T3.3 GLACIATION, DEGLACIATION AND SEA-LEVEL CHANGES

As early as the late 1800s, when the glacial theory was born, the nature of glaciation in Nova Scotia was being debated. Was glacial ice from local areas, originating in uplands and confined to the province, or was the ice part of a great continental mass that crossed the Bay of Fundy? The Reverend D. Honeyman, curator of the provincial museum at that time, discovered amygdaloidal basalt boulders along the Atlantic coast near Halifax. They had been transported a distance of 130 km. He used the observation to support the concept of a continental-based ice movement that crossed the Bay of Fundy.

Robert Chalmers of the Geological Survey of Canada mapped surficial deposits and glacial features in eastern Canada.[1] He carefully mapped glacial grooves and striations in Nova Scotia and interpreted a sequence of local ice movements. He proposed that northern Nova Scotia had been glaciated largely by local glaciers, with floating ice a secondary agent in low-lying areas. In contrast to Honeyman, he did not believe that a glacier had crossed the Bay of Fundy.

L.W. Bailey[2] and W.H. Prest[3], working in mainland Nova Scotia, observed erratics that supported both previous views.

Over the next 80 years, as new evidence arose, the two models were debated, with either one or the other and sometimes both, being at the forefront of scientific acceptance. During this period, the radiocarbon-dating method became established, and processes of glacier mechanics were being more fully examined.

Pleistocene mapping in the Annapolis Valley was initiated at Acadia University, Wolfville.[4,5]

Since 1977, the Nova Scotia Department of Natural Resources has conducted regional glacial mapping and till-geochemistry programs. These programs have also involved the systematic stratigraphic and lithological analyses of till sections. The mapping and till-provenance data from over 3000 samples have enabled us to construct a picture of the ice-flow events that is different from either of the two models that have been favoured since the 1800s.

Today, in most continent-wide interpretations of the late Wisconsin, a relatively simple, monolithic glaciation model is advocated (maximum model).[6] In this model, a vast ice sheet centred in Hudson Bay or Quebec (Laurentide) overrode much of Maritime Canada and extended to the shelf edge. This single-glaciation model—one major advance and generally linear retreat—contrasts with the terrestrial record of successive glacial advances from shifting ice centres in the Maritimes themselves.[7,8]

The major features of the landscape of Nova Scotia—the overall relief, the distribution of highland, upland and lowland areas—are all the product of its long geological history. The minor features—the final rounding of surface features, the alignment of surface lineations, surficial deposits and sea-level changes—are the product of glacial activity during the Quaternary Period.

The last phase of glaciation ended about 10,000 years ago and left behind an unconsolidated mantle of sediment (see T3.4). On this substrate, drainage patterns were re-established and soils developed.

THE GLACIAL HISTORY OF NOVA SCOTIA

Deep-ocean-sediment core samples provide evidence that there were more than sixteen glaciations during the Quaternary. These glaciations generally each lasted about 100,000 years and progressed slowly and hesitantly from a warm interval (interglacial) to colder and colder conditions, until huge ice sheets covered most of Canada. The transition from glaciers to renewed warmth was rapid. The present relatively warm, ice-free period may mark the end of the ice age, but it could also be an interglacial or even an interstadial interval—a pause before the next advance.

In Nova Scotia, only the last two glaciations (called the Illinoian and Wisconsin after type localities in the United States) have been identified. The Wisconsin glaciation started about 75,000 years ago and ended between 12,000 and 10,000 years ago.[8] Each major glacial advance, by its nature, tends to destroy evidence of previous glaciations. The glacial deposits and features in Nova Scotia are therefore almost all of Wisconsin age.

During the Wisconsin stage, glaciers crossed over Nova Scotia and also formed over Nova Scotia itself. This is not surprising, because Nova Scotia has the highest rainfall in eastern Canada. When it cools down sufficiently, this turns to snow and then to ice.

The last interglacial period, the Sangamon, is represented by marine and terrestrial deposits underly-

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ing tills of the Wisconsinan glacial period. Shelly marine sand in cliff sections in southwest and northern Nova Scotia has a warm-water fauna, indicating present-day conditions. During this time, sea level was four or six metres higher than at present. This higher sea level cut a shoreline of which the remnants are flat, wave-cut rock benches underneath glacial deposits. A wave-cut platform rings Cape Breton and is also exposed on the western shore of mainland Nova Scotia (District 820).

The main events of the Wisconsin glaciation have been interpreted from the deposits resting on top of this marine platform and from striation patterns which indicate ice-flow patterns. Figures T3.3.1 show the timing, location and extent of a glaciers in Nova Scotia during the last 75,000 years.[9]

ICE-FLOW PHASES

Ice-flow phases are determined by the mapping of striations and other ice-flow indicators, such as glacial deposits.[8, 9, 10] Each phase is associated with one or more distinct till sheets. Stacked till sheets and superimposed striae are interpreted as changes in ice flow and help determine the direction of movement.

Phase 1

Patterns of glacial striations (grooves formed by ice) and distinctive erratics (boulders transported from rock sources far away) show the earliest and most extensive ice flow following the Sangamon in Nova Scotia was eastward (see Figure T3.3.1a) then southeastward (see Figure T3.3.1b) across the Bay of Fundy. This is called the Fundy Stade.[11]

The vast majority of the drumlin fields in Nova Scotia were formed during this phase and modified during Phase 2.[12]

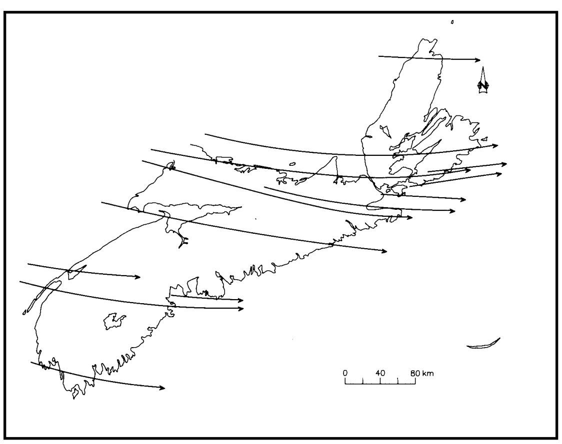


Figure T3.3.1a: Ice-flow Phase 1a. Ice moving eastward across Nova Scotia.

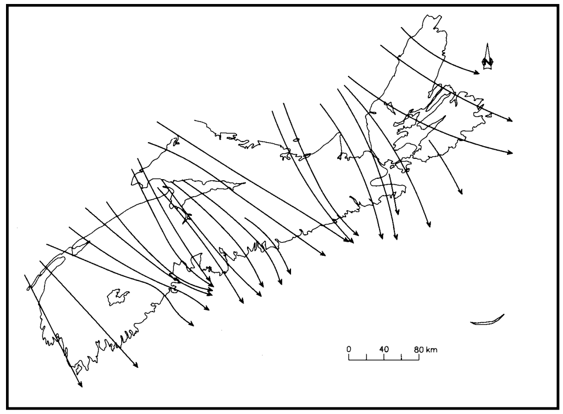


Figure T3.3.1b: Ice-flow Phase 1b. Ice moving southeastwards across Nova Scotia.

Phase 2

The second major ice flow was southward and southwestward from the Escuminac Ice Centre in the Prince Edward Island region (see Figure T3.3.2).[13] Loamy material from the vast area of redbeds in northern mainland Nova Scotia and Carboniferous basins associated with Prince Edward Island were transported southward onto the metamorphic and igneous bedrock terranes of mainland Nova Scotia. Southward dispersal of distinctive Cobequid erratics occurred with the dispersal of the red material.[14]

The major glacial advance from the north established much of the drumlin topography in southern and eastern Nova Scotia. It also produced the north–south and northwest–southeast alignment of geomorphological features on the mainland.

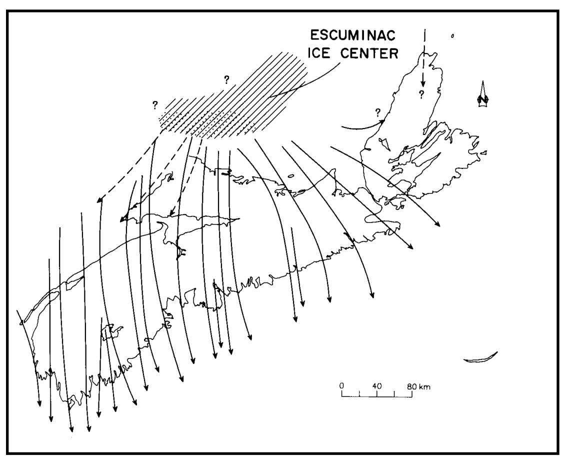
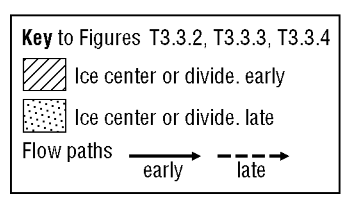


Figure T3.3.2: Ice-flow Phase 2.



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Phase 3

An ice divide in southern Nova Scotia (Scotian Ice Divide) precipitated a northward ice flow across the northern mainland of the province (see Figure T3.3.3). During this phase, granites from the South Mountain Batholith were transported northward onto the North Mountain basalt cuesta. Cobequid erratics can be found throughout the Carboniferous Lowlands to the north.[13] This phase correlates with Grant's interpretation of the ice dome located south of Cape Breton Island.[14, 15, 16, 17]

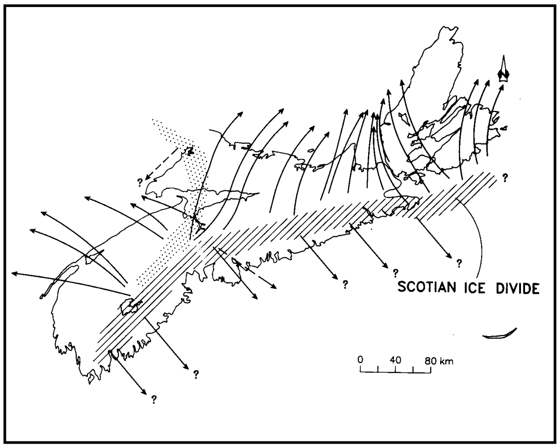

Figure T3.3.3: Ice-flow Phase 3.

Phase 4

Remnant ice caps developed from the Scotian Ice Divide and formed over the Chignecto Peninsula and southern Nova Scotia marked by moraines, ablation till and glaciofluvial sediments. The ice flow during this last phase was strongly funnelled into the Bay of Fundy (see Figure T3.3.4).

None of the advances in the late Wisconsin was as strong as those before, and they became progressively weaker, until the ice caps finally disappeared from Nova Scotia about 10,000–12,000 years ago.

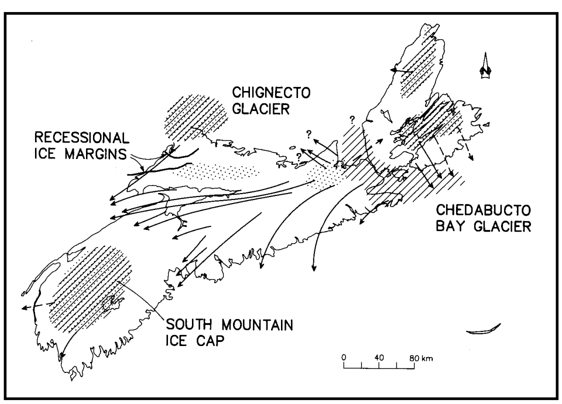

Figure T3.3.4: Ice-flow Phase 4.

OFFSHORE MARGINS OF FLOW PHASES

The offshore extent of the various flow phases is not generally known. A major moraine system known as the Scotian Shelf Moraine System was thought to represent the margin of late Wisconsin glaciers.[18] Other margins have since been proposed. Stea et al[9] have shown that the moraine material appears similar in texture and composition to stony, ground moraine of the Eastern Shore called the Beaver River Till[11], which was deposited by ice stemming from the Scotian Ice Divide (Phase 3) in Nova Scotia.[19]

If the correlation with the Beaver River Till is valid, then it would suggest that flow from the Scotian Ice Divide overrode or formed these moraines and was more extensive than generally believed.[20, 21] This interpretation is consistent with striation data that implies extensive flow from the Scotian Ice Divide across highland regions in northern Nova Scotia above an elevation of 200–300 metres.[15] The location of the Scotian Shelf end-moraine system is illustrated in Figure T3.5.1.

DEGLACIATION

The distribution of late-glacial features during ice-flow Phase 4 suggests that the last glaciers flowed radially from centres of remnant ice. Earliest deglaciation occurred in the Bay of Fundy. Ice flowed southwestward out of Chignecto Bay and westward out of Minas Basin, probably as a response to marine incursion into the isostatically depressed Bay of Fundy. The timing and extent of this ice-flow phase is uncertain; however, evidence suggests that the Bay of Fundy was ice free up to the Chignecto Peninsula by 16,000 years ago[22] or, at the latest, 14,000 years ago. Stea and Mott [23] estimated that the ice retreated to the present coastline by 13,000 years ago. Dates on glaciomarine deltas and minimum dates on lake sediments and buried organic horizons in northern Nova Scotia, however, imply residual ice until at least 12,000 years ago and, in some highland areas, probably much later.[23, 24]

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The retreat of the ice in northern Nova Scotia after 15,000 years ago was slow or interrupted by several stillstands and possible readvances. A late-glacial readvance is documented in northern Nova Scotia, stemming from the Antigonish Highlands (Unit 312).[15] This ice sheet flowed southwestward and southward into the adjacent lowlands. Along the Eastern Shore, the margin of this ice mass was presumably offshore. Moraines off Sheet Harbour, in Unit 911, indicate two stillstands and possible readvances after the deposition of the Eastern Shore Moraine.

REBOUND AND SEA-LEVEL RISE

Since the last recession of glacial ice, global sea level has been rising, rapidly up to about 6000 years ago and at a much slower rate since then. Following the removal of the ice burden, the land surface rebounded in proportion to the former degree of loading. Since the ice had decreased in thickness from north to south over Nova Scotia, there was a parallel pattern of rebound. Almost simultaneously, sea level rose as water was released from the ice caps to the north.

The Bay of Fundy was greatly depressed by the weight of the glacial ice, so that as the ice melted, seawater flooded onto the present land surface. As the mass of glacial ice on land and coastal waters melted, the load was removed and the surface rebounded. This isostatic uplift extended the land surface of Nova Scotia into the Bay of Fundy. Uplift soon exceeded the rise in sea level and the coastline became raised, leaving strandlines several tens of metres above the present high-tide mark; good examples can be seen in the Advocate Harbour area (District 710).

The remainder of Nova Scotia was not depressed to the same extent. Around Yarmouth, the uplift and sea-level rise were about equal, leaving the coastal features in the same position relative to the sea. In the southern parts of the province, from Shelburne County to Guysborough County, there was less crustal rebound, and the coastline was drowned as the sea moved landwards across the continental shelf.

RELATIVE SEA-LEVEL CHANGE

During the Quaternary, the sea level cyclically rose and fell as much as 120 metres. The first comprehensive work on changing relative sea level (RSL) in the Maritimes was that of Grant, who documented many sites with C_{14} dating of former sea levels during the Holocene.[25] This work demonstrated that RSL during the Holocene was rising. Later work has provided rates of RSL rise for many locations around eastern Canada.[26–34]

The rates of RSL rise tend to be higher along the Atlantic coast of Nova Scotia and inside the Bay of Fundy, and show a trend of decreasing rates from east to west; i.e., the rate of RSL rise decreases towards the former ice centre.[25]

It is debatable exactly how low relative sea level was. Some place it at 120 m below present,[18] while others say it was 80–90 m lower than sea level today.[30]

The sea-level record based on field observations from emerged features and lake cores will be discussed in three segments: Sangamon sea levels, Late Wisconsin sea levels and Holocene records. Coastal and marine features related to sea-level rise are described in T3.5 and T7.3.

Sangamon Sea Levels

(ca. 120,000–100,000 Years before Present [yr. BP])

The earliest record of former sea levels in the Bay of Fundy predates Phase 1 in Nova Scotia's glacial history. Tills formed during Phase 1 lie above a rock bench 4–6 metres above sea level.

This bench suggests a wave-cut feature relating to higher sea levels during the Sangamon Interglacial.[35] There are no direct dates on this feature, but peat beds have been found above the bench that possibly date to the last interglacial. Grant pointed out that the feature records a former equilibrium state between sea level and crustal rebound after a major glaciation.[35] The present interglacial period will presumably reach this state in another 2000 years, assuming the current rate of submergence of about 30 cm per century.

Late Wisconsin Sea Levels

(16,000–10,000 yr. BP)

The Bay of Fundy is part of a zone of emergence followed by subsidence. Raised marine features dating from 16,000 to 12,500 years ago are found at various levels around the Bay of Fundy. Wave-cut terraces, raised beaches and deltas were the major landforms produced during the late-glacial high sea level. The general pattern is a north-to-south decrease in marine emergence from 80 to 40 metres in the western region and a west-to-east decrease from 40 to 0 metres at the head of the Bay.[29,36]

In the only continuous record offshore, from Sable Island (District 890), the oldest dates we have are 11,000 years ago, and extrapolation suggests sea levels were about –80 m at 15,000 years ago.[30] It is possible that a strip of unglaciated land or a series of

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islands on the outer continental shelf connected Nova Scotia to New England during the last glacial ice advance. Evidence for this comes from freshwater peat dredged from depths of 100 m in the Gulf of Maine and mastodon teeth found at similar depths.[37] This connection would have been flooded about 15,000 years ago during the initial rapid rise of sea level.

Holocene Sea Levels
(10,000 yr. BP to present)
There are a number of theories regarding the rates of RSL rise during the early Holocene. However, all studies indicate fluctuations, with an average decrease in rates towards the late Holocene. More recently, the rates have increased quite rapidly, as indicated by records during the last 250 years.[25]

RSL was somewhere below 40 m at 10,000 years ago. Some records suggest it then rose rapidly with high rates of submergence at 1.1 m/century occurring prior to 7000 years ago.[33] Sea-level inflection points dated at 7000 years ago have been reported.[31,38] Other records suggest that sea level was falling in that period.[26,29]

The latest theories show RSL to be a two-tiered process, with a very rapid rate between 12,000 and 11,000 years ago, a decrease between 11,000 and 8000 years ago, and a rapid rise between 8000 and 5000 years ago.[39]

In most areas where we have RSL data back to 4000 years ago, we can see a break in the rate of RSL rise at 2500 years ago.

Rates of RSL rise prior to 2500 years ago can be as high as 1 m/century. Rates of RSL after 2500 years ago are usually less than 20 cm/century, except at the edge of the continental shelf, where rates do not appear to have changed since 4500 years ago.[30]

Average RSL rise in Nova Scotia is between 25 and 30 cm/century, almost all of which is due to crustal subsidence resulting from isostatic adjustment at the Earth's surface following glaciation.[26] It has also been suggested the current rate of RSL is possibly part of a sea-level rise.

Analysis of tide-gauge records at Halifax, Saint John and Charlottetown indicates an average rise of 41 cm/century (see T8.1). Geodetic levelling has confirmed this,[40] indicating a depression of the crust southeast across the Maritimes from the St. Lawrence River. Maximum depression of the crust is in the Amherst-to-Truro area of the Bay of Fundy (see Figure T3.3.2).

Associated Topics

T3.1 Development of the Ancient Landscape, T3.4 Terrestrial Glacial Deposits and Landscape Features, T3.5 Offshore Bottom Characteristics, T7.3 Coastal Landforms

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