MAP 2020-17

GEOLOGY OF THE INDIAN LOOKOUT (NTS 12I/03) AND PORTLAND CREEK (12I/04) MAP AREAS

Scale 1:50 000

Open File 012I/0325

NOTES FOR MAP USERS
(These notes apply to this map and to Map 2020-16; the contents are, therefore, not all relevant to this sheet.)

SUMMARY

The Cambrian–Ordovician shelf and foreland basin rocks of the study area are located approximately midway, on the Great Northern Peninsula, western Newfoundland, and centred near the community of Daniel's Harbour. There, they extend west of the Proterozoic granitic and gneissic spine of the Long Range Mountains to the long, essentially straight, shoreline of the Gulf of St. Lawrence, a coast of low rocky and gravelled cliffs and storm beaches north and south of Bellburns. The shelf terrane consists of a broad coastal landscape of low-carbonate barrens seaward of a locally rugged landscape of deep, lake-strewn valleys and wooded ridges that terminate at a prominent granite scarp marking the western edge of the Long Range Massif. The scarp coincides with the trace of the thrustal front of the massif, the Long Range Thrust. The shelf terrane in the west is dissected by long, sinuous, high-angle, north- to northeast-trending faults linked by shorter, and straight, west-trending faults. Approaching the Long Range Massif, however, the terrane is deformed by thrust slices and associated reverse faults that include the Blue Mountain, and Western Blue Pond thrusts, and the Brian's Pond and Flat Pond faults, lying adjacent to, and west of, the Long Range Thrust.

South of Bellburns, the belt of shelf rocks begins to narrow and wedge southwards as they trend inland toward Portland Creek Pond on the Portland Creek and Indian Lookout map areas, east of the Parsons Pond Thrust. Much of these map areas, southwest of the shelf rocks are occupied by a wide coastal plain of marsh-covered Quaternary tills, gravels and raised beach deposits, which overlie mostly Middle Ordovician foreland basin siliciclastic rocks, believed here to be mostly parautochthonous, rather than allochthonous, as shown on earlier maps. The Middle Ordovician foreland basin siliciclastic rocks are structurally overlain to the southwest and south by allochthonous shelf slope and basin deposits of the Cow Head Group and an overlying foreland basin clastic succession, the Lower Head Formation. The two allochthonous units form long ribbon-like zones that are repeated by several north-trending and west-verging thrust faults.

South of Portland Creek Pond, shelf rocks occupy two thrust slices that are not contiguous, although previously linked together as the Parsons Pond Thrust Slice. A northern thrust slice is a long arcuate-shaped, steeply westward-dipping to inverted succession of shelf rocks defined here as the Portland Creek Pond Thrust Slice (PCPTS). It outcrops from Portland Creek Pond, 12 km south, dominantly in the Portland Creek map area, where it pinches out against the Long Range Thrust many kilometres north of Parsons Pond. Immediately south of the pinchout, the Long Range Thrust carries Grenvillian crystalline rocks above shale-dominated rocks of the Cow Head Group. Beyond the Cow Head Group rocks, at the southern edge of the Portland Creek map area, Paleozoic shelf rocks separate the basement massif and the Cow Head Group as a southward widening, yet narrow thrust slice that reaches beyond the southern edge of the map area and projects to the north shore of Parsons Pond on the adjoining St. Paul's Inlet map area (NTS 12H/13). The thrust slice does not connect with the PCPTS to the north beneath or in front of the Long Range Thrust, hence the use of the name Parsons Pond Thrust Slice (PPTS) is restricted to this southern structural wedge only.

The autochthonous shallow-water and foreland basin succession consists of two sequences; a lower shallow-water shelf succession deposited along Newfoundland's Laurentian passive margin, and an overlying foreland-basin succession deposited in the East Anticosti subbasin in response to continental-scale Taconian convergent crustal tectonics. A major regional sequence boundary, the St. George Unconformity, separates the two sequences. The shelf and foreland basin succession is not well exposed inland but does include classic sections of the foreland basin carbonates and flysch along the shoreline of the Gulf of St. Lawrence.

The shelf succession comprises Labrador, Port au Port, and St. George groups. It consists of mixed clastic and carbonate rocks in the Labrador Group overlain by a shallow-water shelf succession of subtidal and peritidal limestone and dolostone, with minor shale deposited in the Port au Port and St. George groups. The succession is approximately 1600 m thick; it comprises several sedimentary megacycles.

The foreland-basin succession, between 300- to 500-m thick, consists of the Table Head and Goose Tickle groups. The former consists of a basin-deepening, variably thick succession of peritidal to subtidal shelf carbonate blanketing the St. George Unconformity. The shelf foundered and deepened as the basin evolved leading to accumulation of a thick flysch succession of shale and sandstone, the Goose Tickle Group. Intrabasinal faulting reflecting inversion of shelf-penetrating faults, accommodated a complex of basins and horsts in the foreland basin,

with uplift and erosion of Table Head carbonates to form thick but laterally thinning lensoid deposits of limestone conglomerate (Daniels Harbour Member) adjacent to the faulted horsts.

The carbonate shelf hosts Mississippi valley-type mineralization in a northeast-trending belt near Daniel's Harbour, where a mine operated throughout the 1980s. Several small sphalerite showings occur elsewhere in the area but no significant prospects have been highlighted. The now defunct mine produced just over 7 million tons of ore grading 7.8% Zn. The mine consisted of numerous narrow sphalerite ore bodies in a thick stratiform, stratabound unit of sucrosic and sparry, polygenetic, locally porous dolostone that lies approximately 100 m below the St. George Unconformity. The dolostone replaced the upper part of a succession of subtidal to peritidal limestone (Catoche Formation) overlain by a thick succession of tight peritidal dolostone and lesser shale (Aguathuna Formation) immediately below the unconformity. The ore is spatially associated with matrix breccias that cluster close to northeast-trending faults, active in the late stages of the carbonate shelf, and likely conduits for both subsurface karst and later mineralizing fluids. Detailed regional studies of the vast network of shallow and deep drillholes, as well as open pits and deep subsurface mine workings, indicated active karst-related dolines formed in the pre-unconformity succession before the shelf was itself exposed and karstified.

Dolomitization of carbonate rocks in the map area is generally pervasive, with limestones in both shelf and foreland basin sequences replaced, the latter spatially linked to the major faults in the map area and characterized by extensive vuggy porosity suggesting reservoir potential to trap hydrocarbons generated in the foreland basin.

INTRODUCTION

The study area is located midway along the western side of the Great Northern Peninsula (GNP) in the area north and south of Portland Creek Pond, west of the Long Range Mountain spine and extending north to the southern shore of River of Ponds Lake. This large terrane, contained within the Bellburns (NTS 12I/5, 6), Indian Lookout (NTS 12I/3) and Portland Creek (NTS 12I/4) map areas, is underlain by four lithological and structural terranes. These are: 1) the Long Range Proterozoic basement; 2) the Lower Cambrian–Lower Ordovician carbonate and lesser siliciclastic shelf rocks of the Laurentian margin; 3) the Middle Ordovician carbonate shelf, siliciclastic flyschoid rocks, and minor carbonate flysch of the eastern lobe of the Anticosti foreland basin succession; and 4) the allochthonous rocks of the Cow Head Group and overlying foreland basin flysch, originally deposited in shelf–slope and deep-water basin settings fringing the margin of Laurentia.

This diverse geological terrain was first mapped by the Geological Survey of Newfoundland and Labrador (GSNL) in the early 1980s (Knight, 1985a, b). Field camps were established at Hawkes Bay and River of Ponds in 1983 and 1984, as part of a larger project that also included areas north of Hawkes Bay to Castor River, Plum Point and Roddickton (Knight and Saltman, 1979; Knight and Delaney, 1986; Knight, 1993). This coincided with the operation of the Daniel's Harbour (zinc) Mine just inland and northeast of the fishing community of Daniel's Harbour. Extensive drilling programs, prospecting and geophysical surveys focused on enlarging mine reserves and extending the life of the mine. The mine was opened by Teck Corporation in 1975 (Dearin, 1978a, b), and operated until 1990.

Mapping by the GSNL utilized a series of contemporaneous and older resource roads for general access to much of the terrane. The roads radiated from Hawkes Bay, Daniel's Harbour, Five Mile Road and the Bateau Barrens. Mapping was done using map and compass, paced foot traverses and airphotos (flown in 1979 and 1980; Knight, 1985b). Boat traverses on the larger accessible lakes, such as River of Ponds Lake, Portland Creek Pond and Blue Pond, were also important. A helicopter was used to access challenging terranes close to the Long Range Mountains, the marsh-strewn coastal lowlands inland of Portland Creek, and Parsons Pond. Resource roads were drawn by hand onto the published topographic maps of the time; accuracy was inconsistent. Significant parts of the study area were poorly exposed and lacked reliable outcrop, hence dislodged blocks and rubble were used to assign a lithological designation during mapping.

New resource roads off the Bateau Barrens Resource Road were developed in the late 1990s and early 2000s. The roads penetrated the terrane south of River of Ponds Lake and around the foot of Blue Mountain, areas that were poorly exposed in the 1980s survey. Earlier woods roads were upgraded and extended but not all of these roads were re-examined before the publication of this map. The construction of the power line for the Muskrat Falls hydro development in central Labrador has provided additional access to the area close to the Long Range Mountains near Inner Brian's Pond on the Bellburns map area.

The Portland Creek map area was also mapped and described by Cawood *et al.* (1987).

LOCAL SETTING

The map area underlain by lower Paleozoic sedimentary rocks, from River of Ponds south to Parsons Pond, is a low-relief coastal plain that lies northwest of a glacially dissected upland plateau of the Long Range Mountain spine, midway along the GNP. The coast of the Bellburns map area is, for the most part, fronted by a virtually straight, fault-controlled north-northeast trending coastline of rock cliffs, only offset by the southeast-trending bays of Freshwater Cove and Table Cove near Bellburns in the south, and an unnamed cove near Bateau Barrens resource road in the north. The wave-cut bench exposes broad shoreline sections through a number of stratigraphic units in front of the cliffs. In the north, near River of Ponds and in the south near Daniel's Harbour, retreating high cliffs of Quaternary outwash gravel and till cover the bedrock many tens of metres. In the Portland Creek area, the less imposing low, northeast-trending, more or less straight shoreline wanders, reflecting the interplay of stretches of low, sedimentary bedrock benches and pebble-built beach ridges. Sand dunes occur near the mouth of large rivers such as at Portland Creek.

In the Bellburns area, the coastal plain is about 25 km wide. It consists of a low-relief carbonate barren, widespread shrub and marsh west of a terrain of northeast-trending, wooded rock and gravel/till ridges and lake- and marsh-strewn valleys, immediately northwest of the mountain spine. A steep, prominent, fault scarp defines the inland edge of the shelf-carbonate terrain with the Long Range Mountains, the scarp marking the contact of metamorphic and granitoid basement beneath the mountains with the more easily eroded lower Paleozoic sedimentary terrain to the west. The trend of the fault scarp is broken and locally offset by faults that mark several, deeply eroded, southeast-trending, U-shaped, lake-drowned glacial valleys that penetrate several kilometres into the mountain spine. Blue Mountain, a bold upstanding, scarp-lined mountain encircled by several large lakes, projects west out into the lowland from the Long Range Mountains. Its flat-lying strata are carried above basement by a series of faults, and its domal physiographic mass resembles Gros Morne Mountain in Gros Morne National Park.

In the Portland Creek area, the equally broad coastal plain is of low relief and marsh strewn. Where the latter is thin, a planated rock bench hides beneath moss, lichen and tuckamore dressed outcrop. The monotony of the coastal plain is locally broken by a few upstanding, scarp-faced hills such as Portland Hill consisting of resistant rocks. Portland Hill comprises thick and massive bedded, pebbly sandstone east of which is a prominent ridge of limestone conglomerate (Cow Head Group). Linear rock ridges define the general structure of the area in the rest of the map area. Dissected arkosic sand and gravel outwash occur close to the Long Range Mountains and in meandering raised beach ridges just south of Portland Creek Pond. Only adjacent to the Long Range Mountains does the topography rise reflecting a belt of steeply tilted shelf rocks and glaciomarine and fluvial outwash gravels derived from erosion of the Long Range Mountains. A curved scarp defines the edge of the mountains, reflecting a change in the structural control of the mountain front and locally, defined by west-trending narrow lakes; the mountain front is offset, suggesting hidden cross faults.

The map area lies within the outer part of the Humber (tectonostratigraphic) Zone of Williams (1979; Hibbard *et al*., 2006). It occurs northwest of the Long Range Massif and east of the frontal Ten Mile Lake Fault zone, projected by these authors to form the leading edge of the foreland side of the zone although Knight and Boyce (2015) suggest the likely front lies to the west at the Brig Bay Fault. The lower Paleozoic sedimentary succession comprises an autochthonous shelf succession and a succession of transported co-eval rocks that are essentially the western leading edge and most northerly part of the Humber Arm Allochthon, here referred to as the Cow Head Allochthon.

As elsewhere in the western Newfoundland Humber Zone, the lower Paleozoic shelf succession in the Bellburns to Parsons Pond area is presently considered to be autochthonous. However, based on the regional aeromagnetic maps, the northwestward projection of the shelf succession away from the Long Range Massif and into the foreland basin beginning just north of Portland Creek Pond and a possible small window of Cow Head Group limestone conglomerate, structurally interleaved with shelf carbonate and foreland basin flysch near the mouth of Brian's Pond Brook at the eastern corner of the head of the same pond, give good grounds to support the shelf terrain of the

Bellburns area as parautochthonous. The rocks are generally gently deformed with shallow dips, except near faults, where strata are moderately to steeply inclined. The intensity of deformation increases from west to east with a narrow zone of steep thrust slices shortening the succession immediately west of the Long Range Mountains. The area is well known for its many, long linear, gently curved, northeast-trending, high-angle faults that project tens to hundreds of kilometres along the GNP.

LOWER PALEOZOIC SHELF ROCKS

As elsewhere in western Newfoundland, the lower Paleozoic autochthonous succession in the Bellburns to Parsons Pond area comprises a lower shelf succession of late Early Cambrian to late Early Ordovician age (Dyeran to Floian), and an upper foreland basin succession of early Middle Ordovician age (Darrawilian). The two successions are separated by the St. George Unconformity (Knight *et al.*, 1991), an erosional karst surface of subtle to significant relief throughout western Newfoundland's Humber Zone and its foreland. Beneath the unconformity are a widely developed array of carbonate filled fractures, bodies of matrix breccia and other features of subsurface karst indicating the unconformity was partly controlled by reactivation of major basement faults and broad warping, related to the passage of a Taconian peripheral forebulge across the Newfoundland margin in the late Early Ordovician (late Floian stage, Knight *et al*., 1991, 2007; Baker and Knight, 1993; Knight and Cawood, 1995). Detailed work in the Daniel's Harbour area by Lane (1997) indicated that large doline sags, initiated by subsurface dissolution and diagenesis, were sites of thickened carbonate sedimentation on the shelf prior to its exposure and formation of the unconformity. Therefore, a protracted series of karst processes influenced the late Floian landscape and there is evidence of substantial local relief, of at least 300 m, on the unconformity as one crosses faults. In addition, widespread, northeast-trending fracture fills, below as well as post-unconformity indicate that protracted fault activity controlled local thickness and facies of carbonate rocks (Table Head Group) that were deposited in the early stages of the foreland basin and buried the Taconic landscape as the shelf margin foundered (Knight *et al*., 1991, 2007).

The shelf succession in the area consists of three groups, the Labrador, Port au Port and St. George. The Labrador Group that rests unconformably upon Grenvillian Proterozoic basement is a mixed succession of dominantly siliciclastic and lesser carbonate rocks deposited during the earliest phases of the passive margin shelf. It is overlain by the Port au Port and St. George groups dominated by shallow-water, peritidal and subtidal carbonate rocks; shale beds are scattered throughout the Port au Port Group and occur high in the St. George Group. The foreland basin succession comprises the Table Head and Goose Tickle groups, the former a variably thick succession of peritidal to subtidal, upward deepening limestone that transitions up into basinal shale and clastic flysch of sandstone, siltstone and shale; minor carbonate also occurs in the flysch including lenticular units of limestone breccia.

LABRADOR GROUP

The Labrador Group comprises three formations: Bradore, Forteau, and Hawke Bay. In the Bellburns map area, the group is exposed in the 648-m high, round buttress of Blue Mountain (locally called Bluey Mountain) formed of essentially flat-lying group strata above Proterozoic basement. It also marks the shoreline of adjacent Eastern, and Western Blue ponds (the latter locally called John Williams Blue Pond) and forms a narrow fault-bounded sliver west of the Long Range basement complex south of Blue Mountain to Inner Brian's Pond. Much of the group strata are structurally cut out by the thrust faults of this area.

North of Blue Mountain, outliers of gently west-dipping Labrador Group strata underlie a series of wooded, smooth-sloped, crested ridges above granitoid basement. Several faults in this area disrupt the succession juxtaposing formations against each other. In the Portland Creek–Indian Lookout maps areas, the group is exposed south of Portland Creek Pond in the canoe-shaped Portland Creek Thrust. Only the Forteau and Hawke Bay formations are exposed there, although logs of two deep drillholes in the Inner Long Pond area (NALCO, 1971) indicate that the succession penetrates the Labrador Group to Grenville basement in the footwall of the Long Range Thrust.

The upward change from clastic to carbonate to clastic-shelf facies represents the first Sauk sequence of the Newfoundland Laurentian shelf, a 3rd order transgressive and regressive depositional cycle that formed mega sequence 1 of James *et al.* (1989). The sequence began with a transgressive system tract (Bradore and lower Forteau formations) associated with marine drowning of rifted Proterozoic basement that reached its maximum flooding in the middle member of the Forteau Formation. Above this, the succession preserves a long-term shallowing progradational system with the establishment of a high-stand system tract in the upper part of the Forteau Formation, and the regressive but cyclic system tract in the overlying Hawke Bay Formation.

The **Bradore Formation** is a succession of red arkosic sandstone, grey micaceous sandstone and siltstone, purple and green glauconitic sandstone and minor grey mudstone. The succession is little more than 50 m thick in outcrops on the north scarp of Blue Mountain, a sharp contrast with the 150 m succession of dominantly arkosic red sandstone known in the type area of southern Labrador (L.M. Cumming *in* Bostock *et al.,* 1983*;* Hiscott *et al*., 1984; Delong and Yi, 2004), drillholes near Flowers Cove (Nalcore hole NF-1A and B; I. Knight, unpublished logs, 2012) and the formation at Mount St. Margaret (Knight, 1991; Knight and Boyce, 2015; Knight *et al.*, 2017).

The formation in drillhole PC-2-70 (Portland Creek map area; NALCO, 1971) is about 62 m thick and comprises two sequences, 20 and 42 m thick. The sequences commence with a thin basal quartz-pebble conglomerate and intraclastic glauconitic and haematitic sandstone overlain by red and green mudstone intercalated with thin-bedded glauconitic sandstone, host to red shale intraclasts and thick green-grey glauconitic and micaceous sandstone. This mixed, lower succession is overlain by red arkosic sandstone that is locally pebbly and glauconitic. A quartz pebble, granular conglomerate, 1.5 m thick, with well-rounded sand grains and a ferruginous matrix caps the formation. This succession in the drillhole appears to compare favourably with the succession at Blue Mountain where micaceous and glauconitic, purple and green-grey sandstone, is overlain by several metres of crossbedded, red arkose, below a ferruginous quartz pebble, granular conglomerate having well-rounded coarse sand grains. Simple, bedding parallel, tubular trace fossils occur in the grey and green, micaceous and glauconitic, sandstone facies. Vertical *Skolithus* burrows common in the red arkoses in Labrador and northern GNP are rare in the map area. The contact with the overlying Devils Cove limestone of the Forteau Formation is sharp and planar (Knight and Boyce, 2015; Knight *et al*., 2017). The succession appears to include open-shelf shoreface sands and muds that shoal into red fluvial or estuarine sandstones.

The overlying **Forteau Formation**, generally about 120 m thick, consists of a basal white to pink to purple, stylobedded, argillaceous and skeletal limestone, the Devils Cove Member, a middle member of grey shale and siltstone with minor nodular limestone, and an upper member of dark-grey limestone with interbeds of mudstone, siltstone and sandstone (Knight *et al*., 2017). Trilobites and other macrofossils indicate that the formation was deposited in the mid- to late *Bonnia-Olenellus* zone (Skovsted *et al*., 2017; Knight *et al*., 2017).

The Devils Cove Member comprises a stylobedded, argillaceous lime mudstone to skeletal packstone and grainstone that ranges from red to pink, and purple and white. It is 5.45 m thick at Blue Mountain (Knight *et al.*, 2017) and is likely part of a 13 m basal interval of limestone and dark-grey shale at the base of the formation in drillhole PC-2-70, 45 km to the south near Inner Long Pond (NALCO, 1971). This thickness is unlikely to be accurate because the log description includes dark-grey shale, not usually found in the member on the GNP, although it is present in the classic section at Southeast Hills in Gros Morne, 90 km to the south (Knight, 2013). Because the member is thin, it is not separated on the maps but is included in the Middle shale member.

The Middle shale member, 30 to 40 m thick, is a succession of dark-grey shale, nodular limestone layers and interbeds that give way upwards to interbedded shaly mudstone and extensively bioturbated siltstone recognized in drillhole PC-2-70, where it is 31 m thick (NALCO, 1971). It is abruptly overlain by the Upper limestone member, a heterolithic succession, approximately 80-m thick, of dark-grey oolitic, oncolitic, intraclastic and skeletal grainstone, shale, argillaceous siltstone, dolostone and sandstone (Knight *et al.*, 2017). The oolitic limestone that marks the base of the member at PC-2-70 is about 35 m thick (NALCO, 1971). Dark-grey shale and bioturbated and fossiliferous sandstone overlain by thick dolostone, marks the top of the formation locally.

The **Hawke Bay Formation** caps the upper slopes and plateau top of Blue Mountain as well as being exposed on the western shores of Eastern and Western Blue ponds. It also outcrops in a series of north-trending ridges and along the eastern shoreline of Inner Long Pond in the Portland Creek Pond Thrust panel (Portland Creek map area); narrow structural slivers also occur between the footwall of the Long Range Thrust and the Parson Pond Thrust just north of Parsons Pond. It is in sharp planar contact with the underlying Forteau Formation and is known to be approximately 150 m thick in drillholes near Flowers Cove, and its type section at Hawke Bay (L.M. Cumming *in*

Bostock *et al.*, 1983; Knight, 1991; Nalcore drillholes NF-1A and B: I. Knight, unpublished logs, 2012). Only the upper 40 m of the formation is logged in drillhole PC-1-70, north of Inner Long Pond (NALCO, 1971).

The formation is characterized by thick beds of well cemented, white to pink quartz arenite (commonly referred to as quartzite in most publications), red and green-grey, often bioturbated, sandstone, dark-grey shale, thin-bedded sandstone and shale, and yellow-weathering, dolomitic sandstone to arenaceous dolostone, especially close to the top of the formation. The succession comprises several metre- to decametre-thick, upward-coarsening (shallowing) sequences with dark shale overlain by interbedded sandstone and shale below thick beds of quartz arenite. Phosphatic pebbles and siltstone intraclasts are common in the uppermost sequences of the formation; bioturbation especially *Teichichnus* is also common. Fossils recovered from the formation elsewhere in western Newfoundland indicate that it was deposited from the latest part of the Early Cambrian Dyeran *Bonnia-Olenellus* zone through the Middle Cambrian Delamaran *Glossopleura* zone and perhaps continues into the younger *Marjuman* zone.

PORT AU PORT GROUP

The Port au Port Group in western Newfoundland is divided into three formations, March Point, Petit Jardin and Berry Head, based on stratigraphic studies on the Port au Port Peninsula, where limestone form a significant part of the group, and the group is shown to consist of a number of large sedimentary megacycles or grand cycles (Chow and James, 1987; James *et al*., 1989; Cowan and James, 2003). In the north of the GNP and in the study area, much of the succession is dolostone and lesser shale, and only very rare limestone occurs at the base and in the middle of the Petit Jardin Formation (Knight, 1977, 1991). No grand cycles are recognized, although measured sections along extensive coastal exposures along the St. Barbe coast, 100 km north of the area (Knight, 1977), indicate that the group attains about 500 m in thickness.

The group underlies the Bellburns map area west and north of the frontal thrusts and a west-trending array of high-angle faults, just southwest and northwest of Blue Mountain; the group wedges out against the frontal thrust just south of Western Blue Pond. A narrow wedge of the group also occurs west of the Bellburns Pond Fault. In the Portland Creek Thrust slice, the group is best exposed along the western shores of Inner Long Pond and the river bed and gorge of Southwest Feeder (also named Greavett Brook on 1:250 000-scale maps, Government of Newfoundland and Labrador, 2007) immediately west of the pond's drainage point. Drillhole PC-1-70, which occurs northwest of the pond, is host to about 340 m of Port au Port Group dolostone and shale beneath 10 m of Quaternary overburden (NALCO, 1971). It is noteworthy, that although the dolostone and shale in the upper 210 m of the vertical hole bear some resemblance to lithologies of the Aguathuna Formation, top of the St. George Group, a dark-grey crystalline dolostone unit at the base of the dolostone section (465 m down the hole) rests upon Hawke Bay Formation quartz arenite. This dolostone is assigned to the March Point Formation as it is elsewhere in the north of the GNP (Knight, 1977, 1991) implying that the full 340 m dolostone section in the drillhole belongs to the Port au Port Group.

Outcrops of the **March Point Formation** are generally poor and sparse. It consists of a brown-weathering, dark-grey, stylobedded, burrow-mottled, argillaceous to fine- to medium-crystalline dolostone cut by white dolostone veins. It is 45-m thick in the PC-1-70 drillhole. It outcrops along the west side of Western Blue Pond (Bellburns map area), locally along the north shore of Inner Long Pond in the Portland Creek Thrust and in narrow fault slivers in the Parsons Pond Thrust Slice (PPTS) in the footwall to the Long Range Thrust at the southern edge of the Portland Creek map area. Trilobites recovered in the unit elsewhere on the GNP indicate that the formation was deposited during the Topazan *Ehmaniella (Bathuriscus–Elrathina)* zone (Boyce, 1977; Knight, 1977)

Above the March Point Formation, the remaining succession in the Port au Port Group is undivided throughout much of the map area. It consists of buff- to yellow-weathering, light-grey to grey, fine to microcrystalline dolostone intercalated with beds of recessive green-grey, red and locally dark-grey shale and argillaceous dolostone. These lithologies occur in both, the Petit Jardin and Berry Head formations on the GNP. The Berry Head Formation is distinguished by the presence of intercalated thick beds of dark-grey to black, cherty, medium-crystalline dolostone.

The **Petit Jardin Formation** consists of three members; Lower dolostone, Middle stromatolite and Upper dolostone (Knight, 1977, 1991), but it is not possible to recognize these divisions in the map area except locally, due to generally poor outcrops.

The Lower dolostone member is thin and thick bedded. The thin-bedded dolostone displays flaser bedding, dololaminite with algal fabrics, desiccation cracks and intraformational conglomerate and breccia pavements whereas the thick-bedded dolostone is generally burrow-mottled and have rare stromatolite mounds. The Middle stromatolite member comprises stacked domal stromatolite mounds as well as some fossiliferous, intraclastic and oolitic dolostone and limestone; beds of intraclastic dolo and lime edgewise conglomerate also occur. Red and green dolomitic shales, replete with desiccation cracks, small-scale ripple marks and dolostone lenses, intercalate sporadically in the lower and middle members. Rare trilobites and inarticulate phosphatic brachiopods occur in both members, the trilobites indicating that the members were deposited during the Topazan *Cedaria-Crepicpehalus* zone (Boyce, 1977; Knight, 1977, 1991). The Upper dolostone member consists of similar dolostone to that of the lower member but includes crossbedded, grainy dolostones, local quartz-sand-rich dolostone and chert nodules.

The overlying **Berry Head Formation** (originally called the Cherty dolostone and Unfortunate Cove member in some reports of Knight (1977, 1978) is a succession of thick-bedded, buff-weathering, grey, fine- to medium-crystalline dolostone intercalated with dark grey to black, cherty, medium-crystalline dolostone. The latter display burrow-mottle fabrics as well as large microbial mounds, and include a basal marker that defines the base of the formation throughout western Newfoundland (Knight and Cawood, 1997). The basal marker consists of metre-thick complexes of large, metre-scale-diameter and thick, algal mounds of columnar and/or thrombolitic structure; dark-grey chert is common in the marker. The topmost bed in the formation is a thick unit of grey bioturbated dolostone that has also been traced throughout western Newfoundland. Fossils have not been recovered in the Upper dolostone of the Petit Jardin Formation or the Berry Head Formation in the map area.

The succession in the Port au Port Group marks the establishment of a broad carbonate ramp shelf on the Newfoundland Laurentian margin (James *et al.,* 1989). A significant Topazan transgression drowned the last coarse clastic sediments of the Labrador Group shelf leading to deposition of the dark burrowed dolostone of the March Point Formation. This shallow, subtidal carbonate is succeeded by a thick succession of peritidal carbonate of the Petit Jardin Formation, which included a lagoonal shelf associated with carbonate sandflats and stromatolitic mound complexes as well as algal tidal flats, and desiccated inner shelf mudflats during low-stand events (*see* Knight, 1977; Cowan and James, 1993; Knight and Boyce, 2015). The deposition of the Berry Head Formation commenced with the extensive deposition or development of microbial mound complexes throughout western Newfoundland, suggesting the transition of the carbonate ramp to a platform late in the Cambrian. The formation lithologies support a less restricted and more normal marine platform as it transitioned to Early Ordovician sedimentation that characterized the overlying St. George Group.

ST. GEORGE GROUP

The Early Ordovician (Skullrockian to Floian) to earliest Middle Ordovician (earliest Darriwilian) St. George Group, consists of a succession of fossiliferous subtidal and peritidal carbonates mapped throughout the western Newfoundland Laurentian platform. Regionally, the succession comprises both limestone and dolostone arranged in two transgressive–regressive megacycles. A lower Tremadocian cycle of the Watts Bight Formation and lower part of the Boat Harbour Formation and an higher Arenigian cycle comprising the Barbace Cove Member (Boat Harbour Formation), Catoche Formation and Aguathuna Formation (Knight and James, 1987; James *et al.*, 1989; Knight *et al*, 2007, 2008); the megacycles are separated by the regional Boat Harbour Disconformity (Knight *et al.*, 2007, 2008). In the map area, the Tremadocian sequence is overwhelmingly dolomitized unlike other areas of the GNP such as Eddies Cove West, Canada Bay, Hare Bay and Pistolet Bay, where unaltered limestone allows understanding of the depositional settings of this part of the succession.

The **Watts Bight Formation** comprises tan-grey-weathering, dark-grey, medium- to coarse-grained, sucrosic dolostone, a distinctive dolostone unit mapped throughout the carbonate barrens of the western side of the GNP; it contrasts markedly to the underlying light-grey fine dolostone of the Port au Port Group. In the map area, the formation is approximately 90 m thick in drillholes west of Flat Pond (US Borax, 1979), similar to its type section on the GNP (Knight and James, 1988). The succession consists of a complex of large thrombolitic boundstone mounds and thick-bedded, burrow-mottled dolostone with interbeds of grainy dolostone and a rare interbed of thin stratified dolostone; the unit is characteristically cherty, hosts ghosts of large coiled gastropods and straight cephalopods; it often has a slight bituminous odour when fractured.

The **Boat Harbour Formation** consists of two members. The lower unnamed member, part of the Tremadocian sequence, makes up most of the 85 to 110 m succession, overlain by an upper member, the Barbace Cove Member, 10 to 15 m thick on the western side of the GNP, resting conformably upon the cryptic Boat Harbour disconformity (*see* Knight, 1991; Knight *et al*., 2007, 2008). The lower unnamed member comprises finely crystalline, grey dolostone with only very rare vestiges of limestone; it is generally poorly exposed. The dolostone replaces a succession of metre-scale cycles of fossiliferous, bioturbated limestone, and thrombolitic and stromatolitic lime boundstone mounds overlain by undulose, wavy to lenticular and flaser bedded, thin-bedded dolomitic lime mudstone commonly capped by dolostone, dololaminite and dolomitic lime mudstone displaying mudcracks, intraformational breccias and tepees, amongst other subaerial structures. The character of this undolomitized succession is best examined along the Eddies Cove West shoreline exposures north of Port au Choix on the Port Saunders map area (Knight, 1991).

Stratiform collapse breccias occur extensively in the basal beds of the unnamed member and can be examined along the middle riverine reaches of River of Ponds, just east of River of Ponds Lake. They are characterized by large and small angular dolostone blocks displaying a range of sedimentary structures as described above, set in a fine crystalline dolostone matrix. Beds of vuggy, salt-and-pepper-textured, sucrosic, dark-grey to black dolostone cut by white sparry dolomite veins (often called pseudobreccia) also occur locally. A deep drillhole, A-1, drilled underground at the Daniel's Harbour (zinc) Mine penetrates through a thick succession of dolostone of the Tremadocian succession; it also includes significant breccias and vein complexes suggesting that these may be widely developed throughout the map area.

The ***Barbace Cove Member*** is not well exposed in the map area but has been recognized along a southern branch of the Bateau Barrens resource road system, a few kilometres inland of the coastline north of Freshwater Cove; it is also noted at roadside outcrops near Northeast Pond and along new roads in the area south of the middle reaches of River of Ponds river. There it consists of metre-thick peritidal sequences of skeletal, bioturbated limestone, minor thrombolitic boundstone and laminated shaly and dolomitic limestone above a basal conglomerate. The latter consists of chert and dolostone pebbles and rare silicified fossils such as short, straight cephalopods set in a fine-grained matrix. The contact with the underlying lower unnamed member dolostone is locally exposed on the resource road where it exhibits a few 10s of cm of relief (Knight, 1985). Because these are the first limestone mapped in the St. George Group in the map area, it is likely the Barbace Cove Member is hidden in the lowest rocks of the overlying Catoche Formation elsewhere in the map area.

The **Catoche Formation** is a succession of dark-grey limestone capped by a unit of tan-grey-weathering, dark-grey sucrosic dolostone referred to as the Daniel's Harbour dolomite by Collins and Smith (1975) and "diagenetic dolostone" by Knight (1978, 1991). The sucrosic dolostone unit is host to the numerous ore bodies of the Daniel's Harbour (zinc) Mine; it is well exposed throughout the map area and is intersected in numerous exploration drillholes, although it appears to be less well developed locally as it is traced to the southeast.

The succession is about 160 m thick with the dolostone at the top up to 45 m thick. The dark-grey, rubbly-weathering limestone, up to 133 m thick in a drillhole, west of Flat Pond (US Borax, 1978), consists of thick beds of lime wackestone to packstone, characterized by dolomite burrow mottling, chert rich horizons, and abundant fossils that include trilobites, gastropods, cephalopods, brachiopods, sponges and ostracods. Stacked complexes, as well as scattered horizons, of large, thrombolitic-sponge boundstone mounds, some of which have elongated canoe shaped forms that suggest fashioning by bottom currents on the Catoche shelf, occur spaced throughout the limestone. Grainstone also occurs in the limestone.

The well-bedded Daniel's Harbour dolomite consists of decimetre to metre-thick beds of fine, burrow-mottled dolostone displaying ghost of fossils and cut by thin, white dolospar veins, alternating with beds of sucrosic, medium crystalline, dark-grey dolostone rich in spar-filled vugs, burrow-mottle replacement and inclined to horizontal white, sparry dolomite veins with local breccia-like fabrics, known popularly as pseudobreccia. The unit generally ranges from 35 to 45 m thick in drillcore logs and in sections near Port au Choix (Knight *et al.,* 2007). Distinctive burrowed beds define marker beds, such as the "worm's marker". Many core logs, especially in the southeast of the area but also locally elsewhere, indicate that dolostone and pseudobreccia beds intercalate with limestone. The intensity of pseudobreccia development also ranges from incipient to strong from section to section and vertically in the unit. Pseudobreccia beds decline in importance towards the north of the map area passing into the fine burrowed and fossiliferous dolostone alternating with medium-crystalline, sucrosic dolostone with burrow and vuggy fabrics outlined by millimetre-thick, white dolospar druse. The sucrosic beds replace grainy limestone in the Port au Choix area where bituminous residues in porosity suggests hydrocarbons were once hosted by the dolomitized unit (Baker and Knight, 1993; Cooper *et al.,* 2001; Knight *et al.,* 2007). The petrology, diagenesis, geochemistry, and isotopic character of the dolostone unit has been extensively studied by Lane (1994), Azomani (2012) and Azomani *et al.* (2013).

The overlying **Aguathuna Formation** is a succession, about 74- to 80-m-thick, consisting of two unnamed members separated by the **St. George Unconformity** (Knight *et al.*, 1991). The ***lower member*** consists of a succession of cyclic peritidal metre-scale sequences, some of which were shown by their sedimentary architecture to deepen upward (Lane, 1990). The sequences consist of burrow-mottled, patterned and laminated, white to light grey to blue grey, finely crystalline to microcrystalline dolostone intercalated with beds of light green-grey dolomitic shale and shaly dolostone as well as a rare bed of stromatolitic dolostone. Chert nodules are common, as are beds and bedding surfaces encrusted by white to light coloured chalcedonic chert interpreted as fossil silicrete. Fossils are rare but do include spired gastropods, graptolites and conodonts. The type section of the formation occurs along the shores of Freshwater Cove, just north of Table Point (Knight and James, 1987, 1988), a section that in recent years has been largely covered by seaweed. A marker unit of dark-grey burrow-mottled dolostone 14 to 16 m thick, called the "dark grey dolomite" in the drillholes throughout the area occurs at the base of the formation. Locally it rests upon a grey limestone bed in some drillholes and in the coastal section north of Table Point at Freshwater Cove (suggesting that it might be better placed in top of the Catoche Formation than in the base of the Aguathuna Formation). Several stratiform beds of dolostone breccia (matrix breccia), some showing demonstrable evidence of ceiling collapse, also occur in the lower part of the formation and are visible in the coastal section north of Table Point. A number of distinctively burrow-mottled multicoloured dolostones and dololaminites underlie the topmost beds of the member, and were shown by Lane (1990) as part of an interval that thickened into actively subsiding local depo-centres (doline depressions; Lane, 1990; Knight *et al.*, 1991), related to penecontemporaneous subsurface dissolution and local tectonism.

The **St. George Unconformity** occurs about 15 m from the top of the formation, where it is a cryptic, essentially conformable erosional surface developed on brecciated dolostone and overlain by laminated dolomitic shale. The overlying ***upper member*** of the Aguathuna Formation is a cyclic succession of peritidal mottled dolostone and laminated and mudcracked, argillaceous dolostone and shale below the base of the Table Point Formation; the peritidal cycles of the member contain thin beds and lenses of chert and dolostone pebbles and sand. Regional studies indicate that the unconformity has significant relief of many tens of metres over long distances and is associated with a significant array of sediment-filled fractures, and sub-surface breccias (that range from crackle or fracture breccia to collapse matrix breccias), commonly associated with northeast-trending faults and fractures (Lane, 1984; Sangster, 1988; Knight *et al.*, 1991, 2007; Leach and Sangster, 1993). Microbreccia, chert sand and pebbles, and dolostone-silt filled vertical and inclined fractures, penetrate down from the unconformity to the Catoche Formation limestone, 160 to 200 m below the St. George Unconformity (Knight *et al.*, 2007).

The unconformity with its associated breccias is co-eval with the Knox Unconformity that occurs in the Beekmantown, Ellenburger and Arbuckle groups in Québec through to west Texas and into the Great Basin (Kerans, 1988, 1989; Lynch and Al-Shaieb, 1991; Leach and Sangster, 1993; Cooper and Keller, 2001).

FORELAND BASIN ROCKS

The foreland basin succession, approximately 300 to 500 m thick, consists of the Table Head and Goose Tickle groups. It is a thick, variable succession that reflects basin deepening, and the transition from carbonate shelf to clastic flysch sedimentation as the influence of Taconic orogenesis migrated across Newfoundland's Laurentian margin and the Anticosti foreland basin, evolved above the foundered early Paleozoic shallow-water platform/shelf.

TABLE HEAD GROUP

The Table Head Group is a succession of dark-grey limestone and shale, the deposits of a foreland basin shelf as sea level rose over the foundered karst landscape of the St. George Unconformity. In the map area, it comprises two formations; the Table Point and Table Cove formations (Stenzel *et al.*, 1990). A distinctive unit of cyclic, fenestral, off-white limestone, the Spring Inlet Member, occurs at the base of the Table Point Formation; both, the member and formation are pervasively dolomitized locally in the map areas. A third formation, the Cape Cormorant

Formation, is not present in the area. The group is overlain by a succession of dominantly clastic flyschoid rocks of the American Tickle Formation, Goose Tickle Group that also includes thick lenticular bodies of limestone breccia derived from the Table Head Group. The breccias were correlated with the Cape Cormorant Formation in earlier studies (Klappa *et al.*, 1980) but are now recognized as lensoid limestone conglomerate bodies delineated as the Daniels Harbour Member randomly dispersed stratigraphically in the flysch from place to place in western Newfoundland (Stenzel *et al.*, 1990; Quinn, 1993).

The **Table Point Formation** comprises two members, the basal Spring Inlet Member and an overlying, unnamed member of dark-grey to grey, thick-bedded, rubbly-weathering, fossiliferous limestone, with scattered beds of argillaceous, stylonodular, dolomitic limestone having well-preserved fossils. The type section of the formation at Table Point is about 250 m thick (Stenzel *et al.* 1990). This thickness is maintained throughout the map area in drillcores and contrasts to the much thinner 120-m thick succession to the north of the map area at Port au Choix.

In the map area, the **Spring Inlet Member** consists of two peritidal facies associations, a lower cyclic facies not present everywhere and a succession of fenestral limestone. The lower facies association is rarely more than several metres thick and consists of grey, stylonodular, fossiliferous and bioturbated fine-grained limestone alternating with buff-weathering dolostone, laminated dolomitic limestone and clean limestone; the laminites display mudcracks. The facies is exposed at the base of the formation at Table Point where it includes a few metres of dolomitized carbonate, the member lying paraconformably upon the dolostone of the upper member of the Aguathuna Formation. Pratt (1979) described a horizon of *Trypanites* borings and other bioturbation in this dolostone and interpreted it as a possible hardground and disconformity. Comparison of the contact in sections at Port au Choix and Table Point suggested to Knight (1991) that the Aguathuna–Spring Inlet contact represented a dolomitization front rather than a disconformity.

The fenestral limestone association consists of metre-scale cycles of pale-yellow-weathering, off-white, peloidal and fossiliferous limestone rich in fenestrae and stromatactis-like vugs that alternate with laminated and fenestral-rich lime mudstone. Fenestrae range from laminar to tubular; they are occluded by clear and white calcite spar. Vugs are lined by geopetal mud laminae and by pendant cements and druse linings of clear spar (*see* Knight, 1991). Ostracods are common in the fenestral association.

The fenestral fabrics are readily recognized in light coloured, vuggy dolostones that replace the member. The thickness varies from section to section and is easily recognized in drillcore logs; it ranges up to 50 m thick where it is best seen along a woods road that transects the wooded hills south of the Daniel's Harbour mine site.

The upper unnamed member of the formation consists predominantly of fossil-poor to fossil-rich, burrowed, stylonodular to pseudo-brecciated limestone. It also includes crossbedded lime grainstone, lithistid-sponge-oncolitic biostromal to biohermal mounds, horizons of soft-sediment slumping and rotated bedding, and bedding planes of chert nodules (Stenzel *et al.*, 1990). Fossils include trilobites, brachiopods, ostracods, echinoids, spiral and coiled gastropods, cephalopods, sponges, graptolites, radiolaria and conodonts (Ross and James, 1987). A significant thick fossil rich biostrom that hosts bryozoa as well as very large gastropods and straight cephalopods marks the top of the unit at Table Point, where it is conformably overlain by the limestone and shale of the Table Cove Formation.

The **Table Cove Formation** is generally well developed throughout the map area where its thickness ranges from a few metres to 42 m in drillcores inland, to as much as 75 to 150 m at Table Point and Spudgels Cove, respectively (Stenzel *et al.*, 1990). The lower 21 to 90 m in these coastal sections consists of stylo-thin bedded, bioturbated and fossiliferous limestone that are frequently deformed by slump folds and slides. It gives way upward to planar thin bedded, lime mudstone and shale. Slump folds, slump/slide scars and slump breccias occur throughout the section at Table Point and Spudgels Cove, but have not been recognized inland where the strata appears to be thinner. Graptolites, trilobites and brachiopods amongst other fossils occur in the formation (Ross and James, 1987). The formation is conformably overlain by the Black Cove Formation.

GOOSE TICKLE GROUP

The Goose Tickle Group is a succession of shale and turbiditic sandstone laid down in the eastern part of the Anticosti Basin overlying conformably to paraconformably upon the Table Head Group in the map area. The group comprises the Black Cove and American Tickle formations and also includes large lensoid bodies of carbonate breccia, conglomerate and calcarenite of the Daniels Harbour Member (Stenzel *et al.*, 1990; Quinn, 1993).

The **Black Cove Formation** is a succession of black to dark grey, laminated shale and laminae of green-grey siltstone that increase in number towards the conformable top of the formation; it is also fossiliferous containing a fauna similar to that of the Table Cove Formation. The formation is well exposed at coastal sections south of Table Point and at Spudgels Cove but is rarely seen inland or recorded in drillhole logs, likely because it was not separated from the American Tickle Formation. It is approximately 20 m thick. Hydrocarbon studies of the Anticosti Basin indicate that the shale is a likely source rock, although gas prone with total organic content (TOC) values of up to 4% (Fowler *et al.*, 1995).

The **American Tickle Formation** is a succession of shale, siltstone, sandstone and pebbly sandstone, thin dolomitic limestone and thick limestone breccia (Daniels Harbour Member). Like the Black Cove Formation, it is best exposed along the shoreline south of Table Point and Spudgels Cove and also outcrops along the shore, south of the estuary of Portland Creek. It is mapped inland near Bellburns Pond and Brian's Pond as well as north and south of Portland Creek Pond, especially along Southwest Feeder. In much of this area, the formation is poorly exposed and largely hidden beneath expansive bogland and Quaternary gravels. A log of drillhole PC-3-70 (NALCO, 1971), east of Southwest Feeder shows siliciclastic flysch overlying carbonate and shale, most probably the Table Cove and Black Cove formations.

A wave-cut rock pavement at Table Cove provides the best exposure of the American Tickle Formation broadly folded in a gently, southward plunging syncline; the incomplete succession likely measures in excess of 60 m. It consists largely of metre-thick sequences of shale and thin turbidites, alternating with metre-thick sequences of medium-bedded turbidites and lesser shale; complete and partial Bouma sequences are common. However, the highest beds in the section include thick-bedded sandstone and pebbly sandstone suggesting the area is the locus of a prograding channel and fan lobe system. South of Portland Creek Pond, where the succession overlies the Daniels Harbour Member, the succession continues as repetitive intervals of thin-bedded and medium-bedded turbidite and shale with some thick-bedded sandstone; the thickness of the succession is unknown but likely exceeds several hundred metres.

The succession culminates in thick-bedded sandstone and pebbly sandstone that makes up Portland Hill just east of "The Arches"; the centimetre-size pebbles in the sandstone include limestone and chert of Cow Head Group affinity. This succession on the hill sits structurally below and west of the first strata that demonstrably belong to the Cow Head Group. Dolomitized limestone breccias and calcarenites below this clastic succession at The Arches Provincial Park are interpreted as dolomitized Daniels Harbour Member. This clastic flysch succession and the dolomitized carbonate is therefore interpreted to belong to the autochthonous/parautochthonous foreland basin succession rather than part of the allochthonous Lower Head Formation carried in structurally low, frontal slices of the Cow Head Allochthon (Cawood *et al.*, 1987; Williams and Cawood, 1989; *see* discussion below).

The **Daniels Harbour Member** limestone breccia is well exposed at Daniel's Harbour (type section) and Eastern Head, a prominent headland just northwest of Portland Creek estuary. It is also exposed on the large island in Portland Creek Pond. In the north of the map area, the member is exposed along the northwest shore of the large island in outer River of Ponds Lake as well as locally along the southern and northern shore of the same lake. The major exposures south of Daniel's Harbour occur intercalated in American Tickle Formation flyschoid rocks. However, at River of Ponds Lake, the member sits erosionally upon the top of the Table Point Formation as it also does in the section at Gargamelle Cove, Port au Choix, some 40 km to the north (Knight, 1991) and in the Portland Creek Pond Thrust Slice, just north of Southwest Feeder.

The member also occurs at The Arches Provincial Park where it is dolomitized. This shoreline outcrop (known for a petroliferous odour) has been placed in the Cow Head Allochthon on earlier maps (Cawood *et al.*, 1987; Williams and Cawood, 1989). However, it occurs sandwiched in Goose Tickle Group flysch and has clast types and a stratigraphy very similar to the undolomitized limestone breccia and grainstone at the top of the member, outcropping on the beach just east of Eastern Head where it is mapped in this study and by others (Cawood *et al.*, 1978; Williams and Cawood, 1989) as part of the Daniels Harbour Member. No bedding discordance occurs between the Eastern Head outcrop, north of the mouth of Portland Creek, and flyschoid outcrops south of the river suggesting that they belong to a concordant succession.

The member comprises limestone breccia up to tens of metres thick of limestone clasts, some as large as small houses, but mostly in the range of a few centimetres or so, set in a fine-grained limestone and argillaceous limestone matrix. Many of the limestone blocks are readily identified as part of the Table Point and Table Cove formations and show deformed margins indicating they were still unconsolidated but competent during the deposition of the debrites.

White and grey mottled limestone, lithistid sponges and *Lepidopanis* also occur as scattered clasts, as do clasts and metre-scale blocks of bedded conglomerate and calcarenite, clearly cannibalized by erosion or collapse of previously deposited, penecontemporaneous conglomerate deposits of the unit; the latter occur especially in the Eastern Head section. Bedded calcarenites, calcisiltites and siliciclastic flysch overlie the conglomerate at a beach, just east of Eastern Head near the mouth of Portland Creek. Based on the similarity of the succession at the Eastern Head beach to that at The Arches west of Portland Hill and the lack of any definitive or subtle structural bedding discordance, the dolomitized carbonate conglomerate overlain by calcarenite and siliclastic flysch at The Arches is correlated here with the top of the Daniels Harbour Member at Eastern Head. The significant difference in the stratigraphic thickness of the Eastern Head and The Arches sections is not unusual in western Newfoundland, where multibedded outcrops of decimetre-thick Daniels Harbour Member rapidly thin laterally to singularly thin metre-thick deposits within a few kilometres as for instance Port au Port Peninsula (I. Knight, unpublished observations, 1996), the Phillips Brook and North Brook anticlines north of Stephenville (Knight and Boyce, 2000, 2002), and areas of Pistolet and Hare Bay on the GNP (Knight, 1980, 1986).

The breccias were derived from submarine erosion or collapse of once buried Table Head Group uplifted along active faults within the Anticosti Basin in response to the advancing Taconic Allochthon (Stenzel *et al.*, 1990; Quinn, 1993). The presence of large blocks of limestone conglomerate and calcarenite in the Eastern Head breccia suggests that this process was multi-staged and locally resulted in reworking of the rudites. The deposits at Eastern Head also suggest that the collapse was on a huge scale in this area as proposed by Cawood *et al.* (1987), but the general lack of bedding precludes a positive understanding of both the thickness and the structural attitude of the member. The only bedded strata in the area occurs east of Eastern Head where calcarenite and calcisiltite overlie the conglomerate, and indicate that the strata there strikes and dips east and south, respectively. However, in contrast north of Eastern Head, the breccia occupies a number of headlands, large and small, along the shore north to Daniel's Harbour. The attitude of blocks in the conglomerate and other potential bedding surfaces at these headlands suggest a west-dipping succession implying Eastern Head is the culmination of a southward plunging anticline. The terrain inland of the limestone headlands is low lying and marshy so is interpreted to be underlain by flyschoid rocks as are marshes farther inland in the map area. Projecting the breccia at Eastern Head to the bedded breccia rocks on the island in Portland Creek Pond also suggests the Daniels Harbour Member is folded in a south-plunging syncline beneath the western end of the pond. Bedding attitudes therefore correspond with bedding in the American Tickle Formation flysch on the northern shores of Portland Creek Pond and support an autochthonous foreland basin setting for the deposit(s) not an allochthonous one as interpreted by Cawood *et al.* (1987).

HUMBER ARM ALLOCHTHON

The map area contains the northern limit of the Humber Arm Allochthon where it is believed to sit, at depth, structurally upon the autochthonous succession described above. The allochthonous succession, essentially time equivalent of the shelf carbonates of the Port au Port and St. George groups and the foreland basin shelf carbonates of the Table Head Group, is preserved in a series of thrust slices in the allochthon. Thick carbonate conglomerate associated with lime grainstone, thin-bedded ribbon limestone and thin-bedded ribbon limestone and shale, marks the westernmost, frontal thrust slices of the Cow Head Group. This conglomeratic succession is included in the Shallow Bay Formation, is subdivided into several members (not discussed here), and is interpreted as the proximal slope deposits of the ancient margin (James and Stevens, 1986; James *et al.*, 1989). Traced eastward farther into the hinterland, thrust slices just west of the Long Range Massif are dominated by shale and mudstone, lesser mostly fine-grained carbonate and some sandstone of flyschoid aspect. This distal shelf edge basinal succession is assigned to the Green Point Formation (James and Stevens, 1986; James *et al.*, 1989); it includes several members not discussed here.

The mapping reflects data collected by GSNL in the area coupled with earlier map relationships and data points on the Portland Creek map of Cawood *et al.* (1987). The Cow Head Group conglomerate outcrops along a resource road that branches from Route 430 (the Viking Highway) just east of Portland Creek village and crosses a wooded ridge east of Portland Hill. The conglomerate is underlain by a faulted and folded succession of black to green shale intercalated with medium beds of yellow-weathering, massive to thin bedded, and laminated dolostone exposed in a quarry at the foot of the ridge. The interbedded shale and dolostone compares lithologically to the succession at Lobster Cove Head near Rocky Harbour designated the Lobster Cove Member of the Green Point Formation by James *et al.* (1987). There, the member is interpreted as a large raft of late Ibexian to early Whiterockian deepwater off-shelf strata within the Rocky Harbour Mélange (James *et al.*, 1987, 1988). Recently, Reusch and Waldron (2015) informally called the shale and dolostone, the Yellow Point formation, and suggested that the dolostone beds are linked to weathering of Taconic ophiolites, are deposits of the foreland basin, and are unrelated to the Cow Head Group.

No contact is exposed along the woods road between the shale–dolostone succession and the structurally higher limestone conglomerate unit east of Portland Hill. Whether the contact is structural or stratigraphic is difficult to assess although the former is preferred. This is because the limestone conglomerate interval, although not yet dated, consists of stacked conglomerate, many tens of metres thick, comparable to conglomerate low in the Cow Head Group and dissimilar from the poorly sorted and chaotic megaconglomerate intercalated with shale and thick-bedded dolostone marking the upper part of the Cow Head Group (*see* James and Stevens, 1988; James *et al.*, 1987, 1988). The megaconglomerate likely relates to pulses of margin collapse and local uplift initiated during the Taconic destruction of the ancient Laurentian shelf margin; their association with thick beds of dolostone support their correlation with the Lobster Cove Member. This evidence, plus that presented earlier, that dolomitized carbonate conglomerate at The Arches and the overlying clastic flysch of Portland Hill belong to the American Tickle Formation of the autochthon, rather than the Cow Head Group. This suggests that the Cow Head Group limestone conglomerate succession is in thrust contact with underlying Lobster Cove Member shale–dolostone interval, which, in turn, is juxtaposed structurally against coarse-grained, massive-bedded clastic rocks of the autochthonous foreland basin succession. Joint surfaces cutting the dolostone are veined by dry black oil stain and by blackened calcite spar suggesting hydrocarbon migration followed structural emplacement.

If the shale–dolostone interval is indeed the Lobster Cove Member, then it suggests it is widespread in the western Newfoundland allochthon. In the Portland Creek map area, the thrust contact with the Goose Tickle Group sandstone of Portland Hill is projected to lie in the low saddle between Portland Hill and the quarry and is projected south of the hill. In this interpretation the leading edge of the allochthon is placed at this thrust and not west of Portland Hill near The Arches as shown on the regional map of Cawood *et al.* (1987) and Williams and Cawood (1989) (*see* discussion of Daniels Harbour Member, Goose Tickle Group).

Extensive water-strewn bogs blanket the allochthonous shale and flyschoid rock over much of the map areas, hence tracing thrust faults and lithological contacts can be difficult and arbitrary. However, because the Cow Head Group limestone conglomerate units form upstanding linear ridges, they can be readily traced north–south across the map area. Locally, finer grained siliciclastic rocks occur below moss-covered, wave-cut benches; flyschoid rocks of the Lower Head Formation in the lowlands are generally folded reflecting their structural position in the footwall to the major thrust faults/slices. Details of the terrain are given in Cawood *et al.* (1988).

STRUCTURE

Structural domains in the map area include the lower Paleozoic autochthonous (perhaps parautochthonous) shelf in the north and northwest (Bellburns and Portland Creek map areas), the Taconic allochthon in the south (Portland Creek and Indian Lookout map areas), a narrow domain of thrust slices that include both shelf sequence and allochthon rocks west of the Proterozoic Long Range Massif (Bellburns, Portland Creek and Indian Lookout map areas) and the Proterozoic Long Range Massif bounded by the Long Range Thrust along it western edge (Bellburns, Portland Creek and Indian Lookout map areas). Only the Long Range Thrust, the lower Paleozoic autochthonous shelf domain, and the narrow thrust domain fringing the Long Range Massif, are discussed here.

The Long Range Thrust – The Long Range Thrust bounds the western edge of the Long Range Massif (Cawood *et al.*, 1987) and in the map area is commonly associated with a prominent scarp and increase in topographic elevation; it is not exposed in the map areas. It is traced from a valley immediately east of Blue Mountain along the western edge of the massif as far south as Deer Arm in Bonne Bay, Gros Morne National Park (Williams and Cawood, 1989; Knight, 2016); north of Blue Mountain, the thrust is projected to strike northeast across the massif towards the Hatters Pond, Chimney Arm and other faults in the northwest of Canada Bay (Knight, 1987). The thrust gently meanders southwestward from Blue Mountain to just east of Inner Brian's Pond, where it is offset by a number of dextral steps that project the thrust several kilometres to the northwest. The steps are likely associated with high-angle dextral, transfer faults. Dextral faults may also occur near Portland Creek Pond, southwest of which, the thrust follows a prominent arcuate trace south to Parsons Pond, mimicked by the trace of the Portland Creek Pond Thrust Slice (PCPTS), a few kilometres to the west; northwest-trending transfer faults in the south of the PCPTS are sinistral.

Lower Paleozoic autochthonous domain – The lower Paleozoic autochthonous domain is at its narrowest on the north shore of Portland Creek Pond and widens, as it is traced north, to occupy most of the northern limit of the Bellburns map area. The domain is dissected by several north- to northeast-trending high-angle faults as a well as a suite of east–west faults in the vicinity of Eastern Blue Pond. Rocks in the domain are generally gently dipping, younging overall in a south to southwestward direction, although dips commonly steepen close to high-angle faults.

The domain is bounded in the west by the west-verging Bateau Cove Fault that is exposed along the coastline, north of Table Point, from Deer Cove to Bateau Cove. The steeply east-dipping to subvertical Bateau Cove Fault, itself a narrow zone of closely spaced faults, juxtaposes strata of the St. George Group in its eastern hangingwall against footwall limestone of the Table Point Formation exposed at low tide. Bodies of collapse matrix breccia are recognized along with different formations of the St. George Group, all ubiquitously dolomitized within the fault zone (Knight, 1985; Knight *et al.*, 1991). Minor folds deform the footwall Table Point Formation limestone, the folds trending almost parallel to oblique to the main fault, hinting at both reverse and dextral movement on different fault strands along the fault zone and perhaps suggesting oblique slip (*see* Knight, 1985); no slickensides were observed. The maximum vertical displacement estimated on the Bateau Cove Fault is approximately 350 to 400 m.

East of the Bateau Cove Fault, the St. George and Table Head groups are broadly folded in a doubly plunging, northeast trending domal anticline that is offset by several northeast-trending faults in the southwest. It is bounded to the east by the north-trending Bellburns Pond Fault that locally cuts across the axial trend of the anticline. The Belvans Cove Fault is one of the faults that offset and demarcate the western limb of the anticline south of Table Cove to Spudgels Cove. The fault mostly juxtaposes Table Head Formation to the east against synclinally folded, Black Cove and American Tickle formations (Goose Tickle Group) along the foreshore to the west; several southwest-plunging folds deform the footwall Goose Tickle Group at Table Cove. A wall of sucrosic dolostone, several metres wide that may include dolomitized Aguathuna Formation and Spring Inlet Member marks the hangingwall at Table Cove adjacent to footwall Black Cove Formation. Several southwest-plunging folds deform the footwall Goose Tickle Group at Table Cove. Traced south towards Spudgels Cove, bedding in the Table Point Formation steepens as it approaches the Belvans Cove Fault that lies just offshore; bodies of sucrosic and sparry dolomite locally replace limestone along the shoreline. Vertical displacement across the fault is likely only a few hundred metres.

The Bellburns Pond Fault is an east-verging, essentially north-trending, steep to probably near vertical, reverse fault where lower St. George and uppermost Port au Port group rocks to the west, override uppermost Table Head and basal Goose Tickle group rocks to the east. A maximum vertical displacement of at least 800 to 1000 m is likely. A series of doubly plunging, essentially north-trending anticlines mark the hangingwall of the fault in the vicinity of the Daniel's Harbour (zinc) mine; the anticlines are offset by several northeast-trending faults that merge with the Bellburns Pond Fault. The overall structural architecture of the large domal anticline, bounded by two major faults with opposing, outward polarity suggests that the western margin of the carbonate shelf terrain may represent a popup domain.

The Bellburns Pond Fault merges with the northeast-trending Killdevil Pond Fault just south of the southern join of the Bellburns and Portland Creek maps. The latter fault, which traverses the entire Bellburns map area as it diverges from the junction with the Bellburns Pond Fault, verges to the east and has a maximum downthrow to the southeast of about 500 to 600 m south of Cobos Pond.

The sense of vergence and downthrow reverses to the northwest across the Cobos Pond Fault, one of a number of northeast-trending faults diverging from the Killdevil Pond Fault. Vertical displacement varies between 200 and 350 m across this fault. Vertical displacement and vergence across several other northeast-trending faults transecting the Paleozoic carbonate in the area near Eastern Blue Pond, Flat Pond, Northeast Pond and Inner Brian's Pond is however variable. This perhaps reflects the interaction of these faults, which are related to the Bellburn Pond and

Killdevil Pond faults, with faults that verge and downthrow to the northwest in the immediate foreland to the Long Range basement massif, similar to the vergence of thrusts and reverse faults that mark the southeastern structural edge of the carbonate domain.

A few kilometres north of Cobos Pond and east of the Killdevil Pond Fault, rocks of the lower St. George Group are juxtaposed against Aguathuna Formation and Spring Inlet Member to the west. This relationship is not understood and may indicate wrongful identification of rock units as part of the lower rather than the upper St. George Group. Alternatively, the rock relationships may suggest the Killdevil Pond Fault is a scissors fault.

A suite of east–west trending faults cut the succession at the northern edge of the Bellburns map area west and north of Eastern Blue Pond. Vertical displacement across these faults is dominantly down to the north, varying from minor to a few hundred metres.

Thrust domain west of the Long Range Proterozoic massif – The thrust domain, west of the Long Range Proterozoic massif, is generally only a few kilometres wide throughout much of the map area south of Portland Creek Pond, where it was collectively named the Parsons Pond Thrust Slice (PPTS; Cawood *et al*., 1987; Grenier and Cawood, 1992). They showed the zone to extend almost continuously from the southern end of Western Blue Pond, on the Bellburns map area to south of St. Paul's Inlet on the St. Paul's Inlet map area (NTS 12H/13). In this mapping study, however, the PPTS is mapped as three separate narrow thrust slices that are not contiguous even though each one lies in the footwall of the Long Range Thrust and new names are proposed for the each thrust slice. One of these thrust slices (Western Blue Pond Thrust) occurs north of the Portland Creek Pond, where it is grouped with several west-vergent reverse faults including the Brian's Pond Fault, as part of a northward widening zone of compressional shortening that includes the Blue Mountain Thrust and Blue Pond Fault.

Sub-domain south of Portland Creek Pond – South of Portland Creek Pond, Paleozoic shelf rocks are carried over allochthonous strata in two non-contiguous thrust slices west of the Long Range Thrust. The newly named Portland Creek Pond Thrust Slice (PCPTS) occupies the centre of the Portland Creek map area and the redefined PPTS occurs in the south of the map area, continuing south to Parsons Pond and beyond; the use of the name PPTS is restricted to this southern thrust slice. The two thrust slices are separated from each other by a zone, a kilometre long, where Grenvillian crystalline basement is thrust over allochthonous Lower Head Formation along the Long Range Thrust.

Portland Creek Pond Thrust Slice – The PCPTS is a 12-km-long, westward curving, steeply westward dipping to inverted arcuate succession of Paleozoic shelf rocks south of Portland Creek Pond (*see* Portland Creek map area). The thrust slice pinches out against the Long Range Thrust in the southern half of the map area several kilometres north of Parsons Pond itself. Labrador to Table Head groups occupy the main part of the thrust slice, in contrast to only rocks of the Labrador Group occurring in the area of the southern pinch-out. A southwest trending, reverse fault separates the two parts implying uplift of the southern pinch-out.

The PCPTS hosts a full succession of lower Paleozoic shelf carbonate and clastic rocks, although basal Labrador Group and underlying Proterozoic basement are only known in subsurface at the base of drillhole PC-2-70 just northeast of Inner Long Pond (NALCO, 1971). Mapping of the stratigraphy, although much of the succession is pervasively dolomitized, is relatively straightforward and complete in the middle part of the thrust slice near Inner Long Pond, as, for example, along the entrenched river gorge of Southwest Feeder immediately west of the outflow from Inner Long Pond. The thrust slice overrides American Tickle Formation flysch in much of area north of the elbow bend of Southwest Feeder where it escapes the shelf sequence hangingwall and flows parallel to the northward trace of the thrust. The American Tickle Formation flysch is pinched out to the south of Southwest Feeder as the PCPTS overrides Cow Head Group and Lower Head Formation. Approaching the southern pinch out of the PCPTS, carbonate shelf rocks end abruptly against a northeast-trending, high-angle fault, south of which only sandstone of the Hawke Bay Formation overrides the allochthonous terrain.

North of Inner Long Pond, poor outcrop, dolomitization and intersection with a suite of late northwest and northeast trending faults obscure and offset the stratigraphy within the thrust slice. Consequently, the succession in the north of the thrust slice is not straightforward and contiguous with that to the south. For example, drillhole PC-1-70, 3 km north of Inner Long Pond, is dominated by Late Cambrian dolostone and shaly dolostone of the Petit Jardin Formation beneath a cover of Quaternary gravels. No St. George Group rocks appear to be present above the Petit

Jardin Formation, which is bounded to the southwest by a northwest-trending high-angle fault that separates it from the full carbonate succession described above. This drillhole is located topographically above and less than a kilometre from dolomitized Table Point Formation marking the northern edge of the PCPTS, implying a thrust contact likely occurs between the two units, a vertical throw of about 500 m. The Table Point Formation rocks are postulated to overthrust folded American Tickle Formation flysch south of the shore of Portland Creek Pond along the outer valley of Southwest Feeder (called Greavett Brook in this area on page 5 map, Government of Newfoundland and Labrador, 2007) as it flows north to Portland Creek Pond. Folded American Tickle Formation flysch itself is likely thrust over the eastern edge of the Cow Head Group just west of Southwest Feeder, the sole of the allochthonous Cow Head Group occurring just east of Portland Hill where the allochthon rests structurally upon east-dipping flysch assigned here to the American Tickle Formation (*see* earlier discussion of this relationship in the section on the allochthon). These relationships suggest that the leading edge of the PCPTS is probably an imbricate zone and that stratigraphic relationship in the hangingwall changes as the PCPTS is traced from northeast to southwest because the thrust slice is cut by northeast and northwest trending later faults. The structural relationships in the area therefore suggest that the shelf succession and the American Tickle Formation flysch of the PCPTS overthrusts the allochthon that, in turn, sits structurally upon the American Tickle Formation flysch at depth to the west.

Parsons Pond Thrust Slice (PPTS) – The Parsons Pond Thrust Slice in the footwall of the Long Range Thrust is host to Paleozoic shelf rocks that are thrust over allochthonous Lower Head Formation. They are a southward widening, yet narrow series of thrust slices that project beyond the southern edge of the Indian Lookout map sheet to the north shore of Parsons Pond on the next adjoining map area (NTS 12H/13); together they constitute the PPTS (*op. cit.*). Table Point Formation carbonates are intercalated both stratigraphically and structurally with limestone conglomerate of the Daniels Harbour Member (American Tickle Formation) at the northeast terminus of the thrust slice. Farther to the south, narrow slithers of Hawke Bay and March Point formations overlain by Port au Port Group dolostone occur beneath the Long Range Thrust and in turn overthrust St George Group and Table Point Formation carbonates.

Sub-domain north of Portland Creek Pond – The sub-domain north of Portland Creek Pond is structurally complex and widens northward from the pond. It is bounded to the west by the Brian's Pond Fault just north of Portland Creek Pond and the Blue Mountain Thrust and Blue Pond Fault at the north of the sub-domain. Strata in this zone ranges from complexly faulted and folded to largely undeformed, gentle to horizontal dipping strata overlying Proterozoic basement (Blue Mountain Thrust). The sub-domain also includes the long narrow Western Blue Pond Thrust Slice (WBPTS), just south of Western Blue Pond adjacent to the Long Range Thrust. The 20 km long thrust slice lies in the footwall to the Long Range Thrust from Inner Brian's Pond north to Western Blue Pond. It consists for most of its length of steeply northwest-dipping to overturned, westward younging strata from the upper Forteau and lower Hawke Bay formations that override to the west gently south to southwestward dipping strata of the Port au Port and St George groups. At its northeastern terminus at Western Blue Pond, the thrust slice is postulated to be emplaced above southeast dipping March Point Formation.

Complex structural relationships occur on the north shore of the east end of Portland Creek Pond. There, fault-bounded Table Cove and American Tickle formation rocks as well as grey shale and light grey, carbonate conglomerate assigned to the Cow Head Group appear to underlie Table Point Formation carbonate. This suggests a window of Cow Head Group allochthon and a faulted slice of Table Head and Goose Tickle Group rocks in this area. In addition, dolomitized shelf strata outcropping on an unnamed island at the east end of Portland Creek Pond about 1 km west of the PCPTS is also puzzling. It is host to a north-trending, steeply west-dipping succession of Aguathuna Formation overlain by dolomitized Spring Inlet Member and upper Table Point Formation (*see* Knight *et al.*, 1991). The porous dolostone is visually typical of that associated with dolomitized Table Point Formation carbonate in other structurally complicated areas of the GNP (Knight, personal observations, 1986 to 1988). The relationship of the strata on the island to that on the mainland may imply it is part of the footwall to the PCPTS and perhaps part of a lower structural thrust slice. Alternatively it may link to the main lower Paleozoic shelf succession outcropping north of Portland Creek Pond where it would structurally overlie American Tickle Formation flysch above a low-angle fault present at depth in the pond.

North of Portland Creek Pond, the sub-domain is projected north to the east shore of Brian's Pond where Table Point Formation limestone structurally overlies American Tickle Formation along the steep reverse Brian's Pond Fault. Westward-verging displacement is also distributed across several other northeast-trending high-angle faults such as the Flat Pond Fault in this area. The Brian's Pond Fault is offset sinistrally by a number of northwest-trending, high-angle faults that largely show normal displacement to the southwest.

A narrow thrust slice, the Western Blue Pond Thrust (WBPT) that is mapped for 20 km adjacent to the Long Range basement complex from Inner Brian's Pond north to Western Blue Pond forms the eastern edge of this subdomain. The WBPT consists only of steep, west-dipping to locally overturned strata of the upper part of the Labrador Group. It overthrusts south-dipping carbonate of the St. George and Port au Port groups south of Western Blue Pond, whereas its northeastern terminus places the slice above southeast dipping March Point Formation.

North of Western Blue Pond, the sub-domain terminates with two large uplifted blocks of Labrador Group associated with Proterozoic basement. The fault-bounded blocks are each about 5 to 10 km wide and long, and interpreted to be carried by the Blue Mountain Thrust and Blue Pond Fault that intersect with a suite of east–west trending reverse faults over a broad zone, at least 2.5 to 4 km wide in the Eastern Blue Pond area; north down displacement on these east–west faults varies from minor to as much as 200 to 300 m on the two faults that project to the western arm of Eastern Blue Pond and across the Blue Pond Fault.

Blue Mountain, a massive upland, 600-m high, similar in shape and geological structure to Gros Morne (Gros Morne National Park) consists of a mountain of essentially gently southward dipping Labrador Group rocks unconformably overlying Proterozoic basement. The bounding Blue Mountain Thrust that encloses the Blue Mountain block extends from just south of Western Blue Pond and projects as an arc to the west and then north of the mountain, just to south of Eastern Blue Pond; the fault then strikes northeastward into the Proterozoic basement massif (*see* above). Overall the Blue Mountain and Blue Pond faults trend in tandem and are essentially parallel to the northeast projected extension of the Long Range Thrust east of Blue Mountain.

Bedding in the hangingwall of the faults generally dips gently to the west and south although approaching the projected faults, it steepens to near the vertical suggesting frontal rollover to the west-northwest. Bedding also is steep in the immediate footwall that is also host to numerous minor folds. Labrador Group and underlying basement is faulted to the west and north against Port au Port Group and locally Labrador Group indicating a vertical displacement of about 300 to 400 m for each fault block. However, at the northwest corner of the Blue Mountain Thrust, Proterozoic basement abuts against uppermost Port au Port Group, a throw of about 800 m; this anomaly is likely coincidental rather than reflecting local complexity of the regional faulting in this area, and in general supports a thrust relationship across the fault.

North of the Blue Pond Fault, the succession consists of gently west dipping strata dissected by several north to northeast trending faults as well as a few east–west faults; the domain links to that mapped on the Port Saunders map area (Knight, 1991).

Discussion of the structure of the Bellburns, Portland Creek and Indian Lookout map areas – Cross sections illustrated by Cawood *et al.* (1987) provide a model for the structural style from east to west across the map area. Proterozoic basement in the east is structurally emplaced steeply above the various narrow thrust slices that comprise their Parsons Pond Thrust. The thrust slices are shown as essentially west-verging, reverse faults that displace westward-facing slivers of eastward rising lower Paleozoic autochthonous strata that plunge westward below the Cow Head Group and Lower Head Formation of the northern part of the Humber Arm Allochthon. The lower Paleozoic shelf and foreland basin strata beneath the allochthon and in the north in the vicinity of Daniel's Harbour is shown diagrammatically as a broad belt of essentially flat lying, although gently folded strata unconformable upon Proterozoic basement, the autochthon lying at a depth of 2 to 4 km below the surface.

The structural rock relationships described above here however, suggest that Proterozoic basement overrides both lower Paleozoic shelf and foreland basin rocks as well as locally the allochthonous domain along the Long Range Thrust. The lower Paleozoic shelf and foreland basin rocks lying below the Long Range Thrust also structurally overlie the allochthon suggesting that they are structurally high and unconnected to lower Paleozoic shelf rocks at depth beneath foreland basin flysch and Allochthon in the west of the Portland Creek map area. This suggests that the lower Paleozoic shelf rocks in the narrow thrust slices adjacent to the Long Range Proterozoic basement complex formed part of the hangingwall succession of the Long Range thrust, locally steepened to form a frontal roll that was ultimately overridden by the Proterozoic Long Range complex following basement break through along the Long Range Thrust. This breakthrough lead to the narrow thrust domain of disconnected thrust slices (from north to south, WBPT, PCPTS and PPTS) immediately west of the Proterozoic massif.

In contrast, the structure of the Cow Head Allochthon is shown by Cawood *et al.* (1987) as an imbricated stack of east-dipping, west-verging thrust slices that transport Taconic allochthon above the autochthon at depth; its thrust sole essentially conforms to the contact with the structurally underlying rocks of foreland basin flysch. Nowhere is this contact exposed to define its nature and none of the imbricate thrusts that internally shorten the allochthon are visible. However, a zone of east dipping, planar surfaces were noted in east dipping, thick massive, locally pebbly sandstone on the road east of Portland Hill. The sandstone is interpreted, here, to occupy the footwall to a thin slice of Lobster Cove Member, Green Point Formation, which marks the base of the allochthon in this area (*see* earlier discussion of the allochthon). This suggests a zone of bedding parallel shear marks the footwall flysch as the allochthon was emplaced in this area. Similar fabrics occur along the shores of Hare Bay where mélange overlies Goose Tickle flysch (Knight, unpublished observations). The imbrication of the transported shelf and basin margin rocks likely preceded the emplacement of the allochthon.

Recently however the transition from the northern margin of the Allochthon to the southern edge of the lower Paleozoic shelf succession at Portland Creek Pond and Daniel's Harbour, was interpreted differently (Figures 40 and 41, Waldron *et al.*, 2012). This interpretation combined previous regional mapping with magnetic anomaly patterns (first vertical derivative) over the allochthon to project the Parsons Pond Thrust northwestward away from the Portland Creek Pond Thrust of this report. The thrust crosses the Portland Creek lowlands into the offshore south of Eastern Head before turning northward in the offshore beyond Daniel's Harbour. The thrust follows the fault that separates American Tickle Formation flysch above Cow Head Group carbonates on the east side and north edge of the topographic ridge east of Portland Hill (*see* Portland Creek map and above discussion).

This interpretation of the regional geology implies that the lower Paleozoic shelf succession north of Portland Creek Pond is carried upon the same thrust or a blind thrust at depth in this area. Stratal evidence in support of this is suggested by the complex relationships of the PCPTS and small footwall windows of Cow Head Group rocks and American Tickle Formation flysch at the east end and north shore of Portland Creek Pond (*see* above). Additional geological evidence (unproven but plausible) includes juxtaposition of the Paleozoic shelf succession to the north against the thickened sequence of foreland basin flysch and Cow Head Allochthon to the south. The present day surface location of the Paleozoic shelf succession at the same level as allochthonous strata of the Cow Head Group, implies a vertical ascent of the cover sequence by over 2 km or more in this area, a relationship highlighted as potentially indicative of a thrust relationship by John Maher (Leprechaun Resources, pers. comm., 2008). The present geological relationship suggest that the thrusting and uplift of the lower Paleozoic shelf and foreland basin sequence post dated the emplacement and shortening of the Allochthon into and over the foreland basin.

Regional aeromagnetic maps of the Bellburns and Port Saunders map areas may also support this interpretation. A steep southwards decline in the total magnetic expression occurs across the area to the south and southwestward of the Port au Choix–River of Ponds area in the north to the area north of Portland Creek Pond in the south. Generally, gently dipping shelf strata occurs throughout this area. This would suggest that if relatively shallow Proterozoic basement underlies the shelf strata in the south it should maintain a fairly strong magnetic expression not the decline as described. Although lithological change in the underlying basement might also explain this southward decline of magnetic expression, it is plausible that that Proterozoic basement is at substantial depth in the south below a structurally thickened stack of sedimentary rocks that include repetition of the shelf and foreland basin sequence and elements of the Cow Head allochthon. This suggests that the shelf rocks in the Bellburns map area and north of River of Ponds in the Port Saunders map area are carried on a thrust fault(s) that occurs beneath the extensive bogs inland of or beneath Portland Creek Pond itself. Puzzling geological relationships in the poorly exposed River of Ponds area including north of River of Ponds Lake (Port Saunders map area) may also reflect unrecognized additional thrusts also in this area.

MINERALIZATION

The Bellburns map area is well known for the Daniel's Harbour (zinc) Mine, a complex of several underground and near surface (open pit) sphalerite deposits. The deposits were discovered in the 1960s by New Jersey Zinc/Cominco Ltd, and the mine opened in 1975 by Teck Corporation-Amax (Dearin, 1978a, b). It was shuttered in 1990 after producing 7.2 million tons of ore averaging approximately 8% Zn; cadmium was also significant.

Renewed exploration interest since the mine closure has included assessment files that discussed potential targeted exploration to find additional ore resources. This has been based on re-evaluation of existing Tech Corporation databases, drillhole logs, geophysical and geochemical surveys and some new drilling and field studies (Boliden, 2000; Messina, 2010; Ubique Minerals, 2015).

The geological setting and character of the Daniel's Harbour (MVT) deposit is detailed by Collins and Smith (1975) and Lane (1984, 1990). The ore bodies occur along a northeast fault-associated trend in dolostone of the upper Catoche Formation. They lie adjacent to large and small, oval to elongate bodies of matrix breccia that are interpreted as collapse breccias contemporaneous with the St. George Unconformity that occurs at or close to the top of the Aguathuna Formation in this area. The upper Catoche dolostone replaced coarsening and shallowing upward, metre-scale sequences of sparsely bioturbated, fossiliferous lime mudstone overlain by peloidal and fossiliferous lime packstone and grainstone that was pervasively bioturbated. Tight, finely crystalline dolostone marks the lower part of each sequence in contrast to medium to coarse crystalline, frequently porous and vuggy, sucrosic dolostone that marks the top of the sequences (Baker and Knight, 1993).

The dolostone is a regional, stratabound, stratiform deposit widely mapped on the GNP west of the leading edge of the Long Range Thrust and its accompanying narrow belt of frontal, carbonate platform-carrying thrusts in the Portland Creek and Bellburns areas as well as the leading edge of thrusted lower Paleozoic shelf rocks in the Hare Bay and Pistolet Bay area at the tip of the GNP (*see* King and Conliffe, 2017; Conliffe *et al.*, 2018). The dolostone is only economically mineralized in the Daniel's Harbour area, however. In the Port au Choix area, the same dolostone is tilted and gently deformed between major northeast trending reverse faults that are also the locus of fault-controlled hydrothermal dolomitization. Consequently, widespread porous and hydrothermal crystalline dolostone occurs in the Bellburns and Port au Choix area however affecting both the upper Catoche Formation as well as the basal Table Point Formation. Pyrobitumen and locally live oil in the porosity and local fractures suggested to Baker and Knight (1992) that the Port au Choix area represents an exhumed oil field (*see* also Cooper *et al.*, 2001).

The upper Catoche dolostone in the Daniel's Harbour area is characterized by widespread replacement, vug fillings and sheet-like often inclined white sparry dolomite vein systems (zebra dolomite). These occur in the upper beds of metre-scale sequences where remnants of dark Catoche dolostone is encased by later white sparry dolomite to suggest a brecciated fabric called pseudobreccia. It is the pseudobreccia beds that are associated with the zinc mineralization, in distinctive intervals within the 40 to 50 m Catoche dolostone (Lane, 1990; Leach and Sangster, 1993; *see* also Ubique Minerals, 2015). A total of 19 ore bodies occur in the mining district. They are generally northeast trending, narrow bodies that range from 9600 to 4.3 million tons grading 5 to 9% Zn. Although there is a significant areal exploration target in the greater mine area particularly down plunge of the matrix breccia and main ore bodies of the mine, deep drilling by both Tech and US Borax failed to discover additional reserves southwest of the mine.

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Kim Morgan digitally drafted the revised edition of the map; Neil Stapleton provided the latest base maps and modified existing geological maps to provide positioning data for the Daniel's Harbour (zinc) mine. Doug Boyce re-examined fossil samples and provided corroborating fossil data where samples were collected; they are also available on the provincial fossil database.

The map is dedicated to the memory of the late Dr. Tom Lane who dedicated more than two decades to the study and understanding of the host carbonate and its mineralization in the area of Daniel's Harbour while working at the Teck mine. He will be remembered for his insightful enthusiasm, gracious spirit, generous sharing of his knowledge and his ready laugh over the many years of this survey.

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