Ice on the Rocks: To the Edge of the World and Back
A History of Glaciers and Sea Level Change
on Fogo Island and Change Islands
Accompanied by Surficial Geology of the Fogo Map Sheet (2E/9)
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The Fogo Island Inn (inset background) appears to be floating in the North Atlantic Ocean on the cusp of the rocky terrain in the foreground. The Inn is the centre-piece of the Shorefast Foundation’s initiative to promote geotourism, among other things, on Fogo and Change islands. The Inn’s architecture bears a striking resemblance to the profile of the pair of tabular icebergs drifting eastward in the Labrador Current north of Barr’d Islands in August 2014.
Author’s Background

Kevin was born on Fogo Island at the former Fogo Island Hospital in the community of Fogo. Kevin is a 9th generation Newfoundlander, his ancestry dating back to the late 17th century, when people came from southern England to fish. His father, grandparents, and great-grandparents lived on Indian Islands off the south coast of Fogo Island. His family moved and floated their house from Indian Islands to Stag Harbour during the provincial government’s relocation program nearly 60 years ago. Kevin lived on Fogo Island until the age of six, when his family moved to the community of Embree on the inner part of Notre Dame Bay, where he grew up.

After high school, Kevin attended Memorial University and obtained undergraduate (B.Sc. Honours) and graduate (M.Sc.) degrees in the Department of Geography, where his focus of studies were glacial environments, geomorphology, and sedimentology. During his studies, Kevin also worked at the Newfoundland and Labrador Geological Survey for five years in varying capacities. From 2001 to 2015, Kevin was employed by the Ontario Ministry of Transportation’s Engineering offices (Geotechnical sections) in both Thunder Bay and North Bay, Ontario. Since that time, Kevin now resides in St. John’s and is the Director of the Mineral Lands Division, Mines Branch, Department of Natural Resources.

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INTRODUCTION

Reconnaissance-level Quaternary geology mapping was carried out on Fogo and Change islands during the summers of 2014 and 2015 and covered much of the Fogo map area (NTS 2E/9). This work was completed as part of the Geology at the Edge Residency Program, an initiative of the Shorefast Foundation to promote geotourism on Fogo and Change islands.

The objectives of the study were to map glacial ice-flow indicators and depositional and erosional landforms to further understand the glacial and sea level history of the islands. The coastal areas were the prime focus of study owing to the excellent access and for the purpose of guiding tourists and residents on interpretive geological excursions as part of the residency program.

Data collected during the study will be used to supplement existing documented geological points of interest of the coastal trails and also to supplement other Quaternary research in the Notre Dame Bay area. Field observations were accompanied by analysis of 30-cm resolution colour digital aerial photography produced in 2012.

LOCATION AND ACCESS

The study area is located in Notre Dame Bay off the northeast coast of the island portion of Newfoundland and Labrador, and accessed via ferry departing from Farewell (Figure 1). Access on the islands is generally good via a series of provincial highway routes and numerous coastal trails. Most inland areas on Fogo Island, particularly in the southeast, have limited vehicular or trail access. However, the general lack of vegetation in significant areas, particularly the northern third of Fogo Island, provides excellent access.

PHYSIOGRAPHY AND GEOLOGY

Physiography

The study area is contained within the Newfoundland Uplands physiographic division defined by Sanford and Grant (1976). This division comprises most of the central to northeast areas of the island of Newfoundland, with localized relief ranging from 10s to 100s of metres.

The terrain on Fogo and Change islands is rugged and rolling with relatively low relief, generally less than 15 m. Fogo Island has numerous points of land greater than 75 m ASL, with a maximum elevation of 114 m above sea level (ASL) on John Paynes Hill northeast of Island Harbour. Most coastal areas have relatively higher relief, such as Brimstone Head, Cyphers Head, Fogo Head, and Hare Bay Head, which reach elevations of ~90 m ASL. In contrast, the maximum elevation on Change Islands is 45 m ASL on Change Lookout in the central part of southern Change Island.
Figure 1. Top: Regional view of northeastern Newfoundland. Bottom: Fogo and Change islands showing names of places referred to in the text.
There are extensive areas at various elevations that contain wetlands and associated ponds and water courses, particularly in the southern half of Fogo Island and the central and south areas of Change Islands.

**Bedrock Geology**

Initial bedrock mapping on Fogo and Change islands was carried out by Baird (1958), revisited several decades later (Currie, 1997; Currie 2003), and recently synthesized by Kerr (2013). Bedrock on the islands consists of a suite of Paleozoic (Silurian and Devonian) sedimentary, intrusive, and volcanic rocks (Figure 2). The sedimentary rocks are represented by the Fogo Harbour Formation of the Botwood Group, and located in the southwest and northwest parts of Fogo Island and the south-central area of Change Islands. These rocks consist of interbedded sandstone, siltstone, quartzite, and localized tuff.

The intrusive rocks, referred to as the Fogo Island Intrusion by Kerr (2013), comprise a variable composition of gabbro and localized cumulate rocks, granite, intrusion breccia, and boundary zone rocks composed of granitic to intermediate to mafic rock types. These rocks form most of Fogo Island and are located in the Deep Bay to Stag Harbour area in the west, to Joe Batt’s Arm to Cape Fogo area in the east.

The volcanic rocks are located in the northwest part of Fogo Island and most of Change Islands. These rocks are part of the Brimstone Head and Lawrencton formations of the Botwood Group and comprised of ignimbrite and breccia (Brimstone Head Formation) and dacite, andesite, rhyolite, agglomerate, and various sedimentary rocks (Lawrencton Formation).

**Previous Quaternary Research**

A conceptual model of deglaciation for Atlantic Canada was presented by Shaw et al. (2006). They proposed various positions and dates of glacial ice margins from maximum extent to recession to local regional ice centres. On Fogo and Change islands, glacial striation mapping was completed by St. Croix and Taylor (1991). Surficial geology mapping was carried out by Kirby et al. (2011) and the results of a till geochemistry program were reported by Brushett (2014).

There has also been some detailed Quaternary research carried out in adjoining areas to the south (Munro and Catto, 1993) and southwest (Liverman et al., 1991; Scott et al., 1991; Scott and Liverman, 1991; Mackenzie and Catto, 1993). Offshore areas around and east of Fogo and Change islands have also been subject to Quaternary mapping (Shaw and Edwardson, 1994; Shaw and Forbes, 1995; Cumming et al., 1992; Shaw, 2003). In addition to the above authors, others have also reported specifically on the relative sea level history of the northeast coast area of Newfoundland (Shaw and Forbes, 1990; Shaw and Forbes, 1995; Liverman, 1994; Daly et al., 2007).
Figure 2. Bedrock geology of Fogo and Change islands (from Kerr, 2013).
Shaw et al. (2006) indicate that Late Wisconsinan glaciers reached the extent of the continental shelf areas of Atlantic Canada, including Notre Dame Bank off the northeast coast of Newfoundland. Fogo and Change islands remained partially ice-covered by the Fogo Lobe of the Newfoundland Ice Cap until approximately 13 ka BP (thousand years before present), when the ice margin became terrestrial, but with a marine-based terminus (Figure 3). The islands became ice-free between 12 and 13 ka BP.

_Ice-low history_

St. Croix and Taylor (1991) indicate that northeastern Newfoundland was affected by four ice-flow events during the Late Wisconsinan glaciation (Figure 4). Initially, an east-southeast ice flow followed by north-northeast and northwest flows occurred from ice centres in central Newfoundland; and an east-southeast flow from an area near the coast west of Botwood. Brushett (2014) noted northeast and northwest ice-flow directions on Fogo and Change islands and concluded these flows represent the second and third flows, respectively, documented by St. Croix and Taylor (1991).

_Terrestrial Surficial Deposits_

Kirby et al. (2011) indicated most areas of Fogo and Change islands have relatively thin to no surficial sediments, consisting mainly of exposed or concealed bedrock and minor amounts of till with varying thickness and geomorphological signature. Glaciomarine deposits related to higher relative sea level are mapped locally in the Little Seldom and Tilting areas and glaciofluvial deposits are absent. They also identified significant areas covered by organic deposits in the central and west areas of Fogo Island and north-central areas of Change Islands.

In contrast to Fogo and Change islands, the Carmanville area south of Fogo Island contains significantly more areas of till (Munro and Catto, 1993). The Carmanville area also contains localized areas of exposed bedrock and relatively more abundant glaciomarine and glaciofluvial deposits. The Botwood area mapped by MacKenzie and Catto (1993) also contains significant glaciofluvial and glaciomarine deposits, compared to that identified by Kirby et al. (2011) on Fogo and Change islands.

_Offshore Deposits_

Shaw and Edwardson (1994) and Shaw (2003) documented a various assemblage of deposits in Hamilton Sound and Notre Dame Channel, south and northwest of Fogo and Change islands, respectively. Similarly, Cumming et al. (1992) mapped various deposits in Bonavista Bay southeast of Hamilton Sound.
Figure 3. Extent of glacial ice cover in Atlantic Canada at 13 and 14 ka BP. Thick dashed lines are ice divides and solid lines are ice flows radiating from the divides (modified from Shaw at al., 2006). Ice retreated across Fogo and Change islands between 13 and 14 ka BP.
Figure 4. Top: Regional ice-flow patterns for northeastern Newfoundland, including Fogo and Change islands. Three separate flows are documented, but the latest northerly flows affected the islands. Bottom: Striations on bedrock on Fogo and Change islands indicating the northerly flows (from Brushett, 2014).
Deposits in Hamilton Sound consist of locally drumlinized Late Wisconsinan till, a thin draped unit of glaciomarine gravelly mud, and a variable unit of sandy mud to sandy gravel derived from reworking of the till and glaciomarine deposits (Shaw and Edwardson, 1994). In the broader areas of Notre Dame Bay, Shaw (2003) documented coast-parallel morainal ridges, draped by glaciomarine mud. Generally consistent with areas near Fogo and Change islands, Cumming et al. (1992) interpreted a basal till overlain by a suite of fine-grained glaciomarine sediments in Bonavista Bay.

Relative Sea Level Change

The coastlines of Atlantic Canada demonstrate varying rates of relative sea level change in response to isostatic rebound and migration of a pro-glacial forebulge that was initially created by loading of the earth’s crust by glacial ice. The forebulge migrated back toward the origin of the glacial loading following deglaciation. As a result, four types of sea level curves have been developed (Quinlan and Beaumont, 1981; Quinlan and Beaumont, 1982; Liverman, 1994). Type A curves show continuous emergence, whereas Type B has initial emergence followed by submergence; and Type C and Type D curves indicate sea level below modern levels following deglaciation (Figure 5).

Based on numerous radiocarbon dates derived from onshore shell fossils and geomorphological evidence, Newfoundland has been divided into geographic areas related to the above-noted sea level curves (Liverman, 1994). Generally, the pattern from west to east across Newfoundland shows emergence (Type A) on the tip of the Northern Peninsula; emergence, then submergence (Type B) across the broader areas of Newfoundland; and submergence (Type C) in a local area in the east. Fogo and Change islands lie within the category of a Type B sea level curve.

Shaw and Edwardson (1994) show a relative sea level curve for Hamilton Sound, south of Fogo and Change islands (Figure 6). They indicate that following a marine limit of 43 m ASL (proposed by Grant, 1980) established between 11 and 12 ka BP, relative sea level fell to -17 m ASL around 9 ka BP, and then continuously rose to present. Relative sea level approached modern levels at approximately 3 ka BP (Shaw and Forbes, 1990; Daly et al., 2007). Batterson and Liverman (2010) project an approximately 1 metre rise in sea level by the end of this century for portions of the Newfoundland coastline that includes Fogo and Change islands.

Along the northeast coast of Newfoundland, there is varying evidence on the elevation of marine limit. Based on the elevation of a raised delta in Halls Bay (~120 km southwest of Change Islands) in western Notre Dame Bay, Scott et al. (1991) indicated marine limit is 75 m ASL. In the Botwood area (~90 km southwest of Change Islands), MacKenzie and Catto (1993) also used the elevation of a raised delta at 58 m ASL to establish marine limit. Munro and Catto (1993) documented marine limit based on an erosional platform at 67 m ASL in the Carmanville area.

Both MacKenzie and Catto (1993) and Munro and Catto (1993) noted that during isostatic rebound, relative sea level stillstands were recorded at elevations below marine limit in each of
their project areas. MacKenzie and Catto (1993) indicated levels at 42, 35, and 11 m ASL in the Botwood area, whereas Munro and Catto (1993) documented elevations of 52, 38, 34, 17, 11, 5, and 2 m ASL in the Carmanville area.

Figure 5. Sea level curves for various geographic areas depending on location on the crustal forebulge, based on varying isostatic rebound (from Liverman, 1994). Glacial loading causes the earth’s crust to warp downward and also results in the development of a forebulge in areas beyond the extent of glacial ice. Upon glacial retreat, the forebulge migrates toward the downwarped area, resulting in differential rising and falling of lands depending on their location on the forebulge.
RESULTS

Surficial Geology and Geomorphology

There are four main types of surficial exposures on Fogo and Change islands (see accompanying 1:50,000 scale map). These consist of exposed and concealed bedrock, till, glaciomarine, and organic deposits.

Bedrock

Exposed bedrock is the most prominent surface expression on Fogo Island, particularly in approximately the northern third of the island, localized areas of the interior, and most coastal zone areas (Figure 7). On Change Islands, exposed bedrock is limited to the coastal zone and inland near the community of Change Islands.
Exposed bedrock is the dominant surface expression on Fogo Island. This view is looking southwesterly across Hare Bay toward the community of Deep Bay.

Exposed bedrock is generally extensively weathered, but most prominent in rocks of the Fogo Island Intrusion (granitic and gabbroic varieties). In some locations, weathering has resulted in the development of localized residual sediment, including grus, which is specific to the weathering of granite (Figure 8). Localized talus and colluvium deposits of varying grain size also flank some of the relatively steep bedrock faces (Figure 9).

Concealed bedrock is the second most distinct surficial unit on Fogo and Change islands covering significant portions of inland areas. These areas are characterized by relatively thin soils (residual or weathered bedrock) and/or vegetation mats (Figure 10).

Areas of exposed and concealed bedrock also contain numerous scattered boulders and/or boulder clusters (Figure 11) and isolated areas of sandy to boulder gravel deposits (Figure 12).

Till

Till deposits on the islands are localized, occurring mainly in the southwest and south-central parts of Fogo Island, and conform to the underlying bedrock topography. The thickness ranges from veneers (<1 m) to deposits less than 5 m thick, particularly along Route 333 between Stag Harbour and Little Seldom. The deposits are matrix-supported (silty-sand) with a mix of rock types ranging in size from pebbles to boulders (Figure 13). Clast morphology is angular to subangular, typically striated (some faceted) with silt/clay coatings on the upper sides in section (Figure 14). Clasts consist mainly of local rock types (Fogo Harbour Formation sediments and Fogo Island Intrusion granite and gabbro).
Figure 8. Residual sediment (grus) developed from the weathering of Hare Bay Granite along the trail adjacent to the lookout platform in the community of Deep Bay.

Figure 9. Angular cobble to boulder talus deposit below exposure of Fogo Harbour Formation (sandstone) above Back Cove in Fogo.
Figure 10. Bedrock concealed by vegetation including mosses and black spruce near the community of Seldom’s water supply area.

Figure 11. Boulders resting on exposed bedrock on the east side of Hare Bay, opposite the community of Deep Bay.
Figure 12. Isolated angular to subangular bouldery gravel deposit above Back Cove (Fogo) at the south base of Cyphers Head.

Figure 13. Four-metre exposure of till in the Department of Works and Transportation aggregate pit on the north side of Route 332 east of the community of Stag Harbour. This deposit is moderately compact, matrix supported (silty-sand) with angular to subangular pebble to boulder clasts that are silt-coated and also shows sorting of sand underneath the clasts. Inset left: silt-coated striated clast in section. Inset right: Cavity from cobble clast showing sorting of sand on top and along the sides of the clast.
Glaciomarine deposits occur in many locations on Fogo and Change islands, particularly in the immediate coastal areas, and relate to marine submergence following deglaciation (Figure 15). These deposits consist mainly of variable grain size (mainly pebble to cobble), clast-supported gravel beaches arranged in linear formations at various elevations and typically parallel to the existing coastline (Figure 16; Appendix A). Deposits are relatively coarse grained in the northern coastal areas compared those located on the east, west, and south portions of Fogo Island and Change Islands. In some areas, the beach deposits occur adjacent to eroded bedrock, where angular rock fragments have accumulated (Figure 17).

The morphology of the beach deposits is generally flat-topped (with localized undulating topography), with seaward slopes ranging from gradual (<5°) to steep (near vertical), and ranging in overall dimensions from <5 m wide to <30 m long, up to >50 m wide to >100 m in length (Figures 18). The elevation of raised beaches ranges from 2 to 60 m ASL with individual beach elevations at 2, 3, 5, 6, 7, 8, 10, 11, 12, 13, 15, 17, 20, 21, 24, 25, 35, and 60 m ASL. Elevations were determined from digital altimeter, topographic maps, and Google™ earth data (Appendix A).
Figure 15. Location of glaciomarine and marine deposits (blue squares) on Fogo and Change Islands. Numbered labels refer to Site ID in Appendix A.

Figure 16. Left: Looking north across an ~100 m long cobble to boulder gravel beach ridge ~6 m ASL at Pumbley Cove east of the community of Tilting. In this particular location, the modern beach is immediately to the east bounded by bedrock to the north and south. Right: Looking west across raised cobble beach ~15 m ASL west of the Fogo Island Inn (black backpack for scale). The western flank of this deposit has an arcuate extension toward the north.
Figure 17. Angular talus deposits adjacent to or at the same elevation of raised beach deposits. The talus may have been derived from freeze-thaw action in the intertidal zone when the land was emerging after marine limit was established. **Top**: Talus (dashed) at the base of Hare Bay Granite bedrock north of 60 m ASL raised beach south of Fogo. **Top inset**: close-up of talus deposit. **Bottom**: Portion of raised beach (dashed area) at 35 m ASL flanked by talus deposits (solid outline) below Fogo Harbour Formation bedrock south of Fogo.
Figure 18. Raised beach deposits on Fogo and Change islands have variable dimensions, morphology, and grain size.  

A. Looking east toward arcuate cobble gravel beach deposit perched atop bedrock along Payne’s Harbour Trail (north of Island Harbour).  

B. Looking east toward undulating upper surface of angular cobble beach in Seal Cove below Brimstone Head in Fogo.  

C. View northwest toward angular cobble to boulder deposit above location in Photo B (Brimstone Head at left of photo).  

D. Lichen-covered rounded cobble to boulder deposit south of Oliver’s Cove on the trail to Cape Cove.  

E. Sandy-gravel (cobble) on the west side of Change Islands along the Shoreline Trail.  

F. Rounded cobble deposit west of Deep Bay.
Terraces/wave-washed platforms cover relatively larger areas and generally correspond to the locations of raised beach deposits, such as at Tilting and Little Seldom. The peninsula east of Tilting that extends easterly from Tilting Harbour and Oliver’s Cove consists mainly of exposed bedrock ranging in elevation from 2 to 12 m ASL and fronted by beach deposits ranging from 3 to 8 m ASL (Figure 19). Interestingly, a gneissic erratic at 12 m ASL also occurs in this area (Figure 20; Appendix A). Similarly, the community of Little Seldom, including a relatively narrow peninsula that extends southerly from the community is part of a glaciomarine terrace that is characterized by an exposure of imbricate, clast-supported gravel on the eastern part of the deposit (Figure 21). This terrace is also overlain by a basalt (flow-breccia) boulder erratic.

The highest interpreted wave-washed platform in the study area occurs on the hills south of Joe Batt’s Arm (Appendix A). This surface is ~80 m ASL and contains mainly exposed bedrock with isolated areas of thin (<0.1 m) deposits of silty, gravelly (pebble to cobble) sand with boulder lags (Figure 22); and random boulders of local and distant origin (Figure 23). Fine-grained sediments associated with deep water glaciomarine deposition, such as silt and clay, were not observed, although may exist underneath areas covered by organic terrain, particularly overtop the rock platforms in the north part of Fogo Island. Anecdotally, fossiliferous clay was excavated in preparation for construction of the hockey arena in the Fogo Island central area (west of Shoal Bay).

Postglacial Organics and Other Deposits

Extensive wetland and bog areas occur on Fogo and Change islands and neighbouring offshore islands, including Indian Islands. These areas are typically bedrock controlled and relatively shallow.

A fossil-bearing sand and pebble gravel deposit at 3 m ASL was identified in the Oliver’s Cove area east of Tilting (Appendix A) and shell samples (blue mussel (*Mytilus edulis*) and other undetermined species) provided a radiocarbon date of 1410±15 ka BP (Figure 24). Due to the age, the deposit containing the shells cannot be considered glaciomarine, but rather postglacial marine in origin (See Discussion below).

DISCUSSION

Ice-flow Indicators

Despite surface weathering, exposed bedrock surfaces demonstrate features indicating glacial ice flow direction, including striations/grooves and erosional landforms such as roche moutonnée and U-shaped valleys (Table 1). Striations and grooves are scratches on bedrock surfaces caused by the erosion of subglacial debris carried in moving glaciers. Striations on a particular rock outcrop are generally parallel to the direction of glacial ice flow. Numerous striations occur on Fogo and Change islands, including adjacent to the west side of Route 333, 1.5 km north of Fogo
Island Central Hospital (Figure 25; Table 1). The striations at this site are moderately weathered in Fogo Island Intrusion bedrock (Shoal Bay Granite). This site and many others are shown in Figure 4.

Figure 19. Looking northwest across 8 m ASL glaciomarine terrace east of Tilting. Platform is backed by Tilting Gabbro bedrock and underlain by boulder gravel including an angular to subangular boulder lag exposed at the surface. Boulder lag may be a remnant till deposit. Arrow identifies location of surface boulder shown in Figure 20. **Inset:** Extensive boulder deposit on the beach side of the terrace.

Figure 20. Gneiss boulder erratic resting adjacent to Tilting Layered Complex (gabbro) bedrock above glaciomarine platform shown in Figure 19. Surface elevation is 12 m ASL. **Inset:** Close-up view of gneiss boulder (compass for scale).
Figure 21. **Top:** Looking northwest across glaciomarine terrace toward Observatory Hill in the community of Little Seldom. Terrace is protruded by bedrock (right inset) and overlain by a basalt (flow-breccia) boulder erratic (left inset), and underlain by sandy pebble to cobble gravel (bottom photo). **Bottom:** Exposure of matrix to clast supported sandy angular to subangular pebble to cobble gravel. **Inset:** Material is crudely planar stratified and contains a relatively coarse gravel section (above the notebook).
Figure 22. Various photos of surface exposures atop a ~80 m ASL wave-washed platform on the hills south of Joe Batt’s Arm.  

A: View east toward Joe Batt’s Arm harbour showing surface boulder lag covered partially by vegetation mat.  
B, C, D, E: Views northeast, north, northwest, and west, respectively showing surface boulders and discontinuous gravelly silty sand (circled; See Photo F).  
F. Discontinuous, thin (<0.1 m) deposit of gravelly silty sand overlying bedrock. This type of material can be observed in various locations on this surface.
Figure 23. **Top:** Fogo Harbour Formation (sandstone) boulder erratic resting on Fogo Island Intrusion bedrock (Shoal Bay Granite). **Bottom:** Shoal Bay Granite boulder overlying Shoal Bay Granite bedrock. Fogo Island Inn and water tower in the background.
Figure 24. Fossiliferous (whole and fragmented marine shells including blue mussel (*Mytilus edulis*) pebbly sand deposit along the Oliver’s Cove trail east of Tilting. The deposit is bounded by and has a relatively lower surface elevation than the adjacent bedrock exposures. The deposit is arcuate (convex toward the west) and tapers easterly toward exposed bedrock to the east. **Top left and right:** Easterly view toward fossiliferous exposures (circled). **Middle left and right:** Views westerly toward the exposures. **Bottom left and right:** Mussel-rich bed (left) and fragmented shells exposed in test pit adjacent to exposure.
Figure 25. Weathered striations developed in Shoal Bay Granite bedrock adjacent to Route 333 north of the Fogo Island Central Hospital. **Top:** Flow from right to left (350°). **Bottom:** Flow from bottom to toward top of photo.
Roche moutennée are bedrock landforms sculpted by the subglacial erosional forces of moving glaciers and are also an indication of glacial ice flow direction. The up-ice (stoss) side is typically sculpted by the glacier and the down-ice side (lee) is subjected to glacial plucking (via freeze/thaw cycles) causing relatively steep (near vertical) rock faces. This type of feature may vary in size from several to tens to hundreds of metres.

In the north part of Change Islands, there are several roche moutennée along the road in the vicinity and northwest of the Anglican Church (Figure 26). The relief of these features ranges up to 6 m on the down-ice (plucked side) and length is up to 100 m from the crest to tail on the down-ice side. Orientation is 140° to 320°, but ice-flow direction is toward 320° (northwest).

Smaller-scale roche moutenée were identified at several locations. These features are less than 0.5 high on the plucked side and no more the 2 m long from crest to tail on the up-ice side (Figure 27). Orientation ranges from 140°-320° to 200°-020°, with flow direction ranging from 320° to 020° (northwest to north-northeast).

Other relatively large-scale erosional indicators of ice-flow are U-shaped valleys, which are pre-existing topographic valleys that become contoured (molded) by the forces of moving glaciers. Such a valley occurs in Fogo in the valley separating Cyphers and Fogo heads (Figure 28). Approximately half-way up the easterly (Fogo Head) side of this valley, there is also a roche moutennée feature indicating a northwesterly ice flow through the valley (Figure 29).

Till clast fabrics can also be used to interpret the mode of glacial deposition and direction of ice flow (eg. Benn, 1994). One fabric assessment was carried out near Stag Harbour in a provincial Department of Works and Services aggregate pit (Figure 13). Using the methodology outlined in Rappol (1985), the orientation and dip angle of 50 clasts with a length:width ratio equal to or greater than 4:1, were recorded using a compass (corrected for declination). The data was plotted using Stereonet© software, the processes for which are described in Allmendinger et al. (2013).

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Figure 26. **Top**: Area of roche moutonnée landforms (individual arrows) on northern Change Island indicating ice-flow toward the northwest (320°). Circled arrow represents area shown in bottom photos. **Bottom left**: View looking north from the down-ice slope of the feature toward the crest in middle part of the photo. Elevation is ~3 m above the roadway. **Bottom right**: View looking east across the ~6 m high up-ice (plucked) part of the landform; ice-flow from left to right.
Figure 27. Relatively small-scale roche moutonnée along the Cape Cove trail south of Tilting. 
**Top:** View generally easterly across the up-ice (plucked face) and the down-ice sloped surface. 
**Bottom:** View generally southward perpendicular to the plucked face. Ice flow is toward the viewer (020°).
Figure 28. View northwesterly across Seal Cove through U-shaped valley developed in Brimstone Head Formation bedrock between Cyphers Head and Fogo Head in Fogo. Note 6 m ASL raised cobble beach in foreground.

Figure 29. View southerly toward the plucked face and across the down-ice face of a roche moutonnée surface along the Fogo Head side of the U-shaped valley wall shown in Figure 28.
Using Bingham Analysis output in the Stereonet© software, three eigenvalues were generated for the till deposit at Stag Harbour (Figure 30). These eigenvalues summarize the strength or degree of clustering of the fabric, and added together, total one. In addition to the eigenvalues, other statistics can be generated to categorize the fabric. For instance, a k-value (shape parameter) and c-value (strength parameter) can be established graphically by plotting \( \ln(S2/S3) \) vs. \( \ln(S1/S2) \) as shown in Figure 31 (Woodcock, 1977; Rappol, 1985). In addition, eigenvalue \( S1 \) can be plotted against eigenvalue \( S3 \) to determine the mode of deposition (Figure 32).

![Figure 30. Stereo plot of a till fabric from an aggregate pit east of Stag Harbour (see Figure 13). The plot shows a bi-modal cluster oriented northeast-southwest (red shaded areas). The tabular data are the results of the measurements of the direction of dip (trend) of the clasts, and the plunge is the angle at which the clast is below horizontal.](image)
Figure 31. Graph of $\ln(S_2/S_3)$ versus $\ln(S_1/S_2)$ showing how the $c$ and $k$ values are determined. The Stag Harbour till fabric (red star) plots in the area indicating a strong cluster.

Figure 32. Graph of eigenvalues $S_1$ versus $S_3$ for various deposits including glacial till. Batterson (1998) grouped various data into categories to determine the mode of deposition. Note that fabric data (red star) from the Stag Harbour till overlaps the categories of lodgement, deformation, and meltout tills. Similar to Figure 31, the fabric data indicates a strong cluster.
Eigenvalue $S_1 > 0.6$ and $k > 1$ suggests a strong cluster and is typically associated with subglacial till, and can be used to infer former ice flow direction (Liverman et al. 1999). Based on the statistical results, data plotting, and sedimentary characteristics (see Figure 13), the till at Stag Harbour is consistent with a subglacial melt-out till resulting from northeastward flowing glacial ice. This direction is also consistent with the striation record from the area (see Figure 4 bottom), where striations indicate both northwesterly and northeasterly flows.

**Relative Sea Level Change**

Fogo and Change islands lie within an area of Newfoundland categorized by a Type B relative sea level curve, which consists of a period of submergence, followed by relatively rapid isostatic rebound and emergence, then gradual submergence (Liverman, 1994). Upon southerly retreat of the Fogo Lobe of the Newfoundland Ice Cap, the isostatically depressed islands would have been submerged by the North Atlantic Ocean. Retreat across the islands was in a tidewater setting, where the ice margin was in direct contact with the sea (Shaw et al., 2006). The aerial extent to which the sea would have affected the islands was influenced by the rate of glacial retreat and glacial ice coverage during the submergence period.

The relative sea level curve for northeastern Newfoundland indicates submergence began ~13 to 14 ka BP, when marine limit was registered (Shaw and Edwardson, 1994). This was followed by emergence, where relative sea level fell below present about 11 ka BP to reach a minimum elevation of -17 m ASL at about 9 ka BP; then gradual submergence toward the present. Relative sea level approached modern levels by about 3 ka BP (Shaw and Forbes, 1990; Daly et al., 2007). Sea level is projected to rise an additional 1 m by the end of this century (Batterson and Liverman, 2010).

**Initial Submergence**

Marine limit for the general area was originally proposed by Grant (1980) to be 43 m ASL, but others have since documented marine limits ranging from 58 to 75 m ASL in three different locations in northeastern Newfoundland (Scott et al., 1991; MacKenzie and Catto, 1993; Munro and Catto, 1993). In particular, in closest proximity to Fogo and Change islands, a marine limit of 67 m ASL was established on the south side of Hamilton Sound in the Carmanville area (Munro and Catto, 1993), approximately 15 km south of Fogo and Change islands.

It is thus expected that the minimum marine limit on Fogo and Change islands should be no lower than that recorded in the Carmanville area, given that Carmanville would have been ice-free after the islands were deglaciated. Furthermore, Shaw et al. (2006) showed that glacial ice began to retreat across Fogo and Change islands between 13 and 14 ka BP coincident with retreat at Halls Bay in western Notre Dame Bay, where Scott et al. (1991) documented a 75 m marine limit. Thus, a minimum marine limit of 75 m ASL on Fogo Island is not unlikely.
On the basis of glaciomarine deposits described above, a wave-washed platform (boulder lag) on the hills southwest of Joe Batt’s Arm at ~80 ASL is considered to be a minimum marine limit for Fogo Island. This elevation is consistent with marine limits in Carmanville and Hall’s Bay, and since Fogo Island is the most northerly geographic area in northeastern Newfoundland where glacial ice would have initially become terrestrial, marine limit would likely have been highest at this location. The nature of the isolated deposits on the 80 m ASL platform suggest that it was initially covered by till and related deposits during glacial advance; but these deposits were then entirely or partially eroded during relative sea level lowering due to isostatic rebound. The residual sediment and boulder lags suggest winnowing of tills and other glacial-derived sediment during emergence and regression/shallowing of marine waters (Hansom, 1983, 1986).

_Emergence_

Relative sea level fall and emergence of Fogo Island occurred in multiple stages based on the varied elevations of glaciomarine deposits. Although raised beaches and terraces are documented at numerous elevations, only ~25% were established using a digital altimeter; the balance estimated from available topographic mapping and Google™ earth. The elevations established with a digital altimeter are considered accurate, whereas those determined through other means are approximate. However, for this report, estimated elevations will be associated with the closest elevation established with an altimeter (Appendix A). Thus, rather than documenting 18 different elevations that were presented earlier, these can reasonably be grouped with altimeter-derived elevations by rounding to the nearest altimeter elevation. Altimeter-derived elevations for raised beach/terrace deposits are 2, 6, 7, 8, 10, 13, 15, 20, and 35 m ASL (Appendix A), although a 60 m ASL elevation will also be included given the consistency of glaciomarine features at this elevation in various areas on Fogo Island. The range of elevations shows that emergence was initially rapid (owing to the relatively large intervals between marine limit and 20 m ASL), then became more gradual.

These elevations are somewhat correlative with those of raised glaciomarine features identified by Munro and Catto (1993) in the Carmanville area. Carmanville elevations between 2 and 17 m ASL are similar to Fogo and Change islands’ elevations ranging from 2 to 20 m ASL; and 34 to 38 m ASL in the Carmanville area are similar to the 35 m ASL elevation from Fogo Island. The 52 m and 67 m elevations documented in Carmanville were not identified on Fogo Island, although features on Fogo Island estimated at 60 m ASL south of Fogo and east of Joe Batt’s Arm (near Round Head) may be contemporaneous.

It is suggested that the extensive areas of exposed and concealed bedrock, particularly in northern Fogo Island are the result of erosion of till and related deposits during emergence. This area would have been exposed to the open fetch and erosional forces of the regressing/shallowing North Atlantic Ocean. As a result, any pre-existing deposits would have been reworked into the various beach deposits that are documented at numerous elevations below marine limit (cf. Hansom, 1983, 1986).
Raised beach/terrace deposits in the northern part of Fogo Island have a higher observed frequency and elevation; and are coarser-grained compared to deposits at comparable elevations in the southern portion of the Island. For instance, north of a line (approximate) connecting Deep Bay to Tilting, raised beach/terrace deposits range from 2 to 60 m ASL compared 2 to 20 m ASL south of this line (Appendix A). Cobble to boulder gravels are common in the northern deposits compared to relatively finer gravel deposits in the south.

The contrast in locations and elevations of raised beach/terrace deposits across Fogo Island may be explained by considering that all or parts of the southern portion of Fogo Island remained ice-covered during deglaciation. Glacial ice cover would have protected till deposits in the southern (particularly southwestern) portions of Fogo Island from the erosional forces of shallowing ocean waters as Fogo Island emerged from marine limit. However, in order for this to have happened and allow for registration of a 67 m ASL marine limit in Carmanville, Hamilton Sound would have to have been ice free to allow open water conditions in Carmanville.

It is possible that upon continued deglaciation, glacial ice became detached from the main body of the retreating Fogo Lobe of the Newfoundland Ice Cap and occupied areas in the southern part of Fogo Island (Figure 33). This would have created open water in Hamilton Sound, allowing for the submergence of the coastline in the Carmanville area and registration of marine limit (67 m ASL) there. This would account for the lower marine limit elevation in Carmanville compared to Fogo Island (~80 m ASL) and the lack of relatively higher elevation (above 20 m ASL) raised beach deposits generally in the southern part of Fogo Island. Cumming et al. (1992) indicated that the Bonavista Peninsula (east of Hamilton Sound) in Bonavista Bay hosted glacial ice that became separated from the retreating Newfoundland Ice Cap.

Relative sea level during the registration of marine limit on northern Fogo Island, along with the interpreted glacial ice cover in the southern part of Fogo Island that followed, would have resulted in the isolation of several small islands in various areas (Figure 33). If all of Fogo Island was ice free when marine limit was registered, only localized areas would have extended above the ocean surface.

Change Islands would have been submerged for a significant period after marine limit was registered on Fogo Island, since the maximum surface elevation on Change Islands is 45 m ASL (Change Lookout in the central part of the islands). Based on the various elevations of glaciomarine deposits recorded on Fogo Island, the highest record of marine limit on Change Islands would be 35 m ASL, although a single raised beach at an estimated 20 m ASL on North Change Island (Appendix A) is the highest glaciomarine feature observed. However, given the relative close proximity of 35 m ASL raised beaches in Fogo ~6 km northeast of the community of Change Islands, it can reasonably be assumed that raised beach deposits at this elevation are also present on Change Islands, unless Change Islands also remained covered by glacial ice that was suggested for southern Fogo Island. However, since much of the Change Islands terrain is
≤15 m ASL, there is likely a higher frequency of raised beaches at or below this elevation (i.e. 2, 6, 7, 8, 10, 13, and 15 m ASL; see Appendix A).

As noted earlier, during the submergence period of Fogo and Change islands, the retreating Fogo Lobe of the Newfoundland Ice Cap was situated in a tidewater environment (Shaw et al., 2006). Simultaneously, much of the remaining Newfoundland Ice Cap on the island portion of the Province; the Laurentide Ice Sheet in northern Newfoundland, Labrador, and eastern Canada; and the Greenland Ice Sheet; were also retreating in tidewater settings. Thus, glacial calving and the production of icebergs would likely have been significant, and as a result, it is expected that deposits associated with icebergs such as dropstones would also be preserved in areas that were isostatically submerged.

**Figure 33.** Area of Fogo Island proposed to have remained covered by glacial ice (blue dash), which detached from the retreating Newfoundland Ice Cap at ~13 ka BP. Minimum marine limit of ~80 m ASL was registered southwest of Joe Batt’s Arm (red star). Till deposits are found/interpreted generally in the ice-covered areas. Red-filled areas represent general locations of islands that were above the marine surface coincident with registration of marine limit. Yellow-filled areas represent other general locations that are above 80 m ASL and indicate that most of Fogo Island would have been submerged if completely ice free at onset of marine limit.
There are three surface boulders interpreted as iceberg dropstones based on their locations atop glaciomarine terraces discussed earlier. These boulder dropstones are also erratics, since their lithologies differ from the underlying bedrock on which they rest. These erratics consist of gneiss overlying Tilting Layered Complex (gabbro) east of Tilting (Figures 19 and 20); flow-breccia (basalt) overlying Fogo Harbour Formation in Little Seldom (Figure 21); and anorthosite bearing gabbro overlying Fogo Island Intrusion (Shoal Bay Granite) bedrock north of Joe Batt’s Arm (Figure 34).

The origin of the basalt at Little Seldom is likely from areas south of its location based on the established generally northerly glacial ice flow across Fogo Island documented by Brushett (2014). The basalt boulder at Little Seldom was likely derived from bedrock on Cann Island (Lawrencton Formation; see Figure 2) south of Fogo Island (Paul Dean, personal communication, 2014).

The gneiss boulder east of Tilting and gabbro (with anorthosite) boulder north of Joe Batt’s Arm have relatively more complex origins. Based on their lithologies, these boulders were not transported by the northerly flowing Newfoundland Ice Cap, as these types of bedrock are absent toward the south on Fogo Island and the island portion of Newfoundland. However, gneiss bedrock is present on the Northern Peninsula of Newfoundland, eastern Canada (including Labrador), and Greenland; and anorthosite bedrock occurs in Labrador (Paul Dean, personal communication, 2015).

As a result, it is expected that the gneiss and gabbro boulders were transported by icebergs derived from northerly derived calving tidewater glacier margins such as the Newfoundland Ice Cap (Northern Peninsula), Laurentide Ice Sheet (Labrador and eastern Canada), or Greenland Ice Sheet (Figure 35). Upon deglaciation of Fogo Island, icebergs from local and distant ice margins would have been able to float above what was then a submerged landmass. The surface elevation upon which the gneiss rests is 12 m ASL; thus, a significant depth of water would have been required for an iceberg to float across the submerged coastline. If this occurred at the onset of marine limit (minimum 80 m ASL), the depth of water at the gneiss boulder location would have been 68 m; and 74 m deep at the gabbro boulder location (6 m ASL).

Holocene submergence

Shaw and Edwardson (1994) indicated that following a relative sea level lowstand of -17 m ASL at ~9 ka BP, sea level has risen toward the present. During the lowstand, the land masses of Fogo and Change islands were larger than today and an area between Seldom and Stag Harbour, extending southerly across Hamilton Sound was above sea level (Figure 36). Relative sea level approached modern levels by ~3 ka BP (Shaw and Forbes, 1990; Daly et al., 2006).
Figure 34. Gabbro (containing anorthosite) boulder (locally named Powder Rock) erratic dropstone resting on a glaciomarine terrace overlying Fogo Island Intrusion (Shoal Bay Granite) bedrock along the Joe Batt’s Point trail north of Joe Batt’s Arm.

Figure 35. Potential origins of the gneiss and gabbro boulders overlying glaciomarine terraces near Tilting and Joe Batt’s Arm, respectively, are from icebergs calved from tidewater ice margins on the Northern Peninsula, Labrador (and remaining parts of eastern Canada), or Greenland (north of the extent of map coverage), where these types of bedrock are known to occur; and brought southerly by the Labrador Current. This would have occurred between 13 and 14 ka BP when parts of Fogo Island were submerged (base map from Shaw et al., 2006).
Figure 36. Extent of coastlines at the ~9 ka BP relative sea level lowstand (solid black line) compared to the present coastline. Areas under the patterned area would have been above sea level during the lowstand, when the coastline extended farther seaward compared to present. Fogo Island was connected by an isthmus to the mainland portion of the island of Newfoundland (from Shaw and Edwardson, 1994).
The modern coasts of Fogo and Change islands are impacted by wave action, ocean currents, sea ice, and migrating icebergs calved from tidewater glaciers in northern Canada and Greenland. It is expected that evidence of these impacts (e.g., storm surge, ice-shoving) may be preserved above normal tidal range and imprinted on the glaciomarine raised beach deposits/terraces that were deposited before 11 ka BP (see Figure 6). This would particularly be the case along the northern coastal areas of the islands, where wind fetch from the Atlantic Ocean is greatest. The presence of modern cultural items (e.g., fishing equipment, boats) that have been deposited well above current sea level (Figure 37) and the apparent morphological changes in some of the glaciomarine deposits (e.g., over-steepening; Figure 38), are evidence of modern coastal impacts.

Although it is anticipated that erosion and modification of near-shore glaciomarine raised beach deposits have occurred during the last 3 ka as sea level approached modern levels, there had previously been no precise date to demonstrate when particular events occurred. Modern cultural artifacts such as boats, fishing equipment, and other debris can be used to date relatively recent events, although there was an absence of older materials that could radiocarbon-date prehistoric coastal impacts.

Radiocarbon-dated shells (including *Mytilus edulis*) obtained from the fossiliferous beach deposit at 3 m ASL adjacent to Pumbley Cove east of Tilting, provided an age of 1410±15 BP (see Postglacial Organics and Other Deposits section; Figure 25). Since the baseline for radiocarbon dating is established at 1950 AD, the radiocarbon age places deposition at 540 AD (±15 years). *Mytilus edulis* live in intertidal zones attached to rocky substrates, which is common adjacent to Pumbley Cove. The abundance of multiple-species of fragmented shells and the concentration of *Mytilus edulis* in localized areas (interbedded with the pebbly sand) indicate the shells are not in life position. The shell species along with sand and gravel in the nearshore zone were likely transported landward by a major storm event, perhaps similar to Hurricane Igor in 2010 AD, which impacted areas along the northeast coast of Newfoundland.

Erratic boulders related to northerly ice flow and dropstones deposited during initial submergence were presented earlier. Along the modern coast within the intertidal zone, there are a significant number of gneissic clasts (Figure 39) and other lithologies that could not have been derived from Fogo and Change islands or areas south of there. As noted earlier, the nearest bedrock sources of gneiss are on the Northern Peninsula, eastern Canada (including Labrador), and Greenland. As a result, likely modes of transport of these erratics are via icebergs (Figure 40) that deposited dropstones:

1. during initial submergence of the islands between 13 and 14 ka BP. The dropstones were reworked seaward by littoral processes as the islands emerged from marine limit, and/or
2. near the modern coastline derived from northern Canada and Greenland following a sea level lowstand at 9 ka BP. Subsequent ice-shoving and littoral processes transported the erratics landward (Figure 40).
Figure 37. Various debris associated with recent storm activity near the modern coastline. Debris includes wood, fishing equipment, household waste, and a boat. **Top:** Looking west across ~2 m ASL glaciomarine cobble to boulder beach deposit with buried and strewn debris, composed mainly of driftwood. Note the lichen-covered (blackened) surfaces of the south (landward) part of the deposit. Lichen is absent in the northern (seaward) beach face (inset) due to reworking of the sediment during the Holocene submergence. **Bottom:** Looking north across glaciomarine terrace east of Tilting. The circled object is a small boat ~6 m ASL resting on a raised beach deposit. The boat is believed by local residents to have been brought ashore by Hurricane Igor in 2010.
Figure 38. View southwesterly across Pumbley Cove east of Tilting, modern beach (center), and 6 m ASL glaciomarine raised beach (right side; boulders and turf-covered area). This cove is bounded by bedrock along the north and south flanks. The modern beach area contains relatively fine-grained sediments (gravelly sand; dashed area), compared to cobble to boulder size in the glaciomarine portion. The boat shown in Figure 37 is at the far right of the photo coverage (arrow). It is expected that the greyish gravelly sand was deposited during Hurricane Igor in 2010 atop the cobble boulder material and caused erosion in some of the turf-covered areas.

Figure 39. Gneiss boulders in the modern beach areas on Fogo and Change islands. **Left:** west of Deep Bay. **Middle:** Barr’d Islands. **Right:** western Change Islands.
Figure 40. Boulder (unknown lithology) resting on an iceberg near the coast at Lumsden, approximately 40 km east of Fogo Island in Notre Dame Bay. Photos courtesy of Lumsden resident, Barry Melindy (May 2014).

Links to offshore deposits

Similar sedimentary sequences have been noted by various authors in different locations in Notre Dame Bay and nearby areas (Shaw and Edwardson, 1994; Shaw, 2003; Cumming et al., 1992). These deposits generally consist of till (related to the advance of glacial ice) overlain by a suite of relatively fine-grained (silt and clay) glaciomarine sediments placed during deglaciation.

Deposits on Fogo and Change islands are only consistent with offshore deposits insomuch as the discontinuous and relatively thin till deposits that occur mainly in the southern parts of Fogo Island. Fine-grained glaciomarine deposits were not observed on Fogo Island, although there is anecdotal evidence of such in local areas. The only observed glaciomarine deposits on the islands consist of an extensive series of variably grained raised beach deposits, glaciomarine terraces, and localized boulder lags at various elevations that relate to registration of marine limit and subsequent emergence due to isostatic rebound.

Summary and Future Work

Fogo and Change islands were covered by the Newfoundland Ice Cap, which generally flowed northerly across the islands. This is evidenced by an extensive striation record and other
erosional evidence such as roche moutonnée and a U-shaped valley. Retreat of ice in the study area began after ~14 ka BP, when the glacier margin became terrestrial, but with a calving tidewater margin exposed to the North Atlantic Ocean.

Due to isostatic loading by glacial ice, the islands were initially submerged by ocean waters as the ice retreated. The minimum marine limit on Fogo Island is 80 m ASL, as evidenced by boulder lags atop the hills south of Joe Batt’s Arm and elsewhere. This elevation is in the range of other areas of northeastern Newfoundland that have been documented to be ice-free at the same time. The boulder lags are interpreted to represent winnowing of tills as relative sea level lowered due to isostatic rebound. As relative sea level continued to fall, shallowing ocean waters caused much of the pre-existing till and other glacial-derived deposits to be eroded and carried seaward by littoral processes and deposited in beach formations as relative sea level fall paused (stillstands) at various elevations. The general absence of surficial sediments in the northern approximately one-third of Fogo Island attests to the erosional forces of regressing ocean waters.

Despite an interpreted minimum 80 m ASL marine limit, till deposits in the southern part of Fogo Island are preserved. This suggests that this area remained ice covered when marine limit was registered in the northern areas; otherwise, these deposits would have also been eroded and incorporated into beach deposits as relative sea level fell.

Marine limit on the south side of Hamilton Sound in the Carmanville area is 67 m ASL, although on the south part of Fogo Island (in relative close proximity to Carmanville), raised beaches above 20 m ASL were not observed. This suggests that the southern part of Fogo Island maintained an ice cap that became detached from the retreating Newfoundland Ice Cap. In ice-covered areas, till deposits would have been protected from erosional littoral processes as relative sea level fell. After glacial ice receded on Fogo Island, shorelines were developed at elevations at and below 20 m ASL. An area in Bonavista Bay east of Notre Dame Bay is also documented to have hosted glacial ice (detached from the Newfoundland Ice Cap) during deglaciation.

Relative sea level continued to fall below present to -17 m ASL at about 9 ka BP, then subsequently rose toward the present, approaching modern levels by ~3 ka BP. An additional sea level rise of approximately 1 metre is projected by the end of the century for portions of the Newfoundland coastline, including Fogo and Change islands. The modern coast, including glaciomarine beach deposits near the coast, have been and currently impacted by sea ice, waves, storm surge activity, and icebergs. This is evidenced by modern artifacts including fishing equipment incorporated into the various deposits well above tidal range. A fossiliferous deposit at 3 m ASL indicates that a storm surge event impacted the coast in the mid-6th century (~540 AD); and other similar events are likely to have occurred since that time, including Hurricane Igor in 2010 (AD).
Future work on Fogo and Change islands should include continued mapping of glaciomarine deposits and their geomorphology and elevation; and the distribution and lithologies of the various erratics, particularly those in the modern coastal zone. This will provide more details on the depositional processes and timing, particularly where material is available for radiocarbon dating; and accurately provide the range of elevations to more fully understand past and current relative sea level change. Given the impacts of storm activity and documented sea level rise along the northeastern Newfoundland coastline, other work may focus on identifying hazards associated with coastal flooding, as occurred in local areas of the Province during Hurricane Igor in 2010.

Closing and Acknowledgements

The title of this report makes reference to the status given to Fogo Island by the Flat Earth Society as being one of the four corners of the earth. The northerly flow to the “edge of the earth” by the Newfoundland Ice Cap across Fogo and Change islands during the Late Wisconsinan glaciation is an interesting connection to this status.

I am grateful to The Shorefast Foundation and Zita Cobb’s team for the opportunity to participate in the Geology Residency Program. My personal connection to the Province and Fogo Island in particular, made the experience even more interesting and enjoyable. Excellent logistical and technical support was provided by Paul Dean, Glenda Gill, Pauline Payne, Paddy Barry, Sandra Cull, and Amanda Decker-Penton. I also enjoyed participating in field trips and learning about the local botany and culture with Mona Brown and Norm Foley.

I met Andrew Kerr (the inaugural resident geologist) for the first time during my residency and benefitted greatly from his guidance, discussions, and field trips highlighting the bedrock geology of Fogo and Change islands. I also thank Andy for making available equipment from the Newfoundland and Labrador Geological Survey and also coordinating and funding the radiocarbon-dating of shells from the deposit in the Tilting area. The Newfoundland and Labrador Geological Survey is also thanked for publishing the surficial geology map of Fogo and Change islands.

Colour digital aerial photography was made available by Jeff Wood of the Government of Newfoundland and Labrador’s Department of Municipal and Intergovernmental Affairs. I originally made a request to Jeff for access to the photos, after which he coordinated the creation of a licence agreement between Shorefast Foundation and his department for the use of the photography by Shorefast Foundation for business purposes.

David McConkey of Change Islands is also thanked for his support through promoting the residency program and providing logistical support deliver a lecture and carry out guided geological excursion on Change Islands.
The Ontario Ministry of Transportation is thanked for their support of my involvement with this project via an extended period of absence.

Thank you to those who provided feedback and suggestions to improve the document. In the interim, this report will remain an open file with Shorefast Foundation and may later be published formally.
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## Appendix A – Glaciomarine and marine deposits on Fogo Island and Change Islands

<table>
<thead>
<tr>
<th>ID</th>
<th>Site/area</th>
<th>Trail</th>
<th>Feature</th>
<th>Description</th>
<th>Easting (m ASL)</th>
<th>Northing</th>
<th>Recorded/Estimated*</th>
<th>Normalized to altimeter</th>
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<tbody>
<tr>
<td>1</td>
<td>2/Tilting</td>
<td>Oliver’s Cove</td>
<td>Beach</td>
<td>Fossiliferous (whole and fragmented shells) sand to fine gravel (Composite Sample 14-KRS-1000) – 1 sample from excavated pit, 1 from exposed face; radiocarbon age 14100±15 ka BP</td>
<td>712945</td>
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<td>Tilting east side to Oliver’s Cove</td>
<td>Oliver’s Cove</td>
<td>Terrace</td>
<td>Rock platform with localized gravel deposits (beaches)</td>
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<td>5509650 (Centroid)</td>
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<td>2 to 13</td>
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<td>Little Seldom</td>
<td>Little Seldom</td>
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<td>5497648 (Centroid)</td>
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<td>14</td>
<td>7d/Joe Batt’s Anglican Cemetery (southwest of Inn)</td>
<td>Barr’d Islands</td>
<td>Terrace</td>
<td>Gravel</td>
<td>703237</td>
<td>5512272</td>
<td>20</td>
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</tr>
<tr>
<td>15</td>
<td>8 (North of Inn)</td>
<td>Barr’d Islands</td>
<td>Beach</td>
<td>Cobble to boulder</td>
<td>703338</td>
<td>5512577</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>16</td>
<td>14/Seldom; Burst Point Road</td>
<td>n/a</td>
<td>Beach/Terrace</td>
<td>Pebble to cobble</td>
<td>704523</td>
<td>5499012</td>
<td>10</td>
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<tr>
<td>17</td>
<td>Fogo</td>
<td>Britstone Head</td>
<td>Beach</td>
<td>Pebble to boulder</td>
<td>694723</td>
<td>5510204</td>
<td>35</td>
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<tr>
<td>18</td>
<td>21a Fogo</td>
<td>Simm’s Beach</td>
<td>Beach</td>
<td>Cobble</td>
<td>695007</td>
<td>5510213</td>
<td>13</td>
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<tr>
<td>19</td>
<td>21b Fogo</td>
<td>Simm’s Beach</td>
<td>Beach</td>
<td>Cobble</td>
<td>695052</td>
<td>5510179</td>
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<tr>
<td>20</td>
<td>18 Fogo</td>
<td>Back Cove</td>
<td>Terrace</td>
<td>Sand and gravel</td>
<td>694971</td>
<td>5510668</td>
<td>2 to 20</td>
<td>2 to 20</td>
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<tr>
<td>21</td>
<td>Fogo</td>
<td>Back Cove</td>
<td>Wave-cut platform</td>
<td>Winnowed till?</td>
<td>694654</td>
<td>5510981</td>
<td>60*</td>
<td>60</td>
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<tr>
<td>22</td>
<td>27/Change Islands)</td>
<td>Shoreline</td>
<td>Beaches/Fossil cliffs</td>
<td>Gravelly sand</td>
<td>685162</td>
<td>5500717</td>
<td>3 to 6*</td>
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<tr>
<td>23</td>
<td>28/outer Hare Bay (north side)</td>
<td>n/a</td>
<td>Beach</td>
<td>Gravelly sand</td>
<td>695925</td>
<td>5507469</td>
<td>60*</td>
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<tr>
<td>24</td>
<td>30 Fogo; outer Seal Cove</td>
<td>n/a</td>
<td>Beach</td>
<td>Cobble (subangular) gravel beach, mixed rock types over Fogo Harbour Formation</td>
<td>695380</td>
<td>5508504</td>
<td>35*</td>
<td>35</td>
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<tr>
<td>25</td>
<td>Near 30Fogo; outer Seal Cove</td>
<td>n/a</td>
<td>Rock cliff</td>
<td>Eroded Fogo Harbour Formation (talus and subangular gravel)</td>
<td>695380</td>
<td>5508704</td>
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<td>26</td>
<td>Near 30 Fogo; outer Seal Cove</td>
<td>n/a</td>
<td>Rock cliff</td>
<td>Eroded Fogo Harbour Formation (talus and subangular cobble gravel)</td>
<td>695580</td>
<td>5508504</td>
<td>60*</td>
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<tr>
<td>27</td>
<td>33a Fogo; outer Seal Cove</td>
<td>n/a</td>
<td>Beach</td>
<td>Cobble subangular to subrounded</td>
<td>695641</td>
<td>5509169</td>
<td>15*</td>
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<td>28</td>
<td>33b Fogo; outer Seal Cove</td>
<td>n/a</td>
<td>Beach</td>
<td>Cobble subangular to subrounded</td>
<td>695541</td>
<td>5509219</td>
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<td>Location</td>
<td>Geology/Formation</td>
<td>Notes</td>
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<td>Y</td>
<td>Z</td>
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<tr>
<td>29</td>
<td>33c Fogo; outer Seal Cove</td>
<td>Terrace</td>
<td>Gravel with angular boulder pavement</td>
<td>712624</td>
<td>5509830</td>
<td>8*</td>
<td>n/a</td>
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<tr>
<td>30</td>
<td>37a Tilling</td>
<td>Oliver's Cove/Brimstone Head</td>
<td>Dropstone/Sand to boulder (reworked till?)</td>
<td>712531</td>
<td>5509080</td>
<td>12</td>
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<td>31</td>
<td>40</td>
<td>Barr'd Islands</td>
<td>Beach Cobble to boulder (two deposits separated by rock outcrops)</td>
<td>703132</td>
<td>5512547</td>
<td>7</td>
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<tr>
<td>32</td>
<td>Fogo Island Inn</td>
<td>Barr'd Islands</td>
<td>Beach Cobble to boulder</td>
<td>703181</td>
<td>5512475</td>
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<td>33</td>
<td>Fogo Island Inn</td>
<td>Barr'd Islands</td>
<td>Beach Cobble to boulder</td>
<td>703181</td>
<td>5512475</td>
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<tr>
<td>34</td>
<td>Mickey's Beach</td>
<td>Joe Batt's Point</td>
<td>Beach/Terrace Sandy gravel</td>
<td>704606</td>
<td>5513216</td>
<td>2</td>
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<td>North of Long Studio</td>
<td>Joe Batt's Point</td>
<td>Beach Cobble to boulder</td>
<td>704753</td>
<td>5513619</td>
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<tr>
<td>36</td>
<td>North Change Island</td>
<td>n/a</td>
<td>Beach/Terrace Unknown particle size; excavated for aggregate; bedrock escarpment on south side</td>
<td>687450</td>
<td>5506140</td>
<td>5 to 6*</td>
<td>6</td>
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<tr>
<td>37</td>
<td>North Change Island</td>
<td>Squid Jiggers</td>
<td>Beach/Terrace Unknown particle size (Barachois)</td>
<td>687228</td>
<td>5506100</td>
<td>5 to 6*</td>
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<td>38</td>
<td>North Change Island</td>
<td>Squid Jiggers</td>
<td>Beach/Terrace Unknown particle size</td>
<td>686848</td>
<td>5506034</td>
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<td>39</td>
<td>North Change Island</td>
<td>Squid Jiggers</td>
<td>Beach Cobble to boulder (Barachois)</td>
<td>685900</td>
<td>5506351</td>
<td>24*</td>
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<td>40</td>
<td>East of Joe Brookes Point</td>
<td>Near Joe Batt's Point</td>
<td>Beach/Terrace Unknown particle size; extends from current shoreline westerly toward Brookes Point through bedrock controlled valley</td>
<td>705382</td>
<td>5514599</td>
<td>6 to 10*</td>
<td>6 to 10</td>
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<tr>
<td>41</td>
<td>On Joe Batt’s Point trail</td>
<td>Joe Batt’s Point</td>
<td>Beach/terrace Sand and gravel extending easterly through narrow bedrock controlled valley</td>
<td>704673</td>
<td>5513456</td>
<td>3 to 10*</td>
<td>2 to 10</td>
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<td>42</td>
<td>South of Great Auk monument</td>
<td>Joe Batt’s Point</td>
<td>Beach Coarse gravel</td>
<td>704339</td>
<td>5514426</td>
<td>3*</td>
<td>3 (marines)</td>
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<td>43</td>
<td>South of Great Auk monument</td>
<td>Joe Batt’s Point</td>
<td>Beach Boulder gravel</td>
<td>704340</td>
<td>5514609</td>
<td>6*</td>
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<td>44</td>
<td>South of Great Auk monument</td>
<td>Joe Batt’s Point/Terrace</td>
<td>Sand and gravel flanked by rock and raised beaches</td>
<td>704379</td>
<td>5514514</td>
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<td>South of Great Auk monument</td>
<td>Joe Batt’s Point/Dropstone?</td>
<td>2 m weathered gabbro (locally known as Powder Rock)</td>
<td>704359</td>
<td>5514390</td>
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<td>46</td>
<td>Fish plant to Mickey's Beach</td>
<td>Joe Batt’s Point</td>
<td>Terrace Sand and gravel over bedrock</td>
<td>704880</td>
<td>5512891</td>
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<td>Southwest of Round Head</td>
<td>n/a</td>
<td>Beach Boulder gravel</td>
<td>708416</td>
<td>5514113</td>
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<td>48</td>
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<td>Beach Gravel</td>
<td>708548</td>
<td>5514215</td>
<td>24*</td>
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<td>49</td>
<td>North of Wild Cove (Tilting)</td>
<td>n/a</td>
<td>Beach Gravel</td>
<td>709504</td>
<td>5512030</td>
<td>35*</td>
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<tr>
<td>50</td>
<td>South of Oliver’s Cove</td>
<td>Cape Cove</td>
<td>Beach Gravel</td>
<td>712300</td>
<td>5508226</td>
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<td>51</td>
<td>South of Oliver’s Cove</td>
<td>Cape Cove</td>
<td>Beach Gravel</td>
<td>712422</td>
<td>5508000</td>
<td>11*</td>
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<td>Cape Cove cemetery</td>
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<td>Beach/Terrace Gravel</td>
<td>714137</td>
<td>5503706</td>
<td>5*</td>
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<td>n/a</td>
<td>Beach/Terrace Gravel</td>
<td>712807</td>
<td>5503878</td>
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<td>54</td>
<td>South of Shoal Tickle</td>
<td>Lion’s Den</td>
<td>Beach Gravel</td>
<td>658651</td>
<td>5511830</td>
<td>17*</td>
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<td>Lion’s Den</td>
<td>Beach Gravel</td>
<td>658647</td>
<td>5511853</td>
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<td>Lion’s Den</td>
<td>Beach Gravel</td>
<td>658646</td>
<td>5511881</td>
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<td>Lion’s Den</td>
<td>Beach Gravel</td>
<td>658651</td>
<td>5511825</td>
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<td>Location</td>
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<td>Deposits</td>
<td>X (m)</td>
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<td>Error</td>
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<td>58</td>
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<td>698921</td>
<td>5511820</td>
<td>3 to 5°</td>
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<td>61</td>
<td>South of Shoal Tickle</td>
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<td>Beach</td>
<td>699261</td>
<td>5511833</td>
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<td>62</td>
<td>South of Shoal Tickle</td>
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<td>Beach</td>
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<tr>
<td>63</td>
<td>Wild Cove (Shool Bay)</td>
<td>n/a</td>
<td>Beach</td>
<td>699849</td>
<td>5509841</td>
<td>25°</td>
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<td>64</td>
<td>Wild Cove (Shool Bay)</td>
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<td>Terrace</td>
<td>699800</td>
<td>5510561</td>
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<td>Shool Bay (west side)</td>
<td>n/a</td>
<td>Beach/Terrace</td>
<td>700681</td>
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<td>Shool Bay (west side)</td>
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<td>Beach/Terrace</td>
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<td>Beach/Terrace</td>
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<td>72</td>
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<td>78</td>
<td>Island Harbour</td>
<td>Payne’s Harbour</td>
<td>Beach</td>
<td>693869</td>
<td>5501947</td>
<td>3°</td>
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<td>79</td>
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<td>Payne’s Harbour</td>
<td>Beach</td>
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<td>80</td>
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<td>Payne’s Harbour</td>
<td>Beach (Barachois)</td>
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<td>Beach</td>
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<td>82</td>
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<td>Payne’s Harbour</td>
<td>Beach/Terrace</td>
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<td>5503300</td>
<td>5 to 25°</td>
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<tr>
<td>83</td>
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<td>Beach</td>
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<td>5504190</td>
<td>20°</td>
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<td>84</td>
<td>10 Joe Batt’s Arm</td>
<td>n/a</td>
<td>Boulder lag</td>
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<tr>
<td>86</td>
<td>Eastern Indian Island</td>
<td>n/a</td>
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<td>5491475</td>
<td>15°</td>
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</table>

*Requires confirmation with altimeter