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Post-glacial Geomorphic Features in Newfoundland, Eastern Canada

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ABSTRACT

Whereas a fair amount of information has been published on the pre-glacial morphology of the island of Newfoundland and on its glacial forms and deposits, comparatively little attention has been paid to its less striking post-glacial morphological development. In this paper an attempt is, therefore, made to assess the amount of geomorphic changes that have taken place during post-glacial time. This discussion is based on observations made since 1958 chiefly in southeast Newfoundland (Avalon Peninsula) but also in the north and west of the island.

If allowance is made for variations due to the different bedrock and mantle materials involved and the different geographic conditions encountered, the results can be listed in the following generalized manner: Physical and chemical weathering of outcropping bedrock and glacial deposits have made only small to moderate progress. Mass wasting has been of little significance, except for solifluction. Stream and river erosion and deposition have made little progress. The amount of mechanical sedimentation in the glacial lake basins has been small, but bog development in shallow basins, valleys, and flat ground in general is striking. Coastal bedrock erosion has been small to moderate. Coastal deposition is restricted to bay mouth bars and comparatively few other beaches, with pebbles reworked by the waves from glacial drift dominating almost everywhere. On the west coast of Newfoundland coastal dunes occur adjacent to some of the rare sandy beaches. Remnants of raised wave-cut benches exist at several levels, and associated alluvial deposits are fairly common.

The results obtained in Newfoundland are likely to be valid for a much larger part of eastern Canada.

ZUSAMMENFASSUNG

Während das präglaziale Relief Neufundlands und seine glazialen Formen und Ablagerungen bereits in verschiedenen Arbeiten anderer Autoren besprochen worden sind, hat die postglaziale morphologische Entwicklung des Landes bis jetzt relativ wenig Beachtung gefunden. Die vorliegende Arbeit widmet sich dieser Lücke, gestützt auf Beobachtungen, die seit 1958 überwiegend in Südost-Neufundland (Avalon-Halbinsel), aber auch im Norden und Westen der Insel gemacht wurden.

Wenn man für Verschiedenheiten im Widerstand der einzelnen Formationen gegen Erosion und Verschiedenheiten geographischer Natur einen gewissen Spielraum lässt, kann man die wesentlichen Ergebnisse wie folgt zusammenfassen: Sowohl im anstehenden Fels als auch in den Glazial-Ablagerungen zeigt die Verwitterung nur geringes Ausmass, und gravitative Massenbewegungen sind von untergeordneter Bedeutung, mit Ausnahme von Solifluktion. Erosion und Sedimentation der Bäche und Flüsse waren im allgemeinen gering; in den Glazialseen hat deshalb nur geringe klastische Sedimentation, in den flachen Wannen und Tälern aber üppiges Moorwachstum stattgefunden. Küstenerosion in anstehendem Fels zeigt geringen bis mässigen Fortschritt. Strandstrecken und Nehrungen bestehen ganz überwiegend aus Geröllen, welche zumeist den Moränen im Brandungsbereich entstammen; Sandstrand tritt dagegen nur vereinzelt auf. An der Westküste sind manche Sandstrandstrecken von Küstendünen begleitet. Gehobene Küstenlinien und zugeordnete Alluvialbildungen sind an vielen Orten zu beobachten.

Die Ergebnisse dieser Studie dürften nicht nur für Neufundland, sondern auch für grosse Nachbargebiete in Ostkanada Geltung haben.

RÉSUMÉ

Alors que la morphologie glaciaire et pré-glaciaire de Terre Neuve a été fait l'objet de plusieurs travaux, la morphologie post-glaciaire de cette île a été jusqu'ici quelque peu négligée. Le présent travail cherche à combler cette lacune. Il se base sur des observations faites par l'auteur depuis 1958 surtout au sudest, dans la presqu'île d'Avalon, mais en partie aussi au nord et à l'ouest de l'île.

En tenant compte de la variation du degré de résistance que les diverses formations offrent à l'érosion et des différences d'ordre régional, nos observations peuvent se résumer comme suit: La désagrégation et décomposition post-glaciaire des roches ce montre faible à modérée aussi bien dans les roches en place que dans les dépôts des glaciers. Les déplacements dus à la pesanteur sont d'importance secondaire, la solifluction exceptée. D'une manière générale, l'action des eaux courantes est faible, et les lacs d'origine glaciaire ont de ce fait peu de dépôts clastiques, tandis qu'une abondante végétation de marais s'est développée dans les bassins peu profonds et les vallées de faible pente. L'érosion côtière est, selon l'endroit, faible ou modérée. Presque partout, les plages et les cordons littoraux ne se composent que de galets provenant le plus souvent de moraines soumises à l'action des vagues; le sable n'apparaît qu'en peu d'endroits. Sur la côte occidentale, quelques plages ont des dunes. Des soulèvements ont affecté la ligne de rivage en bien des points, comme en témoignent les terraces rocheuses et alluviales.

Nos résultats trouveront sans doute leur équivalent dans un territoire beaucoup plus vaste du Canada oriental.

Introduction

This paper is concerned with the island of Newfoundland which, together with part of Labrador to the north, forms the Province of Newfoundland, the easternmost of Canada. Using approximate figures, the island lies between latitudes N 46.5° and N 51.5° (corresponding roughly to the latitudes of Geneva and London respectively in western Europe) and longitudes W 53° and W 59°. It is surrounded by the waters of the Atlantic Ocean in the east and south, the Cabot Strait and the Gulf of St. Lawrence in the west, and the Strait of Belle Isle in the north (Fig. 1).

The island of Newfoundland has a deeply indented coast-line generally bordered by a well dissected coastal strip of predominantly rocky nature, while the interior has a flat to gently rolling relief interrupted only here and there by higher hills. In many parts of the island slopes rise rather abruptly from the coast to elevations of between 250 and 500 feet (75 and 150 metres). In the east and centrally there is a further gradual rise inland to heights of 1,000 to 1,200 feet (300 to 365 metres), while in the west there are fairly large areas at elevations close to, or exceeding 2,000 feet (600 metres), and the highest point of the island (Lewis Hill) rises to 2,673 feet (815 metres) above sea level. In the western part of Newfoundland impressive mountain fronts and deep valleys are present.

Preliminary but comprehensive studies of the morphology of Newfoundland were made about 30 years ago (W.H. TWENHOFEL and P. MACCLINTOCK, 1940; P. MACCLINTOCK and W.H. TWENHOFEL, 1940), which were essentially concerned

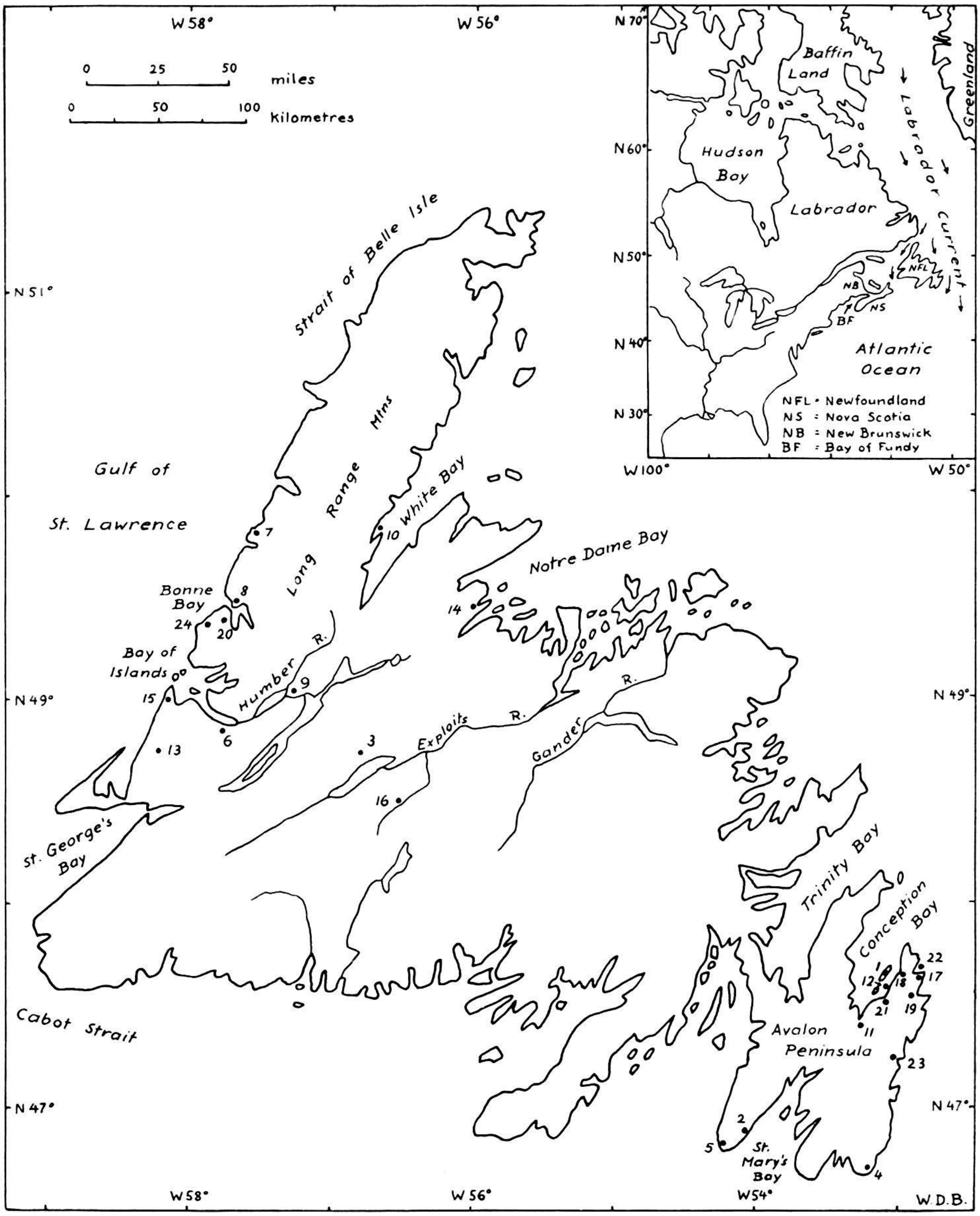

Fig. 1. Sketch map of the island of Newfoundland giving location of places mentioned in the text.

1	Bell Island	9	Deer Lake	17	Outer Cove
2	Branch	10	Great Coney Arm	18	Portugal Cove
3	Buchans	11	Holyrood	19	St. John's
4	Cape Race	12	Horse Cove	20	Table Mountain
5	Cape St. Mary's	13	Lewis Hill	21	Topsail
6	Corner Brook	14	Little Bay	22	Torbay Bight
7	Cow Head	15	Little Port	23	Tor's Cove
8	Crabb Brook	16	Noel Paul's Brook	24	Trout River

with features attributable to Pleistocene glaciation and to pre-glacial erosion. Of the features of post-glacial origin raised shore-lines alone have so far been investigated comprehensively (R. F. FLINT, 1940; S. E. JENNESS, 1960, 1963), whereas other post-glacial phenomena have been mentioned only here and there in reports and theses dealing mainly with areal bedrock geology.

In this paper the writer attempts to give an overall account of all the main types of post-glacial geomorphic feature in Newfoundland. This account is based on field work done at various times between 1958 and 1968, when some areas (especially on the Avalon Peninsula in southeast Newfoundland) were studied in detail and others (spread across the island) traversed in reconnaissance. Given the size of the island it has, of course, not been possible to see and record every post-glacial feature of importance.

The main geomorphic characteristics which Newfoundland had acquired by the end of glacial times can be summarized as follows: Once or several times during the Pleistocene, the whole surface of the island (and probably most or all of the surrounding shelf) was covered by an ice sheet which, after melting, left either rounded, grooved, striated, and locally plucked bedrock surfaces more or less littered with erratic blocks and stones (Fig. 2), or a continuous blanket of moraine of varying and often considerable thickness (Fig. 20). Glacial lake basins abound in both bedrock and moraine. As far as can be ascertained in spite of the substantial glacial modification, the pre-glacial relief featured several surfaces of erosional planation, with occasional relict hills rising above the lower of these surfaces[1]) (Figs. 12 and 13). In addition, the sharp and relatively high drop in the coastal zone (Fig. 24) and the accompanying incision of all the valleys in that zone must essentially have been of pre-glacial (or perhaps in part interglacial) origin; these features were probably the direct results of sea advance on the shores and associated valley rejuvenation over a prolonged period.

The post-glacial geomorphic features to be discussed in this paper include all those that have developed at the expense of the glacial landscape, earlier or later after the waning of the ice. It is not possible, however, to determine the time of ice retreat in Newfoundland exactly. In some regions the ice melted earlier, in others later, and although it is generally accepted and reasonably certain that all the glacial features encountered in Newfoundland received at least their final form and distribution during the Wisconsin glaciation, it is not so far known whether Newfoundland's ice cap melted during the early or the later stages of retreat of this ice age. C. EMILIANI (1956) considers that the beginning of the last main temperature rise was about 16,500 years ago, whereas A. HOLMES (1965, p. 692) places the major climatic change at 12,000 to 10,000 years ago (Alleröd—Two Creeks Interval). If the present cool and humid climate of Newfoundland (fostered by the cold Labrador current flowing southward along the island's shores) can be taken as an indicator, its glacial ice cap (or substantial parts of it) may have persisted until considerably later. It is known, how-

[1]) W. H. TWENHOFEL and P. MACCLINTOCK (1940) have distinguished three separate gently eastward-sloping 'peneplains', with the lower two surrounding occasional 'monadnocks'. According to I. A. BROOKES (1963), however, the number of planation levels discernible in western Newfoundland is greater.

ever, from C^{14} dating that peat bogs had begun to develop on the Avalon Peninsula 7,400 years ago (E. A. OLSON and W. S. BROECKER, 1959), and this figure may, therefore, be taken as the very latest possible date for the beginning of post-glacial changes in Newfoundland's scenery.

For an understanding of Newfoundland's geomorphology, brief mention is necessary of the nature of the island's bedrock. Geological maps of the island (D. M. BAIRD, 1954; H. WILLIAMS, 1967) show that it comprises sedimentary rocks as well as igneous and metamorphic rocks which range in age from Proterozoic to Carboniferous. The most resistant rock types are found among the volcanic and intrusive igneous rocks of various ages, whereas shale-rich or phyllitic formations are among the weakest; the resistance of other rock types, such as limestones and sandstones, or the bedded cherty rocks common in southeast Newfoundland, is of an intermediate order.

Weathering

In outcropping bedrock signs of physical weathering are more obvious than signs of chemical weathering. In weak rocks a breakdown into medium-size and small fragments is often well advanced, and glacial rounding has, at least surficially, disappeared. In more resistant rock types the amount of angular fragmentation is usually smaller, and in the most resistant rocks very little change since glacial times can be seen (Fig. 2). Frost heaving, frost shattering, exfoliation, and sheeting seem to be the predominant processes of physical breakdown.

Fig. 2. Glacier-rounded surface in massive Pre-Cambrian granite, with a sprinkling of erratic blocks. Physical and some chemical weathering have removed and altered the ice-polished 'skin', and a small amount of additional physical disintegration (frost shattering, exfoliation) has taken place. Near summit of 'Butter Pot', east of Holyrood, Conception Bay, Avalon Peninsula.

Chemical effects on outcropping bedrock are usually superficial and although a leached and altered rind is normally present, unaltered rock lies only a few millimetres, rarely a little more, below the surface. More pronounced chemical action can be seen where rain water and run-off have corroded limestone, dolomite, or gypsum. While in the carbonate rocks karst phenomena are only known to a limited extent (see, *e.g.*, J. H. McKillop, 1963), the gypsum outcrops of western Newfoundland are riddled with sinkholes (J. H. McKillop, 1959, p. 6).

In glacial drift the signs of physical and chemical weathering are similar to those in bedrock wherever stony surfaces are directly exposed to the atmosphere (see p. 423). Where medium to fine-grained material is also present chemical weathering is usually more intense. A moderately leached A-horizon then exists, which may be clearly underlain by a B-horizon in which rusty-coloured iron oxides have become somewhat enriched. The most intense leaching of fine-grained material and included stones is found under the wide-spread cover of peat, bog, and boggy black top soil (see p. 430). In this highly acid environment stones are usually fairly deeply leached or even completely rotten and may exhibit well-developed spheroidal weathering. Whitish, leached stones are a conspicuous feature of the Newfoundland scenery.

Mass Wasting

In areas of outcropping bedrock gravity-induced movement of debris is only possible where such debris is forming on slopes so steep that gravity (assisted by rain and wind) can overcome friction.

As physical weathering in massive bedrock has so far had a negligible, or only a small effect, slopes or cliffs of such massive rock have given rise at best to little patches of scree or to occasional small rock falls. Landslide and scree cones are more obvious, however, under the precipitous cliffs 2,000 and more feet in height which exist in some of the valleys near the west coast of Newfoundland, and they may occasionally reach up-slope for several hundred feet. Where the bedrock is less resistant there has been a greater development of talus, and scree slopes have been seen that are about half the height of cliffs in such rocks. In still less resistant rocks ice work has hardly anywhere left cliffs or slopes steep enough for scree formation.

In contrast to these findings inland, the steeper coastal cliffs under the constant attack of the sea have from time to time suffered gravity collapse, and older and younger scars of small to medium-size landslides can be recognized (Fig. 3). Marine erosion ensures that the landslide debris is removed within a comparatively short time so that landslide heaps known to have fallen only a few years ago have already partly or completely disappeared (see also p. 433).

In areas underlain by glacial drift many slopes have smooth, gently concave gradients so that many of the valleys lined by moraine materials show an excellent open U-shaped cross profile. Locally one or several bulges, sometimes of lobate form, may be seen on such slopes. These smoothened surfaces (Figs. 10 and 15) are distinct from moraine blankets of irregular surface normally appearing *in situ* from under melting ice, and where they have been cut into by man or by erosion the upper part of the material is seen to consist of a concentration of boulders and stones more or less devoid of fine-grained matter, and crude bedding features and also contortions may occasionally be observed in it.

Two processes probably acting simultaneously can be invoked to explain the shape and structure of these smoothened slopes: (a) down-slope creep or sliding of the moraine material, and (b) eluviation of the fine-grained particles. The creeping and sliding was certainly facilitated by the clayey material in the ground moraine. In addition, much water must have participated in weighting and lubricating the sliding material and in washing out the fine-grained particles from its upper layers. It seems plausible, especially in view of the often very gentle gradients, to ascribe most, if not all, of this movement to solifluction when (in early post-glacial times?) permanently frozen ground was the rule and allowed sliding and eluviation during the summer thaw[2]).

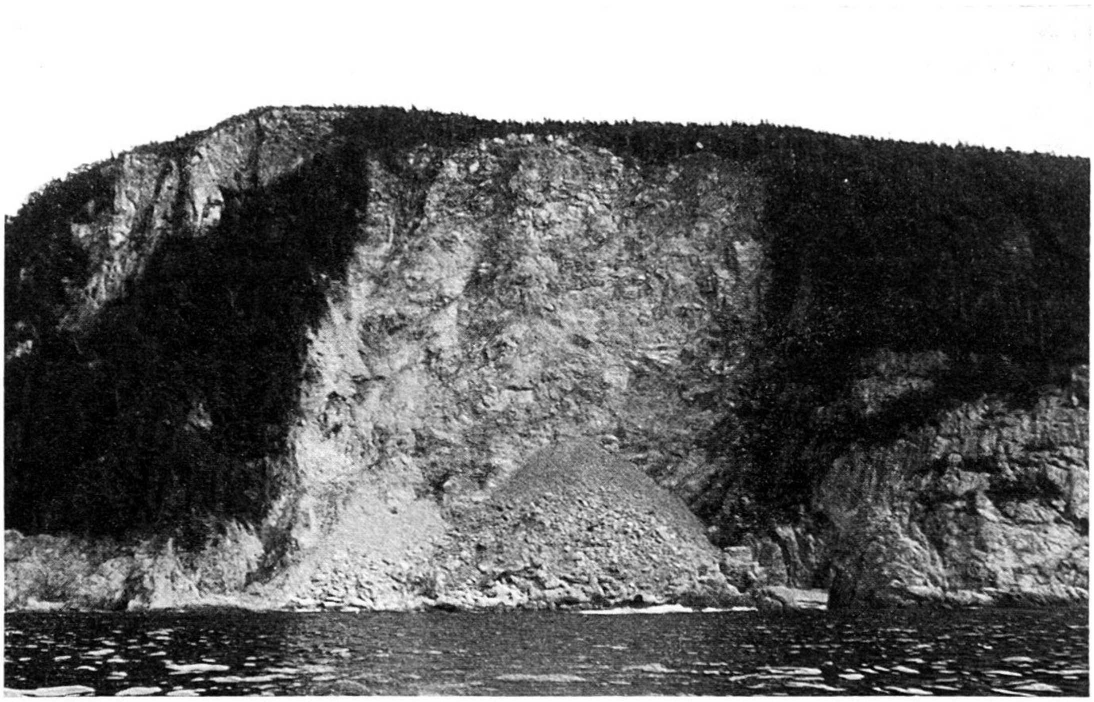

Fig. 3. Recent landslide at the sea coast, in fairly weak lower Palaeozoic phyllitic rocks. Eastern shore of Great Coney Arm, west side of White Bay, north Newfoundland.

It seems that at present solifluction processes have ceased throughout the island and that there is no permafrost left in the ground. However, at a few places creep on slopes does still seem to be taking place, *e.g.*, along the north and west slopes of the Table Mountain area in Bonne Bay where polygonal stone patterns occurring near stony slopes with bulges make it probable that ice in the ground is still, at least intermittently, playing a role. Other mobile slopes are found on shaly or phyllitic bedrock

[2]) Surficial eluviation of glacial drift seems to have occurred everywhere in Newfoundland, not only where creep or sliding has taken place but also where the glacial drift is apparently still *in situ*. Where the mantle of drift is relatively thin, eluviation has often affected it down to the underlying bedrock.

which allows wet creep of overlying drift material to take place and which itself may surficially participate in the creeping movement[3]).

Running Water

Apart from the deeply dissected mountainous regions of west and southwest Newfoundland and parts of the coastal zone where stream headwaters may be found to begin on the flanks of mountains or hills, running water normally originates within the larger or smaller 'flattish' areas dominating the island's surface, *i.e.*, in the lakes, ponds, and bogs (p. 428). These still-water bodies are connected in an apparently haphazard manner by streamlets or streams, and eventually the overflow finds a valley proper through which it reaches the sea. Thus, the post-glacial drainage pattern clearly shows the influence of glacial derangement, and even some of the large river courses seem to have been reconnected in a new manner after the ice age (Gander River, see S. E. Jenness, 1960; probably also Humber River). Glacial modification also dominates the form of the valleys; their cross-profile is more or less regularly U-shaped,

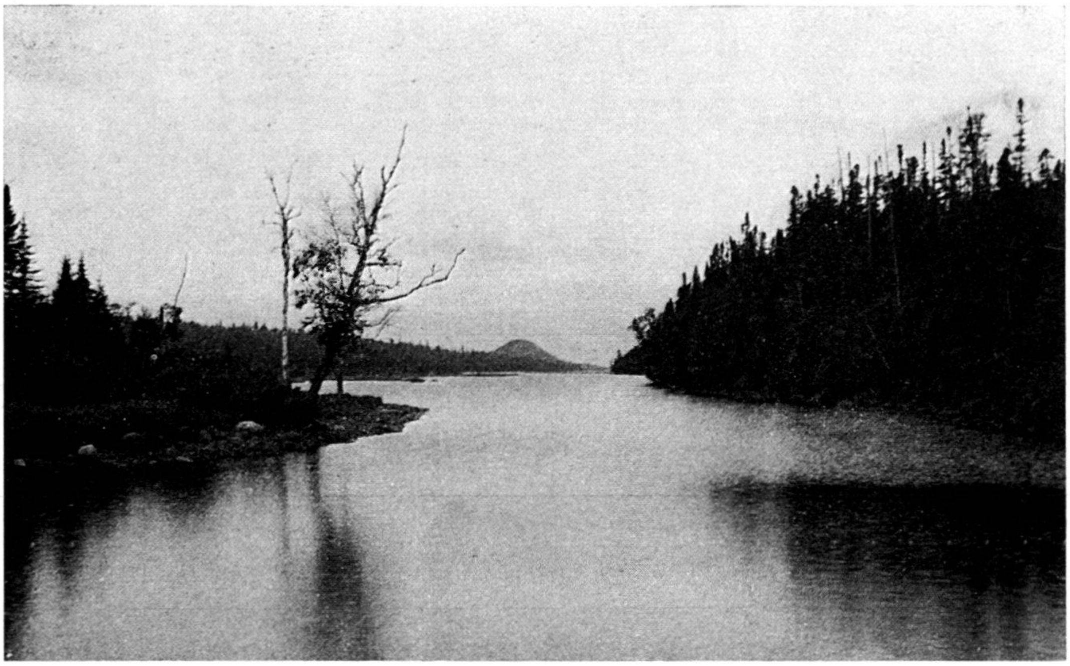

Fig. 4. A sluggish river tract. Beginning of 'Seven Miles Steady' in Noel Paul's Brook, about 25 miles (40 kilometres) southeast of Buchans, central Newfoundland.

and along their course basins are separated by ledges. The streams and rivers, therefore, are sluggish in some segments (Fig. 4) where they frequently widen to ponds or lakes, while they are fast-flowing in other segments that are generally interspersed with rapids and waterfalls (Fig. 5).

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[3]) Surficial bending of shales or phyllites has locally also been caused by overriding glacier ice. This cause is to be inferred where the direction of bending is markedly different from that of the maximum slope gradient but roughly parallel to the direction of Pleistocene glacier flow. An example of this kind was discovered by J. H. McKillop (personal communication) in cuts along the railway yard of Corner Brook, west Newfoundland.

Fig. 5. A river stretch with rapids, in fairly resistant Ordovician (?) andesite. 'Pine Falls' in Noel Paul's Brook, about 25 miles (40 kilometres) southeast of Buchans, central Newfoundland.

Stream and river erosion has, in general, made very little progress yet in the massive types of bedrock. Here and there, blocks bounded by joints, bedding planes or other 'lines of weakness' have been dislodged and carried on, perhaps aided initially by frost action (Fig. 5). Some sculpturing due to corrosion and/or corrasion can also frequently be noted. In weak materials however (especially in glacial drift and other unconsolidated materials, but also in weak kinds of bedrock) young gorges and V-shaped valleys[4]) have already been incised (Figs. 6 and 7). Stream courses in either drift (Fig. 6) or weak bedrock (Fig. 7) may already be graded, but streams which have cut through drift and encountered massive bedrock underneath have a bed still showing an irregular gradient due to the unevenness of this resistant material. Large to medium-size boulders are common in stream and river beds; they have been washed out of glacial drift and reached their location by undercutting, but have rarely been moved far downstream (Figs. 8 and 9).

Features of sedimentation in the present-day courses of streams and rivers quantitatively correspond fairly closely with the features of erosion just mentioned. As the headwaters of streams with their lakes, ponds, and bogs, and those stream and river stretches that lie in massive bedrock yield little clastic debris, there is practically no material for deposition in these parts of the drainage areas. This situation also accounts for the virtually complete absence of alluvial fans or cones at places where tributaries reach larger valleys. Where, however, glacial drift (and other unconsolidated materials) or weak bedrock have been eroded, alluvial flats are found here and

[4]) Including young torrent tracts on the mountain flanks of west Newfoundland.

Fig. 6. A young graded stream incised into glacial drift, with a subrecent narrow alluvial floor adjusted to a slightly raised sea level. Outer Cove, about 5 miles (8 kilometres) north of St. John's, Avalon Peninsula.

there downstream from the stretches undergoing erosion (Fig. 6). Along the lower stream and river courses such alluvial material has, *e.g.*, filled, partly or entirely, some

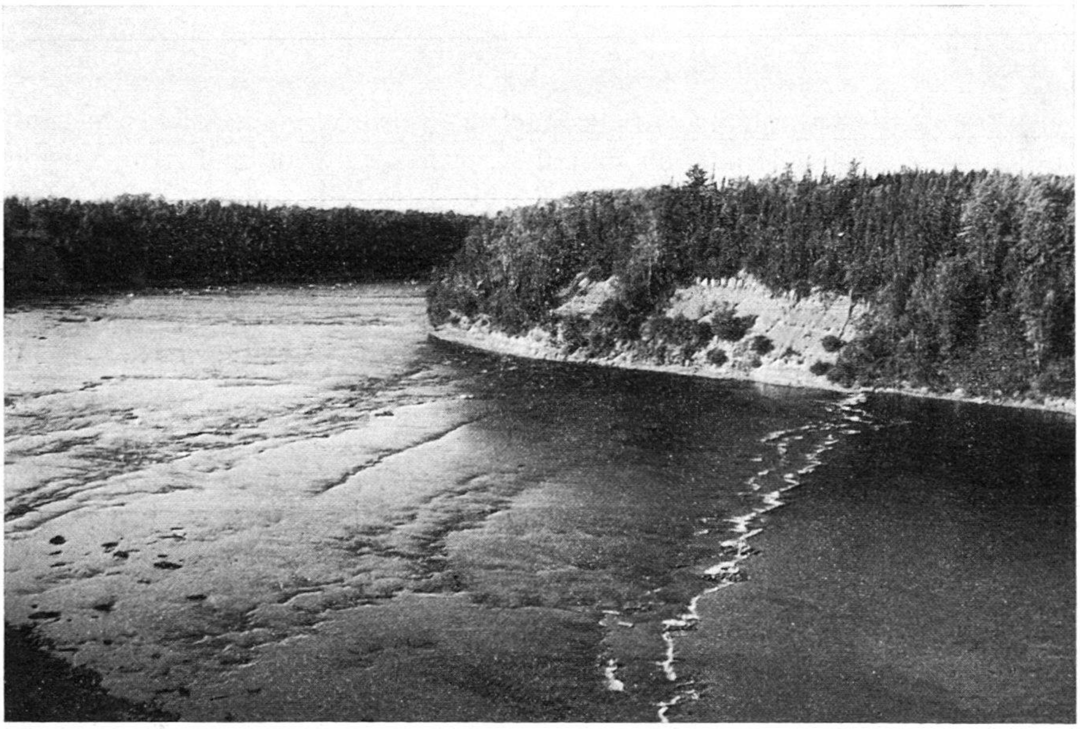

Fig. 7. A graded river bed incised into weak Carboniferous shales with a few sandstone layers. Humber River between 'Little Falls' and 'Big Falls', about 15 miles (24 kilometres) northeast of Deer Lake, west Newfoundland.

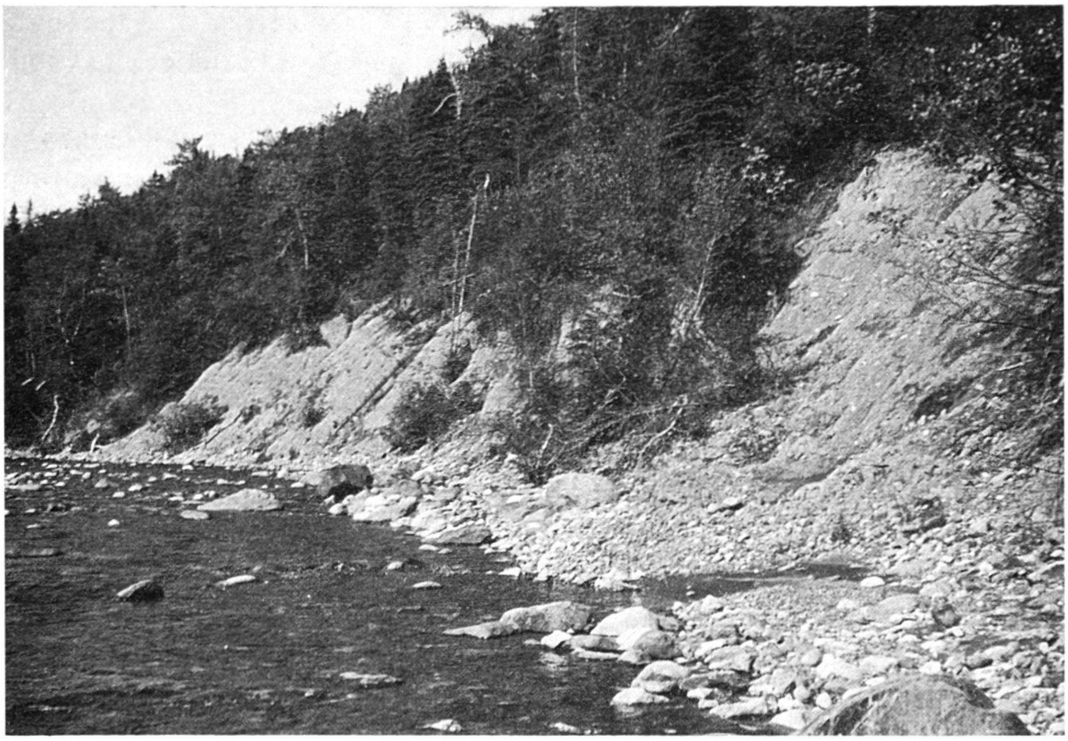

Fig. 8. River cutting laterally into glacial drift, with a fresh slide. Lower course of Crabb Brook, north side of Bay of Islands, west Newfoundland.

of the lakes, ponds, and beach bar-dammed lagoons. Recent alluviation is usually best developed in the areas where raised alluvial terraces are the source of the alluvial material. Not infrequently, however, and especially in the shorter stream courses of

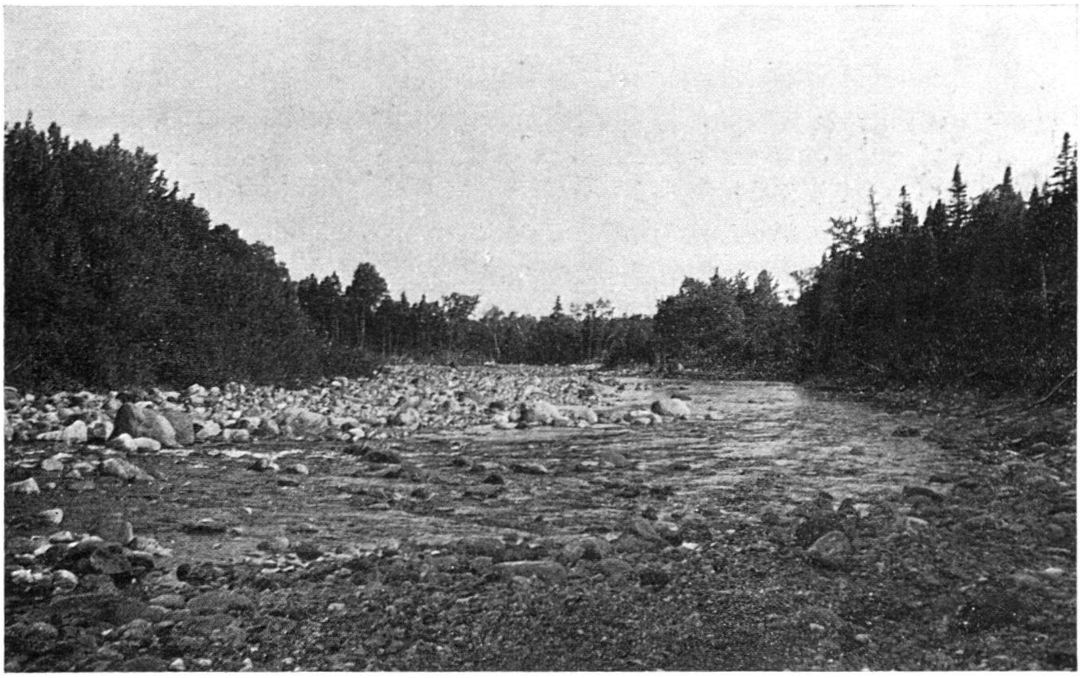

Fig. 9. River bed full of blocks washed out of glacial drift. Lower course of Crabb Brook, north side of Bay of Islands, west Newfoundland.

the coastal zone, eroded debris has all (or almost all) been carried into the sea where waves and currents have further disposed of this material and counteracted and even prevented the development of deltas (see also p. 433–436).

The raised alluvial terraces just referred to were formed as alluvial fill and as deltas in numerous valleys of the coastal zone when the ice front had withdrawn from the coast, or at least from those places where the terraces are now found. As many of these deposits are quite extensive and of considerable thickness, much meltwater must have been available at that time to redistribute the moraine material that became exposed. Some of the outwash trains are now found in valleys of minor significance, which lost most of their water supply when the ice disappeared. At many places raised terraces at several elevations exist as proof of repeated rejuvenation with redistribution of moraine and/or alluvial material whenever the shore-line became stationary for some time at successively lower levels (R. F. FLINT, 1940; S. E. JENNESS, 1960, 1963).

The writer has little knowledge of other glacio-fluvial deposits occurring in Newfoundland, such as eskers, kames, and kame terraces, and the reader is referred to the papers of S. E. JENNESS mentioned above and to other workers cited by that author.

Lakes, Ponds, and Bogs

Features of erosion along the shores of the countless ponds and smaller lakes are either absent or weakly developed. Usually lake waves have only removed some of the sand, silt, and clay particles from between the stones and blocks of the surrounding glacial drift material, but some of the larger lakes have developed typical features of shore-line erosion, low cliff-lines slowly retreating. Where this development occurs it has taken place in either unconsolidated material or bedrock of weak to moderate resistance, but little or no erosion has resulted from waves where lakes are bounded by massive bedrock.

Lakes capable of some shore erosion have locally developed beaches. These usually consist only of stones; sand and finer-grained matter are found but rarely. Rounding of stones along the beaches by wave action is negligible, and the rounded stones that are occasionally found on lake beaches have normally acquired their rounding earlier in their history (in moraine, a river bed, before incorporation in a conglomeratic stratum of the local bedrock, etc.).

Along the shores of smaller lakes and ponds a continuous, or interrupted line of boulders can often be seen, and in some cases there is a veritable rampart of stones and boulders a few feet high (Fig. 11). While wave erosion of finer-grained matter may account for part of the concentration of these blocks, outward pressure by expanding lake ice in winter is probably the main agent, especially in the case of the elevated block ramparts. This expansion pressure is believed to develop when lake ice is warming up after formation of a complete and thick ice cover during spells of very cold winter weather.

The amount of mechanical sedimentation in lake and pond basins corresponds closely to the amounts of clastic debris carried into them by streams and rivers and by the undertow of the waves along the shores. In view of the circumstances already described these amounts are quite small in most instances, and only along the

Fig. 10. Blocky surface with very gentle, regular gradient, derived from glacial drift by solifluction and eluviation. About 8 miles (13 kilometres) north of Cape Race, Avalon Peninsula.

courses of rivers which had the opportunity to erode substantial amounts of unconsolidated material or weak rocks are there alluvial flats encroaching upon lakes and lagoons (p. 425–427).

Fig. 11. Lake shore with boulder rampart formed by lake ice pressure. 'Octagon Pond', about 7 miles (11 kilometres) westsouthwest of St. John's, Avalon Peninsula.

Organic sedimentation, on the contrary, occurs abundantly. Wherever water basins are shallow, bog and peat development is in progress, gradually closing the basins, thickening, and encroaching on the surrounding higher ground. Similar bog encroachment is found along sluggish stretches of streams and rivers and almost universally over flattish, humid ground. Bog and peat growth is in fact the most obvious and clearly the most widespread post-glacial geomorphic process of Newfoundland (Figs. 12, 13, and 14).

On the floor of a number of lakes, or hidden here and there under the boggy cover, diatomaceous earth is known to occur as a post-glacial sediment. Studies of the distribution and composition of these deposits have been carried out recently by the Department of Mines, Agriculture, and Resources of the Province of Newfoundland.

Fig. 12. Boggy flat encroaching upon low forest, with 'monadnocks' composed of a post-Ordovician(?) dyke rock in background. South of Noel Paul's Brook, about 25 miles (40 kilometres) southeast of Buchans, central Newfoundland.

The Sea Coast

Along the coast of Newfoundland features of post-glacial erosion and sedimentation are found at the present sea level as well as at several raised levels. For the developments at each of these levels only a fraction of post-glacial time was available, and it is unlikely that these fractions were of equal length considering the differences in the features exhibited by the levels present at any one locality. Because younger shore modifications generally tend to obliterate older ones (and especially the older features of sedimentation), it is difficult or even impossible to assign to each stage its share of the total post-glacial changes. Their total amount, however, can usually be estimated at least approximately.

When the coast reappeared from under the melting Pleistocene ice sheet, glacial rounding had probably affected every bedrock outcrop, and sharp corners and niches existed only here and there as the result of plucking. Between outcrops glacial drift

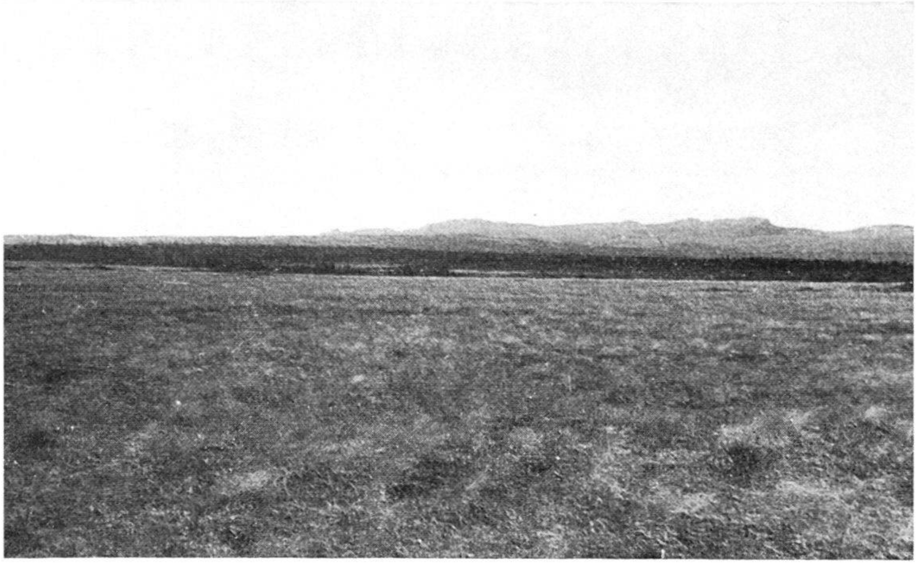

Fig. 13. Wide boggy flats, with hills of resistant Pre-Cambrian volcanic rocks in background. About 12 miles (19 kilometres) north of Cape Race, Avalon Peninsula.

was spread over the bedrock. Both rounded bedrock and blankets of drift must have continued below sea level, at whatever elevation it may have been at that time.

If the present coast-line is followed from sheltered to exposed stretches and across the various kinds of bedrock and unconsolidated materials, the following picture of post-glacial shore erosion emerges: In well sheltered stretches of the coast outcrops

Fig. 14. Coastal section showing bog covering solifluction debris derived from glacial drift, with Cambrian sedimentary rocks and a diabase sill at base; cobble beach in foreground. 'Gull Cove', 3 miles (5 kilometres) southwest of Branch, west shore of St. Mary's Bay, Avalon Peninsula.

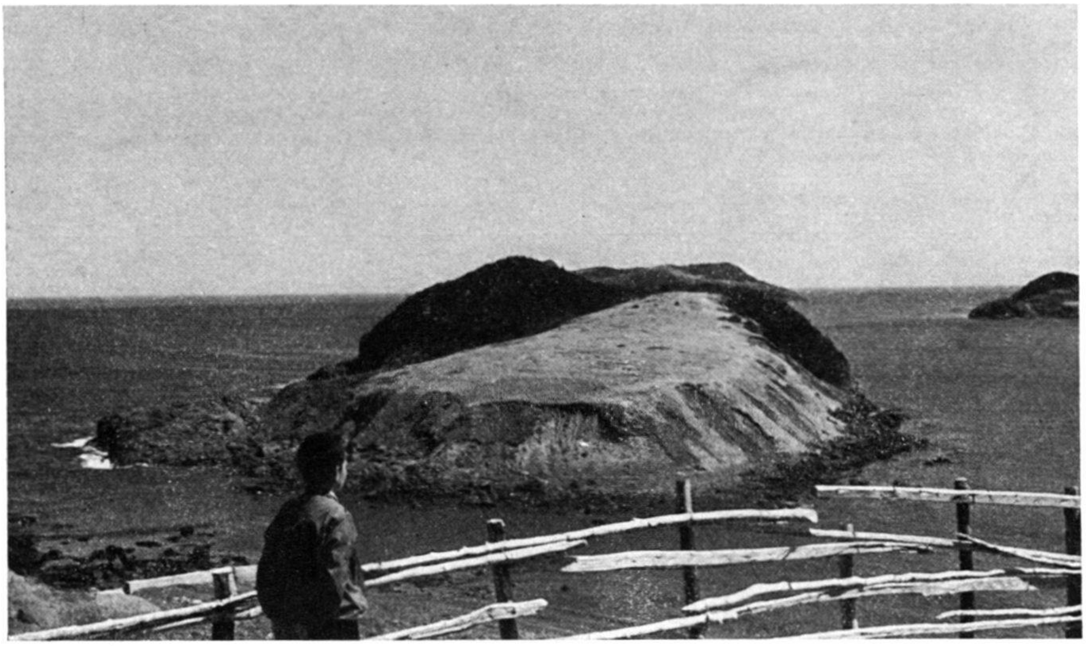

Fig. 15. Wave erosion of glacial drift in moderately sheltered position. The 'beach' is composed essentially of boulders washed out of the drift. The drift surface is smoothened because of solifluction. Island off Tor's Cove, about 25 miles (40 kilometres) south of St. John's, Avalon Peninsula.

of massive bedrock are almost unchanged, and even weak types of bedrock are very little eroded. Only glacial drift and other unconsolidated material show the steepened and graded slopes characteristic of young erosion in such deposits. In less sheltered

Fig. 16. Low recent cliff-line (below road) in fairly resistant Pre-Cambrian sedimentary rocks and dykes at a moderately sheltered coast; height of cliff increases at headland to right. Glacial rounding and drift descending to top of cliffs. Portugal Cove from the north, east side of Conception Bay, Avalon Peninsula.

bedrock segments a low cliff-line normally occurs, which grows higher towards the headlands or in weaker rock types than is the case in the bays and coves and in more resistant rock (Fig. 16); segments in drift may also show higher erosional slopes (Fig. 15). Along the exposed portions of the coast the rocky cliffs are often quite high (there is hardly ever any drift still left at sea level along these stretches), with the most spectacular cliffs usually in the weaker types of bedrock (Fig. 18). Where the exposed cliffs are in massive rocks, however, glacial rounding may locally still be discernible

Fig. 17. Arctic drift ice thrown against cliff-line of low to moderate height in Pre-Cambrian sedimentary rocks. Torbay Bight, about 7 miles (11 kilometres) north of St. John's, Avalon Peninsula.

down to the line reached by storm waves and spray. The post-glacial loss of land by wave erosion thus ranges from nothing at protected places to some dozens of metres at exposed headlands; a greater loss has occurred only in those exceptional localities where weak materials face the full force of storms[5]).

Sedimentation along the present coast is represented most obviously by beaches. They normally occur intermittently, within the bays and coves and at small sheltered spots in between (Figs. 14 and 19), or swing across coastal indentations as bay mouth bars (Fig. 20). Most beaches are made up of pebbles and cobbles, and occasionally, at places particularly exposed to very strong wave action, of boulders. With few ex-

[5]) It may be worth noting here that large stretches of Newfoundland's coast-line are 'besieged' every spring in a more or less severe manner by arctic drift ice and by occasional icebergs. The large scouring influence of this ice on the shallow sea floor near the coast has been established beyond doubt by SCUBA divers (H. D. LILLY, personal communication). It is obvious that this ice must also have a share, though perhaps only a minor one, in the erosion of the coast-line proper (Fig. 17).

ceptions these stones were removed by the waves from glacial drift within their reach, or they have fallen down from drift lying above the bedrock cliffs, and were then carried along-shore, and they are being refurnished from these sources as fast as the waves can abrade and wash away the earlier supply. Clearly, the average power of the waves in all these cases is strong enough to remove all finer material from the littoral zone.

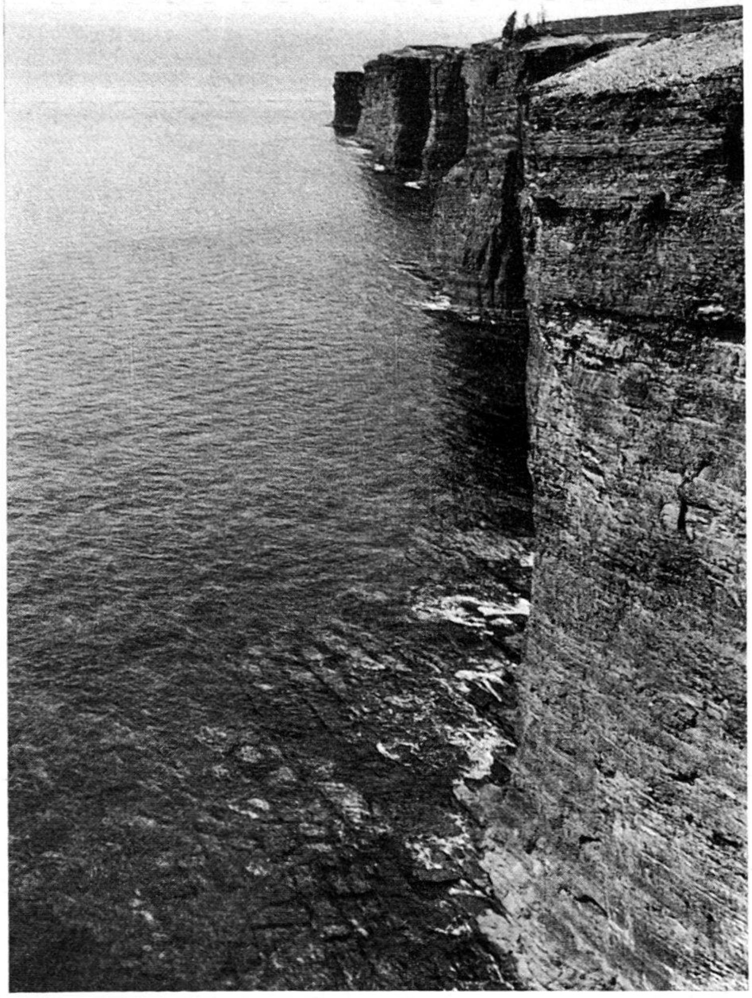

Fig. 18. Vertical cliffs, about 200 feet (60 metres) high, in moderately resistant shale-rich lower Ordovician sequence. Present-day wave-cut platform with joint pattern is visible below sea level. Southwest side of Bell Island, Conception Bay, Avalon Peninsula.

Sandy beaches occur at only a few places and are more frequent along the west than the east coast of Newfoundland. At these places either no stones are available for deposition although the waves may be of 'normal' strength, or the average wave power is so reduced that no particles coarser than sand can be shifted onto the beach.

The writer has little information concerning sedimentation beyond the beaches. Undoubtedly the material eroded from the coast since the beginning of post-glacial time has been deposited somewhere offshore. Landslide deposits may lie in deep water

Fig. 19. Pebble beach under a slope of glacial drift, from which the beach gravel is derived. (The shack on the beach was destroyed and the drift slope attacked again by storm waves since this picture was taken in 1958.) Outer Cove, about 5 miles (8 kilometres) north of St. John's, Avalon Peninsula.

Fig. 20. Continuous gravel beach damming several lagoons along its course. Stone supply comes from glacial drift, which is exposed to wave erosion along the headlands and covers the bedrock in the whole area shown. The drift area beyond the lagoon in foreground is interrupted by two zones of flat solifluction and / or alluvial material, which were probably adjusted to a slightly raised sea level. Topsail area seen from the northeast, southeast shore of Conception Bay, Avalon Peninsula.

under some of the steep cliffs, but most of the eroded material was probably comminuted to sand, silt, and clay and carried farther away from the coast. A number of estuary-like inlets on the east and west side of the island have tidal flats which continue outward under very shallow water. These are littered with blocks and stones, obvious residuals of eroded glacial drift, and between these are flat patches of sandy to silty, and locally muddy, sediment. The amount of post-glacial sedimentation in these areas can only be quite small. Farther offshore, the hydrographic charts of the coastal waters show rocky, gravelly, sandy, and muddy ground with rather irregular distribution.

Fig. 21. Raised wave-cut platform in fairly shattered and therefore only moderately resistant Ordovician basalt. North of Little Port, west coast of Newfoundland.

The raised shore-lines of Newfoundland are represented by relics of wave-cut platforms or notches in bedrock (Figs. 21 and 23) and by land-derived unconsolidated accumulations of material with surfaces that are more or less clearly related to the elevations of the wave-cut features (Fig. 22). Most of these accumulations are deltas at the end of early post-glacial outwash trains (see p. 428), but there are places where it appears that solifluction sheets at the coast may have been as closely adjusted to raised sea levels as the delta fronts. Wherever the surfaces of such unconsolidated deposits are used to determine the elevation of raised shore-lines, the amount of erosional retreat of their fronts since their formation must be estimated and the heights then corrected according to the gradients observed or assumed; the gradients of solifluction blankets are generally larger than those of delta plains.

The number and varied elevation of raised shore-line features have led R. F. Flint (1940), S. E. Jenness (1960, 1963), and others to various conclusions and speculations, essentially regarding the magnitude of the post-glacial isostatic rebound of the island and its regional variations and also the mode of glacier retreat and eustatic

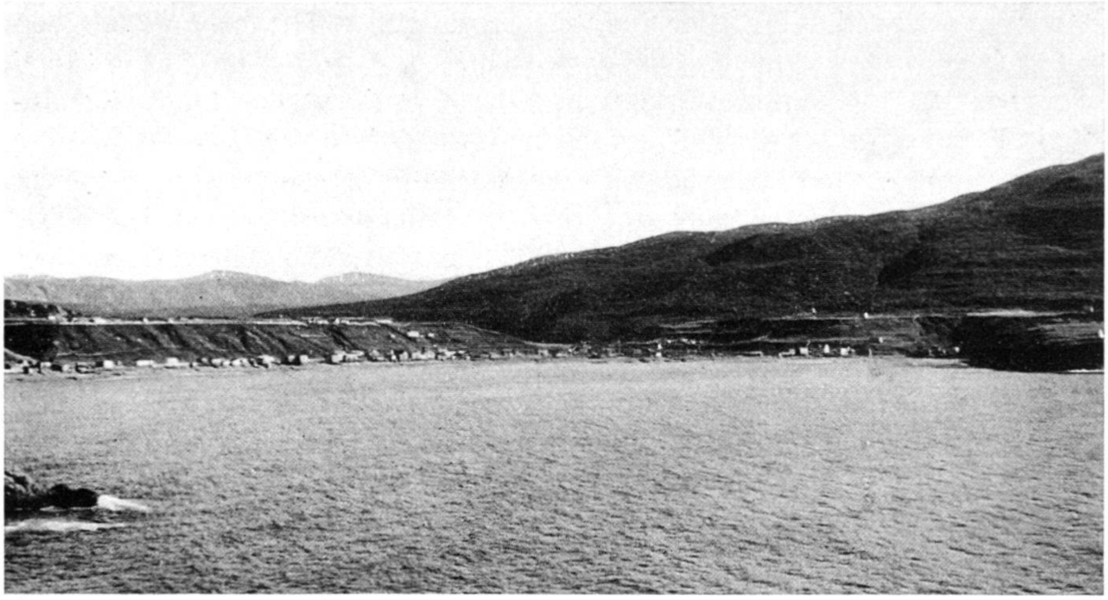

Fig. 22. Alluvial terrace in left half of picture adjusted in height to wave-cut platform in right half, where a lower wave-cut platform relic can also be discerned. Trout River, west coast of Newfoundland.

rise of ocean level. The writer does not wish to enter into a discussion of these rather involved questions here; far more detailed studies than he has made would be necessary for confirming, rejecting, or modifying his predecessors' views. Two points, however, are worthy of note in the present context:

(1) R. F. FLINT (1940) states that wave-cut benches are well developed at present sea level, but according to the writer's observations this is not really so. The great majority of these benches or bench remnants are actually a few feet above the base level of present-day wave attack although they are normally still awash and are being

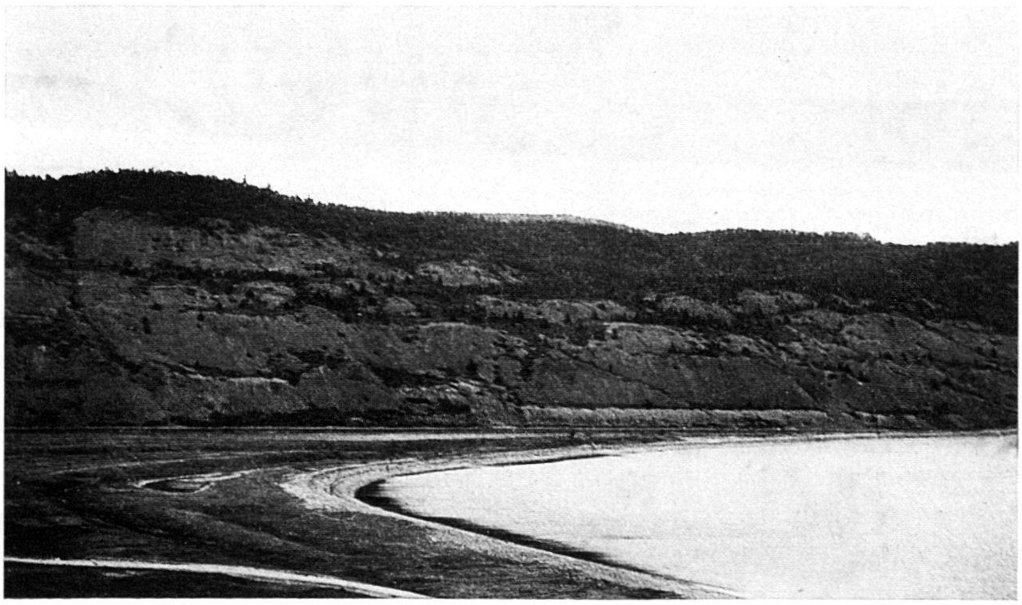

Fig. 23. Remnants of raised wave-cut platforms and notches at five distinct levels (lines of vegetation) in massive Ordovician basalt. Little Bay, Notre Dame Bay, north Newfoundland.

lowered and extended at high tide and in stormy weather. The truly modern benches lie a few feet lower, and the sea withdraws from them only slightly at lowest tides; they are well developed, however, only in bedrock of the weaker kinds (Fig. 18).

(2) E. P. HENDERSON'S surficial geology map (1960) shows no traces of raised shore-lines around the Avalon Peninsula with the exception of one locality on the eastern shore of Trinity Bay, but actually numerous remnants of benches occur at a few feet above sea level (Fig. 24), and some remnants also exist at about 20 feet. At one locality, Horse Cove (or St. Thomas Cove) on the eastern shore of Conception Bay (Fig. 25),

Fig. 24. Fairly extensive remnants of a low raised wave-cut platform in Cambrian shales and mud-stones of fairly low resistance. This picture also shows the essentially pre-glacial drop of several hundred feet (about 100 metres) from the flattish interior to the sea in the coastal zone. About 4 miles (6.5 kilometres) east of Cape St. Mary's, Avalon Peninsula.

even remnants of a stratified beach deposit were found overlying the higher bench relics; this seems to be a unique occurrence, however, at least for the storm-swept coast-line of the Avalon Peninsula.

Coastal Dunes

At several places along Newfoundland's west coast, especially from Cow Head towards the north, but also along the inner part of St.George's Bay, sand dunes are developed adjacent to sandy beaches of the recent shore-line from which the wind is taking the sand. The dune ridge in St.George's Bay is low and essentially fixed by a thin cover of vegetation. The dunes in the north, however, are fresh and constantly shifting, burying and killing the forest and other vegetation (Fig. 26). At one place, sand is even drifting across the road that follows this shore some distance inland.

Comparison with other Regions

From a field trip to the northeast of Labrador, from several air journeys across Nova Scotia and New Brunswick, and from a study of air and terrestrial photographs of areas in eastern and northern Canada as well as various papers on these regions, the writer has gained the impression that the post-glacial geomorphic development of large parts of northern North America, and particularly of those regions adjacent to Newfoundland, has been very similar to that outlined on the preceding pages. Naturally, there are differences due to differing local or regional conditions such as the large tidal range of the Bay of Fundy, or the dwindling of vegetation towards the north, variations of permafrost conditions, etc. However, most of these differences can probably be considered as 'variations of a theme' rather than as fundamental contrasts.

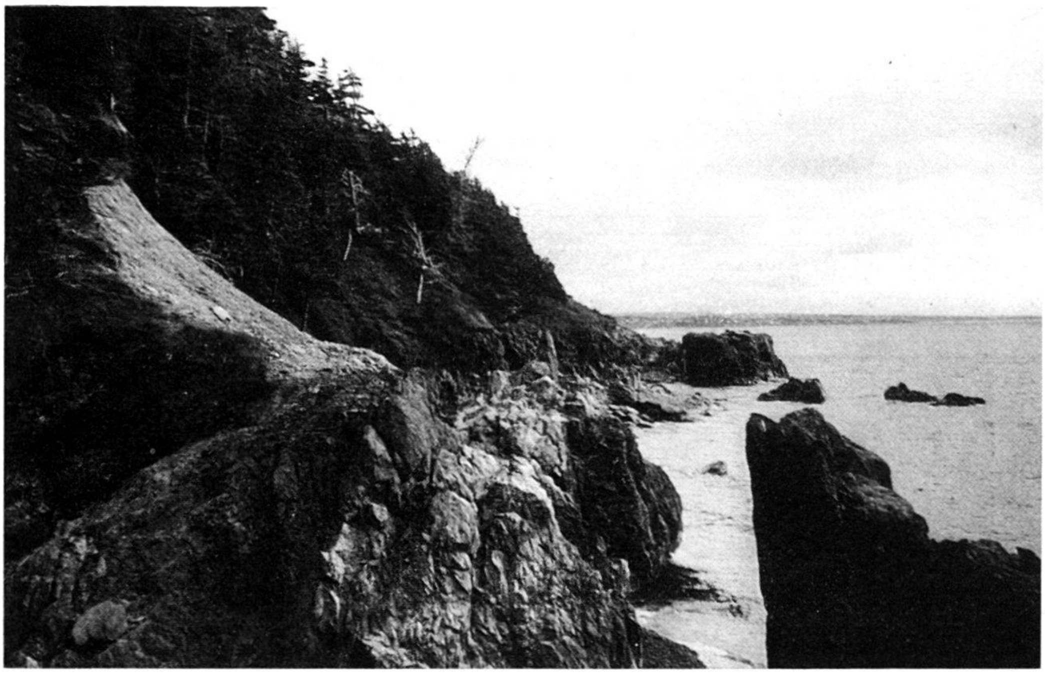

Fig. 25. Small remnants of a raised wave-cut platform about 20 feet (6 metres) above present sea level, overlain (in foreground left and spur in background) by a bedded beach deposit (sand with pebble streaks). South side of Horse Cove, east shore of Conception Bay, Avalon Peninsula.

As the writer has been working in the Swiss Alps for many years, he has also been interested in a comparison of the post-glacial geomorphic changes observed there with those seen in Newfoundland. Such a comparison should, of course, be made only with those parts of the Alps that correspond more closely in climate and type of vegetation than others to the conditions in Newfoundland, *i.e.*, with a zone lying (in central Switzerland) between about 1,300–1,400 metres and 2,100–2,200 metres above sea level. While some of the geomorphic features of Newfoundland described above cannot be compared with Alpine counterparts because they are either absent altogether in the Alps (features of the sea coast, coastal dunes) or too rare (bogs), a comparison of the others is fairly easy. The results are as follows:

Physical weathering (especially frost shattering) seems to be more advanced in the Alps than in Newfoundland. The general lack of progress of chemical weathering is characteristic of both regions although karst development in the carbonate formations of the Alps is far more obvious. Among the kinds of mass wasting slope creep, talus, and landslides, slow and fast, are much more abundantly developed in the Alps; solifluction phenomena, however, were not noticed there by the writer at the elevations under consideration. Running water has caused considerable post-glacial modifications in the Alps by incision of stream valleys and smaller-scale erosive sculpturing of mountain slopes, as well as by deposition of alluvial cones, fans, and flats in the lower parts of the valleys and of deltas in lake basins. Lake shore features are similar to those in Newfoundland; ramparts due to ice pressure are not, however, known to the writer to occur in the Alps.

Fig. 26. Advancing front of recent coastal dune belt. North of Cow Head, west coast of Newfoundland.

If an attempt is made to understand why the physical weathering, mass wasting, and running water work have had a greater effect in the Alps than in Newfoundland in post-glacial time, differences in the climatic development could probably be invoked as well as the fact that the Alps had only valley glaciers in Pleistocene times instead of the 'continental' ice sheet that covered Newfoundland. Certainly, the greater overall steepness of the slopes in the Alps was largely responsible for the greater amount of mass wasting; and for the greater effects of running water the availability of rock debris in quantity right from the headwaters on must have been a significant factor. The different overall resistance of the bedrock, however, has definitely been most important in causing the differences notable in the two regions compared. In Newfoundland, where erosive processes have worn down the land continuously since Palaeozoic times, compact and resistant bedrock originally buried deeply under the mountain chains of the Appalachian fold belt now outcrops widely. In the Alps, folded and lifted essentially in Cainozoic times, the cores of compact rock have, on the contrary, been uncovered only locally, while poorly to moderately resistant sedimentary formations, phyllites, schists, and other foliated, sheared, or fractured rock types dominate at the present-day surface.

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