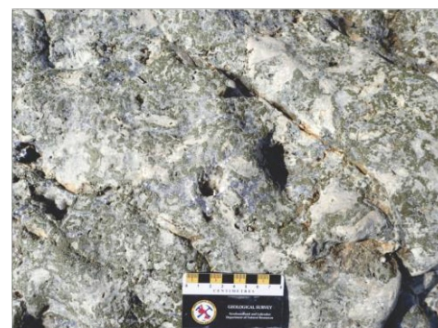


# GAC NL 2016 FALL FIELDTRIP

## GEOLOGY OF THE BAY OF ISLANDS AND PORT AU PORT PENINSULA, WESTERN NEWFOUNDLAND

SEPTEMBER 29TH TO OCTOBER 2ND, 2016



Open File NFLD/3321



**GAC**  
Newfoundland  
and Labrador

Larry Hicks and James Conliffe  
with contributions from Karen Waterman and Shawn Duquet



**Geological Association  
of Canada**



**Newfoundland and  
Labrador Section**

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**September 29<sup>th</sup> to October 2<sup>nd</sup>, 2015**

*Cover photos (clockwise from top): Aerial view of the Bay of Islands (Alana Hinchey), Galena and marcasite mineralization at Lead Cove (James Conliffe), Sea-level adit at York Harbour (Larry Hicks), Carboniferous and Ordovician strata at Lead Cove (James Conliffe)*



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## **INTRODUCTION AND OVERVIEW**

Western Newfoundland has had a huge influence on the development of Appalachian geology and the Humber Arm, one of several spectacular fjords that meet in the Bay of Islands, has given its name to the Humber Zone of the Appalachians (Williams 1979), representing the margin of the Laurentian continent, that can be traced along the full length of the Appalachians (Figure 1). This fieldtrip aims at providing a broad overview of the geology of Western Newfoundland, from the platform sequences laid down on the margins of Laurentia, ophiolite complexes and deep water sedimentary sequences that were subsequently thrust over this platform during the Taconic Orogen, and the late carboniferous sediments that were deposited in later Paleozoic Basins. It will cover many aspects of geology, including sedimentary, igneous, structural and economic geology and paleontology. We also aim to cover many of the social and historical impacts this varied geology has had on western Newfoundland, and discuss the possible future impacts geotourism and geoheritage may have on this region. Like many previous GAC-NL field trips, it is not our intention to present one interpretation as if it were fact, but rather to foster discussion about multiple possibilities and missing information that might be acquired through future work.

## **ACKNOWLEDGEMENTS**

The support of the Geological Survey of Newfoundland and Labrador and the Department of Natural Resources in terms of time and organization, support for participation, and assistance with vehicle support is gratefully acknowledged. Without this, such ventures could rarely happen.

The Department of Earth Sciences at Memorial University provided valuable subsidies to encourage student participation, which is an important aspect of these excursions.

The Alexander Murray Geological Club provided direct financial assistance to undergraduate student participants, which is greatly appreciated.

GAC-NL also wishes to acknowledge direct financial support for the 2016 trip from the Geoscience Education Trust of Newfoundland and Labrador (GET-NL), established from revenues accrued from National GAC-MAC meetings in 1988, 2001 and 2012. GET-NL previously operated under the name “St. John’s 88-01 Trust Fund” but has now been rebranded.

Captain Cook Cabins are thanked for providing accommodation in York Harbour. Editorial assistance from Chris Pereira with the final version of this field trip guide is greatly appreciated.

The fieldtrip guide is based on a number of previous fieldtrip guides, held in conjunction as part of the Western Newfoundland Oil and Gas Symposium and the 2012 GAC MAC meeting held in St Johns, and the co-authors on these guidebooks are acknowledged here.

## **SAFETY INFORMATION**

### **General Information**

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

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

Above all, field trip participants are responsible for acting in a manner that is safe for themselves and their co-participants. This responsibility includes using personal protective equipment (PPE) when necessary (when recommended by the field trip leader or upon personal identification of a hazard requiring PPE use). It also includes informing the field trip leaders of any matters of which they have knowledge that may affect their health and safety or that of co-participants. Field Trip participants should pay close attention to instructions from the trip leaders and GAC representatives at all field trip stops. Specific dangers and precautions will be reiterated at individual localities.

### **Specific Hazards**

Many of the sites we will visit require off-road walking across uneven and often wet terrain. Sturdy hiking boots, preferably with some ankle support, are therefore recommended for all stops. A walking pole may be useful for some participants.

Since many localities are on or near the coast, please keep away from cliff edges, and stay on the trails. Also be aware of slippery rock surfaces, especially those coated in black or green algae. Large waves are common all along the Newfoundland coastline, so be alert to these when examining outcrops close to the water's edge. Take care when descending to localities down small, rubble-covered slopes. Follow the instructions of trip leaders at all times, and stay with the group.



## GAC Newfoundland and Labrador Section – 2016 Fall Field Trip

Some of the fieldtrip stops are located in quarries or in areas of former mining activity (e.g. adits). Please do not go too close to faces of quarry walls or enter adits, these locations present a very real risk of falling rocks.

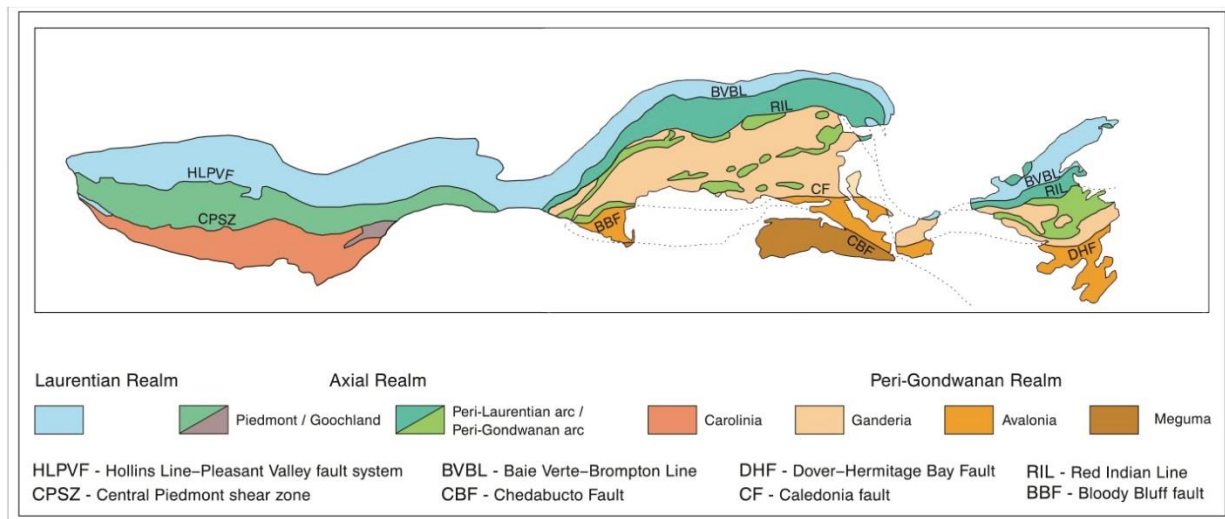
You have a responsibility to your fellow participants to behave in a safe manner. This is particularly relevant when hammering (though note that **HAMMERS ARE NOT PERMITTED ON SPECIFIED OUTCROPS, INCLUDING BLANCES BROOK PETRIFIED FOREST AND AT LEAD COVE**); if you must hammer an outcrop, please warn those near you prior to starting, and wear safety goggles.

Finally, more specific guidance about the hazards associated with particular stops will be provided later in the guidebook, under each stop description. These will be reiterated by the field trip leaders upon arrival at each locality. Field trip participants are advised to read these sections carefully, and to take necessary precautions to maintain both their own safety, and the safety of fellow participants.

## GEOLOGICAL OVERVIEW – WESTERN NEWFOUNDLAND

*This section is, in part, summarized from Waldron et al. (2012) and Hinchey et al. (2015). For more detailed discussions on the geology of western Newfoundland, please check the reference list.*

The Humber Zone is the westernmost of five tectonostratigraphic zones in the Canadian Appalachians (Williams, 1979), and its rocks record the evolution of the Laurentian margin from ca. 610 to 390 Ma (James et al., 1989; Stenzel et al., 1990; Cooper et al., 2001; Waldron and van Staal, 2001; van Staal, 2005).



**Figure 1:** Map of the Appalachian orogen, after Hibbard et al. (2006).

Within the Humber Zone, the least metamorphosed, western portion is distinguished as the **external Humber Zone**, while to the east; metamorphic rocks dominate the **internal Humber Zone**. Our focus during this fieldtrip will be the mainly sedimentary rocks of the external Humber Zone, within which several large-scale assemblages of rock can be recognized (Figure 2).

### *Grenville basement*

In the stratigraphically and structurally lowest position are Mesoproterozoic metamorphic and igneous rocks of the Grenville basement. These rocks record the assembly of an earlier supercontinent Rodinia at ~1 Ga during the Grenville orogeny and form the foundation on which the Laurentian margin was built.

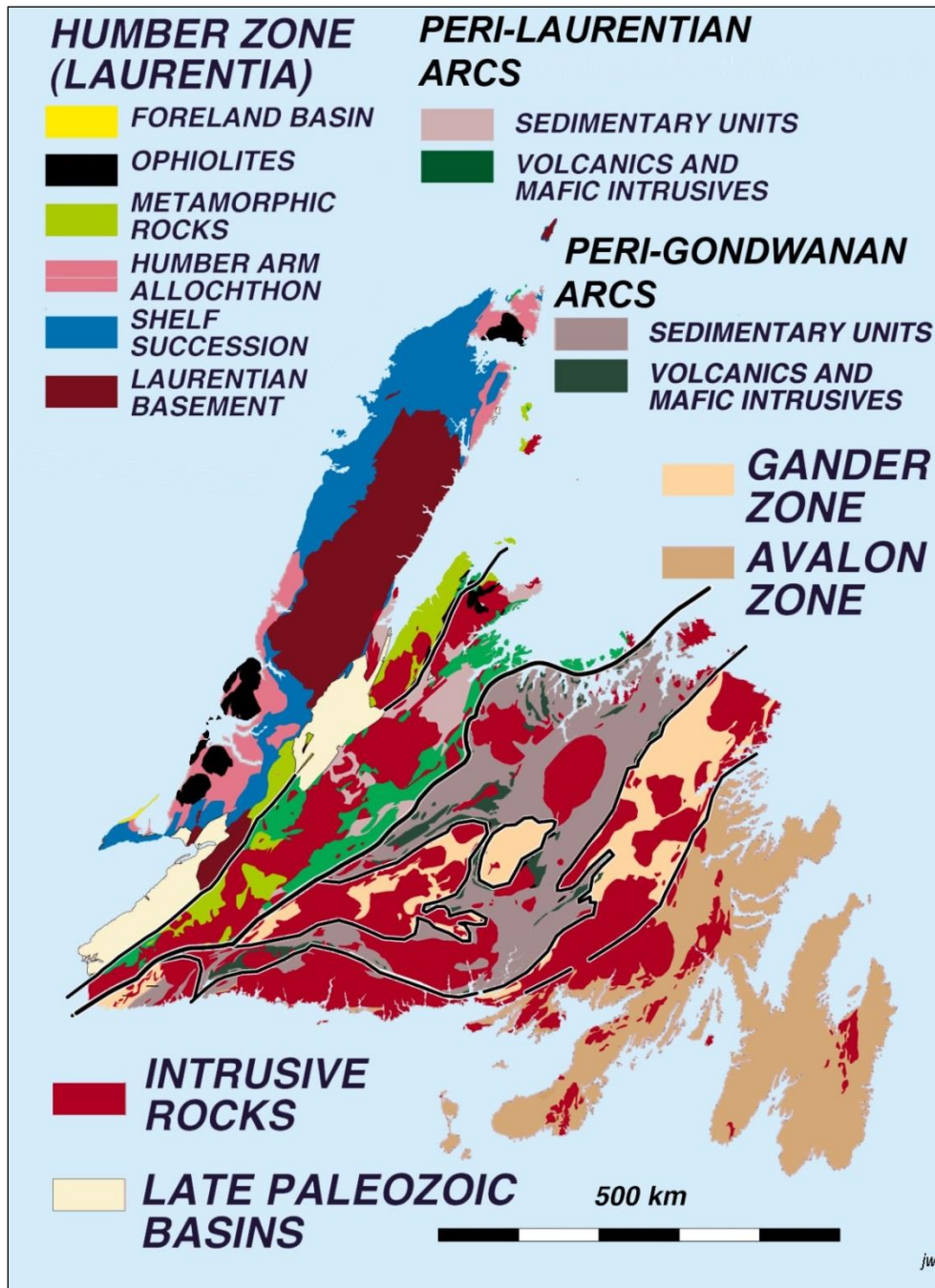


Figure 2: Summary geological map of Newfoundland, showing main tectonic units

*Laurentian margin rift and shelf succession*

These early successions were deposited on Grenville basement between latest Neoproterozoic (~610 Ma) and Early Ordovician (~470 Ma). Significant rifting, associated with the opening of the Iapetus Ocean, began during the late Proterozoic and early Cambrian (Waldron and van Staal, 2001) and is first recorded in Western Newfoundland by late Proterozoic, fault-bounded, terrestrial clastics and volcanics of the lower Labrador Group. These are unconformably overlain by clastic rocks of the late Cambrian, upper Labrador Group and a thick (~ 1.5 km) middle Cambrian to lower Ordovician carbonate platform succession (Port au Port and St. George groups), deposited on a passive margin to the south of Laurentia (James et al., 1989). The middle to late Cambrian Port au Port Group is a narrow, high-energy carbonate platform which evolved into a wide, low-energy carbonate platform represented by the early to middle Ordovician St. George Group (James et al., 1989). The St. George Group forms a sequence of subtidal and peritidal limestones and dolostones and is subdivided, in ascending order, into the Watts Bight, Boat Harbour, Catoche and Aguathuna Formations. It has been mapped throughout western Newfoundland (Knight and James, 1987) and is extensively dolomitized in many areas (Knight et al., 2007). A regional unconformity, the St. George Unconformity, marks the top of the St. George Group and a shift from a passive margin to a foreland basin at the beginning of the Taconic orogeny (Knight et al. 1991). Shallow to deep subtidal carbonates and shales of the Table Head Group were deposited in this foreland basin (Stenzel et al. 1990), and were subsequently buried by muddy flysch of the Goose Tickle Group (James et al., 1989).

*Humber Arm Allochthon (HAA)*

Contemporary with these predominantly shallow-water sedimentary rocks, deeper-water facies were deposited on the continental slope and rise. These units, together with ophiolitic rocks of the Bay of Islands and Little Port Complexes, representing oceanic island arcs that encroached on the margin from the southeast, comprise the Humber Arm Allochthon (HAA). Although they were undoubtedly formed well to the southeast of the Laurentian shelf, they are now found in a highly deformed state, tectonically emplaced above the shelf succession.

The deepwater sedimentary rocks of the HAA consist of Middle Cambrian to Middle Ordovician sediments which are considered to be the distal equivalents of the autochthonous rocks (James and Stevens, 1986). The Early Cambrian Curling Group, a sequence of deep water clastic turbidites which are equivalents of the Labrador Group (Palmer et al., 2001), occurs at the base of the HAA. It is overlain by the Middle Cambrian to Middle Ordovician sediments of the Cow Head and Northern Head groups (James and Stevens, 1986, Botsford, 1988). The Middle Ordovician Lower Head and Eagle Island formations unconformably overlie the Cow Head Group and were deposited in satellite basins during the early stages of a foreland basin development and Taconic deformation (Quinn, 1995).

*Late Paleozoic Maritimes Basin*

Overlying these deformed rocks of the Appalachians are non-marine clastic sedimentary rock, marine limestone, evaporites, and coal of Carboniferous (Missipian and Pennsylvanian age). These represent the fill of a large successor basin, the Maritimes basin which straddled the entire Appalachian orogen. In western Newfoundland there are two major Carboniferous sedimentary basins (the Deer Lake and Bay St. George basins) which occur along the trace of the southwest-trending wrench system of the Cabot Fault.

*Quaternary deposits*

In addition to the above units of consolidated rock, western Newfoundland displays a fascinating record of Quaternary history recorded by spectacular glacial valleys, raised beaches, glacial, and periglacial sediments. We will remark on these where their distribution affects bedrock outcrop and human history, but they will not be a major focus of our trip.

**Deformation of the rocks of Western Newfoundland**

Newfoundland's Appalachian mountain fold belt is distinguished by three major orogenic episodes: Taconic, Salinic and Acadian (van Staal and Barr, 2012). Subsequently the Alleghenian Orogeny resulted in brittle faulting of the Carboniferous basins, but the Appalachian fold belt in Newfoundland largely escaped the penetrative effects of this orogeny (van Staal and Barr, 2012). The effects of the three major orogenic deformation episodes are discussed below.

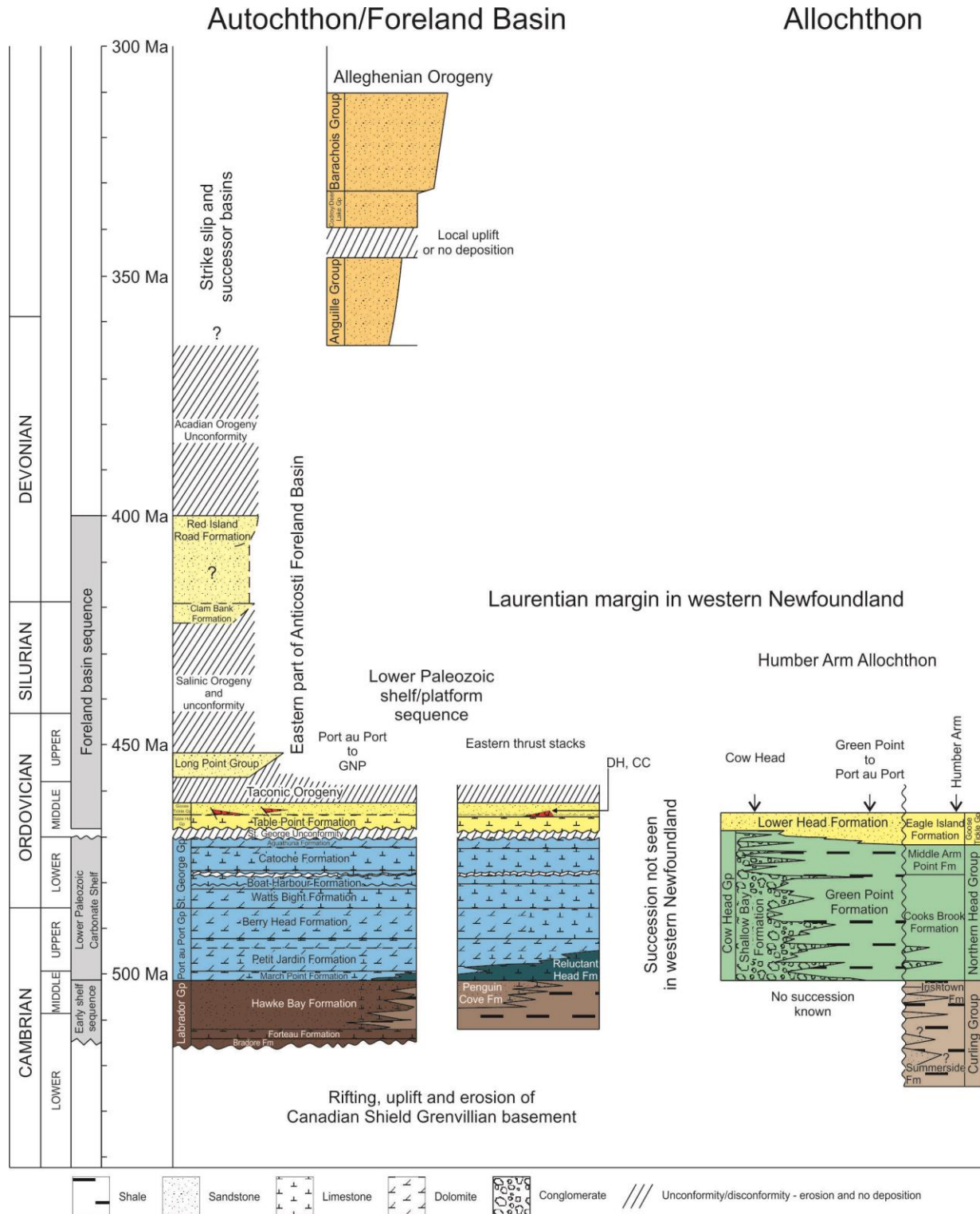
The Taconic Orogeny has a long history beginning in the Late Cambrian and culminating in the Late Ordovician (ca. 475 to 455 Ma), and the obduction of the Taconic allochthons of the deep sea floor and continental slope to their present position in western Newfoundland (van Staal, 2007; van Staal and Barr, 2012).

The orogeny influenced sedimentation in western Newfoundland from about 478 to 468 Ma, affecting the last deposits of the carbonate platform, and driving the development and infill of the first phase of the eastern Anticosti foreland basin. The deformation of the Taconic HAA occurred when the tectonic slices were transported to their present position off the Port au Port Peninsula to Parson's Pond. Mapping of the Cow Head Group and associated rocks north of Bonne Bay show the succession is assembled into a serial stack of imbricate thrust slices, each consisting of the Cow Head rocks overlain by Lower Head flysch (Williams and Cawood, 1989). The succession is polydeformed and ranges from gently dipping to overturned and is folded in many places. The rocks rimming the shores of Port au Port Bay are similarly deformed although mapping, to date, is only at a reconnaissance level (Cooper et al., 2001).

The Salinic Orogeny is Middle to Late Silurian (ca. 440–420 Ma). Deformation is best preserved in central Newfoundland (Van Staal and Barr, 2012); however, rocks in the western Newfoundland foreland basin and in the deformed shelf rocks near Corner Brook, Deer Lake and Canada Bay were also affected by this orogenic event.

The Acadian Orogeny of Middle to Late Devonian (ca. 393–360 Ma) is recognized throughout Newfoundland and, because it is the youngest of the orogenies, it deformed most rocks in western Newfoundland except those of Carboniferous age. In western Newfoundland, its best known feature is a suite of inversion faults, of which the Round Head Fault on the Port au Port Peninsula is a prominent example, as it is illustrated in the formation of the Garden Hill Oil Field discovered in 1995.

Carboniferous sedimentary rocks of the Bay St. George and Deer Lake basins were both syndepositional with, and deformed by, repeated Alleghenian wrench movement along the Cabot Fault system. Carboniferous faults also offset lower Paleozoic rocks of the Humber Zone.



**Figure 3:** Simplified stratigraphy of Lower Paleozoic sequences in western Newfoundland (from Hinchey et al., 2015). DH = Daniels Harbour conglomerate, CC = Cape Cormorant conglomerate.

## FIELDTRIP ITINERARY

The field trip itinerary is broken into three days, a partial day enroute from St. John's to York Harbour, as well as two additional full days. Day One includes an overview stop at Captain Cook's Lookout in Corner Brook. Day Two focuses on the area around the north shore of the Port au Port Peninsula and Stephenville. Day Three will look at the geology of the Bay of Islands, from Lark Harbour to Corner Brook.

Field trip stops for Day Two are indicated in Figure 6, and the field trip stops for Day One and Day Three are indicated in Figure 23. All UTM coordinates are in NAD 27, UTM Zone 21N.

### DAY 1 Fieldtrip Stops: Corner Brook

#### ***Stop 1.1: Crow Head and Captain Cook's Lookout***

**(Long: -57.96376734 Lat: 48.95322646)**

*Drive to Corner Brook, and take signs to Captains Cook Lookout overlooking the town.*

***Safety: Do not climb onto or over safety barriers and fences. The north side of the hill is fronted by precipitous cliffs.***

Crow Head overlooks the city of Corner Brook and on a clear day provides a 360<sup>0</sup> panoramic view of contrasting geological terranes related to the opening and closing of the Iapetus Ocean. Captain Cook's Monument is located at the top of Crow Head, and is located just above the Crow Hill thrust, which places older Cambrian Summerside Formation on top of younger (but still Early Cambrian) rocks of the Irishtown Formation. The Summerside Formation here consists of interbedded arkosic sandstone and maroon to brown slate, weakly metamorphosed, with cleavage dipping to the west. In the fine-grained rocks (originally mudstone, now slate) the cleavage is a slaty cleavage, defined by flakes of sheet silicate minerals which have oriented themselves perpendicular to the shortening direction. In the sandstones, the cleavage is defined by seams along which quartz has been preferentially dissolved - it is a pressure solution cleavage.



The structure at the top of the hill is notable because the beds dip and get younger to the west (as shown by graded bedding and rare cross-bedding) but the cleavage planes pass downward through the beds in this direction - the bedding is said to face down on the cleavage planes. This is an unusual situation and shows that these rocks have been deformed twice - once during westward thrusting ( $D_1$ ) in the Taconian Orogeny, and then again during the deformation ( $D_2$ ) that produced the cleavage, which probably transported higher rocks back towards the east. The age of the cleavage-forming event is poorly constrained, but some preliminary Ar-Ar data suggest that it was Late Ordovician or Early Silurian.

**View East, Northeast and Southeast** - the city of Corner Brook east of Crow Hill is mainly underlain by the Irishtown Formation (Curling Group), and slightly further to the east, as defined by the prominent north-south trending ridge behind Maple Valley, lies the contact between Humber Arm Allochthon strata and the shelf carbonates. This contact parallels the TCH and dips towards the west, presumably placing platform carbonates beneath our feet at Crow Hill.

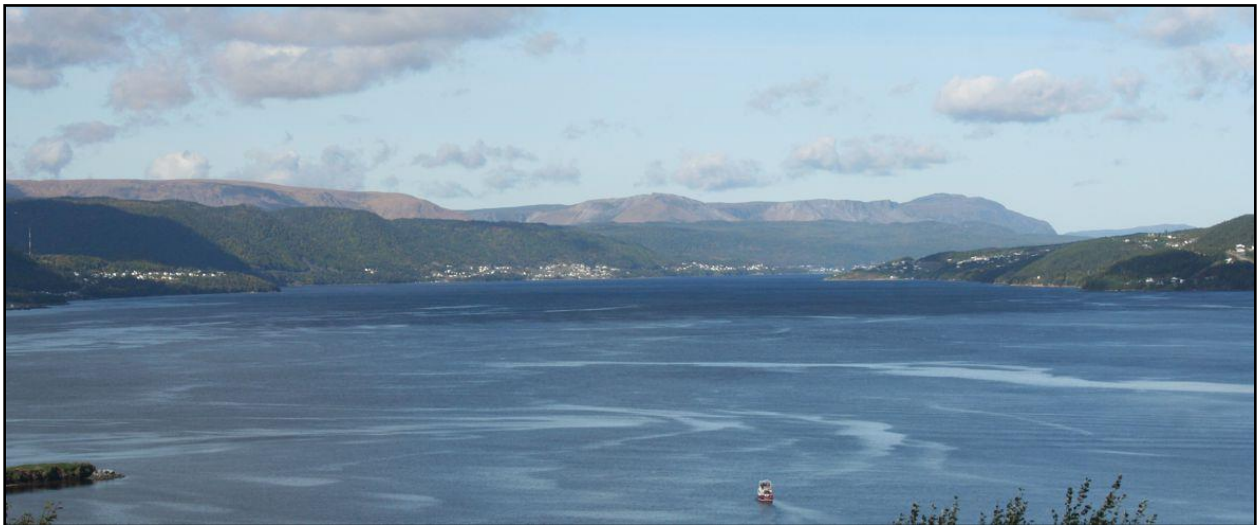
The carbonate succession trends in a north northeast – south southwest direction and encompasses all the rock units observed within Humber gorge eastwards to Marble Mountain, where they are in fault contact with the Upper Proterozoic to Lower Cambrian Mount Musgrave Group. The Mount Musgrave Group forms part of the Internal Domain (highly deformed and metamorphosed rocks) of the Humber Zone, and the internal and external domains are separated by a structural front, referred to as the Humber River Fault (Williams and Cawood, 1989).



**Figure 4:** Crow Hill / Head (Captain Cook's Lookout) as seen from downtown Corner Brook.

**View North** - to the north, the view is across Humber Arm. The eastern part around the community of Irishtown is occupied by Irishtown Formation of the Corner Brook Slice. To the west, the community of Summerside rests on Summerside Formation, which due to the nature of the underlying bedrock produces a somewhat more rugged topography. The two formations are separated by the west dipping Crow Hill Thrust, easily spotted due to the change in topography between the two communities.

**View West** – to the west, most of the forested ground in the middle distance is occupied by the Humber Arm Allochthon (Curling and Northern Head groups). In the far distance, the skyline (Blow Me Down or Blomidon Mountain) is dominated by the highest thrust sheet, ophiolitic rocks of the Bay of Islands Complex - a slab of the Iapetus ocean floor formed within an encroaching arc system (Figure 5). Depending on weather and time of day, it may be possible to make out the distinctive dun to orange colour of the upper mantle peridotites which form the eastern part of Blow Me Down Mountain (Figure 5).



**Figure 5:** Panoramic view of the outer Humber Arm; lower elevation – Curling and Northern Head Group strata; higher elevation – ophiolitic Bay of Islands Complex.

## DAY 2 Fieldtrip Stops: Port au Port Peninsula



Figure 6: Field trip stops for Day 2.

## **Stop 2.1: Blanches Brook Petrified Forest**

**(Long: -58.58029341 Lat: 48.56384534)**

*Drive to the town of Stephenville, and take Route 460 towards the Port au Port Peninsula. There's a parking area on the north-west side of the road, between the Blanches Brook and an ATV dealer. Take the Blanches Brooke hiking trail for approximately 1km.*

***N.B. This is a protected site and sample collection is strictly prohibited.***

At Blanche's Brook within the town of Stephenville one can observe a permineralized to petrified, upland, Cordaitalean prehistoric forest (Figure 7). The "petrified" forest is thought to be Middle Pennsylvanian in age (approx. 300 my) and tentatively has been assigned to the Barachois Group. Trees may have been up to 50 m in height, with preserved trunks up to 2 m in diameter. Fossil remains have been located mainly within basal lag conglomerates, envisioned to have formed in an alluvial fan to braided stream environment. Flood waters may have been responsible for transporting and depositing these trees from their upland habitat to their final resting place.



**Figure 7:** Blanche's Brook "Petrified Forest", with large Cordaitalean tree exposed along streambank.

## **Stop 2.2: Romaine's Brook Gypsum Deposit**

**(Long: -58.6711558 Lat: 48.55125961)**

*Continue along Route 460, until you cross Romaine's Brook. To view the complete sequence, participants must proceed approximately 200 to 250 m north along the gravel road situated immediately to the west of Romaine's Brook and stop opposite a low lying rock outcrop exposed on the brook's east bank. Although not recommended, to acquire a close-up view of the exposed section it will be necessary for participants to cross the stream. To fully appreciate though, especially from a big picture viewpoint, participants should remain on the west bank.*

At this stop, limestones of the Carboniferous Ship Cove Formation (basal Codroy Group) are conformably overlain by evaporites of the Codroy Road Formation. Exposed in the low lying cliff face is a 2.1 m thick, basal conglomerate bed, conformably overlain by medium grey limestone (Figure 8). The conglomerate unconformably (angular unconformity) overlies moderately dipping, red and green shales of the allochthonous Humber Arm Supergroup, and is a poorly bedded, oligomictic, clast supported unit consisting of moderately to well sorted, cobble to boulder size material (up to 0.75 m diameter) of St. George Group carbonates, Table Head limestones and rare clasts of red, calcareous, quartzose arenite. The overlying, laminated Ship Cove limestone is a pelletal packstone containing rare ostracod fragments (Dix, 1981).

Overlying the Ship Cove limestone are evaporates (gypsum and anhydrite) of the Codroy Road Formation (Figure 9). The contact although not exposed is believed to be conformable. The gypsum located to the north of the highway appears massive, although close examination reveals numerous, continuous to discontinuous, contorted and/or faulted, grey-green, sandy or clayey laminations. Structural discontinuities observed in the gypsum may be related to later tectonics or due to anhydrite/gypsum hydration (Dix, 1981). The uneven surface topography observed over the gypsum zone is a direct result of sinkhole development in combination with regional erosion.

A thin layer of micaceous, green-grey sandstone is faulted against the gypsum east of the bridge and overlies the gypsum along the shoreline. The sandstone is a platy, plant bearing, feldspathic arenite with a maximum thickness of 3.5 m (Dix, 1981). Locally, the sandstone contains well preserved, symmetric ripples.

Based on observed geology and internal structures, strata exposed along the lower reaches of Romaine's Brook suggest initial deposition (conglomerate) under very high energy, flood conditions along an Early Carboniferous shoreline or within a shallow basin. The conglomerates were overlain by laminated limestones, suggesting deposition away from a higher energy (possibly nearshore) environment. Restricted marine conditions under semi-arid climatic conditions led to the development of a thick evaporite sequence. Regional uplift eventually led to an overabundance in sediment supply, resulting in progradational sand lenses being emplaced seaward over the basin evaporites.



Figure 8: Carboniferous age Ship Cove limestone overlying conglomerate and steeply dipping Humber Arm Allochthon shales.



Figure 9: Carboniferous age (Codroy Road Fm., Codroy Group) evaporates exposed along the Romaine's Brook shoreline.

**Historical Note** - From an exploration perspective, the Romaine's gypsum deposit was first worked during the 1890's by Charles Osman who extracted 900 tons from the cliff face and exported it to US and Canadian markets. Mr. Osman was forced to abandon the site in 1894 following visits by French protection squadrons demanding he remove all buildings and mine equipment from along this section of French Shore. The deposit lay dormant until the Reid Newfoundland Company conducted further exploration work in 1926. At that time, they dug seventeen test pits and drove two adits (tunnels) into the hillside north of the bridge. In 1955, the Government of Newfoundland undertook a fifteen hole diamond drilling program and Flinkote Canada Ltd. drilled an additional six holes in 1970. Based on these drilling programs, the Romaine's deposit is estimated to contain 2,277,000 tons of gypsum grading 93.89%  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ , 1.58%  $\text{CaSO}_4$ , 3.82%  $\text{CaCO}_3$  and 0.08%  $\text{MgCO}_3$ .

### **Stop 2.3: St. George Unconformity at Aguathuna Quarry**

**(Long: -58.77984519 Lat: 48.55648476)**

*Continue along Route 460 to the Port au Port Peninsula. After crossing the isthmus, continue straight towards Bellmans Cove and Aguathuna. Continue along this road till you reach Aguathuna Quarry.*

***Safety: Open pit mine site, be cautious of rubble underfoot and do not venture near vertical cliff sections.***

The St. George Unconformity is a regional unconformity correlated with the Knox Unconformity in the southern Appalachians. It forms a major sequence boundary in the Appalachians, marking the Arenig-Llanvirn boundary and the contact of underlying carbonates of the St. George Group deposited along the Laurentian passive margin of Iapetus Ocean and those above of the Table Head Group that were deposited in a Taconian foreland basin. The boundary is believed to be largely the product of the passage of a peripheral forebulge across the margin coincident with eustatic sea level fall (Knight et al., 1991).

The unconformity is brilliantly exposed in the face of the outer quarry where its erosional relief of several meters cuts down into the predominantly burrowed and laminated dolostones of the Aguathuna Formation, St. George Group (Figures 11, 12). The surface hosts local small karren draped by pockets of rubbly protosoil, a basal conglomeratic lag and near surface cave deposits. Bedding plane caves marked by stump-like pillars protruding from the floor and ceiling also occur in the subsurface. The caves formed where limestones were dissolved from between dolostone beds. Such caves are likely important petroleum reservoirs.

The Table Point Formation, consisting of dark grey bioturbated limestone, overlies the unconformity. A thin member of nodular limestone, grainstone and fenestral limestones, plus or minus dolostone interbeds, occurs immediately above the unconformity; it is known as the Spring Inlet Member (Ross and James, 1987), and was deposited upon the unconformity throughout western Newfoundland as the Middle Ordovician sea rose and drowned the unconformity.

At this locality, carbonate and clastic sequences of the Upper Mississippian (Carboniferous), Big Cove Formation (Ship Cove Limestone equivalent) unconformably overlie karsted limestones of the Table Head Group. This is just one of numerous Carboniferous outliers that unconformably overlie carbonate strata of the Port au Port, Table Head and St. George Groups on the Port au Port Peninsula (see also Stops 2.2 and 2.5). Lithologically, the Big Cove Formation at Aguathuna Quarry consists of an intercalated sequence of bedded biohermal limestones and bedded carbonate mudstones. The biohermal limestones consists of grey to beige, massive, unbedded bryozoan mounds, intermound bedded skeletal to pelletal packstones and/or grainstones and well developed biolithites of similar lithology to mounds, but lacking internal bedded sediment (Dix, 1981). Mounds and biolithites exhibit

tiny colloform structures with cores of bryozoans, algae and serpulid-type worm tubes. Associated fauna include brachiopods, pelecypods and large cylindrical worm tubes (Dix, 1981).

Based on observed lithological features, Dix (1981) postulated the depositional environment to be a near shore, shallow water, marine environment episodically influenced by fluvial clastic deposition. The presence of worm tubes and hydrothermal sulfide mineralization led von Bitter and co-workers (1990) however, to speculate whether the biohermal mounds were actually chemosynthetic communities clustered around shallow water, low-temperature hydrothermal vents (analogous to deep water hydrothermal “black smoker” vents). They argue that the low diversity composition of mound biota can be explained by a vent origin. Restricted fauna such as bryozoa, brachiopods, pelecypods, conularids, serpulid worms and tubes occurring without normal Carboniferous groups like corals and echinoderms can be best explained, when one considers only “certain specifically adapted invertebrates can live in the specialized vent environment”. The validity of this hypothesis will be discussed further when we examined the abundant sulphide mineralization at Lead Cove.

**Historical Note** - the future Aguathuna mine site was discovered in 1910 by Arthur House, a representative of the Dominion Iron and Steel Company (DISCO) who was manager at the Wabana iron mine on Bell Island. He was tasked with finding a cheap source of limestone for the steel mills in Sydney, Nova Scotia and while examining Port au Port Bay came upon a large source of limestone at a place called Jack of Clubs Cove. In 1911, mining commenced with Arthur House as the first mine manager.

Over the next two years, the company constructed employee lodgings, ore storage bins, built a shipping pier on winter ice and still found time to petition the Post Master General to change the name of the community from Jack of Clubs Cove to Aguathuna, supposedly a native name for “white rock”. The first shipment of limestone bound for Sydney left Aguathuna aboard the Heathcote in early 1913. Mining methods in the early days were fairly crude, ore was blasted from the cliff face, cobbled to size and hand loaded into horse drawn carts and brought to a crusher to be reduced in size and then loaded by conveyor into waiting ships or stockpiled to await arrival of an ore carrier. Later on, coal steam shovels and trucks, then diesel powered shovels loaded and transported the ore to the crushing facilities.

Arthur House remained mine manager until 1956 when he was replaced by J. N. Gillis, who served as manager until mine closure in 1964. All total around 70 employees lost their livelihood and in 1966 DOSCO sold their mine holdings back to the Newfoundland government for \$1000.

In 1969 a company called Sea Mining Corp. tried to re-open the quarry with the aim to extract magnesium hydroxide from sea water by using limestone as a precipitator. The venture however failed almost as quickly as it had begun. Since 1969, quarry stone has been used sporadically for road construction, breakwater construction / repair and for lining or stabilizing stream banks following severe flooding which took place in the area in 2005.





**Figure 10:** Wide shot view of Aguathuna Quarry, looking east; (left) – Carboniferous limestones; (right) - Ordovician carbonates.



**Figure 11:** Close up, St. George Unconformity separating Table Head Group from St. George Group (Aguathuna Formation).



**Figure 12:** St. George Unconformity; dark grey, Table Head Group limestone above tan dolostones of the St. George Group.



**Figure 13:** Fossiliferous, Carboniferous age limestone; infilling karst valleys cut down into underlying Mid-Ordovician limestone.

## **Stop 2.4: West Bay Quarry**

**(Long: -58.92220895 Lat: 48.59176524)**

*Return towards the Bellmans Cove and take a right turn to Lourdes. When you re-join Route 460, take a right and follow signs towards Lourdes (along Route 463 after Abrahams Cove). Directly after the Western Petroleum Station in West Bay, you will see West Bay Quarry on your left.*

***Safety: Be careful when crossing this busy road. In the quarry be aware of the potential for falling rocks and wear protective headgear if examining the steep surfaces.***

The quarry in West Bay (Figure 14) is well known for the abundance of fossils found in rocks of the Table Head Group. At the back (south) wall of the quarry, the uppermost beds of the Table Point Formation can be recognized by their thick bedded, bioturbated facies. These are overlain by a succession of interbedded fine-grained fossiliferous ribbon limestone and shale of the Table Cove Formation. The fossils include graptolites, the trilobite *Cybelurus mini* and inarticulate brachiopods. The fauna are Darriwilian (Middle Ordovician) in age. These were deposited in slope or basin settings adjacent to remaining horsts of platform carbonates in the Taconian foreland basin, which was dissected by faults. The Table Cove Formation is contemporary with the much coarser conglomeratic rocks of the Cape Cormorant Formation. The Black Cove Formation (Goose Tickle Group), which overlies the ribbon limestone, is a dark grey, organic rich shale that is a potential source rock with TOC of up to 2%. Thin Daniel's Harbour Member occurs in the upper terrace of the west face of the quarry. An oil seep is reported in the southeast corner of the quarry.



**Figure 14:** Quarry at Piccadilly; Table Cove Formation, Thinly bedded graptolitic shale and ribbon limestone of the Table Cove Formation, at West Bay Quarry.

## **Stop 2.5: West Bay Shoreline**

**(Long: -58.92355354 Lat: 48.59409373)**

*Cross the road (care for oncoming traffic) and walk 50m down to the shoreline.*

***Safety: The shoreline outcrops are typically extremely slippery. Choose your route to the shore carefully and take care to avoid overhanging cliffs.***

The Table Cove Formation is well exposed at the mouth of the small stream that descends to the shoreline west of the store. Traced to the west, at low tide, the succession passes up through ~5m of dark shale of the basal Goose Tickle Group (Black Cove Formation) into basal units of the overlying turbiditic sandstones. However, to the east and in the base of the cliff the Goose Tickle Group is absent. Instead, the ribbon limestones and shales of the Table Cove Formation are increasingly broken up, and distinctive green and black shales appear between the more competent blocks of limestone. The base of the Humber Arm Allochthon (West Bay Thrust) is marked by highly deformed scaly shales of the Humber Arm Supergroup (Figure 15). These have distinctive green and black banding that contrasts with the consistently grey to black colour of the younger, but underlying, units of the Table Head and Goose Tickle Groups. The West Bay Thrust is here offset by several later steep faults that change its level in the cliff.

Higher in the cliff, and to the east, there are distinctive nodular green cherts and siliceous shales that are most likely part of the Middle Arm Point Formation of the Northern Head Group, or the laterally equivalent Green Point Formation of the Cow Head Group. These siliceous sedimentary rocks are thought to have provided material for lithic tools of ancient peoples who inhabited western Newfoundland. To the east, beyond a small point, is a tectonic contact with a spectacularly folded succession of turbiditic sandstones and shales, with asymmetric, west-facing folds that appear to re-fold a series of extensional faults (Figures 16). The stratigraphic affinity of these units is not known for certain. They could be the youngest unit of the Humber Arm Allochthon (Eagle Island Sandstone), or they could be a tectonically incorporated slice of Goose Tickle Group. The two units (Eagle Island and Goose Tickle) can be lithologically very similar but are of slightly different age; unfortunately no graptolites have been found. However, the tectonic state of the unit and the observed lithological differences from the Goose Tickle Group located at the west end of the section favour assignment to the Eagle Island Sandstone. Traced along the shoreline, the section also contains a number of compressional and extensional faults (Figure 17). Towards the west, the Table Cove Formation consisting of dark grey to black shale is highly fossiliferous, containing a number of species of graptolites (Figure 18).



**Figure 15:** Melange zone at Piccadilly Beach; Table Cove shale & limestone in thrust contact with overlying Humber Arm Allochthon shale.



**Figure 16:** Spectacular recumbent folds in shale & ribbon limestone at Piccadilly Beach, possible Goose Tickle lithology.



**Figure 17:** Extensional and compressional faults exposed at Piccadilly Beach, possible Goose tickle lithology.



**Figure 18:** Highly graptolitic shale at Piccadilly Beach; Table Cove Formation, Table Head Group.

## **Stop 2.6 Lead Cove**

**(Long: -58.74387534 Lat: 48.55998064)**

*Return to the isthmus, and take a left towards Aguathuna. After ~300m, park in the carpark of Our Lady of Mercy Church. Proceed approximately 200 m beyond the church and then follow the dirt track (north side of paved road) approximately 300 m to the cove.*

***Safety: The shoreline outcrops are typically extremely slippery. Choose your route to the shore carefully and take care to avoid overhanging cliffs.***

***Note: Please do not hammer the spectacular outcrops. Samples of mineralization can be collected from the beach rocks.***

At Lead Cove, highly fossiliferous carbonate and clastic sequences of the Upper Mississippian (Carboniferous), Big Cove Formation (Ship Cove Limestone equivalent) occurs in a narrow northward-trending graben and overly thickly-bedded karsted limestones of the Ordovician Table Head Group. This is similar to what we observed at Aguathuna Quarry (Stop 2.3) and the erosional surface is clearly visible on both sides of the cove (Figure 19). The following summary of mineralization at Lead Cove is adapted from Saunders et al. (1992).

The Big Cove Formation observed at the head of the cove is synclinal in structure and is highly brecciated for a considerable distance adjacent to the vertical faults which bound the graben. Galena, marcasite and calcite are found in the limestone breccia on both the eastern and western sides of the cove (Figure 20), where they occur as disseminations, replacements and in veins and vugs. Breccia fragments are sub-angular, 1 mm to several cm, and are set in a limey matrix, and the limestone breccia locally passes into massive, oncolithic limestone. Mineralization occurs predominantly in the breccia matrix and in irregular veins with no consistent orientation. It consists of galena cubes up to 1 cm, marcasite rosettes up to 1 cm in diameter (Figure 21) and clear calcite spar. Zoning in vugs and veins, when complete, is marcasite-galena-calcite, and galena-calcite veins are observed cross-cutting disseminated marcasite. Minor barite has also been observed in some vugs.

Mineralization is also recorded in an overlying limestone pebble conglomerate, where the matrix of fine grained calcite is extensively replaced by marcasite and calcite spar. This pebble conglomerate passes upwards into calcareous sandstone and siltstone, and thin coal seams and plant fragments may be seen in overlying siltstones in the middle of the cove.

Whether the mineralization found in Carboniferous strata on the Port au Port Peninsula was emplaced syn-genetically during mound growth or emplaced at some later time is an important test of the chemosynthetic hypothesis proposed by von Bitter et al. (1990) (see Stop 2.3). Von Bitter et al. (1990) argued that mineralization was syn-genetic, with local and regional concentrations of mineralization in mounds in the stratigraphically lowest units (associated with “vent” communities), with mineralization

absent from the intermound facies or in overlying units. However, Dix and Edwards (1996) showed that the onset of mineralization postdated burial and development of early fabrics in the mounds. They proposed that Pb-Zn-Ba-Sr mineralization was associated with fault controlled fluid migration. Metals and fluids would have been mobilized from the underlying allochthonous shales and these hot, metal bearing brines would have risen along faults and mixed with high salinity sulphate bearing fluids (sulphate sourced from overlying evaporates, e.g. Stop 2.2) in a shallow burial environment and deposited sulphides. This model is similar to Irish-Type Pb-Zn mineralization.

**Historical Note** - *The Lead Cove mine was discovered in 1873 by Captain Andrew Harvey who had been sent to the area by the Anglo-American Telegraph Company to prospect their lands. Before returning home at the end of summer Andrews happened to discover lead ore, not on Telegraph land but on claims staked by C.F. Bennett who by the way just happened to be premier of Newfoundland (1870 – 74). Bennett heard of the discovery and managed to coerce Andrews and twelve miners to work the property (Martin, 1983). The miners arrived on site in 1874 and proceeded to erect accommodations, a shipping pier and mine related infrastructure.*

*Throughout the summer they diligently extracted the ore (from Carboniferous Big Cove Formation strata) and waited for a British ship to arrive and transport the ore to a smelter site. Unfortunately for them the first ship to arrive was a French man-o'-war, skippered by a Capitaine Aubrey who under no uncertain terms informed the British navy that the mining pier obstructed French fishermen and therefore violated terms of the French Shore treaties. The British navy supported Harvey and bolstered by their indifference Harvey refused to budge despite numerous visits and warning by the French. The Colonial Secretary of Newfoundland however, feared to incur French disfavour so he ordered Harvey to dismantle and abandon the mine site. The miners departed in 1877, leaving the ore to disperse with storm and tide (Martin, 1983). Years later local people were still convinced that a French man-o'-war returned some time after the miners had departed and took the stockpiled ore.*



**Figure 19:** Western side of Lead Cove, with thickly bedded Table Head limestone (right) and Big Cove Formation sediments infilling karstic depression (to left).



**Figure 20:** Limestone breccia from west side of Lead Cove, with marcasite-galena-calcite mineralization infilling spaces between limestone fragments.



**Figure 21:** Rosette of marcasite at Lead Cove



**Figure 22:** Former adit at Lead Cove

## DAY 3 Fieldtrip Stops: Bay of Islands

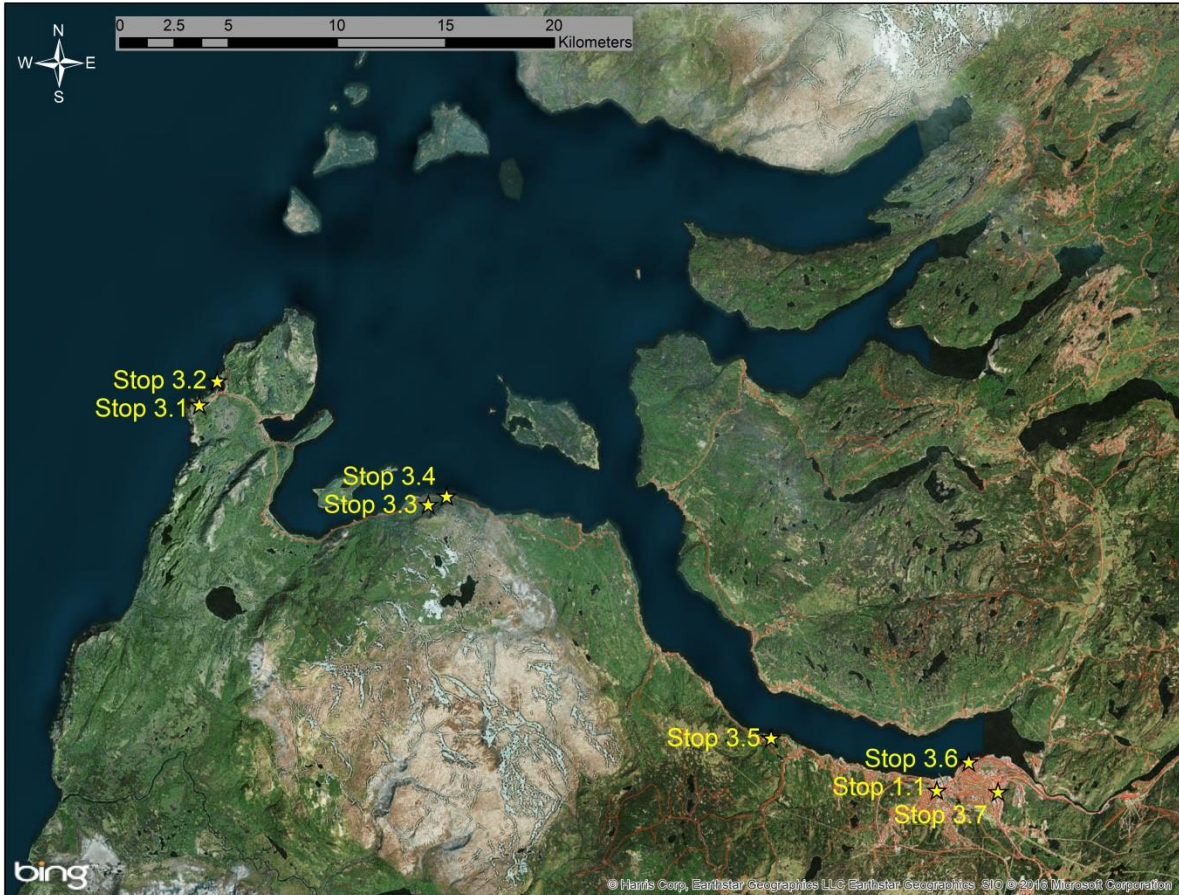


Figure 23: Field trip stops for Day 3.



### **Stop 3.1: Little Port**

**(Long: -58.42262016 Lat: 49.10762732)**

(Notes on this stop taken from Waldron et al., 2012, adapted from descriptions by E.Burden in Hicks et al., 2010)

*Drive through Lark Harbour and take turn up Little Port Road to the wharf at Little Port.*

***Safety: Exercise extreme caution when walking over wet (slippery) shoreline cobbles and patches of exposed seaweed. Stay away from cliff edges (top and bottom).***

The Little Port Complex represents the leading, westernmost edge of the ophiolites that cap the Humber Arm Allochthon. The Little Port Complex includes mafic volcanics and more felsic intrusive units, and displays a complex history of deformation and intrusion. It includes some of the oldest known ophiolitic units in the Allochthon. Interpretations of the tectonic environment of formation of the Little Port Complex have varied. It has been suggested that it may represent a transform fault, for example. However, most modern interpretations suggest that the Complex represents an island arc in the Iapetus Ocean, and that the younger Bay of Islands Complex formed by spreading within this arc environment, above a subduction zone.

Little Port volcanics are typically overlain by sedimentary strata. Typically strata with relatively well defined stratigraphic relationships with the volcanics are overlain by fault panels separated by minor breaks, then by strata that are intensely folded, faulted and phacoidally cleaved. Collectively, the sediments are loosely called the Little Port Assemblage. Genetically, they are thought to have formed in the same tectonic unit as the Little Port igneous complex, and represent an episode of deep water marine sedimentation after volcanism ended.

At Little Port, the Little Port volcanics on the west shore of the harbour are dark green adjacent to the wharf and elsewhere in this bay, crudely pillowed basaltic lavas pass into irregular bodies of pillow breccia. The volcanic rocks are locally non-conformably overlain by volcanic agglomerate grading to sedimentary conglomerate with contacts dipping moderately east. Volcaniclastic strata are interbedded with green, coarse-grained sandstone lenses.

On the southwest side of Little Port Harbour an unconformable contact exists between the Little Port volcanics and an overlying succession of volcaniclastic sediments, cherty shale, ribbon limestone and shale of the Little Port Assemblage (Figure 25). Immediately above the contact the strata are relatively little deformed. Farther away from the contact, the overlying beds become significantly and progressively deformed. Higher in the section is a 5-6 m layer of boulder conglomerate. The conglomerate is unsorted and clast supported with a highly variable and hematized matrix. Clasts are mainly mafic volcanics, occasional fresh and epidotized gabbro, felsic igneous lithologies, and chert. Clast size decreases up-section. The boulder conglomerate is overlain by 4 to 5 m of medium- to thick-

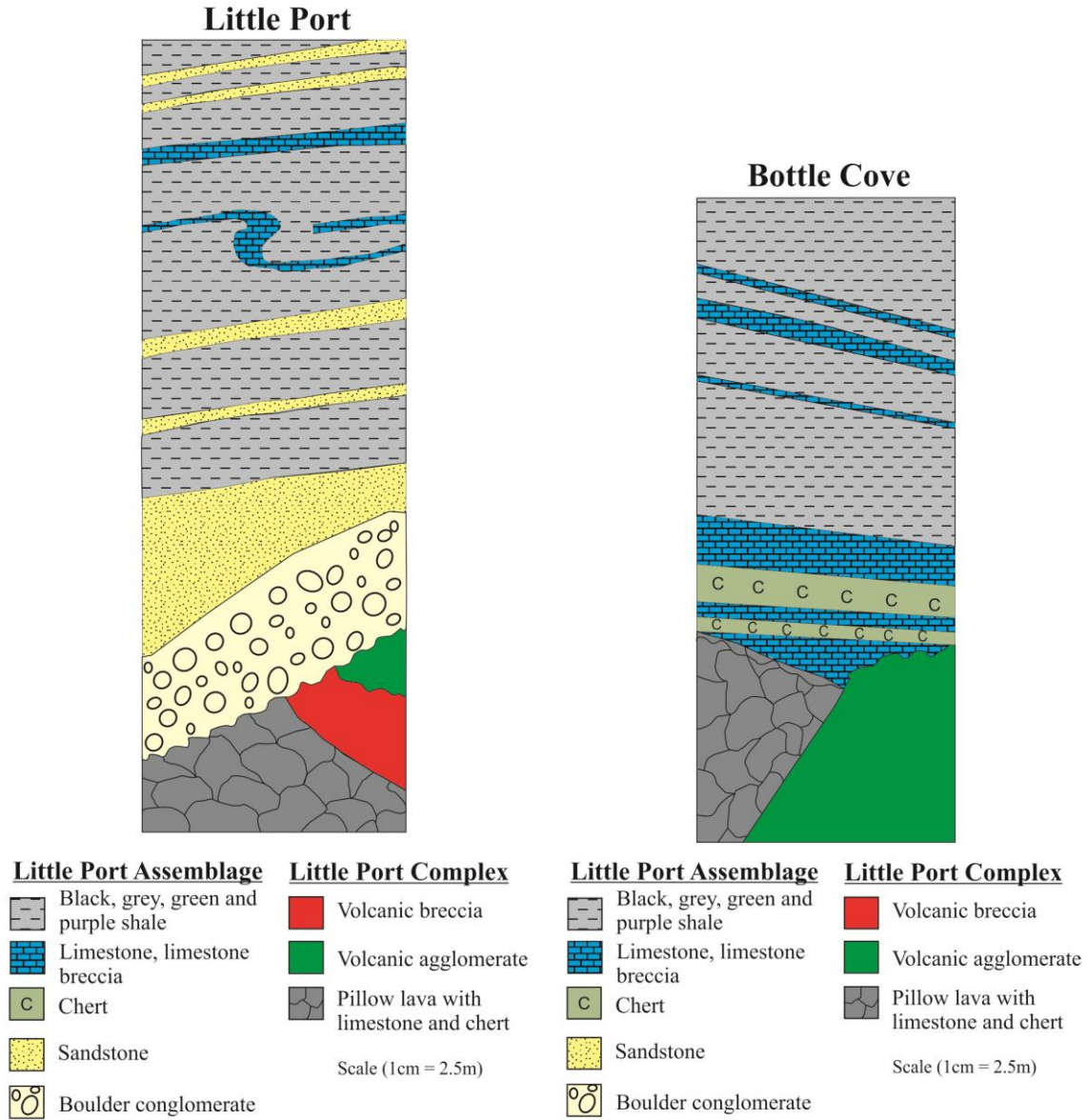
bedded, coarse-grained, laminated, green sandstone. These rocks pass into a narrow interval of green and black siliceous shale that contains metre-sized lenses of volcanic breccia. In the northwestern part of the exposure, the sandstone and shale beds are truncated to the west by a steep fault contact with mafic volcanics.

The conglomerate, sandstone and shale succession is fault-bounded to the east with a prominent high-angle sinistral reverse fault (175/86 E). Farther east are faulted rusty brown shale, laminated limestone and several limestone breccia horizons, with a large intrafolial fold interpreted as a syn-sedimentary slump fold. Despite the fact that the shale-limestone unit lies within a sheared panel, it is inferred to form the upper part of the succession.

A small occurrence of oil stained sedimentary rock is also located on the northeastern side of Little Port harbour. The rocks include an oligomictic volcanic conglomerate with a thickness of 2-3 m lying within a package of shale and sandstone. This unit unconformably overlies massive and pillowed basaltic flows.



**Figure 24:** View of Little Port (NE side) showing Little Port Complex volcanic rocks. Rocks along both sides of the cove are dark green, locally hematitized, mafic volcanic of the Little Port Complex.



**Figure 25:** Schematic stratigraphic section showing the main features for the Little Port and Bottle Cove areas.

### **Stop 3.2: Bottle Cove**

**(Long: -58.40356829 Lat: 49.11349685)**

(Notes on this stop are adapted from Waldron et al. (2012) and from descriptions by E. Burden in Hicks et al., 2010)

*Drive to back towards Lark Harbour and take the turn off to Bottle Cove. Park in the car park overlooking the beach.*

***Safety: Exercise extreme caution when walking over wet (slippery) shoreline cobbles and patches of exposed seaweed. Stay away from cliff edges (top and bottom).***

At Bottle Cove, a slightly different unconformable contact exists between the igneous rocks of the Little Port Complex and sedimentary rocks of the Little Port assemblage (Figure 25) than that observed 2 kilometers to the south-southwest at Little Port, with the unconformity at the top the volcanics an irregular undulating to folded surface with variable dip.

The igneous complex is divided into two north-trending, fault-bounded blocks, consisting of an epidotized high-level gabbro intrusion to the west and a mafic volcanic suite to the east. The volcanic rocks are mainly dark green pillowed flows with porphyritic and amygdular textures, subordinate massive flows, and volcanic breccia. Pillow lavas, near the unconformity, locally contain pockets of both red chert and pink recrystallized limestone in the interstices. Red chert and shale locally also form the matrix of the volcanic breccias.

The sedimentary succession at Bottle Cove is also quite different from the one recorded in Little Port harbour (Figure 25). The unconformity is overlain by a 0.5-6 m unit of grey to pink limestone with minor lenses of partially recrystallized limestone breccia. The limestone is bitumen stained. Lenses (10-50 cm thick) of thinly bedded red chert occur in the upper portion of the unit. A package of siliceous grey, purple and black shale at least 15 m thick overlies the limestone. It contains near its top thin beds of brown-weathering sandstone with cross lamination. Locally, the limestone is missing and red shale and chert directly overlie the volcanic rocks. The succession is truncated by a steeply east dipping fault in the northwestern corner of the cove. To the east is a 60 m wide, strongly deformed section of green and black siliceous and rusty pyritiferous shale interbedded with thin boudinaged sandstone and chert. A poorly sorted volcanic conglomerate with clasts of chert lies in the core of a south-plunging anticline in the western part of this section. The strata seen in this section are tentatively assigned to the Cooks Brook Formation based mainly on the succession of limestone and shale.



**Figure 26:** Panoramic view of Bottle Cove, looking west towards the Gulf of St. Lawrence.



**Figure 27:** Bottle Cove - northwest side: fault contact between Little Port Complex volcanics (L) and Little Port Assemblage sediments (Cook's Brook Formation, Northern Head Group) (R).

### ***Stop 3.3: York Harbour Copper Mine***

**(Long: -58.30440125 Lat: 49.06134119)**

(Notes on this stop adapted from DNR MODS ID# 1775 and Tallman, 2010)

*Drive to through the town of York Harbour towards Corner Brook. Take the exit marked Copper Mine Hiking Trail, and park in carpark at trailhead.*

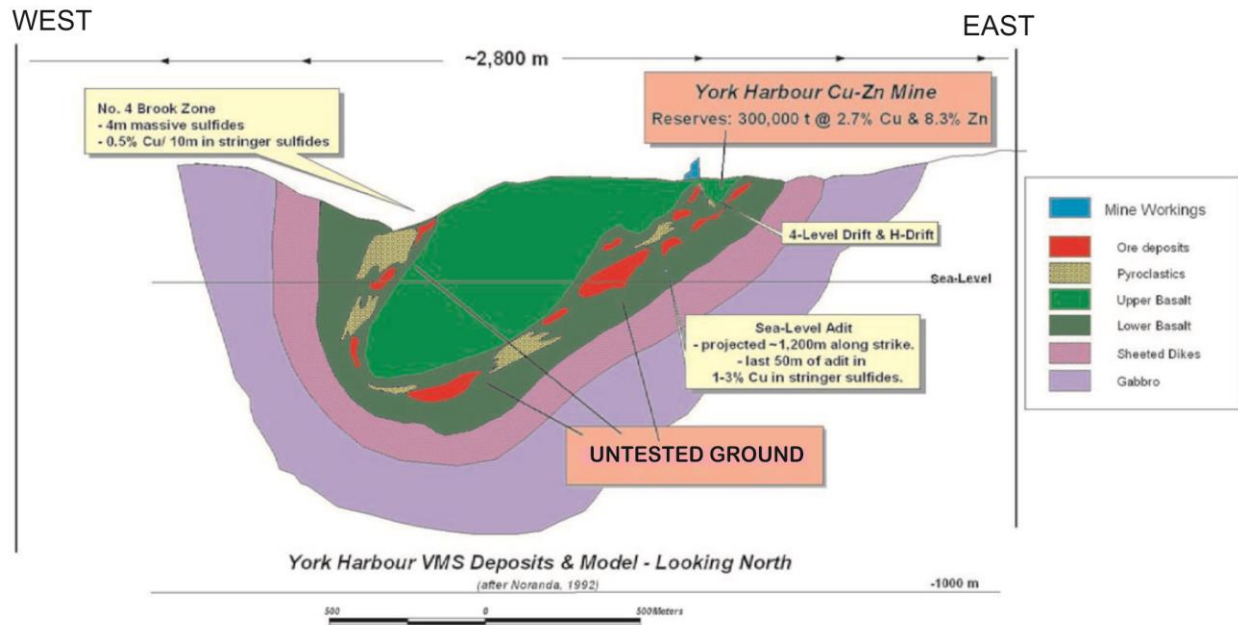
***Safety: Do not stand too close to cliff face, danger of falling rock.***

The Bay of Islands Ophiolite Complex (BIOC) is one of the stratigraphically highest structural slices of the allochthon, and is host to mafic dominated (Cyprus-type) massive sulphide style mineralization. The BIOC consists of a lower sequence of serpentinized ultramafic rocks (harzburgite, dunite, pyroxenite and lherzolite), overlain by layered to massive, intermediate to mafic intrusive rocks (diorite, trondhjemite and gabbro) and sheeted dikes, which in turn are overlain by a Lower Basalt unit (characterized by highly altered basalt flows, pillow lavas, pillow breccias and sheeted dykes), a middle pyroclastic-sedimentary horizon (characterized by coarse andesitic agglomerate with minor interbedded felsic tuffaceous beds, chert-pyrite horizons and thin hematite – iron formation) and a less altered Upper Basalt horizon (mainly undeformed basalt flows, pillow lavas and pillow breccias, with interstitial red jasper). A major, shallow, south dipping thrust separates the rocks of the BIOC from the underlying rocks of the HAA (exposed on the islands directly in front of this stop), and cross sections through the BIOC show it forms a north-northeast trending syncline (Figure 28).

The York Harbour deposit is a stratabound, Cyprus-type volcanogenic Cu – Zn +/- Ag, Au massive sulphide deposit, which consists of multiple, small (eg. <60,000 tonnes), irregular lenses of Cu – Zn rich ore contained within the upper altered Lower Basalt unit. Mineralization consists of massive pyrite, sphalerite and chalcopyrite with minor pyrrhotite and galena. Silver and gold values are sporadic throughout the deposit. The massive sulphide ore lenses are often brecciated and are underlain by a variably developed stringer-stockwork zone, typically associated with intense hydrothermal brecciation. In contrast, the hanging wall contact is sharp and overlying basalts are unaltered and contain on average less than 1% disseminated pyrite.

Footwall rocks in the vicinity of the ore stockwork zones exhibit extensive alteration, characterized by quartz-carbonate veining, sulphidization and chloritization. Previous work in the area has shown that the favorable horizon occurs over a 100 m width and appears associated with high angle, north-northwest to southeast trending shear zones.

The rocks in the adit walls are relatively unaltered pillow basalts of the Upper Basalts. Although we are unable to visit the former mine site, samples of ore from stockpiles will be available for viewing.



**Figure 28:** Cross-section through the BIOC, showing stratigraphic location of the York Harbour Deposit (adapted from Tallman (2010)).



**Figure 29:** A' Zone shaft and mine buildings, (ca. 1899-1913), York Harbour mine.

**Historical Note** - (early history mostly from Wendy Martin – “Once Upon a Mine”) - The York Harbour copper deposit (Figure 29) was discovered near the top of Blow Me Down Mountain in 1893 by prospector Daniel Hendersen. Being of poor financial means, Hendersen sought out and received monetary support from St. John’s merchant A.J. Harvey in return for part ownership of the property. Mining began in 1897 with Hedley Smythe as mine manager and Charles Rendell as mine captain. The company sank four shafts and constructed a make shift chute and pulley contraption to transport pork barrels of ore down the cliff to the coast. By 1899 the company had raised only 500 tons of ore and in their frustration the directors fired Rendell and leased the property to the York Harbour Copper Company.

The new mine captain James Hooper appears to have had little mining experience and worse still, very little luck. A fire destroyed the mine site, an epidemic rendered everyone sick for a period of time and the miners were constantly harassed in their efforts to build a tramway and pier by the French navy. By the time the property lease expired (sometime in late 1901 – early 1902), the York Harbour Copper Company had raised a meager 100 tons of ore. Based on these results, A.J. Harvey refused to extend the lease and in 1902 he formed the Western Copper Company Limited with, among others, Charles Willis of the Humber Consolidated Mining & Manufacturing Company and the original discoverer of the property Daniel Hendersen.

The Western company leased the property to Willis who then leased it in 1902 to the Humber Company. Within a very short period of time the mine was operating as expected and between the years 1902 to 1905, about 15,000 tons of ore was shipped to the United States. A shortage of funds however, forced the Humber company to mortgage the mine and other assets. This violated the original contract with Harvey and he sued, with the judge awarding the property back to the Western Copper Company in 1906.

Instead of continuing with mining operations, the Western company optioned the property in 1909 to a group of British mining engineers and merchants, who immediately formed the York Harbour Mine (Newfoundland) Limited. Things ran smoothly for a while, so good in fact that the Newfoundland government actually considered financing the erection of a smelter on site and in 1910 and 1911 passed two copper smelting acts to allow this to happen. However, the smelter was never built and by 1913 the mine was running out of known reserves and company directors were reluctant to expend further money in underground exploration / production. In July, 1913 the last load of ore left York Harbour for the United States and by September of the same year the mine was closed. Over the life of the mine, the York Harbour Mine (Newfoundland) Limited shipped approximately 15,000 tons of ore.

The mining operations that shut down in 1913 remained idle until 1950 when the property was optioned by Independent Mining Corp. Ltd. In 1953, they dewatered the shaft and extended the 4<sup>th</sup> level north-northeast to a portal entrance at surface. In addition, the company conducted field mapping and ran a VLEM geophysical survey. No additional work was completed. Later diamond drilling in 1953 and 1954 allowed the company to estimate total reserves at 93,000 tonnes grading 2.38% Cu and 6.80% Zn. In 1955, the mining rights were acquired by Big Nama Creek Mines Ltd. who conducted a surface and underground drilling program. Reserves were calculated at 176,000 tonnes grading 2.65% Cu and 8.25% Zn.

Big Nama decided to re-open the mine in 1965. An adit was collared east of Mine Brook at 40 m ASL with the intent to intersect the old mine workings along the Lower Basalt / Upper Basalt contact. Work was halted in 1966 when fire destroyed the diesel-electric plant and surface buildings. New reserve calculations reported 198,000 tonnes grading 2.68% Cu and 8.25% Zn.

Between 1968 and the present day a number of companies conducted various levels of exploration work at the York Harbour site, and Tenacity Gold Mining Co. Ltd. of St. John’s, NL currently has rights to the property.



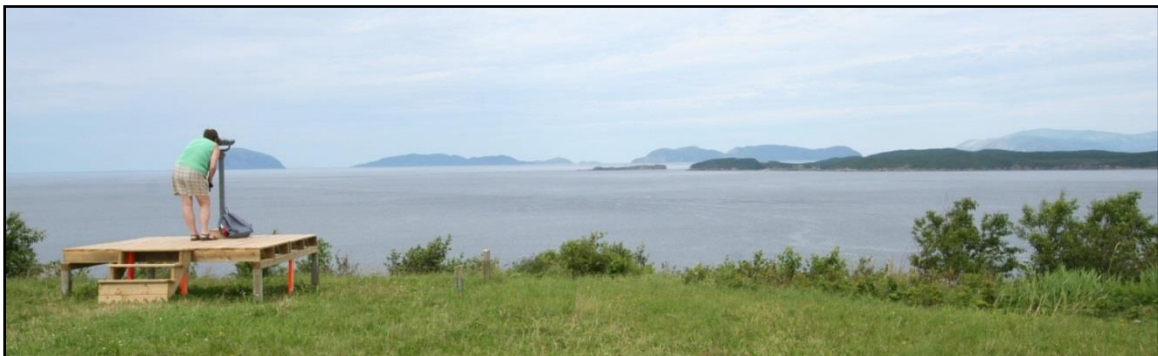
### **Stop 3.4: Candlelite Bay Inn**

**(Long: -58.28662738 Lat: 49.06679469)**

*Continue towards Corner Brook, and park in the entrance to the former Candlelite Bay Inn. Walk down towards the shoreline.*

This stop provides a panoramic view of the outer Bay of Islands (Figure 30), thereby giving participants an excellent opportunity to observe sections of the intermediate and higher slices of the Humber Arm Allochthon. The high summits to the south-southwest comprise the northern extremity of the BIOC. A metamorphic sole defines the tectonic contact with underlying Blow Me Down Brook rocks. Above this contact to the south are ultramafic mantle rocks. These are quite noticeable due to their monotonous brown color and overall lack of vegetation. Towards the west the ultramafic rocks are overlain by mafic intrusive rocks and extrusive volcanic rocks discussed at the previous stop.

In the bay to the northwest, the three distant large islands (l. to r. – Guernsey, Tweed and Pearl) form part of the Little Port Complex. Across the Bay of Islands lies the North Arm Mountain ophiolite complex. Lower structural slices (Curling and Northern Head Groups) of the Corner Brook succession as well as Eagle Island Fm. comprise the northeastern to eastern portion of the visible landscape. Wood's Island located immediately in the foreground is mostly comprised of Woods Island and Corner Brook succession lithologies. The two smaller islands directly to the west (Governors and Seal) are underlain by Blow Me Down Brook Formation.



**Figure 30:** Panoramic view of the outer Bay of Islands, as viewed from shoreline near Candlelite Bay Inn.

At this location, the rocks of the Blow Me Down Brook Formation, directly below the BIOC thrust sheet, are exposed (Figure 31). The Blow Me Down Brook formation occupies a belt of thick-bedded grey-green coarse-grained arkosic sandstone extending from Bonne Bay in the north to perhaps as far south as the east shore of Port au Port Bay. Sandstones show a combination of thick- and thin-bedded deposits of coarse and pebbly rocks that may be massive, graded, and cross bedded. Finer interbeds include black,

green and red shale and siltstone. In a few places a carbonate boulder conglomerate is seen in the middle of the formation (Gillis and Burden 2006).

The Blow Me Down Brook formation was originally interpreted as Early Ordovician flysch positioned at the top of the Humber Arm Supergroup (Stevens, 1970). However, the discovery of the trace fossil *Oldhamia* in the shaly strata of the formation indicates that it is Early Cambrian and therefore should be placed at the base of the Humber Arm Supergroup (Lindholm and Casey, 1990; Cawood et al., 1988). From palynomorph studies Lavoie et al. (2003) suggest the Blow Me Down Brook formation may be laterally correlative to the Summerside and Irishtown formations of the Curling Group with the Labrador Group of the shelf successuon.

The Blow Me Down Brook formation is interpreted as a deep marine deposit, formed on a rifted continental margin. Paleoflow measurements taken at numerous locations suggest a southerly trend, and possibly down the axis of a graben. Channels, dewatering structures, conglomeratic units and partial Bouma sequences support the submarine fan interpretation. However, it is likely that the coarse arkosic unit was deposited in a shallower marine setting. In contrast, the upper parts of the formation contain more quartzose sandstones likely sourced from mature coastal sands, which tend to have a little more porosity and may be petroliferous (Hicks et al., 2010).



**Figure 31:** Thick bedded, steeply dipping, greenish-grey Blow Me Down Brook Formation turbiditic sandstone exposed at Candlelite Bay Inn shoreline.

### **Stop 3.5: Cooks Brook**

**(Long: -58.06770367 Lat: 48.97013911)**

*Continue towards Corner Brook until you reach Cooks Brook.*

***Caution: Take care crossing the road, if necessary. The rocks in the brook may be slippery.***

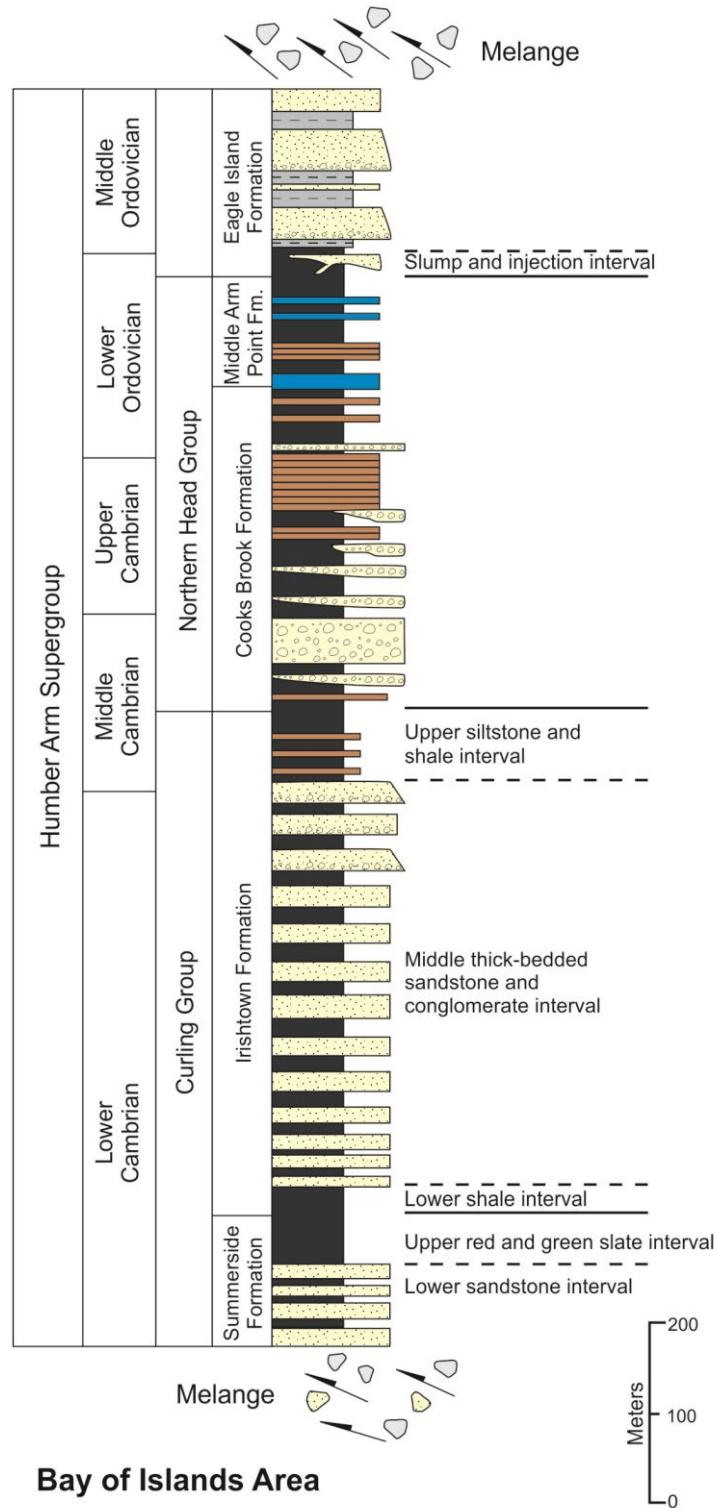
Enter the brook on the north side of the road and work downstream to see typical sections near the base of the Cooks Brook Formation (Figure 32) and the top of the underlying Irishtown Formation. There are substantial sections of dark grey to black shale in both the uppermost Irishtown Formation and the lower Cooks Brook Formation, and there is the possibility of structural repetitions complicating the stratigraphy. The Cooks Brook Formation here represents the Middle Cambrian deep-water equivalents of the Port au Port Group and lower part of the St. George Group of the shelf succession. Thin beds of limestone represent carbonate turbidites that flowed down the continental slope. Finer-grained limestones may also represent the deposition of shelf muds that were suspended in major storms and then settled in deeper water. Locally, the Cooks Brook Formation contains substantial layers of limestone conglomerate derived from slope failures at the platform edge or higher up on the continental slope. One of these is visible in the highway cut about 400 m west of Cook's Brook (Figure 33).



**Figure 32:** Cook's Brook Formation (Northern Head Group); at Cook's Brook, Route 450.



**Figure 33:** Cook's Brook Formation (Northern Head Group) Conglomerate.



**Figure 34:** Generalized stratigraphy of the Humber Arm Supergroup within the Bay of Islands (modified from Botsford, 1987).

### **Stop 3.6: Seal Head, Corner Brook Waterfront (Railway Syncline)**

**(Long: -57.93743795 Lat: 48.96126432)**

*Continue towards Corner Brook, drive towards the waterfront area. Park safely on the waterfront side of the road.*

***Caution: Please stay on the waterfront side of the road; if crossing for any reason, take care to avoid traffic and under no circumstances should one stand directly beneath the cliff where falling rocks pose a serious and potentially deadly hazard.***

This stop provides an excellent vantage point to observe a spectacular folded section within strata of the Humber Arm Allochthon at the Corner Brook waterfront (Seal Head) (Figure 35). The cliff section displays a magnificent syncline in quartz-rich sandstone and conglomerate of the Irishtown Formation (Lower Cambrian) of the Curling Group. Although the fold appears symmetric in the SW-NE cutting, this is an illusion; the hinge actually trends north northeast –south southwest, so the view in the cliff is very oblique, and the observed dips are apparent. A profile view reveals that this is an overturned fold, with a near-vertical to overturned west limb and a much gentler east limb. The cleavage dips moderately west, and is axial planar to the fold, making it an F2 fold, formed after the original stacking of thrust slices onto the continental margin. The syncline can be traced through the hill and is exposed in three more cross-sections to the south southeast: on both sides of the Lewin Parkway roadcut and on the southwest side of Hospital Hill behind West Street (northeast direction).



**Figure 35:** East verging, close to tight, F2 synclinal fold at Seal Head, Corner Brook waterfront.

### ***Stop 3.7: Riverside Drive / TCH Intersection (Route 1)***

**(Long: -57.87857137 Lat: 48.95011558)**

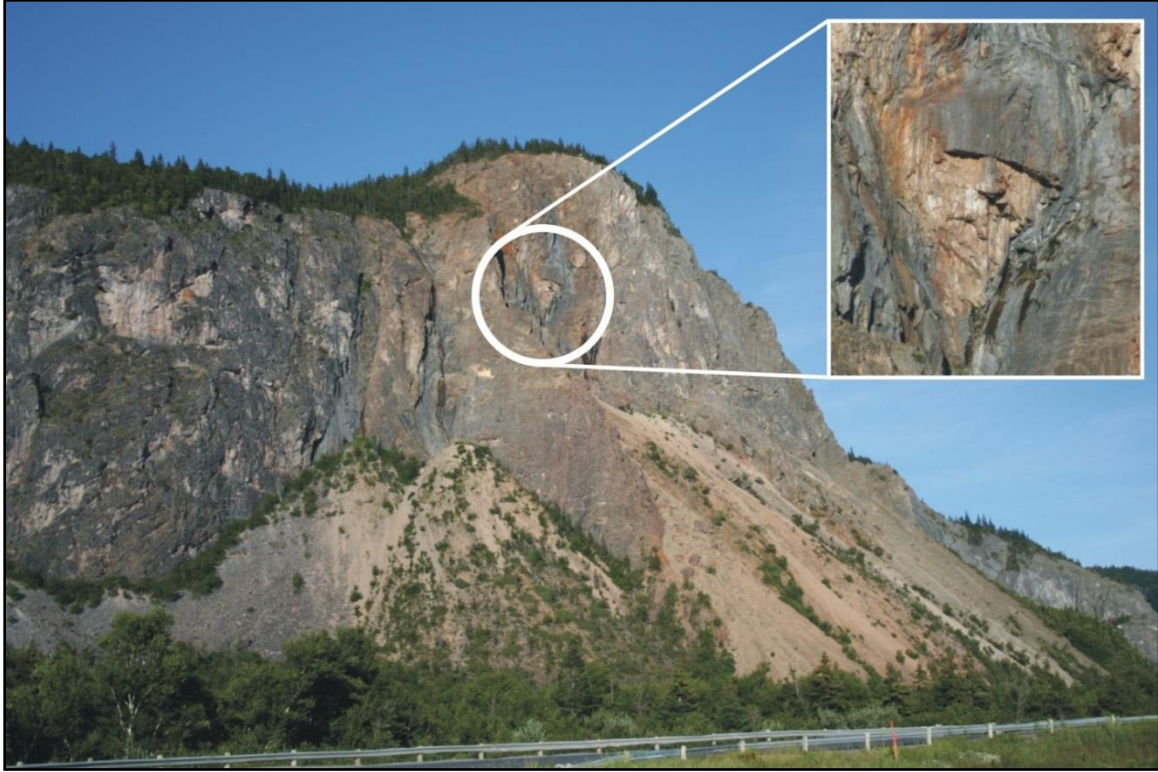
*Leave Corner Brook and drive east along TCH. Take exit to Riverside and park in the carpark on the north side of the road.*

***Caution: There are no perceived safety hazards at this site; participants are advised to stay within the parking area and not stray onto the TCH.***

The south facing cliff seen on the opposite (north) side of the Humber River exposes a thick section of steep to vertically dipping, mid to late Cambrian, Port au Port Group (Petit Jardin and Berry Head formation) carbonates (dolostone, limestone), underlain eastward at Bear Head by Reluctant Head formation ribbon limestone, grainstone, limestone conglomerate/breccia and phyllite. The contact is conformable and diachronous (Knight and Boyce, 2009). The same contact, repeated by folding is exposed a few kilometers upstream at the entrance to Humber gorge.

Referred to as the Goose Arm Thrust Stack from Bonne Bay to the south of Corner Brook (Knight, 1997), the carbonate succession is a narrow, NE – SW trending belt of predominantly limestone and dolostone, limestone conglomerate/breccia and minor shale. Field mapping by Knight and Boyce (2009) show the thrust stack to be a detached thin skinned sequence, with transport distance problematic at best. The stack is bounded to the west by the Hughes Brook fault (Cawood and van Gool, 1998) or alternately, the Watson's Brook shear zone (Waldron et al., 2003), separating the para-autochthonous (minimal transport) carbonates from overlying Humber Arm allochthonous (substantial transport) rock sequences. Towards the east at Marble Mountain, the lowermost Reluctant Head formation is in fault contact with metaclastic rocks (pelites and psammities) of the Mount Musgrave Group. The contact, termed the Humber River fault parallels the base of the NE – SW trending ski hill and defines the boundary between the Internal (highly deformed / metamorphosed) and External (weakly deformed / mostly non-metamorphic) Domains of the Humber tectono-stratigraphic zone of the Appalachian orogen (Williams, 1979).

Above the steep talus slope and about halfway up the cliff face at Bear Head, there occurs within the limestone strata a natural rock feature locally referred to as the "Old Man in the Mountain" (Figure 36). Legend has it that pirates had at one time sailed into the outer Bay of Islands and hid for a short period of time behind one of the many islands to escape detection from naval ships. To avoid capture and run the risk of losing their plundered treasure, they decided to sail further up the bay into Humber Arm and bury their treasure on Shellbird Island, which lay a few kilometres from the mouth of the Humber River. In order to locate their treasure at some future time, the pirates marked its location by carving an old man's face into the cliff, positioning it to stare remorsefully down on the treasure location. According to local folktales, many attempts have been made to locate the pirate riches, but to this day it has escaped detection.



**Figure 36:** Port au Port group carbonates underlain (extreme right of photo) by Reluctant Head formation ribbon limestone, limestone conglomerate/breccia and phyllite. These units form part of the Goose Arm Thrust Stack. Insert – close up view of the “Old Man in the Mountain”.

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