioturbated dolomitic limestone is also found. Silicified opercula are characteristic of the Aquathuna Formation but straight cephalopods and gastropods also are present. Based on the outcrop width, the formation appears to range up to about 85 m in thickness in the anticline but is measured at about 20 to 30 m thick in the klippe.

St. George Unconformity

The St. George Unconformity marks the contact of the St. George Group and the overlying Middle Ordovician Table Head Group (Knight *et al.*, 1991). Uncharacteristically for the region, the unconformity is well exposed at a number of localities in the map area in both the anticline and the klippe. The unconformity surface is commonly a roughly planar surface sculptured by karren. This is particularly true along the western side of both the klippe and the anticline, but is also characteristic of the surface to the east of Bond Pond in the anticline. Karren are mostly irregularly shaped, some etched as much as 10 cm deep into the unconformity but they also include elongate and oriented karren, 3 cm wide and up to 30 cm in length. In one outcrop along the west side of the klippe, narrow vertical fractures link the unconformity to small, breccia-filled paleo-caves, 30 cm below the unconformity. The surface at western localities is buried by clean peloidal limestone and in the east by stylonodular lime mudstone, both of the Spring Inlet Member, Table Point Formation.

Erosional channels having a relief of 20 cm or more, are overlain by a basal conglomerate and are exposed at a number of dispersed localities in the centre of the anticline and in the northern parts of the klippe. The local relief supports evidence of significant erosion at the unconformity. This is indicated by the marked variation in thickness of the underlying Aguathuna Formation (*see above*). The basal conglomerate generally ranges from a true conglomerate to pebbly dolomudstone to a pebbly dolarenite and locally attains a thickness of at least 1.2 m. Pebbles are generally small (1 to 5 cm in diameter) and consist of dolostone, lime mudstone, dark-grey chert and white cryptocrystalline chert, the latter possibly being reworked evaporitic chert nodules. Exceptional blocks of basal conglomerate, 750 m north of Bond Pond, enclose cobbles up to 15 cm in diameter and

angular boulders and slabs up to 1 m across, supported by a fine-grained dolostone matrix. The clasts include bioturbated dolomitic limestone, dolomitic oolitic grainstone, thin-bedded and laminated dolomitic limestone, burrow-mottled dolostone, massive dolostone, dololaminite and chert-nodule-bearing dolostone. The blocks suggest that the bed is graded normally from the coarse, dolostone-matrix-supported conglomerate, up into crudely stratified, small-pebble and granular conglomerate, to pebbly dolarenite.

The unconformity and basal conglomerate are also exposed at a roadside outcrop along Loggers School Road. At this location, the conglomerate consists of small pebbles forming three, scour-based conglomerate beds, 24 to 30 cm thick, that are intercalated with nodular dolomitic limestone beds, 50 to 70 cm thick; skeletal mudstone and wackestone nodules are enclosed by dolostone. The uppermost conglomerate bed grades up into pebbly, partly dolomitized, fine-grained, peloidal grainstone, which in turn grades up to a nodular dolomitic skeletal limestone and then a laminated, peloidal limestone. The laminite is overlain by a few metres of crossbedded and laminated, partly dolomitized grainstone containing lenses of small pebbles.

Table Head Group

The Table Point Formation of the Table Head Group is best exposed in the North Brook Anticline and at the north end of the klippe. It is also found in some small structural windows through the slate terrane to the west and south of Spruce Ponds. The formation is divided into the basal Spring Inlet Member and an upper unnamed limestone member.

The Spring Inlet Member includes the basal conglomerate described above, and is also characterized by metre-scale sequences of various limestones capped by dolostones. In the north of the klippe, the unit is at least 27 m thick. That part of the unit overlying the basal conglomerate and grainstone succession along Loggers School Road is characterized by parasequences of stylonodular dolomitic lime mudstone, 50 cm to 2 m thick, capped by 15 to 70 cm of dolostone–dololaminite and laminated dolomitic limestone. Intraclastic and oncolitic rudstone mark the base of some of the sequences, and fossil-rich limestone occurs locally, immediately below the dolostone caps. The fossils are dominated by gastropods but also include brachiopods, ostracodes, trilobites, crinoids and possibly sponges. A limestone bed, 1.5 m thick, composed of stromatolitic mounds associated with grainstone and capped by microbial-laminite, occurs midway through the unit.

In the North Brook Anticline north and west of Bond Pond, the Spring Inlet Member is approximately 10 to 14 m thick and consists predominantly of clean, crossbedded, intraclastic, skeletal and peloidal grainstone containing minor dolostone interbeds and some fenestral laminites and grainstone. The crossbeds range from planar tabular to trough cross-sets, up to 25 cm thick. A few paleocurrent features suggest dominant flow was west to northwest. The crossbedded grainstones persist for 4 km to the east where they are 10 to 11 m thick. In this area, they consist of skeletal, intraclastic and oolitic beds that overlie an interval of interbedded, planar, thin-bedded and laminated limestone and dolostone, stylonodular dolomitic lime mudstone and some grainstone.

The grainstone unit is sharply overlain by stylonodular to lumpy, dolomitic lime mudstone, above which is a higher interval of grainstone comprising 40-cm-thick beds of skeletal grainstone intercalated with bioturbated dolomitic limestone and lumpy limestone. Gastropods, brachiopods, crinoids, bryozoa, trilobites and ostracodes, as well as some large straight cephalopods, occur in the grainstones at several localities. These upper rock types are more properly placed in the upper member of the formation but are described here to highlight the need for a fluid, flexible, rather than static, understanding of this extremely multifacied stratigraphic interval.

The upper unnamed limestone member is dominated by well-bedded, dark grey, dolomitic limestone beds formed mainly of bioturbated to nodular and lumpy, skeletal lime mudstone to muddy wackestone. The lime mudstone is interspersed with scour-based lenses as well as thin wedges and sheets of intraclastic and skeletal small-pebble rudstone to grainstone and thin beds of crosslaminated, very fine-grained grainstone. Within the stylo-nodular to lumpy limestones, fabrics are locally brecciated to conglomeratic having a fine-grained argillaceous dolostone matrix supporting the pseudoclasts. Remnants of ribbon bedding are also preserved in the lime mudstone beds. High-spired and macluritid gastropods, cephalopods, ostracodes, trilobites, and crinoids are common in the member.

Toward the top of the member, the brecciated and conglomeratic facies becomes more common and form beds up to 1 m thick, but are still interbedded with bioturbated and stylonodular limestone. A few 15-cm-thick interbeds of thin-bedded dolomitic ribbon limestone, similar to facies of the Table Cove Formation (Stenzel *et al.,* 1990), also occur. The conglomeratic facies is reminiscent of the Daniel's Harbour Member conglomerates but, because it is intercalated with normal Table Point lithofacies, it is not assigned to that member. The conglomerates are poorly sorted and matrix supported consisting largely of clasts, a few centimetres in diameter of nodular to lumpy lime mudstone. However, they also host flagstones of ribbon limestone and rare large

clasts, 30 by 20 cm in area, of crinoidal-intraclastic grainstone. The matrix is formed consistently of fine-grained dolostone and locally carries scattered coarse-grained quartz sand. Within the matrix, a fairly abundant and diverse, but delicate and small, fossil fauna includes stick and sheet bryozoa, ostracodes, brachiopods, crinoids, trilobites, small gastropods and graptolites. At a number of localities north of Spruce Ponds, the conglomerates appear to be either onlapped or otherwise overlain by ribbon limestone typical of the Table Cove Formation.

Table Cove Formation and American Tickle Formation

Dolomitic ribbon limestone and dolostone more than 6 m thick is intercalated with one or more limestone conglomerate beds, 0.6 to 4 m thick above the top of the Table Point Formation, west of Spruce Ponds. The ribbon limestone–limestone conglomerate association can be traced northward to outcrops near the western edge of the Spruce Ponds klippe where they occur in the klippe footwall. The strict stratigraphic definition of these units defines the ribbon limestone as Table Cove Formation of the Table Head Group and the limestone conglomerate as Daniel's Harbour Member of the American Tickle Formation (Goose Tickle Group; Stenzel *et al.*, 1990). The ribbon limestones and conglomerate are overlain by grey slate that displays thin bedding and lamination and is assigned here to the American Tickle Formation.

Limestone conglomerate of the Daniel's Harbour Member is also found within the slates of the American Tickle Formation at a number of localities north and northwest of Bond Pond. Here the conglomerate appears to overlie dark grey slates, possibly the Black Cove Formation, and are in turn overlain by rocks typical of the American Tickle Formation. The latter consist of grey slates intercalated with thin beds of green-grey laminated siltstone and rusty-weathering, laminated and crosslaminated very fine-grained sandstone. In both associations, the limestone conglomerate consists of nut-sized, irregularly shaped clasts of lime mudstone, derived from the Table Point Formation, set in a fine-grained dolostone matrix. Some slightly larger clasts of grainstone are also scattered in the conglomerate. This association of limestone conglomerate and slate appears to be missing above the Table Point Formation at outcrops 2 km east-northeast of Bond Pond where the unsheared Table Point Formation limestone is overlain by broken shaly slate.

American Tickle Formation slates and sandstones are also exposed along the disused gravel road south from Loggers School Road to the community of Spruce Brook, approximately 2 km east of the Spruce Ponds klippe. The formation here consists of 5- to 10-cm-thick, laminated, crosslaminated and locally convoluted, very fine-grained sandstone, intercalated every 10 cm or so with grey slates. Some thicker beds of massive green-grey, fine-grained sandstone occur locally. The Goose Tickle Group in this area appears to form the core of an anticline, informally called the Spruce Brook anticline.

THE SLATE TERRANE

Much of the slate terrane surrounding the Spruce Ponds klippe and lying north of the North Brook Anticline was mapped as undivided Ordovician mélange by Williams (1985) and Williams and Cawood (1989). New mapping of the slate belt around the Spruce Ponds klippe suggests that the slates, other than those assigned to the Goose Tickle Group, are divisible into a number of types that reflect their original protolith, which may be either autochthonous or allochthonous. These rocks appear to structurally overlie the succession of the North Brook Anticline and form the footwall to the Spruce Ponds klippe.

Dark Grey Slates

Grey, dark grey and black, locally rusty-weathering slates are common in the area. They generally lack sedimentary fabrics even on cleavage surfaces and so give little evidence for their origin. However, they appear to be associated with nearby outcrops that have some green-grey siltstone beds and folded units of Daniel's Harbour Member limestone conglomerate and therefore may be assigned to the Goose Tickle Group. They occur along the western edge of the Spruce Ponds klippe and also east of the klippe.

Slates with Scaly Cleavage and Dismembered Competent Rock Types – Mélange and/or Broken Formation

Mélange and/or broken formation appear to structurally overlie the dark-grey slates and other elements of the Goose Tickle Group. They are characterized by green, grey, and black slates in which are found rhomboid augen of sandstone, mudstone, siltstone and, locally, pyrite nodules. In some outcrops, the slates contain folded thin-bedded limestone, crosslaminated and laminated calcareous siltstone and very fine-grained sandstone.

A grey slate protolith consisting of grey sandstone and laminated siltstone probably belongs to the Goose Tickle Group. Colour-banded green and black shales containing pyrite nodules, siltstone augen, and thin beds of limestone probably compare to distal lithofacies of the Cow Head Group and Northwest Arm Formation. The augen are associated with an early fabric that is cut by a later slaty cleavage.

The unit ranges from broken formation to "mélange". It may mark the base of the allochthon but the presence of broken American Tickle Formation immediately above other intact Goose Tickle Group is common throughout the region (Knight, 1997; Knight and Boyce, 2000) and implies that much of the slate terrane actually still lies in the footwall to the allochthon.

Black Shales Containing Melanocratic Blocks

At the Bond Asbestos Mine of Walthier (1949), 1.5 km northeast of Spruce Ponds, rounded dark green, coarsely crystalline melanocratic blocks occur in sheared black, carbonaceous, pyritic and sulphurous shales. The blocks, which may be ultramafic (Williams and Cawood, 1989), are cut by veins of serpentine. The black shales also contain augen of pyrite, green sandstone and polydeformed zones of shale hosting sandstone laminae and ribbon beds of yellow-weathering calcareous siltstone; the rocks are best interpreted as mélange. Black shales containing exotic volcanic blocks also occur near the base of the allochthon along the western margin of the Phillips Brook Anticline (Knight and Boyce, 2000; Williams, 1985) where they are structurally overlain by shales of the Green Point Formation.

Slates Containing Interbeds and Augen of Meta-quartz Arenite (Irishtown Formation)

Structurally above the slates that exhibit a scaly cleavage and spatially east of the Spruce Ponds klippe, grey slates are intercalated with thin- to thick-bedded, light grey-weathering, grey meta-quartz arenite, the latter ranging from competent layers to broken and boudinaged beds. The succession along Loggers School Road, 1 km east of the northern end of the klippe, consists of an intercalated succession of 0.6- to 2.0-m-thick shale beds, 2- to 4-m-thick intervals of grey slate/black shale interbedded with thin beds of sandstone, some of which is laminated, and isolated beds and/or intervals, up to 4.0 m thick, of fine- to medium-grained quartz arenite. The thick-bedded sandstone is massive or less commonly massive to crossbedded or crosslaminated, and many beds carry basal load casts. The succession is overturned to the west, at least along Loggers School Road and for 3 km to the south.

South of Loggers School Road to just south of Spruce Ponds, thick-bedded massive sandstone beds are coarse- to very coarse-grained and locally pebbly. A 2-m-thick, upright isolated bed of pebbly sandstone south of Spruce Ponds is either amalgamated or shows inverse grading of pebbly medium-grained sandstone overlain by pebbly very coarse-grained sandstone above a loaded base. Pebbles are 0.5 to 1.0 cm in diameter and consist of greenish argillite, white feldspar, grey and white opaque quartz and grey shale.

Slate Containing Thin-bedded Limestone and Limestone Conglomerate

An outcrop of grey slate enclosing detached and folded fragments of thin-bedded limestone occurs in the centre of the klippe. Two kilometres away, just east of the klippe, another outcrop of slate includes a segment of grey limestone conglomerate that is over 3 m thick and has a dolostone matrix. The conglomerate is matrix- to clast-supported and contains 1 to 3 cm pebbles of dark grey, fine-grained limestone and a single angular pebble, 15 cm long, of parted dolomitic limestone.

Slates on either side of these outcrops include folded thin beds and augen of quartz arenite. The presence of quartz arenite suggests that the carbonates may be still part of the Irishtown Formation although they could have originated in the overlying Cooks Brook Formation.

Slates Containing Conglomerate, Sandstone and Mafic Volcanic Clasts

A series of slate outcrops enclose two, thick intervals of massive amalgamated grey conglomerate, conglomeratic sandstone, sandstone and lime grainstone. They occur in the footwall to the Spruce Ponds klippe, 2.5 km northwest of Spruce Ponds.

The bedding is not discernable between lithofacies, but prominent surfaces in one interval and remnant bedding in underlying slate outcrops suggest the rocks may dip and young to the west at about 50°. This would allow a lower interval, about 8 m thick, to be separated by 10 m of covered interval from an upper sequence about 30 m thick. However, because the outcrops are located near the crest of an anticline it is possible that the beds are essentially gently dipping and that the section is only a few metres thick, sandwiched between slate intervals.

The conglomerates are unique in the area in that they contain clasts of vesicular basalt occurring as numerous pebbles and at least one large boulder. They also contain pebbles of limestone, shale and grey siltstone. The pebbles are characteristically well-rounded, smooth and polished.

The rocks in the two sequences range from pebbly mudstone through true conglomerate to pebbly, granular, coarse-grained sandstone, grey sandstone and lime grainstone. The sequence, which is intact and cut by only a single cleavage, appears to structurally overlie slates that have a scaly cleavage, rhomboid augen and are interpreted as "mélange".

The pebbly mudstone, possibly up to 4 m thick, occurs at the east end of the series of outcrops and near the possi-

ble base of the sequence. It consists of 0.5 to 1.5 cm diameter, rounded limestone pebbles suspended in a fine-grained matrix and grades into pebbly and granular, calcareous sandstone containing deformed shale clasts. Vesicular basalt marks the western end of this outcrop and is believed to be composed of large, rounded, obscure-bordered clasts, about 25 cm diameter. A covered interval, 14 m wide, lies west of the mafic volcanic clasts. Beyond this covered interval there is a thick interval of pebbly muddy sandstone containing 1 to 5 cm in diameter pebbles of grey siltstone that apparently grades into barely pebbly sandstone. West of this, conglomerate grades into both lime grainstone and granular muddy coarse-grained sandstone and pebbly calcareous sandstone, containing basalt pebbles.

These rocks were assigned to the volcanic Fox Island Group on the map of Williams and Cawood (1989). However, the section is sedimentary in origin and the thick-bedded, massive conglomeratic sandstones were probably deposited as debris and thick turbidity flows. The basalt pebbles in the conglomerates suggest that the unit may be affiliated with the Woods Island Volcanic Member of the Blow Me Down Brook Formation (Waldron and Palmer, 2000; Palmer *et al.,* 2001). However, the conglomeratic sandstones in other parts of the Blow Me Down Brook Formation are quartz rich and feldspathic, unlike the conglomeratic sandstones of the map area.

The mix of volcanic pebbles with limestone pebbles and other sedimentary intraclasts may imply that the conglomerates are a facies of the Irishtown Formation. The presence of limestone pebbles virtually requires that the deposits are no older than Cambrian, and limestone pebbles are known in Irishtown and McKenzie formation conglomerates near Corner Brook and Bonne Bay (*see* James and Stevens, 1982; James *et al.,* 1988). However, the limestone pebbles in these areas are derived from erosion of Lower Cambrian grainstone and fossiliferous beds of the Forteau Formation, whereas the limestone pebbles in the conglomeratic sandstones north of Spruce Ponds are grey and fine grained giving little hint of their source.

Another possible correlative may be the Howe Harbour Member of the Goose Tickle Group. This member is characterized by conglomeratic sandstone facies that include rounded pebbles of shale, chert, argillite, siltstone, fine-grained limestone, and mafic volcanic rocks (Quinn, 1995). The member occurs immediately below the base of the Taconian allochthons (Quinn, 1995). The pebble assemblage is, at least in part, like that of the facies in the map area.

ULTRAMAFIC ROCKS

Just east of the Spruce Ponds klippe, a narrow north-trending unit of rusty and brown-weathering, dark green-grey, foliated ultramafic rock is extensively brecciated. It is approximately 100 m wide and can be traced for 2.5 km. The unit is chloritic, foliated to banded, and contains folded to crenulated microfoliae enclosing augen of amphibolite schist and massive ultramafic rock.

The unit was assigned to the metamorphic sole of the ophiolitic Bay of Islands Complex by Williams and Cawood (1989) and is shown to be in direct contact with the carbonate klippe. However, the new mapping shows that the unit is separated from the carbonate klippe by a 10- to 20-m-wide interval of slate containing deformed beds and augen of Goose Tickle Group sandstone. Only in the southernmost outcrop do the ultramafic and the carbonate klippe come into direct contact. There, the limestone is quite coarsely crystalline but is finely brecciated and veined. The ultramafic unit is also brecciated. The contact is sharp but not planar and has an undulating to lumpy aspect.

STRUCTURE

The map area is divided into four terranes (Figure 3). Carbonate rocks underlie two of these, *viz.,* the northern end of the North Brook Anticline and the various outliers of the Spruce Ponds klippe. They are also present in a few small bodies of deformed Table Point Formation, which may be outliers of the North Brook Anticline or parts of a small limestone klippe that would underlie the Spruce Ponds klippe. The third terrane is a belt of deformed slates that lies structurally between the North Brook Anticline and the Spruce Ponds klippe. The belt of slates consists mostly of intact and broken rocks of the Goose Tickle Group and overlying broken formation and mélange at the base of the Humber Arm Allochthon. A fourth terrane, east of the North Brook Anticline and Spruce Ponds klippe, consists of deformed siliciclastic rocks of the Irishtown Formation. These form the west limb of an overturned anticlinal fold that is cored by structurally underlying Goose Tickle Group, which is overlain by shaly mélange. The anticline's western boundary is marked, in part, by the narrow ultramafic body that is in fault contact with the klippe and slate terrane to the west.

The various terranes are deformed about a number of northeast- to north-trending and plunging folds. A regional cleavage, largely axial planar to the folds, is strongly developed throughout the area, and is manifested as a slaty cleav-

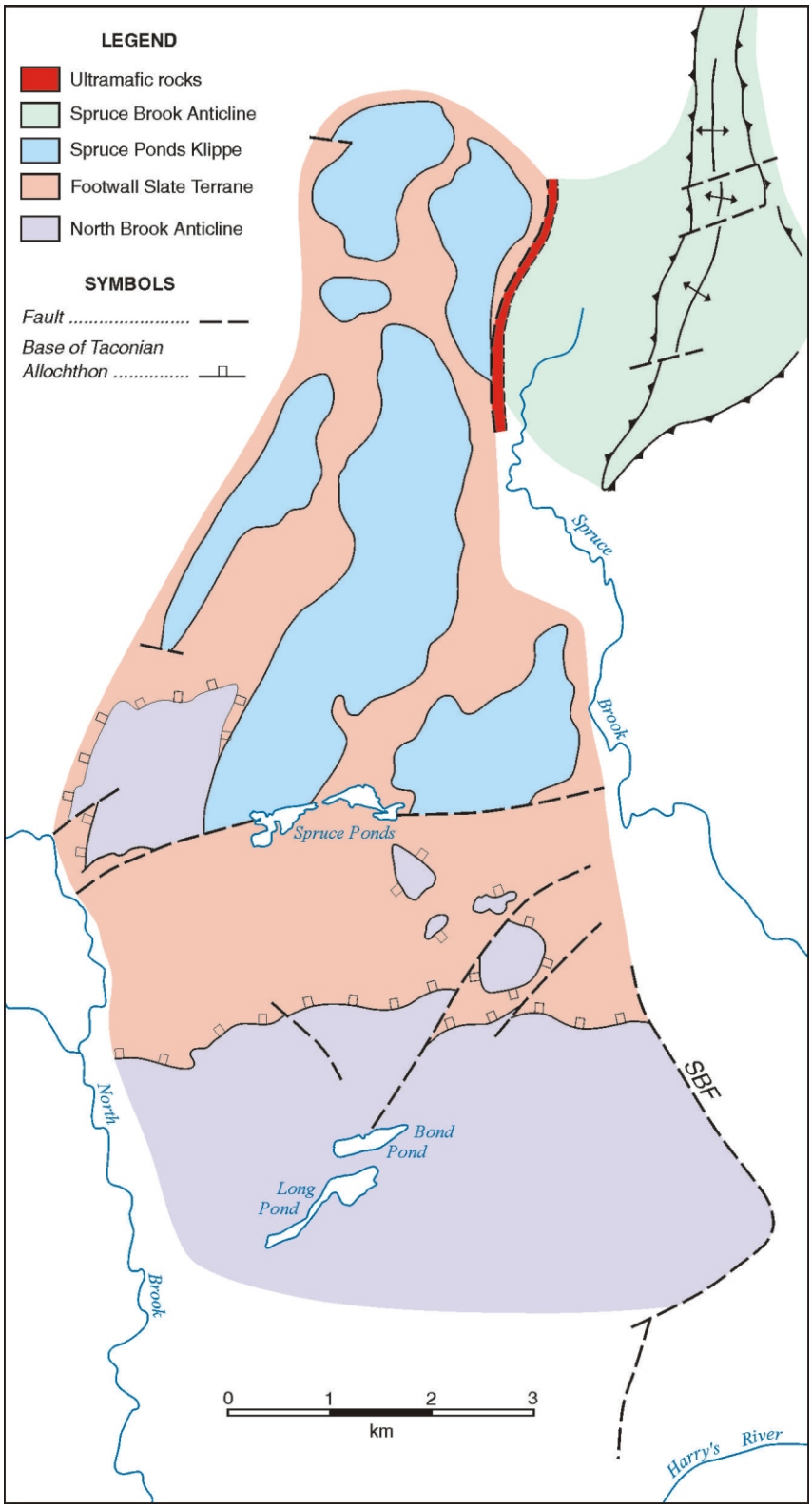

Figure 3. *Distribution of the main geological terranes discussed in the report. SBF = Spruce Brook Fault.*

age in fine-grained siliciclastic rocks. The cleavage is moderately to steeply inclined to the east. The folds postdate the emplacement of the Spruce Ponds klippe, the development of the scaly fabric in basal mélange, and a number of shear zones within the North Brook Anticline. They also fold some east-trending folds at the sole of the Spruce Ponds klippe, at the north end of the klippe and locally in the footwall to the klippe.

THE NORTH BROOK ANTICLINE

Only a small portion of this large anticlinal structure has been mapped so far. The anticline is related to the late regional deformation. Although the overall dip is gently to the north at 6 to 25°, the strata are deformed by numerous small folds. The latter plunge northeastward, in many instances have steep eastern limbs, and are associated with an east-dipping cleavage. Fold axes and cleavage on bedding lineations trend from 010 to 040° and plunge mostly between 10 and 25°N.

Repetition of the Boat Harbour–Catoche formations contact just south of Long Pond suggests that thrusts shortened the succession before it was folded. The thrusts verge to the west.

There are also a number of high-strain shear zones that principally cut rocks of the Boat Harbour and Watts Bight formations. Small dolostone augen formed after burrow-dolomite are common in the narrow zones whereas in the wider zones, which are several metres wide, augen also include boudinaged dolostone beds. Limestones are foliated essentially sub-parallel to bedding. The lineation on the foliation consistently trends between 290 and 320° but varies between subvertical to oblique across the foliation plane. The sense of shear in these zones is not consistent, some having west-verging fabrics and others suggesting east-vergence.

The high-strain zones are locally cut by the main cleavage with development of an

intersection lineation on the foliation. This suggests that the zones may be early structures subsequently folded about the main folds, a hypothesis that has yet to be verified by mapping. Nonetheless, similar fabrics and structural relationships are commonly associated with folded thrust zones in the Blue Pond carbonate thrust stack 10 km to the east. In this area, thrusts predate folds that are probably of the same generation as the North Brook Anticline (Knight, 1997).

The Slate Terrane, between the North Brook Anticline and Spruce Ponds Klippe

Slates that overlie the carbonates of the North Brook Anticline can be divided structurally into three parts. The lower part is composed of slates with thin sandstones and a limestone conglomerate member; it clearly belongs to the Goose Tickle Group. The middle part consists of slates whose protolith was shaly broken formation. The upper part ("mélange") comprises shaly rocks, which compare to allochthonous deepwater rocks of the Green Point Formation, and black shales with exotic inclusions of sedimentary and plutonic origin. The "mélange" hosts an early scaly cleavage that is characterized by anastomosing, polished, cleavage surfaces that enclose small sedimentary augen. All the slates are dominated by the regional north-trending, largely east-dipping cleavage.

Within the slate terrane south of Spruce Ponds and between the North Brook Anticline and the Spruce Ponds klippe, are a number of small domal inliers of Table Point Formation limestone and Goose Tickle Group. These inliers are surrounded by the middle and upper divisions of the slate terrane. They are deformed by intersecting east- and northeast-trending folds. The Table Point Formation limestone hosts well-preserved shelly and graptolitic fossils, especially close to the tops of the inliers, and is overlain by Goose Tickle Group rocks. This suggests that the inliers may be whale-back folds attached to the North Brook Anticline. Alternatively, they may lie in the hanging wall of small, thin-skinned thrusts that repeat the top of the Table Point Formation and overlying Goose Tickle Group. The interpretation that they are isolated shelf and flysch blocks detached from the top of the carbonate sequence and incorporated into the mélange is thought to be less likely considering the coherence of stratigraphy and the consistent upright attitude of the fossiliferous and largely unaltered carbonates.

Relationship of the North Brook Anticline to the Overlying Slate Terrane

North of Bond Pond, slate-grade shaly flysch of the Goose Tickle Group includes folded beds of the Daniel's Harbour Member. The flysch sequence appears to be relatively thick below broken formation and mélange. The Goose Tickle Group is, however, only a few metres thick in the core of the anticline, northwest of Spruce Ponds. Northeast of Bond Pond, the Goose Tickle Group appears to be absent so that the limestones of the Table Point Formation, which are essentially undeformed, are immediately overlain by broken formation and "mélange". West of the Spruce Ponds klippe, folded flysch with Daniel's Harbour Member is again relatively thick below broken formation "mélange".

The variable thickness of the Goose Tickle Group between the North Brook Anticline and the allochthonous slates suggests that the base of the allochthon locally cut out the flysch during its emplacement. However, it is surprising that Table Point Formation limestones show no visible signs of shear or deformation where they are directly overlain by broken formation "mélange" northeast of Bond Pond. This suggests perhaps that the Goose Tickle Group was not deposited in this part of the succession and that, rather than being structurally emplaced, broken formation was deposited on the limestone by mass wasting of the front of a semi-consolidated sedimentary allochthon as it moved into the Taconian foreland basin.

The Spruce Ponds Klippe

The Spruce Ponds klippe is one of a number of outliers of Lower Paleozoic shelf carbonates surrounded by slates. The largest intact carbonate klippe is the Serpentine Lake outlier, 12 km^2 in area, 4 km to the north. The mapping of 2001 shows that the several small carbonate outliers that comprise the Spruce Ponds klippe are the erosional remnants of a single structural slice, which underlies an area of 15 to 20 km^2.

Compelling evidence supports a single klippe. In particular, the carbonate shelf stratigraphy in the separate outliers of the Spruce Ponds klippe is readily linked without displacement of stratigraphic boundaries across valleys that have cut through the basal thrust and into the slate footwall. The footwall slates include the Goose Tickle Group, broken formation assigned to the Goose Tickle Group, and "mélange" that includes shaly rocks with a variety of lithic augen ranging from rocks of Green Point Formation type and black shales with ultramafic and sedimentary components.

Slates with dismembered rocks of Irishtown Formation affinity are common just east of the klippe. One outcrop of Irishtown Formation, however, also occurs just south of Spruce Ponds where it unequivocally occurs in the footwall to the klippe.

The boundaries of the klippe are rarely exposed. The eastern margin outcrops along and south of Loggers School Road. At Loggers School Road and again 1 km to the south along a skidder trail, the carbonates are in fault contact with slates hosting augen and broken beds of Goose Tickle Group type. The slates intervene between the klippe and the north-trending narrow belt of ultramafic rocks assigned to the metamorphic sole of the Bay of Islands ophiolite (Williams and Cawood, 1989). The klippe/slate contact trends 225° and dips northwest at 67° at the road locality but rotates to 350° and dips 60°E, 1 km to the south. The limestones are brecciated and veined by coarse, blocky, sparry calcite in the hanging wall to the fault and dolostone beds are broken and disarticulated as the fault is approached. Several minor normal faults, trending 210° and dipping 65°W, displace the carbonate bedding near the fault.

Two kilometres south of Loggers School Road, the slates have been structurally wedged out and the klippe is in contact with the narrow unit of ultramafic rocks. Both carbonates and ultramafic rocks are brecciated. The surface trends 010° and dips 35° to the east. Traced north to Loggers School Road, the western contact of the ultramafic with slate, 12 m east of the klippe, strikes 025° and dips 88° to the southeast. The foliation within the ultramafic strikes 025°, and dips 60 to 65° to the southeast at Loggers School Road and has an attitude of 065/65°E where it abuts the carbonate klippe.

The western contact of the klippe is not exposed. However, the carbonates of the klippe appear to consistently abut against folded rocks of the Goose Tickle Group including numerous outcrops of the Daniel's Harbour Member.

Mapping of the klippe and the slates indicates that the basal thrust and the strata in the klippe are folded about the north- to northeast-trending folds. As a result, the basal thrust has a convoluted outcrop pattern that locally crosses the contours of the rounded hills; the low ground is occupied by footwall slates. Where the carbonates can be seen to overlie the slates, the limestones are locally sheared within a few metres of the contact and are cut by deformed calcite veins, whereas the dolostones are commonly brecciated and veined by quartz.

One kilometre west of Spruce Ponds, the slates are cut off by the base of the klippe. In the hanging wall, Cambrian dolostones of the Berry Head Formation are juxtaposed against limestones of the Table Point Formation, which are stratigraphically overlain by Goose Tickle Group. The Table Point Formation and Goose Tickle Group rocks occupy the core of a north-northeast-plunging anticline that, to the north, folds the klippe and its footwall slates. The hanging-wall dolostones are finely brecciated for several metres and the breccia is cemented locally by mosaic calcite. The Table Point Formation limestone and Daniel's Harbour Member conglomerates of the footwall, however, are foliated and transposed to form a limestone mylonite across a zone which, in the south, is tens of metres wide but narrows as it is traced northward. The shear foliation has truncated the bedding in moderately northeast-dipping limestones, as can be seen when the rocks are traced out of the shear zone and into the core of the anticline. The foliation is folded about northwest- to north-plunging minor F_2 folds and hosts a west- to northwest-trending lineation on the foliation. A few dolomite augen and calcite veins extended in the plane of the mylonitic fabric suggest down-to-the-west vergence of the shear zone.

So far it has not been possible to trace the shear zone north or south of the few outcrops described here. This suggests that if the mylonite is related to the base of the Spruce Ponds klippe then the thrust follows the contact between the slates and the carbonates toward the north. Alternatively, the mylonite may be related to a late vertical shear zone suggested by a number of straight lineaments that are observed on air photographs to cut the Spruce Ponds klippe and its slaty footwall. The loss of the mylonite to the south may reflect truncation by an east–west fault that is postulated to mark the southern edge of the klippe.

The Spruce Brook Anticline and Fault

The Spruce Brook anticline is the informal name given to an anticlinal structure that lies east of the Spruce Ponds klippe. The anticline, which is overturned to the west, is cored by upright Goose Tickle Group, which outcrops along the roads in the floor of a deeply eroded, basin-like valley. The Goose Tickle Group is cut by the regional D_2 cleavage, which trends 025° and dips 70°E. A belt of shaly "mélange", which has an early scaly cleavage and lithic augen, structurally overlies the Goose Tickle Group. The outcrop distribution of the "mélange" in the western limb of the Spruce Brook anticline is narrow but appears to widen in the eastern limb. The "mélange" is, in turn, overlain by the allochthonous Irishtown Formation, which in its lower and middle parts is essentially intact, but is more broken in its upper parts, close to the western edge of the anticline. The overturned beds strike between 325° and 020° and dip 65° to 85° to the east. They are cut by a northwest-striking, moderately northeast-dipping cleavage. The western limb contains a crenulated cleavage and folded lineation, as well as downward-verging structures that include southeast-plunging recumbent folds and C–S fabrics parallel to bedding. These structures apparently predate the second deformation.

The overturned succession on the western limb is separated by a 300-m-wide covered interval from the narrow belt of rocks described earlier. The foliation in the ultramafic unit close to its eastern margin trends 330° and dips 80° to the east. This is close to the trend of the Irishtown Formation strata and implies they are part of the same structural plate. Williams (1985) placed the Spruce Brook Fault along the western margin of the ultramafic unit. The fault was projected south to truncate the eastern extension of the North Brook Anticline and is shown on the map of Williams and Cawood (1989) to separate the North Brook Anticline from rocks of the Irishtown Formation. The fault on both maps is interpreted as a normal fault, downthrown to the east.

IMPLICATIONS OF THE STRATIGRAPHY AND STRUCTURE OF THE SPRUCE PONDS KLIPPE

The Spruce Ponds klippe is host to a structurally incomplete shelf sequence that resembles the Lower Paleozoic shelf succession found in nearby structures such as the Blue Pond Thrust Stack and the Phillips Brook Anticline (Knight, 1997; Knight and Boyce, 2000). The structural style is that of an early thrust deformed about later northeast-trending and plunging, regional folds. This is similar to the Blue Pond and Goose Arm thrust stacks and perhaps the Phillips Brook Anticline. The metamorphic grade is closer to that found in the Phillips Brook Anticline. All these factors suggest that the klippe is not far traveled.

The klippe rests upon slates that include broken formation/"mélange", overlying largely shaly flysch of the Goose Tickle Group including limestone conglomerate of the Daniel's Harbour Member. The flysch rests upon Table Point Formation which, is characterized by nodular and lumpy and brecciated fine-grained limestones similar to the formation in both the Phillips Brook Anticline and the Blue Pond Thrust Stack. The broken formation/"mélange" appears to be largely a mixed terrane of Goose Tickle Group and allochthonous limestone and clastic rocks similar to the Late Cambrian to Early Ordovician deepwater sequences of the Green Point and Northwest Arm formations. The "mélange" locally includes black shales enclosing blocks of ultramafic and volcanic origin and a rare block of quartz arenite of Irishtown Formation affinity. The footwall to the Blue Pond Thrust Stack is also dominated by similar broken formation and "mélange" and these rocks also surround and locally overlie the Phillips Brook Anticline.

Like the North Brook Anticline and the Spruce Ponds klippe, the footwall slates are deformed by late northeast-trending folds and cleavage. Nonetheless, the broken formation/"mélange" association has a scaly cleavage that surrounds rootless augen of lithic fragments and predates not only the northeast structures but the emplacement of the Spruce Ponds klippe. The early cleavage, however, may postdate mélange. If so, much of the mixed broken formation/ "mélange" may be the product of mass wasting in front of the sedimentary parts of the Humber Arm Allochthon as they entered the Middle Ordovician flysch basin. The allochthon may have also carried rare exotic blocks of ultramafic and mafic volcanic rocks. Since the sedimentary part of the allochthon is largely composed of rocks of Cow Head Group affinity, may be it is reasonable to suggest that the broken formation and "mélange" formed as the Cow Head Group was transported across the foreland basin in the late Middle Ordovician. Volcanic and ultramafic lithoclasts derived from erosion of the western Newfoundland ophiolite were incorporated into the "mélange" during this sequence of events. The scaly cleavage would have been formed by tectonic processes as the Cow Head Group advanced westward across the already deposited broken formation and mélange.

ECONOMIC GEOLOGY

No mineralization has been found in the area. Crystalline dolostone units with sparry dolomite vein complexes that replace limestone in the St. George Group and host Mississippi Valley-type deposits elsewhere in western Newfoundland are not present in the succession of the map area. However, stylolitic clean limestones, which are common in the Costa Bay Member of the St. George Group and the basal member of the Table Head Group, are now attractive grey marbles (Bardiglio) possibly suitable for use as dimension stone. In addition, both of these grainy limestone units are clean and would be expected to produce high-quality limestone aggregate.

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