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DEPARTMENT OF ENERGY, MINES AND RESOURCES

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SURFICIAL GEOLOGY OF AVALON PENINSULA, NEWFOUNDLAND

E. P. Henderson

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SURFICIAL GEOLOGY OF

AVALON PENINSULA, NEWFOUNDLAND

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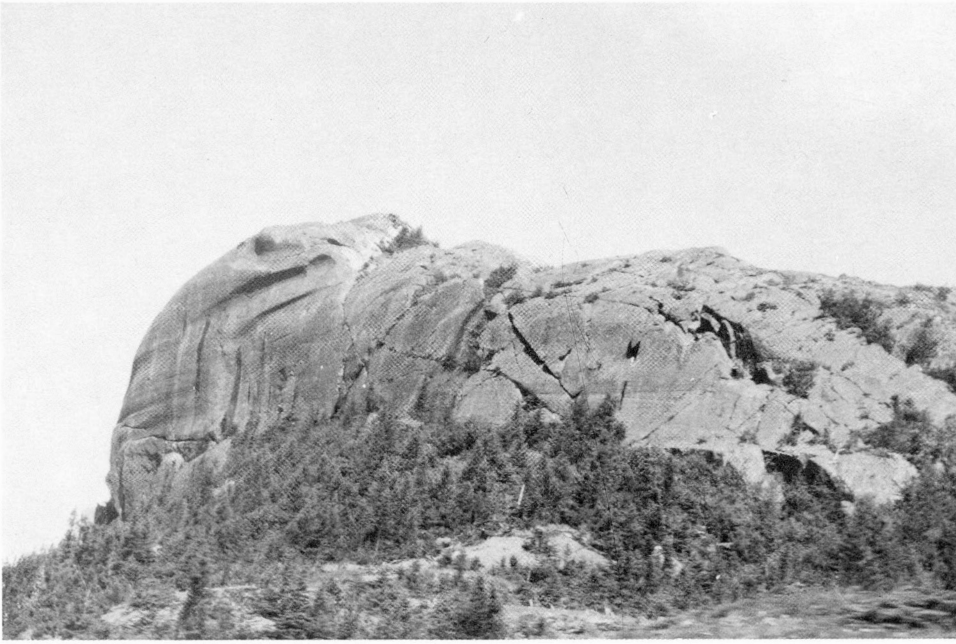

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Grooved and striated wall,
Deer Harbour. (Part of the wall is
overhanging at this point.)

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By

E. P. Henderson

DEPARTMENT OF
ENERGY, MINES AND RESOURCES
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PREFACE

Avalon Peninsula in eastern Newfoundland is one of the most populated parts of the province and the surficial deposits of the region are of considerable importance to engineering projects, agricultural development, and water supply.

Herein the author describes the glacial and postglacial deposits, from which he deduces the glacial and postglacial history of this part of Newfoundland. In addition the physiography, climate, vegetation, and hydrogeology of the area are outlined.

This report is part of the Geological Survey's contribution to the development of a program designed to facilitate the optimum utilization and conservation of the physical environment for the maximum benefit of the nation.

Y. O. FORTIER,
Director, Geological Survey of Canada

OTTAWA, August 28, 1970

MEMOIR 368 — Die Oberflächengeologie der Halbinsel Avalon (Neufundland)

Von E. P. Henderson

Die Halbinsel war in der Wisconsin-Zeit und vermutlich auch in verschiedenen früheren Abschnitten des Pleistozäns vergletschert. Die Enteisung hat vor mehr als 10 000 Jahren stattgefunden. Seither hat sich der nordwestliche Teil der Halbinsel im Verhältnis zum Meeresspiegel gehoben, während in anderen Teilen eine Küstensenkung festgestellt wurde.

МЕМУАР 368 — Поверхностная геология п-ва Авалон, Ньюфаундленд.

Э. П. Хендерсон

Этот район был покрыт ледником в течение висконсинского периода и, вероятно, несколько раз до того в течение плейстоценовой эпохи. Конец оледенения наступил более 10.000 лет до современной эпохи. С тех пор северо-западная часть района поднялась по сравнению с уровнем моря, но остальное побережье понизилось и было залито водой.

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SURFICIAL GEOLOGY OF AVALON PENINSULA, NEWFOUNDLAND

Abstract

In this report the physiography, climate, vegetation, and hydrogeology of the Avalon Peninsula and the immediately adjacent areas are outlined, the glacial and postglacial deposits described, and the glacial and postglacial history of the area developed. Although there were probably several Pleistocene glaciations, all the observed evidence is related to the Wisconsin.

A separate, vigorous ice cap is considered to have formed over the Avalon early in the Wisconsin and its radial outflow dominated all the peninsula except the northern extremities, which had thin local coverings of their own. Ice flowing east from Newfoundland areas to the west of the Avalon was diverted northeast and southwest down Trinity and Placentia Bays and did not reach the Avalon proper, although it did cover the northern half of the Isthmus of Avalon. At the Wisconsin glacial maximum, large trunk glaciers from the Avalon cap flowed down the main bays, greatly overdeepening them in parts and depositing morainic banks on the ocean floor at their mouths. From the character and disposition of the glacial and glaciofluvial deposits and of glaciofluvial erosion features, it is possible to trace shifts of the ice centre and the mode of final ice retreat.

Since retreat of the ice, differential uplift has raised the northwest corner of the area relative to the sea, but over the rest of the peninsula the isostatic rise of sea level has exceeded uplift and there has been postglacial coastal submergence. Relative stability of present sea level on the east coast is postulated until further data bearing on any anomalous modern rapid rise has been accumulated, if, indeed, such data exist.

The cool, humid, postglacial climate has resulted in the azonal development of areas of patterned ground and has made possible the growth of extensive organic deposits. Radiocarbon dating of these deposits suggests deglaciation of the Avalon took place more than 10,000 years ago.

Probable interglacial benches have been cut in sheltered positions along the Avalon eastern coast south of St. John's. They all appear to have the same age and show no tilt because they run parallel to postglacial uplift isobases. A tentative age of Sangamon may be assigned to them. Benches cut elsewhere may not be correlated with the east-coast group.

The economic potential of surficial deposits in the peninsula is outlined and discussed.

Résumé

Le présent rapport étudie physiographie, le climat, la flore et l'hydrogéologie de la presqu'île Avalon et des régions environnantes; il en décrit les dépôts glaciaires et postglaciaires et présente l'historique glaciaire et postglaciaire de la région. Bien que plusieurs glaciations semblent avoir eu lieu au cours du Pléistocène, les observations n'ont précisé que celle du Wisconsin.

Il semble qu'une intense calotte glaciaire distincte se soit formée sur la presqu'île Avalon au début du Wisconsin, recouvrant graduellement toute la presqu'île à l'exception de l'extrémité nord, qui fut recouverte de sa propre nappe, bien que mince. Les glaces de Terre-Neuve, en mouvement d'est en ouest vers l'Avalon, ont dévié vers le nord-est et le sud-ouest le long des baies de la Trinité et de Plaisance, n'atteignant pas la presqu'île Avalon tout en recouvrant la moitié nord de l'isthme d'Avalon. Au cours de l'avancée maximum de la glaciation du Wisconsin, de vastes glaciers se déplaçaient vers les grandes baies depuis la calotte centrale d'Avalon, en creusant profondément les baies et en déposant des bancs morainiques à leurs débouchés dans l'océan. D'après la nature et la disposition des dépôts glaciaires et fluvioglaciaires et les particularités de l'érosion fluvioglaciaire, il est possible de reconstituer le mouvement central du glacier et la direction du recul définitif des glaces.

Après ce recul, un soulèvement différentiel a haussé le niveau du secteur nord-ouest de la région par rapport à la mer, mais dans le reste de la presqu'île, le relèvement isostatique du niveau de la mer a été supérieur à ce soulèvement et les côtes de la région ont subi la submersion postglaciaire. Le niveau actuel de la mer sur la côte est est considéré comme relativement stable jusqu'à ce que paraissent des données sur toute élévation rapide, si vraiment de telles données existent.

Le climat postglaciaire frais et humide a entraîné une évolution azonale de certaines régions de sols à figures géométriques et a probablement occasionné l'accumulation d'imposants dépôts organiques, dont la datation au radiocarbone laisse supposer que le retrait des glaces dans l'Avalon s'est produit il y a plus de 10,000 ans.

Il semble que des banquettes interglaciaires se soient formées dans des emplacements protégés le long de la côte est de la presqu'île au sud de St-Jean, Terre-Neuve. Elles ont apparemment toutes le même âge et n'accusent pas d'inclinaison du fait qu'elles sont parallèles aux isobases de soulèvement postglaciaire. On leur attribue provisoirement l'âge du Sangamon. Les banquettes formées ailleurs n'ont peut-être aucun rapport avec le groupe de la côte orientale.

Le rapport étudie et évalue le potentiel économique des dépôts de la presqu'île.

Chapter I

INTRODUCTION

Avalon Peninsula forms the southeastern corner of the Island of Newfoundland to which it is connected by the long, ruggedly indented, tapering Isthmus of Avalon. Nearly one third of the population of the province lives on "the Avalon," as it is called. The port of St. John's, the provincial capital, on its eastern coast, is a city of about 100,000 people. Cape Spear, some 5 miles southeast of St. John's, is the easternmost tip of the North American continent.

This report deals with the Quaternary deposits and the associated and derived topographic features, and considers the economic importance of these surficial deposits. The area studied includes Avalon Peninsula and immediately adjacent areas to the northwest (Fig. 1). It extends from 46°36′N to 48°10′N, and from 52°37′W to 54°13′W. Its total area is approximately 3,800 square miles, of which the irregularly shaped peninsula comprises more than 95 per cent. Although distances are considerable — more than 100 miles from Cape Freels in the south to Grates Point in the north, and more than 70 miles from Norther Head in Placentia Bay on the west to Cape Spear on the east — no part of the interior is more than 15 miles from the sea. Aside from sea[1] and air transport into St. John's, the only access onto the peninsula is along the Isthmus of Avalon, either by railway or by the transinsular highway completed in 1958. Coastal roads or branch rail lines provide connections to long stretches of the coast, and the railway and several roads cross the interior.

Field work was carried out during the summers of 1956–59, inclusive. As much of the area is densely wooded or covered by scrub and extensive peat bogs, access to most of the rugged interior was generally by foot, even though such travel was slow and difficult. Otherwise inaccessible coastal points could be reached in calm weather by small boats hired in fishing villages. Canoe travel on the larger lakes and streams permitted access to the more remote points of the extensive lowland north of St. Mary's Bay.

In addition to data collected from aerial photographs, information on the various unconsolidated materials was obtained in the field by examining gravel pits and sporadic cuts along the roads, rare exposures in excavations and stream valleys, and vertical sections along the coast. Shallow pick-and-shovel excavations were also made, but the characteristically stony deposits hampered deeper digging by post-hole auger or similar methods. The scarcity of vertical sections, indeed their complete absence over most areas, combined with a concealing surface mat of organic material in many places, made positive interpretation of the nature and extent of the glacial sediments heavily

[1]As well as sea transport into St. John's, there is now (1972) a North Sydney–Argentia ferry connection.

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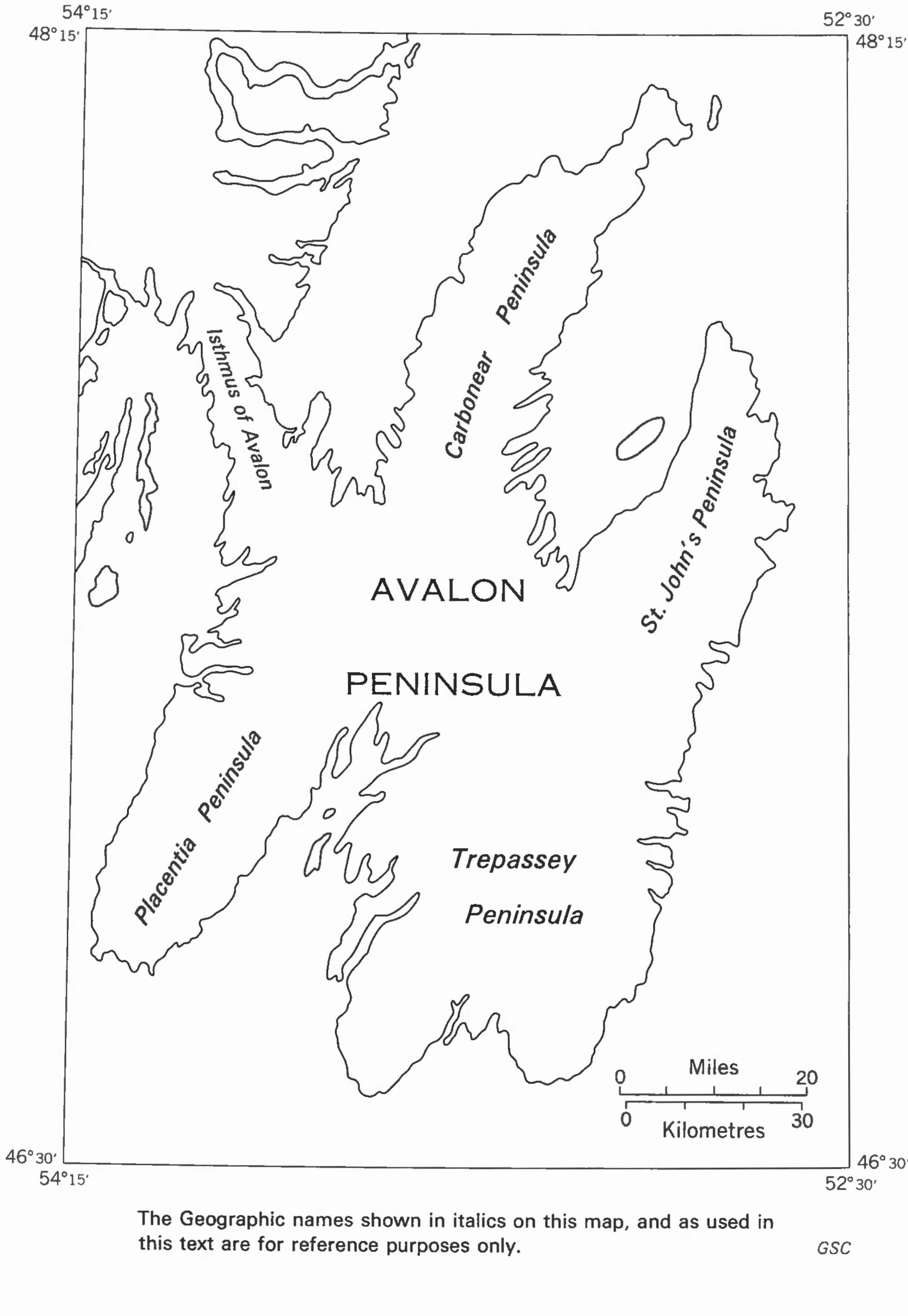

FIGURE 1. Location and extent of study-area.

dependent upon evaluation of the geomorphology. Thus, in most instances, surface form was an important criterion in recognition of the unit mapped. Altitudes of major features were obtained from maps with 50-foot contour intervals, minor intervals being determined by an Abney hand level, supplemented where necessary, by steel-tape measurements of slope distances.

Previous Work

Early literature concerning Avalon Peninsula, though sometimes written by keen observers, predates the general theory of the ice age evolved since 1836–37 from the ideas of Venetz, Agassiz, and Charpentier (*see* Flint, 1947, p. 2, 3, 536, 542). These early studies deal mainly with the natural history of the peninsula, but they also make many references to the surficial deposits when describing location of the most arable land.

Jukes, the first government geologist in Newfoundland, gives a careful and comprehensive account of the physical geography of Avalon Peninsula (Jukes, 1842, p. 9–84; 1843, p. 25–30). In the 1843 general report of the Geological Survey of Newfoundland (p. 134–147), he describes the nature and distribution throughout the peninsula of what are plainly glacial materials, notes the presence or absence of foreign boulders both there and on the main part of the island, and speculates upon their bedrock sources, particularly upon those of the large blocks resting on the tops of prominent hills. He showed apparent reluctance to state definitely that their present position had resulted from diluvium transport, which suggests he had at least heard of the newly evolving theory of widespread glacial transport.

In the second half of the nineteenth century references to glaciation of Newfoundland as a whole, as well as to the Avalon Peninsula in particular, appear in numerous reports: Kerr (1870, p. 704–705), Milne (1874; 1876; 1877), Packard (1876), Murray (1883), Howley (1918, p. 303–307), Wright (1895) and Chamberlin (1895, Abstract). Both Milne and Packard believed all Newfoundland had been glaciated, Murray and Howley considered the whole island had been overrun by a continental glacier moving down the Gulf of St. Lawrence from the west, and Chamberlin advanced the theory that the Avalon "was formerly covered by an independent ice-cap whose borders moved out in all directions."

Since 1900 there have been numerous references to glacial and postglacial events in Avalon Peninsula, largely contributed by scientists employed by the Newfoundland Government and the Geological Survey of Canada. These include studies by Buddington (1916; 1919), Daly (1921), Hayes (1931), Vhay (1937), Snelgrove (1938), Gutsell (1949), Rose (1952), Hutchinson (1953), McCartney (1954; 1956a; 1956b; 1958). Most are regional studies of the physiography, stratigraphy, or economic deposits, and references to Pleistocene phenomena were incidental to the main work. However, Coleman (1926), MacClintock and Twenhofel (1940) and Twenhofel and MacClintock (1940) made important specific studies of the Pleistocene glaciations of the whole of Newfoundland, Twenhofel and MacClintock being of the opinion that the absence on Avalon Peninsula of granite erratics of Newfoundland High Central Plateau derivation supported the view that the Avalon had a separate ice cap, at least during the waning phases of glaciation.

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Thanks are expressed to W. J. Power, J. G. Burns, D. A. St-Onge, and N. L. Journeaux, who so ably assisted in the field during the summers of 1956–59 inclusive; to D. M. Baird, then provincial geologist, for discussion and suggestions, and for access to unpublished reports of the Newfoundland Geological Survey; to H. W. R. Chancey, superintendent of the Dominion Experimental Farm at Mount Pearl for his helpful suggestions and discussions concerning the climate and soils of Avalon Peninsula; to J. V. Healy of the provincial Department of Mines, Agriculture and Resources, for information about Newfoundland bog reclamation procedures and for the suggestion that evidence of regression existed in some bogs within the study-area. Farmers and fishermen of the area were invariably most helpful, the fishermen giving much information on depths and bottom configuration of coastal waters.

Chapter II

PHYSIOGRAPHY, DRAINAGE, AND VEGETATION

Physiography

Avalon Peninsula lies within the Appalachian System, that great belt of deformed Paleozoic rocks extending from the southern United States to Newfoundland and beyond. Most of the bedrock within the limits of the present study is Precambrian, with restricted areas of Paleozoic rocks in the lowlands or on the bay floors. The area is characterized by rolling uplands a few hundred feet above sea level, with monadnocks or short ranges of hills rising to maximum elevations of more than 1,000 feet. High land along most of the coasts generally drops steeply, in places even vertically, to the sea, and only where lowland areas lie between the water and higher ground does the shore slope gently. The most extensive lowland stretches northward from the head of St. Mary's Bay.

Two large bays, Trinity and Placentia, separate the Avalon from the rest of Newfoundland. Two others, Conception Bay and St. Mary's Bay, with headwaters separated by barely 20 miles, penetrate deeply into the peninsula from opposite directions, dividing it into the four large subpeninsulas that comprise most of its area (Fig. 1). In the main, the long coastline is steep, irregular, and deeply indented. Where it is straight, as on the east side of Conception Bay, it probably runs parallel to a major fault.

The most striking physiographic feature of the country is the parallelism of most major geomorphological elements — the coasts of the main bays, the axes of major folds, the faults, and the strike of many rock formations. All trend northeasterly. That faults are a major factor in the alignment of coasts, and even in the shapes of some subsidiary bays in the Conception Bay area, was noted as early as 1916 by Hayes as stated in his 1931 report (p. 51). Buddington (1916) and Summers (1949) also described the profound faulting of the Precambrian on the Avalon, Summers considering the major bays to be aligned over fault zones.

The present complex surface is the response, over a long period, to many changes in intensity of erosion as a result of variations in elevation. The last major cycle prior to glaciation was one of more intensive erosion due to increased elevation. It was followed by widespread downwarping which, although it erased some of the uplift, greatly increased the effects of present coastal erosion by submerging the shoreplain deposits that would normally protect stable coasts from marine attack. Modification of the landscape by ice is only the final touch given preglacial landforms. Compared to the sweeping transformations that changed the surface configurations during the many millions of years elapsing between Ordovician and Quaternary times, the morphological changes resulting from glaciation are more apparent than real. Except for restricted areas where concentrations of moving ice caused deep local excavation, the larger landforms have not been greatly altered by the ice and reflect essentially the preglacial landscape, though with the addition of a wealth of glacial detail impressed on rock surfaces. Glacial deposition has masked large areas of the preglacial surface generally reducing relief, usually by a veneer only a few feet thick. In some lowlands, however, and in highland basins where differences in elevation are few, thicker glacial deposits may have slightly increased relief. Even here, only minor landforms are involved.

Twenhofel and MacClintock (1940, p. 1719, Fig. 15) considered that the upland erosion surfaces of the Avalon are remnants of the older, much-dissected High Valley Peneplain and the Lawrence Peneplain, both of which appear in western and central Newfoundland. The High Valley Peneplain with elevations of 1,300 to 1,500 feet asl on the west coast, reaches its best development at about 1,000 feet asl on the Newfoundland High Central Plateau. In the Avalon it is represented by uplands and by separate hills or ridges, 700 to 800 feet high, that have been isolated by erosion. Above this surface, monadnocks rise to elevations of 1,000 feet or more.

The Lawrence Peneplain, present in the west at elevations of 500 to 1,000 feet asl, has been correlated by Twenhofel and MacClintock with the extensive upland surfaces of gently rolling topography between 350 and 500 feet asl that make up most of the peninsula. A third and even lower erosion level, described by Twenhofel and MacClintock (1940, p. 1718) as a gently rolling surface about 200 feet asl, is thought by Summers (1949, p. 22) to result from differential erosion of softer rocks developed during the formation of the Lawrence erosion surface rather than as evidence of a separate erosion surface.

Monadnocks on the Lawrence erosion surface provide the greatest local relief in the interior. Centre Hill, just north of Bull Arm, with an altitude of 1,133 feet, is the highest elevation in the study-area. Other prominent hills such as Butter Pot, northeast of Holyrood, twin hills 4 miles south of Placentia Junction, and the Butter Pot west of Fermeuse reach heights of 1,000 feet or more asl. The massive group of hills northwest of Bull Arm rise 500 to 700 feet above the surrounding area, their isolated eminences dominating the countryside. Hills on the Isthmus of Avalon and southwest of Conception Bay have somewhat lower elevations but give local relief of a similar magnitude. The differential erosion that left the high hills and ridges of the rough, indented topography of the coasts and the Isthmus of Avalon, probably occurred after the uplift that followed an earlier lowering and levelling of the land.

Upland Areas

The uplands form the largest physiographic unit of the area. They are developed on hard bedrock consisting of granite, volcanics, and the more resistant of the sedimentary strata (Fig. 2). The surface, for the most part, is a plateau of moderately rolling terrain, some tracts being rugged and others gently sloping, with practically no local relief. The more rugged tracts have been developed on volcanic rocks and certain areas of steeply dipping sedimentary rocks.

On the basis of altitude, the uplands may be divided roughly into two categories. The larger, corresponding to the Lawrence erosion surface of Twenhofel and MacClintock, lies between 350 and 500 feet asl. The smaller category, corresponding to the High Valley erosion surface, is generally 500 feet or more asl, much of it lying between elevations of 700 and 800 feet.

The uplands may also be divided geographically into an eastern and a western tract, separated by the wide, drift-covered lowland extending north from St. Mary's Bay to Trinity Bay. The larger tract, located east of the lowlands, includes most of St. John's

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FIGURE 2. Looking west over a mature erosion surface developed on granite, 6 miles southeast of Holyrood.

and Trepassey Peninsulas, extends around the head of Conception Bay, and except for a lowland area along the shore of Trinity Bay, comprises most of Carbonear Peninsula. The tract to the west of the St. Mary's Bay lowland includes most of Placentia Peninsula and a large part of the Isthmus of Avalon.

The largest continuous stretch of upland at elevations above 700 feet and, therefore, part of the High Valley erosion surface, is the Hawke Hills region south and southwest of Holyrood in the eastern tract. It is a rugged, irregularly shaped area developed on volcanic and granitic rocks. In the western tract, the slightly smaller and less rugged upland of Castle Ridge and Beaver Pond Hills constitutes an area of gentle slopes and nearly level ground that covers some 40 square miles in the centre of Placentia Peninsula. Other eastern tract remnants of this much-dissected erosion surface include the scattered, flat-topped uplands rising to elevations of 700 feet or more and extending for 20 miles south of Mobile Big Pond; the coastal range of hills between Bay Bulls and St. John's Harbour; a similar range on the east side of Conception Bay; and part of the high central section of Carbonear Peninsula (Fig. 3). The extremely rugged, rocky area north of the Isthmus of Avalon, between Bull Arm and Random Sound appears to belong to the Lawrence erosion surface.

Extension of the upland surfaces to the shore forms long stretches of steep coast (Fig. 4). It is usually the lower, Lawrence erosion level that forms the shoreline, with the more abrupt parts of the coast generally rising steeply between 200 and 400 feet above the water. Where the High Valley surface forms the coastline, the land may rise almost sheer from water level nearly to the maximum elevations of Avalon Peninsula. For example, on the east side of Conception Bay, where some of the steepest and most spectacular coastline is near Bauline, the shore towers 800 feet above

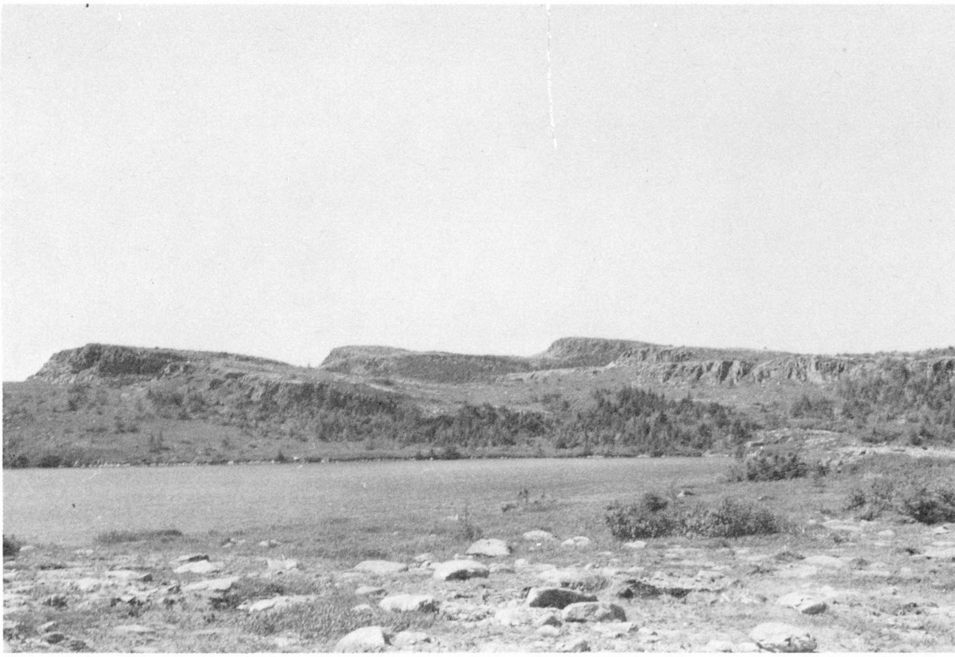

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FIGURE 3. Escarpments facing south of east near Western Bay on Carbonear Peninsula.

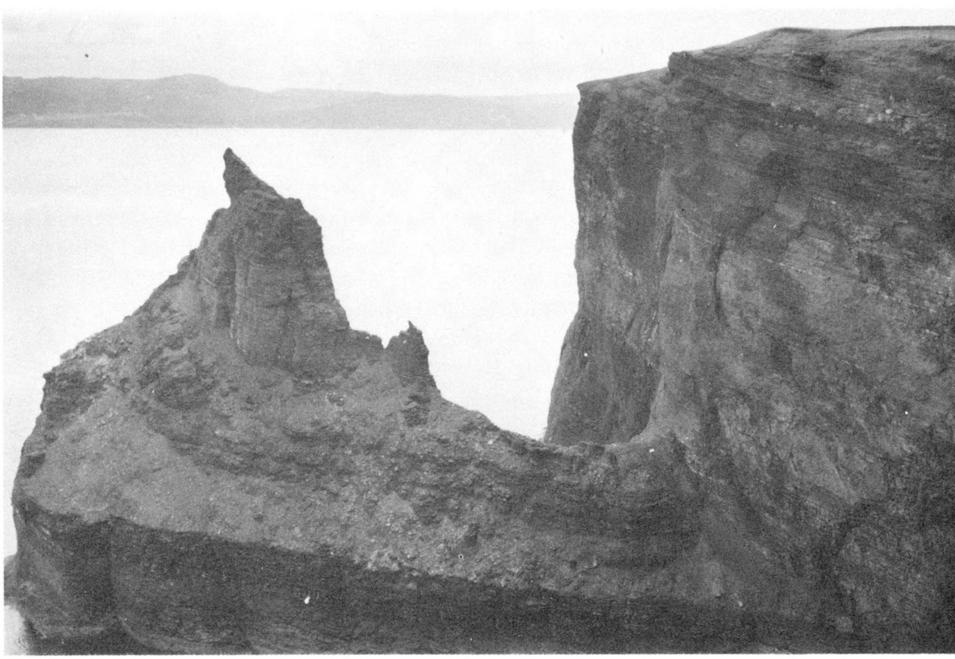

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FIGURE 4. Sea stack 300 feet high on northeast end of Bell Island. The edge of the flat levelled upland is at right.

the water; 2 miles south of Bauline the coast rises sheer to more than 900 feet. Much of the coastal rim of St. John's Peninsula is higher than the interior plateau. Steepened stream gradients near the high-rising coasts have greatly increased the erosive power of streams, dividing much of the Avalon shoreline into a succession of bold headlands separated by short, steep re-entrant valleys whose floors rise rapidly to the levelled uplands of the interior.

Lowland Areas

Central Lowland

The most extensive lowland on Avalon Peninsula, developed on sedimentary rocks that are only moderately hard, stretches north for 20 miles from St. Mary's Bay to Trinity Bay and separates the eastern and western highland tracts. From Colinet at the head of St. Mary's Bay, the larger part of this lowland slopes gently north for more than 13 miles to just west of Whitbourne. Here, at an elevation of barely 200 feet, lies the divide between the south-flowing tributaries of Rocky River and the north-flowing drainage into Dildo Pond. Northeast of Colinet the surface rises more rapidly to elevations of 350 feet or more and merges gradually into the Lawrence erosion surface that extends, with gradually increasing altitudes, as far as the high land rimming the head of Conception Bay. Just south of Whitbourne the lowland reaches its maximum width of more than 10 miles.

Outcrops are rare in the lowland area. The generally flat to gently sloping bedrock surface is covered by thick glacial deposits that form a level or gently sloping till plain in the west with relatively few lakes and, in the central and eastern parts, a distinctive pattern of hummocks and parallel or subparallel moraine ridges, separated by numerous lakes and swales. These hummocks and ridges are generally low but in places the moraine ridges rise to 40 feet or more and a few measure more than 80 feet from base to crest. Locally the moraines form rough, wooded tracts of steep-sided hills and ridges that constitute terrain as difficult to traverse as any found in the Avalon.

Other Lowland Areas

Narrow coastal plains form undulating lowlands along stretches of the shores of Conception and Trinity Bays. The lowland on the southeast side of Conception Bay is underlain by Cambrian shales and is the better developed. The lowland on the east side of Trinity Bay is underlain by both Cambrian shales and harder Precambrian rocks. It is less continuous than the Conception Bay coastal strip, with considerable relief where hills and ridges, underlain by the harder rocks, interrupt the surface.

Avalon Peninsula was heavily glaciated during the Quaternary. That a very long erosional stage greatly exceeding the duration of the entire Quaternary Epoch preceded the Wisconsin glacial period seems certain. Rocks of Cambrian and Ordovician age were probably once much more widely distributed than now, but together with any more recent rocks deposited above them, were stripped from the Precambrian surface by erosion. At the end of this erosion cycle, the entire area was glaciated, possibly repeatedly. Soil and rock were removed from the surface and later redeposited on or beyond the limits of the land. Today, many higher areas still remain bare rock, but the lower areas usually have a thin to moderate cover of glacial deposits. Small areas of Cambrian and Ordovician rocks are found at several places, generally beneath low-lands or downfaulted blocks. Although erosive activity appears to have been intense, as a rule the glaciations only lightly modified the older surfaces of the preglacial topography. The general aspect of the land before the Pleistocene differed little from that of the present. The pre-Pleistocene bedrock topography, now largely buried by Pleistocene deposits, shows many characteristics of maturity: broad, mature valleys and old bevelled uplands (Fig. 2) above which monadnocks rise a few hundred feet. Exceptions to this may be found either in large pre-existing depressions, such as Trinity and Conception Bays, that were strongly eroded by ice channelled down their long axes, or in smaller fiord-like valleys, parallel to the ice flow, that cut across the strike of the rock formations such as those on the Atlantic coast south of St. John's.

During postglacial time there has been little modification of the surface forms produced by glaciation. In a few places where gravelly, unconsolidated deposits were of considerable depth, the rivers rapidly cut their channels; but almost everywhere else the streams either met bedrock beneath the thin superficial cover or failed to cut deeply into the stony glacial deposits. The surfaces of many of the harder rocks remain comparatively unweathered. In some places even minor glacial markings have been preserved. The grosser forms impressed on slates, siltstones, and softer rocks remain, but, except where the rock surfaces were protected by overlying drift, postglacial weathering has removed striae and most glacial grooving and associated markings.

Drainage

The many rivers and profusion of lakes form a dense drainage network throughout Avalon Peninsula. Around St. Mary's and Conception Bays streams flow obliquely toward the axes of these bays; elsewhere they flow directly toward the coasts, at least in their lower courses. Summers (1949, p. 24) suggested that the general pattern is inherited from a preglacial drainage system in which major rivers flowed in the wide valleys now submerged beneath the four main bays. The streams now flowing obliquely into St. Mary's and Conception Bays are considered to be the truncated upper reaches of tributaries that formed the preglacial dendritic pattern of these master rivers. The submarine channels that cross the continental shelf, particularly those originating in the vicinity of Trinity and Placentia Bays are considered as extensions of the main streams (*see* Spencer, 1903, p. 212).

Although Northwest Brook is the only Avalon river longer than 20 miles, several streams are between 10 and 20 miles long. Many of the longer rivers originate from chains of lakes on the uplands. They do not flow in definite valleys but tend to follow circuitous routes from lake to lake for several miles before flowing directly to the coast. They descend from the plateau to sea level in the last few miles of their courses. Other streams, such as Crossing Place River and Northwest Brook, flow in large valleys that are well incised below the general surface level and are clearly preglacial in origin.

The clear waters of the numerous streams carry little sediment and in most places have laid down little or no alluvium. Either modern flood plains are completely lacking, or flats adjacent to the streams are covered with only a foot or two of material. An exception to this is found where streams have reworked and redeposited outwash deposits, especially gravels, e.g., along the lower parts of Peter's and Crossing Place Rivers and Northwest Brook.

Glaciation has disrupted and changed details of the old integrated drainage patterns of the area in varying degrees. The most disorganized drainage found now is in upland areas of granitic rocks, in areas where the glacial sediments are thickest, and where volcanic rocks outcrop. In the interior, areas of little relief are as a rule poorly drained and extensively covered by irregularly shaped bogs and marshes, some extending many miles. On the granite southeast of Conception Bay, numerous irregularly shaped lakes occupy basins excavated by ice or dammed by glacial debris. They drain haphazardly, spilling from basin to basin through short rapid streams whose courses tend to follow joints and fractures. In the central lowland northeast of St. Mary's Bay, the area of moraine ridges mainly drained by Colinet and Rocky Rivers, has a thick cover of glacial drift in which bedrock outcrops are rare or absent. Numerous lakes form a complex, interlocking pattern controlled by the hundreds of parallel and subparallel drift ridges, and as in areas underlain by granite, the drainage is unintegrated with little or no bedrock control.

Where the drift cover is thin or discontinuous, glaciation has disrupted drainage less and the drainage patterns are controlled to a greater extent by bedrock structures. Stream courses and lake basins are largely controlled by fracture and joint systems in the more massive rocks and by bedding planes and folds in the sedimentary rocks. On both Carbonear and Placentia Peninsulas, close structural control of the drainage is evident where lakes and connecting streams follow curvilinear courses around the noses of plunging synclines or anticlines.

A few streams flow through broad channels much too large for their present size but which were incised in the drift by former meltwater streams of much larger volume. The best examples are found a few miles west of Cape Race and on the west side of St. Mary's Bay northeast of the village of Branch.

With precipitation on Avalon Peninsula abundant throughout the year — averaging more than 55 inches in the south and more than 45 inches everywhere else, and slightly heavier in the winter than in the summer — the widespread bogs in many parts of the peninsula act as sponges to absorb the heavy rainfall. In conjunction with the numerous lakes, they provide storage to regulate stream flow so that for most rivers the normal low-water flow is a large fraction of the maximum flow. Because many rivers fall from the interior uplands in their lower courses even streams with a comparatively small flow but with a high fall over a short distance are suitable for the development of commercial power. The headwaters of rivers that flow in deep preglacial valleys and lose altitude gradually over longer distances may be diverted across drainage divides to increase the flow in streams more suitable for power development. Examples of this are the south-flowing Northwest Brook, whose headwaters were diverted across a drainage divide more than 600 feet high into a stream that flows east into the Atlantic at Cape Broyle Harbour; and Manuels River, diverted over a drainage divide about 500 feet high to flow into Topsail River and, ultimately, into Conception Bay. Dams that raise water levels of the larger upland lakes a few feet make large water reserves available.

Vegetation

Most of the forest cover of the area is coniferous, with hardwoods such as birch and maple being almost entirely confined to the central lowland about St. Mary's Bay where somewhat sunnier weather and slightly higher temperatures favour their growth. Forests containing timber of any size are largely confined to lowland areas, to deep valleys, and to some of the more sheltered basins. This distribution is largely attributed to the more extensive areas of deeper glacial drift usually found in these locations.

Exposed uplands and the summits of higher hills and ridges are generally stony barrens underlain by bedrock or a thin layer of drift. Here, the vegetation cover consists of copses of black spruce, dwarf bushes, grass, and moss. Extensive areas of bog occur in the central and southern regions. In sheltered depressions and over some extensive areas in the rolling interior, stunted spruce 2 to 5 feet high — the obstructive 'tucking bushes' mentioned by Jukes (1843, p. 23) — grow close together with interlaced boughs and spreading tops, forming a dense mat that may be penetrated only with the utmost effort. In places it will even support the walker's weight for a step or two before allowing him to sink waist deep into their hampering grasp. The most extensive of these dense scrub-spruce areas lies south and southwest of Franks Pond.

How much of the treeless country not occupied by bogs is naturally barren, and how much has been denuded of its vegetation by recurrent fires, is uncertain. It is believed that much of the barrens was originally forested and subsequently stripped of trees by fire. Stumps and tree trunks, many still coated with charcoal, are to be found here and there, remote from present trees. However, many of the higher and more exposed areas were probably as open and treeless when the first settlers arrived as they are today. Barrens supporting valuable blueberry picking are burned over every 2 or 3 years to sustain the yield of the berry bushes. The largest of these barrens lies between Cappahayden and St. Shotts, in the southern parts of Trepassey Peninsula, and except where interrupted in two or three places by wooded river valleys, extends almost continuously for more than 30 miles.

Chapter III

BEDROCK GEOLOGY

Bedrock throughout the map-area is folded and faulted, rocks of Precambrian age generally being more severely deformed than the subsequent strata. The folding is generally open, with moderate to steep dips, and there is comparatively little metamorphism except for well-developed cleavage. Some of the faults transecting both Precambrian and Cambrian rocks are thought to have been most active during the Precambrian (McCartney, 1954). However, most or all of the Avalon rocks are considered to have been affected by folding during the Devonian Acadian Orogeny, whose activity probably accounts for most of the deformation in the region since Precambrian time. Younger beds in Conception Bay dip very gently and are disturbed only by minor faulting. Certain tightly folded Cambrian beds south of Trinity Bay are exceptional in that they are more severely deformed than the adjacent Precambrian strata, perhaps because of their incompetent nature.

Precambrian Rocks

Sedimentary, volcanic, and granitic Precambrian rocks underlie almost all the map-area. Most are Proterozoic in age though the oldest group, the Harbour Main volcanics, may possibly be Archean (Hutchinson, 1953, p. 9). The hard, resistant rocks consist mainly of volcanics, granitic rocks, siliceous slate and siltstone, sandstone, conglomerate, arkose, greywacke, and quartzite, with minor amounts of other sedimentary and igneous rocks. South of Conception Bay, an extensive area of mainly granite intrusives, the Holyrood Batholith, extends for more than 20 miles into the interior of the peninsula and underlies some of its highest and roughest terrain. Small bodies of quartz monzonite, quartz diorite, and gabbro, apparently Precambrian, intrude the Precambrian sediments at several places. Rocks of the Powder Horn Diorite Complex that form the high hills immediately north of Come By Chance may be a hybrid granitic complex comprising Precambrian volcanics and sediments intruded by post-Cambrian granite, possibly in Devonian time (McCartney, 1958).

Possible Precambrian Tillite[1]

Late Precambrian rocks, tentatively identified as tillite, are exposed at five locations: on the east shore of St. Mary's Bay 2 miles south of Gaskiers, northwest of the town of St. Mary's at Double Road Point and Frapeau Point; at the south end of Great Colinet Island and on the west side of Little Colinet Island. This last exposure, mapped as conglomeratic sandstone by McCartney (1967, p. 31), closely resembles the other sections except that the top 20 feet are 'red beds,' suggestive of subaerial

[1]Brückner, W. D. and Anderson, M. M.
1971: Late Precambrian glacial deposits in southeastern Newfoundland—a preliminary note; Geol. Assoc. Can. Proc., v. 24, no. 1, p. 95–102.

deposition. McCartney considered that the Little Colinet Island beds were atypical for conglomerate and that they presented puzzling features. He would have called the rocks tillite rather than conglomeratic sandstone, except for the lack of other evidence of glaciation in southern Newfoundland Precambrian rocks.

The glacial origin of numerous, previously supposed tillites has been questioned in recent years (Chumakov, 1966, p. 400–401; Crowell, 1964, p. 99), and it has been suggested that criteria cited to explain their origin can result from other processes such as subaqueous and subaerial gravity sliding (*see* Dott, 1961, p. 1290, *et seq.*; Pettijohn, 1957, p. 265). Both these processes may destroy stratification and evolve a poorly sorted mudstone.

The best diagnostic evidences of glacial origin are generally considered to be striated, polished pavement on the rock immediately underlying the bed in question, large areal extent, a high pebble content and undeniably foreign erratics. By definition 5 to 10 per cent of the pebbles in a true tillite should be striated or faceted, although some tills have lower percentages. No single criterion yields a positive identification; the presence of a combination of them, or indisputable evidence of one good one, helps to make identification more certain. For example, a large expanse of glaciated pavement with crossed striae or gouges would not be considered slickensides though a pavement with straight parallel scratches might.

Due to the character of outcrop, no striated, polished pavement was observed under the St. Mary's Bay tillite. Indeed, it could not be determined if such a pavement were present. Enclosing slates on the exposed shorelines had weathered at a faster rate than the tillite, concealing the underlying surface. Though the deposit is bracketed by marine rocks, a sequence less favourable than a subaerial one, it should be remembered that the till beneath St. Mary's Bay overlies hard, fine-grained marine sediments and that presumably marine sediments are now being deposited above it. This would duplicate the succession observed in the east coast exposure of the bay near Gaskiers. Also, the tillite has been traced for more than 15 miles and is thick for at least 10 miles. It contains many erratics representing a variety of rock types, some striated and faceted, though perhaps less than the desired 10 per cent. Some of the erratics have travelled considerable distances.

The tillite at Frapeau Point is a dark brown, gritty rock with foreign pebbles of chert, syenite, and monzonite, and a few cobble and boulder-sized erratics of similar lithology. Some pebbles are striated and, rarely, faceted. For the similar bed at Double Road Point, a true thickness of more than 700 feet was estimated from pacing and from slate attitudes at slate–tillite contacts. This bed contained several large slate erratics. On Little Colinet Island erratic stones of chert, felsite, jasper, and minor granite, including one of Holyrood granite which must have travelled at least 28 miles from the nearest source, were identified by McCartney. The Little Colinet Island section occurs in a marine sequence underlain and overlain by well-bedded siltstone which McCartney has identified as of late Precambrian age, an age that Dow (1965, p. 411) notes has been applied to many postulated tillites throughout the world.

The author considers that evidence cited for glacial origin of the St. Mary's Bay beds is sufficient to tentatively identify these extensive, thick deposits as tillite of late Proterozoic age, at least until further data, such as discovery of striated, polished pavement immediately underlying the beds, becomes available.

Paleozoic Rocks

Small areas of Cambrian rocks, in part fossiliferous, occur at various places, usually underlying lowland areas adjacent to the main bays. Generally they are preserved as synclinal or downfaulted remnants of Cambrian strata. Ordovician rocks (which contain the long-worked Wabana iron beds) outcrop on islands off the east coast of Conception Bay and underlie some adjacent parts of the bay itself. This is the only known occurrence of Ordovician rocks on the Avalon. Cambrian rocks are more widely distributed. They are present in areas near the head of Conception Bay, on the eastern and southern shores of Trinity Bay, and in scattered patches from Trinity Bay almost to St. Mary's Bay. They occur in the vicinity of Branch on the west side of St. Mary's Bay, at St. Bride's on Placentia Bay opposite Branch, around the heads of Bull Arm and Come By Chance, and north of Come By Chance on Come By Chance River (*see* Hutchinson, 1953; McCartney, 1956a, 1956b, 1958; Rose, 1952; Baird, 1954). According to Greene (1962) the largest stretch of Paleozoic rocks covers approximately 45 square miles and is found in the Branch–Point Lance area of St. Mary's Bay.

The Paleozoic cover was originally much more extensive, but together with any rocks deposited later, was removed from the Precambrian surface during the long erosional stage that extended up to the glacial period. The present widely separated patches are remnants preserved from erosion by downfaulting and folding. In the Conception Bay area, Cambro-Ordovician strata have been estimated by Hayes (1931, p. 51) to be present in sequences up to at least 10,000 feet thick, and Cambrian rocks as much as 1,500 feet thick (McCartney, 1967, p. 64); and Ordovician rocks as much as or more than 8,000 feet thick (Rose, 1952, p. 33). The Paleozoic rocks are found generally under lowlands or downfaulted blocks in the vicinities of Conception, Trinity and St. Mary's Bays, and a few other coastal areas.

Minor mafic intrusives of Paleozoic age are present in a few places, as are some contemporary volcanics. Small gabbro plugs and dykes and thin, Middle Cambrian pillow lavas possibly related to them, are restricted to the areas south of Trinity Bay and west of St. Mary's Bay. Gabbroic to granitic intrusions of possible Devonian age are found only in the western and northwestern extremities of the map-area. They include the Northern Bight granite, the Powder Horn Diorite Complex and the gabbro-to-granite sequence on the Iona Islands and Fox Island off the east coast of Placentia Bay (McCartney, 1956a, 1956b, 1958).

Chapter IV

GLACIATION, GLACIAL EROSION, AND POSTGLACIAL EVENTS

Glaciation

During the Pleistocene Epoch, this part of Newfoundland was glaciated, perhaps repeatedly, but the author has found no definite evidence of pre-Wisconsin glaciation. For discussion of its glacial history, the study-area has been divided into two sections: the area glaciated by ice radiating from St. Mary's Bay area and by confluent, thin, local ice cover on Carbonear and St. John's Peninsulas; and the area glaciated by ice flowing east and southeast from the Newfoundland interior. The central parts of the Isthmus of Avalon, which connects these two areas, were covered at different times by ice from each source.

The assumption made by MacClintock and Twenhofel (1940, p. 1750), among others, that Labradorian ice moved across the whole of Newfoundland at the Wisconsin maximum to "deposit the well-known drift of the Grand Banks," is based on the unproved supposition that the Grand Banks are massive terminal moraines. No evidence for this is cited by those authors from Avalon Peninsula itself, it being assumed that later local glaciation either obliterated any evidence, or swept it into the sea (MacClintock and Twenhofel, 1940, p. 1747).

Earlier concepts of ice from a Newfoundland ice cap west of the Avalon, or even of Labrador-derived ice, invading Avalon Peninsula and moving across it to the sea cannot, in the opinion of the author, be substantiated. Orientation of striae, erratic provenance and landforms, all indicate ice of local origin and suggest that this Avalon ice cap, far from being a late-glacial local dome formed by separation from withdrawing ice from an outside centre, was probably formed early in the Wisconsin glacial stage and flourished vigorously enough to dominate the peninsula and to exclude any ice attempting to encroach from the northwest. If valid for the Wisconsin, this pattern might also be expected to apply to previous Pleistocene glaciations; though if earlier ones were of greater relative severity and extent the balance between Avalon and mainland ice may have been different.

Existence of a former ice cap over Avalon Peninsula that moved outward in all directions across its borders was inferred before the turn of the century by Chamberlin (1895, p. 467, Abstract), who observed kames and moraines on the Isthmus of Avalon indicative of westerly movement from the heart of the peninsula into Placentia Bay. Coleman (1926, p. 201) reasoned that there was evidence of two glaciations by an Avalon Peninsula ice cap, one ancient, possibly Kansan or 'Jerseyan,' the other Wisconsin. He based his conclusion principally on observations of Butter Pot hill west of Fermeuse, and on the hilltops south of Holyrood where weathering is more advanced compared to the exposed, fresh, reputedly Wisconsin surface on Signal Hill at St. John's. He considered the thick morainic deposits in the vicinities of Whitbourne and Placentia Junction to be interlobate between the Avalon ice and ice from the more westerly Newfoundland centre (Coleman, 1926, p. 203). He postulated two invasions of this western ice into the area, one corresponding to his "ancient glaciation," the other to the Wisconsin. This author found nothing to substantiate Coleman's conclusions that ice from the main Newfoundland centre had invaded Avalon Peninsula. Rather, he agrees with Chamberlin's interpretation.

Initiation of Glaciation

Mather (1954, p. 300) pointed out that weather patterns which existed in former cold periods were similar to those of today, though the climatic fluctuations might be slightly larger and of longer duration. Once cooling is initiated, the most important factor in the accumulation of ice is precipitation (Zubov, 1950, p. 20). Climatic conditions on Avalon Peninsula, already subjected to heavy falls of snow, would, at that period, result in greatly increased snowfall with each degree drop in temperature. The total amount of precipitation would probably increase since the temperature difference between land and sea would become greater because of the greater lowering of temperatures over the land relative to those over the water.

The first ice accumulations on Avalon Peninsula were probably on the uplands, in areas more than 1,000 feet asl that ring St. Mary's Bay and that lie between the 50-inch isohyet on the north and the 55-inch isohyet on the south. Because of their height and direct exposure to the moist, oceanic airmasses, these uplands would probably have received an annual precipitation several inches more than the present 55 inches. As the mean annual air temperature at St. John's is now 40.6°F, it seems probable, in view of the long, moderately cold winters and the cool summers, that even today the mean annual temperature on the St. Mary's Bay uplands is less than 40°F. The present climate is already sufficiently severe there to generate patterned, frost-soil features of a type usually found only much farther north.

It is postulated that during a period of deteriorating climate, ice accumulation on Avalon Peninsula would begin as soon or sooner than on other parts of Newfoundland, with the possible exception of Long Range. Following the initiation of ice accumulation, buildup would be rapid because of the maritime climate. Precipitation would increase because of the chilling effect of the high, cold, ice-covered surface, and this condition would probably persist into a glacial stage. Ice would first move east and west from north–south divides on Trepassey and Placentia Peninsulas. With increasing flow, the thickening ice would appear to have invaded the basin of St. Mary's Bay, where its surface continued to rise until the highest part of the ice cap lay over the bay. From this point on, throughout Wisconsin time, radial flow from this source appears to have dominated most of Avalon Peninsula and the surrounding shelf.

This concept of early buildup disagrees with the view of MacClintock and Twenhofel (1940, p. 1750), who held that the Avalon ice cap is residual, probably left by invading ice of Labrador origin, and that it only acquired radial motion as a late, local phase of the Wisconsin glaciation, at which time it eradicated evidences of the earlier invasion. Examination by this author of numerous tills, some in deep cuts to bedrock, revealed only rocks found on Avalon Peninsula itself that do not require glaciation from Labrador or other parts of Newfoundland to explain their presence. The author believes the area was never glaciated from the northwest for it seems unlikely that local glaciation following an invasion of outside ice would scour away all foreign detritus down to bedrock, carry every fragment beyond the coasts, and then lay deep deposits of local genesis with no redeposition of any outside erratics.

Once a vigorous ice cap flowing radially across the coasts was formed on the Avalon, it would require a tremendous thickness of outside ice to overwhelm it. To reach the Avalon from the west or northwest, ice would have had to cross deep Placentia and Trinity Bays, both of which would have acted as main drainage channels to the

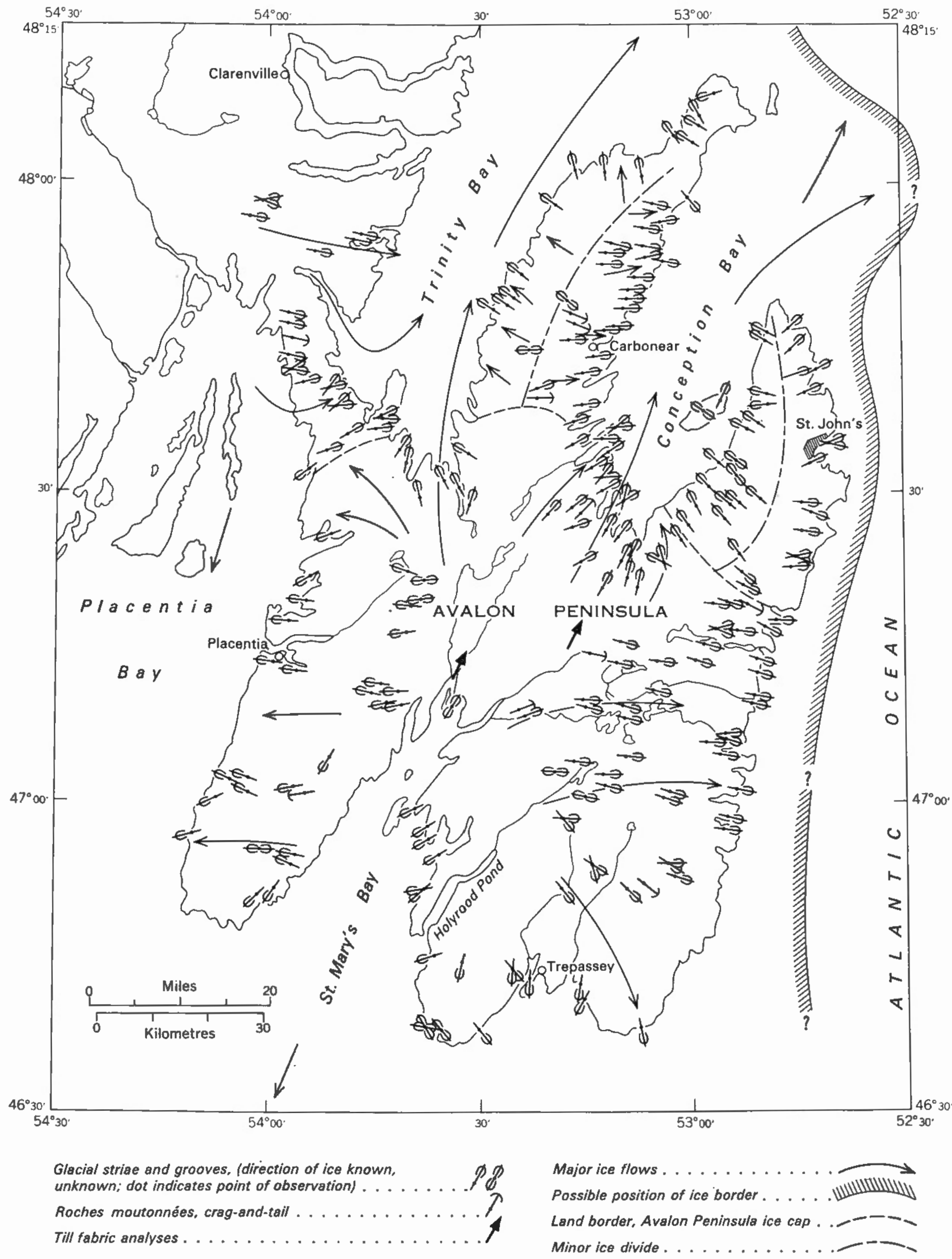

FIGURE 5. Orientation of ice-flow indicators and probable extension of ice at the Wisconsin glacial maximum.

Atlantic. It would also, while undergoing major divergence down these bays, have had to rise to at least 2,000 feet to attain sufficient thickness to overwhelm the St. Mary's Bay ice cap. If, as suggested, the precipitation pattern of the past was similar to that of the present, the heaviest accumulation of ice would always be on the Avalon ice cap, not over other parts of Newfoundland. The position of the zero isobase of postglacial uplift along the western edge of Avalon Peninsula strongly supports the interpretation that ice from west of the peninsula would be blocked by a vigorous Avalon cap and would be diverted into the easy drainage routes offered by Trinity and Placentia Bays. This was also the position taken by Coleman (1926, p. 203) to explain the lack of any postglacial raised beaches on the Avalon. Massive flow of western ice across the Avalon and onto the continental shelf would have sufficiently depressed the peninsula so that the subsequent crustal rebound following deglaciation would have resulted in raised beaches. Absence of such beaches has a bearing also on the thickness and extent of Avalon ice.

Wisconsin Glacial Maximum

All evidence points to the conclusion that at the Wisconsin glacial maximum, the Avalon ice cap, centred over St. Mary's Bay, radiated outward in all directions, as shown on Figure 5. Further, it must have been at least 2,000 feet thick to have glaciated the uplands east and west of the bay that reach elevations of nearly 1,100 feet asl, and to fill the bay whose floor, in places, lies 650 feet below sea level. If the bay floor at that time lay at its present level, the minimum thickness of ice necessary at all places to cross the uplands, could not have been less than this. How much greater depths of ice were attained is difficult to say, depending as they would on the distance the cap extended beyond the present coasts. The absence of raised beaches suggests it did not greatly exceed this minimum thickness nor extend far beyond the present peninsular limits.

Outflow from the accumulation dome over St. Mary's Bay would probably be easiest to the south over the wide threshold that is only slightly below present sea level. In the north and northwest, low cols, one at 200 feet, the other at just more than 400 feet above sea level, gave somewhat less free egress to the large volumes of ice that escaped through Trinity and Conception Bays. *Roches moutonnées* and striae show that the cols have been scoured by northward-moving ice (Fig. 6) and the manner in which both bays have been overdeepened indicates ice moving down them from their heads. In spite of the apparently open outlet to the south, striae, *roches moutonnées*, and moraines indicate that the ice must have accumulated until it was sufficiently thick to overtop the uplands east and west of the bay and to move vigorously across them.

It is difficult to explain the thick accumulation of ice over St. Mary's Bay unless the ice drainage south and southwest had been blocked. The author believes this restriction to southward movement was the ice flowing east in Cabot Strait from the Gulf of St. Lawrence and south from the other parts of Newfoundland — with possible additions, at the time of greatest eustatic lowering of sea level, from accumulated ice on parts of the emergent continental shelf. That a large volume of ice did move through Cabot Strait is indicated by recent studies on the bottom topography of the passage (Canadian Hydrographic Service, Charts Nos. 4015, 4016, 4041) that show a very large, steep-sided trough, many hundreds of feet deep, running southeasterly from the gulf to the edge of the continental shelf. Several closed basins have been excavated in the flat, trough floor, and the trough itself must have been excavated in the soft, semiconsolidated Tertiary rocks by ice from the various sources just mentioned.

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FIGURE 6. *Roche moutonnée* 24 feet high, 120 feet long, in slate on east side of Hodgewater Line (No. 66 Highway) northeast of Grand Pond.

Smaller troughs from Fortune and Placentia Bays join this larger one and mark the routes followed by much of the ice from areas of Newfoundland west of the Avalon. Ice moving seaward through Cabot Strait, or accumulating on the emergent parts of the continental shelf, could have formed the barrier that blocked south-flowing ice from St. Mary's Bay and caused it to thicken until it overflowed its land barriers.

According to Flint (1957, p. 261), sea level at the Wisconsin maximum was at least 293 feet (90 metres) lower than at present. It is unlikely it was ever much lower than 400 feet (123 metres). As even deeper water lies off the mouths and nearly up to the heads of Trinity and Conception Bays, the outlet glaciers debouching there from the Avalon ice cap must have had calving fronts continuously throughout their life. Though the glacier in Trinity Bay also carried ice from the areas to the north and west, and must have been considerably larger than the one in Conception Bay, it discharged into deeper water and therefore probably did not extend any farther seaward. At the ice fronts, wastage by calving and melting would prevent the ice from projecting more than about 20 miles beyond the protecting, bay-mouth headlands. The broad 80-fathom bank off the mouth of Conception Bay, long considered to be of morainic origin (Kerr, 1870, p. 705), and another bank with somewhat deeper water over it off the mouth of Trinity Bay, imply glacier fronts stabilized at these positions for a long period. As gradients on the ice surface of the outlet glaciers would decrease as the glaciers lengthened, and would increase as the ice in St. Mary's Bay thickened, stabilization of the position of the glacier fronts at a short distance outside the bay mouths would be an important control on the height attainable by the ice cap. With an increase in height, the amount of ice flowing northward from St.

Mary's Bay would become greater; but because of the stationary calving front, increased flow would not increase the length of the glaciers although it would increase their surface gradient and their rate of flow. Ice flowing out across the uplands to the east and west would also rapidly check the thickening of the dome, once its height exceeded 2,000 feet.

Erosion of valleys at Cape Broyle and Aquaforte Harbour indicates that considerable quantities of ice flowed across the east coast to the sea. The total volume of this outflow was large, though probably not so great as that of the outflow into Trinity and Conception Bays. Because of the underwater configuration offshore it would have been insufficient to maintain an ice shelf more than a few miles wide.

The volume of ice flowing from the Avalon cap into Placentia Bay was small, much less than the amounts flowing north and east, and there is little evidence on Placentia Peninsula of intensive glacial erosion west of the Placentia Bay–St. Mary's Bay divide. Blocked by the ice in Cabot Strait, the ice draining south and east through Placentia Bay apparently became sufficiently deep at the northern end of the bay to overflow into Trinity Bay across the Isthmus of Avalon as far south as the Doe Hills. These broad summits more than 800 feet high show unusually well developed mamillary rock surfaces, excellent *roches moutonnées*, crescentic fractures and numerous unweathered striae, all formed contemporaneously. This ice must have risen to heights that prevented a flow westward from the Avalon cap.

Even at the glacial maximum, the heavy drainage through Trinity and Conception Bays appears to have drawn off so much ice that outflow from the main Avalon centre was unable to advance far along the high, central axes of St. John's and Carbonear Peninsulas. A thin, local ice cover confluent with that of the main ice cap extended along the central ridges of these peninsulas from near their bases to their northern tips. As indicated in various places by the boulder provenance, this local ice drained east and west at right angles to the central ridges. At lower levels, *roches moutonnées* and associated striae give further evidence of this flow. Though not thick, this ice covered the entire surface of the peninsulas, its profile controlled by underlying topography. Generally, its erosive action was feeble, in places little more than enough to move loose blocks short distances, and leaving much rotted bedrock in place. Near the coasts the steeper gradients increased the erosive power of the ice sufficiently to develop heavy striations, *roches moutonnées*, and plucked lee slopes.

The peak of erosion intensity of Avalon ice occurred during the glacial maximum and was concentrated along margins of the ice sheet that had sufficient topographic relief to channel the flow into deep, fast-moving ice streams capable of vigorously plucking and scouring the underlying rocks. Glacial overdeepening occurred on the floors of the two northern bays, valleys on the east coast were reshaped, and crests of the highest hills were glaciated. Both south of Holyrood and west of Fermeuse, heights that Coleman (1926, p. 201) considered had remained unglaciated during the Wisconsin, are underlain by granite and rough-weathering volcanics which during postglacial time have in exposed areas lost all but the heaviest striations, but which in areas with even a thin protecting cover retain polished and scratched surfaces. At Brigus Junction, 8 miles east of the Holyrood volcanic hills described by Coleman, crests at approximately the same elevation are underlain by hard, fine-grained rocks and are characterized by grooved and striated *roches moutonnées* formed by Wisconsin ice. Though exposed to weathering for the same length of time as the volcanics, nothing has been removed except the polish and perhaps the very finest of striae.

As already suggested, the Avalon centre probably contributed little to the volume of ice moving down Placentia Bay, which always carried a preponderance of drainage from the more westerly parts of the island. The most active erosion probably took place before and after the glacial maximum, at a time when southward flow would have been less restricted by ice in Cabot Strait. The closed basin beneath St. Mary's Bay (enclosed depth 440 feet; 135 metres) may owe more to glacial erosion before or after the glacial maximum than to erosion during it, though glacial deposits south of the bay mouth could account for much of the "overdeepening" effect disclosed by soundings. The deeper parts of this bay lie one third of the distance from its head, and at the time this area lay under higher parts of the ice dome little or no erosion would take place. Movement at that time would then have been downward and outward rather than along the axis of the bay. There is, however, some reason to believe that the highest part of the ice dome lay somewhat south of the upper third of the bay, probably near the bay mouth. If so, ice moving northward up the bay would erode the floor toward the head. The large amount of thick till in the morainal areas north of the bay contains stones and pebbles derived from bedrock formations underlying the bay, suggesting that late Wisconsin ice came from that direction. These deposits were laid down during deglaciation and indications are that the ice moved from the south, because erratics, which one would expect to find had the ice flowed from other directions, are absent.

Ice From Other Parts of Newfoundland

As indicated by erratic provenance, orientation of striae, grooves and shaped bedrock bosses, thick ice from the Newfoundland interior flowed south of east toward Trinity Bay, across the northwest corner of the study-area, approximately at right angles to the coast. Almost all the ice-movement indicators are oriented between 15 and 25 degrees south of east, a direction that continues for about 4 miles along the Isthmus of Avalon as far south as Little Southern Harbour and Rantem Cove. Distinctive granitic erratics, that could only have originated in areas to the northwest or on islands in Placentia Bay, are in tills on the isthmus to a point east of the Doe Hills. Either source would indicate a generally east or southeast flow of the ice. Farther south, similar rocks are found only on the modern Placentia Bay beaches north of Placentia Sound, evidently carried there by ice rafting. Inland, they are absent from the tills everywhere south of Doe Hills.

On the northernmost part of the isthmus and in the adjacent areas to the north and west, most oriented, glacial, bedrock markings were probably inscribed by late Wisconsin ice — although ice movement at the Wisconsin glacial maximum is also believed to have been in the same direction or very close to it. Going farther south toward the Doe Hills about halfway down the isthmus, the ice moved first to the east, then, farther south, to north of east (*see also* McCartney, 1956b, 1956c; Jenness, 1960, p. 164). A late local movement followed during which the ice moved north-easterly. Thus from the vicinity of Little Southern Harbour-Rantem Cove, south to Doe Hills, two ice movements are recorded at numerous places in the central and eastern parts of the isthmus: the older one oriented some 20 degrees north of east, the younger one more nearly northeast. The summits of the Doe Hills, composed of hard volcanics and rising to more than 800 feet above sea level, higher than any other land for several miles around, were also glaciated intensely by ice moving 20 degrees north of east, and more lightly, by ice moving 40 degrees north of east.

Numerous crossed striae date the relative ages of the two movements, and at Rantem, striated, intersecting, planed surfaces confirm flows that continued long enough to bevel flat the hard, andesitic rock (Fig. 7). The relative ages of the striae were mainly determined in locations where the fine, northeasterly, younger striae were incised below the edges of the older, heavy, east 20 degrees north striae, and where striae oriented 20 degrees north of east were preserved only in the protecting lee of rock surfaces striated northeast. The older flow, which registers the movement of ice from Placentia Bay into Trinity Bay, deposited the granitic erratics; the later, northeast movement represents axial flow of local ice from the high central parts of the isthmus.

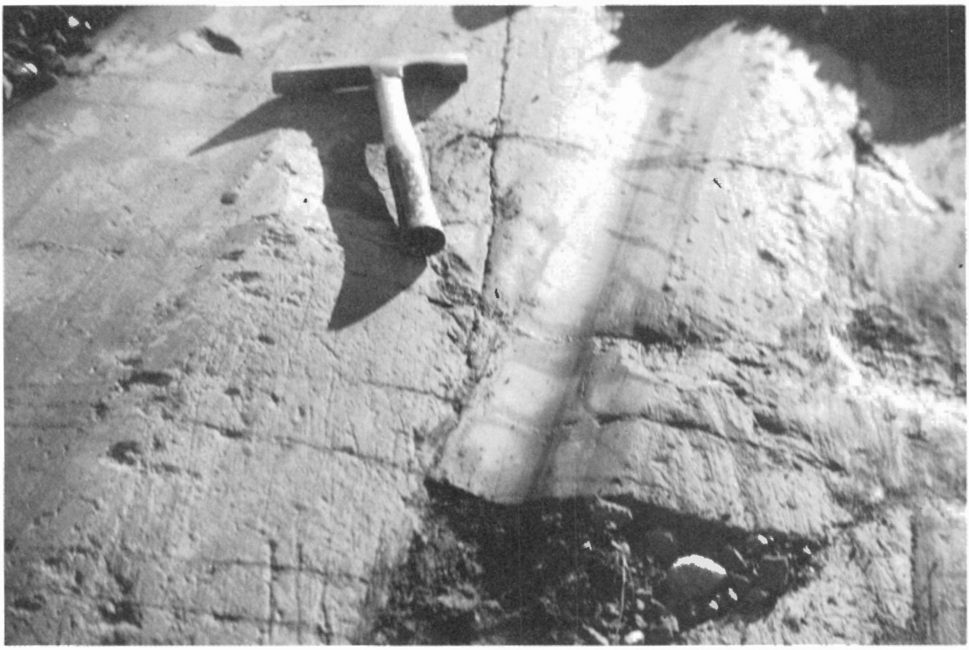

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FIGURE 7. Crossed striae and intersecting planed surfaces in till pit on the highway north of Rantem.

Even at the glacial maximum the flow from the west does not appear to have been sufficiently strong to carry western ice across Trinity Bay and onto Carbonear Peninsula. However, it did force the heavy, north-flowing stream of Avalon ice against the eastern side of the bay, resulting in asymmetrical overdeepening of the bay floor. Ice thickness of only 1,000 to 2,000 feet rather than several thousands of feet is implied; otherwise Trinity Bay would have been overwhelmed. This lesser thickness may also be inferred from the moderate isostatic rebound indicated by raised shorelines only 15 to 30 feet above present sea level. Christie (1949, field notes as quoted by Jenness, 1960, p. 175) noted that "striations are oriented S 70 E on a smoothly polished bedrock surface just south of Grates Point, at the northern end of the Carbonear Peninsula," and considered this observation as supporting evidence for the movement of ice from west to east across Trinity Bay. The present author searched unsuccessfully for these striations. If they do indicate actual movement *onto* rather than *off* the land, they still may not be a record of an encroachment of western ice onto Carbonear Peninsula. As ice from the Avalon ice cap presumably flowed up the eastern side of the bay, the striations may only represent the forcing of the Avalon ice back onto the tip of the peninsula under pressure from western ice pushing eastward into the bay. Such an interpretation would be consistent with distinctive erratics from areas to the west of Trinity Bay being absent from the Carbonear tills in this area.

The narrow channel of Bull Arm probably carried the heaviest stream of ice east into Trinity Bay. Its precipitous sides plunge to more than 600 feet below sea level near its mouth (U.S. Navy Hydrographic Office, Chart H.O. 1102) and a deep trench leads from the inlet across the floor of Trinity Bay.

Large volumes of ice also entered Placentia Bay both at its head and from the northwest across Burin Peninsula (GSC Glacial Map of Canada, 1968). Flow out of the bay would have been checked by ice in Cabot Strait, in the same way that St. Mary's Bay ice was checked. Thus, during the heaviest ice drainage of the glacial maximum, this obstructed ice backed up and spilled over east and northeastward across the Isthmus of Avalon and extended as far south as the Doe Hills, which it overtopped. East of the isthmus divide, a few striae oriented between 20 and 27 degrees north of east are found on hilltops for about 5 miles south from Doe Hills. They may record flow of ice to Trinity Bay from the west in the same way as the striae farther north, but as no granites of western provenance were found in the tills, they could indicate merely local movement. Since ice from the Avalon ice cap probably did not reach more than a mile or two north of the Long Harbour–Chapel Arm road, the 10-mile stretch of the isthmus between the road and the Doe Hills may, like Carbonear and St. John's Peninsulas, have been subjected throughout the Wisconsin period to local glaciation only. On the other hand, because of the heavy glaciation of the Doe Hills crests, it is possible that western ice may at the glacial maximum have extended even farther south of the hills. A search for granitic rocks of western origin in the tills of this part of the isthmus should clarify the question of whether ice from more westerly parts of Newfoundland merged in this area with ice from the Avalon cap.

Deglaciation

Climate is the major control factor in glaciation. Usually, a more or less gradual retreat of the ice sheet and its glaciers from low peripheral areas is initiated when the rate of ice accretion in accumulation areas feeding the draining glaciers decreases either because of lessened precipitation and/or increased ablation. Retreat continues until the budget of the ice field is again in balance. At the glacial maximum the southward flow of Avalon ice was obstructed by ice in Cabot Strait. This ice, being in a low peripheral position relative to its distance source, would have been readily sensitive to any amelioration of climatic conditions. A thinning of the Cabot Strait ice would affect the flow from St. Mary's Bay even though accumulation rates over Avalon Peninsula remained relatively unchanged. That something similar did happen seems indicated by evidence of an early migration of the highest part of the ice cap northeastward from the mouth of St. Mary's Bay toward its head.

The following reconstruction, based on indicated patterns of ice flow (Fig. 5) and their associated deposits (*see* Chapter V), outlines the most probable course of events following the last glacial maximum. Grooves and striae on the tip of Trepassey Peninsula between Trepassey Bay and St. Mary's Bay record easterly movements from the direction of the mouth of St. Mary's Bay — location of the centre of the Avalon ice dome at the time of the glacial maximum when Cabot Strait ice was thickest. Even had accumulation rates over Avalon Peninsula remained little changed, increased drawdown into Cabot Strait at a later period, due to the thinning of ice there, would have lowered the ice surface in the vicinity of the bay mouth. Ice farther up St. Mary's Bay would then be relatively higher and the centre of radial flow would move northeastward. As the southerly flow of ice out of St. Mary's Bay increased, northward movement through the outlet glaciers in Trinity and Conception Bays would slacken, and less ice would reach the east coast. This change may have occurred fairly rapidly, depending upon how quickly the eastward flow of ice from Labrador and the more western parts of Cabot Strait decreased.

After the glacial maximum, radial flow from a dome centred nearer the head of St. Mary's Bay appears to have continued for a considerable time. Even allowing for the local drainage from Trepassey Peninsula, most of the ice moving through Holyrood Pond, a much-overdeepened fiord with truncated spurs, could only have come from this source. To the west of this ice centre, many striae and grooves on ridges north of Branch record ice movement toward Placentia Bay and away from the upper parts of St. Mary's Bay. To the east, movements of local ice apparently destroyed any earlier, similar, easterly oriented markings that may have existed on the west side of Trepassey Peninsula.

The flow of ice, east and north of east out of Placentia Bay and across the Isthmus of Avalon, appears to have ceased at about the same time that the ice centre over St. Mary's Bay shifted north, and for the same reason: a lessening of the volume of east-moving ice in Cabot Strait that gave easier southerly egress for the thick, obstructed ice in Placentia Bay. This lowered the ice surface near the head of the bay and brought to an end the diversion of ice into Trinity Bay. That climatic conditions were still severe, possibly only little milder than during the glacial maximum, is suggested by the subsequent development of local glaciation on the Isthmus of Avalon. Though the higher parts of the Isthmus are less than 1,000 feet asl, ice accumulation was sufficient to support axial flow into Placentia and Trinity Bays, as shown by boulder provenance and associated striae east of Fair Haven and, farther north, by late changes of ice direction into Trinity Bay.

Although severe glacial conditions still prevailed along the west shore of Trinity Bay, continued lowering of the Avalon ice cap reduced the nourishment of the outlet glaciers flowing into Trinity and Conception Bays. Even when Avalon ice had almost ceased to move north into Trinity Bay, a large volume of ice continued to flow in from the west. The Bull Arm tongue reached across the bay and impinged on the shore of Carbonear Peninsula, carrying with it distinctive western erratics that were deposited in the angular gravels now exposed in low shore bluffs. Because the gravels extend inland only a few yards from the shore over a short stretch of coast across the bay from Bull Arm, they probably represent a kame terrace deposit. Stones of western provenance are absent in adjacent till.

Most of the early ice recession appears to have been caused by increased southerly drainage out of St. Mary's and Placentia Bays. However, at about the time the Trinity Bay glacier retreated to the head of the bay, continued amelioration of the glacial climate had lessened the annual amounts of ice accretion. Higher summer temperatures and the resulting increased ablation would quickly affect the whole ice cap, reducing the flow of ice westward across Placentia Peninsula. Wastage by melting eventually became dominant as active flow diminished. Meltwater deposits were laid down and the first large meltwater channels were eroded on the largely ice-free slopes west of the north–south divide of Placentia Peninsula. These west-facing slopes were the first to be ice free. After an interval during which several deep meltwater gorges were cut across the main peninsular divide, the ice continued its eastward retreat across central Branch valley and toward St. Mary's Bay. No evidence for the late centre of outflow on Placentia Peninsula recorded by Summers (1949, p. 83) was found by this author.

At about the same time, ice ceased to move from the St. Mary's Bay area into Trinity and Conception Bays, though some ice probably still flowed into Conception Bay from St. John's and Carbonear Peninsulas. Most of the meltwater from the main Avalon ice centre escaped freely downslope, but a glacial lake was impounded southwest of Whitbourne when a mass of residual ice blocked drainage northward across the low col into Trinity Bay. This lake was of short duration and drained upon disintegration of the ice plug, leaving a foot or two of silt over lower elevation moraines.

Ice retreated first from coastal areas, and the reduced flow was concentrated into tongues that extended seaward down the major valleys and beyond the retreating ice margins. The main accumulation area shifted east from St. Mary's Bay to the highlands of Trepassey Peninsula. Trepassey Peninsula, broader and with a much greater expanse of upland than Placentia Peninsula, remained an area of accumulation and outflow for some time after the glacial regimen on Placentia Peninsula had come to an end. Meltwater erosional and depositional features, formed when the main ice centre lay over St. Mary's Bay, remain unmodified on Placentia Peninsula but are absent over much of Trepassey Peninsula. South from Little Colinet Island, striae on shore rocks of the Trepassey coast record the westward movement of this late ice into St. Mary's Bay after most or all of the thick St. Mary's Bay ice that formerly discharged eastward over the same area, had disappeared.

Final wastage of St. Mary's Bay ice was swift. Once the Cabot Strait ice had disappeared, the sea invaded the area and came into contact with the long southern edge of the ice cap. Melting and calving caused rapid ice recession up-bay and the last main centre of active Avalon ice retreated to the uplands of Trepassey Peninsula. On the west shore of St. Mary's Bay, marginal drainage channels and numerous spillways leading shoreward from gorges cut across coastal spurs, mark the marginal positions of the ice retreat. South from Little Colinet Island, these indicators are absent on the eastern side of the bay. Instead, glacial markings, oriented toward the bay, and recessional moraines deposited in front of ice tongues retreating into the interior of Trepassey Peninsula, are found. Eskers and large meltwater channels around Trepassey Bay and along the eastern coast also record retreat from coastal areas into the interior of this peninsula. Hummocky moraine and scattered ablation moraine mark the area where the last ice melted, largely as stagnant masses trapped in highland basins in the Hawke Hills and south from there to the vicinity of Franks Pond.

As the ice withdrew from the cols leading to Trinity and Conception Bays, a series of ridges composed mostly of till formed parallel to the ice front. Whether they were laid down directly at the ice front by marginal melting and ice shove, or were formed by the flow, into basal crevasses, of saturated till under hydrostatic pressure, has not been proved. This author strongly favours some kind of frontal accumulation. The asymmetry of most better developed moraines, some of which are paired, suggests that the ice retreat was fluctuating rather than continuous, and that it was interrupted by a series of pauses followed by surges during which the margin advanced short distances. Recessional moraines formed in front of ice tongues draining the main Avalon cap and those draining the local ice cover on St. John's and Carbonear Peninsulas. This suggests that climatic control caused simultaneous pauses and slight advances at most ice-marginal positions, not just on the St. Mary's Bay lowland. A cycle of short cooler periods and warmer periods could cause these fluctuations, and the heavy precipitation of the area would tend to augment their effect.

On the east coast, south and west of Bay Bulls, the distribution of granite erratics suggests a late-glacial shift of the southern end of the St. John's Peninsula ice divide that separated the southeasterly flow into the Atlantic from the northwesterly flow into Conception Bay. Though granites comprise 15 to 20 per cent of the drift at the junction of the Witless Bay Line and the eastern coastal highway, they rapidly decrease to zero halfway between the junction and Bay Bulls, 1⅓ miles farther north. The granite erratics have been transported over slates 7 to 8 miles east 35 degrees south from the Holyrood Batholith whose western boundary in this area runs north–south for many miles. Close to the batholith, however, granites have been transported east 35 degrees south from points as much as 4 miles north of the intersection of the batholith boundary and a line from the halfway point just mentioned (Fig. 8). Between the batholith and the coastal highway all ice flow in the area toward and

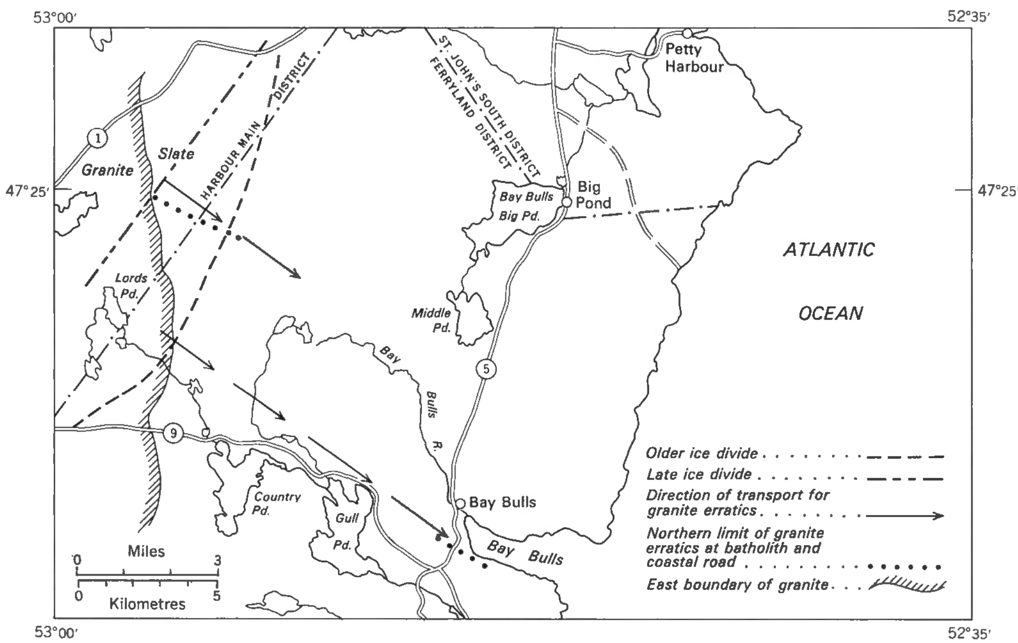

FIGURE 8. Late-glacial northwesterly shift of St. John's Peninsula ice divide.

north of Bay Bulls is either roughly in the same direction or a little more to the north; therefore, the ice divide must have shifted 4 miles north along the edge of the batholith following withdrawal of the ice from the vicinity of the coastal highway. Otherwise, granites would be found at the highway for at least 3 miles to the north of Bay Bulls. As the ice divide lay at right angles to the direction of transport of erratics, the observed conditions indicate a 2-mile shift of its axis in the direction west 35 degrees north, which in turn would cause the approximate 4-mile northward shift of its intersection with the north–south granite–slate contact. It is probable that late-glacial shifts of this or even greater magnitude also occurred on ice divides on the undulating uplands of both St. John's and Carbonear Peninsulas but have not been observed because of the uniformity of the underlying bedrock formations.

Glacial Erosion

Glacial erosion on Avalon Peninsula varies from practically nothing in the north where weather-rotted bedrock still forms the surface cover, to excavations hundreds of feet deep along the channels of former outlet glaciers. Where the ice was thin and had little lateral movement its erosive power was weak regardless of the character of the rock beneath it. Where it was thicker, particularly where it converged into rapidly moving ice streams, the effectiveness of its more concentrated erosive power was influenced by the structure and hardness of the rock over which it passed.

The more northerly, interior parts of Carbonear and St. John's Peninsulas do not appear to have ever been invaded by ice from other areas; in fact, all evidence seems to suggest that the higher central areas of these peninsulas were subjected to very little erosion even by local ice. Near the narrow tip of Carbonear Peninsula, a mile north of Bay de Verde village, 5 feet of well-rotted bedrock are exposed under thin moraine. Eight miles to the southwest a large area is covered with shingle derived from underlying, reddish greywacke that appears to be residual material never disturbed or removed by the ice. Observations were made, principally in the higher central parts of southern Carbonear Peninsula, of both undisturbed rotten shale in exposed positions and of large rock surfaces with only local boulder erratics, many of which appeared to have been shifted only a few feet or a few yards. On both St. John's and Carbonear Peninsulas evidence of erosion by ice increases the lower the elevation and the closer to the coast. However, except in southern parts that were invaded by ice from the main Avalon cap, this erosion seems to have resulted only from the ice that drained perpendicular to the long axes of these peninsulas.

In marked contrast to little-eroded sections of St. John's and Carbonear Peninsulas, the rest of the map-area shows signs of more active glaciation. Numerous fresh-appearing landforms evolved as degradation proceeded by abrasion and quarrying. These are seen wherever there are outcrops of rocks resistant to postglacial weathering (*see* frontispiece and Fig. 9). If the generalization advanced by Flint (1957, p. 81) — that on average, glacial erosion is able to remove only a few feet or tens of feet of unweathered rock — is true for Avalon Peninsula where hard granitic and volcanic rocks abound, most of the larger features must be inherited, with modifications of detail, from a time of long-continued, preglacial erosion. The scanty drift in such areas indicates how small were the amounts that originated from these rocks. Spalling of granite and quarrying on the lee sides of hills would cause much deeper local removal.

The hard, siliceous slates over much of the area appear to have been more deeply eroded than the granites or volcanics. Fractures along cleavage planes allowed extensive quarrying, and the resulting large boulders were rapidly fragmented during transport. Many thick tills derived from local slates, such as those of the St. Mary's Bay lowlands that are largely composed of rock fragments a foot or less in size, contain relatively few large erratics.

An example of modification of a hill profile by plucking was observed in a slate area 2 miles north of Franks Pond (Fig. 9). Three cirque-like hollows with flat, level floors and steep back walls have been formed in the low, smooth, gently sloping hill. The two larger hollows are 150 feet across at the front, with back walls 25 and 30 feet high. Three large slate erratics on the floor of one of them are 10 to 14 feet long and 6 to 8 feet high. Since being quarried by the ice, they have apparently been moved only a few feet from their original position in the back wall where bedrock is exposed. No slate erratics larger than a foot or 2 feet in diameter are to be

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FIGURE 9a. Hollows quarried in slate by ice plucking.

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FIGURE 9b. Back wall of large hollow shown in Figure 9a. (Note large erratics at left, bedrock at right.)

found in the adjacent ground moraine for a considerable distance in any direction, demonstrating that this type of slate erratic breaks up rapidly if moved more than a few yards. Possibly many more plucking hollows exist in the area but they are concealed beneath the cover of glacial drift.

A low ridge of pebble-conglomerate outcrops 1½ miles southwest of the slate zone. From this ridge many large, resistant erratics have been plucked and distributed over the surface in the direction of ice flow (Fig. 10). The profusion of large erratics quarried from so small an area may possibly result from a pressure release that supplied blocks to the plucking action of the last ice to move over that part of the country. The high rate of denudation implied by the volume of material in these erratics could only have been sustained for a short time without entirely removing the small source ridge. This phenomenon of pressure release (*see* Lewis, 1954, p. 419) was previously observed in granitic rocks in Labrador (Henderson, 1959, p. 59) and may also be the explanation for some of the fields of large, angular, granitic erratics seen elsewhere in the Avalon.

Glacial erosion was most intense where outlet glaciers channelled ice to the sea. Some of this ice moved across the grain of the bedrock structure, markedly modifying the confining valleys, e.g., along the central Atlantic coast of the Avalon and along the outlet routes in the northwest part of the study-area. The largest ice streams, however, flowed out down the four main bays, parallel to both their general alignment and their major structural trends (Hayes, 1948, geologic maps; Rose, 1952, p. 40; McCartney, 1954, 1956, 1958, geologic maps). It is in these bays and in Holyrood

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FIGURE 10. Group of large pebble-conglomerate erratics. The dimensions of the largest, which fills the foreground and looks like a bedrock ridge, are 30 x 35 x 18 feet.

Pond on Trepassey Peninsula that evidence of greatest erosion is to be found. Zones of fault-brecciated rock and planes of weakness in the soft Paleozoic shales beneath Trinity and Conception Bays contributed to the effectiveness of ice erosion in these two basins. The greatest overdeepening, 1,170 feet, took place in Trinity Bay. The maximum recorded depth in the bay, 1,920 feet, occurs more than halfway toward the bay mouth, 4 miles from the eastern and 8 miles from the western shore (U.S. Navy Hydrographic Office Chart H.O. 1102, 1956). The long, irregular, closed basin runs up the eastern side of the bay, swerves past the tip of Carbonear Peninsula, and rises to about 750 feet beneath the surface some 27 miles northeast by north, well off the mouth of the bay (Fig. 11). Jenness (1960, p. 168) pointed out that the asymmetrical cross-section of the bay floor, with its short, steep eastern slope and longer gentle western slope, is not typical of a glaciated valley. Rather, he considered the bottom topography indicative of a major submarine fault scarp, and based his conclusion partly on the fact that ice entered the bay from the west at right angles to the northeasterly oriented basin. The supposition does not take into account the ice flow from the south that would have entered the more easterly of the two inlets at the head of the bay and would have moved up the east shore. Pressure of ice entering the bay from the west would tend to hold this ice stream in its easterly position, thus concentrating erosion on that side of the bay. The curve of the deep trough northeastward across the tip of Carbonear Peninsula may reflect the pressure effect of ice moving east out of Smith and Random Sounds. Faults under the bay, assumed to run parallel to its long axis, could have contributed greatly to overdeepening by providing zones of weakness in the underlying rock strata; but when all sources of ice flow are taken into account that may not be necessary to explain eastward displacement of the deep-water trough.

Overdeepened troughs are indicated by soundings in Conception and St. Mary's Bays and in the western part of Placentia Bay. Though less overdeepened than the basin in Trinity Bay, they are more symmetrically located and lie closer to the heads of the bays. St. Mary's Bay is the shallowest of the four main bays but overdeepening there is greater than in Conception Bay and nearly as great as in Placentia Bay. St. Mary's Bank, a broad shallow area 10 miles off the bay mouth, is covered by less than 120 feet of water except where it is crossed by a slightly deeper, narrow, centrally located channel less than 2 miles across. This bank may be a massive terminal moraine; if so, its location on the basin rim would give an apparent increase in the depth of water in the basin equal to the height of the moraine. Soundings south of St. Mary's Bank seem to indicate that the depth of the closed basin cannot be entirely explained by morainic deposits because, to a distance of at least 30 miles off the bay mouth, the floor of Cabot Strait is nowhere deeper than the floor of St. Mary's Bay outside this basin. The lengths and depths of the four main bays, the amount of overdeepening and the location of the enclosed basins, are shown in Table I.

Apparent increase of the effects of overdeepening resulting from deposition of morainic material off the mouths of any of the four main bays cannot be eliminated. Nearly 100 years ago Kerr (1870, p. 704, 705) suggested that the 80-fathom bank across the mouth of Conception Bay is a great terminal moraine. If, as suggested by Summers (1949, p. 24), the bays are drowned stream valleys, it is reasonable to expect that the ice which eroded rock from the shallower, inner parts of the bays would, upon encountering deeper water, tend to deposit some of it as moraine. Thresholds off the mouths of all the bays are part bedrock, part glacial deposits.

On Trepassey Peninsula overdeepening of perhaps several hundred feet may be

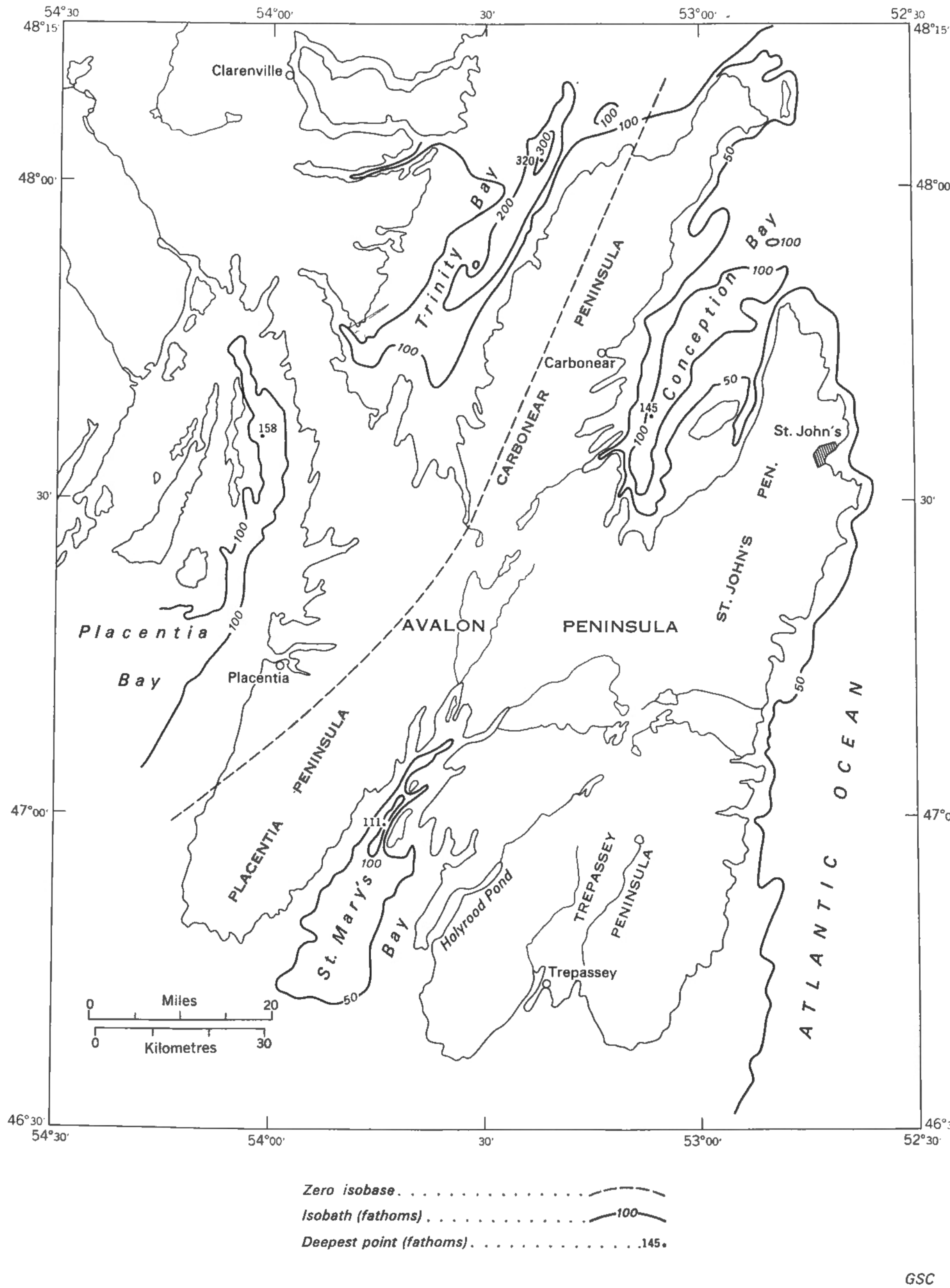

FIGURE 11. Closed basins in main bays overdeepened by ice, with some additional overdeepening through deposition of morainal material off bay mouths. (Data from U.S.N. Hydrographic Chart 1102, 1956.)

present in Holyrood Pond, which lies in a straight, steep-sided valley with truncated spurs along the west side of its upper reaches, and which extends back from the coast for more than 10 miles. A massive bar shuts it off from the ocean, though its deep waters are still salty. By local report, pond depths exceed 720 feet near its head. Outside the bar, the 120-foot contour lies 5 miles offshore and there is no channel leading seaward from the bay, sand from the adjacent bluffs having probably filled any that existed. With steep walls rising in places more than 400 feet above the water, the valley appears to be a fiord that carried a strong southwesterly flow of ice seaward from Trepassey Peninsula.

Several other valleys resemble fiords, though their confining hills are not sufficiently high to create the impressive inlets found in regions of greater relief. Three of the best developed are Cape Broyle Harbour (Fig. 12) on the east coast, and Bull Arm and Deer Harbour on the west shore of Trinity Bay. Bull Arm, largest and deepest of the three, is more than 600 feet deep less than three quarters of the way down the channel where it is only little more than a mile wide. Near the mouth of the inlet depths decrease to less than 300 feet before descending again into a trough that crosses the floor of Trinity Bay and merges with the other deep submarine channel from the south to form the closed basin. The sides of Deer Harbour are among the steepest of any of the glaciated valleys. One wall in particular has been spectacularly striated and grooved by ice (frontispiece). The harbour itself is rather shallow, and of the three valleys has been the least deepened by glacial erosion.

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FIGURE 12. Looking east toward the mouth of Cape Broyle Harbour–a probable fiord.

TABLE I *Dimensions of the major bays and amount of overdeepening in their enclosed basins*

Bay	Depth (in feet)	Approximate amount of overdeepening in enclosed basin (in feet)	Distance of deepest part from head of bay (in miles)	Length of bay (in miles)
Conception	960	400	17	40
Trinity	1,920	1,170	40	62
St. Mary's	666	440	18	45
Placentia	1,100	480	20	70

Data from U.S. Navy Hydrographic Office Chart H.O. 1102.

Inland valleys are rarely sufficiently glaciated to have acquired the U shape associated with through troughs subjected to intensive erosion by moving ice. When thickest, the ice probably moved toward the coast and lower country over wide areas. Although a few col valleys on the divides acquired shallow U shapes, it was only at lower levels, as it neared the coast, that the ice channelled its flow. The valley below Black Mountain Pond, 7 miles northeast of Holyrood has been modified by ice to a greater degree than any other valley seen at high elevations. More than 150 feet deep, it has a distinct U shape and descends to Lower Gullies River over a well-formed glacial step.

Postglacial Events

Redeposition, Erosion, Weather, and Effects of Weathering

Following disappearance of the ice and cessation of meltwater deposition, modern streams rapidly cut through outwash accumulations, but had little effect on stony glacial deposits or bedrock. Inland, alluvial flats were deposited below dissected valley-train deposits and some small alluvial fans were formed below the larger till-mantled slopes. The total of such alluviation is small and most of it occurred in the larger, mature, southern valleys. The greatest amount of outwash was deposited either on the coast or immediately inland. Debris from stream dissection was either transported out to sea or redistributed by shore currents.

Coastal outwash is vulnerable to wave erosion and thus the greatest postglacial changes have taken place where thick till or outwash deposits have been subjected to marine attack, e.g., at Seal Cove on Conception Bay, and at Point Verde and St. Bride's on Placentia Bay. At Point Verde thick proglacial sands and gravels have been eroded back at least 1¼ miles and an amount of coastal recession almost as great has occurred in similar deposits at St. Bride's and Seal Cove. An actively receding, till bluff north of Great Barasway, one point of which stands 230 feet above the level of Placentia Bay, has retreated an unknown distance under wave attack. Bedrock is exposed in its central part and further recession will therefore be slower.

Where eustatic sea-level rise exceeds isostatic rebound, most redeposited sediments lie offshore under the transgressive sea. Where the land–sea levels have remained relatively unchanged, large amounts of sand and pebbles eroded from thick glacial deposits have been transported by shore currents and redeposited as numerous massive bars and storm beaches. The largest of the bay-mouth bars, the one damming Holyrood

Pond, rises 33 feet above mean tide and probably extends many hundreds of feet below sea level. Some constructional shore features are built largely of coarser material such as cobbles and boulders. On uplifted parts of the coast in the northwest, several massive raised bars have been preserved from wave attack by lower bars and beaches formed more recently. At the head of Deer Harbour on Trinity Bay, a raised, postglacial delta has been almost completely dissected by the stream that originally deposited it and has been redeposited in the sea as a modern delta that is just awash at low tide.

The postglacial climate of Avalon Peninsula is more severe than that of other similarly located maritime areas in the same latitudes of Europe and North America. Winters are only moderately cold but the stream of arctic sea ice carried on cold waters of the Labrador Current offshore, ensures that spring is long and cold, and summer short and cool. Long periods of fog and drizzle are common, particularly in the south. There is no dry season. Amounts of cloud and fog cover are high, and long sunny periods with their associated higher temperatures are rare. Heavy, year-round precipitation and the scarcity of fine sand have almost entirely prevented formation of eolian deposits. A few small sand dunes at the south end of Placentia Peninsula and some beds of wind-transported sand on the tops of bluffs represent almost the entire postglacial eolian deposits in the region.

Extensive organic deposits, azonal frost-structure soils, and mechanical weathering resulting from low temperature and abundant moisture, are the most widespread postglacial modifications here. Many of the deeper organic deposits appear to have existed since shortly after deglaciation of their sites. Palynological studies by Terasmae (1963, p. 162) indicate that no major climatic changes have occurred in the last 3,000 years, though the presence in one bog of pollen from jackpine, which is no longer indigenous, suggests that an earlier postglacial climate may have been rather less severe than the present. Muskeg has probably increased slowly in areal extent throughout postglacial time. Under the present climate, paludification in southern parts of Trepassey and Placentia Peninsulas is still active, with muskeg swamps invading uncovered ground, in some places covering more than half the terrain. Palynological studies of two Avalon Peninsula peat bogs by Terasmae (1963, p. 161) suggest that better drained sites were formerly more numerous in the area and that the development of muskeg was therefore less extensive in late-glacial and early postglacial time than it is now.

Frost-structure soils such as large, stone polygons (*see* Fig. 34) occur in the southern, interior parts of both Trepassey and Placentia Peninsulas. Such soils are usually considered polar or subpolar phenomena (Troll, 1944, p. 553; Washburn, 1956, p. 828) and are generally only found much farther north. They are, therefore, azonal in this area. Stretches of ground moraine as large as 20 square miles, covered with frost-structure soils, show the effectiveness of several factors which combine to keep temperatures on the Avalon lower than those in surrounding areas: low incidence of summer sunshine and long periods during which fog and drizzle are carried onshore by moist air blowing off the cold Labrador Current. As poor drainage and the physical structure of the soil increase the effectiveness of these climatic factors by encouraging frost, the extent of tracts of frost-structure soils seems to be either stationary or slowly expanding.

Mechanical weathering has been active throughout the area during postglacial time. Abundant moisture and the freezing of water in joints and crevices, furthers disintegration of the rocks. Frequent temperature fluctuations across the freezing point in both winter and spring extend the period of effective mechanical weathering on the Avalon to more than half the year.

The effects of this widespread and rapid mechanical weathering vary greatly from place to place. Hard, fine-grained rocks, such as the glacially moulded volcanics on exposed summit areas of the Doe Hills, and the high hills east of Brigus Junction, still retain most of their fine glacial markings little affected by weathering since deglaciation. Though bare of glacial markings, coarse-grained granitic rocks found over large areas have had little more than an inch removed. This can be seen when the thin till is stripped from striated surfaces contiguous to pitted, weathered rock without striations. Rocks weakened by jointing and cleavage fractures show more severe effects of mechanical weathering. Extensive splitting and heaving of blocks on high exposed areas in the interior of Carbonear Peninsula, which is underlain by Precambrian slates, have developed tracts of felsenmeer where the bedrock may be shattered to depths of from 4 to 6 feet. Water freezing in joints and crevices breaks off pieces of rock that may vary in size from mere fragments to blocks many feet long. Frost heaving displaces blocks of considerable size (Fig. 13), and small stones, falling into the spaces between the heaved blocks and adjacent bedrock, prevent the blocks falling back into place after the ice melts. Frost fracturing usually proceeds at a rapid rate on finely fissured and jointed cliffs and the angular fragments accumulate to form large talus.

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FIGURE 13. Frost-heaved volcanic block, 2 x 8 feet, on ridge 2½ miles west of Red Hill (altitude 750 feet).

Differential Uplift

Compensatory crustal adjustment for depression caused by the last glaciation is still not completed. According to available data, the zero isobase within the map-area runs roughly south 30 degrees west down Carbonear Peninsula a few miles inland from Trinity Bay, continues past Whitbourne in central Avalon, and then curves gently southwest to pass under Placentia Bay south of Point Verde. The position given is only as accurate as the data used to calculate it and it may well lie 4 or 5 miles to either side of the delineated line. In the extreme northwestern part of the study-area, raised shorelines formed at the postglacial marine limit indicate that the land there, approximately 30 miles distant from the zero isobase, has risen about 30 feet higher than the eustatic rise of sea level. Differential uplift has tilted the land upward at right angles to the isobase at the rate of a foot per mile. Isobases drawn by Jenness (1960, p. 176) for northeastern Newfoundland yield the same rate of uplift over a much wider area when their zero isobase is shifted several miles east 30 degrees south to the position given above. If tilt due to the differential uplift remains unchanged as far as the east coast — which is plausible over the short distance involved if the Avalon ice itself has not distorted the isobases — postglacial downing along this coast, due to the excess of eustatic rise of sea level over crustal rebound, is about 40 feet. As the coast parallels the zero isobase, the minus 40-foot isobase runs down the coast. The uniformity of elevations on east-coast rock benches of probable Sangamon age, supports this conclusion.

The further amount of crustal adjustment along the east coast thought necessary to restore equilibrium after the ice loading of the last glaciation, has been put tentatively at 15 feet. This is not an unreasonable figure for an area depressed less than the amount of eustatic lowering of sea level, though it is probably a minimum one. When postglacial crustal adjustment is complete, the zero isobase may lie somewhere in the eastern half of Conception Bay parallel to its length, a shift of 15 miles or more at right angles to its present position. Postglacial drowning of the east coast would thus be reduced to about 15 to 25 feet if possible warping due to other causes were disregarded.

Dating the Last Deglaciation

A bottom sample of peat from the bog west of Goulds, on rolling ground moraine 7 miles southwest of St. John's, gave a radiocarbon age of 7,400 ± 150 years B.P. (L-391 I). A palynological study by Terasmae (1963, p. 157) of pollen from below this radiocarbon-dated peat indicates that at least 7,500 years ago the ground now occupied by the bog was a lake in an area forested by balsam fir, black spruce, white spruce, and birch, and possibly also red pine and alder. At Whitbourne, some 36 miles southwest of Goulds bog, another peat sample from a bog in a recessional moraine depression had a radiocarbon age of 8,420 ± 300 years B.P. (I(GSC)-4). The development of a mature mixed forest at the Goulds bog site at 7,500 years B.P. together with the extension of the pollen record in sediments at greater depths than that of the dated sample, imply deglaciation there considerably earlier than the radiocarbon date. Similarly, at the Whitbourne bog the pollen sequence in sediments underlying the dated layer extends down another 3 feet. Other similarly located depressions in these two areas have no organic accumulations, which suggests that bog development does not necessarily start soon after deglaciation but may be initiated by some minor factors after which, as the bog creates its own environment favourable to the accumulation of organic sediments, it probably continues to develop. For the bog sites, Terasmae (1963, p. 159) suggests a deglaciation date of 10,000 years ago or earlier, a date which the author considers reasonable. Radiocarbon dates obtained by the author on the northeast coast of Newfoundland from sites comparable to those parts of the Trinity Bay west shore that had been glaciated by ice from the west, furnished minimum deglaciation dates of just less than 12,000 years B.P. (Dyck and Fyles, 1960, p. 17). This supports an assumed deglaciation date for Avalon Peninsula bog sites of more than, rather than less than, 10,000 years.

Rock abrasion benches south of St. John's, cut prior to the last glaciation of the east coast, at a time when stable sea level stood higher than at present, were tentatively dated as of Sangamon age. This is based on their altitude and on an estimate of the vertical amount of crustal lag required to bring the coast back to its pre-Wisconsin equilibrium position. For the cutting of the benches, the overlying till indicates a date at least earlier than the last glaciation of the coast. Farther west, rock abrasion benches appear to have been cut at sea levels higher than that indicated by the benches south of St. John's. They are overlain by sediments judged to be marine because of their position and their abundance of cobbles and large boulders, all well rounded apparently by wave action. These sediments in their turn are overlain by till. Present information does not justify making any estimate of either their absolute age, or of their age relative to other benches.

Sea-level Changes

There are, in the Avalon, widespread evidences of sea-level fluctuations over a long period, both in the large-scale modifications of coastal morphology that occurred chiefly following pre-Pleistocene downwarping, and in minor erosional and depositional forms of Pleistocene and Recent date. Rapid marine erosion followed the last regional change in elevation during which downwarping was accompanied by widespread drowning of coastal areas. Long-continued submergence, perhaps as much as several hundred feet, is indicated by coastal features characteristic of a heavily drowned coastline (Fig. 14). Rocky, near-shore islands, deep, penetrating inlets, and large estuaries at the mouths of small streams are the most prominent evidence of extensive drowning by epeirogenic downwarping in Avalon Peninsula and all along the Atlantic coasts. Drainage patterns about St. Mary's and Conception Bays suggest that streams forming the patterns are the truncated upper reaches of tributaries of major preglacial rivers that once flowed where these long bays now lie (Summers, 1949, p. 24). The slow crustal downwarping that has deeply flooded the coastal regions is probably largely pre-Pleistocene, but may have continued until now.

Whether it continues, has slackened, or even reversed, would be difficult to determine, for throughout the area sea-level changes due to slow epeirogenic movements are masked by the much more rapid synchronous adjustments following glaciation.

Interglacial Marine Benches

Raised, wave-cut, rock benches and marine abrasion platforms are found at several points on Avalon Peninsula coasts. The marine abrasion platforms are cut mostly in places where there has been little postglacial emergence of the coast or postglacial transgression by the sea. Hence they are apparently interglacial in age. Some of the best-preserved benches and platforms are cut about 10 feet above present sea level along more sheltered sections of the exposed east coast south of St. John's: at Bay Bulls (Fig. 15), Witless Bay, Mobile Bay, and on Coldeast Point, Ferryland. Benches

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FIGURE 14. Coastline of submergence. Gull Island and Green Island off mouth of Witless Bay on the east coast.

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FIGURE 15. Interglacial rock bench 10 feet above low tide on the north shore of Bay Bulls. (The bench runs under a till bluff 20 feet thick and is reflected in the drift as a terrace.)

are also found at higher levels in St. Shores Cove on Trepassey Peninsula and on Cuslett Point, Placentia Bay, 2 miles north of St. Bride's. There are other benches in the map-area that may be wave cut but for which other modes of formation could not be ruled out. Two of the best developed, one east of Renews on the north side of Renews Harbour, the other 1½ miles north of Cappahayden, may simply be more southerly members of the east-coast group south of St. John's.

With the exception of a bench near Cappahayden, the surfaces of the east-coast group of benches transect structural features of underlying rocks. At Cappahayden, approximately horizontal bedding or sheeting in the rock beneath the bench runs almost parallel to the bench surface. Also present is vertical jointing that would probably permit large blocks to be easily freed. The back parts of nearly all benches are overlain by till that mantles the low cliffs terminating the old abrasion platforms and conceals the junction of bench and cliff.

The higher benches at Cuslett Point and St. Shores Cove, above the reach of present wave action, are more completely covered by overburden than are the east-coast benches. One Cuslett Cove bench, a quarter of a mile long and 50 to 100 feet wide, is overlain by 10 feet of gravel, in turn overlain by 5 feet of till-like material. The gravel, which contains stones too poorly rounded for beach origin, is presumed to be outwash with stones more rounded than usual. The 5-foot upper zone is probably till, but is very gravelly and could equally well be dirty outwash or colluvium. However, it closely resembles a nearby deposit above the cliff that has been identified as ablation till.

At St. Shores Cove, 15 feet of gravel or gravel and sand of marine origin cover most of the bench, and are topped by till that mantles the lower parts of the high cliff behind. Two gravel sections examined in detail were composed of stones and boulders identical to rocks of the same size range found below on the exposed modern beach. Some boulders, 4 feet or more in diameter and almost perfectly rounded, formed a layer immediately over the original bench surface, a feature not seen in hard rocks elsewhere throughout the Avalon except in places that had been exposed to prolonged marine action.

Though the original bench surfaces at Cuslett Point and St. Shores Cove are concealed and thus relationships between them and rock they transect are less obvious, rock was well exposed below both benches in near-vertical cliffs. As no horizontal structure can be seen in the underlying rock, the benches are apparently eroded across the rock structure and are not developed on planes of weakness.

Origin and Age

Rock benches on the Avalon coasts, with elevations varying from 9 to more than 30 feet above present mean tide levels, originated from the abrasive action of waves at a time when the sea level was higher relative to the land than it is at present. Transection of structure in the hard, unfractured rock that underlies most benches, eliminates such modes of bench origin as quarrying or differential above-water erosion.

The spatial relationship of a former marine plane to a raised rock bench of possible marine origin varies with several factors and influences the accuracy of the determination of the elevation of earlier sea levels. The most important factors are the degree of exposure of the bench sites and the part of the bench measured. On exposed promontories where wave action is violent, benches tend to develop to depths well below the low-water mark. In bays or other sheltered places they may develop at shallower depths, some in places just awash at low tide. Bench surfaces are not perfectly horizontal but slope gently up toward the land. The seaward side of even a sheltered bench is generally below the old low-tide level and the bench–sea cliff juncture is at or above high tide. The bench surface relief developed by structural control of abrasion may approximate several feet (Fig. 16).

Measurements on east-coast Avalon benches were taken by sighting parallel to the shore as near to the bench centre as possible. The bench centre was assumed to represent mean tide level at the time the bench was cut, and bench height was calculated as the height above modern mean tide. Though heights of uneven bench surfaces vary from 7 to 12 feet or more above present mean tide, measurements of the general level consistently yielded elevations of from 9 to 12 feet asl. Validity of

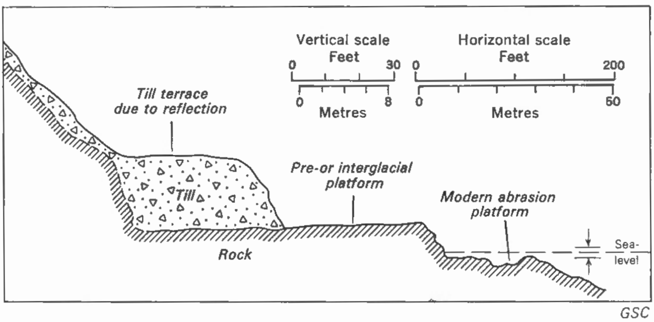

FIGURE 16
Interglacial bench on the north side of Witless Bay. Note till terrace formed as a reflection of the rock bench.

this method of measurement was established by checking against levels of modern benches in slightly more exposed positions near the zero uplift isobase. The central parts of the modern benches, many of which are as wide as the raised ones, were awash or just above water at low tide. Average tidal ranges at locations where modern benches are forming are the same or very close to the 2½-foot current range along the eastern coast.[1] It is doubtful that tidal ranges on these steep, open coasts have varied appreciably since the earlier benches were formed.

Accordance of bench levels within the east-coast group strongly suggests that they were cut by the same sea-level stand. The absence of any tilt along 20 miles of glaciated coast — 30 miles if the benches north of Cappahayden and at Renews Harbour are included — place them on the same isobase of equal depression and uplift, an observation that receives confirmation from the trend of the Avalon zero isobase of postglacial uplift that lies almost exactly parallel to the east coast.

It is difficult to assign a more definite date to the east-coast benches than to say they were cut prior to last glaciation, an estimate made on the basis of their till cover. It is tempting to consider them as pre-Wisconsin or Sangamon in age, but cutting during the ice withdrawal of a Wisconsin interstadial recession, accompanied by coastal depression greater than at present, cannot be dismissed. However, the

[1]Atlantic Coast, Tide and Current Tables, Canadian Hydrographic Service.

removal by coastal retreat of all but a few of the sheltered benches of Wisconsin age along the entire east coast during postglacial time when sea levels were rising, would have required an exceptional degree of coastal erosion to be sufficiently rapid to eliminate the benches at the Wisconsin level in all but the most exposed locations. Most postglacial erosion would have taken place well below the modern shoreline and would not have affected benches at sites that were then considerably higher above sea level than they are now. Postglacial sea-level rise along the Avalon east coast, based on the position of the coast relative to the zero isobase, should be a minimum of 40 feet. Because of these factors, a Sangamon age for the benches seems more reasonable.

The best estimate that can be made for a standstill culminating the Sangamon eustatic rise of sea level would probably be at 25 feet above modern sea level (Flint, 1947, p. 440; Fairbridge, 1961, p. 151). However, Kuenen (1955, p. 201) reports considerable agreement for a glacioeustatic origin and a Sangamon dating of a wide terrace 48 feet above sea level. Recent work by Flint (1966, p. 679) on the interpretation of deposits both on the Virginia coastal plain and in the vicinity of Nome, Alaska, suggests that the maximum level during the Sangamon may have been about halfway between these two estimates. Based on Sangamon benching at a sea level 25 feet above the present one, at a time when Sangamon glacial isostatic adjustment was complete, further rise of the coast due to recovery from the crustal depression of Wisconsin ice should not exceed 15 feet and should be very slow. As no sign of uplift has been found during the relatively stable sea levels of the past 3,000 or 4,000 years (Schofield, 1960, p. 478), probably no measurable uplift has taken place for at least that length of time. The above argument would require that the earlier epeirogenic movement which deeply drowned the Newfoundland coastal regions would have ceased prior to the cutting of the benches, or at least would have slowed to a negligible rate following their cutting. King (1959, p. 292) concludes that stability during bench cutting is necessary and says: "Most authorities such as Davis, Johnson and Cotton, in what may be called the classical view of platform cutting, consider that sea level must be stationary during its development." Around the coasts of Avalon Peninsula this would explain the positions of modern platforms near the zero isobase of postglacial uplift, particularly those in Trinity Bay.

On the basis of the tide-gauge records kept at St. John's between 1936 and 1957 that suggest an apparent sea-level rise of 2½ feet per century, Jenness (1960, p. 177, footnote) postulated that the east coast at St. John's may be sinking at the rate of a foot per century, in addition to a similar eustatic rise. Unless very local downwarping is involved, unacceptably rapid uplift would be demanded for the Bonavista Bay area, less than 100 miles to the northwest, to compensate for both eustatic rise and coastal submergence by subsidence, at the same time reporting uplift rates of a foot to 2 feet per century (Jenness, 1960, p. 177). Records of tide-gauge readings covering much longer periods than those at St. John's may be extremely difficult to analyze for true secular fluctuations due to eustatic change in sea level. Sources of error are numerous and, considering the brevity of the St. John's records, factors other than coastal submergence may be better able to account for their suggested sea-level rise of less than half a foot.

On the benches cut at St. Shores Cove and Cuslett Point where the heavier overburden and the greater unevenness of the rock surface make it more difficult to measure their average elevation above sea level, an interval of 31 feet was obtained for both locations. The position of the benches on an exposed coast at the foot of high cliffs may have permitted erosion for a considerable depth below low-tide level, especially under the more turbulent conditions that occur in such locations where all wave energy is dissipated at the shoreline. For this reason, any figure for the mean tide interval between modern sea level and the waterplane at which bench cutting took place should be treated with caution, and those mentioned above may be low. The St. Shores Cove bench is at nearly the same distance from the Avalon zero uplift isobase as are the east coast benches, but does not correlate with them. Cuslett Point is almost on the zero isobase, but any isostatic adjustment there would presumably tend to be greater than similar adjustment at the east-coast bench sites some 40 miles farther from the centre of uplift. A greater uplift rate at Cuslett Point would increase the vertical displacement of a waterplane cutting the Cuslett Point bench and one cutting the east-coast group, and cannot be correlated with east-coast benches. The Cuslett Point bench may, however, correlate with the St. Shores Cove bench, for any change in relative elevations between the two bench sites, introduced by differential uplift, should be within the error inherent in measuring their elevations above sea level. The closest dating that can be assigned to either the St. Shores Cove or Cuslett Point benches would be prior to the last occupation of the coast by ice.

Postglacial Sea-level Changes

Emergent marine features of postglacial origin are present on the Isthmus of Avalon and the area immediately adjacent to its northern end. They probably also existed formerly on the western coast of Placentia Peninsula, but later erosion has obscured relationships there. Scattered emergent features have been reported on other coasts of Avalon Peninsula, some of them relatively recently (Summers, 1949; Rose, 1952; Hutchinson, 1953). Jenness (1960, p. 177) considered them as evidence of a small, local, recent coastal emergence of the Avalon, but thought that submergence is now occurring. Investigation of lately described emergent sites and consideration of further evidence support the view that submergence, rather than emergence, has dominated most Avalon Peninsula shoreline in postglacial time.

At Cape Broyle, where the Cape Broyle River flows in a glaciated, mature valley — one that he considers to have been previously eroded nearly to base level — Summers (1949, p. 96) records a waterfall over a shelf in the river. He ascribes the presence of the waterfall to local postglacial uplift of 35 feet. It is, however, difficult to follow his reasoning as glacial steps and the divergence of streams from their original beds are common features in heavily glaciated valleys, and both are processes that form waterfalls in such positions.

Rose (1952, p. 7) describes what he considers to be a water-laid Recent deposit of possible marine origin at an elevation of 200 feet near the southwest end of Bell Island. There is no support elsewhere for so great an amount of postglacial marine emergence and the deposit itself appears rather to be of fluvioglacial origin. Terraces identified by Rose (1952, p. 7) as "marine terraces of silt, sand, and gravel, at elevations up to 35 feet" and preserved in bays along the east coast south of St. John's, are principally underlain by till of the local ground moraine (Figs. 15, 16) with pockets of fluvioglacial material here and there. The 'terraces' reflect the configurations of unexhumed parts of rock abrasion platforms of interglacial age, such as those discussed earlier, and they terminate at the back edge of the old platforms.

Sand and gravel underlying a terrace at an elevation of about 30 feet in the valley southwest of Bay de Grave on the west side of Conception Bay is presumed by Hutchinson (1953, p. 27) to be of marine origin. Large gravel pits in these deposits reveal an internal structure more consistent with a fluvioglacial origin. The original surface, which slopes toward the sea, can be traced for 1½ miles northeast of the point at which it has an elevation of 60 feet to where, on the seaward side of the Conception Bay highway, it disappears beneath the present sea level.

The presence of undisturbed, unconsolidated, generally friable, till material overlying bedrock in exposed positions, is almost incontrovertible evidence that sea level has not been higher during postglacial time than it is now; or if so, only to the extent of about a foot at most. On the north side of Witless Bay is a 15-foot rock knoll topped by 5 feet of loose, sandy till. The knoll is at the end of a small flat point projecting into the water, and waves entering the bay have removed till from the seaward-facing east side, but have not touched the till on the top or landward side of the knoll. A water level even a few feet higher would have removed the till capping.

Some smoothed and rounded shale hills, veneered by several feet of till, are found at Long Pond on the east side of Conception Bay. At present sea level they are sheltered from waves of the open bay, and easily eroded till covers them down almost to high-water mark. Viewed from any side, the hills present a smoothly curved profile and it is difficult to envisage any higher water level leaving their steep slopes unmarked.

Till also caps a rock knob joined to the land by a shingle spit at Old Perlican, near the northern tip of Carbonear Peninsula. The knob is about 18 feet high and has a till cover on the side protected from wave erosion. As in Witless Bay, the undisturbed till rules out any but slightly higher postglacial sea levels. The uneroded till deposits at Long Pond and Old Perlican strongly support the thesis that no postglacial uplift has occurred around Conception Bay, and the Bay de Grave ice-marginal terrace, with uneroded gravels down to sea level, further supports this view.

Evidence of postglacial, sea-level fluctuations along the eastern shore of Trinity Bay is less consistent. Poorly sorted gravels, generally horizontally bedded or dipping very gently parallel to the shore, are exposed at several places in shore bluffs between Heart's Delight and Whiteway Bay, at elevations as much as 30 feet asl. Several unusual paragneiss and gneissic granite stones from the gravels were identified by McCartney and Jenness of the Geological Survey of Canada, as types whose nearest bedrock sources lie northwest of Avalon Peninsula. Examination of hundreds of other stones of similar sizes in adjacent tills revealed none that could have originated from the same areas. The presence of the unusual stones in gravels of the shore bluffs, therefore, implies either a marine origin for the gravels, with the foreign stones ice rafted from the area west of Trinity Bay, or deposition by meltwater drainage marginal to ice from the same direction.

Although places favourable for preservation of topographic forms generated by either removal or deposition of easily eroded drift were examined closely, no evidence of higher sea level was found either north or south along the shore where the gravels occur. On the other hand, southwest of Heart's Desire, a low point and the rock knob on its seaward end were both covered by 3 or 4 feet of gravelly till that would have been rapidly removed by a water level 5 or 10 feet higher than the present one. The gravel is often dirty and poorly sorted, and most of the stones are angular to semiangular, with only a few that might be classed as semirounded. Though the bedding is more even than that usually found in outwash, it closely resembles the gravels exposed in bluffs that cut the outwash plain on the southeast shore of Conception Bay. The gravels appear to represent deposition by meltwater drainage marginal to ice that at a late stage of deglaciation moved eastward across

Trinity Bay — perhaps as a tongue flowing out of Bull Arm — but never advanced onto Carbonear Peninsula.

Other than the shore gravels, available evidence indicates little or no postglacial uplift along the eastern shore of Trinity Bay. The zero isobase is thought by the author to lie either at this eastern shore or, more likely, a short distance inland, as there is excellent evidence for uplift a few miles to the west on the opposite side of Trinity Bay. At Broad Lake, 12 feet of uplift is recorded along the east side of the lake where a raised spit is continued as a modern spit of identical form. The modern spit is just awash at low tide, and lies 12 feet lower than its old forerunner. Further evidence for this or a slightly higher amount of uplift is found 3 and 4 miles to the northwest in foreshore gravels (Fig. 17) and small beach ridges at protected locations in Big Chance and Little Chance Coves.

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FIGURE 17. Foreshore gravels in raised marine flat, Little Chance Cove.

North and northwest of Broad Lake, on the Isthmus of Avalon and the adjacent parts of the island, steadily greater uplift is recorded in old shorelines, beaches, bars, tombolos, and a raised delta. Perhaps the best evidence is to be seen at the sheltered head of Bull Arm where gravels, shore breaks, and a graded river terrace all indicate between 28 and 34 feet of uplift (elevations adjusted for tide and wave influence). On Placentia Bay southwest of Bull Arm, uplift of a few feet higher is evident on a bar and tombolo at Little Southern Harbour and in shore gravels at Come By Chance. The amount of uplift must be estimated with caution because of the higher tides in Placentia Bay (5 to 7 feet, rather than less than 3 feet which is common elsewhere) and the exposure to southwest storms. Thirty feet may be close to the mean sea-level interval between postglacial and modern seas at the head of Placentia Bay, and it is probably nowhere more than 35 feet.

Farther south on Placentia Bay, the coast steepens and becomes straighter, particularly south of Argentia. Erosion here has been greater, and the ice-contact deposits and proglacial deltas protruding from the coast that originally provided evidence of uplift, have been largely removed. On the other hand, 5 miles south of Point Verde at Little Barachois, the gravel-filled stream channels of Little Barachois River are incised in the thick, well-bedded, outwash sands of a 32-foot shore bluff. Near the sea, on the north side of the valley of the river at Great Barasway, a terrace underlain by outwash stands 18 feet above high-tide level. Without knowing how far erosion has cut them back, these outwash deposits, that originally graded to an early postglacial sea, are suggestive of uplift but do not provide an accurate measure.

Unmodified outwash lies behind the sea beach at Ship Cove, and at Gooseberry Cove small kames resting on rock are almost at sea level behind the beach. In Patrick's Cove, 15 miles south of Point Verde, an untrenched alluvial flat is graded to the sea and may indicate a slight amount of drowning rather than uplift. There is no definite proof of drowning in St. Mary's Bay, since trenched outwash on streams there may record nothing more than normal downcutting following cessation of outwash deposition. However, nothing observed in St. Mary's Bay supported uplift.

On his isobase map of Newfoundland, Jenness (1963, p. 11) shows the zero isobase in a position off the east shore of Trinity Bay and then curving more westerly across the Isthmus of Avalon to Burin Peninsula north of Grand Bank. This zero isobase would appear to have been placed 15 to 20 miles northwest of its true location as it passes north of Broad Lake where uplift of 14 feet is indicated. It might be better placed about 5 miles inshore on Carbonear Peninsula, running from there southwesterly through Whitbourne and curving westerly to emerge from Placentia Peninsula about 10 to 20 miles south of Point Verde (*see* Fig. 11).

Chapter V

QUATERNARY DEPOSITS

The whole Avalon Peninsula shows evidence of glaciation and much of it is covered by thin, unconsolidated Quaternary deposits, interrupted by outcrops or stretches of bare rock. The main rock areas are generally found on upland surfaces or form the tops of the higher hills. Two of the largest areas of exposed bedrock are in the escarpment country of central Carbonear Peninsula north of Carbonear, and in the rugged coastal belt between Random Sound and the northern part of the Isthmus of Avalon. The Pleistocene deposits consist of glacial and fluvioglacial materials, thin lacustrine silts, and, in the western parts of the study-area, sparse marine deposits in shore exposures a few feet above sea level. Peat and postglacial muck are widespread in the central and southern parts of the peninsula, and alluvium is present in the lower courses of several rivers. A few patches of eolian sands occur, generally in the lee of sea bluffs that are being eroded by strong onshore winds. There are also one or two small tracts of coastal dunes.

Damming of meltwater caused small proglacial lakes to form after the main ice had retreated south and east of the height of land separating the St. Mary's Bay drainage from that of Conception and Trinity Bays in the north and of Placentia Bay in the west. Little evidence of these former lakes can now be found beyond thin stratified silts that cap recessional moraines south of Whitbourne, and one or two meltwater channels that carried drainage across the height of land from basins now draining south or east into St. Mary's Bay.

Deposits laid down or reworked by meltwater, such as outwash sand and gravel, eskers, kames, and other ice-contact materials, are scanty or even lacking in many parts. They are particularly scarce in places that were not reached by the main ice sheet. Many of the larger deposits are located close to the sea or extend into it. Their small total volume on land suggests that most of them may have been swept out into the basins of the large bays that penetrate deeply into the peninsula.

Toward the end of the glacial period, increased rates of wastage apparently generated meltwater streams of such volume and power that channel networks were quickly eroded. These meltwater channels, although found throughout the whole area, are large and numerous at only two places: west of Cape Race on the southeast tip of Avalon Peninsula, and around St. Mary's Bay, particularly on the west side, where graded channels near Branch carried south-flowing meltwater across the high divides on either side of the present west–east section of Branch River. Tracts of thin stratified sediments and reworked till are associated with the meltwater channel systems.

Shoreline features suggest that the zero isobase, separating areas of postglacial emergence to the west from those of submergence to the east, runs down Avalon Peninsula parallel to, and a short distance east of Trinity and Placentia Bays. Data, however, are insufficient to determine its exact position and it may lie farther west a short distance offshore. Though the land along the eastern part of Avalon Peninsula rose following removal of the ice load during deglaciation, the postglacial sea rose even faster and encroached on land. The pronounced submergence of the eastern coastline is, however, due to an earlier relative change of water level, greater even than the eustatic rise that followed the last deglaciation, although the latest rise accentuated the drowned appearance of the coast.

Glacial Deposits and Related Features

Ground Moraine

General Characteristics and Distribution

Over most of the area, the ground moraine consists essentially of till but may also include stratified drift in amounts that vary randomly from place to place. In some localities ablation moraine forms the upper layer of the moraine. It is generally coarser than the basal till as much of the fine material has been flushed away by meltwater.

Ground-moraine tills are commonly stony (Fig. 18), composed of stones of pebble to cobble size with a preponderance of angular or very slightly rounded fragments. Boulders and large blocks of rock are common in most areas, the chief exception being the morainal stretch northeast of St. Mary's Bay where larger sizes are less evident. The matrix of most tills is composed of sand and coarse silt, with little or no clay or fine silt. The conspicuous coarse fraction in many places exceeds 60 per cent of the total weight of the till, with mechanical analyses indicating that lodgement till averages more than 50 per cent above sand size. An estimate of the percentage of the largest fragments was made for each sample at the time it was collected.

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FIGURE 18. Stony ablation (ground) moraine along the Tor Bay–Bauline road.

After analysis an adjustment was made for this estimated fraction to obtain totals believed to be accurate to within a few per cent. Sand and coarse silt make up almost the entire fine fraction except for a few rarely occurring tills that contained a significant percentage of clay and fine silt. These tills were chosen for analyses because of their unique appearance.

The factors having most influence on the size of till components are the nature of the parent materials and the distance the components were transported before deposition. As stated earlier, granitic and volcanic rocks, hard sandstones and well-cemented conglomerates form most of the Avalon bedrock; the remainder consist of Paleozoic shales and hard siliceous Precambrian slates. Except for the slates and shales, these rocks are resistant to both abrasion and crushing, and the ice eroded them mainly by quarrying, a process that can yield large blocks. Abrasion of bedrock fragments embedded in the ice produced much sand and some coarse silt but little finer material. The Precambrian slates, however, yielded blocks which, by fracture along cleavage and joint planes, broke down more readily to smaller stone sizes. Also more silt was produced from these finer grained rocks, probably through direct abrasion of the bedrock by debris-laden, overriding ice. Where ice flowed over slaty rocks and continued for some miles over drift-covered ground that afforded no fresh outcrops, it deposited surface tills that contain few large erratics but are rich in clasts of cobble size and smaller. Such tills are widespread east and northeast of St. Mary's Bay.

The small areas of soft, easily eroded shale of Paleozoic age, found at several places near the shores of the main bays on Avalon Peninsula, in small patches near Bull Arm, and along the Come By Chance River, affect the till only locally. Some long narrow belts also extend south from Trinity Bay, to the west of Whitbourne. Generally they have influenced the tills very little as most of the material eroded from them was transported directly into the sea. In a narrow belt along the east side of Trinity Bay, however, sections show deeper-than-average till, high in silt and sand content and with few large blocks. This is probably due to the soft Cambrian shales along the shore to the south, since ice moving north down Trinity Bay, parallel to the strike of the shales, would redeposit the material eroded from this narrow shale belt close to the water. Between Placentia and St. Mary's Bays, possibly the largest area of the Avalon underlain by Cambrian shales, the thin till is more silty in places and contains less coarse material because of dilution by soft, friable Cambrian shales.

As the distance from source increased, the transported non-shaly rock fragments were gradually reduced in size. They could, however, never be carried very far before reaching the sea. When deposited, they formed tills composed entirely or almost entirely of material sand sized and coarser. As the ice rarely moved very far without encountering fresh outcrops, larger blocks were continually being added to its load of debris and therefore the ratio of large to small stones in the glacial load generally did not decrease much with distance. Material carried by the Avalon ice never travelled more than a few miles, generally less than 20, before reaching the sea. Maximum possible distance would be about 40 miles.

Most stones in the tills are angular or, at best, slightly rounded. They are normally angular even in many of the deeper tills derived from slates in which usually the stones are smaller. Almost all these slates are hard, highly siliceous rocks with apparently low resistance to crushing, although the fragments derived from them are rather resistant to rounding by abrasion. The fragments were therefore not much rounded before deposition and generally exhibit greater angularity than other lithologic types.

Like other Avalon tills, those originating mainly from slaty bedrock are composed of materials removed only short distances from their sources.

Slightly or moderately rounded stones are most common in the deep tills of the end-moraine area northeast of St. Mary's Bay. In this region the later ice moved across a large area of deep, unbroken drift deposited earlier, and the till deposits were thus transported longer distances without encountering outcrop areas that might add freshly broken blocks. Some of the stones in the present till may have been rounded by both water and glacier transport. The incorporation of these stones into upper layers of the till sheet probably occurred during the retreat of the ice, particularly if there was any fluctuation of the glacier margin, for at such periods meltwaters are abundant near the ice edge. Also, at such times, water-rounded stones would more likely be incorporated into the till instead of being swept beyond the limits of the peninsula by advancing ice. Any moderately rounded to well-rounded stones in the tills probably owe their markedly greater rounding to stream transport prior to incorporation into the ice. According to Holmes (1960, p. 1642), even when glacier transport has produced well-rounded stones, such stones still retain more traces of original concave surfaces than do stream pebbles or cobbles. With the relatively short distances travelled by the materials composing the Avalon tills, a well-rounded, hard, compact stone would only likely be produced by a combination of both water and ice transport.

The hardness of much of the generally friable ground moraine is directly due to its high content of coarse pieces. This is particularly true for tills derived mainly from siliceous slate and siltstone, where cleaved, interlocking, angular fragments form a mass that may prove almost impervious even to a pick. Such hard tills were examined in a fresh excavation of the Trans-Canada Highway north of Kenmount Hill east of St. John's, and in a gravel pit one third of a mile north of Pouch Cove (Fig. 19)

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FIGURE 19. Stony till (50 to 75 per cent coarse angular fragments) in a gravel pit 1,500 feet north of northern boundary of Pouch Cove.

near the tip of the St. John's Peninsula. Throughout the study-area, this type of ground moraine is little affected by water. Unless muck soils or muskeg overlie the till, trails across its rolling surface are generally as passable after heavy rain as in the driest weather. Its surface shows few of the characteristic long grooves and flutings that generally parallel the last movement of the ice.

In many places the ground moraine is partly composed of irregular, unoriented, till ridges and hills whose mode of occurrence gives no indication of any particular circumstances that may have led to their formation. Oriented markings such as flutings, however, formed where the ice shaped the ground moraine as it flowed across it; for though clay or silt tills are ductile and easily moulded by moving ice, granular tills, such as the majority of those of the Avalon, do not flow or mould so easily. It is significant that the largest and best-developed oriented ridge, located 2 miles northeast of Little Southern Harbour on the Isthmus of Avalon, was found at one of the only two places where sampling showed that the ground moraine included much clay (Table II, Sample 33). With one exception all the prominent, shaped till ridges lie in the lee of bedrock knobs and form part of crag-and-tail features that indicate the direction of ice movement.

TABLE II | *Percentages of gravel (2 mm and more), sand (0.02–2 mm), silt (0.002–0.02 mm), and clay (less than 0.002 mm) in tills*

Sample No.	Depth below surface (in feet)	Gravel	Sand	Silt	Clay	Type of till
1	9	51	27	19	3	lodgement
2	10	62	20	18	trace	lodgement
3	4	80	15	5	0	ablation
4	9	60	32	8	0	lodgement
5	5	85	10	5	0	ablation
6	8	70	9	21	0	lodgement
7	10	60	20	20	0	lodgement
8	7	56	18.5	24	1.5	lodgement
11	15	55	15	27	3	lodgement
12	7	56	21	20	3	lodgement
13	5	59	21	19	1	lodgement
14	8	45	29	25	1	lodgement
16	8	48	19	30	3	recessional moraine
17	15	57	27	14.5	1.5	lodgement
18	8	60	23	16	1	recessional moraine
19	10	54	25	19	2	recessional moraine
21	12	60	24	15	1	lodgement
23	5	45	25	29	1	lodgement
24	8	45	27	27	1	lodgement
33	8	47	18	27	8	lodgement (oriented ridge)
35a	85	65	19.5	14	1.5	lodgement (Lower, St. Shotts Cove)
35c	14	43	30	20	7	lodgement (Upper, St. Shotts Cove)
42	8	55	29	15	1	lodgement
45	10	62	24.5	11	2.5	recessional moraine
46	10	36	21	30	13	lodgement

Samples did not include stones of more than an inch in diameter. When sampling was done an estimate was made of the amount of gravel composed of fragments with diameters greater than an inch, and the percentages of the various fractions were adjusted accordingly.

On the Isthmus of Avalon, 2 miles northeast of Little Southern Harbour, the largest of the oriented till ridges, 25 feet high near its up-ice end, extends east 15 degrees south for half a mile from a high rock knob just west of the main highway. The highway crosses its central part through a 15-foot cut, exposing a brown, silty till that breaks easily into cubes a half to an inch across. No other till in the area possesses this property, and mechanical analysis reveals that for an Avalon till it has an unusually high content of both silt and clay: 27 per cent silt and 8 per cent clay. By a small lake northeast of this, another three or four oriented till ridges, 500 to 1,500 feet long but only 5 or 6 feet high, run almost parallel to the main ridge.

In the northwestern corner of the study-area, a mile south of Centre Hill, three oriented ridges run east 25 degrees south from three small rock knobs, the largest ridge being about 8 feet high and more than 1,200 feet long. South of Red Hill on the east coast near Cappahayden, a group of small ridges, apparently formed in the lee of small rock knobs, can be seen on aerial photographs of the area. They lie in thin ground moraine.

Lineations of somewhat different nature occur in a thickly forested area of heavy ground-moraine cover about 3 miles east of the head of Salmonier Arm, St. Mary's Bay. These ridges, about a mile long, were not examined on the ground, but on the aerial photographs no rock exposures could be detected near them. It appears to be an area of alternating wide, shallow grooves and broad, low ridges that control local drainage and extend long fingers into the lake at the western end. They were apparently formed by ice flowing east 22 degrees north out of a late glacial centre in nearby St. Mary's Bay.

Though large oriented ridges with sharp outlines are rare, other more irregular and less prominent drift features have been widely impressed by the ice on the granular Avalon tills. Difficult to see on the ground, they show clearly in aerial photographs, principally through their control over minor drainage. The alignment of lakes, strings of small ponds and the small streams lying more or less parallel to the direction of ice movement that are so evident throughout the study-area, are largely the effects of moulding of the drift by flowing ice. However, patterns diverging at the greatest angles from the direction of ice movement may have had their origin in basins formed along rock-controlled depressions as a result of irregular damming by drift deposits. The alternate strips of forest and of wetter, treeless ground, found in flat or gently sloping areas, and that are similarly aligned parallel to ice movement, appear to be due to moisture changes controlled by a very minor troughing of the till and emphasized by sensitive vegetative indicators.

Because of the nature of the till, the prominent, sharply defined grooves and ridges that result from ploughing by ice formed only rarely and only under exceptionally favourable conditions; e.g., in areas where the ice has passed over steep-sided, bedrock knobs. Here the till may have been pressed up into channels created by the ice downstream from the hillocks, perhaps in the manner suggested by Hoppe and Schytt (1953, p. 114) for small ridges forming behind boulders frozen into ground moraine. Even then they appear to have formed only when a higher-than-usual content of silt or clay made the till more plastic than is customary on the Avalon. The ridges lying east of Salmonier Arm may be exceptions.

Ground moraine covers more than 85 per cent of the study-area. It is thin compared to its areal extent, generally being less than a few tens of feet thick. For more than half its extent it is continuous, but there are also large stretches of discontinuous cover where bedrock exposures are common. In low country frequent rock outcrops are probably an indication that the bedrock surface is uneven. The till is thickest and most continuous in the lowlands, in areas of moderate local relief, and at higher elevations in wide, shallow basins, where it may average 10 to 20 feet deep. Southwest of St. John's, excavations for a dam and a power canal showed that the till cover there is 10 feet or more thick, and well borings on the plateau between St. John's and Conception Bay record similar depths. Such depths appear representative of the general thickness in areas of continuous ground moraine on St. John's Peninsula, and probably in most similar tracts throughout the map-area.

Ground moraine is much thicker in a few areas:

(1) just south of St. Vincent's, on the west side of Holyrood Bay, more than 100 feet of till is exposed in the bluff facing the sea. The till sheet extends inland with diminishing depths less than a quarter of a mile until it reaches a rock-controlled ridge;

(2) ten or eleven miles farther south on the same coast, just northwest of St. Shotts, till and stratified sediments have been laid against the lower parts of the ancient sea cliff where a steep rocky face extends above the drift stratum. An exhumed marine rock bench, a short distance above water level, protects the till from further erosion. The horizontal extent of the till coincides with the length of the bench;

(3) north of Great Barasway on Placentia Bay, a coastal bluff exposes a till deposit more than 200 feet thick that is interrupted only once by a layer of gravel 10 feet thick, that cuts across the bluff face about 40 feet above the sea. The glacial sediments appear to coat an old sea cliff, for bedrock outcrops in a ditch beside the coastal road that runs parallel to the cliff about a quarter of a mile inland. These deposits suggest that great depths of till may be restricted to pockets in the lee of steep or vertical slopes near the sea that appear to have favoured deposition when ice moved across them.

In general, the effect of ground-moraine cover is to smooth the surface relief by filling small bedrock valleys and depressions. In areas of continuous or nearly continuous ground-moraine cover, the thickness of till is most uniform where there is little local relief on the bedrock surface, although long, gentle or moderate slopes, or even-sloped ridges that are broad in comparison to their height, may also only slightly affect the till depths. Till thickness varies most where a rolling, bedrock surface has moderate local relief approximating 10 to 30 feet, with crests and troughs fairly closely spaced. Though the bedrock relief is still reflected through the till, the ground moraine does not cover closely spaced heights and hollows uniformly but possesses a swell and swale topography of its own (Fig. 20). When till ridges and depressions of the drift layer coincide with underlying bedrock depressions and ridges, till depths vary rapidly and small outcrops may occur in areas of otherwise thick, continuous ground moraine, often at elevations well below those of the higher ridges in the area. Where bedrock is hummocky, knolls of till may be interspersed among knolls of rock or knolls with rock cores, with no apparent difference between the surface forms of the various hills and ridges. Ground-moraine areas with this characteristic are found southwest of Franks Pond and in the knolly country south from the western side of the two high hills 4 miles to the south of Placentia Junction.

Two till sheets, separated by stratified deposits and possibly deposited by separate ice advances, occur at two widely separated points along the coast: at St. Shotts Cove near the extreme southern tip of Avalon Peninsula, and at Great Barachois on Placentia Bay. What may possibly be two separate tills were also found at three other

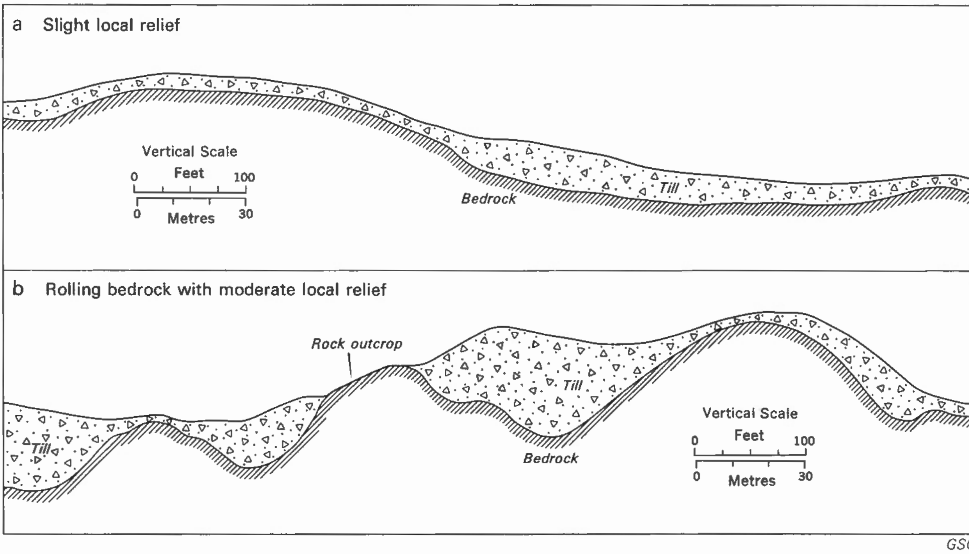

FIGURE 20. Variations in depth of ground moraine over bedrock, with (a) slight local relief, and (b) rolling bedrock with moderate local relief.

localities: one inland in the valley of the Waterford River, the other two in coastal bluffs — the first, near Topsail Head on the east coast of Conception Bay, the second, near Branch on the west coast of St. Mary's Bay. Positive identification of different till sheets in direct contact with each other, unseparated by other sediments, has not been made anywhere in the study-area.

St. Shotts Cove Till Sheets

On the north side of St. Shotts Cove, three quarters of a mile west of St. Shotts village, a 25-foot-thick section of older till underlies the surface till and is separated from it by a 45-foot-thick sequence of sand, silt and gravel (Fig. 21). The section lies midpoint in a drift bluff 100 feet high that extends eastward more than 2,000 feet from the rocky cliffs of Western Head on the west side of the cove and terminates at a rock point. It fills the head of the more westerly of the two embayments forming the cove.

The lower till extends to the beach and in several places continues below the high-tide line. It appears to rest on rock which outcrops here and there on the beach itself. Above this are 45 feet of stratified sediments covered by 30 feet of the surface till that forms the top of the coastal bluff. Both tills have a sandy matrix and a similar brown colour. The upper till breaks into friable chunks an inch to 2 inches across, probably because it has an unusually high clay content for an Avalon till (*see* Table II, Sample 35c), whereas the lower till breaks irregularly, or crumbles readily to a loose mixture. Although the top till has the larger small gravel fraction, the lower till contains more of the larger sizes of the coarse fraction (an inch or more in diameter). These coarse fragments are also less angular than those of the upper till, and many of the stones appear to have been transported and rounded by water. The rounded stones were probably picked up and incorporated into the till as the ice advanced over marine or river gravels. Sea or ice has eroded away all the

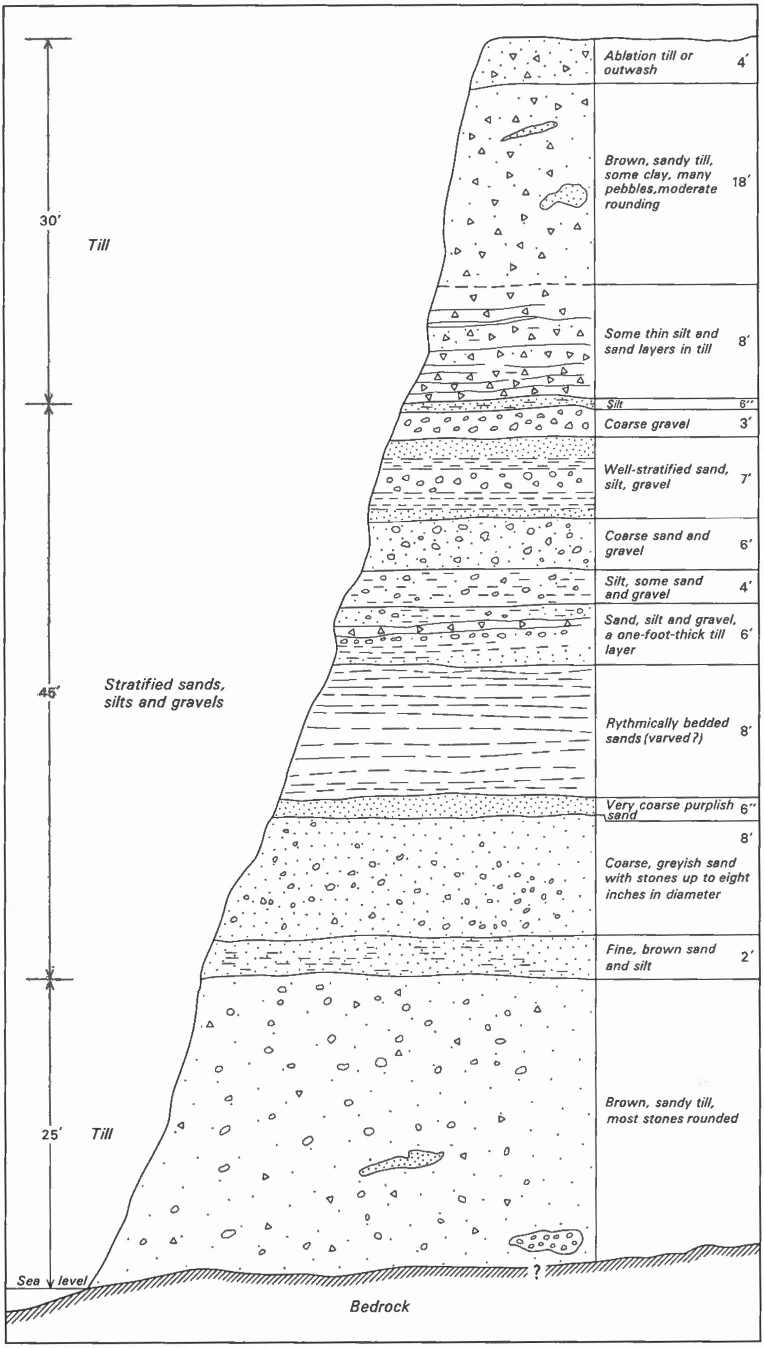

FIGURE 21. Diagrammatic cross-section of the Pleistocene deposits exposed in the shore cliff of the western embayment of St. Shotts Cove, Trepassey Peninsula.

lower till except for this remnant at St. Shotts Cove and the deposit is not thought to extend far inland as, everywhere, a thin, bedrock-controlled cover of ground moraine begins half a mile or less from the coast.

The section was traced laterally for more than 300 feet over the central part of the drift bluff, with no change in the thickness of the tills or of the separating stratified deposits. This suggests that the relationships outlined also continue across the head of the western bay of St. Shotts Cove. Eastward beyond the rock point, the drift bluff fringing the rest of the shore of the cove is formed of surface till right to beach level. West and north along the coast, a varying thickness of till caps the rocky cliffs for 2 miles to St. Shores Cove. There 90 feet of the upper till overlies 12 feet of marine sand and gravels which in turn rest on rock. There is no exposure of the lower till.

Identification of the St. Shores Cove gravels as marine in origin is based on two factors: first, their presence on an apparently mature marine abrasion bench; secondly, on the wave-washed appearance of a basal layer of boulders, 2 to 4 feet in diameter, that immediately overlies the rock, and of stones in finer gravels higher in the gravel bed. On the exposed modern beach, just above the low-tide line, well-rounded gravels of all sizes were indistinguishable in appearance from their counterparts in the fossil gravels 40 feet above them on the marine bench.

Stratified deposits separating the till sheets at St. Shotts Cove appear to be largely outwash. Stones in the gravels are semiangular and like the angular grains in all but the bottom few feet of the coarser sand beds, they resemble the coarse fraction in other outwash gravels. Large rounded pebbles and cobbles as much as 8 inches in diameter are scattered throughout the lower few feet of the coarse sands. Water-worn stones in the lower sands may be second-cycle stream sediments derived from either an earlier stream deposit or, by meltwater erosion, from the lower till, and redeposited in their present location. Absence of any erosional contact between the top of coarse sand strata containing the rounded stones and the stratified layers considered to be outwash, or below between them and a bed of fine sand and silt overlying the lower till, seems to indicate that all the stratified beds of the St. Shotts section were deposited as a continuous sequence.

Great Barasway Till Sheets

Two tills separated by stratified gravels outcrop on the east side of Placentia Bay in a high drift bluff that extends northward from Great Barasway for more than three quarters of a mile. Near its southern end, the bluff rises from the beach to a height of 230 feet. It is still being actively eroded. The thickest drift section observed by the author in the study area is exposed in this bluff, and the following section lies just north of its highest point:

Type of deposit	Description of deposit	Thickness (in feet)	
		Unit	Cumulative
Ablation till (?)		8	8
Till	Silty, with numerous scattered boulders; dries to a hard, light grey to white compact mass with powdery rock flour on face; forms very steep, heavily gullied slopes; retreats by undercutting of the lower till.	138	146
Gravel	Outwash; well stratified, medium size; moderate rounding.	14	160
Till	Sandy matrix with fewer boulders and silt than upper till; softer; forms a less steep cliff face.	40	200

South of the highest part of the bluff, toward the valley of the river at Great Barasway, the upper till thins rapidly as the bluff height decreases. The gravels separating the tills thicken in the same direction to 35 feet at a point about 600 feet north of the valley. Here they end abruptly against till 125 feet high which forms the entire bluff. The till contains thick lenses of massive sand and disturbed gritty silt, with included angular stones. Apparently ice moving down the valley removed the gravels and possibly some of the older till, and replaced them with younger till mixed with partly incorporated silt and sand that had been deposited in water ponded against adjacent valley sides.

Exposures near Topsail Head, Branch, and St. John's

Two other coastal bluffs have fairly extensive exposures of two tills separated by stratified sediments: the first, on the east side of Conception Bay about three quarters of a mile southwest of Topsail Head; the second, on the west side of St. Mary's Bay 1½ miles east of Branch. The Conception Bay section consists of 25 feet of hard sandy till separated from an overlying 20 feet of similar but softer and less cohesive till by a band of alternating silt and fine gravel layers, a foot or more wide. Each layer is a half to three quarters of an inch deep. On St. Mary's Bay near Branch, 8 feet of till resting on rock is overlain by 15 feet of fine to coarse sands which are in turn overlain by 5 feet of a similar till that forms the top of the shore bluff. Pebbles in the stratified materials of both sections are similar to those in adjacent outwash deposits laid by meltwater entering the sea. Such relationships, combined with the marked similarity of the till above and below the stratified materials, suggest there is no marked time break between the upper and lower tills.

Two miles southwest of the head of St. John's Harbour, on the east side of Waterford River, an excavation shows 3 feet of grey till overlying 15 feet of brown till. The brown lower till contains considerably fewer stones than the overlying grey till. Because this section is located at the bottom of a moderately steep, valley-wall slope, and because in the grey layer there is a faint horizontal banding parallel to the hillside, it is thought the upper layer may be colluvium from higher up the slope. The deposit is nevertheless included here for, if it is not colluvium overlying till, this valley is the only known place where two distinctly different tills, possibly of different age, were found in direct contact. A similar relationship was found in a poor exposure half a mile farther up the valley, though here the contrast between the two tills was not so distinct and sharp.

Ablation Till

Ablation till has been mapped over parts of the interior of Avalon Peninsula, and near the head of Salmonier Arm it extends in a belt along both shores (*see* map *in pocket*). It represents the superglacial and englacial loads of the last ice in the area (Fig. 22) and is actually more widespread, in thin patches or as scattered coarse surface material, than the extent of ablation-covered areas on the map would indicate (Fig. 23). Having been transported gently with little grinding and crushing, and probably for shorter distances than lodgement till, it tends to contain a greater portion of angular and coarser material. Also reworking by meltwater has removed most of the finer materials, generally leaving it sharply differentiated from underlying drift (Fig. 24). Although ablation till is not confined to clusters of small, gravelly hillocks and their intervening flats, where it does occur in such associations it may be found throughout their entire extent. It is usually found capping the till, and in gravel pits

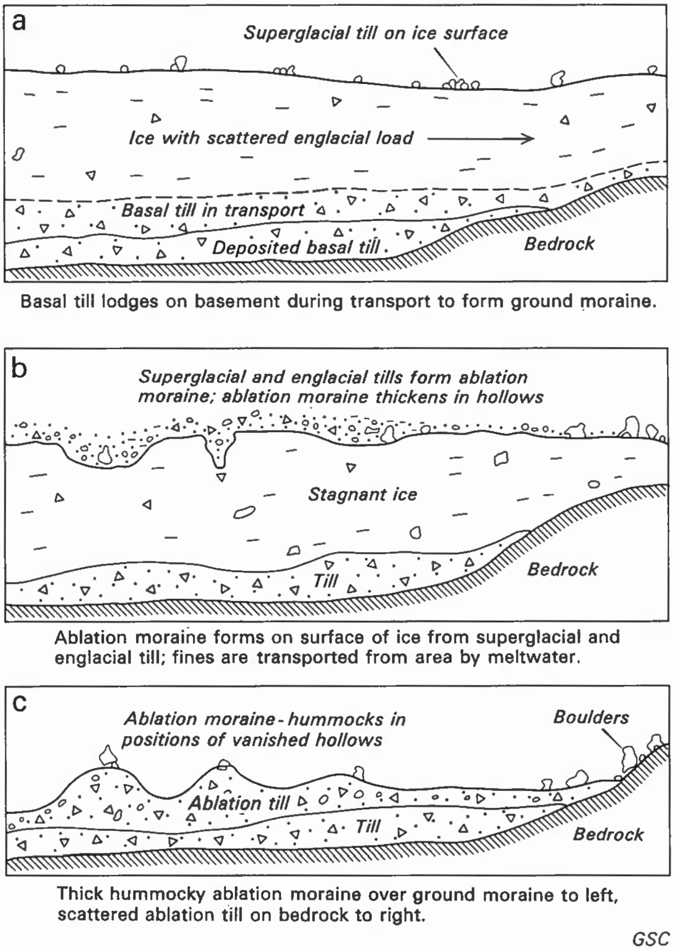

FIGURE 22
Origin of ground and ablation moraines.

and other excavations it is revealed resting on the underlying, more compact, lodgement till.

The presence of ablation till may be suspected wherever surface boulders and cobbles are unusually abundant. Nevertheless it does not generally form a mappable unit and its separate existence is usually only revealed in some of the numerous small active gravel pits. Furthermore most of the till is so stony that throughout the study-area the more gravelly phases of lodgement till present surfaces similar to those underlain by much of the ablation material. Many sections along the Topsail highway, as well as pits and sections on other roads, cut through homogeneous, stony till to depths of 20 feet or more. Only here and there are the top few feet different from the lower material, indicating limited patches of ablation till. Restricting the mapping of ablation till to places where the relationship between ablation and lodgement till is clear, has

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FIGURE 23. Sparse ablation till deposited as large boulders scattered over bare conglomerate ridges. Looking south 40 degrees east, 5 miles southwest of Franks Pond.

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FIGURE 24. Six feet of ablation till overlying gravelly lodgement till on the south side of Portugal Cove Road, just east of Portugal Cove.

probably meant that in some areas considerable amounts of ablation material may have been mapped as lodgement till.

As much as 7 feet of ablation till has been observed in isolated hills and slopes and in a large gravel pit a quarter of a mile north of the Topsail railway station. Although fairly extensive deposits are thought to exist in the areas of hummocky moraine, actual exposures are rare. Here and there, especially in the areas of hummocky moraine, ablation till takes the form of a sparse cover of scattered erratics, commonly of a single rock-type, and includes some unusually large blocks. The erratics lie on the surface of the underlying drift rather than being part of or wholly enclosed by it, and in some places are even perched upon bare rock (Fig. 23). In this study, these scattered boulder fields were not mapped as ablation till.

The largest mapped area of ablation till lies north of and along the west side of Windsor Lake, northwest of St. John's. Here the floors of several wide, shallow valleys, in which lobes of ice stagnated behind the Conception Bay coastal hills during a late stage of deglaciation, are covered by small, round, drift hills with the occasional uneven, irregular ridge. The ridges are apparently formed of several, overlapping drift hills. These areas are uniformly covered with several feet of ablation till, which, seen in section, is sharply separated from the stony ground moraine which everywhere underlies it (Fig. 24). Where these drift hills and ridges are best developed and most numerous, concentration of the coarser drift fragments by water is obvious in places, with sheets of boulders and cobbles covering the sides of the hills or flooring the depressions between them. On either side of Voiseys Brook, east of Portugal Cove, the hills and ridges are covered by about 8 inches of a gravel composed of small, flat, shale pebbles. The stones in these concentrations are angular to subangular and show little evidence of rounding by water, probably because they are largely derived from hard slate and siltstone, having been little exposed to erosion by meltwater. After meltwater had removed most of the fines, and after some minor sliding and washing into gullies and depressions in the wasting ice, the saturated bulk of the till reached its present position. The drift that filled the gullies and depressions in the ice now forms the characteristic ridges and rounded hills.

Though little of the flat-lying ablation moraine that forms a featureless top surface layer could be mapped, isolated exposures suggested that it might cover a fairly extensive area. Good examples of deposits of ablation till from 2 to 6 feet deep were found in several large gravel pits on St. John's Peninsula, notably at one north of St. John's, just west of the Mount Pearl Experimental Farm, and between Paddys Pond and Manuels River. The low silt content in such deposits is a desirable property when a till deposit is worked for gravel and sand.

Large fields of scattered erratics of superglacial origin are rare. Much more common are the smaller accumulations of erratics that occur as swaths of boulders in down-slope depressions, on flats below converging slopes, and in morainic areas. Although some of these small boulder fields may be of superglacial origin, most appear either to have been left behind when meltwater removed the finer parts of the till, or to have been transported to their present locations by shallow, rapid, meltwater streams.

Two outstanding areas of boulder fields formed of superglacial material are found on rough hummocky moraine in a basin of the Hawke Hills a few miles southeast of Holyrood, and on otherwise bare, rock ridges southwest of Franks Pond (Figs. 23, 24). The Hawke Hills area is the more extensive; the boulders are larger and in places more numerous, with some stretches being covered by granite erratics only, whereas others have a mixture of granite and lava. All the boulders are close to their points of origin and individual blocks may measure more than 20 feet long. Most of the big erratics are perched on the underlying drift, giving the appearance of having been gently lowered onto the surface as the last of the material deposited by the wasting ice. Some, particularly granites, tend to be cubical or rectangular, the rock appearing to have split along joint cracks. Toward and beyond the east side of the basin, lenses and patches of the more commonly occurring ablation moraine cover some slopes of hillocks that are, in some instances at least, partly constructed of roughly sorted gravels.

In the Franks Pond area, the boulders are smaller and more scattered. They appear as the only constituent of the ablation deposit, possibly because the wasting ice may have been cleaner here than it was farther north in the Hawke Hills.

The larger zones of ablation till seem to have formed chiefly as a result of the isolation of ice masses on flat or rolling tracts surrounded by higher ground. During general retreat of the ice, as movement across the higher ground ceased, these isolated masses became stagnant and wasted by thinning in situ instead of by frontal retreat. Surface and enclosed material, much of it subjected to considerable reworking by meltwater, settled into place to form the ablation till. Whether the ablation till formed a coherent layer several feet thick or was a mere scattering of boulders depended on the average amount of debris per unit volume of ice and on the thickness of the stagnant ice.

Recessional (End) and Hummocky Moraine

During glacial recession, systems of moraine ridges were formed at various places throughout Avalon Peninsula, principally in the thickly wooded area north and east of St. Mary's Bay. Limited exposures indicate that most of the recessional moraines and many of the hummocky moraine ridges are formed of till. Fluvioglacial deposits, ablation moraine, and reworked glacial deposits are present locally, most commonly in areas of hummocky moraine, where in places they may comprise most of the moraines.

Origins and Description

Moraine ridges on Avalon Peninsula may, for discussion of their mode of origin, be divided into the following groups: perimeter areas — small areas of recessional moraine near the coasts where the drift is generally thin; St. Mary's Bay area — the main area of recessional moraines about the head of the bay; areas of hummocky moraine, mainly located in high interior basins.

Perimeter Areas

These would have been the first areas to become ice free. Early in the deglaciation period, while most of Avalon Peninsula was still covered by ice, glacial moraines formed close to the sea in a number of outlet valleys, particularly those trending east and south toward the Atlantic. Most of them were formed by the main Avalon ice sheet, but a few also formed in front of the small glaciers that flowed from the thin ice cover extending axially along St. John's and Carbonear Peninsulas.

Further withdrawal of the ice resulted in similar deposits being laid down farther inland. Although less controlled by pronounced valleys, which are generally restricted to the coastal areas, these moraines still formed in depressions that tended to channel the ice into lobes in front of the main ice margin. Most of the ridges appear to have originated either as push moraines in front of ice tongues, or as marginal accumulations of debris transported by moving ice (Fig. 25).

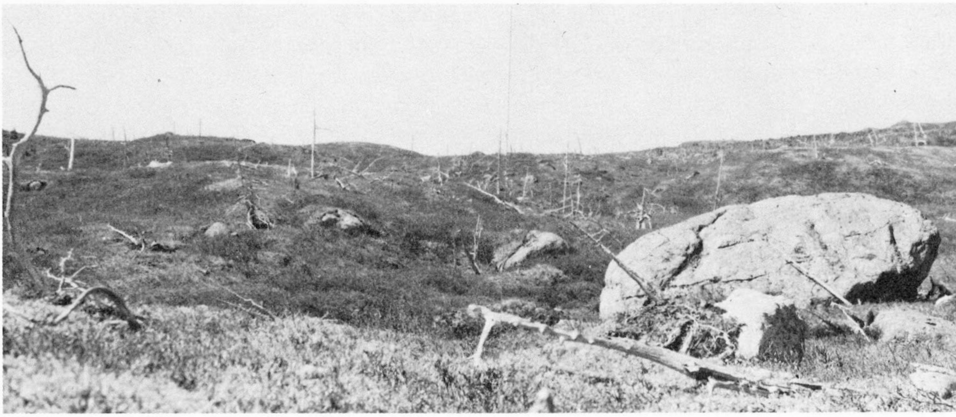

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FIGURE 25. Recessional moraine belt to east of Red Hill, near Cappahayden.

Not only the form and site of the moraines but, in many places, their composition and the character of adjoining areas, indicates origin through frontal accumulation. Many, particularly those in valleys, are ridges or series of till hillocks, arcuate and concave to the ice. Rocky hills on either side and rock exposures in the valley floor both upslope and downslope from some morainic belts, suggest that the moraines have probably been pushed into place by ice that scraped material from the rock floor. They are composed largely of rock blocks of all sizes, with only a little fine material. It is difficult to picture such materials being forced by squeezing or seepage pressure into crevasses or basal cavities in the ice, and the moraines, therefore, must clearly be some sort of frontal accumulation. Because the more active ice at the front of mobile valley lobes favoured moraine formation, these moraines are for the most part confined to valleys and are rare on intervening higher ground. Fluctuations of the ice margin would tend to favour the formation of push moraines during forward-moving phases, particularly in areas where bedrock was covered by loose glacial materials.

Farther inland the moraines may be younger and less stony, but there are no hills or breaks in slope in the underlying ground adjacent to most of them to cause the extensive crevassing required for the formation of ridges by the squeezing of basal till under stagnant ice. The moraines rarely occur near pronounced eminences where the strongest crevassing in the ice would be expected.

St. Mary's Bay Area

This is an area of recessional moraines. The main body formed late in the deglaciation of the Avalon, as the ice sheet retreated from main drainage divides and down the long slope of St. Mary's basin toward an ice centre which, this author believes, still lay more than 50 miles to the southwest. By this time ice had ceased to flow northward through cols into Conception Bay or through the low trough of Dildo Pond into Trinity Bay. Much of the northern half of the moraine plain is flat and several of the larger lakes that now extend deep into it, notably Dildo Pond, The Pond that Feeds the Brook, and Avondale Pond South, drain into the northern bays. Others are separated from the drainage of Trinity and Conception Bays by cols only a few feet, or at the most a few tens of feet, high. Because meltwater streams could drain north through outlets level with or little higher than the present lakes and streams, water levels in this area at the time of moraine formation were similar to the modern ones. Meltwater from about two thirds of the morainal area, from the central part, and probably from much of the eastern part, also discharged through Avondale Pond South and Middle Gull Pond, across bedrock sills less than 450 feet above sea level. Big Pond and Gull Pond in the east-central section of the moraine area, are a little less than 400 feet asl and most of the moraine ridges between them rise to more than 450 feet asl. Most of these moraines were built on dry land or in bodies of shallow water only slightly larger than the modern ponds. Absence of stratified deposits on the tops of any ridges examined supports the hypothesis of subaerial formation of the moraines in the east-central section and north of the Salmonier River.

The western third of the St. Mary's morainal belt is partly separated from the east-central section by a discontinuous ridge covered with ground moraine that crosses the area diagonally from roughly north of Colinet to near Bay de Grave. Segments of this ridge continue west of the Colinet River and east of Ocean and Snows Ponds. Except for a few moraines in the southwest where Rocky River emerges, the western moraine ridges and some of those just east of the ground-moraine covered ridge in the Colinet River valley, lie above the 200-foot level. West of Whitbourne, a col less than 200 feet high separates the headwaters of Rocky River which drains south to St. Mary's Bay from waters draining north to Trinity Bay. Blocking of the southward drainage at Whitbourne would have left the water–land ratios north and east little changed from those of today, for meltwater could escape northward into North River and Conception Bay through Snows Pond and The Pond that Feeds the Brook. South of Markland, blockage of the drainage left most moraines in this exposed area standing above lakes that were slightly larger than the present ones and that drained north through Dildo Pond to Trinity Bay. With southward drainage blocked, Colinet River escaped westward across depressions in the ground moraine-covered ridge and thence flowed north. Free northward escape of meltwater in the western half of the moraine belt provided subaerial depositional conditions there similar to those in the east. The moraines in both areas are similar in height and outline though those in the west are not so long nor so evenly patterned.

Differences in composition of moraines were noted in exposures around Whitbourne. Excavations in two moraines just west of the town showed 4 or 5 feet of ablation till overlying lodgement till in one exposure, and a sandy till with very few large stones in it in the other (Table II, Sample 19). A gravel pit in a moraine 2 miles north of Whitbourne shows 2 to 4 feet of ablation till overlying sandy till. Exposures in moraines south of Whitbourne showed pockets of gravel and sand in the till and a layer of sand and silt 12 to 18 inches thick covering many of the moraines. The sand and silt were not stratified, but this may be because of disturbance of the top foot or so subsequent to deposition. They appear to have been laid down in a short-lived glacial lake near Whitbourne that submerged the moraines, a condition that presupposes either a large plug of stagnant ice in the basin of Dildo Pond blocking drainage to the north, or some other type of more local ponding. The second explanation seems the more probable, for more meltwater flowed across this low-lying part of the morainal belt than elsewhere, some of it from the Colinet valley to the east. So much of the till consists of sand and silt that there is a ready source of supply for the sandy layer on top of the moraines. The presence of ablation till on moraines to the north suggests the possibility of their formation behind the ice margin rather than right at the edge. Nevertheless, similarities between these moraines and others in the morainal belt are so great that all are considered to be contemporaneously formed, recessional moraines.

In addition to the arcuate form of the moraines and their alignment transverse to the ice flow (patterns also associated by some authors with crevassing in stagnant ice) there are other reasons for considering them as ice-marginal features. Steepened proximal faces characterize most of the high, single ridges of the well-developed moraines in the central part of the morainal belt and many of the ridges in marginal locations. It is difficult to explain the occurrence of steepened faces on the side toward the ice unless the moraines were formed against a supporting ice wall. The distal side would then be unsupported and material would either be able to slide or would be modified by meltwater. Benches or subsidiary ridges usually also occur on the side nearer the ice.

An explanation for periodic surges of wasting but still-active ice is not easy to find. The size and spacing of the large moraines argues against any suggestion that they may be a type of annual deposit. The ice that formed them originated in an ice centre, still perhaps 1,000 feet thick, that lay in the rather deep basin to the south, and would have thinned several hundred feet in the course of its retreat from the hills fringing Conception Bay to the southern end of the morainal belt. This would require a much greater number of years than the number of moraines present. The benches or subsidiary ridges also require explanation.

Annual precipitation in this area is one of the heaviest in Newfoundland, with the 55-inch isohyet crossing St. Mary's Bay close to where this author believes the Avalon ice cap may have been centred. The chilling effect of the ice cap on moist, onshore winds at the time the moraines were being formed, may have resulted in an increase in precipitation. During cooler periods, this precipitation would fall as snow. Alternating cool and warm years, at a time when temperatures over the ice cap were close to the critical point determining whether the precipitation would fall as snow or as rain, could result in marginal surges of the ice cap. Assuming the ice cap to be in the St. Mary's Bay area, it would be bordered and confined by high land on both east and west, and marginal surges would therefore be directed north and south. Such fluctuations would favour formation of frontal moraines by pushing marginal material forward during the advance phase of a cycle and depositing it. The ice melted during stationary or retreatal phases. This mechanism may not be necessary to account for the recessional moraines of the perimeter areas previously discussed as they may simply mark pauses in a more continuous retreat.

Although it is not easy to explain the moraine formations solely as frontal deposits, there is throughout the area a conspicuous lack of features such as eskers, large ice-block depressions, rimmed plateaus, or meltwater channels crossing ridge crests, that are usually associated with areas of dead ice or with areas of heavily crevassed ice located well back from the ice front. Meltwater deposits, e.g., the moraines northwest of Mahers or south of Whitbourne, conform to what would be expected at a wasting ice front. Even the presence of ablation moraine over morainic ridges in the low area near Whitbourne might be explained as being due to local conditions such as floating ice in the glacial lake in which silts were deposited elsewhere. Nevertheless, the possibility that some of the moraines were formed subglacially by the squeezing of water-soaked till into basal cracks of crevassed ice cannot be completely ruled out.

Areas of Hummocky Moraine

Hummocky moraine, frequently called 'dead-ice moraine' because of its origin in areas of stagnant ice, is found throughout the Avalon in patches extending 10 square miles or more. It occurs mainly in the high plateaus and elevated basin country around St. Mary's Bay, in places where the ice stagnated after flow across the major topographic divides had ceased. In rough terrain, the ice that lay in partly enclosed basins or on uneven, elevated country became stagnant, even though sometimes it was still several hundreds of feet thick. Such masses waste unevenly, forming channels and cavities both subglacially and on the surface, and separating into irregular blocks. This pattern of melting is strongly suggested by the variable composition and extremely irregular shapes of most of the deposits.

In certain ways these deposits closely resemble those found in the Scandinavian areas of hummocky moraine, especially the Veiki type described by Hoppe (1959, p. 7). The stony nature of much of the Avalon till gives it low plasticity and may have restricted formation of this type of drift ridges. Meltwater deposits such as kames, eskers, outwash lenses, outwash veneers and, probably, crevasse fillings, are common. Heterogeneous mingling of till and stratified deposits, and the presence of many till ridges, suggest sliding and squeezing of the till during melting of blocks of ice. Hollows left after these blocks had disappeared add to the roughness of the terrain.

Superimposed eskers, meltwater erosion channels, and ablation moraine deposits demonstrate that to a large extent the hummocky moraines of the Avalon evolved subglacially. The surface ablation moraine generally consists of large erratics and in at least one instance such ablation moraine covered an esker that was itself laid down on hummocky moraine. The almost complete absence of all such features in the area of recessional moraines is one of the strongest pieces of evidence that those features were not formed under stagnant ice.

The bedrock is an important factor in formation of hummocky moraine, which is best developed above or adjacent to granitic or volcanic rocks, types that contributed the largest quantities of detritus to the late ice. Furthermore, the topography developed on granitic and volcanic bedrock is usually rougher than that in areas underlain by other rocks, a circumstance favourable to large-scale stagnation of ice. In areas where slate or other fine-grained rocks are dominant, the hummocky moraine is more subdued, has fewer large erratics, and less admixed fluvioglacial materials.

Distribution of Recessional and Hummocky Moraines

Recessional Moraine

Most recessional moraines were deposited at some fairly early stage of deglaciation in restricted areas where tongues or lobes of active ice projected beyond the main ice mass, down valleys, or into broad open depressions. This occurred when the Avalon ice flowed from the St. Mary's Bay region, across the main watersheds toward the sea. About one eighth of all moraine ridges mapped in the area appear to have been formed by such ice tongues in numerous small areas scattered about the perimeter of the peninsula. Moraine ridges did not form along more stable stretches of the ice margin on the intervening higher ground.

Hummocky moraine, which consists of steep, uneven drift hills and short, unoriented ridges, is much less widespread than are recessional moraines. It is almost entirely confined to partly enclosed upland basins, having formed where large bodies of stagnant ice, trapped in depressions, wasted in situ. At several places areas of end moraines are contiguous to areas of hummocky moraine or rough ground moraine. The boundary between the two types of deposits is drawn through transitional areas where considerable numbers of the ridges might reasonably be assigned to either class of deposit. The largest and best-formed moraine ridges are in the central parts of the extensive area of recessional moraines around the head of St. Mary's Bay. They are among the youngest moraines in the area and were deposited during a fairly late stage of glacial retreat when ice had become restricted to St. Mary's Bay and the adjacent shores. Moraines formed at several places where the ice abutted against high, steep, bedrock hills projecting above the surface. These drift ridges (shown on the map as end moraines) could include some lateral moraines and crevasse fillings. Possibly the youngest moraine ridges are those found in a number of small areas inland along the east coast, near the mouth of St. Mary's Bay. They were formed during a short-lived flow of residual ice from the southern part of Trepassey Peninsula after the main ice cover had disintegrated.

All the moraines mapped appear to have been formed by local ice. None was found in those parts of the map-area that had been covered by ice originating to the west of Avalon Peninsula. Most of the recessional moraine ridges examined are composed of till, with only minor amounts of outwash. Although, except in parts of the hummocky moraine areas, there are fewer stratified deposits than might be expected, some belts of recessional moraine contain groups of kames or other ice-contact deposits and a few have extensive outwash trains or flats associated with them. Possibly the largest outwash deposits formed contemporaneously with moraine belts are those in southern Avalon at Peter's River on Holyrood Bay, and along the lower reaches of Northwest Brook. Similar but smaller deposits are found on the southwest side of Conception Bay, and on its west coast at Clarke's Beach and Shearstown.

All moraines observed in the study-area are considered to be recessional, formed during momentary halts or minor advances in the general retreat of the Avalon ice. Any true end moraines that may have been formed must have been laid down by ice that had advanced beyond the present limits of the land either at the edge of ice standing in the sea, or upon land subsequently submerged by a rising late glacial or postglacial sea. That big moraines do lie off the coasts is strongly indicated by hydrographic charts, which as mentioned earlier show shallow banks off the mouths of all the large bays. In all except Trinity Bay, the deepest water lies considerably closer to the bay head than to the mouth (*see* Fig. 11).

The possibility of major moraines offshore was recognized by Kerr (1870, p. 705) who suggested that the 80-fathom bank off the mouth of Conception Bay was a submerged terminal moraine formed when the ice stood at its maximum advance. The broad ridge known as St. Mary's Bank, which rises above the 30-fathom contour and extends southeast of Cape St. Mary's across the mouth of St. Mary's Bay (U.S. Navy Hydrographic Office Chart H.O. 1102), appears to be a terminal moraine laid down at a fairly late stage in the retreat of the Avalon ice. The channel separating St. Mary's Bank from the shallow water on the east side of the bay may represent a breach in this moraine, possibly cut by meltwater. It is only a few fathoms deeper than the bank, and probably formed when, as a result of the low sea level prevailing at the time the moraine was formed, the region near the mouth of St. Mary's Bay stood above water.

Belts of end moraines covering numerous small perimeter areas in the Avalon (*see* map *in pocket*) for the most part lie in valleys leading to the sea, either on the Atlantic coast south of St. John's or around the upper shores of Conception and

Trinity Bays. They are considered by the author to have been formed by ice tongues draining from the main ice centre sometime after the ice had withdrawn from the advance offshore positions occupied during the glacial maximum. Ice still flowed vigorously seaward, however, across divides in the St. Mary's Bay area and down coastal valleys. As these tongues retreated by wasting, they left morainic hills and ridges where halts or minor advances occurred. The better developed ridges are 15 to 30 feet high and a few reach 40 or more feet. Till in the ridges is generally stonier than that in the ground moraines and includes more large blocks. A notable exception is found in small areas of recent moraines on the east side of St. Mary's Bay, where the till resembles that of the moraines about the head of the bay and contains few large blocks. The largest moraine belt in this area extends southwest from the town of St. Mary's around the head of La Haye Pond. Nearly a mile across and about 2 miles long, its central part is composed of steep-sided till hills, some of them as much as 35 feet high. Only rarely is the internal composition of moraine ridges well exposed, but, in this particular belt, sections along the road through the central parts of the hills reveal the structure of the ridges. The till exposed in these sections is mainly composed of coarse materials but contains few large erratics. One sample taken from a typical exposure comprised 86 per cent stones and sand (Table II, Sample 45) and appears typical of other morainic hills in the belt. Lenses and pockets of stratified sand and gravel are common, indicating considerable water action during formation of the moraines. In some cuts the till has practically no silt-sized material and shows crude layering suggestive of sliding and washing by water during deposition.

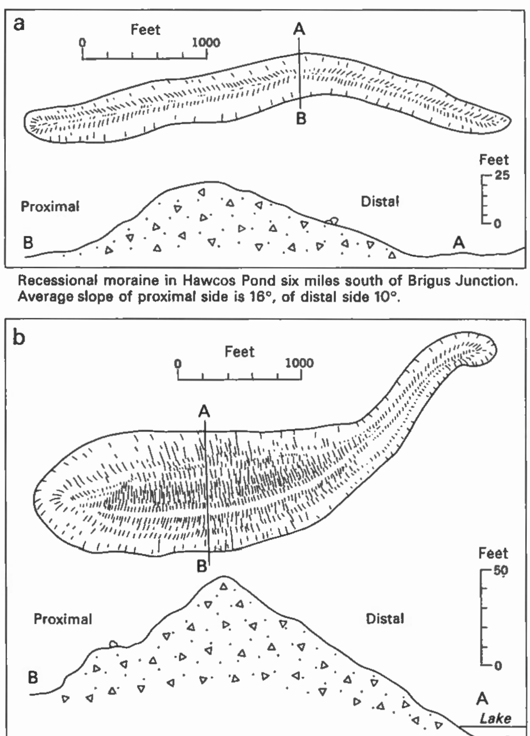
Generally the recessional moraines are composed of till, although the composition may vary from stony moraines in which large blocks are the conspicuous component to moraines in which most of the clasts are less than a foot or 2 feet large. Examination of stony moraines suggests that their high proportion of coarse fragments results from proximity to granite, volcanic bedrock or pebble-conglomerate as sources of erratics; and from their location in areas where there is so little drift that the ridges themselves constitute the major glacial deposits. As there are no deep sections through good stony moraine ridges, it could not be determined whether the large erratics are distributed throughout the body of the moraines or are mainly confined to the surface.

Few moraines are found beyond the regions covered by ice flowing from the St. Mary's Bay centre. The thin, axially draining ice, believed to have covered the northern parts of Carbonear and St. John's Peninsulas, would generally have had little erosive or transporting power, particularly on the high central plateaus. This is substantiated by the sparseness of the widespread ground moraine and the lack of evidence of intensive glaciation. In the northern sections of these peninsulas and in parts of Trepassey Peninsula, the few small, stony, recessional moraines were deposited either in areas of thin drift or directly on exposed bedrock, usually at low altitudes near the coast where topography favoured more vigorous drainage of the thin ice cover. On St. John's Peninsula, a few stony moraines 15 to 30 feet high lie on the south side of Pouch Cove and two other patches of similar morainic ridges occur about 3 miles to the south and southwest respectively. Between Heart's Content and Heart's Desire, three areas of small, stony moraine ridges and hillocks, all about a mile long, are found within a few miles of each other. On Trepassey Peninsula they are found west of Cappahayden and west of Franks Pond.

About 80 per cent of all morainic ridges in the map-area lie north and east of St. Mary's Bay. Most of this region is a heavily drift covered plain of moderate elevation that extends south and southeastward for almost 50 miles in a great arc from south of Dildo Pond nearly to Holyrood Pond. Most of the ridges lie southeast of Dildo Pond, within a large oval area of about 20 by 17 miles. Another irregular area of moraines extends southward from this oval for more than 10 miles and varies in width from a mile to 4 miles. Two long projections extend eastward from it into areas of thin drift on the high intèrior plateau. South of this the moraine belt continues toward the head of Holyrood Pond as a series of small disconnected patches. Most of the terrain underlying these widespread moraines is either flat or slopes gently up to higher ground north and east from St. Mary's Bay. Between the main area of morainic ridges and the shore the slopes are covered with ground moraine.

Simple moraine ridges reach heights of 20 to 35 feet, and widths of 300 to 500 feet. They are generally a half to two thirds of a mile long, and steeper on their proximal than on their distal side (Fig. 26). Where they occur as a series, most of the crests are 600 to 1,200 feet apart. Elsewhere, they are much more widely separated, particularly toward the edges of the larger morainic areas and in smaller outlying groups, where they also are smaller. Generally the crestlines are even, except where moraines, usually aligned across the direction of the last ice flow, are formed of ridges or of two or three round or oval hills joined by saddles; here they have

FIGURE 26
Recessional moraines.



High recessional moraine at south end of Ocean Pond, three and one-half miles southwest of Ocean Pond station. Average slope of proximal side is 22°, of distal side 14°.

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undulating crests. Most of the ridges run fairly straight, their long axes perpendicular to the movement of the ice, though a few bifurcate or coalesce into small, irregular, groups. Here and there they are arcuate, generally concave toward the ice, though a sufficient number are convex toward the ice to prohibit formulation of any general rule. The longest observed ridge, located 4 miles northeast of Whitbourne on the northwest side of Gander Pond, is nearly 2 miles long, and is convex toward the ice. Its shape, however, is believed to be due to a high bedrock ridge immediately to the north, up each side of which the ice flowed.

Southeast of Dildo Pond, in the centre of the large, oval area where moraines are well formed, the ridges are narrower and longer than elsewhere and have even crests. Asymmetry is best developed in this type of moraine which mostly has south-facing proximal slopes as steep or steeper than the north-facing distal ones. Where the proximal slope is less steep, it is generally because of a secondary accumulation of drift piled against that side of the moraine in the form of a bench. This gives a sharp break in slope, or even a secondary ridge (Fig. 26). Moraines with benches or minor auxiliary ridging are commonly higher and broader than simple ridges. The highest moraine observed, at the southern tip of Ocean Pond, is of this type. Its base width is nearly 700 feet, and its crest stands 82 feet above the lake surface on the north and 63 feet above the flat swale on the south. In contrast to other compound ridges, this moraine has a sharp crest and so is not overly broad. It is, therefore, somewhat atypical.

Moraines in the large oval central moraine region, in zones transitional to other types of glacial deposits, tend to be much more irregular in symmetry, height of crest, and orientation. Also, they are generally shorter, many being only a few hundred to a thousand or so feet long. In plan, many of these appear to be composed of three or more roundish, morainic hills, separated by saddles but nevertheless forming a distinct unit.

Morainic ridges in the large oval of recessional moraines are composed of tills in which large blocks and erratics measuring as much as 2 or 3 feet, are rare. The till cover is thicker here than in other parts of the study-area, granite boulders are absent, and large volcanic rocks occur in only a few places. Hard siltstone and slate, with some greywacke and arkose, comprise the bulk of material in the ridges, particularly in the southern parts. To the northeast, where moraine fingers extend up some valleys, they may contain some volcanic or other boulders derived from nearby rock formations.

Although no sections have been made in the moraines of the interior of the oval, cuts about 20 feet deep occur along the Salmonier Line (Highway 6) in the southeast, along the Trans-Canada Highway and the railway to the north, and in several large gravel pits beside the two roads. In spite of the small number of large erratics, about half the bulk of most of the hills is composed of gravel more than 2 mm in size (*see* Table II, Samples 16, 18, and 54).

An exceptional morainic area is located north of the railway line, a mile northwest of Mahers. Here a large complex moraine that has been cleared of bush rises 45 to 75 feet over a distance of several hundred feet. There are very few erratics of cobble size or larger on its uneven surface and only a few, small, stone piles on the undulating farm fields to the west. The moraine and adjacent morainic area occupied by the farm have fewer stones and boulders than any other place in the Avalon where tills have been identified at the surface.

On the northwest side of the moraine, a 7-foot road cut exposes poorly sorted, silty gravel containing lenses and thin layers of cleaner, stratified gravel and sand. The strata are somewhat disturbed, for the sand layers run across the bank in wavy bands and in one place vertical beds are exposed for several feet. This section occurs in typical ice-contact deposits that have been disturbed either by subsequent sliding or, more probably, by ice shove. The considerable thickness of sand and gravel, together with the absence of coarser surface material nearby, suggests that an integral part of the ridge is composed of fluvioglacial material. Subsequent clearing of trees from other wooded moraines in the vicinity may reveal more composite ridges of this type. However, it seems likely that rather than being constructed entirely of stratified materials, the larger ridges are composed mainly of till with a veneer of ice-contact, stratified materials, and perhaps with some interspersed, small kames superimposed.

At a few places till ridges, parallel or at low angles to the direction of ice flow, occur low on the slopes of steep, high bedrock hills that apparently formed nunataks or re-entrants in ice that was still moving. These ridges are generally more irregular in outline and contain more boulders than most recessional moraines, and their varying directions bear no relation to the orientation of the nearby moraines. Six miles west of Colinet, ridges of this type half surround an 850-foot hill south of the highway; they are also found southwest of Cappahayden, on the north and east slopes of the high ridge south of the Portugal Cove South road and 4 miles west of Chance Cove. They may be crevasse fillings rather than true lateral moraines. The till ridge more than a mile long that lies south of Seal Cove on Conception Bay is probably a lateral moraine. It appears to have been deposited by a tongue of active ice moving west down the adjacent deep valley parallel to Seal Cove River. Where the highway crosses it, the moraine is 20 to 30 feet high; elsewhere, in the erratic-littered knolls along its length, it has a minimum relief of 10 to 15 feet. A gravel pit adjacent to the highway exposes 8 feet of stony, bouldery till overlying 4 feet of stratified gravel and sand. A similar but shorter ridge 1,000 feet to the east, parallels the southern half of this moraine in the area between it and Seal Cove River.

Hummocky Moraine

Hummocky moraine observed at several places throughout the Avalon, consists almost entirely of rough, irregular, drift hills and short, unoriented ridges. It occurs much less frequently than the recessional moraine and covers only about 7 to 10 per cent of the total area of morainic hills and ridges. It is found chiefly in high, rolling, lake-studded sections of the Hawke Hills, in similar terrain on north-facing slopes of Castle Ridge in Placentia Peninsula, and inland, at the base of Carbonear Peninsula (*see* map *in pocket*). Most of the other scattered, small patches of hummocky moraine lie close to the main areas. Typical hummocky moraine is generally sharply differentiated from well-developed recessional moraine by greater roughness, diversity of slope and height of individual units, and the irregular pattern its units form.

Some of the most spectacular hummocky moraine lies around Four Mile Pond and south of the Trans-Canada Highway near Holyrood (Fig. 27). It consists of steep drift mounds and short, irregular ridges 30 to 50 feet high. The surface of many of them is littered with many angular granite and lava erratics of all sizes. Toward the main hill west of the pond, the drift deposits are smaller. The lower slopes are covered with hillocks about 6 to 10 feet high, and intermingle with a few, large, rock-cored ridges that expose bedrock outcrops on their flanks or crests. Rolling ground moraine begins 150 to 500 feet above the lake, but as rock outcrops are either rare or lacking, it is difficult to determine whether the higher mounds and ridges of

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FIGURE 27. Hummocky moraine forming stagnant ice topography south of the Trans-Canada Highway and the Witless Bay Line, 0.6 mile east of the turnoff to Holyrood.

the rougher hummocky moraine are composed entirely of drift or whether some are rock cored. Both conditions may be present. Up the slopes of the larger hills the drift thins rapidly, and rock outcrops may be seen between and in the sides of many drift hills at points where the moraines merge into rocky hillsides or thin ground moraine. Even in the rougher, central zones of hummocky moraine, it is the mounds and ridges themselves that contain the bulk of the drift. The intervening swales have generally only a thin cover of till over bedrock. This contrasts with areas of recessional moraine where the drift mantle is usually much deeper than the individual moraines are high. There are no deep cuts that show the total thickness of the drift in either the recessional or the hummocky moraine.

Hummocky moraine is more varied in composition than recessional moraine; many of the ridges have lenses and veneers of gravel or ablation moraine, and some are entirely composed of fluvioglacial deposits. Thus, in form and surface appearance, elements of hummocky moraine may resemble kames, esker segments or possibly crevasse fillings.

Meltwater channels, rare in recessional moraine areas, cross some tracts of hummocky moraine; e.g., the tract 2 miles east of Holyrood that covers about 4 square miles is crossed by three large meltwater channels, two of them well over a mile long. Before entering the north end of the hummocky moraine area, the two northerly meltwater channels cross an outwash flat that is half a mile long and completely surrounded by hills and short ridges of drift. This hummocky moraine area is largely hemmed in by higher ground and most of it lies between 300 to 550 feet asl. It contains large fluvioglacial deposits and erosional features and the internal structures of some of the ridges in its southern part are exposed in several small gravel-pit excavations. The most southeasterly of these pits exposes gravelly till; another, 700 feet to the north, is half in stony till, half in sandy, poorly sorted gravel; a third, a quarter of a mile farther north, lies in outwash sand and gravel deposited against the ridges; a fourth, still farther north, just outside the hummocky moraine, is in sand and gravel covered by 3 feet of ablation till. Still another gravel pit, on the northern edge of the hummocky moraine area around Four Mile Pond shows the interior of the ridge in which it is situated to be a mixture of extremely angular, friable, loosely packed fragments, few of them larger than 6 to 8 inches. They are crossed by streaks of gravel and overlain by several feet of harder stratum, evidently a till, that contains most of the erratics in the exposure. It would seem that on deposition the lower sediments were water sorted, but not transported very far. They were then covered by the till.

In another area of hummocky moraine about a mile to the west, another large pit exposed a stratum of cobbles 4 feet thick that extends for 150 feet, and several feet of stratified sand and gravel are exposed in a trench just west of the pit. Lenses and streaks of poorly sorted sediments also occur at places along with till. The till varies from a hard, ice-laid material of tightly interlocked, angular fragments, to a loose friable material that appears to have been reworked by water during or immediately following deposition. Some of the drift mounds might be described as 'tilly kames,' so intimately mixed are the ice-laid and water-laid sediments.

The largest area of hummocky moraine covers 10 square miles and extends eastward 7 miles from the low ground a mile east of Dildo to the high ground on Carbonear Peninsula. It has a few sections that expose the materials in some of its ridges: two gravel pits in the western half and shallow cuts in the eastern half in 10- or 15-foot-high till hills. One gravel pit, in a 30-foot ridge, reveals nothing but till; the other, in a smaller ridge, exposes 5 to 7 feet of bouldery ablation till that rests on lodgement till and contains lenses of stratified gravel and sand. All available evidence indicates that the morainic areas east of Holyrood and in the vicinity of Four Mile Pond contain a higher ratio of fluvioglacial deposits than do similar areas elsewhere in the Avalon.

Fluvioglacial, Glaciolacustrine, and Glaciomarine Deposits

Within the map-area, sorted glacial drift transported by meltwater during the waning phases of the last glaciation and deposited usually at or near the ice margin includes such ice-contact deposits as eskers, kames or kame terraces, and such proglacial deposits as fans and outwash flats. In addition, aggrading meltwater streams deposited valley trains for considerable distances beyond the ice margin. Deltas formed where such streams entered lakes or reached the sea.

Only 1 or 2 per cent of the map-area is covered by fluvioglacial deposits, a surprisingly small extent considering the widespread evidence of meltwater activity and the sandy, gravelly nature of the abundant glacial sediments. Small, unmapped deposits may be scattered over sections otherwise barren of meltwater sediments, but their volume would be insufficient to change the picture revealed by mapped deposits. During Recent time, marine erosion was intensified by encroachment of a rising sea, at least in the eastern half of the map-area, and may have removed considerable amounts of these deposits that had possibly been laid down at or near the shore. Stratified fluvioglacial sediments are probably to be found on the floors of many of the bays, particularly in areas adjacent to large shore deposits, but a large percentage has undoubtedly been distributed farther afield by longshore currents. Large meltwater channels, eroded into the drift around Trepassey Bay and on the west coast of St. Mary's Bay north and south of Branch, are further evidence that large quantities of fluvioglacial sediments have been removed and deposited in the sea. Most of these channels terminate either at the sea, sometimes at vertical rocky cliffs, or in shoreside outwash deposits that broaden toward the water.

Most of the large fluvioglacial deposits lie adjacent to the sea. This distribution could be explained, at least in part, if much of the meltwater carried little sediment and eroded rather than deposited material. Some credibility is lent to this hypothesis if one considers the conditions at the ice front at the time the ice had withdrawn to the main divides about St. Mary's Bay.

To discharge sediments at the ice margin most meltwater streams would have had to erode basal drift and then transport this load uphill to the margin. Also, the proglacial precursors of the numerous modern lakes in the area would have acted as sediment traps and their outlet flows would be clear. It seems likely, therefore, that surface streams carrying little sediment would comprise much of the meltwater discharge. Though this process probably limited deposition of fluvioglacial sediments in many localities, particularly near divides, efficient stream transport had an even greater effect in limiting the incidence of fluvioglacial landforms. During deglaciation, meltwater streams were short, rapid, and with high gradients; hence they had great carrying power for their size. As a result much, perhaps most, of the fluvioglacial sediments discharged at the ice front were carried directly into the sea. Exceptions to this are found west of Cape Broyle and on Placentia Peninsula in localities where several deposits of fluvioglacial sediments lie well inland.

Eskers

Esker deposits are confined mainly to two areas: the Trepassey Peninsula south from the La Manche River (though not along the shore of St. Mary's Bay) with twenty-seven eskers observed; and the Placentia Peninsula from just north of the Colinet–Placentia road to the southern tip of the peninsula, with nineteen eskers observed. More than half the Trepassey Peninsula eskers are approximately half a mile long, eight are about a mile long, three are 2 miles or a little more, and the one that runs north into Chance Cove is 5 miles long. The longest esker of the entire map-area, more than 10 miles long, extends along the route of the Colinet–Placentia highway from about 7 miles west of Colinet to Southeast River. Other eskers on the Placentia Peninsula range in length from 2 to 5 miles. Throughout the rest of the map-area there are only three or four eskers even as long as half a mile. Some eskers, however, bifurcate at one or more places to form ridge systems. This has resulted in a more extensive area of esker forms than the quoted lengths would suggest.

Most of the larger esker ridges contain gaps of varying lengths where material either was not deposited or has been removed by erosion. Some present-day streams cross eskers through gaps obviously created by their own flow. Despite gaps, segments laid down by the same meltwater stream are considered to form a single unit or esker. Average heights of the ridges range between 15 and 30 feet, a few eskers reaching elevations of 40 to 50 feet. The majority are somewhat sinuous in outline, steep sided, with sharp crests, and with heights varying throughout their lengths.

Generally the sides slope at the angle of repose for coarse material. A few are massive and some of these broader eskers have wide, level tops — a feature that probably reflects their mode of origin. Though most commonly found along the sides of valleys or on valley floors, some eskers are located on open slopes or uplands. One, near the north end of the Platform Hills on the Placentia Peninsula, runs westward out of the Branch River valley across the main peninsular divide toward Placentia Bay.

Parts of some eskers examined are believed to have been deposited in open channels rather than in subglacial tunnels. They are composed mainly of finer grades of gravel and sand, have broad level tops, and their gradients are low and even, descending in the direction of the former stream flow. The direction of their course is sometimes continued by meltwater channels. At a few places, generally toward the lower end of an esker system, a broad ridge of moderate height with a wide flat top has been formed; e.g., one part of the esker that crosses the road to Branch, 6 miles east of St. Bride's.

Kames or uneven ridges and heaps of sand and gravel are found beside some eskers, apparently where cavities or fractures in the ice have either slowed the flow or allowed dispersal of previously confined subglacial waters, with consequent deposition of their load. The more disordered mounds and ridges may represent deposits laid down originally on top of the ice by surface streams, and subsequently lowered to their present position when the ice melted.

Crevasse Fillings

Crevasse fillings are considered to be moulds of open cracks in the glacier which were filled by material from surrounding ice that was either washed in or slid in. Melting of the supporting ice walls left a straight, steep-sided ridge. Depending upon the process that contributed most to their construction, the fillings may be level and flat topped, or undulating and of varying elevations. Flint (1957, p. 150) considers them a form closely related to kames. They may also form a gradational series with one type of esker ridge.

Two miles east of Holyrood, south of Fenelons Pond, a flat-topped, straight ridge more than 1,500 feet long, composed throughout of sand and some fine gravel, stands 4 to 12 feet above surrounding bog flats.

Three miles east of New Harbour, on the east side of the large pond lying south of the New Harbour–Spaniard's Bay road, two parallel ridges more than 1,500 feet long and one third of a mile apart are believed to be crevasse fillings. A similar ridge on the west shore of the pond is directly in line with the more southerly ridge and is apparently an extension of it. Although the two easterly ridges have undulating, uneven tops, both run straight and are steep sided. They are considerably higher at their eastern end, where they blend into the hillside, than at their western end toward the lake, even though they still reach a height of almost 30 feet there. Only the more northerly one was examined closely, but they appear to duplicate each other. The northern ridge consists of till and coarse fluvioglacial material, with angular boulders as much as 5 feet in diameter scattered over parts of its broad top. A boulder-lined depression at one place on its top resembles a small kettle. Most of the material in the ridge probably reached its present position as a result of till and boulders, intermixed with large amounts of coarse, crudely sorted, fluvioglacial gravel, avalanching into a large open crevasse. Because of the large proportion of coarse fragments and lack of fines, it is probable that no addition of material by lateral flow of basal till contributed to the formation of these three crevasse fillings.

Although no crevasse fillings possessing the distinctive form of those just described were seen elsewhere, they may nevertheless exist in areas covered by hummocky moraines. As the moraines were developed under and between thick masses of stagnant ice, many may have formed initially as crevasse fillings, as well as by plastic flow of subglacial till under the weight of the ice blocks (*see* Fig. 22).

Kames

Kames are generally rather symmetrical mounds that stand either singly or in groups, but may be joined together to form irregular masses. Under some conditions they may even form initially as irregular mounds. In the Avalon they are generally distributed throughout the same areas as eskers, and are therefore most numerous in the Trepassey Peninsula south of La Manche River and on Placentia Peninsula. They may, however, be found wherever there are fluvioglacial deposits. They also occur in areas of hummocky moraine and in some places are found in association with recessional moraines. In rare instances a single kame or small group of kames may be found in a ground-moraine area with no fluvioglacial deposits or meltwater channels nearby.

The largest groupings of kames occur in thick, fluvioglacial deposits at several coastal locations, where they may comprise most of the stratified sediments (*see* map *in pocket*). On Trepassey Peninsula the most prominent of these areas are: 2 miles north of Cape Broyle, Chance Cove, the head of Trepassey Harbour on Northwest Brook, and Peter's River on Holyrood Bay; and, on Placentia Peninsula: Jigging Cove north of Branch. A few kames are found in most of the larger inland areas of outwash deposits, particularly on Placentia Peninsula. Within the map-area kames average 15 to 30 feet high. A few reach 50 feet, and the highest one examined measured more than 60 feet from top to base. Rapid changes in volume, velocity, and direction of flow of the depositing meltwaters, is reflected in their uneven bedding. Cuts show them to be composed of mixtures of material that commonly exhibit large, abrupt changes in grain size. Some lenses and bodies of sediment are well sorted, some are chaotically cross stratified or torrentially deposited, and others show stratification that varies from good to barely distinguishable. Deformation of the beds is common and has been caused by sliding or collapse due to melting of the supporting ice. Many kames include bodies of till, and a few of the large ones are littered with surface erratics of all sizes or covered by a layer of till. One, whose structure is exposed in a gravel pit, has a covering of ablation till several feet thick over stratified deposits. Most fragments in kame gravels are less well rounded than those in the gravel of outwash flats or valley trains.

Within the map-area, the largest groups of kames, and the most symmetrically formed, developed at the ice margin at the end of esker systems where large volumes of meltwater were discharged (Fig. 28). Additional kames are scattered either along many of the esker ridges, or attached or close to the esker deposits. Many of these are the irregular type, with less steep slopes. A few appear to be composed largely of stratified drift that originally filled depressions in the glacier or under stagnant ice and was subsequently deposited as the underlying ice melted. Kames formed of intermixed till and stratified deposits are referred to here as 'tilly kames.'

Although some kames found throughout the areas of hummocky moraine are symmetrical, most are irregular and likely to contain till. Many appear to have originated in crevasses or on uneven terrain surrounded by ice, and to have grown through increments of till received from flows and from avalanching till chunks intermixed

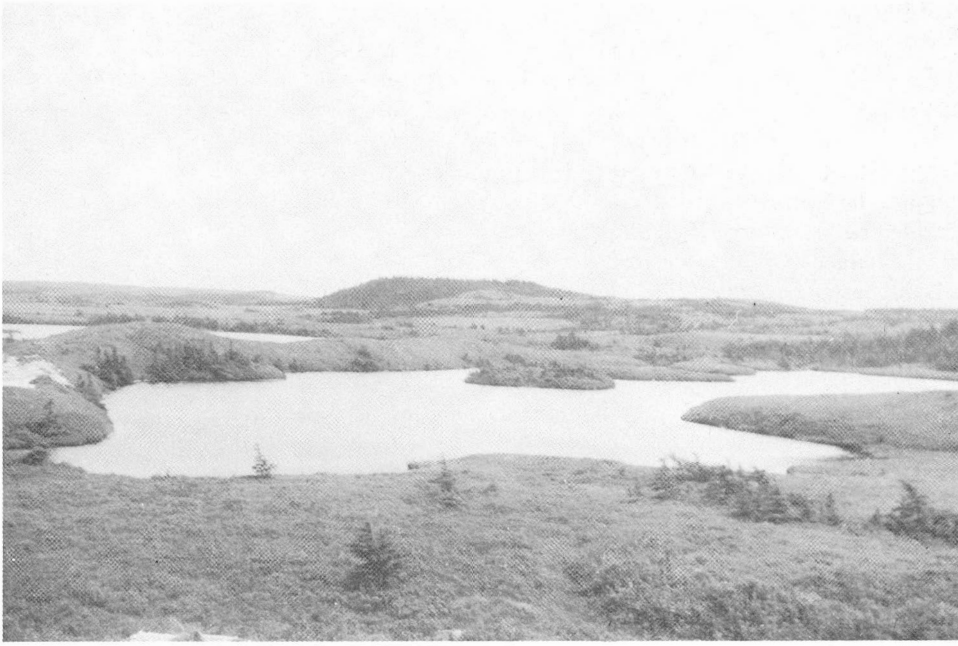

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FIGURE 28. Esker-kame complex on south side of the Colinet-Placentia highway.

with water-deposited sand and gravel. There is little sorting of the water-laid sediments, and the individual fragments tend on the average to be more angular than those in kames formed elsewhere.

The kame on the west side of the road a mile north of St. Bride's rises to a height of 40 feet and, like many of the isolated kames in the map-area, is probably a moulin kame. It is constructed of well-sorted gravels, with stones an inch to 4 inches in diameter and unusually well rounded for kame gravels. The supraglacial stream that formed it must have transported the gravels a considerable distance.

Kame Terraces

Although kame terraces are not generally well developed within the map-area, some large ones are found at Clarke's Beach on Conception Bay, and others have been identified near Fermeuse and Riverhead.

At Clarke's Beach, North and South Rivers flow for their last 2 or 3 miles through deep valleys, a mile to 1½ miles apart, separated by a 700-foot hill. Along the north wall of the North River valley, an irregular kame terrace extends inland for more than 2 miles from the sea. From an altitude of 63 feet asl at its head, its top slopes northeast, at about 9 feet per mile, down to 45 feet asl at the end near the sea. It was apparently built between the valley wall and a large mass of stagnant ice that lay in the valleys of North and South Rivers and at the head of Bay de Grave. For much of its length a shallow channel in the terrace top marks the last position of the marginal meltwater stream that built it. An irregularly shaped lake 2 miles long now occupies that part of the North River valley where stagnant ice lay at the time the terrace was constructed.

Near the centre of this lake is a younger, lower kame terrace, its top surface 22 feet above the water. Steeply dipping beds, at angles as much as 34 degrees, exposed at the front of this lower terrace indicate it is part of a delta that was deposited in water still dammed by the disintegrating ice plug. A similar but wider kame terrace extends along the south side of the South River valley. An ice-block lake, a mile long, lies between its upstream section and the hill to the north. Steeply dipping beds of well-sorted gravels exposed in pits in the 50-foot high terrace front facing the lake, suggest that part of this terrace also is deltaic, built into a lake that enlarged with the melting of an ice dam after construction of the main part of the terrace to the south. Kame-terrace deposits, mostly extensions of the wide South River terrace, continue around the nose of the hill separating the two rivers. They were separated from the South River terrace when the river excavated its present channel through their midst. The part of the terrace near the north bank of South River is greatly pitted, and the bottoms of some of the kettle holes are almost at lake level.

Because the top of the main terrace on North River does not fall to elevations lower than 45 feet as it approaches Bay de Grave, it would seem that the meltwater stream that built it must have reached the sea over a bedrock sill in the valley wall. The large South River terrace, however, appears to have been graded to sea level. Part of the original terrace top still remains on the south side of Bay de Grave although along most of its seaward face erosion has removed its most easterly extension, leaving instead a low bluff of stratified sediments behind a barrier beach. This remnant is covered with coarse, stream-rounded cobbles and is graded directly to the sea. Vestiges of old meltwater channels on it are visible only a short distance back from the present shore.

A mile northwest of Fermeuse, another small kame terrace forms a gravel bench that ends in an irregular, southwest-facing, ice-contact slope and lies between the road and the steep valley wall on the northeast. Just north of Riverhead, along the stream flowing into St. Mary's Harbour, similar gravels lying between the road and the eastern slope of the valley have been identified as kame terraces. Small kame terraces probably occur elsewhere throughout the map-area, particularly where meltwater channels are abundant. Gravelly hillside benches that lack identifiable ice-contact slopes or strongly pitted surfaces, could not be distinguished from similar benches underlain by till.

Outwash

Streams depositing outwash sediments originate on ablating glaciers. They are often the same ones that, nearer their source, have deposited ice-contact stratified drift. In its proximal parts, outwash may grade into these ice-contact deposits and may also cover or surround older ice-contact drift. Generally, outwash deposits are better sorted, more thinly bedded, and composed of more rounded grains than are ice-contact deposits. This is relative, however, for outwash is still coarse grained, and sharp variations in grain size, both horizontally and vertically, are numerous. The sediments generally show decreasing grain size with increasing distance from the glacier. As with ice-contact deposits, there is little material smaller than sand size, the finer grain sizes having been flushed away. Boulders may be present, either rafted in by floating ice or, where gradients are very steep, carried in by rapid meltwater streams.

Outwash Plains and Flats

Outwash is deposited where the gradients of glacial meltwater streams flatten or where topography checks the velocity of the flow. Outwash flats are generally deposited immediately in front of a wasting glacier, but outwash may also be laid down at a considerable distance from the ice margin if steep, efficient channels are available to carry the sediments away from the vicinity of the ice.

Although in many places outwash and ice-contact forms may be deposited simultaneously from the same meltwater streams, when outwash surrounds deposits such as eskers or kames, or when it lies higher upstream than the ice-contact deposits — e.g., in the flats near Mount Carmel Pond — it must be considered as younger than the ice-contact forms, having been laid after the ice had retreated to a position at or beyond the highest part of the outwash. Outwash without ice-contact material is more apt to have been deposited some distance downstream from ablating ice, but again may either surround or bury older ice-contact forms.

A narrow outwash plain extends half a mile to a mile inland for more than 9 miles along the southeast coast of Conception Bay, from Seal Cove to Topsail Head. This is the largest continuous body of stratified drift in the map-area. The outwash mantles and is largely coincident with the Paleozoic rocks on which the low-lying, rolling coastal plain is developed, for both terminate inland at steep hills of Precambrian outcrops. Valley-train deposits continue a short distance up some of the valleys entering the plain. Thickness of the stratified beds ranges from more than 50 feet in shore bluffs at Seal Cove to nothing at all where till or bedrock knolls protrude above the surface. The largest such stretch is a three-quarter-mile-long, till-covered rock ridge that forms the west bank of Manuels River north of the highway.

Numerous exposures in the low sea bluffs indicate that the normal sequence in the outwash plain at the shore is a foot to 10 feet of sand and gravel over till. Thicker stratified sediments occur where ice-contact or proglacial delta deposits are present. Sand and fine gravel, gently dipping toward the shore, make up most of the outwash east of Manuels River. Less sand and coarser gravel, with less even bedding, are present west of the river. Between Lance Cove and the mouth of the stream draining Lawrence Pond, parts of the stratified deposits exposed along the shore show confused bedding and chaotic deposition of more than 20 feet of gravel. This gravel, probably an ice-contact deposit, is interrupted by sections of well-sorted horizontal sand. East of Manuels and Seal Cove Rivers, and possibly also west of Kelligrews River, the gravel–till contact dips below sea level, presumably at places where older, postglacial channels of these rivers, now choked with outwash, entered the sea.

As well as being interrupted laterally by ice-contact deposits, the outwash also grades in places into other stratified deposits inland. Thus outwash deposits lie between kames and the sea east of Manuels and Seal Cove Rivers. For 1½ miles westward from Topsail River, ablation moraine fringes the inland southern edge of the outwash plain. Apparently, when the glacier margin had withdrawn to the south edge of the eastern sections of the shore plain, stagnant ice still lay just east of Manuels and Seal Cove Rivers between Lance Cove and Kelligrews River as far north as the present coastline. While most of the coastal plain was being covered by outwash, kames and an esker were formed in the stagnant ice areas; in some locations such as Seal Cove, large surface erratics were deposited directly from stranded masses of melting ice. Extensive deltas formed off the mouths of Seal Cove and Manuels Rivers, and a smaller one developed at the mouth of Kelligrews River.

When deposition by meltwater ceased, the entire shore was composed of outwash sand and gravel, generally thin except where deltas of larger streams projected into the water. Probably no ice-contact deposits extended as far north as the sea but rather stood well inland surrounded by flat-lying outwash. Subsequent erosion removed much of this stratified drift, particularly from the deltas. It is difficult to estimate the amount of this erosion, but the presence on top of the Seal Cove deposits of more than 30 feet of gently dipping topset beds with a surface gradient of 30 to 40 feet per mile, suggests that this particular outwash fan may once have extended as much as a mile farther north than it now does. The amount of coastal retreat due to erosion was less at other locations. West of Lance Cove the sea encroached sufficiently far to expose ice-contact deposits in the shore bluffs. Some postglacial rise in sea level, evident from the below-sea-level position of outwash-filled stream channels and the minor flooding of present estuaries, may slightly increase the suggested amounts of retreat of these outwash deposits along the coast.

Sediments in different outwash flats show a wide range of grain sizes, some being composed almost entirely of cobbles, as is the flat on La Manche River, others being composed largely of sand with lenses of gravel. Clay is absent, and silt nearly so. Some flats show a large change from one end to the other in the average grain size of their sediments. Current bedding, cut-and-fill structures and lensing are common. Most outwash flats large enough to map are found either on Placentia Peninsula or in eastern and southern sections of Trepassey Peninsula. Many are small, perhaps a quarter to half a mile across, but several are a mile to 2 miles long. On Trepassey Peninsula, inland from Cape Broyle, four outwash flats each more than a mile across lie east and southeast of Mount Carmel Pond. A fifth, on the La Manche River, lies astride the coastal highway just north of Cape Broyle. As explained below, the large outwash flat at St. Bride's on the Placentia Bay coast differs in its origin from inland outwash flats.

Much of the Conception Bay outwash plain accumulated as a series of flat, coalescing fans where numerous small streams flowed from the ice and spread out in an interlocking pattern of shallow, shifting channels. The preserved fossil stream channels, generally only a foot or so deep, are difficult to follow for any distance on the ground although some, particularly those between Lance Cove and Kelligrews River, can be easily traced on air photographs. Only a few of the sediment bodies mapped as 'outwash' may be considered purely as outwash, for almost all are associated with either ice-contact or glacial forms laid down either simultaneously or just a little earlier. The large outwash flat on the La Manche River and the smaller flat, 1½ miles upstream from the mouth of Witless Bay Brook, lie between areas of recessional moraine. Eskers protruded above the surface of three of the four large tracts of outwash east and southeast of Mount Carmel Pond. A few kames are also present, particularly in the smallest tract 3 miles directly south of the pond outlet. The fourth area, the one nearest Cape Broyle, covers the low, level country upstream from a deep, narrow valley that evidently obstructed and reduced the velocity of meltwater flowing through it into Cape Broyle River. The meltwater thus checked spread out and deposited sand and gravel. A few older ice-contact deposits may be present, some possibly in the form of kames. On Trinity Bay the small outwash flat on the valley floor of a stream flowing into Spread Eagle Bay, is of similar origin. It lies upstream from a narrow gorge cut through an obstructing bedrock ledge that crosses the valley at its lower end.

The thickest section of stratified drift seen underlying an outwash flat is exposed in the coastal bluff at St. Bride's. The 35 feet of coarse gravel forming the upper layer of the deposit is separated by a sharp, horizontal contact from 20 feet of flat-lying, laminated sand containing minor amounts of silt in bands (Fig. 29). Most of the gravel shows cut-and-fill bedding with dips in various directions. Strata in the upper few feet parallel the coast and dip gently westward toward the sea.

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FIGURE 29. Outwash deposit, St. Bride's. Dark area at left centre marks seepage of water at the sharp contact between gravel and underlying laminated sand containing silt beds.

This deposit must have grown in a landward direction from a marine delta built into the sea by the large meltwater discharge that laid the outwash train down the St. Bride's valley. As the delta advanced westward, the surface of the outwash at St. Bride's rose to its present level of 55 feet above high tide at the modern shoreline. Though the outwash deepened as the delta grew, the coarse gravel exposed in the modern shore bluff has all been deposited subaerially. The laminated sand at the base of the section resembles freshwater sediments rather than marine delta bottom sets, for no marine fossils could be found. They may represent early, finer grained sediments, deposited in deep water ponded between the steep coast and the ice still lying offshore, especially as it is improbable that the postglacial sea level at St. Bride's ever stood high enough for still-water deposits of this type. Because of its internal structure, this deposit is classified as an outwash flat rather than a delta remnant. It is considered an extension of a valley train that occupied the stream valley at St. Bride's and merged seaward into a marine delta. Erosion has completely removed the proglacial delta portion of this fluvioglacial landform.

Valley-Train Outwash

Outwash that is confined to a valley floor as a fill and that is long in comparison to its width, is called a valley train. Those within the map-area lie in the larger, deeper valleys. As most Avalon streams flow in shallow open valleys, or spill from lake to lake through flat country in the interior, entering deep valleys only when approaching the coast, most valley trains are found near the sea. Apparently all were graded to tidewater when deposited, with the exception of two located well upstream on Peter's River and Northwest Brook. Both these streams flow in deep, well-developed valleys that extend unusually far inland.

All valley trains have been dissected and now remain only as various-sized remnants below terraces along the valley sides. Originally they may have been somewhat longer, but removal of valley fill upstream or downstream from the terraces prevents meaningful measurements that could give some estimate of their lengths at the time outwash deposition ceased. Today they average less than half a mile wide and are from 1½ to 3 miles long. Valley trains composed of coarse gravels had steep gradients, generally steeper than the alluvium of the modern stream. As a result, the surfaces of the remnants of any given valley train become lower downstream relative to the present water level. Alternatively, where average grain sizes of the outwash were smaller, terrace surfaces may have much the same grade as the alluvial flats and their elevation above the stream varies little.

The bulkiest valley train observed extends downstream from the head of Peter's River valley for at least 3 miles. On the north valley wall, 2½ miles upstream from the head of the large pond on Peter's River, is a mass of outwash more than a mile long. Trenching of the fill has left three terraces with elevations of 15, 40, and 50 feet above the river, the 15-foot elevation surface having much the greatest extent. A probable fourth terrace surface lies 55 to 60 feet above the stream and may represent the original surface of the fill. As there is still an unknown depth of gravel below the river, the fill at this part of the valley must have been more than 60 feet deep. A smaller outwash remnant, a mile above the pond on Peter's River, on the same side of the valley, preserves part of the original surface 30 feet above the river. This gives a valley-train gradient some 20 feet per mile greater than that of the present alluvial floor. Contours on the modern alluvial flats show an average gradient of 40 feet per mile, suggesting that the gradient on the old valley-train surface was about 60 feet per mile. As gravel derived from the Peter's River fill is coarser than gravel in other valley trains, the latter probably all have lower gradients.

Thick valley trains were also deposited in the Placentia Bay area by Northeast and Southeast Rivers. In the valley of Northeast River there is trenched fill to bedrock, and terraces remain on both sides. Southeast River also has cut down to bedrock, and the remnant outwash, all on the south side of the river valley, stands 50 feet above the water at its upstream end. This valley fill is the only one with deep kettles in addition to the well-defined stream channels found on some of the others.

Moderately thick fills were laid by Crossing Place River above Holyrood Pond, Shearstown Brook on Conception Bay, and Northwest Brook flowing into Trepassey Harbour. Trenching has left terraces 10 to 15 feet above the streams, but as the streams flow over modern alluvial flats below these terraces, the total depth of the original outwash deposits is not revealed by the stream cutting. They probably had total thicknesses of about 25 feet. Thinner deposits of outwash fill, perhaps 10 to 20 feet thick, formed in the valleys of Lance River on Placentia Peninsula, the streams around St. Bride's, and those at the head of St. Mary's Harbour. A few small outwash deposits laid down in stream valleys occupy only a small part of the valley floor and are located to one side of the stream. They are not much longer than they are wide, and are classed as outwash flats rather than valley trains.

The extent to which outwash fills valleys in front of an ice terminus depends on the gradient of the valley floor and the amount and grain size of the meltwater load. Retreat of the ice up a low-gradient valley would favour outwash deposition thickening upstream so as to maintain a steeper gradient there than on the underlying valley floor, as the stream aggrades its bed. This process would explain the thick fill in the valley of Peter's River. Slightly steeper valley floors, perhaps with finer outwash, have produced valley trains of more uniform thickness; e.g., those in the valleys of Lance River and Shearstown Brook. As in other forms of outwash deposition, formation of valley fill would not begin at the ice margin so long as gradients were steep enough to allow the streams to carry all their load, but rather at some downstream point where gradients became more gentle. Examination of valley train deposits throughout the Avalon shows that they were laid down under all of these conditions. The Peter's River deposit is probably the best example of outwash thickening upstream in a low-gradient valley; Shearstown Brook and Lance River have average grades on the original valley bottoms, nearly the same as the grades on the fill surfaces; the St. Bride's valley train was formed from outwash carried into the valley through a large, steep-gradient meltwater channel that extended back from the head of the outwash into the highland to the east. Deposition at St. Bride's continued until the ice lay well east of the head of the valley train.

Proglacial Deltas

Following glacial retreat from the coast, proglacial deltas were formed either where large meltwater channels reached the coast, or seaward from the many coastal locations now fringed by ice-contact deposits and outwash. Over the eastern two thirds of Avalon Peninsula the sea has risen in postglacial time relative to the land, the greatest rise occurring along the indented eastern coast, in whose inlets and bays deltas would originally have been most protected from marine erosion. Any delta deposits laid down along the east coast now lie offshore beneath the transgressive sea. Some postglacial emergence has occurred along the west coast of Placentia Bay, but south of Placentia Sound the exposed coast is steep and straight, and north of Placentia Sound little outwash was deposited. Any deltas built along the southern stretch of this coast would necessarily have projected beyond the present shoreline into the deep water of Placentia Bay and would have been exposed to wave erosion on three sides. Subsequent coastal emergence would have been insufficient to prevent their destruction by the sea. With one or two exceptions, locations of former deltas are marked, at best, only by sea-washed bluffs of outwash or ice-contact stratified drift that originally lay on the land-ward side of the stratified drift complexes of which they once formed part. The outwash bluffs at the mouth of Seal Cove River in Conception Bay and at St. Bride's in Placentia Bay are considered to be remnants of former outwash delta complexes.

At the sheltered head of Deer Harbour north of the Isthmus of Avalon, raised delta deposits form the only well preserved marine delta remnant observed. Though much of the delta has been destroyed by a river that emerges from the deep valley behind it, a considerable part of the original surface remains, particularly east of the river mouth where it stretches for one fifth of a mile and is bounded on its seaward side by what appears to be part of the old delta front. The top surface behind this front stands 17 feet above the modern delta which is just awash at extreme low tide and which is largely constructed of redeposited materials resulting from dissection of the old proglacial feature. The difference in elevation between the two deltas is taken to represent the amount of coastal emergence at this point.

Point Verde on the south side of Placentia Sound is the largest mass of stratified drift laid down in the sea in an exposed position. This prominent landmark, crowned by a lighthouse at its northern tip, has been partly eroded away. Originally an island separated from the shore by a shallow lagoon, it now is joined to the mainland by massive bars at its north and southwest points, and in the central area, by a short stretch of artificial fill that carries the road to the lighthouse. The mass of drift is in the form of a blunt crescent, almost a mile long from tip to tip, that rises gradually southwestward from the lagoon and ends in west and south-facing sand and gravel bluffs that rise 40 to 50 feet. The highest parts of the original delta may have lain immediately behind the present cliff line. There are several kames at the broad southern end, and one or two kettles at the eastern part. A meltwater channel runs from the centre of the formation to the high west bluff. The narrow northward part of the mass is smoother, with high flat areas behind the bluffs.

The Point Verde deposits appear to represent a large mass of ice-contact stratified drift that was transported by meltwater directly into the sea from ice that lay just offshore, possibly the foot of a glacier flowing out of Placentia Sound. That they originally were much greater in extent is indicated by the large expanse of shallow sea in front of them, greater in area than any found elsewhere along the coast. A broad bank covered by less than 5 fathoms stretches southward for 1¼ miles from their southwestern tip, and similar shallows extend half a mile west of the lighthouse (Canadian Hydrographic Service Chart 4622). The shallows probably indicate the minimum extent of the original proglacial delta. The external form and structure of the remaining portion show that the sediments were transported from an ice-front located in the direction of the shallow-water areas to the northeast. Deltaic deposits may still be present in lower parts of the section at the north end near the lighthouse.

Materials exposed in the Point Verde bluffs appear to be ice-contact deposits, particularly those toward the south. Rapid variations in grain sizes, and in the dips and strikes of beds, are typical. At one point, a steeply dipping bed of clean cobbles more than 6 inches in diameter is in contact with fine sand. Elsewhere, boulders 4 to 6 feet across lie among pebbles and sand. Toward the north end of the long west bluff, the gravel is less coarse, the sand content increases, and the bedding is less irregular.

Eyewitness accounts indicate how little resistance to erosion these isolated masses of unconsolidated gravel and sand offer when exposed to waves from the open sea. The modern rate of retreat of the coastal bluff would be more than sufficient, if continued over postglacial time, to remove such deposits. The lighthouse keeper, when visited in the summer of 1959, estimated retreat of the bluff at the lighthouse as 50 feet in 30 years, a rate of 1½ to 2 feet per year. Also there is a current report of a rock, now lying nearly half a mile offshore, that was embedded in the coastal bluff little more than a century ago. This, however, gives a rate of retreat too high to credit. If the shallow-water banks are taken to outline the maximum area of stratified deposits that once stood above the sea, an average retreat rate of less than a foot per year would be enough to account for the present position of the shore. Point Verde appears to be a rapidly vanishing remnant of a once extensive deposit of stratified drift. The rate of retreat of the shore bluff may be increasing as the thicker parts are eroded away.

Four miles farther south at Little Barasway, coastal exposures in an outwash flat, whose upper surface is now 40 feet above the sea, show many similarities to the deposits at Point Verde. North of the stream that flows into the sea at this point, 30 feet of coarse outwash are exposed above the beach, and erratics and some bouldery kames are located a short distance inshore. For several hundred feet to the south of the stream, fine to medium sand is exposed in beds 14 to 20 feet thick south of the river. These are overlain, conformably in part, by several feet of gravel. The modern beach conceals the base of all sections to a height of about 12 feet above the high-tide line. The sands strike parallel to the beach, with low dips to seaward and with much crossbedding. The generally horizontal contact between sand and gravel becomes uneven in places where stream channels, now filled with crossbedded gravel, were eroded 3 to 6 feet into the sand. Strikes and dips elsewhere in the gravel resemble those in the sand. The section terminates in the south in 12 feet of torrentially bedded gravel underlain and overlain by 6 feet of horizontally bedded sand and gravel.

South of Little Barachois River, the deposits behind the bluff are probably delta topsets that grew rapidly thicker as the proglacial delta was built seaward by outwash from the adjacent ice. The abundance of the meltwater is indicated by channel scouring in the sand and by the torrentially bedded gravel to the south. The presence of till over outwash at the back of the flat shows that the ice readvanced at least once during the time a delta was being built and indicates deposition over a fairly long period. Postglacial coastal emergence has raised the beds an unknown amount, probably about 5 feet.

In St. Mary's Bay there has been little or no change in sea level. Erosion appears to have largely destroyed deltas that may have existed there or in sheltered locations such as Crossing Place River at the head of Holyrood Pond. The trenching of outwash upstream and the consequent formation of modern deltas have covered any older deposits.

Only two proglacial deltas have been identified inland in freshwater bodies. Their apparent scarcity may stem from the fact that most of the lakes were small and shallow and would have quickly filled with outwash. Continued deposition would mask the deltaic nature of the initial deposits. The former basins of these lakes are now buried beneath outwash flats. Moreover, streams continued to flow through the larger lakes that were not filled by proglacial deposits, and after outwash deposition had ceased, modern delta deposits became indistinguishable from any earlier proglacial ones already laid down. The best example of this is the delta deposit located where Peter's River flows into a large pond 8 miles northeast of Holyrood Bay.

Two large fan-shaped landforms, obviously proglacial deltas, lie in lakes in the northwest corner of the map-area. Sediments for the larger of these were transported northward into the central part of a lake, 2 miles long and 3 miles northwest of the head of Deer Harbour. The delta extends completely across the former lake, dividing it into the present two smaller ones. The other proglacial delta, much smaller, was built out into the pond 2 miles north of Great Southern Harbour.

Prominent delta forest bedding in kame terraces, exposed in gravel pits at Clarke's Beach on the west shore of Conception Bay, were formed by infilling of ice-block lakes.

Ice-marginal Lacustrine Deposits

For 4 miles along the road leading south from Whitbourne, a layer of sandy silt, 12 to 18 inches thick, covers many of the moraines. It is not known how far east and west of the road this layer extends, but it must include an area of several square miles. Where it is thickest, the sand is fairly well sorted, with few surface pebbles or larger-sized sediments. Laminae are absent even in fresh cuts, but because of the thinness of this sandy mantle, any original bedding would probably have been destroyed by frost action or by soil disturbance caused by roots of the indigenous forest cover. Any stones now present were probably introduced into the layer by these processes, for when large trees fall stones entwined in their deeper roots are lifted above the ground and later deposited upon the surface as the tree decays. Most of the moraines thus mantled with silt and sand are found at higher elevations than the lowest part of the St. Mary's Bay–Trinity Bay divide southwest of Whitbourne, across which meltwater from the region escaped into Trinity Bay.

Ablation till on top of ridges west and northwest of Whitbourne marks where a remnant of stagnant ice persisted in the vicinity of the low part of the divide after the ice front had retreated south. This ice remnant would have prevented free northward escape of meltwater, and would have sufficiently raised the level of the proglacial lake lying between divide and ice cap to cause flooding of the morainic ridges. Submergence of these ridges lasted long enough for the thin deposit of lacustrine silty sand to form over them. Subsequent disintegration of the ice lowered the lake level to less than 200 feet asl, well below most of the ridge crests and nearly to the level of lakes that now drain south to St. Mary's Bay. Lacustrine deposits laid down in proglacial lakes have not been identified at any other place in the St. Mary's Bay area, where as almost everywhere else throughout the map-area, the ice retreated upslope and conditions were unfavourable for the formation of ice-marginal lakes.

Meltwater Erosion

Meltwater erosion within the map-area is best demonstrated by the presence of large, flat-bottomed channels in unconsolidated deposits and by steeper, more irregular, V-shaped channels cut in bedrock. Today most of the channels are dry and are either situated in places where their formation by any combination of modern drainage would be difficult or impossible, or are occupied by streams much too small for them. The smaller channels tend to be V-shaped. A few wide, shallow, low-gradient channels have flat, rock floors from which little material other than the overlying thin drift has been eroded. Where fair-sized modern streams flow in old meltwater channels, it may be difficult to detect their original meltwater origin because of postglacial erosion. Examination of surrounding country, particularly if it contains fluvioglacial erosional features, may permit such an inference to be made with accuracy.

Other phenomenon caused in whole or part by meltwater erosion are: (a) tracts of bedrock on upper slopes or on rocky ridges with broad summit areas that have been swept clear of glacial debris even though adjacent slopes are generally littered with the loose, thin ground moraine that partly covers most higher areas; and (b) some wide shallow draws paved with a jumble of boulders ranging in size from a foot to several feet in diameter.

Meltwater Channels

Channels eroded by former meltwater streams are found in many parts of the map-area but are numerous in only two locations, where they form integrated drainage patterns. Both locations are in the extreme south: one, on Trepassey Peninsula, particularly between Portugal Cove and Cape Race; the other, in the southern half of Placentia Peninsula where especially fine examples are found on slopes draining east and south to St. Mary's Bay. Old meltwater channels are either few or entirely absent on the lake-strewn, undulating plateaus of central Avalon. This is probably due to low gradients that inhibited erosion, and to the masking effect of the many modern lakes and streams that follow the same courses. Furthermore, plateaus beyond the area covered by the thickest parts of the Avalon ice cap, had a more restricted supply of meltwater.

Northern Meltwater Channels

In the northern part of the map-area only three or four small areas of well-formed meltwater channels have been found. The largest channel in the most northerly of these is occupied by Half Moon Brook, a small stream that enters the sea 2 miles north of Flat Rock near the tip of St. John's Peninsula. All these channels are eroded in till and lead across and away from small areas of end moraines between Pouch Cove and Flat Rock. Another six or eight prominent meltwater channels are found about a mile south of Lance Cove on Conception Bay, approximately 24 miles to the southwest. Five of these channels originate on a high-level, outwash flat east of the bedrock ridge that at this point forms the boundary of the low coastal outwash plain (*see* map *in pocket*). Three of these channels run northwest to the ice-contact deposits at Seal Cove, and have cut gorges in the crest and steep seaward flank of the ridge. From the coastal highway, the upper sections of the gorges appear as deep notches in the ridge crest. In their descent to the coastal outwash plain, these channels drop more than 100 feet in less than one third of a mile. Three other channels run northeast to Lawrence Pond. They are cut into till and have gradients of less than 200 feet to the mile. Immediately east of Lawrence Pond, two more short, dry, runoff channels, also excavated in till, slope down the west valley wall of the Lower Gullies River. Both drop more than 200 feet in little more than half a mile.

Elsewhere, meltwater channels are fragmentary, ill-formed features, difficult to separate from other minor, postglacial, erosional forms. No channels of mappable size were found on Carbonear Peninsula, the Isthmus of Avalon, or that section of the map-area north of the isthmus. Shallow channels on outwash, such as those found on kame terraces at Clarke's Beach and over much of the outwash plain between Topsail Head and Seal Cove, are considered to be fossil channels of aggrading rather than eroding streams.

Central Avalon Meltwater Channels

Meltwater channels are more numerous in central Avalon, most of them to be found in the vicinity of Holyrood or near the east coast. One of the most unusual is a wide, shallow channel, nearly half a mile across at one point, that can be traced for 3 miles from Nine Island Pond South east of north toward Avondale. Evidently an overflow channel, it drained the lakes in the eastern part of the great end-moraine belt between the St. Mary's Bay–Conception Bay divide and the ice retreating toward St. Mary's Bay, and carried a large volume of water across the divide into Conception Bay. Throughout its length, the bedrock floor of the channel floor is bare, and has an unusually low gradient of less than 50 feet to the mile. Although they removed the thin ground-moraine cover, the sediment-free waters from the lakes to the south had little power to erode the rocky channel floor. The low till banks can be traced only to a point a mile south of Avondale railway station. From there to Conception Bay, the wide valley floor has little or no till cover — in contrast to the mantle of ground moraine on the valley slopes. The modern Salmon River, an underfit stream, meanders from pool to pool over the rocky valley floor.

Two miles to the west of this channel, between Middle Gull Pond and Briens Pond, is a second, smaller overflow channel across the St. Mary's Bay–Conception Bay divide. It, too, has a low gradient, but carries no modern drainage. Meltwater flowed through this smaller channel to join the Avondale channel at about its midpoint. The few other channels in this vicinity have steep gradients, but carry no drainage other than small amounts of local runoff.

Three channels cross the area of hummocky moraine 2 miles southeast of Holyrood. The two largest, both more than a mile long, descend the high ridge east of the hummocky moraine. The more northerly of these, with its outlet at Butter Pot Pond, originates east of the ridge crest, through which it has cut a col gully. The channel bottoms have average gradients of 200 and 330 feet per mile.

Two miles north of Holyrood, a large, flat-bottomed channel, floored with rock in places, runs from the highway west of Hawco Pond down to the shore of Conception Bay. It drops 200 feet in four fifths of a mile and has a maximum depth of at least 35 feet. Just south of Colliers Station, about 8 miles northwest of Holyrood, another channel, three quarters of a mile long, descends from the highest point of the ridge above Nine Island Pond to the pond shore, a drop of more than 200 feet in two fifths of a mile.

Most of the other twenty or so prominent channels in the central area either reach the Atlantic coast between La Manche River and Chance Cove, or lie inland from this same stretch of shore. Some are longer than those discussed, but all have characteristics similar to the types already encountered. Two are overflow channels, one of which was the outlet of a large pond, more than a mile northwest of Cappahayden, during the short time that direct meltwater drainage eastward from the pond was blocked by stagnant ice. A shallow, low-gradient channel incised in till, it runs south and east to enter the sea at Cappahayden. The second overflow channel crosses a 50-foot col between the northeast tip of Franks Pond and the most northerly of the Saunders Ponds. It is a wide, shallow channel and like the large Avondale overflow channel, it has a bare bedrock floor. Again, erosion of the rock has been negligible.

Southeast of Mount Carmel Pond an east–west channel more than 1½ miles long is the largest central-Avalon representative of the group of channels that drained directly from high isolated summit areas to lower ground. Such channels drained pondings that formed where high areas had melted free while the surrounding lower ground was still largely occupied by ice. Downstream sections of these streams may have flowed partly or wholly in subglacial tunnels, an inference strengthened by the presence of eskers near some of their outlets. In its central part, the large channel southeast of Mount Carmel Pond forms a deep rock gorge whose floor drops nearly 300 feet in less than three quarters of a mile. A similar smaller channel that heads a few hundred feet from the upper section of this large east–west channel, runs north off the same hill.

Four miles upstream from the mouth of La Manche River two channels descend the south valley wall. The larger, a wide channel 2 miles long, divides near its upper end and both branches cross a divide into a small drainage basin to the west. An underfit stream now drains in through its southern branch and flows down the main channel to La Manche River.

One of the more extensive meltwater drainage systems runs east of and parallel to Chance Cove Brook. It is composed alternately of esker segments and of glacial drainage channels that occur singly or in sets parallel to each other, sometimes with as many as four channels to a set. This esker–channel complex never operated as a single integrated drainage system but was formed at two or three different periods as the ice retreated from the coast. Each parallel set of channels was formed as a series of successive marginal streams beside shrinking ice that lay in the depression now occupied by Chance Cove Brook. The channels nearest the present stream were cut last. Individual channels are more than a mile long and 20 feet deep, and have flat bottoms as much as 50 feet wide.

Three miles north of Cape Broyle, an unusual channel more than a mile long is crossed from west to east by the coastal highway. It leads from a large area of ice-contact deposits to a rocky valley running down to the sea. Just east of the highway a small irregular esker occupies the channel bottom, its position indicating deposition subsequent to channel formation. This is one of two instances of this relationship, though the opposite combination, channels forming subsequently to eskers and either cutting through or running alongside the esker, is common. Deposition of eskers in the two channels suggests that the channels were cut by streams that flowed in subglacial tunnels and changed from eroding their beds to aggrading them.

The remaining channels in central Avalon are small and of the V-shaped type. A set of this type furrows a hillside just north of Aquaforte Harbour.

Trepassey Peninsula Meltwater Channels

As indicated earlier, the largest concentration of meltwater channels in the map-area is to be found in southern Trepassey Peninsula. East of Trepassey Bay, long channels are incised in a till plain whose surface falls gently from north to south, with grades of 100 feet or less to the mile. The largest continuous channel is 4 miles long, more than 5 if a steep inland section separated by a small lake from the longer section is included. The whole 5-mile system appears to have operated as a single unit at the time of formation. Some nearby channel systems are 2 to 4 miles long. Most of them steepen and fork at least once in their upstream sections. They originate near the crest of a broad ridge, descending from it as steep rock gorges before developing the wide, flatter channels observed on the till plain. Where they are crossed by the Portugal Cove–Cape Race road, the most westerly channels form an anastomosing pattern. The largest channels in this braided network are mainly steepsided and flat bottomed. Depths may exceed 25 feet although, in many sections, rock bars have checked deepening. Their appearance suggests that for a short time at least they carried very large volumes of glacial drainage.

With one exception the other large channel systems in Trepassey Bay area, nearly a dozen in all, lie west of the bay. The exception is an isolated system that funnels into the valley of Northwest Brook some 3 miles upstream from the mouth. All are shorter than the Trepassey channels just described, less than 2 miles long, and in the main have steeper gradients. On many the average rate of fall is more than 200 feet to the mile. Most of them originate near the eastern edge of the rolling plateau that stretches west from Trepassey Bay and they drop rapidly down its steep, seaward slope to the vicinity of the bay shore.

A group of ten small, V-shaped channels, some as much as 1½ miles long, cross the slopes that run down to Back Brook and Portugal Cove Brook from their common divide. All but two of these channels lead into the Back Brook drainage. They were apparently cut by meltwater streams originating on the high land between these two streams.

Placentia Peninsula Meltwater Channels

The remainder of the mapped channels is found in the southern part of Placentia Peninsula. They vary in length from a mile to more than 4 miles and most of them at some time carried large volumes of meltwater. They probably formed during the final stage of deglaciation of Avalon Peninsula when ice wastage was rapid. These channels may be divided into two groups according to their position west or east of Branch River.

The first group west of the river consists of several channels that carried water westward toward Placentia Bay across the main drainage divide and away from the ice centre. Largely cut in rock, much of their length consists of gorges 30 feet or more deep. The downstream, westerly sections of some of them, eroded where gentler slopes have a cover of ground moraine, are incised in till.

A mile north of Sugarloaf Peak and 5 miles east of Patrick's Cove, the large northern branch of one channel originates from a saddle on the main Placentia Bay–Branch River divide. A large esker, running west up the west valley wall of the Branch River almost to where the meltwater channel begins, lies in direct line with the ravine cut by escaping meltwater. The glacial drainage channel was obviously cut by the same stream that laid the esker deposits, and the two geomorphic forms, one erosional, the other depositional, appear to have been formed contemporaneously. The stream deposited sand and gravel as it flowed under hydrostatic pressure in a subglacial tunnel up the side of the present Branch valley. As it crossed the saddle, it eroded a rock gorge in its rapid downslope flow toward Placentia Bay. The gorge, too, may have been cut beneath ice but more probably it formed in the open, for ice retreat would be well advanced by the time eskers were forming under stagnant ice in the Branch valley.

The second group of channels in southern Placentia Peninsula lies close to St. Mary's Bay. No part of any channel is more than 3½ miles from the sea. The longest and largest runs parallel to the bay shore for more than 4 miles, from just south of Little Barachois River to Red Head River, and must have carried a large volume of water during at least part of its existence. Toward its southern end, about 2½ miles directly north of Jigging Cove, a short esker on the channel bottom was deposited, apparently when drainage shifted east to a parallel branch of the channel. Because of the presence of the esker, it would seem that at least this particular section of the channel floor lay in a subglacial tunnel. At several places north and south of the hamlet of Branch, ice standing in St. Mary's Bay forced meltwaters to cross east–west divides separating Branch and adjacent rivers, sometimes at altitudes of nearly 500 feet. The escaping water cut short gorges into the hard rocks of the ridge crests, one north of Branch being more than 50 feet deep. In two channels south of the Branch valley, dry cataracts mark the location of large falls that interrupted the courses of the meltwater streams.

Origin of Meltwater Channels

Within the map-area, the longer meltwater channels are commonly of composite origin. Generally, their upper reaches were formed subglacially, and the meltwaters then continued their journey to the sea as ordinary proglacial streams. Some channels, however, were apparently eroded by streams that entered subglacial tunnels only after having flowed outside the ice for considerable distances. West of St. Mary's Bay there is evidence that at least one meltwater stream may have simultaneously occupied channels eroded beyond, beside, underneath, and across the surface of the wasting ice. This complexity is suggested by an esker in a central part of the channel that leads downstream to a low stretch of uneroded, unconsolidated deposits beyond which, on higher ground, the channel again continues and finally develops a meandering stream bed typical of ordinary subaerial drainage.

Meltwater continued to flow in some of the channels after the disappearance of overlying ice had changed their positions from subglacial to proglacial. It is not easy to determine the origin of channel segments that have had a complex history, though composite channels may usually be considered as intermediate between subglacial and proglacial. Determination of in which of these two categories any given channel belongs, may depend partly on the morphology of the channel and partly on its relationship to adjacent topographic forms. Subglacial chutes that lead directly down steep slopes to the lower ground where ice lay longest, and that continue on from there, are those most clearly subglacial. Meandering and anastomosing channels with gentle gradients are those most clearly subaerial. Though subaerial channels may also have steep gradients, their location in front of divides to which the ice had retreated, or leading away from lakes as outlet channels, may serve to distinguish them from channels formed subglacially.

Of the drainage channels formed in various positions relative to the ice, those of undoubted proglacial origin comprise only a small percentage of the total, although many regarded as of uncertain origin must also belong in that category. Some proglacial channels were formed beside or in front of morainal tracts by drainage from the ice tongues that laid the moraines; e.g., those at Pouch Cove. Others served as overflow channels of ice-dammed, proglacial lakes, such as those near Avondale and Cappahayden, and east of Franks Pond. A few were eroded across elevated areas that became ice free before surrounding lower areas emerged. Except where they continue downstream as subglacial chutes, such channels usually stop at the edge of the high ground. Where smooth, till-veneered slopes led from the ice edge to lower ground, any local glacial drainage easily eroded proglacial channels. Much of the drainage network preserved on the seaward slopes at Cape Race appears to consist of channels formed proglacially, although it also includes many composite or subglacial ones.

Some col gullies were formed proglacially. The large channel that carried water over the divide south of the Branch valley to Red Cove, is believed to have originated subaerially and to have been eroded following the abandonment of the more westerly subglacial col gullies that led to Gull Cove. Its clearcut appearance and the absence of large erratics, usual in the other proglacial channels, support the premise that it is of subaerial origin. The most probable source of large channel erratics would be by deposition from above as the overlying ice melted. Some erratics may also have originated through erosion of the till containing them.

The large quantities of rock that must have eroded during the formation of many of the col gullies, particularly in areas where the rock was relatively hard and unfractured, suggest that these gullies carried water for comparatively long periods. This would seem particularly true for the gullies in the vicinity of Branch most of which probably belong to the composite or subglacial class of channels, eroded originally while ice still lay on or against the higher ridges on either side. Other gullies of this group may have carried meltwaters only after ice withdrawal.

In addition to positions athwart ice-submerged divides, subglacial drainage channels also formed where superglacial streams descended to the glacial floor beneath the ice, or where surface streams from ice-free areas descended into ice-filled valleys by way of steep subglacial chutes. These subglacial chutes drop steeply, sometimes precipitously, and generally run straight down the hill or valley slope. Drops of more than 200 feet in one third of a mile were measured on some chute beds, usually where large volumes of water from restricted upland areas entered bordering valleys still filled with wasting ice.

Good examples of chutes are to be seen on the ridge east of Seal Cove (east side of Conception Bay). These were cut by the same meltwater-transported material that was deposited downstream on low-lying ground of the coastal plain as eskers. Other examples are found on the northern slopes of Branch valley just west of Branch. Other chutes seam the plateau edge west of Trepassey Bay, and still others form steep upper-channel sections in the complex Cape Race drainage network. In some places, subglacial col gullies have been cut across high ridges, with chutes leading away from many of them. Deep, subglacially formed, col gullies indicate active use during many melt seasons. Some of these would carry meltwater, first as subglacial, and later as proglacial channels, and would be abandoned finally when continued deglaciation had opened lower meltwater escape routes closer to the ice.

Marginal streams that more or less followed slope contours sometimes assumed submarginal positions over parts of their courses. Although still flowing approximately parallel to the ice edge, they excavated subglacial rather than proglacial channels. Large erratics let down by the ice are more common in the subglacial parts of these channels.

Gradients of submarginal channels are less steep than those of most other subglacial channels. Because in their morphology, submarginal channels closely resemble ice-marginal and proglacial channels, they are difficult to distinguish from those features, particularly where they may all have formed parts of a continuously operating system. A submarginally formed segment of the large complex channel north of Jigging Cove is identified by a small esker on the channel floor. Following subglacial formation of the channel, plastic flow of ice partly closed it, probably after some slackening of the meltwater flow, and the esker was deposited in the more restricted ice tunnel contained within the confines of the larger channel. The esker, which was preserved when subsequent drainage shifted to a parallel channel to the east, is one of only two instances where esker deposits were found preserved within channels. Others may possibly have been destroyed when meltwaters again flowed in the subglacial channels in which they had been laid down.

No sequences of evenly spaced marginal channels or lateral terraces, such as those in Sweden used by Mannerfelt (1945) to estimate the annual thinning of ice, were found within the map-area. Whether the topography inhibited multiple-channel formation on slopes, or whether the condition of the ice and configuration of its margin were unfavourable, channels once established appear to have carried meltwater for more than one melt season, and possibly for many. The tendency seems to have been for the formation of one large, semipermanent, meltwater channel rather than several smaller, temporary, closely spaced ones. In the few places where several channels do lie close together, their attitude and vertical separations appear haphazard and bear no known relationship to rates of ice wastage.

Meltwater Flushing of Slopes

As already mentioned, zones of bare rock on the upper parts of long, major slopes leading from some highland areas, stand out conspicuously in contrast to the thin, discontinuous ground moraine that covers much of the adjacent high land and neighbouring slopes. The change from debris-covered to debris-free rock is abrupt, though both areas lie on topographically identical slopes. No deposition mechanism seems capable of producing this sharp surface change, particularly as some of the bare areas lie topographically lower than adjacent areas covered with morainic material. Probably the morainic cover was originally distributed fairly evenly and stretches of it were later removed by erosion after the slopes became ice free. Even though there may be no other evidence of meltwater activity in the vicinity of most of the washed-bedrock slopes, the flushing of loose material by meltwater seems to be the process best able to explain this irregular erosion pattern. Removal of the till mantle must have been effected by short-lived, meltwater sheet flows of considerable volume. In most places no distinctive water-deposited beds are evident below bare areas. The amount of eroded materials was not large and appears to have been spread over and blended into the generally thicker ground-moraine cover of the lower slopes.

Less common than areas of swept bedrock are the shallow draws, floored with boulders of various sizes, that descend some of the long, moderately steep slopes. Except for intermittent, local slope runoff, they carry no modern drainage. Two large draws of this type were observed on east-facing slopes of the upland area west of a lake about 5⅓ miles northwest of Chance Cove Brook. Boulders in the draws are identical to, but several times more numerous, than those on the adjacent slopes. As in the bare-rock zones, these boulder concentrations appear to have formed when shallow meltwater torrents poured through them, perhaps only once, and even then only for a brief time. Although some of the boulders are a type of lag deposit left after removal of the finer materials by the fast-moving water, others, particularly the smaller ones, a foot to 2 feet in diameter, have been transported short distances. Many of the smaller ones are slightly more rounded than the erratics of similar size on nearby ground moraine, but the larger boulders show little or no evidence of rounding. Material eroded from the draws has not been deposited below them in quantities sufficient to be noticeable on the rough surface of the ground moraine, but it may have been largely transported into the lakes that generally lie below the lower ends of the boulder concentrations. The lack of water-deposited drift or of erosion channels below the draws strongly supports the theory of a brief flow, never or rarely repeated.

It is difficult to account for the sources of meltwater that produced these limited but intense erosional phenomena. The most probable explanation is that they resulted from a sudden release of ponded meltwater. Quick drainage either of dammed ground depressions or of flooded depressions on the ice surface could unleash rushes of water across adjacent ice-free slopes or could fill the nearest downslope draw with a shallow torrent. The rush of water would be quickly dissipated downslope as the source rapidly emptied. It is perhaps significant that the draw northwest of Chance Cove Brook, containing the larger of the two boulder concentrations, leads directly away from two small lakes on the rolling upland of the slope. Had the water level in these lakes been raised even a few feet (possibly by an ice dam in the normal outlet channel) and if at the same time the outlets leading to the draw had been free, this could have resulted in a one-time flooding that would account for the boulder deposits now present in the draw. Many of the bare slopes lie below broad depressions, a topographic location susceptible to meltwater floods of short duration during deglaciation.

Recent Deposits and Related Features

Eolian Deposits

Eolian deposits are rare on Avalon Peninsula, and none is of mappable size. A reason for this is the absence of large expanses of sand of suitably fine grain size. The deposits of finer sand, laid down as alluvium by some streams, form long, narrow strips of limited area. Furthermore, the high, year-round precipitation and abundant vegetation strongly inhibit the wind transport of sand.

At the southern end of Placentia Peninsula, several small, stabilized dunes, a few feet high, lie on an outwash flat behind the beach at the head of Lance Cove. As they are not moving now there is no way of estimating their age; they may only date from some exceptionally dry, windy periods in the last century or two.

Beyond a little windblown sand on beaches and bars, the only present-day transport of sand by wind takes place along the faces of modern bluffs that have been cut in delta or outwash deposits. Extremely strong air currents from onshore winds flow up the faces of the larger bluffs, drying them and carrying aloft sand and even small pebbles which they deposit farther inland behind the bluff face. The greatest amount is deposited immediately back of the bluff face, and this cover rapidly thins to nothing as the moving sand is trapped by the grasses and bushes that almost invariably grow right up to the edge of the bluff. As exposed vertical bluffs of sand and gravel are susceptible to rapid erosion, these are constantly in retreat, removing the accumulated eolian deposits before they have attained any great thickness.

On the west coast of Placentia Bay, the bluff running south from the Point Verde lighthouse is the only place where significant amounts of windblown sand have accumulated as a result of wind-stripping of the bluff face. The Point Verde bluff, cut

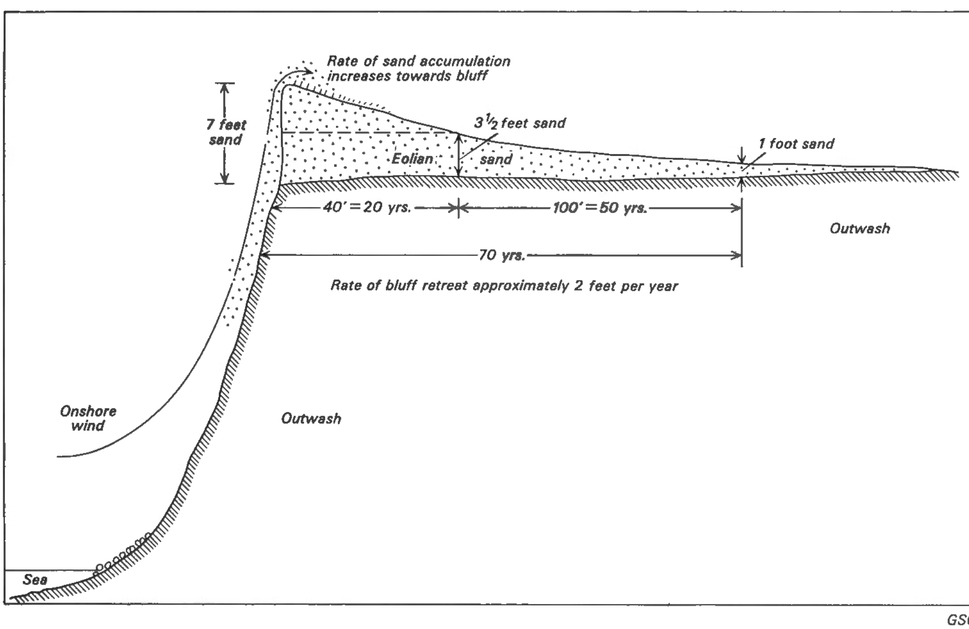

FIGURE 30. Eolian sand on Point Verde outwash bluff.

in a rapidly eroding mass of outwash, is perhaps the largest in the Avalon composed solely of sand and gravel. It rises to 50 feet or more just south of Point Verde lighthouse. Elsewhere the outwash is largely gravel but this particular section also contains considerable amounts of sand. Accumulations of windblown sand on the flat surface just behind this northern section reach depths of 5 to 7 feet at the bluff edge but thin rapidly to a foot or less some 150 feet inland. A 1-gallon paint tin and a wooden box lid buried 3½ feet below the surface were found projecting from the bluff face about midpoint in the eolian sand section. Their state of preservation suggested a rate of sand sedimentation at that point of 3½ feet in about 20 years. As the eroding bluff face approached ever closer, the outer seaward part of the sand section would be built up more rapidly than the more inland parts; thus a period of approximately 50 years would seem a reasonable period for deposition of the bed of eolian sand separating the artifacts and the outwash (Fig. 30). This suggests it took approximately 70 years to deposit the 7-foot deep section at the bluff edge.

An independent check on the rate of sedimentation is given by the lighthouse keeper who reported an increased depth of 6 to 12 inches of sand in 10 years, sufficient to cover the bottom strand of a wire fence built that long ago close to the bluff. He also estimated the retreat of the bluff at the lighthouse as 50 feet in 30 years: a rate of 1½ to 2 feet per year, which supports the ages suggested above, and explains the copious amounts of sand eroded off the bluff face by wind. As the fine fraction is blown upward and deposited, the stones and boulders weathered out of the bluff face roll down to the foot of the slope and add to the mass of coarse material forming the beach.

Alluvium

Almost everywhere on the Avalon, except in the most southerly parts, alluvial deposits are small or absent, principally because of the unintegrated drainage pattern. Most of the streams are short and rapid, with clear water flowing in shallow valleys over stony beds. Such small quantities of sediment as may be carried are trapped by the numerous lakes that interrupt their courses. Where larger alluvial flats have formed, the alluvium is commonly derived from outwash previously laid down as valley train. Alluvial materials underlying a few flats have been derived by erosion of the till covering the surrounding terrain.

Examples of alluvial flats a mile to 2 or more miles long, formed by the erosion of subsequent streams cutting through valley-train outwash formerly aggraded by meltwater streams, are found on the lower courses of Branch and Lance Rivers in the St. Mary's Bay area, on Crossing Place River and Peter's River (where they enter Holyrood Pond and Holyrood Bay respectively), and on Northwest Brook, beginning about 3 miles above Trepassey Harbour. Perhaps the largest of these flats is the one that closes the upper end of the pond on Peter's River (Fig. 31). Its materials have been derived from what was once the most extensive of all the valley trains. Uneroded, flat-topped remnants of this fill remain as terraces on the valley sides and upstream from the modern alluvium, where they rise sharply as much as 40 feet above its surface. The only two similar deposits elsewhere in the Avalon are both much smaller. They lie on the west side of Conception Bay, west of Clarke's Beach, where there are also thick valley-train deposits.

Of the alluvium derived from erosion of sediments other than valley trains, the more extensive deposits are nevertheless similarly situated, having been laid down in the wide, deep valleys along the lower parts of the larger streams. Probably preglacial,

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FIGURE 31. Alluvial flats at Peter's River underlain by redeposited valley-train gravels.

these valleys are mature, with spurless sides and gentle curved courses. They have no lakes nearer than their headwaters on the uplands which resemble the rest of the Avalon drainage. Alluvium from erosion of the surrounding till-mantled slopes has accumulated in the wide, level valley bottoms, the largest alluvial flats being those on the lowest part of the Salmonier River valley at the head of St. Mary's Bay. Other fairly extensive flats are found on the Branch and Biscay Bay Rivers, and two or three wide flats, half a mile or so long, are found where small streams flowing in short, deep valleys meet the sea, e.g., Patrick's Cove and Ship Cove on the west coast of Placentia Peninsula.

Although they cover a total area of only a few square miles, flats underlain by alluvium have a greater importance than their limited extent would imply. Most of the terrain of Avalon Peninsula is stony and rough, and the level, more fertile surfaces of most easily accessible alluvium flats have long been utilized for building or agriculture.

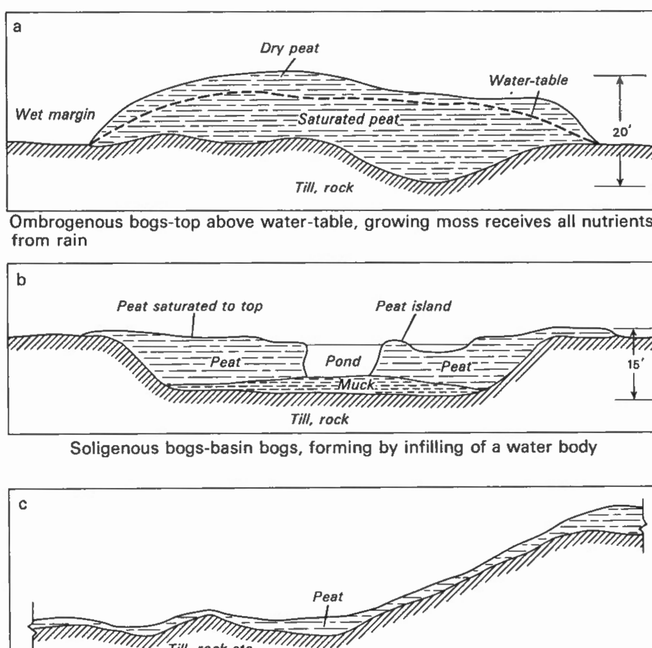
Organic Deposits

The organic or peaty soils that develop in bogs and swamps are found almost everywhere throughout the Avalon and present serious problems to builders and roadmakers (*see* MacFarlane, 1963). Because of excessive moisture and poor drainage, bogs and swamps are abundant throughout the map-area, and even some areas of otherwise agriculturally useful soils have become waterlogged and unusable. Fens, with muskeg a foot to 3 feet deep, blanket many square miles of both level and sloping terrain.

In discussing the need for a meaningful classification of muskeg, Radforth (1952, p. 1200) pointed out the bewildering range of definitions that has become attached to this term — derived originally from the Chippewan Indian word *maskeg* meaning 'grassy bog.' Though widely used, it is a word to which he noted, many researchers "are content to ascribe their own particular set of values, no matter how this might be at variance with the views of others." As used in the present study the term 'muskeg' covers all gradations of organic soil types and includes a great variety of peat and muck terrains ranging from the deposits found in small peat bogs of thick sphagnum moss to those in continuous expanses of sedge marsh and fens.

These organic deposits vary in thickness. In some areas they cover slopes and small valleys as well as lowlands and level stretches of plateau (*see* both Healy and [Radforth] *in* MacFarlane, 1963). Within the map-area, muskeg thickness was probed in four small bogs. In two, it was more than 15 feet deep; in another — a sphagnum bog three quarters of a mile in diameter, located a few miles southwest of St. John's — it was 17 feet deep; and in a slightly larger bog just north of Whitbourne, it was 16 feet deep. Further investigation on the large bogs and swamps of southern Avalon will probably discover peat thicknesses of 20 feet or more. Indeed, Healy (*see* MacFarlane, 1963, p. 33) claims a known depth of 28 feet for a bog near Whitbourne.

Although some muskeg is found in the northwest corner of the map-area, the higher precipitation, high humidities, and greater percentage of fog and overcast in southern Avalon favour its extensive development there, especially in poorly drained, flat or lowland areas. It is best developed around Colinet at the head of St. Mary's Bay, on more than half of south central Placentia Peninsula, and over much of Trepassey Peninsula. It occurs less commonly on Carbonear Peninsula, the Isthmus of Avalon, and St. John's Peninsula north of a line from Holyrood to St. John's. In the high, hilly districts of both north and south, the better developed patterns of drainage restrict swamp development and, therefore, the occurrence of muskeg.



a. Ombrogenous bogs-top above water-table, growing moss receives all nutrients from rain

b. Soligenous bogs-basin bogs, forming by infilling of a water body

c. Paludification swamps-extension of waterlogged conditions across flats and up slopes with rapid growth of sedge, fen plants, and moss

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FIGURE 32
Main muskeg (bog and fen) types.

Distribution of Bog Types

Ombrogenous Bogs (as defined by Sjörs, 1961)

In northern Avalon, where bogs are least numerous, ombrogenous or rain-nourished bogs are the most common type, comprising almost the entire bog acreage. They are convex in form, with flattish tops and steeply sloping sides (Fig. 32a). The sphagnum moss in them has grown upward until dry conditions at the top have slowed growth and balanced it by wastage of dead vegetation. In many instances a 'bog ditch' (that flooded strip resulting from excess water oozing out of the bog) lies adjacent to their edges. The water-table in the smaller bogs may lie several feet below the surface of the higher central parts. Larger bogs, where the muskeg surface is undulating rather than slightly domed, may have surface pools in the depressions.

Where bogs and swamps are continuous in all directions for long distances, ombrogenous bogs may be surrounded by stretches of swamp in which the muskeg is saturated to the surface. Such conditions are common in southern Placentia Peninsula and southwest Trepassey Peninsula where a single traverse across a large area of bog may cross the boundaries between wet and dry muskeg several times.

On some uplands, thick deposits of sphagnum-moss peat have accumulated to form ombrogenous blanket bogs, some of them extending more than a mile.

Minerotrophic Bogs (as defined by von Post, 1937, and Sjörs, 1961)

Soligenous bogs. Soligenous or basin bogs, formed by the infilling of a water body, are widespread throughout the Avalon, particularly in the central and southern parts where relief is slight and where numerous lakes and ponds form a large part of the unintegrated drainage pattern. Generally these bogs surround those portions of the lake or pond that have survived infilling and peat development (Fig. 32b). Many extend beyond the original basin and surround ombrogenous bogs. Others have expanded as paludification swamps.

Where their development is well advanced, soligenous bogs are deep, with firm muskeg deposits extending to the edge of the central pool. These muskeg banks descend vertically to the pool bottom; depths as much as 14 feet have been sounded along their edges. Final filling of the deep residual waters appears to be a slow process.

Paludification swamps. These are swamps in which the muskeg growth, by continually blocking incoming drainage, continually floods the borders of the swamp and continually expands to occupy the flooded areas. Such swamps cover a greater area of the Avalon than do ombrogenous and soligenous swamps combined. On Placentia Peninsula, paludal peat blankets many of the long slopes leading to the interior (Fig. 32c) and, in some places, the crests of the divides. It also spreads over more than 50 per cent of the higher coastal areas. The long slopes are commonly covered by sedges and other marsh vegetation, for paludification swamps support a greater variety of plant types than do ombrogenous or soligenous bogs. The peat cover on till slopes generally varies between a foot and 4 feet thick, with large boulders either projecting in places through its surface or being clearly indicated just below it.

Toward the coast many marshy slopes grade into rolling ground moraine that supports a low bushy vegetation and contains little humus in the soil. Even in such terrain, muskeg will develop in suitable sites.

Although not so extensive as on Placentia Peninsula, paludification muskeg is well developed over much of southwest Trepassey Peninsula, in central Avalon north of Colinet, and north of the Isthmus of Avalon.

Stability of Muskeg Distribution

With only local exceptions, muskeg on the Avalon appears to be either expanding or to be in equilibrium with the environment. Examples of both advance and retreat are to be found within the map-area. Advance has been noted in southern Trepassey Peninsula where muskeg was observed encroaching onto flats of patterned ground (*see* Fig. 35). Also, around certain swamps, the flooding of the 'bog ditch' over fresh, heath-covered terrain, indicates that swamp conditions are spreading.

Evidence of retreat is less widespread. Erosion of peat, especially in some of the larger bog ponds has been deduced from the presence of peat islands considered to be remnants isolated by wave action. J. V. Healy, engineer in charge of agricultural bog development (Newfoundland Department of Mines, Agriculture and Resources), considers the peat islands in small lakes near Colinet may be evidence of some climatic change or of increasing wind velocities following the cutting of the surrounding trees.

It is estimated that 1.9 per cent of Avalon Peninsula is now covered by swamps (Wilton, 1956).

Beach and Bar Deposits

Throughout the map-area, the present-day beaches and bars are products of coastal wave erosion and are derived principally from reworked till and fluvioglacial deposits. Additional material is brought down to the coast by a few of the larger streams that are dissecting outwash deposits. Fragmentation of bedrock also contributes, though much more slowly. These deposits occur mainly either as strand beaches or as bay-head bars. Large spits and bay-mouth bars also occur, but are not so common.

Strand beaches are best developed at the heads of exposed bays where storm waves may build ridges of sand and gravel rising more than 25 feet above high tide. Along less indented shorelines, slackening longshore currents allow transported material to accumulate as beach deposits. Where bluffs of gravelly till or fluvioglacial material form the coast, the offshore currents cannot remove material from the base of the bluffs as fast as erosion supplies it.

One of the largest bay-head beaches lies in the southerly embayment of Whiteway Bay in southeast Trinity Bay, at the outlet of Backside Pond. Toward the north this embayment is open to the ocean, and a massive pebble and cobble ridge, 20 feet high and 300 feet across, fringes a muskeg flat as its head. Fresh driftwood on both its crest and landward side shows that storm waves still sweep over the ridge.

The largest bay-head bar on the Avalon is probably that at the head of Shoal Bay on St. Mary's Bay. Almost 4,000 feet long, this bar has a crest 22 to 25 feet above high tide and is surfaced in places with stones up to more than a foot in diameter. Between the present bar and the head of Shoal Bay, are the curved remnants of several older bay-head bars. The central parts of two or three of them have coalesced to form a small, vegetation-covered island that is connected to the present active bar by thin spits (Fig. 33). Underwater bars probably form offshore outside the latest emergent bay-head bar, and the bar thus 'migrates' seaward by successively occupying the offshore bars as they build up to the surface of the water. Shoal Bay is also open to the sea, and the present bar and beach, both entirely devoid of vegetation, are evidence that the heavier storm waves drive across the whole formation.

Holyrood Pond, originally a long, narrow, deep fiord running inland for more than 12 miles from St. Mary's Bay, is now closed off from the sea by a large bay-mouth bar more than 1½ miles long. Erosion of the thick cliffs of gravelly till and ice-contact

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FIGURE 33. Bay-head beach and bar, Shoal Bay on St. Mary's Bay. Several old bars may be seen to left of present one.

sand and gravel that extend along the coast for more than a mile to the south–southeast, have supplied the great quantities of material required to build the bar. Winter storms may close the outlet at its south end and then the water level in Holyrood Pond may rise 10 feet or more during spring runoff before an outlet is eroded and the water in the pond again lowered to sea level. The north end of the bar at St. Vincent's stands 33 feet above mean sea level, but local fishermen report that even this extreme height is crossed by storm waters every 8 or 9 years.

The town of Placentia on the west side of Placentia Bay is situated on a beach plain that closes the southeast arm of Placentia Road and partly blocks Placentia Harbour. This ridged sand plain is built of beach ridges, successively younger as one advances outward to the sea. Only the crests of the old beach ridges now project above the surface of the plain, the embankments having coalesced to form the massive compound spit that constitutes the present beach plain. The large amount of material in this compound spit resulted from erosion of the proglacial delta, the remnant of which is the modern Point Verde.

Surface material in beaches and bars may vary from fine sand to coarse cobbles or even small boulders. When coarse fragments cover a beach, they form only a top layer, and excavation beneath this reveals that the deposits either grade rapidly downward into finer material, or end abruptly where finer material begins at depths ranging from shallow to comparatively deep (McKillop, 1955, p. 111). In almost all beaches and bars, the size of material grades from coarser at one end to finer at the other, indicative of a longshore current flowing from the coarser-sediment end of the formation toward its finer-sediment end.

Along the shores of Trinity Bay, and north of Placentia on the east shore of Placentia Bay, postglacial isostatic adjustments have raised old strandlines to elevations more than 35 feet above present mean sea level (*see* map *in pocket*). There are no really large uplifted beach ridges, perhaps because of lack of time for their formation during the period of most rapid uplift, or because of wave damping by floating ice which at that time would have been prevalent. Some raised bar deposits, however, such as those in Placentia Bay on Great and Little Southern Harbours and on Broad Lake on the east side of Trinity Bay, show large quantities of sand and gravel in the lower parts that were originally submerged.

The best-developed beach ridges and bars on the Avalon lie close to the zero isobase through Carbonear and Placentia Peninsulas, along which sea level is unchanged. This contrasts strongly with the Atlantic coast, the area of greatest postglacial submergence, where no very large beach ridges are found and where there is only one bar sufficiently large to map. Stability of water levels during postglacial time appears essential to allow beaches and bars to reach maximum size under present coastal conditions.

Colluvium

Material classified as colluvium was recognized at several places in the Waterford River valley a short distance above St. John's. At the base of steep, till-covered slopes, it occurs in fresh cuts as a layer several feet thick, overlying undisturbed till. Though further deposits have probably formed under similar conditions they have not been identified elsewhere, partly because of the similarity of colluvium to both ablation and stony lodgement till, and partly through lack of suitable exposures. No attempt was made by the author to map it separately.

The colluvial layer is identifiable by: a sharp colour change from grey below to deep brown above, at depths greater than that reached by normal weathering; by the similarity in stone content between it and underlying till; and by a tendency for the contained shale fragments to lie parallel to the slope at the same angle to the horizontal as the ground surface — in contrast to the more random distribution observed in till immediately underlying the colluvial layer. In one exposure, faint banding, parallel to the slope of the hillside, had developed within the colluvial stratum. It had probaby been produced by upper zones sliding over lower zones during deposition. There was no ridging or other surface indication of colluvium emplacement.

Colluvium, formed by movement of glacial deposits down valley slopes, produces a deposit commonly very difficult or impossible to distinguish by simple surface identification from ablation till overlying ground moraine. Where an upper till-like layer lies on gentle slopes or across hummocky terrain, or where it extends in undiminished thickness to the top of slopes, it may confidently be assigned to some other category, probably ablation till. If it is confined to a low position on moderately steep to steep, drift-mantled slopes, the probability of its being colluvium must be considered. No evidence of active downslope movement of glacial deposits was seen. It is therefore believed that any colluvium present in the map-area represents mass-wasting under climatic conditions colder than now experienced; i.e., probably soon after deglaciation and before vegetation had stabilized the slopes.

Patterned Ground[1]

'Patterned ground' is a collective term introduced by Washburn (1950, p. 7–8) to describe certain geomorphological forms evolved mainly by frost action, principally in high latitudes and at high altitudes. The patterned ground found on Avalon Peninsula

[1]A more detailed discussion of this subject may be found *in* Henderson, 1968.

included sorted polygons and circles, nonsorted circles, debris islands, and a few sorted stripes and nets (Washburn, 1956, p. 827, 830).

On the Avalon all but the most minor developments of patterned ground are restricted to the southern half of the peninsula. Local distribution is controlled by type of material and by altitude. The larger areas of patterned ground (*see* map, *in pocket*, unit 3b) are developed in till on flat-lying or gently sloping ground moraine, generally where abundant water is available. Altitude is less important. Although frost forms found at higher altitudes are typically better developed than those found lower down, the range of elevations involved is small, from 150 to 700 feet. Moreover, the best large sorted polygons, of a form and size generally considered to be polar in type and indicative of severe climatic conditions, lie less than 250 feet above sea level and are found on a small flat area close to St. Mary's Bay.

Some 10 square miles, more than half the Avalon total of just less than 20 square miles of patterned ground, is found on the ground moraine-covered upland that extends west and northwest from Riverhead, at the head of St. Mary's Harbour, to St. Mary's Bay. The upland surface is either flat to gently sloping, or rolling with broad, low ridges rising 15 to 25 feet above the surrounding terrain. Surfaces with frost forms slope only a few degrees.

Elsewhere throughout the area, patterned ground covers less than 10 square miles, almost all of it in seven areas that range in size from half a mile to 4 square miles. A few smaller patches have also been mapped. The largest of the seven tracts, roughly circular in outline, is on Placentia Peninsula south of Great Gull Pond. In it, till-covered ridges separated by lakes and muskegs form a terrain resembling that northwest of Riverhead. At Great Gull Pond, however, only about half as much ground is occupied by frost forms, because the greater relief combined with rock outcrops on some ridges has restricted the area of flat or gently sloping ground. Both sorted and unsorted forms are present, but are generally less well developed than at Riverhead in spite of their occurrence on higher ground (at elevations ranging from 400 to more than 650 feet asl).

The remaining six areas, each extending half a square mile or more are all in the southern part of Trepassey Peninsula. Frost forms are only moderately well developed here. Most are unsorted circles with no large sorted forms. This is well illustrated in the two largest tracts, located on broad, treeless ridges on either side of the coastal road between Cappahayden and Portugal Cove South. Descriptions of these serve equally well for all.

Description and Degree of Development

The well-developed patterned ground northwest of St. Mary's Harbour consists of poorly to moderately well formed polygons and a few sorted circles. Perfect polygons with six sides outlined by stones are rare; generally one or two sides are lacking (Fig. 34). Either a side is left open, or two or three polygons combine to form irregular, multisided, angular, closed figures (Fig. 35). The polygonal nature of most sorted forms is distinct, however, and forty or fifty polygons, both partial and complete, may combine to make a rectangular mesh of stone borders enclosing centres composed of finer material. Single polygons may attain dimensions of 6 by 12 feet, but compound ones, completely enclosed by stone borders, may be much larger. Stones in the borders fringing the sorted polygons commonly range from a few inches to a little more than a foot in diameter, with occasional stones 1½ to 3 feet across. Some of the larger polygons have several small, weakly developed polygons within their borders. Most

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FIGURE 34. Sorted polygons on wet till flat north of St. Vincent's, St. Mary's Bay. The polygons are 4 to 12 feet long, 2 to 6 feet wide, and contain no nets of smaller polygons.

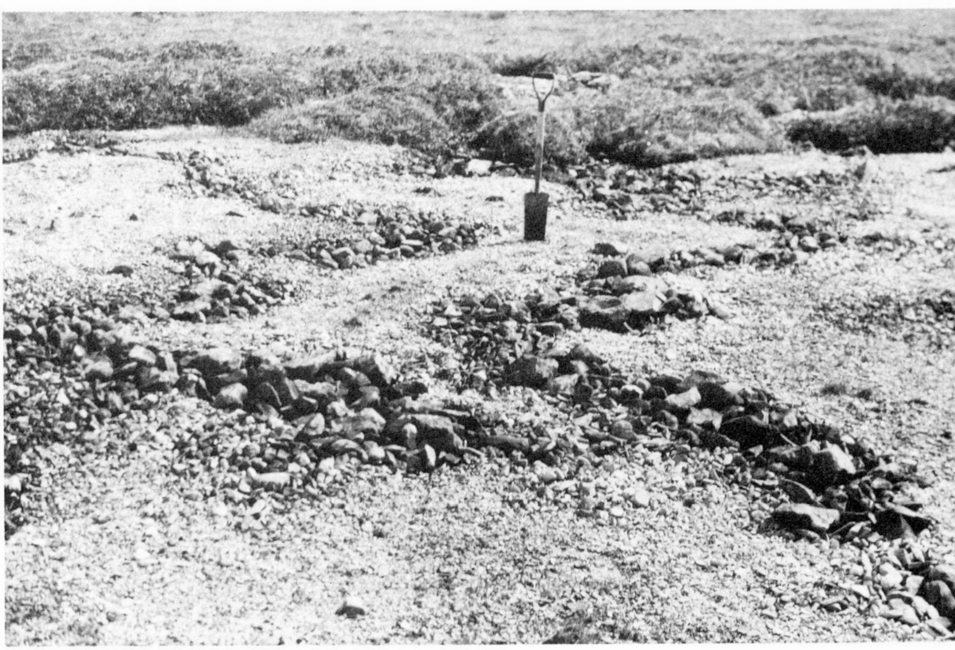

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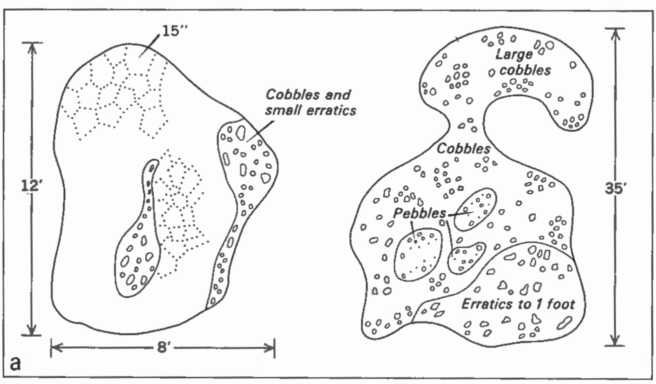
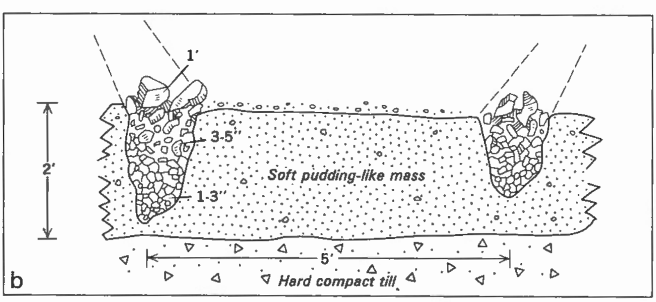
FIGURE 35. Patterned ground on a wet till flat showing imperfect polygons about 3 x 5 feet.

sorted forms have pebbles a quarter of an inch to 1½ inches in diameter evenly spread over the central areas. They generally form a single layer, but in some places several inches of loose pebbles and stones may have accumulated over the centres. The borders, composed of cobbles or small erratics, may consist of loose stones to depths of as much as 24 inches. Lichens are absent from stones in all larger areas where patterned ground forms are developed, suggesting that the forms are currently active. They were noted, however, on stones of a few isolated, sorted forms developed in thin till overlying bedrock; these were presumably instances where frost activity had slowed or ceased.

Even northwest of St. Mary's Harbour in the area with the best frost forms, well-developed sorted features constitute only a small part of the patterned ground. Much of it consists of a pebble-covered surface with irregularly shaped lenses of segregated cobbles and erratics (Fig. 36). A few small, weakly developed polygons or sorted circles, 9 to 15 inches across, and similar to those found within larger polygons, were observed. Small debris islands may also form in the accumulations of cobbles or erratics. In these islands the till matrix, presumably what is left after removal of stones by frost action, has risen to form circular patches of fine-grained material within the coarser fraction. Beyond the larger areas of continuous patterned ground,



Stone sorting on wet till flat. Note small incipient polygons developing on fines in left diagram. Ground outside of bare frost-churned areas is covered by thin muskeg or heath vegetation.



Diagrammatic cross-section of stone polygon.

GSC

FIGURE 36
Patterned ground northwest of Riverhead, St. Mary's Harbour.

single mud circles, half a foot to 2 feet across are common and are surrounded by the low, heath-like vegetation that carpets most of the exposed uplands.

Northwest from St. Mary's Harbour, a layer of gravelly mush 12 to 20 inches thick underlies the loose stones that cover most of the patterned ground. All stones larger than about an inch in diameter have been removed from this layer, and a shovel can easily be driven through it. This soft, churned material rests on hard, undisturbed, compact till, from which it is separated by a sharp contact. Although the area was examined near the end of an exceptionally long, dry summer, the mushy, frost-churned layer was wet immediately beneath the loose surface stones. Water could also be seen between the stones of some of the coarser polygon borders, particularly those on flat ground or near the bottoms of slopes bordered by muskeg.

Many of the forms of patterned ground on Avalon Peninsula, particularly sorted polygons, sorted circles, and debris islands, appear to be truly azonal, existing here in a warmer climate and at a more southerly position than any formerly reported. The presence of fossil forms of these frost structures has frequently been considered sufficient evidence of a former more severe climate. Their presence in southern Avalon Peninsula suggests it might be prudent in some instances to consider whether intensification of maritime climatic conditions and the resultant cooler summer temperatures might produce mean annual temperatures sufficiently low to explain more satisfactorily the presence of such frost forms.

Chapter VI

ECONOMIC GEOLOGY

The Pleistocene deposits of Avalon Peninsula are of importance to engineering projects and to agricultural development and water supply. Though sorted coarser materials suitable for highway surfacing and building are scattered throughout the region, deposits with large quantities of commercially acceptable material are not usually located close to the larger consuming areas such as St. John's. An exception is the large fluvioglacial deposit at Seal Cove on Conception Bay, about 20 rail miles southwest of the capital. Some high-quality material has also been trucked to St. John's from as far away as the pits at Clarke's Beach on the west side of Conception Bay. Because of the high cost of transporting material from sorted deposits in more distant locations, pits in the stony ground moraine around St. John's have been worked periodically for sand and gravel for many years; cleavage fracturing, prevalent in the hard Precambrian slates forming the coarser fraction, however, reduces the suitability of the final product for many purposes.

Throughout the area agriculture has been developed on a variety of soils. Suitability for the various crops depends largely on the nature of the parent surficial material and the degree to which they have been modified by topography through the influence of drainage and erosion. Small postglacial deposits of mineral soils are confined to alluvial flats along a few streams. Organic soils are more widespread and are beginning to be utilized.

Surface supplies of potable water are widespread and where the permeable Pleistocene deposits are sufficiently thick, readily abundant supplies for domestic needs are obtained from dug wells. Drilled wells have become increasingly common in the last few years, many obtaining their water from bedrock underlying the Pleistocene sediments.

Construction Materials

Knowledge of the nature and distribution of surficial deposits assists in locating construction materials such as gravel, sand, or base fill materials. It also facilitates decisions pertaining to siting power dams, routing new roads and canals, and making preliminary estimates for cut-and-fill requirements. The properties of construction materials, as determined by their composition and method of formation, decide the extent and limitations of their uses for various purposes. Costs may be reduced or suitable substitutes found by relating projects to their geological environment.

Gravel and Sand Deposits

Consumption of coarse, granular materials is steadily increasing, chiefly in constructing and maintaining a growing network of roads, and, in the rapidly expanding urban area of St. John's, in building construction. Until now, excavation of gravel and sand has been made in deposits of several different types that may be geologically classified as outwash and ice-contact sand and gravel; beach and bar sand and gravel; present-day river gravel; and till-derived sand and gravel.

Outwash and Ice-contact Gravel and Sand

Outwash and ice-contact deposits are here considered together for in many places they grade directly into each other, and deposits exploited commercially may share the characteristics of both. Economically, the most important ice-contact deposits are eskers, kames, and kame terraces, many of which, however, lie inland, too remote to hold much commercial interest at present. To date, the largest commercial gravel operations have been in proglacial deposits around Conception Bay. As they still contain large easily exploited reserves it seems that most production for some time to come will likely be from these sources.

For many years the extensively worked sand and gravel deposit on the main railway line at the mouth of Seal Cove River, has been the main source of sand and gravel for St. John's. Its eastern part, near the coastal highway, is composed of ice-contact deposits, mostly kames and esker ridges. Toward the sea, where sand and gravel is extracted, it consists of deep, better sorted outwash. Reserves are large, though the presence of varying amounts of soft Cambrian shale and siltstone as a minor constituent throughout much of the deposit is undesirable. East of the highway, on the north side of Seal Cove River, a small part of the deposit upstream from the Precambrian–Cambrian contact was found by the author to be underlain by pre-Cambrian bedrock and to be almost free of Cambrian fragments. This limited deposit has also been selectively worked for the use of the city of St. John's. At Clarke's Beach, almost directly across Conception Bay from St. John's, kame terraces and proglacial deposits on North and South Rivers contain large reserves of commercial sand and gravel. Little from this deposit has been shipped to St. John's because of the long road haul, but it supplies the populated west side of Conception Bay and ships construction material by schooner to Bell Island.

Probably because of the rough, hilly nature of the coastal road below Bay Bulls, the large ice-contact deposit of gravel and sand 2 miles north of Cape Broyle and just west of the main road, has not yet been used as a source of gravel and sand for the St. John's market, though it lies less than 40 miles south of the city. Improvement of the coastal highway, including paving, should make shipment from this deposit to St. John's economically feasible. Farther south and west, at several places along the coast of Trepassey Peninsula, large fluvioglacial deposits, used only locally in small quantities, are found close to the road. The principal ones are those at Renews Harbour, Portugal Cove South, Trepassey, and Peter's River; in an esker 2 miles north of Cappahayden; and in an esker-kame complex between Chance Cove and the road 3 miles to the north. Large quantities of less accessible sand and gravel underlie dissected valley-train terraces on either side of the upper part of Peter's River and on Crossing Place River above Holyrood Pond.

At present rates of use, the reserves of sand and gravel found in fluvioglacial deposits within a few miles of the population concentration in the Placentia–Freshwater–Argentia district are ample for a long time. A good-sized pit is at present utilizing valley-train deposits a few miles east of Freshwater at the mouth of Northeast River, and large reserves, both in the eskers on either side of the highway midway between Placentia and Colinet and in the remnant of the proglacial delta that forms Point Verde, are almost untouched. Other similar fluvioglacial deposits, either completely or almost unused, lie inland or along the coast, particularly on Placentia Peninsula which has a small population widely dispersed in coastal villages.

Beach and Bar Gravel and Sand

Shore deposits in beach strands and bars contain concentrations of sand and gravel. Large amounts are found on the shores of Trinity, Conception, and St. Mary's Bays, close to and west of the zero isobase. Lesser amounts occur along the east coast of these bays where high relief and postglacial drowning have tended to restrict the development of large, longshore accumulations. Bars have a greater total potential of sand and gravel than do strand beaches.

Most settlement within the map-area is coastal. In the rugged, stony terrain along most of the coasts, broad emergent bars and the flats behind beach strands have been used selectively for the siting of settlements, fishing facilities and equipment, and for rail and highway routes. Other beaches are spawning grounds for caplin, a principal source of bait for the fisheries. Except for limited local consumption, removal of sand and gravel from strands or bars may be forbidden or severely restricted to prevent damaging the deposits, perhaps to a degree far exceeding the value of materials being removed. Unfortunately, the heaviest demand for construction materials is in populated areas, and most beach and bar deposits not already utilized tend to be isolated and/or accessible only by water.

A survey of strand and bar beaches throughout the area (McKillop, 1955) recommended the types of local or general use to which these resources may be put and the amounts to be removed. If care is taken in the removal some bars and beaches with settlements adjacent to or on parts of them could be large enough to supply construction materials for both local and general use. On Trepassey Peninsula these include the bars at Biscay Bay, Portugal Cove, Holyrood Pond; the strand extending southeast to Peter's River; the bar at New Bridge on the southeast side of Salmonier Arm; elsewhere the bar at Bellevue on the west side of Trinity Bay, and the bar at New Harbour on the east side of Trinity Bay; the east end of the bar at Long Pond on the east side of Conception Bay; and the strand at Renews. Substantial amounts of sand and gravel are also available in postglacially raised bars in the northwest, particularly at Great Southern and Little Southern Harbours at the head of Placentia Bay.

Present-day River Gravel

Almost all deposits of modern river gravel have formed as the result of dissection and redeposition of outwash accumulations. The largest lie inland on streams flowing south in southern parts of Trepassey Peninsula, and are not readily accessible for exploitation. Large quantities of gravel above the big pond on Peter's River will be available only after 7 miles of road have been built north from the Peter's River–Trepassey road. On Placentia Peninsula a large gravel flat above Branch, and two or three smaller ones at the mouths of streams on the west coast offer easily worked supplies for local use.

Till-derived Gravel and Sand

Tills throughout the area have generally a gravelly or bouldery texture, with a sand and silt matrix containing little or no clay (*see* Table II). In lodgement tills, by far the most common type, a silt content of 20 to 30 per cent renders the majority of these deposits unsuitable for most construction purposes unless the gravel and sand are washed to remove undesirable silt. Many ablation tills, however, have less than

6 per cent silt content and require little processing other than crushing and sieving to secure commercially acceptable sand and gravel. As siliceous slate, perhaps the most widespread bedrock type throughout the map-area, cleaves easily into elongated, sharp shards unsuitable for many purposes, tills containing little silt but with high percentages of granitic or hard volcanic stones yield the best commercial sand and gravel.

Before 1957, when road maintenance began to be more widely mechanized, small till pits spaced closely together and worked with pick and shovel, were extensively used for road gravel. Their product varied widely in suitability for road building or dressing. After mechanization, systematic sampling, designed to eliminate pits with high silt content, was undertaken and extraction was concentrated in fewer of the better pits which were then greatly enlarged.

Lodgement tills from pits around St. John's, yielding material that requires washing, crushing, and sieving to produce suitably sized gravel and sand, have been worked for many years. Though this product contains much slate and siltstone, the distance from the capital of more acceptable material has created a ready market for it as a construction material.

When it is necessary to site new pits in glacial tills for production of large quantities of construction material, close attention to the type of till and the lithology of nearby bedrock formation should aid in making a choice. An area underlain by ablation till, common in areas of hummocky moraine, would most probably yield a product low in silt. If positioned where the ice had flowed across a large area of granitic or volcanic rock, the stones contained in the deposited till would more likely be of desirable shape and lithology. In a large-scale operation it might be more economical to move pit products longer distances rather than utilize inferior tills nearer at hand; processing costs could be lower and the quality of the product higher.

Postglacial Soils

Glacial and fluvioglacial deposits resulting from the last glaciation constitute the parent materials of most existing soils on Avalon Peninsula. Organic deposits, shore deposits, and tracts of alluvium along streams compose the remaining parent material.

The porosity and permeability of the soil and its capacity to store available water for commercial plants or other users, are largely controlled by grain size and the degree of sorting of soil constituents. Steepness of slope largely determines its susceptibility to erosion. Coarse rock fragments on the surface or within the soils may make land preparation for crops too expensive or render it suitable for pasture only. Thus, in the Avalon, these varying conditions have produced soils with a wide range of fertility.

Mineral Soils

The glacial deposits upon which most soils of the area have been developed are principally a mixture of sandstone, volcanic and granitic rocks, and hard siliceous slates. Under cool, humid, climatic conditions they have produced stony, podsolic soils of low fertility, with a grey, leached top layer and yellow-brown subsoil, coloured by secondary accumulations of iron salts and organic compounds from the surface. The soils are almost everywhere thin, full of fresh rock fragments, and strongly acidic. In many places they have an indurated layer of iron salts in the *B* horizon which causes poor drainage. Development of good, arable land on till is expensive. It requires clearing of vegetation and the almost ubiquitously prevalent stones and boulders; then improvement of the soil by drainage, and finally, the addition of lime, organic matter, and artificial fertilizers. Based on experience of progressive farmers in the vicinity of St. John's, one estimate of the cost per acre to bring newly broken land, developed on glacial deposits, up to the standard of arable land in the same area, is 500 dollars (Nfld. Royal Comm. Agric., 1956, p. 246). Of this, the greatest cost is for lime, fertilizer, improvement of the soil structure, and buildup of humus content.

The largest area of arable land developed on glacial deposits is close to St. John's, chief market of the Avalon. Smaller areas of arable land developed on morainic ridges are found near Whitbourne, where there is less than average relief, and along the west side of Conception Bay. Elsewhere scattered patches close to settlements are worked mostly for local consumption. Some small areas of glacial deposits, derived from the more easily decomposable Cambrian and Ordovician rocks near the heads of Conception and Trinity Bays and in the vicinity of Branch, have produced patches of soil of superior quality.

Although outwash sediments constitute less than 1 per cent of areal deposits, they make up a much higher percentage of the arable land. Principally, they underlie low outwash plains and terrace areas, either kame terraces or remnants of dissected valley trains. Some outwash consists of coarse gravel, but much contains a low proportion of smaller stones or may be almost free of gravel. Though these areas develop podzols, the soils are more fertile than ordinary podzols, being generally finer grained and with a higher content of organic matter. They need little clearing, and require the addition of less lime to counteract acidity.

The largest area of outwash covers the narrow coastal plain south of Topsail Head on Conception Bay, and runs south for 9 miles to Seal Cove. It varies from half a mile to a mile wide, though it is interrupted in places by ice-contact deposits. Almost all of it is extensively cultivated and produces crops of vegetables and fodder.

A large area of outwash at Clarke's Beach between North and South Rivers and on either side of them, consists of an undulating outwash plain near the sea that grades into kame terraces upstream along both rivers. A concentration of farms on the well-drained, fluvioglacial deposits covers almost all the surface except that part underlain by the coarser materials of the kame terraces.

Some arable land is worked on a few of the more accessible alluvial flats, but this comprises only a small fraction of the total acreage of cultivated land. Shore deposits are also used in places for rough grazing or local gardens. Rough pasture and blueberries — whose value may vary greatly from season to season — constitute the only valuable uses for unimproved land.

Because of the nature of their parent materials, almost all mineral soils are subject to drought in spite of the humid climate, with rainfall well distributed throughout the growing season. The soils are coarse in texture and have little water-holding capacity because of their low content of fines and organic matter. Excess water quickly drains below the crop root systems and lack of rainfall for even a week or 2 weeks during warm weather rapidly checks crop growth.

Organic Soils

Widespread accumulations of vegetative matter in various stages of decomposition form the mucks and peats upon which the second main class of productive soils in the Avalon are now being developed. It has been found that muskeg can be farmed economically under Newfoundland conditions, a fact of immense value to the agricultural economy. Much of the area covered by peat may be reclaimed for agricultural use after appropriate preparation, principally the development of drainage and the addition of lime and fertilizers. At the head of St. Mary's Bay east of Colinet, many hundreds of acres of bog, underlain by partially decomposed peat, have been drained, fertilized, and seeded to grass and other crops. Costs of reclamation and preparation are considerably less for organic soils than for stony glacial terrain, and the land is more productive. The rich black soil can produce grass and vegetables in greater yields than other soils, and sheep have been able to winter successfully on the bogland. Eventually these soils should supply range and fodder for a greatly enlarged livestock industry, and could help overcome the chronic lack of suitable arable land. Intensification of the bog reclamation program is being considered with a view to producing summer pasture and winter silage for an increased number of sheep and cattle, and for increased production of vegetables. Compared to present acreage of arable land, the area of muskeg suitable for exploitation is very large.

In addition to their increasing agricultural use, many organic deposits are of value as sources of peat litter. Used as a soil conditioner it adds vegetable matter to farm and garden soils, improves their texture, and increases their water retention capabilities. Litter is currently shipped from the bog at Cochrane Pond, southwest of St. John's to the local market; and small quantities from the Bay Bulls Big Pond, 9 miles south of the capital, have been shipped to the same market in the past. A large potential for increased production of peat litter could develop in the export market to the eastern United States if costs of processing and shipment can be made competitive with other sources of supply. The eastern United States now imports many millions of dollars worth of peat litter both from overseas and from adjacent parts of Canada. The use of peat as fuel in the development of electric power may also become economically practical in the future as demand for electrical energy grows.

Water Supply

Numerous lakes and streams throughout the area yield adequate surface supplies of good potable water to most urban centres and to many individual users. St. John's, the largest single consumer, obtains water from Windsor Lake, 3 miles northwest of the city. It also has a large reserve supply in Petty Harbour Long Pond, 4 miles south of the city. As most communities using surface water supplies are situated near the coast, and as the interior is generally uninhabited, there is little danger of upstream contamination. High rainfall combined with low evaporation ensures a continual supply of naturally pure water.

The glacial tills are relatively porous, with numerous lenses of sand and gravel. Almost everywhere shallow wells dug in the till yield water sufficient for domestic purposes. Settlements like Clarke's Beach, built on sandy outwash deposits, can also obtain large yields from wells. A few small isolated communities, situated on rocky, streamless shores, must carry water from the nearest surface supply. Drilled wells have become more common recently where increased supplies are required for institutional and industrial use. Many drillings tap water in the underlying bedrock, almost everywhere impervious, and obtain water in fractures or shattered zones of the rock.

Though streams in Avalon Peninsula are short, with moderate flows, a considerable amount of electric power is generated. As most of the area is an upland that drops abruptly to the adjacent lowland areas, low-cost sites for power generation are readily available. The numerous lakes and ponds dammed by irregularly distributed glacial deposits, present on the upland surfaces, commonly form lake chains with little change in elevation between the individual water bodies in the system. Small dams that raise the levels a few feet will generate large storage capacities in these interconnecting lakes. As fairly even flows are maintained throughout the year, the available water can be used efficiently for power generation. Muskeg areas within drainage basins serving power stations help maintain steady flows, acting as giant sponges to store water during periods of higher rainfall and feeding it slowly back into the run-off cycle during drier periods.

Chapter VII

SUMMARY

The oldest rocks observed in the map-area are in the deposit tentatively identified as a late Precambrian tillite, exposed along the eastern shore and offshore islands of St. Mary's Bay. After Ordovician time, the region was subjected to prolonged erosion. This produced a mature topography with bevelled uplands, above which rose monadnocks. Subsequent rejuvenation through uplift produced a rugged topography near coasts and on the Isthmus of Avalon. The last major change prior to glaciation was coastal drowning and extensive cutting of cliffs. Interglacial marine abrasion benches were cut at several places along the coasts at a time when sea level was higher than it is now. Those on the east coast may be of Sangamon age.

Although no conclusive evidence of Pleistocene glacial deposits older than Wisconsin have been found, the study-area was probably glaciated several times during the Pleistocene, and was most definitely glaciated during the Wisconsin glacial maximum. Ice from more western parts of Newfoundland flowed eastward over the northwest corner of the map-area and the northern half of the Isthmus of Avalon, but did not reach Avalon Peninsula itself. A vigorous local ice cap covered all the Avalon except Carbonear and St. John's Peninsulas, which had thin local ice covers of their own. Labrador ice moving east through Cabot Strait obstructed the southward movement of ice from Placentia and St. Mary's Bays, and the resultant blocking forced a thickening of the ice over St. Mary's Bay. This ice, therefore, overflowed west and north across the adjacent higher land to discharge into Placentia, Trinity, and Conception Bays. It also flowed eastward to the Atlantic across hills with elevations as much as 1,000 feet asl. In Placentia Bay, backing and filling ice from farther west caused flow north of east across the Isthmus of Avalon into Trinity Bay.

At the glacial maximum, great outlet glaciers projected seaward from Trinity and Conception Bays well beyond the limits of the land, an ice shelf extended along the east coast, and ice in St. Mary's Bay reached a depth exceeding 2,000 feet. Masses of ice probably accumulated on emergent parts of the continental shelf when eustatic lowering of sea level was greatest, and these masses may have been confluent with the land ice. Hundreds of feet of overdeepening by ice occurred in St. Mary's, Placentia, Trinity, and Conception Bays, but is most evident in Trinity Bay which has the largest and deepest of the closed basins.

During the glacial recession, the ice retreated from the coast and topographic control increased as it thinned. On the lowlands north and east of St. Mary's Bay recessional moraines formed in front of ice tongues retreating up coastal valleys. No large proglacial lakes were dammed by the retreating ice, but silt covers many moraines south of Whitbourne where water was trapped briefly between an ice plug on the low divide leading to Trinity Bay, and the ice retreating toward St. Mary's Bay. Meltwater deposits were formed during upslope withdrawal of ice margins, though inland, fluvioglacial deposits are surprisingly few. Most of this type of deposit was formed adjacent to the coast and several massive proglacial deltas were built out into the sea. Much of the sand and gravel carried by rapid meltwater streams was deposited over the bottoms of the major bays. Meltwater channels were carved in some till-covered hillsides, and gorges were cut across divides, particularly east and southeast of Holyrood and on the west side of St. Mary's Bay. The ice persisted longest on Trepassey Peninsula, and reversal of flow from there into St. Mary's Bay has left striations and *roches moutonnée* oriented southwest along the east shore of the bay. Upper slopes, swept bare of ground moraine, and shallow draws, paved with a heterogeneous mixture of boulders of all sizes, were formed by short-lived rushes of meltwater that resulted from the sudden draining of ice-dammed depressions or ponds on the surface of the ice.

Following deglaciation, debris from valley-train trenching either formed alluvial flats or was carried into the sea. Together with sand and gravel from the marine erosion of coastal outwash and glacial deposits, this debris was distributed along the coast by shore currents to form beach and bar deposits. Postglacial coastal retreat of as much as 1¼ miles has occurred in proglacial delta deposits.

Muskeg began to form early in postglacial time and is now widespread, particularly on Placentia Peninsula and in southern parts of Trepassey Peninsula. Paludification is still active in cooler, wetter parts of the Avalon. Bog deposits range up to 20 feet thick and extend for many miles. Frost-structure soils, present on parts of Trepassey and Placentia Peninsulas appear to be slowly spreading. They are the result of a favourable combination of climatic and physical factors and are azonal, being far to the south of any similar soils at equally low elevations in other parts of the northern hemisphere. The damp, cool climate of the Avalon has inhibited development of eolian deposits, confining them to a few bluff-top sands and a small group of sand dunes.

There is evidence of postglacial changes of sea level at widely separated points in Avalon Peninsula. On the Isthmus of Avalon and in the extreme northwestern part of the map-area, old shorelines emerge 30 feet or more. The zero isobase trends south 30 degrees west a little east of the eastern shore of Trinity Bay and parallel to it, and from there swings southwest into Placentia Bay south of Point Verde. All points east and south of the zero isobase have undergone drowning during postglacial time. The rate of upwarping between the zero isobase and emergent features to the northwest is approximately a foot per mile, a rate which, if extrapolation to the east coast is justified, would indicate maximum postglacial drowning there of 40 feet. Tidal records suggest there may be current epeirogenic downwarping in the St. John's region, but more evidence is needed to clarify this.

Pleistocene deposits are of importance to engineering projects, agricultural development, and water supply. Most high-quality sand and gravel deposits on the Avalon are not located close to the large consuming areas. However, in the near future, increasing population and improved roads will make much of their material economically worth exploiting. Mineral soils suitable for agriculture are of small extent, and not entirely desirable, largely because of the high cost of developing them for crops. The more widespread organic soils are proving less expensive to develop agriculturally under Newfoundland conditions, and are becoming increasingly important. They are of importance also as sources of peat used as a soil conditioner locally and for export. Surface supplies of potable water are widespread, and runoff has been used to develop a considerable amount of electric power.

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