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SURFICIAL GEOLOGY OF THE ST. FINTAN'S, LITTLE FRIARS COVE AND FLAT BAY MAP AREAS (NTS 12B/2, 12B/3 and 12B/7)

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ABSTRACT

The surficial geology of southern St. George's Bay consists of a broad coastal plain covered by till inland and gravel closer to the coast. In the highland areas, a mix of bedrock, till veneers and patches of thicker till is found. Ice-flow mapping was through a combination of till fabric analysis and striation mapping. An early, coast parallel flow, possibly originating from outflow from the Stephenville area, deflected by ice in the Gulf of St. Lawrence, is identified. As ice retreated, ice-flow directions changed to be dominantly westward, from an ice cap centred over the adjacent Long Range Mountains. Although there is no conclusive evidence, erratics and striae found in the Anguille Mountains suggest that their summits were over-topped by ice. Further retreat led to topographic control of ice flow, with diversion of ice along the valley containing Codroy Pond. Deglaciation resulted in complex sedimentary sequences, now exposed at the coast, as the ice sheet grounded in the sea. Thick marine clays pose a geotechnical problem in construction. Such clays are highly susceptible to slope failure, as shown by large rotational slumps along the coast. The coast is eroding rapidly, and construction close to the current cliff edge should be avoided.

INTRODUCTION

Southern St. George's Bay is an important area in the study of the Quaternary history of insular Newfoundland. The excellent coastal exposure of thick sequences of Quaternary sediments encouraged detailed study over many years (MacClintock and Twenhofel, 1940; Brookes, 1969, 1974, 1977; Liverman and Bell, 1996), and is the basis of the only formalized Quaternary stratigraphy in Newfoundland. This three-fold stratigraphy of the St. George's River Drift, overlain successively by the Bay St. George Delta, and the Robinson's Head Drift, was first identified by MacClintock and Twenhofel (1940); and formalized and dated by Brookes (1969, 1974, 1977). Later, Liverman and Bell (1995) suggested that the sediments were amenable to alternative interpretations, particularly with regard to sedimentology and chronology.

Comparatively little attention has been paid to the surficial geology of the area away from the coast. This part of Newfoundland is a mixed land use area, having numerous small agricultural and fishing villages along the coastal plain that runs from Flat Bay to Highlands, and extensive logging operations inland on the coastal plain and in the foothills of the Long Range and Anguille mountains. A better understanding of the surficial geology will aid in soil mapping, agricultural development, road construction, groundwater studies, waste disposal, forest management, and fisheries management in the area. In terms of mineral resources, the area hosts a former mine (the gypsum operation at Flat Bay), an active gypsum quarry in the Robinsons area, and has potential for salt mining. The foothills of the Long Range Mountains are being actively prospected for base metals and gold. The extensive cover of Quaternary sediments has resulted in significant aggregate resources. An understanding of surficial geology and ice-flow history will aid in mineral development in this area.

The 1998 field season had the following objectives:

- mapping the surficial geology of southern St. George's Bay;
- mapping the ice-flow history using striations and clast fabrics;
- logging coastal sections to more fully understand the deglacial stratigraphy and sedimentology, and
- develop the Quaternary geological history of the area.

The stratigraphic studies are the subject of a companion article (Bell *et al., this volume*), and are not discussed in detail here.

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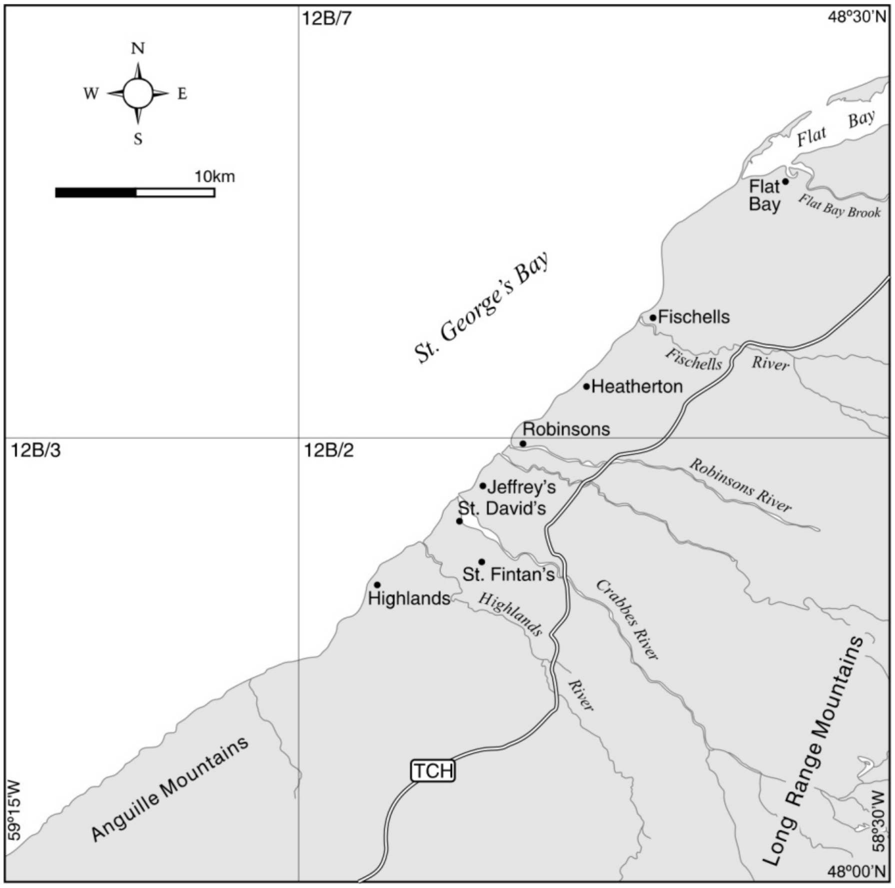

Figure 1. *Location map of the study area.*

The area was divided for the purposes of efficient field mapping (Figure 1). DL was responsible for mapping NTS 12B/7 (Flat Bay) and part of NTS 12B/2 (St. Fintan's) north of the Crabbes River. KS mapped NTS 12B/3 (Little Friar's Cove) and part of NTS 12B/2 south of the Crabbes River. DT conducted striation mapping throughout the area.

LOCATION AND ACCESS

The study area lies almost halfway between the larger communities of Stephenville and Port-aux-Basques. Numerous smaller communities are found along the coast including (from south to north), Highlands, Maidstone, St. David's, Jeffrey's, Mackay's, Robinsons, Heatherton, Fischells, Journois, and Flat Bay (Figure 1). Field access is generally good, through coastal exposure, the Trans-Canada Highway that runs northeast–southwest through the study area and provincial highways 403, 404 and 405 that link the communities along the coast to each other and to the Trans-Canada Highway. Numerous logging roads run from the Trans-Canada Highway into the foothills of the Long Range Mountains, and into the Anguille Mountains. The former rail-bed allows further access to the coastal plain. The only substantial areas that do not allow access by all-terrain vehicles or truck are the western slopes of the Anguille Mountains (a large part of the Little Friar's Cove map area), the southeastern part of the St. Fintan's map area, and the area lying between the rail-line and the Trans-Canada Highway, north of the Fischells River.

BEDROCK GEOLOGY

Bedrock geology is important for determining clast provenance in surficial sediments. The distinctive nature of the sedimentary rocks of the Anguille Mountains and St. George's Bay Lowlands, and the igneous rocks of the Long Range Mountains, may be useful in reconstructing ice-flow patterns in the area.

The Anguille Mountains to the south are composed of Mississippian (Carboniferous) rocks of the Friars Cove, Snakes Bight, and Kennels Brook formations (Anguille Group; Knight, 1983). These formations consist mainly of grey, green-grey, and red sandstone; grey and black shale; thin grey, red, and interbedded grey and brown siltstone; and minor limestone and dolomite. The Kennels Brook Formation is limited to the central part of the Anguille Mountains.

The lowlands to the north of the Anguille Mountains also include Mississippian rocks: the Barachois (undivided) and Codroy groups. The Codroy Group contains the Robinsons River Formation (Highlands and Jeffrey's Village members). Dominant rock types include green-grey and red sandstones, conglomerates, shales, siltstones, and limestones (Knight, 1982). The southern Long Range Mountains to the southeast include the Central Gneiss Terrane (van Berkel, 1987a,b) consisting of diorite and granodiorite, and biotite granite and leucogranite; Cambrian granite, calcareous gneiss, and amphibolite are also present.

PHYSIOGRAPHY

The area can be divided into three physiographic areas. The coastal plain, the Long Range Mountains, and the Anguille Mountains. The coastal plain is mostly of low relief, and is cut by incised river valleys. The coast consists of cliffs up to 75 m high, of mostly surficial material, but toward the Anguille Mountains, bedrock cliffs are common. The river valleys run almost perpendicular to the coast, and in most places are down-cut to bedrock. The coastal plain

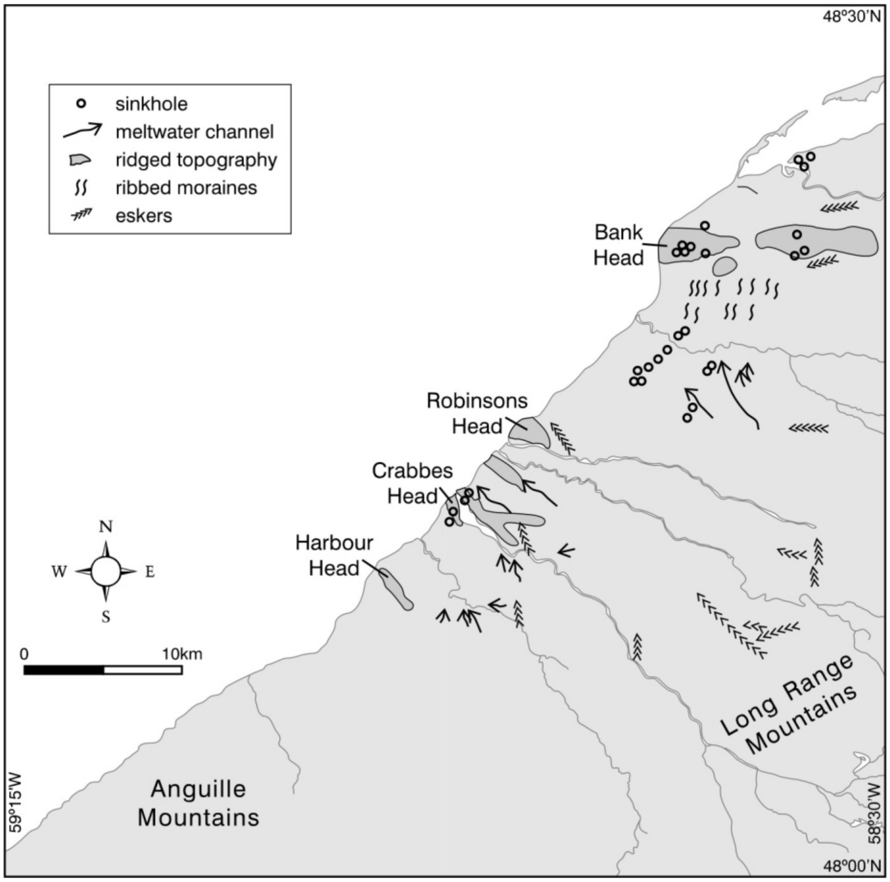

Figure 2. *Geomorphology of the study area.*

slopes at a gentle angle seaward and extends back 10 to 20 km, rising toward the Long Range Mountains. Several ridges of varying height interrupt the generally flat plain, notably at Bank Head, Robinsons Head and Harbour Head (Figure 2). The Bank Head ridge is the highest, rising 50 to 75 m above the plain. These ridges are oriented perpendicular to the coast and range from 4 to 8 km long, and 0.5 to 2 km wide. There are few ponds or lakes in the lowland. The Long Range Mountains, the southern part of the range of mountains that extend down most of the western part of the Island, rise to 500 m in this area, and consist of highlands having subdued relief, cut by broad valleys. Numerous small lakes and ponds are found. The Anguille Mountains form a highland plateau mostly at an elevation of 500 m or more.

PREVIOUS WORK

Coastal cliffs in St. George's Bay were studied by MacClintock and Twenhofel (1940), who described a three-fold stratigraphy: a lower till (the St. George's River Drift) overlying bedrock; a deltaic sequence, the Bay St. George Delta; and the upper coarse till and ice-contact gravels, known collectively as the Robinson's Head Drift. Brookes (1969, 1974, 1977) described these sequences in more detail in the course of regional mapping of western Newfoundland. He also identified and briefly described key sections at Highlands, Robinsons Head, and in the Stephenville–Port au Port area; provided chronological control on the stratigraphic units through dating of marine shells and terrestrial peat; and developed a history of postglacial sea-level change (Brookes 1969, 1974, 1977).

Brookes (1974) described the St. George's River Drift as 1 to 4.5 m of compact lodgement till directly overlying bedrock. He suggested that on the north shore of St. George's Bay, west to northwestward ice flow at the glacial maximum was followed by southwest and southward ice flow, related to the development of a calving bay in St. George's Bay.

The Bay St. George Delta was related by Brookes (1969, 1974) to postglacial marine invasion of the coastal margin up to 44 m asl. The marine limit was defined by the upper limit of sediments tentatively identified as foresets found in the Robinsons Head section, and a terrace of similar elevation on the coast between Fischells and Bank Head.

The Robinson's Head Drift was described by Brookes (1974) as being "a coarse, loosely-structured till of englacial and supraglacial origin". This till was related to ice-contact gravels deposited in nearby kames and eskers. At Robinsons Head, a moraine associated with this drift was identified by Brookes (1974) and consisted mostly of kame sediments, where sand and gravel beds dip inland toward a kettle depression. At Highlands, Brookes (1974) suggested that the Robinson's Head Drift is marked by a lodgement till overlying delta foresets.

The ice margin at the time of the Robinson's Head Drift readvance was portrayed by Brookes (1974) and Grant (1987). Brookes (1974) showed three lobes of ice reaching the coast in southern St. George's Bay, at Highlands, Robinsons Head, and Bank Head, with the intervening areas lying outside the limits of the readvance; also, he proposed that sea level stood at 28 m asl during the readvance (Brookes 1969, 1974, 1977). Grant (1987) showed a single lobe of ice lying seaward of the present coast between Bank Head and Robinsons Head, then landward between Robinsons Head and Highlands. In contrast, Grant (1991) mapped an extensive area of hummocky outwash forming a distinctive ridge perpendicular to the coast. This ridge was shown by Grant (1987) as lying between two lobes of ice related to the Robinsons Head readvance.

In summary, the glacial and deglacial history of this area is thought to consist of a late Wisconsinan advance of grounded ice to well beyond the present coast. This was followed by retreat, to or landward of the present coast, having a maximum sea level at approximately 44 m asl, followed by a localized readvance or stillstand of ice when the sea level stood at 28 m asl.

SURFICIAL GEOLOGY

The surficial geology is varied, and reflects, to some extent, the physiography. The dominant feature of the area is the broad coastal plain. This is covered by a thick blanket of surficial sediment, with bedrock exposed at the coast, in the floors of major river valleys, but very rarely elsewhere. The surface sediment is variable, with gravel, sand and mud near the coast, and tills inland.

GRAVEL

Near the coast, gravel is most commonly found at the surface, as a veneer or blanket over the underlying sediment. This gravel is generally pebble to cobble, planar-bedded, and was deposited in fluvial and glaciofluvial environments as outwash plains and terraces. In places, the gravel forms prominent ridges (Figure 2), and here the gravel tends to be coarser with cobblenboulder gravel common. In the area close to the coast, gravel stratigraphically overlies either thick sequences of medium to fine sand (up to 40 m thick in ridged areas) or marine muds, up to 20 m thick (Plate 1). These sediments and sequences are described in more detail in Bell *et al.* (*this volume*). Between the coast and the Long Range Mountains, the surface sediments on the coastal plain show a lateral transition between gravel and till (diamicton). The boundary between these sediments is not always well defined, but tends to lie between 5 and 10 km from the coast.

TILLS

The till on the coastal plain generally has a silt-clay matrix, with clasts representing 20 to 40 percent of the volume. Clast lithology is varied, but usually has 20 to 80 percent igneous and metamorphic clasts derived from the Long Range Mountains, or re-worked from Carboniferous conglomerates, and 80 to 20 percent siltstone and sandstone respectively, from the local bedrock. The matrix colour is variable from grey to brown to reddish brown, and reflects the incorporation of soft local bedrock. Sediment thickness is difficult to determine in the absence of good sections

Plate 1. *Robinson's Head seen from the north. This prominent ridge is composed of gravel overlying thick sequences of sand.*

through the sequence, but is likely greater than 3 m for the most part, thinning toward the Long Range and Anguille mountains. The surface morphology varies, but mostly consists of till blankets, forming a planar-tabular near-continuous unit, in contrast to diamictons exposed in the coastal sections (Bell *et al.*, *this volume*). Ribbed moraines (mostly overlain by wetlands) are found in the area north of the Fischells River, and patches of hummocky moraine are also seen.

Where the coastal plain abuts the Long Range Mountains and slope angles increase, the surface till changes in character over a 1- to 5-km transition zone from that typical of the coastal plain to that found within the Long Range Mountains. Long Range Mountains tills contain 40 to 60 percent clasts, and have a dominantly sand matrix. The clasts are entirely igneous or metamorphic. Patches of thicker till (more common in valleys) are interspersed with till veneers over bedrock, and bedrock exposed at the surface. The summits of the Anguille Mountains are covered by a blanket of heavily weathered bedrock and till, containing sparse erratics.

Clast fabrics (Figure 3) are interpreted to show that basal tills are common, with at least half of the 66 fabric determinations showing strong unimodal or bimodal distributions. In the coastal areas, weaker girdle clast fabrics are also common, and this, combined with sedimentological evidence, suggests that primary tills often were remobilized in debris flows at the ice margin (*see* Bell *et al.*, *this volume*).

COLLUVIUM

Colluvium is common on steep slopes along the river valleys, in the Long Range Mountains and in places along

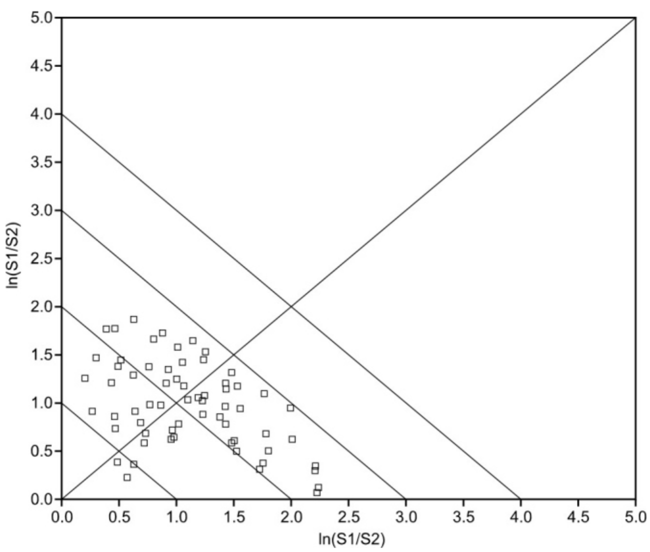

Figure 3. *Clast fabrics plotted following the method of Woodcock (1973).*

the coastal cliffs. Along the coast, particularly in areas underlain by marine clays, slope failures are common, usually in the form of rotational slumps. A large rotational slump occurred in 1996 in the area between Bank Head and Journois Brook, affecting about 300 m of coastal cliff. Such large-scale slope movements are infrequent, but have the effect of producing a colluvial apron along large areas of the coast.

BOG AND OTHER WETLANDS

Organic sediments are common throughout the area where they are interspersed with other sediments. Where cuts through these organic units were observed, they ranged in thickness from 0.5 to 3 m. The surface morphology varies from small bogs, to larger areas of blanket bog, covering wide areas of the coastal plain. These blanket bogs are particularly prominent in the area between the Robinsons River and Bank Head where they are the dominant surface sediment.

MODERN MARINE SEDIMENT

Active coastal erosion supplies sediment to narrow gravel-dominated beaches along the coast. In the river mouths, small baymouth barriers are formed, such as at Robinsons. North of the study area, the eroding coastal cliffs provide an ample supply of sediment to the spectacular Flat Bay spit, a dynamic large-scale coastal feature whose evolution was described by Shaw and Forbes (1992).

GEOMORPHOLOGY

RIDGES

The dominant feature of the coastal plain are the large elongate ridges that intersect the coastline, oriented roughly eastnwest (Figure 2). From south to north these ridges are found at Harbour Head, Crabbes Head, between Mackay's and Jeffrey's, Robinsons Head (Plate 1), and Bank Head. The two northerly ridges are the most prominent, rising to over 75 m asl, and extending in each case 2 to 3 km laterally. The stratigraphy in these ridges is discussed by Bell *et al.* (*this volume*). The ridges are sometimes associated with meltwater channels and eskers inland, and a transition from an association of fluvial and marine sediments to just glaciofluvial sediments is also noticed moving inland from the coast. The ridges thus seem to mark the locations of major conduits of meltwater and sediment as the ice retreated from St. George's Bay. The rise in ridge crest toward the coast thus relates to the interaction between the ice margin and sea level. The maximum amount of sediment is deposited when the subglacial meltwater system reaches the ice margin, depositing large quantities of sediment, as flow competency decreases as the meltwater exits into the open sea.

ESKERS

Several eskers are mapped in the field area, at various orientations (Figure 2). They indicate the location of subglacial meltwater drainage as the ice retreated and stagnated. They range from 20 to 1500 m long, 50 to 150 m wide, and 2 to 15 m high.

SINKHOLES

Numerous sinkholes are noted in the northern part of the map area, and close to the Crabbes River (Figure 2). They normally take the form of small water-filled potholes, but rarely form larger lakes up to 300 m long. They tend to be aligned in linear, mostly northeast-southwest-oriented belts. Their association with surface outcrop of gypsum in the Fischells River area indicates that they are created by subsurface dissolution of gypsum, although the presence of anhydrite and salt in the subsurface as noted by Knight (1983) might cause sinkholes elsewhere. Clast fabrics in the areas adjacent to sinkhole formation, particularly close to the gypsum quarry at the Fischells River show unusual patterns, with most clasts dipping at high angles. Examination of the face of the quarry provides an explanation. The surface of the gypsum bedrock is pitted with numerous small potholes, up to 2 m in diameter and extending downward at least 10 m (Plate 2). These potholes and fissures are filled with diamicton, the surface sediment in the area, and many of the clasts are lying at high angles. The incorporation of soil horizons into these structures suggests that dissolution is an active process, and has continued through the post-glacial to the present day. Thus it is likely that much of the surface sediment in these areas overlying gypsum bedrock has been disrupted by continuous collapse on a small scale, disturbing and re-aligning clasts within diamictons.

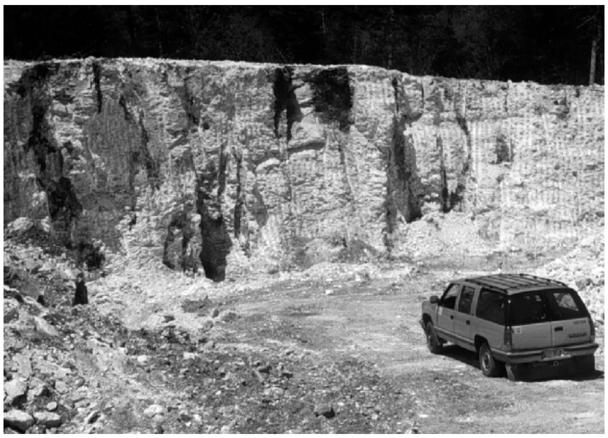

Plate 2. *Gypsum quarry near Fischells River, showing diamicton infilling "pipes" produced in the gypsum bedrock caused by solution by percolating surface water.*

MELTWATER CHANNELS

Minor meltwater channels are mapped in several places in the field area (Figure 2), but more noteworthy are several major channels, apparently related to the ridges seen at the coast. These channels are 2 to 5 km long, 2 to 400 m wide, and have a flat-bottomed cross section. They currently contain wetlands and underfit streams, and the overall gradients are low.

ICE FLOW

In most surficial mapping in Newfoundland, ice flow is defined by striae. In this area, a combination of unsuitable bedrock and an extensive sediment cover means that very few striae were observed. They were found only on parts of the Anguille Mountains and the Long Range Mountains, and thus a different approach must be taken in defining ice flow in the St. George's Bay lowlands. Over 60 clast fabrics were taken from diamictons across the study area, and these can indicate ice flow. The clasts of basal diamictons inherit their orientation from the ice that transports them, and reflect ice flow. Mean orientation, and strength of alignment were calculated by the eigenvector methods of Mark (1973, 1974) and Woodcock (1977). The S1 value measures the strength of the mean clast alignment, and can range from 0.33 (weak) to 1.0 (strong). Figure 3 is a plot following the method of Woodcock (1977) and Rappol (1985). In this diagram, fabrics plotting in the upper left side of the diagram are considered to have a cluster distribution, whereas those in the lower right have a girdle distribution. The parallel diagonal lines mark increasing values of a strength parameter (k), with weak fabrics plotting closer to the origin. As arbitrary criteria, an S1 of greater than 0.6, and a k greater than 1 is considered to indicate ice flow, combined with a visual inspection of the plotted fabrics to allow inclusion of samples with strong bimodal distributions.

The striae evidence suggests a westward to northwestward flow out from a southern Long Range Mountains ice-centre (Figure 4). Abundant striae on the Anguille Mountains indicate that this flow crossed them, although the striae are concentrated into the lower valleys. There is evidence here for a valley-parallel flow in the Codroy Pond area (the valley that separates the Long Range and Anguille mountains), although there is evidence for both northeast and southwest flow. Clast-fabric data shows ice flow both perpendicular and parallel to the coast. A group of northeast-southwest-oriented fabrics in the Robinsons River area pro-

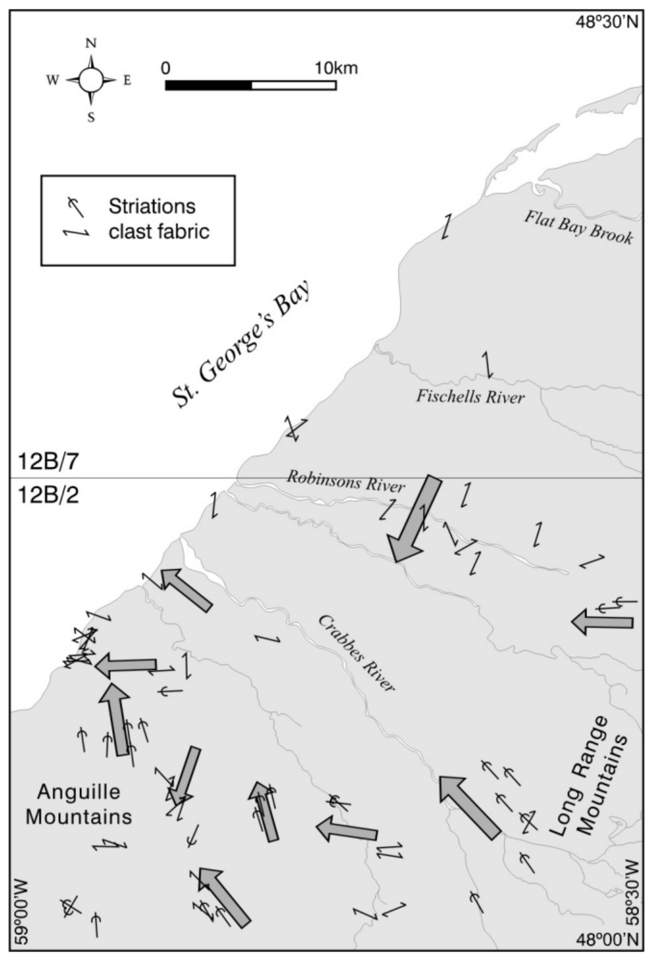

Figure 4. *Ice-flow indicators, study area.*

vides the best evidence of coast parallel flow. The origin of such a flow direction is unknown. Individual fabrics having this orientation may occur due to clasts dominantly being aligned transverse to flow, but this is unlikely to be the case when numerous similar fabrics are found. The coast-parallel ice flow indicated by these fabrics is puzzling in that it crosses topography, and is perpendicular to the regional gradient. Coast-parallel ice flow has been identified elsewhere in western Newfoundland from isolated striation sites, notably on the isthmus between the Port au Port Peninsula and Stephenville (Brookes, 1974). In order for ice to cross a topographic gradient on a regional scale, the natural gravitationally induced flow must be obstructed, presumably by ice. It is possible, therefore, that St. George's Bay was filled with ice, from a source lying north of the field area, and flow from the Long Range Mountains was thus obstructed, and diverted southward. The source of the obstructing ice is problematic. This could be Laurentide ice diverted down the Gulf of St. Lawrence from southern Labrador, or Newfoundland-based ice flowing from the north of the Stephenville area. Either possibility is hard to substantiate with the available geological evidence.

QUATERNARY HISTORY

There is some evidence of pre-late Wisconsinan sediments in the surrounding area, with Sangamonian deposits located in the Codroy Valley (Brookes *et al.*, 1982), and old marine deposits on the Port au Port Peninsula (Batterson *et al.*, 1992). The Codroy sediments were preserved in a sinkhole, and it is possible that similar age sediments might exist in this area; however, examination of karst infills in the gypsum quarries failed to yield any datable material. Most of the surface sediment was deposited during and after the late Wisconsinan glaciation that covered most of Newfoundland. There is evidence for an early, coast-parallel flow as flow from the southern Long Range Mountains was deflected by ice in the Gulf of St. Lawrence. This would likely have occurred at the last glacial maximum. Although there is no conclusive evidence, erratics and striae found in the Anguille Mountains suggest that their summits were overtopped by ice, although it had little erosive effect, possibly being cold-based. As ice retreated, ice-flow directions changed to be dominantly westward, from an ice cap centred over the Long Range Mountains. Further retreat led to topographic control of ice flow, with diversion of ice along the valley containing Codroy Pond.

Deglaciation resulted in complex sedimentary sequences, now exposed at the coast, as the ice sheet grounded in the sea (*see* Bell *et al., this volume*). The contrast between the complex glaciomarine sequences in the ridged areas and the relatively simple deglacial sequences between them may be explained by the configuration of the ice margin. The ice sheet became anchored at the points of major meltwater and sediment supply to the ice margin - the ridged areas. The supply of meltwater at these points resulted in enhanced calving, and these became embayments within the ice margin, with intervening areas still ice covered, possibly by floating ice. Sediment built up in these ice walled embayments to well above sea level. As retreat continued, there was a rapid retreat to inland positions, and thus outside of the ridged areas, a simple sequence of diamicton to marine muds to sands is found, as the sea level dropped. As the sea level fell and the ice margin retreated, the ice margin became terrestrial rather than marine, and glaciofluvial sediment was deposited in outwash plains across the coastal plain.

Sea-level history is not well defined in the area. The marine limit in the area is greater than 35 m asl as shown by marine shells at this elevation at Robinsons Head. There are no marine limit deltas, as the ice margin was marine based, followed by rapid retreat. Coastal erosion has removed any evidence of such deltas that might be formed in the later stages of raised sea levels. Thus sea level was >38 m asl at approximately 13 800 BP, and fell below modern sea level by 13 400 BP. Shaw and Forbes (1995) describe submerged deltas and spits at −25 m asl in St. George's Bay, estimated to have formed at 9500 BP. Sea level rose to close to current levels by 2000 BP.

As the level fell to the postglacial minimum of 25 m below sea level (Shaw and Forbes, 1995), the major rivers continued to incise down through the coastal plain, depositing gravels in terraces. Since sea level began to rise, the rivers have ceased to down-cut, and particularly along the coast have formed estuaries choked with gravel. Modern coastal processes caused active erosion of the sea cliffs, and development of a major spit at Flat Bay (Shaw *et al.*, 1997).

ECONOMIC IMPLICATIONS

The thick marine clays pose a geotechnical problem in construction. Such clays are highly susceptible to slope failure, as shown by a major rotational slump that occurred in 1996 near Bank Head. The thick units that occur along the coast need to be considered in any construction in this area. It is difficult to estimate their extent inland, but they are common below 25 m asl, and thus any construction that takes place at low elevations must consider the presence of such sediments. The clays form an impermeable layer, and there is usually significant ground-water flow at the boundary between them and the overlying units, an important consideration in examining the hydrogeology of the area. The clays may also have industrial uses. They vary from silty clay to a very pure clay, which may have potential for brick making and pottery. Such material is also of use as a liner in waste disposal and landfill sites.

The coast is eroding fast - estimated at 0.3 to 0.5m/year (Forbes *et al.*, 1995), and construction close to the current cliff edge should be avoided. At present, there is little development in these hazardous areas, with most dwellings set well back from the cliff edge. The sinkholes associated with gypsum dissolution in the area represent a significant hazard that need to be considered in future development. The sinkholes are active, and changing in size. Examination of air photographs suggests that new sinkholes have developed over the last 30 years (N. Catto, Department of Geography, Memorial University, personal communication, 1998). The areas subject to sinkhole development are mostly remote from major roads and settlements, apart from in the community of Flat Bay and in the St. David'snSt. Fintan's area. A sinkhole opened up close to a house in St. David's in 1985, and further sinkholes are visible on aerial photographs forming a well-defined belt.

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