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QUATERNARY GEOLOGY AND TILL GEOCHEMISTRY OF THE BONAVISTA PENINSULA

M.J. Batterson and D.M. Taylor
Geophysics, Geochemistry and Terrain Sciences Section

ABSTRACT

Surficial geology mapping and a regional till geochemistry survey were completed on the Bonavista Peninsula and areas to the west. Mapping involved the identification of landform and sediment types and included the measurement of paleo ice-flow indicators, as a means of reconstructing the areas' ice-flow history. Sampling of surface tills was at a density of 1 sample per 1 km^2 in areas of road access, to 1 sample per 4 km^2 in areas where helicopter support was required. A total of 1135 samples were collected during the survey.

During the last glaciation, the Bonavista Peninsula was almost entirely covered by eastward-flowing ice, derived from an ice dispersal centre to the west of the study area, likely Middle Ridge. Glacier flow was drawn down into Goose Arm, Sweet Bay and Southern Bay and thence into Bonavista Bay, or through Smith Sound, Northwest Arm or Trinity Harbour into Trinity Bay. This drawdown effect was more pronounced as the ice began to thin and became topographically controlled during deglaciation. The Bonavista Peninsula, north of a line between Trinity and Plate Cove West, was covered by an independent ice centre. Ice flow from this latter centre was coastward from a northeast–southwest-trending ice divide that followed the height of land.

Deglaciation was toward the major dispersal centres. The trend of esker ridges on the Tug Pond area shows westward retreat, likely toward the Middle Ridge area. Raised marine terraces are found at similar elevations around the peninsula (maximum 28 m asl), suggesting simultaneous retreat of ice and the accompanying marine incursion. The timing of deglaciation and the pattern of postglacial sea-level change are uncertain because of the paucity of dateable material.

INTRODUCTION

Mapping of the surficial geology and associated sampling for till geochemistry were completed on the Bonavista Peninsula as part of an ongoing program by the Geological Survey to provide complete till-geochemistry coverage for, at least, the island portion of the province. This is the first year of a multi-year till sampling and surficial geology mapping project covering the Bonavista, Burin and Avalon peninsulas. The results from this project will add to that collected from similar projects in the Grand Falls – Mount Peyton area (Batterson *et al.,* 1998), Hodges Hill area (Liverman *et al.*, 2000) and the Buchans – Robert Arm Belt area (Liverman *et al.,* 1996).

The objectives of the program included surficial geological mapping, and the determination of the paleo ice-flow history of all, or parts, of the eight 1:50 000 NTS map areas that form the Bonavista Peninsula and areas to the west; it includes part of Old Perlican (NTS map area 2C/3), part of Random Island (NTS map area 2C/4), Sweet Bay (NTS map area 2C/5), Trinity (NTS map area 2C/6), Bonavista (NTS map areas 2C/10 and 11), part of Eastport (NTS map area 2C/12), Tug Pond (NTS map area 2D/1, excluding the Bay du Nord wilderness area), and part of Port Blandford (NTS map area 2D/8) (Figure 1).

LOCATION, ACCESS AND PHYSIOGRAPHY

The Bonavista Peninsula is located in eastern Newfoundland and access to the area is good because of a network of paved and gravel roads, and abandoned railway tracks. The area west of the Trans-Canada Highway (TCH) generally has poor access, except for the abandoned railway line adjacent to the highway, a few woods-roads or those accessing granular aggregate pits. Much of the Tug Pond map area and the southwestern part of the Port Blandford map area could only be efficiently accessed by helicopter.

The shaded-relief map (Figure 2) shows a land surface having elevations up to 350 m above sea level (m asl) west of Clarenville, corresponding to areas of a Devonian granite

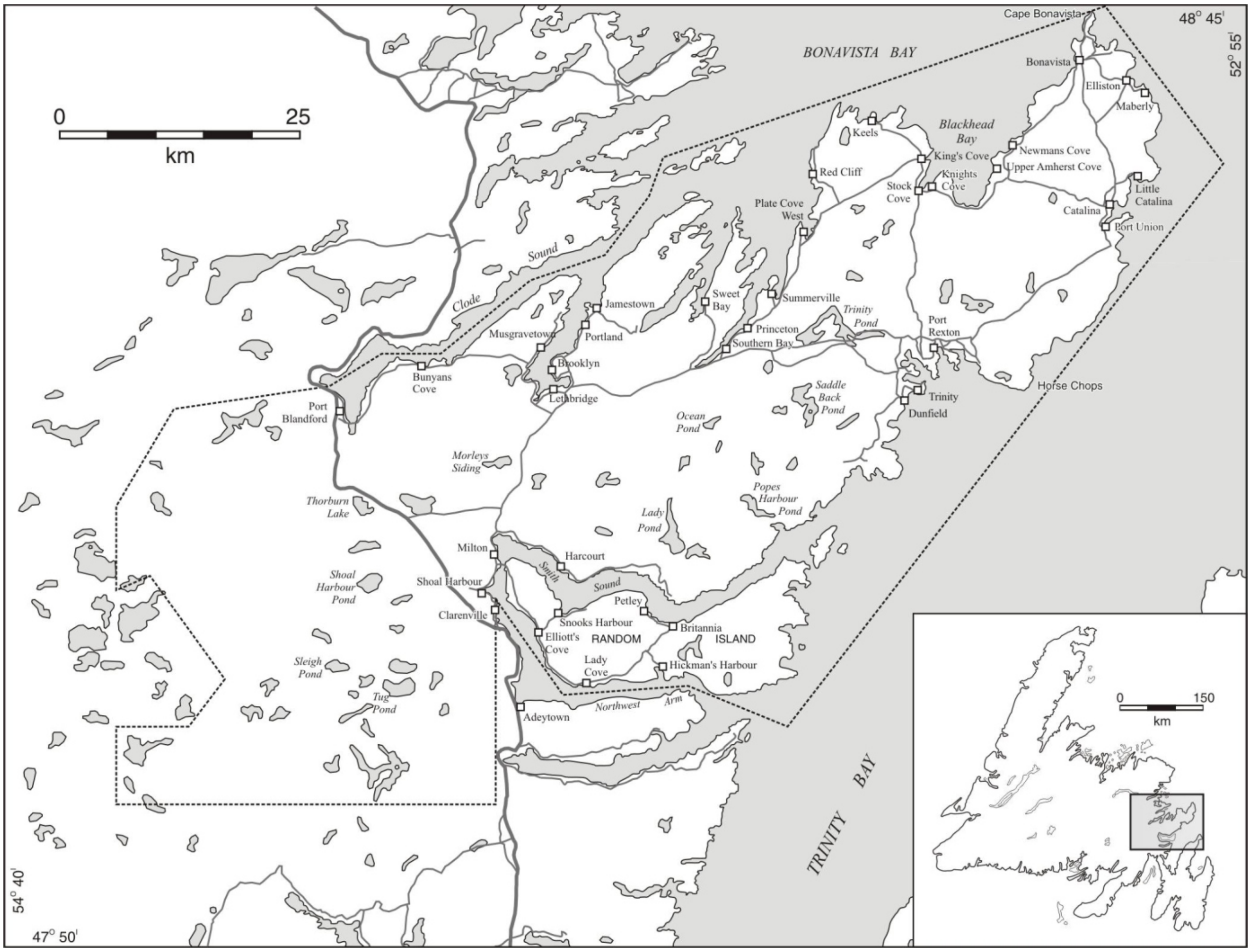


Figure 1. *Index map showing the study area and locations of various geographic sites.*

batholith. Much of the area to the east is below 180 m with the higher elevations corresponding to the western edge of the Musgravetown Group. The irregular relief pattern indicates thin sediment cover. Thicker tills producing a smoother topographic surface overlie the Late Cambrian Harcourt Group shale at the head of Smith Sound. The Bonavista Peninsula is flanked by Trinity Bay (down to 500 m deep) and Bonavista Bay (down to 200 m deep), and incised by fiord valleys including Clode Sound, Goose Bay, Sweet Bay and Southern Bay on the north coast, and Northwest Arm and Smith Sound on the south coast. These fiords reach depths of 200 m.

BEDROCK GEOLOGY AND MINERAL EXPLORATION

The study area lies to the east of the Dover Fault and is entirely within the Avalon Zone. Bedrock in the area has been mapped by Jenness (1963) and Christie (1950); some areas have been more comprehensively remapped by Dickson (1983) and O'Brien (1992).

Neoproterozoic rocks of the Love Cove, Connecting Point and Musgravetown groups (Figure 3) underlie much of the peninsula. The Love Cove Group has the oldest rocks in the area; these are mostly sericite and chloritic schist, associated acidic and intermediate volcanic lava and pyroclastic rocks that are common south of Clode Sound. The Love Cove Group is unconformably overlain by the Connecting Point Group, a north–south-trending sequence of greywacke and slate containing minor quartzite, conglomerate and volcanic rocks. Most of the area is underlain by the Neoproterozoic Musgravetown Group rocks that consist of red and green conglomerate, sandstone, siltstone and some lava and tuff. Some small areas of Early and Middle Cambrian shale, slate, quartzite and limestone (Adeytown Group), and Middle and Late Cambrian shale and siltstone (Harcourt Group) underlie the remainder of the field area.

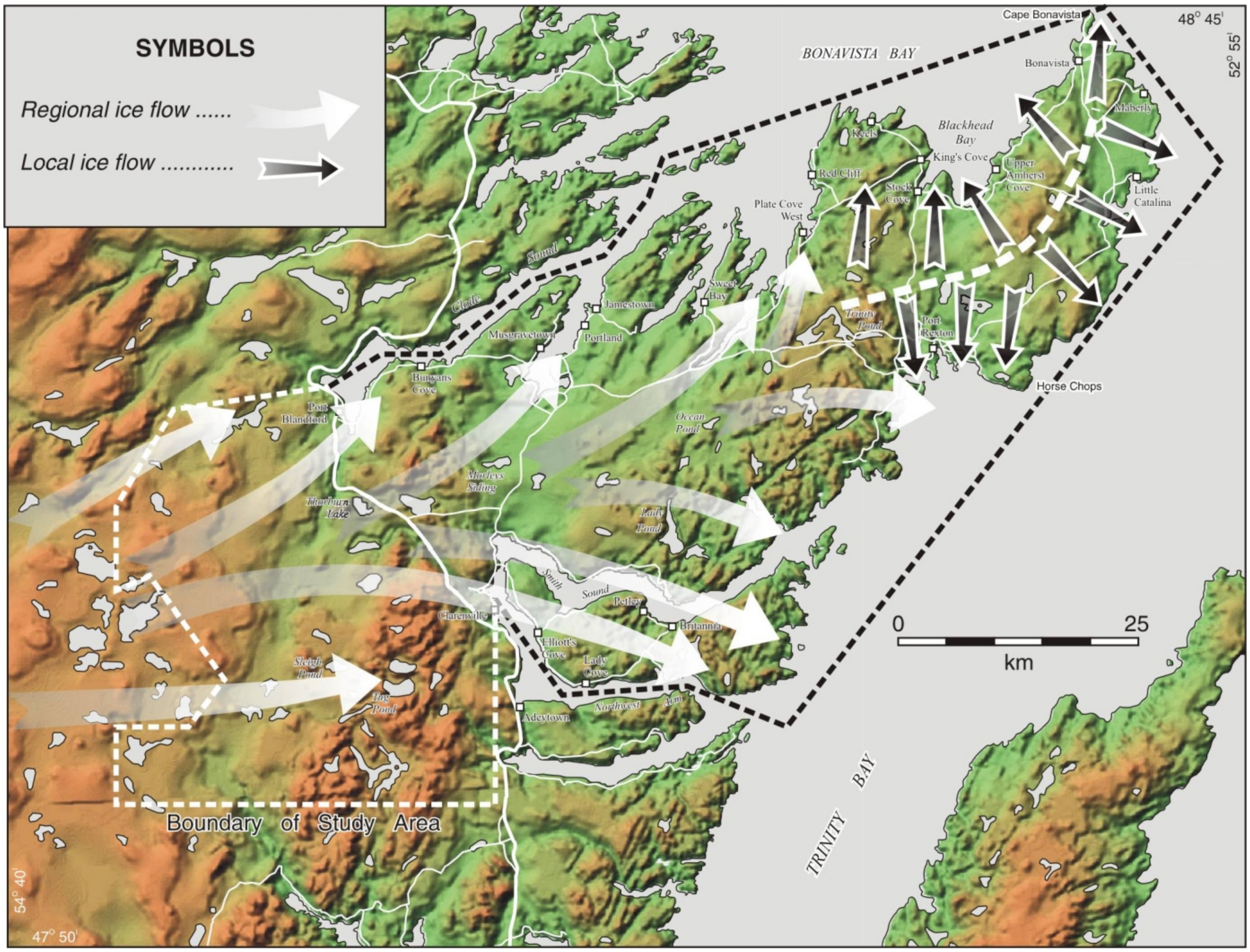


Figure 2. *Shaded-relief and generalized ice-flow map. Data derived from the Newfoundland Striation database (Taylor* et al., *1994).*

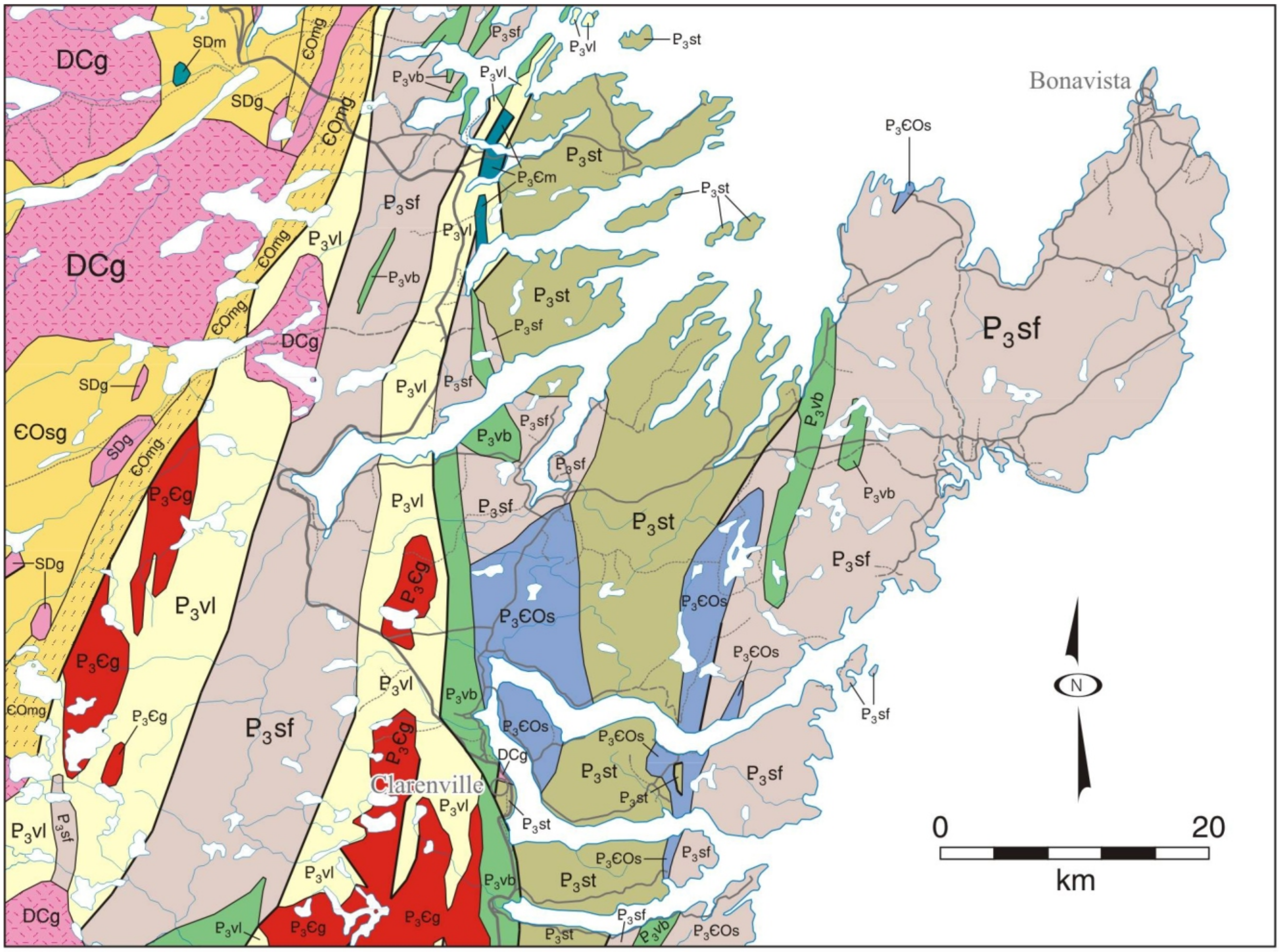
The southeast part of the Tug Pond map area, and the western margin of the field area, are underlain by Devonian granitic intrusions. The granites exhibit a variety of textures, colours and mineralogy, but are commonly pink, buff and orange-red, fine to coarse grained, and some are biotite-rich.

The ubiquitous distribution of rock types that cover much of the Bonavista Peninsula make clast–provenance studies difficult. Gross patterns of clast dispersal were identified from mapping the distribution of plutonic rocks from Devonian batholiths in the western part of the field area.

MINERAL DEVELOPMENT

The Bonavista Peninsula has a history of mineral development, particularly industrial minerals. Random Island and the northwest corner of Smith Sound are underlain by grey to black Harcourt Group shale that was the focus of the Newfoundland brick industry (Jenness, 1963; Martin, 1983) (Plate 1). Brickyards existed at Elliots Cove (1890 to 1903), Snooks Harbour (1895 to 1951), Harcourt (ca. 1835 to 1920), and Milton (1886 to present). All these brickyards initially used Quaternary sediments for their raw material, commonly clay-rich diamictons derived from the shale, except for the Milton site where glaciolacustrine or glaciomarine mud was mined. Early brickmaking was labour intensive and involved the hand-picking of clasts from the sediment before it could be pressed into moulds. In 1953, the construction of the causeway to Random Island allowed mining of shale bedrock from Random Island, and transportation to the brick plant at Milton.

Slate has been quarried since the 1850s from the Bonavista Formation that bisects Random Island extending northward to Ocean Pond, with a small outlier near Keels in the northern part of the Peninsula. Several quarries have



POST-ORDOVICIAN INTRUSIVE ROCKS

Devonian and Carboniferous

DCg — Granite and high silica granite

Silurian and Devonian

SDm — Gabbro and diorite intrusions

SDg — Gabbro-syenite-granite-peralkaline granite suites and minor unseparated volcanic rocks

GANDER ZONE

Stratified rocks

Cambrian(?) and Ordovician

ЄOsg — Quartzite, psammite, semipelite and pelite, including minor black slate, conglomerate and limestone

ЄOmg — Migmatitic schist, gneiss, and minor amphibolite

AVALON ZONE

Stratified rocks

Eastern Newfoundland

Neoproterozoic to Early Ordovician

P_3ЄOs — Mainly fine grained, siliciclastic sedimentary rocks, including limestone and volcanic rocks

AVALON ZONE

Stratified rocks (continued)

Neoproterozoic

HARCOURT AND ADEYTOWN GROUPS

P_3sf — Fluviatile and shallow marine siliciclastic sedimentary rocks, including limestone and bimodal volcanic rocks

MUSGRAVETOWN GROUP

P_3vb — Bimodal, mainly subaerial volcanic rocks, including unseparated siliciclastic sedimentary rocks

CONNECTING POINT GROUP

P_3st — Sandstone and shale turbidites, including tillite, olistostromes and volcanic rocks

LOVE COVE GROUP

P_3vl — Submarine to subaerial volcanic rocks, including siliciclastic sedimentary rocks

Intrusive rocks

Neoproterozoic to Cambrian

P_3Єm — Mafic rocks

P_3Єg — Granitoid rocks

Figure 3. *Bedrock geology (from Colman-Sadd* et al., *1990).*

existed at Nut Cove (Carberry's from ~ 1850 to 1900; Currie's from 1860 to 1906), two at Hickmans Harbour (1906 to 1910); at Black Duck Cove on the south side of Northwest Arm; and at Keels (Martin, 1983). The quarry at Nut Cove reopened in 1999 as Hurley Slateworks and is producing slate roof tiles for the United Kingdom and United States markets.

Plate 1. *Remains of the brickyard at Snooks Harbour, Random Island operated by the Smith family from 1895-1951.*

There has been only a limited amount of mineral exploration on the Bonavista Peninsula. In 1971, Radex Minerals and Sheeba Mines identified small reserves of copper within the Love Cove Group meta-andesites (Forgeron and Goodman, 1971) near Tug Pond. Lead (Hatchet Cove, Little Catalina and Bloomfield) and copper (near Hickmans Harbour) showings have been reported, but all are small and currently uneconomic (Mineral Occurrence Data System, 2000). Cornerstone Resources has been exploring for copper on the Bonavista Peninsula since the mid-1990s (Cornerstone Resources Inc., 2000). Copper mineralization has been found at their Princess Group and Red Cliff properties. The Princess Group property near Musgravetown is within late Neoproterozoic siliclastic sedimentary rocks of the Connecting Point Group that are unconformably overlain by clastic sedimentary and volcanic rocks of the Musgravetown Group. Most mineralized zones are within the Canning Cove Formation and an overlying unnamed unit that contains mafic and felsic volcanic rocks, both in the lower units of the Musgravetown Group. The Red Cliff property is located between Plate Cove East and Kings Cove. This area is underlain by the Neoproterozoic Crown Hill Formation of the Musgravetown Group (Jenness, 1963). The Crown Hill Formation contains redbed sequences intercalated with green to grey reduced units of sandstone and siltstone that host copper mineralization (Cornerstone Resources Inc., 2000).

QUATERNARY GEOLOGY REVIEW

The entire Bonavista Peninsula, apart possibly from Burnt Ridge near Bonavista (Brookes, 1989; Grant, 1989) were covered by ice during the last, late Wisconsinan, glacial period (Jenness, 1963). Coastal areas were ice-free by 13.0 ka based on radiocarbon dates of marine shells from cores beneath Bonavista Bay (Cumming *et al.*, 1992).

Jenness (1963) described a sequence of late Wisconsinan glacial events for the Bonavista Peninsula consisting of an initial eastward advance across the entire area followed by retreat to a position defined by an arcuate margin between Tug Pond and Clode Sound, and subsequently complete deglaciation. The early retreat position defined the boundary between an "inner" and "outer" drift zone. The inner drift zone is characterized by thicker drift and numerous esker ridges, whereas the outer drift zone contains generally thinner sediment cover and valleys containing outwash sediment from the melting ice inland.

Brookes (1989) identified two separate sources of late Wisconsinan ice on the Bonavista Peninsula, based on striation and clast–provenance data. The western Bonavista Peninsula was covered by eastward-flowing ice derived from the Newfoundland Ice Cap (likely Middle Ridge), which was progressively drawn-down into the larger bays that indent the Peninsula. The northern Bonavista Peninsula maintained a dynamically independent, but contiguous ice cap termed the Bonavista Ice Divide (Brookes, *op. cit.*). Ice flow from this divide was coastward into Trinity or Bonavista bays. The inferred boundary between the two late Wisconsinan ice masses was approximately along a line between Trinity and Plate Cove West. Brookes (*op. cit.*) also described a nunatak in the area of Burnt Ridge, a low (140 m asl) ridge near Bonavista. The nunatak was inferred by the presence of felsenmeer (Plate 2), the absence of erratics and a subdued moraine wrapping around the base of the hill.

Plate 2. *Felsenmeer on Burnt Ridge near Bonavista. Brookes (1989) suggested the area may have been a late Wisconsinan nunatak.*

Over 600 ice-flow indicators have been recorded from the study area (Taylor *et al.*, 1994), of which, 342 were collected during this study. The results from this data indicate the existence of two separate ice-dispersal centres (Figure 2). Most of the study area was covered by eastward-flowing ice from a centre to the west of the study area, likely the Middle Ridge area of central Newfoundland. In the area west of the TCH, commonly only a single flow is found, whereas farther east on the Bonavista Peninsula two or more flows are recorded. Later flows are consistently oriented coastward, suggesting the influence of topography as thinning ice was drawn-down into the major bays during deglaciation.

Cumming *et al.* (1992) used high-resolution seismic and core data from Bonavista Bay to show that grounded ice extended well beyond the present coast during the late Wisconsinan maximum (20 to 18 ka). Radiocarbon dating of marine macrofossils from cores showed a sequence of initial retreat at about 13.5 ka, to eventual open marine conditions by 12.8 ka, although remnant ice may have remained on the Bonavista Peninsula following this time.

ICE-FLOW HISTORY

The movement of paleo ice-flow on the Bonavista Peninsula was determined from erosional evidence, commonly striations on bedrock, and from limited clast–provenance data. In the study area, constructional landforms (moraines either parallel or perpendicular to ice flow) are rare. Where possible, direction of ice flow was determined from stoss-and-lee patterns and rat-tail structures on bedrock surfaces, and nailhead striations. A brief, clast–provenance study, based on 71 sites from across the Peninsula, was completed to test the hypothesis of Brookes (1989) that flow from the Newfoundland Ice Cap did not extend beyond a line running between Trinity and Plate Cove West. About 50 clasts (5 to 20 cm in diameter) were collected from each site, including samples of those rock types not derived from the underlying bedrock as determined from the bedrock geology maps (Jenness, 1963).

The northern Bonavista Peninsula record coastward-directed striations from an ice divide oriented northeast–southwest along the height of land. Commonly, only a single flow was recorded, although two flow directions (southeast crossed by northeast) were found along the highway south of Bonavista. The ice cap on the tip of the Bonavista Peninsula acted independently of ice covering the remainder of the Peninsula. This ice-flow regime for the Peninsula is inferred by the striation pattern, and confirmed by the clast–provenance data. Granite clasts derived from the Devonian rocks, west of Clarenville, are common in tills on the western part of the Peninsula, indicating transport of up to 50 km from their source (Figure 4). In contrast, tills examined on the northeastern part of the Peninsula contained no granitic clasts. Rare volcanic clasts found in tills were derived from the Musgravetown Group that underlies most of the northern part of the peninsula. The ice-flow pattern as determined from this new data is generally consistent with that originally described by Brookes (1989). No ice-flow indicators or erratics were found on the proposed nunatak at Burnt Ridge. Similarly, no erratics were located on the ridge, although this finding is consistent with the rest of this part of the Peninsula.

Glacial retreat was toward the major dispersal centres. To the west of the TCH, meltwater was directed down valleys into Northwest Arm, Smith Sound and Clode Sound.

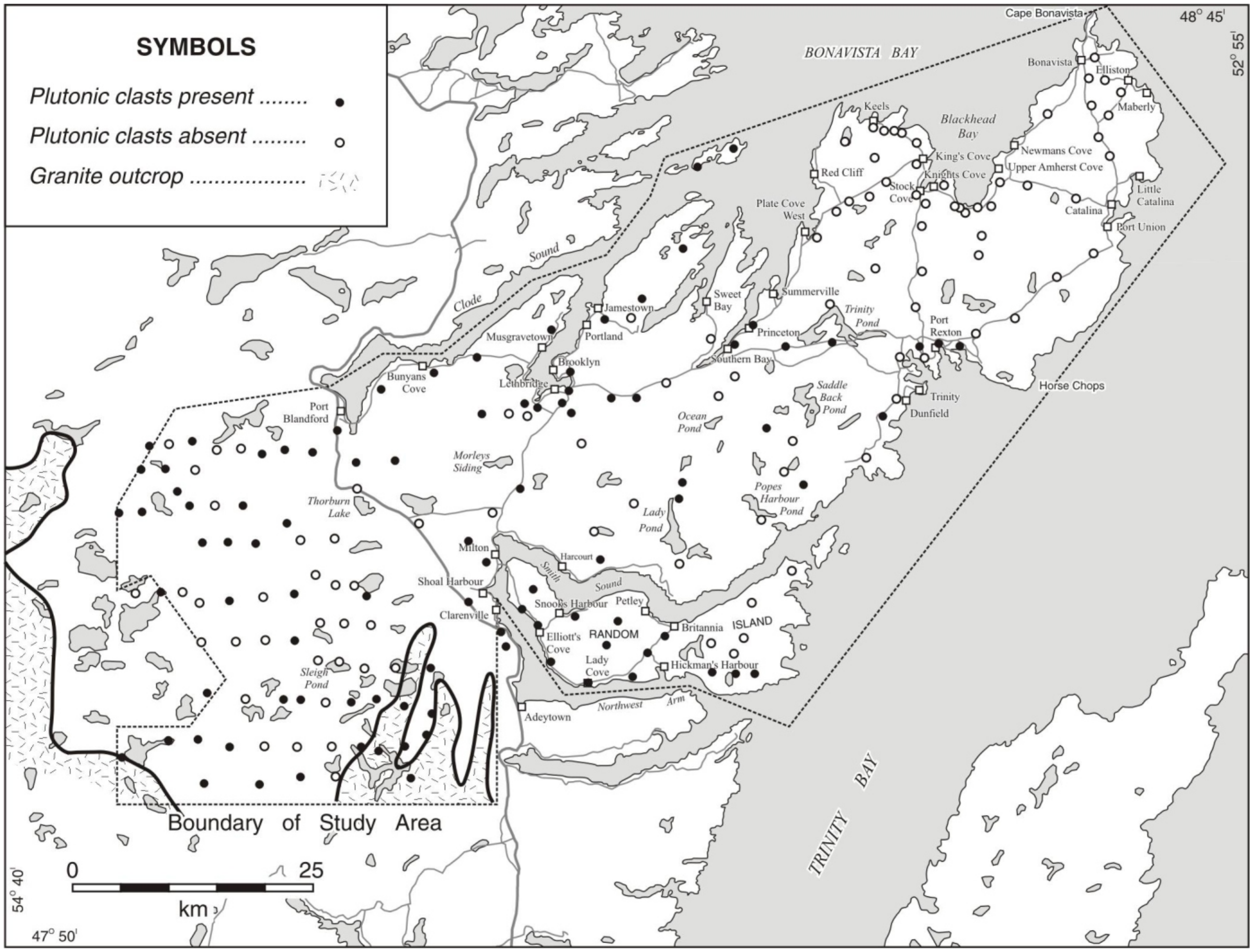


Figure 4. *Map showing dispersal of granite clasts across the Bonavista Peninsula. Source areas are Devonian granite outcrop in the western part of the area. Includes data from Brookes (1989).*

Some of these valleys contain thick deposits of sand and gravel, whereas others (e.g., lower reaches of Northwest River) are generally devoid of sediment. The pattern of esker distribution found on the peninsula suggest a westward retreat of the ice.

SURFICIAL GEOLOGY

BEDROCK

Large parts of the study area, particularly those underlain by the Musgravetown Group rocks and areas adjacent to the modern coast, are dominated by exposed bedrock. These areas include the eastern end of Random Island (Plate 3), and the area east of Ocean Pond. Much of the remainder of the area contains sporadic bedrock exposures. Few bedrock exposures are found at the head of Smith Sound (except along the coast), and on parts of the Tug Pond map area that are mainly bog and diamicton covered.

DIAMICTON

Diamicton occurs as thin (<2 m thick) discontinuous deposits. An exception to this distribution is the area underlain by, and immediately down-ice of, the Harcourt Group shale, which is covered by thicker, fine-grained diamicton. The texture of the diamicton on the Bonavista Peninsula is mostly bedrock controlled, with the finer grained bedrock producing finer diamictons than coarser grained bedrock. Diamicton distributed across the Peninsula are sedimentologically variable and difficult to characterize. Colour includes dark brown (Munsell colour 7.5YR 3/4), dark reddish brown (5YR 3/4), yellowish brown (10YR 5/6), olive brown (2.5Y 4/4), dark greyish brown (2.5Y 4/2) and dark red (2.5YR 3/6); most have a sandy matrix. Clast content of the diamicton is between 20 and 70 percent, and some clasts are invariably striated. Structures were not generally noted due to poor exposure, but where larger exposures were found, structures identified commonly included small (1 to

Plate 3. *Musgravetown Group bedrock exposed in the eastern part Random Island.*

10 cm long and 1 to 5 cm thick), planar, horizontal to sub-horizontal, normal graded to ungraded, sand lenses. These features are common in subglacial meltout tills (Ashley *et al.*, 1985; Shaw, 1987; Dreimanis, 1988).

GLACIOFLUVIAL

Sediments deposited by meltwater from receding glaciers are found in the western part of the field area. The valleys draining into Clode Sound, Smith Sound and Northwest Arm contain thick deposits of ice-proximal to ice-distal outwash sediment. In particular, the Shoal Harbour River, Shoal Harbour Pond, and Northwest Pond areas contain considerable reserves of outwash-derived granular aggregate, currently being mined. The western part of the Tug Pond map area contains several eskers more than 2 km long (Plate 4). These are potential aggregate deposits, but are currently inaccessible by road.

GLACIOMARINE–GLACIOLACUSTRINE–MARINE

In the study area, sediment deposited in either a marine or glaciomarine environment are found adjacent to the modern coast. They are more common at the head of bays than on exposed headlands that are commonly dominated by bedrock. Most marine sediment forms a veneer (<2 m thick) over till or bedrock, although geomorphological features such as terraces or beach ridges are found. Sediment is commonly coarse-grained gravelly sand to sandy gravel. Silt–clay is commonly less than 5 percent, and fossils are absent. The sediment texture suggests a moderate- to high-energy coastal environment, similar to that found today around the Bonavista Peninsula coastline.

At the head of Smith Sound are sediment deposited within an ice-proximal glaciomarine or glaciolacustrine environment; sediment such as these are difficult to distinguish from each other. The exposed section, adjacent to the abandoned brickyard at Milton, is a case in point; it is a 15 to 18 m high exposure having a surface elevation of 22 m asl. The section exposes planar interbedded sand, silt, clay and diamicton. Pebble to cobble clasts are common throughout, and are interpreted as dropstones (*cf.* Thomas and Connell, 1985; Powell and Molnia, 1989). The sediment was likely deposited within an ice-proximal aqueous environment, but it is not possible to determine whether it was either marine or lacustrine. Marine fossils were not found in the section, although this in itself is not unusual because coastal areas were dominated by freshwater inflow from melting ice inland (*cf.* Batterson, 1999). Such areas commonly contain sparse palynofloral assemblages, and determination of a marine or lacustrine origin is based on geomorphic evidence such as strandlines, channels connecting lake phases, or channels connecting a lake and the sea. These features are not evident at the head of Smith Sound, although Jenness (1963) suggested a glaciolacustrine origin, produced by ice blocking the head of Smith Sound.

Constructional features associated with a higher postglacial sea level are found in isolated places around the coast. A delta at Port Blandford (surface 15 m asl) contains no evidence of ice-proximal sedimentation. Exposures show a coarsening-upward sequence of clay, silt, sand and gravelly sand; marine terraces are more common (Figure 5). Of these, the highest was at Plate Cove West (28 m asl) (Plate 5), Dunfield (25 m asl), Plate Cove East (24 m asl) and Duntara (22 m asl). Raised beaches were noted at Bonavista (Plate 6) at an elevation of 14 m asl. No marine shells were found within Quaternary deposits on the Peninsula, and the timing of deglaciation and the postglacial history could not be determined from terrestrial evidence.

Plate 4. *East–west-trending esker on the western part of the Tug Pond map area. These features indicate westward retreat of late Wisconsinan ice and also provide excellent sources of granular aggregate.*

Plate 5. *Marine terrace at Plate Cove West. This feature has a surface elevation of 28 m asl and is the highest raised marine feature on the Bonavista Peninsula.*

Plate 6. *Raised beach at Bonavista at an elevation of 14 m asl.*

TILL GEOCHEMISTRY PROGRAM

Sediment sampling was conducted across the entire Peninsula, guided by the surficial geology. Marine and fluvial–glaciofluvial sediment was avoided during the sampling program. Most samples were BC- or C-soil horizon samples from till, although in rare cases the lack of surface sediment necessitated the sampling of bedrock detritus. A total of 1135 samples were collected, providing a sample density of 1 sample per 1 km^2 for road accessible areas to 1 sample per 4 km^2 for helicopter-supported sampling. Samples are being analyzed for a wide range of elements in the Geological Survey's geochemical laboratory, plus at an external laboratory for INAA analysis.

GLACIAL HISTORY AND IMPLICATIONS FOR MINERAL EXPLORATION

The Bonavista Peninsula was covered by ice from two distinct sources during the last, late Wisconsinan glacial period. Most of the area was crossed by northeastward- to eastward-flowing ice from an ice-dispersal centre west of the field area, likely Middle Ridge. The ice-flow pattern is indicated by the direction of glacial striations etched on bedrock surfaces and on the distribution of clasts. The dispersal of granitic clasts from their source areas, west of Clarenville, indicates dispersal distances up to at least 50 km, although most material (>95 percent) at a site is contiguous to that of the underlying bedrock. However, individual clasts may be far-transported. The northern tip of the Bonavista Peninsula maintained an independent ice cap, with ice flow being coastward from a central divide, supporting the reconstruction of Brookes (1989). No evidence, striations or clasts, were found to indicate the regional northeast ice flow crossed this area. This suggests that the northern ice cap developed before the main ice advance reached the area, and that it was of sufficient thickness not to be overtopped by it. The draw-down of ice into Bonavista

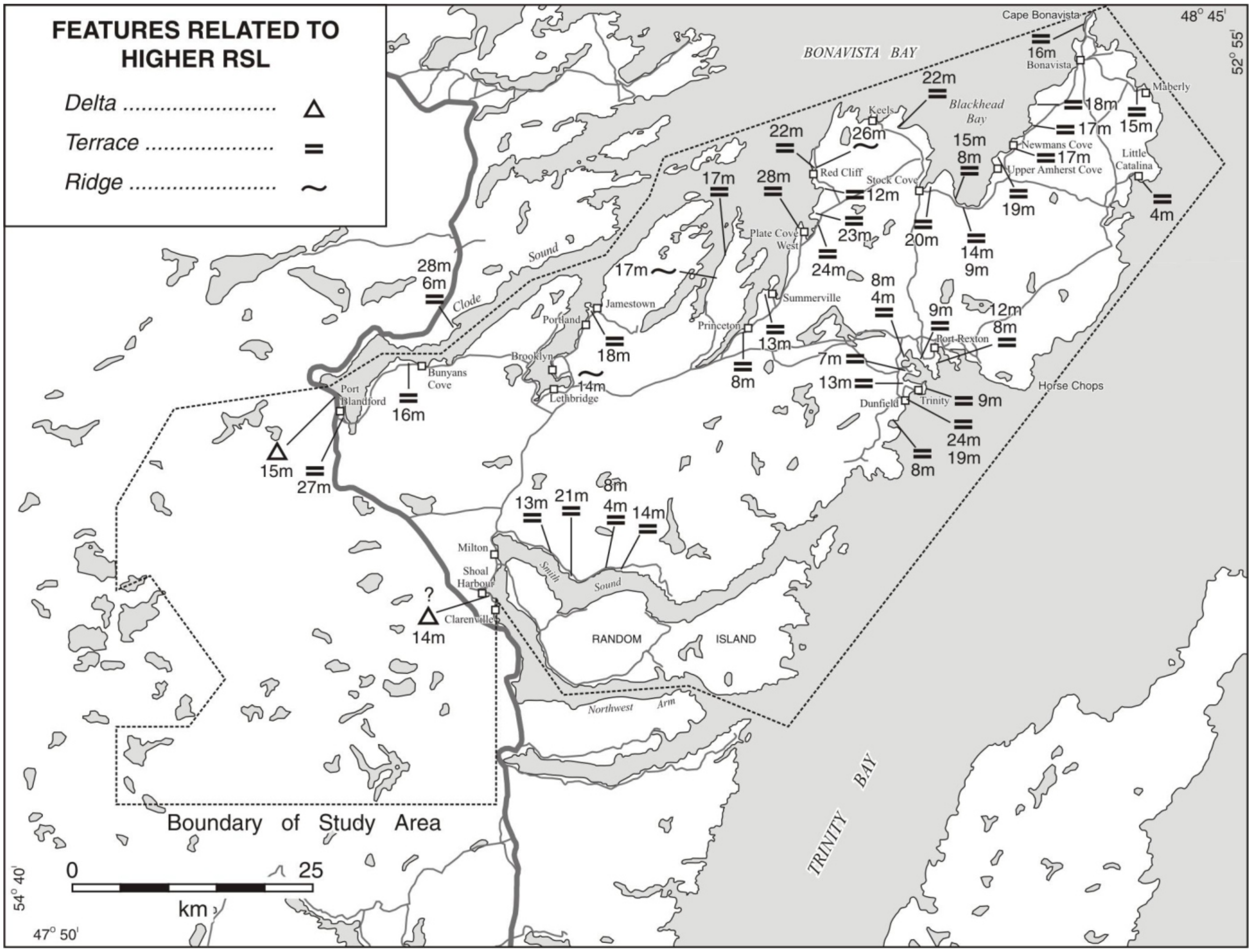


Figure 5. *Map showing distribution of raised marine features.*

and Trinity bays indicates that the regional ice flow was likely confluent with that from the northern ice cap. Glacial dispersal distances in this area are likely short, probably less than 10 km.

During deglaciation, the two ice masses disintegrated at about the same time. This is suggested by the similarity in elevation of raised marine features found around the Bonavista Peninsula coast. Marine / glaciomarine sediments are found around the modern coastline, more common at the head of bays rather than on exposed coastal headlands. These areas should be avoided in drift exploration sampling programs. The timing of deglaciation is uncertain because of the lack of dateable material within marine sediments. The closest terrestrial-based radiocarbon date is from St. Chads on the Eastport Peninsula. The date of 12 400 ± 110 years BP (GSC-5413) is from *Hiatella arctica* shells at 14 m asl within marine muds, and was interpreted as a minimum date for deglaciation of the area (Batterson *et al.*, 1992). This is similar to the conclusion of Cumming *et al.* (1992) that Bonavista Bay was deglaciated by 13.5 ka and that inner coastal areas were ice free by ~13.0 ka, based on radiocarbon-dated marine shells recovered from cores.

The area contains some potential for granular aggregate deposits, mostly eskers found on the Tug Pond map area. However, these are currently inaccessible by road. Other granular aggregate deposits are currently being quarried.

PROJECT DEVELOPMENT

This is the initial year of the Quaternary mapping and till geochemistry of eastern Newfoundland project. Surficial mapping of the Bonavista Peninsula will be released in 2001, and may accompany the till-geochemistry data release. Subsequent work will involve till sampling of the northern Burin Peninsula and the Avalon Peninsula, with associated surficial mapping as appropriate.

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